statement

European Academies'
Science Advisory
Council

For further information:

secretariat@easac.eu

www.easac.eu

European Academies
easac
Science Advisory Council

Extreme weather events in Europe

Preparing for climate change adaptation: an update on EASAC's 2013 study

1. Introduction

EASAC report number 22 (EASAC, 2013) examined trends in extreme weather within Europe. That report was published because, from an economic perspective, risks are not just through the change in the mean of climate variables such as temperature, precipitation or wind, or in derived variables like storm surge or water runoff, but also the changes in their extremes. As a result, that study looked at trends in the specific extremes of heat and cold, precipitation, storms, winds and surges, and drought. The report found evidence for overall increases in the frequency and economic costs of extreme events, which emphasised the importance of society adapting its future planning to allow for these new extremes.

In 2017, members of the original expert group, under the auspices of the Norwegian Academy of Sciences and Letters and the Norwegian Meteorological Institute, updated some of the statistics on which the original report was based. There has also been more recent evidence on some of the underlying drivers, which include weakening of the Atlantic Meridional Overturning Circulation (AMOC) and other phenomena such as a weakening and meandering jet stream. This short addendum to our earlier report presents these findings, which update and extend the previous analysis and confirm the conclusions in the original report.

2. Quantitative update

The original report included a figure (Figure 2.1 in EASAC, 2013) on the number of natural catastrophes worldwide for the period 1980–2012. This has been updated with 4 years' additional data and is shown in Figure 1 on the next page. As with the original report, these data are not peer-reviewed.

The updated figures show a continuation in the trends previously observed whereby climate-related extreme events are rising, with particularly sharp rises in hydrological events. However, such trends need to take into account socio-economic developments that influence exposure to and reporting of natural hazards that result from climate variability. As far as reporting is concerned, this has improved through the use of the Internet, and smaller events in particular are better recorded today than they were 30 years ago. This effect accounts for part of the trend in increasing numbers of loss events. However, trends in reporting are unlikely to have any significant impact on the loss amount trend, since annual losses are dominated by the major loss events, which have always been recorded.

From the economic perspective, assessing past loss events according to today's economic standards requires two adjustments: firstly, adjusting the costs of the events to today's money; and secondly, assessing what damage that event would

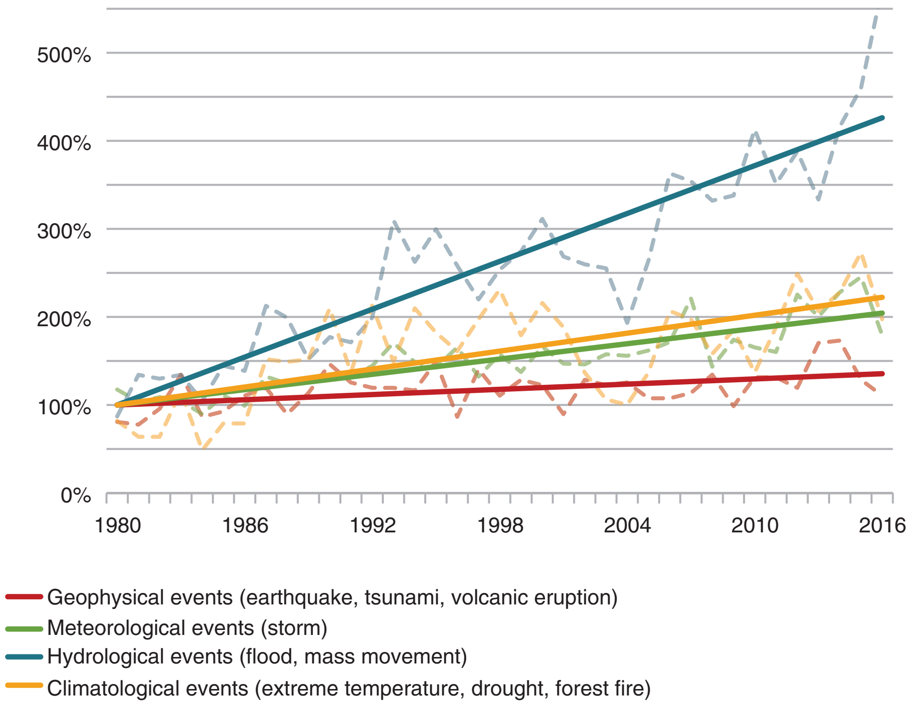

Figure 1. Trends in different types of natural catastrophy worldwide 1980–2016 (1980 levels set at 100%). MunichRe NatCatSERVICE.

have caused today (taking into account changes in infrastructure vulnerability, etc.).

The first adjustment merely involves applying inflation to the historically determined loss data. This can use an established price index, which should represent the actual development of prices in the region in question and be based on the currency of the country concerned.

The second adjustment needs to take into account changes in the exposed assets and their vulnerability, which involves assessing the effects of development on the values in the area affected. Such an adjustment is known as normalisation (Eichner *et al.*, 2015). Such data are not available for all losses worldwide, but two examples of trends that have been normalised are shown in Figure 2: for losses due to thunderstorms in North America and for flood losses in Europe. Whereas there are meteorological reasons for the increase in the normalised losses from severe thunderstorms, protection measures that have been implemented must also be taken into account in explaining the near-static trend in flood losses (Eichner *et al.*, 2015).

A second figure in the original report (Figure 2.4; updated in Figure 3 below) showed trends in large European floods. As pointed out in that report, **severity** class 1 includes large flood events, often causing significant human and economic damage, with an estimated (commonly from news reports) mean return period (recurrence interval) of the order of 10–20 years. Severity class 1.5 contains very large events whose return period is greater than 20 years but less than 100 years. Finally, severity class 2 includes truly extreme events, with an estimated return period equal to or greater than 100 years. Flood **magnitude** is the product of duration in days, severity as given above and the area affected in square kilometres. It is given on a logarithmic scale, similar to the Richter scale for earthquakes. Flood magnitudes of 7, 8 or 9 represent very large events.

The spatial distribution of large floods in Europe can also be shown as in Figure 4 over the entire 32-year time interval (1985–2016) for which records are available.

3. Other recent findings

EASAC's original report (EASAC, 2013, page 6) also mentioned a weakening of the AMOC and amplified Arctic warming influencing the behaviour of the jet stream as potential sources of future disruptions in weather patterns. We thus include a brief summary of recent findings on these aspects.

3.1. AMOC (Gulf Stream)

A recent review by McCarthy *et al.* (2017) assessed the overall evidence on trends in the AMOC against the predictions that it will decline in the 21st century

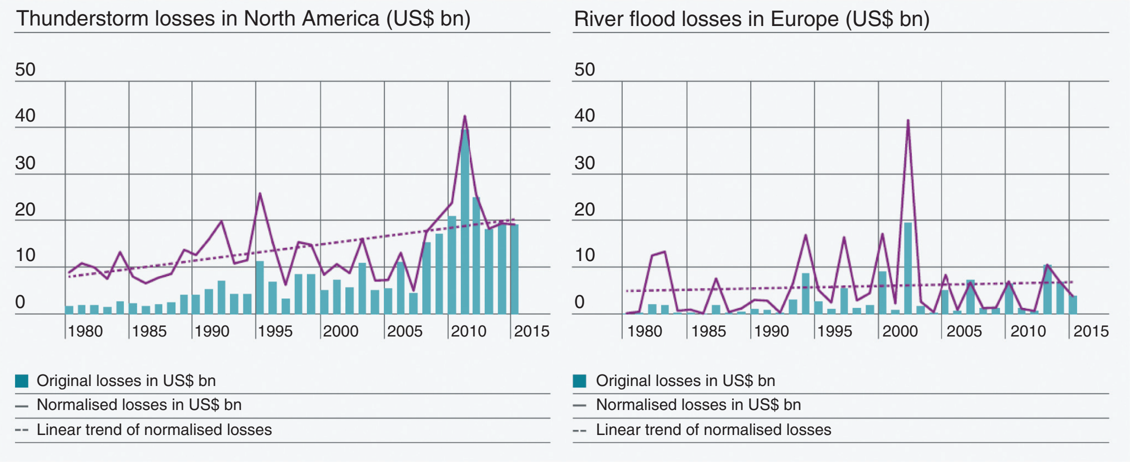

Figure 2. Nominal and normalised annual losses from severe thunderstorms in North America (left) and flood losses in Europe (right).

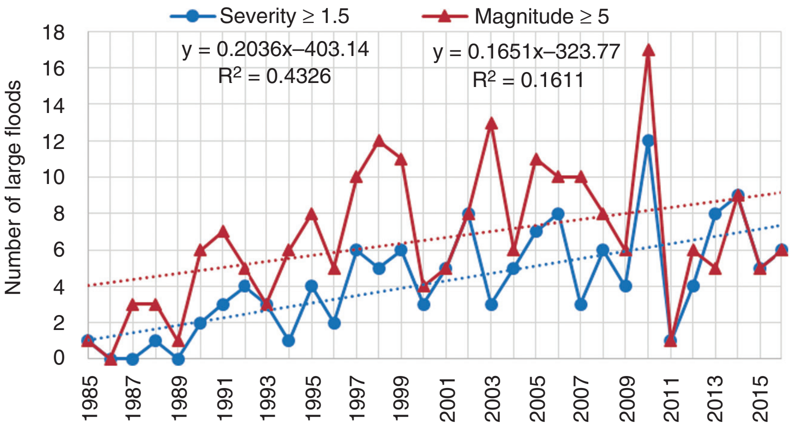

Figure 3. Number of large floods of severity ≥1.5 and magnitude ≥5 in Europe each year during 1985–2016, based on Dartmouth Flood Observatory (USA) records (from Kundzewicz et al., 2017).

in response to a changing climate[1]. There is consensus on the forces driving this (warming and increased precipitation in the high latitudes is predicted to increase the stability of the water column and inhibit the formation of the deep, cold branch of the AMOC), but the magnitude of decline varies widely between models. Moreover, Hansen *et al*. (2016) and Rahmstorf *et al.* (2015) have suggested that ongoing melting in the Arctic could provide a sufficient perturbation to the formation of the deep, cold branch of the AMOC to make a contemporary shutdown of the AMOC possible, with dramatic climate consequences (although at present, such an impact of high latitude melt on the AMOC has not been detected (Böning *et al.*, 2016)).

With potentially substantial implications for the climate of Northwest Europe, it is clearly desirable to quantify this risk further. Unfortunately, historical data on the flows of the AMOC are limited but in 2004, direct observations of ocean heat transport and the AMOC at key locations started with the UK-led RAPID array, which directly measures ocean transport across 26.5° N in the North Atlantic (McCarthy *et al.*, 2015). This has provided data on the AMOC's seasonal and decadal variability, including a 30% drop in the strength of the AMOC in 2009–10. McCarthy *et al.* (2017) note that much of the inter-annual and shorter-term variability recorded seems to have been wind driven and is consistent with climate models.

Studies before the establishment of the RAPID array had already suggested a decline of around 30% in the strength of the AMOC over 50 years (Bryden *et al.*, 2005), but this had been based on very limited data. However, the increased quality of observations in recent work (Smeed *et al.*, 2014) provides much more

---

[1] The IPCC (2013) predicted that an AMOC slowdown is 'very likely' (90–100% probability) over the coming century in response to human-made climate change, but that "It also remains *very unlikely* that the AMOC will undergo an abrupt transition or collapse in the 21st century for the scenarios considered."

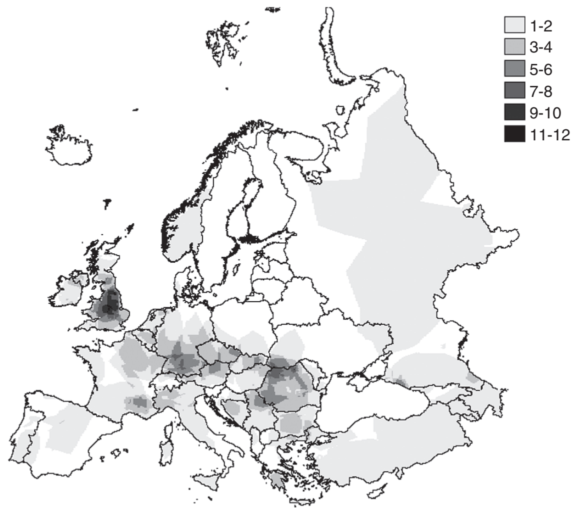

Figure 4. Spatial distribution of floods of losses of severity equal to or greater than 1.5 (from Kundzewicz et al., 2017).

confidence in the observed multi-year decline since the mid-2000s. This is also supported by data on Labrador Sea density changes (Robson *et al.*, 2014). Together with a substantial cooling of the subpolar North Atlantic, McCarthy *et al.* (2017) note that there is gathering evidence of an emerging negative phase of the Atlantic multi-decade variability[2], driven by a declining AMOC.

A major point of debate remains whether the AMOC will just decline or could switch 'off' entirely with substantial implications for Northwest Europe's climate. Most earlier climate models did not support stable 'off' states, but more complex models including the influence of increased Arctic melting (see, for example, Böning *et al.*, 2016; Hansen *et al.*, 2016) suggest that the AMOC could have stable 'on' and 'off' states. A critical point of uncertainty is the net flow of freshwater across the Atlantic. Since measuring precipitation and river flows for this vast area is difficult, it is more realistic to infer from salinity gradients, which can be measured easily from ships. Many models predicting a resilient AMOC do not match such observed salinity distributions, and Liu *et al.* (2016) investigated the sensitivity of AMOC future forecasts to this uncertainty. Models on the AMOC's response to a doubling of atmospheric CO_2 levels (Figure 5) showed that, when their climate model showing a resilient AMOC was adjusted to a freshwater flow that matched salinity observations, the AMOC did break down, which would lead to cooling of the land masses in Greenland, Iceland, UK and Scandinavia of up to 9 °C.

The second uncertainty arises from the potential influence of Greenland's ice cap melt. Bakker *et al.* (2016) found in their model that, with the IPCC high-emissions scenario (RCP8.5 scenario) and taking into account Greenland meltwater, the Gulf Stream system weakens by 37% (by 2100) and continues to fall by 74% by 2290–2300. Another study by Böning *et al.* (2016) has also indicated that meltwater from Greenland is likely to weaken the AMOC considerably within a few decades.

Overall, while the decline in the AMOC has been confirmed, it is still not possible to resolve considerable uncertainties on the rate and magnitude of possible future changes. Recent evidence questioning the long-term stability of the AMOC makes it important to use the data emerging from the RAPID array and other sources to improve and validate climate models in order to provide a more reliable forecast of impacts of global warming on the AMOC.

3.2. Polar amplification and the jet stream

Evidence on polar amplification and the potential implications for the jet stream have been reviewed by the US National Academy of Sciences (NRC, 2016). They noted studies that had indicated influences of sea-ice change on large-scale atmospheric dynamics, which some had linked to an amplified jet stream and cold winters in middle latitudes (Francis and Vavrus, 2012, 2015). However, NRC (2016) concluded that any such changes were not yet detectable above natural variability (Barnes *et al.*, 2014). Since then, however, Mann *et al.* (2017) have examined the persistent episodes of extreme weather in the Northern Hemisphere summer that had been shown to be associated with the presence of high-amplitude quasi-stationary atmospheric Rossby waves[3]. They suggested a mechanism[4] and provided evidence of an increase in the conditions favourable to the formulation of these extreme weather-associated states, possibly linked to amplified Arctic warming and thus a climate change influence. Most recently, Cohen *et al*. (2018) studied weather anomalies from 1950 to 2016 and found an association between warming in the Arctic (especially when extending into the upper troposphere and lower stratosphere) and severe winter weather in the USA. Both models and observations suggest this signal has only recently emerged from the background noise of natural variability. It remains to be seen whether further observations will continue to support the mechanism proposed.

---

[2] The Atlantic multi-decadal variability (AMV) or oscillation (AMO) is a natural climate cycle involving changes in the sea surface temperature of the North Atlantic, which in turn is related to the likelihood of hurricane formation.

[3] Rossby waves are the large meanders in high-altitude winds resulting from the rotation of the planet and which are associated with pressure systems and the jet stream.

[4] The phenomenon of quasi-resonant amplification (QRA) of synoptic-scale waves.

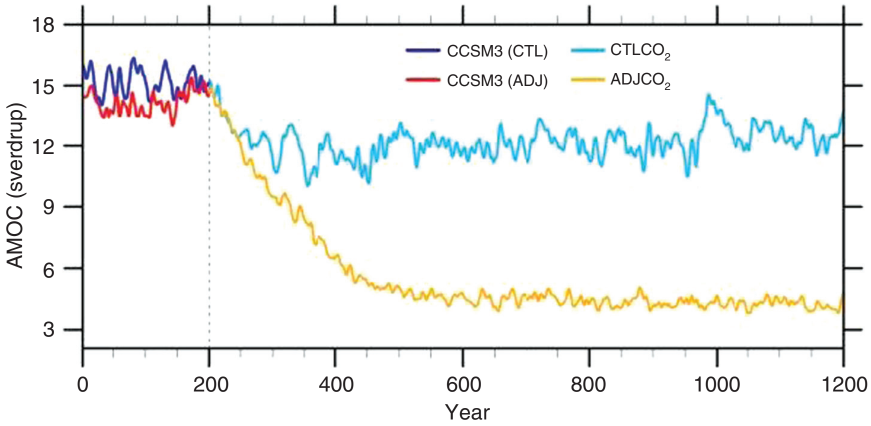

Figure 5. Time series of the Atlantic flow (AMOC) in the two model variants: without correction (blue) and with correction (orange). In model year 201, the CO$_2$ concentration in the model is doubled and then left at this level. Source: Liu et al., 2016.

3.3. Attributing the contribution of climate change to specific extreme weather events

Historically, it has been difficult to analyse the contribution of anthropogenic warming on individual extreme weather events against the backdrop of natural variability. However, the increased sophistication of models and access to computing resources have allowed researchers to simulate the probability of specific weather events with and without the additional effects of climate change on temperature, atmospheric water content and other factors associated with warming (Diffenbaugh *et al.*, 2017). Such studies are too numerous to review in this short update (see, for example, the annual analyses of extreme weather events by the American Meteorological Society (such as Herring *et al.*, 2016)), and include those where an influence of climate change is not found. However, events where climate change is concluded to have increased the probability (in some cases substantially) of extreme events include the following:

- Heatwaves in Australia (see, for example, Perkins and Gibson, 2015; Hope *et al.*, 2016; Black *et al.*, 2016); China (see, for example, Sun *et al.*, 2014) and Europe (see, for example, Uhe *et al.*, 2016; King *et al.*, 2015);
- Increased risks of wildfires (see, for example, Yoon *et al.*, 2015; Abatzoglou and Williams, 2016);
- Extreme rainfall and associated floods (see, for example, van de Wiel *et al.*, 2017; Pall *et al.*, 2011);
- Coastal flooding due to sea-level rise (see, for example, Sweet *et al.*, 2016).

4. Conclusion

This update on some of the figures and underlying drivers of extreme weather raised in EASAC report number 22 (EASAC, 2013), confirms the earlier conclusions on the importance of increasing the adaptability of Europe's infrastructure and social systems to a changing climate. However, evidence on AMOC and the effects of amplified Arctic warming continue to emerge from ongoing research and monitoring programmes. In view of the importance of these large-scale phenomena to Europe's climate, EASAC will keep a watching brief on this and other findings to provide further updates in the future.

Acknowledgement

EASAC thanks Øystein Hov, Peter Höppe and Zbigniew W. Kundzewicz for their work in updating the figures.

References

Abatzoglou J. and Williams A. (2016). Impact of anthropogenic climate change on wildfire across western US Forest. *Proceedings of the National Academy of Sciences of the United States of America* **113** (42), 11770–11775

Bakker P. *et al.* (2016). Fate of the Atlantic Meridional Overturning Circulation: strong decline under continued warming and Greenland melting, *Geophysical Research Letters* **43**, 12,252–12,260

Barnes E. *et al*. (2014). Exploring recent trends in Northern Hemisphere blocking. *Geophysical Research Letters* **41** (2), 638–644

Black *et al*. (2016). Southern Australia's warmest October on record. *Bulletin of the American Meteorological Society* **97** (12), S118–S121

Böning C. *et al*. (2016). Emerging impact of Greenland meltwater on deepwater formation in the North Atlantic Ocean. *Nature Geoscience* **9**, 523–527

Bryden H. *et al*. (2005). Slowing of the Atlantic meridional overturning circulation at 25° N. *Nature* **438**, 655–657

Cohen J. *et al*. (2018). Warm Arctic episodes linked with increased frequency of extreme winter weather in the United States. *Nature Communications*, DOI: 10.1038/s41467-018-02992-9

Diffenbaugh N. *et al*. (2017). Quantifying the influence of global warming on unprecedented extreme climate events. *PNAS* **114** (19), 4881–4886

EASAC (2013). Trends in extreme weather events in Europe: implications for national and European Union adaptation strategies. Policy report 22

Eichner J., Low P. and Steuer M. (2015). Innovative new ways of analyzing historical loss events. Munich Re Topics Geo 2015

Francis J. and Vavrus S. (2012). Evidence linking Arctic amplification to extreme weather in mid-latitudes. *Geophysical Research Letters* **39**. DOI: 10.1029/2012gl051000

Francis J. and Vavrus S. (2015). Evidence for a wavier jet stream in response to rapid Arctic warming. *Environmental Research Letters* **10** (1). DOI: 10.1088/1748-9326/10/1/014005

IPCC (2013). The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Hansen J. *et al*. (2016). Ice melt, sea level rise and superstorms: Evidence from paleoclimate data, climate modeling and modern observations that 2 C global warming could be dangerous. *Atmospheric Chemistry and Physics* **16**, 3761–3812

Herring S. *et al*. (2016). Explaining extreme events of 2015 from a climate perspective. *Bulletin of the American Meteorological Society* **97** (12), S1–S4

Hope P. *et al*. (2016). What caused the record-breaking heat across Australia in October 2015? *Bulletin of the American Meteorological Society* **97** (12), S122– S126

King A. *et al.* (2015). Attribution of the record high Central England temperature of 2014 to anthropogenic influences. *Environmental Research Letters* **10** (5), 54002

Kundzewicz Z., Pińskwar I. and Brakenridge G. (2013). Large floods in Europe, 1985–2009. *Hydrological Sciences Journal* **58**, 1–7

Kundzewicz Z., Pińskwar I. and Brakenridge G. (2017). Changes in river flood hazard in Europe. *Hydrology Research* **49** (1), DOI 10.2166/nh.2017.016

Lewis S. *et al*. (2014). The role of anthropogenic forcing in the record 2013 Australia-wide annual and spring temperatures. *Bulletin of the American Meteorological Society* **95** (9), S31–S34

Liu W. *et al*. (2017). Overlooked possibility of a collapsed Atlantic Meridional overturning circulation in warming climate. *Science Advances* **3** (1), e16011666

Mann M. *et al*. (2017). Influence of anthropogenic climate change on planetary wave resonance and extreme weather events. *Scientific Reports* **6**, 45242

McCarthy G. *et al.* (2015). Ocean impact on decadal Atlantic climate variability revealed by sea-level observations. *Nature* **521**, 508–510

McCarthy G. *et al*. (2017). Atlantic Meridional overturning circulation. Marine climate change impacts partnership science review. *MCCIP Science Review 2*

NRC (2016). Attribution of Extreme Weather Events in the Context of Climate Change. US National Academy of Sciences

Pall P. *et al.* (2011). Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. *Nature* **470**, 382–385

Perkins S. and Gibson P. (2015). Increasing risk of the 2014 Australian May heatwave due to climate change. *Bulletin of the American Meteorological Society* **96** (12), S154–S157

Rahmstorf S. *et al*. (2015). Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. *Nature Climate Change* **5**, 475–480

Robson J. *et al*. (2014). Atlantic overturning in decline? *Nature Geoscience* **7**, 2–3

Smeed D. *et al.* (2014). Observed decline of the Atlantic Meridional Overturning Circulation 2004 to 2012. *Ocean Science* **10**, 39–38

Sun Y. *et al.* (2014). Rapid increase in the risks of extreme summer heat in Eastern China. *Nature Climate Change* **4**, 1082–1085

Sweet W. *et al*. (2016). In Tide's way - Southwestern Florida's 2015 sunny-day flood. Bulletin of the American *Meteorological Society* **97** (12), S25–S30

Stott P. *et al.* (2004). Human contribution to the European heatwave of 2003. *Nature* **432**, 610–614

Uhe P. *et al.* (2016). Comparison of methods: Attributing the 2014 record European temperatures to human influences. *Geophysical Research Letters* **43** (16), 8685–8693

van de Wiel K. *et al.* (2017). Rapid attribution of the August 2016 flood-inducing extreme precipitation in south Louisiana to climate change. *Hydrology and Earth System Sciences* **21**, 897–921

Yoon J. *et al*. (2015). Extreme fire season in California: a glimpse into the future? *Bulletin of the American Meteorological Society* **96** (12), S5–S9

EASAC

EASAC – the European Academies' Science Advisory Council – is formed by the national science academies of the EU Member States to enable them to collaborate with each other in giving advice to European policy-makers. It thus provides a means for the collective voice of European science to be heard. EASAC was founded in 2001 at the Royal Swedish Academy of Sciences.

Its mission reflects the view of academies that science is central to many aspects of modern life and that an appreciation of the scientific dimension is a pre-requisite to wise policy-making. This view already underpins the work of many academies at national level. With the growing importance of the European Union as an arena for policy, academies recognise that the scope of their advisory functions needs to extend beyond the national to cover also the European level. Here it is often the case that a trans-European grouping can be more effective than a body from a single country. The academies of Europe have therefore formed EASAC so that they can speak with a common voice with the goal of building science into policy at EU level.

Through EASAC, the academies work together to provide independent, expert, evidence-based advice about the scientific aspects of public policy to those who make or influence policy within the European institutions. Drawing on the memberships and networks of the academies, EASAC accesses the best of European science in carrying out its work. Its views are vigorously independent of commercial or political bias, and it is open and transparent in its processes. EASAC aims to deliver advice that is comprehensible, relevant and timely.

EASAC covers all scientific and technical disciplines, and its experts are drawn from all the countries of the European Union. It is funded by the member academies and by contracts with interested bodies. The expert members of EASAC's working groups give their time free of charge. EASAC has no commercial or business sponsors.

EASAC's activities include substantive studies of the scientific aspects of policy issues, reviews and advice about specific policy documents, workshops aimed at identifying current scientific thinking about major policy issues or at briefing policy-makers, and short, timely statements on topical subjects.

The EASAC Council has 29 individual members – highly experienced scientists nominated one each by the national science academies of EU Member States, by the Academia Europaea and by ALLEA. The national science academies of Norway and Switzerland are also represented. The Council is supported by a professional Secretariat based at the Leopoldina, the German National Academy of Sciences, in Halle (Saale) and by a Brussels Office at the Royal Academies for Science and the Arts of Belgium. The Council agrees the initiation of projects, appoints members of working groups, reviews drafts and approves reports for publication.

To find out more about EASAC, visit the website – www.easac.eu – or contact the EASAC Secretariat at secretariat@easac.eu

EASAC, the European Academies' Science Advisory Council, consists of representatives of the following European national academies and academic bodies who have issued this statement:

The Austrian Academy of Sciences
The Royal Academies for Science and the Arts of Belgium
The Bulgarian Academy of Sciences
The Croatian Academy of Sciences and Arts
The Czech Academy of Sciences
The Royal Danish Academy of Sciences and Letters
The Estonian Academy of Sciences
The Council of Finnish Academies
Académie des sciences (France)
The German National Academy of Sciences Leopoldina
The Academy of Athens
The Hungarian Academy of Sciences
The Royal Irish Academy
The Accademia Nazionale dei Lincei (Italy)
The Latvian Academy of Sciences
The Lithuanian Academy of Sciences
The Royal Netherlands Academy of Arts and Sciences
The Norwegian Academy of Science and Letters
The Polish Academy of Sciences
The Academy of Sciences of Lisbon
The Romanian Academy
The Slovak Academy of Sciences
The Slovenian Academy of Sciences and Arts
The Spanish Royal Academy of Sciences
The Swiss Academies of Arts and Sciences
The Royal Swedish Academy of Sciences
The Royal Society (United Kingdom)

Academia Europaea
ALLEA

The affiliated network for Europe of
iap SCIENCE RESEARCH HEALTH
the interacademy partnership

EASAC Secretariat
Deutsche Akademie der Naturforscher Leopoldina
German National Academy of Sciences
Postfach 110543 06019 Halle (Saale), Germany
Tel +49 (0)345 4723 9833; fax: +49 (0)345 4723 9839
Email: secretariat@easac.eu

EASAC Brussels Office
Royal Academies for Science and the Arts of Belgium (RASAB)
Hertogsstraat 1 Rue Ducale 1000 Brussels Belgium
Tel: +32 (2) 550 23 32; fax: +32 (2) 550 23 78
Email: brusselsoffice@easac.eu
web: www.easac.eu

Printed on 100% recycled paper by Schaefer Druck und Verlag GmbH, Teutschenthal, Germany.