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PALEOCLIMATE

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Session 3: Paleoclimate

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Hammer and Jouzel presented recent research on climate change in paleogeological times, focusing on results form ice cores in Greenland (Hammer) and the Vostok core in Antarctica (Jouzel), but also drawing on information from ocean sediment cores and other paleoclimate sources. The ice cores provide a richly detailed record of climate and climate change over a period extending back to 200,000 years before present (BP). Annual layer counting is used to precisely date the two Greenland cores down to ca 40 kyr BP. For earlier periods an age model is used. At Vostok the age model is used from the surface because the accumulation is too low for the annual layers to be counted. For Greenland

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cores, there has been discussion of possible errors due to folds or other disruptions associated with ice flow for the deepest layer especially over the previous interglacial (Gemian). The GRIP camp at the center of the Greenland dome is favorably located from this perspective (relating to present ice flow).

Principal features in ice cores that are examined are isotopic abundances of ^{18}O and D in water, which vary with temperature because of Rayleigh distillation, and concentrations of chemicals especially H^+ (acidity), SO_4^{2-}, NO_3^-, methanesulfonic acid (MSA) and dust. Large spikes in SO_4^{2-} and H^+ can be related to known volcanoes in historic times, often exhibiting widespread geographical distribution. Spikes of volcanic ash are also observed but these are generally more local, e.g., due to an Icelandic volcano, observed only in Greenland, perhaps just in a small area of the ice sheet. Dust is eolian in origin, with principal mass in the size range 0.4-4μm radius.

A key feature noted in the Greenland ice record is the occurrence of numerous periods of less glaciation (interstadials) occurring during the last glacial period. These interstadials last roughly 500 to 2000 years, with a rapid warming towards temperature intermediate between interglacial and full glacial, followed by a slower cooling and a relatively rapid return to glacial conditions. The time record is characterized by its complexity. It is triggered in part by oscillating changes in insolation due to astronomical causes ("Milankovitch forcing"), but also presents more erratic features, which are attributed to the highly nonlinear nature of the climate system and may also correspond to purely internal instabilities of the system. There is a general asymmetry between cooling episodes (which often happen slower) and warming episodes (often more rapid). Some of the climate transitions may be rapid or very rapid. Here rapid means within the span of a human lifetime and very rapid means two years to perhaps half a year in some quantities such as the rate of dust accumulation. These changes are geographically widespread (north polar to south polar) although the rapidity of the change sometimes seen in the Greenland record (0.5-2 years) is sometimes not matched in Antarctic record where the changes are less important and much less abrupt. Recent research on the Greenland cores show remarkably rapid high magnitude fluctuations in the Eemian period (113-135 kyr BP) and instances of interglacial periods with temperatures somewhat warmer than at present. However questions have recently arisen regarding the validity of interpreting those isotopic changes in terms of climate changes because of differences between the two summit cores for this part of the record. Key observables exhibiting change between glacial and interstadal epochs are isotopic abundances of D and ^{18}O and concentrations of MSA, dust and trapped gases - CO_2 and CH_4. Dust exhibits much lower concentrations (order of magnitude) in interstadal periods than glacial. This can be due only in small part to the rate of water deposition (lower in glacial epochs by a factor of 2) and is attributed to greater source strength resulting from larger exposed area of soil surface (resulting from lower sea level), and possibly drier soils (resulting from decreased precipitation) and possibly greater wind speeds. CH_4 concentration is high in interstadal periods, possibly because of greater production rate in moist soils.

In the discussion it was noted that the climate change events noted in the paleo record present a challenge to the climate modeling community. In particular with reference to the present workshop on clouds, chemistry and climate there are issues where this research community may be able to provide insights or where present understanding may be challenged. It was observed that the same laws of microphysics must continue to apply, despite differences in the microphysical climate between glacial epochs and the present. Atmospheric chemists may be able to contribute insight to interpretation of relations between deposition rates of substances and their atmospheric concentrations. A key issue to the ice core community is reconstruction of the water deposition flux and more generally improved understanding of the hydrological cycle in glacial epochs. Did the decrease in precipitation extend to lower latitudes, as perhaps interpreted in lower CH_4 concentrations in glacial epochs?

An issue that arose in discussion was the relation between temperature and isotopic composition. In both polar regions an excellent correlation is observed for example between temperature and $\partial^{18}0$ that is used to infer temperature from the measured $\partial^{18}0$. However it was noted that the isotopic composition reflects the lagrangian history of the water deposited in precipitation, and thus the empirical calibration is perhaps subject to question if this lagrangian history were systematically different in climatic epochs different from the present. Attempts to model changes in $\partial^{18}0$ using GCM's have thus far not been entirely successful. Perhaps the key question facing the paleoclimate community is the reason for the complex and nonlinear nature of the climate record and, closely coupled, the mechanism whereby the transition can be as rapid as observed. It was noted that the transitions are not symmetric; that warming can take place much more rapidly than cooling. A suggested mechanism involves marginal ice-sheet instability with resultant massive amounts of fresh water ice entering the ocean and, upon melting, leaving low density pools of surface water that inhibit large scale ocean circulation, perhaps affecting the so-called "conveyer belt" circulation. There was considerable discussion of the possible role of dust as a climate forcing agent, thus leading to a possible feedback. Dust in clouds can enhance short-wave absorption in clouds thus decreasing solar heating at the surface. Changes in cloud microphysical properties due to dust may also contribute to changes in the hydrological cycle. The ice core measurements of dust (and perhaps also sulfate) can possibly be used in cloud models to address this issue.