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Continents under Climate Change

Wilfried Endlicher and
Friedrich-Wilhelm Gerstengarbe (Eds.)

Deutsche Akademie der Naturforscher Leopoldina –
Nationale Akademie der Wissenschaften, Halle (Saale) 2010
Wissenschaftliche Verlagsgesellschaft mbH Stuttgart

Continents under Climate Change

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Continents under Climate Change

Conference on the Occasion of the 200th Anniversary
of the Humboldt-Universität zu Berlin

In cooperation with the Potsdam Institute for Climate Impact Research
and the German Academy of Sciences Leopoldina

Under the auspices of the German Federal Foreign Office

April 21 to 23, 2010
Federal Foreign Office, Berlin

Editors:

Wilfried Endlicher (Berlin)
Member of the Academy

Friedrich-Wilhelm Gerstengarbe (Potsdam)

With 103 Figures and 17 Tables

**Deutsche Akademie der Naturforscher Leopoldina –
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Preface

Climate Change and its subsequent impacts are amongst the most urgent problems that mankind has to face at present. The articles assembled in this volume pay an important contribution in uncovering the existing global problems. A number of lectures held at the international conference "Continents under Climate Change" from 21 to 23 April 2010 in Berlin form the basis of these articles. The congress "Continents under Climate Change" was planned as a special event of the *Humboldt-Universität zu Berlin* on its 200th anniversary. The conference was organized in close co-operation with the Potsdam Institute for Climate Impact Research (PIK) and the German Academy of Sciences Leopoldina.

The authors, belonging to the worldwide leading scientists of their continents, give an expressive review of the climate change and its impacts taking place on their continents. For the first time, the reader can get a short and clear but well-founded picture of the changes that are already underway throughout the world.

The organizers wish to thank all those who contributed to the synthesis of these proceedings.

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Welcome Addresses

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Welcome Note

Christoph Markschies (Berlin)

President of the Humboldt-Universität zu Berlin

Dear participants of the congress “Continents under Climate Change”,

As President of the *Humboldt-Universität zu Berlin* and patron of this conference, I welcome you most warmly to the *Alma Mater Berolinensis*.

In our bicentenary year, as we celebrate our university’s 200-year existence with numerous special events, we are proud to present the *Humboldt-Universität* as “the modern classic” to the wider public. This slogan can also aptly be applied to our conference “Continents under Climate Change”: the conference carries forward a tradition of climate research reaching all the way back to Alexander von Humboldt, and at the same time offers a platform to present cutting-edge contemporary research on the global consequences of climate change.

The organizers from the *Humboldt-Universität* have been able to put together an international conference which will open avenues for fruitful dialogue across disciplinary boundaries. Recognized specialists in various fields will discuss their research on the functions and mechanisms of the climate system, considering not only the purely natural-scientific aspects but focusing also on the socio-economic and political impacts of global climate change. This transdisciplinary approach, the international, academic orientation, and the composition of the individual panels taken together make the conference “Continents under Climate Change” an important and influential forum for climate research. With the conference the organizers moreover aim to strengthen the exchange between science, business, politics and society, and to highlight the complex interlinkages between these areas.

We hope that our wide-ranging and stimulating supporting program – ranging from excursions and film screenings to the presentation of the *Bayer Climate Award* – will also contribute to making your days in Berlin a most worthwhile experience.

I would like to thank all those involved in organizing the conference, particularly my colleagues Professor Endlicher and Professor Gerstengarbe and their team, for the scientific and administrative preparation and realization of the conference. In addition, we are deeply thankful to the conference’s promoters and sponsors from industry and banking, as well as to the German Research Foundation (DFG). Without their generous financial aid it would not have been possible to plan and organize a congress of this scope.

We are also grateful to our co-operation partners, the Potsdam Institute for Climate Impact Research (PIK) and the German Academy of Sciences Leopoldina. Both institutions have been valuable partners to our scientists at the *Humboldt-Universität* for many years.

That climate science is not only a fascinating discipline but has become a highly topical and important theme for both science and society at large is shown by the participation of Minister of Education and Research Annette Schavan and Minister of State Cornelia Pieper, whom I would also like to thank most warmly for attending.

I hope you will all enjoy productive discussions and fruitful encounters in the course of the conference "Continents under Climate Change", and I wish you a stimulating visit to the *Humboldt-Universität zu Berlin*.

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Nova Acta Leopoldina NF *112*, Nr. 384, 15 (2010)

Greetings

Hans Joachim Schellnhuber ML (Potsdam)

Director of the Potsdam Institute for Climate Impact Research (PIK)

Dear Participants, dear Colleagues,

Sometimes an idea doesn't fully reveal its value in its time, but proves to be fruitful for centuries to come. Such an idea was realised with the foundation of the "Humboldt-Universität zu Berlin", following Wilhelm von Humboldt's vision of an institution that excels in both teaching and research. The conference "Continents under Climate Change" on the occasion of the university's 200th anniversary gives proof of this idea's great vividness.

Scientists and students, decision makers and the interested public are invited to discuss and to expand the current knowledge of climate change and the associated risks for nature and society. The manifold impacts of global warming on a continental scale pose a challenge that we will only be able to meet by ensuring the engagement of the best minds of our as well as future generations.

Since its foundation, the Humboldt University has provided a most fertile environment for the formation and dissemination of knowledge that makes a difference. However, although the picture of anthropogenic interferences with the Earth's life support systems – through global warming, land degradation, ocean acidification, and the reckless exploitation of limited resources – becomes clearer every day, it has so far failed to evoke concerted countermeasures by the international community.

This gathering is one of the first major climate-change conferences after the COP15 in Copenhagen that ended without a clear mandate for the protection of the atmosphere, so there is plenty of work to be done here!

With my very best wishes,

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Nova Acta Leopoldina NF *112*, Nr. 384, 17–19 (2010)

Welcome Address

Gunnar Berg ML (Halle/Saale)

Member of the Presidium of the Leopoldina Academy

Dear Minister of State at the Foreign Office, Mrs. Cornelia Pieper!
Dear President of the Humboldt University, Professor Christoph Markschies!
Dear Colleagues Wilfried Endlicher and Friedrich-Wilhelm Gerstengarbe!
Ladies and Gentlemen!

It is a pleasure for me to welcome you on behalf of the German Academy of Sciences Leopoldina to the conference "Continents under Climate Change". First, however, I would like to congratulate the Humboldt University on its 200th anniversary, also on behalf of the Presidium of the Leopoldina Academy and especially of our President, Professor Hacker, who unfortunately cannot be here today. One can say that there is a connection between Humboldt University and Leopoldina in so far as one of the co-founders of the University, Alexander von Humboldt, became a member of our Academy in 1793. Therefore we are very pleased that this conference, which takes place in cooperation with our Academy, is part of the anniversary events and therefore a kind of gift of the Academy to the University.

I would like to thank our member Professor Endlicher from Humboldt University for having taken the initiative to organize and to hold the conference. I would also like to thank the Potsdam Institute for Climate Impact Research and its fellow Professor Gerstengarbe as co-organizer of the conference as well as the German Federal Foreign Office and its Minister of State, Mrs Cornelia Pieper, for being patron of our conference. Furthermore, I would like to thank the supporters of the conference, the enterprises Münchener Rück, GASAG, Siemens, Vattenfall, Bosch and Bayer. Last but not least, I would like to thank all people presenting papers or chairing sessions, especially our colleagues from abroad.

The topic of the conference "Continents under Climate Change" is a very important one as we know from the partly controversial discussion over the last years. We expect interesting lectures and discussions during these three days, but I do not want to anticipate the conference program, because outstanding experts are gathered here. Instead I will use the opportunity to give a short insight into the Leopoldina.

The Academy was founded shortly after the Thirty Years War in 1652 by four physicians in Schweinfurt. So the Leopoldina is the oldest continuously existing Academy of the world, even older than for example the Royal Society. The aim of the Leopoldina has always been the exploration of nature to the practical benefit of humankind. Therefore the working field of the Leopoldina traditionally includes medicine, mathematics and natural sciences. The seat of the Academy changed depending on the place of residence of its president, but since 1878 Halle has been the permanent seat of the Academy, because the size of the library and the archive, which had increased substantially by that time, made a removal more difficult.

The Leopoldina is a German Academy, but with international members. About a third of the 1,200 members of our Academy are from outside of the German-speaking countries Germany, Austria and Switzerland. The members of the Academy are organized in sections. I have already mentioned the working fields medicine, mathematics and natural sciences, but another traditional field of interest of the Academy is the history of natural sciences and medicine. Recently, however, the interdisciplinary work is increasing and methods of the natural sciences are becoming part of the so called human and social sciences. Therefore, at the end of the 1990s, the Senate of the Academy organized the sections in a new manner and opened its circle to different disciplines with a background similar to that of natural sciences. That means, sections, working with so-called exact methods, were founded. One example is the Section of Economics and Empirical Social Sciences, which means economics in a quantitative sense. Another example is the Section of Psychology and Cognitive Sciences. Last but not least I would like to mention as a third example the Section of Engineering Sciences.

An important aim of the Academy is to make a contribution to public debate. The organization of meetings, symposia and conferences at different locations in Germany has a long tradition. Increasingly such events also take place outside of our country, for example in the last years in France, in Hungary, but also in China and in India, as a rule jointly organized with the academies of those countries.

For some years, the Academy has been giving science-based policy advice. So-called *ad hoc* commissions deal with problems, which are significant for public debate. Recent examples are the statement in support of a new policy on Green Genetic Engineering and the statement on a concept for Energy Research in Germany. Both papers were worked out in strong cooperation with other academic institutions in Germany. Another activity of the Academy refers to the so called G8 plus 5-Summits, where the Academies of those countries prepare recommendations and statements on important scientific and social topics. The Leopoldina represents Germany in this circle. In preparation of the Heiligendamm-Summit our Academy was in charge of the scientific program. Also participants of this conference were involved in working out the recommendation on Global Response to Climate Change, which was handed over to the heads of government of the participating countries of the Summit.

Probably all those activities contributed to the appointment of the Leopoldina as the National Academy of Sciences by the Federal Minister Annette SCHAVAN, in the presence of the Federal President Horst KÖHLER, in 2008. As National Academy, the Leopoldina represents Germany in international institutions, where national academies are working together. Apart from that, the Academy is responsible for the preparation of papers and statements for advising politics and politicians in Germany, in cooperation with the Academy of Engineering Sciences acatech and the Union of the German Academies of Sciences and Humanities. I believe that this conference will contribute to the important discussion of climate change, which can also influence future Academy papers on that topic.

Once more I would like to thank the local organizers for their efforts in preparing this conference and, on behalf of the Presidium of the Leopoldina, I wish all participants a successful conference, interesting lectures and discussions, an optimistic outlook for the future, and, if time allows, a nice stay in Berlin outside this hall.

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Address

Guido Westerwelle (Berlin)

Federal Foreign Minister

Global warming and its effects will have a profound impact on our way of live and our economic activities. Countries in both North and South face this challenge in equal measure. However, it will be countries in Asia, Africa, Latin America, and the smaller island states that will be worst hit by climate change. They are rightly counting on the cooperation and help of the international community. For tackling climate change is one of the greatest challenges of humankind. It is the task of the entire international community of nations to find the right responses to the global questions raised by climate change.

Germany wants to help shape the international regulatory framework for the market economy in such a way that all participants in economic life can and will do their bit to reduce global warming. Sustainable economic structures and climate-friendly investments are aimed at achieving both ecological and economic goals. In order to reduce emissions, the German Government is promoting innovations in renewable energies and energy efficiency. It is looking for ways of ensuring that modern climate-friendly technologies are adopted everywhere. German enterprises lead the world when it comes to environmental technology. By investing in innovative technologies, they are making a sustainable contribution towards stimulating the global economy, which has been weakened by the economic and financial crisis.

This tremendous task for policy-makers, business and societies worldwide can only be mastered on the basis of an in-depth and comprehensive scientific discussion. In order to do justice to the complexity of the ecological and social challenge, scientific climate research must take into consideration the political and socio-economic impact of climate change. Therefore, I am particularly pleased that experts from quite different branches and from various regions of the world have brought their research results and ideas to Berlin to devise recommendations. Nothing embodies the concept of a university more than scientific cooperation beyond borders – be it borders between different fields of research, or borders between countries and continents. Thus, I am delighted that your conference is celebrating the 200th anniversary of the Humboldt-Universität zu Berlin.

I hope you all have a successful conference, interesting encounters as well as a fruitful exchange, and wish you all the best for your own personal future!

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Message

Klaus Wowereit

Governing Mayor of Berlin

Berlin welcomes you to the "Continents under Climate Change" conference.

There's no doubt about it – the worldwide fight against climate change could use some new momentum. Over the past few years, scientists have called for swift and decisive action on the basis of solid data on the dangers of global climate change. Your voice is needed yet again to remind the international community of its responsibility after the failure of the conference in Copenhagen.

I am delighted that your congress is taking place in Berlin. Not only does it pay tribute to the German capital city region's scientific excellence in the area of climate protection, it also spotlights the rich academic tradition we are looking back on in 2010, Berlin's Science Year. The institutions celebrating anniversaries right now include the *Humboldt-Universität*, your conference host, which was founded 200 years ago.

Climate change ranks among the greatest challenges we face today. Large cities, which are responsible for the vast majority of harmful emissions, bear a special responsibility for moving the international community towards a less destructive economic approach. Berlin has been confronting this challenge for years now, and considers itself a trailblazer in effective and innovative climate protection. The programs and measures already instituted range from renovating most of our existing buildings to make them more energy efficient, expanding the use of renewable energy and combined heat and power, and promoting climate-friendly mobility options to forging an alliance with big companies in Berlin who have committed themselves to protecting the climate and are documenting their efforts in regular reports.

The necessity of change also holds enormous opportunity, since effective climate protection also pays economic benefits. In Germany's capital city region alone, more than 500 Green Economy companies are already giving work to at least 40,000 people. With all this in mind, I would like to welcome you again to Berlin and to wish you a stay that is both inspiring and eventful. Above all, however, I hope that your conference will help to bring new energy to international efforts to step up climate protection.

Nova Acta Leopoldina NF *112*, Nr. 384, 25 (2010)

Address

Katrin Lompscher (Berlin)

Senator for Health, the Environment and Consumer Protection

Dear participants,

The conference "Continents under Climate Change" held in Berlin on 21 to 23 April 2010 will take place about four months after the UN-Climate Summit in Copenhagen.

Much to our regret, that summit has not led to a follow-up agreement to the Kyoto Protocol which will expire in 2012. Although the European Union has recently communicated that it considers it unlikely that a follow-up agreement could be concluded already this year, we hope that current negotiations on the basis of the minimum consensus achieved in Copenhagen in December 2009 will step by step help draw up a new legally binding agreement to govern global action on climate change after 2012.

However, we are losing precious time in our effort to effectively fight against climate change on the global level. And this is even more problematic since we can already feel the impacts of climate change.

Besides gradual changes in the livelihoods of the diverse forms of life on earth, there are more frequent and intense extreme weather events in metropolitan regions. Long lasting heat periods, storms and extreme rains are increasingly threatening people living in those densely built-up urban areas. The effects of those developments will also be felt in the German capital.

According to climate forecasts for the future, Berlin will have to adapt to a climate within the next fifty years, which nowadays is typical for cities such as Rome or Madrid. Climate change will among others threaten our water supply and cultural landscape as well as jeopardize the livelihood and health of the local population. That is why, we have to develop adaptation strategies today to cope with the climatic conditions of tomorrow. In this context, exchange and cooperation with other German federal states and research institutions are extremely important. I am convinced that they are even more important in view of the exchange on the international level.

The Humboldt-University of Berlin has a great history since many internationally renown scientists and researchers, such as Wilhelm and Alexander von Humboldt, have shaped the profile of the university for many centuries. The fact, that this university has, on the occasion of its 200 anniversary, invited experts from all over the world to discuss global impacts of climate change makes Berlin proud and confident, for we think that those experts would give an important impetus for the solutions to the challenges we are facing at present.

I wish you a successful conference and an interesting stay in Berlin.

Keynote

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A Tipping-Elements Expedition in the Footsteps of Alexander von Humboldt

Veronika Huber and Hans Joachim Schellnhuber ML (Potsdam)

With 1 Figure

Abstract

When Alexander von Humboldt set out to explore the American continent, he came across terrestrial and marine (eco-)systems that are considered tipping elements today. Small perturbations linked to climate change may trigger abrupt and/or irreversible change in these systems. If Alexander von Humboldt had undertaken his expedition in modern times, he might have studied potential tipping behavior of the marine biological carbon pump, the Amazon rainforest, coral reefs in the Caribbean Sea, and the El Niño-Southern Oscillation (one of the major oceanic/atmospheric circulation modes on Earth). Likewise, when he later travelled across the vast plains of Russia, he might have been most interested in signs of approaching tipping points in boreal forests, permafrost soils, Tibetan glaciers, and marine methane hydrates off the Siberian coast. Here, we follow Alexander von Humboldt on a mental journey. We present recent scientific findings on tipping elements that are located along his expedition routes. To conclude, we sketch a research agenda whose successful completion would provide society with the knowledge and tools required to handle the risks arising from tipping elements.

Zusammenfassung

Auf dem Weg, den amerikanischen Kontinent zu erforschen, stieß Alexander von Humboldt auf Regionen und Ökosysteme – auf dem Land und im Meer –, die heute als Kippelemente im Erdsystem betrachtet werden. Kleine Störungen, bedingt durch den Klimawandel, könnten in diesen Systemen zu abrupten und/oder irreversiblen Veränderungen führen. Wäre Alexander von Humboldt heutzutage auf seine Forschungsreise aufgebrochen, hätte er wohl das Kipprisiko der biologischen Kohlenstoffpumpe im Atlantik, des Amazonas-Regenwaldes, der tropischen Korallenriffe in der Karibik und des ENSO-Phänomens (eines der bedeutendsten atmosphärisch-ozeanischen Zirkulationsmuster der Erde) studiert. Später – auf seiner Reise durch das russische Zarenreich – hätte er wahrscheinlich mit großem Interesse nach Zeichen sich nähernder Kipppunkte in den borealen Nadelwäldern, in den Permafrostgebieten, in den ostasiatischen Gletscherregionen und bei den Methanhydraten vor der Sibirischen Küste gesucht. In diesem Aufsatz gehen wir mit Alexander von Humboldt auf Reisen. Wir diskutieren neueste Forschungsergebnisse zu Kippelementen, die entlang seiner Reiserouten gelegen sind. Zum Abschluss umreißen wir eine Forschungsagenda, die darauf abzielt, die Gesellschaft mit dem notwendigen Wissen und den Werkzeugen auszustatten, um den Risiken der Kippelemente in geordneter Weise zu begegnen.

On 5 June 1799, Alexander von Humboldt left La Coruña on board of a Spanish ship, heading towards the American continent. He was accompanied by one scientific partner, the botanist Aimé Bonpland, and with them they had taken innumerable measuring instruments. His intentions were to shed light “on the interactions of all forces, the effect of the inanimate creation on flora and fauna” (Moheit 1993). During the five years that followed he crossed the North Atlantic, explored the Amazon rainforest, climbed the Andean mountains, and sailed along the West coast of South America and through the Caribbean Sea.

Humboldt probably never imagined that, in the not-so-distant future, humans would become a planetary force, with the power of significantly transforming the processes and objects that he was studying. At a time when less than one billion people lived on Earth, humans – rather unsurprisingly – did not belong to the "forces", whose interactions Humboldt set out to investigate. If he had repeated his exploration along the same route in modern times, he might have called his trip a "tipping elements expedition to the Americas".

He might have intensively studied the marine biological carbon pump while crossing the Atlantic, the rainfall regime of the Amazon rainforest, parts of the El Niño-Southern Oscillation (ENSO), and tropical coral reefs of the Caribbean Sea. (The prospect of an ENSO shift towards more persistent El Niño conditions [see below], implying a vanishing Humboldt Current along the West coast of South America, would have probably worried him most …) All of these (sub-)systems fulfill the criteria of tipping elements in the Earth's climate system.

When Alexander von Humboldt, thirty years after his expedition to the Americas, toured the vast plains, extensive forests and swamps of Tsarist Russia, he also came across regional features and ecosystems that are considered potential tipping elements today. In modern times, he might have observed melting of permafrost, massive disturbance of boreal forests, retreating of Tibetan glaciers, and destabilization of methane hydrates along the East Siberian Arctic coast.

1. Definition of Tipping Elements

A tipping element is a component of the Earth system that is at least subcontinental in scale and might be switched to a qualitatively different state by small perturbations (Lenton et al. 2008). A tipping point is the associated critical threshold of a pertinent forcing parameter at which the (future) qualitative change is triggered. The formal definition of tipping elements encompasses a variety of phase transitions. The system might run through a bifurcation and show hysteresis, such that recovery is much slower than the initial state switch. Systems that produce quasi-continuous transitions with full reversibility might also qualify as tipping elements (Lenton et al. 2008, Lenton and Schellnhuber 2010). All tipping elements contain some type of internal feedback mechanism triggered by (or coupled to) the climate that gives rise to highly non-linear dynamics.

Paleoclimatic data suggests that the Earth's past climate system has many times undergone large-scale regime shifts, i.e. has passed tipping points (Alley et al. 2003). Based on these observations, one can conjecture that the forcing deployed by the anthropogenic emissions of greenhouse gases – if unchecked – might similarly bring about abrupt and possibly irreversible changes in the Earth system. Gauging the scientific deliberations about tipping elements to society's needs, Lenton et al. (2008) have proposed additional criteria that define "policy-relevant" tipping elements. In short, this subset of tipping elements are defined as those elements which (*i*) include a tipping point that could be crossed already this century, and (*ii*), as a consequence, experience a qualitative change in state within this millennium, affecting a large number of people (Lenton and Schellnhuber 2010).

2. Starting Point and Overview

Lenton et al. (2008) presented a shortlist of nine policy-relevant tipping elements. At present, the scientific community is still far from providing comprehensive risk assessments and definite conclusions on tipping elements (Schellnhuber 2009). However, since the publication of Lenton et al.'s shortlist, considerable progress has been made in identifying critical forcing thresholds and in narrowing down likelihoods of passing a tipping point. The main aim of this paper is to present advances in the science related to specific tipping elements. The update is based on recent literature, particularly a recent Special Feature of the *Proceedings of the National Academy of Sciences* on tipping elements (2009) and a review by Lenton and Schellnhuber (2010).

Figure 1 depicts a map of potential tipping elements that will be discussed. We do not present an exhaustive overview of currently investigated or suspected tipping elements. Instead, we limit our discussion to some tipping elements that are located along Humboldt's expedition routes.[1] Tipping elements, whose status is particularly uncertain, are denoted with a question mark. For each tipping element, we consider (*i*) the known internal feedback processes that can give rise to threshold behavior, (*ii*) recent advances in the understanding of these feedbacks, (*iii*) observational records of key indicators from the recent past, and (*iv*) critical temperature thresholds (if known) and the likelihood of passing a tipping point this century.

3. Tipping-Elements Expedition to the Americas

Marine biological carbon pump? – Global oceans currently absorb approximately 2 Gt carbon per year, which is equivalent to around 20 % of annual anthropogenic carbon emissions (Le Quéré et al. 2009). Sequestering of carbon by the oceans is largely mediated by the so-called biological carbon pump, i.e., the fixation of carbon by algal photosynthesis and the export of organic carbon to deeper ocean layers. Increasing temperatures and acidifying waters may affect this biological pump in a multitude of non-linear ways. Deoxygenation of large ocean domains, linked to warming, acidification and nutrient enrichment (Hofmann and Schellnhuber 2009, Keeling et al. 2010), may also contribute to triggering a qualitative change in marine biological productivity. Therefore, a rapid decline in the ocean carbon sink as well as ocean anoxia have been discussed as potential tipping points in the oceans (Lenton et al. 2008, Kriegler et al. 2009).

Recently, it has been suggested that tipping-element behavior of the biological carbon pump primarily arises from the detrimental effects of ocean acidification on marine calcifying organisms (Riebesell et al. 2009). Reduced biogenic calcification critically lowers the supply of calcium carbonate, which serves as a carrier of organic carbon and forms a critical component of the mineral ballast transport to the deeper ocean. Weakening of the biological pump translates to a positive feedback on atmospheric CO_2 concentrations and in turn on ocean acidification. However, large uncertainties about the mechanisms involved remain. The attenuation of biogenic calcification also creates a negative, stabilizing feedback on at-

1 For a complete discussion of currently known tipping elements the reader is referred to Lenton and Schellnhuber (2010).

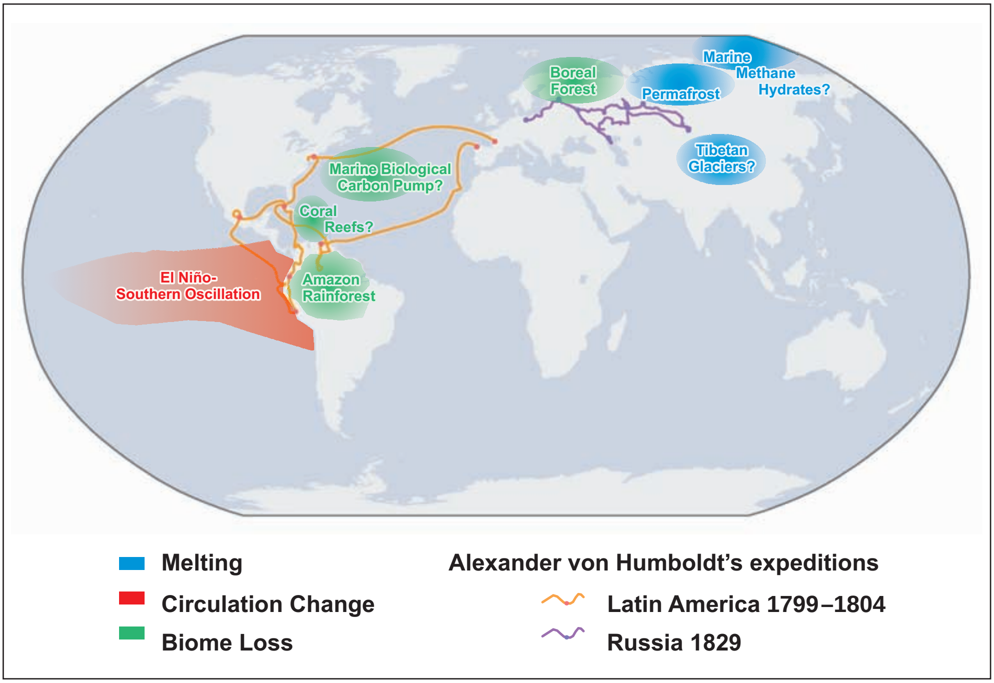

Fig. 1 Selected potential tipping elements in the Earth system alongside Alexander von Humboldt's expedition routes to the Americas and Russia. Tipping elements are large-scale features of the Earth system that may undergo a qualitative change in response to small (climatic) perturbations. Tipping elements shown in blue involve melting of large masses of ice, those shown in red involve changes in atmospheric and oceanic circulation patterns, and those shown in green involve loss of unique biomes. Source: Martin Wodinski and Veronika Huber 2010.

mospheric CO_2 levels, which according to one study (Hofmann and Schellnhuber 2009) may outweigh the positive feedback of a weakened biological pump. The loss of calcium-carbonate ballast could also be at least partially compensated by increased aggregation of organic matter and non-calcium-carbonate minerals in carbon-enriched waters (Riebesell et al. 2009). Additional feedbacks may arise from the marine nitrogen cycle, which is closely linked to the biological carbon pump and oxygen saturation of the oceans. Recent studies suggest that deoxygenated oceans could outgas more nitrogen oxide (N_2O), acting as a very potent greenhouse gas (Codispoti 2010).

It is now a well-established fact that oceanic CO_2 uptake of the last century has made the marine pH drop from 8.2 to 8.1 (Orr et al. 2005). Shell thinning in calcifying organisms has been documented in the field. However, it remains to be resolved whether the latter observation can be clearly attributed to ocean acidification (de Moel et al. 2009). Negative effects of acidification on biological calcification rates have been unambiguously demonstrated in experimental studies (Riebesell et al. 2009). It is still under debate, though, whether these are species-specific and confined to the laboratory or whether they can be generalized to entire groups of calcifying organisms and the open oceans (Ridgwell and Schmidt 2010). To our knowledge, no study has yet presented clear evidence for a weakening of the biological carbon pump due to the ocean acidification over the last century.

Under business-usual-scenarios, CO_2 concentrations might reach 800 ppm by the end of the century, implying a drop in ocean pH of 0.3 – 0.4 units (Orr et al. 2005). Bloom-forming coccolithophore species, especially important for carbon export to the deep ocean, have shown significant declines in calcification rates when exposed to 750 ppm CO_2 (Riebesell et al. 2000). In recent model studies, however, much higher CO_2 atmospheric concentrations on the order of >1500 ppm needed to be reached until considerable responses in the marine biological carbon pump could be observed (Hofmann and Schellnhuber 2009). In summary, no definite conclusions can be drawn yet on the existence of a policy-relevant tipping point in the marine biological carbon pump.

Amazon rainforest – Droughts in Amazonia tend to cause (partial) dieback of the rainforest, and a reduction in forest cover, in turn, tends to amplify the decrease in precipitation. Several processes give rise to this positive feedback loop and the possibility of tipping-element behavior of the system (Betts et al. 2004). First, deforestation reduces the local evaporative recycling of water in the Amazon basin. Second, forest dieback releases large amounts of CO_2 into the atmosphere. Third, rising CO_2 concentrations may suppress precipitation over the Amazon region by altering atmospheric and oceanic circulation patterns (towards more persistent El Niño) and by directly affecting plant physiology (involving increased stomatal closure and decreased transpiration). Additional feedbacks that amplify forest dieback arise from ecosystem disturbance processes such as increased fire frequency and pest infestation. Lenton et al. (2008) noticed that the Amazon rainforest "may exhibit bistability" (i.e., may exist in either of two distinctive states, depending on the medium-term history) and included it in the list of policy-relevant tipping elements.

The occurrence and extent of forest dieback in climate forecasts differs among models. Dieback is less sensitive to the choice of vegetation model, but not all global climate models (GCMs) project a reduction of precipitation over the Amazon basin (Salazar et al. 2007, Lenton and Schellnhuber 2010). Recently, Malhi et al. (2009) found that many GCMs underestimate current rainfall in the region. Correcting for this bias shifts forecasts in the direction of seasonal forests rather than replacement by savannah-type ecosystems. Yet a recent analysis has indicated that the Amazon rainforest may lag climate forcing significantly (Jones et al. 2009). Therefore, it may be committed to considerable dieback long before the loss of forest cover becomes apparent.

The western and southern parts of the Amazon basin experienced a severe drought in July to October 2005. Rivers fell dry, and some forested areas that had been a carbon sink turned into a source of CO_2 (Phillips et al. 2009). Reduced precipitation was linked to unusually warm sea-surface temperatures in the North Atlantic (Cox et al. 2008). Also, weakening of the tropical Pacific atmospheric circulation, affecting the length of the Amazon dry season, has been observed since the mid-nineteenth century (Vecchi et al. 2006).

Dry-season water stress is likely to further increase in Amazonia. One model predicts that the drought of 2005 may become the norm as early as 2025 (Cox et al. 2005). Several models show dieback of up to 70 % of Amazon rainforest by the end of this century (Cook and Vizy 2008). However, the likelihood of passing a tipping point this century will depend largely on whether the natural resilience of the forest can be maintained or not (Malhi et al. 2009). Fire ignition associated with logging and forest fragmentation act as nucleation points that may speed up the transition to seasonal, low-biomass forests and savannah. Experts estimate that dieback of the Amazon rainforest is more likely than not if global warming exceeds 4 °C (Kriegler et al. 2009). A recent study concludes that the risk of significant loss of forest cover in Amazonia increases rapidly for a global mean temperature rise above 2 °C (Jones et al. 2009).

El Niño-Southern Oscillation (ENSO) – The El Niño-Southern Oscillation (ENSO) phenomenon is the strongest internal climate mode on year-to-year timescales. ENSO manifests itself most conspicuously in the sea-surface temperatures of the central equatorial Pacific. The warm extreme is called El Niño, the cold La Niña. ENSO affects regional and global climate, e.g., ENSO has contributed to the record global surface temperatures of 1998. Strong feedback processes, involving sea-surface temperatures, thermocline depth, and atmospheric circulation cells, drive the oscillations between El Niño and La Nina states (Latif and Keenlyside 2009). Paleo-data suggests that warmer climates might have been accompanied by more persistent El Niño conditions (Wara et al. 2005). Lenton et al. (2008) considered there "to be a significant probability of a future increase in ENSO amplitude" with the "required warming to be accessed this century".

The first coupled model studies predicted a future shift from current ENSO variability to more persistent or frequent El Niño conditions. More recent analysis indicates that models do not produce any consistent response of ENSO to global warming (Latif and Keenlyside 2009). Some models exhibit increases in amplitude and/or frequency, some decreases, and some no change at all. If a tendency can be identified at all among models, it is a trend towards an El Niño-like mean state change of the ENSO (Solomon et al. 2007). One recent study forecasts a shift toward so-called Modiki events, which correspond to modifications of the typical El Niño pattern (Yeh et al. 2009). During these events, the warm pool shifts from the West to the middle rather than to the East of the equatorial Pacific.

Over the past half century sea-surface temperatures in the equatorial Pacific have increased, with an El Niño-like trend pattern, i.e., stronger warming in the East relative to the West. However, according to Latif and Keenlyside (2009), sea-surface temperatures do not yet provide unambiguous evidence for significant changes in either ENSO activity or mean state. At the same time, recent studies show that the canonical El Niño has become less frequent and that Modiki events have become more common during the late twentieth century (Yeh et al. 2009).

Large uncertainties persist about the response of ENSO to additional global warming of the twenty-first century. One model simulates increased El Niño amplitude when climate stabilizes at 3 – 6 °C higher global temperatures (Guilyardi 2006). Others suggest that tipping-element behavior, in the sense that ENSO vanishes or becomes overly strong, is very unlikely to occur until the end of this century (Latif and Keenlyside 2009). However, even a gradual change in amplitude or location of El Niño could entail severe consequences in many regions.

Coral reefs? – Experts agree that acidifying and warming oceans might trigger widespread coral bleaching and reef collapse. Yet Lenton et al. (2008) did not include coral-reef systems in their shortlist of policy-relevant tipping elements. In contrast, marine biologists now talk about a 'point of no return' as rising CO_2 emissions put coral reef system increasingly under pressure (Veron et al. 2009).

Hence the world's largest coral reef systems, such as the Great Barrier Reef and the cold-water coral-reef systems extending from Northern Norway to the West coast of Africa, may turn out to be tipping elements in the Earth system (Lenton and Schellnhuber 2010). Abrupt changes in coral reef systems are expected as ocean acidification causes the aragonite (a crystalline form of calcium carbonate) saturation horizon to shallow (Riebesell et al. 2009). Once bathed in corrosive water, skeletons and shells may dissolve and the reef could collapse. Cold-water coral reefs that grow down to 3000 m depth are particularly vulnerable to ocean acidification. Also, a clear causal link between increasing ocean temperatures and mass bleaching events in the tropical coral reefs has been established (Hughes et al. 2003). The geological record suggests that reefs take thousands to millions of years to re-establish after massive extinction events (Veron et al. 2009). Thus, they could be irreversibly lost on human timescales.

Anthropogenic penetration of CO_2 into the oceans has contributed to a shoaling of the aragonite saturation horizon by 30–200 m from the preindustrial period to the present (Doney et al. 2009). Upwelling of corrosive waters has been observed on the continental shelf off the West coast of North America, decades earlier than had been predicted by models (Feely et al. 2008). Decreasing calcification rates in corals have been recorded worldwide, most prominently on the Great Barrier Reef (De'ath et al. 2009). In response to increasing sea-surface temperatures, the extent and severity of coral bleaching in the tropics has also dramatically increased in recent decades (Veron et al. 2009).

If CO_2 emissions remain unabated, 70 % of the presently known cold-water coral reef locations may be affected by aragonite undersaturation by the end of the century (Guinotte et al. 2006). Adaptation and migration capacities increase resilience, but may not keep up with the speed of acidification (Ridgwell and Schmidt 2010). Increases in sea-surface temperature of 1 °C to 3 °C – likely to take place already this century even if ambitious global mitigation measures are undertaken – are projected to result in more frequent coral bleaching events and widespread mortality unless there is substantial (and surprising) thermal adaptation or acclimatization by corals (Smith et al. 2009, Veron et al. 2009).

4. Tipping-Elements Expedition to Russia

Boreal forests – Documented incidents of species invasions of the past demonstrate the potential for abrupt change in boreal ecosystems (Chapin et al. 2004). It is a general ecological phenomenon that species alter their environments so as to improve their competitive abilities and increase their survival chances. For example, black spruce is a strongly fire-adapted tree of the boreal zone that itself promotes fire through its high flammability. This type of internal feedback mechanisms may amplify the response of boreal vegetation to climate change. Lenton et al. (2008) explain that a combination of increased temperature and drought stress, fire frequency, and pest infestations may rapidly shift boreal forests to a new biome type, consisting of open woodlands and grasslands, once certain critical thresholds have been passed.

Besides the potential dieback of coniferous forests, the expansion of deciduous forests northwards into the tundra has recently been intensively discussed as another important consequence of climate warming in the boreal zone (Soja et al. 2007). A new model analysis shows that positive feedbacks associated with the global carbon cycle are largely driven by increasing forest cover in northern latitudes (O'Ishi et al. 2009). Expanding forests on formerly bare grounds in the Arctic region strongly reinforce regional/global warming by changes in land-surface albedo and transpiration of water vapor (Swann et al. 2010). However, albeit important as a feedback mechanism, the northward migration of the tree line is less likely to involve an abrupt switch to a qualitatively different state. In fact, the tree line is expected to move rather gradually because, at the northern limits of species ranges, competitive species interactions are less important than in central portions of the boreal forests (Chapin et al. 2004).

Mild weather conditions of recent years have brought outbreaks of insect pests damaging boreal forests all across the circumpolar region (Berg et al. 2006, Soja et al. 2007). The boreal forest in Western Canada, for example, is currently suffering from a disastrous invasion of mountain pine beetle that has caused widespread tree mortality (Kurz et al. 2008). Moisture-stress-related dieback in white spruce trees in Alaska has also been documented (Barber et al. 2000). Extreme fires have occurred more frequently and have affected larger boreal areas in all of Alaska, Canada and Siberia, concurrent with rising temperatures of recent decades (Soja et al. 2007).

According to expert elicitation, dieback of the boreal forest is more likely than not if global warming exceeds 4 °C (Kriegler et al. 2009). At least one model predicts widespread replacement by grasslands when regional temperatures reach around 7 °C above present (Lenton and Schellnhuber 2010). Further research is required to confirm these temperature thresholds and the possibility of passing a tipping point this century.

Yedoma permafrost – Perennially frozen soils in the Northern circumpolar regions may contain the gigantic amount of up to 1500 Gt organic carbon (Tarnocai et al. 2009). If only part of this carbon reservoir was mobilized, and degassed as either CO_2 or methane, a substantial positive feedback on global warming would result. Lenton et al. (2008) did not include permafrost regions in their shortlist of policy-relevant tipping elements because thawing of soils was considered to happen in a "quasi-linear" manner.

On the other hand, Khvorostyanov et al. (2008) have recently shown that during mobilization of highly labile frozen carbon deposits, so-called Yedoma, threshold behavior may arise from microbial decomposition activity that generates additional heat. In their simulations, a comparatively small amount of external heat was sufficient to trigger irreversible thawing. Yedoma consists of frozen carbon loess (windblown dust), occurring predominantly in northeastern Siberia. Once started, thawing processes could release 2.0–2.8 GtC per year over a century, transforming up to ~ 75 % of the initial carbon stock into CO_2 and methane.

When Yedoma thaws, melting of ice wedges releases large amounts of water. While part of the melt water runs off in summer, it also creates long-lasting thaw lakes, which are a significant source of methane. These so-called thermokarst lakes have expanded across northeastern Siberia, concurrent with regional warming since the mid-1970s, and have contributed to a significant increase in methane emissions (Walter et al. 2006). In the Yedoma permafrost region, the soil depth at which active cycling of carbon takes place has also increased by at least 10 cm over the second half of the twentieth century (Sazonova et al. 2004, Khvorostyanov et al. 2008).

The tipping point marking irreversible decomposition of Yedoma permafrost soils may lie at around > 9 °C additional regional warming (Khvorostyanov et al. 2008). Given polar amplification of global warming, under high emission scenarios this magnitude of temperature rise can well be reached by 2100. Thus, the Yedoma permafrost has recently been added to the list of policy-relevant tipping elements (Lenton and Schellnhuber 2010).

Ocean methane hydrates? – Estimates of the global inventory of methane hydrates in the ocean range from 700 to 10,000 GtC (Archer et al. 2009). As heat diffuses into the ocean sediment, hydrates melt and methane may be released into the ocean waters, and subsequently into the atmosphere. Destabilization of marine methane hydrates might have been an important positive feedback mechanism during major warming events in the Earth's history, such as during the Paleocene-Eocene Thermal Maximum around 55.5 Myr ago (Archer 2007) and, more controversially discussed, also during Quarternary deglaciations ("clathrate gun hypothesis"; Kennett et al. 2003, but see Sowers 2006). However, the melting of hydrates is thought to be taking place on a time scale of thousands of years (Archer and Buffett 2005). Lenton et al. (2008) did not classify ocean methane hydrates as a policy-relevant tipping element, because they considered the full draining of the reservoir – a qualitative change – "extremely unlikely to occur within this millennium".

Recent analyses have corroborated this conclusion. The only conceivable abrupt releases of methane triggered by warming oceans could originate from submarine landslides. These may be provoked by bubbles associated with the melting of hydrates. However, even the largest known landslide of the past (the Storrega slide off Norway around 8,150 years ago) has not released a climatically significant amount of methane to the atmosphere (Archer 2007). Based on current paleo-climatic evidence, the most likely impact of a melting hydrate reservoir is therefore a long-term chronic methane source (Archer et al. 2009).

Where hydrate deposits are located at great ocean and sediment depths, it will take hundreds to thousands of years until they are reached by the thermal perturbations of anthropogenic warming. The only significant release of methane from the ocean has been documented along the Arctic coastline of Siberia, where shallow shelf waters today are highly supersaturated with methane (Shakhova et al. 2005, Archer 2007). According to recent observations, the annual methane outgassing from these waters adds as much to the atmosphere as the entire methane emissions from the global oceans (Shakhova et al. 2010).

Archer et al. (2009) have estimated that, on timescales of several thousand years, the equivalent of between 35 Gt to 940 Gt carbon could be released from marine methane hydrates in response to a 3 °C uniform warming. The relatively small external forcing involved and the irreversibility of the release clearly qualify marine methane hydrates as a tipping element in the Earth system. However, unless a plausible mechanism for large-scale abrupt methane release is found, a qualitative change in the global reservoir of marine methane hydrates is extremely unlikely to occur within this millennium.

Tibetan glaciers? – The Hindu-Kush-Himalaya-Tibetan (HKHT) glaciers have recently been proposed to be a policy-relevant tipping element (Ramanathan and Feng 2008). If these glaciers disappeared, the regional impacts would be huge. Three of the largest rivers that drain these glaciers, the Indus, Ganges and Brahmaputra, alone currently supply around 500 million people with water for drinking, agricultural and industrial purposes (Kehrwald et al. 2008). The question, however, is whether the HKHT glaciers really qualify as tipping elements or whether they rather fall into the category of "high impact eventualities" that do no necessarily show threshold behavior (Lenton and Schellnhuber 2010).

To our knowledge, no study exists to date that has explicitly investigated tipping points associated with the melting of the HKHT glaciers. However, some feedback mechanisms involved in the waxing and waning of mountain glaciers have been identified. Most importantly, the snow-ice-albedo feedback that causes amplification of warming in high mountain regions (Pepin and Lundquist 2008) may generate non-linear responses of HKHT glacier melting. In addition, Oerlemans et al. (2009) have found that the deposition of dust on glacier snouts may considerably accelerate their retreat. As the glacier area decreases, it exposes side moraines that provide important sources of mineral dust. A feedback arises because mineral dust stimulates the growth of algae and lowers the surface albedo, thereby enhancing the melt rates of the glacier. Studying a glacier snout in the Swiss Alps, the authors measured a dust-caused decrease in surface albedo during a period of four years, which constituted a forcing equivalent to a rise in air temperature of ~ 1.7 °C.

The Himalayan/Tibetan region has experienced a decline in snow cover and an advance in the melt season during recent decades (Rikiishi and Nakasato 2006). Over the last half century, the Tibetan Plateau has warmed at around 0.36 °C per decade (Wang et al. 2008), more than twice as rapidly as global mean temperatures, which have risen by around 0.17 °C per decade (Solomon et al. 2007, p. 248). While a few glaciers in the HKHT region have increased in mass (Hewitt 2005), probably due to precipitation effects, loss in area and volume has been recorded at the majority of the sites (Solomon et al. 2007, chapter 4). For example, satellite data indicates that over 80 % of the glaciers in western China have retreated in the past fifty years (Ding et al. 2006). Widespread thinning of glaciers has been observed at elevations up to 6,000 m (Kehrwald et al. 2008).

Ramanathan and Feng (2008) named 1 to 3 °C global warming above preindustrial levels as the temperature range that might commit the environment to major reductions of area and volume of HKHT glaciers. However, due to inertia involved in the melting of large glaciers, it could take several hundred years until the majority of HKHT glaciers will have completely vanished (Paterson 2004). Some estimate that even small glaciers are unlikely to disappear before the end of the century (Schiermeier 2010; contrary to Parry et al. 2007, p. 493). Further research is required to elucidate whether HKHT glaciers constitute a policy-relevant tipping element, involving a temperature threshold that could be passed in the 21st century.

5. Conclusions: A Tipping-Elements Research Agenda

When still travelling in America, Alexander von Humboldt was appointed member of the Academy of Sciences based in Berlin. Later, upon return to his hometown, he became the driving force and focal point of the scientific community – in Prussia and beyond. In 1828, he organized and presided a natural science congress (‘Naturforscherkongress’), which was the first of his kind regarding interdisciplinary and international participation. If this conference had taken place in modern times, there would have certainly been a session on tipping elements in the Earth system. The great Alexander would have possibly presented an update on tipping elements that he had visited during his expeditions – just as we have done in this essay. At the end, he might have added his view on the most important research gaps. As a conclusion to our paper, we sketch three items of such a research agenda, aimed at providing society with the knowledge and tools to handle the risks arising from tipping elements.

Interactions among tipping elements – Tipping elements across the globe are closely interlinked. It is easily conceivable that abrupt changes in one of them triggers – in a domino-like process – tipping in others. For example, droughts in the Amazon basin have been related to a shift in the ENSO (Latif and Keenlyside 2009). First attempts have been made to elucidate critical teleconnections between tipping elements (Kriegler et al. 2009). However, much more research is necessary to gain a better understanding of the interactions among tipping elements and the potential additional risks arising from these interdependencies.

Impacts of passing tipping points – At some point in the future, societies may be confronted with a situation in which several tipping points are close. Limited capacities and resources (for instance, for investing in renewable energy sources or large-scale ecosystems management) might allow to avoid the passing of some, but not of all of them. A comprehensive impact assessment could then become the basis of deciding which tipping elements to focus on. Up to date, no convincing metric has been developed to properly quantify impacts of climate change, let alone of passing tipping points. Establishing such a metric is also the prerequisite for ranking tipping elements according to their associated risks today (Lenton and Schellnhuber 2010). Understanding the capacity of societies to absorb environmental shocks of the kind associated with tipping-elements activation is still intellectual *terra incognita,* waiting for exploration by contemporary Humboldts.

Identification of early-warning signals – Successful early-warning systems exist for hurricanes and tsunamis. These natural catastrophes are low-probability-high-impact events, similar to the passing of tipping points. Developing reliable methods to identify the proximity of tipping points far in advance would be of the highest value for society. Science has already identified several indicators signalizing that critical transitions in dynamic systems are close. Slower recovery from perturbation, increased autocorrelation and increase variance in time-series data are considered generic early-warning signals for a wide class of systems (Scheffer et al. 2000). Applying these indicators (and others) to paleoclimatic time-series data will contribute to testing their general validity. As a side benefit, new tipping elements might be identified that have so far not been thought of. However, one recent study cautions that the class of natural systems which exhibit leading indicators might be limited (Hastings and Wysham 2010). Where abrupt transitions occur without warning, the only possibility to forecast sudden changes is process-based modeling and simulation.

In summary, the emerging field of tipping elements in the Earth system poses research challenges that would match the capacities of giants like Alexander von Humboldt. Unfortunately, these giants do not abound and, more worrying, there may be little time left for them to do their job before irreversible environmental changes start to unfold.

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Changes of the Climate System in Europe

Heinz Wanner and Raphael Neukom (Bern, Switzerland)

With 7 Figures and 2 Tables

Abstract

After the Holocene Thermal Maximum the European climate was subject to a progressive cooling after about 4,500 years BP, called Neoglacial. It was mostly induced by the decreasing solar insolation in the Northern Hemisphere during the boreal summer, due to orbital forcing. The Neoglacial lasted until the preindustrial period. Cooler periods were interrupted by warmer sequences, due to changes in the natural forcing (solar activity changes, volcanic eruptions). The most recent example was the shift from the temperate Medieval Climate Anomaly to the cooler Little Ice Age. Present European climate is characterized by a remarkable warming. This process will continue in the 21st century, mainly due to the anthropogenic greenhouse effect. Warming will be most accentuated in northeastern Europe in winter and in the Mediterranean area in summer. Precipitation will increase in northern Europe (mostly in winter) and quite remarkably decrease in southern Europe (mostly in summer). These changes will cause both, negative and positive impacts on ecosystems and society.

Zusammenfassung

Nach der markanten mittelholozänen Erwärmung kühlte sich das Klima nach etwa 4500 Jahren vor heute auch in Europa zusehends ab und trat bis in die vorindustrielle Zeit in das kühlere Neoglazial ein. Der Grund lag vor allem bei der erdbahnbedingten Abnahme der Sonneneinstrahlung auf der Nordhemisphäre während des borealen Sommers. Auch während des Neoglazials lösten sich wärmere und kältere Phasen ab, vor allem hervorgerufen durch Schwankungen des natürlichen Strahlungsantriebes infolge von Vulkaneruptionen sowie Schwankungen der Solaraktivität. Das letzte und bekannteste Beispiel war der Wechsel von der mittelalterlichen Wärmeanomalie zur Kleinen Eiszeit. Das gegenwärtige Klima Europas ist gekennzeichnet durch eine allgemeine Erwärmung. Dieser Prozess wird auch im 21. Jahrhundert andauern, in erster Linie hervorgerufen durch den anthropogenen Treibhauseffekt. Die Erwärmung wird im Winter in Nordosteuropa und im Sommer im Mittelmeerraum am stärksten sein. Im Norden werden die Niederschläge vor allem im Winter zunehmen, im Sommer wird mit Schwerpunkt im Mittelmeerraum eine starke Niederschlagsabnahme eintreten. Diese Klimaänderungen werden in Europa sowohl negative als auch positive Einflüsse auf Natur und Gesellschaft haben.

1. Introduction

Europe reaches from the Mediterranean Sea to the Arctic Ocean (35°–85° N) and from the Atlantic Ocean to the Ural (25° W – 60° E). Meteorological observation and research in Europe has a very long tradition. Already in 1745 the Danish missionary Hans Egede Saabye wrote in his diary that "when the winter in Denmark was severe, the winter in Greenland was mild, and conversely" (Stephenson et al. 2003). This was possibly the first statement about the existence of the North Atlantic Oscillation. In 1780 the *Societas Meteorologica*

Palatina founded the first meteorological network around Europe with 39 stations, which were equipped with prescribed instruments. The network existed until 1795. The longest temperature timeseries in the world with monthly mean values for Kew (central England) starts already in 1659 (Manley 1974). In the mid-19th century national weather services with fixed networks were established in most European countries.

European weather and climate is strongly influenced by the dynamics of the northern hemisphere westerlies. Figure 1 shows the mean sea level pressure in the area of the northern hemisphere for boreal winter (*A*) and summer (*B*). Three pressure systems normally dominate European weather. During winter the Icelandic low is well developed, the Azores high is weaker, the meridional pressure gradient is also enhanced over the continent and, for longer time periods, westerly winds dominate. Over the Eurasian land mass an extended cold high pressure system forms, cold spells periodically invade central Europe and block the westerly winds, mainly during the high winter phase. In summer the Azores high extends further to the continental area and causes longer lasting heat periods mainly in southern Europe and the Iberian Peninsula. Over the large Eurasian continent several heat lows are formed. The main centre normally lies over Iran. Two main moisture sources feed the European precipitation systems, the Mediterranean Sea in southern and the North Atlantic Ocean in western Europe.

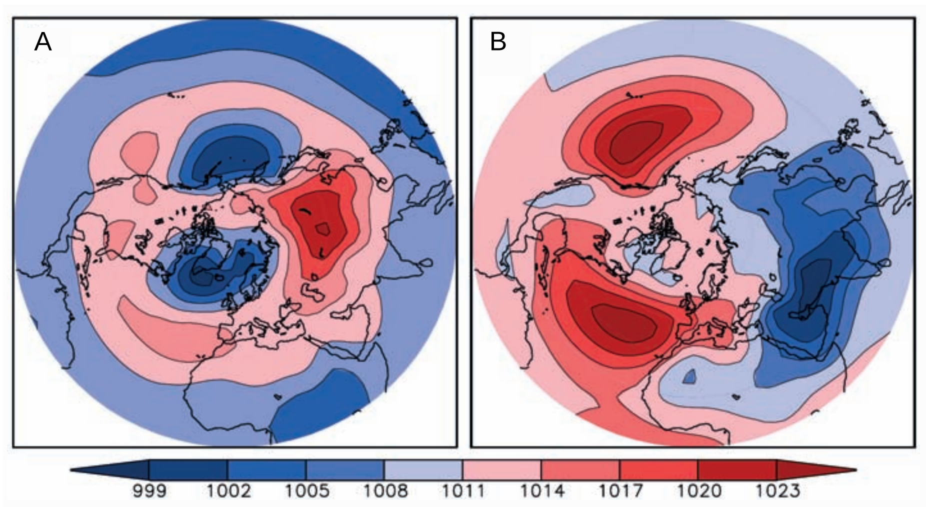

Fig. 1 Mean sea level pressure in the northern hemisphere during boreal winter (DJF; *A*) and summer (JJA; *B*), averaged over the years 1901–2006 (data source: HadSLP2r data set, Allan and Ansell 2006).

The long-term heat memory of the European climate system sits in the Atlantic Ocean, the upstream area of the westerly winds. Climate in this area is dominated by the interaction between the dynamics of the Arctic sea ice and the Gulf Stream, the northernmost branch of the Atlantic meridional overturning circulation. Figure 2 shows an overview of the mean ocean circulation in the surface layer between the Tropics and the Arctic area. Two important gyres are part of the three-dimensional circulation system, the subtropical gyre between Florida and western Africa, and the subpolar gyre south and west of Greenland. The water masses of the Gulf Stream and the North Atlantic and Norwegian Currents flow from southwest to northeast, transporting heat to northwestern Europe. The progressively cooling and salty water masses sink in the area southwest and southeast of Greenland, forming a deep water current in the opposite direction (not visible in Fig. 2) and driving the meridional overturning circulation. A smaller part of the warm surface current branches off and flows towards Iceland forming a third gyre.

Fig. 2 Overview of the main surface currents in the area of the Atlantic ocean between the Tropics and the northern Arctic area (source: Wikipedia).

2. From the Past to the Present

2.1 Holocene Climate Change

The last of likely more than 20 warm interglacials which occurred between the cold glacial cycles during the Quaternary, the last about 2.6 million years, is called Holocene. During the glacial periods, a vast area of northern Europe was covered by a continental ice sheet. According to Figure 3 the Holocene started around 11,700 years before present (BP; in this paper present means 1950 AD) after the warming at the end of the last glacial. Interestingly, this warming phase was interrupted by a cold reversal between about 12,900 and 11,700 years BP, called Younger Dryas. This cooling was most likely caused by a downturn of the meridional overturning circulation in the North Atlantic Ocean due to a massive meltwater influx from the Laurentide ice sheet (Broecker 2006).

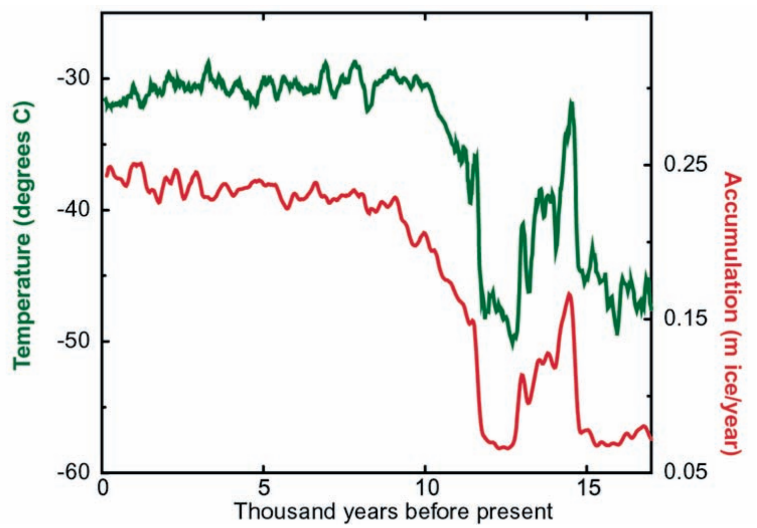

Fig. 3 The climate of Central Greenland during the last 17,000 years as a rough indicator for the Holocene climate in Europe. The reconstructed curves show mean temperature (green) and ice accumulation (red; after Alley et al. 1993).

The temperature curve in Figure 3 shows that, compared to the glacial period with its high number of interstadials, climate during the Holocene was relatively stable. Interestingly, the amount of ice accumulation in Greenland increased parallel to the rising temperature, possibly due to changes of the atmospheric circulation and the meridional overturning circulation in the Atlantic Ocean (Alley et al. 1993). The reconstruction indicates that the highest temperatures occurred between about 9,000 and 5,000 years BP. This period is called Holocene Thermal Maximum (other names are Hypsithermal, Altithermal or Holocene Climatic Optimum). After this period the melt of the large Eurasian ice sheets was finished. The main reason for the warming was the higher solar insolation during the northern hemisphere (boreal) summer due to changing orbital parameters (excentricity of the earth's orbit around the sun, obliquity of the earth axis and precession of the equinox). This is illustrated in Figure 4 which represents the insolation changes during the last 10,000 years at 65° and 15° north and south during the corresponding summer season. At about 4,200 years BP a cross-over with similar insolation values in both hemispheres occurred.

In Europe the high insolation values during the Holocene Thermal Maximum led to a northward shift of the Arctic forest limit up to 150 km compared to the present state (Prentice et al. 2000), and the ice volume of the Alpine glaciers was even smaller than today

(Ivy-Ochs et al. 2009). Despite the relatively low variability of the Holocene temperature a number of cold relapses was observed in the North Atlantic – European area or even globally (Wanner et al. 2008). Based on the analysis of hematite stained grains in ocean sediments in the North Atlantic, which were transported southward during cold periods by icebergs, Bond et al. (2001) defined totally nine such cold episodes, the so-called Bond cycles. Before the Holocene Thermal Maximum most of these cold relapses likely also occurred due to a damped meridional overturning circulation in the North Atlantic Ocean due to meltwater pulses form the Laurentide ice sheet, similar to the much stronger Younger Dryas event.

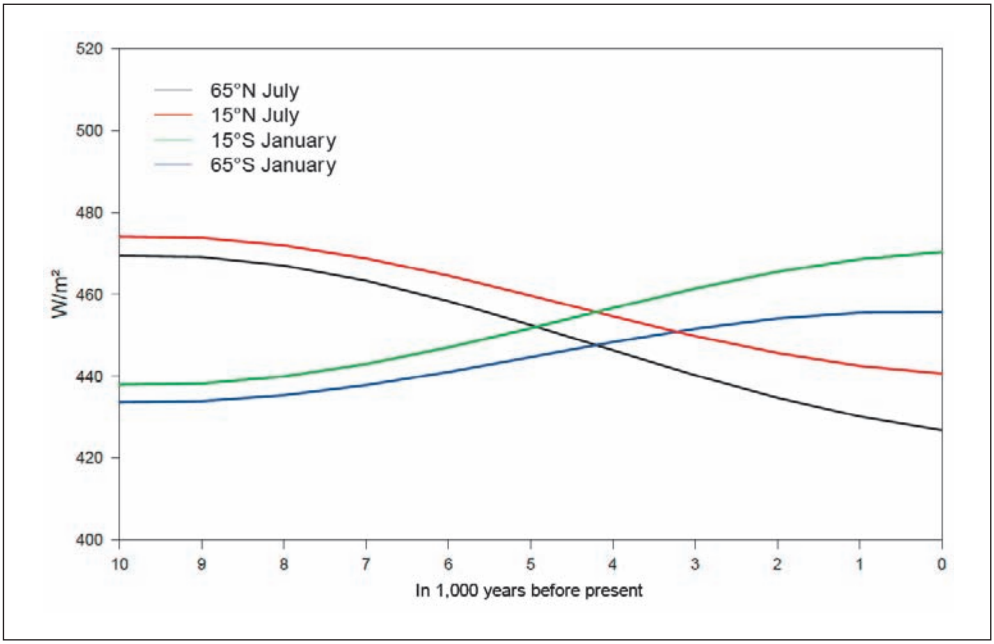

Fig. 4 Insolation changes based on the orbital forcing during the last 10,000 years at 65° and 15° north and south during the corresponding summer season (Berger and Loutre 2002).

The best known is the 8,200 years BP event which is clearly visible through its low temperature peak in Figure 3 (Rohling and Pälike 2005). After around 5,000 years BP the temperature in the northern hemisphere started to decrease due to the lowering solar insolation and, subsequently, four remarkable cold relapses occurred in Europe: The 4,200 year event, the Iron Age cooling around 2,800 years BP, the Dark Ages cooling around 450 – 850 AD and the Little Ice Age (LIA) from 1350 to 1860 AD. During these periods remarkable glacier advances were observed mainly in the northern hemisphere. Therefore, the period after about 4,500 years BP was called Neoglacial (Denton and Karlén 1973). The processes which gave rise to these coolings are not completely known. Beside the above mentioned long-term cooling due to the low orbital forcing and possibly complex feedback mechanisms, the influence of a reduced solar acticity (the so-called grand solar minima; Steinhilber et al. 2009), in combination with groups of large tropical volcanic eruptions may have played a major role (Wanner et al. 2008).

2.2 The Little Ice Age – 21st Century Transition

Between the cold events of the Neoglacial, temperature was remarkably rising. The Medieval Climate Anomaly was the last warm period prior to the LIA. Mean temperature in Europe was about half a degree warmer than during the LIA (Bradley et al. 2003, Mann et al. 2008). Some authors attribute the change between the warmer Medieval Climate Anomaly and the cooler LIA to a switch between a positive and a negative state of the North Atlantic Oscillation (Trouet et al. 2009).

Figure 5 shows the temporal evolution of the external forcing factors and mean European temperature 1500–2000. The impact of volcanic eruptions on the decadal scale temperature fluctuations is relatively small, because such eruptions influence the climate on relatively short timescales of a few years, and they have an opposite influence on warm and cold season temperatures in Europe (Fischer et al. 2007). A cooling effect is only visible if a group of volcanic eruptions occurs in a very short interval (Wanner et al. 2008).

Variations of solar activity or solar irradiance are reflected by European temperatures, especially during the Late Maunder Minimum (1675–1715), where European temperatures reached their LIA minimum. The strong increase in anthropogenic forcing in the 20th century, mainly caused by the increase of greenhouse gases in the atmosphere, is clearly reflected in the temperature curve on Figure 5. There are some periods, where the fluctuations in annual mean temperature in Europe can not only be explained by the forcings, e.g. the pronounced cold period in the second half of the 19th century. This cold period is not reflected in Northern Hemispheric reconstructions, which follow the fluctuations of the external forcings much closer (not shown, see e.g. Jansen et al. 2007). This underlines the importance of studying climate variations and their steering factors on regional to continental scales, where the influences on the climate (e.g. by feedback mechanisms) and its possible reactions are much more complex than on hemispheric or global scales.

2.3 The Dominating Climate Modes

On the synoptic timescale of days or 1–2 weeks the dynamics of the climate system can be characterized by a limited number of typical patterns or modes (Barnston and Livezey 1987, Stephenson et al. 2004). EOFs (Empirical Orthogonal Functions) are a well suited linear procedure to detect these modes. Figure 6 shows the first modes, explaining the highest amount of variance, for each season in Europe (Casty et al. 2007). The different patterns were calculated based on gridded 500 hPa geopotential height, temperature and precipitation reconstructions which were carried out based on independent proxy data for the period 1766–2000 AD. The bottom row represents the timeseries of the normalized prinicipal components (PCs) of the combined EOFs. A highly positive value of a single year means that the corresponding pressure, temperature and precipitation pattern is very distinct. A negative value means that the corresponding correlation values change sign.

The winter pattern (top row, left) explains the highest amount of variance (25.2 %). This is not surprising because it represents the well known North Atlantic Oscillation (NAO) pattern with a distinct Icelandic low and Azores high and, therefore, a positive state of the NAO (Wanner et al. 2000, Hurrell et al. 2003). The corresponding temperature pattern shows the classical structure with a positive correlation in continental Europe and a negative one in Iceland-Greenland and North Africa. Because the axis of the well developed westerly winds faces southwest-northeast, northern (southern) Europe shows a positive (negative) correlation

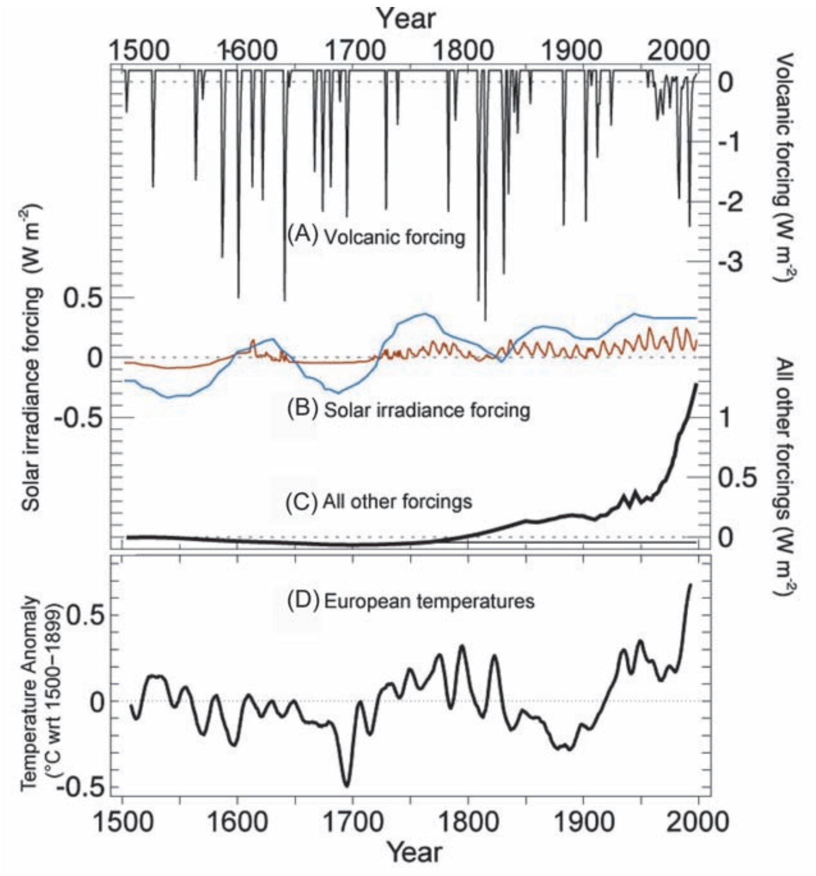

Fig. 5 Top: Global mean radiative forcing due to (*A*) volcanic activity, (*B*) strong (blue) and weak (brown) solar irradiance variations, and (*C*) all other forcings, including greenhouse gases and tropospheric sulphate aerosols (adapted from Jansen et al. 2007). Bottom (*D*): 15-year Gaussian filtered average European annual temperatures reconstructed by Luterbacher et al. (2004) and Xoplaki et al. (2005). All curves are shown as anomalies from their 1500–1899 means.

with precipitation. The PCs show a clear trend to positive values after about 1970. The second winter PC (not shown) represents the classical blocking pattern with weak westerlies and strong outbreaks of cold continental air from northeastern to central Europe. The spring pattern looks similar to the winter one, but it only explains 18.2 % of variance. The positive trend of the first PC during the last decades also occurs in spring. During summer local heating effects dominate over the European land mass. Therefore, the first PC only explains 15.5 % of variance. During the last decades a trend to negative values is clearly visible. According to the presented pattern it means that the correlation coefficients within the area of the blue ellipse get positive indicating that positive pressure anomalies dominated in this area during the last three decades. Accordingly, temperature raised and precipitation decreased in this area.

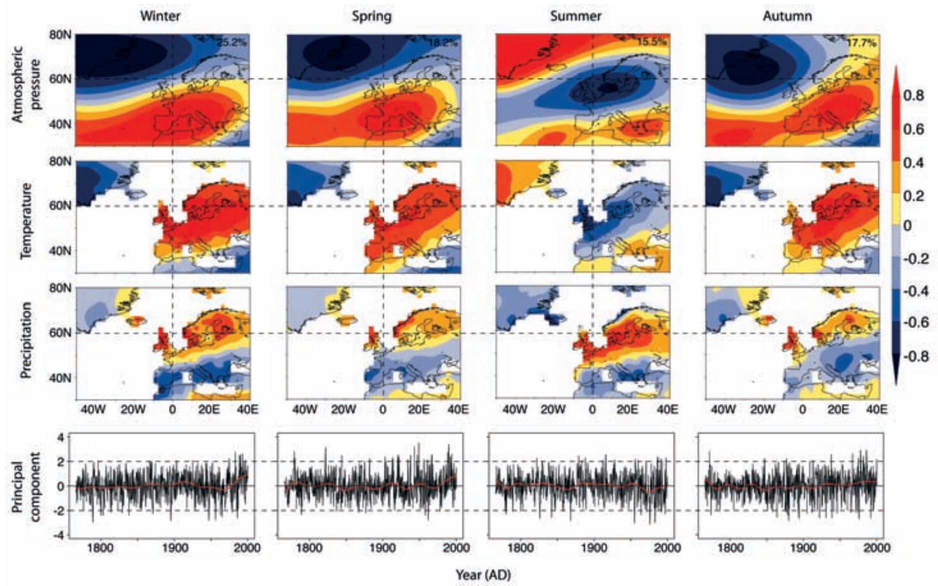

Fig. 6 EOF based reconstructions of 500 hPa geopotential height (top row), land surface temperature (second row) and land surface precipitation (third row). Values indicate correlations. Bottom row shows graphs of the corresponding normalized principal components of the combined first EOFs for each year of the period 1766–2000 (black curves) and their multidecadal trends obtained from a 31-year smoothing (red curves; after Casty et al. 2007, from *PAGES* 2009).

The second summer PC (not shown) shows a strongly positive pole indicating anticyclonic conditions over southern Europe. This pattern shows a positive trend during the last decades, as well. The autumn patterns are similar to the spring ones.

3. Future Climate Change

Figure 7 presents the expected seasonal temperature and precipitation changes in Europe for the period 2080–2099, compared to the period 1980–1999. It represents the average of simulations with 21 state-of-the-art climate models, based on the A1B scenario (Solomon et al. 2007). A more comprehensive overview is given in the contribution of Jacob and Podzun (this volume). In general, the scenarios reveal a clear warming trend between 1.5 and 10 °C which is somewhat greater than the global mean. For the winter season the highest temperature rise is expected in the northeastern Arctic area. This is mostly due to the retreat of the Arctic sea ice. In summer the strongest changes will likely occur in the Mediterranean area. Both precipitation scenarios show an increasing trend in northern Europe, however, it is much stronger in winter. During summer the whole area south of Scandinavia shows a trend to drier conditions, which is most accentuated in the already dry Mediterranean area. One of the challenges of climate analysis is to estimate whether the changes in temperature or precipitation are mostly caused by circulation changes or changes within the same circulation type. Most modern studies prove that the effects of the within-type changes clearly exceed the changes due to varying weather or circulation type frequencies (van Ulden et al. 2007, Küttel et al. 2010).

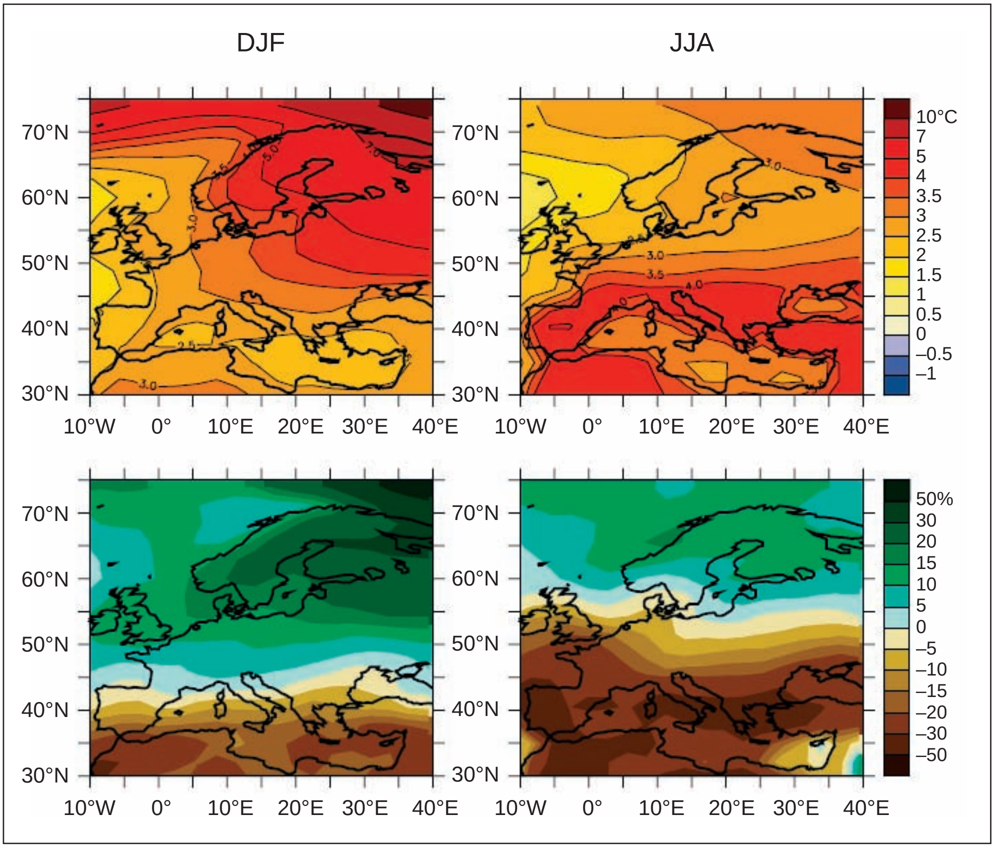

Fig. 7 Temperature (upper Figures) and precipitation changes (lower Figures) for winter (DJF) and summer (JJA) over Europe from the MMD-A1B simulations (*IPCC* 2007). The four Figures represent the changes between 1980 to 1999 and 2080–1999, averaged over 21 models.

4. Impacts of European Climate Change

Table 1 and Table 2 summarize the most severe expected negative or positive economic and environmental impacts of the projected climate change in Europe (source: Alcamo et al. 2007). Generally, the impacts on biodiversity and ecosystem stability are expected to be negative, but there are some species and habitats that will probably cover larger areas in the future, mainly due to the expansion to formerly too cold regions. Agricultures and fisheries may profit from the changing conditions in Atlantic and Northern Europe, whereas in Eastern Europe and the Mediterranean, conditions will probably become less favorable. Although cold related mortality is expected to decrease, overall impacts on human health will rather be negative.

Generally, the most affected regions in terms of negative impacts are Eastern Europe and the Mediterranean, where heat and drought related impacts are projected to be strong to severe.

Tab. 1 Expected negative impacts of climate change in Europe during the 21st century (adapted after Tab. 12.4 in Alcamo et al. 2007). Strength of the risk is divided in three categories (moderate, strong, severe), the areas considered are Northern, Atlantic, Central, Mediterranean (Med) and Eastern Europe.

Phenomenon	Affected area	Strength of the impact
Increase of flood events (including surge-driven coastal flooding)	entire Europe	strong to severe (East and North)
Decrease in water availability and increased water stress	Central, Med and East	moderate (Central), strong (East),
Glacier and permafrost retreat	entire Europe	severe
Shortening of snow cover duration	entire Europe	severe
Biodiversity (species losses)	entire Europe (except Amphibians and Reptiles in Central, Med and East)	severe
Disturbance of marine ecosystems (erosion, river sediments supply, eutrophication etc.)	all coastal areas	strong to severe
Disturbance of forests, shrub- and grasslands (decreasing primary production and stability)	Med and East	strong to severe
Disturbance of wetlands and aquatic ecosystems (drying, eutrophication etc.)	entire Europe	moderate to severe
Agriculture and fisheries (decrease in area and yield, increase in irrigation needs)	Central, Med and East	moderate to severe
Increase in summer energy demand	entire Europe	moderate to severe (Med)
Decrease in tourism	Central (winter); East and Med (summer)	strong to severe
Increasing property insurance claims	North, Atlantic and Central	moderate to strong
Health (increased heat related mortality, diseases, effects of flooding)	entire Europe	moderate to severe

5. Conclusions

We would like to draw our conclusions in a shortened form:

- The European climate is strongly determined by the interaction between the Atlantic Ocean and the large Eurasian land mass.
- During the recent interglacial, the Holocene, the mean European temperatures decreased by about 2–3 °C until the preindustrial period, mostly due to the decreasing summer insolation.

Tab. 2 Expected positive effects of climate change in Europe during the 21st century (adapted after Tab. 12.4 in Alcamo et al. 2007). Strength of the positive impact is divided in three categories (moderate, strong, very strong), the areas considered are Northern, Atlantic, Central, Mediterranean and Eastern Europe.

Phenomenon	Affected area	Strength of the impact
Increase in water availability and decreased water stress	North and Atlantic	strong
Coastal and marine ecosystems (northward migration of species, extension of inshore waters)	all coastal areas	moderate to very strong
Tree line upward shift	entire Europe	moderate (Med) to very strong (others)
Forests, shrub- and grasslands: increasing productivity and forest areas	Atlantic, North and Central	moderate to very strong (North)
Agriculture and fisheries (increase in suitable area and yield)	Atlantic, North and Central	moderate (Central) to very strong
Decrease in winter energy demand	entire Europe	moderate to strong
Increase in tourism	North (all seasons), Atlantic Central and East (summer), Med (winter)	moderate to very strong (Med)
Health (decrease in cold related mortality)	entire Europe	moderate to very strong (East)

- The last 2,000 years were characterized by a permanent change between warmer and colder periods: Roman Age warm period, Dark Ages cooling, temperate Medieval Climate Anomaly, Little Ice Age, modern period warming. Prior to the present warming, which is with a high probability due to the anthropogenic greenhouse effect, the earlier fluctuations were likely caused by a complex mixture between the two most important natural forcings, volcanic and solar, as well as by internal feedbacks.
- The North Atlantic Oscillation, expressed by the strength of the Icelandic low and the Azores high and indicating the strength of the Northern Hemisphere westerlies over Europe, are the dominant mode of North Atlantic climate.
- The future European climate is characterized by a warming from 1 to several degrees C. Winter warming is most accentuated in northeastern and summer warming in southern Europe. Precipitation is increasing north of 40 °N in winter and north of 60 °N in summer. The Mediterranean area will be subject of a strong drying, mainly during summer.
- The most remarkable negative impacts of 21st century climate change are: Increase of floods, retreat of glaciers and permafrost, shortening of snow cover duration, disturbance of ecosystems and loss of biodiversity, increase of summer energy demand, heat related mortality, increase of insurance claims.
- Positive impacts of 21st century climate change are: Increase of precipitation in northern Europe, upward shift of the treeline, increasing forest an grassland productivity, decrease in winter energy demand, increasing tourism in favored areas (e.g. warmer mountain areas in summer or snow rich northern Europe in winter).

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Elements – Continents
Approaches to Determinants of Environmental History and their Reifications

Leopoldina-Workshop
Deutsche Akademie der Naturforscher Leopoldina in Zusammenarbeit mit dem DFG-Graduiertenkolleg Interdisziplinäre Umweltgeschichte

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Zu den Gebieten, die zurzeit verstärktes Interesse finden, gehört die Umweltgeschichte. Der Band konzentriert sich auf Grundfragen des umwelthistorischen Diskurses durch Rückbesinnung auf elementare Mensch-Umwelt-Beziehungen durch zwei Annäherungen: „Elemente“ und „Kontinente“. Mit Hilfe dieses kleinen wie großen Maßstabes wurde der Bedeutung am Konkreten und im historischen Aufriss nachgegangen. Unter der Überschrift „Elemente“ werden Feuer, Wasser, Luft und Erde als unmittelbare, für das Leben determinierende Qualitäten, die sich im ökologischen Prozessgeschehen abbilden, analysiert. So wird etwa die Rolle der Feuerökologie am Beispiel mitteleuropäischer und nordamerikanischer Wälder behandelt oder dem Element Wasser und seinen Aggregatzuständen in der Bedeutung für die Geschichte der Niederlande nachgegangen. Hinzu kommt als weitere Dimension die Biosphäre. Die „Kontinente“ Afrika, Amerika, Asien, Australien und Europa bilden das thematische Äquivalent. Insbesondere werden hier die Auswirkungen der naturräumlichen Grundausstattung auf die wirtschaftliche und kulturelle Entwicklung thematisiert. Die Palette der Themen reicht dabei vom „europäischen Sonderweg“ bis zur chinesischen Umweltgeschichte. Darüber hinaus liefern Beiträge von Nachwuchswissenschaftlern einen Einblick in die Bandbreite laufender umwelthistorischer Projekte.

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From Utopia to Common Sense: Global Climate Policy that Could Work

Ottmar Edenhofer, Brigitte Knopf, and Gunnar Luderer (Potsdam)[1]

With 5 Figures

Abstract

The international community has recognized the 2 °C target as a focal point of international climate policy. The negotiators struggle to make the required emissions reductions binding under international law and to agree on a burden-sharing among nations that is in line with this objective. While climate policies will diminish the rents of coal, oil and gas resource owners, they will create a new climate rent. This climate rent is reflected in the price of carbon and it arises due to the scarcity of the remaining atmospheric carbon budget. The enormous welfare reallocation implied by this transfer of rents lies in the heart of the political bargaining over a global climate deal. A reasonable climate policy architecture thus needs to specify a binding overall carbon budget that is in line with the 2 °C target, spell out the regional allocation of this budget and create the institutional framework for a global carbon market.

Zusammenfassung

Die internationale Staatengemeinschaft hat sich darauf verständigt, den Klimawandel auf 2 °C gegenüber dem vorindustriellen Niveau zu begrenzen, ohne jedoch dieses Ziel völkerrechtlich verbindlich festzulegen. Das Grundproblem der politischen Umsetzung des Klimaschutzes besteht in der Tatsache, dass die Ressourcenrenten der Besitzer von Kohle, Öl und Gas durch den Emissionshandel in eine Klimarente überführt werden. Die Verteilungskonflikte über diese Klimarente dürfen nicht zu dominant werden, ansonsten wird das Klimaproblem unlösbar. Eine sinnvolle Architektur der Klimapolitik muss deshalb eine Konkretisierung des 2 °C-Ziels über ein Kohlenstoffbudget beinhalten, eine Aussage über die Verteilung dieses Budgets treffen und einen institutionellen Rahmen für einen globalen Emissionshandel schaffen.

1. Introduction

Despite of the failure of the Copenhagen Summit in December 2009 the world will move forward with plans to limit greenhouse gas emissions much more aggressively than before. The Copenhagen Accord makes reference to the 2 °C target as a potential goal for global climate protection but without binding this target under international law. It was also missed to express the willingness to take the necessary measures to let this targets become reality. Climate policy therefore requires a clear look at the historical challenges humankind is facing. The climate negotiations are about to get wrapped up in bargaining for rather unimportant details.

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The task of the century is thereby increasingly left unnoticed. We should therefore first concentrate on the most crucial questions and realize which cornerstones need to be included in an international agreement. Only on this basis, the compromises in the negotiations can be evaluated. International climate policy will lose any creditability if it formulates on the one hand ambitious targets but on the other hand does not even show the slightest willingness to take the necessary measures. Not exclusively but at first place, a reasonable architecture of climate policy needs to be based on three cornerstones:

– Agreement upon the amount of carbon that can be deposited in the atmosphere by the end of the century.
– Allocation of emission rights according to an equitable allocation scheme among all nations.
– Design of the institutional prerequisites for a global emission trade.

The negotiators in Copenhagen will most likely not agree on all aspects. As a start, it is however much more important that at least an architecture for a global agreement becomes visible that follows this logic.

2. Limited Disposal Space in the Atmosphere

Cornerstone 1: The disposal space of the atmosphere is limited. If dangerous climate change shall be avoided, the global mean temperature increase relative to pre-industrial levels needs to be limited to 2 °C. In order to reach the 2 °C target with a probability of 75 %, emissions from the combustion of fossil energy sources has to be limited from now until the midcentury to no more than approximately 830 Gt CO_2 (Knopf et al. 2009). In the last ten years, we deposited approximately 270 Gt CO_2 – if we continue at this pace the disposal space will be exhausted in about 30 years time. Therefore, the energy system needs to be transformed. The 2 °C target is a pragmatic definition of the precautionary principle in order to lower the risk that the sea level will rise drastically, the oceans will acidify, and the monsoon in China and India will change. International climate negotiations following Copenhagen will already be a success if the world community can agree upon ambitious climate protection since an agreement upon the global carbon budget needs to be reached quickly. The main focus needs to be put on the precision and concrete implementation of the 2 °C target to give a clear definition for climate policy. If one reduces the probability from 75 % to 50 % for keeping the 2 °C target, the carbon budget will increase by more than 100 Gt CO_2, and the mitigation costs will turn out to be smaller (see Knopf et al. 2009). The probability with which the 2 °C target should be reached depends upon how high the precautionary principle is weighted by the negotiators. This weighting is in turn determined on how high the expected risks of climate change are and which economic costs the compliance of a global carbon budget is associated with. The economic costs of mitigation depend decisively upon how fast a global climate agreement can be reached and upon the availability of advanced low-carbon technologies.

Therefore, the question arises how a transformation of the world-wide energy system can be pursued that is consistent with this goal. Figure 1*A* shows a projection for the business-as-usual (baseline) case and two climate protection scenarios. Figure 1*B* shows the necessary transformation of the energy system for a climate protection target that corresponds with a probability of 15 % to reach the 2 °C target. Figure 1*C* shows a path which keeps the 2 °C

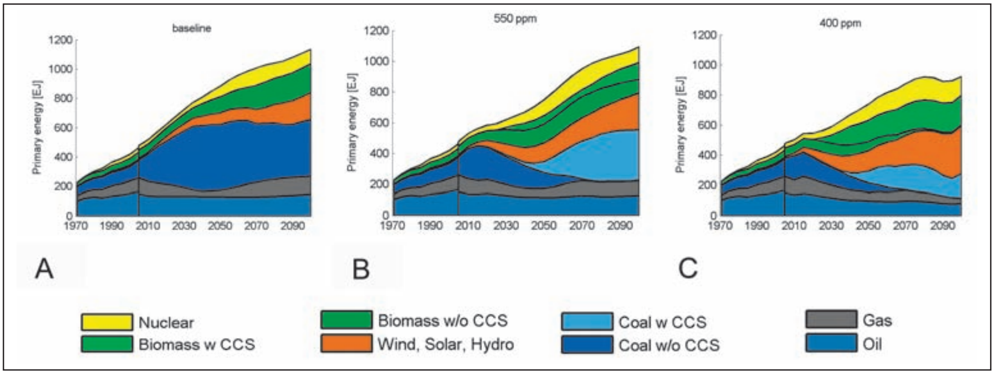

Fig. 1 Transformation of the world-wide energy system for the business-as-usual case and two climate protection targets (550 and 400 ppm) that comply with the 2 °C target with approximately 15 % and approximately 75 %. Source: Knopf et al. 2009. Historical data: *IEA* 2007a,b.

target with a probability of 75 %. Two things become obvious: First, the energy system has not undergone any considerable changes during the last three decades; it is an energy system that is dominated by fossil energy sources. Second, the primary energy consumption will considerably increase during the 21st century. Particularly energy efficiency improvements, renewable energy sources and Carbon Capture and Storage (CCS) for curbing atmospheric emissions – from the combustion of fossil fuels as well as in combination with biomass – will play a key role for ensuring that the demand increase is met in a climate-friendly way. The latter option is above all especially important due to the fact that it can withdraw CO_2 from the atmosphere and thus allows generating "negative emissions". This presupposes that the use of biomass can be provided in a carbon-neutral way. It is so far an open question to which extent it will be possible to use bioenergy in a climate-friendly and sustainable way. The problem regarding the competition with food production has also not sufficiently been solved. Moreover, CCS technology is today not yet commercially available. Figure 1 shows furthermore that the importance of renewable energy sources is the more emerging the more ambitious the climate target is. The renewable energies, however, do not replace the other options. This is to a smaller extent also true for nuclear energy. Since the feasibility of CCS, the massive expansion of renewables or nuclear energy is not yet secured, the question remains how much the costs will increase if these options are not available at all or only to a limited extent. We have addressed this question with a model intercomparison exercise (Edenhofer et al. 2010, Knopf et al., 2009, see Fig. 2). It becomes apparent that the economic costs of climate protection mainly depend upon the assumptions about the amount of a sustainable biomass potential. With a bioenergy supply of less than 100 EJ per year ("halved biomass potential" in Fig. 2), the economic welfare losses double in some cases. Should it turn out that only small storage potential is available for CCS, the mitigation costs will also strongly increase ("limited CCS potential"). If the CCS option for the use of coal and gas and especially in combination with the use of biomass is not at all available ("without CCS") ambitious climate targets can most probably not be reached. This is also true for the case that the share of renewable energy sources cannot drastically be increased compared to its use in the baseline ("no expansion of renewables"). The expansion of nuclear energy against baseline use (assuming a relatively high level in the baseline case) can however almost cost-neutrally be abandoned: only low additional costs for a scenario "no expansion of nuclear" are reported. A nuclear phase-out could be reached with increased costs ("phase-out of nuclear"). It thus becomes obvious that there can be no ambitious climate protection without technical progress in the energy sector. Technical progress also assures that the economic costs of world-wide climate protection amount to a loss of 1–2.5 % GDP and can be kept at a moderate level compared with the potential damages of dangerous climate change.

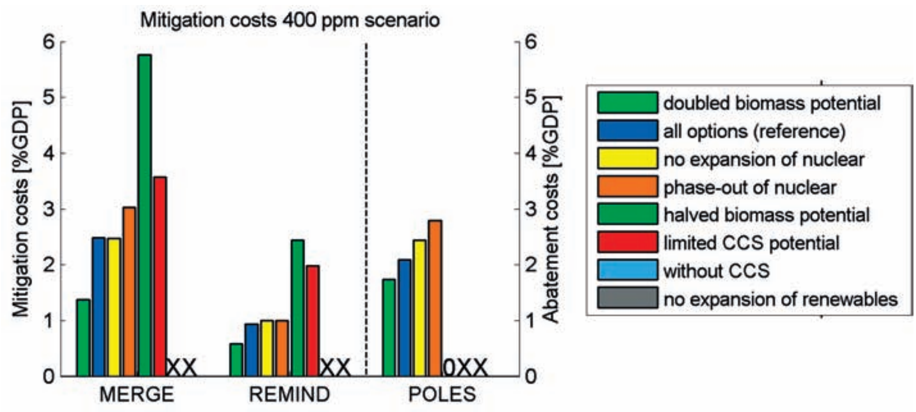

Fig. 2 Global mitigation costs for a 400 ppm-eq scenario (calculated as GDP losses from 2005–2100 compared to a business-as-usual scenario) with different technology scenarios for the energy system economy models MERGE, REMIND and POLES (Source: Knopf et al. 2009). Scenarios are explained in the text. "X" means that the climate protection target cannot be reached under these technical restrictions; "0" means that the relevant scenario has not been calculated. In the reference case (blue), all technologies are available.

The energy scenarios presented here are comparable with the energy scenarios of IEA or also even with those from the IPCC. Only a portfolio of mitigation options allows for an ambitious climate protection. This finding, however, should not give the impression that there is only one way to a CO_2-low world economy. It is indeed possible to limit for example the use of CCS and/or the expansion of nuclear energy if the large-scale use of these technologies is perceived to be too hazardous or if there is too little acceptance for them. If CCS is only used to a limited extent correspondingly higher economic costs need to be accepted (see Fig. 2). Science cannot be prescriptive concerning the weighting between additional economic costs and reduced risks. Rather, a public debate on such value judgments is necessary. For this reason, the IPCC more increasingly tends to explore and assess scenarios that represent extreme scenarios over the last years. Such scenarios can be regarded as extreme scenarios of either renewable energy sources, nuclear energy or CCS. These scenarios concede a mitigation option to an especially high share of the entire portfolio of mitigation options or with an abandoning of this option. The added value of these extreme scenarios consists in the fact that they enable the public to openly discuss the future path of the energy economies in times of climate policy. Even with ambitious climate policy, there is not only one but there are many ways to reach the target.

This is one of the most important messages that were formulated in the Fourth Assessment Report of the IPCC (*IPCC* 2007): Humankind has the technologies on hand that allow for an ambitious climate protection at acceptable costs. In other words, it is possible to get along with a carbon budget of almost 830 Gt CO_2 by mid-century. The crucial question, however, is how high the global carbon budgets will be distributed among nations and thus how the mitigation costs will be divided among the players in the international climate poker.

Cornerstone 2: An international climate agreement can only be reached if the participating national states accept a national budget for their emissions. The cake of global emission rights can either be allocated as a cumulative budget or as a global emission cap that needs to be lowered in the course of time in such a way that the sum of national emissions is not higher than the global budget agreed upon.

Since the damages of climate change primarily depend upon the cumulated emissions and not upon annual emissions, it is possible to take advantage of the intertemporal flexibility and to reduce emissions temporarily in such a way that welfare losses of the involved economies are minimized. In the past, many research groups have calculated economically optimal emission pathways that are compatible with different carbon budgets. For instance, a 50 % chance to comply with the 2 °C target would require that the global emissions need to be reduced at least by half until 2050 compared to 1990. The industrial countries would need to reduce their emissions by approximately 80 % compared to the level of 1990 (*IPCC* 2007).

Politicians often formulate climate targets in terms of relative reduction efforts. Such statements are, however, not very helpful for international climate negotiations since the reduction effort then depends on a base year or a reference scenario. The reference scenario describes the hypothetic emission course that would be the result in case of no climate policy. If we assume high emissions in the reference scenario the necessary emission reductions will be higher compared to a low reference scenario. The negotiators could use these uncertainties by assuming a high reference scenario to promise apparently high reductions. Due to the reference made to a hypothetic and thus speculative emission course, the negotiations about the future economic, technical and demographic developments will be burdened with unnecessary uncertainties. If there was full certainty about the reference scenario, each reduction scenario could *ex-ante* and *ex-post* be converted into a budget and *vice versa*. But since the reference scenario is a great unknown, an *ex-ante* agreement on a national carbon budget is the only reasonable way to create clarification about the target agreements. This motivation was probably crucial for the latest report of the German Advisory Council on Global Change (*WBGU* 2009) in which a proposal was submitted to negotiate no longer about reduction scenarios but about national carbon budgets.[2]

3. Allocation of Pollution Rights

Another advantage of the budget approach (or also a temporal emission cap) compared to pure percental reduction obligations is not only to precisely determine national obligations but also to

2 The budget approach of the WBGU clearly indicates that the *ex-ante* determination of a budget makes the allocation questions transparent. The economic implications of the budget approach have however not yet been illuminated satisfactorily since it is unclear which instruments should be used for the implementation and how the temporal flexibility can be guaranteed.

explicitly put the allocation conflicts on the table: The individual national states will surely have different ideas about an equitable allocation key. From the viewpoint of developing countries and emerging economies, an equal carbon budget per capita would be advantageous; industrial countries, by contrast, would benefit from an allocation per gross domestic product. It needs to be considered, however, that the economic costs that will arise from global climate policy will not only be determined by (*i*) the allocation of emission rights but also by (*ii*) national mitigation costs and potentials for climate-friendly technologies as well as (*iii*) the devaluation of fossil resource stocks that will in particular affect the oil and gas exporting countries.

Only model calculations can determine the magnitude of these three effects. An example of such a scenario has been calculated with the model REMIND (see Fig. 1). The industrial countries have to bear relatively low consumption losses since they are able to invest quite quickly into the expansion of renewable energies, the increase of energy efficiency, Carbon Capturing and Sequestration (CCS) as well as nuclear energy.

Countries of the Middle East, however, have to incur very high losses since the value of oil and gas is decreasing and they are able to sell less which reduces their resource rents drastically. In other words: The rents of the owners of coal, oil and gas are devaluated by determining a carbon budget and are replaced by a climate rent. This rent is the object of the allocation conflicts. It is not amazing that especially those countries that made high rents through the use of oil and gas will lose them by climate policy. It is, however, interesting that some countries are able to escape from this devaluation of their resource rents. Although Russia would see a devaluation of its fossil resources, it could in case of an ambitious climate policy benefit from its large potential for biomass combined with CCS. Russia would produce biogas in combination with CCS and thus contribute to the removal of CO_2 from the atmosphere. The owners of coal could also reduce their rent losses by introducing CCS. This is one of the key reasons why CCS technology is of great importance for climate policy.

Countries that are allocated much more emission certificates than they can use themselves can profit from emissions trading by selling excess permits. As shown by the model, this holds e. g. for Africa (see Fig. 3).

Therefore, there is no difference between the budget approach and the allocation on the basis of a temporally flexible emission cap since the emission cap has been calculated cost-minimal and welfare-optimal. The budget approach has therefore economically no other implications than the 2 °C target where the emission rights are allocated according to the per capita rule and where the emission cap is calculated welfare-optimal.

Moreover, Figure 3 reveals that the influence of the three allocation rules on the economic consumption losses is relatively small compared with the differences between the regions. This comparatively small difference is primarily due to the fact that the assumptions about the technical progress are relatively optimistic in the model REMIND. The influence of the allocation of the emission rights on the economic consumption losses is higher in models that presuppose a low economic flexibility since higher carbon prices incur and thus higher rents are allocated. This fact is shown in Figure 4: Models with low technical flexibility show a stronger influence of the allocation rules on the regional mitigation costs than models with high technical flexibility. A crucial conclusion can be drawn from it: The higher the technical flexibility, the more efficient the capital markets are when mobilizing investments in carbon-low technologies, the lower are the rents that need to be allocated and the lower will the allocation conflicts be.

Moreover, Figure 4 shows that the uncertainties about the regional allocation of mitigation costs are still significant. The reason for this uncertainty is that the (model) assumptions still

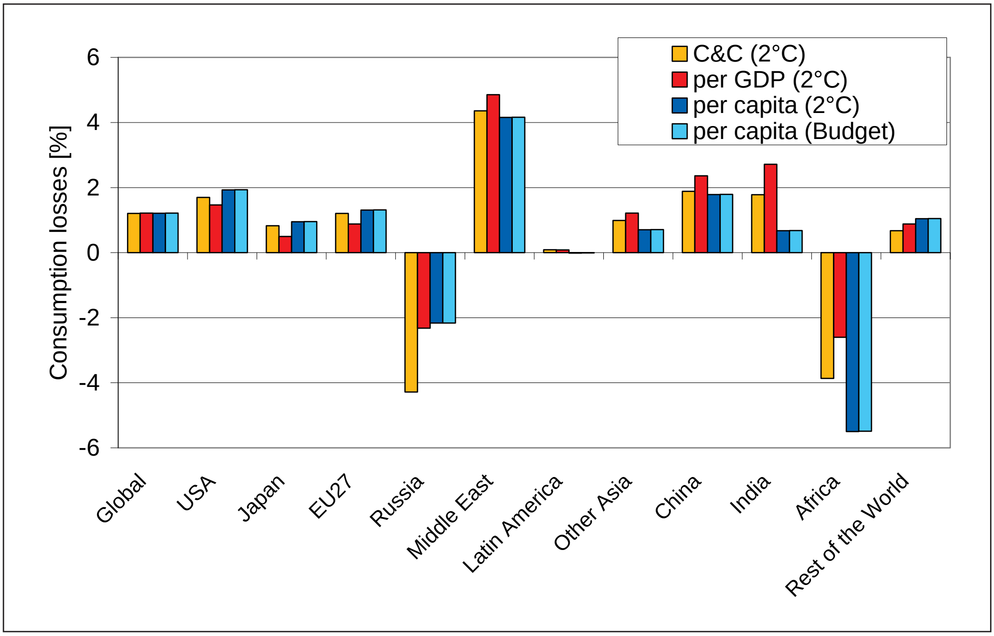

Fig. 3 Regional mitigation costs (2005–2100) for different allocation rules of emission rights calculated with REMIND for a 2 °C target with a compliance probability of 75 % and/or for an equivalent CO_2 budget of 770 Gt CO_2 until 2050. The 2 °C target and the budget is maintained in all allocation rules, only the allocation will change: it will be done according to the share of the population ("per capita"), share of world gross domestic product ("per GDP") and Contraction and Convergence (C&C). In case of C&C, emission rights will be granted to the individual countries in a fixed basic year (here 2005) that corresponds with the emissions they actually produce. The allocation key will change in the temporal course so that in 2050 each human will have the same per capita rights.

differ widely about how easy economies can be decarbonized and which technical potentials exist for the individual technologies. In order to reduce this uncertainty in the estimation of the regional costs, the governments should ensure that an international expert group will be commissioned with cost estimations. The international work on such figures will create mutual trust and a common basis for speedy negotiations.

4. Establishing International Emissions Trading

Cornerstone 3: From the perspective of economy theory, taxes and emission trade are equivalent in a world without uncertainty. It has up to now been an economic commonplace that the allocative effects of taxes and quantity instruments will not differ from each other if the climate damages and/or costs of mitigation are known. However, in the case of uncertainty of the social planner and firms about damages and costs it can be shown that both instruments are no longer equivalent. Originally, Weitzmann (1974) formulated this model as a "flow problem" in which the damages are related to the annual rather than the cumulative emissions. Therefore, this frame of reference developed by Weitzman (1974) has first been regarded as inadequate for the climate problem. The climate problem, however, is a "stock pollutant"

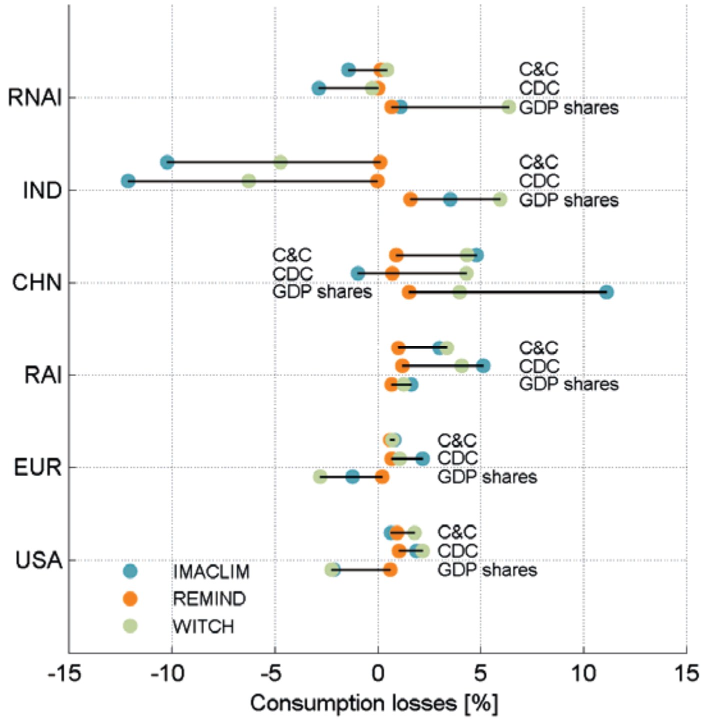

Fig. 4 Regional mitigation costs (2005–2100) for three different energy-economy-models for the distribution keys according to the GDP share, Common but Differentiated Convergence (CDC) and Contraction and Convergence (C&C). The CDC approach stipulates that the emissions of the developing countries may first rise to its upper cap before they are also obliged to produce reductions. For the other schemes see legend of Fig. 1. For REMIND, the model with the greatest technological flexibility and low CO_2 prices, there is little influence of the allocation of emission rights on regional costs (small range). In WITCH, a model that assumes a lower technological flexibility, and IMACLIM that requires a high CO_2 price due to largely myopic investors, there is a considerably larger range. RNAI: Rest of non-Annex-I, RAI: Rest of Annex-I. Source: Luderer et al. 2009.

problem where the damages of climate change are determined by the cumulated budget of emissions, i.e. by the stock which is deposited in the atmosphere. It can, however, be shown that the basic statements of the Weitzman model are also valid for a "stock problem". Newell and Pizer (2003) demonstrated that under certain assumptions a tax is advantageous on the short-term; on the long-term, however, emission trading as a quantity instrument should be preferred. The reason for this is that in the long-term the damage function will, due to the accumulation of emissions, become steeper than the costs of emission mitigation which only depend on the flow of emissions. On the condition of a long-term "steep" damage function, the advantageousness of quantity control could already be derived in the original Weitzman model. In the light of the results, a tax solution should be preferred in the short-term and only in the long-term emissions trading should be opted.

It is, however, questionable if the selected model framework is suitable for the climate problem: Here, the social planner or a well-intentioned government plays against "nature", as the future climate damages and/or mitigation costs are uncertain. Thus, the decisive problem of the economy of climate change will not at all get into sight. The basic problem of the economy of climate change will only become apparent if the question is asked who today has *de facto* the property rights to the atmosphere. The owners of fossil resources (coal, oil, gas) can until now exploit their resources according to their intertemporal calculation. Would the deposit space of the atmosphere now be limited, the result would be that the scarcity rent of resources would be converted into a climate rent. This is in summary the focal problem of the economy of climate change.

This situation is explained in Figure 5: Below the zero line, the exhaustible resources and reserves are shown that are still stored in the ground. The fossil resources that can still be deposited in the atmosphere are shown above the zero-line. Figure 5 shows that even in case of no international climate policy, a great part of gas and oil reserves would be used but only a fractional part of the coal reserves. On the one hand, this is due to the fact that the substitution options for oil, e. g. in the transport sector, are small; on the other hand, coal reserves are almost "unlimited" (compared to the projected consumption for the next century). The undamped use of coal would, however, lead to an increase of the global mean temperature of far more than 2 °C; without climate policy, almost 4,000 Gt CO_2 from the use of coal alone would be stored in the atmosphere. In case of a climate policy which is consistent with the 2 °C target, only 364 instead of 922 Gt CO_2 from the use of coal can be emitted. Of this quantity approximately 210 Gt are stored in geological formations with the aid of CCS technology. This drastic decline is the reason why the owners of coal will have to accept the greatest rent losses. The owners of gas and oil would also need to empty their stocks much slower and would above all need to offer them at lower prices.

These considerations make it obvious that in case of a climate policy that wants to comply with a global carbon budget, the CO_2 tax would need to rise over time corresponding to the modified Hotelling rule (Edenhofer and Kalkuhl 2009). But how will the suppliers of coal, oil and gas react on it? They will accelerate the extraction of their resource with the risk that the global carbon budget will be exceeded despite of a rising CO_2 price (see also the discussion about the "Green Paradox" in Sinn 2008 and Edenhofer and Kalkuhl 2009). A CO_2 tax is therefore no effective instrument because it is rational for the resource owners to bring forward the extraction of fossil resources: otherwise, they need to expect that future profits will be strongly reduced. This incentive does not exist for emissions trading since a budget of emission rights is determined here a priori. The only way for owners of coal and gas reserves to secure part of their rents is to introduce CCS technology in combination with coal, gas or biomass (see Fig. 5). Otherwise, there is no alternative for the suppliers of fossil resources: their resource rents will be reduced and transformed into a climate rent. The budget approach in combination with a global emissions trading scheme has thus the potential to cut the Gordian knot of climate policy. If the carbon budget is managed by a fiduciary institution, a clear signal will be given to the markets that no emission in excess of the budget will be issued. A global system of regional and national climate central banks should undertake the task to ensure an economically efficient compliance with the carbon budget. For this purpose, an institution which acts as a climate bank needs to issue emission rights in such a way that the firms themselves can decide at what time they reduce emissions and which technologies they will use. Depending on the economic situation, the central climate banks can limit or

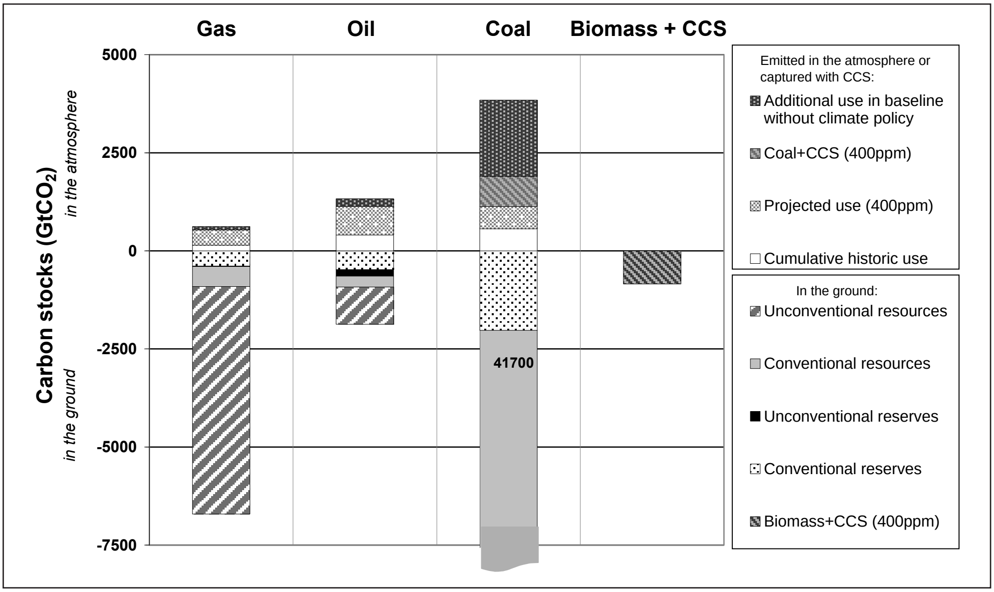

Fig. 5 The basic problem of climate economy – fossil resources and related historical and potential future CO_2 emissions. Reserves are understood as natural resources economically extractable with today's methods and prices. Resources are understood as the future extractable amount of natural resources that exceeds the reserves. Sources: Reserves: *BGR* 2008; historical consumption: Marland et al. 2008; Scenarios: Knopf et al. 2009.

extend the temporal flexibility by issuing certificates. Such a system cannot be implemented overnight. One important step in this direction is the reform of the European Emissions Trading System (EU ETS). It turned out to be a great weakness of the EU ETS that important economic sectors are not included. This applies e. g. to the building sector where emissions can be reduced at especially low costs. One can include all important sectors in the emission trade if one uses the first trade level as a starting point. Those who extract coal or import gas or mineral oil do not only pay the price for the resource but should also be obliged to acquire at the same time a certificate for the emissions that will be produced with the future resource use. In such an upstream system, all sectors are integrated in the emission trade and the market forces make sure that the cheapest mitigation option will be realized. The *Sachverständigenrat für Umweltfragen* (SRU) has prepared relevant suggestions on this and has already reflected about how the EU ETS could be reformed in line with these considerations (*SRU* 2008, Hentrich et al. 2009). The emissions trading system should not only be expanded sectorally, but also regionally. In the United States, the debate about the introduction of a national emissions trading system enters its decisive phase. Policy-makers in the EU should ensure that this emission trading system will be linked to the European trade system as a transatlantic carbon market (Flachsland et al. 2008). This project would have a strong signal effect for the creation of an international agreement that also includes China, India, Brazil and Russia. An important question is if there is still enough time to incrementally achieve an international agreement. Model calculations show that the costs could increase by half if a global agreement would only be launched in 2020 instead of 2010 (Luderer et al. 2009). In case of a further delay, we even have to give up the 2 °C target.

5. Embedding into a *Global Deal*

While emission trading is the most important instrument of climate policy, it will not suffice in order to incentivize the necessary investments for a carbon-free world economy. It needs to be supplemented by the additional cornerstones technology transfer, reduction of deforestation and adaptation. As the barriers on the capital markets are too numerous to mobilize investments, in particular for necessary infrastructure, complementary measures cannot be forgone. Avoiding deforestation also needs to be part of a global agreement since 20 % of the world-wide emissions alone are caused by deforestation, mainly in Brazil, Indonesia and Africa. Even if we succeed in restricting climate change to 2 °C, this does not mean that there will be no climate change. Especially the developing countries will need to adapt to the residual climate change which even at 2 °C will entail substantial adverse effects. The consolidation of the individual cornerstones has been explained in detail in our version of a *Global Deal* (Edenhofer et al. 2008).

Much of what is demanded here exceeds the scope of the near term climate negotiations. But the suggestions here are not utopian. Because they simply take into account that the resource rents of the owners of coal, oil and gas are transferred into a climate rent by the emission trade. The distribution conflicts about this climate rent may not become too dominant since otherwise the climate problem will be unsolvable. The size of this reallocation of rents can be contained by mobilizing emission-free technologies. The basic problem, however, consists in the fact that an institutional framework is required. Setting up such a multilateral institutional framework is highly ambitious. One is tempted to qualify these demands as unrealistic since they contradict the self-interests of the countries. Many authors have pointed out that international environmental agreements can be realized all the more the more dispensable they are (Finus et al. 2006, Carraro et al. 2006). Recent investigations, however, show that the chances of international cooperation should not be estimated to be so pessimistic (Wagner 2001, Lessmann et al. 2009, Lessmann and Edenhofer 2010). There is indeed the chance that a coalition of the willing will form that then can provide the nucleus for an expansion of international cooperation. There is thus no reason to give up hope even though one cannot help feeling dizzy due to the challenge of these tasks. In this sense, the requirements made to such an agreement are also no utopia. While utopias are perceptions beyond space and time, the cornerstones presented here are concrete requirements for a climate policy that lives up to its self-defined goals. Those who formulate ambitious goals and denounce the necessary tools as utopian undermine their credibility.

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Global Warming below 2 °C Relative to Pre-Industrial Level: How Might Climate Look Like in Europe?

Daniela Jacob and Ralf Podzun (Hamburg)

With 3 Figures

Abstract

Within the European ENSEMBLES project, an aggressive mitigation scenario was developed which aims eventually to stabilize the anthropogenic radiative forcing to that equivalent to a CO_2 concentration at around 450 ppm during the 22nd century. This scenario, called E1, was designed for attempting to match the European Union target of keeping global anthropogenic warming below 2 °C above pre-industrial level. Here, temperature und precipitation changes from an ensemble of regional transient simulations for Europe are presented including those from downscaled SRES IPCC scenarios A2, A1B and B1 to define a range of possible changes. Even under the E1 scenario for most parts of Europe, a warming of more than 2 °C in annual near surface temperature is projected until 2100 compared to 1961–1990, but only small changes in the annual total precipitation.

Zusammenfassung

In dem Europäischen Forschungsprojekt ENSEMBLES wurde ein Treibhausgasszenario entwickelt, das aggressive Vermeidungsstrategien enthält. Es zielt auf eine Stabilisierung der CO_2-Konzentrationen bei etwa 450 ppm im 22. Jahrhundert. Dieses Szenario, das E1 genannt wird, wurde so gestaltet, dass das europäische Ziel, die globale anthropogene Erwärmung unter 2 °C gegenüber dem vorindustriellen Level zu halten, möglichst eingehalten werden kann. Im Folgenden werden Temperatur- und Niederschlagsänderungen aus einer Schar von regionalen transienten Klimaszenarien präsentiert und mit Ergebnissen aus regionalisierten SRES-IPCC-Szenarien A2, A1b und B1 verglichen, um die Bandbreite möglicher Veränderungen aufzeigen zu können. Auch unter E1, wird für weite Teile Europas eine Erwärmung der bodennahen Lufttemperatur im Jahresmittel um mehr als 2 °C gegenüber 1961–1990 projiziert, jedoch ohne nennenswerte Änderungen im Jahresniederschlag.

1. Introduction

Meteorological and hydrological observations demonstrate that during the last decade the climate has changed. Today the global average temperature is 0.7 °C higher than in pre-industrial times, and a mean increase of temperature by 0.09 °C per decade was observed globally from 1951 to 1989. Up to now, 2009, this trend has continued. Europe experienced an extraordinary heat wave in summer 2003, with daily mean temperatures being about 10 °C warmer than the long term mean. The increase of temperature varies depending on the region and season. If the temperature of the atmosphere increases, it should be assumed that the water cycle is intensified. However, it has not been possible until now to present clear statements on changes in the water cycle as a consequence of climate change.

Global climate models (GCM) have been developed to study the Earths climate system in the past and future, for which assumptions of greenhouse gases are needed. Theses models are mathematical images of the Earth system, in which dynamical physical and biogeochemical processes are described numerically to simulate the climate system as realistically as possible.

Even today global climate models provide information only at a relatively coarse spatial scale, which are often not suitable for regional climate change assessments. To overcome the deficiency two different principles to bring the information from the global model to the region of interest are used: statistical downscaling and dynamical downscaling. Statistical downscaling techniques connect the climate change signal provided by the GCM with observations from measurement stations out of the region to achieve higher resolved climate change signals. Dynamical downscaling describes the use of high resolution three dimensional regional climate models (RCM), which are nested into GCMs. RCMs are similar to numerical weather forecasting models, which take into account non-linear processes in the climate system. The results of both methods depend on both the quality of the global and the regional models. In the following, the focus will be on dynamical downscaling, to be able to detect easily new extremes, which have not been observed so far, and to take into account possible feedback mechanisms, which might appear under climate change conditions, like snow-albedo or soil moisture-temperature feedbacks.

As for GCMs, the model quality of RCMs needs to be analyzed before addressing climatic changes. Therefore RCMs are nested into re-analyses data, which can be seen as close to reality as possible. The results of the RCM simulations of the last decades are compared against independent observations, means as well as extremes are considered. For Europe, large efforts have been made by many research groups to analyze the quality of RCM simulations (Jacob et al. 2007). Within the European project ENSEMBLES an entire research theme addressed uncertainties in regional climate model simulations for Europe (van den Linden and Mitchell 2009).

The investigation of possible future climate changes requires information about possible changes in the *drivers* of climate change. So-called *drivers* are for example, amount and distribution of aerosols and greenhouse gases (GHG) in the atmosphere, which depend directly on natural and man-made emissions. The AR4 IPCC emission scenarios follow so-called story lines, describing possible developments of the World (Nakicenovic et al. 2000). The emissions are directly used within GCMs and RCMs, and they initiated changes in global and regional climates through numerous non-linear feedback mechanisms.

Within the European ENSEMBLES project and in preparation for the IPCC Fifth Assessment report an aggressive mitigation scenario (E1) was developed, which is based on the SRES A1B scenario, but aims at 2.9 W/m^2 with a peak in emissions around 2010 and a stabilization of atmospheric greenhouse gas concentrations at around 450 ppm during the 22nd century (van Vuuren et al. 2007). A reverse-engineered approach was used starting from atmospheric concentrations or forcings, instead of usual emissions, which avoids uncertainties arising in the calculations from emissions to concentrations. This new technique has been developed for the IPCC AR5 scenarios, called Representative Concentration Pathways.

The E1 scenario was designed to match the European Union target of keeping global anthropogenic warming below 2 °C relative to pre-industrial level (Fig. 1).

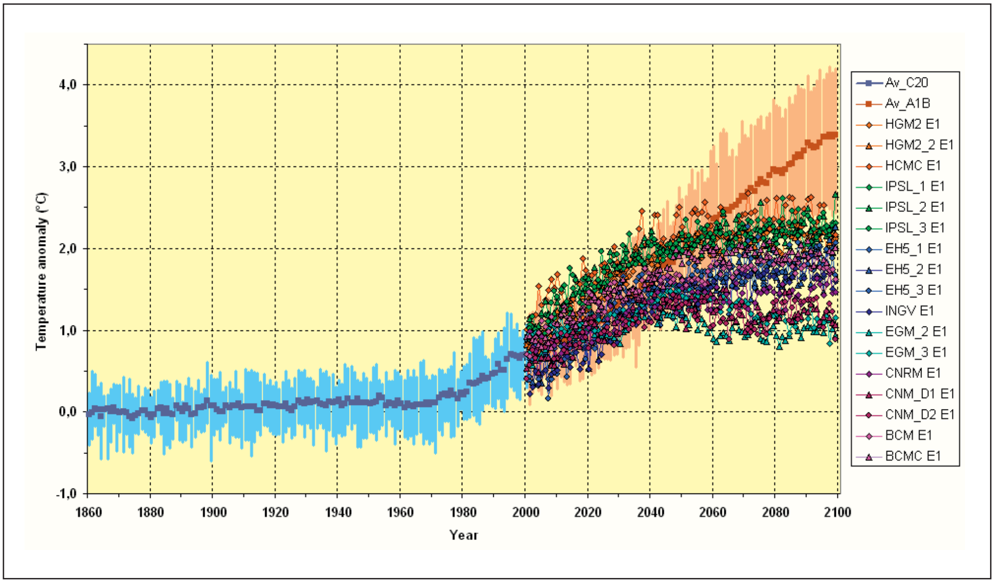

Fig. 1 Global average temperature projected by a range of models for E1 in the 21st century (Fig 2.8 from the ENSEMBLES report).

2. Simulations

For this study an ensemble of regional transient simulations for 1950 to 2100 was performed with the MPI-M regional climate model REMO (Jacob et al. 2007) on 0.44 ° horizontal resolution for Europe (the ENSEMBLES domain). Lateral boundary conditions as well as concentrations originate from simulations provided by the ECHAM5/MPI-OM coupled atmosphere-ocean model (Jungclaus et al. 2006). With the global modeling system an ensemble of historical forcing experiments (1860–2000) was performed followed by a 450 ppm CO_2 (equiv.) stabilization scenario provided by the IMAGE 2.4 integrated assessment model. Results from the global SRES IPCC scenarios A2, A1B, and B1 were used for downscaling.

In addition to the uncertainty arising from the emission the internal variability has been studied by downscaling 3 members of each emissions, scenario provided by the GCM (the Figures below only show results from one member). In total, 12 transient regional climate change simulations from 1950 to 2100 have been carried out with REMO for Europe. REMO is a three-dimensional, hydrostatic RCM (Jacob 2001). The model is based on the "Europamodell", the former numerical weather prediction model of the German Weather Service (Majewski 1991).

3. Projection of Future Changes over Europe

Regional patterns from the E1 scenarios have been investigated with focus on changes in temperature and precipitation. The results are compared to those from downscaled SRES

IPCC scenarios A2, A1B and B1 to define a range of possible changes which can be expected during this century.

Even under the E1 scenario for most parts of Europe, a warming of more than 2 °C in annual near surface air temperature is projected until 2100 compared to 1960–1990 (Fig. 2), but only small changes in the annual total precipitation (Fig. 3). Compared to the A1B scenario, in which an annual warming of more than 4 °C is projected for large parts of southern Europe, a clear reduction in the warming signal is visible, as well as considerable less decrease in annual total precipitation (about 10 % less reduction than in A1B). For northern Europe the increase of annual precipitation is also less strong in E1 compared to A1B.

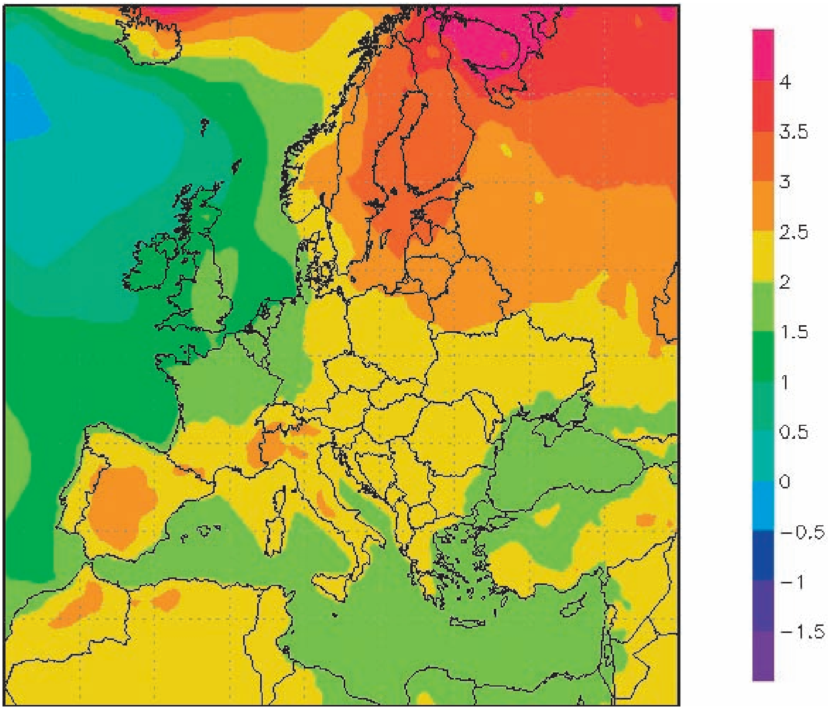

Fig. 2 Annual near surface air temperature signal (°C) for one member of the E1 scenario for the time period 2070–2100 compared to 1960–1990.

The seasonal analyses of the temperature signals resulting from E1 shows, that for southern Europe a warming of approximately 3 °C is projected for summer and fall, whereas for northern Europe the strongest simulated warming is visible in winter with more than 4 °C over large areas in Scandinavia. These changes are still large, but considerable smaller than those projected for an IPCC A1B emission scenarios, for which the annual near surface air temperature signal of southern Europe is calculated to be larger than 4 °C and for example, the summer warming larger than 6 °C in parts of Spain.

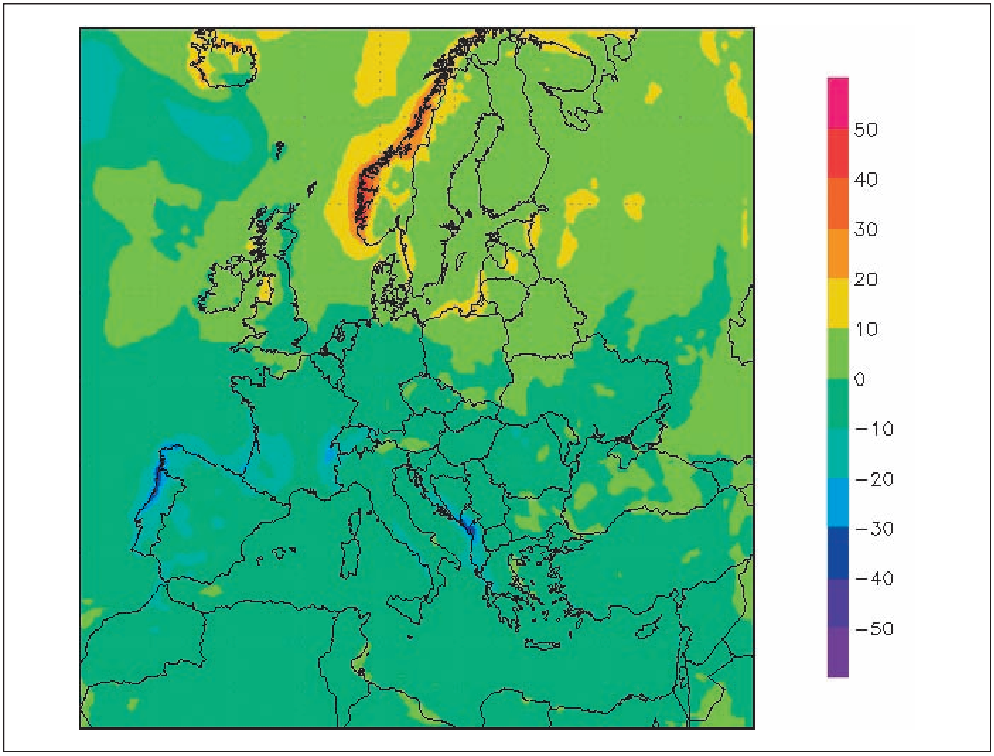

Fig. 3 Annual total precipitation signal (mm/month) for one member of the E1 scenario for the time period 2070–2100 compared to 1960–1990.

The projected changes for temperature and precipitation within the E1 scenarios are relatively similar to those projected for the IPCC SRES scenario B1. However, all changes are less strong. Further investigations are needed for climate impact indices, which are not only based on changes in means but also in extreme values. It is planned to present a more in depth analyses during the conference.

4. Conclusion

First results of the comparison of several climate change projections for Europe have been presented. Special focus was given to the newly developed E1 scenario, which aims at a warming of less than 2 °C until the end of this century compared to the pre-industrial level. Even under a restricted global warming until 2100 of less than 2 °C compared to pre-industrial level, large parts of Europe might face a warming of more than 2 °C in annual mean temperature. Several regions will undergo an even stronger change, in which the changes in annual cycle of temperature and precipitation will impact on the regional and local climate. Please note that the projected increase in temperature is not relative to the pre-industrial level, but to the end of the last century. This means that the projected changes must be added to the change which has been observed until now.

These first results show clearly that even with strong mitigation activities, adaptation to climatic changes will be needed in several regions of Europe.

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Sea Level Rise and Coastal Protection – Adaptation Strategies for Sandy Coasts

Peter Fröhle (Rostock)

With 10 Figures and 1 Table

Abstract

Consequences resulting from future Climate Change may be one of the most severe threats for people and economies in many countries of the world. With respect to Coastal Protection, the resulting changed hydrodynamic impacts are discussed globally. At present, *IPCC* (2007) is estimating a world-wide average sea level rise of less than 1.0 m within the 21st century. Other sources (e.g. Rahmstorf and Schellnhuber 2007), which are taking into account possible melting of the two main continental ice covers (Greenland and Antarctica), estimate significantly higher values, especially over long periods. Besides the problem of sea level rise, also possible general changes in the frequency and intensity of storms as well as general changes in the average wind field are discussed world-wide. With respect to the protection of the coast against flooding and erosion, possible future coastal protection strategies and also possible future coastal protection measures are analysed and assessed.

Zusammenfassung

Die Folgen des Klimawandels könnten die schwersten Bedrohungen für die Menschen und die Ökonomien in vielen Ländern der Erde sein. Für den Küstenschutz sind die resultierenden Veränderungen der hydrodynamischen Bedingungen eine der wesentlichen Herausforderungen. Derzeit (*IPCC* 2007) wird vielfach von einem mittleren Meeresspiegelanstieg in einer Größenordnung von bis zu 1 m ausgegangen. Andere Quellen (z. B. Rahmstorf and Schellnhuber 2007), welche das Abschmelzen der beiden wesentlichen Eiskappen (Grönland und Antarktis) mit berücksichtigen, schätzen deutlich höhere Werte für den mittleren Meeresspiegelanstieg, insbesondere über längere Zeiträume. Neben dem Problem des Meeresspiegelanstiegs werden mögliche Veränderungen der Häufigkeit und Intensität von Stürmen, aber auch grundsätzliche Veränderungen von mittleren Windfeldern weltweit diskutiert. Neben diesen grundsätzlichen Betrachtungen werden im Folgenden zukünftig denkbare Küstenschutzstrategien sowie technische Maßnahmen analysiert und bewertet.

1. Introduction – Global Warming

Climate change and the predicted global warming are on everybody's lips. Serious estimations assume – depending on the selected scenario – a rise of the temperatures of at least 2 °C during the next 100 years (see Fig. 1). Despite the fact that politicians world-wide have agreed that the rise of the temperatures has to be limited to 2 °C by 2100 and have also decided to implement measures accordingly, many climate change researchers still assume that the future rise of the global temperatures will be significantly higher. Moreover, the world-wide distribution of the temperature rise is extremely irregular distributed over the globe (Fig. 2).

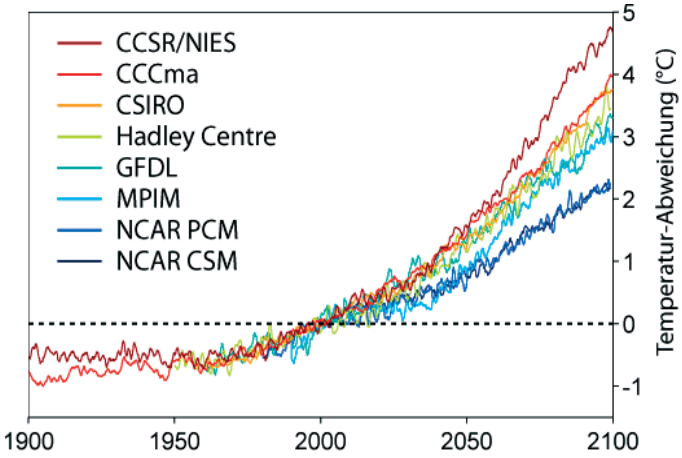

Fig. 1 Projections of global warming for the scenarion A2 (www.globalwarmingart.com)

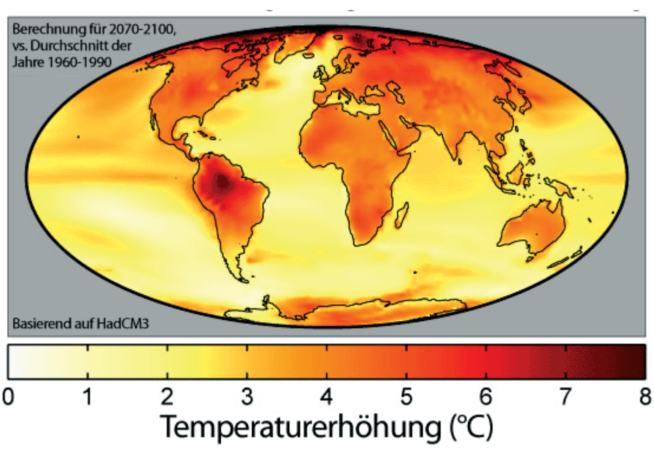

Fig. 2 Global distribution of temperature rise 2070–2100 related to 1960–1990 (www.globalwarmingart.com)

Consequences resulting from future Climate Change may be one of the most severe threats for people and economies in many countries of the world. At present, *IPCC* (2007) is estimating a world-wide average sea level rise of less than 1.0 m within the 21st century. Other sources (e.g. Rahmstorf and Schellnhuber 2007), which are taking into account possible melting of the two main continental ice covers (Greenland and Antarctica), estimate significantly higher values, especially over long periods.

Small Islands and low lying coastal regions are the most vulnerable areas against accelerated sea level rise. The main questions for these areas are, whether the natural morphological development of these low lying areas is fast enough to adapt to the sea level rise, or, whether coastal protection measures can protect the areas against flooding in the long-run.

The Baltic Sea Coasts of Mecklenburg-Vorpommern and Schleswig-Holstein are underlying ongoing erosion of coastal sediments along approximately 70% of their entire length. Hence, 70% of the coast-line is retreating permanently. The protection of the coast, i.e. the stabilization of the coast-line and the protection of the hinterland against flooding, already currently demands considerable amounts of capital appropriations. Against the background of the predicted climate change with raising water levels and changed wave conditions it must be expected that the expenditures for Coastal Protection will rise if the level of protection shall remain constant in the future.

With rising water levels and changed hydrodynamic loads on the coast the question arises whether the actual coastal protection constructions and coastal protection concepts are effective on medium term (decadal scale) and long-term (end of 21st century) engineering time scales. Within the context of the changed climatic conditions and the planning periods in coastal engineering, it is necessary to develop sustainable long-term strategies for coastal protection based on the actual situation. In addition, it is also necessary to identify, as early as possible, future hot spot areas on the coast and sensitive and vulnerable as well as robust coastal protection constructions and concepts. This includes the analysis and assessment of possible scopes of action and possible periods of action. The comparatively long planning periods make it necessary already now, to analyze the development of the safety of existing coastal protection measures under changed hydrodynamic conditions.

2. Sea Level Rise

One of the most important expected effects resulting from the global warming are the worldwide rise of the local water levels in the seas and oceans. The changes of the sea level are related to (*i*) a rising of the mean sea level and/or (*ii*) possible increase of storm induced extreme water levels (wind set-up). Whereas a (moderate) rise of the mean sea level ("saecular sea level rise") is monitored since more than a century (Fig. 3), and an accelerated sea level rise is expected for the future and partly already monitored, it is at the moment not directly derivable that the intensity and the frequency of storm events is also rising (e.g. von Storch et al. 2009).

2.1 Mean Sea Level

Basically, the absolute changes of the mean sea level are divided into eustatic and isostatic changes (Fig. 4), where isostatic changes in the Baltic area are still resulting from the loading/unloading of the earth crust caused by the last ice age. The eustatic changes are resulting mainly from the temperature effects of climate change and are therefore directly related to global warming. The relative changes, which are in the last consequence decisive for Coastal Protection, result from the addition of the local isostatic and eustatic changes.

The German Baltic Sea coast is locally especially affected by the sea level rise, since coastal areas are sinking due to isostatic balance movements (Fig. 5). The accelerated sea level rise (eustatic changes) increases the danger of flooding, especially in the low lying Bodden- and Haff-Areas and the wide bights and firth of the Baltic Sea.

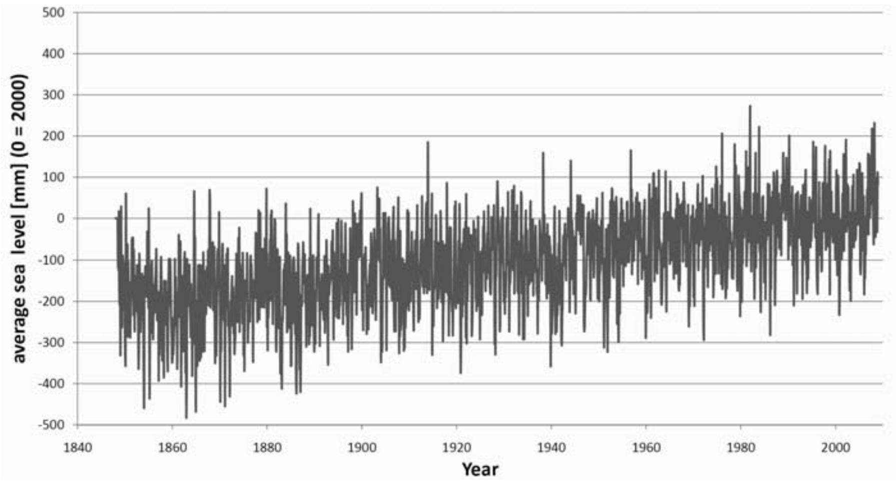

Fig. 3 Sea level changes gauge Wismar, Baltic Sea, PSMSL data

Fig. 4 Eustatic and isostatic sea level rise (schematic)

Authoritative forecasts of the local sea level rise in the southern part of the Baltic Sea are at present still not available. The effects of global warming have been assessed on the global scale and will be transferred to the local scale at present. According to *BACC* (2008) it can be expected that the water level changes in the Baltic Sea will not be equally distributed. At present, a maximum sea level rise of 1 m per 100 years (10 mm/a) is expected for the German North Sea and the German Baltic Sea. The local authorities are discussing to consider a climate safety margin of approximately 0.5 m in the design water levels. Analyses of measurements (Fig. 6) indicate that – at present – the relative sea level rise is in an order of magnitude of approximately 3mm/a.

Analyses on the global scale are indicating an accelerated sea level rise already for quite some time now (*IPCC* 2007).

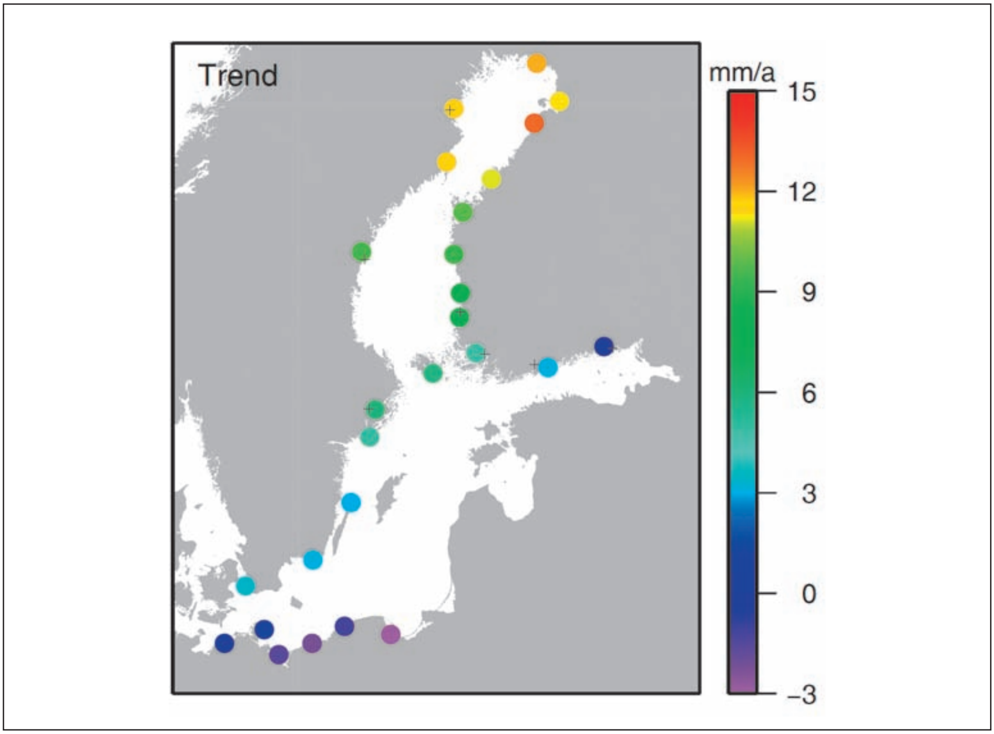

Fig. 5 Isostatic changes in the Baltic Sea (NOVOTNY 2007)

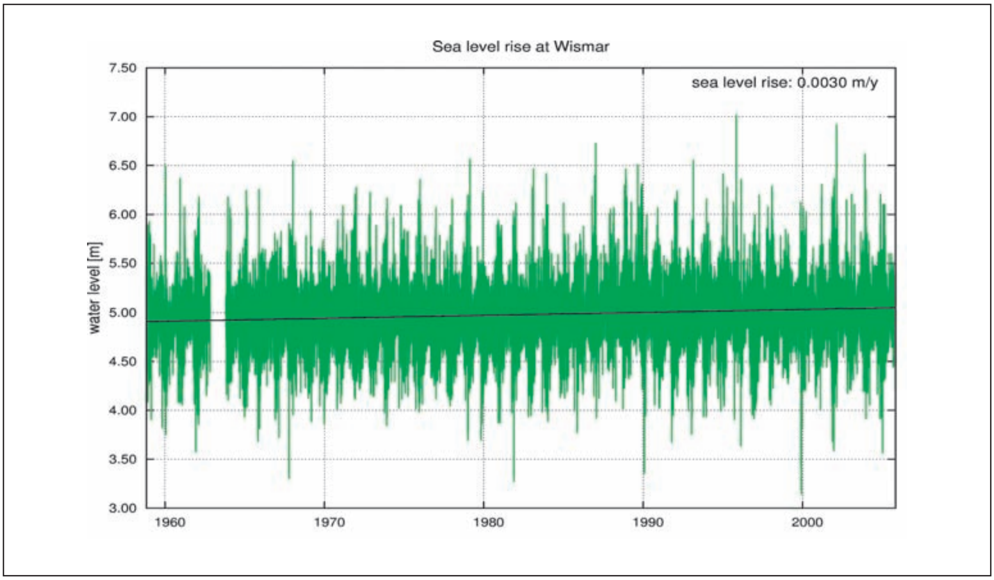

Fig. 6 Mean sea level and sea level rise at the gauge Wismar (1958–2008), DIMKE and FRÖHLE 2009

2.2 Storm Surge Water Levels

Many people assume that the intensity and frequency of storms and, correspondingly, the intensity and frequency of coastal flooding will increase in the future. Direct scientific evidence for this is at present not available. After the information distributed by the north Germany Climate Bureau (*Norddeutsches Klimabüro*) it is still unclear, whether or not the intensity of storms in average per year will increase up to the end of the 21st century (period 2071–2100) compared to the period 1961–1990 (Fig. 7). There are some indications that in the winter period the storm intensity will increase even if the statistical significance of the simulation results is not very high at present (Fig. 8). The values given in the BACC Report (2008) also indicate an increase of the storm intensity and resulting on the storm surge water levels, even if the order of magnitude of the water levels for a storm flood event with a return period of 1 per 100 years is especially for the German Baltic Sea Coast significantly too low.

According to the results of climate researchers it must be expected that storm surge water levels are significantly higher at the end of the 21st century compared to the present situation. This increase is on one hand cause by the rise of the mean sea level and on the other hand caused by the intensification of the storms. Quantitative predictions are not possible at present. The increase of the storm surge water levels will at least be in accordance with the increase of the mean sea level.

3. Waves and Sea State

3.1 Average Sea State

The local average sea state (wave conditions) in the region of the German Baltic Sea coast is generated by the wind-field over the Baltic Sea. This means that changes in the wind-field (velocity and direction) are affecting the wave conditions directly. After the analyses of the north German Climate Bureau (*Norddeutsches Klimabüro*), no significant changes of the wind-velocities have to be expected up to 2100 for the German Baltic Sea, if moderate scenarios are assumed in the numerical simulation runs. Merely for the fall month of a year the model results show a slight increase of the wind velocities. Correspondingly, the wave heights will also increase. Analyses of the BACC group (2008) indicate locally a maximum increase of the wave heights up to the end of the 21st century of – in average – up to 0.4 m.

Possible changes in the wind-directions over the Baltic Sea are as relevant as changes of the wind speed, especially in connection with waves and the effects of waves. Information on possible changes of wind directions and also wave directions are not available from the literature at present. Some meteorologists assume that, caused by the far field relocation of the path of depressions and the changes in the location of high pressure areas, changes of the local wind directions have to be assumed. Qualitatively, an increase of westerly winds and a decrease of easterly winds are expected. Quantitative numbers are, nevertheless, not available. If the wind-directions are changing in future, the wave directions will follow these changes correspondingly.

3.2 Extreme Events

Detailed analyses to the changes of extreme wave conditions are not available at present. After the results presented by the BACC group (2008), it could be possible that extreme wave conditions increase at least in a statistical sense. The BACC group states an increase of the 90 % percentile of the wave height of up to 0.5 m for the Baltic Sea.

Figure 7 shows changes in the off shore wave heights for selected increases of the wind speed under the assumption that the fetch conditions are not changing. The values are calculated using the CERC-approach (*SPM* 1984). The off shore wave conditions are increasing almost linear with the wind velocities. The increases are higher for deeper waters (d = 100 m) compared to shallow water conditions (d = 5 m).

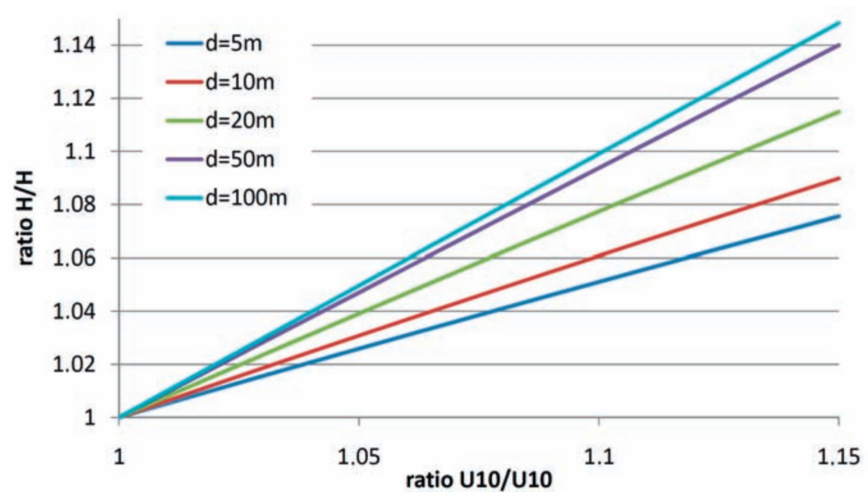

Fig. 7 Increase of the significant wave heights for changed wind conditions in different water depth (CERC approach)

4. Consequences for the Protection of Coasts

4.1 Basic Considerations

Planning and execution of flood protection and coastal protection systems are geared to guarantee a life and operating time of approximately 50 years to 100 years. Hence, also long-term gradual changes of the loads are of importance. Saecular changes of the mean sea level in a range between 0.15 m/100 years (Baltic Sea) and 0.25 m/100 years (North Sea) have been taken into account for the design of coast and flood protection structures since several decades. Within the context of the accelerated sea level rise caused by the global climate change the question arises, which consequences have to be drawn for the methodology and design of future coastal protection concepts and constructions.

4.2 Flood Protection

In the context of this contribution, wave run-up and overtopping at dykes and revetments will be considered, exemplarily. Here, the wave conditions at the toe of the construction are the critical values used for the design. The wave conditions at the toe are normally depth limited. Hence, not the deep water conditions but the shallow water wave conditions are the applicable design values.

Under the assumption that the morphology of the coast in front of a dyke or a revetment can follow the sea level rise, solely the changes of the storm surge water level are the reason for higher waves at a construction and have to be taken into consideration. If the morphology cannot completely follow the sea level rise, consequently, the wave conditions at the toe of a construction will change i.e. increased wave heights and most probably also longer wave periods. Figure 8 shows exemplarily the changes in the wave run-up at a sloped construction for changed water levels at the toe of a construction. The results indicate that without taking into consideration higher wind speeds and/or higher additional flood water levels the height of the constructions has to be increased to ensure comparable safety for the construction and, consequently, in the protected areas.

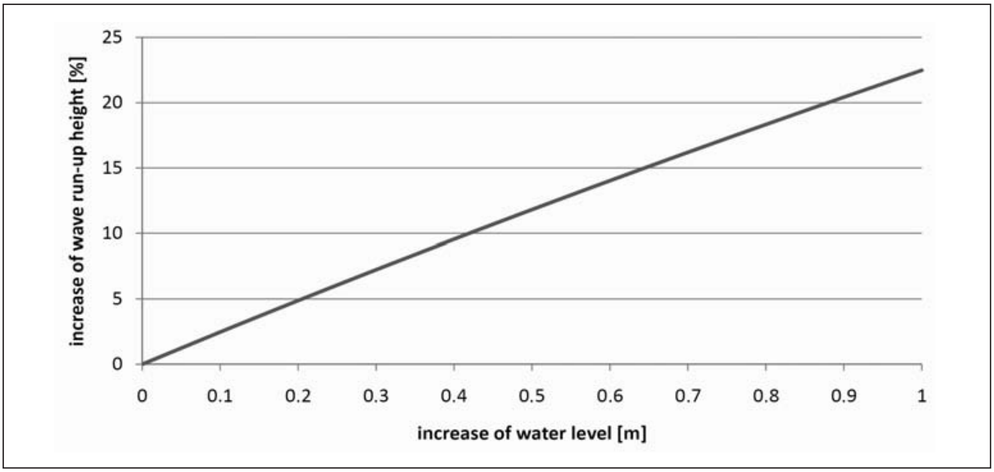

Fig. 8 Wave run-up as a function of changed water levels at the toe of a construction (h_0 = 2.0 m, slope = 1:6)

4.3 Sediment Transport and Protection of Sandy Coasts

The amount of the long-shore sediment transport is depending mainly on the incoming wave energy. The direction of the long-shore sediment transport is depending from the direction of the incoming wave energy. Comparison calculations for the Island of Sylt (Witte et al. 2002) showed that, as long as the morphological changes of the coast are accepted and taken into consideration (see also cross-shore transport) and a moderate climate change is assumed, the amount of transported sediments is practically the same and that merely the directions of the sediment transport is changing. These changes are strongly depending on the actual location and have to be taken into consideration for practical applications, respectively.

For an assessment of the morphological development of a cross-shore coastal profile it is often assumed that a so called dynamic equilibrium profile, which is depending on the incoming waves, is developing at a coastal stretch. Based on this equilibrium profile a possible morphological development of the coast can be calculated.

For the calculation of the reaction of a coast on a changed mean sea level, it is assumed in the following that the necessary amount of sediment for the development of the profile is coming from the cross-shore sediment transport and that the long-shore components of the sediment transport can be neglected. Under these assumptions, a freely chosen example area will retreat in an order of magnitude of approximately 100 m for a sea level rise of 1 m (Fig. 9). Other calculations showed that for the selected case the retreat of the coast is approximately 100-times the amount of the sea level rise. This retreat is high compared to the actual rates of coastal retreat which is presently in average around 10 m to 30 m per century at the German part of the Baltic Sea.

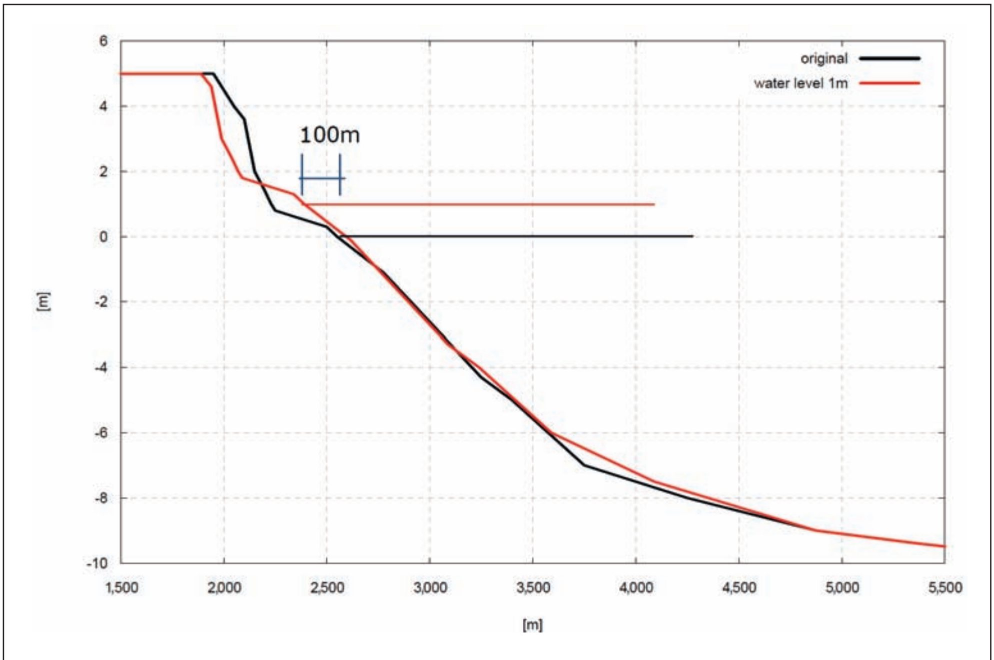

Fig. 9 Adaptation of a selected example cross-shore profile calculated under the assumption of balanced sediment masses to an hypothetic sea level rise of ΔSWL = 1.0 m

4.4 Design of Structures

Consequences of the accelerated sea level rise for the design of coastal protection construction are manifold. In this context the development of the overtopping discharge of an actual sea dyke with nearly no overtopping is used as an example (Fig. 10). The expected development of the overtopping discharge rates as a function of sea level rise are compiled in Table 1. The discharge rates are increasing with increasing sea level rise, and the dyke is going to be unsafe from a sea level rise of approximately 0.5 m onwards.

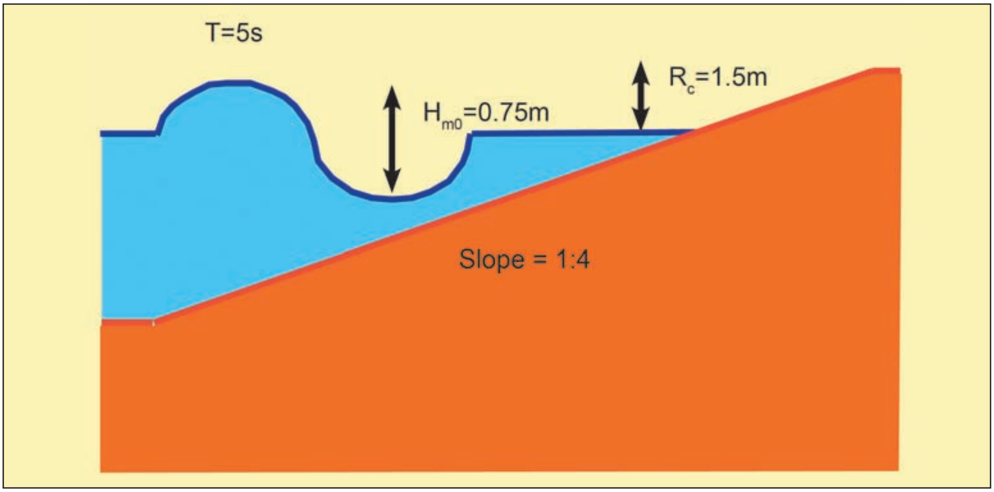

Fig. 10 Wave run-up and freeboard at a dyke

Table 1 Discharge rates as a function of local sea level rise (SLR) for a dyke

SLR (m)	Elevation (m)	Discharge rate (l/s/m)
0.0	1.5	2.5
0.3	1.5	7.3
0.5	1.5	14.7
1.0	1.5	85.0

4.5 Consequences

The described changes of flood protection and the local sediment transport as well as possible morphological development of coasts have a wide variety of consequences for the protection of sandy coasts. Examples are:

- the future practical applicability of established coastal protection measures and constructions;
- the functional and constructional design of measures and constructions for the protection of sandy coasts;
- the future safety of protected areas and changed risks in coastal areas;
- the development of adapted strategies, measures and constructions.

5. Possible Strategies in Coastal Protection

In general, five policies of coastal protection have been developed and applied in coastal engineering. These policies are:

- Do nothing,
- Managed realignment,

- Hold the line,
- Move seaward,
- Limited intervention.

Based on first analyses of possible sea level rise, *IPCC* (1990) identified three possible adaptation strategies to accelerated sea level rise. These three strategies are:

- Retreat,
- Accommodation,
- Protection.

A direct separation of these strategies is not always possible. At present (Hofstede et al. 2009) nearly all strategies are being applied by the responsible authorities in German coastal areas. The selection of an actual strategy is mainly a political question which has to take into account several technical and especially non technical conditions.

6. Project RADOST

As one of seven regions in Germany, the German Baltic Sea coast is funded by the German Ministry of Education and Research within the research program "KLIMZUG – Klimawandel in Regionen zukunftsfähig gestalten". A regional adaptation strategy to climate change will be developed within the project RADOST for the German Baltic Sea coastal region through a dialogue between research institutions, businesses, public administration and civil society. In addition to research institutions and engineering companies, the core team of 17 partners includes several Federal State authorities and one non-governmental organization. Furthermore, the project involves a multitude of network partners. Focus topics are: coastal protection, tourism, agriculture and landscape/natural heritage, ports and maritime economy, environmental protection and uses as well as renewable energies.

Main focus of the works in the topic coastal protection will be the development of adaptation strategies of concepts, methods and constructions for coastal and flood protection. Key questions are:

- How will the Sea Level Rise affect the coast on a local scale?
- Will local storm flood events be changed in the future?
- Are established coastal protection concepts, measures and constructions applicable in the future?
- How does Coastal Protection at the Baltic Sea look like in 2050?

Acknowledgement

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Simulating the Future – Responses of Ecosystems, Key Species, and European Provenances to Expected Climatic Trends and Events

Anke JENTSCH (Landau) and Carl BEIERKUHNLEIN (Bayreuth)

With 4 Figures and 1 Table

Abstract

Future climate change is expected to rapidly modify the long-term average and variation in temperature and precipitation regimes. The local climate that has been experienced by organisms and ecosystems does no longer exist. More frequent and more pronounced extreme weather conditions are expected in the near future. Monitoring both future climate and the ecological responses will be important. However, monitoring can not supply the necessary insights for the design of adaptation strategies in time. Ecological modeling is heuristically limited due to the simple fact of hitherto not available evaluation and adjustment of results. Thus, the experimental simulation of climatic trends and events is urgently needed in order to identify responses of important communities and species that are exposed to a novel climate. Experimental approaches are artificial to some degree, but they can yield fundamental insights into crucial mechanisms of response to rapid climate change. In the EVENT experiments (EVENT I to V), we simulate expected future climatic conditions including extreme weather events along a gradient ranging from highly standardized and replicated pot experiments over manipulation of strongly controlled artificial plant communities (with defined number of specimen and with standardized substrate) to manipulation of semi-natural established grassland communities on old-grown soils. We are testing the effects of summer warming, winter warming, increased winter precipitation, recurrent extreme summer drought, excessive summer rain, and modified frost-thaw-cycles. In addition, we are combining different drivers in multi-factor experiments (e.g. land use intensity and warming or more extreme precipitation regimes). The main focus of the EVENT-experiments is on grasslands, but also shrubland (heath) on the community level and important tree species on the within-species diversity level are experimentally exposed to future climatic scenarios. The role of biodiversity – in terms of species richness and richness of various growth forms and functional groups – for the buffering of extreme weather events is of special interest for us. Surprises occur! Total biomass did not respond as strongly as expected, but single species performance was very specific. For particular species, significant effects of drought, heavy rain and increased freeze-thaw cycles were found in parameters related to e.g. nutrient cycling, gas exchange, phenology and reproductive fitness. Biodiversity did both, buffer extremes in some cases and accelerate stress in other cases.

Zusammenfassung

Der zukünftig erwartete Klimawandel wird mit Veränderungen regionaler Temperatur- und Niederschlagsregime einhergehen. Der Rahmen bisheriger Klimabedingungen, welchen Organismen und Ökosysteme ausgesetzt waren, wird in vielen Regionen verlassen. Zusätzlich werden häufigere und stärkere Extremwetterbedingungen erwartet. Die Beobachtung ökologischer Antworten ist wichtig. Dennoch kann diese nicht die Einblicke vermitteln, die für die rechtzeitige Entwicklung von Anpassungsstrategien benötigt werden. Die Möglichkeiten ökologischer Modellierung sind erkenntnistheoretisch limitiert, da noch nicht auftretende Bedingungen zur Evaluierung und Anpassung der Modelle benötigt würden. Folglich wird eine experimentelle Simulation von erwarteten Trends und Events benötigt, um die Antworten wichtiger Lebensgemeinschaften und Arten unter neuartigen Bedingungen erkennen zu können. Experimentelle Ansätze sind immer zu einem gewissen Grad artifiziell, aber sie können signifikante Aussagen zeitigen. In den EVENT-Experimenten (EVENT I bis V) simulieren wir in naher Zukunft erwartete Klimabedingungen inklusive extremer Wetterereignisse in einem Gradienten unterschiedlicher Naturnähe, von stark kontrollierten Topfexperimenten über kontrollierte Feldexperimente (mit definierter Zahl von Pflanzen und einheitlichem Substrat) hin zu naturnahen Experimenten in etablierten Lebensgemeinschaften auf gewachsenen Böden. Wir testen die Auswirkungen von Sommererwärmung, Wintererwärmung, erhöhtem Winterniederschlag, Sommertrockenheit, sommerlichem Starkregen, veränderten Frost-Auftau-Zyklen. Zusätzlich kombinieren wir verschiedene Steuergrößen in Multifaktor-Experimenten (z. B. veränderte Landnutzungsintensität und Erwärmung mit dem Auftreten extremer Wetterereignisse). Hauptsächlich konzentrieren wir uns auf Grünland, doch berücksichtigen wir auf der Ebene der Lebensgemeinschaften auch Strauchvegetation (Heide) und Bäume verschiedener europäischer Herkünfte als Schlüsselarten. Die Rolle der Biodiversität – sowohl der Artenzahl als auch der Vielfalt von Wuchsformen und funktionellen Eigenschaften – in der Modulation der Effekte des schnellen Klimawandels ist für uns von besonderem Interesse. Überraschende Ergebnisse zeigen sich! Die Gesamtbiomasse von Pflanzengemeinschaften reagiert nicht so stark wie erwartet, aber einzelne Arten werden zum Teil stark ausgelenkt und reagieren komplementär. Biodiversität trägt nicht nur zur Pufferung von Extremen bei. In einigen Fällen führt sie zur Verstärkung des auftretenden Stresses.

1. Heuristic Value of Ecological Experiments in the Face of Climate Change

Humans will be affected by direct climatic impacts. Even more important, indirect effects that are mediated by organisms can severely restrict the societal benefits from ecosystem services. Resources such as drinking water, food and raw materials can be impaired. Pest outbreaks and other natural hazards are promoted. In addition, declining biodiversity is expected to reduce functional resilience of ecosystems.

However, ecological effects of climate change are largely unclear. Of course, we can learn from the past. Paleo-ecological records are valuable. However, their temporal resolution is quite often very coarse. First of all, the expected climate of the future will be surpassing historical records, at least for the last 10,000 years of ecosystem development and memory relevant in Central Europe.

As a consequence, the modeling of biotic responses suggests to be applied. By generalizing ecosystems and biomes in a low spatial resolution at the global scale, conclusions on carbon cycles can be drawn. A higher resolution is constricted partly due to the fact that regional ecosystems and key species perform individual traits and responses. First of all, it is hypothetical to model responses to hitherto not experienced conditions and to project biotic performance outside of the historic range of regional biota. In case of novel site conditions modeling options are limited.

However, "novel" has to be defined. Here, we apply the ecological perspective, meaning environmental conditions that were not imposed to either a given gene-pool of a species (regional populations) or to a given species composition of an ecosystem. Ecological evidence shows that summarizing ecosystems to biomes such as "tropical rain forest" or "broad-leaved deciduous forest" does only support a preliminary and shallow approach but cannot contribute substantially to the understanding of possible responses.

Actual comparisons between local populations and populations that are found under different climates can not be translated into the evaluation of the natural adaptive capacity. Climatic envelopes, which are derived from recent records of species across a range of site conditions, ignore the genetic variability within species. The occurrence of a species in a warmer climate than the one that is in focus for a certain place, does not guarantee the survival and vitality of local populations of this species. Adapted ecotypes within species must not be morphologically distinct. Conclusions from pattern to process can be misleading and support the illusion of safety, as far as key species for ecosystem functioning are concerned.

However, in the face of the drastic climatic changes, which are projected for the 21st century to occur worldwide, we urgently need a better understanding of possible responses of natural systems. Coping and adaptation strategies have to be developed and implemented, soon.

Traditional approaches of ecology and biogeography are aiming to investigate organisms and ecosystems in nature. This is self-evident, because natural systems are addressed with conceptual, theoretical and practical questions.

In the face of climate change, ecological findings can hardly be derived from observations and monitoring. Too many pitfalls are waiting for the investigation of climate change effects on ecosystems, organisms and local populations. These pitfalls include a locally varying history, delayed response and inertia, small-scale site differences and gradients, and autocorrelation. There is an inherent need to prove the results of monitoring approaches in experimental setting. Records and measurements in natural systems have to be seen as a contribution to the generation of hypotheses.

Due to the complexity of nature, a true testing of hypotheses in natural and diverse ecological systems is almost impossible. We can only get a first glimpse on processes, functioning and mechanisms that create a certain pattern, but these cannot be verified in a natural science understanding.

Experiments, on the other hand, can only pick up a selected and very limited number of variables (Fig. 1). The epistemological approach of experiments is indispensably reductionist. Many aspects of natural systems have to be ignored in order to install replicates and controls. But, only then new unbiased insights can be gained when the design of a study allows hypotheses to be falsified or, in the case of non-falsifiable null-hypothesis, that the correlation between the quality of an exposed system (e.g. ecosystem, community, population) and the conducted treatments is significant.

Combining the output and projections of climate models with manipulation experiments is very promising. But, still, there are deviations between models. Plus, only few larger regions of the earth can be covered by regional models at higher resolution. In Europe, WETTREG, STAR, CLM and REMO are providing informative regional projections for a plenitude of climatic parameters. But scenarios on the future frequency and magnitude of extreme weather events are very limited. Uncertainties exist concerning the most probable global emission scenarios. The IPCC has developed such scenarios based on demographic, technological, political, and societal projections. The COP 15 conference in Copenhagen has clearly demonstrated that even if there is conviction and will for decision, the requirements of internal policy are stronger than for international agreement.

2. Overview on Previous Experimental Approaches in Field Ecology

Although hypotheses can hardly be tested in nature, traditional ecology and biogeography were very much orientated to field research, exploring and analyzing patterns. Early experimental studies, important for hypotheses testing, such as the extinction and recolonization experiment on Florida Keys mangrove islands by Simberloff and Wilson (1970), were not criticized for being artificial but for being destructive (e.g. Farnsworth and Rosovsky 1993).

The major problem when experimentally manipulating communities and ecosystems is the complexity of biotic interactions. Ecological systems are not sealed and often diffuse in their spatial extent. This is why influential historical case studies preferred defined catchments (e.g. Hubbard Brook) or concentrated on other distinct units such as lakes (Likens 1985). As in any field experiment, true controls and true replicates are impossible. Unavoidably, noise and variance sets may hide the targeted response patterns.

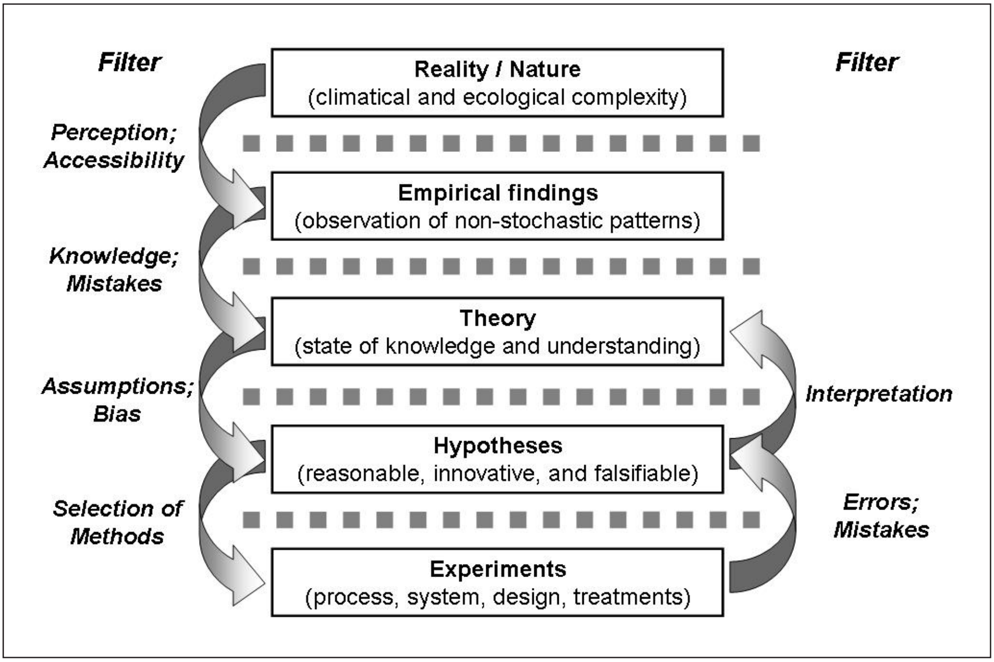

Fig. 1 The development of scientific understanding is mostly stimulated by filtered observation of natural patterns. However, in case of expected future developments a more heuristic and experiment-oriented approach is needed. Restrictions (filters) have to be considered but, with every loop, hypotheses can be refined and theoretical understanding will be improved. Another advantage is the reduction of complexity in experiments by concentrating on a certain mechanism, ecosystem or simulations of expected climatic changes.

As a consequence of the Rio Conference on Biodiversity and the international Convention on Biodiversity, and stimulated by the idea that biodiversity loss may have consequences on ecosystem functioning and services to mankind, a new generation of ecological experiments was installed since the 1990ies (Hector et al. 2007). First of all, the Cedar Creek Experiment in the USA (Tilman et al. 1996) and the European BIODEPTH Experiment (Hector et al. 1999) yielded remarkable results (Beierkuhnlein and Nesshoever 2006) and a follow-up of more and more sophisticated experiments (e.g. Jena-Experiment, Roscher et al. 2004) even manipulating tree species richness (Scherer-Lorenzen et al. 2005).

With some delay but in certain parallelism to the development of biodiversity experiments, climate change experiments evolved. Initially, at the end of the 20^{th} century, mainly CO_2 enrichment and warming were simulated. In first experiments, the majority of manipulations was affected in natural and supposedly sensitive ecosystems (e.g. high mountains, tundra). Simple "Open-Top-Chambers" (OTCs) were established in the International Tundra Experiment (ITEX) in the whole arctic in order to reduce wind speed and thereby increase surface-near air temperature. Harte and Shaw (1995) installed infrared heating devices at wet and dry sites in high mountain ecosystems and found specific responses of plant functional groups on both sites proving that resource availability and functional attributes of plant species have to be considered. In recent years, manipulations of the precipitation regime were carried out in semi-natural ecosystems (e.g. Kahmen et al. 2005). In contrast to slight modifications of temperatures, changes in the temporal availability of water will be directly reflected in the vegetation. It is evident that his field of research is rapidly expanding (Fig. 2).

3. The Simulation of Future Climate and Extreme Weather Events

As far as projections of climatic extremes are concerned, we can only argue on the basis of probabilities. Neither global nor regional climate models are capable of delivering reliable data. There is too much noise in the data stream. Nevertheless, an increase of energy in the atmosphere will necessarily enhance climatic variability in general, making extremes more pronounced and more frequent.

Recognizing the necessity to investigate the effects of rare but possibly influential extreme events, we installed a set of experiments, which are explicitly designed to dissect the role of extreme conditions (Jentsch et al. 2007, Jentsch and Beierkuhnlein 2008). In the EVENT Experiments (I to V, see Tab. 1), we simulate the expected future Central European climate.

Based on experience from field and biodiversity experiments, we organized the experiments along a gradient of naturalness ranging from pot experiments through defined communities to manipulations of established semi-natural ecosystems. The effects of simulated weather extremes are detected in various kinds of replicates and controls (Fig. 3). Modifications of carbon sequestration appear at the ecosystem scale (Mirzaei et al. 2008). Various species-specific responses appear in the vegetation, but surprisingly, biomass productions remains quite stable at the community level (Kreyling et al. 2008a). The same is found true for microbial activity in soils (Kreyling et al. 2008b).

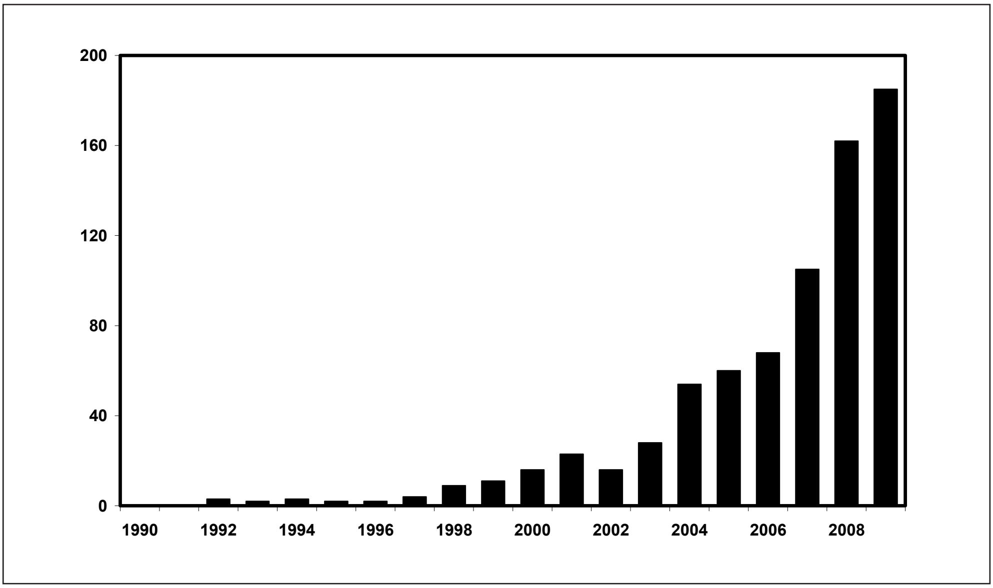

Fig. 2 Development of the number of publications found in peer-reviewed journals for the search string: “climat* change” + biodiversity / “biol* diversity” + experiment* (February 2010, ISI web of knowledge).

Tab. 1 EVENT-Experiments at the University of Bayreuth

	EVENT I	EVENT II	EVENT III	EVENT IV	EVENT V (ex BIODEPTH)
Begin	2005	2008	2008	2010	1996/2009
# Replicates	5	5	21	5	2
# Plots (*Pots)	150	225	2,352*	140	64
Communities	grassland, shrubland	grassland	–	grassland, shrubland	grassland
Functional Types	grasses, herbs, legumes, shrubs	grasses, herbs, legumes	grasses, trees, shrubs	grasses, shrubs	grasses, herbs, legumes
Biodiversity					
Gradient of species diversity (# species per plot)	artificial 1, 2, 4	natural 9–32	none	artificial 1, 2, 4	initially artificial 1–6, now 16–26
Gradient of functional diversity	1, 2, 3	none	none	1, 2, 3	1, 2, 3
Total # species	10	55	10	4	54
Simulation of climatic extremes					
Extreme precipitation in summer	×	×	×	–	–
Extreme drought in summer	×	×	×	–	–
Intensified frost-thaw-cycles in winter	×	–	–	×	–
Simulation of climatic trends					
Summer warming	–	×	×	–	–
Winter warming	×	×	–	–	–
Winter-rain	–	×	–	–	×
Types of control					
Ambient control	×	×	–	×	×
Artefact control	×	–	×	–	–
Average control	×	×	–	–	–
Naturalness					
Naturalness of the installed system	intermediate	high	low	low	intermediate
Simulation of land use intensity (mowing)	–	×	–	–	–
Simulation of land use intensity (fertilisation)	–	×	–	–	–
Combined treatments					
Warming / drought	–	×	×	–	–
Warming / heavy rain	–	×	×	–	–
Warming / land use	–	×	–	–	–

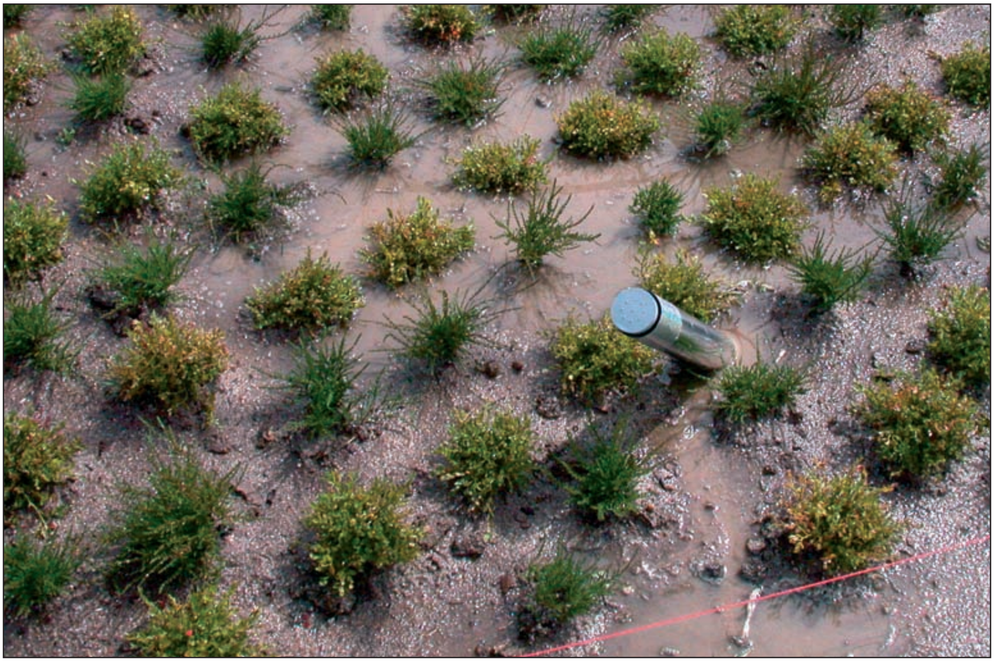

Fig. 3 Newly installed regular distribution of dwarf shrubs in the EVENT I Experiment in the Ecological-Botanical Gardens of the University of Bayreuth after artificial heavy rainfall.

Increased thermal variety in winter time is expected to come along with more frequent changes between freezing and thawing at the soil surface. The repeated melting of insulating snow cover exposes the overwintering parts of plants to night time frost. We interrupted soil frost several times and found strong responses during the following vegetation period. However, the underlying mechanisms are not yet understood (Kreyling et al. 2010).

Flower phenology was found to answer sensitively to short-term extreme events and in a much stronger way than expected for long-term trends (Jentsch et al. 2009).

In accordance with the insurance hypotheses (Yachi and Loreau 1999), species diversity contributes to the buffering of responses and increases resilience due to species-specific responses. In flower phenology, however, we also find counteracting effects of biodiversity. Drought delays phenology of heath (*Calluna vulgaris*) considerably, but only when grasses are present. Grasses are efficient in the development of dense and shallow rooting systems, which intensifies the experienced water shortage in drought treatments for the dwarf shrub (Jentsch et al. 2009).

Community stability is not only controlled by intrinsic responses. Invasion processes may be enhanced by stress that is imposed to the established community. Compared to controls, we found increased community invasibility after heavy rain and reduced invasibility after drought (Kreyling et al. 2008c). Species richness reduced invasibility and contributed to the structural maintenance of established ecosystems.

In addition to approaches at the community and species level, we looked at the genetic variability between populations and their performance in face of climatic extremes. For key species such as *Arrhenatherum elatius* we found a differentiated response, indicating that selecting certain provenances can be seen as an adaptation strategy for the maintenance of ecosystem functioning (Fig. 4).

4. Conclusions

Future experiments on the ecological effects of climate change are needed at larger spatial scales. Ecological complexity can hardly be addressed at small plot sizes. Reliable results can only be achieved in long-term research. However, specific responses are to be expected to a certain year's climate. Also, the climate of early spring may influence the legacy of the whole experiment. Such kinds of singularities can be identified in a stratified design, only, where the start of the experiment is replicated several times in order to produce communities of different ages, which are exposed to climatic manipulations.

Concepts for experimental controls (ambient, artifact, average conditions) and references for manipulations (historical time series, ecological impact, and future projections) are not elaborate and mature until today. Meta-analyses would profit from more standardized and defined approaches. Generality in responses could easier be identified. Obviously, the intensity, duration and also the timing of weather and climate change simulations is decisive – but appropriate data, scales and reference systems are still missing. Finally, we need more multi-factorial experiments, as it is not only one driver that is changing. Interactions between

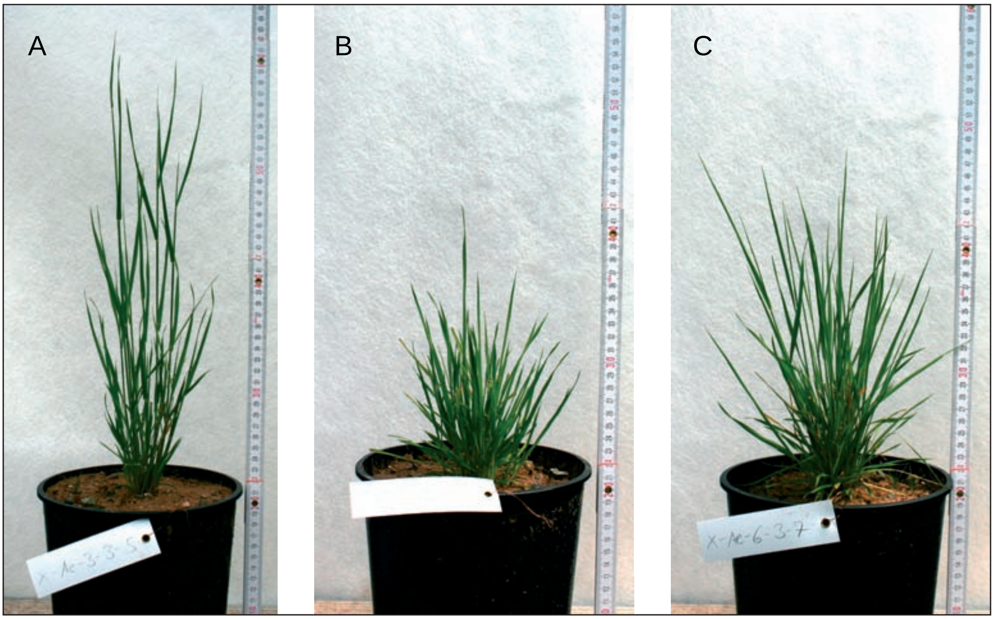

Fig. 4 Comparison of an italian (*A*), hungarian (*B*), and german provenance (*C*) of *Arrhenatherum elatius* (EVENT III). These plants are grown from seed and have been exposed to the same treatment (here combined treatment: warming plus drought). Within the same species, the resilience against climatic stress differs strongly depending on genetically fixed preadaptation.

drivers of ecosystem change are to be expected. Additive effects but also complementary compensation effects are likely to occur and modify the responses to single variables.

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Climate Change Effects on Vector-Borne Diseases in Europe

Dominik Fischer, Stephanie Thomas, and Carl Beierkuhnlein (Bayreuth)

With 2 Figures and 1 Table

Abstract

The most dangerous infectious diseases occur in tropical or subtropical regions. Climate change, however, will be associated with the spread of vector-borne diseases to higher latitudes. Here, the resulting bio-risks for Europe are presented in more detail. Knowledge on suitable future habitat for disease vectors in Europe is scarce. Here, one approach – the modeling of bioclimatic envelopes – is presented. By combining these envelopes with explicit regional climate change simulations, maps of future suitable climatic conditions for disease vectors can be developed. In addition to climatic drivers, globalization might also contribute to the spread of disease vectors in Europe. High invasive capacity combined with travel and trade has turned several disease vectors into "global players". Conceivably, climate change might create the ideal conditions at sea- and airports, from which imported vectors could then go on to conquer other areas in Europe. Nevertheless, vector establishment does not always equate to disease outbreak. For this, additional factors such as the abundance of reservoir hosts and pathogen requirements (e.g. thermal constraints) must be fulfilled. As a matter of fact, European health care is challenged by novel threats for which it must be prepared. This will require both interdisciplinary research and close links between policy and science in order to become proactive and if necessary to adapt monitoring systems in time.

Zusammenfassung

Die gefährlichsten Infektionskrankheiten treten in tropischen bzw. subtropischen Gebieten auf. Der Klimawandel wird jedoch mit sich räumlich ausbreitenden vektor-übertragenen Krankheiten in höhere Breiten in Verbindung gebracht. Die dadurch auftretenden Biorisiken werden im Folgenden für Europa näher beleuchtet. Bisher ist sehr wenig darüber bekannt, welche europäischen Regionen künftig gefährdet sein werden. Als erster Ansatz kann das Modellieren der bioklimatischen Nische, die der Vektor unter aktuellen klimatischen Bedingungen bevorzugt, verstanden werden. Die ermittelte Nische kann mithilfe regionaler Klimaszenarien auf künftig veränderte Bedingungen übertragen werden. Neben klimatischen Faktoren begünstigten intensivierte Handels- und Reisetätigkeiten die weltweite Ausbreitung invasiv auftretender Krankheitsüberträger. Ausgehend von großen europäischen See- und Flughäfen, könnten die importierten Vektoren weitere, für sie klimatisch geeignete, Gebiete besiedeln. Neuauftretende und sich etablierende Krankheitsüberträger sind jedoch nicht gleichbedeutend mit Krankheitsausbrüchen. Hierzu müssen zusätzliche Faktoren wie die thermischen Anforderungen des Erregers erfüllt sein, damit dieser zwischen Wirtstieren zirkulieren kann. Das europäische Gesundheitssystem wird unausweichlich mit dieser neu bzw. wieder auftretenden Gefährdung konfrontiert werden. Dies erfordert den interdisziplinären Wissenschaftsaustausch sowie enge Verknüpfungen zwischen Wissenschaft und Politik. Mithilfe frühzeitig angepasster Überwachungsmaßnahmen könnten die Risiken somit minimiert werden.

1. Vector-Borne Diseases: Risk for Human Health

From an ethical point of view, human health should generally be an issue that is given priority in science, policy, and in particular in climate change research. According to regional climate models, Central Europe will be subjected to above-average warming and its precipitation regimes are expected to change in a patchy and non-uniform way, thus creating irregular regional conditions (Kysely and Beranova 2009).

In 2003 human mortality rates were found to respond to climatic extremes. A more hidden and latent health threat from climate change is related to vector-borne diseases, where organisms and pathogens are highly sensitive to the climate. Recent occurrence has been strongly controlled by the climatic constraints of the biota constituting a chain of infection: pathogen, vector, reservoir and host (Fischer et al. 2009a).

Here, we briefly highlight the potential effects of climate change on vector-borne diseases, which could provoke the (re-)emergence of hazardous bio-risks within Europe in the 21st century. We identify potential risk vectors that are expected to expand their range or become invasive in Europe. We present methodological tools for estimating the tendency to spread and finally, we suggest additional drivers that are contributing to the supposed spread of vector-borne diseases.

2. Disease Vectors in the Light of a Changing European Climate

Disease vectors are carriers that transmit pathogens from one host to another. The majority of vectors are ectothermal arthropods. They are unable to regulate their body temperature and depend directly on their environment. Hence, they react promptly to changing thermal conditions as a survival strategy. The competence of vectors has been compiled in Table 1 for selected species.

In the light of climate change, northward and altitudinal spread has been observed for ticks such as *Ixodes* and *Dermacentor* species (Lindgren and Gustafson 2001, Gray et al. 2009) with warming leading to increased winter activity, as has been observed for *Ixodes ricinus* in a Berlin forest (Dautel et al. 2008).

Risks from regionally restricted infectious diseases, such as sandfly-borne diseases (e. g. Leishmaniasis), are still underrepresented in European science and policy (Dujardin et al. 2008). Although the basis of knowledge on future trends assumed for native and alien disease vectors in Europe is limited there is some cause for alarm: Recently, a northward expansion of sandflies has become increasingly more apparent (Aspöck et al. 2008, Naucke et al. 2008).

3. Projecting the Future: Bioclimate Envelope Modeling of Disease Vectors

The establishment of vector-borne diseases directly depends on the presence of disease vectors. While several studies and observations provide general information on the preferred habitats of vectors, only very little is known about the role of spatio-temporal variation in resource availability. Advanced and more sophisticated bioclimatic models may close this gap as they aim at defining the bioclimatic envelope (Fig. 1) that best describes the limits of a species' spatial range. Species records are correlated with selected bioclimatic variables (Heikkinen et al. 2006) and those variables are selected that best describe the current distribution pattern.

Projections of species' biogeographical ranges for the future are conveyed by simulating future distributions for selected climate change scenarios (Hijmans and Graham 2006). Data

Tab. 1 Selected major vectors and their transmitted pathogens that may cause zoonotic diseases in Europe. Abbreviations behind vector species means: mosquitoes (M), ticks (T) and sandflies (S). Assumed but unproven vector competence is marked with [A], while proven Laboratory competence is marked with [L]. Pathogens, with few occurrences in Europe are marked with *.

Spread of endemic vectors and their transmitted pathogens	
Ixodes ricinus (T) northward trend	Anaplasmataceae, *Babesia divergens*, *Bartonella*, *Borrelia* (*afzelii*, *burgdorferi, garnii*, *valaisiana*), Central European and Tick-borne Encephalitis, *Coxiella burnetii*, *Francisella tularensis*, *Rickettsia helvetica*
Phlebotomus mascittii (T) northward trend (Germany)	*Leishmania infantum*[A]
Phlebotomus perniciosus (S) north-eastward trend (France, Germany)	*Leishmania infantum*, *Arbia* and *Toscana virus*
Widespread European vectors and their possible transmitted emerging pathogens	
Aedes vexans (M)	Eastern Equine Encephalitis, Rift Valley fever (subspecies: *Ae. vexans arabiensis*) and West Nile Virus
Culex pipiens pipiens (M)	Rift Valley fever and West-Nile Virus (enlargement)
Spreading tendencies of endemic vectors and their possible transmitted emerging pathogens	
Dermacentor marginatus (T)	Crimean-Congo Haemorrhagic Fever Virus*
Possible emerging vectors and their transmitted pathogens	
Aedes albopictus (M) recently introduced (Italy 1990)	Chikungunya, Dengue and further 20 arthropod-borne viruses!
Aedes japonicus (M) recently introduced (Switzerland 2007)	Eastern Equine[L],- Japan B[L] and St. Louis Encephalitis[L], West Nile Virus
Possible re-emerging vectors and their transmitted pathogens	
Aedes aegypti (M) disappeared in the last century	Dengue and Yellow Fever Virus
Anopheles maculipennis complex (M)	*Plasmodium* ssp.*

on projected climate change in the 21st century are supplied on global and regional scales by climate models (e.g. Jacob 2008). In contrast to their driving global models, regional climate models (RCM) are capable of taking topography into account at the meso-scale. They simulate climate change at a much higher spatial resolution, which is crucial in very structured relief such as European high mountain regions. The fine grain of regional projections improved the quality of impact studies on human health (Giorgi and Diffenbaugh 2008). Furthermore, assessments on the dispersal of vector organisms in the face of climate change benefit in particular from a high spatial resolution (Jacob 2008, Fischer et al. 2009b).

An intrinsic problem that is apparent in climate models is also a problem in regional models: climatically extreme and thus extraordinary phases are difficult to distinguish from statistical noise and modeling artifacts. In particular, forecasts on precipitation are still rather unreliable. Projections vary strongly between scenarios and, more importantly, between regions (Beniston et al. 2007).

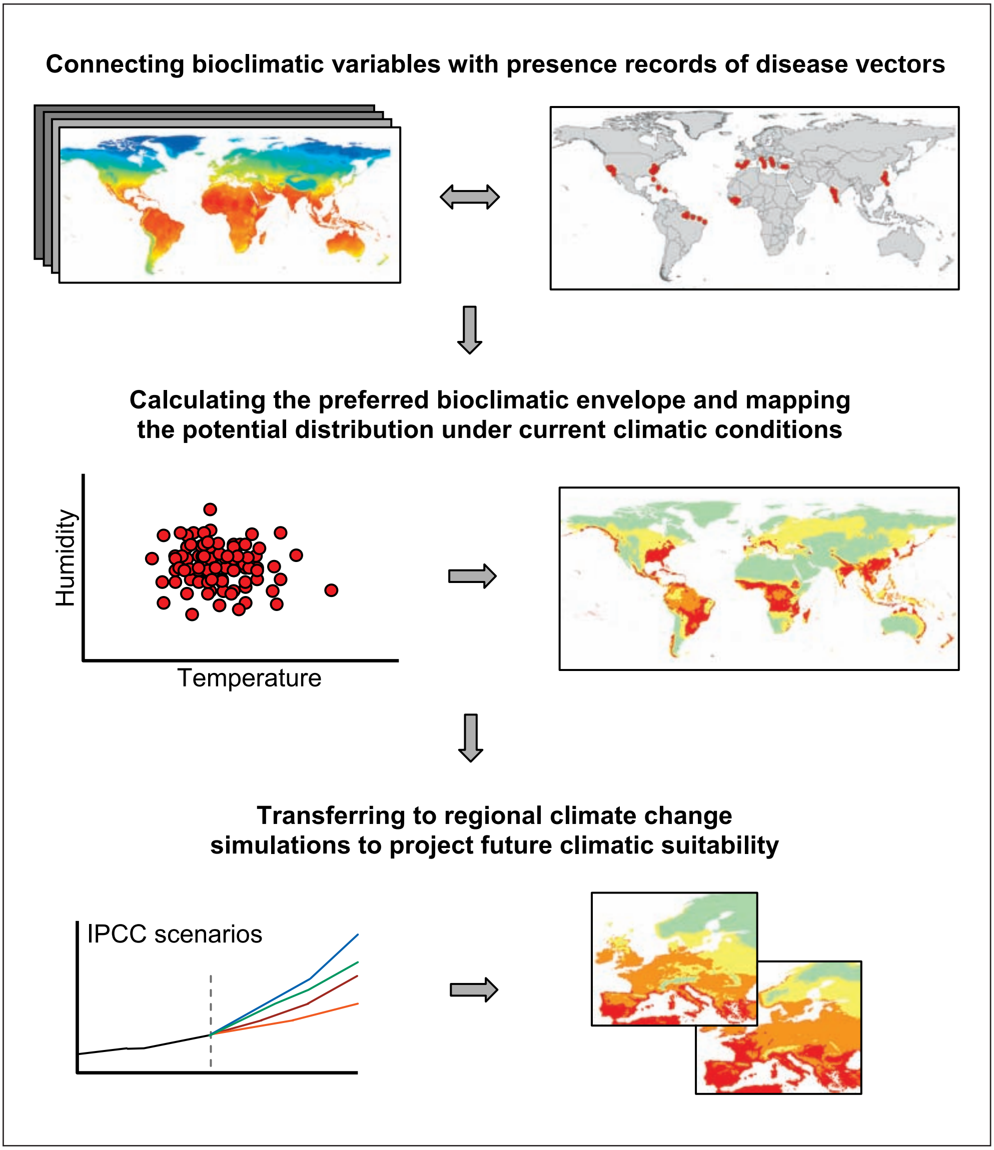

Fig. 1 Principle of bioclimatic envelope modeling of climate-sensitive disease vectors in regional climate change investigations

We realize that other environmental variables (e.g. land use change) contribute to the successful establishment of vectors. Here, uncertainties are striking. Even when limitations are taken into account, we are convinced that bioclimatic envelopes remain a powerful tool for estimating the potential responses of vector distribution to climate change (Fischer et al. 2009c). Hence, the investigation of spatio-temporal climatic suitability of disease vectors in Europe can be considered to be a first step in detecting potential risk areas.

4. Climatic Constraints of Pathogens and Climatic Effects on Reservoir Hosts

The presence of vectors does not necessarily imply disease outbreaks. Moreover, risk analysis on vector-borne diseases in a rapidly changing European environment requires profound knowledge on the thermal constraints of pathogens.

Several mosquitoes (genus *Anopheles*) with vector competence for Malaria are now even endemic to Europe. These species do not only establish in the Mediterranean but also in temperate regions. Serendipitously, neglecting a few individual autochthonous cases (Kampen et al. 2003), the pathogen *Plasmodium vivax* is not established in Europe. Jetten and Takken (1994) called this the phenomenon of "Anophelism without malaria in Europe". These authors stated that these mosquitoes require more than 100 days with a mean temperature of at least 14.5 °C to become infectious. However, rising temperatures may exceed these constraints in the future.

Common European vectors such as *Aedes vexans* and *Culex pipiens pipiens* could function as vectors for other emerging pathogens such as Eastern Equine Encephalitis (endemic to the USA) and the Rift Valley Fever Virus (currently endangering African populations) (Tab. 1). Unfortunately, there is not much knowledge available on pathogen constraints in general let alone on sustainable strategies. Microorganisms and viruses usually perform with high turn-over rates and undergo mutation to adapt to a changing environment.

The Hantavirus (*Bunyaviridae*) for instance, used to only occur in limited regions of South-East Asia but is now present in many areas of the world. The different strains, which are named according to the regions where they first occurred (e.g. Hantaan, Dobrava, Puumala, Korea, Sin-Nombre), are closely related to specific interactions with rodent hosts. Puumala Virus, the most common Hantavirus in Europe, is carried by the bank vole (*Myodes glareolus*). Humans contract the virus by inhaling aerosols or the dust particles of rodent excreta that are contaminated with the virus.

The infectious capacity of reservoir hosts is an additional factor contributing to the performance of a vector-borne disease. Based on the Hantavirus mode of transmission and circulation in nature, it seems reasonable to assume that climate change might influence Hantaviruses through impacting their reservoir host populations (Klempa 2009). Drought and heat waves, experienced by Europeans in 2003 as a memorable example of climatic extremes, are expected to increase both in amplitude and frequency under a changing climate (Jentsch et al. 2007, Jentsch and Beierkuhnlein 2008). They may also cause intensified fructifications of deciduous trees. Such mast years combined with anthropogenically-created or storm-related sparse forests may cause an increase in rodent populations and hence increase the risk of human infections with the Hantavirus (Beierkuhnlein and Foken 2008, Clement et al. 2009).

Furthermore, the spatial pattern of some infectious diseases (e.g. the West-Nile Virus) is related to the routes of migratory birds, which carry the pathogen as reservoirs over short and long distances. The West Nile Virus, originally identified in the West Nile district in Uganda, was commonly considered as a minor risk, inducing a fundamentally non-symptomatic disease or a mild influenza-like illness in humans. However, over the last 15 years, several infections of humans were reported with fatal cases of encephalitis. These cases were mainly related to elderly people in Southern Europe i.e. Romania 1996, Italy 1998, and France 2000 (Zeller and Schuffenecker 2004).

Empirical evidence suggests that climate change alters the speed, timing and typical routes of bird migration (Hedenström 2007). Research on the potential reduction of bird migrations, resulting in less pathogen transport to higher latitudes is valuable for risk analysis.

5. Global Change Factors Contributing to the Spread of Vectors and Diseases

The Asian tiger mosquito (*Aedes albopictus*) is native to South-East Asia. Obviously, the spread of the species has been assisted by human introductions and has not only responded in its global pattern to climatic constraints or favorable conditions (Fischer et al. 2009a). Meanwhile the mosquito has been introduced to almost all continents including Europe due to the global shipping of goods (Fig. 2) and its high adaptive capacity (Enserink 2008). However, as its introduction to Europe already took place in Albania in 1979 and in Italy in 1990, climate change is thought to be assisting in its dispersal across the continent (*ECDC* 2009).

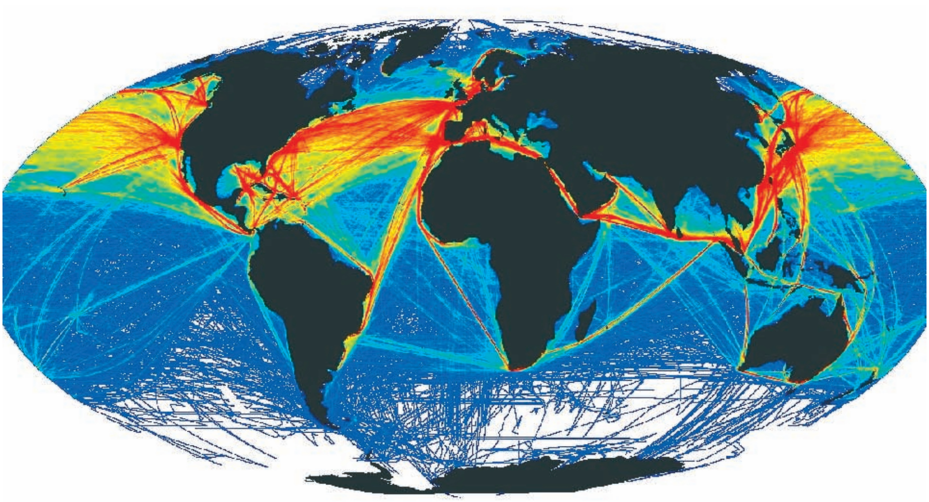

Fig. 2 Global shipping net. Frequency is coloured from blue (low) to red (high). Hence Europe is closely connected intensively with almost all continents. Endangered are therefore many European harbours. Biosecurity controls at European harbours may help to avoid accidental introductions of harmful organisms. Adapted from Halpern et al. 2008.

Long-distance transport and travel enhance the risk of global invasions from vector-borne diseases and have become important supporting mechanisms for their non-linear spread. Infected people from endemic areas may carry "exotic" pathogens to Europe. As a consequence of increased international travel, an increasing number of cases of Malaria and Dengue Fever have been reported at higher latitudes. Returning travelers become infected in endemic areas for instance and transport the pathogen back to Europe.

Still, most pathogen's thermal constraints have prevented them from establishing near European airports. However, one cannot entirely rely on this theory, as the Chikungunya-virus was introduced by an Indian traveler to Northern Italy (near Ravenna) and caused a local epidemic. In addition to the introduction of the pathogen and a fulfillment of the thermal requirements, a competent vector for Chikungunya (*Aedes albopictus*) was present. Hence, this invasive species was able to transmit the pathogen in the summer between (human!) reservoir hosts. Such an unexpected disease outbreak documents the complex interactions that have to be considered.

Trade and the import of pets (especially dogs) – regardless of whether these are legal or illegal – can also become a serious health problem. Many Europeans take pets from their preferred holiday destination – the Mediterranean. These pets (in most cases dogs) could be infected, in particular with the *Leishmania* species. The imported dogs then constitute a lasting reservoir. Sandflies appear to be undertaking climatically-induced range shifts towards the northern and eastern regions in Europe. These insects feed on mammals and can contract pathogens and transmit the disease to humans (Tab. 1). In this case, the introduction of the pathogen could be controlled efficiently by avoiding the trade and transportation of dogs. Sandflies are not very mobile and will perform rather diffusive and slow range shifts.

6. Adaptation Strategies – from Monitoring to Biosecurity

It is very likely that new kinds of climate-driven natural hazards will occur. In addition to abiotic responses such as avalanches, floods, storms, and drought, the ecological responses to changes in temperature and precipitation regimes have to be considered.

Taking into account the post-Copenhagen political environment, a great deal of uncertainty is constituted in deviating international politics. Nevertheless, there are options for a variety of latent and previously not experienced responses in ecosystems and organisms. Pest outbreaks may damage forests and crops. However, the most serious threat to humans is related to the probable occurrence and spread of vector-borne diseases. In particular vector-borne diseases without any options for a vaccination or a cure should be given high priority.

In the face of potentially novel climate-driven biorisks, adaptation strategies are urgently required. Preventative strategies may contribute to minimizing the consequences of climate change on human health. However, coping with uncertainty is difficult when large scales and severe consequences are involved.

Many climatically-controlled vector-borne diseases (e.g. Leishmaniasis) are still not eminent in European countries, even if they constitute serious health hazards. As a result of their expected surge, standardized notification regulations are required to detect any tendency of spread and direction as well as local kernels of establishment.

Improved knowledge on the biology and ecology of the species is needed. In addition to laboratory experiments, geographical analyses, correlations, and models all represent promising approaches.

In terms of monitoring efforts, an interdisciplinary cooperation with traditionally low interaction ranging from entomology, to ecology, microbiology, virology, climatology, geography, and medicine must be implemented (Fischer et al. 2009c). Studies on the economic repercussions of spreading vector-borne diseases will also become imperative. Research needs are evident, but incentives from the scientific community are lacking.

Due to globalization, continental and oceanic barriers are easily overcome. Biosecurity is recognized as being essential for islands that host sensitive endemic species with low competitive capacity and not occupying ecological niches. Continents, in contrast, are perceived to be more or less ecologically saturated and in equilibrium. If this was an illusion in the past, it is ignorance in the future. Climate change is increasingly contributing to the development of novel habitats and to potential invasions.

Implementing efficient biosecurity measures at European airports and harbors may reduce the risk of accidental introductions of exotic disease vectors and pathogens. Strict import and immigration controls of the oceanic islands (e.g. Hawaii, New Zealand) serve as role models. Australia managed to avoid the establishment of *Aedes albopictus* although climatically suitable habitats occur. This stresses the importance of detecting the preferred bioclimatic suitable habitats of disease vectors. Specific monitoring systems can then be concentrated in the respective regions.

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Wüsten –
natürlicher und kultureller Wandel in Raum und Zeit

Leopoldina-Meeting
Deutsche Akademie der Naturforscher Leopoldina in Zusammenarbeit mit der Gesellschaft für Erd- und Völkerkunde zu Stuttgart e. V.

am 2. und 3. Mai 2008 in Stuttgart

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Wüsten üben eine eigenwillige Faszination aus: Sie sind heute einerseits attraktive, mystifizierte, abenteuerträchtige Reiseziele, andererseits aber noch immer extrem lebensfeindliche Naturräume. Die aktuelle Diskussion um den globalen Klimawandel und seine möglichen Folgen wirft ein Schlaglicht auf die lebensarmen Wüsten der Erde. Im vorliegenden Band werden vielfältige Aspekte des Lebens- und Wirtschaftsraumes „Wüste" anhand von Beispielen aus der Sahara und der Namib-Wüste in Afrika, der Atacama in Südamerika und den Wüstengebieten Zentralasiens thematisiert, z. B. die Rekonstruktion der klimatischen und landschaftlichen Geschichte, die kulturelle und kulturgeschichtliche Bedeutung, der aktuelle Wandel und die zukünftige Entwicklung dieser Regionen. In diesen Kontext ordnen sich auch archäologische Forschungsbefunde ein und liefern erstaunliche Erkenntnisse über frühere Kulturmilieus. Aber auch Fragen des Wüstentourismus in der Gegenwart werden kritisch beleuchtet. Die Beiträge zum sozialen, wirtschaftlichen und politischen Wandel in wüstenartigen Gebieten zeigen, welche – teils unerwartete – Rolle solchen Grenzräumen der Ökumene zukommt. Es wird deutlich, wie verletzlich diese Naturräume sind, welche – teils verderbliche – Rolle der Mensch in vielen dieser Ökosysteme spielt und welches gesellschaftlich-politische Konfliktpotenzial sich darin verbirgt. Klimatologische Modellierungsansätze werfen einen Blick in die mögliche zukünftige Entwicklung der Wüsten vor dem Hintergrund des aktuellen Klimawandels in einer stark anthropogen beanspruchten und veränderten Welt.

Wissenschaftliche Verlagsgesellschaft mbH Stuttgart

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Vattenfall's Experience with CCS Technology

Wolfgang Dirschauer and Antje Schirmer (Berlin)

With 5 Figures

Abstract

Vattenfall has strongly invested in climate change technologies, among which CCS holds a very special position. The goal is to technically and economically validate the full CCS chain, including the demonstration of the two most promising emission capture technologies, oxyfuel and post-combustion. In September 2008, Vattenfall began the operation of the world's first ever oxyfuel CCS pilot unit at Schwarze Pumpe. Further research will secure the experience and "know-how" required for the successful scale-up to the 250 MWel oxyfuel demonstration plant project at Jänschwalde. The Jänschwalde demo was found to be Europe's best project and is to receive up to € 180 million in funding from the EEPR budget.

Zusammenfassung

Vattenfall hat umfangreich in Klimaschutztechnologien investiert, unter denen CCS eine herausgehobene Stellung einnimmt. Ziel ist es, die CCS-Kette technisch und wirtschaftlich zu validieren, einschließlich der Demonstration der beiden vielversprechendsten Technologien, Oxyfuel und Post-Combustion. Im September 2008 nahm Vattenfall den Betrieb der weltweit ersten Oxyfuel-Pilotanlage in Schwarze Pumpe auf. Weitere Forschungsarbeiten werden die Erfahrungen und das Know-how für das erfolgreiche Aufskalieren zur 250 Mwel Oxyfuel-Demonstrationsanlage in Jänschwalde generieren. Die Jänschwalder Demonstrationsanlage wurde als bestes europäisches CCS-Projekt bewertet und erhält bis zu 180 Mio. € Fördermittel aus dem Budget des EEPR.

1. About Vattenfall

Vattenfall Europe is an integrated energy company which operates the complete industry value chain, with long-standing expertise particularly in both the construction and operation of coal-fired power plants. Vattenfall Europe's core business is the demand-based production of electricity for wholesale and provisional service markets, as well as the production of heat primarily for domestic and municipal heating in Berlin and Hamburg. Vattenfall Europe is the leading operator of combined heat and power (CHP) for municipal heating in the European Union (EU). Vattenfall Europe operates its own lignite coal mines with a production capacity of approximately 60 million t/y, which predominantly service the company's lignite power plants in the German Federal States of Brandenburg and Saxony.

The company's portfolio consists of power generation facilities using fossil-fuels as well as nuclear and renewable energy. In 2008, Vattenfall Europe produced 70.9 TWh electricity and serviced about 1.3 million households in Berlin and Hamburg with 14.7 TWh heat. Under the

European Emissions Trading System (ETS), Vattenfall emitted 70.4 million t of CO_2.[1] Vattenfall Europe is a significant part of the Vattenfall Group, which is owned by the Swedish State.

2. The Climate Challenge

Climate Change has emerged as one of the major challenges of the 21st century. In the opinion of many leading economists and climate scientists, fighting climate change has become a "challenge comparable to that of fighting poverty" (Stern 2007). Given how poverty and climate change are often self-reinforcing, it is absolutely crucial to link the dual challenges of climate change and unsustainable developing in a coordinated, synchronized manner. Consequently, climate policy must become an integral part of comprehensive policies for sustainable development.

Climate change has thus fundamentally altered the parameters of energy policy and energy business. In the traditional thinking, the energy "triangle" balances "security of supply", "economic competitiveness" and "environment". The latter has effectively been replaced by "climate change", although both terms are by no means synonymous and more often than not turn out to be at odds with one another.[2] Still, climate change has been firmly established as a major vector – or shaper of change – for energy policy.

Furthermore, as energy – and energy policy – is so fundamental to welfare of all societies, one might rightfully state that climate change has also already changed the very fabric of our economies and societies – and will continue to do so to ever-greater extends.

According to the findings of the IPCC, global warming must be contained to approximately 2 °C above pre-industrial levels to avoid dangerous climate change. Achieving this goal necessitates the global concentration of greenhouse gases (GHGs) to be limited in a legally binding and enforceable manner. Over the past few years, the consensus regarding the acceptable threshold for this stabilization bandwidth has shifted notably from about 550 ppm CO_{2eq} to levels around 450 ppm CO_{2eq}, while recent scientific research suggests that we might have already reached levels in the 430's. The PIK argues that the sum total of GHG "expenditure" for the rest of this century has to be strictly limited. According to a business as usual assumption, CO_2 emissions could grow up to 2,500 metric gigatons (Gt) by 2050 and result in a global rise in temperature of up to 7 °C over pre-industrial levels (Edenhofer et al. 2009). The latest scientific findings suggest that additional emissions until 2050 must be held below 750 Gt CO_2.

It has become quite clear that achieving the IPCC target means no more and no less than the complete transformation of not only the energy sector but also the entire economic systems, placing essentially all major societies on track for a low-carbon future, ultimately, this has to result in a state of carbon-neutrality by the end of this century. Without any doubt, climate change presents us with unprecedented challenges.

Today all the climate parameters look worse than they did in 1992 (the year of the Rio Conference) or 1997 (the year of the Kyoto Protocol). Addressing climate change is uniquely

1 For more information see: www.vattenfall.de/www/vf/vf_de/225583xberx/231617finan/231647finan/index.jsp; Vattenfall Europe – Zahlen und Fakten 2008 (englisch).

2 There is increasing evidence of the adverse impact of so-called "first-generation" biofuels on biodiversity, groundwater and even climate.

challenging, because global warming exhibits three characteristics which are uncommonly complicated in comparison to most other policy topics. Firstly, climate change is a truly global challenge. Secondly, it is interdisciplinary in nature from both analytical and political perspectives. And lastly, the problem is extremely long-term – more so than perhaps any other issue high on the political agenda. We need an economically feasible global framework for curbing greenhouse gas emissions and – on a global scale – substantial innovation coupled with unprecedented investment in low-to-zero carbon emission technologies.

As measured in terms of this Herculean agenda, COP15 was anything but encouraging. The 15th United Nations Climate Change Conference in Copenhagen, Denmark, was intended to establish a comprehensive, concrete and legally binding agreement capable of ultimately replacing the 1997 Kyoto Protocol, which expires in 2012. Copenhagen fell short of most EU and UNFCC expectations and left the future global framework for 2012 onwards highly uncertain – even the viability of carbon markets is in question. EU climate policy has lost both ground and momentum, although it will most likely stay on course. Following a decade of EU-leadership in global climate policy, an "eastward" shift towards the Pacific (Asia and the US) is clearly visible, as is the growing impact of economic, financial, and military security stakeholders in the negotiations. It remains to be seen whether the UN will remain the sole or even dominant forum for discussion, or whether new ones will emerge. Thus, Copenhagen might prove to be a watershed for post-Cold-War UN-policy.

It is yet to be seen whether Europe has fully accepted its new role and which policies will be developed in response to new scenarios. The recent motion in the European Parliament[3] is still much in the vein of conventional EU multilateralism (Wortmann-Kool et al. 2010).

3. Vattenfall's Climate Policy

For many years, Vattenfall has been actively engaged with development in international climate policy. Vattenfall has founded the business leadership initiative "Combat Climate Change – 3C", which promotes global caps on GHG emissions, market mechanisms for driving the transformation towards a low-carbon society and shared responsibilities regarding the adaptation to inevitable climate change.[4]

In cooperation with McKinsey, Vattenfall designed a tool to identify and evaluate key measures and technologies to reduce GHG emissions, this tool, the so-called "Climate Map"[5], has been since introduced to many regions and countries in order to provide policy makers and stakeholders with valuable information and insights.

The key principle underlying these initiatives is the early and consistent support for market based policy instruments and international cooperation. Among market-based mechanisms, carbon pricing is the instrument of choice. Thus, the ETS and the future linking of carbon markets are both considered crucial drivers of sound climate policy.

Vattenfall has strongly invested in climate change technologies, and in recognition of the need for international collaboration and knowledge sharing, is actively engaged in a number

3 European Parliament resolution on the outcome of the Copenhagen Conference Summit on Climate Change (COP 15), www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P7-TA-2010-0019+0+DOC+XML+V0//EN

4 For more information see: www.combatclimatechange.org.

5 For more information see: www.vattenfall.com/climatemap/.

of organisations such as the Zero Emissions Platform[6], the North Sea Basin Taskforce[7] and the Global Carbon Capture and Storage Institute (GCCSI).[8]

Vattenfall is focused on the strategic goal of making its electricity and heat production climate-neutral by 2050. The intermediate target is to halve the specific emissions from both electricity and heat by 2030. Thus, sustained CO_2 emission reductions are an integral part of our business mission.

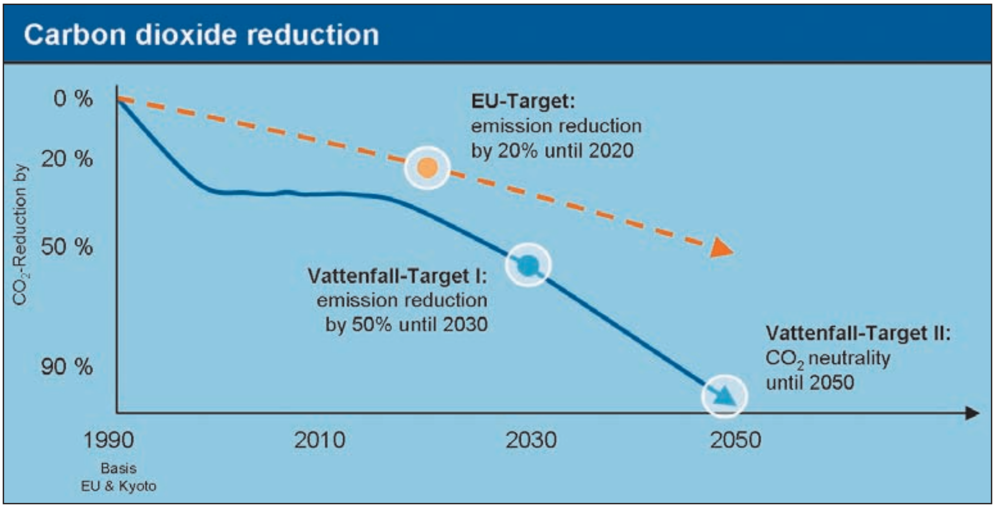

Fig. 1 Vattenfall's pathway to reduce CO_2 emissions

To accomplish this mission, substantial efforts and investments are needed across various areas: efficiency, renewable energy, smart grids, nuclear power and clean coal/CCS.

4. The Role of CCS

Vattenfall's climate strategy consists of a broad portfolio of projects and technologies, in which carbon capture and storage (CCS) holds a very special position. While renewable energies are set to become increasingly important and nuclear energy will have a future if and when society and markets permit this, fossil fuels, especially coal, will continue to represent a significant portion of global energy supply.

In Germany, lignite plays a special role given its abundant supply as an unsubsidized, domestic energy source. In order to reduce the CO_2 emissions from lignite-generated electricity, Vattenfall is focused on research and development which seek to continuously optimize power plant efficiency levels.

6 For more information see: www.zero-emissionplatform.eu.
7 For more information see: www.nsbtf.org.
8 For more information see: www.globalccsinstitute.com.

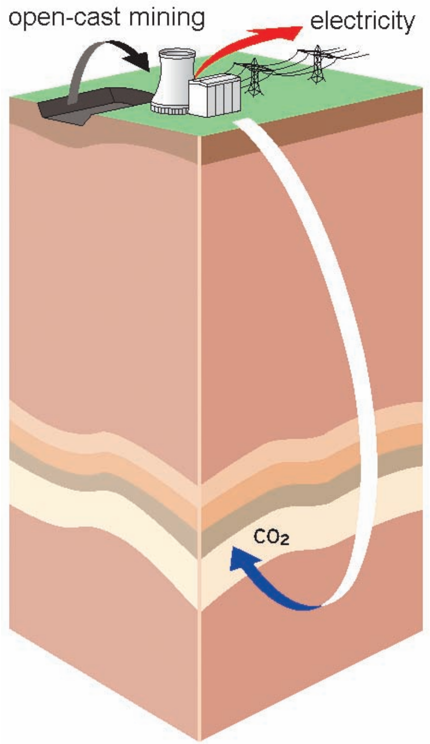

Fig. 2 Scheme of the CCS process

As a result of traditional power plant efficiency reaching its physical limits, CCS is, as of today, the only applicable technology capable of significantly improving the climate-compatibility of fossil-fuel fired power plants. CCS will effectively eliminate more than 90 % of the CO_2 emissions at the plant site, providing coal and gas plants life-cycle carbon footprints on par with today's wind turbines. By using biomass, CCS also paves the way for possibly achieving "carbon-negative" power production, a unique technological feature which may evolve into a dire necessity if the more pessimistic scientific assumptions and prognosis concerning the impact on GHGs on climate change prove to be right, and we might have to resort to even lower emission levels.

Thus, CCS is one of the most significant climate technologies currently "in progress". The mass-introduction of CCS into markets might be crucial to our capability to manage climate change. If we take climate change seriously, CCS is also essential to maintain a strong industrial base. With IPCC scenarios leading to emissions reductions of 85 % or even lower emission levels, CCS will become a necessity not only for the electricity sector, but also for all mayor single-point emitters as well as even – in an aggregated manner – for decentralized emitters, such as in the transport and heating sectors.

In a carbon-constrained world, the role of electricity will increase. E-mobility is more than just a catchy example. There is profound analysis pointing at scenarios for a massively growing relevance of electricity as a "primary" energy source. Thus, it is by no coincidence that CCS has very quickly become a cornerstone of EU energy and climate policy. Both leading politicians and business managers are only too aware that CCS is a classic case of strong leadership in strategic risk-management. CCS allows for a greater diversity of primary energy sources. Otherwise, European carbon-neutrality by 2050 would ultimately result in an irresponsible high-risk-strategy of "renewables only" with very limited amounts of new nuclear – as well as the looming spectre of carbon leakage and de-industrialisation, both of which are completely unacceptable to all responsible stakeholders.

Globally, CCS is without any question a necessity. Given the energy and development needs of an ever growing world population, fossil fuel consumption has already dramatically increased, there is simply no other option available to contain climate change in the light of accessible fossil fuel resources. We might experience unforeseeable breakthroughs in the field of renewables – but then again, we might be not. This is why CCS is probably the quintessential backstop technology in any robust policy scenario.

5. The Vattenfall CCS Experience – Progress and Lessons Learned

For over a decade, Vattenfall has researched completely new high-tech approaches for reducing CO_2 emissions from the combustion of fossil fuels. Through this work, the company has become a pioneer in the CCS technology. The main goal of these projects is to technically and economically validate the full CCS chain, including the demonstration of the two most promising emission capture technologies, oxyfuel and post-combustion. The R&D scope touches all aspects of the respective CCS technology chains, as well as "auxiliary" fields, such as advanced research on lignite drying technology to enhance energy-efficiency.

Vattenfall has participated in various international R&D projects and runs a number of highly innovative projects with numerous research partners from universities and industry. Since the founding of group-wide projects in 2002, an ambitious schedule has been set for a swift step-by-step R&D and upscaling strategy. In 2005, Vattenfall laid down the complete roadmap for an intermediate stage test facility with 0.5 MW_{th}, a pilot plant with 30 MW_{th}, and a near industrial-scale demonstration facility with approximately 700 MW_{th}. In 2007, the 0.5 MW_{th} test facility at the Vattenfall Europe power plant site Jänschwalde was commissioned, and a contract was signed to enter into a joint R&D project for enhanced gas recovery (EGR) at the Altmark-Field, a large natural gas field in a very late stage of its productivity, whose commercial lifespan should be prolonged *via* the injection of CO_2.

During September 2008, Vattenfall began the operation of the world's first ever oxyfuel CCS pilot unit. This breakthrough technology is featured at Vattenfall's Schwarze Pumpe site in the Lusatia region. Investments upwards of more than €70 million have allocated to this first step from the lab into practice, paving the way towards a future in which the conversion of lignite into electricity can be almost entirely climate-neutral.

The pilot plant is located next to the 2 × 800 MW_{el} Schwarze Pumpe power station near Spremberg in southeastern Brandenburg. This location allows the full advantages of the existing infrastructure, as the plant can receive pre-dried lignite dust as fuel and feed the steam produced at the oxyfuel plant into the steam grid which serves the nearby industrial area.

The pilot plant only produces steam, as the innovative oxyfuel process is the primary focus of R&D, whereas the electricity production would have been a fairly conventional process and an added cost factor only. The pilot consists of a 30 MW_{th} burner with complete

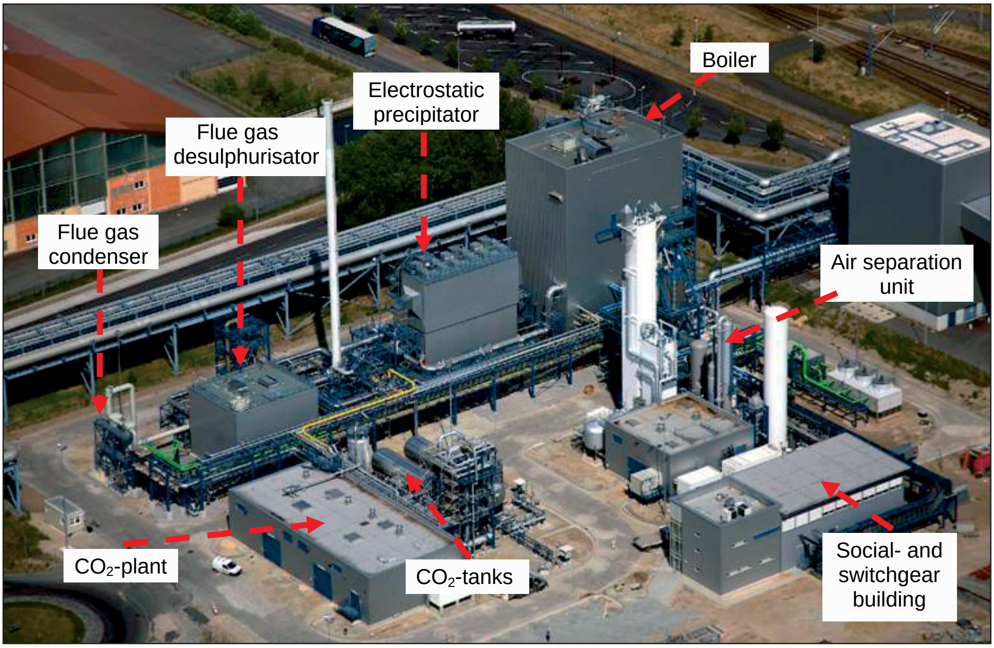

Fig. 3 The oxyfuel power plant in Schwarze Pumpe

subsequent flue gas cleaning equipment, feeding into a CO_2 separation plant where the CO_2 is further purified and then finally liquefied for intermediate storage in two 180 m^3 tanks with attached loading stations for trucks. An on-site cryogenic air separation unit supplies the plant with gaseous oxygen of 99.5 %+ purity levels. Separated CO_2 can be used for diverse industrial purposes and has recently been qualified for use in the EU CO_2SINK project.[9] The pilot is fully licensed to operate both with ambient air and oxyfuel.

The test phase has already provided essential knowledge about the entire oxyfuel process chain. The oxyfuel pilot unit will remain in operation as a research and development test facility until 2013. The coming years will feature intensive research into the oxyfuel concept. In doing so, a range of technical solutions will be tested. The results will secure the experience and "know-how" required for the successful scale-up to the 250 MW_{el} oxyfuel demonstration plant project at Jänschwalde, located 120 km southeast of Berlin in Brandenburg.

During the 2009 testing phase, approximately 1,400 t of CO_2 were liquefied in the oxyfuel pilot unit and about 3,000 operating hours were completed, providing an average availability rate of 40 %. A large number of tests and different measurements were carried out during this time. Not only do these tests help to evaluate the oxyfuel process as a whole, they also provide the test team with vital operating experience. One of the most important results from the test phase is that the concept of the oxyfuel process could now be verified on a scale relevant for industry. At the pilot plant, the entire process chain is conducted, from the air separation unit through to CO_2 purification and compression. Series of measurements are also being recorded to investigate various performance aspects of the unit. One examined aspect is the quality

9 For more information see: www.co2sink.org.

of the CO_2 as a product. The results show that the CO_2 can have a high level of purity as a result of the extensive scrubbing in the pilot CO_2 purification unit. The achievable capture rate exceeds 90 %. In other words more than 90 % of the liquefied CO_2 can be separated out of the flue gas. A feasibility study has also been initiated in order to assess the potential for co-firing biomass with lignite at the CCS pilot unit. The feasibility study is examining which types of biomass to combust, but also looking at other issues such as transport, logistics and on-site storage.

In 2008, Vattenfall also completed the conceptual phase for demonstration projects within the corporate Group, thus continuing the quick upscaling of the capture segment of the technology chain.

6. The Next Step: CCS Demonstration Plant Jänschwalde

Vattenfall is set on a course to construct a CCS demonstration plant with a gross capacity of approximately 470 MW_{el} at the company's Jänschwalde site (Fig. 4). The aim is to commence operations during 2015, which reflects the timeline set by the EU for bringing the first generation of CCS demonstration plants online.

Fig. 4 Planned demonstration plant in Jänschwalde

Jänschwalde, with its unique design of 500 MW_{el} turbine units, fed by two boilers each, has proven well-suited for a CCS demo project, because this layout enables an integrated approach and the parallel testing of two different types of capture technologies at one unit simultaneously.

The lignite-fired power plant complex at Jänschwalde has a total gross capacity of 3,000 MW_{el} and consists of six units. The plant consumes about 25 million t of lignite per year, resulting in total CO_2 emissions of about 25 million t in 2008, with approximately 4.2 million t from the unit F, at which the demo will be built.

One of the steam generators of unit F will be replaced by an oxyfuel steam generator, while post-combustion technology components will be fitted onto another steam generator. The planned layout shows an oxyfuel boiler equipped with an integrated coal drying unit, gross capacity of 260 MW_{el}, as well as a post-combustion capture unit with a gross capacity of 125 MW_{el}. Post-combustion will be applied to only 50 % of the flue gas volume as treating 100 % would only result in two identical parallel post-combustion lines, providing little added technological value but significant additional costs. Thus, about 75 % of the flue gas will be treated, with a capture rate above 90 % and a targeted CO_2 purity above 99 %. Depending on the actual hours of full-load operation equivalent, the CCS demo will separate up to 2.7 million t of CO_2 annually.

The integration of two different capture technologies at one demonstration plant here increases the complexity of the project, but it will also deliver more significant findings for the future commercial uses of CCS. This integrated concept is perhaps the most innovative and unique feature of the Jänschwalde project. Consequently, Jänschwalde, will be a milestone on the road towards the commercialization of CCS post 2020, as the site will uncover invaluable knowledge as well as expertise about the integration of lignite pre-drying and co-firing biomass along the way. Intended to operate as an integral part of the power plant complex, the demo should be run under market conditions, aiming for a full load capacity equivalent of 7,000 hours annually after the initial start-up phase.

In order for CCS to become available on a commercial scale by 2020, storage facilities must be identified and a CO_2 transport infrastructure (pipelines) constructed in a timely manner. Right from the very start, Vattenfall investigated two potential storage types – depleted gas fields and saline aquifers, and two potential storage areas, advancing two parallel projects. Cooperation with partners from the gas industry has been established, bringing experts and technology leaders in the fields of reservoir characterization, storage and transport into the projects. In addition, partners have also been found at highly recognized research institutes such as German Research Center for Geosciences (*Helmholtz-Zentrum Potsdam – Deutsches GeoForschungsZentrum* – GFZ)[10] and Federal Institute for Geosciences and Natural Resources (*Bundesanstalt für Geowissenschaften und Rohstoffe* – BGR).[11]

In partnership with Gaz de France Suez, Vattenfall is seeking to assess the use of CO_2 to augment natural gas production in line with the German government's Altmark (CLEAN) research and pilot project. At the same time the issue of continued storing CO_2 in mature CO_2 storage facilities is also being investigated at this location.

Together with the industrial partners, Vattenfall also intends to survey saline aquifers in east Brandenburg for use as CO_2 storage facilities. The potential storage layers at Beeskow and Neutrebbin are located at depths of 1,200 and 1,500 m and should be surveyed and validated within the next two years. Since the results of these assessments cannot be fully anticipated, Vattenfall is pursuing two additional research areas dealing with the transport of CO_2 *via* pipelines. The pipelines are planned to follow existing gas pipeline routes as far as possible in order to speed up the permits process and avoid "right of way" conflicts.

Vattenfall is extremely open to private-public partnerships. The emerging new CCS infrastructure will be accessible to third parties. Potential partners from industry or public institutions are welcome to cooperate with the analysis and development of the transport and storage aspects.

10 For more information see: www.gfz-potsdam.de
11 For more information see: www.bgr.bund.de.

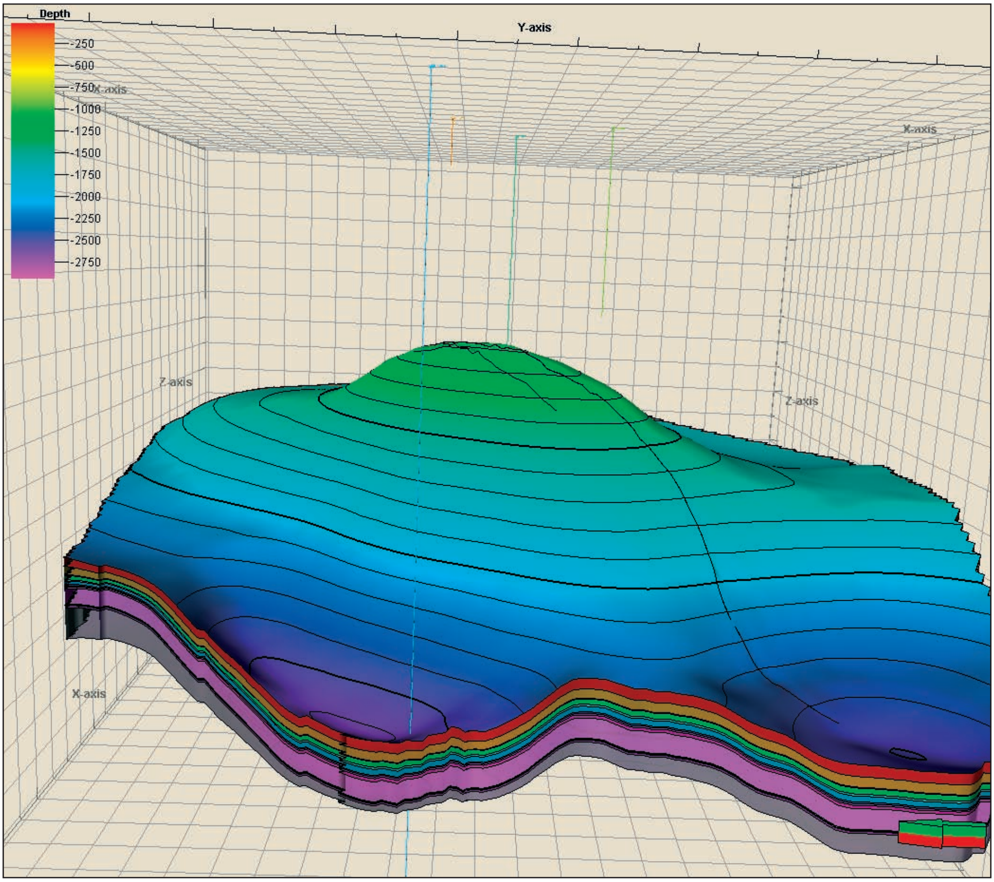

Fig. 5 Anticline structure

The Jänschwalde demo was found to be Europe's best project due to its technological concept (two capture technologies integrated into one existing unit), real carbon reductions (reducing the effective CO_2 emissions from the Jänschwalde power plant complex) mature project development, and unique experience in CCS operations from the pilot plant at Schwarze Pumpe. It is to receive up to € 180 million in funding from the European Commission. The money comes from the European Energy Programme for Recovery (EEPR), the EU's energy related economic stimulus programme that was adopted in June 2009.

While the project planning and up-scaling has proceeded thus far according to our road-maps, CCS is by no means just a matter of engineering or technological development. As with all major technologies, CCS is challenged and questioned regarding its necessity, risks and side-effects. As CCS is most fundamentally a technology driven by the findings of climate science and political decisions, it features significant risk-exposure.

Major challenges of a strictly non-technical nature lie ahead of us. Although the EU has, in a most memorable demonstration of speed and efficiency, laid down the basics for the legal and regulatory framework in its CCS Directive[12], many important decisions remain in the hands of the member states, which are responsible for not only the implementation of the directive into the respective national law but also for the permitting procedures along the entire CCS technology chain. Many crucial issues have only been superficially resolved in the directive, thus the actual legal framework is still to a very large extend "work in progress". As one of the frontrunners and risk-takers in this field, Vattenfall naturally hopes for both speedy and investment-friendly legislation. Time is of the essence if we are to reach the milestones in EU energy and climate policy. And billion euro investments require a reliable and incentivised legal basis.

As the demo phase of CCS cannot be – as with all demo stages of any new technology – economically viable on its own. Additional financial support will be crucial for the realization of demo plants. The EU is very aware of this fact and provided not only the mid- and long-term supportive framework (i.e. the carbon pricing *via* the European emissions trading scheme – ETS) but also quickly created two completely new instruments for supporting CCS demo projects on the EU level. The EEPR has already – with exceptional efficiency and speed – been implemented, which has tremendously stimulated many countries and industrial stakeholders to proceed with their efforts. However, considering the actual investment sums, the main support instrument will undoubtedly be the NER300. Thus, the architecture of the NER300 funding will be of the utmost importance. This is especially true when it comes to the EU timeline and the 2015 deadline, by which at least most of the CCS demo plants are expected to be running. Considering the necessary engineering, planning and permitting phases, 2015 is a very challenging deadline which should not be made even more challenging by the EU's postponement of NER300 funding decisions until the end of 2011.

Last, but by no means least, there is the issue of public and political support – otherwise known as "acceptance". It goes without saying that, in today's Europe, no major industrial investment stands a chance without adequate public and political acceptance. In addition, it is also true that acceptance can neither be bought nor blue-print-built. Basically all industries have experienced a year-long decline in acceptance regarding industrial investments, regardless if these investments are power plants, transmission grids, refineries, or chemical plants. We, too, are concerned about this NIMBY approach to industry, recently accompanied by NOMBY, NUMBY and even BANANA.[13] If this anti-industrial mindset prevails, not only will our industrial base suffer, but it will also become completely impossible to effectively manage climate change. All significant policies for reducing GHG emissions imply massive investments, whether in large-scale wind-farms and biomass plants, reinforced or newly-built transmission grids, pipelines, power plants, and the list goes on. This is why Vattenfall Europe encourages the free and easily accessible distribution of information about CCS and welcomes the explicit support of the EU Commission and many member state governments for CCS.

CCS is a model case for cooperative efforts among industry, politics, public institutions, and society at large. If even one of these stakeholders fails to deliver, the result will be deeply

12 For more information see: Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006.

13 NIMBY = "Not In My Backyard", NOMBY = "Not Over My Backyard", NUMBY = "Not Under My Backyard" and BANANA = "Build Absolutely Nothing Anywhere Near Anybody"

worrisome. As far as can be seen, fossil fuels, especially coal, will be used in the future, either with or without CCS. Phrased simply, this means either with 100 % emissions or with less than 10 %. Moreover, this also shows the limited relevance of many heated discussions about "acceptable" leakage rates from storage. If 99 % storage integrity over 100 years is not good enough, we might as well just end up with a 100 % of emissions every year. We have the choice to make the important difference.

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Adaptive Governance within Europe – the Need for Integrated Adaptation Strategies

Christoph Görg (Leipzig/Kassel)

With 1 Figure

Abstract

Adaptation to climate change raises fundamental challenges concerning the development of integrated adaptation strategies. In the presentation, four overarching challenges and how to respond to them will be elaborated in more detail: the integration of climate change mitigation and adaptation measures; the need to address the adaptation requirements of important economic and political sectors of society, the need to address specific regional vulnerabilities and the interplay of several levels of decision making. The issue of adaptation to climate change thus presents far-reaching challenges in terms of shaping societal development and, more specifically, societal relationships with nature as a whole.

Zusammenfassung

Die Anpassung an den Klimawandel bringt grundsätzliche Herausforderungen im Hinblick auf integrierte Anpassungsstrategien mit sich. Vier übergreifende Herausforderungen, und wie ihnen begegnet werden kann, werden im Vortrag genauer erläutert: die Integration von Klimaschutz und Klimaanpassung, die Integration von Anpassungserfordernissen in wichtige wirtschaftliche und politische Teilbereiche der Gesellschaft, die Berücksichtigung spezifischer regionaler Verwundbarkeiten und das Zusammenspiel verschiedener Entscheidungsebenen. Es wird gezeigt, dass die Anpassung an den Klimawandel weitreichende Gestaltungsprobleme gesellschaftlicher Entwicklung und insbesondere gesellschaftlicher Naturverhältnisse aufwirft.

Since publication of the last assessment report of the Intergovernmental Panel on Climate Change (*IPCC* 2007a) climate change has come to be regarded worldwide as a reality. Even the recent controversies about the work of the IPCC have not really questioned the fundamental message that action in response to ongoing climate change has become a necessity. Moreover, governments around the world have been more willing to take up these challenges since the 'Stern Report' sets out the costs of climate change as well as the notion that costs of inaction are higher than those of taking preventive action (Stern 2007). Thus, alongside the issue of avoiding or reducing greenhouse gas emissions (mitigation), the 'taboo on adaptation' has been lifted (Pielke et al. 2007) and is currently being accorded greater attention. Within Europe, this has led to political action at different levels; from the European (*COM* 2007, 2009) and national levels (e.g. *BMU* 2008, see Swart at al. 2009) down to lower levels of decision making such as for example, the majority of German states (Länder), which have established adaptation strategies or are preparing them, and even within smaller regions where several regional adaptation strategies are under development (as within the BMBF funding activity KLIMZUG: see http://www.klimzug.de/).

Adaptation to climate change, however, raises fundamental challenges concerning the development of integrated climate change adaptation strategies involving multiple societal sector and level of decision-making. Climate change adaptation must not only address a few economic activities or societal sectors,[1] but most sectors and development patterns of modern societies: from architecture, infrastructure and urban development up to spatial planning, water management, agriculture and forestry, among others. Moreover, whereas climate mitigation focuses on the reduction of green house gas emissions, climate change adaptation cannot be measured by a single indicator (*BMU* 2008). Instead, reducing vulnerabilities and improving adaption capacities are mentioned as long term goals of adaptation measures (*BMU* 2008). Sometimes these goals are supplemented by using the term resilience as a concept for guiding adaptation measures (*COM* 2009), but all of these terms represent very broad and unspecific societal goals. They carry different meanings for different sectors of society and neither their success nor failure is easily to measure. Moreover, the aim of adapting to climate change has to be included in the goals, strategies and measures of nearly every single sector of modern societies to adequately address the challenges expected to result from climate change. Thus, the need for integrated strategies (not completely novel to environmental policy) becomes even more urgent than in other fields of environmental decision-making. In the following, four overarching challenges and how to respond to them will be elaborated in more detail, taken from several research projects conducted to analyze the challenges of climate policies at different levels.[2]

1. Integrated Perspective on *Mitigation* and *Adaptation Measures*

The first challenge requires avoiding or at least minimizing conflicts between climate change mitigation and adaptation: neither should adaptation measures undermine the mitigation of green house gas (GHG) emissions nor should mitigation measures harm the capacity for adaptation to climate change. But neither intellectually nor practically, is this challenge so easily addressed, as ongoing discussions about the relationships between both clearly reveal. We can quickly demonstrate the challenge to our understanding if we look closer at the exact meaning of climate change and the relationships between mitigation and adaptation that follows this definition. On one hand there is a certain narrow understanding defined in the *Framework Convention on Climate Change* (FCCC) which focuses on the anthropogenic causes of climate change (see *FCCC* 1992: Article 1, 2). According to the FCCC climate change is 'attributed directly or indirectly to human activity that alters the composition of the global atmosphere'. This narrowing down to 'human activities' as a cause of climate change certainly makes sense from a political point of view, because it emphasizes the question of political

1 Climate change mitigation was seen for a long time as a challenge mostly for the energy and mobility sectors. Over the last years, however, it was realized that we face a more comprehensive challenge where most sectors of industrialized societies are affected, from land use up to housing and consumption patterns; see Mickwitz et al. 2009.

2 The paper builds upon a comparative project on climate policy integration in different European countries (Mickwitz et al. 2009, Beck et al. 2009), on an ongoing project about synergies and conflicts of national adaptation measures at the UFZ (SynKon, focusing on the German adaptation strategy DAS), on research about integrated strategies for climate adaptation in the context of land use change (Seppelt et al. 2009), on research about experiences with participatory methods within the multi-level-governance architecture of Europe (GoverNat; see: http://www.governat.eu/) and on regional adaptation strategies in the contexts of the project KLIMZUG-Nordhessen (see http://www.klimzug-nordhessen.de/).

responsibility. However, there is a threat to evoke a limited perspective on climate adaptation: following this definition adaptation is needed because of the *failure* of climate change mitigation. And this close relationship between adaptation and the failure of mitigation has contributed to the long-standing taboo on adaptation (cf. Pielke 2005, Pielke et al. 2007), On the other hand, the broad definition of the *Intergovernmental Panel on Climate Change* (IPCC) has led to a broader understanding of climate change. According to the IPCC, climate change is 'change arising from any source' (*IPCC* 1996, p. 13). This includes both anthropogenic and natural causes (e.g. natural variabilities in the global climate) in equal measure. If we accept this broad definition, adaptation to climate change is not restricted to a failure of climate change mitigation. Moreover, according to the IPCC's broad definition, mitigation and adaptation can no longer be placed in abstract opposition to one another, because both are immediately linked with each other.

From a practical perspective, however, further challenges arise. As we have learned from discussions on bioenergy, and in particular on biofuels, mitigation measures can indeed harm the capacity to adapt to climate change if their potential impacts on our natural environment or on other sectors of society are not comprehensively analyzed before action is undertaken. This example reveals an overarching challenge of integrated climate policies: There should be an *ex-ante evaluation* of every single mitigation and adaptation measures, not only in terms of success or failure concerning their intended goals, but also in view of external effects. According to the results of a study on climate change policy integration within several European countries (Mickwitz et al. 2009), the need for better monitoring and evaluation of policy measures to support policy coherence is crucial. Most European countries have evaluation tools for policy options (such as regulatory impact assessments), but there is significant room for improvement regarding both *ex-ante* assessments and *ex-post* evaluations of climate change mitigation and adaptation measures.

2. Integrated Perspective on Several *Economic and Societal Sectors*

The aforementioned argument regarding *ex-ante* evaluation of policy options leads to the second challenge: To reduce societal vulnerabilities and to improve adaptation capacities, integrated response strategies need to address the adaptation requirements of important industrial sectors as much as the distribution of costs and gains. For European societies significant changes in production processes as well as in consumption patterns are required if they are to be capable of tackling climate change. Such transformations will require that climate change and the need for adaptation is taken into account in both general and sector-specific policies. If climate policies, in particular adaption measures, are not supported by other policies, the required transformations will not be achieved. The degree to which climate change issues are considered and integrated into existing policy areas is therefore a key issue.

Over recent years we observe an increased inclusion of climate change mitigation and adaptation goals across countries, governmental levels and policy sectors, which has led to the issuing of new and more ambitious national mitigation (Mickwitz et al. 2009) and adaptation strategies (Swart et al. 2009). An emerging trend is the broadening of policy integration in terms of sectors, actors, levels and scales. Climate change mitigation and adaptation goals are included into a wide variety of sectors (ranging from energy, transport and infrastructure to innovation and technology policies and education) and are reflected in new policy instruments or changes of existing ones. Significant challenges remain however (see Mickwitz et al. 2009 for the following): detailed implementation plans or sufficiently financial commitments are frequently absent; reporting, monitoring and evaluation processes sufficient for societal learning, are still not established; consistency between policy aims is seldom addressed and their priorities are often only implicit. Moreover, due to the current emphasis on win-win solutions and innovation opportunities, trade-offs and conflicts of climate policy are often more concealed than resolved. Not all conflicts, however, can be resolved by technologies or innovations, and very often climate policy reopens and/or reframes old discourses and conflicts, such as those surrounding nuclear power, or the relationship between nature protection and agriculture.

3. Integrated Adaptation Strategies Need to Address the Specific *Social Vulnerabilities*

Integrated approaches to climate change adaptation need to address specific regional vulnerabilities, taking into account high levels of uncertainty concerning the predictability of climate change impacts and different temporal scales of decision-making (from short time legislative periods up to long time planning of forests and landscapes). Here again, our comprehension of the interplay of natural and societal factors of climate change is particularly important for analyzing climate-related vulnerabilities. Concerning estimations of regional vulnerabilities, top-down approaches have prevailed, trying to predict vulnerabilities using regional climate models down-scaled from global climate models (see Dessai und Hulme 2003). What is still needed, however, is more research from the complementary perspective of social vulnerability (see Fig. 1).

In addition to the *exposition* of a certain region to climate change (which includes the extent of global climate change and regional specificities), it is also important to analyze the *sensitivity* of socioeconomic processes (cf. *IPCC* 2007b): which societal processes are particularly under pressure in, which may benefit from climate change? Consideration needs to be given also to the fact that sensitivity is not a given, but produced by former socioeconomic activities. If you build more houses in areas exposed to risk of flooding, economic threats are intensified – independently of whether additional risks due to global warming appear or not. Moreover, vulnerabilities do not have one single cause but are caused by the interplay of several drivers. Very often, climate change is perhaps not the main driver but often intensifies existing problems (e.g. effects of intensified droughts on marginalized social groups). Finally, the existence of, or lack of, societal *adaption capacity* is crucial: which regions have the necessary resources, know-how and political will to meet these new challenges?

To analyze social vulnerabilities seriously is important for an estimation of the threats of climate change for different social groups within societies and to appraise their capacity to cope with regional vulnerabilities. Moreover, it represents an approach to deal with limits concerning the prediction of regional impacts of climate change. Irrespective of ongoing attempts to reduce uncertainties in our prediction of climate change by improving regional climate models, we are not able to reduce all uncertainties and provide exact estimations to decision makers concerning the exposition of certain regions to further climate change. Of course some uncertainties can be narrowed, but there is an ongoing debate about how to communicate remaining uncertainties to users of regional climate models (decision makers and other researchers; see Dessai and van der Sluijs 2007, Hulme et al. 2009, *NKGCF* 2010). An investigation of social vulnerabilities, however, provides new opportunities to analyze und reduce socioeconomic threats of global warming without waiting for safe impact prediction.

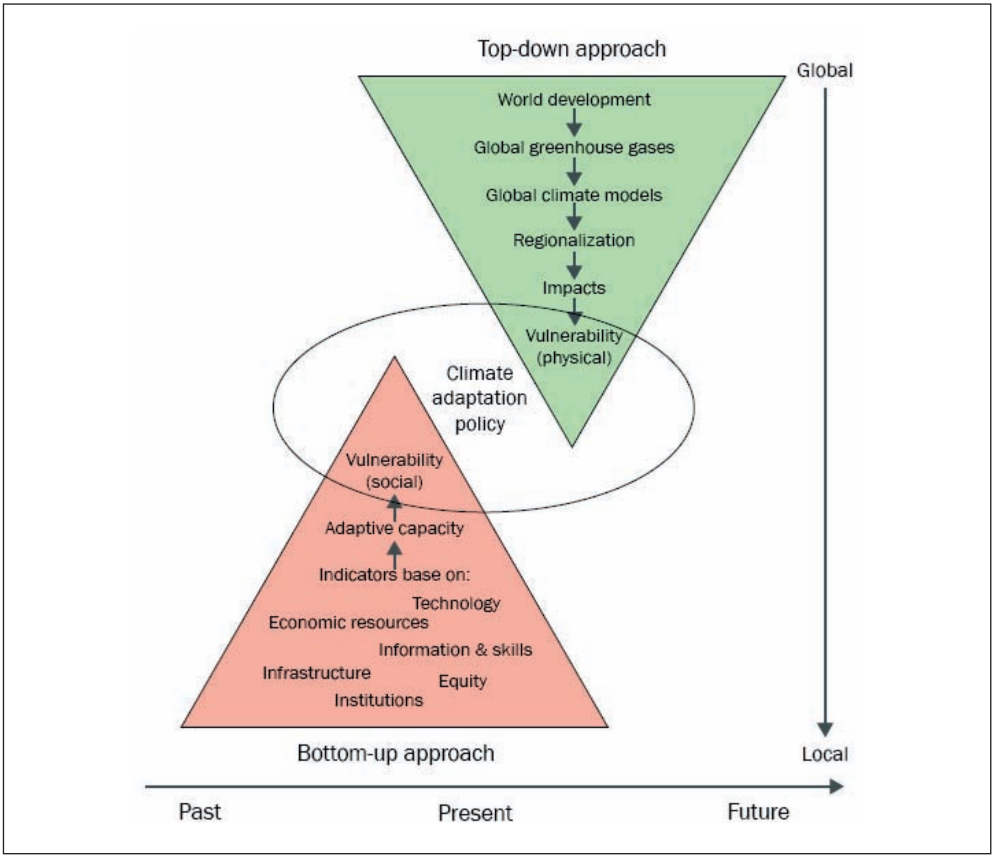

Fig. 1 "Top-down" and "bottom-up" approaches used to inform climate adaptation policy (Dessai and Hulme 2003)

4. Integrated Strategies Have to Deal with the Interplay of Several Levels of Decision-Making

As within other environmental policies, climate policy has to deal with the interplay of several levels of decision making in a quite ambitious way. This challenge goes far beyond the conventional assumption that mitigation is primarily a matter of national governments and international negotiations, whereas adaptation is primarily seen as a challenge at the local or regional level due to the specific conditions in certain regions. But looking closer at both mitigation and adaptation, we observe that mitigation is also local and regional (e.g. carbon neutrality declared by regions or cities; regional land use planning as tool for mitigation etc.) and adaptation is also affected by national and EU policies (e.g. concerning funding or EU directives, EU Common Agriculture Policy). As in other fields of environmental policy (e.g. biodiversity and water), the interplay of levels on decision-making is absolutely crucial. Regional and local decision-making on climate change impacts and specific regional vulnerabilities must be supported (or faces impediments) by the institutional framework and financial support from the European or national levels.

Concerning the implementation of European directives at the regional or local level, however, experiences are very mixed. Even where stakeholder involvement and public participation is required (as in the EU Water Framework Directive), many challenges remain. For successful participation processes, additional efforts are required, for example: more emphasis on stakeholder expectations and the cultural context; on the variety of actors including bottom-up initiatives; and on the sharing of benefits and costs (*GoverNat* 2010). For adaptation strategies, further challenges arise from the fact that regions are not necessarily given entities but are constructed artificially in relation to their natural boundaries by political historical and political economic forces. This creates other challenges for the participation of actors particularly affected by climate change or important for the development of regional adaptation strategies.

5. Conclusion

The issue of adaptation to climate change thus presents far-reaching challenges in terms of shaping societal development and, more specifically, societal relationships with nature as a whole. Particular emphasis is required concerning the ways in which particular regions and social groups will be affected by regional climate fluctuations, and what kind of social vulnerabilities and adaptive capacities exist in those particular locations. To adequately comprehend the issues then, a dialectical understanding of the relationship between nature and society is required, one capable of taking into account the mutual dependencies and interactions between various biophysical and societal processes as well as the possibilities for reshaping these interactions. Moreover, the specific spatial (scalar) dimensions of the mutual interdependencies in different regions and the interplay between global and national climate policies and local or regional adaptation strategies must be analyzed carefully.

What is necessary, thus, is to reshape the interrelationships between society and nature. Current debates around adaptation to climate change offer a certain opportunity to 'rethink climate' (Brunnengräber et al. 2008) in order to gain an understanding of the multiple connections between society and nature at different spatial levels. Seen from this perspective, the need for a comprehensive re-shaping of societal relationships with nature (Görg 2003) becomes pressing, and it is apparent that this need extends far beyond previous climate change mitigation measures. This is because the issue of adaptation now presents considerable challenges based on the often overlooked precise interplay of natural and societal factors – in particular questions about: complexity; our ability to influence specific natural conditions; political responsibility; scientific uncertainties; and so forth, including the question of different time scales.

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Natur und Migration

Vorträge anlässlich der Jahresversammlung vom 5. bis 7. Oktober 2007
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„Natur und Migration" – assoziiert sehr verschiedenartige Phänomene, die sich durch Wanderungsprozesse auszeichnen. In diesem Band wurden besonders interessante Gebiete ausgewählt, u. a. Migration und Seuchen, Reisen und Epidemien in einer globalisierten Welt, der Vogelzug, aber auch die Migration geologischer Fluide, die Elektronenmigration in Halbleitern, die Migration als treibende Kraft in der Organogenese, die Biophysik der Zellbewegungen, die Migration von Tumorzellen, Migration als Phänomen in der Neurobiologie oder die Migration wissenschaftlicher Ideen. Besondere Akzente setzen die Themen „Diversität als neues Paradigma für Integration?" und „Vorspiel der Globalisierung. Die Emigration deutscher Wissenschaftler 1933 bis 1945".
Die Beiträge sind von herausragenden Experten der jeweiligen Gebiete, u. a. durch die Leopoldina-Mitglieder Markus Affolter, Lorraine Daston, Wolfgang Frühwald, Michael Frotscher, Jörg Hacker, Hans Keppler und Otmar Wiestler, in anspruchsvoller, aber durchaus gut verständlicher Form verfasst.

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Polar Regions

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Changes of the Climate System in the Polar Regions

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Peter Lemke (Bremerhaven)

With 9 Figures and 2 Tables

Abstract

In the Arctic and at the Antarctic Peninsula temperature changes have observed to be approximately twice as high compared to the global average. The rapid warming of the polar regions results in associated changes, such as melting of ice sheets on Greenland and Antarctica with resulting effects on sea level rise, reduction of sea ice, loss of permafrost regions and alterations in the polar ecosystems. Changes have been documented over the last 3 decades and are predicted to continue. First indications of changes in the biological system have been found, but their extent and consequences are not well known. The observed and predicted climatic and environmental developments in the polar regions will lead to fundamental changes with global consequences.

Zusammenfassung

In der Arktis und an der Antarktischen Halbinsel wurden Temperaturerhöhungen beobachtet, die etwa doppelt so hoch sind wie die globalen Mittelwerte. Die rasche Erwärmung der Polarregionen führt zum Schmelzen der Eisschilde in Grönland und der Westantarktis mit Auswirkungen auf den Meeresspiegelanstieg, Verringerung des Meereises, Verlust von Permafrostregionen und Veränderungen des polaren Ökosystems. Diese Änderungen wurden in den letzten 3 Jahrzehnten beobachtet, und es wird prognostiziert, dass sie sich in Zukunft fortsetzen werden. Anzeichen von Änderungen in biologischen Systemen wurden beobachtet, aber Ausmaß und Konsequenzen sind kaum bekannt. Die jetzigen und zukünftigen Klima- und Umweltentwicklungen in den Polarregionen werden zu tiefgreifenden Veränderungen führen, die globale Konsequenzen haben.

1. Introduction

Polar regions have been considered remote and hostile for most of human history. Persistence of low temperature, dark winters, highly variable seasonal ice cover and a biological community well adapted to these environmental conditions are characteristics that have persisted over long periods. However, the polar system is not isolated and static. It has complex and dynamic connections to lower latitudes *via* ocean currents and water exchange, atmospheric transport of heat, pollutants and aerosols, and ties to sub-polar ecosystems and communities. These leave a noticeable imprint on the polar system. In particular the Arctic shows clear signals of increasing changes and multiple impacts due to external influences, including climate change.

The two polar realms differ fundamentally. The Antarctic is an ice-covered continent surrounded by the Southern Ocean, which is delineated by the polar front. The largest current system on Earth, the Antarctic Circumpolar Current (ACC), separates the Southern Ocean from the adjacent Pacific, Atlantic and Indian Ocean. Each winter, sea ice forms around the Antarctic continent covering a huge expanse of 19 Mio km^2 maximally and shrinking to less than 3 Mio km^2 in austral summer. The Antarctic ecosystem is adapted to and dependent on this enormous seasonal change. In contrast to this, the Arctic can be described as a nearly enclosed sea, surrounded by the land masses of Asia, America and Europe. The Arctic Ocean is connected to the Atlantic Ocean *via* the Fram Strait, and considerable exchange of water occurs between Atlantic and Arctic Ocean *via* this passage way. The expansion of sea ice between winter and summer varies from 16 Mio km^2 to 7 Mio km^2. At both polar regions, extremely cold and dense sea water is formed that sinks to the deep ocean and fills as 'deep water' the bottom layers of the world ocean. This process is a major driver of the global thermohaline circulation (the "ocean conveyor belt").

Perhaps the most influential differences can be seen in the political settings. The Arctic is populated and economically used in parts. National boundaries and claims regulate access to, and use of, land and sea. In contrast, Antarctica is an international territory under the regulation of the Antarctic Treaty. No military actions or exploitation of natural resources are allowed and very strict protection measures apply to safeguard the sensitive Antarctic environment.

Climate change has now led to a fundamentally different view of the Arctic. Reduction of sea ice and permafrost regions may provide easier access to the High North, opening possibilities for development and use of these areas and their resources. Therefore, heightened political and commercial interests are directed towards these new frontier regions.

In this article, a broad overview of the most obvious climatic change impacts and effects in the polar regions is given. More detailed analyses of climate and environmental changes can be found in "Arctic Climate Impact Assessment" (*ACIA* 2005) and "Antarctic Climate Change and the Environment" (*SCAR* 2009). The emphasis of the article is placed on changes occurring in the Arctic because of the rapid climatic shifts observed in this region. However, we want to stress that the south polar region is also subject to some, if smaller, changes. Due to the vast expanse of Antarctica, these changes have the potential to impact the global system in the long run much more severely than any other changes elsewhere on Earth.

2. Temperature Trends in Polar Regions

The IPCC Fourth Assessment Report (Solomon et al. 2007) identified a global temperature increase of ca. 0.12 °C per decade since the 1960s. In contrast to these still relatively moderate temperature changes, the Arctic has experienced the greatest annual warming of all regions on Earth by 2 °C to 3 °C since the 1950s, equivalent to 0.3 – 0.5 °C increase per decade (*ACIA* 2005) (Fig. 1). The highest temperature rise was observed over the Siberian land areas. Similarly, at the Antarctic Peninsula, a very steep rise in temperature of 0.3 – 0.5 °C (in certain areas even up to 1.1 °C) per decade was observed (Tab. 1). While the Antarctic Peninsula has been identified as a 'hot spot' of climate change, the rest of the Antarctic continent seems less or not affected, and temperatures have remained fairly stable. Generally speaking, the temperature rise in the Arctic and at the Antarctic Peninsula over the last 50 years is approximately twice as fast as the global average.

Model forecasts indicate that this trend will persist into the future. As an example, the scenario A1B of IPCC modeled for the next 100 years (Fig. 2) clearly shows an extreme warming in parts of the Arctic that far surpasses temperature trends in other regions of the Earth. On the

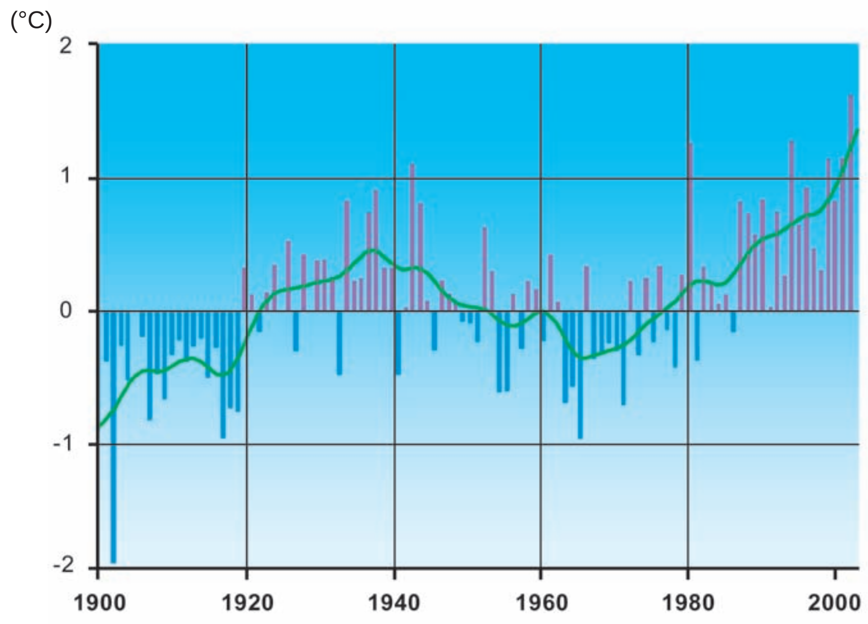

Fig. 1 Annual average near surface air temperature from stations on land relative to the average for 1961–1990, for the region from 60° to 90° N (updated from PETERSON and VOSE 1997, in *ACIA* 2005).

Tab. 1 Temperature changes at different stations of the Antarctic Peninsula and other Antarctic stations (modified after VAUGHAN et al. 2001).

	Station	Period/years	Trend (°C/century)	Significance (%)
Long-records on the Antarctic Peninsula	Faraday (renamed Vernadsky in 1996)	50	+ 5.6 ± 4.3	99
	Esperanza	50	+ 3.3 ± 2.8	95
	Bellingshausen	32	+ 3.5 ± 4.6	90
Short-records on the Antarctic Peninsula	Marambio	26	+ 5.7	unknown
	Rothera	23	+ 11 ± 13	95
	Butler Is. Automatic Weather Station	9	+ 20 ± 16	not significant
Other Antarctic records	Halley	44	0.0 ± 4.6	not significant
	Orcadas	96	+ 2.0 ± 1.0	99
	Amundsen-Scott	43	– 2.0 ± 2.1 (cooling)	95

basis of the observed and potential future fast temperature increases in the Arctic, this region is not only “early warming”, we consider it as an “early warning” system for climate change. Alterations will happen here faster than in other areas of the World, and it is of utmost importance to observe and analyse these changes in order to be prepared for changes elsewhere.

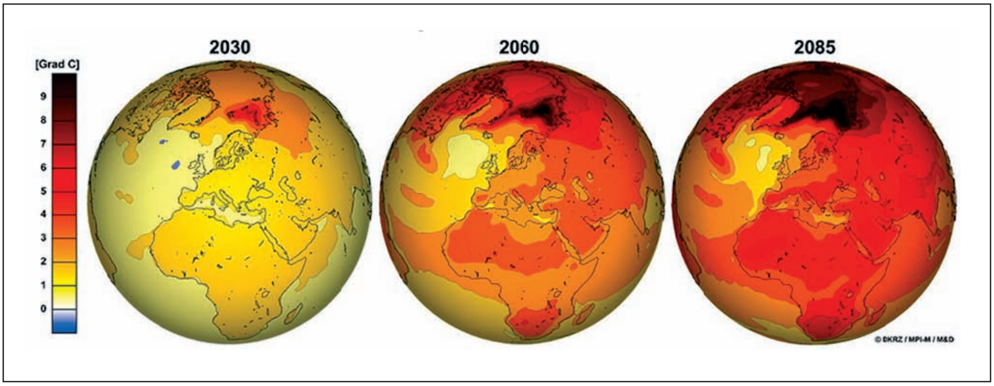

Fig. 2 Simulated temperature changes assuming the A1B scenario of the IPCC using the ECHAM5 model of the Max Planck Institute for Meteorology (Source: DKRZ/MPI-M/M&D)

The consequences of temperature rise in the polar regions are manifold. The most important effects are:

– melting of ice sheets in Greenland and Antarctica that contribute to accelerated sea level rise,
– reduction of sea ice with impacts on the global climate system and massive changes for the ecosystem,
– reduction of permafrost and accelerated release of green house gases.

3. Ice Sheets and Sea Level Rise

The rise in global temperatures has lead to accelerated melting of glaciers world-wide. There are spectacular impressions of retreating glaciers, when comparing photographs of the start of the last century with present day conditions. Only a few glaciers have increased in size due to heavier snow fall in some regions, but the vast majority of glaciers (> 80 %) has been, and is, loosing mass.

The ice sheet of Greenland is decreasing due to melting processes at the coastal edges and an accelerated flow of ice through outlet glaciers (Lemke et al. 2007). Both processes have increased, although there are large interannual variations. If the Greenland ice sheet should melt completely, this would lead to a global sea level rise of around 7 m.

The vast Antarctic ice sheet is more stable than the one in Greenland, but there are relatively large loss processes at the Antarctic Peninsula. Best known are the spectacular collapses of large parts of ice shelves in this region: the Wilkins ice shelf that broke up in several steps between 1993 and 2008, and the Larsen ice shelf, where 3,250 km^2 (around 720 billion tons) of ice shelf disintegrated in a 35-day period beginning on January 31, 2002 (Fig. 3).

Since the shelf ice is floating on the sea, the disintegration does not contribute to sea level rise directly. But loss of such large parts of shelf ice can trigger a faster flow of the inland ice masses that were previously blocked by the ice shelf in front of it. While the Greenland ice sheet loses mass in equal parts due to melting and glacier flow, Antarctica loses ice mass due to increased export through outlet glaciers and ice streams (Lemke et al. 2007). From 1993

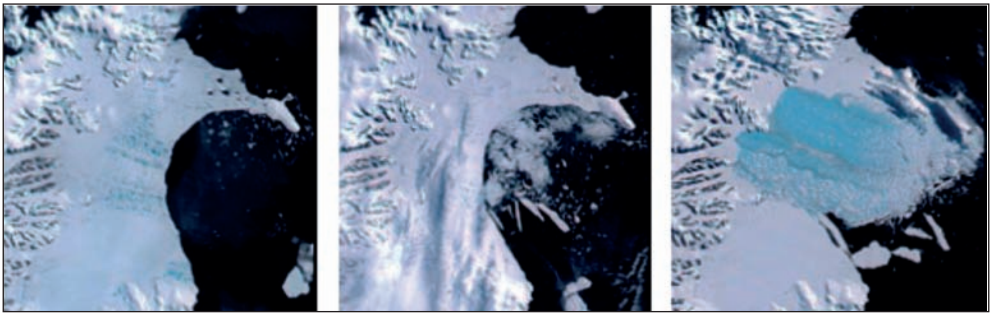

Fig. 3 The breakup of the Larsen Ice Shelf, Antarctica. Moderate-resolution Imaging Spectroradiometer (MODIS) satellite imagery taken on 7 March 2002. Image courtesy Ted Scambos, National Snow and Ice Data Center, University of Colorado, Boulder, based on data from MODIS. (Source: NASA)

to 2003 each of the two ice sheets contributed 0.2 mm per year to sea level rise (Tab. 2). It should be noted, however, that the assessment of the ice sheet mass balance is subject to large uncertainties due to insufficient data, especially in Antarctica.

Tab. 2 Observed sea level rise and estimated contribution from different sources. Data prior to 1993 are from tide gauges and after 1993 from satellite altimetry (modified after Bindoff et al. 2007).

	Rate of sea level rise (mm per year)	
Source of sea level rise	1961 – 2003	1993 – 2003
Thermal expansion	0.42 ± 0.12	1.6 ± 0.5
Glaciers and ice caps	0.50 ± 0.18	0.77 ± 0.22
Greenland ice sheet	0.05 ± 0.12	0.21 ± 0.07
Antarctic ice sheet	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	1.1 ± 0.5	2.8 ± 0.7
Observed sea level rise	1.8 ± 0.5a	3.1 ± 0.7a
Difference (Observed minus sum of estimated climate contributions)	0.7 ± 0.7	0.3 ± 1.0

Melting of mountain glaciers, ice caps and ice sheets and the thermal expansion of the warming ocean contribute to sea level rise (Tab. 2). In recent years (1993–2003) a more rapid rise of sea level was observed than indicated by assessments over a longer period (1961–2003). Part of the problem may be due to differences in methods; but even when same techniques are applied the trend to more rapid melting of ice on the continents is confirmed (Kerr 2009). A bit more than half of the sea level rise during 1993–2003 was due to the thermal expansion of ocean water (1.6 mm/year) and less than half was caused by melting of mountain glaciers and the Greenland and Antarctic ice sheets (1.2 mm/year). New data indicate that the melting processes of glaciers and ice sheets now contribute 2 mm per year to the sea level rise (Pritchard et al. 2009).

This trend of sea level rise is estimated to continue. Projections by IPCC Fourth Assessment Report indicate a global average rise in sea level of up to 0.6 m until the end of this century. However, other empirical models arrive at more than 1 m sea level rise at the end of this century (Rahmstorf 2007). It has to be considered that sea level rise it not evenly distributed over the ocean, but that some regions will experience higher and others lesser increases. This is caused by the respective hydrographic setting of the regions and differences in the gravity field of the Earth. The consequences of sea level rise will affect regions far away from the polar oceans. It is therefore crucial to know the extent and rate of this development in order to establish adequate mitigation and adaptation measures. As an example, parts of Northern Germany and the Netherlands would be endangered (Fig. 4) and need to be protected by dikes of adequate height to be prepared for the expected sea level at the end of century plus the impact of storm surges. Particularly difficult in this respect is the protection of megacities at the coast and of low-lying island nations. While in Europe technical solutions for sea level rise are largely ready and can be installed, this may not be easily possible in developing countries.

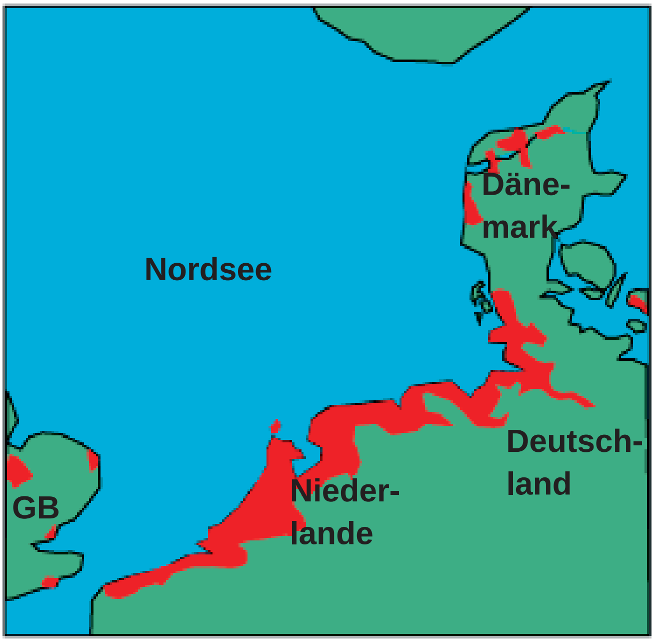

Fig. 4 Potential flooding at a projected rise of average high tide by 70 cm until 2050 (calculated by model). (Modified after Brooks et al. 2006)

An additional aspect of the ice sheet research should be mentioned briefly. The polar ice sheets are formed by snow that becomes with time compacted to ice as more snow accumulates on top. During this process, small air bubbles are enclosed within the ice, preserving the air of the past, ranging from a few centuries up to around 800.000 years. This archive of the historic air composition can be analyzed with high precision methods and forms the basis of our present knowledge of changes in green house gases, including CO_2, and past climatic conditions.

4. Sea Ice Reduction

Sea ice fulfills multiple functions in the polar system. It isolates the relatively warm sea surface from the cold polar atmosphere and thus regulates heat exchange between ocean and atmosphere. It also regulates the evaporation and, hence, sea ice cover has an effect on the hydrological cycle. Since ice coverage reflects the sunlight much more effectively than the dark sea surface, absorption of solar energy in the polar regions is affected massively by changes in sea ice coverage. In addition to the physical effects, sea ice is also an important habitat for ice-associated organisms (see chapter 6).

Sea ice coverage is subject to strong variation from year to year, which is driven by variations of wind stress and thermal effects. Nevertheless, satellite observations revealed a general trend of declining summer sea ice coverage in the Arctic Ocean over the past 30 years (Fig. 5). The summer sea ice minimum, occurring in September, has steadily declined from 7 million km^2 in the early 1980s to about 5.5 million km^2 in 2006. In summer 2007, record low sea ice coverage of 4.3 million km^2 was observed (Comiso et al. 2008).

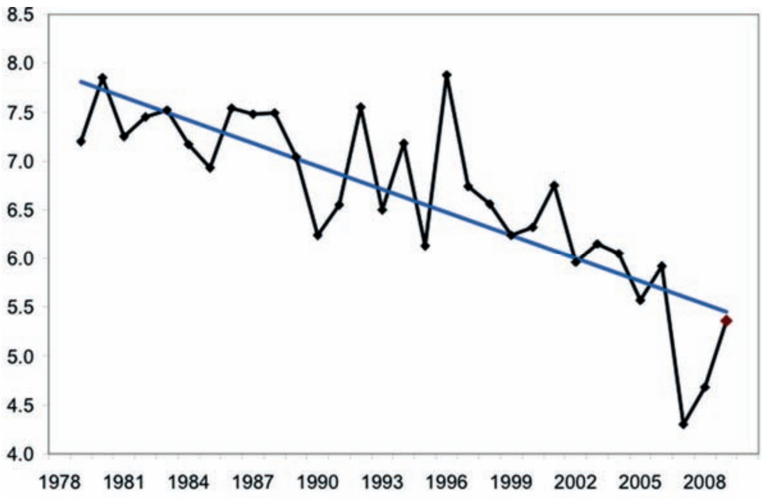

Fig. 5 Changes of sea ice coverage in the Arctic for September from 1978 to 2009 observed by satellite imagery. The mean sea ice coverage 1979 – 2000 is 7.7 million km^2. During the observation period the slope of the linear regression is 11.2 % (+/– 3.1 %) per decade. (Source: National Snow and Ice Data Center; nsidc.org)

Sea ice thickness is a key parameter that determines the 'survival' of sea ice during the summer melt period. If the sea ice thickness is above a critical value, it will not melt completely during summer and forms 'multi-year ice'. Only if it is too thin, sea ice may disappear during summer ('seasonal ice'), thereby exposing the sea surface with resulting effects on exchange of heat, water vapor and reflection of sun light. Therefore, measurements of ice thickness attain high importance, but are difficult to accomplish at sufficient accuracy and coverage over the Arctic Ocean. Sea ice thickness is measured *in situ* by ships, submarines, moored sensors or by electro-magnetic measurements from helicopters or airplanes (Haas et al. 2008). The latter were carried out, *inter alia*, in the region north of the Fram Strait and in the western Arctic Ocean, which demonstrated that the ice thickness here has declined since 1991. While in 1991 the most frequent ice thickness was around 2.5 m, it was only 2 m in 2004 (Haas et al. 2008). However, these measurements do not cover the Arctic Ocean sufficiently for accurate assessments of the total sea ice volume. Remote satellite observations, calibrated by good ground truth data, are needed to obtain a better overview of distribution of sea ice thickness across the entire Arctic Ocean. Such satellite measurements revealed a decline of total Arctic sea ice volume from 18,000 km³ in winter 2004 to less than 14,000 km³ in winter 2008 (Kwok et al. 2009). Although the various assessments of sea ice volume are flawed with uncertainties, all estimates indicate a reduction of sea ice thickness and total volume.

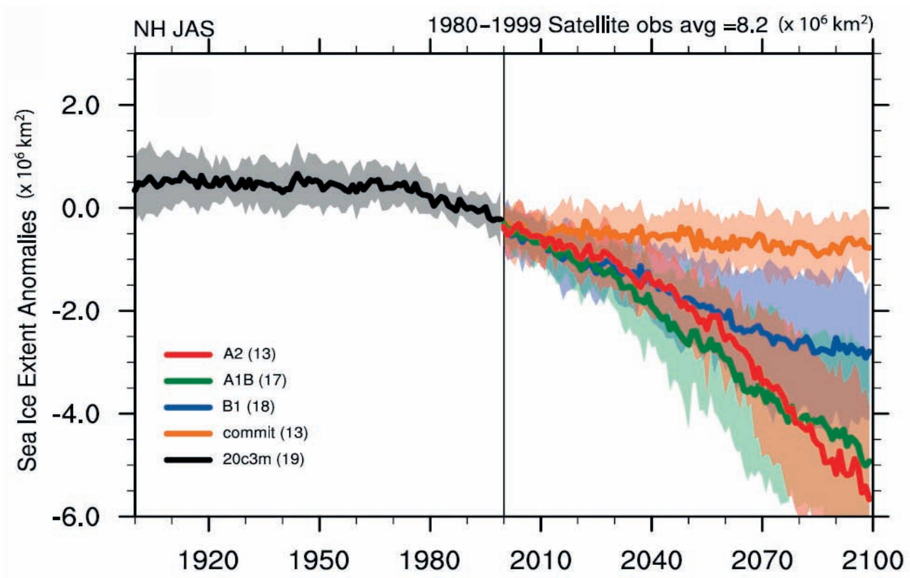

Fig. 6 Scenarios of future reduction of summer sea ice extent in the Arctic. The anomalies relative to the average sea ice coverage (1980–1999: 8.2. Mio km²) are modeled according to the standard IPCC scenarios (Meehl et al. 2007).

Figure 6 shows model forecasts of changes in Arctic sea ice extent according to various scenarios until the end of the century. Most models cannot reproduce the fast reduction of sea ice during the decade 1995–2006, that reached 17.9 % (Stroeve et al. 2007). High natural variability, insufficient data and variable export of ice from the Arctic Ocean through the Fram Strait are formidable challenges for modeling of future development of sea ice coverage.

The sea ice loss is not only an important factor for the Arctic climate and environment, it is also of high relevance for access to resources in the Arctic Ocean. Considerable deposits of mineral oil, gas and metal ore are suspected below the seafloor of this ocean. As yet, their exploitation is not possible (or commercially viable) under present sea ice conditions. Future loss of sea ice could, however, facilitate and ease the access to these new resources. It would also open the northern sea routes along the Canadian or Russian coast for commercial shipping. Transport *via* Northeast Passage would reduce transit times from Europe to Asia by 30 %. These potential commercial uses of the Arctic Ocean are under consideration, but depend crucially on reliable forecasts of sea ice coverage. Increased utilization of Arctic resources would also require development of measures to safeguard the fragile environment and ecosystems of the Arctic Ocean.

5. Changes in the Permafrost System

Permafrost is defined as layers of soil, sediment or rock that are continuously frozen during two consecutive seasons. According to this definition, almost 25 % of the earth land surface contains permafrost layers (Zhang et al. 2000). It is characterized by annual thaw and freeze processes at the surface that can melt a layer of 50 cm to several meters thickness ("active layer"). Permafrost can penetrate to several hundred meters and, in some parts of Siberia, up to 1,200 m deep into the ground. It is particularly extensive in the boreal and polar regions of Eurasia and North America. Permafrost was formed during the cold periods of the Late Pliocene. It exists in Siberia since more than 2.5 million years and continuous permafrost conditions have been found since 600,000 years (Schirrmeister et al. 2002). Permafrost does not occur only on land, it also underlies some of the shelf regions of the Arctic Ocean at the Siberian coast. It was formed during cold periods, when sea level was much lower than today, and was subsequently submerged by the sea during warm periods.

Permafrost thawing is mainly driven by increase in air temperature. Long-term measurements at Russian stations showed an increase of air temperature of 0.02–0.3 °C per year in the European North of Russia, 0.03 – 0.07 °C per year in NW Siberia and 0.01– 0.08 °C in Jakutia (Pavlov 1997). In Siberian permafrost, temperature in 3 m depth increased by 2–2.5 °C over the last 20 years and in 10 m depth by 1 °C. Some Alaskan permafrost regions show a similar rise in temperature (Romanovsky et al. 2003). This wide-spread warming has already caused complete loss of permafrost in some regions, with accompanying increase of seasonal thawing and depth of the "active layer". The permafrost coasts are generally stabilized by frozen ground, but they become increasingly unstable upon thawing and disintegrate rapidly. Collapse of thawing permafrost coasts is enhanced by wave action, because simultaneously sea ice cover declines and exposes the coasts to stronger waves. Therefore, permafrost coasts are considered some of the most endangered environments.

Permafrost soils contain a high proportion of organic matter that is preserved in a frozen state (Lantuit et al. 2009). Thawing of permafrost releases the stored organic matter and makes it available for microbial breakdown that produces CO_2 (and methane). Furthermore, this material can be transported by rivers into the coastal zone, where it may be deposited or biologically utilized. It is at present unclear, which ecological effects such increased input of organic matter into the Siberian or North American shelf seas may have.

In addition to the above mentioned release of CO_2 and methane from surface or near surface layers, permafrost may also emit considerable amounts of methane from greater depth (Fig. 7). The methane is stored in form of gas hydrate within terrestrial and submarine permafrost sediments, and is stable as long as the ground remains frozen. At rising temperatures, the gas hydrates disintegrate, and methane can be released into the atmosphere. Microbial methane oxidation can reduce the amount of volatile methane (Koch et al. 2009). While this

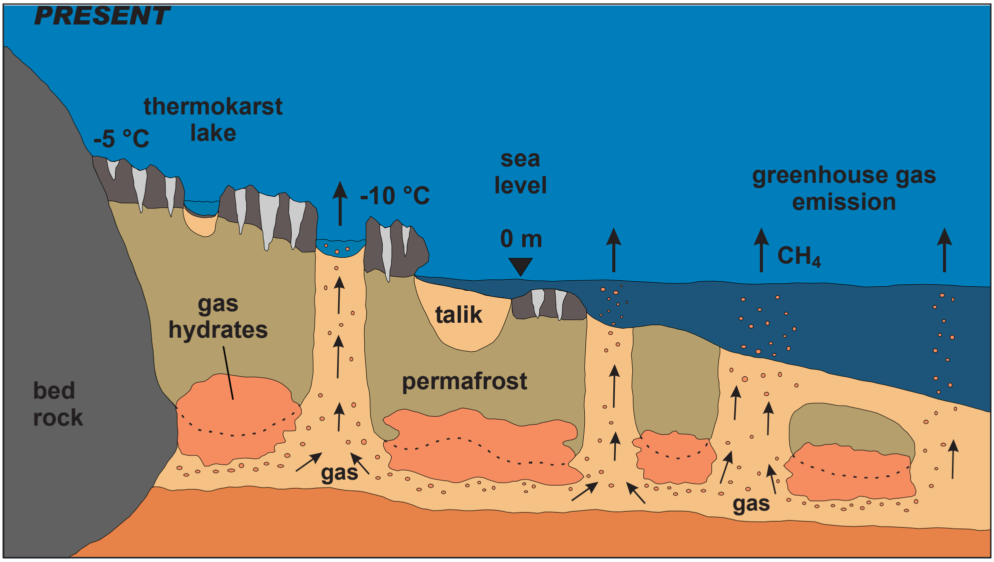

Fig. 7 Schematic representation of coastal and submarine permafrost under present climatic conditions. Sources of methane emission triggered by degradation of the permafrost layer are shown (Hubberten and Romanovskii 2001)

biological process to a certain extent counteracts the emission of methane, it produces CO_2, so that in any case climatically active gases are released.

The quantification of release of methane and other green house gases from permafrost regions into the atmosphere is therefore one of the major future tasks in order to assess their impact on atmospheric processes and on climate change.

6. Impacts on the Polar Ecosystem

Polar organisms are considered to be well adapted to the (for humans harsh) seasonal changes in physical conditions, such as temperature, light, ice cover etc. Species are often endemic to one of the polar regions and do not occur elsewhere. Changes in the environmental conditions due to climate change are likely to lead to major alteration in species distribution and biological processes in the polar regions. Three processes have been identified as the main drivers and consequences of environmental change: reduction of sea ice, acidification of the polar ocean, spread of alien species. In this chapter we will focus only on the first of these factors, but emphasize that the other two processes are also having an important impact.

Sea ice is a very special habitat for many organisms in the polar ocean due to its particular structure. When sea water freezes, the freshwater part forms ice, interspersed by a labyrinth of channels filled with brine (condensed salty fluid). These brine channels can be inhabited by small organisms, which are enclosed during ice formation, survive and some even thrive in this relatively protected environment. The conditions in this habitat are harsh. Salinity changes quickly and drastically when fresh water is either bound in ice crystals during freezing (i.e. the salinity rises to high concentrations), or the brine channels are flooded by freshwater during thawing. Simultaneously, temperature changes are more pronounced in sea ice than in the underlying sea water.

Fig. 8 The green-brown discoloration underneath the sea ice is caused by ice algae. (Photos courtesy of Peter Marschall [AWI], Thomas Mock [AWI])

The brine channels of sea ice from a distinct habitat for microalgae, bacteria and small zooplankton that thrive on the algal products (Fig. 8). Larger organisms feed underneath the ice on ice algae and, thus, the biological production in the sea ice provides an important part of the food web of the polar ocean (Legendre et al. 1992). Most importantly, many polar organisms are adapted to the occurrence of sea ice. Their life cycle and feeding strategies are geared to and depend on the presence of sea ice.

A particularly illustrative example for the connection between sea ice and an adapted organism is the life history of krill in the Antarctic. Krill is a small shrimp-like crustacean that feeds by filtering microalgae and small zooplankton from the water and populates the Southern Ocean in great swarms. It is the main food source for many large predators from penguins to whales. Krill is also fished in large quantities (100,000 to 150,000 tonnes per year) for aquaculture feeds and the production of omega-3-fatty acids oil (Siegel 2000). For many years it was a mystery how these large stocks of krill survive in winter, when food supply is scarce. Adult and juvenile krill have different survival strategies for the winter time. Adult krill builds up lipid reserves during the active feeding time in summer and autumn. During winter, they enter a resting stage and survive on their fat reserves (Atkinson et al. 2002). Juvenile krill, however, cannot accumulate sufficient fat reserves to survive the long winter period. They feed on algae and small zooplankton that thrive in connection with sea ice. Therefore, this stage of the krill development is crucially dependent on the presence of sea ice to survive the winter (Meyer 2009).

A correlation was observed between the abundance of adult krill and the extent of winter sea ice coverage of the previous year, which determines the survival of larval and juvenile krill (Fig. 9*A*). During the last three decades, a general decline in krill abundance was recorded (Fig. 9*B*), that is attributed to the simultaneously occurring decline in sea ice in the vicinity of the Antarctic Peninsula (see chapter 4). This long-term decline in krill has consequences for the predators in the food chains, which are based on krill. Some species of albatross, penguins, and seals have less offspring due to the reduced food supply.

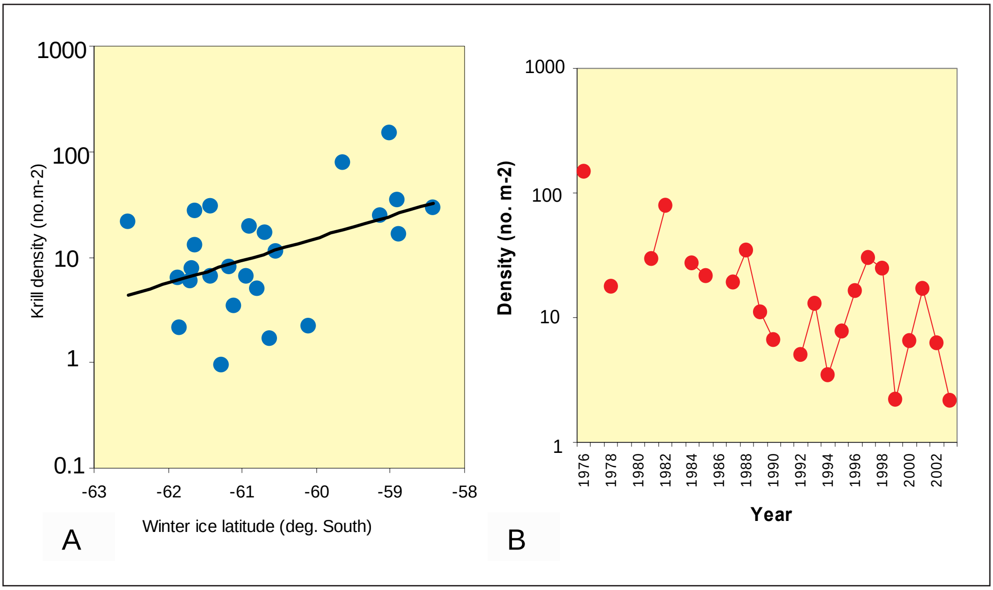

Fig. 9 (*A*) Correlation between krill abundance and sea ice extension of the *previous* winter across Scotia Sea (from satellite observations in September). (*B*) Decline of krill abundance from 1976 to 2003. (Atkinson et al. 2004)

The reduction of sea ice is obviously one of the most prominent factors that affects the polar ecosystems and will trigger substantial changes. At present, we only see the beginning of an ecosystem shift, but this will intensify, if sea ice continues to decline as forecast by models.

7. Concluding Remarks

The observed and projected changes in the Arctic and parts of the Antarctic are all indicating a rapid alteration of the polar system that precedes changes in other parts of the world. Reduction of ice sheet mass, sea ice cover and permafrost all have an effect on the global scale either by sea level rise, by alteration of sun light reflection (albedo) and ocean-atmosphere exchange processes or by accelerated emissions of greenhouse gases. Therefore, changes in the polar system are not remote – they are relevant world-wide.

Observations over the last 30 years have indicated a steady trend towards higher temperatures and increased melting of the frozen part of Earth. However, it is also known that multi-decadal temperature oscillations occur in the high latitudes of the north that may lead to cooling and may reverse the trend of warming. Indications of such a cooling are not yet obvious. It is therefore of utmost importance to observe the polar system in order to detect changes faster and more accurately than up to now. Lack of adequate data is one of the biggest problems in a reliable assessment of polar processes.

Furthermore, critical thresholds within the polar system may – if transgressed – trigger a rapid shift into a new and different system state. One example mentioned before is the critical thickness of sea ice that determines the 'survival' of sea ice during the summer. If melting processes in large areas have reduced the sea ice thickness in winter below a critical value this can lead to widespread loss of ice during summer and little chance of recovery. There are other potential switch points, and it is an important task to identify these thresholds and their critical values.

Changes in the biological system of the polar regions have been observed, but we are certain that this is only a small part of the total changes occurring already. If the physical conditions will change as predicted (temperature, sea ice cover) this will alter the biodiversity, the biological ecosystem functions and the biogeochemical cycling of elements in the polar system profoundly. Here a vast field of research has to be covered as many of the basic facts for the polar biological system are only rudimentarily known.

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Climate Variability and Glacier Response at Vestfonna – A Case Study of Arctic Climate and Glacier Dynamics at Nordaustlandet (Svalbard) in Recent Years

Christoph Schneider[1], Dieter Scherer[2], Matthias Braun[3], Marco Möller[1], Oliver Käsmacher[1], and Roman Finkelnburg[2]

With 3 Figures and 2 Tables

Abstract

Since 2008, and within the International Polar Year (IPY) 2007/2008 a joint project group comprised by the Technical University Berlin, the RWTH Aachen University and the University of Bonn in collaboration with other research groups from Scandinavia, Poland and the United States of America carries out field work related to the climate response of arctic glaciers ("Dynamic Response of Surface Energy and Mass Balance of Vest- and Austfonna [Nordaustlandet, Svalbard] on Climate Change") funded by the *Deutsche Forschungsgemeinschaft* (German Research Foundation, DFG). The ice cap of Vestfonna on Nordaustlandet (Svalbard) at 80 °N extends between sea level and 630 m a. s. l. (above sea level) and covers an area of 2,500 km². Hence, aside from the much larger and neighboring Austfonna it is one of the largest ice masses of the European Arctic. Since May 2008 several automatic weather stations and a net of ablation stakes are operated on Vestfonna. The data from these investigations are combined with remote sensing data regarding snow cover, surface velocity and altimetry as well as reanalyzed numerical weather forecast data (GFS, NCEP/NCAR) in order to model the relation between climate forcing and glacier mass balance. Data from two ablation seasons (2008 and 2009) with distinct weather patterns underline the importance of local meteorological and sea ice conditions as well as wind field patterns. The latter seemingly do strongly influence the redistribution of snow fall by wind drift. A simplified surface melt model for Vestfonna combined with snow cover data retrieved from remote sensing data (MODIS) drastically shows that enhanced climate forcing by rising air temperatures would drive the mass balance of the ice cap substantially towards negative values. However, snow fall and related processes may considerably counteract this possible future development. Large scale synoptic patterns and sea ice cover also influence surface mass balance to a large extent since the inter-annual moisture flux towards the Arctic is dominated by these patterns. Furthermore, it is hypothesized that the overall warming observed in the study region can be traced within near-surface ice temperatures on Vestfonna given that the insulating effect of the varying winter snow cover can be modeled accordingly.

Zusammenfassung

Im Zusammenhang mit dem Internationalen Polarjahr 2007/2008 führt eine gemeinsame Projektgruppe der Technischen Universität Berlin, der RWTH Aachen und der Universität Bonn in Zusammenarbeit mit anderen Forschungsgruppen aus Skandinavien, Polen und den Vereinigten Staaten von Amerika Geländearbeiten, die von der Deutschen Forschungsgemeinschaft finanziert werden, durch, die darauf abzielen die Auswirkung von Klimavariabilität auf arktische Gletscher zu adressieren. Die Eiskappe des Vestfonna auf Nordauslandet, welches zum Svalbard-Archipel gehört, liegt bei 80 °N und erstreckt sich vom Meeresspiegel bis auf 630 m ü. M. und bedeckt dabei ein Fläche von 2500 km². Damit ist sie, abgesehen vom wesentlich größeren und benachbarten Austfonna eine der größten Eismassen der europäischen Arktis. Seit Mai 2008 werden mehrere automatische Wetterstationen und ein Netz von Ablationsstangen auf dem Vestfonna betrieben. Die Daten dieser Untersuchungen werden mit Fernerkundungsdaten bezüglich der Schneedecke,

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Oberflächengeschwindigkeit und Geländehöhe kombiniert und zusammen mit Daten von numerischen Wettervorhersagemodellen (GFS, NCEP/NCAR) analysiert, um die Beziehungen zwischen klimatischem Antrieb und Gletschermassenbilanz zu modellieren. Daten aus zwei Ablationsjahren (2008 und 2009) mit sehr besonderen Witterungsmustern unterstreichen die Bedeutung lokaler meteorologischer Bedingungen, der Meereisbedeckung und ebenso der Anströmung des Windes. Letzteres scheint die Umverteilung des Schneefalls durch Winddrift stark zu beeinflussen. Ein vereinfachtes Oberflächenschmelzmodell kombiniert Schneedeckendaten, abgeleitet aus Fernerkundungsdaten (MODIS), und zeigt sehr drastisch, dass verstärkter klimatischer Antrieb durch höhere Lufttemperaturen die Massenbilanz der Eiskappe substantiell zu negativen Werten hin verschieben würde. Schneefall und andere damit verbundene Prozesse könnten allerdings dem erheblich entgegenwirken. Die großräumigen synoptischen Muster und die Meereisbedeckung beeinflussen ebenfalls die Oberflächenmassenbilanz in hohem Maße, da der interanuelle Fluss von Feuchtigkeit in die Arktis von diesen Mustern dominiert wird. Darüber hinaus besteht die Hypothese, dass die generelle Erwärmung in der Untersuchungsregion in den Eistemperaturen des Vestfonna nahe der Oberfläche nachgewiesen werden kann, sofern es zukünftig gelingt, den isolierenden Effekt der variierenden Wintersschneedecke zu modellieren.

1. Introduction

The polythermal, dome-shaped ice cap Vestfonna (Fig. 1) on the island Nordaustlandet (northernmost Svalbard) at around 80 °N covers an area of around 2,500 km² and extends between sea level and 630 m a. s. l. (above sea level). Hence, aside from the much larger, neighboring Austfonna it is one of the largest ice masses of the European Arctic.

As all arctic climates, the climate of Svalbard is characterized by its close couplings between atmosphere, ocean and land (Serreze and Barry 2005). Influences of both, the cold arctic air masses and the comparably warm ocean water at the northernmost end of the North Atlantic Current are noticeable throughout the archipelago (Schuler et al. 2007). Mean monthly air temperatures range between +5 °C in the short summer season and around –15 °C in winter. However, short term periods with air temperatures rising close to or even slightly above the melting point are present during the winter months due to the maritime climate of the archipelago.

The location of Vestfonna in the northeastern part of Svalbard causes the ice cap to be stronger influenced by atmospheric systems from the Barents Sea region than by westerly systems which usually determine the climate of the archipelago (Taurisano et al. 2007). The ice-free areas of the Barents Sea thus form the major source of moisture for precipitation over Nordaustlandet (Førland et al. 1997). Vestfonna in the West is situated in the lee of the larger Austfonna, which leads to reduced precipitation sums and a possible superimposition of the local precipitation regime by westerly influences.

2. Surface Mass Balance

In contrast to its considerably larger neighbor Austfonna, where marked progress in mass balance studies could be achieved during recent years (e.g. Moholdt et al. 2010, Schuler et al. 2007), the mass balance of Vestfonna Ice Cap still remains in an unknown state. We present a basic surface mass-balance calculation making use of the degree-day method (e.g. Braithwaite 1981) to obtain a first estimate of Vestfonna's balance status. Building on that, the results of a simple climate sensitivity study show the possible impact of climate warming on the health of the ice masses.

The simple model calculates the surface mass balance as sum of ablation and accumulation. Ablation is computed by a degree-day model that assesses snow or ice melt as product of

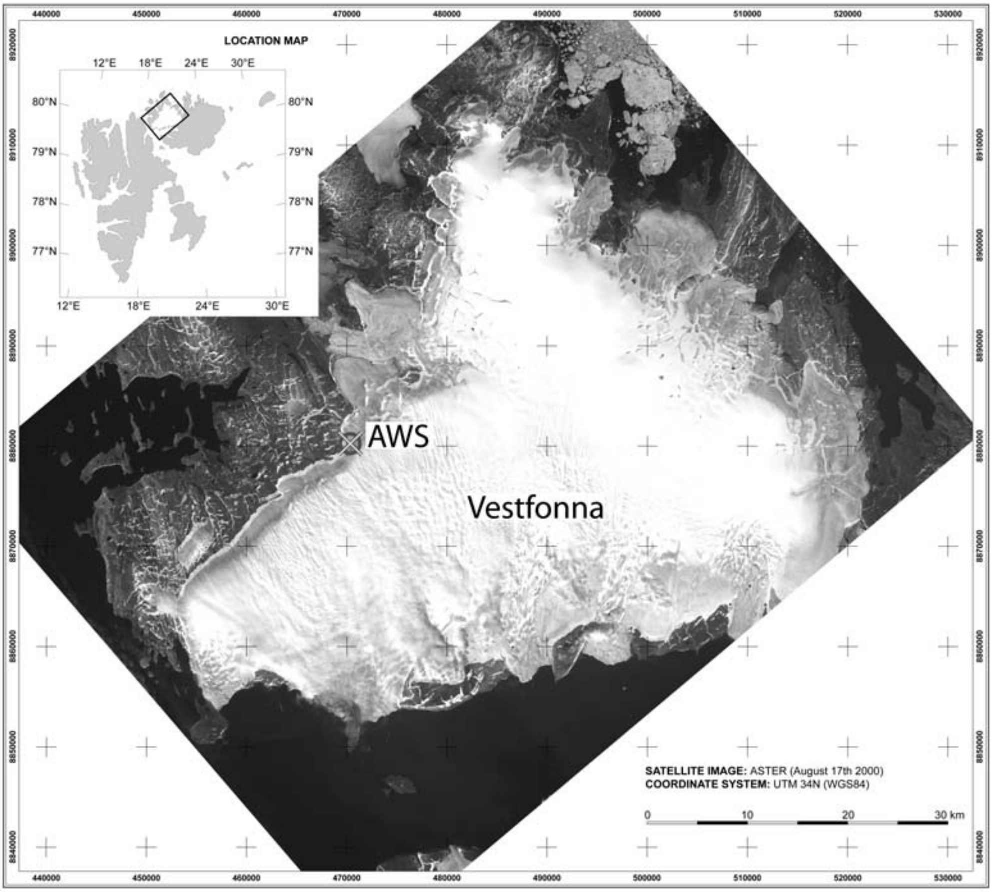

Fig. 1 Overview of the study area. Location of the AWS is marked by a cross.

positive degree-days and a so-called degree-day factor (DDF) differing for snow and ice surfaces. The DDFs are calibrated from hourly air temperature and snow depth change measurements of an automatic weather station (AWS) operated on the northwestern side of the ice cap near the equilibrium line at around 370 m a. s. l. (Fig. 1). Calibration procedure yields a DDF for snow of 5.5 mm w. e. K^{-1} day^{-1} and a DDF for ice of 14.2 mm w. e. K^{-1} day^{-1}. The DDF for snow harmonizes well with other values cited (Singh et al. 2000). On the contrary, the DDF for ice seems to be rather high on the first sight. However, it almost perfectly matches a value previously obtained for the conditions at Vestfonna Ice Cap (13.8 mm w. e. K^{-1} day^{-1}) by Schytt (1964). Accumulation is estimated from records of the nearest synoptic weather station in Ny-Ålesund. Daily precipitation sums are scaled by a factor of 1.4 to fit local conditions at the ice cap represented in the calibration procedure by a set of ablation stake measurements. Final surface mass-balance model runs are performed using air temperature and precipitation lapse rates of 0.63 °K $(100\ m)^{-1}$ and 20 % $(100\ m)^{-1}$, respectively. Modeling period is 06/2008 to 07/2009.

Results reveal an almost balanced status of mass balance throughout the modeling period with monthly values ranging between down to –300 mm w. e. in the most negative months, i.e. July and August, and up to +250 mm w. e. in the most positive one, which in this study is December (Fig. 2). For the year 06/2008 – 05/2009 a slightly positive overall surface mass balance of +200 mm w. e. was retrieved.

In order to analyze the probable response of Vestfonna's ice masses to oncoming climate change, additional sensitivity studies based on altering model input data according to stepwise air temperature and precipitation offsets were carried out. Results (Tab. 1) show that potential climate warming, which currently is particularly strong in the Svalbard/Barents Sea region (Jungclaus and Koenigk 2010) and estimated to be especially pronounced within Arctic regions in general in the future (Solomon et al. 2007), will have a substantial impact on Vestfonna's surface mass-balance. Moreover, it was revealed that this influence of rising air temperatures could not be compensated by any realistic increase in precipitation. A comparably moderate air temperature offset of +1 K would already drive the surface mass balance of Vestfonna to considerably negative values, even if a simultaneous precipitation offset of +20 % is assumed. When maxing out the full range of eventually possible air temperature increase, i.e. assuming an offset of +5 K, the surface mass balance of the ice cap would drop to mean annual values of almost – 6.0 m w. e.

3. Large-Scale Synoptic Modeling

In order to gain a better understanding of the synoptic controls which regulate the weather and especially the distribution of precipitation we conducted a circulation pattern classification that is basically a circulation-to-environment approach (Yarnal 1993) consisting of

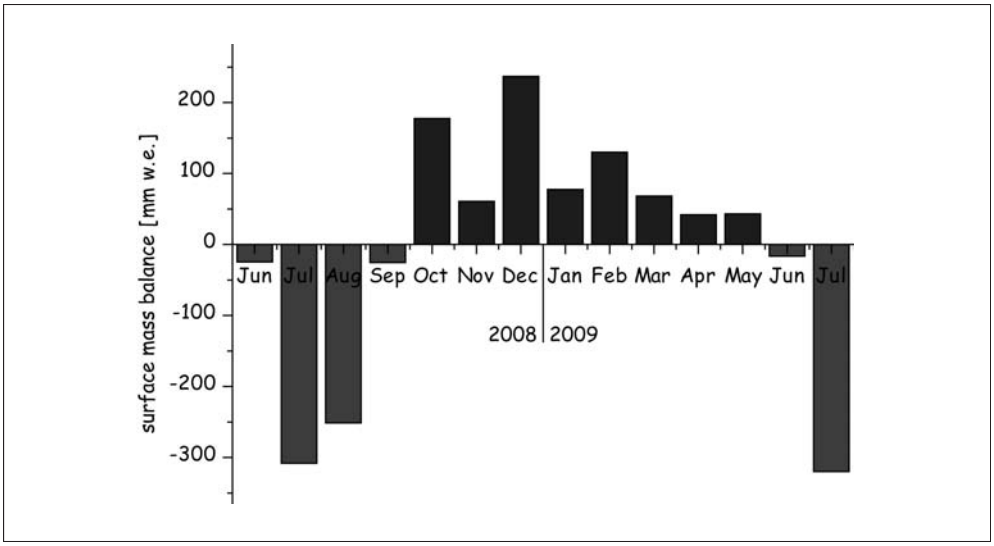

Fig. 2 Surface mass balance of Vestfonna ice cap for the period 06/2008-07/2009.

Tab. 1 Variability of surface mass balance according to different air temperature and precipitation offsets. Values are given in mm w. e.

		Precipitation offset					
		=	+ 1 K	+ 2 K	+ 3 K	+ 4 K	+ 5 K
	+20 %	+443	–255	–1,249	–2,514	–4,048	–5,738
Air temperature	+10 %	+335	–361	–1,352	–2,614	–4,140	–5,828
offset	=	+227	–468	–1,456	–2,714	–4,232	–5,916
	–10 %	+118	–574	1,560	–2,815	–4,325	–6,006
	–20 %	+9	–680	–1,664	–2,915	–4,420	–6,097

two steps. First step is a data (dimension) reduction step (maximum covariance analysis) (Björnsson et al. 1997, Wallace et al. 1992) which is then followed by a clustering procedure (k-means partitioning algorithm).

The first step of this procedure maximizes the joined variance of two fields (e.g. sea level pressure and geopotential height) and leads to a smaller set of data (Björnsson et al. 1997, Bretherton et al. 1992, Wallace et al. 1992). In the second step the synoptic scale circulation patterns are grouped into clusters. The challenging task is to maximize the inter-cluster variability while simultaneously minimizing the intra-cluster variability.

The resultant circulation patterns reflect the seasonally varying influences of the polar night and the polar day situations with their half-yearly changing solar radiation budgets. The most important circulation patterns are shown in Figure 3. Table 2 shows the seasonal distribution of the patterns. The atmospheric conditions during winter time can generally be depicted as cyclonal with a high frequency of cyclonal activity occurring in the examined area, whereas the going-through of cyclones during summer decreases to about two per month.

According to the inflow direction at the 500 mbar level, the strength of the pressure gradient at sea level height and the seasonal occurrence of the circulation pattern the following differentiation can be made:

Tab. 2 Seasonal distribution of the circulation patterns during the examined period (1. 1. 1977 – 31. 12. 2006)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Σ	%
CP 1	0	2	10	15	203	512	836	714	268	56	8	7	2,631	24,01 %
CP 2	58	71	78	277	558	377	94	215	486	331	118	77	2,740	25,01 %
CP 3	445	360	333	62	4	0	0	0	1	34	201	401	1,841	16,80 %
CP 4	182	200	190	248	47	1	0	1	44	188	232	204	1,537	14,03 %
CP 5	245	214	319	298	118	10	0	0	101	321	341	241	2,208	20,15 %

– Pattern 1: West-Southwest / very weak / summer
– Pattern 2: Zonal westerly flow / weak / transition times in spring and autumn
– Pattern 3: Cyclonal / pronounced / winter
– Pattern 4: North-West / weak / not in summer
– Pattern 5: South-West / pronounced / not in summer (peaks in spring and autumn)

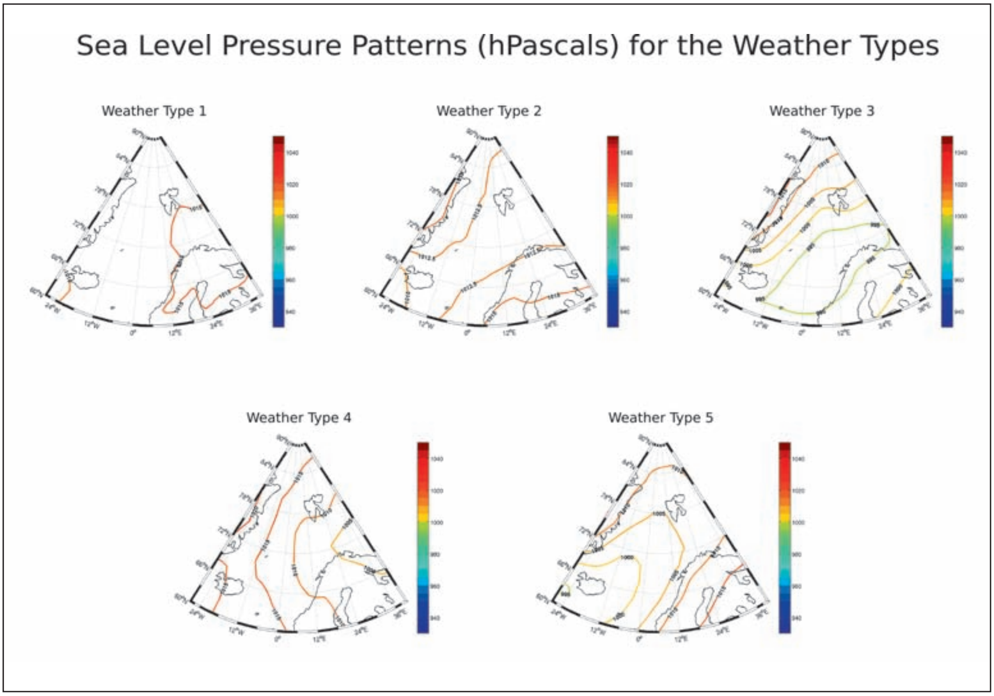

Fig. 3 Sea level pressure patterns for the circulation patterns 1–5. The input data for this classification consist of sea level pressure fields and 500 mbar geopotential heights of the NCEP/NCAR reanalysis data set for the 30 year period from 1977 to 2006. The domain covers the region of the northern part of the Atlantic Ocean with parts of the Arctic Sea and lies between 60° to 90° N and 27.5° W to 40° E.

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Festakt zur Ernennung der Deutschen Akademie der Naturforscher Leopoldina zur Nationalen Akademie der Wissenschaften

Ceremony to Mark the Nomination of the German Academy of Sciences Leopoldina to the National Academy of Sciences

Nova Acta Leopoldina N. F., Bd. *98*, Nr. 362
Herausgegeben vom Präsidium der Deutschen Akademie der Naturforscher Leopoldina
(2009, 76 Seiten, 50 Abbildungen, 21,95 Euro, ISBN: 978-3-8047-2551-5)

Die Deutsche Akademie der Naturforscher Leopoldina wurde am 14. Juli 2008 im Rahmen eines Festaktes in Halle zur Nationalen Akademie der Wissenschaften ernannt. Damit erhielt Deutschland – wie andere europäische Länder oder die USA – eine Institution, die Politik und Gesellschaft wissenschaftsbasiert berät und die deutsche Wissenschaft in internationalen Gremien repräsentiert. Der Band dokumentiert den Festakt mit der Übergabe der Ernennungsurkunde durch die Vorsitzende der Gemeinsamen Wissenschaftskonferenz und Bundesministerin für Bildung und Forschung Annette Schavan. Er enthält die Reden von Bundespräsident Horst Köhler, Sachsens-Anhalts Ministerpräsident Wolfgang Böhmer und Leopoldina-Präsident Volker ter Meulen sowie den Festvortrag „Rolle und Verantwortung nationaler Akademien der Wissenschaften" von Jules A. Hoffmann, Präsident der Académie des sciences, Paris. Der Aufbau einer Nationalen Akademie ist ein richtungsweisender Schritt für die deutsche Forschungslandschaft, da für den kontinuierlichen Dialog von Wissenschaft und Politik eine solche Einrichtung erforderlich wurde. Der Publikation ist eine DVD mit dem Mitschnitt der Festveranstaltung beigefügt.

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Africa

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Downscaling of Future Climate Change for the Mediterranean Region

Elke Hertig and Jucundus Jacobeit (Augsburg)

With 5 Figures

Abstract

The Mediterranean area has been characterized as a "climate change hot-spot" being highly affected by future climate change compared to other regions of the world. Dynamical and statistical downscaling results will be discussed for the supposed changes of temperature and precipitation concerning both mean values as well as extreme conditions. The downscaling assessments show increases of mean temperature in the Mediterranean area during all months of the year with seasonal and regional variations of the corresponding amounts. For mean precipitation increases are only found in the northern and western Mediterranean area during high winter, whereas in other seasons and regions mostly decreases are assessed during the course of the 21st century. Regarding temperature extremes increases of extreme hot days and of heat waves in summer are projected as well as a decrease of the frost-day number in winter. Concerning rainfall-related extremes assessments indicate that more frequent and longer-lasting drought events will occur in the Mediterranean area. In contrast to this, heavy rainfall events show a general tendency towards decreases in the Mediterranean region during winter.

Zusammenfassung

Der Mittelmeerraum kann als ein regionaler „Hot-Spot" im Rahmen des globalen Klimawandels angesehen werden. Im Vergleich zu anderen Regionen der Erde wird er besonders vom anthropogen verstärkten Treibhauseffekt betroffen sein. Ergebnisse aus dynamischen sowie statistischen Regionalabschätzungen werden im Hinblick auf mögliche Veränderungen der Temperatur und des Niederschlags sowohl hinsichtlich der Mittelwerte als auch der Extremwerte erläutert. In Bezug auf die mittlere Temperatur ist mit einem Anstieg im gesamten Mittelmeerraum in allen Monaten des Jahres zu rechnen, wobei die Höhe des Temperaturanstieges regional und saisonal differiert. Beim mittleren Niederschlag werden Zunahmen lediglich in den nördlichen und westlichen Regionen des Mittelmeerraumes im Hochwinter abgeschätzt, während in den anderen Regionen und Jahreszeiten Niederschlagsabnahmen dominieren. Im Hinblick auf Temperaturextreme wird im Verlauf des 21. Jahrhunderts mit Zunahmen der extrem heißen Tage und der Hitzewellen im Sommer sowie mit einer Abnahme der Anzahl der Frosttage im Winter gerechnet. Bei den niederschlagsbezogenen Extremwerten zeigen die Abschätzungsergebnisse für den Mittelmeerraum eine Zunahme in Frequenz und Andauer der Trockenperioden, während Starkregenereignisse im Winter eine eher rückläufige Tendenz erfahren.

1. Introduction

Improved assessments of regional climate change for the 21st century are now available for many parts of the world. Mainly regions with a high climatic variability will be strongly affected by the anticipated climate change. Among these regions the Mediterranean area, which is located in the transitional zone between tropical and extra-tropical circulation dynamics, has been identified as a particular "climate change hot-spot" (Giorgi 2006). This is mostly due to the assessed decrease of precipitation as well as to an increase of the inter-annual precipitation variability during the course of the 21st century.

The uneven intra-annual distribution of precipitation, its high inter-annual variability as well as the anticipated changes of these climatic characteristics are major determining factors for various economic sectors. For instance the UNWTO (*World Tourism Organization* 2007) estimates that the number of tourists visiting the Mediterranean region will more than double by the year 2025, up to 655 million per year. Already nowadays the water consumption of a tourist amounts to 300–850 l per day. Furthermore, agriculture has also a significant part in the national economy of many Mediterranean countries. Thereby irrigation in the area of fruit-growing and market gardening plays a major role in Mediterranean land use with the result that more than 80 % of the total water consumption is caused by agriculture. Future temperature rise will likely reduce the productivity of major crops and increase their water requirements leading to a further increase in irrigation demand. A general decline in precipitation would lead to a further enhancement in water stress. Besides the two examples tourism and agriculture, a substantial quantity of other economic sectors will also be affected by climate change. Additionally, further societal and ecological issues arise, for example in the scope of human health or regarding the ecosystems of the low-lying coastal zones due to the projected sea-level rise.

Furthermore, non-climatic factors may aggravate the impacts of climate change, mainly for the countries in the eastern and southern Mediterranean area. Thus, for instance, it is expected that Turkey, Syria, Egypt and Algeria will have a relatively strong population increase in the next decades. As a result Egypt will be likely to experience an increase in water stress, with the background of a projected decline in precipitation and a projected population of between 115 and 179 million people by 2050 (Boko et al. 2007).

This leads to the conclusion that reliable information on the development of the Mediterranean climate is required to deal in an appropriate manner with the manifold issues which arise from global climate change in its regional specification. More specified assessment results will help to integrate forthcoming climate change into other future developments of the countries surrounding the Mediterranean Sea.

2. Mean Temperature Change

As already outlined in the previous section, regional climate change patterns can be distinguished from the general warming signal of the global scale.

Figure 1 from the latest IPCC Report (Assessment Report 4 of the Intergovernmental Panel on Climate Change) shows a regional pattern of the assessed changes for Europe and the Mediterranean area based on output from 21 dynamical models. Based on the SRES A1B scenario (SRES: Special Report on Emissions Scenarios, Nakicenovic et al. 2000), the simulated annual mean warming from the period 1980–1999 to the period 2080–2099 varies from 2.2 °C to 5.1 °C in the Mediterranean area, with the largest warming rate in summer for the Mediterranean land areas.

Figure 2 shows, for consecutive bi-monthly periods, the temperature changes in the period 2071–2100 in comparison to the period 1990–2019, resulting from statistical downscaling of global climate model output under SRES-B2 scenario assumptions. Thereby regions showing a significant change (95 % confidence level) are marked with transverse hatching in Figure 2.

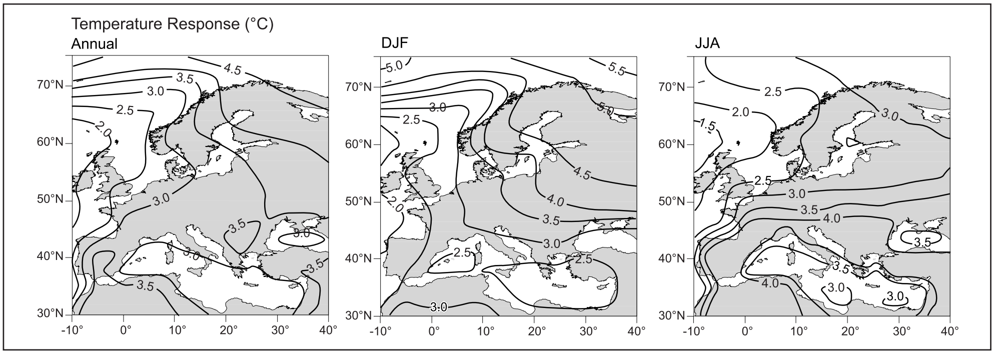

Fig. 1 Temperature changes over Europe and the Mediterranean area for the A1B scenario. From left to right: Annual mean, Winter (DJF) and Summer (JJA) temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 dynamical models (according to IPCC AR4, Christensen et al. 2007).

Just like the results from the dynamical models, statistically downscaled temperature changes also show an increase for the whole Mediterranean area for all months of the year. Looking at seasonal and regional differences, the statistical assessment indicates a relatively small temperature rise in the western part of Northern Africa, whereas significant increases can be found over the Iberian Peninsula, the northern Mediterranean region and in the eastern half of the Mediterranean area during winter (December/January). In summer (June–September) a stronger warming of partially more than 4 °C is indicated in the western Mediterranean area, being significant in late summer (August/September). In the transitional seasons the downscaling results show a relatively uniform spatial distribution of temperature increases with an amount of approximately 3 °C in spring (April/May) and more than 4 °C in autumn (October/November).

Since the multi-model mean global temperature rise for the 2080–2099 period (compared to 1980–1999) is estimated by the IPCC to amount to 2.8 °C (uncertainty range: 1.7 °C to 4.4 °C, Meehl et al. 2007) for the A1B scenario and to 2.4 °C (1.4 °C to 3.8 °C) for the B2 scenario, the warming in the Mediterranean area is projected to be somewhat greater than the global mean.

3. Mean Precipitation Change

The projected changes of mean precipitation in Figure 3, taken from the latest IPPC report, indicate that annual mean precipitation decreases dominate for Southern Europe. The map for the winter months (central panel of Fig. 3) reveals that for widespread parts of the Mediterranean area a reduction of precipitation is assessed, but the northern parts might see slight increases in precipitation. Since precipitation assessments are still affected by considerable model uncertainties, the exact spatial distribution of precipitation changes is yet undetermined. Thus, for the Northern Mediterranean regions positive as well as negative precipitation changes in winter during the course of the 21st century are possible. Looking at the right map of Figure 3 for the summer months reveals that precipitation decreases dominate for the whole Mediterranean area, and this could have serious impacts on water supply.

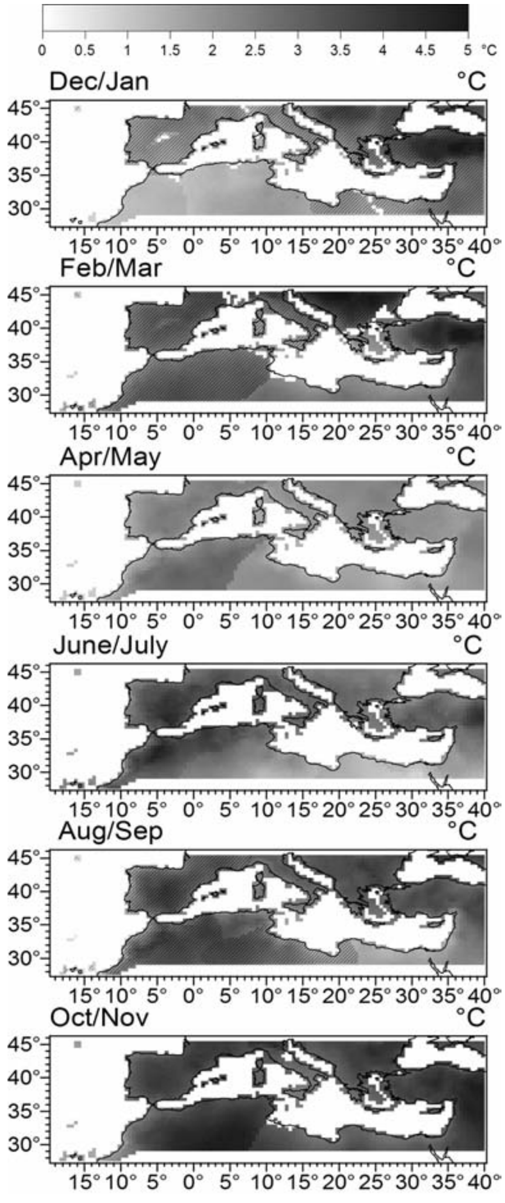

Fig. 2 Temperature assessments for the Mediterranean area using global climate model (ECHAM4/OPYC3) values of 1000 hPa and 500 hPa geopotential heights as predictors for statistical downscaling models: Differences of statistically modeled mean temperatures for the 30-year periods at the end (2071–2100) and at the beginning (1990–2019) of the entire model period 1990–2100. Statistical downscaling method: Canonical Correlation Analysis. Scenario: SRES-B2. Transverse hatching: signal/noise ratio > 1.96 (i.e. 95 % confidence level) (according to Hertig and Jacobeit 2008b).

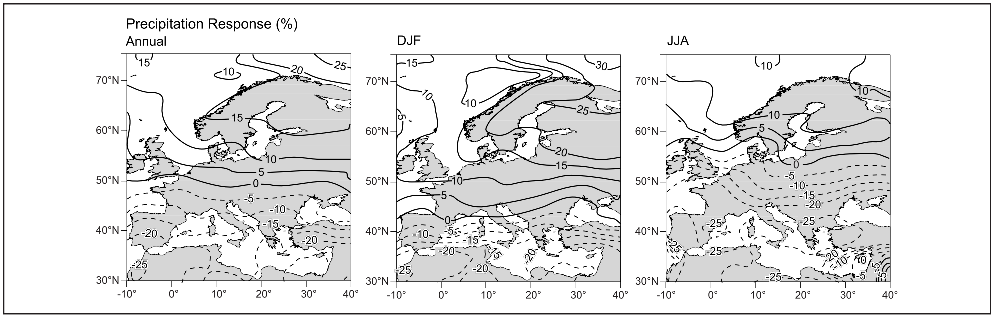

Fig. 3 Precipitation changes over Europe and the Mediterranean area for the A1B scenario. From left to right: Annual mean, Winter (DJF) and Summer (JJA) precipitation change between 1980 to 1999 and 2080 to 2099, averaged over 21 dynamical models (according to IPCC AR4, Christensen et al. 2007).

Figure 4 shows statistically downscaled precipitation changes using the large-scale atmospheric circulation (1000 hPa and 500 hPa geopotential heights) as well as specific humidity as predictors for regional precipitation. Summarizing the seasonal and regional information (assuming SRES B2 scenario conditions) gives a shortening and at the same time an increase in rainfall amount of the wet season for the western and northern Mediterranean regions. These results from estimated precipitation increases in winter for the period 2071–2100 compared to 1990–2019, whereas precipitation decreases dominate in autumn and spring. The eastern and southern parts of the Mediterranean area, on the other hand, exhibit mainly negative precipitation changes throughout the period from October to May under enhanced greenhouse warming conditions. Looking at the northern African regions in particular, stronger precipitation decreases occur for the western Maghreb in autumn (October/November), late winter (February/March) and spring (April/May). In general the Mediterranean part of North Africa is mostly affected by precipitation decreases during all analyzed months. Only for some sub-regions in specific months small increases are assessed like for example for the western Maghreb in winter (December/January) or for the Mediterranean parts of Libya in autumn (October/November).

4. Changes in Extreme Values

Not only changes regarding mean values, but particularly changes of extreme events like droughts, heat waves and heavy rainfall are of special interest in the scope of future climate change. But it has to be emphasized that climate change information regarding extreme events is still affected by considerable uncertainties.

According to Christensen et al. (2007) an increase in frequency, intensity and duration of heat waves and *vice versa* a decrease of the number of frost days is very likely for southern Europe and the Mediterranean area. Statistical downscaling assessments of the 5th percentile of minimum temperatures in winter (as an indicator of the frost hazard) and of the 95th percentile of maximum temperatures in summer (as an indicator of possible heat stress conditions) for the 21st century under enhanced greenhouse warming conditions yield mainly increases of both extremes indices for selected temperature stations in the Mediterranean area (Fig. 5).

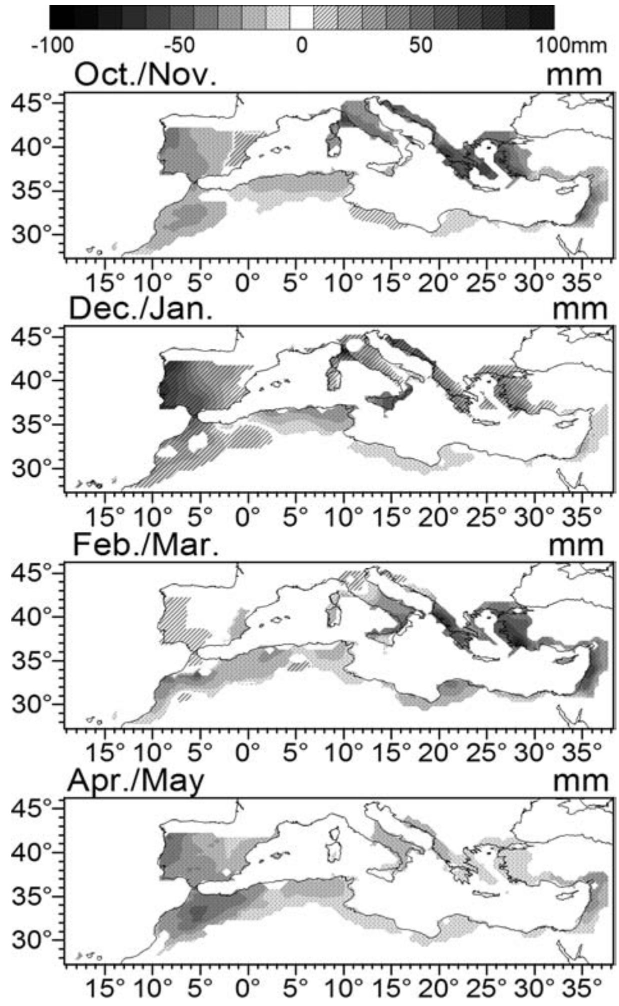

Fig. 4 Changes of Mediterranean Precipitation according to statistical downscaling assessments using ECHAM4/OPYC3 predictors (1000 hPa and 500 hPa geopotential heights and 1000 hPa specific humidity): Differences of the mean 2-month precipitation between the periods 2071–2100 and 1990–2019 (in mm). Statistical downscaling technique: Canonical Correlation Analysis. Scenario: SRES-B2 (according to Hertig and Jacobeit 2008a).

But the statistical assessments also indicate that the intra-annual extreme temperature range (i.e. the difference between the highest and the lowest temperatures of the year) will decrease in most parts of the Mediterranean area during the 21st century, because extreme minimum temperatures in winter will increase stronger (upper part of Fig. 5) than extreme maximum temperatures in summer (lower part of Fig. 5).

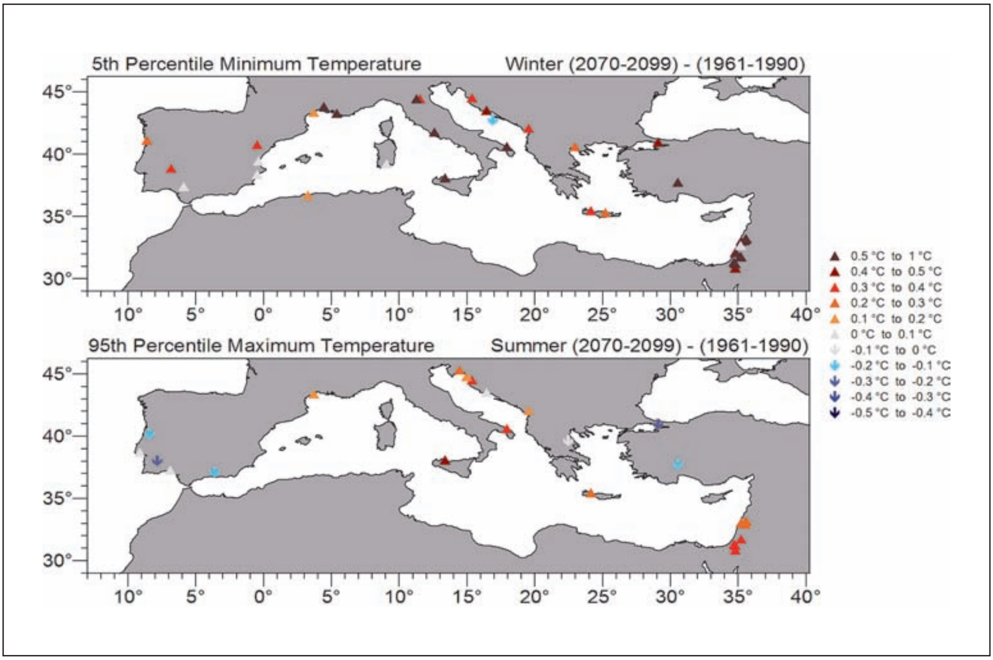

Fig. 5 Changes of the 5th percentile of minimum temperatures in winter (upper panel) and of the 95th percentile of maximum temperatures in summer (lower panel) according to statistical downscaling assessments using ECHAM5/MPI-OM predictors under SRES-A1B scenario assumptions: Differences of the seasonal extremes indices between the periods 2070–2099 and 1961–1990 (in °C). Statistical downscaling technique: Multiple Regression analysis. Predictors: 1000 hPa – 500 hPa- thickness and 500 hPa geopotential heights.

Regarding negative rainfall extremes there is a high probability that warmer and drier conditions will lead to more frequent and longer-lasting drought events in the Mediterranean area (Christensen et al. 2007). Concerning positive precipitation extremes, i.e. heavy rainfall events, a general tendency towards decreases is assessed by Frei et al. (2006) for the Mediterranean region in winter.

5. Conclusions

In correspondence to the observed and projected mean temperature rise on the global scale, dynamical as well as statistical assessments indicate increases of mean temperature also for the Mediterranean area, but with warming rates being probably somewhat greater compared to the global mean. Mean precipitation is assessed to decrease in most Mediterranean regions. Increases are only possible in the northern and western Mediterranean area during high winter, but the exact location of the boundary between the projected rainfall increases in northern Europe and the assessed precipitation decreases in southern Europe is still very uncertain. Regarding temperature extremes, the number of frost days will decrease just as extreme minimum temperatures in winter will increase. At the same time assessments for summer include that extreme hot days as well as heat waves will increase. Concerning rainfall-related extremes, longer-lasting and more frequent droughts are very likely, but on the other hand heavy rainfall events during winter are likely to decrease.

Overall climate change will have particular impacts on different sectors of human life in the Mediterranean area. For instance, according to Alcamo et al. (2007), there will be a greater energy demand for cooling. Estimates for the year 2050 point to a prolonged cooling period of two up to five weeks per year. In contrast to this, the demand for heating purposes in winter will be reduced. Concerning tourism, higher temperatures may lead to a decrease in summer, but to an increase in spring and autumn. Regarding agriculture, general decreases in crops and widespread increases in water demand are expected.

Acknowledgement

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Evolution und Menschwerdung

Vorträge anlässlich der Jahresversammlung vom 7. bis 9. Oktober 2005
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Evolution und Menschwerdung gehören noch immer zu den interessantesten Themen, mit denen sich die Naturwissenschaft auseinandersetzt und die die Öffentlichkeit faszinieren. Die Thematik verlangt eine interdisziplinäre Auseinandersetzung, für die eine Akademie wie die Leopoldina prädestiniert ist. Daher griff die Jahresversammlung 2005 verschiedene Aspekte hierzu auf.

Die Schwerpunkte der Tagung spiegeln den enormen Fortschritt der Erkenntnisse über das Evolutionsgeschehen und den veränderten Blickwinkel wider, der sich aufgrund des außerordentlich großen Wissenszuwachses und veränderter Diskussionsebenen in der Forschung, aber auch zwischen Wissenschaft und Gesellschaft ergeben. Die Evolution des Menschen und dessen physische, geistige und kulturelle Entwicklungstendenzen stehen dabei im Zentrum.

Der Band spannt den Bogen vom Urknall und der Bildung der Planetensysteme über die Entstehung des Lebens, die Entwicklung von Prokaryoten und Eukaryoten, die Evolution und das Sterben der Saurier, die Analyse von Insektenstaaten bis hin zu Fragen der Menschwerdung und Formen der menschlichen Kultur. Hier werden unter anderem „Das Sprachmosaik und seine Evolution“, die „Evolution durch Schrift“, Rituale, Religionen, Gemeinschaftsbildung und sozialer Wandel unter evolutionären Aspekten untersucht, aber auch „Bilder in Evolution und Evolutionstheorie“ sowie die „Griechischen Anfänge der Wissenschaft“ betrachtet.

Wissenschaftliche Verlagsgesellschaft mbH Stuttgart

Nova Acta Leopoldina NF *112*, Nr. 384, 165 – 172 (2010)

Solar Signals in African Climate since 1901

Joachim Rathmann and Jucundus Jacobeit (Augsburg)

With 5 Figures

Abstract

The present paper may contribute to an improved assessment of sun-climate relationships with a regional focus on Africa. Some statistical relationships between solar activity and the climate of southern Africa have been identified since the beginning of the 20th century based mainly on different time series analyses (autocorrelation, spectral and wavelet analyses) in addition to simple correlation and composite analyses. Solar cycle signals can be shown for South African winter temperatures, East African precipitation and northern Namibia / southern Angola precipitation during winter and spring. Furthermore, significant solar signals can be revealed in SSTs (Sea Surface Temperatures) of the southern equatorial Atlantic and SLP data of the subtropical anticyclones above the Atlantic and Indian oceans.

Zusammenfassung

Eine veränderliche Solaraktivität nimmt auf allen Zeitskalen Einfluss auf das Klima der Erde. Am regionalen Beispiel Afrikas werden solar-klimatische Kopplungen seit Beginn des 20. Jahrhunderts mit Hilfe statistischer Methoden aufgedeckt. Dazu wurden Zeitreihenanalysen (Autokorrelationsanalysen, spektrale Varianzanalysen und Waveletanalysen) ergänzt um Korrelations- und Kompositenanalysen berechnet. Aus den Ergebnissen lassen sich signifikante solare Signale im Untersuchungsgebiet aufdecken. Ein solarer Einfluss auf die winterliche Lufttemperatur in Südafrika ist wahrscheinlich, der Niederschlag weist in der Region nördliches Namibia, südliches Angola und in Ostafrika ein markantes quasidekadisches Signal auf, ebenso die Meeresoberflächentemperatur im südäquatorialen Atlantik. Eine weitere Region mit einer möglichen solar-induzierten Klimavariabilität liegt in den subtropisch-randtropischen Hochdruckgebieten über dem südlichen Atlantik und südlichen Indik.

1. Introduction

Since the year 1900 the global climate has warmed by approximately 0.8 °C. Most of this warming is due to the rising concentration of carbon dioxide and other anthropogenic greenhouse gases (Solomon et al. 2007). A noteworthy contribution of solar variability to recent warming is generally dismissed, because the responses to the solar 11-year cycle are too small to be detected unambiguously in observations. But – although there have been hundreds of studies during the last decades concerning climate response to the 11-year sunspot cycle (cf. Benestad 2002) – the influence of solar activity changes on the climate of the Earth is still characterized by a "low level of scientific understanding" (Solomon et al. 2007).

The sun influences the Earth's climate by its whole radiation spectrum, the so called solar wind and its influence on cosmic rays. The most highly variable parts of the sun's radiation spectrum can be found at short wavelengths, e.g. the ultraviolet (UV) ones. Both model and observational studies show some tropospheric circulation changes due to the 11-year sunspot cycle (e.g. Haigh 2003, Gleisner and Thejll 2003, Labitzke 2005, Lean and Rind 2008, Roy and Haigh 2009, Lean 2010). Stager et al. (2007) identify relations between the sunspot number and lake level data of Lake Victoria and other great lakes in East Africa during the 20th century. Roy and Haigh (2009) identify solar cycle signals in global SST data, covering more than 150 years. Camp and Tung (2007) apply composite analyses to detect the influence of the solar cycle on surface temperatures during the last decades. They obtain a significant signal and conclude that a globally averaged warming of almost 0.2 K between sunspot minimum and maximum is much larger than previously reported. But this value might be too large because of volcanic cooling (Lean and Rind 2008). The present paper summarizes some results which have been obtained by regional climate studies focussing on Africa (Rathmann 2009).

2. Data

This study uses the global HadSLP2 data set, a monthly gridded SLP reconstruction (UK Met Office Hadley Centre) with a 5° latitude by 5° longitude resolution. The recent version HadSLP2 spans the years 1850 to 2004 allowing to obtain a long-term perspective on SLP variability and secular changes. HadSLP is a reconstruction based on EOFs derived from recent periods with high data coverage. The data set is based on both marine and terrestrial surface observations. These observational data have been quality-checked and afterwards interpolated on a regular grid by using Reduced-Space Optimal Interpolation (RSOI) (Allan and Ansell 2006).

Sea Surface Temperature (SST) data are taken from the HadISST1.1 data set developed by the UK Met. Office. The data start in 1870 having a spatial resolution of 1° latitude by 1° longitude. The SST grid is based on observational data which have been interpolated by a two-stage reduced-space optimal interpolation procedure (Rayner et al. 2003).

High-resolution temperature and precipitation data, covering the global land areas, are taken from the CRU05 dataset provided by the Climate Research Unit (CRU, Norwich) (New et al. 1999, 2000). The dataset has a spatial resolution of 0.5° latitude by 0.5° longitude, covering initially the 1901–1998 period. Recently, there are updates of this dataset available (Mitchell and Jones 2005), and the present study is based on an improved and updated version of the original CRU05 data (Österle et al. 2003).

As an indicator of solar activity changes over the past century, the sunspot number (ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/YEARLY.PLT) and reconstructed total solar irradiance (TSI) data have been used (Lean et al. 1995).

3. Methods

In a first step, simple correlation analyses between TSI and climate data have been calculated to receive a first indication of possible solar-climate relationships. The resulting correlation maps have to be interpreted very carefully even if the correlation coefficients are highly significant. There has always to be a reasonable physical mechanism that explains why the correlation reflects a linkage between cause and effect. But the scientific concept of causality is more complex, and even cause-effect linkages without correlation are possible (Rathmann 2008).

Furthermore, various composite analyses have been performed: at first calculating differences between composites of temperature, precipitation, SLP and SST for months above and below the long-term mean annual sunspot number, respectively. Additionally, these calculations have been done for months above (below) the 90th (10th) and 75th (25th) percentiles (Fig. 1) in order to check whether some results might only be a matter of chance.

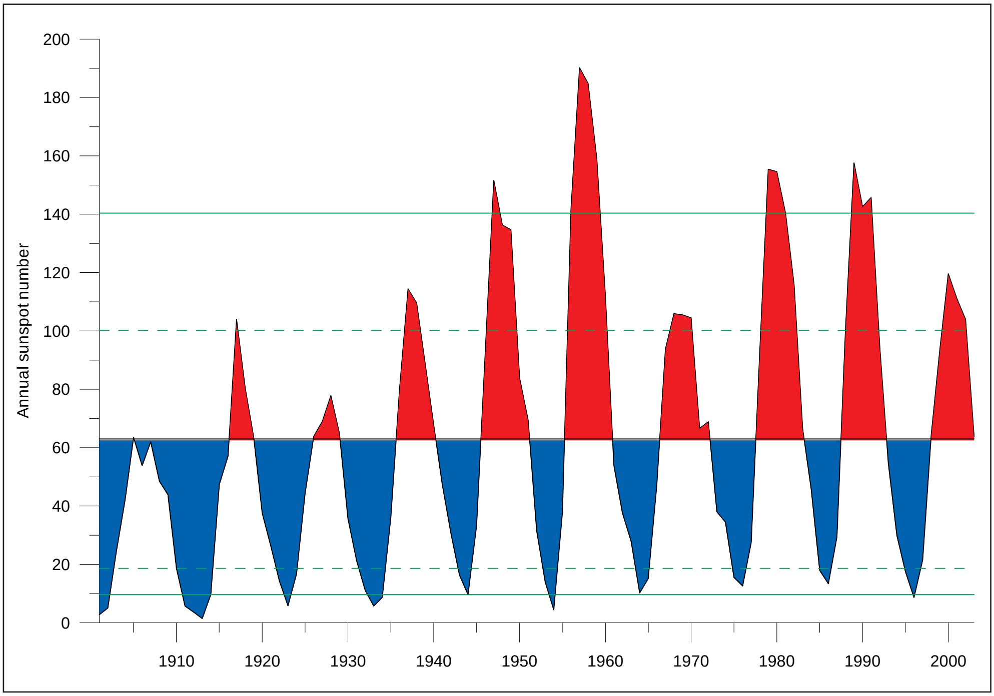

Fig. 1 Annual sunspot numbers (SSN) above (red) and below (blue) the long-term mean (62.55 for 1901–2003), respectively; green dashed lines: SSN corresponding to the 75th and 25th percentiles, respectively); green lines: SSN corresponding to the 90th and 10th percentiles, respectively.

Principal Component Analysis (PCA) is widely used in climate research in order to identify major patterns of atmospheric circulation, to pick out centers of atmospheric (or oceanic) variation or, generally, to reduce dimensions of original data and to remove linear dependencies between basic variables. In the present study, s-mode orthogonally (Varimax) rotated PCAs were carried out for monthly SLP, SST, precipitation and temperature data. All resulting PC time coefficients have further been submitted to different time-series analyses: autocorrelation, spectral variance and wavelet analyses. This has been done to identify cyclic components within the data. Spectral analysis is able to determine periodicities more precisely than simple autocorrelation analyses. But spectral analysis is only able to identify the spectral (frequency) components that exist in the signal, whereas wavelet analysis provides a time scale presentation of the signal. Wavelet analysis of time series is a powerful tool for describing processes that are non-stationary and occur over finite spatial and temporal domains. It allows to show a time-series signal simultaneously in time and frequency (Beecham and Chowdhury 2010).

In the present study, a complex Morlet wavelet has been used as a so called mother wavelet. The software applied for these calculations is based on original routines from Torrence and Compo (1998).

4. Results

Differences of temperature-composites for months with sunspot maxima and minima are reaching up to 1 K in July (Fig. 2). This might be due to the influence of changes in the direct solar radiation on the high pressure system which establishes in winter above the South African highlands. Differences of precipitation-composites (not shown), calculated in the same way, depict increased precipitation during months of strengthened solar activity in East Africa for the long-rains period (Rathmann and Jacobeit 2009).

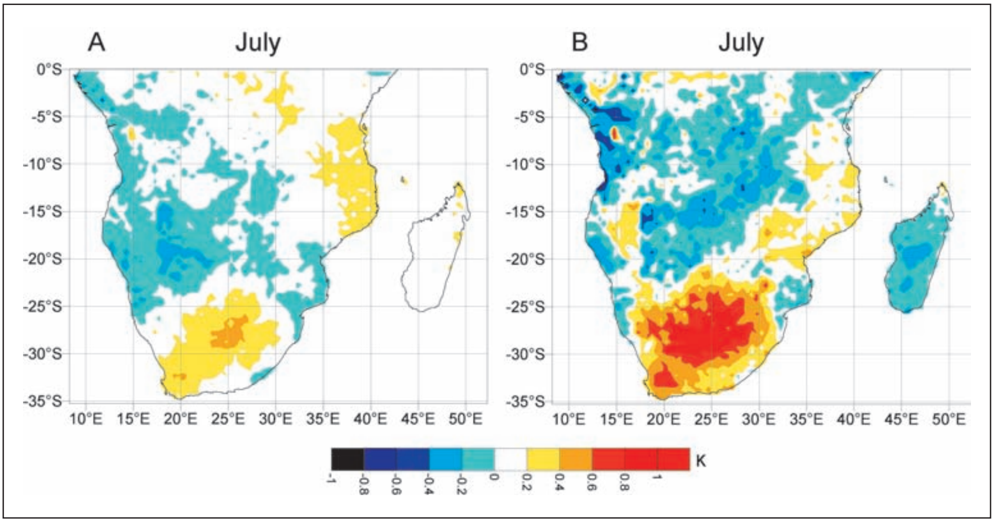

Fig. 2 (*A*) Differences of July temperature composites for sunspot numbers above and below the long-term mean value (62.55 for 1901–2003), respectively; (*B*) as (*A*) but for sunspot numbers above and below the 90th and 10th percentiles, respectively.

Differences of SST-composites include only very small values in the lower latitudes (not shown); this might be due to two opposing effects: Higher solar activity raises tropical SSTs, but due to an enhanced evaporation at the same time, energy is removed from the surface, leading to lower SSTs. Further relationships can also be shown by correlation analyses, for example between the TSI and SST data (with time coefficients for the latter from a s-mode PCA): there are highly significant values ($r = 0.7$ at the 99 % confidence level) for particular centers of SST variation in the midlatitudes between 50° S and 60° S (Rathmann 2009).

Further results are based on time series analyses. For instance, spectral analyses applied to the time coefficients of SST PCs, representing the centre of SST variation in the southern equatorial Atlantic Ocean, confirm a highly significant (99 %) quasi-decadal signal for August

(Fig. 3). Figure 4 shows the wavelet power spectrum of this PC time coefficient, emphasizing a quasi-decadal SST variability.

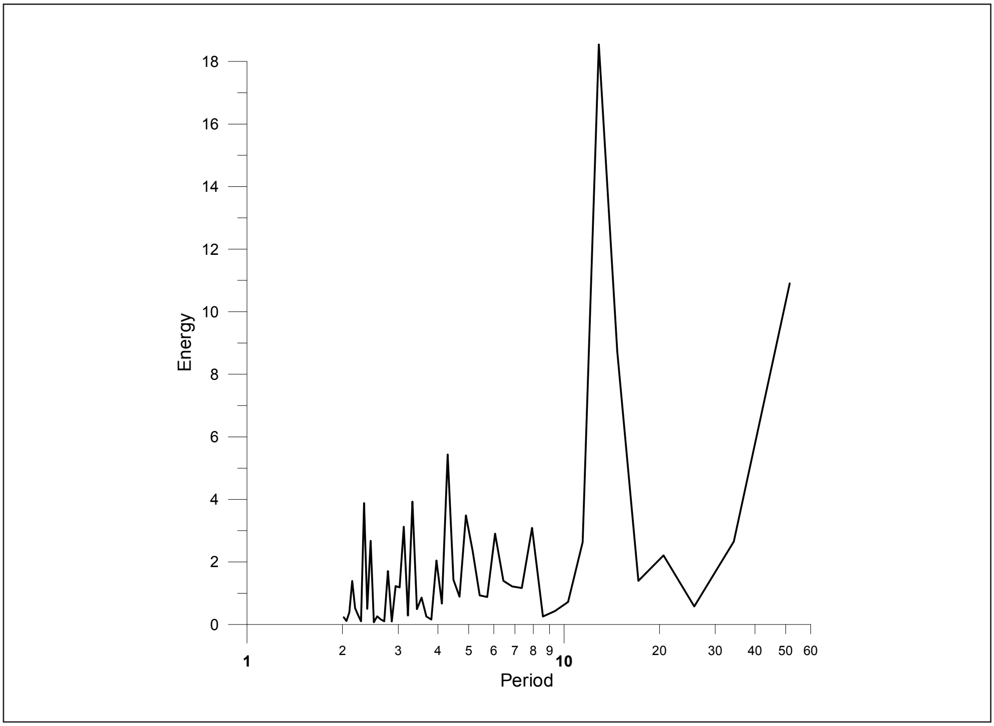

Fig. 3 Power spectrum of the PC time coefficients 1901–2003 for the SST center of variation in the southern equatorial Atlantic for August. Periods (in years) on a logarithmical scale.

The analysis of SLP data gives spectral maxima on a decadal time scale for the southern edge of the St. Helena high pressure system above the central South Atlantic Ocean during all seasons, but most pronounced in southern winter (not shown), when the high pressure cells are intensified. This result indicates an expansion of the Hadley cell during periods of higher solar activity (see also Roy and Haigh 2009).

A spectral peak on a decadal time scale can also be identified in the wavelet power spectrum (not shown) for the time coefficients of a temperature-PC representing the region of South Africa (Rathmann and Jacobeit 2009). This possible solar signal is controlled by the anticyclone above the southern Atlantic Ocean which itself shows a spectral peak at the same period (Fig. 5).

Quasi-decadal and therefore possible solar signals in precipitation time series can be revealed for Namibia and Angola by correlation analyses with TSI data. Just the same regions indicate a significant (95 %) quasi-decadal variability resulting from autocorrelation and spectral analyses (Rathmann 2009). Additional wavelet analyses, based on the monthly time coefficients of the s-mode precipitation-PC representing this region, also show spectral maxima on this time scale. A solar-cycle signal for East African precipitation in March is very

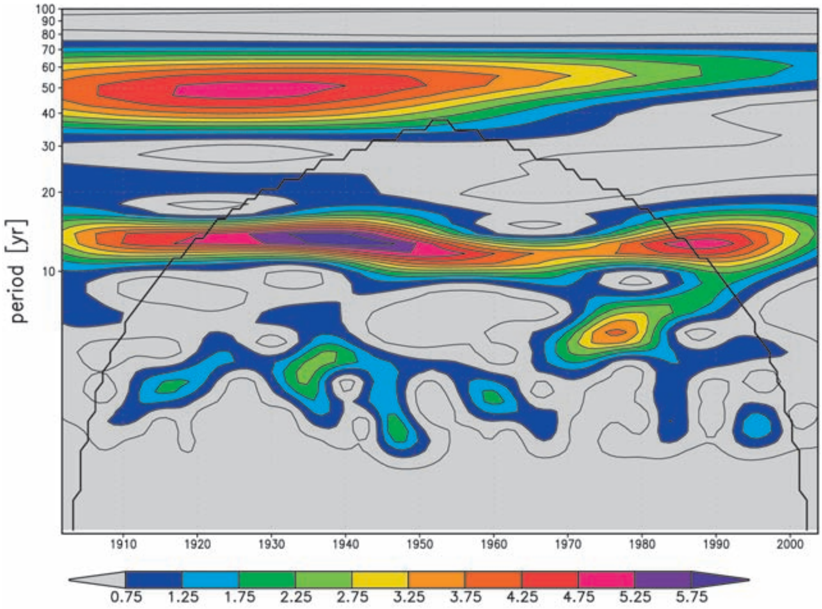

Fig. 4 Wavelet power spectrum of the PC time coefficients 1901–2003 for the SST center of variation in the southern equatorial Atlantic for August. The periods are shown on the y-axis with a logarithmic scale, the years 1901–2003 on the x-axis. The colour scale gives the wavelet power of a particular period during a definite section of time. Black lines outline the "cone of influence", i.e. the area that suffers from edge effects and therefore cannot be interpreted.

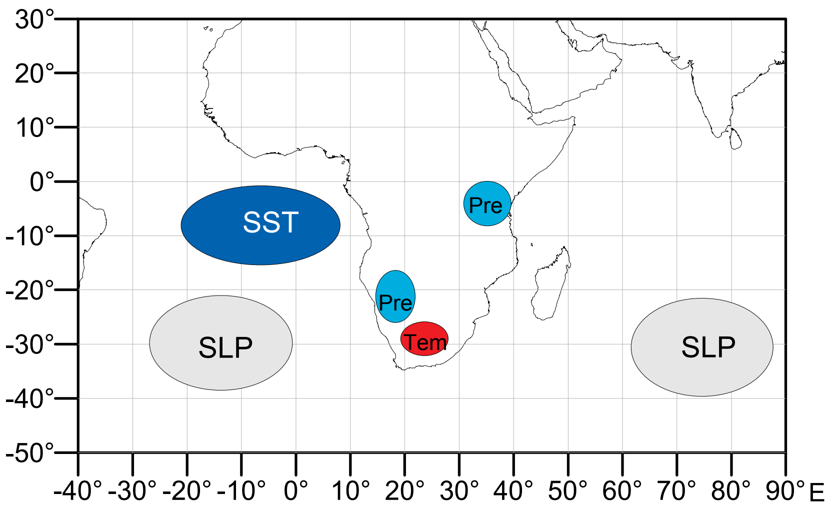

Fig. 5 Synopsis of regions for which solar signals in SST, SLP, Precipitation (Pre) or Temperature (Tem) data have been identified during the 1901–2003 period.

dominant during the first third of the 20th century (Rathmann and Jacobeit 2009), when solar forcing was still stronger compared to greenhouse gas forcing.

5. Summary and Conclusions

It is still unclear how the Sun's variable energy output exactly influences the Earth's climate. The present study contributes some statistical relationships between solar activity and the climate of southern Africa since the beginning of the 20th century mainly based on different time series analyses (autocorrelation, spectral and wavelet analyses) in addition to simple correlation and composite analyses. It could be shown that significant solar signals concentrate on particular regions (Fig. 5).

The present results indicate a strengthening of the subtropical high pressure systems above the southern Atlantic and southern Indian Oceans at solar maxima. A solar signal in South African winter temperatures reaches up to 1 K. Both composite and time-series analyses have shown robust relationships which might be explained by a direct radiation influence on the nearly cloud-free winterly high pressure system above central South Africa.

Precipitation in northern Namibia/southern Angola exhibits a striking quasi-decadal signal, and correlation analyses suggest a relationship with changing solar activity. Positive precipitation anomalies during the 'long rains' could be identified in East Africa during periods of increased solar activity. The increased precipitation might be caused by solar impacts on the Indian Ocean Dipole (IOD) which strongly influences the East African precipitation. Accordingly, Nugroho (2007) has shown by means of wavelet analysis a strong solar signal on the IOD. Furthermore, a stronger Hadley circulation during periods of higher solar activity might lead to changes in the precipitation pattern (Roy and Haigh 2009). Finally, this precipitation pattern during solar maxima is remarkably similar to an El-Niño-induced pattern. Increased solar activity leads to higher evaporation over the nearly cloud-free regions in the subtropics, and this might also lead to lower SSTs. Stronger regional Hadley and Walker cells due to the increased atmospheric moisture content include a stronger upward motion in tropical latitudes and a corresponding intensified subsidence in subtropical regions leading to a reduction of the cloud cover and therefore to an increasing solar irradiance input. These surface feedbacks might explain how a small solar signal is amplified in local climate (Meehl et al. 2003).

Further studies should determine whether the increased solar activity of the recent decades – compared to earlier periods and superimposed on the 11-year solar cycle (Solanki et al. 2004) – has changed the solar fingerprints in the African climate system.

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Climate Change and Land Use Conflicts in Northern Africa

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With 1 Figure and 1 Table

Abstract

For centuries, Arab nomads and African villagers alternately skirmished and supported each other as they raised livestock and tended fields under resource-constrained conditions. The delicate balance has been upset by drought, desertification, crop failure and wide-spread food insecurity. While the interactions are not sufficiently understood, there are growing indications that warming in Africa could become a significant factor of violent conflicts in the coming decades. To test such projections this paper first gives an overview of North Africa's conflict vulnerability and expected climatic changes. Secondly, the paper discusses past and ongoing farmer-herder conflicts in different regions of Mali. Finally, a model framework is built for analyzing the farmer-herder conflict in Northern Africa, taking into account key environmental and economic variables and feedbacks.

Zusammenfassung

Über Jahrhunderte haben sich arabisch-stämmige Nomaden und afrikanische Bauern wechselseitig unterstützt und bedrängt, während sie unter ressourcenarmen Bedingungen ihr Vieh züchteten und ihre Felder bestellten. Diese sensible Balance wurde durch Trockenheit, Desertifikation, Ernteausfall und ausgedehnte Nahrungsmittelunsicherheit gestört. Während die Wechselwirkungen nicht hinreichend verstanden sind, mehren sich zugleich die Anzeichen, dass in den kommenden Jahrzehnten eine Erwärmung in Afrika zu einem bedeutenden Faktor in Gewaltkonflikten werden könnte. Um solche Projektionen zu prüfen, gibt der Artikel zunächst einen Überblick über die Konfliktanfälligkeit des nördlichen Afrikas und die dort zu erwarteten klimatischen Änderungen. Zweitens diskutiert der Artikel vergangene und aktuelle Konflikte zwischen Bauern und Viehzüchtern in verschiedenen Regionen Malis. Drittens wird ein Modellrahmen entworfen mit dem, unter Berücksichtigung von zentralen Umwelt- und Wirtschaftsvariablen, Konflikte zwischen Bauern und Viehzüchtern im nördlichen Afrika analysiert werden können.

1. Introduction

Violent conflicts over land are not a recent phenomenon in Northern Africa. For centuries, the relationship between herders and farmers has been shaped by both *cooperation and violence* (BLENCH 2004, BREUSERS et al. 1998, GALLAIS 1975, MORITZ 2006, SCOONES 1995, SHETTIMA and TAR 2008). However, strong population growth, wide-spread food insecurity and a recent series of drought events have increasingly challenged traditional resource sharing mechanisms while fights for scarce land resources have intensified (BAECHLER 1998, FRATKIN and ROTH 2005, HERRERO 2006, HULME et al. 2001, HUSSEIN 1998, *ILRI* 2006, TURNER 2004).[1] Mean-

1 For a general discussion of the security implications of climate change in Africa see BROWN and CRAWFORD 2009. An introduction to the climate-security subject is given in SCHEFFRAN 2009, 2010. See also BRAUCH et al. 2003, *UN General Assembly* 2009, *WBGU* 2007, BARNETT and ADGER 2007, NORDÅS and GLEDITSCH 2007.

while there are growing indications that warming in Africa could become a significant factor of violent conflicts in the coming decades (Barnett and Adger 2007, Burke et al. 2009). This raises the question in which way climate change affects the sharing of land resources between farmers and herders. Will it lead to more conflict or will it promote cooperative solutions? The paper explores these questions in three steps. First, it gives an overview of the general *conflict vulnerability* and *expected climatic changes* in Northern Africa.[2] Next, one particular country is selected for a discussion of farmer-herder conflicts. Finally, conclusions are drawn from the previous steps to build a *model framework* for analyzing farmer-herder conflicts in Northern Africa in general.

2. Conflict Vulnerability and Climatic Change in Northern Africa

In this research context Northern Africa refers to the eleven African states whose state territory is mainly or entirely located above 15° N (see Tab. 1).[3] This broader definition allows for a more comprehensive view on the conflict vulnerability and climate change impacts on the region.[4] To estimate the basic conflict vulnerability of the region this section takes a brief look at some indicators that have been identified by previous studies (Collier 2000, 2008, Collier et al. 2003, Homer-Dixon 1994, 1999, 1991) to potentially contribute to violent conflict.[5] According to Homer-Dixon's environmental scarcity theory (1994, 1999) environmental change likely leads to violent conflict when it is combined with *population growth* and *unequal resource distribution*. Northern Africa is an economically, politically and socially heterogenic region.

However, the states share a common development: *strong population growth*. The total population of the region is expected to grow from currently 247 million to 322 million in 2025 and 430 million in 2050 (see Tab. 1). Mali and Chad are expected to double and Niger even to almost triple their population by 2050. Sudan is projected to see an increase of 34 million people between now and 2050. For the region as a whole and especially for the states mentioned, it can be stated that the population pressure will increase considerably over the next 40 years. Since no state-based index exists that measures the distribution of land resources, the Gini index is used to assess the wealth distribution within the countries. Most considered states show a *medium level of economic inequality* of around 40 (Tab. 1). Positive exceptions are Egypt and Algeria, while Niger has the highest level of economic inequality.

Unlike Homer-Dixon (1991, 1994, 1999), Collier (2008) does not consider inequality to be a major driver for civil war. He rather stresses the importance of *poverty* as a precondition for violent conflict (Collier 2008). Additionally, he and his associates conclude that states who have experienced violent conflicts before face a significantly higher risk of

2 This should not be misinterpreted as a simplification of the climate-conflict complex but rather be seen as a first basic identification of possible conflict vulnerable regions which already are facing significant climatic changes.

3 Thereby the definition extends the UN definition of Northern Africa by three states (Mauritania, Mali, Niger) usually attributed to Western Africa and Chad, usually attributed to the Central or Middle Africa (*UN* 2000).

4 Based on the UN's definition of vulnerability, we define conflict vulnerability as the measurement of the extent to which a community, structure, service or geographical area is likely to be damaged or disrupted by the impact of violent conflict (*UN* 1997, p. 76).

5 We define violent conflict as a conflict between two or more parties in which at least one party uses violence to achieve its goal. For a typology of violent conflicts over natural resources see Hussein et al. 1999 (p. 401).

Tab. 1 Population, economy, human development and conflicts in Northern Africa (*PRB* 2009, *PRIO* 2009a, b, *UNDP* 2009)

State	Population (in millions)			Gini index[1]	GDP[2] per capita (PPP US$)	HD[3] in 2007	Number of conflicts 1989–2008	Dominant conflict intensity
	2009	2025	2050					
Sudan	42.3	56.7	75.9	N/A	2,086	medium	20	war
Algeria	35.4	43.7	50.5	35.3	7,740	medium	18	minor armed conflicts and war
Chad	10.3	13.9	20.5	39.8	1,477	low	16	minor armed conflicts
Niger	15.3	27.4	58.2	43.9	627	low	8	minor armed conflicts
Egypt	78.6	99.1	122.3	32.1	5,329	medium	6	minor armed conflicts
Mali	13.0	18.6	28.3	39.0	1,083	low	4	minor armed conflicts
Morocco	31.5	36.6	42.4	40.9	4,108	medium	1	minor armed conflicts
Western Sahara	0.5	0.8	0.9	N/A	N/A	N/A	1	minor armed conflicts
Libya	6.3	8.1	9.8	N/A	14,364	high	0	
Mauritania	3.3	4.6	6.9	39.0	1,927	medium	0	
Tunisia	10.4	12.2	13.9	40.8	7,520	medium	0	
Total	246.9	321.7	429.6				74	

[1] average 1991–2007, the Gini index lies between 0 and 100. A value of 0 represents absolute equality and 100 absolute inequality; [2] in 2007; [3] Human Development

violence, especially within the *5 year post-conflict phase* (Collier 2008). Table 1 shows that 8 out of the 11 states considered have experienced armed conflicts in the period between 1989 and 2008.[6] Following PRIO's definition, the vast majority of these armed conflicts were internal and of minor conflict intensity.[7] Only in Algeria and Sudan conflicts were temporarily or mainly classified as war.[8] Most armed conflicts of minor intensity took place in Chad followed by Niger, Egypt and Mali.

The economic situation expressed in per capita income shows a clear north-south distinction. While the northern states are economically stronger, the poorest countries namely Niger, Mali and Chad, are all located in the south of the considered region. The degree of human development mainly mirrors the economic situation, with Libya being the only highly developed nation. Niger is last on the human development ranking which includes 182 states, closely followed by Mali (rank 178) (*UNDP* 2009). After this first evaluation of regional conflict vulnerability, three states seem to be adequate for a more detailed discussion. Mali, Niger and Chad meet the population growth criteria by Homer-Dixon (1991, 1994, 1999) as well as the poverty and previously-violent conflict criteria by Collier (2008). The following

6 PRIO uses the UCDP definition of armed conflict: "a contested incompatibility that concerns government and/or territory where the use of armed force between two parties, of which at least one is the government of a state, results in at least 25 battle-related deaths" (*PRIO* 2009a, p. 1).

7 "Internal armed conflict occurs between the government of a state and one or more internal opposition group(s) without intervention from other states" (*PRIO* 2009a, p. 7). A conflict of minor intensity has between 25 and 999 battle-related deaths in a given year (*PRIO* 2009a, p. 7).

8 To be classified as "war" the number of battle-related deaths in a given year has to reach at least 1000 (*PRIO* 2009a, p. 7).

paragraph will briefly describe the current climatic situation in Northern Africa and discuss the expected changes.

Large parts of Northern Africa are covered by the Sahara desert and shaped by a semi-arid to hyper-arid climate (DePauw 2000, Tucker and Nicholson 1999). The region has an overall low level of soil moisture with strong seasonal variations (see *Japan Aerospace Exploration Agency* 2004). Between 1901 and 2005, the annual precipitation has declined in all states, in the majority by more than 40 % (Bates et al. 2008).[9] The surface temperature in Northern Africa has increased by 1 to 2 °C between 1970 and 2004 (*IPCC* 2007). Projections of precipitation and temperature change for Northern Africa currently lack precision due to insufficient climate data and limited computational and human resources (Boko et al. 2007, Ceccato et al. 2007, Giannini et al. 2008, Stuut et al. 2008). However, most studies suggest a continuation of the current trend of *increasing temperature and decreasing precipitation* (Bigio 2009, Burke et al. 2009, Hulme 2001, Paeth and Thamm 2007, Stige et al. 2006). The IPCC estimates a temperature increase for Northern Africa of 2 to 3 °C until 2100 compared to 1900 (Christensen et al. 2007). Based on data from the Hadley Centre, the German Advisory Council on Global Change expects a significant increase of drought risk, especially for the western part of the considered region (compare *WBGU* 2007, p. 61). UNEP estimates that the boundary between semi-desert and desert has shifted southward by 50 to 200 km since 1930, and it is expected to continue to do so as precipitation declines (*UNEP* 2007).[10] Between 90 million and more than 140 million people in North Africa could suffer from *water stress* in 2055 if the global temperature exceeds 1.8 °C compared to preindustrial levels (Boko et al. 2007).

Even without climate change several countries in North Africa will exceed the limits of their economically usable land-based water resources by 2025 (Bates et al. 2008). While the food consumption in the northern countries of the considered region is currently high and only expected to deteriorate slightly in the future (by about 4.4 % between 2008 and 2018 on average), the states of the Sahel already face *wide-spread food insecurity* which is expected to worsen (*FAO* 2009, Herrero 2006, Shapouri et al. 2009). Cline (2007) roughly estimates the agricultural productivity for Morocco, Algeria, Mali and Sudan to drop by more than 25 % until 2080 (compared to 2003 levels), even if effects of carbon fertilization are incorporated. Niger is estimated to see a decline of agricultural productivity between 15 and 25 % while Egypt could increase its agricultural productivity over the same time period by more than 25 % (Cline 2007).[11] A recent study by the International Food Policy Research Institute calculates that due to climate change the rice production in the Middle East and North Africa could be 30 to 40 % lower in 2050 compared to a situation without climate change, while the production of other crops (wheat, maize and millet) would experience a reduction of less than 10 % or even a slight increase of less than 1 % in the case of sorghum (Nelson et al. 2009, p. 19).[12] In summary, the majority of studies indicate that *climate change will aggravate water stress and scarcity*. That "could generate conflicts over water, particularly in arid and semiarid regions" (Bates et al. 2008, p. 79). Against this background, Mali appears to be particularly appropriate for a climate change related discussion of farmer-herder conflicts.

9 It is noted that for most parts of the Sahara desert data are not sufficient to produce reliable trends (Bates et al. 2008).

10 For a critical discussion of this estimate see Benjaminsen 2008.

11 No estimates were provided for the remaining countries considered here.

12 The study did not consider the use of carbon fertilizers.

3. Farmer-Herder Conflicts in Mali

Mali's population combines diverse lifestyles and ethnicities. The dominant group is the Manding including the Bambara and Malinke who are farmers and together account for about half of the total population. Other groups of mostly settled farmers are the Senoufo (9.7 % of the total population), the Songhai (7 %) and the Soninké (7 %). The nomadic Tuareg and Maur herders (together 5 %) are a minority while the Fulani, a hybrid group of cattle herders and sedentary farmers, are the second largest ethnic group (*Minority Rights Group International* 2007). For centuries the different groups have lived side-by-side in *both supportive and conflictive relationships*.[13] However, over the past decades indications of *intensifying land use conflicts* in Mali have accumulated (Ba 1996, 2008, Beeler 2006, Benjaminsen 2008, Benjaminsen and Ba 2009, Moorhead 1991, Pedersen and Benjaminsen 2008, Turner 1999, 2004). Beeler (2006) reports how Fulani herders increasingly have difficulties to find pasture and access to waterholes in north-west Mali. The local Soninké farmers accuse the herders of letting their livestock consume the millet stalks after the harvest, occasionally leading to the killing of stray animals by the Soninké.[14] This conflict is superposed by conflicts over land and water within groups of farmers and herders (Beeler 2006). Another region of conflict is the inland Niger delta of Mali located in the Sahel (100 to 600 mm of annual rainfall) which stretches roughly south from Timbuktu to Segou along the Niger river (see *Economist Intelligence Unit* 2010, p. 2; *FAO* 1997). While paddy rice is planted in shallow water, burgu grows in deeper water (de Vries et al. 2010, Dingkuhn 1995). Since 1950 the maximum flood levels of the Niger river have decreased overall and especially during the droughts of the 1970s and 1980s (Direction Nationale de l'Hydraulique et de l'Energie, Bamako, in Benjaminsen and Ba 2009). This has led the Songhai farmers to move their rice field continuously into the burgu growing areas (Moorhead 1989). Over the past 50 years about one quarter of the burgu areas in the delta has been converted to rice fields (Kouyaté in Benjaminsen and Ba 2009). Since the Tuareg depend on the burgu to feed their productive livestock during the dry grazing season from December to June, a land use conflict has evolved which occasionally leads to violence between the Tuareg and the Songhai (Benjaminsen 2008).

At the same time the delta has seen a strong population growth of about half a million people between the mid 1960s and the late 1990s (Cotula and Cissé 2006).[15] While recognizing this development, Benjaminsen and Ba (2009) warn against seeing the combination of droughts and the growing population as the main cause for conflict. The authors rather identify a policy driven marginalization and discrimination of herders as well as a general state agenda of agricultural modernization as root causes. However, they state that "the droughts of the 1970s and 1980s played a role in the agricultural encroachment that was driving the conflict" (Benjaminsen and Ba 2009, p. 79). After analyzing the impact of the same droughts on the Tuareg rebellion in Northern Mali between 1990 and 1996, Benjaminsen (2008) draws a similar conclusion. The rebellion was mainly based on dissatisfaction with state policies which economically

13 Tonah speaks of "symbiotic economic relationships" (Tonah 2006, p. 157) between farmer and herders in Ghana, while Moritz even sees agriculture and pastoralism in West Africa as "one integrated production system" (Moritz 2006, p. 8).

14 An overview of the growing and harvesting season as well as of the herder movement can be found in *USAID* 2009 (p. 1).

15 Also see Table 1.

and socially strongly disadvantaged the herders. Only the migration movements of young men to Algeria and Libya "where they were exposed to revolutionary discourses" (Benjaminsen 2008, p. 832) were attributed to the droughts. Baechler (1998) as well as Kahl (2006) put a stronger emphasis on the relationship between land scarcity and the outbreak of the Tuareg rebellion. "Land and water stress is severe in Mali" states Kahl (2006, p. 233) and stresses that the fear of the Tuareg was mainly fuelled by "the biased manner in which the government handled famine relief during the periods of droughts" (Kahl 2006, p. 235).[16]

As we have seen, *farmer-herder conflicts are highly complex* since they are affected by a variety of ethnic, socio-economic and political factors. Climate change already acts as an *additional factor* and will likely continue to do so. How exactly and to what extent is not yet fully understood. To overcome this knowledge gap and to better understand the diverse feedbacks caused by climate change new approaches need to be developed. Moritz (2006, p. 28) urges "to consider more explicitly that individuals are strategic actors who may have to gain from the conflicts". Benjaminsen and Ba (2009, p. 79) also call for "a combination of structural and actor-oriented approaches". The following model framework presents such an approach.

4. Model Framework for Analyzing Farmer-Herder Conflicts in Northern Africa

The previous sections have shown that causal relationships within and between the human and the climate system are complex. To improve the understanding of these relationships it is important to describe them *schematically and actor-centered*.[17] The impact graph in Figure 1 visualizes some of the most important relationships between system variables and key actors.

In the course of climate change precipitation is likely to decrease in Northern Africa while land degradation is expected to increase (see previous section). This development negatively affects the two central resources needed by both farmers and herders: water and land. While only a small portion of water is consumed or used by farmers and herders directly for their own wellbeing, the major amount of water is consumed by plants or animals respectively. The two groups of actors may manage to cope with a certain reduction of available land and water and therefore a reduced yield or livestock production. However, if the loss of production reaches a critical threshold which threatens the minimum calorie intake of one or both groups, the *actors are forced to act*. Then, several options are possible. Theoretically, farmers could switch to a crop and herders to a livestock that needs less water while guaranteeing a similar production level. Since the plants and animals can already be considered to be well adapted to the given resource basis and a shift would require significant investments, this option does not seem to be likely. Another option could be to more effectively use the resources through an increase of labor or through closer cooperation.[18] The already existing exchange of goods such as milk for rice could be intensified or the lifestyles could partly converge.[19]

16 The preferential treatment of farmers over herders by the state government was also identified by Clanet and Ogilvie (2009) as a central cause for conflict between the two groups in the Volta Basin.

17 For an introduction on theories and models of the climate-security link see Scheffran 2010, Scheffran et al. 2010.

18 For example a better use of the livestock's excrement as manure for the fields.

19 Cissé sees the "transformation of nomadic herders into cultivators and the tendency for cultivators to become herder-farmers" Cissé 1981, p. 321) as a result of the droughts in the 1970s and 1980s.

To preserve their original lifestyle, both groups could move to more fertile areas. Especially, herders could use this option as they have a higher level of mobility. However, with an *overall reduction of fertile land* this can become increasingly difficult. The example of Mali shows how a direct movement of farmers into grazing areas and of herders into farming land can lead to conflict. This is especially likely when the movement by one actor is perceived as an aggressive act by the other and when this perception is combined with additional factors such as political and social marginalization (Tuareg in Mali), migration and population growth (see Fig. 1 and Tab. 1).

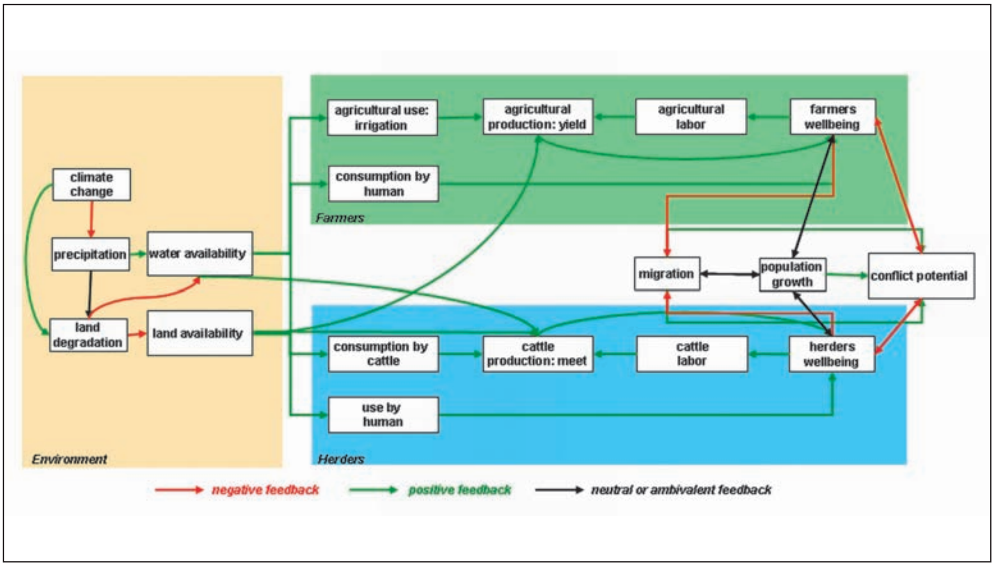

Fig. 1 Schematic overview of the water and land use conflict in Northern Africa

5. Conclusion

Conflicts between herders and farmers over resources are neither a recent phenomenon nor directly caused by climate change. However, climate change will likely *aggravate resource scarcity* in Northern Africa. As seen in Mali, climate change does play a role in conflicts. The extent to which climate change is relevant for conflicts is currently discussed controversially and not yet fully understood. To contribute to the understanding of the linkages between climate change and farmer-herder conflicts, a model framework has been presented. This framework serves as a basis for social network analysis and agent-based modeling, which, combined with qualitative case-studies, further deepens the understanding of the processes driving land use conflicts in Northern Africa.

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How Will the Future Climate of the Southern African Region Might Look Like: Results of a High-Resolution Regional Climate Change Projection

Andreas Haensler, Stefan Hagemann, and Daniela Jacob (Hamburg)

With 5 Figures

Abstract

To estimate the impacts of climate change on the biosphere of the southern African region, high-resolution climate information is needed for both current and future conditions. Therefore, in the framework of the BIOTA South project, the regional climate model (RCM) REMO was applied over the region. A transient climate change simulation was conducted for the time period 1960 to 2100 at 18 km horizontal resolution. In the current study we discuss the projected climate change signal of this high-resolution RCM simulation over the southern African region, thereby focusing on changes in the temperature and rainfall characteristics along the major BIOTA research transect and over the Orange River basin.

Zusammenfassung

Es wird erwartet, dass zukünftige Klimaänderungen einen negativen Einfluss auf die reichhaltige Biodiversität des südlichen Afrikas haben werden. Um die Auswirkungen eventueller Klimaänderungen auf die Biosphäre quantifizieren zu können, sind detaillierte Klimaprognosen erforderlich. Im Rahmen des BIOTA Süd-Projektes wird daher das, am Max-Planck-Institut für Meteorologie entwickelte, regionale Klimamodell REMO über der südafrikanischen Region angewendet. Mit einer horizontalen Auflösung von ca. 18 km wurde eine transiente Klimaänderungssimulation für den Projektionszeitraum 1960–2100 durchgeführt. In der vorliegenden Studie präsentieren wir die von REMO projizierten Klimaänderungen für die südafrikanische Region. Der Fokus liegt hierbei auf prognostizierten Änderungen in den Temperatur- und Niederschlagseigenschaften entlang des BIOTA-Forschungstransekts und für das Orange-Einzugsgebiet.

1. Introduction

The southern African region is known to be a biodiversity hotspot (e.g. Cowling et al. 2003) but future climate change is likely to have a major influence on the state of the region's biodiversity. In the 4th Assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) a severe drying was projected for the southern African region, with a majority of the models used in the report agreeing on this tendency (Christensen et al. 2007). However, this projection was solely based on coarse scale general circulation models (GCMs). For impact studies on a regional to local scale it is essential to have projections of the future climate on a higher horizontal resolution. To quantify the magnitude of future climate change over the southern African region, the Max Planck Institute for Meteorology (MPI-M) applied its regional climate model (RCM) REMO (Jacob 2001) over the region. The work is embedded in the framework of the BIOTA South project (www.biota-africa.org, Krug et al. 2006). The REMO model has already been successfully applied over several other regions of the world (e.g. Europe: Jacob et al. 2007, South America: Silvestri et al. 2009, South Asia: Roy et al. 2008, Saeed et al. 2009). Over tropical and northern Africa REMO already has been applied to assess the future climate and also to estimate the effects of land use changes on the climate (Paeth and Thamm 2007, Paeth et al. 2009).

However, over the southern African region long-term, high-resolution climate change projections are rather sparse. The current REMO projection, which covers a period from 1960 to 2100 at a horizontal resolution of 18 km, is therefore the longest transient climate change projection on such a high resolution ever been conducted over the southern African region. In this paper, the results of this high-resolution climate projection are presented. The focus of the study is on changes in the temperature and the hydrological conditions along the major BIOTA north-south research transect (BNST) and over the Orange River catchment.

2. Simulation Setup

REMO is a three-dimensional, hydrostatic RCM (Jacob 2001). The model is based on the "Europamodell", the former numerical weather prediction model of the German Weather Service (Majewski 1991). As a RCM only covers a limited area of the globe it has to be forced at its boundaries with large-scale meteorological input fields. In the present study we used the output of a regional downscaled 50 km simulation of the ECHAM5/MPIOM GCM (Roeckner et al. 2003, Jungclaus et al. 2006) as boundary fields. The global simulation assumed a greenhouse gas (GHG) emission path following the SRES-A1B (representing an intermediate increase in GHG-emissions) scenario as described by Nakicenovic et al. (2000). Details of the simulation setup can be found in Haensler et al. (2010b). The model domain, excluding the boundary relaxation zone for the 18 km REMO simulation is presented in Figure 1. Further, different sub regions that are considered in the analyses discussed in this paper are indicated.

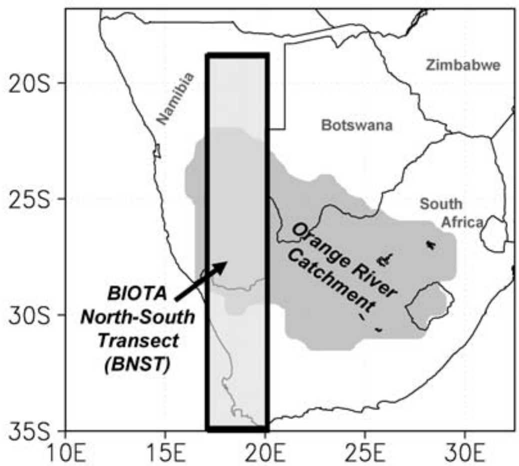

Fig. 1 Domain for the 18 × 18 km REMO simulation (without relaxation zone) as well as the focus analysis regions of the study.

3. Comparison to Observations and Added Value of a RCM

In order to quantify the skill of a RCM in representing the climatological near surface characteristics of a region it has to be validated against observations. In Figure 2, REMO results are compared to observations along BNST for the time period 1961 to 1990. REMO as a climate model is not supposed to identify each single rain event at the correct position. Therefore, the data has to be integrated over a larger area. In the case of BNST, the displayed values represent a zonal mean of 3 degree (see Fig. 1). Generally REMO reproduces the mean temperature and rainfall characteristics along the transect very well. Annual mean temperature is simulated slightly too warm, especially in the dry center, where a warm bias of about 2K is persistent (Fig. 2*A*). Rainfall distribution along BNST, with the very dry center and more humid parts towards the north and south are adequately captured by REMO (Fig. 2*B*).

When comparing the simulated rainfall of REMO to those of the coarse global model ECHAM5/MPIOM, a better representation of the amount of rainfall generated in the winter period (April to October) is obvious (Fig. 2*C*). This improvement can mainly be attributed to the better representation of the orography and surface characteristics in the spatially much

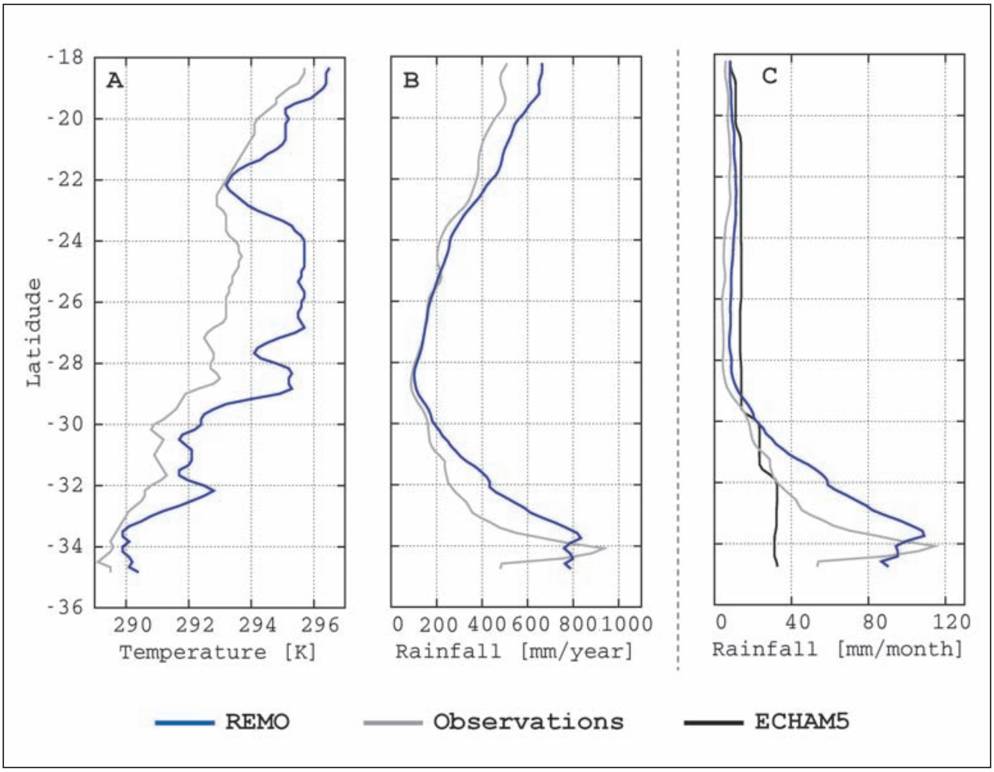

Fig. 2 Simulated and observed mean annual temperature (*A*), annual rainfall (*B*) and mean seasonal winter rainfall (*C*) for the control period (1961 to 1990) as zonal mean over the BIOTA South transect region. The temperature observations are taken from the CRU dataset (New et al. 2002); the GPCC dataset (Schneider et al. 2008) is taken for the precipitation observations.

higher resolved RCM. The added value of a RCM in comparison to the forcing GCMs has already been described by previous studies (e.g. Haensler et al. 2010a, Hagemann et al. 2009). The correct representation of absolute rainfall amounts is especially important, when climate model data are used as input in impact models (e.g. ecosystem models, hydrology models) as it directly influences the results of these studies.

4. Projection of Future Changes over the Southern African Region

For annual mean temperature and precipitation, the REMO projections for the southern African region are depicted in Figure 3. Annual mean temperature (Fig. 3, upper panels) is projected to gradually increase over the whole domain. Especially the interior of the southern African region is supposed to undergo a substantial warming, reaching up to about 6 K at the end of the 21st century. In the regions closer to the ocean, the warming tends to be more moderate with a maximum of about 2.5 K compared to the control period. Annual rainfall is projected to decrease mainly in the western and central parts of the southern African region, whereas around the Drakensberg Mountains in the southeast a slight increase in the projected precipitation is visible (Fig. 3, middle panels). Relative rainfall decrease at the end of the simulation period is in the order of about 50 % compared to the 1961 to 1990 rainfall. The seasonal rainfall distribution (not shown), however, is projected to stay rather constant throughout the time, which indicates that there is no major shift in the circulation patterns. In line with the projected rainfall decrease is an extent of the maximum number of consecutive days without rainfall for the majority of the domain (Fig. 3, lower panels). In connection with a projected increase in rainfall variability (not shown) one can conclude, that future rainfall over the southern African region will be less reliable than the one of the control period.

4.1 Future Changes along BNST

Projected changes along BNST reflect the changes over the whole southern African region. Temperature is projected to rise until the end of the 21st century (Fig. 4*A*). Absolute warming is projected to be strongest in the north, where REMO simulates an increase of more than 6 K over the 140 simulated years. In the southern part of BNST, where a stronger influence of the South Atlantic is visible, the projected warming is more moderate, with a 2 K increase over the simulation period. Annual rainfall is projected to decrease along the whole transect, with a rather uniform relative decrease compared to the 1961 to 1990 base period of about 10 to 20 % towards the middle of the 21st century and of about 40 to 50 % at the end (Fig. 4*B* and *C*). The remarkable drying seems to affect all seasons, as the seasonal rainfall distribution is projected to stay rather constant in the future (Fig. 4*D*). Furthermore, the future water storage in the model's soil layer is shown in Figure 4*E*.

Even the absolute numbers of the simulated soil moisture might not reflect the reality, the changes, however, might imply some important information as it is an integrative variable, combining changes in temperature, rainfall and evaporation. Along BNST, a substantial decrease in soil water content is projected by the model, showing a stronger decrease in the north, where the temperature rise is largest. As available soil moisture affects the latent heat flux and therefore directly influences the energy balance, the indicated strong warming in regions with a strong soil moisture decrease seems to be a rather robust feature in the model.

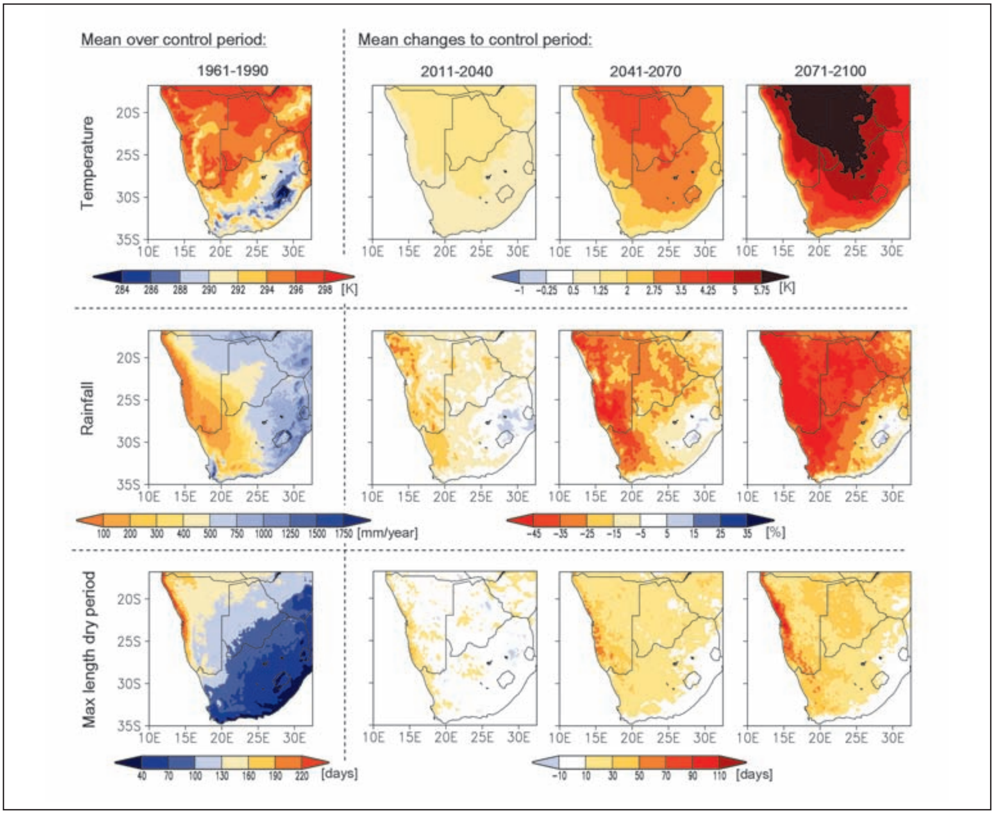

Fig. 3 Climatological mean values for control period (left panels) and three future 30 year period (right panels) for mean annual temperature, annual rainfall, and the maximum numbers of consecutive days without rain in a year.

This feedback mechanism between soil and near surface temperature might also have a severe impact on the habitat distribution of future ecosystems along BNST.

4.2 Projected Changes for the Orange River Catchment

In this section we will focus on the temporal patterns of the projected temperature and precipitation time series over the Orange River catchment. To investigate these patterns, we consider the evolution of the 30-year climatological mean and the respective interannual anomalies for the control as well as for three future periods. For the Orange region the projected temperature changes (Fig. 5*A*) seem to follow a rather linear increase, with a slight amplification towards the end of the century where the warming is supposed to reach up to 5 K. The interannual temperature variation seems to be rather constant throughout the 21st century. For the 2071 to 2100 period a clear linear warming trend is visible in the anomalies, with the first half mainly having cooler than average years and the second half showing warmer than average years. In Figure 5*B* the relative change of the rainfall amounts is shown for the different 30-year periods. Over the Orange a severe rainfall reduction of about 40 % is visible at the end of the 21st century. Interannual rainfall variability sustains rather high over the simulation period.

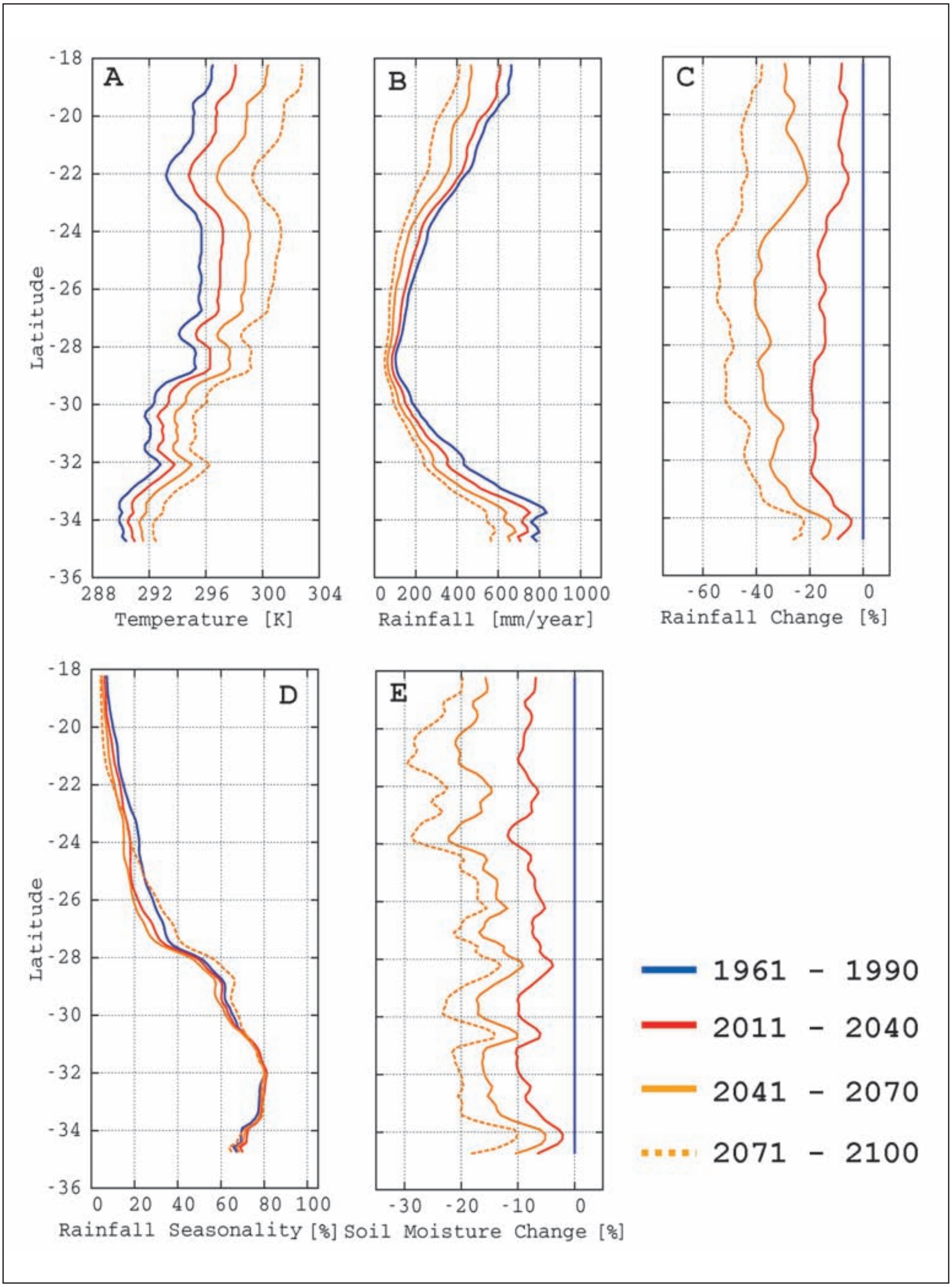

Fig. 4 Projected mean annual temperature (*A*), annual rainfall (*B*), relative change of annual rainfall (*C*), rainfall seasonality indicating the percentage of rainfall falling in the period from April to September (*D*) and relative soil moisture change (*E*) for the control period (1961 to 1990) as well as for three future periods (2011–2040; 2041 to 2070 and 2071–2100) as zonal mean over the BIOTA South transect region.

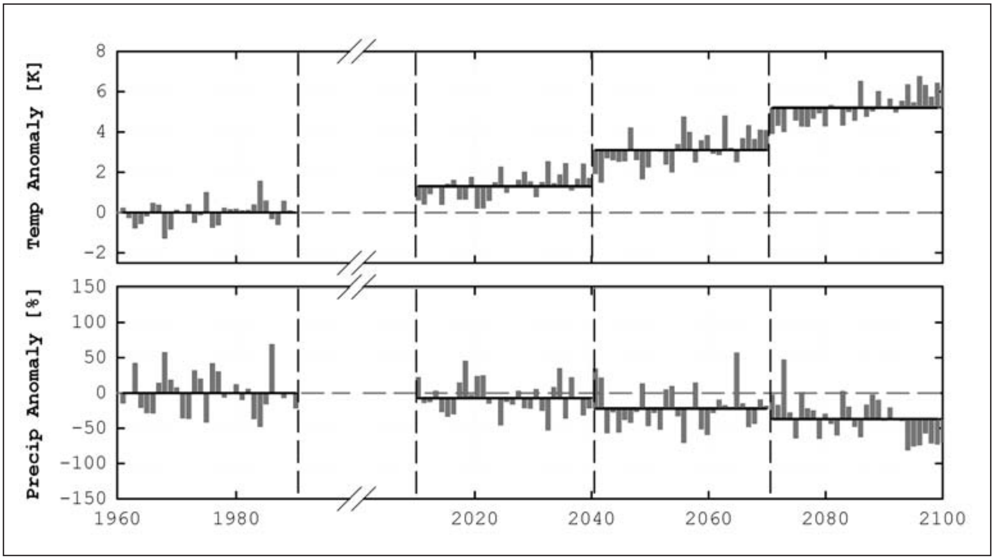

Fig. 5 Simulated temperature and precipitation anomalies and time mean for the control period (1961–1990) and three future 30-year periods as area average over the Orange catchment. The anomalies are calculated with respect to the respective 30-year mean values.

However, despite the remarkable drying in the mean state, the RCM projection shows that until about the year 2080 it is still very likely to observe annual rainfall amounts higher or at least of the same magnitude as the mean rainfall amount of the base period. This feature can mainly be attributed to the large interannual rainfall variability over the Orange River basin. Only during the last 20 years of the simulation, the precipitation mean of the control period is not reached anymore.

5. Discussion and Conclusion

The REMO simulation projects a severe warming and a substantial change in future hydrological conditions over the southern African region. Generally, future water availability is remarkably decreased. The decrease is accompanied by extended dry periods and increased rainfall variability, both having the potential to increase water stress situations in the future. Furthermore, the projected changes would yield a strong impact for the region's biodiversity, as a decrease in water supply strongly affects the state of ecosystems (Midgley and Thuiller 2007).

However, when interpreting the results of the REMO projection one has to keep in mind that the simulation implies a particular degree of uncertainty. The current projection is only one realization of a long-term high-resolution climate change projection for the southern African region. To come up with a more robust assessment of future climate change, ensemble projections based on several simulations should be taken into consideration. Such ensembles of high-resolution climate change projections can be achieved by using different RCMs and downscaling techniques and also by using different boundary fields. Furthermore, it would also be beneficial to consider different GHG emission scenarios to investigate the full range of potential climate change over the region. Nevertheless, due to the immense computational effort only today's high performance computation systems allow for such long simulations on such fine grid spacing. A first step towards the right direction can be the COordinated Regional climate Downscaling EXperiment (CORDEX), which started in the year 2009 and in which the REMO model will also be used for transient climate change projections over the African continent.

Additionally it has to be noted that the presented projections do not include any feedback from future land-use changes or soil degradation processes on the climate. As these processes have the potential to amplify projected changes, they also should be implemented in future simulations. Furthermore, we analyzed projected changes in the near surface wind fields (not shown). For the summer season REMO projects an amplification of the northward flow offshore the Namibian coastline. As the latter is the major driver of the Benguela upwelling system, a change in the wind fields potentially leads to a change of this regional scale ocean circulation feature. Directly connected to changes in the upwelling system would be changes in the region's moisture yield, as the Benguela system drives the generation of the regionally very important moisture input via fog and dew. In the current projection these feedbacks are not included. We therefore might only speculate on the impact of these changes. However, to quantify the importance of these feedbacks, first studies with REMO including these processes are currently performed by the authors.

But even if the presented REMO projection is affected by some uncertainty it has been proven to imply an added value on the representation of regional scale processes and feedbacks compared to the available coarse resolution global climate model data. Consequently, impact studies on a regional or local scale will likely benefit from using data of high-resolution climate change projections.

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Impacts of Global Change on the Hydrological Cycle in West and Northwest Africa

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With 1 Figure

Abstract

The GLOWA-IMPETUS project (2000–2009) assessed the impacts of Global Change on the hydrological cycle of two watersheds in tropical West (the Ouémé catchment in Benin) and subtropical North-West Africa (the Drâa catchment in Morocco) in an interdisciplinary and holistic approach, involving natural, socio-economic, and health sciences. The present contribution puts one strong focus on the methods to obtain high-resolution regional climate change projections that are indispensible for impact studies. All state-of-the-art regionalization methods, such as dynamical downscaling, statistico-dynamical, and statistical approaches, have been used in IMPETUS for the model-based generation of regional scenarios. For Benin, where a relatively good coverage of station data was available over many decades, *we conclude that the application of the bias-corrected regional model, as well as the use of weather generators, was the most suitable approach*. For tropical West and Central Africa as a whole, the IMPETUS regional modeling results suggest *the need to consider projections of land use changes and vegetation degradation in the regional model scenario runs*. In Morocco, the paucity of station data and the relatively low quality of gridded products suggest that the bias-correction and weather generator approach shall be complemented by alternative downscaling methods. In the mountainous region of the High Atlas, the statistico-dynamical approach using circulation weather types is a promising alternative approach. This method, for example, *suggests a somewhat wetter climate for the coming decades south of the High Atlas Mountains – a trend that is contrary to the IPCC global model and the REMO projections*. Using the IMPETUS regional climate change and socio-economic scenarios, two examples of future developments in the water sector in Benin and Morocco are discussed.

Zusammenfassung

Das GLOWA-IMPETUS Projekt (2000–2009) beschäftigte sich in einem interdisziplinären und holistischen Forschungsansatz mit dem Einfluss des Globalen Wandels auf den hydrologischen Zyklus in zwei Flusseinzugsgebieten im tropischen Westafrika (Ouémé-Fluss in Benin) und subtropischen Nordwestafrika (Drâa-Fluss in Marokko). Neben verschiedenen Naturwissenschaften beteiligten sich sozial- und wirtschaftswissenschaftlich geprägte Disziplinen und die Medizin an dem Projekt. Der folgende Beitrag setzt einen Schwerpunkt auf die Methoden zur Erzeugung von regionalen Klimaprojektionen, welche für die Impaktstudien von großer Wichtigkeit sind. In IMPETUS wurden alle derzeit gängigen Methoden, wie dynamische und statistisch-dynamische Regionalisierung und statistische Methoden, z. B. zur Korrektur eines Modellfehlers, angewandt. Für Benin, wo vergleichsweise viele langjährige Beobachtungszeitreihen zur Verfügung standen, wird geschlussfolgert, dass die statistische Korrektur des projizier-

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ten Modellklimas und der Einsatz eines Wettergenerators zur Erzeugung zeitlich hochaufgelöster, virtueller Stationsdaten der angemessenste Ansatz war. Für das tropische West- und Zentralafrika legen die IMPETUS-Resultate weiterhin nahe, dass belastbare Klimaprojektionen die anthropogene Veränderung der Landnutzung und Vegetation im Klimamodell berücksichtigten müssen. In Marokko veranlasste die geringe Anzahl der im Projektgebiet zur Verfügung stehenden Klimadaten und die relativ geringe Qualität von frei zugänglichen Gitterpunktsdaten die zusätzliche Anwendung eines auf Wetterlagen basierenden statistisch-dynamischen Ansatzes. Dieser Ansatz zeigte das interessante Ergebnis, dass im Gegensatz zu den IPCC- und REMO-Klimaprojektionen, ein etwas feuchteres Klima in der trockenen Region südlich des Atlashauptkammes in den nächsten Dekaden möglich sein kann. Zwei zukünftige Entwicklungen im Wassersektor in Benin und Marokko, die mit Hilfe der IMPETUS-Klimaprojektionen und sozio-ökonomischen Szenarien als Rahmenbedingung erstellt wurden, werden diskutiert.

1. Introduction

Tropical West Africa is known for its variable rainfall climate, often exceeding the rainfall fluctuations of many other places on earth. The most recent drought in West Africa commenced in the early 1970s and peaked in the mid-1980s. In recent years, rainfall recovered, though it remained below the values of the wet 1950s. Another aspect of environmental change in West Africa is land degradation. In the countries along the Guinea Coast land degradation often manifests itself in deforestation. Here, the conversion of forests into farmland and for settlements, charcoal production, and logging activities are the major causes of deforestation. In the Sahel, overgrazing and periodic droughts reduce the vegetation cover, thereby increasing soil erosion by water and wind. This second land degradation process is often called desertification. In terms of demographic development, West Africa presently belongs to the regions with the highest population growth worldwide, exceeding 3 % p. a. in several countries. It is expected that this development will be associated with the highest rate of urban growth in the world for the next decades.

Like West Africa, Northwest Africa has experienced large natural fluctuations in precipitation. The region north of the Atlas Mountains has exhibited a decadal precipitation decline commencing in the 1970s. The extensive irrigation-fed cash crop cultivation, overstocking of herds, and the large year-to-year variability of precipitation aggravates the already existing scarcity of natural resources. Overgrazing, as a consequence of the overstocking of sheep and goat herds, reduces the vegetation cover as well as the forest area in the Atlas Mountains. This in turn enhances soil erosion after heavy rainfall events. Deforestation in the Maghrebian countries of Morocco, Algeria, and Tunisia has already occurred during historical times. Presently, the forest area is increasing due to afforestation programs. Another important process of land degradation in the Maghreb is the salinization of soils as a consequence of intensive irrigation. In contrast to the West African region, the population growth in the Maghreb is only moderate, i.e., 1.5 % p.a.

The above-mentioned processes are part of the so-called Global Change, are interdependent and interrelated, and they interact in complex ways, with the consequence that interdisciplinary studies are necessary to find answers for Global Change-related problems. The IMPETUS project pursued the necessary interdisciplinary and integrated approach which is briefly introduced in the next section. In Section 3, the observed and projected climate change is described. This section puts a strong focus on the methods to obtain high-resolution regional climate change projections that are indispensible for impact studies. Section 4 provides two examples of future developments in the water sector, and Section 5 gives a short summary.

2. The IMPETUS Approach

In order to mitigate and adapt to the impacts of Global Change on fresh water and food supply, an interdisciplinary and holistic approach is needed, involving natural, socio-economic, and health sciences. For West and Northwest Africa, the initiative IMPETUS ('An integrated approach to the efficient management of scarce water resources in West Africa', www.impetus.uni-koeln.de) followed such an integrated approach for two representative river catchments. The wadi Drâa in south-eastern Morocco and the Ouémé river in Benin have been chosen for a feasible basin size (< 100,000 km^2), availability of some pre-existing data sets, politically stable conditions, relevance, and representativeness. The Drâa catchment in the southeast of Morocco is typical of a gradient from semi-arid subtropical mountains to their arid foothills; the Ouémé basin in Benin is characteristic of a wet to dry sub-humid climate of the outer tropics.

Food security and sustainable water management in the watersheds of the Drâa and the Ouémé require reliable data and projections for regional planning and political decision making. A comprehensive diagnosis of the water cycle and agricultural practices were carried out during the first project phase (2000–2003). In the second phase (2003–2006), qualitative and quantitative models were adapted or newly developed for both regions. Projections of future developments were derived from scenario calculations, process understanding, and from expert knowledge. In the third project phase (2006–2009), Spatial Decision Support and Information Systems (SDDS/IS), as well as Monitoring Tools (MT) have been developed. In a supplementary phase (2009–2011), the tools are implemented and operationalized in the partner institutions by a thorough capacity development.

3. Observed and Projected Regional Climate Changes

According to the IPCC AR4, regional climate change projections should ideally be based upon information from four potential sources (Christensen et al. 2007):

- Global climate model simulations;
- Downscaling of simulated data from these global models using techniques to enhance regional details;
- Physical understanding of the processes governing regional responses; and
- Recent historical climate change.

All suggested pathways have been pursued within IMPETUS the Drâa and the Ouémé catchments and are discussed below.

3.1 West Africa

The Sahel experienced a multi-decadal wet episode between 1930 and the mid-1960s. A multi-decadal dry episode commenced around 1970 with notable drought periods in the early 1970s and early to mid-1980s. In the west and central Sahelian zones, the period after 1990 is characterized by a return to near-normal rainfall conditions (Fink et al. 2010). Even though year-to-year rainfall variability is higher at the wetter Guinea Coast, it is evident that sequences of dry years dominated the first half of the past century and have prevailed since the 1970s (Fink et al. 2010).

For the sake of brevity, the present contribution highlights findings with respect to downscaling of simulated data from global climate models using techniques to enhance regional details. The full description of regional climate change scenario building within IMPETUS can be found in Christoph et al. (2010). The regional model REMO has been integrated from 1960 to 2050. From 2001 to 2050, a total of six realizations according to IPCC SRES scenarios A1B and B1 have been performed taking into account a "strong" and a "somewhat weaker" land use change scenario, respectively. At the time of writing, no regional climate change projection for Africa considered this anthropogenic impact. As described in Paeth et al. (2009), *a substantial and significant drying trend until 2050 can be observed in the rainforest and savannah regions, the latter area also exhibiting the largest positive temperature trend*. With respect to precipitation, the trend is largely due to the land degradation. Though plausible due to reduced continental "water recycling", the drying and warming trends and patterns in tropical West Africa are in part contradictory to the IPCC 4AR projections that were based on coarse global models. The REMO results have been widely used in the IMPETUS climate impact modeling.

All climate models are subject to systematic errors. These arise from limited resolution, uncertain physical parameterizations, neglected feedbacks, and unknown processes (Xu 1999). While systematic errors may be less troublesome for the analysis of climate trends, they are strictly problematic when climate model data are used as quantitative inputs for impact studies. Because of these limitations, a two-step post-processing of the simulated precipitation data from REMO has been undertaken prior to using the data for impact studies in IMPETUS. A Model Output Statistics (MOS) correction has been developed and is detailed in Paeth (2010) that statistically corrects model biases at the model grid point scale. In order to transform the MOS-corrected regional-mean precipitation from REMO to a local pattern of rain events, a WEGE (weather generator) has been developed in the IMPETUS project (Paeth and Diederich, submitted to Clim. Dyn.). This weather generator is centered over Benin according to the focus of the hydrological models. The WEGE produces virtual station data, matching daily rainfall station observations. The resulting 'virtual' station data set is finally adjusted to the statistical characteristics of the observed daily precipitation by so-called probability matching (Helmer and Ruefenacht 2005). The final data set maintains the larger-scale climate signals from REMO, and it agrees with the typical spatial and temporal distribution of the observed rain events in Benin. An application in hydrology will be shown below.

3.2 Northwest Africa

In Northwest Africa, Knippertz et al. (2003) found three homogeneous rainfall regions with respect to annual precipitation variability. These are the northern and western parts of Morocco, the 'Atlantic region' (ATL), north-eastern Morocco and north-western Algeria close to the Mediterranean coast, the 'Mediterranean region' (MED), and the Moroccan and Algerian stations south of the Atlas mountains called the 'South of the Atlas region' (SOA). In the MED region, below average rainfall has prevailed since the late 1970s (Born et al. 2010), whereas in the ATL region precipitation is low from the late 1970s to the early 1990s, but with some wet years during the late 1990s and after 2000. In the SOA region, precipitation has most recently been above average around the 1990s and remained close to the long-term average since then (Born et al. 2010). A significant warming trend in the annual averaged temperature in the Maghreb has been detected since the middle of the 20th century. As a consequence, a general tendency toward drier and warmer climates in all regions of the Maghreb has been found (Born et al. 2008b). This in particular has led to an upward movement of the snow-line in the high mountain areas.

For the heterogeneous climate region of the High Atlas Mountains in Morocco, the dynamically downscaled data from REMO have been used in a similar "weather generator approach" to create daily time series of rainfall, temperature, moisture, radiation, and wind for the near-surface layer. The most important parameters to be transformed are rainfall rates and temperatures. An additional issue for the practical application of climatic data is the reduction of the amount of data. For this purpose, the Drâa region was divided into a small number of zones either by similar climatic characteristics or as sub-catchments of the Drâa and its tributary rivers. Although relatively easy to determine, the most important predictors for small-scale variability are topographic characteristics like surface elevation and land use data. In the statistical downscaling approach used here, they have been aggregated on a 1-km grid. Details are described in Christoph et al. (2010). *Two pertinent results are an increased return period of extreme dry years* (see Born et al. 2008a) *and, despite the overall drying trend, an augmented risk of extreme daily rainfall in the High Atlas Mountains*. An application in hydrology will be shown in the next section. Aside from the dynamical and subsequent purely statistical approach, IMPETUS has also performed a statistico-dynamical regionalization using weather classification. The results shown in Piecha (2010) are interesting since they show a tendency towards a wetter climate south of the Atlas divide. Such a development is plausible if the intensity and number of tropical-extratropical rainfall events only slightly increases.

4. Two Example Applications in Hydrology

The scenario analysis for the Ouémé catchment and its sub-catchment has shown that climate change, as well as land use change, will have a strong impact on hydrology and soil erosion in the region. While the expansion of croplands leads to an increase of surface runoff, total water yield, and soil erosion in the land use scenarios, the climate scenarios cause a contrasting trend. In the combined land use and climate scenarios simulated with the SWAT (Soil Water Assessment Tool) erosion model, the soil erosion increases, which shows the high impact of land use change. However, the variability of soil erosion within the Upper Ouémé catchment is large. Based on the increase in temperature and the decreasing annual precipitation simulated by REMO, the renewable freshwater resources, as simulated by Universal Hydrological Program (see Giertz 2008), in the Ouémé catchment will decline by more than one third until the mid 21st century (Fig. 1*A*). Especially in the dry season, the unmet freshwater demand, as determined using WEAP (Water Evaluation and Planning System), will therefore significantly increase (Fig. 1*B*). With the WEAP water management model, it was possible to identify future problems of water supply in the Ouémé catchment by linking water availability with water demand. For the simulated climate scenarios, users relying on surface water from rivers and reservoirs, especially, will experience shortages in the future, while the available amount of groundwater is potentially high enough to satisfy the demand. Here the problems of poor access to the available groundwater must be kept in mind.

Interdisciplinary studies on the influence of water use on groundwater and soil resources in the Middle Draa valley led to a model-based system analysis and the development of the

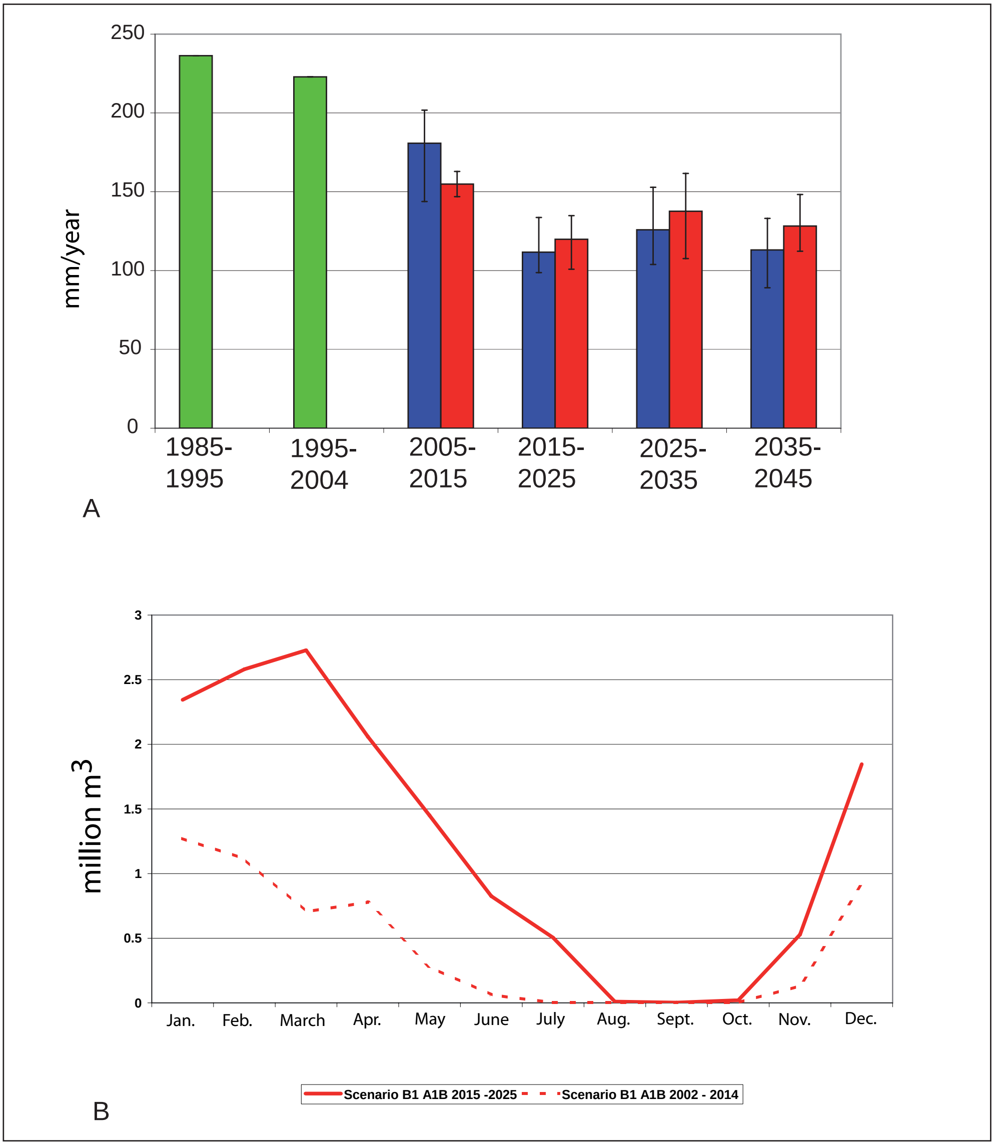

Fig. 1 (*A*) Renewable Water Resources (Rainfall – Evaporation + Surface and groundwater runoff out of the catchment) in mm/year for the Ouémé catchment Benin. Green: observations: blue (red): A1B (B1) IPCC climate scenarios regionalized by REMO; Error bars: REMO ensemble spread (Figure courtesy of Giertz and Diekkrüger). (*B*) Unmet freshwater demand in million m³ according to climate scenario IPCC A1B and IMPETUS B1 socio-economic scenario (for details regarding IMPETUS socio-economic scenarios the reader is referred to Speth et al. 2010, Figure courtesy of Höllermann and Diekkrüger).

IWEGS spatial decision support system (Klose et al. 2010). Scenario analyses of climatic and socio-economic changes reveal significant impacts on groundwater availability and soil salinity. The projected climate change described in Section *3.2* will lead to enhanced water scarcity and soil degradation. Even more, changes in water use strategies will influence the resources. Thus, adapted measures can mitigate drought effects. Because water saving measures such as drip irrigation can be neutralized by salinization effects, integrated research is the most promising base for resource management.

5. Concluding Remarks

All state-of-the-art regionalization methods, such as dynamical downscaling, statistico-dynamical, and statistical approaches, have been used in IMPETUS for the model-based generation of regional scenarios. For Benin, where a relatively good coverage of station data was available over many decades, *we conclude that the application of the bias-corrected regional model, as well as the use of weather generators, was the most suitable approach*. Moreover, the IMPETUS regional modeling results suggest *the consideration of the projections of land use changes and vegetation degradation in the regional model scenario runs for tropical West and Central Africa*. Another important factor possibly governing climate change and variability in West Africa are mineral and biomass-burning aerosols. The land use change and/or aerosol effect will be considered in regional climate models in the coming years.

In Morocco, the paucity of station data and the relatively low quality of gridded products (e.g., CRU data) suggest that the bias-correction and weather generator approach shall be complemented by alternative downscaling methods. In the mountainous region of the High Atlas, the statistico-dynamical approach using circulation weather types is a promising alternative approach. This method, for example, *suggests a somewhat wetter climate for the coming decades south of the High Atlas Mountains – a trend that is contrary to the IPCC global model and the REMO projections.* However, such a scenario was deemed to be plausible due to the strong contribution of tropical-extratropical interactions to the annual rainfall on the Saharan flank of the Atlas Mountains.

In Speth et al. (2010), many examples of the use of the IMPETUS climate change scenarios in impact studies ranging from hydrology to health are described in detail. The IMPETUS project has used the state-of-the-art methodologies to link climate models with impact models. One constraint has been the strong dependence of the impact assessments on a single regional climate model. Recently, Paeth et al. (submitted to Atmos. Sci. Lett.) showed that several regional models (without considering land use changes) yield quite variable precipitation trends. Thus, a high degree of uncertainty in precipitation trends in West Africa will remain. Consequently, both more basic research efforts are necessary to reduce the uncertainty in climate projection and impact models, and more interdisciplinary research to advance our understanding of the geophysical and human driving forces and their interactions.

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Climate Change Adaptation in Africa and Asia: Challenges Ahead and Action Needed

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With 1 Figure and 1 Table

Abstract

It is widely acknowledged that climate change poses a serious problem in attempts to pursue the goal of poverty eradication and achievement of the Millennium Development Goals. As a result of this state of affairs, the search for practical, workable and cost-efficient solutions to climate change adaptation are now a world priority and one which links government and non-government organizations as well as development agencies in a way not seen before. But even though adaptation to climate change is a matter of great scientific relevance and of broad general interest, there are some problems related to its implementation. This paper outlines some of the problems inherent to the implementation and management of climate change adaptation projects. By means of a survey involving a sample of adaptation projects currently being undertaken in Africa and Asia, the paper outlines the problems and the frequency with which they occur as well as their roots and ramifications. The paper also lists a number of measures and instruments, which may be employed with a view to ensuring that climate change adaptation efforts may be integrated into mainstream socio-economic development and environmental protection efforts.

Zusammenfassung

Es ist weitgehend anerkannt, dass der Klimawandel ein gravierendes Problem im Hinblick auf die Beseitigung der Armut und das Erreichen der UNO-Millenniumsentwicklungsziele darstellt. Als Folge dieser Situation hat die Suche nach praxisnahen, tragfähigen und kosteneffizienten Lösungen für die Anpassung an Klimaveränderungen mittlerweile weltweite Priorität, wodurch Regierungs- und Nichtregierungsorganisationen sowie Entwicklungsagenturen auf bislang unerreichte Weise miteinander vernetzt sind. Auch wenn die Anpassung an den Klimawandel ein Anliegen von großer wissenschaftlicher Relevanz und breitem allgemeinen Interesse ist, gibt es mit ihrer Umsetzung zahlreiche Probleme. Der vorliegende Artikel beschreibt einige der Probleme, die mit der Realisierung und Umsetzung der Klimaanpassungsprojekte zusammenhängen. Anhand einer Untersuchung, die eine Auswahl von derzeit in Afrika und Asien durchgeführten Anpassungsprojekten umfasst, umreißt der Artikel die Probleme und die Häufigkeit, in der sie auftreten, sowie ihre Ursachen und Auswirkungen. Aufgeführt ist auch eine Reihe von Maßnahmen und Instrumenten, die mit dem Ziel eingesetzt werden können, Anstrengungen zur Anpassung an den Klimawandel in die generelle sozioökonomische Entwicklung und in Umweltschutzbemühungen einzubinden.

1. Introduction

It is widely acknowledged that climate change poses a serious problem in attempts to pursue the goal of poverty eradication and achievement of the Millennium Development Goals. As a result of this state of affairs, the search for practical, workable and cost-efficient solutions to climate change adaptation is now a world priority and one which links government and non-government organizations as well as development agencies in a way not seen before. All countries in the world are currently searching for mechanisms that allow them to cope, fight and to some extent reverse the adverse impacts produced by climate change. In many countries, there are on-going efforts towards implementing adaptation[1] and mitigation[2] measures in order to minimize or at least reduce the negative effects of climate change.[3]

Due to the pressing need to solve the current and immediate problems deriving from climate change, a special emphasis is currently being given to adaptation, which is meant to reduce the vulnerability and improve the adaptive capacity (also called resilience) of people and communities who rely on climate-dependent resources for their livelihoods. This is not to say that adaptation is more important than mitigation. They are both equally important. However, since some of the consequences of climate change cannot be avoided, adaptation or the ability to cope with current climate change impacts is by its own right a matter of concern here and now. This is so for the following reasons:

– climate change is known in some contexts to have implications for river discharges and may be responsible for changes in the magnitude, extent and depth of floods;
– land losses through beach erosion due to sea level rise may put pressure on coastal communities;
– changes in climate and water cycles have the potential to negatively interfere with industrial and non-industrial agricultural production;
– some plant and animal species with specific biological characteristics may not adapt to increases in temperatures or CO_2 concentrations.

The above elements serve as examples of the fact that measures targeted to climate change adaptation are meant to serve the short and medium-term needs of various groups and hence cater for the search for prompt solutions for acute problems.

2. Trends on Climate Change Adaptation in Africa and Asia

It is worthy at the outset of this section mentioning that in both African and Asian countries, geogaphical regions, economic sectors and social groups differ in their degree of vulnerability to climate change and in terms of their ability to adapt.

Asia and Africa are two distinct regions, with different climatic, geographical and geopolitical settings, also characterized by some common as well as unique features. Among the common features is the fact that Africa and Asia (and not Africa alone which is often regarded as being especially vulnerable to climate change due to the lack of economic, development and institutional capacity) are hosts of some of the poorest countries in the world. This includes many nations which not only have lower GDPs (e.g. Bangladesh, Sri Lanka, Indonesia, as well as Chad, Ethiopia, Mozambique) but which have neither the technology nor the financial resources to fully engage in adaptation programs. In addition, most coun-

1 The Intergovernmental Panel on Climate Change (*IPCC* 2007) defines adaptation as the “adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities”.
2 Mitigation is understood as the prevention of carbon emissions promoting the reduction of greenhouse gas emission, efficient use of energy and other resources or politics that norm the ground usage promoting sustainability.
3 “Climate Change” means a change of climate conditions, which is attributed directly or indirectly to human activity and alters the composition of the global atmosphere and which occurs in addition to natural climate variability observed over comparable time periods.

tries in Africa and Asia provide little contribution to the global levels of CO_2 emissions a fact which – despite some well known exceptions such as China or India – places them in the plus side of any greenhouse gases index.

As to their unique features, the following can be seen:

– many nations in Africa (and not only those in the Sahelian region) are often victims of draughts, whereas in Asia floods are a more common problem;
– soil erosion in Africa takes place at far greater speeds than in Asia;
– Asian countries, especially the low-lying ones, are more vulnerable to floods than most African countries do;
– because of limited irrigation potential, Africa's agriculture is more vulnerable to extreme climate variation trends than in Asia, which may reflect in declines of long-cycle crops.

There have been many studies trying to understand the impact of climate change as a whole and adaptation in particular, in Africa and in Asia. For example, Mehrotra (1999) examined the the regional effects of climate change on various components of the hydrological cycle, namely surface run-off, soil moisture, and evapotranspiration for three-drainage basis of central India, whereas Jacobs (1996) analyzed measures to adjust to climate change in the Lower Mekong. An appraisal of agricultural vulnerability and adaptation in the Asia-Pacific Region was performed by Luo and Lin (1999), while Iglesias et al. (1996) performed a review of the vulnerability and adaptation of crop production in the continent. This was complemented by works from Cross and Hyams (1996), who specifically investigated the potential effect of global warming on the distribution of *Phlebotomus papatasi* in the southwestern part of the region. Ramakrishnan (1998) also looked at the links between sustainability, climate change and Asian tropical rain forest landscapes.

In terms of Africa, Hulme et al. (1995) illustrated the complexity of adaptation measures in the region, where climate variability can be manifest regionally as severe droughts on yearly time-scales or as more prolonged desiccation over one or more decades. Chidumayo (2005) assessed the effects of climate on the growth of exotic and indigenous trees in central Zambia, while Githeko and Ndegwa (2001) made predictions for malaria epidemics in the Kenyan Highlands using climate data.

In addition, there is a plethora of methodologies which have evaluated the incidence of climate change adaptation, both from an economic and a technological perspective, in individual countries. This includes research undertaken by Mirza et al. (2003) on the implications of climate change on floods of the Ganges, Brahmaputra and Meghna Rivers in Bangladesh, as well as a study by Murdiyarso (2000) on adaptation to climatic variability and change as it related to Asian agriculture and food security. Sharma et al. (2000) looked at the sensitivity of the Himalayan Hydrology to land-use and climatic changes, whereas Ososkova et al. (2000) considered adaptation measures to water resources for climate change. Lovett et al. (2005) looked at the links between climate change and ecology in Africa, while Magadza (2000) assessed the climate change impacts and human settlements in Africa under an adaptation perspective.

In both regions, climate change may be expected to exacerbate some trends such as the occurrence and intensity of future disease outbreaks (e.g. malaria) and – thanks to changes in temperatures – may increase the likelihood of certain diseases becoming wider spread in some areas where they were not previously recorded.

Despite the various individual studies performed in each region, a significant research gap still exists in relation to the fact that few studies to date have tried to holistically look at climate change adaptation in Africa and Asia. Therefore, this paper not only fulfills a research gap, but is also useful in the sense that it allows a critical overview of the situation in both geographical regions.

3. Some Current Adaptation Projects

For the purposes of the research presented in this paper, a survey involving a sample of adaptation projects currently being undertaken in Africa and Asia was performed. The rationale behind the study was the pressing need to establish which problems prevent the full development of adaptation strategies, the frequency with which they occur as well as their roots and ramifications. The projects were chosen based on three criteria:

- their focus on adaptation;
- the replicability of their methods and
- the wide use of their results.

Project 1 is the *Climate Change Knowledge Network* (CCKN), a project on the impacts of economic changes and climate change on India's agricultural sector. The project was pursued jointly by the International Institute for Sustainable Development (IISD), the Centre for International Climate and Environmental Research (CICERO) and the Tata Energy Research Institute (TERI). The scheme is innovative in that sense that it uses the concept of "double exposure". This refers to the fact that climate change and globalization are occurring simultaneously, and that regions, sectors, ecosystems, and social groups are often confronted by the impacts of both processes. The development of a program on vulnerability and adaptation has been included among the long-term policy research and capacity-building activities in the network's work plan.

Project 2 is the initiative *Climate Change Adaptation in Africa* (CCAA), led by the International Development Research Centre (IDRC). It aims to improve the pro-poor adaptive capacity of African societies so that the poor across Africa are resilient to climate volatility and change. Four objectives are at the core of the CCAA project, this being to strengthen the capacity of African scientists, organizations, decision-makers and others to contribute to adaptation to climate change; to support adaptation by rural and urban people, particularly the most vulnerable, through action research; to generate a better shared understanding of the findings of scientists and research institutes on climate variability and change and to inform policy processes with good quality science-based knowledge.

Project 3 is the scheme *Global Climate Change Project for Africa* funded by the Biodiversity Support Program (BSP), which aims to identify the extent to which Africa contributes to global climate change and assess Africa's capacity to adapt to global climate change.

Project 4 is the *Climate Change Capacity Project* (C3D+) funded by the European Union's AIDICO program. The C3D+ Initiative involves 6 training centers covering around 30 countries (also in Africa and Asia) which will benefit from a training program on climate change related issues. The C3D+ project strives to deliver targeted training and capacity development at the national and regional levels with the following strategic objectives:

- An improved participation of developing countries in the UNFCCC process;
- A timely implementation of the UNFCCC and Kyoto Protocol by developing countries.

The core beneficiary project partners for capacity development are the following institutions:

- CCCCC (Caribbean Climate Change Community Centre), Belize;
- CSAG (Climate System Analysis Group at UCT Cape Town);
- ENDA – TM (Dakar), Senegal;
- ERC (Energy and Research Center at UCT Cape Town);
- SPREP (South Pacific Regional Environment Programme), Samoa;
- MIND, the Munasinghe Institute, in Colombo (Sri Lanka);
- CIFOR-TroFCCA (Africa-Asia Regional);
- IISD, International Institute for Sustainable Development (Geneva-Ottawa); and
- SEI, the Stockholm Environment Institute (Oxford, UK).

Finally, it also aims to promote a better co-ordination and integration of national climate policies with sustainable development policies.

In Asia, Project 5, titled *Promoting Climate Change Adaptation in Asia and the Pacific*, is financed by the Japan Special Fund and the Government of the United Kingdom. The scheme is aimed at helping to address the need to mainstream adaptation issues into investment planning, the need to develop a national capacity for adaptation, and the need to coordinate and strengthen international community responses for adaptation.

Also in Asia, Project 6, titled *Tropical Forests and Climate Change Adaptation* (TroFCCA) is a four year project of the Center for International Forestry Research (CIFOR) and the Tropical Agriculture Center for Research and Higher Education (CATIE) to contribute to the understanding of adaptation to climate change within tropical forest ecosystems. The project expects to, through the development of specific methods, assess vulnerability, and contribute to mainstreaming adaptation to climate change in development projects. The project is also complementing activities already taking place in the countries in which it will be implemented, and for this reason, working relationships with national governments have been established.

Finally, project 7, titled *Climate Change Adaptation Programme in Central Asia* is undertaken by the UN Development Program (UNDP). Its aim is to support integrated and comprehensive approaches to climate change adaptation in Central Asia and to assist the countries of Central Asia in adjusting their national development processes to address climate change risks. The scheme will address the main policy, institutional capacity and financial barriers to systematic adaptation in Central Asia with particular focus on water, land and food production systems.

The projects here described are illustrative of the range of adaptation initiatives taking place in Africa and Asia today. There are many more in specific areas such as agriculture (Ziervogel et al. 2008). But despite the relevance and usefulness of the adaptation measures adopted in each project, there are some problems related to their implementation. A number of them are outlined in Table 1. Whereas money is an issue of importance and costs of adaptation measures are certainly crucial elements of the debate (*International Institute for Environment and Development* 2009), financial considerations are not the only elements that need to be taken into account.

The problems outlined in Table 1 represent some of the most common barriers seen and by addressing them, it becomes easier to put the principles of climate change adaptation into practice. It however has to be said that, even though most African and Asian countries have a low adaptive capacity due to their fragile ecological base, high levels of poverty, unsystematic land use and models of development based on the exploitation of their ecological basis, they can work against this trend.

Tab. 1 Some problems related to the implementation of adaptation measures in projects

Problem	Implications
Unreliable costs of adaptation measures	Costs often prevent measures from being implemented. The UNFCCC has estimated annual global costs of adapting to climate change to be US$40–170 billion.
Lack of emphasis on gender issues	Participation of female in adaptation projects is reduced.
Lack of adequate infra-structure	Many adaptation measures require infra-structure not readily available.
Lack of training	Lack of trained personnel makes it difficult to implement certain adaptation measures.
Sectoral elements not always considered	Whereas adaptation is a general term, it needs to be contextualized in sectors such as agriculture, water sector, fisheries, etc.
Lack of a scientific basis	Many adaptation responses are not basic on scientific information and may lead to weak or doubtful outputs.
Limited emphasis to local knowledge	Many adaptation measures do not take into account local knowledge and are hence not fully successful.
Lack of sustainability	The majority of adaptation measures and projects are short (e.g. a few years) and not sustained after a given period.

Some of the lessons learned from the examined projects are:

– many communities have managed to identify and adopt different types of coping strategies, which vary from changes in crop seasons, to modifications in the way they build homes;
– seasonal food production has in many areas been successfully modified so as to adapt them to changes in climatic conditions;
– new, alternative crops which may be more resistant to dry periods may offer attractive alternatives – or complements – to crops currently used;
– improvements in rainwater harvesting have been helping many communities to better cope with dry periods.

In addition, it is noticeable that inherent uncertainties in climate modeling efforts have not stopped action on the ground. On the other hand, it is important that capacity to handle climate change adaptation draws on the best available scientific information and that appropriate information be used in support of adaptation efforts.

4. Conclusions: The Way Forward

Despite the inherent problems related to implementing climate change adaptation program in Africa and Asia, there are various measures and instruments, which may be employed with a view to ensuring that climate change adaptation schemes are integrated into mainstream socio-economic development and environmental protection efforts. Some of these measures, which can be implemented in the short and medium-term are:

- Establishing a clearinghouse for information related to the implementation of the UNFCCC and the Kyoto Protocol related information on adaptation, focusing on issues specific to Africa and Asia;
- Taking more advantage of techniques such as blended and e-learning, to "train trainers" – who will work with local communities on the ground and promote knowledge related to adaptation measures and adaptation projects on the one hand, but also on abatement projects and on the other hand, for capacity-building in these regions;
- Disseminating more information on appropriate and successful adaptation measures (e.g. crop rotation, rainwater harvesting), so that they may become more popular;
- Developing and implementing regionally focused strategies towards climate change adaptation, with the active engagement of local stakeholders and bearing in mind the different contexts.

In addition, more communication and interaction between projects is deemed as very helpful. In this context, the International Climate Change Information Program (ICCIP), a scheme coordinated by the Hamburg University of Applied Sciences in cooperation with the UN Environmental Program (UNEP), the Global Environment Facility (GEF) and the German Agency for Technical Cooperation (GTZ) among others, has created a projects' database, where a number of climate change adaptation projects are presented. Figure 1 gives a screenshot of ICCIP's web site.

In addition to ICCIP's efforts, the Secretariat of the UN Framework Convention on Climate Change (UNFCC) has created a tool for local coping strategies, with initiatives gathered

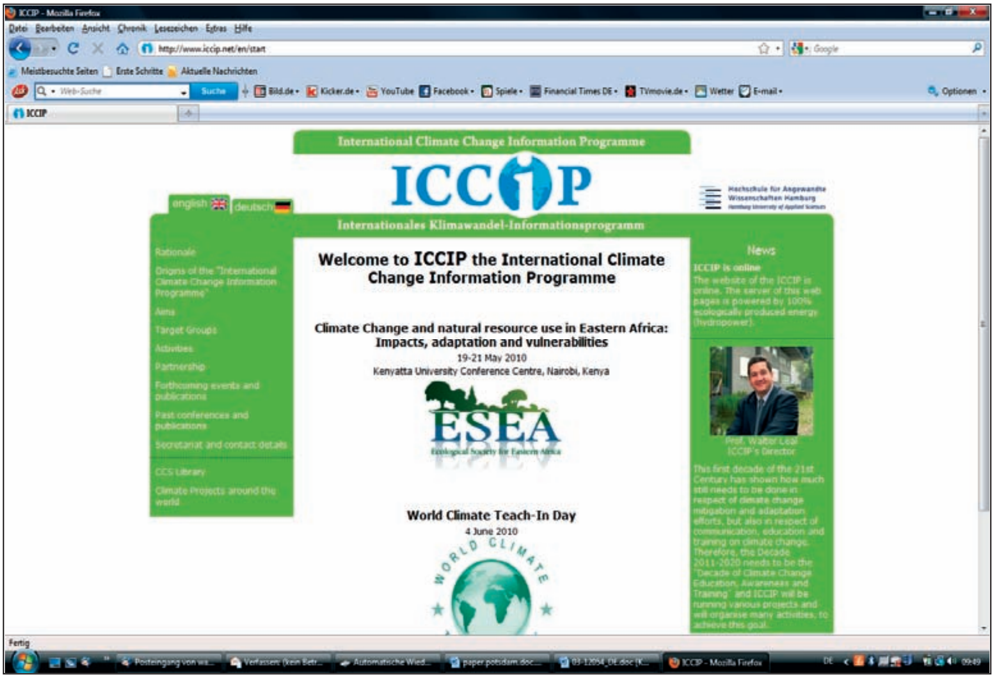

Fig. 1 ICCIP's Project Database (http://www.iccip.net)

on a database under http://maindb.unfccc.int/public/adaptation, where experiences can be shared between developing countries.

The increased emphasis being given to climate adaptation and the development of adaptation strategies means that the relevance of this area is likely to increase. However, due to the inherent problems and risks of "maladaptation", it is vital to select the right approach and the right methods to make sure that the technical and socio-economic barriers to climate adaptation strategies are overcome.

A final message from this paper is that, in order to yield maximum benefits, climate change adaptation activities should be carried out by means of cooperative efforts between local governments, scientific bodies, local NGOs and international donors, to the advantage of vulnerable communities in Africa and Asia to which climate adaptation is not a luxury, but a matter of survival.

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Imaging and Integrating Heterogeneity of Plant Functions: Functional Biodiversity from Cells to the Biosphere

Internationales Leopoldina-Meeting

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Bildgebende Verfahren und Computertechniken spielen auch in der Botanik eine immer größere Rolle. Räumliche Heterogenitäten und zeitliche Dynamik von Strukturen und Funktionen sind essentiell, um das Verhalten von Pflanzen und ihre Wechselwirkung mit Böden und der Atmosphäre verstehen zu können. Ihrer quantitativen Analyse kommt deshalb eine Schlüsselrolle zu – sowohl für die Erforschung der Grundlagen pflanzlichen Verhaltens als auch für die Entwicklung innovativer Anwendungen in der Pflanzenproduktion. Neue Methoden der Bildaufnahme und die quantitative Bild(sequenz)analyse schaffen derzeit die Grundlage für ein völlig neues Verständnis der Bedeutung von Heterogenität und Dynamik in Pflanzen und Umwelt auf allen Skalen von der Zelle bis zum Ökosystem. Der Band verdeutlicht, wie dynamisch Wachstum, Photosynthese und Transport wirklich sind und welche Bedeutung räumliche und zeitliche Muster für Pflanzen haben. Die Beiträge belegen ein hohes Maß an Interdisziplinarität und Kommunikation zwischen Entwicklern von Verfahren, Anwendern aus den Pflanzen- und Umweltwissenschaften sowie Modellierern und Theoretikern. Es erweist sich, dass die Integration von modernen Methoden, innovativen experimentellen Ansätzen und Theoriebildung unser Verständnis von Pflanzen und von ihrem Verhalten in ihrer sich ständig verändernden Umwelt grundlegend wandeln wird. Alle Beiträge sind in englischer Sprache verfasst.

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Asia

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Sustainability: Engaging in Global Change through Harmonious Adaptation in Asia

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With 2 Figures

Abstract

Climate change has emerged as one of the most pressing global issues that need our immediate attention. However, solutions to climate change impacts should not exempt the other important global problems that demand equal attention and should be addressed holistically, integrating various solutions to ensure co-benefits and derive a synergetic benefit. Sustainability science aims to offer such comprehensive and holistic solutions that encompass both social reforms and technological innovations, to establish a vision of a sustainable future. The vision for the future needs to resolve major global problems facing us today, namely; climate change, ecosystems deterioration and resource sustainability. Therefore this vision for future society needs to integrate the approaches for a 'low carbon society', a 'resource cycling society' and a 'society that lives in harmony with nature'.

The importance of the sustainability approach is evident when we consider adverse indirect impacts of measures designed from only one perspective. Use of biofuels as a renewable energy is one important issue due to concerns that increased biofuel crop cultivation will compete with food crop cultivation and cause deforestation. A more fundamental solution to prevent competition with food production and leveling of forests and grasslands is the development of second-generation biofuel technology. Presently, one option that could be used to avoid competition with food production, especially that of cereal crops, is the utilization of cellulose-type organic waste for biofuel production. This shows the importance of looking for holistic solutions in the search for new technologies.

In combating climate change, the Japanese Prime Minister has announced a 25 % reduction of emissions from the 1990 levels by 2020. Many regard this as a daunting task in comparison with the 8 % reduction targets proposed by his predecessor. A study by the National Institute of Environmental Science in Japan has indicated that there is a possibility of achieving 70 % reduction of CO_2 emissions in Japan by 2050 through back casting of two proposed scenarios. Considering not only the feasibility of the scenarios, but also their sustainability and all aspects of societal needs, Japan is now in the process of creation of a master plan for a low-carbon urban development that is also adapted toward Japan's declining birthrate and aging population. The "compact city" concept of urban planning envisions a return of populations to inner cities amid reconstruction of pastoral landscapes in suburbs, and restructuring of cities into more compact areas. This would concentrate and enhance energy use effectiveness and reduce transportation costs and efforts, contributing to the development of low-carbon cities. These concepts can also be applied to rural and mountainous areas with small cities, where bio-resource circulation and energy from biomass can be integrated in the urban-rural community design.

Such integrated approaches are very much relevant to other countries of Asia, especially for the rapidly developing large economies of India and China, where managing energy demands and controlling pollution are the most crucial. Designing responses that have benefits for global environment as well as local communities is the challenge to be undertaken not only by those countries confronted with the problems, but also those who have experienced these transitions in the past and have developed ways to address them. The concepts of integrated responses for climate and ecosystems change are an emerging science that needs further research to customize the methodologies to suit local conditions. For developing countries in South and South East Asia as well as small island states, which are most vulnerable to climate and ecosystems change, outlaying additional resources to investigate and adopt such integrated

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approaches is not easy. Here, the higher education institutions can play an important role to establish education and training programs and create close cooperation among implementing agencies and the research communities to address new and emerging problems that do not have standard responses.

To support the higher education sector in the Asia Pacific to achieve these objectives, the Institute for Sustainability and Peace of the United Nations University and the Integrated Research System of Sustainability Science (with the University of Tokyo as secretariat), established a regional network of leading universities to work together in climate and ecosystems change adaptation research titled 'University Network for Climate Change and Eco Systems Adaptation Research'. Research needs identified by global and regional programs are addressed by the postgraduate research component of the network members. Research outputs will feed into the global and regional capacity development programs such as Education for Sustainable Development, GEOSS, APN, etc. The success and the experience of UN-CECAR network established in Asia Pacific region need to be extended to other parts of the world. A consultative meeting among African Universities was held recently and the program is now being extended to the African Universities.

Zusammenfassung

Der Klimawandel ist zu einem der drängendsten globalen Probleme geworden, das unserer sofortigen Aufmerksamkeit bedarf. Jedoch sollten die Lösungsansätze für Auswirkungen des Klimawandels andere wichtige globale Probleme nicht ausschließen und sollten ganzheitlich angesprochen werden, indem verschiedene Lösungen integriert werden, um Kovorteile sicherzustellen und synergistische Vorteile herzuleiten. Die Wissenschaft der Nachhaltigkeit strebt danach, umfassende und ganzheitliche Lösungen anzubieten, die sowohl soziale Reformen als auch technologische Innovationen einschließen, um die Vision einer nachhaltigen Zukunft zu etablieren. Die Zukunftsvision muss die wichtigsten globalen Probleme lösen, denen wir heutzutage gegenüberstehen, nämlich: Klimawandel, die Zerstörung der Ökosysteme und die Nachhaltigkeit von Ressourcen. Deshalb muss diese Vision für die zukünftige Gesellschaft die Lösungsansätze für eine ‚Gesellschaft mit niedrigem CO_2-Ausstoß', eine ‚Ressourcen-Recycling-Gesellschaft' und eine ‚Gesellschaft, die in Harmonie mit der Natur lebt' integrieren.

Die Wichtigkeit des Nachhaltigkeitsansatzes wird offensichtlich, wenn wir die negativen indirekten Folgen von Lösungen bedenken, die nur aus einer einzelnen Perspektive konzipiert wurden. Der Gebrauch von Biokraftstoff als einer erneuerbaren Energie ist hier eine wichtige Fragestellung, da es verstärkte Bedenken gibt, dass der Anbau von Biokraftstoff mit dem Anbau von Nahrungsmitteln konkurrieren und Abholzung verursachen wird. Eine fundamentalere Lösung, um die Konkurrenz mit dem Nahrungsmittelanbau und das Einebnen von Wäldern und Graslandschaften zu verhindern, ist die Entwicklung einer Biokraftstofftechnologie der zweiten Generation. Momentan ist eine Möglichkeit, die angewendet werden könnte, um die Konkurrenz mit der Produktion von Nahrungsmitteln, insbesondere von Getreide, zu verhindern, der Gebrauch von zelluloseartigen organischen Abfällen für die Produktion von Biokraftstoff. Dieser Ansatz zeigt, wie wichtig es in der Suche nach neuen Technologien ist, nach ganzheitlichen Lösungen zu fahnden.

Im Kampf gegen den Klimawandel hat der japanische Premierminister eine 25 %ige Reduktion der Emissionen des Standes von 1990 bis im Jahr 2020 verkündet. Viele sehen dies als eine entmutigende Aufgabe im Vergleich zu den 8 % Reduktionsziel, die sein Vorgänger vorgeschlagen hatte. Eine Studie des Nationalen Instituts für Umweltwissenschaften in Japan hat durch die Rückrechnung von zwei vorgeschlagenen Szenarien ermittelt, dass in Japan die Möglichkeit einer 70 %igen Reduktion des CO_2-Ausstoßes bis zum Jahr 2050 besteht. Unter Berücksichtigung nicht nur der Machbarkeit der Szenarien, sondern auch deren Nachhaltigkeit und aller Aspekte sozialer Bedürfnisse ist Japan jetzt dabei, einen Masterplan für eine städtische Entwicklung mit niedrigem CO_2-Ausstoß zu gestalten, der auch an Japans sinkende Geburtenrate und alternde Gesellschaft angepasst ist. Das Konzept der „kompakten Stadt" im Städtebau sieht eine Rückkehr von Bevölkerungen in die Innenstädte inmitten einer Rekonstruktion von pastoralen Landschaften in den Vorstädten und eine Restrukturierung von Städten in kompaktere Flächen vor. Dies würde die Effektivität des Energieverbrauchs konzentrieren und erhöhen sowie Transportkosten und -aufwand reduzieren und somit zu der Entwicklung von Städten mit niedrigem CO_2-Ausstoß beitragen. Diese Konzepte können auch in ländlichen oder bergigen Gegenden mit kleinen Städten angewendet werden, in denen die Zirkulation von Bioressourcen und Energie aus Biomasse in den städtisch-ländlichen Entwurf der Gesellschaft integriert werden kann.

Solche integrierten Lösungsansätze sind in anderen Ländern Asiens sehr relevant, vor allem in den rasch wachsenden großen Volkswirtschaften von Indien und China, in denen das Management des Energiebedarfs und die Einschränkung der Umweltverschmutzung besonders bedeutsam sind. Lösungsansätze zu entwerfen, die Vorteile sowohl für die globale Umwelt als auch für regionale Gemeinden haben, ist die Herausforderung, die nicht nur von den Ländern angenommen werden muss, die mit den Problemen konfrontiert sind, sondern auch von denen, die solche Veränderungen in der Vergangenheit erlebt und Wege gefunden haben, um sie anzugehen. Die Konzepte integrierter Lösungsansätze zum Klima- und Ökosystemwandel sind eine neue Wissenschaft, die weiterer Forschung bedarf, um

die Methodologien an lokale Bedingungen anzupassen. Sowohl für Entwicklungsländer in Süd- und Südostasien als auch für kleine Inselstaaten, die am meisten von Klima- und Ökosystemwandel bedroht sind, ist es nicht einfach, zusätzliche Ressourcen zu finden, um solche integrierten Lösungsansätze zu untersuchen und anzuwenden. Hier können die Institutionen des Hochschulwesens beim Aufbau von Bildungs- und Trainingsprogrammen eine wichtige Rolle spielen und eine enge Zusammenarbeit zwischen ausführenden Behörden und der Forschungsgemeinschaft fördern, um neue und gerade aufkommende Probleme, die keine Standardlösungen haben, zu benennen.

Um den Sektor des Hochschulwesens im Asien-Pazifik-Raum im Erreichen dieser Ziele zu unterstützen, hat das Institut für Nachhaltigkeit und Frieden der Universität der Vereinten Nationen und das Integrierte Forschungssystem für Nachhaltigkeitswissenschaft (unter dem Vorsitz der Universität von Tokyo) ein regionales Netzwerk von führenden Universitäten etabliert, um in der Forschung über die Anpassung an den Klima- und Ökosystemwandel unter dem Titel ‚Universitätsnetzwerk für Forschung über die Anpassung an den Klima- und Ökosystemwandel' zusammenzuarbeiten. Mit dem Forschungsbedarf, der von globalen und regionalen Programmen identifiziert wurde, befassen sich die Doktoranden und Postdoktoranden der Netzwerkmitglieder. Forschungsergebnisse werden in globale und regionale Kapazitätsentwicklungsprogramme, wie z. B. ‚Bildung für Nachhaltige Entwicklung', GEOSS, APN u. a., eingespeist. Der Erfolg und die Erfahrung des UN-CECAR-Netzwerks im Asien-Pazifik-Raum müssen in andere Teile der Welt übertragen werden. Ein Beratungstreffen wurde kürzlich mit afrikanischen Universitäten abgehalten, und das Programm wird jetzt auf afrikanische Universitäten ausgeweitet.

1. Why Sustainability

Science and technology has allowed us to push boundaries beyond imagination. Through ingenuity, innovation and new knowledge-creation, we have seen the successive rise of distinct revolutions. In the modern age, we saw the rise of the industrial revolution and its transformation of production and transportation systems; to the green revolution's restructuring of global agricultural systems which has allowed the supply of food to an exponentially-growing human population; and the digital revolution at the end of the 20th century which is still transforming social and economic systems, not the least of which is the way citizens communicate to business today.

Historically, advancements in science, technology and knowledge have always complemented each other. Where scientific fields have bonded in interdisciplinary learning, new discoveries, broader applications and solutions have emerged. Computer science, which has foundations in discrete mathematics, electrical engineering and theoretical linguistics, has advanced the development of artificial intelligence and improved disaster risk management. Material science, which combines chemistry, physics, and several engineering disciplines, has led to the development of revolutionary technologies like plastics, biomaterials, semiconductors and nanotechnology.

However, for the many seen and celebrated benefits, there have been as many unintended, undesirable and at the time – unforeseen outcomes. For instance, while material science has given us plastics, a largely petroleum-based product, it has also caused the innumerable release of toxic pollutants, greenhouse gas emissions and wastes that litters our lands and waterways. The "Miracle Rice" cultivar, IR8, and the Japanese dwarf wheat cultivar, Norin 10 wheat, which led to the Green Revolution, were both instrumental in insuring billions of people against potential famine. Such breeds, however, were voracious consumers of water, chemical fertilizers, pesticides and herbicides. The availability of vast cheap grain has moved agriculture away from traditional systems to large monoculture cropping, causing in the meantime, greater land degradation, deforestation, loss of biodiversity, and changes to the diets of human and animals bred for large-scale meat production. Underlying all this is the huge amount of fossil fuel inputs upon which much of the global food system is now entirely dependent. What was once considered a solution to food security is now not only the cause of food insecurity but also a source of innumerable other social and environmental problems.

There is no doubt now that the rapid advances enjoyed by some today, have given rise to serious and intractable problems. There are societal inequalities in the distribution of wealth, knowledge and decision making capabilities. Disaffection breeds discontent, and at the international level, global peace and cooperation are already vulnerable. Imbalances across human and economic development are polarizing the world into those who live in excess and those who can barely manage an existence. Economic models based on unchecked exploitation of natural resources and environmental services are disrupting ecosystems, and ironically will return to threaten the very existence of humankind.

What we have is a crisis in sustainability. Given the urgency with which we have to address the major problems of complex and interwoven global problems, science needs a new platform, one capable of 'putting the pieces back together'. Taking up the challenge, sustainability science aims to offer comprehensive and holistic solutions that encompass both social reforms and technological innovations, to establish a vision of a sustainable future. In order to promote sustainability science, the Integrated Research Systems of Sustainability Science (IR3S) was established as an interdisciplinary research body in 2005 under the direct control of the president of the University of Tokyo and constitutes a network of four other universities and seven research institutions.

The discussions among these institutes has identified that in addition to addressing problems such as intergenerational equity towards a sustainable society, sustainability should be addressed at three levels of "system", global, social and human. These three systems are indispensable for coexistence of human beings and the environment, and current crisis of sustainability can be traced down to the breakdown of these systems and their inter-linkages. The *global system* comprises of geosphere, atmosphere, hydrosphere and biosphere that make up the planetary base, the *social system* is the political, economic, industrial and other structures created by human beings that provide the societal base, and the *human system* defines all the factors that affect human survival. For the healthy functioning of human system, conditions conducive to experience a fulfilled life must be established, and many of today's problems can be viewed as threats to the sustainability of human system (Komiyama and Takeuchi 2006).

Global environmental problems such as global warming involve complex and interwoven series of factors that make such problems impossible to deal with in the framework of any one existing discipline. The IR3S takes a structural and comprehensive approach to global warming, within the framework of sustainability science as an academic discipline. This vision aims to integrate the approaches for a 'low carbon society', a 'resource cycling society' and a 'society that lives in harmony with nature'.

2. Sustainability Approach to Climate Change

Presently climate change has emerged as an unprecedented multidimensional challenge, particularly for all countries and communities in the Asia Pacific region. Home to a variety of geography, landform, biodiversity and climate, as well as systems of social governance and economies, the region will be affected by climate change in many different ways, requiring a myriad of adaptation strategies to ensure sustained development. The climate crisis is a crisis of sustainability. While climate change was triggered inadvertently with the accumulation of greenhouse gases resulting from fossil fuel combustion for energy and transport generation, the international deadlock on achieving a global agreement on the reduction of greenhouse gas (GHG) emissions shows the inability of compartmentalized processes of energy production to acknowledge and incorporate the risks to other sectors of society, the well being of the globe, or even the very survival of the human race. With the same viewpoint, we can argue that solutions to climate change impacts should not exempt the other important global problems that demand equal attention and should be addressed holistically and integrating various perspectives to ensure benefits for all. Sustainability science aims to offer such comprehensive and holistic solutions that encompass both social reforms and technological innovations, to establish a vision of a sustainable future. The generic approach in developing solutions to global warming is to study physical phenomena and find a solution through integration of science and technology. Sustainability science has the same goal, but calls for a broader perspective that encompasses other development concerns as well. Therefore, the vision for the future needs to resolve major global problems facing us today, namely; climate change, ecosystems deterioration and resource sustainability.

Examination of various measures proposed to reduce global warming shows vividly the dangers of compartmentalized approaches and the need for holistic measures based on sustainability. A classic example is the use of biofuels as an energy alternative. A drastic increase in the use of renewable energy sources such as biofuels is urgently needed to reduce CO_2 emissions. However, there have been concerns that increased biofuel crop cultivation will compete with food production as well as deforestation. It has been estimated that biofuels made from corn grown in the United States will create a carbon deficit over a long period of time, because of the large amounts of carbon released into the atmosphere through the destruction of forests and grassland. Searchinger et al. (2008) have estimated that the potential global trend in the conversion of forest and grass land by farmers in response to rising demand for biofuels would, in fact, increase greenhouse gas emissions two folds instead of the expected 20 % reduction. They propose implementing land conversion regulations and using waste products for biofuel production.

Structural and comprehensive evaluation of the validity of biofuel use and the proposal of specific countermeasures is consistent with the goals of sustainability science. The IR3S has undertaken a study titled “Research on Utilization Strategies of Biomass Fuels for the Sustainable Development of the Asia-Pacific and Other Regions” with support from the Japan Environment Ministry’s Global Environment Research Fund to respond to this need. The study attempts a structural conceptualization of biofuel issues using ontology, a method of visualizing relationships between concepts that was developed by Dr. Riichiro Mizoguchi of Osaka University, a member institution of the IR3S (Kumazawa et. al. 2009). Such visual tools are also effective as aids in formulating countermeasure policies (Fig. 1). The Figure 1 clarifies that production of bioethanol fuel from crops such as corn and sugar cane is closely linked to issues concerning biomass and competition with food production. Dr. Norihiro Suzuki of the University of Tokyo conducted a model analysis of bioethanol production and found that while making bioethanol from corn grown in the United States was not economically feasible without subsidies, fuel made from Brazilian sugar cane was cheaper than gasoline and thereby, potentially, more profitable. Brazil regulates the conversion of forests and grasslands into farmland, and biofuel production may prove to be an effective strategy that can be integrated with this policy.

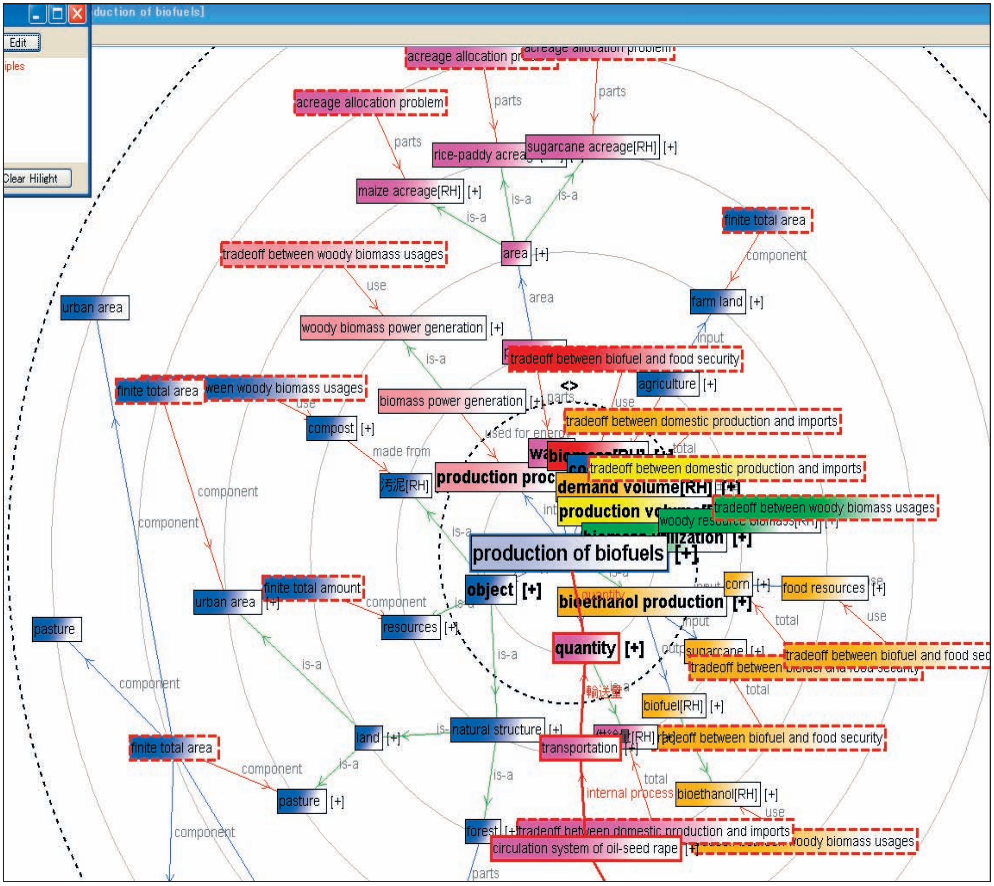

Fig. 1 Conceptual mapping of issues surrounding biofuel production (Saito et al. 2010).

A more fundamental solution to prevent competition with food production and leveling of forests and grasslands is the development of second-generation biofuel technology. Presently, one option that could be used to avoid competition with food production, especially that of cereal crops, is the utilization of cellulose-type organic waste for biofuel production. In addition, utilization of abandoned fields, the number of which is on the rise in many developed countries such as Japan, can prevent destruction of forests and grasslands for such purposes.

Another aspect, to take into consideration in relation to biofuel production, is whether such operations benefit local residents, especially in developing countries. Enlargement of oil palm cultivation areas for production of biofuels in Indonesia and other countries may not always be profitable for residents, resulting only in destruction of ecosystems in such areas. Small-scale biofuel crop production using local ecosystems would probably be more sustainable for residents forced to pay high prices for fossil fuels.

An additional function of sustainability science is the synergetic effect gained by integrating different strategies towards solutions to global warming. Resolving global environmental issues such as global warming will involve huge costs that could place a heavy burden on citizens. Combining different measures could lead to significant reduction in costs and introduce a host of diverse benefits, both short and long term, leading to a greater chance of such measures being accepted by citizens. Japan, with its present pledge for drastic reduction of GHG emissions has to find such integrated solutions urgently that would be acceptable to citizens while not overwhelming a stagnating economy.

3. Japanese GHG Emission Reduction Strategies

In September 2009, in the wake of the Copenhagen COP15 summit, the Japanese Prime Minister announced a 25 % reduction of emissions from 1990 levels by 2020. His predecessor Mr. Taro Aso, in 2009 June announced that Japan would seek to reduce emissions by 15 % from 2005 levels by 2020. Further, Mr. Aso stated that these targets are 'mamizu', meaning clean and genuine like water, implying that the target is to be achieved by pure domestic reduction of CO_2 emissions and not through offsets purchased internationally. Although there had been international criticism of these targets as being too mild, skeptical climate scientist Pielke Jr. (2009) analyzing the pledge, called it extremely ambitious and difficult to achieve. How can the new targets be achieved? Initial estimates show the enormous outlays of capital, as well as enforcement of a regime of strict energy efficiency and other measures would be required in achieving these targets. An overview of measures to achieve these targets, compiled by Tetuo Yuhara (2009) shows that the following measures would need to be implemented including: requiring photovoltaic cells to be installed in all new houses and some existing houses (600,000 houses annually), constructing and operating 15 new nuclear power plants with 90 % capacity utilization rate, increasing thermal power from both gas power plants and bio-mass mixed sources, having 90 % of new car sales comprised of fuel efficient/hybrid next generation vehicles, mandating all new houses and existing houses have heat insulation installed, and mandating energy conservation standards. Under the new target, the price of CO_2 per one ton would be 82,000 yen (910 USD) compared to the 15,000 yen (~165 USD) price tag for the previous target of 8 % reduction. It is worth noting that the current price of carbon is around 7,000 yen (~80 USD). Given the immense challenge in reaching this target through domestic reduction alone, it is expected that all CO_2 emission targets will be achieved by a combination of emission reduction measures as well as through purchase of overseas emission rights.

A study by the National Institute of Environmental Science in Japan (2009) involving more than 60 experts from research institutions, universities and private companies has indicated that there is a possibility of achieving 70 % reduction of CO_2 emissions in Japan by 2050. The study used back-casting of two distinctly different scenarios and derived various policy measures that need to be taken at different periods of time between now and 2050. In the two proposed scenarios A and B, scenario A covers a dynamic, technology-driven society, where as scenario B models a slow paced, nature-oriented society. The target of the study was set at 70 % reduction of CO_2 emissions in 2050 compared with the 1990 level and a set of socio-economic criteria were identified using the iterative back-casting simulation approach to achieve this target. Some of the important criteria that have been identified as prerequisites in arriving at this target include:

– Need to have moderate economic growth;
– Ability to meet energy demands for the specific socio-economic conditions of the scenario;

- Adoption of innovative energy saving technologies and
- Compatibility with national development plans.

The study has been useful in identifying the main actions that need to be taken to arrive at a comprehensive solution to reduce GHG emissions. These include:

- Reducing energy demand by 40 % and supply low carbon energy;
- Reducing energy demand by taking into consideration the shrinking population, conserving energy use, improving energy efficiency and keeping economic growth to a moderate 1–2 %;
- Allocating funds for the costs related to CO_2 reduction that would amount to about 1 % of the GDP in 2050.

The study calls for the government to act promptly and take the leadership in putting into place necessary structural changes in the industrial sector and investing in required infrastructure. The study has provided a framework for these actions, emphasizing on taking a comprehensive approach to move towards a low carbon society through both technological and social innovation. Considering not only the feasibility of the scenarios, but also their sustainability and all aspects of societal needs, Japan is now in the process of creating a master plan for a low-carbon urban-rural development that is also adapted toward Japan's declining birthrate and aging population. The plan calls for not only technological innovations, but also a change of attitude towards consumption and conservation by communities.

4. Behavioral Change for Achieving Low Carbon Communities

Achieving low carbon societies calls for understanding the dynamic interactions of technologies, infrastructure, institutions and their interaction with communities they serve. A systems analysis approach is required to understand the drivers behind community behavior and consumption patterns and to introduce measures to move towards a low carbon society (LCS). What makes people behave and how these behaviors can be changed are the central questions that need to be addressed to make this transition successfully. Personal behavior in the context of adopting practices for moving to a LCS is explained by at least 3 major behavior models. The rational model, which is currently dominant, assumes that individuals make their decisions based on weighing costs and benefits and selecting the option that maximizes their benefits (Jackson 2005). However, critics challenge this model arguing that people make decisions most of the time based on emotional responses rather than from rational deliberation (De Kirby et al. 2007, Smith 2004). This brings to question whether the approach of presenting the right information to the public alone will lead to conversion of communities toward LCS. Another widely used assumption is that if people are presented with the facts on how their actions are affecting the environment, they will respond by changing their behavior to minimize adverse impacts. However, evidence suggest that this is again very much based on the social and cultural context. It is even suggested that increasing information could lead to disinterest, skepticism and fear (Finger 1993, *Australian Psychological Society* 2008).

Moloney et al. (2010, in press) points out that while some behaviors are locked into practices or habits, and are unlikely to be changed due to infrastructural and economic constraints, other behavior patterns may lend themselves to adjustment and change in ways that can reduce adverse environmental impacts. Moloney et al. (2010, in press) question the appropriateness of the above approaches that focus on individual choice rather than collective social values, which may be more important in bringing out behavior changes needed to move towards a LCS. Such an approach is advocated by the *World Wide Fund for Nature* (WWF) (2008), which argues that appealing to 'intrinsic' social values would be more effective in changing community behavior. Apart from the individually-driven behavioral change or the social norms based behavioral patterns, there is a third approach that argues it is the technological and infrastructure system that need to be addressed as it can provide the convenience and incentives to adopt practices that are conducive to a low carbon society.

Moloney et al. (2010, in press) also argue for a 'socio-technical' approach for bridging the social norms and technological advantages to move towards a LCS. In this process, collective practices rather than individual choices are the focus, and are based on the idea that collective practices frame individual's daily actions. The practices are enabled by a range of technologies, infrastructure arrangement, regulations and support institutions. At the same time they are fostered by social values and norms and the context they take place. Their study of 100 programs for behavior change towards LCS in Australia concludes that the current dominant rational choice model of individual choice supported by the 'techo-economic' model is producing technologies that are not effective as they focus on individual choices and inadequately take in to account social practices and norms. They also point out that focusing on individual behavior without addressing broad regulatory, institutional and social norms, which breed individual behaviors, is a misguided effort. Moving towards a low carbon society requires shifts in social practices to support LCS intrinsically. This calls for programs designed to strengthen and advance norms and values which form these social practices.

5. Japanese Initiatives towards Sustainable LCSs

It is clear that solutions to climate change impacts should not exempt the other important global problems that demand equal attention and should be addressed holistically, integrating various solutions to ensure co-benefits and derive a synergetic benefit. The vision for the future needs to resolve major global problems facing us today, namely; climate change, ecosystems deterioration and resource sustainability. Therefore, this vision for future society needs to integrate the approaches for a 'low carbon society', a 'resource cycling society' and a 'society that lives in harmony with nature'. Two initiatives of Japanese government that UNU and IR3S are involved are described below.

5.1 Satoyama Initiative: A Vision for Sustainable Rural Societies in Harmony with Nature

'Satoyama' is an example of programs that address the issue of strengthening and advancing social norms and values for sustainable development that share the vision of low carbon society. The Satoyama initiative is a collaboration between the United Nations University and the Japan Ministry of the Environment. It is an international program with the participation of Government agencies, NGOs and other concerned agencies around the world to develop models and a database for community based sustainable landscape management practices to be shared and adapted to local context.

Traditionally, Satoyama refers to secondary woodlands such as oak coppices, pinewoods and bamboo groves, as well as grasslands managed for thatch, fodder and compost. These secondary environments were maintained by long-term sustainable use of the vital natural resources they provided. Japan's traditional landscape includes various other rural environments, such as arable fields and orchards, rice paddies, irrigation ponds and ditches, and the villages and farmsteads themselves. The complex rural ecosystem formed by the combination of Satoyama and these other environments is called the 'Satoyama Landscape'. In the local Satoyama Landscape many different kinds of woodland, grassland and wetland environments are mixed together in a complicated mosaic pattern. This rich mixture creates habitats for numerous species of wildlife, many of which are now endangered; and also enhances disaster prevention, watershed protection and other vital ecosystem services.

The Japanese people feel a deep emotional attachment to their Satoyama Landscape, which has always been a powerful source of inspiration, imagination and creativity. Satoyama motifs feature prominently in poetry, traditional art and handicrafts, and even music. These motifs are also frequently used as the settings for traditional folk tales and modern-day animation movies.

The natural ecosystems in a Satoyama landscape comprise of secondary woodlands, rice paddies, irrigation ponds and ditches, pastures and grasslands. Proper management of these systems by maintaining balance between human activities and ecosystems to maintain biodiversity is the key to sustainable utilization of Satoyama resources. This is achieved through practices such as coppice management that include clearing and managing undergrowth and periodic cutting or the management of rice paddies as rich wetland systems.

The Satoyama initiative consists of three major steps. In the first step the program is collecting and analyzing data from practices around the world on sustainable natural resource management. In the second stage the program will identify challenges ahead for conservation and development incorporating collaboration with practices such as eco-agriculture, agroforestry or community based forest management with approaches such as ecosystems approach or Addis Ababa Principles and Guidelines.

In the third step the program will develop principles, guidelines and action plans based on the information collected and analyzed. The final outcomes also will include operational guidelines for implementation and evaluation of sustainable land management practices, a data base on such practices around the world and action plans to expand these approaches globally.

Moving towards low carbon societies and the revival of these sustainable land management systems by making them to suit modern societal needs and demands are very much interrelated. It creates the social norms and values that are important to form social practices that can guide individual behavior supporting climate change combating measures as discussed previously. At the same time the experiences and insights for Satoyama are very valuable in the design of new types sustainable LCS.

5.2 Compact Cities

Another example in Japan is the creation of a master plan for a low-carbon urban development that is also adapted towards addressing the country's declining birthrate and aging population. The "compact city" concept of urban planning envisions a return of the population to inner cities amid reconstruction of green spaces in suburbs, and restructuring of cities into more compact areas. This would concentrate and enhance the effectiveness of energy use and reduce transportation costs and efforts, contributing to the development of low-carbon cities.

At the same time, public facilities such as government offices, hospitals and schools should be moved back to city centers, reversing their depopulation and stimulating redevelopment. The relocation of aging populations to inner cities would reduce the burden of transportation on the elderly, and help create a lifestyle appropriate for them. Suburban areas can be redeveloped as residences with gardens or other cultivated areas, providing healthy and comfortable homes for the aged. Our plan shows that improvements in lifestyles and low-carbon urban planning can both be realized through careful planning.

In Japan, it should be noted that almost all of the fossil fuels are imported, as are most mineral resources and much of agricultural and marine products and lumber. Since Japan does not have abundant mineral resources, it is advantageous to invest on recycling systems for minerals that are already being used in industrial products. With respect to agricultural, marine and forestry resources, Japan has the potential to be self-sufficient, so the issue becomes one of reconstructing and sustaining these industries to become as self-sufficient as possible. This paves the way to connect the goal of becoming a low-carbon nation with that of becoming a resource-recycling society.

6. Global and Regional Collaboration

6.1 A Sustainable City Model – Support to Asian Countries

In other Asian nations including China, economic growth and increases in urban populations have raised demand for energy. Such countries face many challenges as they strive to become low-carbon societies. Integrated approaches are very much relevant to other countries of Asia, especially for the rapidly developing large economies of India and China, where managing energy demands and controlling pollution are the most crucial. Designing responses that have benefits for the global environment as well as local communities are challenges that need to be undertaken not only by countries confronted with the problems, but also those who have experienced these transitions in the past and have developed ways to address them. The greatest challenge for sustainability science is to provide a vision or plan for those countries that is environmentally friendly but does not sacrificing economic growth.

Many Asian cities have been developed on land, which were once agricultural areas. Issues faced by urban and rural areas closely related, and urbanization give rise to various problems that affect both urban and rural areas. Therefore, the key to sustainable cities in Asia is the co-existence of urban and rural areas. Urban expansion in China shows many similarities Japan experienced during its urbanization phase. For sustainability it is essential to reduce disparities between rural and urban areas. Fusion of these two components will form the basis for an 'Ideal City' for Asia. This involves landuse planning for urban and rural mixture at small scale spreading continuously and allowing co-existence and close interaction between urban and rural sectors. The IR3S intends to continue its study towards the possibility of achieving sustainability in developing countries, especially in Asia.

6.2 Higher Education for Climate and Ecosystems Change Adaptation Research

The concept of integrated responses for climate and ecosystems change is an emerging science that needs further research to customize the methodologies to suit local conditions. Climate and biodiversity are both local phenomena that depend on the geographical, biophysical and socio-economic characteristics of a particular location. Hence, strategies to address climate and ecosystems change must evolve locally incorporating the diverse and complex interactions of all affected stakeholders as well as local ecology and environmental processes. For strategies to evolve locally, local human resources and technical capacities should be developed. However, for developing countries in South and South East Asia, as well as small island states, which are most vulnerable to climate and ecosystems change, outlaying additional resources to investigate and adopt such integrated approaches are not easy. Here, already existing higher education institutions can play an important role in establishing education and training programs and enhancing close cooperation among agencies, research communities, local communities and practitioners to address new and emerging problems that require integrated approaches.

To support the higher education sector in the Asia Pacific achieve these objectives, a regional network of leading universities was established by the Institute for Sustainability and Peace of the United Nations University (UNU-ISP) and the Integrated Research System of Sustainability Science (with the University of Tokyo as secretariat). The network, entitled 'University Network for Climate and Ecosystems Change Adaptation Research' (UN-CECAR) aims to bring all available resources and expertise across disciplinary lines to work collaboratively together to advance climate and ecosystems change adaptation research.

There are two key components of this network. First is the postgraduate research component by network members, which aims to address the research needs identified by the global and regional community. The network will provide an open framework for research cooperation and mechanisms for resource sharing (such as experimental fields and facilities, modeling and forecasting systems, short-term training, available funds, etc). It is envisaged that research outputs from the network will then feed into the global and regional capacity development programs such as Education for Sustainable Development, GEOSS, APN, etc., as well as back into the higher education programs by UN-CECAR. This concept is shown in Figure 2.

The other is curriculum development to address the fast growing demand for labor skilled in sustainability science, regionally and globally. The proposed curricula will cover the full spectrum of topics within sustainability science. It is deliberately designed to be flexible to enable users to select modules that both suit the needs of students and the institution. To complement and strengthen curriculum development, UN-CECAR members have established a task force to conduct a region-wide needs assessment of higher education in various countries. The needs assessment will inform members which sectors are in most need, now and in the future, and what type of technical skills and knowledge will be essential for widespread transition towards low-carbon societies.

Since its establishment in 2009, June, three conferences have been organized to discuss specific details on the implementation of the above-mentioned targets. The characteristics of joint programs to be offered are presently identified as:

- Two degree-types will be provided: (*i*) Research masters degree for academia-oriented candidates; and (*ii*) Professionals' master degree for decision-makers.
- The programs consist of three components including (*i*) core courses, (*ii*) elective courses and (*iii*) dissertation/project. Core courses and elective courses to be jointly hosted by UNU and each national level university.

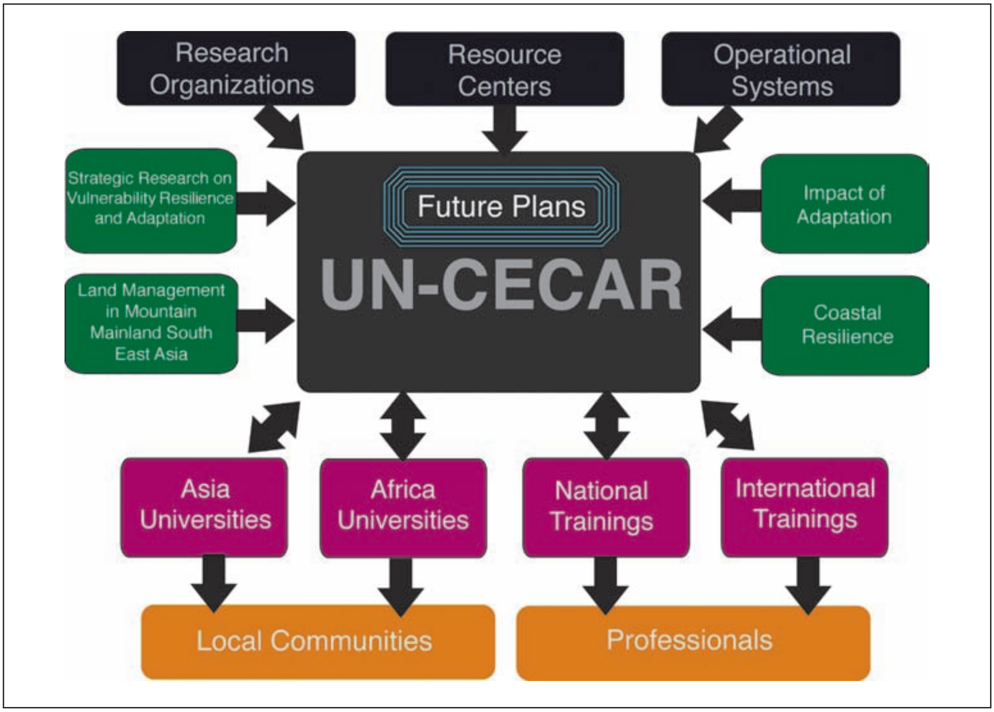

Fig. 2 Framework of activities for University Network for Climate and Ecosystems Adaptation Research.

– Four areas of specialization will be addressed: (*i*) research, (*ii*) policy, (*iii*) science and technology, and (*iv*) the professional community.
– A 'modular' program was also proposed to allow students to expand their interests. Under this module-based system, students can, for example, begin with a diploma course and later transfer to a masters course.
– Core courses can also be tailored for either graduate degree or diploma programs, and shall be drawn from universities' own courses and can be cross institutional. The dissertation research can also be conducted in other member universities or sites supervised by a collaborating university.
– Students can choose from various elective courses (science, technology, hydrological and engineering, etc.).

Core courses are jointly being developed by members and cover the following broad categories:

– Science of climate change (weather and climate, forcing of climate change, uncertainty, sustainability science);
– Impact and vulnerability (risk, vulnerability and resilience, hazards and disasters);
– Adaptation and mitigation (climate change and sustainable development), community and society, governance (planning, policy, law, economics), communication and capacity building.

It is hoped that the success and the experience of UN-CECAR network established in Asia Pacific region can be extended to other parts of the world. A consultative meeting among African Universities was held recently in 2009, and the initiative is now being extended to various African Universities.

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Climate Change in Indian Sub-Continent and its Impact on Agriculture

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With 9 Figures and 6 Tables

Abstract

India is a vast country and it is known as Indian sub-continent. The climatic types in the country vary from per-humid type in Chirrapunji to arid and extremely arid types of climate in Rajasthan. It has been found that the rainfall pattern in some parts of the country is changing and the changes are both positive in some areas and negative in other areas. It was observed that the rainfall pattern in Central part of India is decreasing while in Western and North Western parts of the Indian sub-continent it is in decreasing trend.

Looking into these observations an analysis of the 7 Sub-division temperature data for the period 1901–2003 and 29 meteorological sub-divisions rainfall data for the period 1871–2008 was analyzed to identify the areas where there are considerable changes in temperature and rainfall. It was found that the maximum temperature is increasing as compared to minimum temperature in West coast, North east and North-central sub-divisions of India especially during winter months than in summer months. As a case study an analysis of decadal growth rates wheat area for Chhattisgarh state in Central India was carried out and it was found that the growth rates have become negative during the decades 1981–1990 and 1991–2000 inferring that the wheat zone is moving towards north in this part of India. In fact, this part of India is the southern limit of wheat zone of the country.

The impact of increased temperatures on rice production was studied using crop simulation models, and it was found that an increase of temperature by 1 °C at reproductive stage can reduce the potential yield of rice from 9.35 t/ha to 8.89 t/ha under irrigated and from 8.93 to 8.43 t/ha under rainfed conditions. Similar effect was also found when the temperatures increase during maturity stage.

When the rainfall data for the period 1871–2008 was analyzed it was found that in 14 meteorological sub-divisions the rainfall trend changed from positive trend during the period 1871–1960 to negative during the period 1961–2008. In 4 sub-divisions the trend changed from negative to positive during the same period. Detailed analysis of monthly rainfall for Chhattisgarh sub-division was carried out, and it was observed that in Chhattisgarh the rainfall had decreased from 35 to 0 % in different parts of the state during the period 1951–2000 as compared to the normal values of the period 1901–1950. As a consequence of the changes in rainfall the climate type is also changing from moist sub-humid type to semi-arid in many places. It was also found that due to decreasing trend of rainfall, especially in October month, the farmer are slowly changing rice cultivation from long duration local genotypes to medium duration varieties in this state. This is the adaptation for climate change from the farmers side.

Zusammenfassung

Indien ist ein riesiges Land und bekannt als indischer Subkontinent. Die Klimatypen in diesem Land variieren vom perhumiden Typ in Cherrapunji bis zum ariden und extrem ariden Klimatyp in Rajasthan. Es wurde herausgefunden, dass sich die Niederschlagsstruktur in einigen Regionen des Landes ändert und dass diese Änderungen in einigen Gebieten positiv und in anderen negativ sind. Es wurde beobachtet, dass die Niederschlagsstruktur in Zentralindien abnimmt, während es in westlichen und nordwestlichen Teilen des indischen Subkontinents eine abnehmende Tendenz gibt.

Um die Regionen mit deutlichen Veränderungen hinsichtlich der Temperatur und des Niederschlages zu identifizieren, wurden die Beobachtungen in einer Analyse genauer betrachtet. Für 7 Subdivisionen wurden Temperaturdaten für die Periode 1901–2003 und Niederschlagsdaten für 29 meteorologische Subdivisionen für den Zeitraum 1871–2008 ausgewertet. Im Vergleich zu den Mindesttemperaturen wurde für die Maximaltemperatur ein steigender

Trend an der Westküste, in den nordöstlichen und nord-zentralen Subdivisionen Indiens festgestellt, besonders während der Wintermonate statt in den Sommermonaten. In einer Fallstudie wurde eine Analyse dekadischer Wachstumsraten für die Weizenregion Chhattisgarh in Zentralindien durchgeführt und ergab negative Wachstumsraten während der Dekaden 1981–1990 und 1991–2000. Daraus lässt sich ableiten, dass sich die Weizenzone ins nördliche Indien verschiebt. Tatsächlich stellt dieser Teil Indiens die Südgrenze der Weizenzone des Landes dar.

Die Auswirkungen der steigenden Temperaturen auf die Reisproduktion wurden mit Hilfe eines Ernte-Simulationsmodells untersucht. Dabei stellte sich heraus, dass ein Temperaturanstieg von 1 °C in der reproduktiven Phase den potentiellen Ertrag mit Bewässerung von 9,35 t/ha auf 8,89 t/ha reduziert und unter natürlichen Niederschlagsbedingungen von 8,93 auf 8,43 t/ha. Ähnliche Effekte wurden auch bei einem Temperaturanstieg während der Reifephase herausgefunden.

Bei der Analyse der Niederschlagsdaten für die Periode 1871–2008 stellte sich heraus, dass sich bei 14 meteorologischen Subdivisionen der Niederschlag von einem positiven Trend während des Zeitraums 1871–1960 in einen negativen Trend in der Periode 1961–2008 wandelte. In 4 Subdivisionen ändert sich der Trend vom negativen zum positiven während der gleichen Periode. Es wurden detaillierte Analysen des monatlichen Niederschlags für die Subdivision Chhattisgarh durchgeführt. Für Chhattisgarh wurde eine Abnahme des Niederschlags von 35 % auf 0 % in verschiedenen Gebieten des Staates während des Zeitraums 1951–2000 im Vergleich mit den normalen Werten des Zeitraums 1901–1950 beobachtet. Aus den Niederschlagsänderungen resultiert für viele Gebiete eine Änderung des Klimatyps vom feuchten subhumiden Typ zum semiariden Typ. Ebenso stellte sich heraus, dass infolge des abnehmenden Niederschlagstrends, besonders im Oktober, die Bauern in diesem Staat langsam ihren Reisanbau ändern müssen – von langzeitigen lokalen Genotypen auf mittellange Sorten. Dies ist die Anpassung an den Klimawandel auf Seiten der Bauern.

1. Introduction

It has been well established now that due to emission of green house gases the global temperature is increasing and during last century the global temperature had increased by about 0.57 °C. The Intergovernmental Panel on Climate Change (*IPCC* 2007) reported that eleven out of thirteen years (1995–2007) rank among the twelve warmest years in the instrumental record of global surface temperature.

This clearly shows that the increase in the global temperature is, in fact, a totality of changes at different regions/locations. For example, the temperatures in different parts of the globe during the period 1976–2000 increased from less than 0.2 to more than 1.0 °C. Also there are some regions in the Southern Hemisphere where the temperatures during the period had decreased in the same order as that of increase in temperature in Northern Hemisphere. This clearly indicates that the global change phenomenon is a result of regional changes, and assessment of regional climate changes is the only way to develop mitigation and adaptation strategies.

As climate change has become a real threat, more and more researchers are working on the regional variations of climate and trying to study the impact on social, economical and environmental fronts. Especially in agrarian countries like India, the impact on agriculture is very important. More over, being a very large country, India is considered as a sub-continent and there are considerable variations in the climate change scenarios in different regions. Hence, for assessment of impact of climate change or developing strategies for adaptation and mitigation, regional scale analysis becomes the necessity for Indian sub-continent.

2. Indian Sub-Continent Scenario

Earlier studies on long-term trends of surface temperature covering the period of 1900–1982 from 73 well distributed gauging stations reported a warming trend of 0.04 °C per decade for the period 1901–1982. Later Rupa Kumar et al. (2006) from a network of 31 well-distributed representative stations for the period 1901–2000 studied the trends in mean annual temperatures over India and found warming trends during all the four seasons with higher rate of temperature increase during winter and post-monsoon seasons compared to that of annual (Tab. 1).

Tab. 1 Trends in Mean Surface Air Temperatures over India during 1901–2000

Season	Trends (°C/Decade)
Annual	0.03[1]
Winter	0.04[1]
Pre-Monsoon	0.02[1]
Monsoon	0.01
Post-Monsoon	0.05

[1] Significant at 95 % and more (Source: Rupa Kumar et al. 2002)

Indian Institute of Tropical Meteorology, Pune, India (*IITM* 2009a) had developed time series of monthly temperatures for 7 sub-regions of the country for the period 1901–2003. Using the data, the time trend analysis of maximum and minimum temperatures for all the sub-regions along with all India averages have been worked out as shown in Table 2.

It can be seen that the maximum temperatures are in increasing trends in all the sub-divisions in majority of the months as compared to minimum temperatures. Tyagi (2009) while assessing the climate change in India also pointed out that the warming is primarily due to rise in maximum temperatures. Thus, the rise in the maximum temperatures is more in the Indian sub-continent as compared to minimum temperatures in different sub-divisions, especially North Central and North East Sub-Divisions of India where rice is the main crop during wet season.

Studies were carried out using crop simulation modeling with increased temperatures scenario by 1 °C during reproductive stage of rice crop under Raipur conditions, and it was found that the production potential of rice crop decreases from 9.35 t/ha to 8.89 t/ha under irrigated conditions and from 8.93 t/ha to 8.43 t/ha under rainfed conditions (Fig. 1).

Similarly it was found that if the temperature increases by 1 °C during the maturity stage of rice crop the productivity of rice decreases by about 1.5 to 1.8 t/ha. (Fig. 2) and the duration of maturity period decreases by about 8 days.

3. Temperature Change Impact on Wheat Crop

Because of the increasing trends of temperatures during November and December months, the growth rates of the area of wheat crop in Chhattisgarh state started decreasing during last two decades and they became negative during the decade 1991–2000 as shown in Figure 3. In other words, the wheat area in the state had moved towards north during last decade due to increased winter temperatures.

Tab. 2 Coefficient of determination (R^2) of the time trend equations of monthly maximum and minimum temperatures for 7 sub-divisions and at country-level

Month	Temperature	All India	East Coast	Interior Peninsula	North Central	North East	North West	West Coast	Western Himalaya
Jan	Max. T	0.04	0.19[2]	0.05	0.00	0.04	0.00	0.39[1]	0.05
	Min. T	0.00	0.01	0.01	0.00	0.00	0.08	0.01	0.00
Feb	Max. T	0.15[2]	0.25[1]	0.17	0.07	0.18[2]	0.04	0.41[1]	0.09
	Min. T	0.06	0.07	0.05	0.03	0.09	0.00	0.01	0.07
Mar	Max. T	0.04	0.13	0.03	0.02	0.04	0.01	0.22[1]	0.02
	Min. T	0.03	0.12	0.14	0.01	0.00	0.00	0.01	0.03
Apr	Max. T	0.07	0.05	0.02	0.04	0.06	0.03	0.19[2]	0.08
	Min T	0.01	0.04	0.01	0.00	0.00	0.00	0.01	0.02
May	Max. T	0.01	0.01	0.00	0.00	0.04	0.00	0.15	0.00
	Min. T	0.00	0.02	0.00	0.00	0.00	0.00	0.03	0.00
Jun	Max. T	0.00	0.00	0.00	0.00	0.06	0.00	0.10	0.01
	Min. T	0.01	0.00	0.00	0.03	0.02	0.04	0.30	0.00
Jul	Max. T	0.04	0.05	0.05	0.03	0.08	0.00	0.19	0.00
	Min. T	0.01	0.01	0.11	0.02	0.07	0.03	0.02	0.00
Aug	Max. T	0.14	0.02	0.00	0.14[2]	0.40[1]	0.02	0.21[1]	0.00
	Min. T	0.00	0.01	0.07	0.01	0.00	0.00	0.05	0.04
Sep	Max. T	0.12	0.14	0.07	0.03	0.20[2]	0.03	0.29[1]	0.00
	Min. T	0.01	0.01	0.12	0.01	0.21[2]	0.00	0.09	0.00
Oct	Max. T	0.09	0.07	0.00	0.04	0.28[2]	0.01	0.22[1]	0.05
	Min. T	0.02	0.03	0.06	0.44[1]	0.00	0.00	0.02	0.07
Nov	Max. T	0.28[2]	0.35[1]	0.16	0.23[2]	0.48[1]	0.07	0.37[1]	0.06
	Min. T	0.12		0.05	0.19	0.14	0.01	0.02	0.11
Dec	Max. T	0.29[1]	0.44[1]	0.21[2]	0.15[2]	0.39[1]	0.09	0.60[1]	0.01
	Min. T	0.09	0.09	0.05	0.11	0.17[1]	0.00	0.02	0.07

[1] and [2] significant at 1 % and 5 % levels respectively

Thus, the farmers are adapting for the changes in the climate due to either changes in rainfall or temperature by changing the cropping pattern or crop varieties to suit the changed situation.

4. Rainfall Scenario

The scenario of the rainfall pattern in the Indian sub-continent during last century had been analyzed by Rao et al. (2009) and is shown in Figure 4. They reported that the rainfall during last century had increased by 1 to 12 % in most of the parts of India, especially in Western

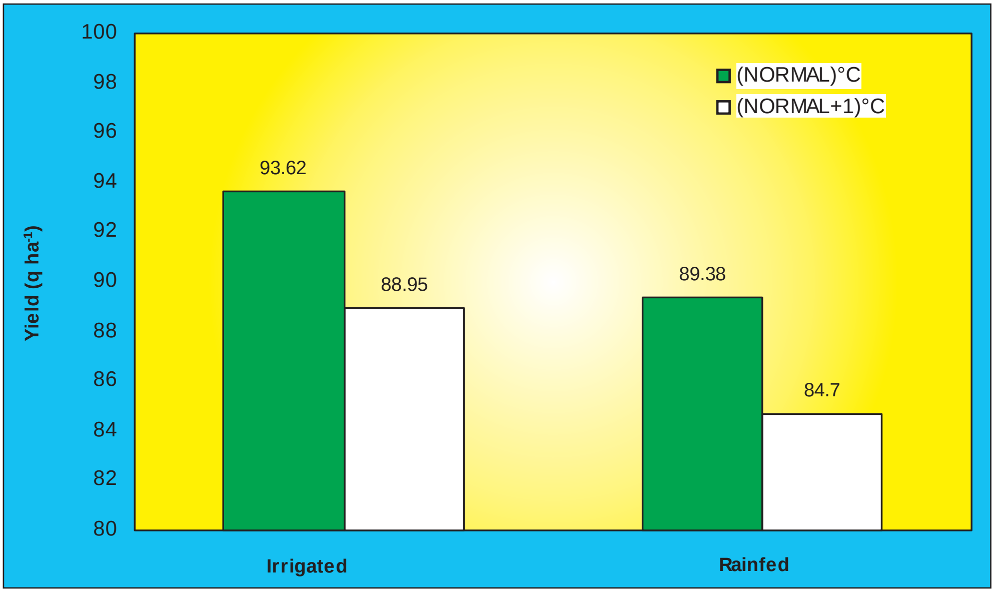

Fig. 1 Effect of increase of 1 °C during reproductive stage of rice crop of the productivity under irrigated and rainfed conditions.

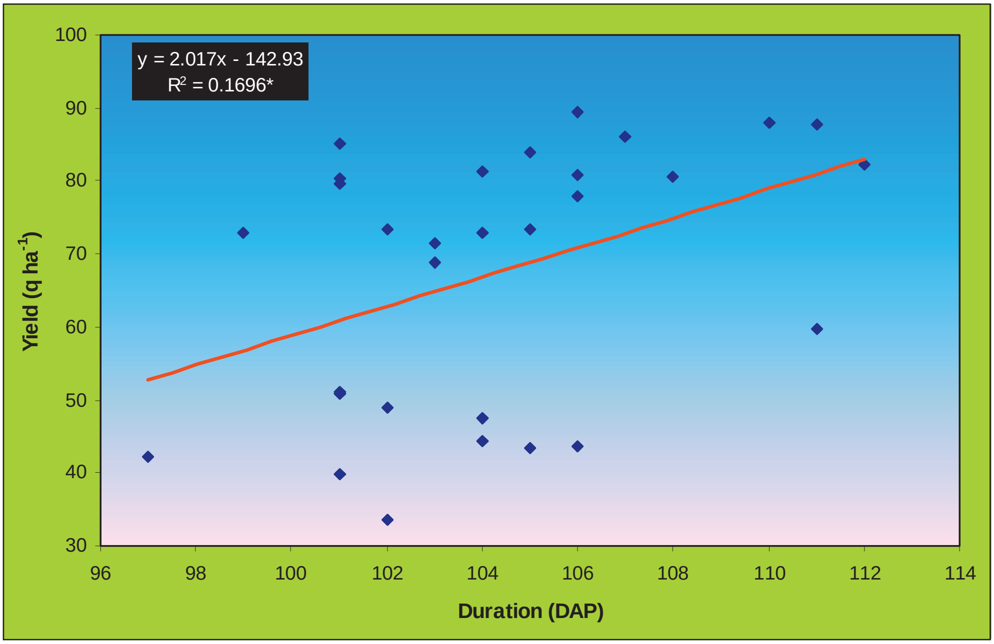

Fig. 2 Relation between temperature and crop duration during maturity period of rice crop.

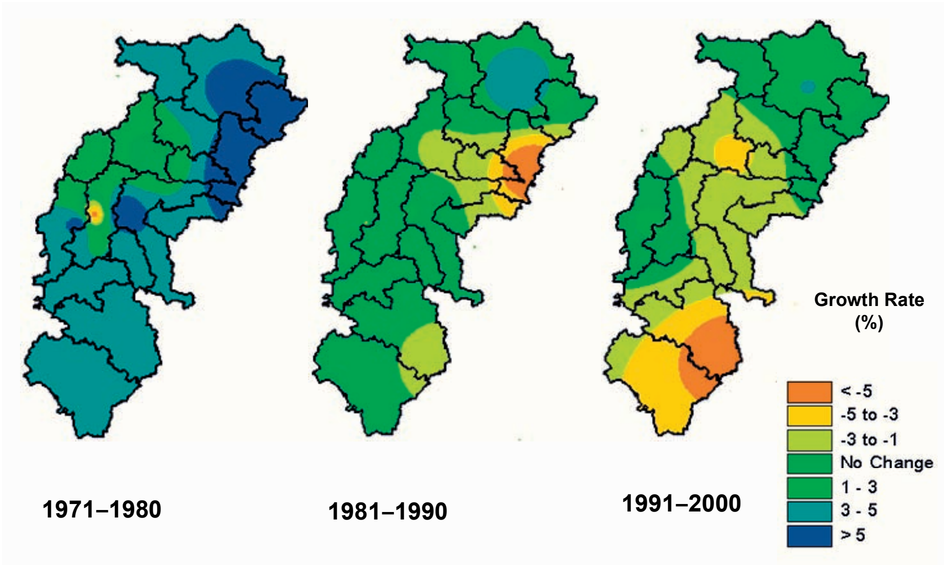

Fig. 3 Decadal changes in the growth rates area of wheat crop in Chhattisgarh

parts of Gujarat, Rajasthan, Maharastra, Jammu and Kashmir besides in Southern parts of the country. Interestingly, the rainfall had decreased in Central India, that is, in the states of Madhya Pradesh and Chhattisgarh as a whole. Besides, there was decreasing trend in parts of Bihar, Rajasthan, a small part in UP and NE States and Tamilnadu. This necessitated the analysis of sub-regional climate changes in those states where there is decreasing trend of rainfall.

Also Guhathakurta and Rajeevan (2008) studied the trends of rainfall pattern over India. They reported that 3 sub-divisions have shown decreasing trend and 8 sub-divisions in India have shown increasing trends of rainfall during last century.

Long term historical rainfall data series at various meteorological sub-divisions in India for the period 1871–2008 were prepared by Indian Institute of Tropical Meteorology (*IITM* 2009b) and are presently used to study the time trend analysis. In this study the time trend analysis for 29 sub-divisions in India was carried out for the period 1871–1960 and from 1961–2008. In fact, the period 1961–2008 is considered as the global warming period where the effect of climate change due to global warming is discernable. The average rainfall during these two periods along with the regression slope(b) of the time trend equations and the percentage decrease of rainfall during period have been computed and are shown in Tables 3 and 4, respectively.

From the Tables 3 and 4, it can be seen that in some sub-regions the rainfall trend for the period of 1871–1960 was positive but when the global warming period data (1961–2008) was examined there was a change from positive to negative trend in the annual rainfall pattern. For example in Haryana and Punjab, the rainfall was in increasing trend with 3.0 and 7.6 % respectively during the period 1871–1960 but it changed to negative trend during the period 1961–2008. Reverse is the case for Bihar in North India and Rayalaseema sub-division in the

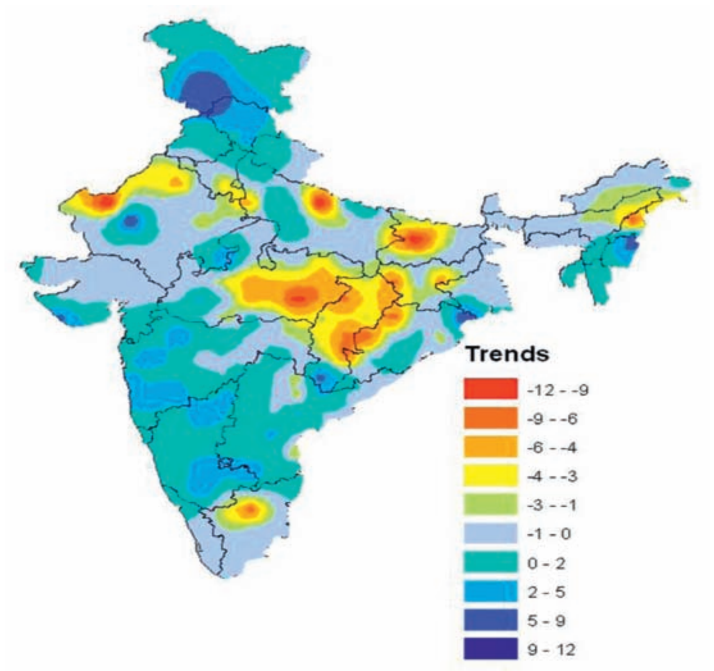

Fig. 4 The trends of rainfall pattern in different states and regions of India during last century (Rao et al. 2009)

South India. For these two sub-regions during the period of 1871–1960, the rainfall was in negative trend with 2.9 and 1.3 % respectively but it changed from negative trend to positive trend with +10.5 and +17.6 % respectively during the period 1961–2008. In Gujarat, there was no trend in the rainfall data if the entire period is considered but if the period 1961–2008 is considered there is a considerable positive trend. For the sub-divisions Nagaland, Bihar, Madhya Maharashtra, Marathwara and Rayalaseema the rainfall trend changed from negative in the period 1871–1960 to positive during the period 1961–2008. But in Haryana, Punjab, East Rajasthan, Telangana, North Interior and South Interior Karnataka, Assam and Meghalaya, West Uttar Pradesh, and Kerala states the rainfall pattern changed from positive trend during the period 1871–1960 to negative trend during the global warming period. These details are shown in Table 5.

5. Chhattisgarh Sub-Region Scenario – A Case Study

In view of the above, detailed analysis of rainfall pattern in different locations of Chhattisgarh state was carried out using long term rainfall records of about 85 stations in the state. The analysis indicated that the rainfall is in decreasing trend in several places during last 20th century. For example, at Kanker in the southern parts of Bastar, the rainfall had decreased from about 1550 mm in 1920's to less than 1000 mm during 2000 (Fig. 5).

Tab. 3 Sub-division wise average rainfall and slope of time trend equation and the corresponding change in rainfall for the period 1871–1960 in India

Sub-Division	Average rainfall (mm)	Regression equation slope (b)	Percentage decrease
Assam and Meghalaya	2,385.6	+1.91	+7.2
Sub-Himalaya West Bengal	2,483.3	+1.15	+4.2
Gangetic West Bengal	1,519.2	+0.31	+1.8
Nagaland	2,020.1	−0.343	−1.5
Orissa	1,503.3	+0.998	+0.6
Jharkhand	1,358.1	+0.52	+3.5
Bihar	1,230.4	−0.40	−2.9
East Uttar Pradesh	1,038.3	+0.53	+4.6
West Uttar Pradesh	879.0	+.04	+0.4
Haryana	542.2	+0.18	+3.0
Punjab	615.0	+0.52	+7.6
West Rajasthan	289.9	+0.01	+0.3
East Rajasthan	698.9	+0.945	+12.16
West Madhya Pradesh	952.7	+0.70	+6.61
East Madhya Pradesh	1,288.2	+0.09	+0.6
Gujarat	923.7	+0.63	+6.1
Saurashtra	468.0	+0.24	+4.6
Madhya Maharashtra	736.7	−0.02	−0.02
Marthwada	825.6	−0.06	−0.6
Vidhrabha	1,102.7	+0.506	+4.1
Chhattisgarh	1,417.2	+1.14	+7.2
Coastal Andhra Pradesh	962.9	+0.379	+3.5
Telangana	877.3	+1.66	+17.0
Rayalaseema	704.9	−0.106	−1.3
Tamilnadu	920.6	+0.175	+1.7
North Interior Karnataka	824.5	+0.588	+6.4
South Interior Karnataka	883.1	+0.548	+5.6
Kerala	2,827.7	+2.93	+9.33
Coastal Karnataka	3,263.7	+3.39	+9.3

In case of Raigarh (Fig. 6), the rainfall decreased from 1800 mm during the beginning of 20th century to about 1200 mm at the end of the century.

In Mahasamund district in Eastern part of Chhattisgarh the rainfall had deceased from about 1800 mm in the beginning of the 20th century to as low as 800 mm at the end of the century.

Thus, there is a spatial variability of decreasing trends of rainfall in Chhattisgarh state. Looking into this, the decreasing pattern of rainfall from period 1901–1950 to the 1951–2000 period was analyzed for all the rain gauge stations as shown in Figure 8.

It can be seen from Figure 8 that the rainfall had decreased by about 35 % in Mahasamund district, and it had decreased by about 30 % during the period 1951–2000 as compared to the normal values of the period 1901–1950 in many parts of Chhattisgarh state. It was only in

Tab. 4 Sub-division wise average rainfall and slope of time trend equation and the corresponding change in rainfall for the period 1961–2008 in India

Sub-Division	Average rainfall (mm)	Regression equation slope (b)	Percentage decrease
Assam and Meghalaya	2,284.6	–0.19	–0.4
Sub-Himalaya West Bengal	2,485.2	+3.3	+6.2
Gangetic West Bengal	1,594.7	+8.05	+23.7
Nagaland	1,930.5	+2.66	+6.5
Orissa	1,149.1	+5.22	+21.3
Jharkhand	1,327.6	+3.3	+11.7
Bihar	1,221.9	+2.27	+10.5
East Uttar Pradesh	1,007.2	+0.35	+1.7
West Uttar Pradesh	816.5	–1.17	–6.7
Haryana	590.3	–0.57	–4.5
Punjab	690.1	–1.98	–13.4
West Rajasthan	302.7	+0.03	+0.5
East Rajasthan	660.4	–2.04	–14.5
West Madhya Pradesh	923.1	–3.90	–19.9
East Madhya Pradesh	1,194.8	–0.78	–3.1
Gujarat	891.4	+3.5	+18.3
Saurashtra	479.0	+1.78	+17.5
Madhya Maharashtra	743.3	+1.28	+8.1
Marthwada	844.5	+0.74	+4.1
Vidhrabha	1,052.4	–0.55	–2.5
Chhattisgarh	1,246.9	–1.76	–6.6
Coastal Andhra Pradesh	1,014.3	+2.27	+10.5
Telangana	911.8	–2.84	–14.7
Rayalaseema	752.1	+2.82	+17.6
Tamilnadu	943.2	+0.81	+4.0
North Interior Karnataka	843.9	–1.74	–9.7
South Interior Karnataka	876.1	–0.18	–1.0
Keraka	2,772.2	–2.25	–3.8
Coastal Karnataka	2,988.9	–8.29	–13.3

and around western parts of the state, that is, Rajnandgaon, where the decrease in rainfall was the least or in fact it increased by 1–2 % during the last century. Rajnandgaon and Kawardha districts in the state come under rain shadow areas.

6. Climate Change

As a consequence of changing rainfall patterns, the general climate type in most of the stations in the state have changed from *sub-humid* type of climate to *semi-arid* type of climates while at Mahasamund district the climate is changing from *moist-sub-humid* to *semi-arid* type of climate and the tend is towards arid type of climate (Fig. 9).

Tab. 5 The sub-divisions where there is a change in rainfall trend during the period 1961–2008 as compared to the total period of 1861–2008

Sub-division where the trend changed from positive to negative				Sub-divisions where the trend changed from negative to positive			
Haryana	+3.0	to	– 4.5 %	Nagaland	–1.50	to	+6.5 %
Punjab	+7.6	to	–13.4 %	Madhya Maharashtra	–0.02	to	+8.1 %
East Rajasthan	+12.2	to	–14.5 %	Marathwada	–0.6	to	+4.1 %
Telangana	+17.0	to	–14.7 %	Bihar	–2.9	to	+ 10.5 %
North Interior Karnataka	+4.3	to	–9.7 %	Rayalaseema	–1.3	to	+17.6 %
South Interior Karnataka	+1.1	to	–1.0 %				
Kerala	+9.3	to	–3.8 %				
Assam and Meghalaya	+7.2	to	–0.4 %				
West Madhya Pradesh	+6.6	to	–19.9 %				
East Madhya Pradesh	+0.6	to	–3.1 %				
Vidharbha	+4.1	to	–2.5 %				
Chhattisgarh	+7.2	to	–6.6 %				
West Uttar Pradesh	+0.4	to	–6.7 %				
Coastal Karnataka	+9.3	to	–13.3 %				

In the rest of the Sub-Divisions same trend continued.

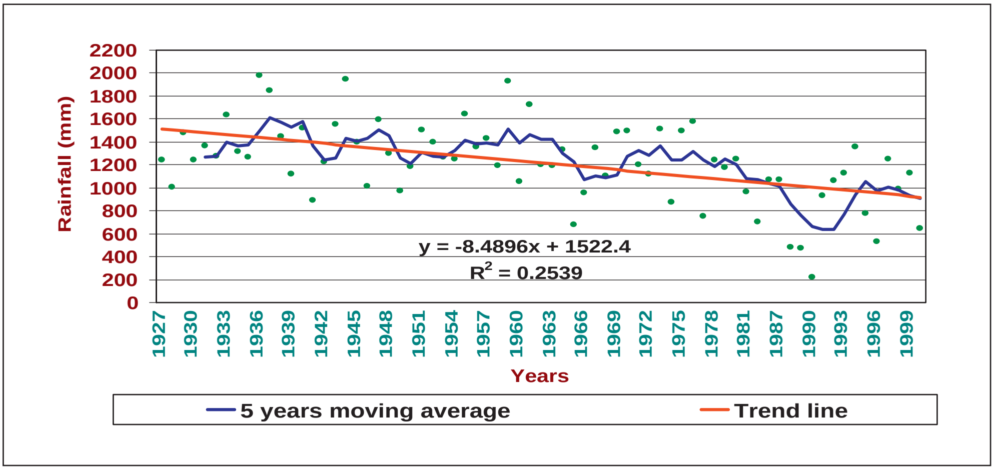

Fig. 5 Annual rainfall pattern and its trend at Kanker

7. Impact of Rainfall Changes

The rainfall pattern in different months was also analyzed, and it was found that the pre- and post-monsoon rainfall pattern is in decreasing trend in the state. The pre-monsoon rainfall, occurring due to thunderstorm activity, is very useful for summer ploughing of rice fields. The summer ploughing has two advantages. Firstly, it exposes the seeds of weed and eggs of

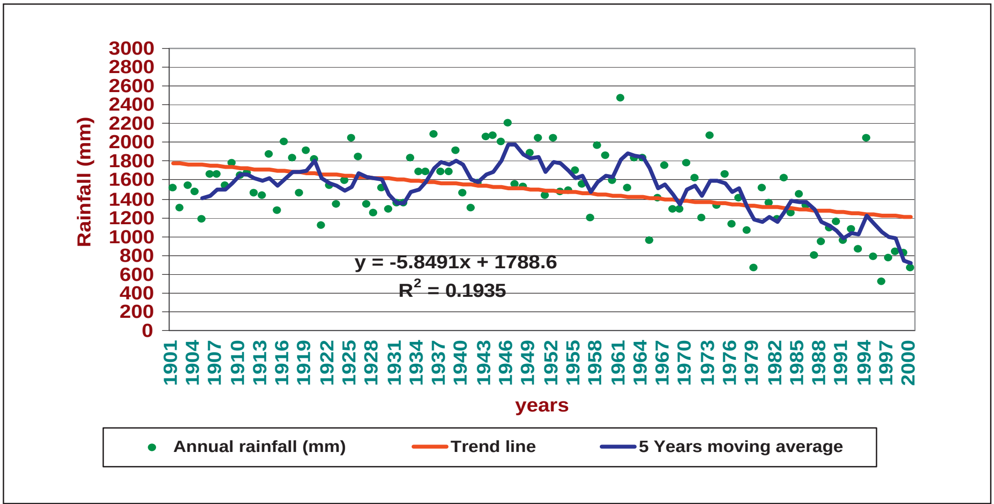

Fig. 6 Annual rainfall pattern and its trend at Raigarh

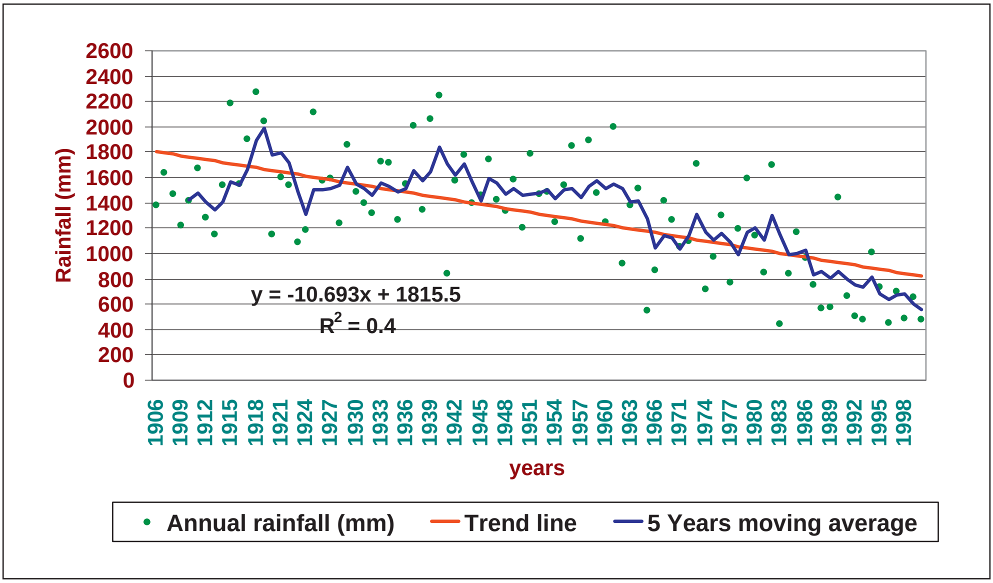

Fig. 7 Annual rainfall pattern and its trend line at Mahasamund

insect lying in the soil and due to very high soil temperatures after the storm during summer season (> 70 °C) the seeds and eggs of insects get desiccated. As a result, the weed and insect infestation in the rice fields are the minimum in pre-ploughed soils. Secondly, in the pre-ploughed fields farmers sow the rice crop immediately after the onset of monsoon rainfall and therefore, they save the time. Thus, due to the decreasing trend of pre-monsoon rainfall during

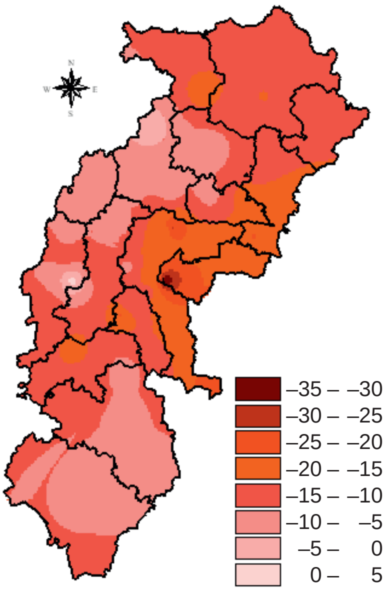

Fig. 8 Percentage decrease in rainfall over Chhattisgarh during the period 1951–2000 as compared to the period 1901–1950

summers, the crop sowing date is getting delayed, as the fields are to be prepared only after receiving the monsoon rains. This affects the crop growing season and it is getting reduced.

8. Adaptability to Climate Change

The decreasing trends of October rainfall is responsible for decreasing area under long duration local varieties and farmers are advised to take early or medium duration varieties of rice in place of long duration local varieties like Safri, Chapti or Mahsuri which flower in October and mature by November end.

During last 6 years, the area under long duration local varieties of rice had decreased from 1.581 million ha to 1.25 million ha under direct seeded method and the trend is continuing. The state government policy is also encouraging the farmers for taking early or medium duration varieties for increasing cropping intensity. This is the adaptability to the changing climate conditions in the state.

Tab. 6 Adaptation for changing rainfall pattern by the farmers of Chhattisgarh state by adapting high yielding medium duration rice varieties in place of local long duration varieties (* Area in '000 ha)

Year	Local varieties				Improved varieties			
	Transplanted		Direct seeded		Transplanted		Direct seeded	
	I	RF	I	RF	I	RF	I	RF
2008	35.9	130.9	168.2	1,253.5	375.7	986.2	686.6	982.6
2002	42.3	133.9	198.2	1,581.2	231.0	353.2	308.0	848.7

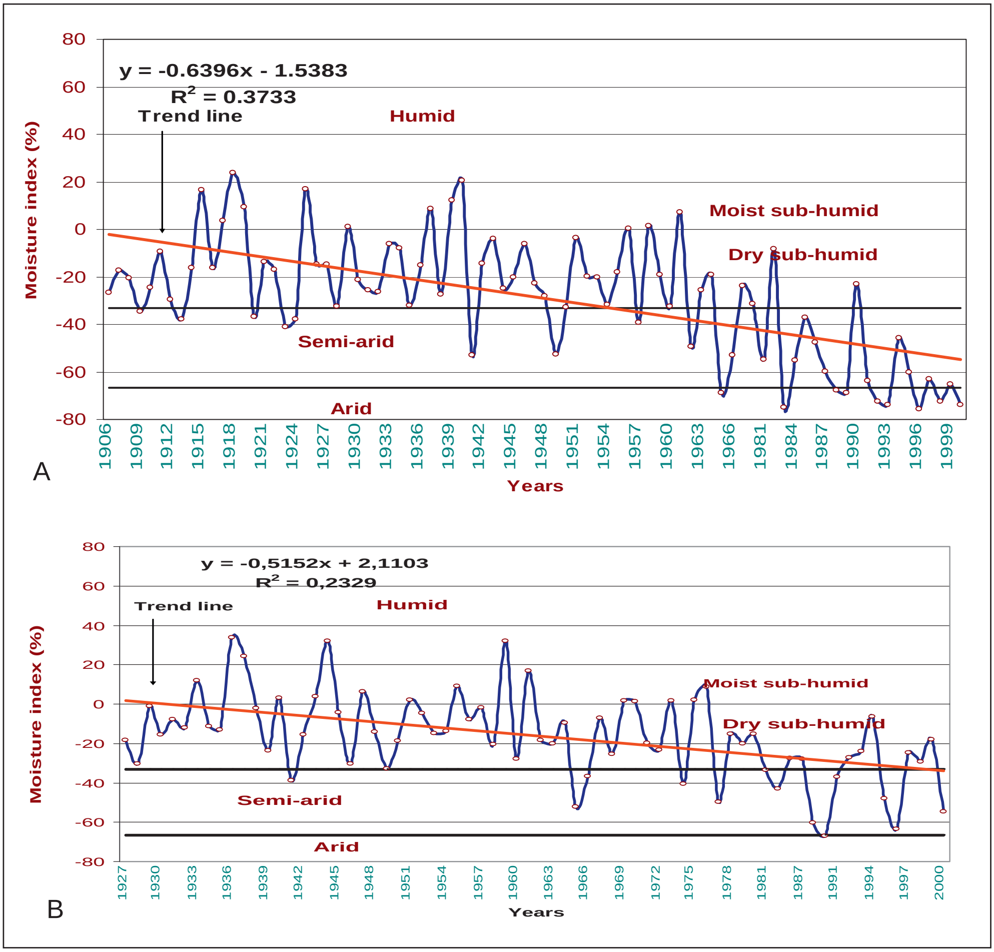

Fig. 9 Climate change in two districts of Chhattisgarh. (*A*) Kanker (*B*) Mahasamund

9. Conclusion

In Indian, being a large country, there are spatial variations not only in various climatological parameters but also its variabilities and changes. Sub-divisional analysis of monthly maximum and minimum temperatures for 7 sub-divisions in India revealed that the increasing trends of temperatures are not uniform in all sub-divisions but varied differently. A perusal of the coefficient of determination (R^2) of the time trend equations of both maximum and minimum temperatures shows that the rise in maximum temperatures is more as compared to minimum temperature that too in West-coast, North-east and North-central sub-divisions of India. Also the increasing trend is more during winter months than in summer months. An analysis of decadal growth rates wheat area for Chhattisgarh state in Central India revealed that the growth rates have become negative during the decades 1981–1990 and 1991–2000 inferring that the wheat zone is moving towards north in this part of India. In fact, this part of India is the southern limit of wheat zone of the country. The impact of increased temperatures on rice production was studied using crop simulation models, and it was found that an increase of temperature by 1 °C at reproductive stage can reduce the potential yield of rice from 9.35 t/ha to 8.89 t/ha under irrigated and from 8.93 to 9.43 t/ha under rainfed conditions. Similar effect was also found when the temperatures increase during maturity stage.

Regarding rainfall variability, the rainfall analysis was carried out for 29 meteorological sub-divisions for the period 1871–2008. It was found that in 14 meteorological sub-divisions the rainfall trend changed from positive trend during the period 1871–1960 to negative during the period 1961–2008. In 4 sub-divisions the trend changed from negative to positive during the same period. The period 1961–2008 is considered as the global warming period as most of the significant changes started from the beginning of this period.

As a case study detailed analysis of monthly rainfall for Chhattisgarh sub-division was carried out, and it was observed that in Chhattisgarh the rainfall had decreased from 35 to 0 % in different parts of the state during the period 1951–2000 as compared to the normal values of the period 1901–1950. As a consequence of the changes in rainfall the climate type is also changing from moist sub-humid type to semi-arid in many places. It was also found that due to decreasing trend of rainfall, especially in October month, the farmer are slowly changing the rice cultivation from long duration local genotypes to medium duration varieties in this state. This is the adaptation for climate change from the farmers side.

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Observed and Projected Sea Level Rise, Impact on the Pacific and Indian Tropical Islands

Gérard Beltrando (Paris, France)

With 3 Figures

Abstract

The global sea level shows an upward trend since the XIX middle century, with acceleration since the 1980's. This trend, which varies in time and space, is expected to continue in the future decades and the tropical islands constitute a pertinent location to observe this evolution. The increased marine submergence, especially during strong disturbed weather (Hurricane), will weaken sandy beaches, atolls and wetlands already affected by various anthropogenic activities. Although the uncertainties of General Climatic Models concerned authorities have different possibilities of response between mass population displacement and protection from the elements.

Zusammenfassung

Seit Mitte des 19. Jahrhunderts kann ein Anstieg des Meeresspiegels beobachtet werden, der sich seit den 1980er Jahren beschleunigt hat. Es wird erwartet, dass sich dieser Trend mit seinen raum-zeitlichen Veränderungen auch in Zukunft fortsetzt. Diese Entwicklung kann auf tropischen Inseln besonders gut beobachtet werden. Eine vermehrte Überflutung insbesondere bei tropischen Störungen (Hurrikane) betrifft Sandküsten, Atolle und Feuchtgebiete, die sowieso schon durch zahlreiche anthropogene Aktivitäten belastet sind. Trotz der Unsicherheiten der Klimamodelle haben die betroffenen Regierungen verschiedene Optionen, um auf diese Bedrohung zu reagieren, die zwischen einem Massenexodus der Bevölkerung und Maßnahmen des Küstenschutzes variieren.

1. Introduction

Relatively stable for nearly 3,000 years, the sea level of the global ocean shows a positive trend since the XIX middle century on the main effect of expansion by warming water and decrease volume of continental ice (Cabanes et al. 2001, Duyrgerov and Meier 2005) and for many authors, as Levitus et al. (2005), this acceleration should continue in the future.

This phenomenon adds to the effects of marine submergence resulting in an atmospheric disturbances episode (reduced pressure and strong winds pushing water towards the coast), a phase with a high tidal coefficient, it will cause a major coastal flooding of the lower cost. The islands are a good place for observation of this evolution and its consequence on sandy beaches, atolls and wetlands which are also affected by the effects of other anthropogenic activities. Moreover, since the middle of the XX century, increase of population and development of economic activities on the coast also occurred at a faster rate than the world average rate. Vulnerability of affected coastal areas also depends on other factors such as coastal erosion, itself largely dependent on human actions on the environment (inland deforestation, drawing of costal material ...). But vulnerability also depends on each state or local government's capacity to anticipate this phenomenon by protecting, adapting or shifting concerned population. Choices have to be made, requiring good knowledge of local and regional situations, taking all national issues (rural decline, cost-utility…) into account.

In view of all these economic, environmental, social and political reasons, low-latitude islands turned out to be an ideal "sentinel" area to observe and quantify physical processes and their dynamics as well as a range of society adaptations.

2. The Positive Trend of Sea Level Rise

Since the XIX middle century, the sea level is measured by few tide gauges whose number has increased specially after the second half of the XX century. However, data are affected by some imprecision: the geographical distribution of tide gauges used does not allow to correctly sample the geographical variability of sea level rise (many worldwide regions are not equipped with gauges); on the other hand, the dynamics of the earth's crust (in particular subsidence ...) over a couple of decades is not always well known, especially on the small low latitude islands). Similarly, observed water temperatures, especially in the superficial layer of the ocean, show an increase in sea surface cumulated heat.

Since 1993, TOPEX-Poseidon (until 2006), Jason-1 (2001–2008) and Jason 2 (since 2008) altimetric satellites have regularly been measuring the sea level with an estimated average of 2 cm accuracy over a month after correction. These data showed that the mean global ocean sea level rose by about 3.4 mm/y (Cazenave et al. 2008), which is significantly higher than that calculated from measurements by tide gauges over the XX century. However, these measurements also showed that the increase in water level is not uniform (Fig. 1): for example, actually the increase is less important and more variable in the Pacific Ocean, where ocean-atmosphere phenomena such as the El Niño-Southern Oscillation has an important role on the sea level.

3. Sea Level Rise Factors and Predicted Trends for the XXI Century

At a multi-decade's scale (excluding locally perceptible descendant or ascendant of the continental mass), two factors may explain a large percentage of the sea level rise:

– Those resulting from water temperature variation expressed by density and volume;
– Those resulting from water exchanges between reservoirs (atmosphere, inland waters, mountain glaciers …).

Using the latest satellite measurements, the sea level rise seems occurring at a faster rate than the estimated rise made for decades prior to the XX century using tide gauge measurements. To explain this recent trend, Duyrgerov and Meier (2005) indicated that contribution of fresh water is more important since the early 1990s, partly due to the mass loss from Greenland. According to calculations by Rignot and Kanagaratnam (2006), ice surface for the Greenland icecap was reduced by 91 km^3 in 1996, 138 km^3 in 2000 and 224 km^3 in 2005. Two third of these losses are due to acceleration of flow velocities of glaciers, the other part to their melting. Cazenave et al. (2008) estimate that the mean elevation of the ocean current level would equally be due to thermal expansion of warming ocean and to melting of polar ice caps and mountain glaciers.

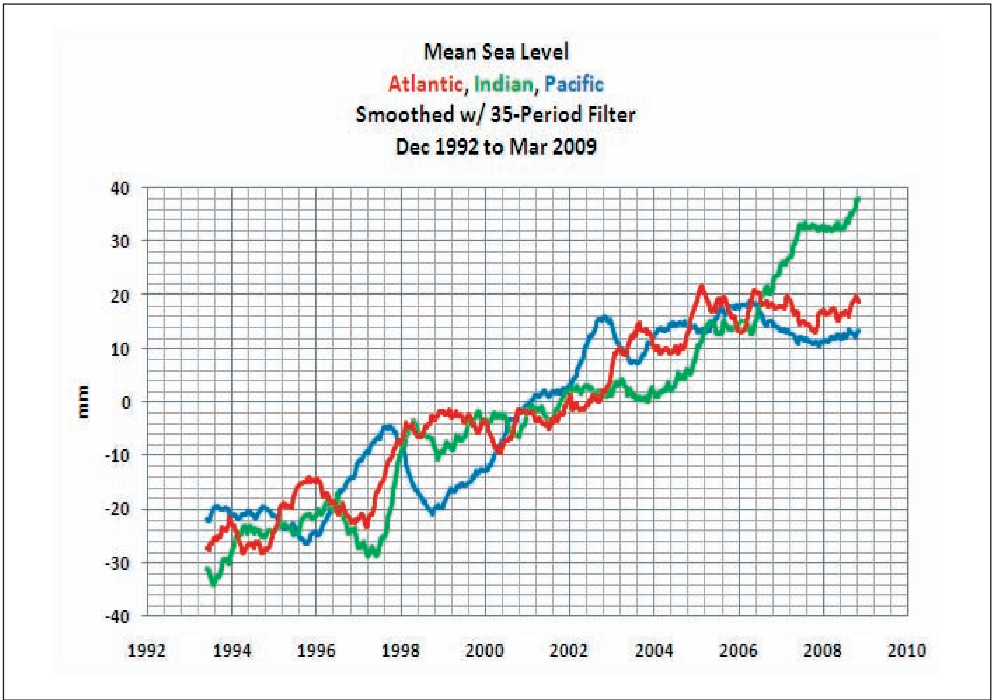

Fig. 1 Atlantic, Indian, and Pacific Ocean sea levels from December 1992 and March 2009. Data has been smoothed with a 35-month filter. Notes from Bob Tisdale on Climate Change and Global Warming.

Newest technology used by researchers (numerical models, satellite observation …) revealed the existence of regional (and seasonal) variability of sea level. However, factors that explain variability at regional scales and over periods of few years are not sufficiently understood (part of salinity and density of water for example). As a result, it's difficult to perform numerical simulations of the sea level regional evolutions over the future decades and quality of forecasts for the current century vary greatly from a variable to another.

3.1 A Very Likely Raising of Sea Level

The extreme range of recent sea level rise estimation of the *International Panel of Climatic Change* (*IPCC* 2007) for the end of the XXI century varies between 18–38 cm and 26–59 cm (with mean around 39 cm) depending on scenario (values are the average difference between the 1971–2000 period and the 2071–2100 period). However, recent publication of Grinsted et al. (2009) showed that the 2090–2099 IPCC projections of sea level rise are underestimated by roughly a factor 3 (Fig. 2).

3.2 For Tropical Turbulence, a Lack of Consensus at the Climate Scale

The response of tropical disturbances to global warming is being investigated although no scientific conclusion has yet been released. The IPCC reports (2007) underscore the lack

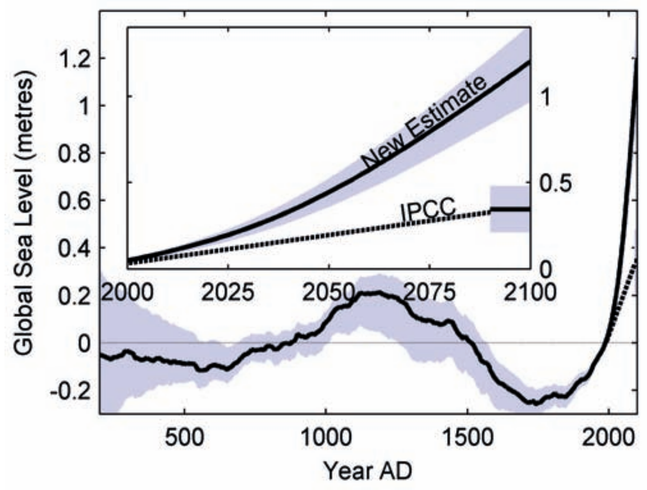

Fig. 2 Projected sea level based on IPCC scenario A1B using temperature reconstructions by Moberg et al. (2005, in Grinsted et al. 2009)

of convergence in the responses of various (GCM) used in the scientific community. This reflects the complexity of cyclonic activities (typhoon, hurricane …), which involves massive ocean-atmosphere coupled system mechanisms that cannot be properly represented in the models currently available. Some simulations provided an overall increase in the frequency and/or intensity of typhoons for the XXI century, while others predicted a decrease (Kushnir et al. 1997, Wang and Swail 2001, Gönnert 2004, Loranzo et al. 2004, Chauvin et al. 2004). Indeed these uncertainties have been the current foundation for scientific debate.

These results showed that GCM are able to integrate parts of the physical variability but they were not able to incorporate all local processes. A margin of incertitude is always present.

4. Some Possible Consequences of Sea Level Rise for Humankind

Sea Level Rise has varying impacts on coastlines. For the case of coastal lagoons, Titus (1990) indicates that three scenarios may theoretically occur:

– When neutralization is possible, the marsh remains into place although forced to migrate towards the land side, which is feasible only with low coastal topography and no polder dikes for example;
– When vertical sedimentation does not compensate for rising sea levels, the marsh is doomed to disappear by flooding;
– Finally, in case of strong vertical and lateral sedimentation, not only rising of sea level will have no effect, but the swamp will even continue to grow at the expense of the sea.

Large dunes protect many coastal areas from direct attack of storms similarly to mangroves or wetlands which prevent from water penetration by increasing friction as well as blocking waves. In a context of rising sea levels, removal or damage of protective barriers leads to amplified vulnerability of concerned sites (Fig. 3). This factor introduces an additional difference between regions subject to seasonal strong tropical disturbances, and those subject to winter storms on the margin of tropical areas, compared to those who are less affected by storms.

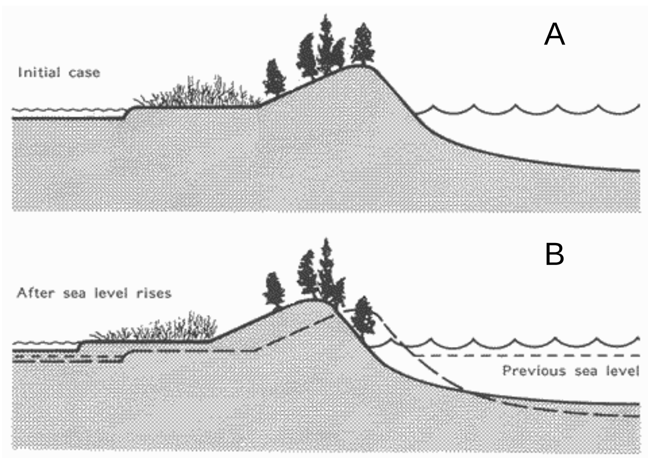

Fig. 3 Compartment of an island barrier at a sea level rise (Titus 1990). (*A*) initial cases; (*B*) after sea level rises

If the XXI century projection for the evolution of level rise is confirmed, several million people living on the coasts will be forced to adapt, to protect themselves or to abandon the coastal regions before they get submerged. In some cases, this rise will extend salt areas in groundwater, causing a decline in freshwater resources, which may be source of conflicts and economic recession.

4.1 Some Examples in Indian Ocean Islands

In the Indian Ocean small island states, where flooding had already important economic consequences, heavy protection has often been the response (Seychelles, Maldives, ...). Cazes-Duvat (2005) noted that since three decades, hazard and vulnerability have increased due to the important growth rate of inhabitants in coastal areas. In the western Indian Ocean islands and archipelago, tourism industry is first affected by these environmental changes and that makes the coast particularly vulnerable.

In the Maldives archipelago (more than 200 indigenous islands, 87 tourist islands and between 800 and 900 uninhabited islands), flooding has long been known. Low islands are characterized by small sizes (0.2 to 5 km^2 in general) and low altitudes (< 4 m in most cases). Similar to other archipelagos, these islands represent a type of sedimentary body, particularly vulnerable to flood risk.

Malé, the capital city, occupies the entire island surface (a 2 km long by 1.5 wide rectangle) situated at the reef coral barrier level. The city is surrounded by ports and dykes that protect the 80,000 inhabitants from the 2 to 3 m high waves. Concerned about this risk, the government has begun the construction of a new artificial island at 2 m above sea level, Hulumalé, intended for future transfer of residents from the lowest and most vulnerable atolls, including some of the capital inhabitants. Malé is currently one of the most densely populated cities in the world. In the longer term, such high cost involved measures will certainly be difficult to generalize and transfer of population to other territories may have to be considered.

In this country, planning is exclusively designed for tourism, which may lead to important economic and environmental consequences. Rufin-Soller (2005) showed that the natural uninhabited islands were traditionally used by the indigenous population because they provide first need materials: coconut, sand for construction (although this is theoretically forbidden) or "alevins" (for non-industrial tuna fishing). Damage to uninhabited islands may have an impact on the economic chain and the island environment.

Also in the Indian Ocean, the Mauritian government has put in 1991 a Climate National Committee for helping in decision making in various economical sectors (agriculture, tourism, infrastructure, health, etc. ...). Regarding economical changes resulting from the sea level rise, a minimum distance of 81 m from beaches are required for the construction of hotels, camps and houses, electrical and phone cables are now buried; some dams are built, including one with a capacity of more than 26 million m^3 to collect maximum drinking water.

4.2 Some Examples in the Pacific Ocean Islands

For the entire South-Pacific Ocean, the projected sea level rise for the end of the century should be similar to the global average (0.35 m; Church et al. 2006). Many islands have small arable land and some already lack of fresh water. Hundreds of islands are inhabited including small islands (Micronesia …), consisting of low-lying atolls. Even in volcanic islands or mountainous terrain, the majority of population lives in coastal areas. The risk of flooding is important; however vulnerability is only due to rising sea levels.

Thus, Tuvalu, a small island state consisting of nine tiny atolls near Fiji Islands, is a vulnerable territory to environmental changes. Medias largely used the case of these islands to often hold climate change solely responsible for increase in flooding. However, Xue (2004) showed that the loss of land in Tuvalu was mainly the results of inappropriate human activities with coastal development and exploitation of aggregates in addition to the effects of cyclones. Moreover, all recent satellite altimetry measurement and tide gauge data do not confirm a rise in sea levels around Tuvalu islands. Rising sea level is certainly an aggravating factor, but it's not certainly the main factor. Consequence on Human activities and hurricanes are surely more responsible of damage on these islands where an important demographic growth rate is recorded and natural resources are limited.

Rising sea level also affect traditional cultivation such vegetables. Their root system does not tolerate the infiltration of salt water. Locally, this factor may be exacerbated by involuntary human actions such as the construction of an airport by the U. S. Army during the Second World War. The digging of corals for the construction of the runway originated the rise of sea water and hence the salinity of freshwater sources (Patel 2006). Flooding due to climate change, often considered as solely responsible, is certainly not the only factor in cause. Isolation, poverty in natural resources and low-lying territory make Tuvalu concerned by rising sea level. Consequences would be dramatic and adaptation very difficult.

5. Conclusion

The average sea level rise, estimated by *IPCC* (2007) between 18 and 59 cm (recent reviews provide larger estimates between 90 and 120 cm …) for the end of the XXI century begins to worry population and economic actors. The forecast announced about the mean elevation of sea level, shouldn't hide that in the short term are the phenomena of surges due to atmospheric turbulence (Hurricane) and who have by far the greatest danger to the coastline. Science is far from a consensus on some points but questions remain unanswered: with climate change, strong atmospheric disturbance will be more active? Will they always occur at latitudes where they occur today? ...

In all cases, even with the continuing uncertainty of GCMs, flooding by the sea on the part of the land is a risk that must be considered, and some communities are already taking steps to adapt the territory or ask questions for best anticipation.

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Regional Climate Change Scenarios in South America in the Late XXI Century: Projections and Expected Impacts

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With 6 Figures

Abstract

Regional climate change projections for the last half of the XXI Century have been produced for South America, as part of the CREAS (***C**enarios **RE**gionalizados de Clima Futuro da **A**merica do **S**ul*) regional project. Three regional climate models were used to project climate change scenarios for the IPCC A2 high emission scenario for 2071–2100. The projections show a consistent pattern of changes in circulation, rainfall and temperatures as depicted by the three models. There are indications that regions such of Northeast Brazil and central-eastern and southern Amazonia may experience rainfall deficiency in the future, while the Northwest coast of Peru-Ecuador and northern Argentina may experience rainfall excesses in a warmer future, and these changes may vary with the seasons. The three models show warming in the A2 scenario stronger in the tropical region, especially in the 5°N-15°S band, both in summer and especially in winter, reaching up to 6–8 °C warmer than in the present. Some experiences of applications on impact assessments using these climate change scenarios are also discussed.

Zusammenfassung

Die Untersuchung des regionalen Klimawandels in Südamerika für die letzte Hälfte des 21. Jahrhunderts ist ein regionales Projekt von CREAS (***C**enarios **RE**gegionalizodos de Clima Futero da **A**merica do **S**ul*). Drei regionale Klimamodelle wurden genutzt, um den Klimawandel in den IPCC A2 „Hohe Emissionen Szenarien“ für 2071 bis 2100 darzustellen. Die Ansätze zeigen in allen drei Modellen ein einheitliches Veränderungsmuster in der Zirkulation, im Niederschlag und in der Temperatur auf. Es gibt Indikatoren, die darauf hinweisen, dass in Zukunft in den brasilianischen Regionen im Nordosten, im Osten und südlich des Amazonas Niederschlagsdefizite zu erwarten sind, während die Nordwestküste von Peru und Ecuador sowie Nordargentinien, bei einem Temperaturanstieg, Niederschlagsüberschüsse erhalten werden. Die Variabilität kann saisonabhängig schwanken. Alle drei Modelle deuten auf eine stärkere Erwärmung hin, als in A2-Szenarien für die Tropen angenommen wird. Zwischen 5 °N – 15 °S können in den Sommermonaten, vornehmlich jedoch in den Wintermonaten, die Temperaturen um 6–8 °C höher liegen als heute. Ausgewählte Ergebnisse aus Studien zur Beurteilung von Einflüssen in den Darstellungen der Klimawandelszenarien werden diskutiert.

1. Introduction

The knowledge of changes in the meteorological fields (e.g. circulation, temperature, precipitation) in future climate scenarios rely upon the use of numerical models. A fundamental issue concerning the use of climate models to provide regional climate change scenarios is that of horizontal resolution. Despite the recent increase in computing power, Atmosphere-Ocean General Circulation Models (AOGCMs) are still run at horizontal grid intervals of 100 to 300 km. While this resolution is sufficient to capture processes and climate statistics down to the sub-continental scale (approximately a few thousand kilometers), it is not suitable for finer regional and local scales. At the regional scale there remains an urgent need for relevant, targeted projections of the regional climate change. Regional climate models (RCMs) are promising tools, which, when nested into a GCM, permit the derivation of GCM-consistent climate change scenarios with more regional detail and a more trustworthy representation of processes active during heavy precipitation (see reviews in Christensen et al. 2007a).

Adaptation to climate change is inherently a local and regional scale issue, and limited by the measure of confidence in the projected changes at these scales. Without appropriate regional projections of climate change, it is arguable whether regional adaptation strategies can be developed or implemented. Developing climate change scenarios at regional scale is, thus, an important component of understanding climate impacts under global warming conditions, with critical implications for climate change adaptation and mitigation.

In view of the pressing need for regional projections, much effort has been expended in recent years on developing regional projections through diverse methodologies (see reviews in Marengo et al. 2009a). Previous experiments on dynamic downscaling of future climate change scenarios in South America have been performed in various regions of South America (Marengo et al. 2009a, Solman et al. 2008, Garreaud and Falvey 2008, Soares and Marengo 2008). An integrated picture of various regional models used suggest future warming, with rainfall increases in southeastern South America, and decreases in the central and eastern Amazon and Northeast Brazil regions.

Various national and international projects have used RCMs to help quantify better regional climate change and provide regional climate scenarios for assessing climate change impacts and vulnerability: the UK Climate Impacts Programme (Hulme et al. 2002), the European Projects PRUDENCE (Christensen et al. 2007a, b, Gao et al. 2006, Giorgi and Pal 2004) and STARDEX (Haylock et al. 2006), ENSEMBLES (Hewitt and Griggs 2004) and North America (NARCCAP, Mearns 2004) are downscaling several GCMs to provide high resolution climate change scenarios for each region, though still only sampling a limited uncertainty range.

A similar initiative has been implemented in South America, CREAS (Marengo et al. 2009a). It aims to provide high resolution climate change scenarios in South America for raising awareness among government and policy makers in assessing climate change impact, vulnerability and in designing adaptation measures. CREAS follows PRUDENCE's strategy, and runs three regional models (Eta CCS, RegCM3 and HadRM3P, resolution of 50 km) nested in the public version of the atmospheric global model of the UK Met Office Hadley Centre HadAM3P. CREAS explores issues such as: the challenge of using regional climate projections to develop plausible scenarios for future changes at daily time scales for extreme events; an assessment of current methods of scenario development for regions where data is not available; assessments of regional impacts in key sectors in South America, and provides the basis for vulnerability assessments and the implementation of adaptation measures.

Therefore, the objectives of this paper are to show the regional climate change projections derived from CREAS for South America for 2071–2100 under the IPCC SRES A2 high emission scenario (Nakicenovic et al. 2000). In addition, we describe some applications of these regional climate change projections in some key sectors of Brazil and South America.

2. Methodology, Models and Experiments

2.1 Regional Models

The HadRM3P regional model was developed at the Hadley Centre and is part of the PRECIS (Providing Regional Climate for Impacts Studies) regional climate modeling system (see Jones et al. 2004), which also includes a detailed description of HadRM3P). HadRM3P has 19 vertical levels and a choice of two horizontal resolutions, 50 km as used in this study (and the standard resolution for larger areas) and 25 km for smaller areas and when higher resolution is particularly important. Lateral boundary conditions for HadRM3P are available from a range of model and observationally based sources and in this study are obtained from the HadAM3P GCM. Matching the SST forcing the HadAM3P and HadRM3P simulations for the present climate incorporated observed Greenhouse Gas (GHG) concentrations and CO_2 emissions and for the future incorporated GHG concentrations and CO_2 emissions taken from two contrasting emission scenarios.

The INPE Eta CCS is a climate version of the NCEP Eta model. The climate change version of the Eta model was prepared by Pisnichenko and Tarasova (2009a, b) for long-term climate integrations. Multiple modifications were made by Pisnichenko and Tarasova (2009a) in the model, such as: new programs to convert the HadAM3P output data to the Eta model data format; new restart programs; new SST update programs, new programs of the Sun's elevation angle, etc.

The Regional Climate Model (RegCM) Version 3 (Pal et al. 2007) is a limited area model built around the hydrostatic dynamical component of the National Center for Atmospheric Research (NCAR)/Pennsylvania State University Mesoscale Model version 5.0 (MM5) (Grell et al. 1993). The model is a primitive equation, hydrostatic, compressible; limited-area model with sigma-p vertical coordinate and the simulations were carried out with a vertical resolution of 23 levels. The soil-vegetation-atmosphere interaction processes are parameterized through BATS scheme (Biosphere-Atmosphere Transfer Scheme; Dickinson et al. 1989).

2.2 Experiment Design

Three integrations were carried out with HadAM3P for both time slices 1961–1990 (present climate) and 2071–2100 (future) for the A2 and B2 emission scenarios, starting from different initial conditions. The output of these runs was made available by the UK Hadley centre to be used as the boundary conditions for the downscaling performed here. The three RCMs ran for only one (but the same) pair of ensemble members and were integrated for the current and future climate periods. The first step in the evaluation of the dynamical downscaling results was the investigation of the consistency between the regional models outputs and GCM data used for driving the simulations (Giorgi et al. 1993).

The three RCMs were forced at its lateral and bottom boundaries by the output of HadAM3P, which was run using SST, SICE (sea ice) and GHG and aerosol concentration as external driving from the coupled model HadCM3. Data for lateral boundary conditions for the RCMs models were provided every 6 h and SST and SICE data every 15 days. Linear interpolation for values on lateral boundaries, SST, and SICE was used between these periods. For the initial conditions of soil moisture and soil temperature the climate mean values were used. Due to the spin up period of soil moisture and temperature, the first year of the integration was not used in analysis. We acknowledge that the underlying assumption adopted in this work, namely that a global model responding to monthly mean observed SSTs is physically constrained to produce a dynamical response over land, may induce a causal interpretation of any agreement between observed and modeled trends over land.

For the present climate, in the HadAM3P model the concentrations of GHG and sulphur are prescribed and their evolution and impact in the sulphur cycle are simulated by both HadAM3P and HadRM3P models. For the A2 future climate scenarios the evolution in the concentration of GHG and sulphur is the same as the HadCM3 (Wilson et al. 2005). In the RegCM3 the concentrations of GHG and CFC-11 and 12 were prescribed each 10 years, since 1960 to 2100 (as shown in Pope et al. 2000). For the Eta CCS model, the CO_2 used for both present and future is the same, 330 ppm (Pisnichenko et al. 2006).

All analyses of the simulations have been performed on the period present time 1961–1990, allowing for models to spin-up their surface variables during the first year of simulation. The climate change experiment used SSTs from an existing HadCM3 simulation. The changes in the future (represented as 2071–2100) are calculated with respect to the AOGCM control 30 year climatology for the present (1961–1990) from the respective RCM. The statistical significance of the changes is determined by conducting a Student's t-test.

3. Results

The main focus will be on the A2 high emissions scenario experiment, as all models clearly show that the B2 experiment gives a relatively scalable result with a similar but weaker climate change signal as compared to the A2 ones. The discussion is on the changes in near-surface climate, in particular the temperature, precipitation and lower and upper level wind conditions. For rainfall and temperature, an analysis of the annual cycle for the five regions of Brazil depicted in Figure 1 is also shown for this A2 scenario. Previously, we include an analysis of the consistency between the HadAM3P GCM and the 3 RCMs for the present time.

3.1 Climatological Fields for the A2 Scenario as Projected by the three RCMs – Rainfall

All fields shown on this section are presented as the projected changes in the future (2071–2100) relative to the present 1961–1990 as produced by the 3 RCMs.

For the A2 scenario, on the annual and summer change fields (Fig. 1), the three RCMs show positive rainfall changes over the northwest coast of Peru–Ecuador and Argentina south of 25°S and negative rainfall changes over eastern Amazon and Northeast Brazil. The Eta CCS and the RegCM3 models show rainfall reductions in the future for most of tropical South America east of the Andes, and extending into southern Brazil during winter, with the largest negative departures (less than 40 %) in the Amazonia and Northeast Brazil. In contrast, the HadRM3P shows a regional pattern with increased rainfall in the future (above 20 %) over the western Amazon, which extends all the way to southern Brazil and into the South Atlantic. The projected changes in precipitation in the three regional models (such as the drying over east-central Amazonia and northeast Brazil and the wetter conditions over south-eastern South America and the Northwest coast of Peru and Ecuador) could be a partial consequence of an El-Niño like response in the three models. This is also projected by the IPCC AR4 models regarding rainfall increases in the Northwest coast of Peru and Ecuador and the wetter conditions over south-eastern South America (Christensen et al. 2007a). Projections of increase of intense rainfall in that region by Tebaldi et al. (2007) derived from the IPCC AR4 models, and by Marengo et al. (2009b) from the HadRM3P projections of extremes suggest that this increase in rainfall in the future would be in the form of more intense and/or frequent rainfall extremes.

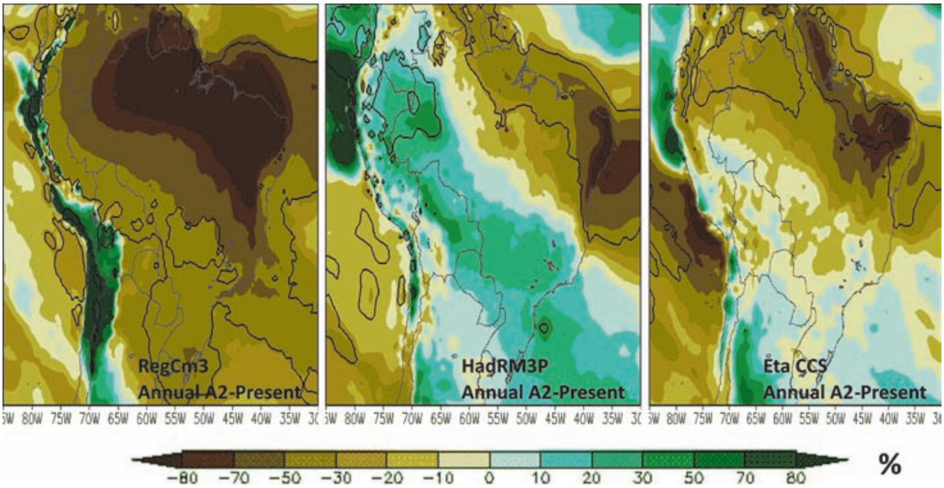

Fig. 1 Projected patterns of rainfall change (%) over South America for the A2 scenario, at annual time scale for 2071–2100 from the RegCM3, HadRM3P and Eta CCS relative to the 1961–1990 model climatology. Shaded areas represent regions where statistical significance at the 95 % level is reached.

From the rainfall projections derived from the 3 RCMS, there is qualitative consistency among the simulations with the IPCC AR4 regional means, particularly and decreasing rainfall increases in southeastern South America and on the northwest coast of Peru and Ecuador.

In sum, all regional models show reductions and increases in precipitation in the future for the A2 scenario, depending on the region and the reductions are lower in the HadRM3P in some regions. Rainfall decrease is detected by all models over the eastern Amazon and Northeast Brazil, while for West Central and Southern Brazil the HAdRM3P model shows rainfall increases in the future, while the other models show reductions. Perhaps the largest uncertainties are in the West Central region; with the largest inter model differences.

The reductions of rainfall in the future from the HadRM3P in North and Northeast Brazil may be explained in terms of changes in the frequency of dry days, as shown in the analyses of future trends in extremes using the HadRM3P by Marengo et al. (2009). In those regions, the risk of drought is likely to increase. In southern Brazil, the increase in mean precipitation is also associated with the increase in the wet day frequency and reductions in consecutive dry days (Marengo et al. 2009a, b).

3.2 Climatological Fields for the A2 Scenario as Projected by the three RCMs – Temperature

On the geographical distribution, all of South America is very likely to warm during this century (Fig. 2). The analyses by Christensen et al. (2007a) for tropical South America from the IPCC AR4 GCMs shows that the annual mean warming under the A1B scenario for the end of the century varies in the tropical region between 1.8 °C to 5.1 °C, with half of the models within 2.6 °C to 3.7 °C, and in the subtropical South America varies from 1.7 °C to 3.9 °C, with half of the models between 2.3 °C to 3.1 °C.

The projected warming from the three RCMs is generally largest in inland regions, such as Amazonia. The temperature field for the A2 scenario from the HadRM3P and RegCM3 is quite similar. The Eta CCS model shows the largest temperature in the tropical region above 30 °C. In the HadRM3 and the RegCM3 the values are lower those from the Eta CCS model (reaching between 28–30 °C), but these two models show the largest temperatures in eastern Amazonia between 5 °N–15 °S. In winter, the temperature fields in Argentina south of 30 °S is colder in the Eta CCS model, as compared to the other models, and the projected warm temperatures in eastern Amazonia by the HadRM3P and RegCM3 are still large. Particularly, the HadRM3P projects warmest temperatures in winter than in summer for this region. Christensen et al. (2007a) suggests that the warming in central Amazonia tends to be larger in JJA than in DJF in the global IPCC AR4 models, while the reverse is true over the Altiplano where, the amplitude of the seasonal cycle of temperature is projected to increase. Similar results were found by Boulanger et al. (2006), who studied the regional thermal response over South America by applying a statistical method based on neural networks and Bayesian statistics.

The three models show temperature increases larger than 3 °C in the entire tropical and subtropical South America. The Eta CCS model shows temperature increases of the order of 6 °C in western Amazonia at annual level, reaching 8 °C in summer, and above 4 °C warmer in southeastern South America in summer, and 2–5 °C warmer in winter. In the HadRM3P and the RegCM3 projections the warming in the tropical region is larger than 6 °C, reaching 9 °C in eastern Amazonia (RegCM3 in summer), while for the rest of Brazil the warming ranges between 3-6 °C in summer and winter. The difference with the Eta CCS simulation is that in this model the warming is more on the western side of Amazonia, while in the HadRM3P and RegCM3 the intense warming concentrated in eastern Amazonia during summer. In wintertime the pattern is similar to those during summer, but during summer the larger changes extend for a large area in the continent, especially to the north of the Argentina. For the A2 scenario, the warming in southern Brazil, Paraguay, Bolivia and northeastern Argentina is particularly large in summer.

In general the three models project warming in the A2 scenario stronger in the tropical region, especially in the 5 °N–15 °S band, both in summer and winter, being larger in summer for the Eta/CCS and the RegCM3 of the order of 6–8 °C, and in winter for the HadRM3P (warming reaching 6 °C) over eastern Amazonia during winter. For subtropical South America South of 20 °S, projected warming from the 3 RCMs is consistent with Nuñez et al (2008) who found the warming larger in winter (3–5 °C) than in summer (3–4 °C) in the MM5 A2 future climate scenarios.

Therefore, all regional models show increase in mean temperatures in the future for the A2 scenario, and in the Amazon region the location of the warmest region varies among models,

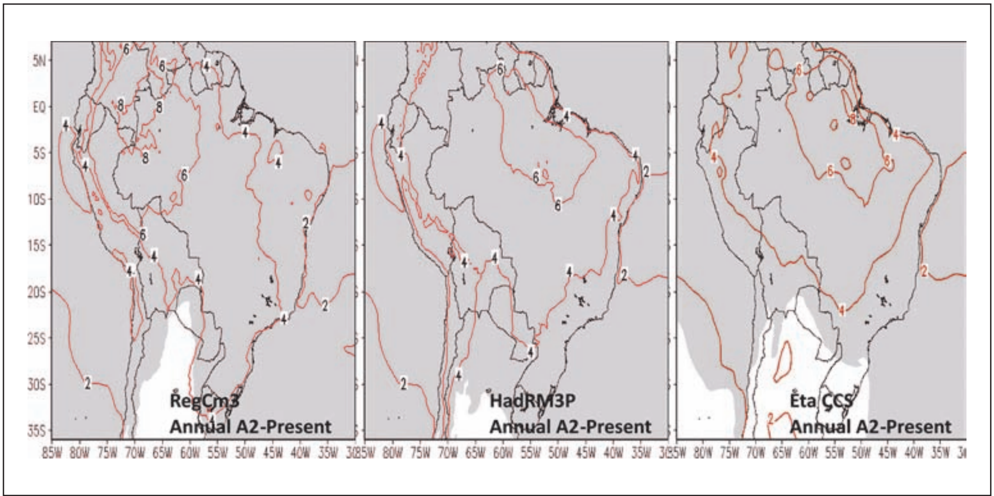

Fig. 2 Projected patterns of air temperature change (°C) over South America for the A2 scenario, at annual time scale for 2071–2100 from the RegCM3, HadRM3P and Eta CCS relative to the 1961–1990 model climatology.

being either eastern or western Amazonia. In any case, the degree of warming for 2071–2100 as compared to 1961–1990 is consistent with that projected by the IPCC AR4 AOGCMs and for the warming projected by the MM5 in South America South of 20 °S (Nuñez et al. 2008).

These increases in air temperature for the future are concomitant with changes in extreme short-term temperature extremes, mainly increases in the frequency of warm nights and warm days, and also reductions in the frequency of cold nights and cold days. As shown in analyses of future trends in extremes using the HadRM3P by Marengo et al. (2009b), the positive trend in the mean is also accompanied by increases in the frequency and intensity of warm nights and days, and negative trends in cold night, consistent with a warming scenario.

The lowest uncertainties are in the region South of 20 °S, where simulations and observations show similar tendencies for the present climate, and the future for the above mentioned seems to show a continuation of the observed warming trends, as shown on the projections of mean and extreme temperature. In tropical regions, as in Amazonia and mainly in West Central Brazil, the lack of observations does not allow for a careful validation of temperature trends.

4. Summary of Future Climate Change Projections for South America by the End of the XXI Century

In general, the RCMs show interesting patterns of change in circulation, rainfall and temperature in a warm future for the A2 scenario by the end of the XXI Century. The three models project reductions of rainfall in regions such as eastern Amazonia and Northeast Brazil, and increased rainfall in the Northwest Coast of Peru-Ecuador and Argentina south of 25 °S. In some regions the annual cycle has not changed but the intensity of rainfall peak and the length of the dry season may change in the A2 scenario, together with a consistent warming all year long, and in some regions winter warms more than summer.

The evaluation of precipitation from the HadRM3P shows increase of rainfall in the future, perhaps in the form of more extreme rainfall events, suggesting that this model shows ability in projecting high-frequency precipitation statistics, in terms of precipitation frequency and extreme events. For the HadRM3P, projections of changes in extremes (Marengo et al. 2009b) together with the regional changes in mean rainfall projected by the HadRM3P, may suggest that the projected increase in precipitation over southern Brazil-Northern Argentina may be due to an increase on frequency of extremes. This is also detected in the future projections using the MM5 RCM by Nuñez et al. (2008) and the RCM projections for the regions as shown in Tebaldi et al. (2007). This type of information provides much added value to the use of regional models on climate change projections.

Figure 3 shows the ensemble of the 3 RCMS, and it is shown in there that for the high emission scenario, the future may feature drier and warmer climates in tropical South America, from Venezuela all the way including central and eastern Amazonia until Northeast Brazil, and southern Chile, while wetter conditions are projected for the Northwest coast of Peru and Ecuador and in the La Plata basin (Fig. 3). Temperature projections for 2071–2100 shows warming 4–6 °C in central Amazonia, 3–4 °C in Northeast Brazil, the La Plata basin, the occidental coast of South America, and the Andean region. In central Argentina, warming may vary between 1 and 3 °C.

As summary for projected rainfall changes and a qualitative assessment of uncertainty of the projections is shown in Figure 4. This figure provides a synthesis of the RCMs annual rainfall projections regarding the number of models that project changes of a given sign. The three models show a reduction of precipitation a vast section of tropical Northeastern South America and southern Chile. Increased future precipitation is detected in the Northern coast

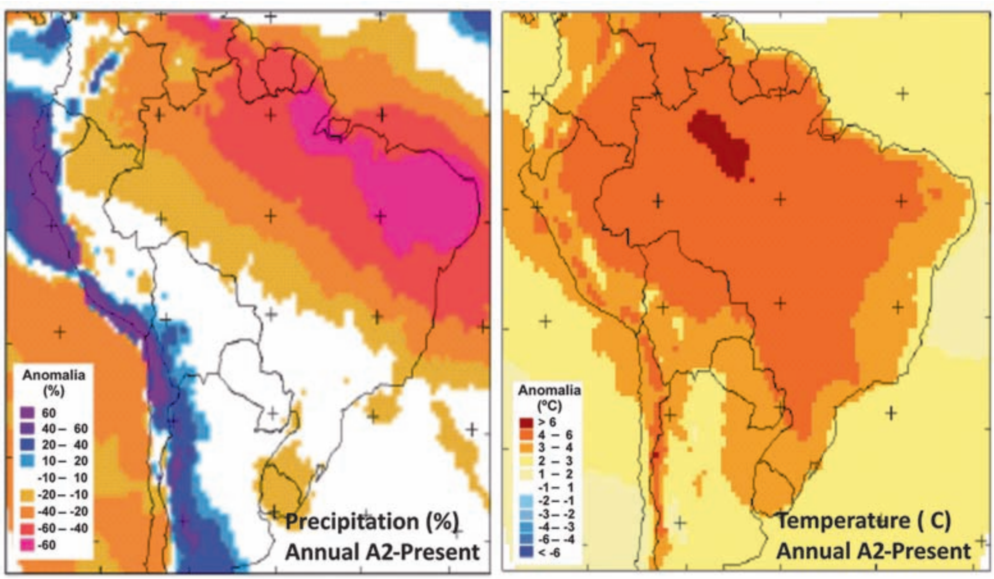

Fig. 3 Projected patterns of rainfall change (%) and air temperature (°C) over South America for the A2 scenario, at annual time scale for 2071–2100 relative to the 1961–1990 model climatology. The maps represent the mean of the three regional climate models.

of Peru and Ecuador and in the southern Andes over Argentina. Moderate levels of agreement (2 out of 3 RCMs) are associated with the overall positive changes in Southeastern South America along the ZACS and the northwestern coast of South America, while rainfall reductions are projected over Northwest Amazonia.

In sum, all regional models show reductions and increases in precipitation in the future for the A2 scenario depending on the region and the reductions are lower in the HadRM3P in some regions. There are indications that regions such as Northeast Brazil and central-eastern Amazonia may experience rainfall deficiency in the future, while the Northwest coast of Peru-Ecuador may experience rainfall excesses in a warmer future. The projections exhibit an increase of rainfall in northern Argentina especially in summer and fall and a general decrease in precipitation in winter and spring, and in southern Brazil during fall. These are consistent with changes in low level circulation from the models.

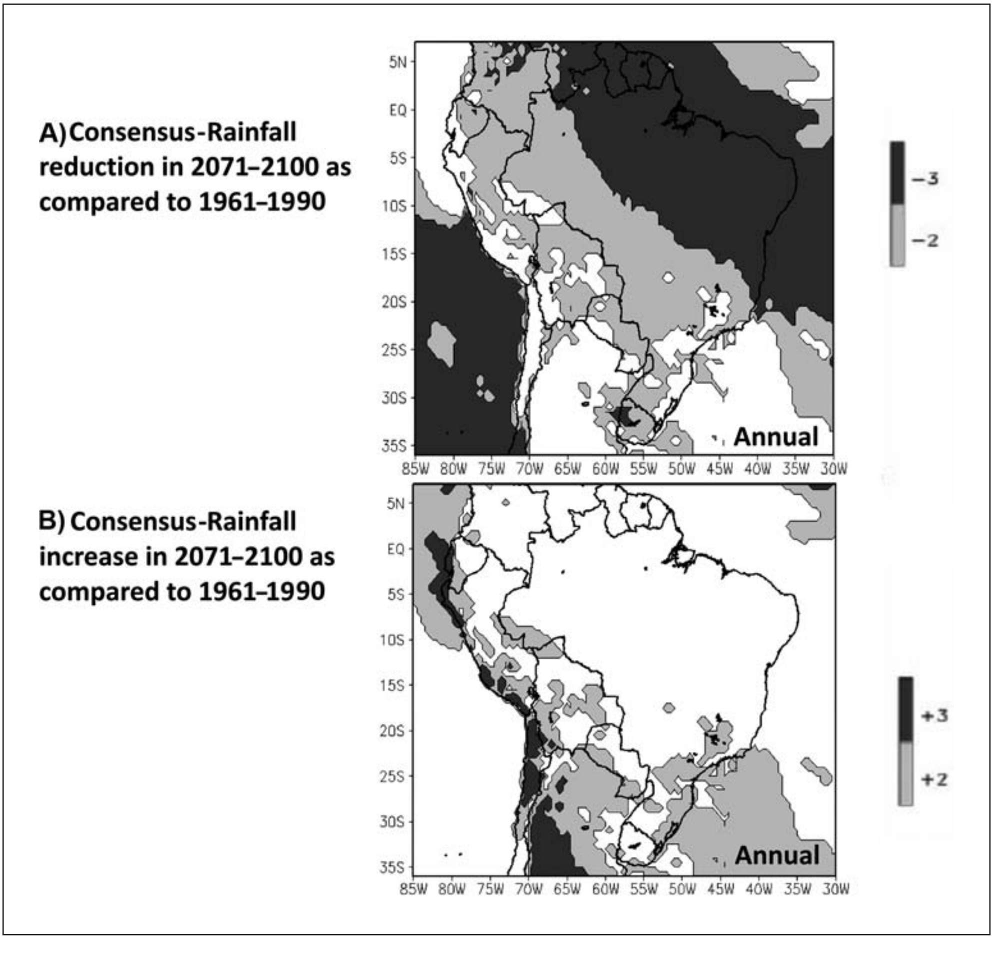

Fig. 4 Consensus maps of annual rainfall changes for the future relative to the present for the A2 emission scenario. Models considered are the Eta CCS, RegCM3 and HadRM3P, for (*A*) for rainfall increase and (*B*) for rainfall decrease. Shaded scale indicating the number of models where the change is of the same sign is shown on the right side.

Figure 5 shows a descriptive summary of changes in climate and extremes in Latin America (*CEPAL* 2009). This figure was prepared considering results of various papers published on climate change for Latin America, or relevant to Latin America (Marengo et al. 2009a, b, Christensen et al. 2007b, Tebaldi et al 2006, Nuñez et al. 2008). Confidence is based on the agreement between the sign of change from various regional and global models from the various studies. High confidence is assumed if at least 80 % of models show consistent change, mean confidence if the agreement varies between 50 – 80 % of models and low confidence is assumed if 50 % or less from the models shows similar sign of change. While all Latin America is affected in some degree by warming, the impacts of drying conditions seem to be more consistent in Tropical South America and Central America-Mexico with drought or increase dry spells. The analysis of changes in extremes suggest that the occurrence of warm nights is projected to be more frequent in the entire tropical South America while the occurrence of cold night events is likely to decrease. Significant changes in rainfall extremes and dry spells are also projected. These include increased intensity of extreme precipitation events over most of Southeastern South America and western Amazonia consistent with projected increasing trends in total rainfall in these regions.

5. Impacts of Climate Change in South America: Changes in Natural Vegetation

Salazar (2009) studied the consequences of regional projected climate change on biome distribution in South America in time-slice 2070 –2099, by forcing a regional potential vegetation

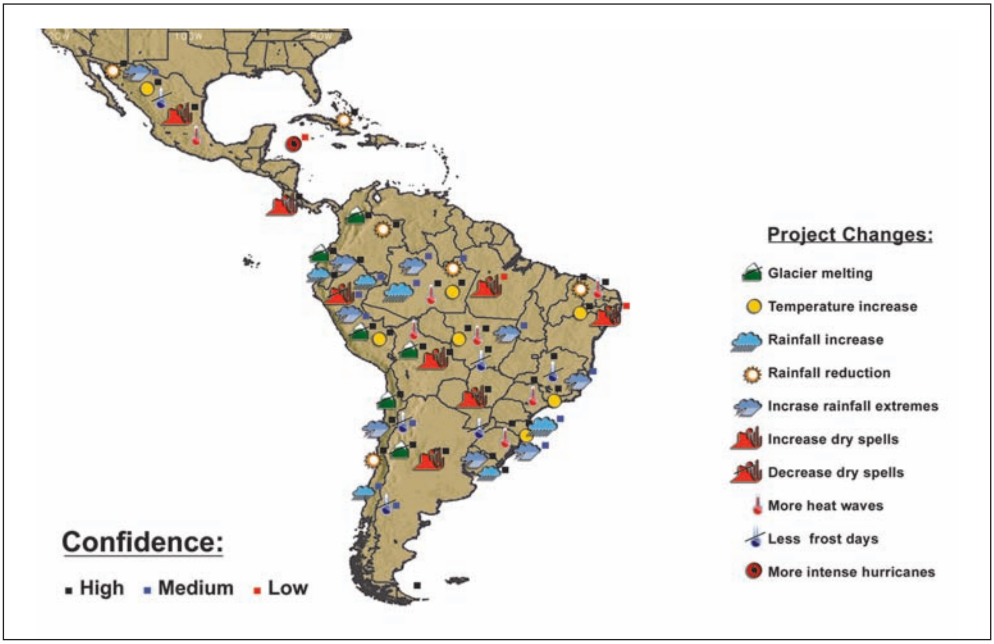

Fig. 5 Summary of climate change impacts in Latin America. Indicators of change are shown of the lower right side, and on the lower left side indicators of confidence are shown (*CEPAL* 2009).

model (CPTEC-PVMReg2.0) with climate scenarios from the 3 regional climate models from the CREAS project under A2 emission scenario. The CPTEC-PVMReg2.0 (Salazar 2009), a regional version of CPTEC-PVM2.0 model (Lapola et al. 2009), considers seasonality as a determinant factor for the delimitation of forest and savannas. It also takes into account physiological responses of vegetation to seasonality (such as primary productivity) under variable atmospheric CO_2 concentration. As a non-dynamic model, the CPTEC-PVM2.0Reg calculates only equilibrium solutions based on long-term mean monthly climate variables.

Figure 6 shows the current potential vegetation (biome distribution simulated by the CPTEC-PVM2.0Reg model under current climate) and the projected biome distribution for the A2 scenario and the 2070–2099 time slice for all the regional models analyzed considering the full fertilization effect. All models show loss of tropical forest in east Amazonia being replaced by savanna (mainly in RegCM3 model). The ETA CCS, different to the other models, shows in Southwest Amazonia the tropical forest being replaced by seasonal forest and savanna, due to greater increase in temperature projected by this model. The biome changes are explained by the net effect of temperature and CO_2 concentration in net primary productivity and the precipitation decrease effect in the increase of dry season length.

Precipitation decrease of 30 % in Southeast and 40 % in Northeast and Southwest represents an increase of dry season length to more than 4 months and shifts to savanna vegetation (Salazar 2009). In agreement with Lapola et al. (2009), we find that this threshold is critical to maintain tropical forest, even in conditions of full fertilization effect. Some areas in Northeast Brazil show substitution of Caatinga to semi-desert in HadRM3P and RegCM3 models, due to decrease of soil humidity (projections of temperature increase and precipitation decrease) and therefore decrease of net primary productivity. These both models show an increase of tropical forest in southeast Brazil (Mata Atlantica) over the regions of grasslands in Uruguay and Argentina, due to the projections of increase in precipitation and temperature to this region.

6. Impacts of Climate Change in South America: Vulnerability of Northeast Brazil to Climate Change

Various studies on impacts and vulnerability of climate change in Brazil have been produced based on the regional climate change projections described in Sections 3 and 4. Among these impacts studies and vulnerability assessments we can include Brazil's Climate Change and Energy Security Report (Schaeffer et al. 2008), the Global Warming Report, and the New Geography of Agricultural Production in Brazil (Assad and Pinto 2008). Another large study in process, which also uses these regional climate projections, is entitled the Economics of Climate Change in Brazil (ECCB) and results from the collaboration of Brazilian institutions representing various productive sectors, from government to academia, instructed to evaluate the economic impacts of climate change in Brazil. We provide some examples of possible impacts in one of the poorest and more vulnerable regions of South America to climate hazards, the Northeast Brazil region. This semi-arid region has experienced strong impacts from drought in the past, and the risks of drought more frequent and intense in the future make its population vulnerable mainly to drought.

Some of the projected impacts in Northeast Brazil that one might expect at 4–6 °C warming, resulting from the 40–60 % reduction in rainfall and longer dry spells as projected by the regional models, may be summarized as follows:

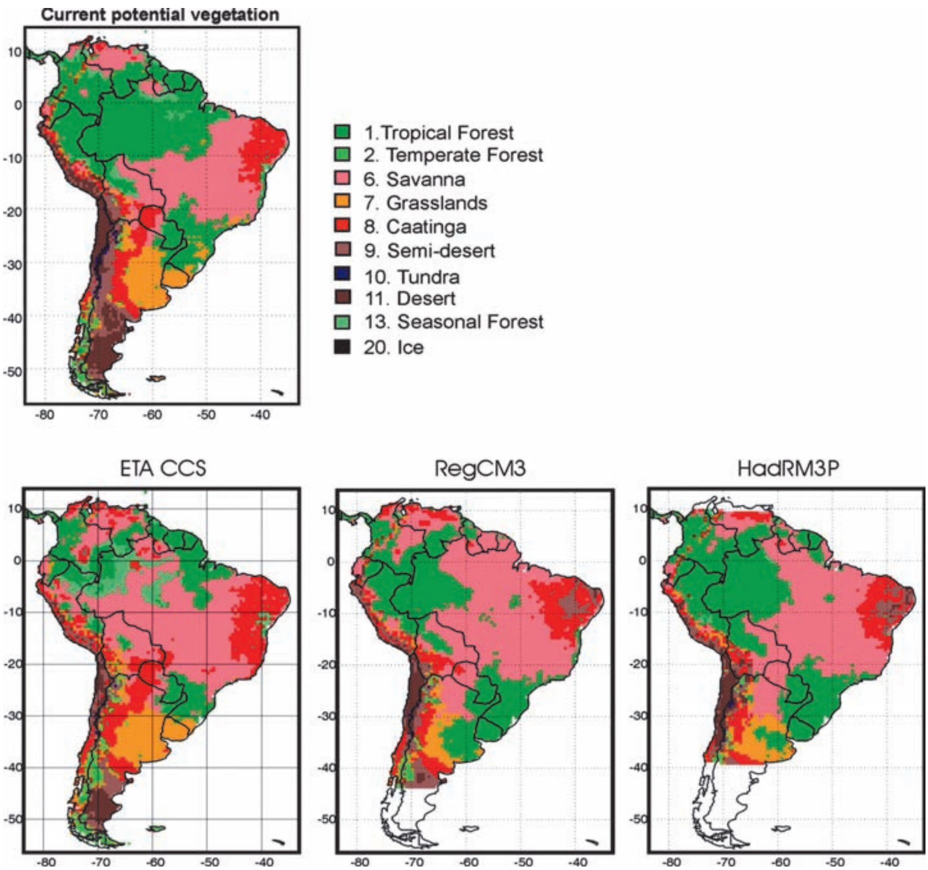

Fig. 6 Projected distribution of biomes in South America for 2070–2099 from ETA CCS, RegCM3 and HadRM3P models for the A2 emission scenario. The top left plot represents the current potential biomes (biomes in equilibrium with observed climatology) (Salazar 2009).

– Water resources would be scarce in a warmer future, affecting mainly generation of hydropower, irrigation and small scale farming. Reduced rainfall and high air temperatures may affect the water balance, exhibiting greater deficiency of soil water for plants in the future, and the drier atmosphere may lead to a process of aridization and to a risk of desertification.
– The elevation of air temperatures and water deficit in Northeast Brazil may increase the area with high risk for some agricultural crops that represent the food basis for the population (beans, corn, cassava, rice) and for agro industry (soybean, cotton, sun flower, sugar cane).
– Social conflicts and migration would be more common, unemployment rate would be high, and health problems would increase. The risk of migration and environmental refu-

gees from this region to other parts of Brazil may exacerbate existing social problems outside the region.

– On the ecological side, the natural vegetation (caatinga) would be replaced by a more arid-type vegetation, with risk of long term desertification.

Acknowledgements

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Life Strategies of Microorganisms in the Environment and in Host Organisms

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Viele Prokaryoten (Bakterien wie Archaeen) in Wasser, Boden oder Wirtsorganismus zeigen häufig spezifische, hoch entwickelte Anpassungen zur Nutzung des umgebenden Milieus als Energie- und Nährstoffquelle sowie als Überlebensraum. Bei prokaryotischen Organismen spielen sich die Anpassungen an die abiotische oder biotische Umgebung fast nur auf der Ebene des Stoffwechsels und der molekularen bzw. makromolekularen Strukturen und Wechselwirkungen ab. Auf dieser Ebene zeigen sich tatsächlich typisch prokaryotische Leistungen: eine Nutzung „ungewöhnlicher" Energiequellen, grundlegende Syntheseleistungen, enzymatische Katalysen, Anpassungen an extreme Verhältnisse, wie hohe Temperaturen, Kolonisations- und Invasionsmechanismen, und Regulationsvorgänge. Der Band behandelt die Rolle von Mikroorganismen in den globalen Elementkreisläufen, wie z. B. dem Schwefelkreislauf, oder aber auch dem Methankreislauf, der Kohlendioxidfixierung oder der Ammoniakoxidation, Symbiosen mit Bakterien-Eukaryoten-Interaktionen auf der Grundlage von Schwefel- oder Stickstoffstoffwechsel, Modelle zum prokaryotischen Ursprung von Organellen in Eukaryoten sowie die Beteiligung von Mikroorganismen an Infektions- und Pathogenitätsvorgängen.

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Urban Latin America under Climate Change: Do Adaptation Strategies of City-Regions Respond to the Challenges?

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With 1 Figure

Abstract

Driven by a growing consensus that climate change is inevitable and predictions are probable, adaptation of cities to climate change has recently entered the academic and political debate as an essential and integral part of climate policy. Cities and city-regions are key sources of greenhouse gas emissions and at the same time highly vulnerable to the consequences of climate change. City administrations around the world are starting to initiate actions to both reduce greenhouse gas emissions and to confront the anticipated effects. Latin America, the most urbanized of all developing world regions, is no exception. This paper attempts to draw first lessons from selected city-regions on how urban responses to climate change address the likely impacts such as increasing water scarcity or extreme events. The research is based on an analysis of official documents, expert interviews, literature reviews and statistical data.

Zusammenfassung

Angesichts einer wachsenden Übereinstimmung, dass der Klimawandel unvermeidlich ist und Abschätzungen zu den zukünftigen Klimaveränderungen wahrscheinlich sind, hat sich in jüngster Zeit die Diskussion um Anpassungsstrategien in Städten als ein integraler Bestandteil von Klimapolitik intensiviert. Stadtregionen nehmen eine Schlüsselrolle als wesentliche Quelle von Treibhausgasemissionen ein. Gleichzeitig sind sie besonders verwundbar gegenüber den Auswirkungen von Klimaänderungen. Weltweit haben Stadtverwaltungen mit der Entwicklung von Maßnahmen sowohl zur Reduzierung der Emissionen als auch zur Bewältigung der Auswirkungen des Klimawandels begonnen. Städte in Lateinamerika bilden dabei keine Ausnahme. Der vorliegende Beitrag bündelt erste Erfahrungen in großen Metropolen der Region und untersucht, inwieweit lokale Klimaanpassungsstrategien auf die zu erwartenden Auswirkungen wie beispielsweise Wasserknappheit und Extremereignisse reagieren. Die Grundlage bilden die Auswertung offizieller Dokumente und statistischer Daten sowie eine Expertenbefragung.

1. Latin America – Expected Climate Changes and Cities

The anticipated climate changes and their impacts are already being felt and observed across Latin America. According to the *IPCC* (2007), median annual temperatures rose by 1 °C between 1961–1990, about 0.5 °C in Brazil, accompanied by glacial melting and a rising sea level of 1 to 2–3 mm per year during the last 10–20 years. Likewise there is an observed increase in precipitation variability and extreme events that often correlate with the El Niño-Southern Oscillation (ENSO) phenomena.

Following the *IPCC* (2007) and its global models, these consequences will in future become increasingly severe in Latin America and the predicted median annual temperature rise of between 1–4 and 2–6 °C to the end of the century, according to different climate models, will exceed historic trends. Apart from some possible positive effects on crop yields in the Southern Cone (De La Torre et al. 2009), the impacts so far have been projected negative. Rising temperatures and precipitation variability are expected to intensify glacial melting along the Andean range, thereby aggravating seasonal shortages in water for irrigation, in drinking water and hydropower supply. Other predicted impacts are salinization and desertification in arid regions with consequences for food production. Sea level rise is likely to make an increase in coastal flooding events inevitable.

These combined impacts on ecosystems and resources will consequently affect the population and functions in cities across the Latin American Region. However, there is still a large degree of uncertainty what exactly the local consequences will be. This is associated to the necessity to downscale global climate models but likewise the complexity of synergetic urban and regional processes that often reinforce local effects. Nevertheless, quite a number of city administrations have launched local climate action plans to confront climate change impacts such as rising water scarcity and energy demand, or likely increases in extreme events. Urban responses are often based on few (if at all) available studies and data from regional models or qualitative studies based on expert knowledge.

This article addresses the question how current urban responses to climate change respond to likely impacts of climate change and how this incorporates 'scientific' knowledge on the predicted changes. Its structure consists of three main parts. The first part presents an overview of the existing specific local climate conditions in four city-regions in Latin America (Bogotá, São Paulo, Buenos Aires and Santiago de Chile) and takes a closer examination of two of these (São Paulo and Santiago de Chile). The second part discusses the interacting processes between climate change and exposed urban functions, sectors and population in São Paulo and Santiago de Chile. It likewise analyses the state of 'formal' responses in the two cities. The fourth and final part compares the findings and provides some general conclusions on the constraints and challenges of local climate responses.

2. Local Climate Conditions and Expected Future Changes in Latin American City-Regions

The four city-regions Bogotá, São Paulo, Buenos Aires and Santiago de Chile, under consideration in this article, are located in very different climate zones. These zones range from subtropical highland climate in Bogotá, with dry and rainy seasons alternate and constant temperature due to the location near the equator throughout the year, to subtropical dry climate in Santiago de Chile and to humid subtropical climate in Buenos Aires and São Paulo with particular precipitation in the warmest months. Figure 1 gives an overview of long-term climate (temperature and precipitation) measurements (1961–1990).

As shown in Figure 1, there exist quite significant differences in current climatic conditions and variations across the four city-regions. This is explained by general differences in local factors. These will likewise shape specific future climate changes and trends in different ways. At the same time, some general trends may apply to all city-regions similarly. A closer examination of two city-regions – Santiago de Chile and São Paulo – provides some illustration.

For the Metropolitan Region of Santiago, projected data on possible future impacts of climate change are currently generated from different sources at different spatial resolutions. The principal reference point for downscaled climate change scenarios is that of the *CO-*

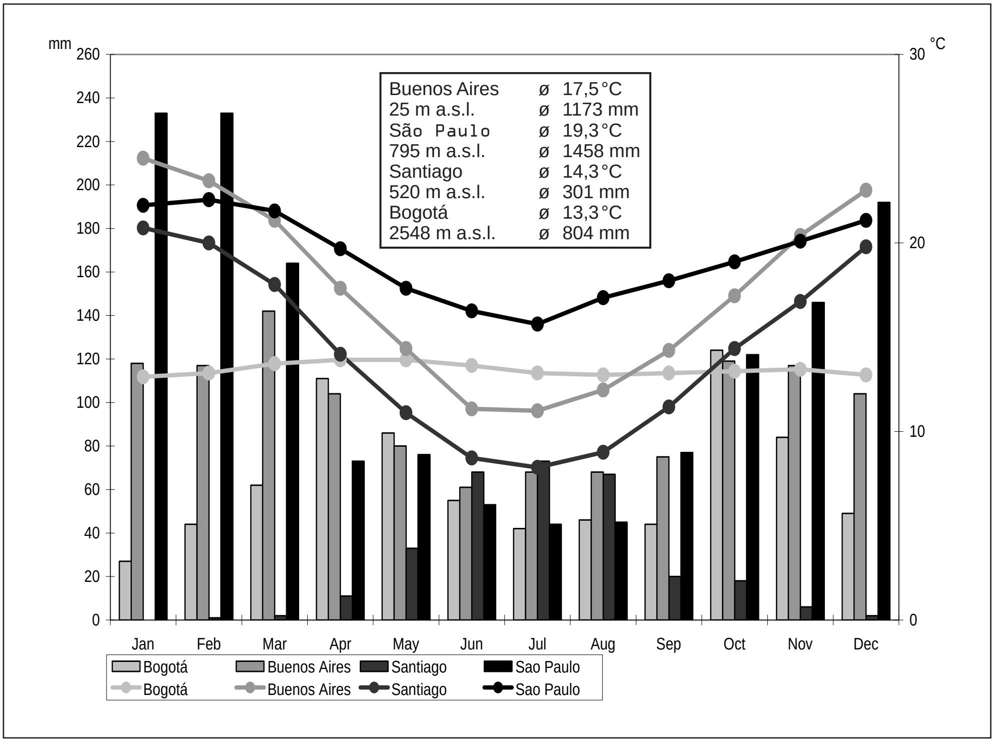

Fig. 1 Temperature and precipitation values for Bogotá, Buenos Aires, Santiago, São Paulo Source: own compilation based on data from National Climatic Data Center (NCDC), Climate information is based on monthly averages for the 30-year period 1961–1990 (a. s. l. = above sea level)

NAMA (2006) study conducted by the University of Chile. Based on long-term measurements (1960–1991) the current climate and two alternatives for 2071–2100 (A2 and B2, according to the IPCC) were modeled for Chile with the PRECIS-model (*Providing Regional Climates for Impact Studies*), developed by the Hadley Centre of the UK Meteorological Met Office. The spatial resolution of cells of 25 km² generates large uncertainties and inaccuracies; one of the 50 km wide transects of the model represents an approximation to the Metropolitan Region of Santiago de Chile.

The projections for the period 2070–2100 under the A2 and B2 scenarios suggest a potential 40 % reduction in precipitation, compounded by reductions in glacial flows and rising evapotranspiration and higher temperatures of between 3–4 °C (in parts to 5 °C) for a more 'pessimistic' A2 scenario (*CONAMA* 2006). This is clearly relevant in terms of glacier dynamics, with their subsequent influence on year-long water availability in the basin's two river systems. The consequence will be higher winter discharges of water, gradually reducing over time as the glacier capacities diminish. The glacial effects will be most evident in the drier months (the first four months of the year in particular) when glacier thaw provides an important water flow through the system.

For the Metropolitan Region of São Paulo, projected data on possible future climate changes can be retrieved from global models like the HadCM3 and GFDL used by the IPCC and first presentations of the results derived from different regional models (HadRM3P, Eta/CPTEC and RegCM3) that were used by the *Centro de Previsão de Tempo e Estudos Climáticos* of the *Instituto Nacional de Pesquisas Espaciais (CPTEC/INPE)* for downscaling the global IPCC scenarios.

Global models present a rather broad overview of projections on regional scale due to their spatial resolution. They show different tendencies for likely changes in precipitation and temperature in Brazil. In general, likely anomalies in temperature are expected to be more intensive than in precipitation (Marengo 2007). Barros et al. (2003) and Camilloni (2004a, b) show that the results of the HadCM3-model best fit to the current climate in South America.

The result of downscaling is a set of maps and graphs representing expected annual and seasonal climate changes (anomalies from the long-term trends between 1961–1990) for Brazil. Downscaling covers five different regions. The Metropolitan Area of São Paulo located at 23° 30′ S and 46° 37′ W falls in the region *Sul do Brasil-Bacia do Paraná* that shows model results at a scale from 1:12,000,000. Analogue to the regional models for Chile, the current climate and two alternatives for 2071–2100 (A2 and B2, according to the IPCC) were calculated based on long-term measurements (1960–1991) (Marengo et al. 2007).

Predicted temperatures based on regional models show for both scenarios (A2 and B2) an increase of temperature, reaching an annual increase up to 2–3 °C in the optimistic scenario and 3–4 °C in the pessimistic scenario for region that roughly represents the Metropolitan Region of São Paulo. The projected changes in mean annual precipitation for both scenarios show anomalies between –10 and +10 %. Remarkable are the expected decreases in precipitation in winter periods of 20–40 % for both scenarios (Marengo et al. 2007).

3. Climate Change Impacts, Local Reinforcing Conditions and Climate Action: Santiago de Chile and São Paulo

3.1 Santiago de Chile

Climate change related impacts: Santiago de Chile, with its population of ~6 million, is located in the Maipo river basin on the western flanks of the Andes. The city contributes a significant share in terms of global greenhouse gas (GHG) emissions and therefore first of all requires adjusted mitigation measures but faces likewise considerable adaptation challenges (*CONAMA* 2005, 2008). Perhaps the most important of these is water management. According to the projections shown in Section 2, pressures will grow to change the current water management system. But this does not only relate future climate changes. Already today, water supply bottlenecks are already evident. The water market is based on water rights that are purchased and transacted (Water Code 1981, modified 2005), based on a total availability calculated by the national water authority and a minimum stream flow condition (DGA: *Dirección General de Aguas*). Supply for new surface consumptive rights to be made available in the Maipo basin is currently insufficient, while groundwater rights are offered provisionally subject to better information about the dynamics of the groundwater hydrology in the basic (*DGA* 2003). The market is also unable to respond to fluctuations in the hydrological cycle, including the El Niño phenomenon for example, since rights are fixed (although subject to extraction volume modifications) and are awarded in perpetuity. In consequence as water availability decreases, existing rights will not be able to be extracted according to initial volumes, and no new uses will be catered for unless old uses are being terminated. In addition, the expected increase in population of Santiago de Chile to more than 8 million people (*MINVU* 2008) in 2030 will add further pressure. This is likely to correspond to urbanization processes that displace agricultural uses in the region as the metropolitan area continues to expand into productive land, areas of increased risk and areas that provide important environmental services for the watershed.

The limitations of the existing water market, its weaknesses in responding to the natural cycles in the water basin, and the anticipated scarcity due to climate change, present a major adaptation challenge. Conflicts over the equitable distribution of water will increase particularly between residential, agricultural, mining demands and environmental services. Assuming that the residential expansion of land will continue, the question remains as to how a potential 40 % reduction in rain water availability (*CONAMA* 2006) will be met by a population in the metropolitan area that is 30 % larger than at present. The city's location in a Mediterranean biodiversity hot spot and current levels of green space per habitant (3.2 m^2/cap, *CONAMA* 2002) well below the WHO recommendation of 9 m^2/cap are raising the issue of water use for maintaining the region's ecosystems, and for increasing public spaces to enhance urban quality of life and reducing e.g. the heat island effect. This will require a significant shift in water management in many areas, e.g. reduced agricultural irrigation capacity, watering of, and species selection in public spaces and domestic gardens, a storm water drainage system that seeks to shift water downstream of the city as swiftly as possible during peak events (rather than capture and storage), and broad-based demand reductions. This connects to a further challenge which is related to the issue of climate change governance within spatial planning.

Climate action: The challenges of climate change are currently not yet taken up in a response at the level of the Metropolitan Region of Santiago but at the national level. Chile established a Climate Commission in 1996, and 10 years later approved a climate change strategy (*CONAMA* 2005). It concentrates on productive sectors, particularly mitigation and CDM commercial opportunities but fails to put much weight on adaptation issues. It also fails to explicitly consider urban centers in spite of over 80 % of Chileans living in urban areas, with over 40 % of the national population living in the metropolitan region. This has changed slightly with the publication of the 2008 national action plan (*CONAMA* 2008). The plan announced to coincide with the Conference of Parties (COP) meeting in Poznan in 2008 still retains a strong emphasis on the early strategy agenda of mitigation and impacts in productive sectors. It focuses on seven fields for action: agriculture, forestry, and mining, fisheries, and energy, biodiversity, health and water resources. Although urban change, except coastal city risk, is not an explicit focus of the plan, all seven issues relate to urban transformations. Their incorporation into planning instruments is going to be a primary challenge for climate change adaptation. Adaptation does not occupy a prominent place in the plan except in the form of several proposed sectoral studies to analyze vulnerability (such as agriculture) for the main climatic regions in the country (*CONAMA* 2008).

To date, the regional development strategy, metropolitan and local regulatory plans, and local development plans have not included climate change considerations explicitly, largely because of the sectoral approach to public sector management. It is yet unclear how this national and sector-oriented document can be translated into local action in the metropolitan region. Less unclear is, however, that climate change adaptation will demand a coordinated response from government agencies, within the context of a regional adaptation plan. Although the DGA manages the water market, the water planning dimension must be brought within the administration of the territorial authority, the Regional Government, as part of a strategy able to engage with the priorities of the national plan (less fisheries) and the multiple public and private actors who are direct stakeholders, from rights holders (agriculturalists, mining firms and others), to the environment commission, the housing and urbanization ministry, the public works ministry, and municipal authorities. It would appear that the limitations of this natural resource market for the climate change challenge to be faced this century are already evident.

3.2 São Paulo

Climate change related impacts: The *Região Metropolitana de São Paulo* is populated by approximately 20 million people in 2006 (*United Nations* 2008), which roughly means that every 10th Brazilian lives in the city-region of São Paulo. The central municipality, the *Munizipio São Paulo*, counted about 11 million inhabitants in 2007 (Pessoa et al. n. D.). The city is situated on the high basin of the rivers *Tietê* and *Rio Pinheiros*.

Climate change in the metropolitan region will, according to available documents and interviews, likely result in an increasing water and energy demand and higher intensity and frequency of extreme events (floods). Further probable effects are worsening air quality and potential health risks (Jacobi 2001). These consequences reinforce existing problems, for example floods. São Paulo is susceptible to flood hazards because of its hydrological situation and its location within the *Bacia Alto Tietê* water catchment (Jacobi 2001). This situation is further aggravated by a long ongoing process of land conversion to urban uses (Pessoa et al. n. D.) and the associated loss of storm water retention capacity. Another problem is water supply. The *Alto Tietê* as the immediate local catchment in which the city is located satisfies only 10 % of the water demand (Edison n. D.). The remaining supply originates from other distant catchments, the largest (with 55 % share of the total supply) being the *Rio Canteira* located in the Mato Grosso.

Climate action: Brazil ratified the United Nations Framework Convention on Climate Change (UNFFC) in 1994 and established a Climate Committee, the *Comite Interministerial sobre Mudanca do Clima* (*CIM*), in 2007. On the basis of the work of this committee, São Paulo has passed in 2008 a legislation to enact its climate action plan (*Plano Nacional de Mudanças Climáticas* [PNMC]) (*CIM* 2008) confronting local problems related to land use, water management, transportation, and disaster risk reduction.

The municipality of São Paulo was one of the first local governments in Latin America to launch a local climate action plan in 2009. The *Plano Municipal de Mudanças Climáticas* (PMMC) operates independently from national activities and was established by the *Prefeitura da Cidade de São Paulo*, the ministry of the environment, and the University and Institute *Fundação Getúlio Vargas* with support from the *International Council for Local Environmental Initiatives* (ICLEI). The plan incorporates a range of objectives and measures that have been prioritized by the local ministry of the environment in earlier plans. Aside from transportation (as the major concern in the public debate in the city), the relevant fields are energy, waste management, buildings, and land use planning. The plan includes ambitious standards for emission reductions (30 % until 2012, based on 2005 emissions). Measures dedicated to adaptation make particular reference to the evaluation of expected climate changes, their consequences and its expected vulnerabilities. This offers first of all the possibility to further implement these aspects and to start a discussion process.

The plan strongly builds on a deliberate combination of local 'political' priorities (in particular transportation) and transfer of ideas, knowledge and insight through "external" networks such as the ICLEI Cities Program and the C40 Large Cities Initiative. The development of the climate action plan as a municipal legislation took about 18 months and was led by the local Environmental Ministry (*Secretaria do Verde e Meio Ambiente*). It consisted of two public discussion fora, expert panels and an internet-based opinion survey. A draft of the plan was circulated among different stakeholders from the local administration, NGO representatives, scientists and media representatives. The preparation of the plan did not include a 'quantitative' vulnerability assessment to climate related changes based on downscaled climate models. Such an initiative has more recently been launched by the *Fundação de Amparo à Pesquisa do Estado de São Paulo* (*FAPESP* 2009).

4. Conclusion: Do Adaptation Strategies of City-Regions Respond to the Challenges?

This brief presentation of climate change action in two Latin American city-regions provides insights on the current state-of-response at the local level.

Firstly, the two cases highlight that identified future impacts add to already existing vulnerabilities connected to high dependency on scarce resources. Clearly, effects need to be seen in connection with 'reinforcing' local conditions and factors. Crucial in both case cities is water with locally available supplies predicted to running into deficits and leading to distributional conflicts.

Secondly, the cases suggest a 'path dependency' with respect to the type of response. The Chilean example favors a strong national lead that hands down specification and implementation of the action plan to sector ministries. On the opposite, the *Munizipio of S*ão *Paulo* assumes an early leadership role quite autonomous from national action. The local action plan in São Paulo also demonstrates a 'path dependency' with respect to focus and priorities. These are not selected independently from those in previous plans but are rather guided (pre-) existing strategies. Likewise, action is motivated by problems that are 'prominent' in the public debated. In São Paulo, the rhetoric links to the transportation situation that attracts much of the public debate. These two aspects (continuity of the agenda and public relevance of the topic) seem to be important 'strategic' considerations in bringing adaptation action into the mainstream of local development.

Thirdly, the cases confirm that there still exist considerable uncertainties and gaps in knowledge about the future local climate trends and their likely effects in cities. Quite remarkable, the plan in São Paulo was prepared without 'vulnerability assessment' based on climate change predictions. Closing this gap and likewise learning how to deal with uncertainty and to design processes that lead to 'legitimate' action will be a major new challenge for local action.

Finally, as the focus on water sector in both cases suggests, policy and practice of service delivery can no longer be disconnected from individual and collective preferences. A main strategy to confront the trend of growing scarcities will have to focus on adjusting consumption levels as a complement to reuse and recycling schemes. Although not new at all, this illustrates the need to find strategies to intensify citizen involvement in local adaptation action.

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Climate Change in Brazil: The Impacts of Different Actors on the Creation of the National Policy

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Abstract

The establishment of the National Policy on Climate Change has caused a change in Brazil's position concerning the adoption of greenhouse gas reduction targets. The decision-making process that led to the development of the climate policy involved several actors. This article studies the government commissions, business initiatives and NGOs as actors involved in this process, addressing their roles, their contributions, and the future challenges of climate governance concerning the national policy in Brazil. Finally, it is argued that despite the growing involvement of NGOs and business initiatives in the discussions of a climate change policy, there are still important challenges in its implementation that need to be overcome.

Zusammenfassung

Seit der Einrichtung einer *National Policy on Climate Change* ist eine Änderung hinsichtlich der Position Brasiliens zur Annahme der Treibhausgas-Reduktionsziele festzustellen. Am Entscheidungsprozess, der zur Entwicklung der Klimapolitik führte, waren verschiedene Akteure beteiligt. Der Artikel beschäftigt sich mit den Regierungskommissionen, Business-Initiativen und NGOs als Akteuren in diesem Prozess und erforscht ihre Rollen, ihre Beiträge und die künftigen Herausforderungen, die die Klima-Governance für die nationale Politik Brasiliens darstellt. Schließlich wird argumentiert, dass es trotz der wachsenden Beteiligung von NGOs und Business-Initiativen an den Diskussionen über eine Politik gegen den Klimawandel noch große Herausforderungen bei der Umsetzung gibt, die es zu überwinden gilt.

1. Introduction

A study released by the NGO *Vitae Civilis* in 2007 argued that Brazil will likely continue to play a leading role in the negotiations of a climate change regime in the following years. However, the country's position on refusing to accept reduction targets for the second period of the Kyoto Protocol was seen as "less constructive" than expected. The study continued, arguing that "in general there is little awareness in all sectors of society and all levels of government regarding the commitments and issues involved in the global climate regime, and there has been little engagement of civil society" (Lutes 2007, p. 40).

Nowadays, the situation in the country is different. Brazil still supports the application of the 'principle of common but differentiated responsibilities' and its implications in the way developed and developing countries must address climate change issues. However, for the first time and shortly before the COP 15 in Copenhagen, the Brazilian government announced voluntary targets to reduce its greenhouse gas (GHG) emissions (considering the business-as-usual scenario) to at least 36.1 % (may reach 38.9 %) by 2020, and also included these targets in the law that established the National Policy on Climate Change.[1]

The development of Brazil's National Policy on Climate Change involved the participation of various actors. This article concentrates on the role played by three of them, namely the government commissions, the business initiatives and the NGOs. First, the main characteristics of these actors, such as their role and responsibilities will be described. Secondly, examples of contributions to the Brazilian policy on climate change suggested by these actors will be presented. Thirdly, the future challenges of climate governance will be highlighted. Finally, conclusions will be drawn from these examples, showing that the participation of the mentioned actors had an impact on the adoption of the policy to reduce greenhouse gas emissions in Brazil and played an important role in the environmental arena.

2. Relevant Actors in Brazil's Climate Policy Arena

Considering governmental boards, the Interministerial Commission on Global Climate Change and the Brazilian Climate Change Forum support the Brazilian government in the implementation of the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. On the one hand, the commission is composed of representatives of ministries and advises the government on proposals for public policies and legal instruments related to climate change, as well as helps set the country's official position in the negotiations of the UNFCCC. On the other hand, the Brazilian Climate Change Forum is composed of ministers, politicians, and representatives of civil society (researchers, NGOs and the private sector) and promotes the dialogue between government and civil society on issues related to climate change. Its main objectives are to raise public awareness about general problems caused by global warming and to encourage the use of the Clean Development Mechanism (CDM).

The increasing attention payed to CDM, by companies looking for opportunities to participate in the carbon market, brings the business sector into the political discussions about climate change. Many executives may not know how to approach the risks and opportunities associated with climate change because of the complexity of the topic. However, by knowing and calculating the risks and opportunities, companies improve their chances to make wise investments and stay in the market (Packard and Reinhardt 2007). Because of that, it is becoming more common to find private organizations discussing ways to achieve a low carbon economy, like the national platform, called Companies for Climate, launched in October 2009 by the Center for Sustainability Studies at *Fundação Getúlio Vargas* (GVces). The platform brings together entrepreneurs to discuss practical ways to achieve a low carbon economy and the legal framework of the carbon market in Brazil (*EPC* 2009). Their intention is to connect business representatives and experts to set position papers to drive their decision-making process. Although it is a recent initiative, they participated in the Copenhagen Communiqué on Climate Change (*ICLEI* 2009) and some of the platform founders have already published their GHG inventories.

Additionally, companies are not only interacting with each other, but also with NGOs and governmental boards. As an illustration, the GVces is also a member of the Climate Observatory, a network of Non-Governmental Organizations working with climate change issues.

1 The Law 12.187 of 2009 was sanctioned by the President on December 29th 2009.

This NGO has among its goals three key elements, namely to monitor the development of public policies related to GHG emissions; to monitor and influence international negotiations and the Brazilian government's positions on climate change; and to promote dialogue between different actors, such as civil society, the Brazilian Climate Change Forum, the media, government officials, and other social actors (*Observatório do Clima* 2009). Another NGO that is engaged with discussions on climate change is the Brazilian Forum of NGOs and Social Movements for the Environment and Development (FBOMS). It has 608 members (as of November 2009) and works closely with the Ministry of Environment (MMA), one of its funders, with representatives on several government boards and commissions, for instance the previously mentioned Brazilian Climate Change Forum (*FBOMS* 2009). The FBOMS have participated in some legislative processes and international negotiations and its Working Group on Climate became involved in the discussions about the National Policy on Climate Change.

3. How do the Mentioned Actors Exercise Governance?

It can be seen that there is some interaction between the actors that are involved in the development of a climate change policy in Brazil. Last October, during a meeting to discuss Brazil's position to be presented in Copenhagen, the Executive Secretary of the Brazilian Climate Change Forum gave the President a document[2] with a compilation of opinions from its members and individuals from civil society, suggesting some measures that should be adopted as the country's strategy at the 15th Conference of the Parties (COP 15).

Similarly, in another event, representatives of Brazilian entrepreneurs handed the Minister of Environment an 'Open Letter on Climate Change' signed by 22 companies with their voluntary commitments to reduce greenhouse gas emissions. The letter also contained suggestions for the government's position at COP 15 since the entrepreneurs consider it extremely necessary to have a delimited system with clear rules and obligations so that companies can organize themselves and invest in green technology (Ângelo 2009). In addition, other entrepreneurs, some of them members of the platform Companies for Climate, joined the Corporate Leaders Group on Climate Change and together with other international companies signed a document that was handed to the representatives of governments at the United Nations meeting in New York and demanded an ambitious, robust, and fair agreement to tackle climate change (*ICLEI* 2009).

Some NGOs also presented their proposals to the government concerning the countries' climate policy. A manifest signed by several NGOs was sent to the Brazilian Ministry of Environment, highlighting shortcomings of the National Climate Change Plan and influencing changes to the final version of the plan before its presentation at the COP 14 (*Observatório do Clima* 2009). A further example of the engagement of Brazilian NGOs in the discussion of the climate policy in Brazil is the Climate Observatory's suggestions to the bill related to the establishment of the National Policy on Climate Change. Included in this bill were some ideas collected by consulting civil society during events in cities like São Paulo, Rio de Janeiro,

2 The document presents suggestions from different organizations and institutions, such as state and local forums and commissions, unions, NGOs, entrepreneurs, industrial and electric sectors, and local governments. For more information see *FBMC* 2009.

and Curitiba. The collection and adoption of these ideas show the influence of these organizations on the political process. Furthermore, the Climate Observatory presented suggestions to the bill 2.635/07, which relates to the creation of the National Fund of Climate Change (*Observatório do Clima* 2009).

In November 2009, another event attended by representatives of civil society, government, and the business sector yielded recommendations of topics that should be part of the country's position in Copenhagen. The President received a petition with more than 200,000 signatures from 38 entities of civil society asking for a leadership position to be taken at the COP 15 (Gonçalves 2009). On the one hand, leadership means demanding industrialized countries set high targets for reducing their GHG emissions. On the other hand, it also means presenting concrete targets that will be adopted by Brazil.

Despite Brazilian NGOs only recently becoming involved with climate change topics, since many of them began to pay more attention to the topic after the implementation of the Kyoto Protocol and the publication of the Fourth Assessment Report of the IPCC (Russar 2008), they are active and try to discuss the issue and participate in the decision-making processes about climate change policies in Brazil. The business sector has also only recently become involved.

Apparently in response to the existing expectations, not only in Brazil, but also worldwide, concerning GHG emissions, the Brazilian government announced before the meeting in Copenhagen, a voluntary target to reduce its GHG emissions to at least 36.1 % (may reach 38.9 %) by 2020 (Lang 2009).

4. Future Challenges of Climate Governance in Brazil

The pressure of environmental NGOs and the business sector is an important influencing factor in the adoption of innovative behavior in the environmental policy arena (Jacob and Volkery 2007). Despite the fact that there are many challenges during the exercise of governance, the examples cited in this paper show that good results in the establishment of a climate change policy can be achieved through the pressure exercised by a variety of actors. This kind of pressure can lead to unprecedented results, such as the Brazilian government accepting targets to reduce its greenhouse gas emissions.

However, there are still key challenges in the implementation of the Brazilian National Policy on Climate Change. The first one is to define the measures and the reduction targets that will be adopted in each sector (industry, transport, construction and so on) in order to achieve the voluntary targets mentioned in the law 12.187 of 2009. This law states that the actions to achieve the reduction target will be detailed in a decree based on the results of the second Brazilian inventory of greenhouse gas emissions to be released in 2010. Additionally, the law states that adaptation and mitigation plans (divided by sectors) will also be regulated by decree. Another important challenge is the definition of the amount of investments that need to be made, as well as the sources of the financial support that will be needed to reduce greenhouse emissions, in other words, to clarify where the financial support will come from. It is clear, however, that the first step in the development of a structure to provide resources and financial support to mitigation and adaptation projects was already made in 2009 with the creation of the National Fund on Climate Change.[3] The fund lists different resources that can

3 The law 12.114 of 2009 created the fund and was sanctioned by the President on December 9th 2009.

be used, such as donations made by national or international entities, resources from the annual federal budget or from agreements concluded with governmental boards, and so forth.

Therefore, the involvement of the private sector will be extremely important in the following years, whether through financial support to projects or through the adoption of actions to reduce emissions. It can be argued that with the 'Open Letter on Climate Change' handed to the Minister of Environment, the companies showed leadership by formally presenting their initiatives to fight global warming and their intention to reduce their GHG emissions. On the other hand, they neither provide concrete numbers of reduction, nor practical measures to achieve their goals. Despite that, the launch of the Brazilian GHG Protocol Program in 2008 by the GVces and the World Resources Institute as a methodology tool to assist companies and organizations in elaborating their own GHG inventories and in preparing their management plans (*CDP Brazil Report* 2008) reflects significant progress in the sense that by knowing the amount of emissions, it is possible to calculate the needed reduction and then make it.

5. Conclusions

It was possible to identify a certain level of interaction among the actors addressed in this paper. As an illustration, some representatives of the business initiatives are members of a network of NGOs and also participate in the meetings of a governmental commission (the Brazilian Climate Change Forum). The NGOs also have connections with each other and with the government, participating as well in the meetings of the Brazilian Climate Change Forum. It was also possible to identify that some connections with the government were closer than having a chair at a government commission since the Ministry of Environment is one of the NGO FBOMS funders.

This apparently 'open channel' between the actors can explain some positive results that have been achieved by civil society in the decision-making process of a national policy on climate change, like the suggestions incorporated in the National Climate Change Plan and in the bill related to the creation of the National Policy on Climate Change in the country. Furthermore, the recent announcement of a voluntary reduction of GHG emissions to at least 36 % can be seen as a great change in posture from the Brazilian government.

The active participation of NGOs and several Brazilian companies, mentioned in this study, shows a growth in their interest and involvement in the political discussion of climate change. Nevertheless, some key points, such as the definition of concrete measures and reduction targets that will be adopted in each sector (industry, transport, construction and so forth) as well as the clarification of the financial resources that will be used to achieve greenhouse gas reductions are challenges to be overcome by the government and climate governance in Brazil.

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Mountain Permafrost – A Valid Archive to Study Climate Change? Examples from the Rocky Mountains Front Range of Colorado, USA

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With 5 Figures

Abstract

Mountain permafrost is highly sensitive to changing air temperatures because they affect the thawing depth of the annual active layer, as well as the time and speed of the refreezing process, mainly in the winter. The Long Term Ecological Research Site (LTER) Niwot Ridge and the Critical Zone Observatory Site (CZO) Green Lakes in Colorado, USA, with their high alpine tundra climate and vegetation, offer ideal conditions to study changes of mountain permafrost. The sites provide high quality climate data, together with studies on permafrost since the 1970's, which make these places rather unique in the US. We present data from our studies on permafrost distribution using different geophysical techniques to portray the shallow subsurface. The data on permafrost and soil temperature are compared with existing models of permafrost distribution and possible thermal degradation, as well as with older data on the existence and distribution of permafrost at these sites. At some locations, we find large differences when compared to the older data and the prognostic model. Sites formerly indicated as permafrost in the 1970's shifted towards sites with annual ice lenses today. We discuss the results and attempt to discern if the observed change is a direct consequence of the current rising air temperatures.

Zusammenfassung

Alpiner Permafrost reagiert höchst sensibel auf Temperaturänderungen, da diese sowohl die oberflächennahe jährliche Auftautiefe als auch den Zeitpunkt und die Geschwindigkeit des Wiedergefrierens im Winter beeinflussen. Die ökologische Dauerbeobachtungsfläche der Niwot Ridge (LTER) sowie das Untersuchungsareal der Green Lakes des *Critical-Zone*-Observatoriums (CZO) in Colorado (USA), bieten durch ihr hochalpines Klima und die besondere Vegetation ideale Möglichkeiten, Permafrostveränderungen zu erfassen. Qualitativ hochwertige Klimadaten zusammen mit diversen Studien zur Permafrostverbreitung sind für die Untersuchungsflächen seit den 1970er Jahren vorhanden, was die Flächen ziemlich einzigartig in den USA macht. Wir stellen Daten unserer Arbeiten zur Permafrostverteilung vor, welche durch oberflächennah arbeitende geophysikalische Methoden gewonnen wurden. Daten zum aktuellen Permafrostvorkommen und zu Bodentemperaturen im Untersuchungsgebiet werden mit aktuellen Modellen zur Permafrostverbreitung und möglichen thermischen Degradation sowie mit älteren Daten zur Permafrostverteilung verglichen. An einigen Stellen sind große Unterschiede zwischen den aktuellen und den alten Daten sowie den prognostischen Modellen aufzuzeigen. So weisen Areale, welche ehemals als Permafrostgebiete klassifiziert waren, heute nur noch jährliche Eislinsenbildung in den kalten Monaten auf. Wir diskutieren die Ergebnisse und versuchen zu erkennen, ob die dargestellten Unterschiede die Folge beobachtbarer Temperaturerhöhungen sind?

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1. Introduction

Permafrost is defined on the basis of temperature as sediments or rocks that remain below 0 °C throughout the year. It forms when the ground cools during the winter to produce a frozen zone that persists throughout two following summers (e.g. Williams and Smith 1989). Permafrost areas can be classified as continuous, non continuous or sporadic, and an overview of their world wide distribution is given by Nelson (2004). Mountain permafrost known from high altitude regions, such as the Himalaya in Asia (Jin et al. 2000), the Alps in Europe (Harris et al. 2003), the Rocky Mountains in North America (Janke 2005) and other high altitude mountain ranges, composes only a small quota of the worldwide permafrost distribution. However, as climate is one of the main factors determining the existence of permafrost, its possible degradation is seen as a major challenge in the actual discussion of globally rising temperatures (Lemke et al. 2007, Harris 2005). The spatial distribution, thickness and temperature of permafrost is highly dependent on the temperature of the ground surface and is influenced by several other environmental factors, such as vegetation type and density, snow cover, drainage, soil type and site-specific internal heat flow. Harris et al. (2003) give clear evidence of rising air temperatures and warming permafrost in European Mountains, and Li et al. (2008) reach similar conclusions for high altitude areas in China.

Mountain permafrost in the US is mainly located in Alaska, but there are also areas of frozen ground described in the Front Range of the Colorado Rocky Mountains above 3,300 m a. s. l. (Janke 2005). Studies on the permafrost distribution and associated processes of the Front Range were started in the late 1960s and the early 1970s (Benedict 1966, 1970, Ives and Fahey 1971). Today, two major US-NSF-funded research projects, the Niwot Ridge Long Term Ecological Research Site (LTER, http://culter.colorado.edu/NWT/) and the Boulder Creek Critical Zone Observatory (BC CZO, http://czo.colorado.edu/), deal with the genesis and the future development of the structure, the physical and the chemical parameters of the subsurface. These sites provide an ideal chance to link older data with modern techniques of permafrost detection and monitoring and to discuss the results in the context of changing temperatures.

2. Study Site

The Niwot Ridge area, located at W105°36' and N40°03', is a set of upland surfaces and adjoining slopes near the US-continental divide within the Colorado Front Range, which forms the eastern flank of the Rocky Mountains (Fig. 1). The Range slopes from elevations over 4,000 m a. s. l. down to the Colorado Piedmont and High Plains at about 1,500 m with correspondingly strong temperature and moisture contrasts that control altitudinal zonation of vegetation and soil types (Birkeland et al. 2003). The study sites at Niwot Ridge (Fig. 1) are located in the alpine tundra zone where mean annual air temperature (MAAT) at 3,743 m is 3.8 °C and annual mean precipitation is about 993 mm (Barry 1973, Williams et al. 1996, Greenland and Losleben 2001, D1 in Fig. 1). MAAT at 3528 m a. s. l., 200 m from the study site (Fahey site), is slightly lower, –2.13 °C based on a temperature record from 1982–2010 ('Saddle' in Fig. 1). Geomorphic, hydrologic, climatic and biogeochemical aspects of the local area have been studied in considerable detail over the past 50 years (c. f., http://www.colorado.edu/mrs/mrspubs.html). We present data from two sites: one is the Fahey site located at 3,500 m a. s. l. close to the saddle station and the other is a site west of the D1 station (Fig. 1).

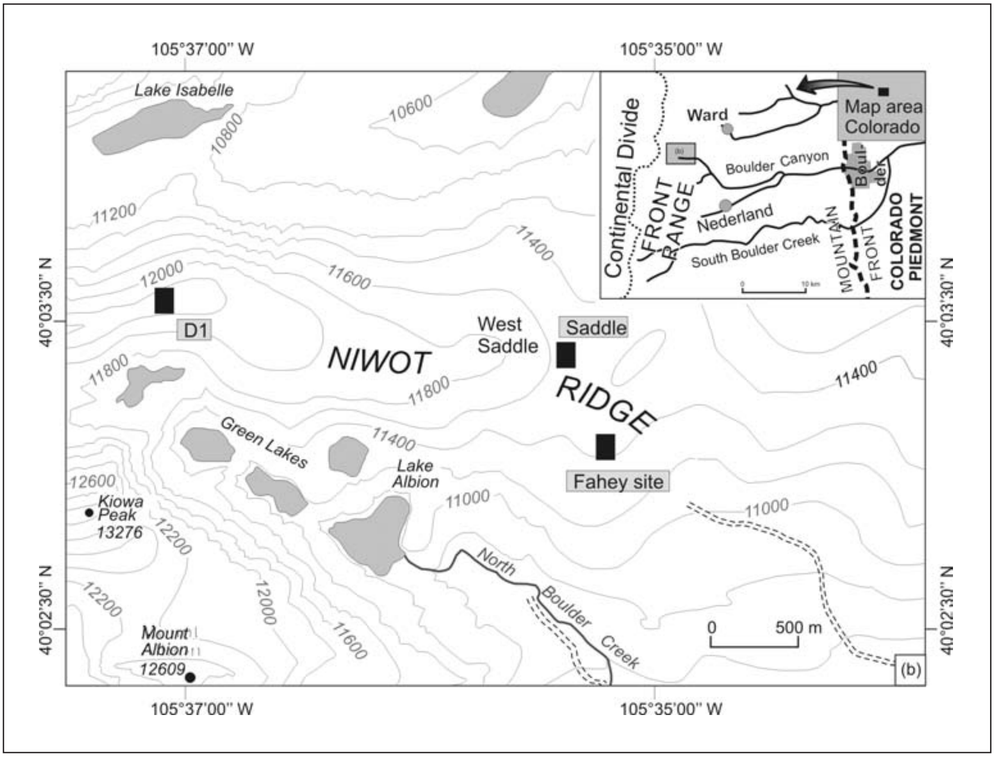

Fig. 1 Overview of the study sites in the Colorado Front Range of the Rocky Mountains, USA. Meteorological data has been sampled at D1 at 3,739 m a. s. l. since 1952 and at the Saddle station at 3,528 m a. s. l. since 1982. The Fahey site and the slope south of D1 were surveyed using geophysical methods.

3. Methods

As frozen materials have characteristic physical properties which differ from unfrozen materials and which are intensified under the presence of ice/water, permafrost can be successfully detected using geophysical methods (Hauck and Kneisel 2008). These methods, such as electric resistivity tomography (ERT), ground penetrating radar (GPR) and shallow seismic refraction (SSR), use electric current or electromagnetic and acoustic waves to measure the electric conductivity and density of the subsurface. These techniques have been successfully applied to portray the shallow subsurface of the study site (for site-specific details see Leopold et al. 2008a, b). Additionally, two bore holes were drilled in 2006 to install temperature loggers on and beside an active solifluction lobe at 3,500 m a. s. l. Loggers were installed every 5, 20, 40, 80, 120, 200 and 280 cm on the lobe (named as east-loggers) and at the same depths, but continuing as deep as 500 and 700 cm, beside the lobe (named as west-loggers). Air temperatures were measured at the 'LTER-Saddle station' about 200 m west of the lobe and at the D1 station (Fig. 1).

4. Results

MAAT at D1 in the period of 1953–2008 was calculated at –3.35 °C with a standard deviation 1.2 (comp. Fig. 2). The Saddle station yielded a MAAT of –2.13 °C with a standard deviation of 1.0. Summer air temperatures (SAT), determined by using the months with potential thaw-temperatures (here June to September), reach values of 6.09 °C at D1 and 7.14 °C at the saddle. Both stations show high annual variability, with a rise of SAT during the last decade. Differences in MAAT between D1 and the Saddle station are mainly caused by differences in the winter temperatures. At both stations MAAT was below the threshold value of permafrost of –1 °C (Ives 1974) except for the year 1956 at D1.

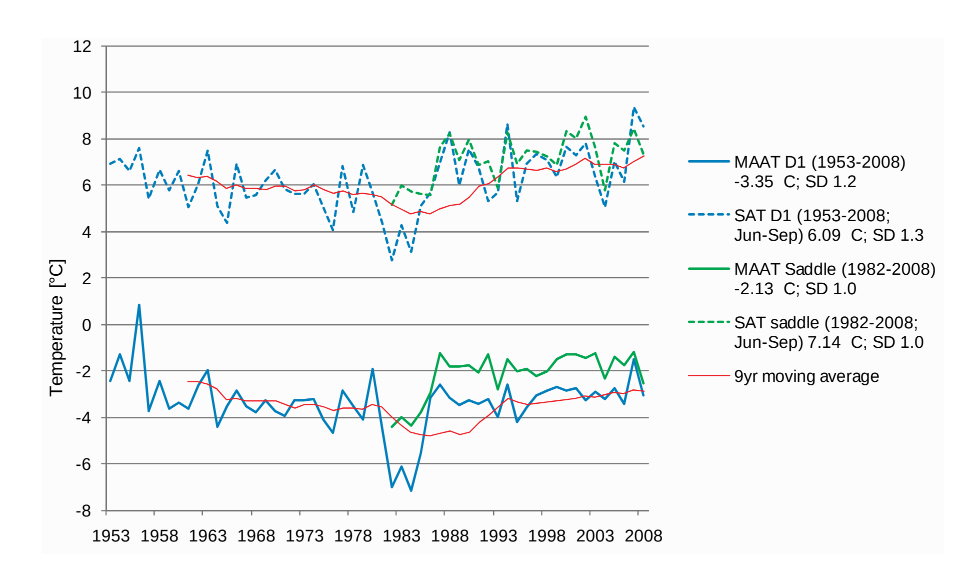

Fig. 2 Air temperature at the D1 and Saddle climate station are given as mean annual air temperatures (MAAT) and summer air temperatures (SAT, June – September) using months with possible ice melting conditions above 0 °C. For the data at D1, a 9 year moving average trend line is given, thus, the lows of 1982–1984 is phase shifted for 4.5 years.

In July 2005 several GPR survey lines were conducted in order to get an initial overview of the subsurface of a solifluction lobe at the Fahey site (see Leopold et al. 2008a). CMP-velocity analysis of the subsurface using GPR allows conclusions on the existence of ice because the electromagnetic signal sharply increases at the border of unfrozen to frozen material. The outcomes suggested the occurrence of ice lenses at a depth of 2 – 2.5 m, but not deeper, which most likely indicates that no permafrost exists at this site. This contradicts the results from Ives and Fahey (1971) and Greenstein (1983) who suggested permafrost below 2 m on wet sites and below 5 m on drier sites above 3,300 m a. s. l. Thus, several new GPR and ERT surveys have been conducted in order to provide more data. The outcomes from 2005 to 2009 document that during the summer month of August, all ice melts to an unfrozen subsoil present down to several meters. The same result was yielded during an ERT survey in August

2006 where unfrozen material was displayed by a high conductivity of the subsurface down to more than 15 m (Fig. 3A). Any remnants of ice would have caused low conductivity conditions and a subsequent increase of electric resistivity as indicated during a survey in late December 2009 (Fig. 3B). High resistivity values down to 1.1 m represent the winter refreezing zone in December above unfrozen material at greater depth (Fig 3B).

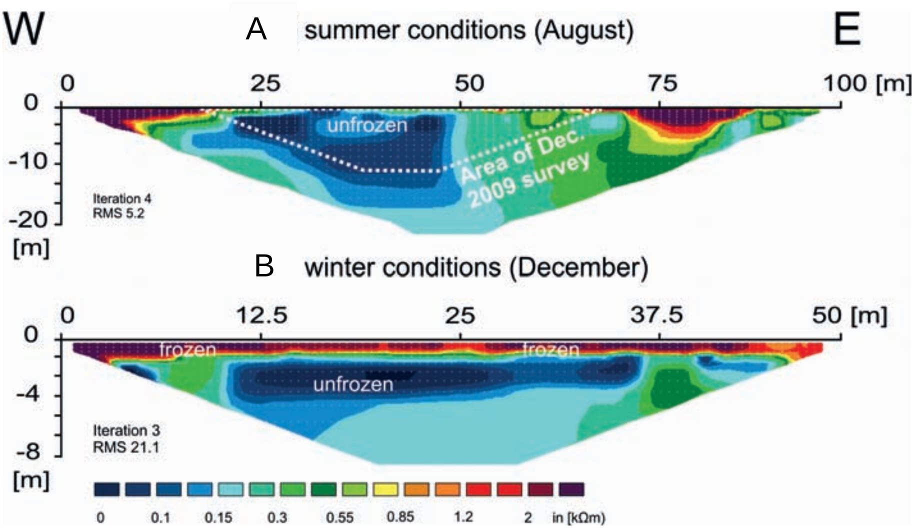

Fig. 3 Results of the electric resistivity tomography at the Fahey site under summer and winter conditions. Note the different horizontal meter scale. (*A*) ERT-results during summer show unfrozen, moist conditions throughout the solifluction lobe between 20–65 m as represented by low resistivity values, and dry conditions with corresponding higher values at two adjacent blocky crevasses. (*B*) ERT-results during winter conditions show a uniformly frozen layer of 1.1 m throughout the whole solifluction lobe and still unfrozen conditions in the deeper parts..

The outcomes of the geophysical survey correlate with data derived from two boreholes, which are equipped with temperature loggers down to 7 m (Fig. 4). While the west-loggers indicate dry conditions beside the solifluction lobe, the east-loggers record the subsurface temperature data from the soilifluction lobe with moist conditions. Both sites show a high thermal variability in the upper 1.2 m, which is closely linked to air temperatures. Further below the surface, temperature variability is decreased, documenting the general ability of the subsoil to filter highs and lows of air temperatures, which makes it a valuable climate archive. The data shows that below 280 cm depth, the ground stays unfrozen all year round. Winter freezing reached depths of slightly over 2.5 m, but by the end of July, it had melted again, just as predicted by the geophysical survey. This temperature trend was generally the same from 2006–2009.

Since the results seen above document the general suitability of the geophysical techniques to precisely locate permafrost, we conducted surveys at a site with even higher elevation. Occurrence of permafrost at 3,739 m a. s. l. next to the D1 site was predicted by Ives and Fahey (1971) and Greenstein (1983), and was modeled with a probability of 63 % by Janke (2005). The results of our ERT survey along the south slope onto the Ridge close to the D1 are displayed in Figure 4. Even though a MAAT of –3.35 °C would suggest the occurrence of permafrost, there is no indication of ice in the subsurface down to about 10 m depth. Values do not exceed 30 kΩm in general, and areas of highest values correspond with the distribution

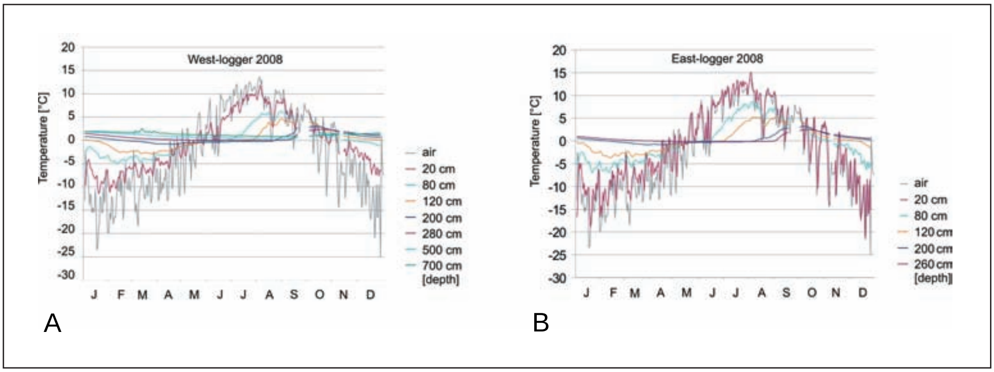

Fig. 4 Temperature profiles for the year 2008 at the (*A*) West- and (*B*) the East-loggers at the Fahey site. Note the high variability and close correlation with the air temperature down to about 120 cm. Ice melt was completed by mid August between 200 and 280 cm.

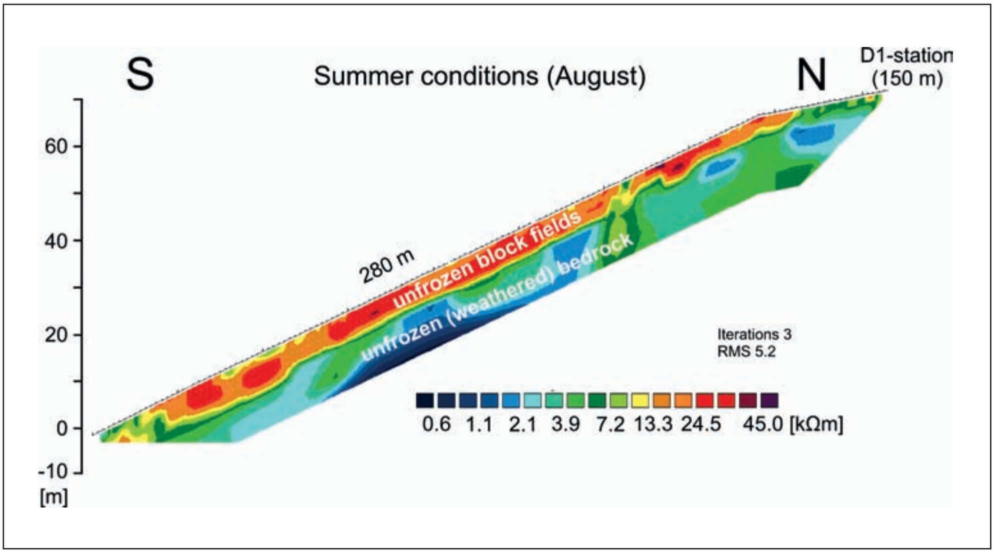

Fig. 5 Electric resistivity survey (Wenner configuration, 2 m spacing) along the south slope near the D1 climate station. A 4–5 m thick layer of blocky materials is portrayed by high electric resistivity values (20–30 kΩm) over weathered bedrock. No permafrost could be detected.

of block fields. Ice rich permafrost would yield much higher values of 100 kΩm or more, as documented on a nearby rock glacier (Leopold et al. 2010) and by many other authors (see Hauck and Kneisel 2008).

5. Discussion and Conclusion

Our data provide no indication on the existence of permafrost at selected sites at Niwot Ridge where, based on older data from the 1970s and 1980s (Ives and Fahey 1971, Ives 1974, Greenstein 1983), we would have expected permafrost. Even newer models calculate a probability of higher than 63 % for permafrost at these sites (Janke 2005). As the selected sites are at the lower altitude of sporadic permafrost distribution, our results could result from permafrost degradation due to globally rising temperatures in the last 40 years, similar to what is known from other sites (Lemke et al. 2007, Harris et al. 2003). However, careful evaluation of the older data presents some questions that must be answered before a final answer can be given for the study site. Since MAAT below –1 °C and bottom temperature of winter snow (BTS) below –3 °C seem to be closely linked with permafrost distribution (comp. Harris et al. 2003, Janke 2005), one would expect permafrost on the Fahey site as well as on the D1 site today. MAAT temperature from 1953 to 2008 at D1 has slightly increased from –3.8 °C in 1996 (comp. Williams et al. 1996) to –3.35 °C. However, Janke (2005) used data from 1988–2002 and calculated MAAT at D1 to be –2.9 °C and at the saddle to be –1.4 °C. If we extend the data from Janke (2005) to 2008, we find a small temperature decrease to –3.0 °C at D1 and to –1.7 °C at the Saddle, values that seem to somehow reflect the known variability. Furthermore, it corroborates the statement from Williams et al. (1996) that 'changes in climate on Niwot Ridge are not in synchrony with lowland warming in the Great Plains' mainly caused by local conditions. On the other hand, ground surface temperatures show an increase of 1 °C over the last decade, which is consistent with the glacial negative mass balance and potential loss of permafrost at the lower altitude sites (Williams et al. 2007). Slope aspect, albedo and winter snow cover also play a major role in the distribution of permafrost, as we found permanently frozen ground on and around a north facing rock glacier in the nearby Green Lake valley at 3,600 m a. s. l. (Leopold et al. 2010) and it was also detected at a steep north facing slope at 3,750 m a. s. l. by Ives (1974).

It continues to astonish us that we cannot detect permafrost where it has been detected in the 1970s at 3,500 m a. s. l. Our explanation to this apparent discrepancy is site-specific conditions. While Benedict (1970) never described permafrost, but instead only seasonal ice lenses, Ives and Fahey (1971) reported of two summers, where temperatures remained fractionally below 0 °C at the Fahey site (3,500 m a. s. l.), and this was done by temperature logging down to 2 m and by digging a trench. Beside the Fahey site summer temperatures remained above 0 °C down to 5 m depth (Ives 1974). The conclusion of widespread permafrost around D1 was produced by the extrapolation of temperature profiles. Deep drills and accurate temperature logger are missing for these sites up to present, except for the Fahey site (2006–2009), which is discussed in this paper. However, permafrost described by Ives and Fahey (1971) at the Fahey site was at the 'edge' of permafrost definition on a south-facing slope. The degradation or the existence at this site could be the result of a freeze lasting a few days longer during the winter, deeper and more long lasting snow cover in the spring or a denser cloud cover during the summer months with a decrease of radiation. These parameters can vary from year to year, leading to conditions that allow ice to stay in the subsurface during the summer. Thus, disappearance of ice or ice lenses during the summer months as documented by our results must not necessarily be interpreted as result of global warming. Moreover, it shows that threshold values of MAAT, BST and permafrost that have been elaborated and proven many times in the European Alps, might not be valid for all parts of Niwot Ridge with its much more southern latitudinal position. This is corroborated by Hoffman et al. (2007), who give evidence that summer temperatures and not winter air temperatures or snow accumulation regulate glacial mass balance here. That suggests that permafrost loss might be driven by SAT at the area around Niwot Ridge, rather than BTS or MAATs. SAT (June – September) did rise at D1 to 7.9 °C in the last decade compared to 6.3 °C from 1965 to 1975, where Ives and Fahey (1971) made their investigations. Higher summer temperatures in the last decade, in combination with less precipitation in the early 2000s as described by Williams et al. (2006) together with differences in snowdrift and albedo might be the reasons for permafrost loss on south slopes. At the least, these conditions anticipate the reformation of permafrost at our study sites. Degradation and reformation of permafrost in combination with increased solifluction have been proved for several periods throughout the Holocene (comp. Benedict 1970), and it seems to be a part of the site specific conditions at Niwot Ridge.

Global temperature variations undoubtedly influence alpine permafrost, as documented many times (e. g. Harris et al. 2003). However, each site needs to be carefully checked and monitored over a sufficient period of time in order to fully understand variation of the local conditions other than temperature that influence permafrost genesis before any climate relevant conclusion can be drawn. In our case the lack of permafrost at two sites at Niwot Ridge cannot be correlated exclusively with general global warming trends as shown above.

Acknowledgement

Data were provided by the NSF supported Niwot Ridge Long Term Ecological Research project and the University of Colorado Mountain Research Station for which we thank. The studies were partly carried out under the funding framework of Boulder Creek Critical Zone Observatory (BC-CZO) funded by the US National Science Foundation (NSF): Proposal 0724960. We also thank Kurt Chowanski and Casey Flynn from the Institute of Arctic and Alpine Research (INSTAAR, University of Colorado at Boulder) for their help to collect geophysical data in the winter 2009. We thank the Keck Geology Consortium, Lancaster PA, for supporting students who helped in the data acquisition.

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Escherichia coli – Facets of a Versatile Pathogen
On the Occasion of the 150th Birthday of Theodor Escherich (1857–1911)

Leopoldina-Symposium
Deutsche Akademie der Naturforscher Leopoldina
in Zusammenarbeit mit der *European Molecular Biology Organization* (EMBO) und der *Federation of European Microbiological Societies* (FEMS)
vom 9. bis 12. Oktober 2007 im Bildungszentrum Kloster Banz, Bad Staffelstein

Nova Acta Leopoldina N. F., Bd. *98*, Nr. 359
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Aus Anlass des 150. Geburtstages von Theodor Escherich, dem Entdecker des Bakteriums *Escherichia coli*, werden hier neue Forschungsergebnisse aus den Gebieten der Genomik, Pathogenese bakterieller Erkrankungen und Wirts-Bakterien-Interaktionen zusammengestellt.
Der Kinderarzt und Mikrobiologe Escherich beschrieb 1885 erstmals das „*Bacterium coli commune*“. Das später nach seinem Entdecker *Escherichia coli*, kurz *E. coli*, genannte Bakterium entwickelte sich zum beliebtesten „Haustier“ der Molekularbiologen. *E. coli* stellt mittlerweile molekularbiologisch den am besten untersuchten Organismus dar und wird von Wissenschaftlern weltweit als Modellorganismus genutzt. Behandelt werden außer der Bedeutung von *E. coli* in der molekularbiologischen Forschung vor allem Fragen der Genregulation, Beziehungen zwischen Kommensalismus und Pathogenität und das Problem der Virulenzfaktoren.

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Australia

Nova Acta Leopoldina NF *112*, Nr. 384, 293–307 (2010)

Impacts of Climate Change in Australia

Neville Nicholls (Melbourne, Australia)

With 5 Figures

Abstract

Since the middle of the 20th century, the average Australian temperature has increased about 0.75 °C, similar to the warming observed globally. The warming has occurred across the country. Associated with this warming trend there has been a substantial increase in the number of hot extremes, and a decline in cold extremes such as frosts. In turn, these changes in temperature extremes have affected human health, reducing the threat of cold episodes but increasing the risk of deaths in unprecedented heat waves. The warming has caused spring snow depths to decline about 40 % over the past 40 years. Spatial trends in rainfall have varied across the country with drying along the south and east coast, and increasing rainfall in the northwest. The prolonged drought in southeast Australia has, with the widespread warming and unprecedented heat waves, contributed to increased bushfire risk. The warming has been attributed to anthropogenic actions, specifically increased greenhouse gas emissions, but the rainfall trends are more difficult to ascribe to a single cause. However, the rainfall decline in southern Australia is closely related to a strengthening of the subtropical ridge that lies across southern Australia. There is little evidence that the rainfall decline is the result of changes in the behavior of natural modes of climate variability such as the El Niño-Southern Oscillation. Climate models project continued warming with continued drying along the southern coast.

Zusammenfassung

Seit Mitte des 20. Jahrhunderts ist die mittlere Temperatur in Australien um 0,75 °C angestiegen, ein Wert vergleichbar mit dem globalen Mittelwert. Die Erwärmung umfasst den gesamten Kontinent. Parallel zur mittleren Erwärmung hat sich die Anzahl von Hitzewellen deutlich erhöht, während die Anzahl kalter Extreme, wie z. B. Frost, zurückgegangen ist. Die Trends in Temperaturextremen zeigen beobachtbare Auswirkungen auf die menschliche Gesundheit mit einem Rückgang in Erkrankungen im Zusammenhang mit Kälte und einem erhöhten Risiko für Todesfälle während Hitzewellen von bisher noch nicht dagewesener Intensität. Die Erwärmung des Kontinents hat zu einem Rückgang der Schneehöhe um 40 % geführt. Die räumliche Verteilung von Niederschlagstrends ist variabel mit einem deutlichen Rückgang entlang der Ost- und Südküste und einem Anstieg im Nordwesten des Landes. Die langanhaltende Dürre im Südosten des Landes führt gemeinsam mit der mittleren Erwärmung und den immer häufigeren Hitzewellen zu einem stark erhöhten Waldbrandrisiko. Während der Erwärmung eindeutig anthropogene Ursachen, vor allem der wohlbekannte Anstieg in der Konzentration von Treibhausgasen, zu Grunde liegen, sind die Ursachen für die Niederschlagstrends wesentlich komplexer. Der Rückgang im Niederschlag in Südost-Australien steht im Zusammenhang mit einer Verstärkung des subtropischen Hochdruckgebietes, das den Süden Australiens beeinflusst. Natürliche Klimaschwankungen, wie z. B. El-Niño zeigen keinen eindeutigen Einfluss auf den Niederschlagstrend. Moderne Klimamodellvorhersagen für das 21. Jahrhundert deuten auf eine weitere Erwärmung und einen weiteren Rückgang des Niederschlags entlang der Südküste Australiens hin.

1. The Changing Australian Climate: Warming Everywhere

In recent years, many Australian locations have been setting and resetting new record high temperatures, with startling frequency and huge increases in the record temperatures. One example is Windorah Post Office in western Queensland. The long-term August mean maximum temperature for this station, since 1931, is 24 °C. The August 2009 mean maximum temperature was 30.6 °C, a full 6.6 °C higher than the long-term average. Prior to 2009, the record daily maximum temperature for August at this station was a very warm 34.2 °C. This record was broken on 16 August 2009, with a new record of 35.2 °C. Five days later this new record was broken with a new record maximum temperature of 35.8 °C. The following day the record was broken again, and again the following day, and again the day after that. Finally, on 29 August the record was broken and reset for the sixth time in the single month, with a new record August maximum temperature of 38 °C, a full 3.8 °C higher than the previous record maximum for August. The seven hottest August days ever recorded at this location all occurred in August 2009.

Other locations across Queensland and New South Wales experienced similar record-breaking temperatures. Charleville, also in western Queensland, had four days in August 2009 that experienced temperatures hotter than the previous record August temperatures, and the August record is now 35.8 °C, 2.3 °C hotter than the previous record. Charleville's record stretches back to 1942. Archerfield, near the east coast and just on the outskirts of Brisbane, the state capital, set a new record of 35.7 °C, 3.5 °C hotter than the previous record. Archerfield's data started in 1929.

A similar phenomenon, the repeated resetting of record temperatures, has been observed across the country in recent years. A heatwave in Adelaide in March 2008 saw 15 consecutive days exceeding 35 °C – seven days longer than the previous record heatwave duration (and the new record was set in March, a month when Adelaide has typically only seen a couple of days exceeding 35 °C). Before 2009 Melbourne had not experienced a run of three days with temperatures exceeding 42 °C. In late January 2009 we saw three days in a row that not only exceeded 42 °C but also exceeded 43 °C. On 7 February, a new Melbourne record maximum temperature of 46.4 °C was established, nearly one degree warmer than the old record highest temperature for any time of the year (and more than 3 °C hotter than the previous February record temperature). Many Victoria locations set new record temperatures in late January this year only to see the new records broken again on Black Saturday, 7 February 2009. The record average daily temperature (the average of the maximum and minimum temperatures) for Melbourne has been broken four times in the last 12 years, after the record stood for 120 years without being threatened.

The impacts on humans and ecosystems of these unprecedented new records are clear. In southeast Australia the record high temperatures of 7 February, now known as Black Saturday, accompanied the deadliest bushfires ever seen in Australia, leading to the deaths of more than 170 people on the outskirts of Melbourne. The three day heatwave a week prior to the fires killed more than 350 people across the state of Victoria and many more in other parts of southeast Australia.

These very recent new record temperatures are occurring on the background of a gradual warming across the country. Much information about recent changes and variations of Australian climate is available from either the Bureau of Meteorology (www.bom.gov.au), where much information about past and current climate change is available, or a joint CSIRO – Bureau of Meteorology publication, *Climate Change in Australia* (http://www.climatechangein-australia.gov.au/). Figure 1 plots annual average rainfall and maximum and minimum temperature anomalies, averaged across Australia, for the period 1910–2008 (prior to 1910 there were insufficient temperature records to produce a credible Australian average temperature).

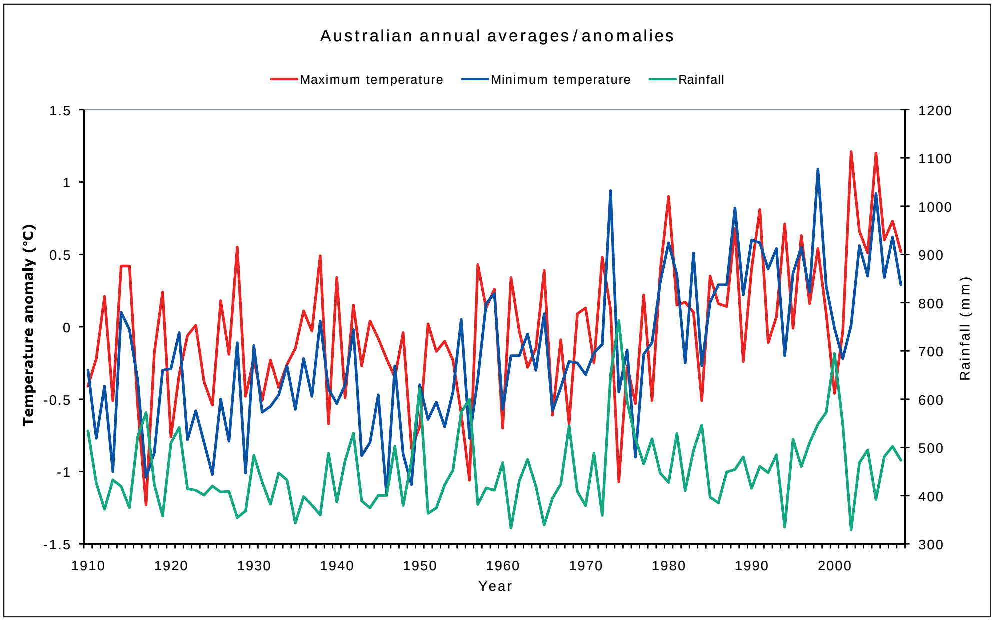

Fig. 1 Time series of Australian average rainfall, and maximum and minimum temperature anomalies. Data from http://www.bom.gov.au/climate/change/.

Figure 1 illustrates that Australian average temperatures (minimum and maximum) showed considerable variability but no obvious trend until the middle of the 20th century. From mid-century average temperatures have increased about 0.75 °C, similar to the warming observed globally. There continue to be strong interannual variations in temperature, for instance, very cool temperatures during the heavy rains around the year 2000.

The warming seen in the temperature averages across Australia is also seen essentially everywhere across the country[1], with no area exhibiting cooling over the period of record.

2. The Changing Australian Climate: Droughts and Flooding Rains

Averaged across Australia, rainfall trends are much weaker than the warming trend observed in temperatures, although rainfall since the mid-20th century has been greater, overall, than was the case earlier in the century. Rainfall exhibits strong geographical variations in the sign

1 http://reg.bom.gov.au/cgi-bin/climate/change/trendmaps.cgi?map=tmean&area=aus&season=0112&period=1910.

and magnitude of the trend, with increasing rainfall in the centre and northwest[2]. Although rainfall averaged across the country has not decreased, two areas of extended and apparently unprecedented drought have appeared: the southwest and southeast of the country. In the southwest low rainfalls have been observed since the early 1970s; the southeast drought has been shorter but each of the last 12 years have all seen below average rainfall averaged across Victoria, and the first ten months of 2009 provided the driest start to the year of any year on record in Melbourne. Prior to the current drought, the longest run of consecutive below average rainfall years at Melbourne was six. The probability of 13 consecutive below-average years, in an unchanging climate, is about 0.0005. Smaller areas of declining rainfall are seen in the south, especially the southwest, and along the Queensland coast. There are some seasonal variations in these trends with the rainfall decline along the south coast clearest in autumn and winter and with the increased rainfall in the northwest mainly occurring in summer.

3. The Changing Australian Climate: Weather Extremes

Detailed analyses of trends in Australian temperature and rainfall extremes have been conducted by Alexander et al. (2007). They showed that maximum and minimum temperatures have been increasing across most of Australia. In the east of the continent the trends in maximum and minimum temperature are up to 0.4 °C per decade – a total increase of about 2 °C since 1957. Consistent with this warming are statistically significant decreases in cold nights and cold days, decreases in frost days and cold spells, and increases in extremely warm nights. At any particular location, the increasing trend in the minimum temperature with concomitant less frequent cool nights is generally larger than the trend for maximum temperature and cool days. This means that the diurnal range (the difference between the maximum and minimum temperatures) is decreasing.

Figure 2 shows that, since 1957 (daily data appropriate for this analysis are not available prior to 1957) the number of hot nights (the number of nights with minimum temperature exceeding 20 °C) has increased by about 25 %, while the number of frost nights (nights with temperatures below 0 °C) has nearly halved. The Australian average number of hot days (35 °C or more) has also increased by about 25 % over this period.

Trends in rainfall extremes have been much less clear. The number of heavy rain days (days with rainfall exceeding 10 mm) has not shown any strong trend, averaged across the country. Variations in the numbers of extreme temperatures and rainfall from year-to-year are closely related, as can be seen in Figure 2. Time-series and maps of trends of many other indices of extreme weather events are available at http://www.bom.gov.au/climate/change/. As was the case with the trends in the average temperatures, the trends in the temperature extremes are quite similar across the country. On the other hand, there is considerable spatial variation in the trends in the precipitation extremes, with a decline in the number of heavy rain days along the south and east coasts (where rainfall totals have declined since mid-century) and increases elsewhere. Alexander et al. (2007) found that the trends in rainfall extremes vary throughout the seasons. The largest trend is the decrease in both the average and the maximum 1-day rainfall in southeastern Australia in March–May – the crucial autumn break

2 http://reg.bom.gov.au/cgi-bin/climate/change/trendmaps.cgi?map=rain&area=aus&season=0112&period=1910.

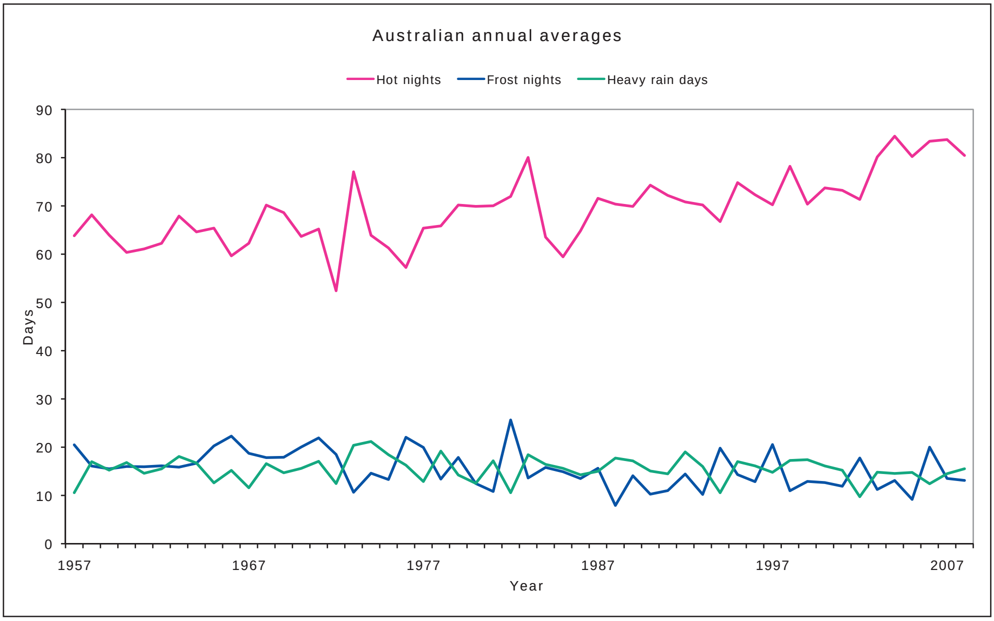

Fig. 2 Trends in Australian average numbers of hot nights, frost nights, and days with heavy rain. From: http://www.bom.gov.au/climate/change/.

period. In some places the trends in the average rainfall and the extremes are not in the same direction (that is, we are truly observing "droughts and flooding rains" in the same location). For example, the trend in the total amount of rainfall that falls on the day with the maximum rainfall is increasing almost everywhere, even in the southwest, indicating that the intensity of the rainfall is increasing. In summer and spring, the trends in one day maximal rainfall were increasing almost everywhere over the period 1910–2005.

What about other extreme events? Unfortunately, the list of extremes for which we know little or nothing about is extensive, and it is generally those extremes that present the greatest risk to life and property (Lynch et al. 2008a). Little work has been done to document the past history of such extremes as hail and thunderstorms, bushfires, and extreme winds. Where studies exist, they are limited geographically or in time because efforts to locate and validate appropriate data are so costly and time consuming. For many types of extremes, the data needed to document changes simply does not exist or is too questionable in quality to be useful. Changes in longer-lived and larger-scale extremes such as droughts and widespread flooding events are also difficult to document. For such extremes there also exists a definitional question that confounds documentation of changes. For instance, there are many definitions of "drought". Which definition is relevant to health-related impact assessments and actions? Tropical cyclone numbers around Australia do not appear to have increased and may have even decreased over the past few decades, while the numbers of mid-latitude storms affecting the southern parts of the continent certainly seem to have decreased, presumably contributing to the rainfall decline along the southern coast.

We have little credible information about trends in other small-scale extremes such as hail events and tornadoes – these systems are very difficult to monitor over the long periods required to determine trends. Monitoring changes in wind is also challenging, because small changes in the immediate environment can affect the measurements of wind strength markedly.

4. What has been the Impact of these Changes?

Human health, especially of the elderly, is strongly influenced by temperature, with increased deaths at hot and cold extremes (NICHOLLS 2009a). The time-series of Melbourne mean daily winter mortality is plotted in Figure 3, along with the time-series of mean winter temperature. The close relationship between the two variables from year-to-year is evident, despite the strong trends in both variables. An increase in temperature from 1 year to the next (note that the temperature scale is reversed in Figure 3) tends to be accompanied by a decline in the winter mean daily mortality. The trends in the two variables are both positive. Ordinary least squares regression was used to estimate the trend in the variables over the 1979–2001 period: winter mean minimum temperature increased 0.7 °C while mean daily winter mortality increased by 32 % over the mortality at the start of the period (1979). The increased mortality presumably reflected the increased population aged over 64 years, partly offset by improved medical services. Since a warming from year-to-year was accompanied by a decrease in mortality, it is reasonable to assume that the warming over the entire period 1979–2001 would also have tended to reduce mortality, offsetting other factors that caused the observed increase in mortality. An estimate of the amount by which the warming would have reduced mortality, in the absence of other confounding effects, can be calculated from the linear regression between year-to-year changes in mortality and year-to-year changes in mean minimum temperature. The correlation between year-to-year changes in winter mean minimum temperature and the year-to-year percentage change in mean winter daily mortality was −0.76 ($n = 23$; $p < 0.001$). The slope of the ordinary least squares regression between the two variables is −6.4 %/°C. This provides an estimated decline in winter mortality of 4.5 % due to the observed warming of 0.7 °C over 1979–2001, relative to the typical winter mortality at the start of this period. So, winter mortality in Melbourne has declined substantially in recent years, because of warmer winters.

Not all impacts have been positive though. The 12 year drought in southeast Australia, the very low rainfall at the start of 2009, and the record temperatures in late January and on Black Saturday all must have contributed to exacerbating the bushfire situation around Melbourne on Black Saturday, when 174 people died, and many hundreds of houses were destroyed in Australia's worst natural disaster.

There have already been clear impacts of the warming trend on other aspects of the Australian climate and ecosystems. NICHOLLS (2005), using snow depth data from Spencers Creek (the highest station with longterm snow depth records in Australia, elevation 1,830 m) in the Australian Snowy Mountains, showed that maximum winter snow depths had declined somewhat between1962 and 2002, but that there had been a strong decline (~40 %) in the snow depth at the start of October (mid-spring). Data are now available for the period 2003–2009 (http://www.snowyhydro.com.au) and these have been used to investigate if snow depths have continued to decline. Time series of the snow depths at the start of October in each year 1954–2009, are plotted in Figure 4. The springtime snow depth decline is still much steeper (about twice as steep, in percentage terms) than the decline in the maximum snow depth. In the period 1954–1996, early October depths exceeding 200 cm were common (13 occasions, i.e. about every three years) but this depth has not been exceeded in the last 12 years. The springtime decline is statistically significant at better than 5 %, but the weaker relative decline in maximum depth (not shown) is not statistically significant.

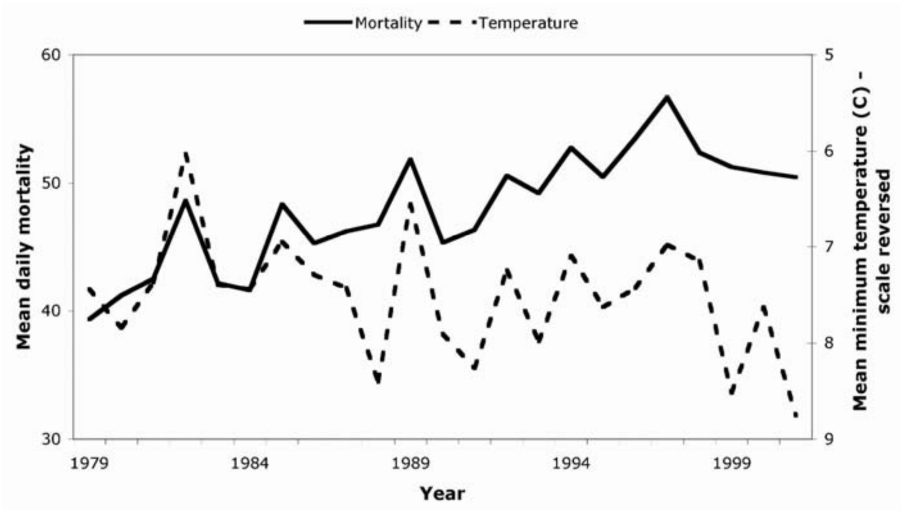

Fig. 3 Time-series of mean Melbourne daily winter mortality of persons aged over 64 years (*full line*) and winter mean daily minimum temperature (*broken line*; scale reversed)

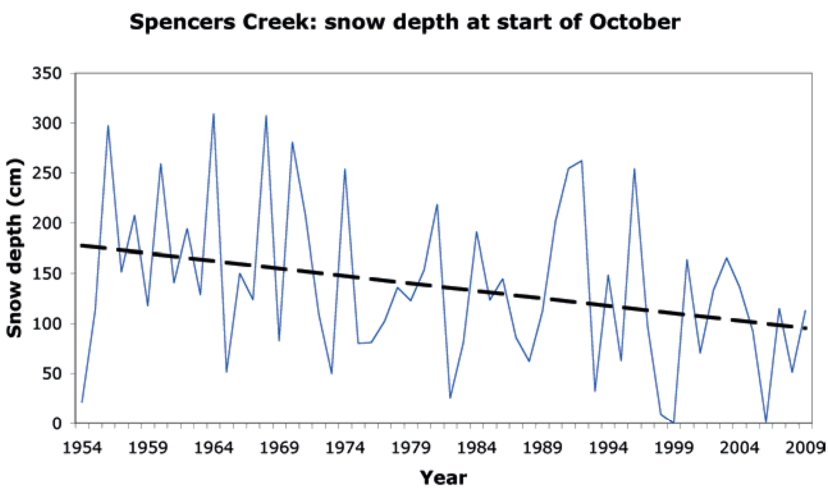

Fig. 4 Time series of the snow depths at the start of October in each year 1954–2009, with linear trend shown (broken line).

5. What has caused these Climate Changes?

How unusual are the recent trends and variations? Australian average temperatures during the first decade of the 21st century were clearly warmer than at any time during the 20th century (Fig. 1), but analyses of the rather sparse paleoclimatic data have not been sufficient, as yet, to determine how unusual these recent temperatures are relative to those of the past. The extended dry periods of the last few decades along the southern coast are clearly unusual. For instance, Victorian average rainfall has not exceeded 700 mm during the past 12 years, a far longer period of low rainfall than has been seen since at least the start of the 20th century.

Of course, just because some recent climate variations have been unusual in the historical context this does not necessarily mean that these climate anomalies are the result of human actions such as increased greenhouse gas emissions. Attribution studies require the demonstration that the climate change is consistent with the expected responses to a specific combination of anthropogenic and natural forcing, and that the observed change is not consistent with alternative, physically plausible explanations (Hegerl et al. 2007). Attempts to attribute the observed climate changes generally employ modern climate models forced by a range of factors. Thus some models will include anthropogenic factors as well as natural factors such as solar irradiance variations and volcanic eruptions. Then the response of the models to these various forcings would be compared with the known variations in climate. Studies of this type over the past few years have concluded that most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. The most obvious alternative explanation for the recent warming, a change in solar irradiance, is not credible since quality observations of solar irradiance over the past three decades indicate that there has been no increase in this forcing.

Could the warming observed across Australia be the result of natural variability? There is a variety of evidence suggesting that this is not the case. Maximum temperature variations from year-to-year are closely related to variations in annual rainfall, with wetter years also being cooler. Nicholls et al. (1996) showed that this relationship between annual mean maximum temperature and rainfall changed in the early 1970s. The relationship was still strong and negative (i.e., high temperatures tended to accompany droughts) but the temperature in the period 1973–1992 tended to be higher, for any value of rainfall, than had been the case in the earlier years. Nicholls (2003) showed that this "anomalous warming" further intensified after 1992. Since 1993, temperatures have tended to be higher, for a given rainfall, than was the case in the 1973–1992 period (which in turn was relatively warmer than previous years). Thus the warming observed over Australia over the last few decades does not reflect changes in rainfall. Stronger evidence comes from model-based attribution studies which have identified anthropogenic factors as the cause of the warming in Australia, as is the case over all inhabited continents (Hegerl et al. 2007).

What about the rainfall trends? The immediate cause of the rainfall decline in southern Australia (which has occurred principally in autumn) has been a strengthening of the subtropical ridge which Larsen and Nicholls (2009) demonstrate is related to variations and trends in rainfall over southern Australia (south of 30 °S). But what causes this strengthening, and the associated decline in rainfall? There seems no reason to suspect that changes in the natural modes of variability affecting Australia (e.g., El Niño) are the cause of these changes. Nicholls (2008) assessed trends in the seasonal and temporal behavior of the El Niño-Southern Oscillation over the period 1958–2007 using two indices of the phenomenon, NINO3.4

and a non-standardized Southern Oscillation Index (SOI). There is no evidence of trends in the variability or the persistence of the indices, nor in their seasonal patterns. There is a trend towards what might be considered more ''El Niño-like'' behavior in the SOI (and more weakly in NINO3.4), but only through the period March–September and not in November–February, the season when El Niño and La Niña events typically peak. The trend in the SOI reflects only a trend in Darwin pressures, with no trend in Tahiti pressures. Apart from this trend, the temporal/seasonal nature of the El Niño-Southern Oscillation has been remarkably consistent through a period of strong global warming. Thus the rainfall trends in Australia do not reflect changes in the behavior of the El Niño–Southern Oscillation. NICHOLLS (2009b) also examined whether trends in temperatures in the Indian Ocean or around northern Australia could be implicated as a cause of the decline in rainfall in southern Australia. Sea surface temperatures around northern Australia are strongly correlated with southern Australian rainfall but the recent warming of the ocean should have led to increased rainfall rather than the observed rainfall decline (Fig. 5).

NICHOLLS (2009b) also noted that the rainfall decline does not appear to be explainable by a change in the behavior of the Indian Ocean Dipole (which is not strongly correlated with Australian rainfall on interannual timescales). The inability of trends in the behavior of known natural modes of variability affecting Australian rainfall to explain the decline in rainfall tends to support earlier studies (NICHOLLS 2006) that suggested that the rainfall decrease in southern is likely due to a combination of increased greenhouse gas concentrations, natural climate variability and land-use change.

Can we attribute changes in extremes to human activity? It is possible to argue that human influences are increasing the likelihood of heatwaves in Australia (LYNCH et al, 2008a).

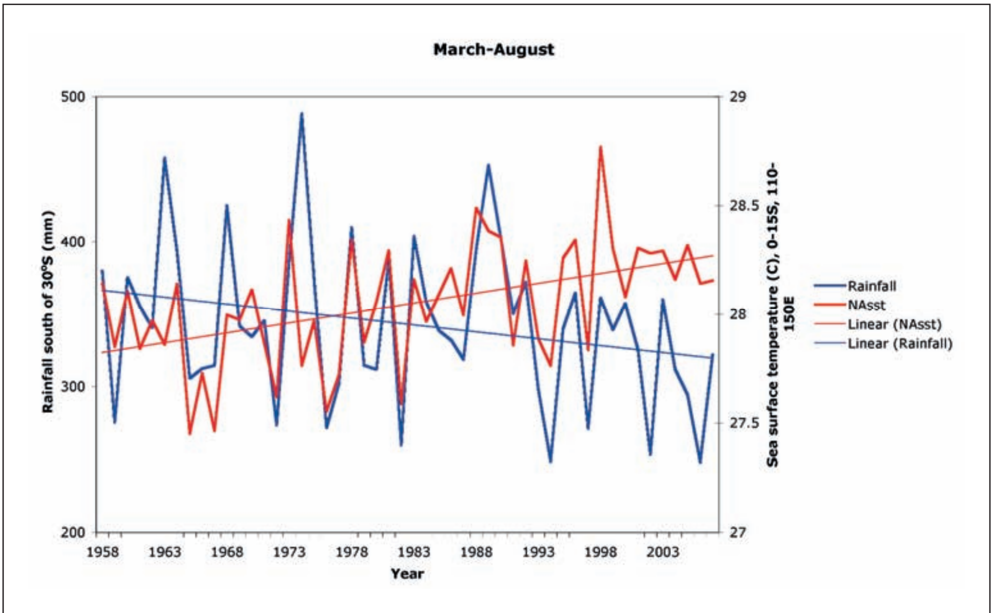

Fig. 5 North Australian sea surface temperature and Australian rainfall south of 30 °S. Linear trends are also shown for both time series.

Extreme temperatures have been increasing similarly to mean temperatures (Griffiths et al. 2005), strongly suggesting that the changes in the extremes, as well as in the mean temperature, can be attributed to anthropogenic factors. Most recently, Alexander and Arblaster (2008) examined multiple simulations from nine global coupled climate models and assessed their ability to reproduce observed trends in a set of indices representing temperature and precipitation extremes over Australia. Observed trends over the 1957 to 1999 period were compared with modeled trends calculated over the same period. When averaged across Australia, the magnitude of trends and the variability of temperature extremes were well simulated by most models particularly for the warm nights index. Thus, evidence continues to accumulate suggesting that human influences on the atmosphere are affecting these Australian extremes.

There is less clear similarity between observed and simulated changes in the frequency of heavy precipitation events over Australia, although globally there is a tendency in both observations and climate model simulations for increased frequency of heavy rainfall events at mid-latitudes. Over Australia, Alexander and Arblaster (2008) found that climate models do not agree on the magnitude of the trend in precipitation extremes, although most models do reproduce the correct sign of trend. The simulation of changes of precipitation, over Australia as elsewhere, remains a significant challenge for the modeling community.

Even less is known about the possible human impact on (the largely undocumented) changes in hail and thunderstorms, floods, bushfires, and extreme winds. Such extremes are difficult to simulate in climate models, and this severely reduces our ability to determine the causes of any observed trends in such variables. The facility possessed by numerical weather prediction models and forecasting services in general is an important resource in developing our capacity for projecting these extremes into the future. Documenting and comprehensively studying the changes in such small-scale events remains a task for the future in the goal to attribute cause. Possible changes in even some larger-scale extremes, notably tropical cyclones, have been difficult to attribute (Walsh et al. 2009).

6. How will the Australian Climate Change in the Future?

The *IPCC* 2007 report predicted that continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century (Solomon et al. 2007, *Core Writing Team* et al. 2007). Even if the concentrations of all greenhouse gases and aerosols were kept constant at year 2000 levels, a further warming of about 0.1 °C per decade would be expected. Regional-scale changes predicted (with decreasing confidence as we go down the list) include:

- Increases in frequency of hot extremes, heat waves and heavy precipitation;
- An increase in tropical cyclone intensity;
- Poleward shift of extra-tropical storm tracks with consequent changes in wind, precipitation and temperature patterns;
- Precipitation increases in high latitudes and decreases in most subtropical land regions, continuing observed recent trends;
- By mid-century, annual river runoff and water availability are projected to increase at high latitudes (and in some tropical wet areas) and decrease in some dry regions in the mid-latitudes and tropics.

Some projected global climate changes such as the following might have indirect effects on Australia, even if they do not have direct impacts in this country (Lynch et al. 2008b):

- *Freshwater flooding*. A future increase in heavy rainfall events would lead to increased flood risk posing challenges to society, physical infrastructure and water quality. It is likely that up to 20 % of the world population will live in areas where river flood potential could increase by the 2080s.
- *Deterioration of water supply quality*. Increased temperatures will affect the physical, chemical and biological properties of freshwater lakes and rivers, with predominantly adverse impacts on many individual freshwater species, community composition and water quality. In coastal areas, sea level rise will exacerbate water resource constraints, due to increased salinization of groundwater supplies.
- *Deterioration of regional food supplies*. By 2020, in some countries in Africa, yields from rain-fed agriculture could be reduced by up to 50 %. Agricultural production, including access to food, in many African countries may be compromised.
- *Environmentally-induced migration and conflict*. Stresses such as increased drought, water shortages, and riverine and coastal flooding will affect many local and regional populations.

These impacts will, ultimately, impact on Australia, even though they are most relevant to other countries, especially developing economies. Impacts on Australia could include increased need to provide aid, or to assist in re-location of affected communities. So, any assessments of the likely health impacts of climate change on Australia have to be cognizant of the projections of climate change globally, as well as local projected changes. There are, of course, other projected changes (e. g. increased frequency and intensity of heat waves) that will have more direct health impacts.

What about specific Australian projected climate changes? Details of projections for Australia area, including spatial variations in projected changes, are available at http://www.climatechangeinaustralia.gov.au/. The magnitude of change predicted depends on assumptions about the rate of emissions of greenhouse gases and other factors. In the following summary a medium "scenario" of emissions is assumed (equivalent to what the IPCC calls the A1B scenario).

Under this scenario, the median prediction of temperature rise predicted by the climate models is about 1 °C by 2030 and about 2 °C by 2050. The warming would be general across the country, although slightly less warming would occur around the coast. Ocean temperatures are expected to warm, but at a slower rate than temperatures over land. Temperature extremes should also change in frequency, with fewer cold days/nights and more hot days/nights including more frequent and unprecedented heat waves. Different models show strong consistency in their predictions of this warming. Rainfall projections are generally unclear, although nearly all models predict continued rainfall declines in the west and along the southern fringe of the continent. There is an expectation that mid-latitude lows will continue to decline in frequency around the southern coast of the continent, continuing the long-term trend noted above and contributing to the continuing decline in rainfall.

The changes in Australian extremes likely to accompany anticipated future increases in atmospheric concentrations of greenhouse gases include (*CSIRO* 2007, Alexander and Arblaster 2008):

- A continuation of the increase in frequency of extremely hot days and warm nights, and a concomitant increase in the frequency of heatwaves;

- A decrease in frequency of frost, which has increased in some parts of Australia recently due to drought conditions (drier conditions can lead to cooler nights where cloud cover is decreased);
- Increase in extreme rainfall events except in the southern half of the continent in winter and spring, where total rainfall and extreme rainfall events both decrease;
- Increase in the frequency and length of drought conditions, especially in southwest;
- Increased wind speed in most coastal areas;
- Conditions less favorable for cool season tornadoes in southern Australia, but hail risk may increase over southeast coastal regions;
- Likely increase in proportion of tropical cyclones in more intense categories, but a possible decrease in total number of cyclones; and
- Substantial increase in fire weather risk in southeast Australia.

There is, however, considerable uncertainty in these projections, arising from the limited number of climate simulations from which they are derived, as well as model deficiencies.

7. What are the Sources of Uncertainty in these Climate Projections?

The reality of the situation is that, apart from the increases in hot days and nights, the decreases in cold days and nights and (with less confidence) increases in heavy rainfall events, little can be said with high confidence, at the moment, about how extreme weather and climate events will change in the future. As noted, this is due to data scarcity, the expense of data rescue, limitations in understanding, shortfalls in model performance and problems with the definition of events. The result of this low confidence in some projections is that planned adaptations to reduce our vulnerability to extremes and to enhance our emergency response and recovery processes will need to be flexible and cost-effective, in order to answer to the evolving context.

The El Niño-Southern Oscillation (ENSO) is an important natural climate phenomenon that has important impacts on Australia's climate, so projecting how ENSO might change as we increase the atmospheric concentration of greenhouse gases is important. El Niño events (when the east equatorial Pacific is abnormally warm) usually accompany drier than normal conditions over much of Australia, so a change in the frequency or intensity of El Niño events could result in major changes in Australian rainfall. Even tropical cyclone activity around the Australian region is related to ENSO, so a change in ENSO behavior could well overwhelm any other influence on tropical cyclone activity (from, for example, the direct effects of warming due to increased atmospheric greenhouse gases). At the moment, however, problems with model simulations of ENSO mean that credible projections of changes in the phenomenon cannot be made. This is perhaps the largest uncertainty regarding the future climate over Australia.

Other natural climate modes that appear to influence the Australian climate include the Southern Annular Mode (SAM), the Indian Ocean Dipole (IOD), and the Pacific Decadal Oscillation (PDO). However, there is considerable scientific debate about the relative importance of these modes and ENSO, whether they might be responsible for some trends in the climate, and even whether these modes themselves are changing (NICHOLLS 2008, 2009b). Nevertheless, there is no doubt that improved understanding of how these modes may change in the future is important, if we are to prepare more credible regional climate change projections.

Apart from these natural "internal" climate modes, other factors external to the atmosphere-ocean system affect the climate, and changes in these factors might enhance or offset warming and associated climate changes resulting from increased atmospheric concentrations of greenhouse gases. The most important of these external factors are solar variability and volcanic eruptions. These natural factors are believed to have played a role in the warming observed in the first few decades of the 20th century. But the warming of the past few decades cannot be attributed to changes in solar irradiance since this has not increased over this period. Major volcanic eruptions (e. g. Agung in 1963, Pinatubo in 1991) have caused cooling of the global climate for a year or two post-eruption, but the long-term warming trend recovered quickly thereafter. However, a series of major volcanic eruptions could delay warming from increased greenhouse gas emissions, while if solar irradiance decreased by even a small amount, substantial cooling could result.

Other anthropogenic influences on the climate have been identified, and need to be considered when projecting future climate change. A decrease in ozone concentrations in the upper atmosphere, caused by various synthetic chemicals, has led to a cooling of the upper atmosphere. However, regulation of these synthetic chemicals means that this problem is gradually being overcome. Industry also releases aerosols and black carbon which can contribute to changes in global temperatures. Although these tend to be short-lived problems (they are usually "rained out" of the atmosphere within a few days, whereas elevated CO_2 concentrations can remain for hundreds of years) the constant replenishment of these pollutants can cause problems, especially regionally. Finally, concentrations of human populations into cities means that the climate in which most of us live from day-to-day is affected by the Urban Heat Island Effect. This is the result of the massive amount of concrete that acts like a "heat bank" in the cities thereby tending to increase atmospheric temperatures, although the effect is mainly restricted to night-time in winter, and to nights with very light winds. Surface temperatures on dry, hard surfaces (typical of urban areas) can also be much greater during the day than moist, vegetated surfaces, leading to a surface heat island effect (http://www.epa.gov/heatisland/about/index.htm).

A warming climate can have other effects that are important to human health, including increased production of ozone near the surface. Similarly, if warming and drying lead to increased wildfires this could increase atmospheric pollutants in rural areas and even in cities close to the fires. In an attempt to reduce the likely increase in wildfires resulting from climate change, deliberate burns to reduce fuels might lead to increased air pollution, leading to increased threats to human health. Warming might also increase the demand on power supplies, through heat-related decreases in the efficiency of generation and supply networks, or through increased demand for air conditioning. This in turn could lead to increased likelihood of power supply disruption, which could increase problems for the medical system, and threaten infrastructure generally.

It is important to recognize that multiple threats to human health could arise from a changing climate. Thus increased tropical rainfall, stronger tropical cyclones, and a more general warming, might synergistically lead to major increases in the threat of disaster. So a stronger tropical cyclone hitting the Australian coast could be accompanied by abnormally heavy rainfall accompanied by unprecedented temperatures. These would increase the likelihood of food and water contamination or disease, at a time when the affected populations are most vulnerable. Higher sea levels could only further complicate such a scenario. It is important, therefore, to consider all the facets of likely climate change in an integrated fashion, rather than simply assume that only one of these likely climate changes will affect populations at any single time and place.

8. Conclusions

There is little doubt that human actions, specifically increased emissions of greenhouse gases leading to increased atmospheric concentrations of these gases, are affecting the Australian climate by causing warming and unprecedented heat waves. In turn, these heat waves are leading to excess mortality above what could be expected with a changing climate. On the other hand, the warming has also led to a decline in the frequency of cold events and this should have led to a decline in human mortality in winter. There have been unprecedented droughts also, but it is more difficult to confidently ascribe these to human actions (although they do not seem to have been due to changes in the behavior of natural modes of climate variability known to affect the Australian climate). Climate models project continued drying along the south coast of the Australian continent, and this, with the continued warming, should lead to increased threats of bushfires. But perhaps the greatest potential problem caused by climate change will come from what we do not understand about the climate system: the chances of compounds or multiple events (e. g. flash flooding during droughts or heat waves being exacerbated by prolonged droughts). Global warming of 4 °C will surely be accompanied by major dislocations of storm tracks, tropical cyclone activity, and natural modes of variability such as the El Niño. All of these would pose enormous risks to the Australian community. But we cannot adapt to these changes, unless we know the details of how they will change. It is a matter of urgency that we determine, with more certainty and detail, how the Australian climate will change in the future, if we are to avoid the worst impacts.

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Deutschlands älteste Akademie, die Deutsche Akademie der Naturforscher Leopoldina, bemüht sich in besonderem Maße um die Förderung von Nachwuchswissenschaftlern. Seit 1992 vergibt sie zur Unterstützung der beruflichen Weiterentwicklung herausragender junger Wissenschaftlerinnen und Wissenschaftler ein Stipendium, ausgestattet durch Zuwendungen des Bundesministeriums für Bildung und Forschung, das es den Ausgezeichneten ermöglicht, innerhalb von zwei bis drei Jahren eigenständig ein außergewöhnlich innovatives Forschungsprojekt an ausländischen Wissenschaftseinrichtungen umzusetzen. Über 320 Forscherinnen und Forscher konnten seit Beginn des Programms gefördert werden. Der vorliegende Band zeigt die Vielfalt der Projekte und liefert Beispiele für die erreichten Ergebnisse seit 2006. Damit werden Chancen und Ansprüche des Förderprogramms für künftige Bewerber deutlich.

Wissenschaftliche Verlagsgesellschaft mbH Stuttgart

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Satellite Observations for Identifying Continental-Scale Climate Change over Australia

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Will Featherstone (Perth, Australia)

With 4 Figures

Abstract

Australia's large extent and relatively low population density, as well as its range of climates, means that it is heavily dependent upon satellite observations to identify the extent and magnitude of climate change. This work examines three types of satellite missions that are used to assess different aspects of climate change. The first involves the use of radio occultation measurements based on signals from Global Navigation Satellite Systems (GNSS) spacecraft made by low-Earth orbiting (LEO) satellites to identify changes in the height of the tropopause, a sensitive indicator of climate change owing to its response to temperature changes in the troposphere and lower stratosphere. The second deals with rainfall over Australia, as measured by the Tropical Rainfall Monitoring Mission (TRMM), in conjunction with other satellite- and ground-based observations. Such observations are invaluable, given the scarcity of ground-based observations over vast areas of Australia. While a comparison between the TRMM product and existing ground-based data is very good, there appears to be a decrease in the correlation between datasets, the reason for which is still being investigated. Finally, we examine the state of terrestrial water storage over Australia as determined from variations in the regional gravity field as measured by the Gravity Recovery and Climate Experiment (GRACE) twin-satellite mission. The loss of substantial volumes of ground water from the Murray-Darling River Basin in the southeast corner of the continent is very apparent, as is an increase over the northern parts of the country. Together, such satellite missions provide a continental-scale picture of climate change over Australia, with temperature and rainfall variations, as well as water resources, able to be monitored, providing valuable information to natural resource managers and climate modellers who endeavour to predict future changes.

Zusammenfassung

Aufgrund seiner großen räumlichen Ausdehnung sowie geringen Bevölkerungsdichte ist die terrestrische Beobachtung von Klimaänderungen über dem australischen Kontinent recht schwierig. Deshalb ist Australien stark von Satellitenbeobachtungen abhängig, um seine diversen Klimazonen adäquat zu erfassen. Diese Arbeit untersucht Beobachtungen von drei verschiedenen Satellitenmissionen auf ihre Anwendung für Klimawandelstudien über Australien. Die erste Untersuchung benutzt Radiookkultationsbeobachtungen von GNSS (*Global Navigation Satellite System*)-Radiosignalen, die durch die Erdatmosphäre gehen und von verschiedenen niedrig fliegenden Satelliten empfangen werden. Diese Beobachtungen sind dazu geeignet, um Änderungen in der Tropopausenhöhe zu untersuchen, die wiederum ein guter Indikator für Klimaänderungen aufgrund von Temperaturänderungen in der Troposphäre und unteren Stratosphäre sind. Die zweite Untersuchung basiert auf den Niederschlagsprodukten der *Tropical Rainfall Monitoring Mission* (TRMM) in Verbindung mit terrestrischen Beobachtungen des australischen *Bureau of Meteorology* (BOM). Hierbei werden TRMM-Satellitenbeobachtungen verwendet, um die teilweise spärliche Beobachtungsdichte der BOM-Daten zu ergänzen. Vergleiche haben gezeigt, dass die TRMM- und BOM-Niederschlagsprodukte generell sehr gut miteinander korrelieren, allerdings mit einer zurzeit unerklärten geringen Reduktion der Korrelation in den letzten Jahren. Die dritte Untersuchung analysiert kontinentale Hydrologieänderungen über Australien, die auf regionalen Änderungen des Erdschwerefeldes basieren und durch die *Gravity Recovery and Climate Experiment* (GRACE)-Satellitenmission beobachtet wurden. Diese zeigt über die letzten Jahre einen Massenverlust über dem Einzugsgebiet des Murray-Darling und einen starken Massengewinn im tropischen Norden von Australien. Diese Arbeit demonstriert, dass alle betrachteten Satellitenmissionen die Auswirkungen von kontinentalen Klimaänderungen, wie Änderungen in Temperatur, Niederschlag und Wasserressourcen, erfassen können. Damit können für öffentliche und private Planer wichtige Informationen für zukünftigen Klimamodellierungen bereitgestell werden.

1. Introduction

Australia is a land of contrasting climates, both across its extent and from year to year as the seasons vary from deluge to drought. However, with increasing public concern and some scientific evidence pointing towards climate change (e.g., Nicholls 2006), the need to quantify climate change over the breadth of the country is important. This has become more relevant to Australia in recent years, with notable events such as the devastating bushfires and dust storms over eastern Australia in 2009, and the contemporary drought, also known as *the big dry* (Murphy and Timbal 2008, Ummenhofer et al. 2009), which is still afflicting many areas of Australia, despite other parts (e.g., Queensland) experiencing major flooding.

The climate of Australia, while dominated in terms of area by the inland arid regions, nonetheless shows a wide variability, ranging from tropical to temperate. This leads to the likelihood that different parts of the continent could experience climate change differently. However, a major problem arises from the very heterogeneous population density, concentrated mainly along the coastal areas, the southeast and southwest, leading, in turn, to a heterogeneous distribution of meteorological recording stations. This is shown in Figure 1, where Figure 1*A* describes the climate of Australia, following the modified Köppen-Geiger climate classification scheme of Peel et al. (2007), while Figure 1*B* shows the distribution of currently operating Bureau of Meteorology (BOM) weather-reporting sites (see the BOM website, http://www.bom.gov.au). The most obvious point is the concentration of stations in the more temperate and densely populated areas. However, while the less instrumented areas tend to be in arid regions, a large proportion of the tropical part of the country also has few recording stations. Therefore, Figure 1 shows that there are areas both in need of the observations provided by Earth observation satellites (EOS), as well as areas sufficiently instrumented to allow ground-truth comparisons.

Australia has long been a significant user of the products of EOS, a result of our relatively low population, vast area, long coastline and extensive Exclusive Economic Zone, combined with serious vulnerability to a wide range of natural hazards. A recent report prepared by the Australian Academy of Science and the Australian Academy of Technological Sciences and Engineering stated that "Earth observations from space are the single most important and richest source of environmental information for Australia" (*Australian Academy of Science* 2009). Such observations are not only of benefit to assessing climate change, but also for addressing issues involving water resources, forestry, agriculture, transport and energy, natural disaster mitigation and national security.

In this paper, we examine three series of EOS observations that allow for continental-scale, and potentially smaller-scale, views of climate change over Australia. Each of these employs different satellites, some built for very specific purposes, while others are designed to have a wider range of applications. While there are many more applications of observations from EOS, these examples provide an overview of the sort of issues that may be dealt with by EOS observations within the context of Australian climate change. The climatic issues of interest in this work are as follows:

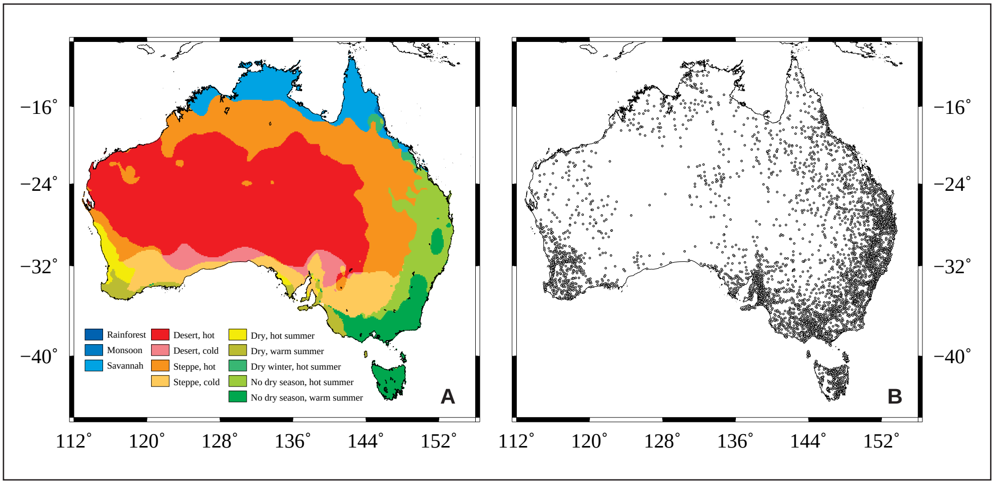

Fig. 1 (*A*) Climate zones of Australia, as described by a modified Köppen-Geiger climate classification scheme (Peel et al. 2007). (*B*) Locations of weather-reporting stations.

– Estimates of tropopause parameters (e.g., height, temperature), based on low-Earth orbiting (LEO) satellites receiving occultation signals from Global Navigation Satellite System (GNSS) spacecraft (Melbourne et al. 1994);
– Precipitation, as described for the purpose of this study, by products from the Tropical Rainfall Measuring Experiment (TRMM; Kummerow et al. 1998, 2000), and compared to ground-based measurements;
– Terrestrial water storage, as determined from changes in the Earth's gravity field observed by the Gravity Recovery and Climate Experiment (GRACE; Tapley et al. 2004).

We outline in the following some background of each of these topics with respect to the satellites involved, showing some examples from each of how these parameters are changing. We then conclude with some comments about other recent and future missions that could benefit climate change studies in Australia.

2. Observations of the Tropopause by low-Earth Orbiting Satellites

The tropopause is one of the most fundamental units of the atmosphere, representing the boundary between the troposphere, the lower-most portion of the atmosphere where we live, and the stratosphere. The tropopause is considered to be a potentially useful measure of climate change, being sensitive to temperatures in the lower atmosphere (e.g., Sausen and Santer 2003). For example, anthropogenic greenhouse gas concentration increases have been proposed to have caused around 80 % of the global tropopause height increase between 1979 and 2001 (Santer et al. 2003).

Traditionally, tropopause parameters have been measured using radiosonde (balloon) observations. However, in recent years, the use of LEO satellites that observe the change in signals from GNSS satellites as they rise or set behind the atmosphere (occulting satellites, or GPS-RO measurements) has opened up new opportunities to monitor the atmosphere, especially the tropopause. The main advantage of GPS-RO observations is that they are global, unlike radiosondes where the oceans are largely neglected, and all-weather.

A number of studies have compared radiosonde observations and the estimates of atmospheric parameters inferred from GPS-RO and – in general – the agreement has been very good (e.g., Schmidt et al. 2005, Fu et al. 2007, Khandu et al. 2010). There are a number of LEO satellites providing GPS-RO observations, in particular CHAMP (launched 15th July, 2000), SAC-C (21st November, 2000), GRACE (17th March, 2002), COSMIC (15th April, 2006), MetOp (19th October, 2006), and TerraSAR-X (5th June, 2007) (Wickert et al. 2009).

For Australia, Fu et al. (2007) and Khandu et al. (2009) have verified that GPS-RO measurements are of an equivalent quality to radiosonde data. Khandu et al. (2010), making use of CHAMP, GRACE and COSMIC GPS-RO observations, investigated how the tropopause was varying over Australia. This is shown for the continent as a whole in Figure 2, where we present the rate of change in tropopause height (Figure 2*A*) and temperature (Figure 2*B*). Given the data density currently possible with the number of GPS-RO satellites operating, one can see how continental-scale climate change could be monitored using such observations.

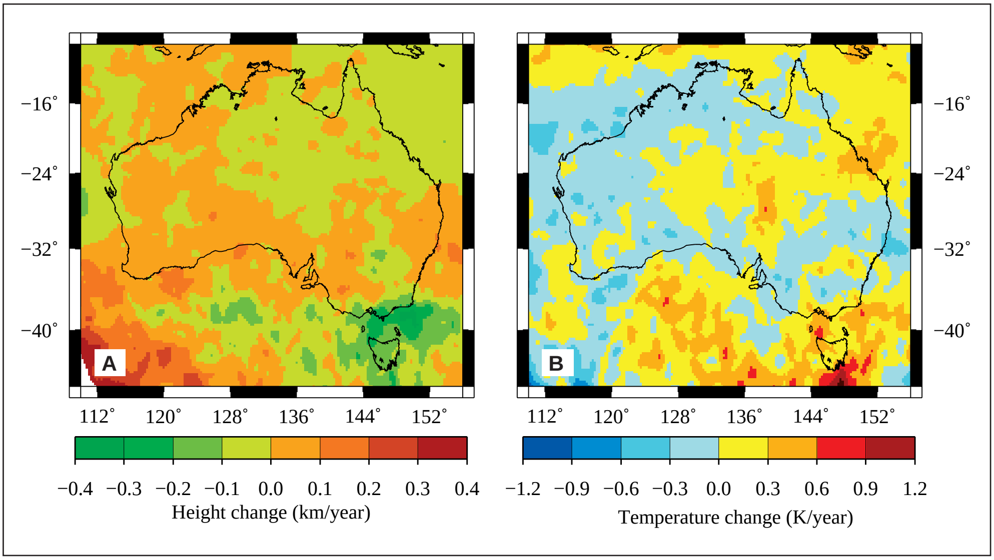

Fig. 2 Changes in the tropopause over Australia as identified by a combination of GPS-RO data (*A*) Elevation, (*B*) temperature (adapted from Khandu et al. 2010).

3. Precipitation from the Tropical Rainfall Measuring Mission

Precipitation is one of, if not the most, important climatic indicator for society to consider. Given the still-existing drought conditions in many parts of Australia, this leads to concerns such as the effect droughts have on the national economy since it adversely affects agriculture and the cost of living, as well as governmental responses such as the construction of desalination plants for coastal urban centers. Nicholls (2006) reports that annual rainfall has increased in the northwest of Australia (mainly during summer), and has decreased along the east of the continent and in the southwest, where the changes have been in winter for the southwest and southeast, and in summer in the northeast.

As mentioned in the Introduction, the distribution of weather-reporting stations is very heterogeneous. Hence, the possibilities offered by satellite-based precipitation measurements become very attractive. The example of such a mission discussed in this work is TRMM, a joint mission between the United States (NASA) and Japan (Japan Aerospace Exploration Agency, JAXA). TRMM was launched on the 27th November 1997 from the Tanegashima Island space center and orbits at an altitude of ca. 403 km with an inclination of 50°, completing 16 revolutions per day (TRMM webpage, http://trmm.gsfc.nasa.gov). The objective of TRMM is to measure rainfall and energy exchange over the tropical and subtropical regions of the world, in particular covering oceans and un-sampled land (Kummerow et al. 1998, 2000).

One aspect of such data is the need for it to be validated by ground-truth data, and this has been carried out for the TRMM products (e.g., Kummerow et al. 2000). Such efforts are currently being undertaken for Australia at Curtin University of Technology, Perth, where we are comparing TRMM results (the TRMM and other satellites' precipitation products, Huffmann et al. 2007) with a similar dataset provided by the Australian Bureau of Meteorology (BOM). Figure 3 shows an example of such a comparison, where Figure 3*A* presents the cross correlation between the two datasets for the period 1998 to 2009. There is generally an excellent correlation, except where there is a lack of ground-truth data (cf. Figures 3 and 1*B*). However, this correlation varies over time, as shown in Figure 3*B* for only those grid cells where there was a BOM recording station, with possibly an increase in scatter of the correlation between datasets being noted. The reasons behind this are currently under investigation.

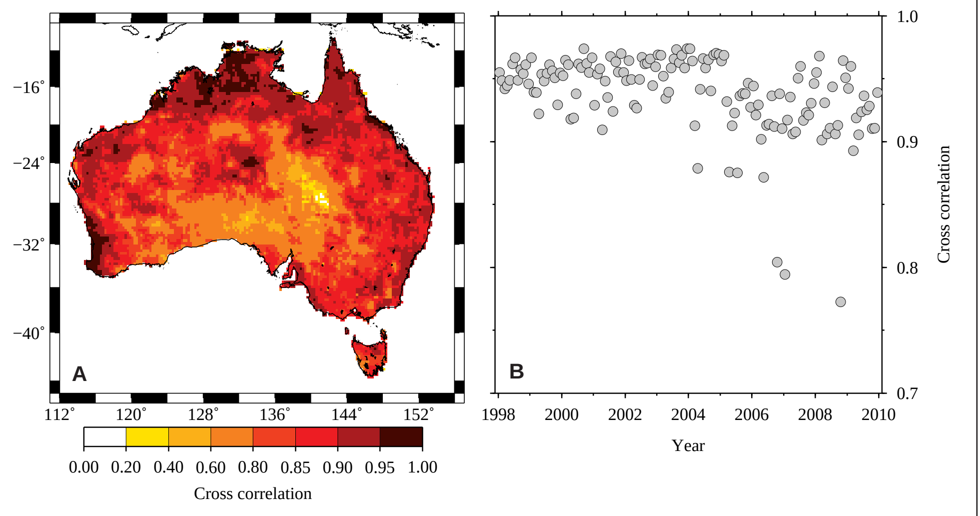

Fig. 3 Variation in the cross correlation between the TRMM and BOM datasets over Australia for the period 01. 1998 to 12. 2009. (*A*) The cross correlation over Australia as a whole. (*B*) The temporal change in the cross correlation.

4. Terrestrial Water Storage from the Gravity Recovery and Climate Experiment

The GRACE satellite mission is a joint United States (NASA) and German (*Deutsches Zentrum für Luft- und Raumfahrt*) mission (Tapley et al. 2004). Its aim is to resolve spatial and temporal changes in the Earth's external gravity field to allow mass exchanges between the atmosphere, cryosphere and hydrosphere to be quantified.

GRACE was launched on the 17th March, 2002, from the Pletsetsk space center, Russia. It consists of two spacecrafts in the same near-polar orbit of inclination 89.5° with an initial altitude of ca. 500 km. The satellites are separated by ca. 220 km, and their distance apart is measured using a K-band range rate system (Tapley et al. 2004). In addition, each satellite carries a GPS receiver, the data from which is used for precise orbit determination, as well as satellite laser ranging reflectors for very precise orbit determination for some arcs. The mission initially had an expected design lifespan of five years, although there are some expectations that it will continue until around 2013 (Chen et al. 2006).

In terms of the major sources of spatio-temporal gravity field change, Australia is relatively 'quiet', given the lack of major tectonic processes within the continent's boundaries and that it did not experience significant glaciation during the Last Glacial Maximum, some 21,000 years ago. Therefore, any gravity field changes observed over Australia (after correcting for the effects of the oceans and atmosphere) are dominated by changes in terrestrial water storage, be they surface waters (lakes, rivers, etc.), groundwater or soil moisture.

However, when one considers Australia's broad aridity and recent drought conditions, a relatively small hydrological signal is expected (with the exception of the tropical north). This makes the detection of terrestrial water-storage variations by gravity-field changes a significant challenge (e.g., Awange et al. 2009). Nonetheless, a number of efforts have been made to exploit GRACE observations for the Australian situation. For example, for the Murray-Darling River Basin (MRDB), the most important agricultural region in Australia, Ellett et al. (2006) commented that GRACE would be suitable for hydrological studies owing to the dominance of groundwater variations in the inter-annual water-storage signal. This was verified by Leblanc et al. (2009) who, by combining GRACE estimates with hydrological observations and modeling results, estimated a loss of groundwater from this region of the order of 104 km^3 between 2001 and 2007.

An example of how results from GRACE can be used is shown in Figure 4. Here, we make use of the latest release from the Center for Space Research at the University of Texas, Austin (Bettadpur 2007), acknowledging that several others are available. Figure 4 shows the linear trend (Figure 4*A*) and the annual cyclic amplitude (Figure 4*B*) in the gravity field, expressed as equivalent water thickness (EWT) (a common measure in GRACE hydrological studies, e.g., Wahr et al. 1998). By way of comparison, we include the same temporal behavior, but for terrestrial water storage as predicted by a hydrological model (WGHM, Döll et al. 2003).

From these linear trends, one can see in the GRACE results a general decrease in EWT in the southeast of the continent around the MRDB, while in the tropical north, there is an increase. Similarly, the annual (seasonal) cycle in terrestrial water storage is apparent. We compare this to the hydrological model to show that, while there are differences and similarities between the two, one can envisage (as has been done, e.g., by Güntner 2008) how GRACE results could be used to assess hydrological models.

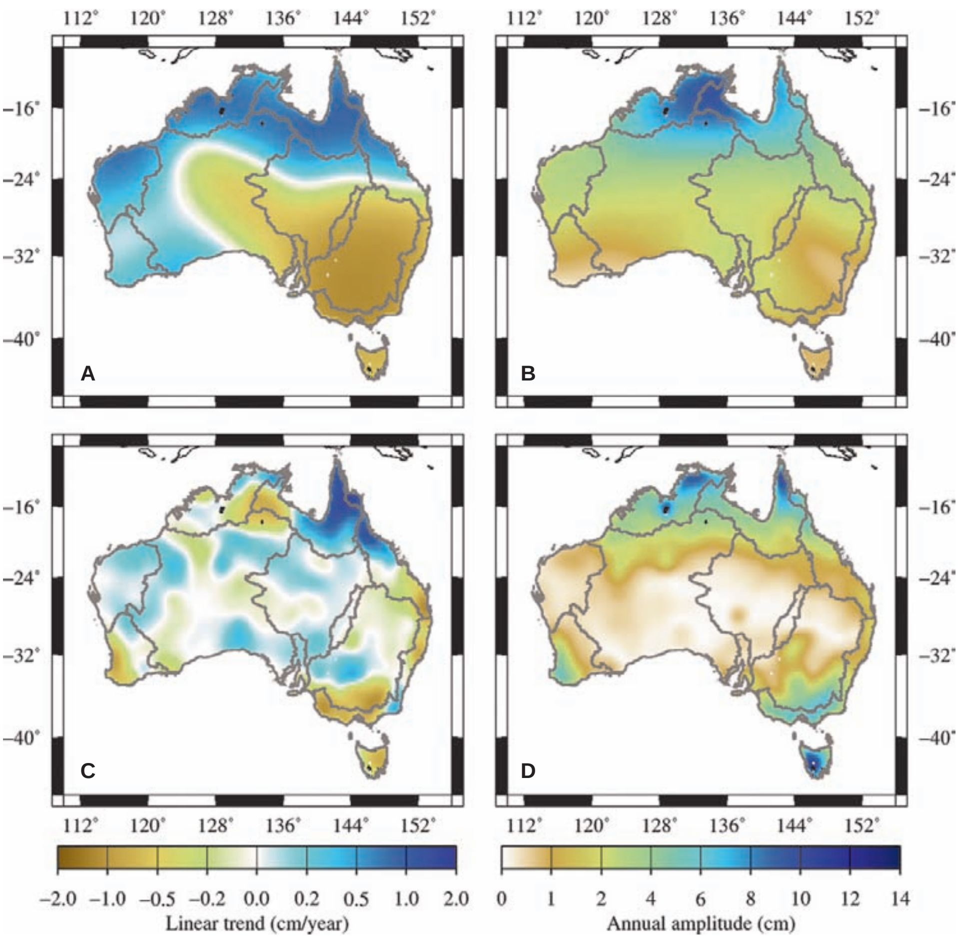

Fig. 4 Temporal trends in the CSR GRACE and WGHM time-series in equivalent water thickness (EWT). (*A*, *B*) GRACE linear and annual cyclic terms. (*C*, *D*) The same, but for the WGHM hydrological model. The internal boundaries define the major river basins.

5. Concluding Statements

There are a number of recently and soon-to-be launched EOS missions that have the potential to directly benefit climate-change studies over Australia. Some examples are

– The Soil Moisture and Ocean Salinity (SMOS) mission, launched on the 2nd November 2009, by the European Space Agency (ESA). This aims to measure soil moisture over the Earth's land masses and ocean salinity. Both of these parameters are essential for climate change studies, with soil moisture being an integral part of continental hydrology, while salinity plays an important role in ocean circulation (e.g., Antonov et al. 2002).

- CryoSat-2, the substitute mission for the original CryoSat mission that suffered a catastrophic launch failure in November 2005, is expected to be launched in early 2010. Its purpose is to measure the change in the thickness of land-based and sea ice. In measuring the changes in land-based ice, constraints may be placed on this contribution to sea-level change, another area of concern for Australia, in terms of inundated land area, the intrusion of seawater into freshwater aquifers, and the potential security issues arising from the dangers sea-level rise will inflict on low-lying Pacific nations.
- Another mission that would contribute greatly is a follow on to GRACE. There are plans for such a mission, however, planning is still in progress. As discussed, GRACE has been used to examine changes in terrestrial water storage (e.g., AWANGE et al. 2009) as well contributing to the improvement of hydrological models.

One of the comments made in the report from the *Australian Academy of Science* (2009) was that Australia should develop a national strategy to secure long-term access to data from EOS missions, as well as to strengthen our capabilities in the various aspects (data acquisition, processing, research, education, etc.) of such missions. The report was received positively by the Ministry for Innovation, Industry, Science and Research, and it is hoped that Australia's involvement in EOS missions will increase in the near future.

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Medicine at the Interface between Science and Ethics

Leopoldina-Symposium

vom 30. Mai bis 1. Juni 2007 in Weißenburg, Bayern

Nova Acta Leopoldina N. F. Bd. *98*, Nr. 361
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Naturwissenschaft und Theologie/Ethik versuchen mit unterschiedlichen Konzepten, ein Weltbild zu erfassen, das die *conditio humana* besser zu verstehen erlaubt. Die Fragen sind weit gefasst; endgültige Antworten wird man nicht leicht finden. Gemeinsame Diskussionen über diese Probleme könnten beiden Gebieten Anregungen geben und der Biomedizin im Umgang mit der sehr kritischen Öffentlichkeit helfen. Voraussetzung ist Offenheit gegenüber der anderen Denkweise. Der vorliegende Band behandelt daher aus der Perspektive von Naturwissenschaftlern und Ethikern so verschiedene Themen wie die neuen Herausforderungen an Moral- und Ethikdiskurse durch die jüngsten Fortschritte der Biowissenschaften, die Grenzen der ethischen Reflexion bei den neueren Entwicklungen der Molekularbiologie, die Geschichte der Auffassungen vom „Gen“ und seiner Bedeutung in der Humanbiologie, aber auch die Missverständnisse zwischen den beiden Kulturen der Naturwissenschaften und der Geisteswissenschaften in der Forschung über Lebensprozesse. Dazu kommen Beiträge zur Stammzellproblematik, der Verwendung von Tiermodellen in der Translationsmedizin, über Würde von Zellen in Kultur, Fragen der Pluripotenz von Zellen und der Reprogrammierung von Zellkernen sowie der Bedeutung von Methylierungsmustern für die Epigenetik. Die Beiträge sind in englischer oder deutscher Sprache verfasst.

Wissenschaftliche Verlagsgesellschaft mbH Stuttgart

Die Gründung der Leopoldina
–*Academia Naturae Curiosorum* – im historischen Kontext

Johann Laurentius Bausch zum 400. Geburtstag

Leopoldina-Symposium

vom 29. September bis 1. Oktober 2005 in Schweinfurt (Bibliothek Otto Schäfer)

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Herausgegeben von Richard Toellner (Kloster Amelungsborn), Uwe Müller (Schweinfurt), Benno Parthier und Wieland Berg (Halle/Saale)
(2008, 336 Seiten, 42 Abbildungen, 22,95 Euro, ISBN: 978-3-8047-2471-6)

Ziel dieser interdisziplinären, internationalen Tagung war es, die Gestalt des Johann Laurentius Bausch (1605–1665) in ihren biographischen, sozialen und wissenschaftsgeschichtlichen Bedingungen darzustellen sowie die Gründung der Leopoldina in den Rahmen der internationalen Akademiengeschichte des 17. Jahrhunderts einzuordnen. Es wurde der über die bisherige Literatur hinausgehende aktuelle Forschungsstand in neun Vorträgen präsentiert, die der vorliegende Band in erweiterter und aktualisierter Form dokumentiert und vertieft durch Anhänge mit der Edition der Leges der Akademie und Bibliographien der im frühen Akademieprogramm veröffentlichten Monographien und ihrer Vorgänger aus anderthalb Jahrhunderten sowie einer Analyse der Selbstdarstellung der Leopoldina in ihrer Korrespondenz mit der Royal Society von 1670 bis 1677.

Wissenschaftliche Verlagsgesellschaft mbH Stuttgart

Der Briefwechsel von Johann Bartholomäus Trommsdorff (1770–1837)

Lieferung 11: Trott – Ziz und Nachträge

Acta Historica Leopoldina Nr. *18*/11
Bearbeitet und kommentiert von Hartmut Bettin (Marburg), Christoph Friedrich (Marburg) und Wolfgang Götz (Wildeshausen), unter Mitarbeit von Henriette Bettin (Greifswald)
(2009, 342 S., 7 Abb., 9 Stammbäume, 20,95 Euro, ISBN: 978-3-8047-2559-1)

Trommsdorff gilt als Vater der wissenschaftlichen Pharmazie. Der Begründer des *Journals der Pharmacie* engagierte sich in standes- und sozialpolitischen Fragen. Seine umfangreiche Korrespondenz spiegelt die Entwicklung von Chemie und Pharmazie im beginnenden 19. Jahrhundert, aber auch die Veränderungen des Apothekenwesens seiner Zeit wider. Die Edition (über 250 Briefpartner und 1500 erhaltene Briefe) stellt eine bedeutende wissenschaftshistorische Quelle dar. Mit dieser Lieferung wird der kommentierte Briefwechsel J. B. Trommsdorffs abgeschlossen. Schwerpunkte bilden die Briefe des Anilin-Entdeckers und Trommsdorff-Schülers Otto Unverdorben und die Briefe des Chemie- und Pharmazieprofessors Heinrich August Vogel. Darüber hinaus enthält der Band zahlreiche Briefe von oder an bedeutende Ärzte und Apotheker, berühmte Chemiker und Naturforscher sowie hochgestellte Persönlichkeiten, beispielsweise Herzog Carl August von Sachsen-Weimar-Eisenach und nachgetragene Briefe Johann Wolfgang Döbereiners, August Peter Julius Du Mênils sowie Johann Friedrich Gmelins. Der Anhang enthält Familien-Stammbäume zur Orientierung sowie Gesamtsachregister und -verzeichnisse über alle 11 Lieferungen.

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