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The nature of abrupt climate change during the last glacial period from detailed isotopic records from the NGRIP ice core

T.J. Popp (1), A. Svensson (1), J.P. Steffensen (1), S.J. Johnsen (1), and J.W.C White (2)

(1) Centre for Ice & Climate, Niels Bohr Institute, University of Copenhagen, Denmark (trevor@gfy.ku.dk), (2) INSTAAR, University of Colorado, Boulder, USA

Isotopic and chemical impurity records from Greenland ice cores with sub-annual resolution across three fast climate transitions of the last deglacial termination reveal complex patterns of environmental change for the onset of Greenland Interstadial 1 (GI-1 or Bølling), the onset of Greenland Stadial 1 (GS-1 or Younger Dryas), and the onset of the Holocene. In the NGRIP ice core each of these transitions is initiated by a 1-3 year mode shift in deuterium excess, which is a proxy for the Greenland precipitation moisture source. These mode shifts in deuterium excess are decoupled in time from the isotopic (deuterium and oxygen-18) transitions from which they are derived. In general the abrupt isotopic transitions follow the corresponding deuterium excess shifts and span decades rather than years. Similar data from GISP2 confirms the clear deuterium excess mode shifts for transitions from cold states to warm states; however the abrupt deuterium excess transition at the onset of GS-1 is not expressed in a similar way at GISP2. Ironically, it appears that this cooling at the beginning of the Younger Dryas, for which we have theories of the triggering event, is less clearly recorded than warming events, the triggering of which is still poorly understood. Along with other available paleo-data, these results indicate that the sum of an abrupt climate change is composed of multiple responses from different parts of the climate system. These responses can be separated by as little as a single year to a few decades and the collection of these responses result in a variety of abrupt transitions giving each a unique anatomy. Here we expand this type of analysis with new isotope, deuterium excess, and accumulation rate time series from NGRIP across the abrupt transitions associated with several interstadial events of the Last Glacial period (Dansgaard-Oeschger events). Indeed the temporal phasing of deuterium excess and the isotopic content of the ice can vary from one event to the next and emerging patterns may depend on the conditions associated with specific events such as Heinrich Events and ice volume boundary conditions. Together with modeling and chemical impurity data, these patterns will provide clues to the timing and origin of ocean and atmospheric changes that comprise an abrupt climate change. The emerging picture indicates that abrupt climate changes have both a temporal and geographic anatomy that can change from one event to the next in how they are recorded across Greenland.