Atmospheric and Oceanic Response to Southern Ocean Deep Convection Oscillations on Decadal to Centennial Time Scales in Climate Models

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Introduction

The Kiel Climate Model (KCM) simulates open ocean deep convection in the Southern Ocean (SO) as a recurring event on a centennial time scale [Martin et al., 2013]. More recently, similar behavior was reported for many models of the Coupled Model Intercomparison Project Phase 5 (CMIP5) though with strongly varying frequency of recurrence ranging from a few years to a century [de Lavergne et al., 2014].

The only observation of such event, however, was the occurrence of the Weddell Polynya in the mid-1970s, an open water area of 350,000 km² within the Antarctic sea ice in three consecutive winters. Our KCM simulations indicate that atmospheric and oceanic responses to the cessation of deep convection in the SO include a strengthening of the low-level atmospheric circulation over the Southern Ocean (increasing SAM index) and a reduction in the export of Antarctic Bottom Water (AABW), potentially masking the regional effects of global warming [Latif et al., 2013; Martin et al., 2014].

Do CMIP5 models feature similar responses to Southern Ocean deep Convection Oscillations (SOCO)?

The Models

- **KCM**: ECHAM5 atmosphere (T42L19, ~2.8°) & NEMO (OPA9-LIM2) ocean sea-ice models (2°, 31 levels), no flux correction, no anomaly coupling
- **MPI-ESM-LR**: ECHAM6 atmosphere (T63L47, ~1.9°) and MPI-OM ocean sea-ice models (~2.8°) & NEMO (OPA9-LIM2) ocean sea-ice models (1.5°, 40 levels)
- **CNRM-CM5**: ARPEGE-Climat atmosphere (T4, 31 levels), NEMO (OPA9) ocean (1°, 42 levels), and GELATO sea-ice models
- **GFDL-CM3**: AM3 atmosphere (C48L49, ~1°.), MOM4-SIS ocean sea-ice models (~1°, 50 levels)

In all cases we analyzed multi-centennial to multi-millennial pre-industrial control simulations.

Model output provided by the CMIP5 repository.

References


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How is the Ocean affected by SOCO?

**Significant heat loss beyond convection site impacts SSH and gyre circulation**

The ocean loses heat to the atmosphere during active deep convection. The associated deep cooling reduces local sea surface height (SSH) and the Weddell (and Ross) gyre circulation slows.

**maps:** heat content change, convective minus non-convective regime

**time series:** total heat content anomaly within region(s) indicated on maps

Are SOCO and the global THC connected?

**AMOC bottom cell strengthens, upper cell weakens; the impact depends on AABW properties and AMOC characteristics in the individual model**

SOCO link to the global Thermohaline Circulation (THC) being driven by warm North Atlantic deep waters and producing Antarctic Bottom Water (AABW). Deep and bottom water compete in the Atlantic Meridional Overturning Circulation (AMOC) as one expression of the bipolar ocean seesaw. Such link shows in models with weaker AMOC and cooler bottom water (KCM, CNRM-CM5). There is no link between SOCO and AMOC in the MPI-ESM1.5.

How does the Atmosphere react to SOCO?

**Antarctic SAT rises by up to 8°C**, Westerlies weaken

**on right:** While surface warming is strongest over the deep convection site itself, the signal spreads widely and is also found over the Antarctic continent and may thus be found in ice core records.

**on left:** SST index of the Southern Ocean defined as the average SST in the zonal band between 50° and 70°S (Latif et al, 2013), which is used here to compute composites for the convective and non-convective regimes (above and below 1σ indicated by red lines).

Southern Ocean deep Convection Oscillations (SOCO)

**SOCO location & frequency varies**

on right: SST standard deviation (>0.6°C) indicates well the deep convection region(s) and shifts in sea ice edge position

below: deep convection varies strongly in both extent and frequency among models, in some it never occurs (100,000 km² threshold line)