Geophysical Research Abstracts, Vol. 8, 04712, 2006
SRef-ID: 1607-7962/gra/EGU06-A-04712

Toward a unified theory of abrupt glacial climate changes

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Paleoclimate records for the last glacial cycles are punctuated by numerous abrupt changes known as Dansgaard-Oeschger (DO) and Heinrich events. The former are directly related to climate changes and are believed to be caused by the rapid reorganizations of the Atlantic circulation, while the latter represent glaciological events, associated with a massive release of icebergs into the Atlantic ocean, although their climate signature is also clearly seen in numerous paleoclimate records. In spite of different nature, both types of events are apparently tightly coupled, with the strongest and longest DO events directly followed Heinrich events, while Heinrich events occurred after the series of DO events ("Bond cycle"), always during the stadial (cold) conditions in the Northern Hemisphere. Using in conjunction paleoclimate data and climate modeling results, I will present an attempt to formulate frameworks of the unified theory of abrupt glacial climate changes and will discuss the mechanisms, feedbacks and teleconnections explaining observed temporal and spatial dynamics of abrupt climate changes during the glacial ages. The theory explains observed instability of the glacial climate as a result of rapid reorganizations of the ocean circulation, and a strong, bi-directionally interaction between North Atlantic climate and the ice sheets. It is argued that while the ice sheets affect the ocean circulation via large iceberg surges and meltwater, changes in the thermohaline circulation strongly affect the surface mass balance of the sheets, as well as the stability of marine ice shelves. During the interstadial (warm) mode of the Atlantic thermohaline circulation, both ablation on the southern flanks of the ice sheets and accumulation over the northern parts increased drastically. The latter caused a delayed response of the iceberg calving directly into the area of the Nordic Seas. Thus, the temporal dynamics of freshwater flux into high and middle latitudes of the North Atlantic is rather different. During cold (stadial) conditions, when deep water formation is completely suppressed in the

Nordic Seas, development of strong negative SST anomalies led to a reduction both in ablation and accumulation, and, at the same time, the temperature of the subsurface water masses in the northern North Atlantic increased during stadials. This caused a strong bottom melting of the marine ice shelves and could eventually cause their destabilization that, in turn, might provoke a large-scale instability of the grounded ice sheets and almost synchronous ice surging events at different locations around the northern North Atlantic. It is proposed that this bi-directional interaction between the ocean and the ice sheets could give rise to the development of self-sustained oscillations in the climate-cryosphere system under a broad range of glacial climate conditions.