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

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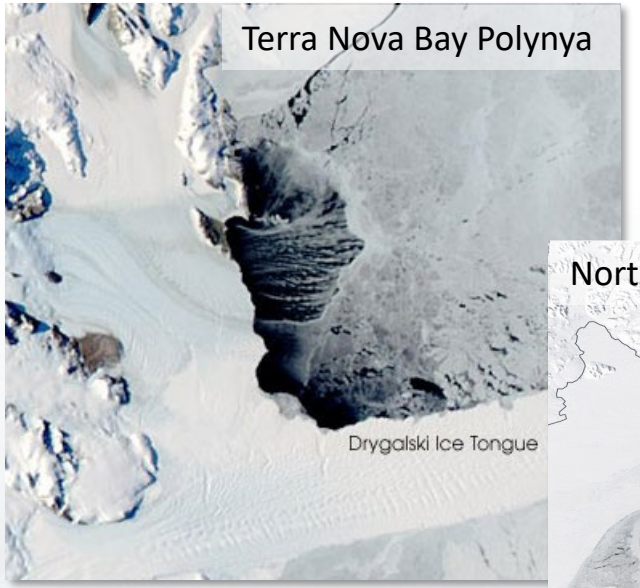
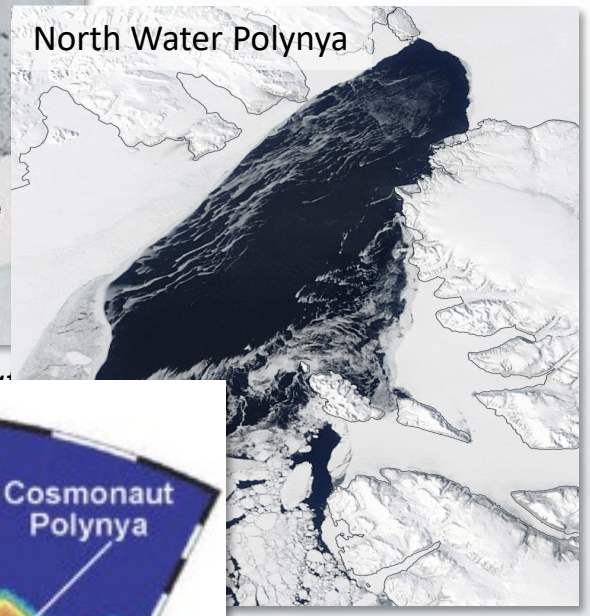
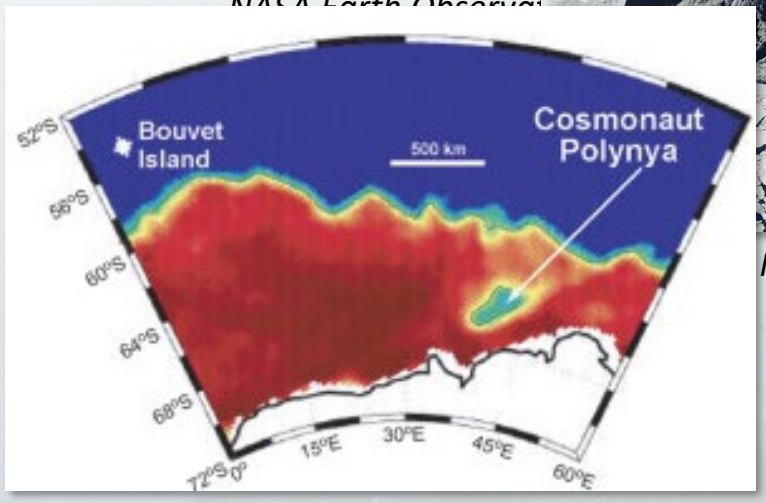
Polynyas

- 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





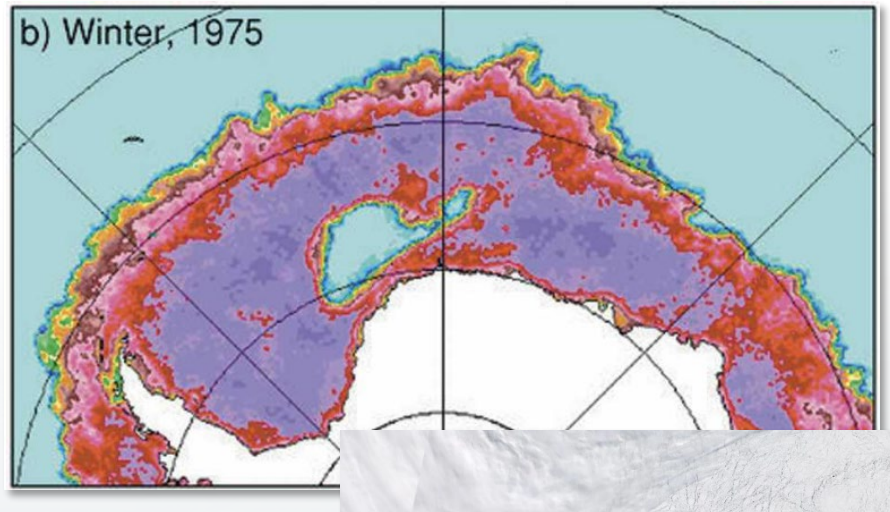
NASA World View

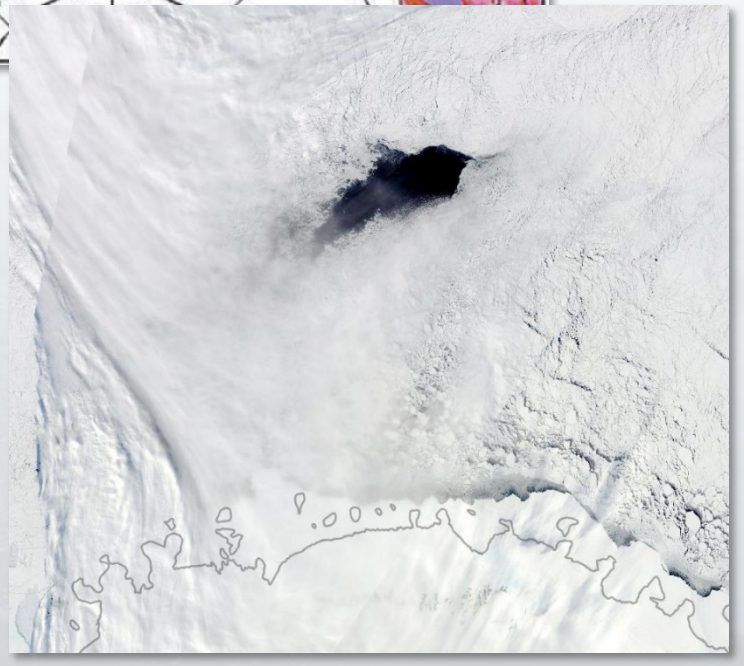


Kent Moore/Barber & Massom (2007)

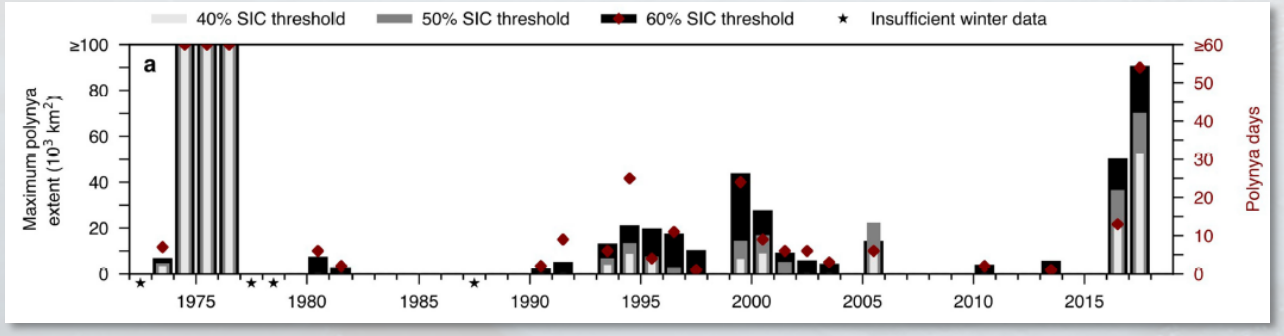
Polynyas in the Weddell Sea

- 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





Lauren Dauphin/NASA Earth Observatory



Campbell et al. (2019)

Motivation

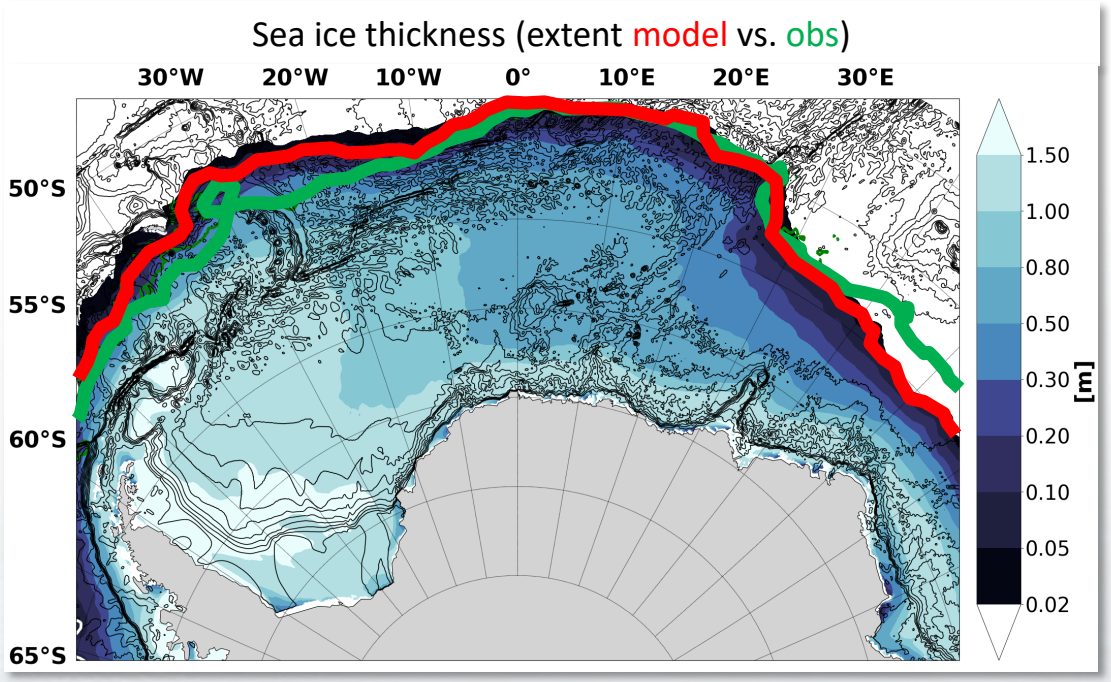
- Understanding the formation and impacts of polynyas in the Weddell Sea is important
  - Was the Weddell Sea polynya in the 70s:
    - The final occurrence of a regular phenomenon that is now being suppressed by climate change?
    - An expression of (multi-)decadal variability in a system with threshold 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. (2018): Maud Rise polynya formation*
  - *Kurtakoti et al. (in review): Weddell Sea polynya formation*
  - *Kaufman et al. (2020): Impacts of Weddell Sea polynyas on heat budget*

Prajvala Kurtakoti (TAMU/LANL)

Zachary Kaufman (UCSC)

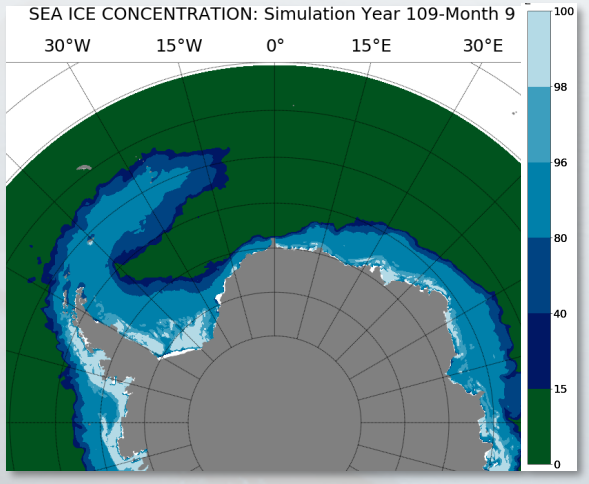
The Model

- 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



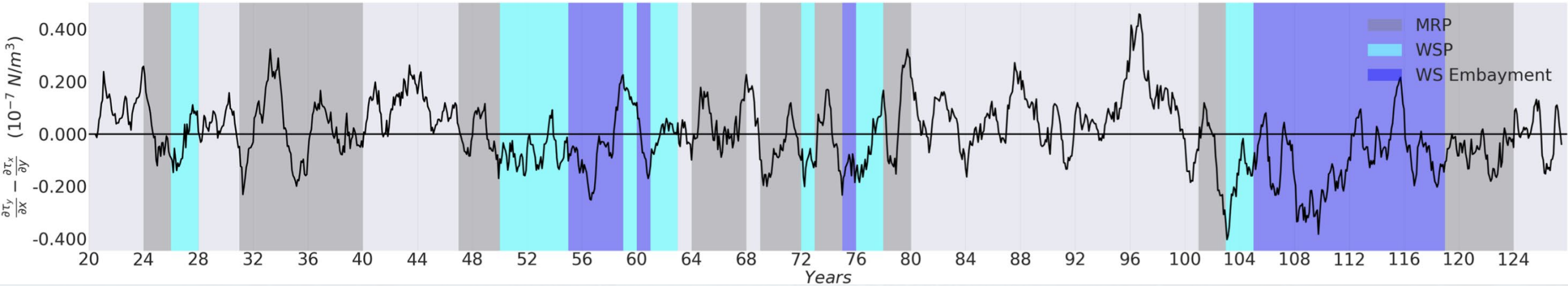
The Model: Polynyas

- 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

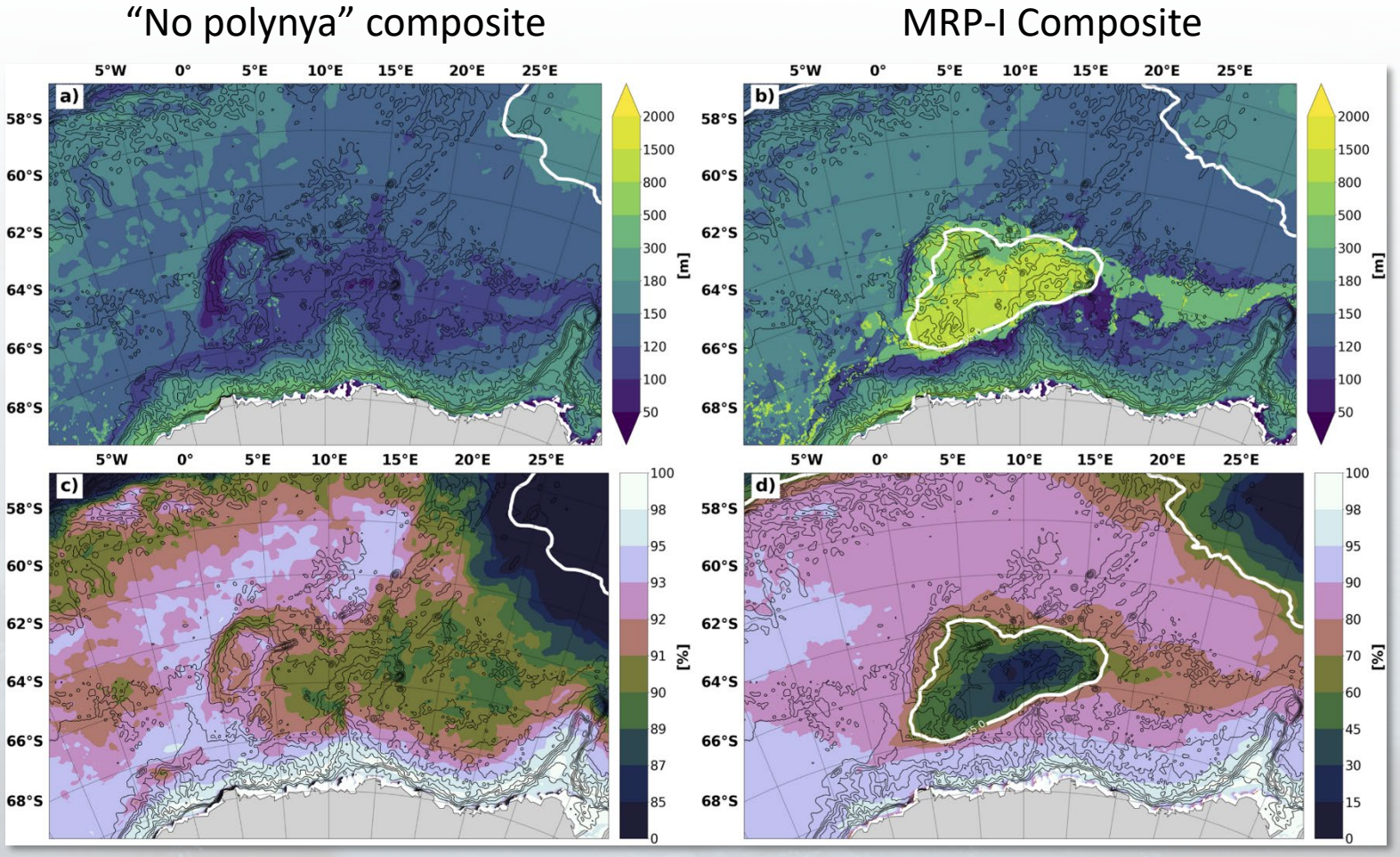
Maud Rise Polynya

Weddell Sea Polynya

Embayment

Maud Rise Polynyas

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

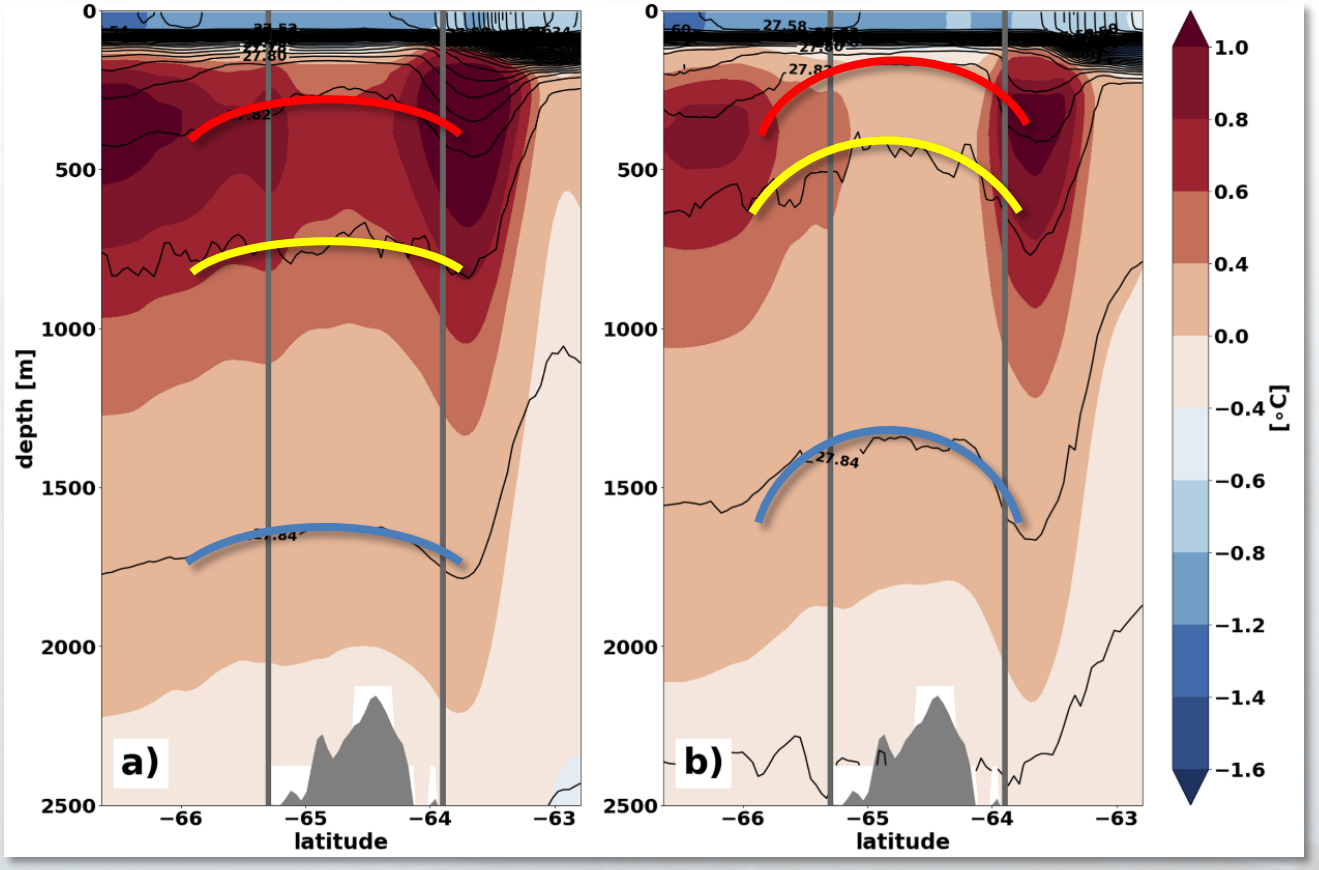


Kurtakoti et al. (2018)

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

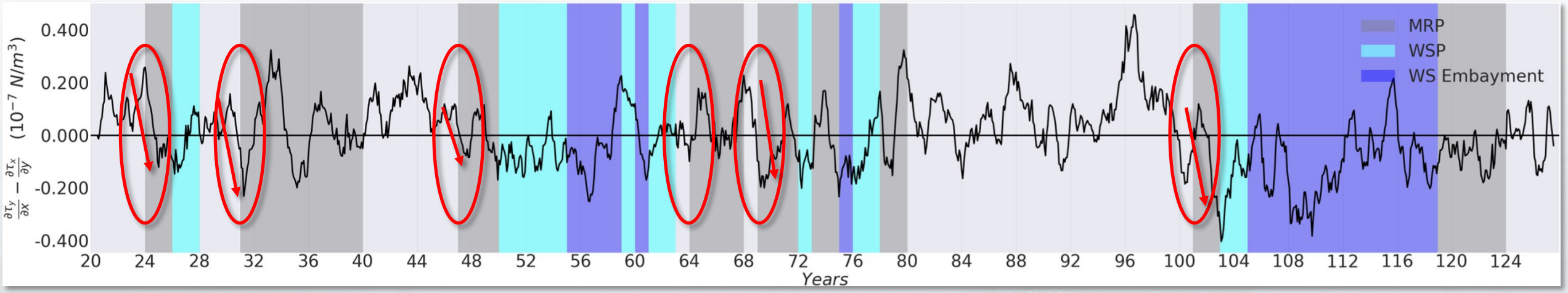


Kurtakoti et al. (2018)

Maud Rise Polynyas

- Initiation of MRPs in most cases associated with rapid transition from positive to negative wind stress curl anomalies

Wind stress curl anomaly over the Weddell Sea



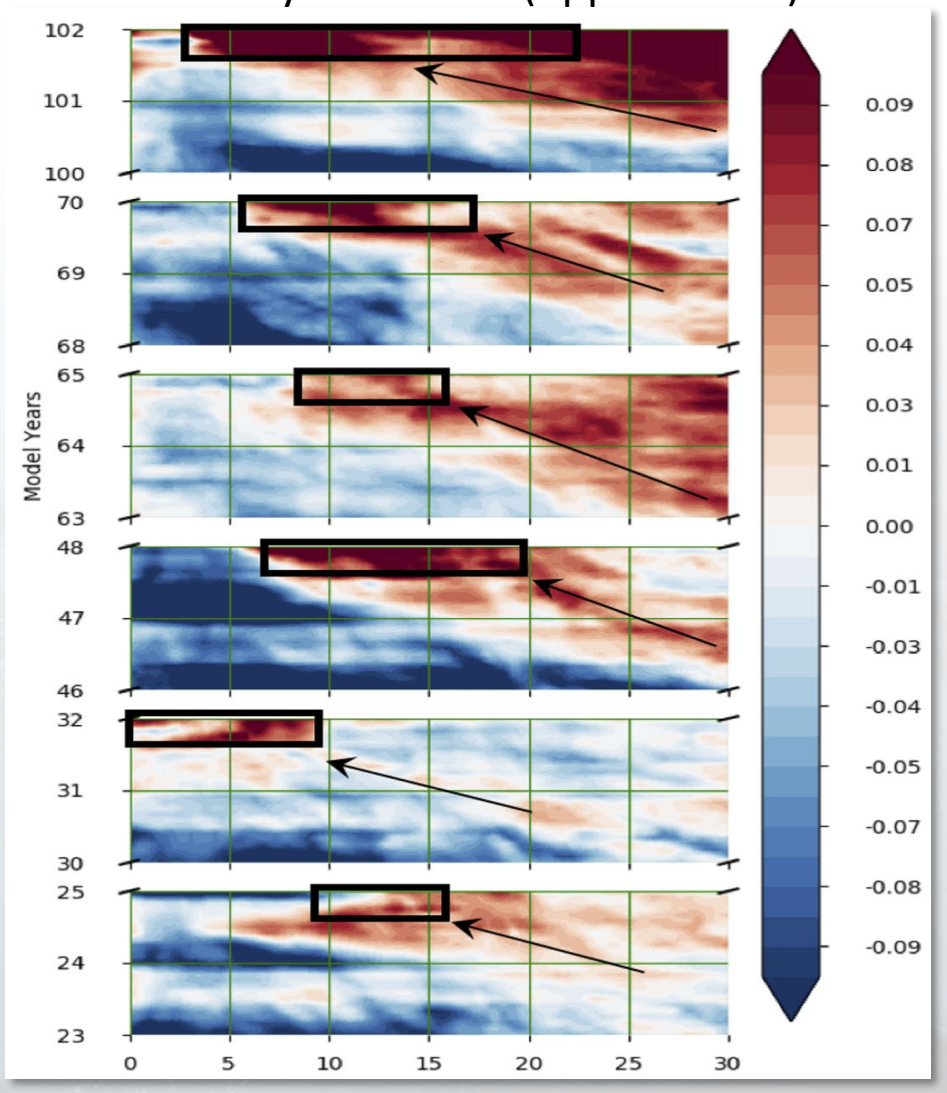
Kurtakoti et al. (2018)

- But not *sufficient* condition
- So what triggers Maud Rise polynyas?

Maud Rise Polynyas

- Initiation of MRPs in all cases associated with *arrival of positive salinity anomaly from the east*
  - Reason is still not clear

Salinity anomalies (upper 100 m)



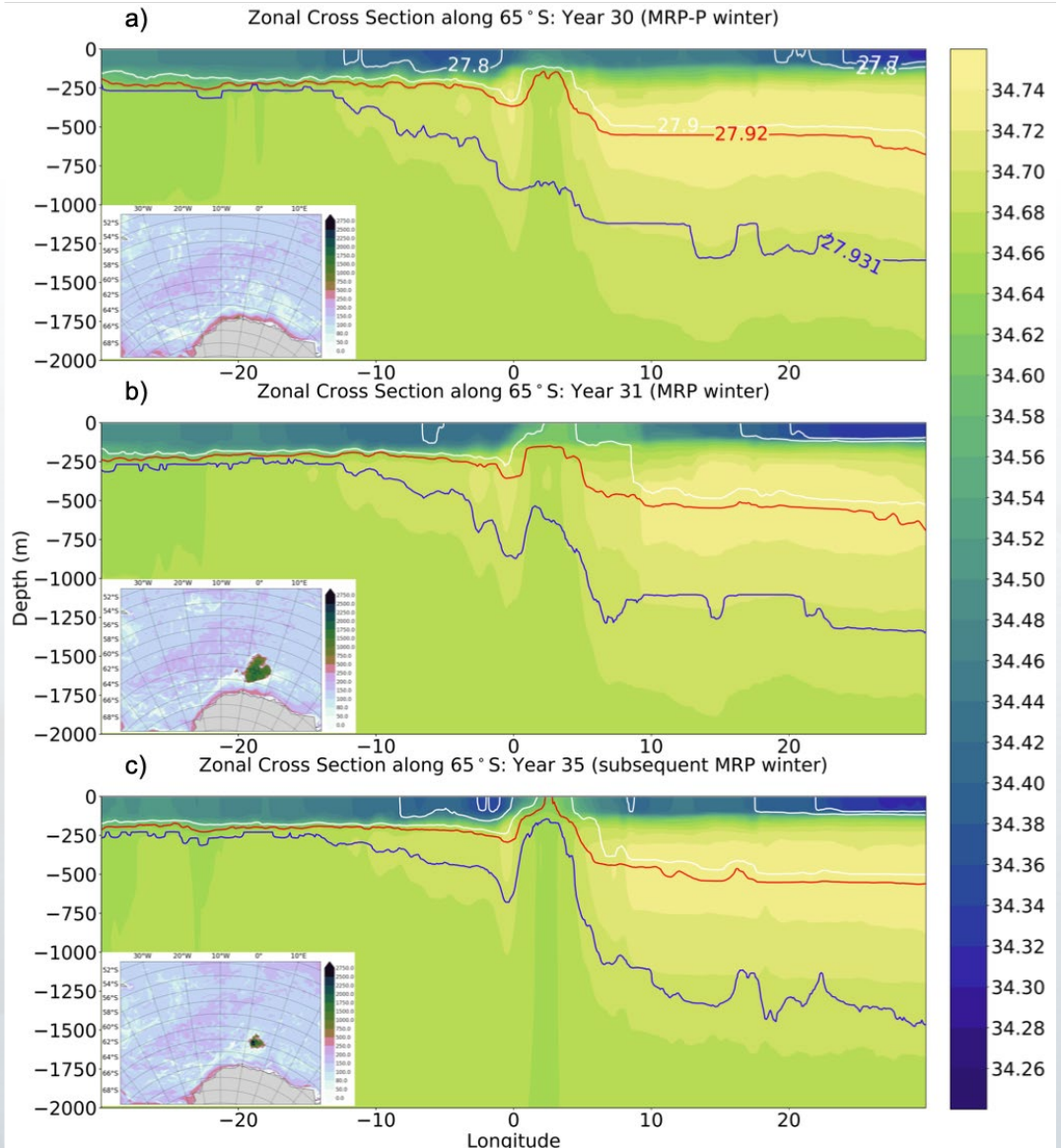
Kurtakoti et al. (2018)

Weddell Sea Polynyas

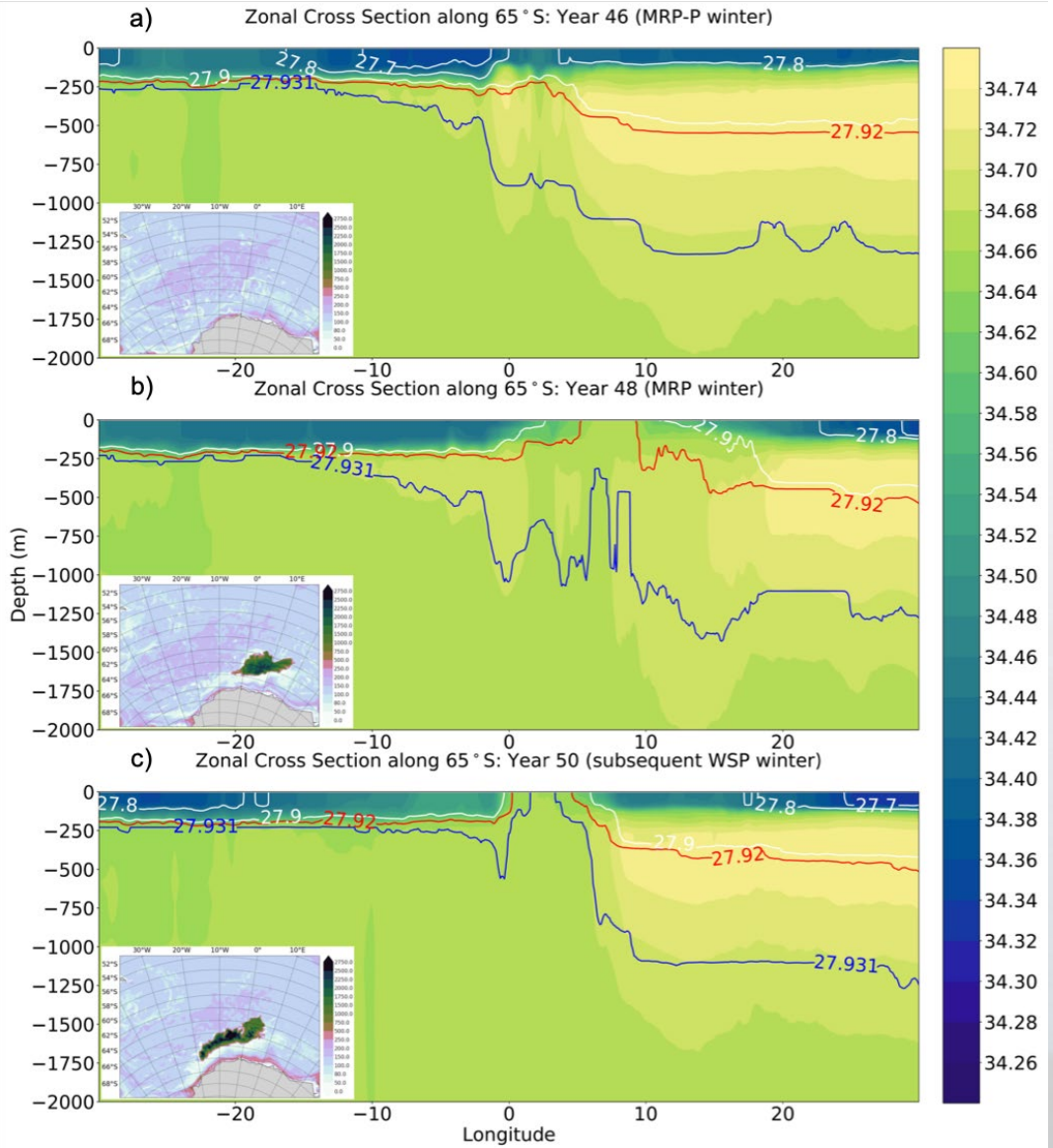
- Why do some Maud Rise polynyas develop into Weddell Sea polynyas (while others don't)?
  - Large Maud Rise Polynyas can create high surface salinity anomalies which flow westward to trigger Weddell Sea Polynyas

Weddell Sea Polynyas

"MRP" CASE

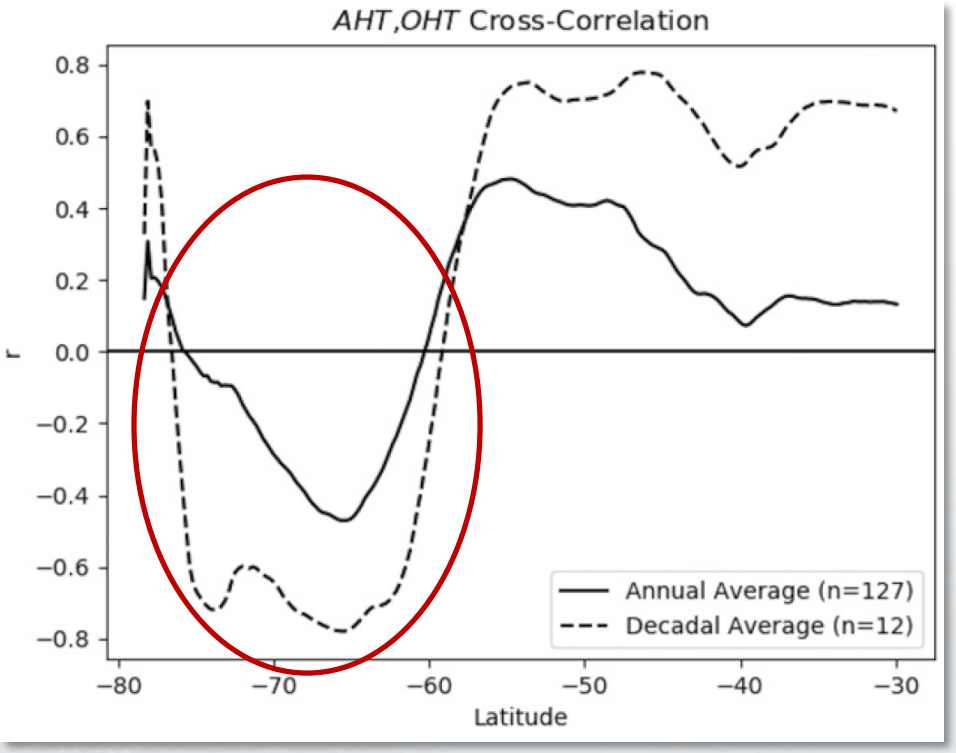


"MRP+WSP" CASE



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?

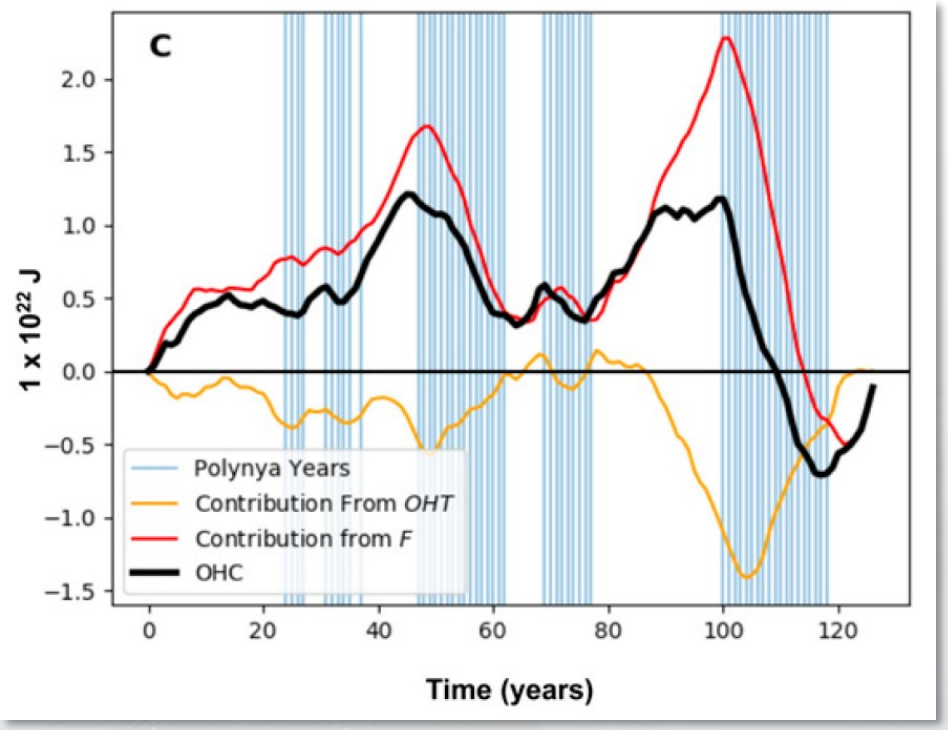


Kaufman et al. (2020)

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