Southern Ocean deep convection in climate simulations: Turning a blind eye does not help

—an opinion piece—

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Scripps, La Jolla, 02/14/2020
Window to the (deep) ocean: The Weddell Sea Polynya

Polynya as observed in early satellite records

- up to 350,000-km² ice-free area
- massive heat release:
  (136 Wm⁻² or 34 TW)
- 2 – 3 Sv convective overturning
- Will it return?
- Did it occur more frequently in the past?

Gordon et al. (2007, 2014)

Polynyas in the Southern Ocean

They are vast gaps in the sea ice around Antarctica. By exposing enormous areas of seawater to the frigid air, they help to drive the global heat engine that couples the ocean and the atmosphere

by Arnold L. Gordon and Josefino C. Comiso
Window to the (deep) ocean: The Weddell Sea Polynya

The recent “Weddell”/Maud Rise Polynya

Campbell et al. (2019, Nature); Gordon et al. (2007)

Cheon and Gordon (2019, Sci. Rep.)


Campbell et al. (2019, Nature)
The Weddell Polynya

1974

The polynya in coarse resolution climate models

oceanic heat loss as simulated with KCM

surface heat flux

mixed layer depth max. in September

ocean heat content change

Martin et al. (2013, Clim.Dyn.)

GEOMAR press release, 2017

Weddel/Maud Rise Polynya: Reality and model world
Symptoms and cause: polynya in coarse res. models

- reduced sea-ice cover → polynya
- unusually warm SST
- excessively deep mixed layer (high MLD variance)
- large upward heat flux
- ACC variations

Martin et al. (2013, Clim.Dyn.)
Symptoms and **cause**: polynya in coarse res. models

*Heat builds in Weddell Gyre sourced from lower branch of AMOC*

→ a thermally unstable ocean + atmospheric/sea ice variations
→ deep convection
→ shut down by surface freshwater anomalies when heat depleted

• The Weddell Polynya • Deep Convection Oscillations in Coarse Models • Bottom Water Formation • Paleo Perspective • Summary

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Martin et al. (2015, DSR2)
Deep convection: an issue across all CMIP models

- basically all CMIP 3 & 5 climate models "suffer" from regular open ocean deep convection, typically in the Weddell Sea
- frequency, duration and convection are differ greatly
- relates to model mean state: stratification, sea-ice volume; also impeded by changes in wind and precipitation (Cheon et al., 2015; de Lavergne et al, 2013)

Reintges et al. (2017 GRL)
Deep convection: an issue across all CMIP models

- unavoidable in CMIP: massive deviations in **bottom temperature** (and density)
- multi-model mean has reasonable AABW properties

*Heuzé et al. (2013, GRL)*

*Reintges et al. (2017 GRL)*
Deep convection: an issue across all CMIP models

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Reintges et al. (2017 GRL)

• unavoidable in CMIP: massive deviations in bottom temperature (and density)
• multi-model mean has reasonable AABW properties

Heuzé et al. (2013, GRL)

climate models have too little deep overturning

Sallée et al. (2013, JGR)

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Bottom water formation and trends

1. The Weddell Polynya
2. Deep Convection Oscillations in Coarse Models
3. Bottom Water Formation
4. Paleo Perspective
5. Summary

WATER MASSES
TW: Subtropical Waters
MW: Mode Waters
IW: Intermediate Waters
CDW: Circumpolar Deep Waters
BW: Bottom Waters

Warming
No warming or cooling

Processes at play: see caption

Schmidtke et al. (2014, Science)
Sallée et al. (2018, Oceanography)
Getting there: high-resolution ocean models

Ocean state estimate

Freshwater flux to ocean

Forced model

Bottom water formation and export

Abernathy et al. (2016, Nat. Geosc.)

Moorman et al. (subm.), courtesy of Adele Morrison
Overflows (vertical coordinates)

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courtesy Jerome Chanut
Overflows (vertical coordinates)

Fig. 1. Location of major gravity currents by type. O: Overflow across a topographic barrier from a regional basin into the open ocean, e.g., the Nordic overflows, Red Sea overflow, and Mediterranean overflow. B: Open-ocean overflow into an isolated regional basin. C: Cascade of dense water from a continental shelf, e.g., the Ross Sea and Weddell Sea overflows (see Table 1 for further information). Not shown are numerous overflows across multiple sills of the midocean ridge system, within the series of basins of the western South Pacific; and the cascades of shelf water over the slope of the Arctic Sea. Bathymetry map from Smith and Sandwell (1997).

Legg et al. (2009, BAMS)
Interpretation of proxy data requires accurate models

Huang et al. (2020, Nat. Comm.)
Were there times when open ocean convection prevailed?

During glacial periods ice shelves reached farther north possibly covering most of the continental shelves and open ocean deep convection would have been the only source of AABW.

- Westerlies shifted equatorward
- cold, dry polar air spreads seaward
- reduced surface freshening
GEOMAR’s Flexible Ocean and Climate Infrastructure (FOCI)

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Matthes et al. (2020, Nat.Clim.Ch.)
GEOMAR’s Flexible Ocean and Climate Infrastructure (FOCI)

- 1/2° global ocean (NEMO3.6-LIM2, ORCA05.L46)
- coupled with ECHAM6.3 atmosphere (~1.8°, T63L95)
- 2-way nested 1/10° refinement region in the North Atlantic (31°N-83°N)
  - 868 x 884 grid points
    (base model: 722 x 511)
  - 10 min time step
    (base model: 30 min)
  - 3D update of base model every 4th time step

Matthes et al. (2020, Nat.Clim.Ch.)
Summary ... and discussion

• Weddell Polynya of 1970s still unique in size, returned as Maud Rise Polynya or thin ice “halos”

• CMIP5-style coarse-resolution models tend to overestimate appearance of the polynya, open ocean deep convection is their means of forming bottom water

• High-resolution (<1/10°) capable of reproducing observed modes of dense water formation

• Terrain-following or isopycnal coordinates superior in maintaining dense water properties during downslope flow of dense water plume

• While 20th & 21st century simulations move towards such grid improvements, paleo oceanography applications are stuck with coarse resolution grids