Geophysical Research Abstracts
Vol. 15, EGU2013-5886, 2013
EGU General Assembly 2013

Heinrich Stadial 4: sequence of events from North to South seen in high resolution Greenland and Antarctic ice cores and suggestion of synchronization to North Atlantic marine records

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The last glacial period was affected by the occurrence of rapid climatic events at the millennial time scale known as Dansgaard-Oeschger (DO) events. In Greenland, these events are composed of a rapid temperature increase of 5-16°C in less than a century, a warm phase lasting several centuries (InterStadial, GI) followed by a more gradual temperature decrease, and finally a cold phase (Stadial, GS). An Antarctic counterpart to each GI of the Last Glacial Period has been identified in Antarctic ice cores. In the North Atlantic Ocean, marine cores also record changes in surface temperature as well as the occurrence during cold phases of ice rafted debris horizons, corresponding to massive icebergs discharges, known as Heinrich (H) events. It has never been possible to identify the presence of H events from temperature proxies in Greenland ice cores. It thus remains difficult to compare the durations of H events and GS.

Here, we focus on the time period covering DO 9 to 7 (41 to 34 ka b2k according to the GICC05/AICC2012 time scales), with H event 4 occurring during GS 9. We present a compilation of high resolution measurements (about 60 years) of this period based on Greenland and Antarctic ice cores data (ice and gas) synchronized on the new time scale AICC2012. Proxies for local Greenland temperature (δ^{15}N-N_2, δ^{18}O-H_2O) record GS9 as a uniform period lasting $\sim$1850 years, followed by a sharp transition to GI8. This pattern is also seen in continuous methane concentration data (NEEM ice core, Greenland) showing a large increase by $\sim$100 ppbv at the GS9 - GI8 transition.

However, using additional proxies and a detailed inspection of the methane profile, GS9 can be divided into 3 phases. The first 600 years of GS9 (phase 1) are characterized by low CO_2 and methane concentration, intermediate δD of CH_4 (tracer of methane sources), high NEEM ^{17}O-excess (proxy for vapor source relative humidity) and a progressive increase in EDML δ^{18}O. The transition between phase 1 and phase 2 is marked by an abrupt increase of CO_2 and CH_4 concentration and δD-CH_4 as well as a decrease of NEEM ^{17}O-excess. All proxies stay constant during the 850 years of phase 2. At the transition between phase 2 and phase 3, 400 years before the onset of GI8, we observe an abrupt increase in NEEM ^{17}O-excess and an abrupt decrease in δD-CH_4 while methane concentration remains constant. In Antarctica, EDML δ^{18}O progressively decreases.

We speculate that these different phases may be linked to different atmospheric and/or oceanic conditions during GS9 probably related to the occurrence of H event 4. To explore this hypothesis, we propose a synchronization of North Atlantic marine records to ice cores records.