Geophysical Research Abstracts
Vol. 13, EGU2011-3485-1, 2011
EGU General Assembly 2011

Two types of multi-centennial variability of the Southern Ocean deep convection: How sea ice tips the scale

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The ocean plays a major role in driving decadal to centennial global climate variability. Due to its larger thermal capacity its memory greatly exceeds that of the atmosphere. Ice sheets and external forcings mostly vary on timescales of millenia and beyond. An important part of the large-scale thermohaline circulation in the ocean is the deep convection in (sub-) polar regions. Bryan (1986, Nature) found that two stable climate states of this circulation exist in a simple ocean general circulation model (OGCM) under different forcing conditions: a symmetric state with convection in both hemispheres and an asymmetric state with convection in one hemisphere only. Later, it was shown that self-sustaining oscillations between states of active and inactive convection are possible in OGCMs of diverse complexity (e.g. Winton and Sarachik, 1993, JPO; Drijfhout et al., 1996, JPO). According to Pierce et al. (1995, JPO) it is the competing role of heat and freshwater fluxes in the ocean that lead to this flip-flop behavior: a slowly forming freshwater cap at the ocean surface stalls the convection, which is re-activated by destabilization of the water column due to accumulation of warm water at mid depth. We present and explain the existence of two types of these oscillations with opposite basic convection characteristics in the Southern Ocean with a state-of-the-art complex coupled global circulation model (CGCM).

We use two multi-millennial simulations with the Kiel Climate Model (KCM), which consists of the ECHAM5 atmosphere and the NEMO/LIM2 ice-ocean model being applied on grids of 3.75° (T31) and 2° horizontal resolution, respectively. The two experiments show a contrasting behavior of the Southern Ocean deep convection flip-flop. The basic state of the control simulation (CTRL) features near-permanent open ocean deep convection cells in the Weddell and Ross Sea regions with quasi-periodic shut-down events. These events occur every 300 to 400 years and last for 2 to 8 decades. The second experiment (NOCON) has no convection in the Southern Ocean most of the time. However, with a period of 200-300 years a convection cell occurs in the Weddell Sea for 2 to 10 decades.

The two model experiments differ in only one parameter, which affects the Southern Hemisphere: the thickness of newly formed, laterally growing sea ice is prescribed with 0.6 m in NOCON instead of 0.1 m as in CTRL. This yields a generally thicker sea-ice cover by up to 3 m in the Weddell Sea and 0.6 m everywhere else around Antarctica in NOCON. The ice cover is also slightly more extensive and less compact as in CTRL. Most importantly, the thicker ice proves to form a more resistive lid on the ocean surface keeping the heat, which accumulates at mid depth, from causing frequent overturning of the water column. The secret player that enables deep convection in NOCON is the wind that coincidentally pushes back the ice edge and allows warm waters to finally reach the surface. Similar to CTRL a freshwater cap shuts down the convection in NOCON. Since the surface ocean is generally warmer in the convection region in CTRL, a coincidental increase in ice concentration accompanying the formation of a freshwater pool at the surface is necessary to form a stable lid.