Drivers and Impacts of Southern Ocean Polynyas in High-Resolution Earth System Models

Wilbert Weijer
Prajvala Kurtakoti
Zachary Kaufman
Milena Veneziani
Achim Stössel
Nicole Feldl
Mathew Maltrud

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Polynyas

• Polynyas are areas of open ocean amidst the winter ice pack
• Characterized by
  – Strong ocean heat loss
  – Water mass formation
  – High biological productivity
• Two end members
  – Coastal polynyas: kept ice-free by offshore winds
  – Open-ocean polynyas: usually kept ice-free by subsurface heat supply
Polynyas in the Weddell Sea

• Weddell Sea polynyas
  – Large open-ocean polynyas
  – Observed last in mid-70s

• Maud Rise polynyas
  – Associated with Maud Rise/Astrid Ridge complex
  – Have occurred regularly, most recently 2016/2017
Motivation

- Understanding the formation and impacts of polynyas in the Weddell Sea is important
  - Was the Weddell Sea polynya in the 70s:
    - The final occurrence of a regular phenomenon that is now being suppressed by climate change?
    - An expression of (multi-)decadal variability in a system with threshold behavior?
  - Could we have predicted the Maud Rise Polynyas from 2016/2017?
    - Could we have predicted that it would not evolve into a Weddell Sea polynya?
  - Even if Weddell Sea polynyas will never form again, they are ubiquitous phenomena in high-resolution climate models
    - Hence a potential source for mean-state bias
- Here we synthesize our work on the formation and impacts of polynyas in the Weddell Sea in an eddy-resolving climate model
  - Kurtakoti et al. (in review): Weddell Sea polynya formation
  - Kaufman et al. (2020): Impacts of Weddell Sea polynyas on heat budget
The Model

- **E3SMv0-HR**
  - Energy Exascale Earth System Model
  - Branched from CESM1.3

- **Model components**
  - **Ocean**
    - Parallel Ocean Program (POP2)
    - 0.1° resolution
    - 42 levels
  - **Sea ice**
    - Los Alamos sea ice code (CICE4)
    - 0.1° resolution
  - **Atmosphere**
    - Community Atmosphere Model (CAM5-SE)
    - Atmosphere: 0.25°

- **Run for 131 years**
  - 1850 conditions
The Model: Polynyas

- The model has range of polynya behavior
  - No polynyas
  - Maud Rise polynyas
  - Weddell Sea polynyas
  - Embayments
The Model: Polynyas

Wind stress curl anomaly over the Weddell Sea

- No polynya
- Maud Rise Polynya
- Weddell Sea Polynya
- Embayment
Maud Rise Polynyas

• 6 initiation events of Maud Rise Polynyas (MRP-I)

“No polynya” composite
MRP-I Composite

Mixed-Layer Depth
Sea ice concentration

Kurtakoti et al. (2018)
Maud Rise Polynyas

- Pre-polynya stratification characterized by strong *Taylor Cap*
  - Preconditions water column for convection

Potential Temperature in May (pre-convection)
Meridional section across Maud Rise

"No polynya" composite
MPR-I Composite

Kurtakoti et al. (2018)
Maud Rise Polynyas

- Initiation of MRPs in most cases associated with rapid transition from positive to negative wind stress curl anomalies
- But not *sufficient* condition
- So what triggers Maud Rise polynyas?

Kurtakoti et al. (2018)
Maud Rise Polynyas

• Initiation of MRPs in all cases associated with *arrival of positive salinity anomaly from the east*
  – Reason is still not clear
Weddell Sea Polynyas

• Why do some Maud Rise polynyas develop into Weddell Sea polynyas (while others don’t)?
  – Large Maud Rise Polynyas can create high surface salinity anomalies which flow westward to trigger Weddell Sea Polynyas
Weddell Sea Polynyas

“MRP” CASE

“MRP+WSP” CASE
Implications for Heat Budget

- There is significant *anti-correlation* between meridional ocean (OHT) and atmospheric (AHT) heat transport
  - *Bjerknes Compensation* south of ice edge
- Is this driven by variability in OHT?

Kaufman et al. (2020)
Implications for Heat Budget

• Polynya formation associated with build-up of sub-surface heat reservoir

• This heat build-up is caused by reduced surface heat loss during ice-covered periods
  – Ocean heat advection *counteracts* heat build-up

Ocean Heat Content (south of 65°S)

*Kaufman et al. (2020)*
Conclusions

• Maud Rise polynyas
  – Taylor column dynamics over Maud Rise
  – Triggered by high surface salinity anomalies over the Maud Rise-Astrid Ridge Bathymetric Complex

• Weddell Sea Polynyas
  – Preconditioning through strong negative wind stress curl over the Weddell Sea
  – Build-up of heat reservoir
  – Triggered by Maud Rise Polynyas

• Bjerknes Compensation in Southern Ocean of eddy-resolving climate model
  – But driven by polynyas, not OHT variability

See also presentation by Xiliang Diao