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Nonlinear atmospheric responses to hemispherically asymmetric surface temperature perturbations

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NGRIP ice core data (Steffensen et al. 2008) reveal extremely abrupt climate shifts during the Bølling-Allerød and Younger Dryas transitions as seen in δ^{18}O and deuterium excess records. Typical for these onsets are corresponding changes in dust deposition reflecting wetting/drying of Asian deserts. These warming and cooling events have occurred within a couple of years only, implying that very fast atmospheric reorganizations have taken place and affected both high and low latitudes.

Due to the very fast processes observed, this modelling study focuses on sea ice and sea surface temperature changes, assuming the existence of a critical boundary condition that (once reached) causes a nonlinear response in atmospheric transport and a very fast reorganization. Our hypothesis does not require a rapid change in the sea ice extent that would alone be responsible for the atmospheric response, but rather crossing of a threshold causing an abrupt change in the poleward heat transport and the main ITCZ location.

The sensitivity of the atmospheric response to different sea ice extents and sea surface temperature (SST) fields is tested using an atmospheric general circulation model (the NCAR CCM3.6.6) with SST anomalies derived from freshwater hosing experiments in the intermediate complexity model ECBilt CLIO. A freshwater forcing of 1.5 Sv has been applied for 20 years in the North Atlantic and anomalies are determined as the SST difference between the resulting off state and the on state (after recovery) of the Atlantic Meridional Overturning Circulation. These anomalies multiplied by different strength factors are added to the present day SST fields in CCM3.6.6 enabling an investigation of the atmospheric response during northern hemisphere cooling and warming from present day conditions.

The results show a displacement of the tropical rain belt that is pronounced in the boreal winter months – precipitation decreases in the southern tropics (20^{o}S) and increases in the northern tropics (5^{o}N) in warming simulations while the opposite pattern is observed during the cooling events. Implied atmospheric and total transports respond considerably more strongly during warmings compared to the coolings. In warming simulations a stronger forcing causes a stronger change (in a normalized sense) in the atmospheric transport while in cooling simulations the opposite is true, i.e. the stronger the forcing the weaker the normalized change in the atmospheric transport. Total transport anomalies show a very nonlinear response when comparing warming and cooling events, with positive zonal anomalies during warmings at all latitudes.

The southern Hadley cell is more sensitive to the forcing applied responding both by changing the strength and the location of its maximum while the northern one is just changing its strength. Hadley cell responses are higher for the warming experiments and are dominated by signals in the Asian region. The summer ITCZ location is unchanged in the warming simulations and migrates southward in the cooling simulations, while winter positions are susceptible to both positive and negative anomalies. There is a much larger span of the ITCZ displacement over Asia compared to the rest of the world thus possibly bearing on the signal seen in the ice core dust records.