# Holocene climate swings – An attempt to understand global dynamics

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Greenland ice core records show that, prior to the 20th century, temperatures during the Holocene in the Northern Hemisphere mid and high latitudes were only higher during the so-called "Holocene Climate Optimum". Pollen analysis has demonstrated that this warmer period, also called "Atlantikum", occurred in the Canadian Arctic, North Atlantic and Europe between approximately 8000 and 4500 cal yr BP. Glaciological evidence reveals that, during the mid-Holocene, the glaciers strongly retreated in the European Alps, the Canadian Rockies, in the Arctic and other regions of the northern hemisphere. Macrofossils bring evidences that the northern tree line moved north and was located at the Arctic coast over most of Russia. Antarctic ice cores show a widespread Holocene warm period between 11,500 and 9000 cal yr BP and secondary warmer phases in the Ross Sea sector (8000 – 6000 cal yr BP) and eastern Antarctica (6000 – 3000 cal yr BP).

There is a lively debate whether the Holocene climate was cyclic or even periodic not only during the last glacials, but also during the Holocene. This debate was strongly triggered by the discussion around the most recent transition from the Medieval Warm Period to the Little Ice Age. Based on the fluctuations of Alpine glaciers Holzhauser et al. (2005) as well as Jörin et al. (2006) have also demonstrated that two examples of a transition from warmer to colder periods during the late Holocene between about 3500 and 2400 cal yr BP (from Bronze Age Optimum to Iron Age Cooling) as well as between 2400 cal yr BP and 500 yr AD (from late Iron Age/Roman Age Optimum to Migration Period Pessimum) exist.

The discussion about Holocene climate cyclicity was strongly stimulated by the investigations of Bond et al. (2001) who, mainly based on petrologic tracers of drift ice in the North Atlantic, postulated a "1500 year" cycle that is supposed to have persisted throughout the Holocene. These cycles were thought to be Holocene equivalents to the Pleistocene Dansgaard-Oeschger cycles. Despite a coherent high- and low-latitude pattern of variability in the western Atlantic Ocean most observations in the northern and southern mid to high latitudes are in stark contrast to major hydrological or circulation changes in the tropics and subtropics. The northern deserts of Africa were significantly wetter in the early to mid-Holocene and have since moved to a drier regime. A similar situation prevailed across the Middle East, over west and central Asia as well as Tibet. Probably the most abrupt change or transition was observed around 4000-4200 cal yr BP. During this period a severe drought was observed in mid-continental North America. In contrast, lakes in the Altiplano of South America were high before ca. 9000 cal yr BP, experienced a multi-millennial low-level during the mid Holocene (9000 – ca. 4500 cal yr BP). Since then the lake levels have increased in a stepwise way to reach modern levels with centennial-scale fluctuations by ca. 3500 cal yr BP (Grosjean et al. 2003). A similar situation also existed in the western United States, and several authors found evidence for a suppressed El Niño and a more La Niña like background before about

5000 cal yr BP which significantly influenced the hydrothermal regime between New Guinea and South America. In the late Holocene the Intertropical Convergence Zone (ITCZ) moved south not only in the Atlantic but also in the Pacific area.

During the last few years, models of different complexity have become more efficient and have then been used to simulate Holocene climate, performing quasi-equilibrium experiments for key time-slices as well as transient simulations covering the whole Holocene or part of it. This has allowed diagnosing the important processes responsible for Holocene climate change, in particular the role of the variations in the external forcing and of the feedback between the ocean, the atmosphere and the land surface (including the interactions with vegetation changes).

The lecture covers the last 6000 years and does intentionally not include the first millennia of the Holocene because the influence of the large melting continental ice shields will be excluded. In a first step the two important climate "provinces" are characterized: Eastern North America – Atlantic – Europe (dominating climate pattern: North Atlantic Oscillation NAO) on one hand, and the Indian – Pacific area, including the southern oceans and the western areas of North and South America on the other hand (dominating climate pattern: El Niño Southern Oscillation ENSO). In a second step two important millennial scale Holocene climate modes of operation are distinguished, based on the changing orbital forcing. Finally, the question is discussed how far other factors like volcanic and solar forcing as well as internal variability determined the decadal to centennial climate swings.

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