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Past Climate Change: Its Facts and Mysteries

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With 2 Figures and 1 Table

Abstract

One of the important preconditions for understanding our future climate is a thorough diagnosis of the important processes which determined the climate of the past. In this contribution we focus on climate variability during the last 2.7 million years, that means the time period of the last series of glacial-interglacial cycles.

Zusammenfassung

Eine der entscheidenden Voraussetzungen für das Verständnis unseres zukünftigen Klimas ist eine gründliche Diagnose der bedeutenden Prozesse, die das Klima in der Vergangenheit bestimmten. In diesem Beitrag konzentrieren wir uns auf die Klimavariabilität während der letzten 2,7 Millionen Jahre, d. h. auf die Zeitperiode der letzten Serie des Glazial-Interglazial-Zyklus.

One of the important preconditions for understanding our future climate is a thorough diagnosis of the important processes which determined the climate of the past. According to Table 1 climate change and variability are determined by three groups of driving factors. Natural and anthropogenic forcings modulate the energy balance of our globe in space and time. Together with the natural (internal) variability of the climate system, caused by the complex physical and chemical interactions and feedbacks between the important subsystems ocean, atmosphere, cryosphere, land and vegetation, they form the driving factors of the observed climate.

In this contribution we focus on climate variability during the last 2.7 million years, that means the time period of the last series of glacial-interglacial cycles. We therefore do not discuss extremely long-term climate changes, for example caused by increasing solar radiation or by decreasing CO_2 concentrations during geological timescales, or by continental drift. Based on the analysis of different parameters in a 645 kyr long sequence of an Antarctic ice core, Figure 1 shows the quasi-cyclic changes between glacial and interglacial periods. Interestingly, there is evidence for longer interglacial periods between 430 and 645 kyr, but these were apparently colder than the actual interglacial, the Holocene (*IPCC* 2007). The glacial-interglacial changes were mostly driven by orbital forcing (factor 1.2 in Tab. 1), that means by changes of the precession of the equinox (periodicity: 19, 23 kyr), by the obliquity of the earth axis (periodicity: 41 kyr) and by the changing Earth-Sun distance (periodicity: 410, 95 kyr). During the last 400 kyr roughly the 95 kyr cycle dominated. Figure 1 shows that several parameters representing a temperature proxy run parallel to the CO_2 curve. Nevertheless, the explanation of glacial-interglacial CO_2 variations remains a difficult attribution problem. It appears likely that a range of mechanisms, which are possibly located in the ocean, have acted in concert (*IPCC* 2007). During both glacials and interglacials, abrupt changes between warm and cold states were observed. Best known are the Dansgaard-Oeschger (D-O) and the Heinrich events. The D-O events were likely caused by changes in the ocean thermohaline circulation. The Heinrich events are thought to have been caused by ice sheet instability and iceberg discharge with freshwater forcing in the North Atlantic Ocean (*IPCC* 2007).

Tab. 1 Driving factors of climate variability and change

Driving factor	Time scale / influence on energy balance near the ground (+/–)
1. Natural forcing	
1.1 Continental drift	10^6 to 10^7 years
1.2 Fluctuation in the Earth's orbital elements	10^4 to 10^5 years
1.3 Fluctuation in solar activity	cycles (11, 90, 210, etc. years)
1.4 Explosive volcanic eruptions	irregular (influence lasts for 2 – 3 years)
1.5 Cosmogenic nuclides	10 years
2. Anthropogenic forcing	
2.1 Greenhouse effect	+
2.2 Aerosol concentration	–
2.3 Thinning of stratospheric ozone layer and increase on boundary layer ozone concentration	+ / –
2.4 Land use changes (urbanisation, deforestation, desertification, ect.)	complex (+/–)
3. Natural variability (incl. internal modes)	
3.1 ENSO (El Niño Southern Oscillation)	3 to 7 years
3.2 NAO (North Atlantic Oscillation)	variable (2.5, 8 years)
3.3 Natural (stochastic) variability	variable

The warm period of the recent interglacial, the Holocene, started about 12 kyr ago. Due to the above mentioned orbital forcing, the solar insolation in the Northern Hemisphere (NH) decreased after about 10 kyr before present (BP). Therefore, a summer cooling was observed in the NH, and a progressive southward shift of the NH summer position of the Intertropical Convergence Zone (ITCZ), roughly called the "tropical weather systems", took place. This shift was accompanied by a pronounced weakening of the monsoon systems in Africa and Asia and increasing dryness and desertification on both continents (Wanner et al. 2008).

This slow, millennial scale change was overlapped by shorter, decadal to multi-century cooling events. The first events were likely triggered by the orbital forcing, causing freshwater fluxes from the melting ice caps in the NH and rapidly slowing the Atlantic thermohaline circulation. During the last 3000 years three coolings with remarkable glacier advances, mainly in the NH, were observed: The Iron Age Cold Epoch around 2800 yr BP, the Migration Period Cooling between about AD 450 and 800, and the Little Ice Age (LIA) between AD 1350 and 1860. The temperature reconstructions in Figure 2 show the oscillation between the temperate Medieval Climate Anomaly (MCA), the cool LIA and, finally, the Modern Warm Period

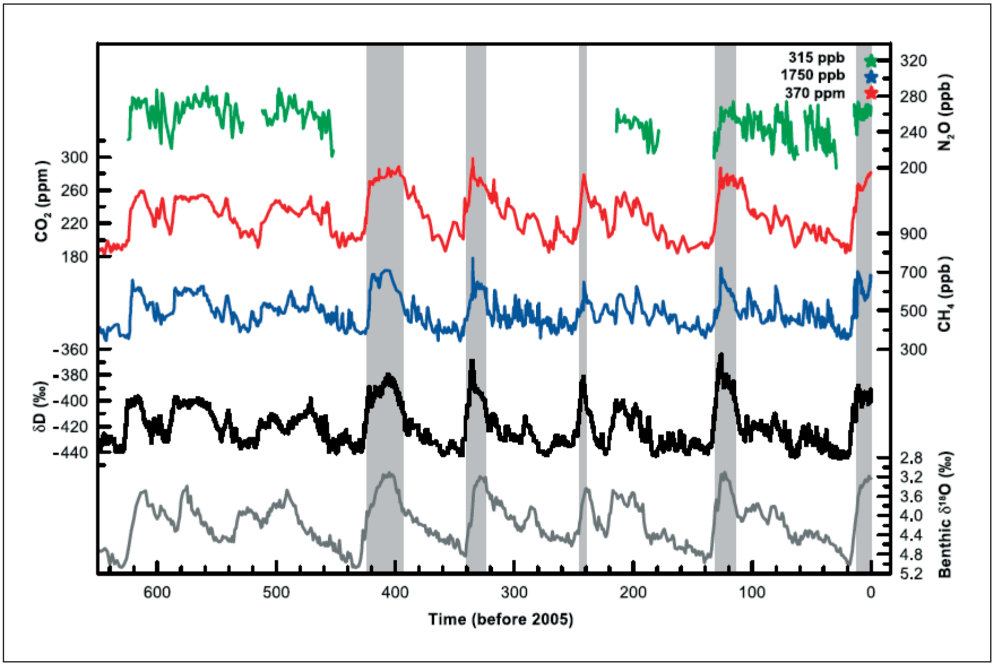

Fig. 1 Variation of nitrous oxide (NO_2), carbon dioxide (CO_2), Methane (CH_4), deuterium (δD) and the isotope $\delta^{18}O$ during the last 645 kyr, derived from air trapped in ice cores from Antarctica and from recent atmospheric measurements (*IPCC* 2007).

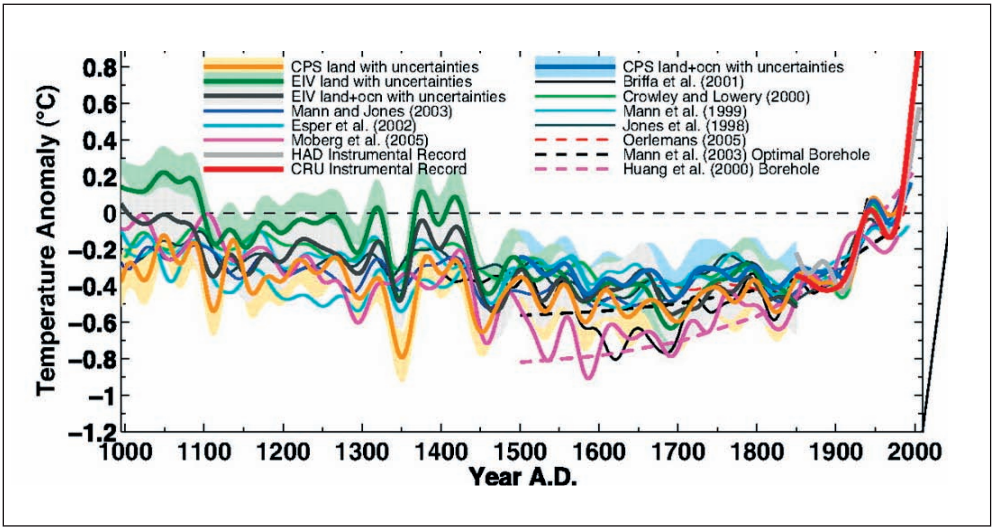

Fig. 2 Different reconstructions of the Northern Hemisphere land or land plus ocean temperature during the last 1000 years, representing the transition from the Medieval Climate Anomaly (MCA) to the Little Ice Age (LIA), and finally to the Modern Warm Period (MWP; from Mann et al. 2008); this paper also references the original papers of all represented reconstructions).

(MWP). The IPCC 4AR (2007) states that the temperature increase of the MWP since the mid-20th century is very likely due to the observed greenhouse gas concentration. The situation is not as clear for the above mentioned rapid cooling events. Probably the combination of the low NH solar irradiance (orbital forcing) with solar irradiance minima and tropical volcanic eruptions played a major role and possibly caused remarkable changes in the ocean thermohaline circulation (Wanner et al. 2008). At least some of the negative peaks in Figure 2 can likely be attributed to such events. On a regional scale the influence of internal variability through feedbacks between the different components of the climate system plays an important role.

According to the existing model simulations based on the natural forcing the Holocene interglacial will only end after about 30 kyr. There remains the question of how the anthropogenic effects will interact with these natural forcings.

References

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