Centennial variability: dynamics and global impacts

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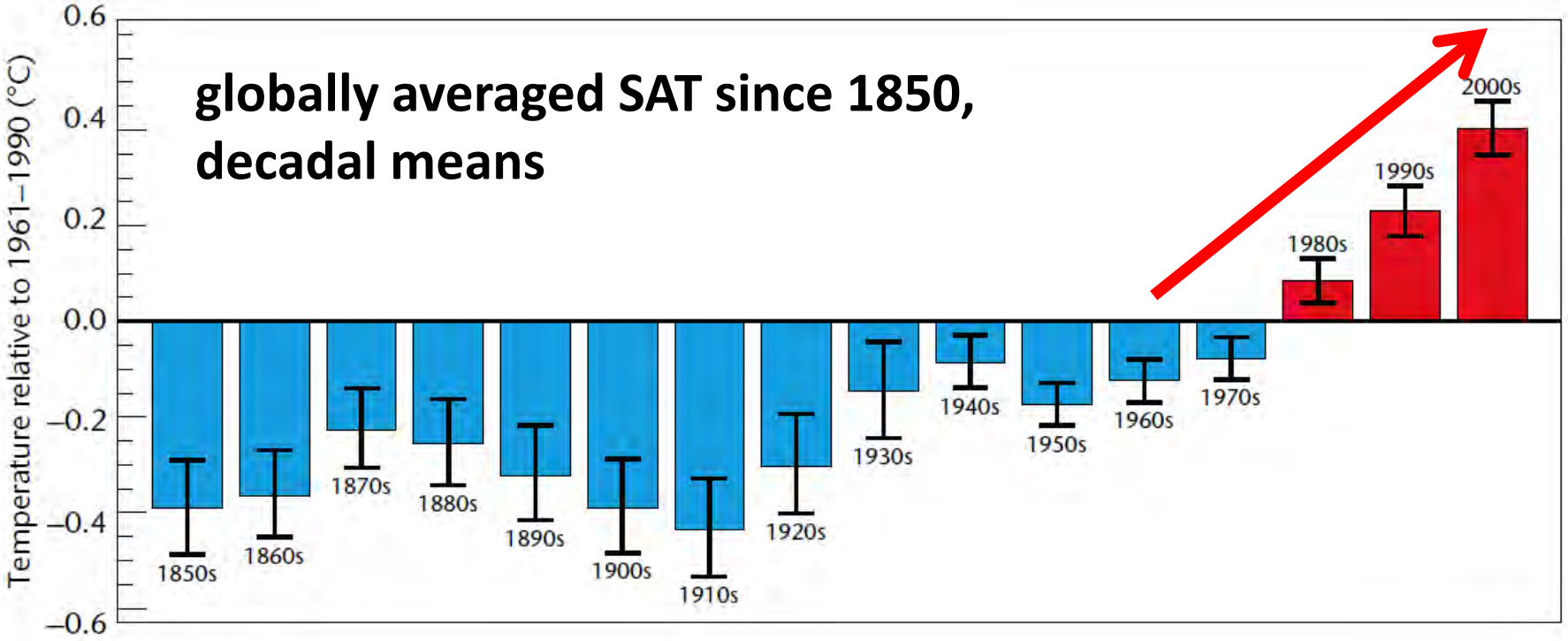
1. Southern Ocean Sector climate change during the recent decades
2. Ocean circulation and climate variability
3. Southern Ocean centennial variability in the Kiel Climate Model
4. Conclusions

Martin et al. (2012), Climate Dynamics (in revision)
Latif et al. (2012), Journal of Climate (in revision)

1. Southern Ocean Sector climate change during the recent decades



There was considerable global warming during the recent decades, but the Southern Ocean Sector behaved differently

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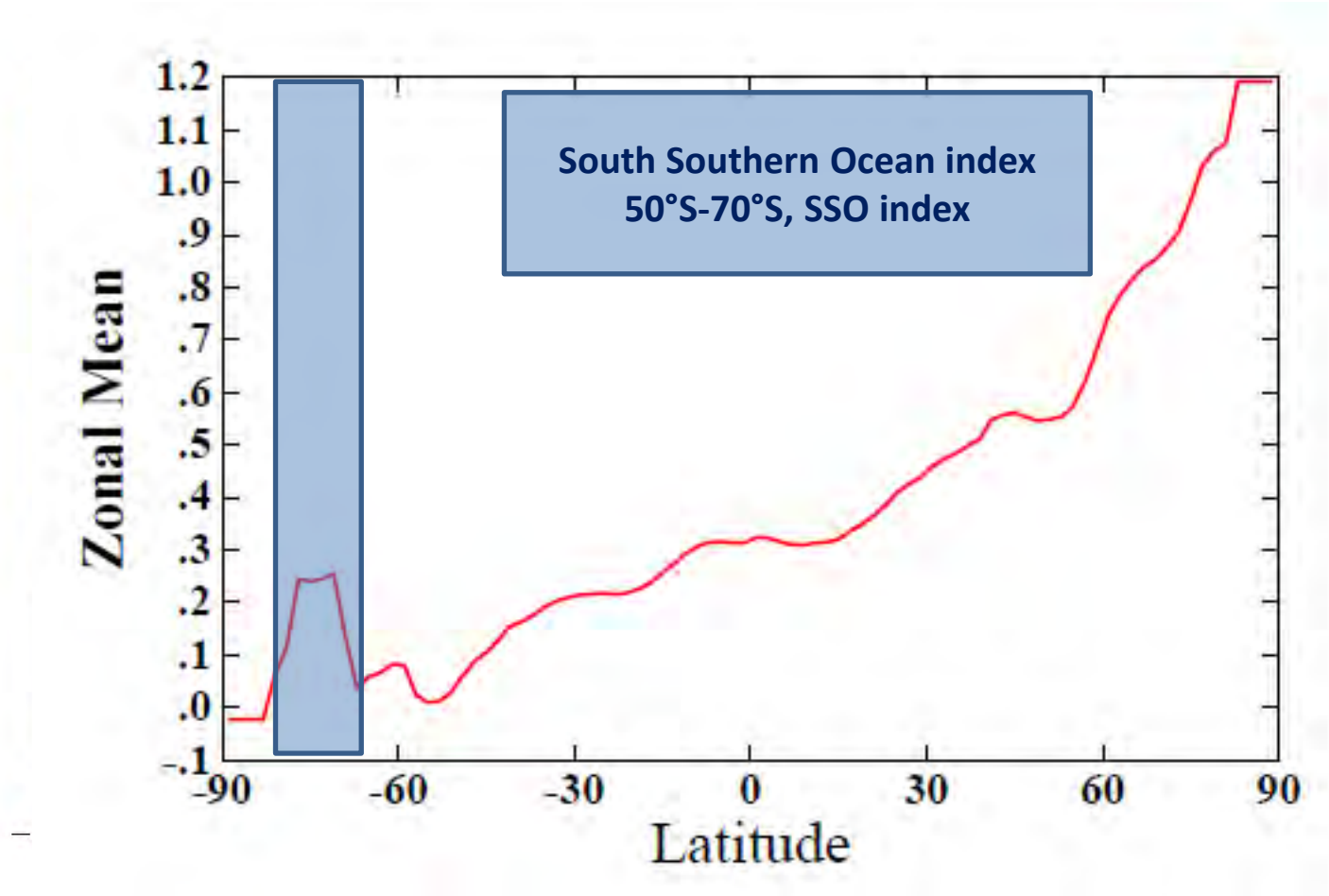
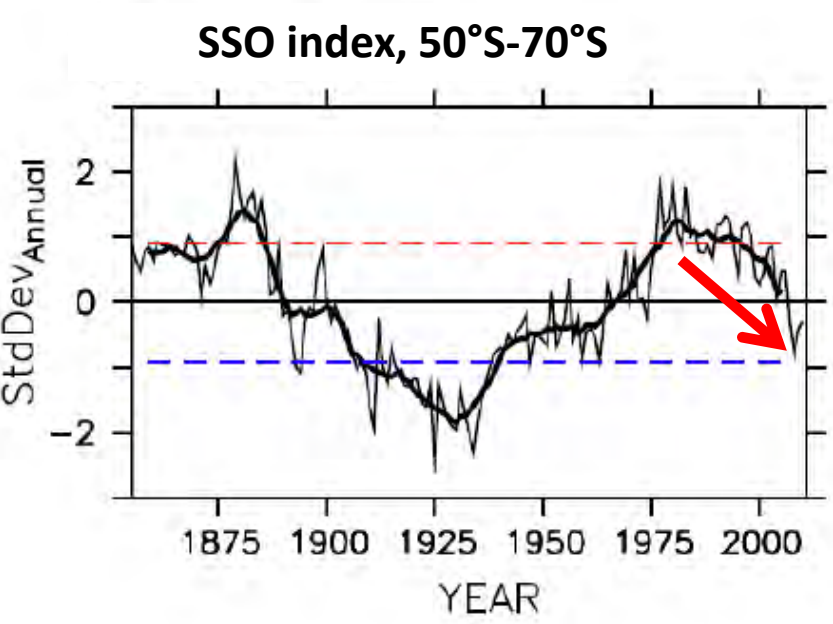
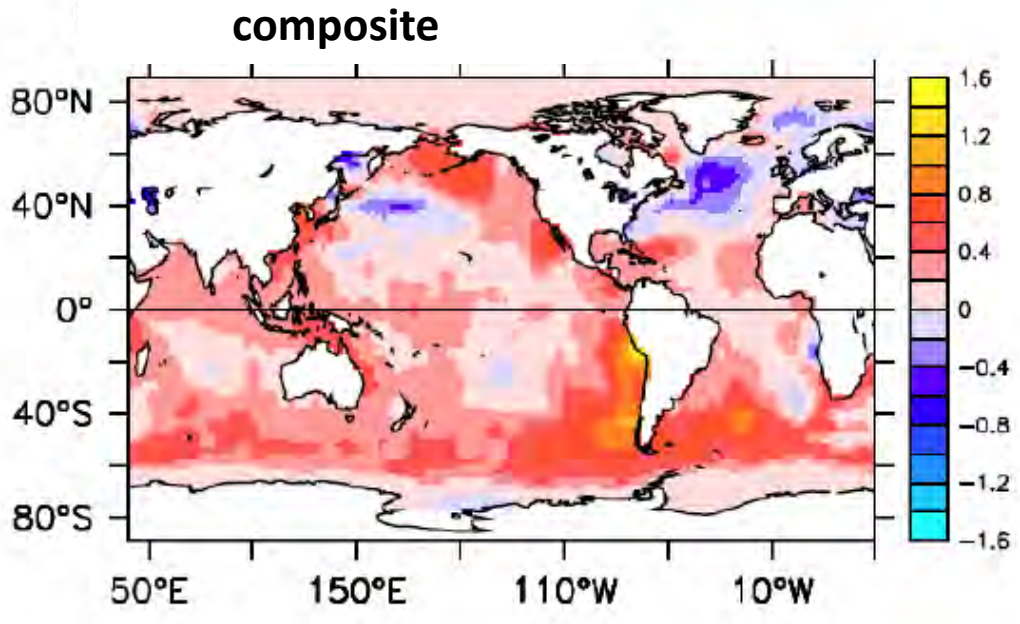
surface air temperature (SAT) 1991-2010 relative to 1971-1990



The Southern Ocean Sector did not warm much, although the global average SAT warmed by almost 0.5°C

instead, the Southern Ocean SST (50°S-70°S) depicted pronounced centennial variability





The hypothesis: some of the recent decadal trends can be understood as part of an internal centennial cycle

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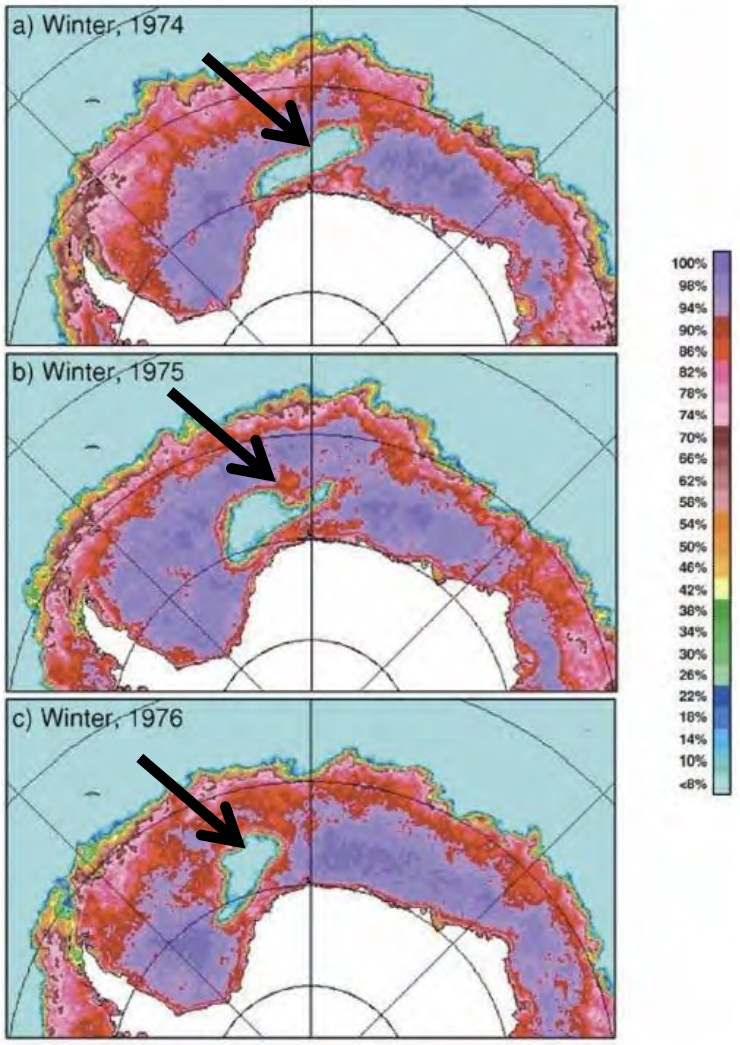
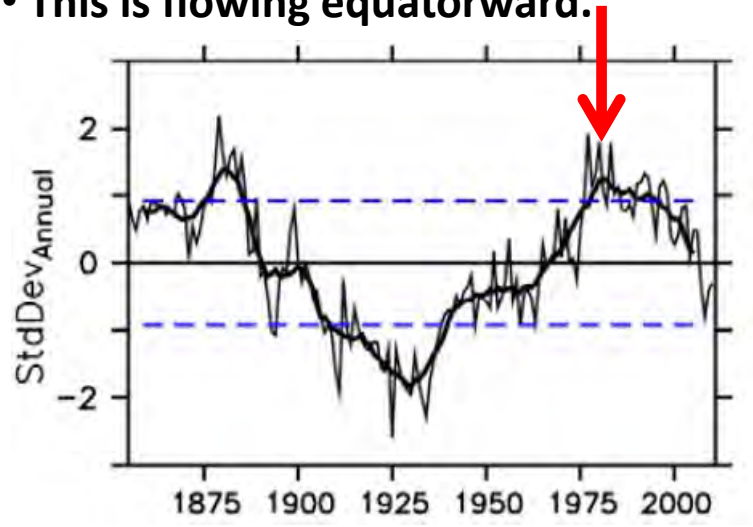
the mid-1970s Weddell Polynya occurred at the height of the warm phase



- Very large area (350,000 km^2) of open water within the ice-covered Weddell Sea.
- There was vigorous air-sea interaction.
- This resulted in deep convection and the formation of vast amounts of cold and very dense Antarctic Bottom Water.
- This is flowing equatorward.



the Weddell Polynya may not re-appear for decades

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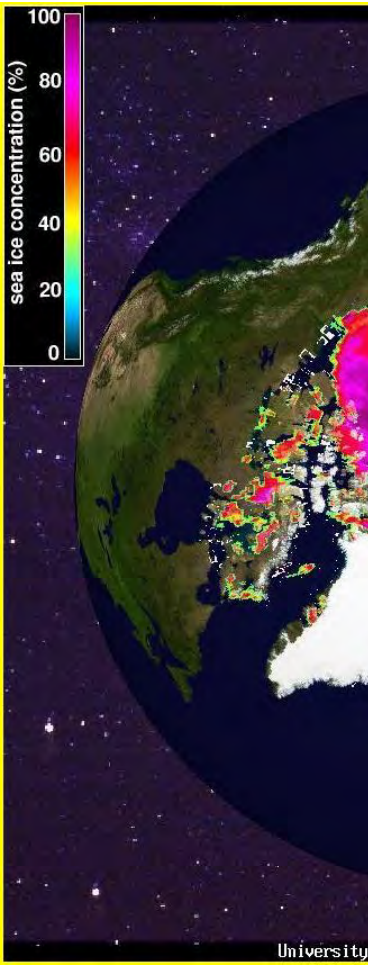
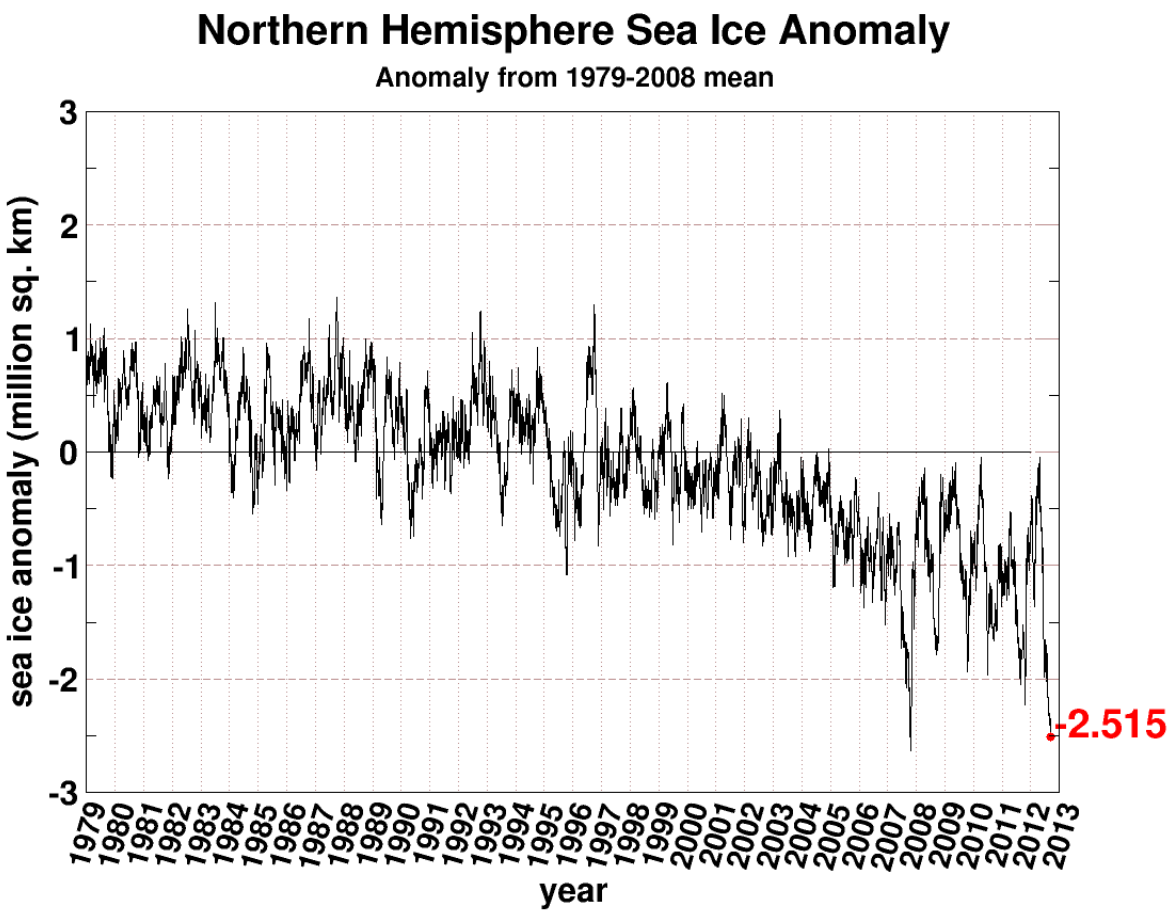
the Arctic sea ice extent is featuring a record decline





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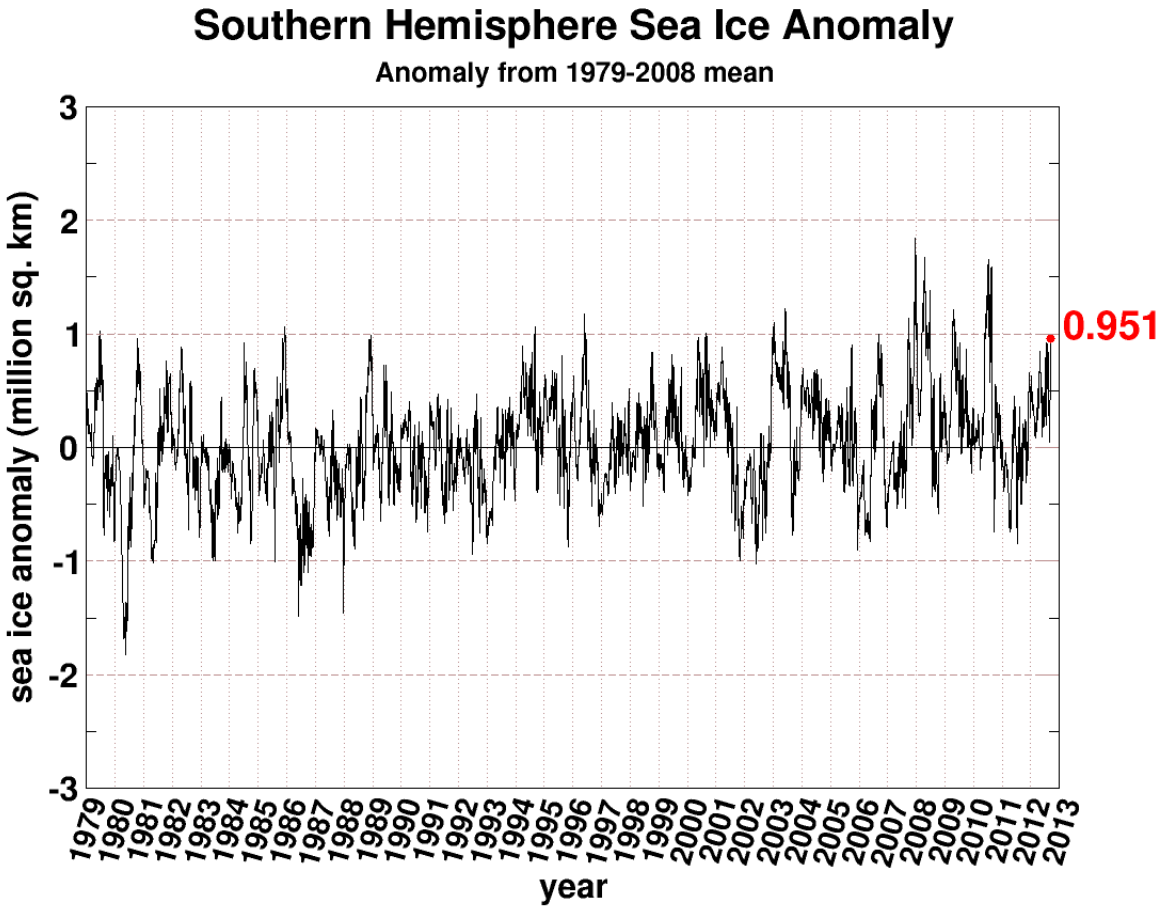
Southern Hemisphere sea ice did not retreat during the last decades



…instead it slowly increased

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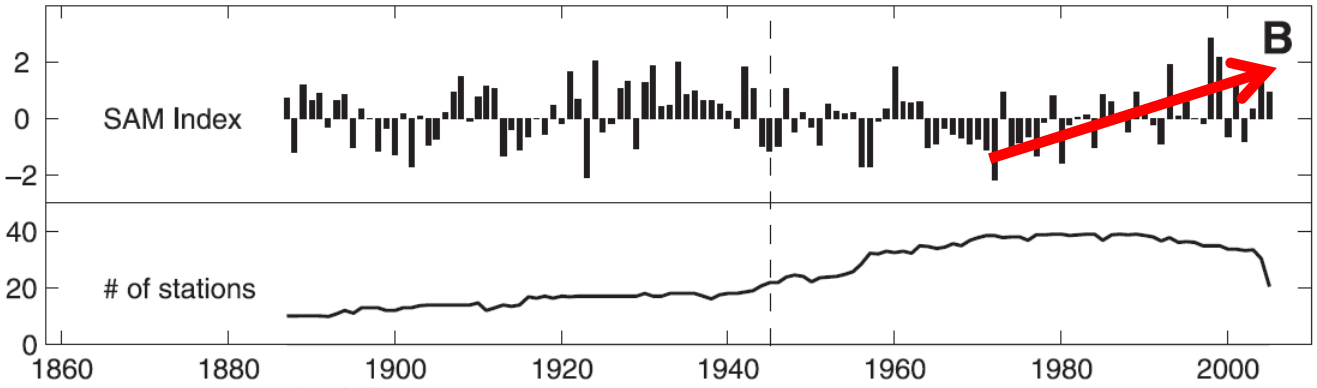
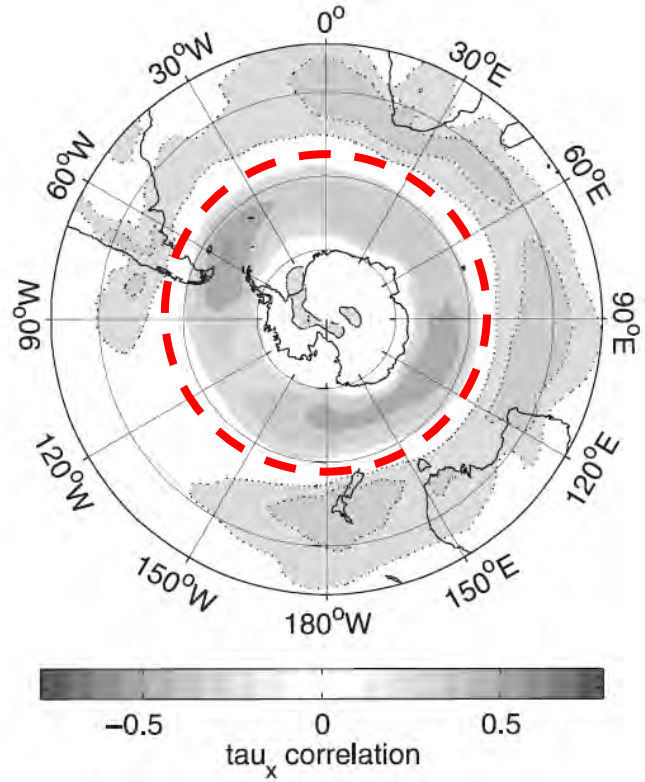
Southern Annular Mode (SAM), Index after Visbeck (2009)





Stronger westerlies were observed over the Southern Ocean during the recent decades

deep Southern Ocean warming since the 1990s

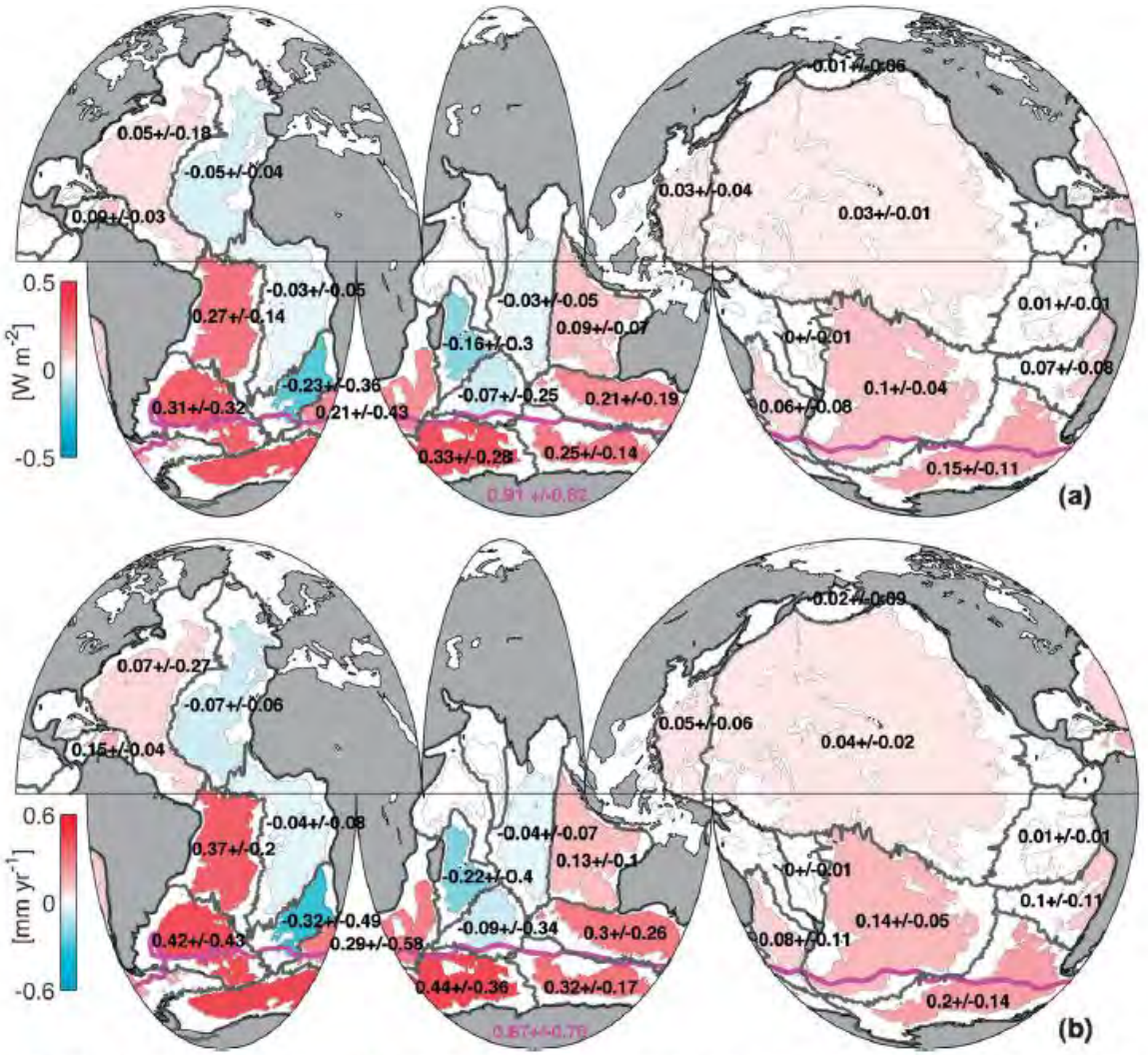


FIG. 8. (a) Mean local heat fluxes through 4000 m implied by abyssal warming below 4000 m from the 1990s to the 2000s within each of the 24 sampled basins (black numbers and color bar) with 95% confidence intervals. The local contribution to the heat flux through 1000 m south of the SAF (magenta line) implied by deep Southern Ocean warming from 1000 to 4000 m is also given (magenta number) with its 95% confidence interval. (b) Similarly, basin means of sea level rise from the 1990s to the 2000s due to abyssal thermal expansion below 4000 m and deep thermal expansion in the Southern Ocean from 1000 to 4000 m south of the SAF. Basin boundaries (thick gray lines) and 4000-m isobath (thin black lines) are also shown.

heat flux through 4000m implied by warming below 4000m

sea level rise due to thermal expansion below 4000m

Purkey and Johnson 2010

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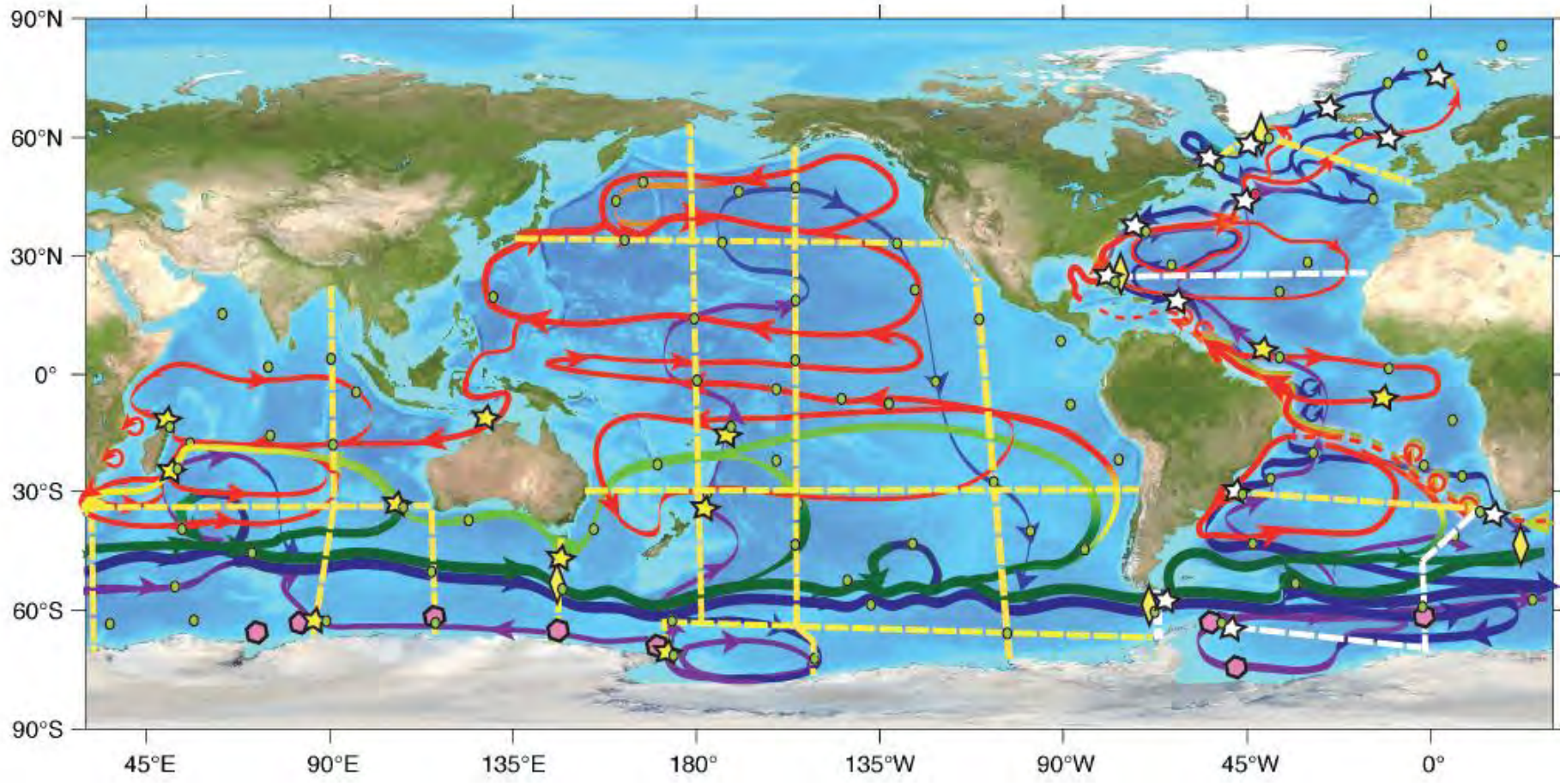
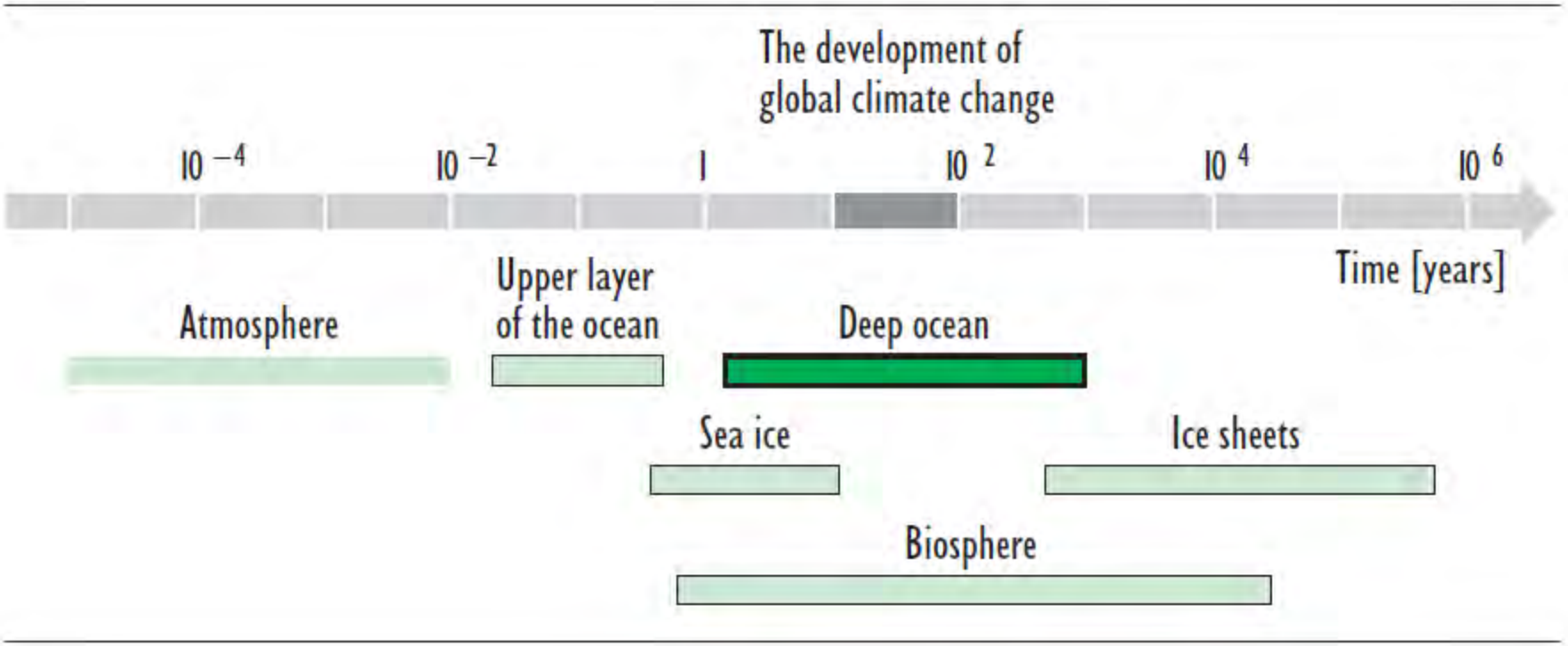
2. Ocean circulation and climate variability



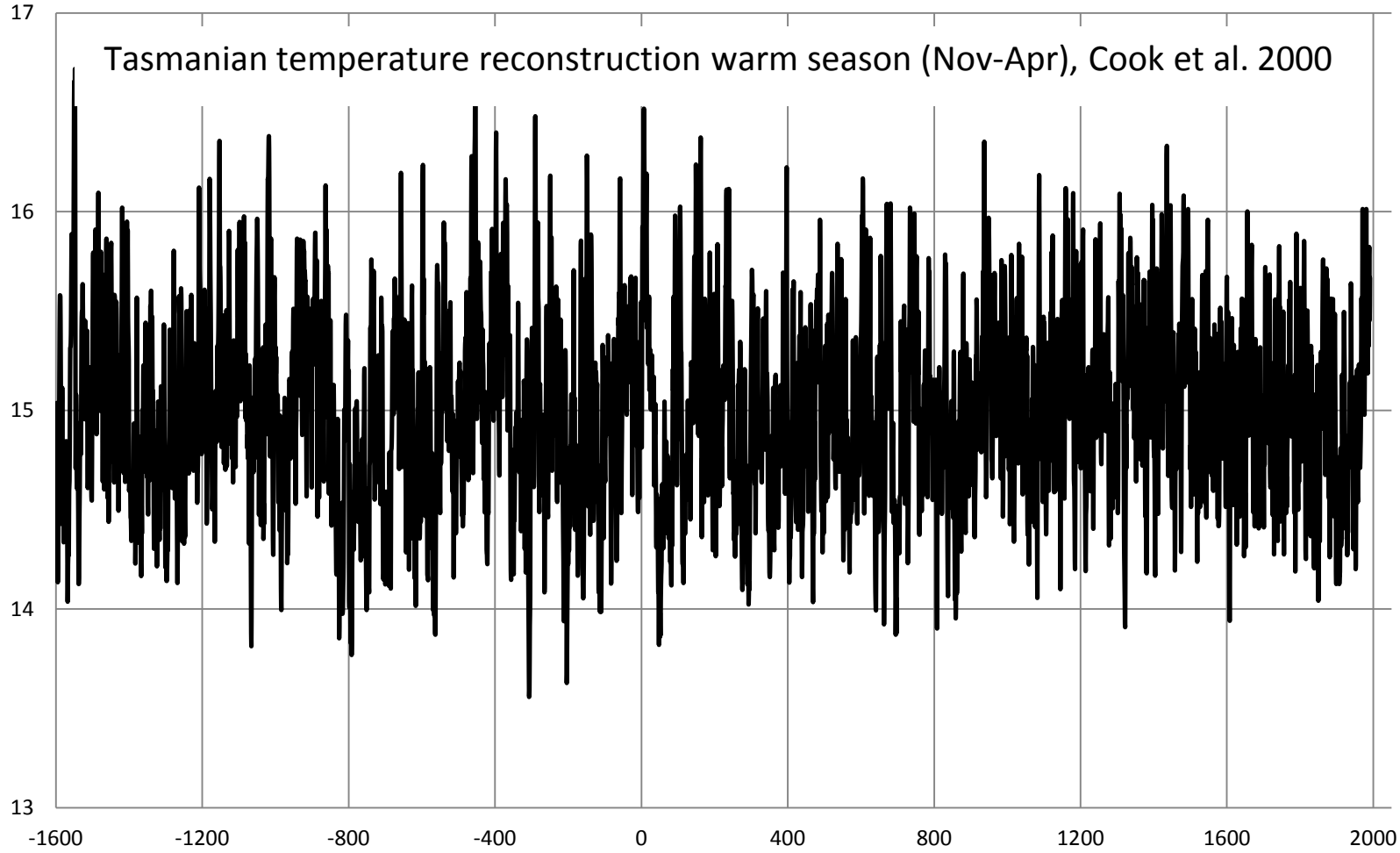
Rintoul et al. 2010

The deep ocean plays an important role in decadal to centennial variability



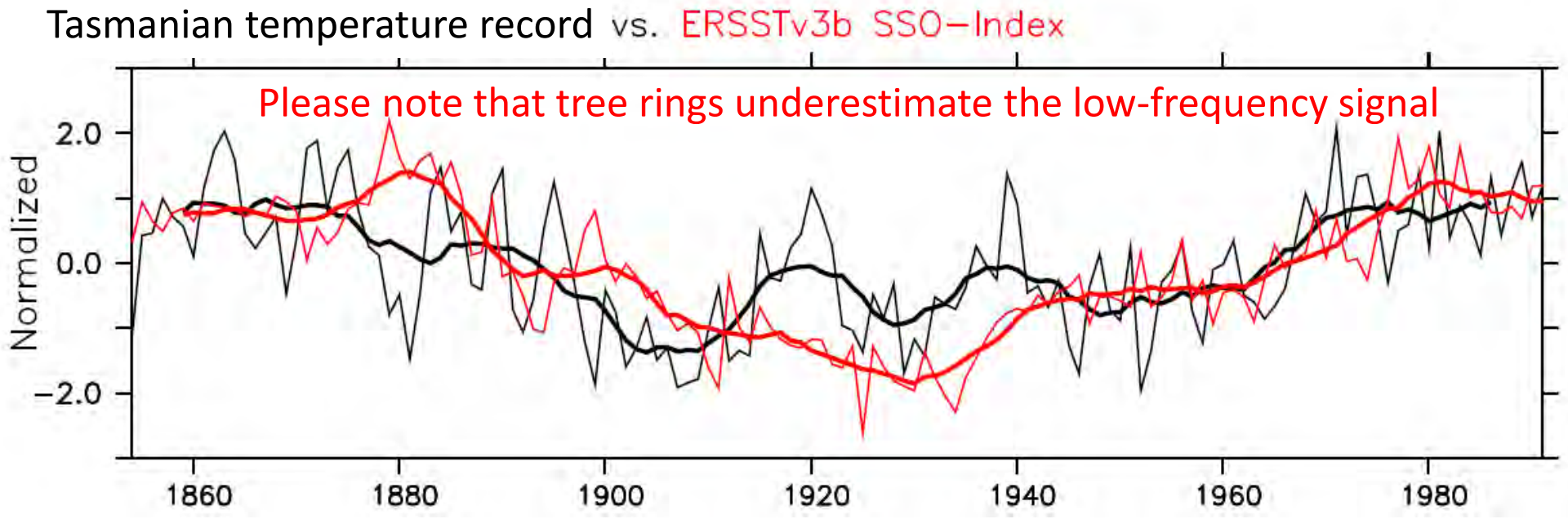
Latif 2009

Tasmanian summer temperature tree ring reconstruction of the last 3,600 years



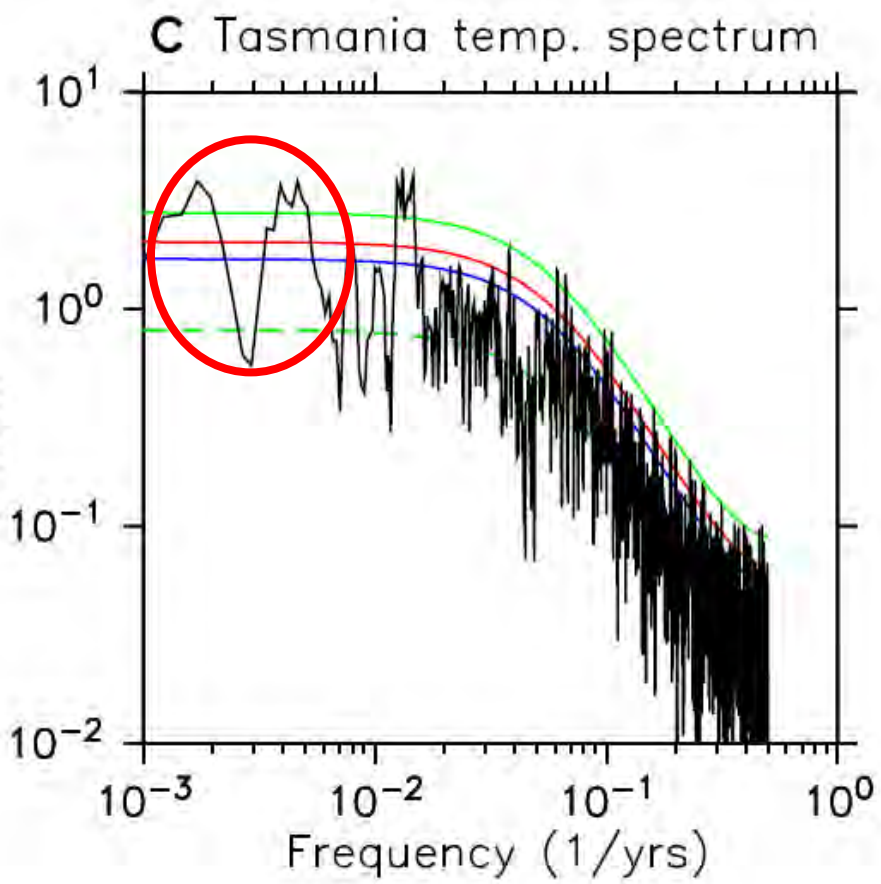
Centennial variability is clearly visible. The correlation with the SSO index amounts to about 0.7 (21-yr running means) in the model

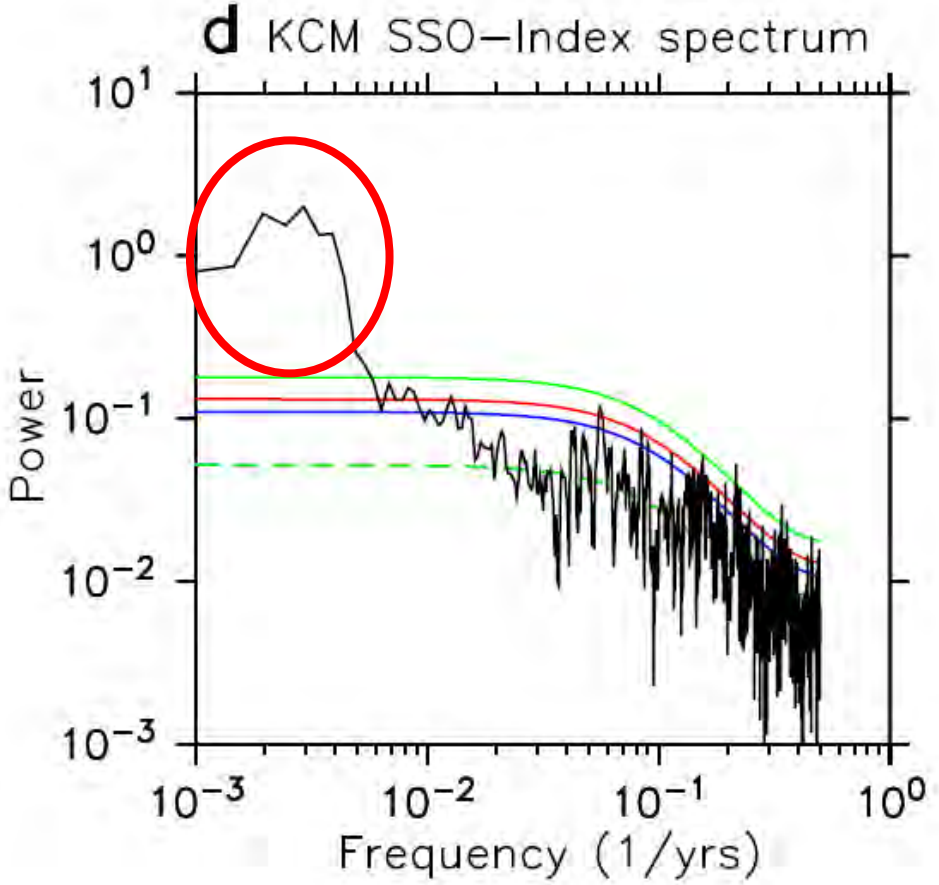
Tasmanian summer temperature from tree rings and the instrumental SSO index



There are many discrepancies, but the centennial signal is somehow captured

Spectrum of Tasmanian tree ring temperature and spectrum of the model SSO index





Enhanced variability at centennial timescales in both the tree ring-derived temperatures and the model

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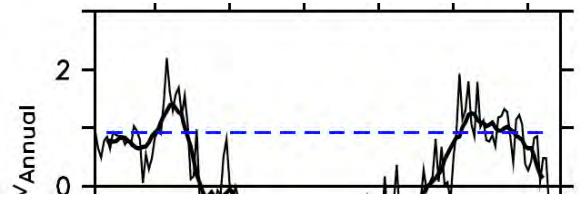
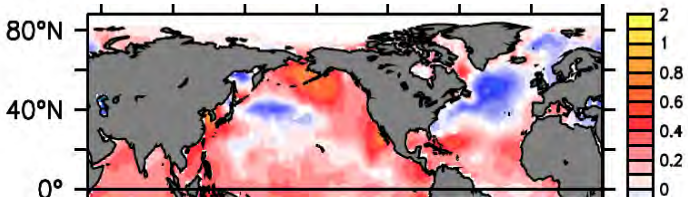
3. Southern Ocean centennial variability in the Kiel Climate Model (KCM)

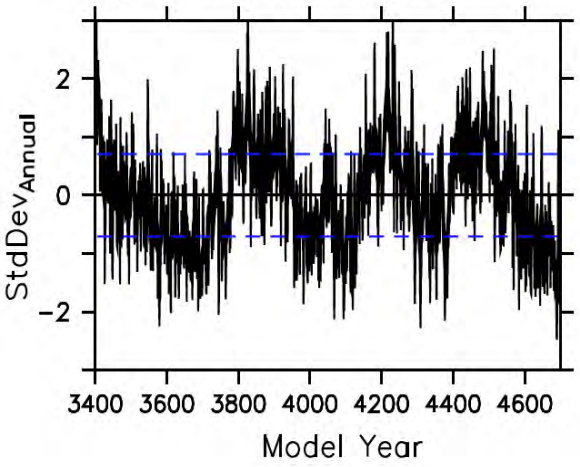
SSO index, 50°S-70°S, obs.

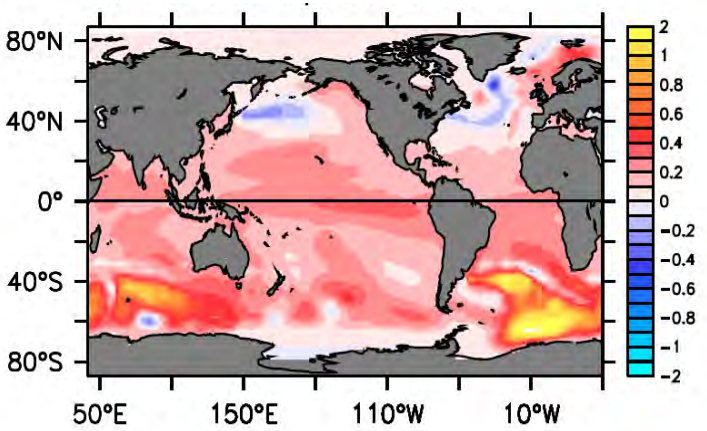


SST composite, obs.



Please note that you can't say anything about the periodicity from the instrumental record. Further, one mode can never explain the full variability





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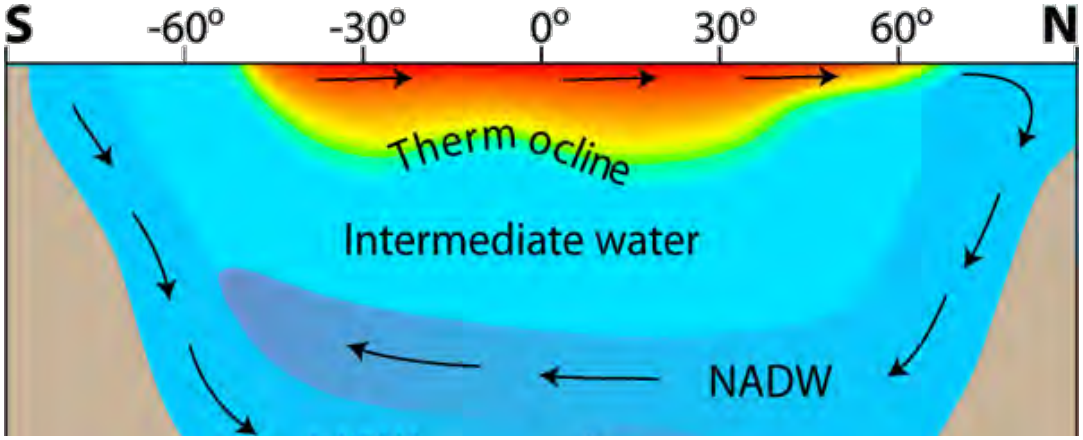
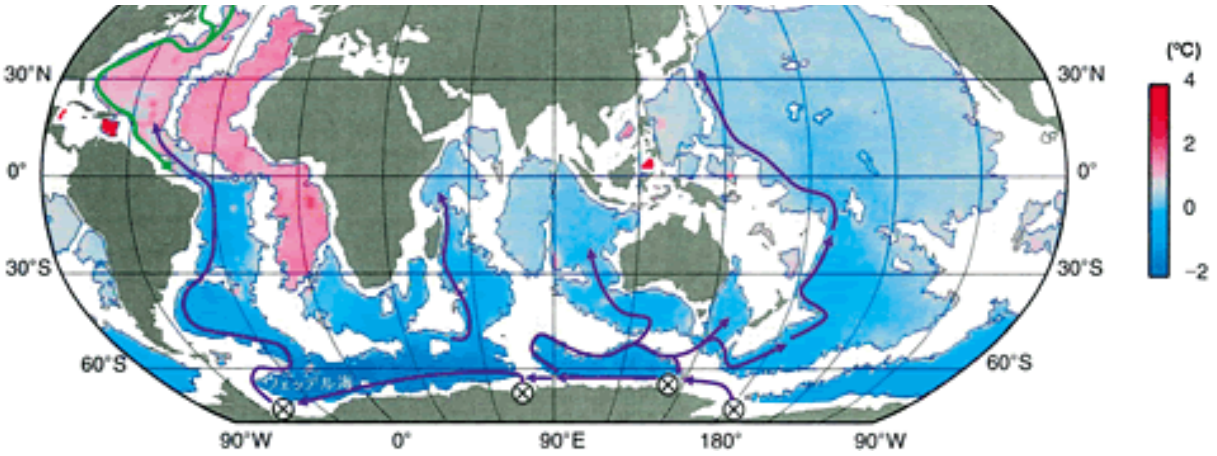
The mechanism of centennial variability in the Kiel Climate Model (KCM)



The North Atlantic Deep Water (NADW) plays a crucial role in the mechanism



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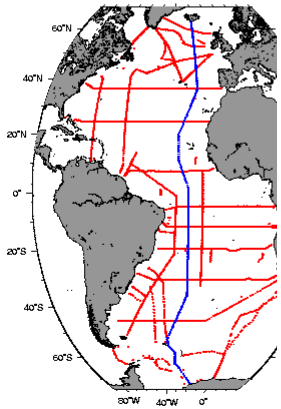
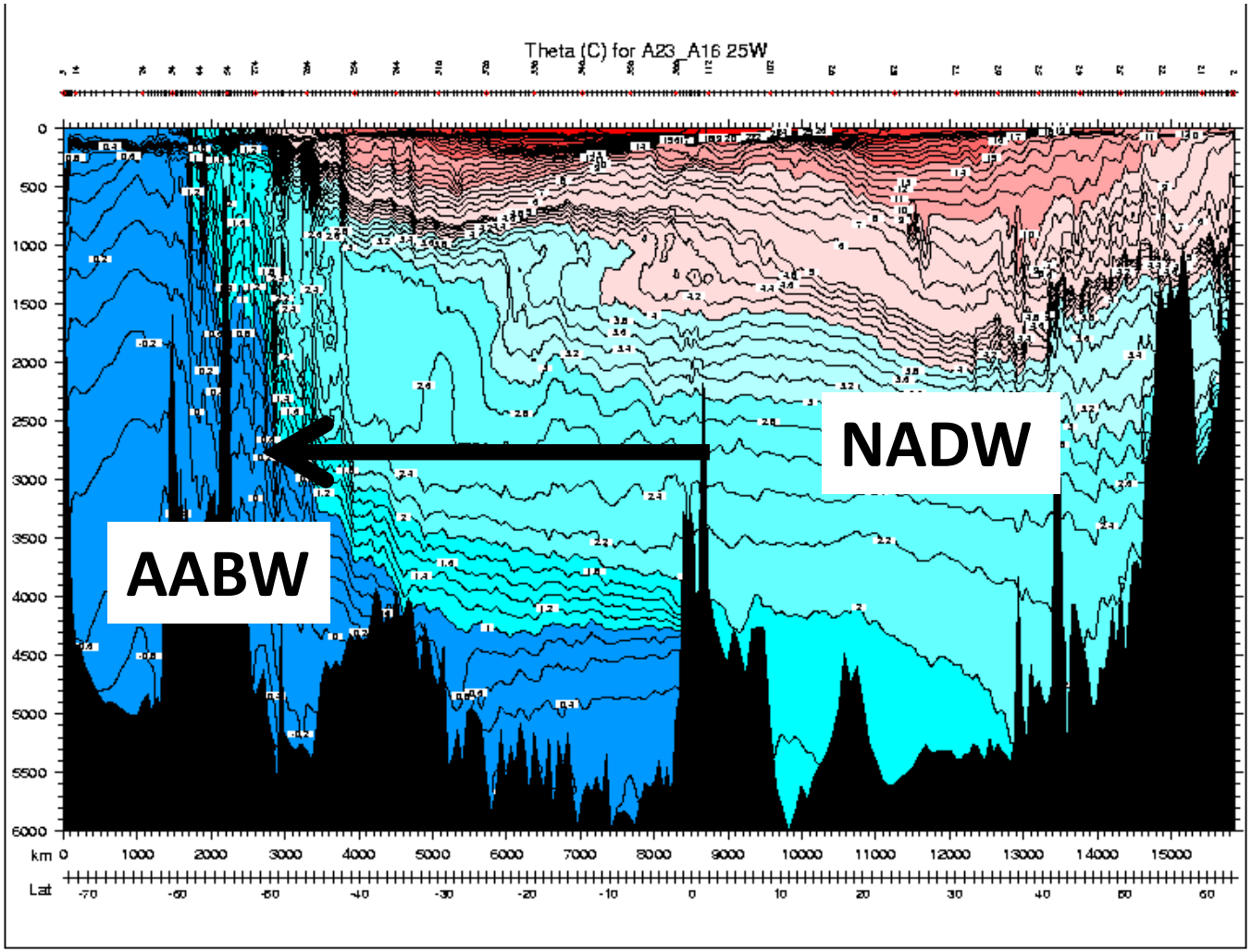
Potential temperature in the Atlantic (WOCE)





NADW (warm water) accumulation in the Southern Ocean by the lower limb of the AMOC

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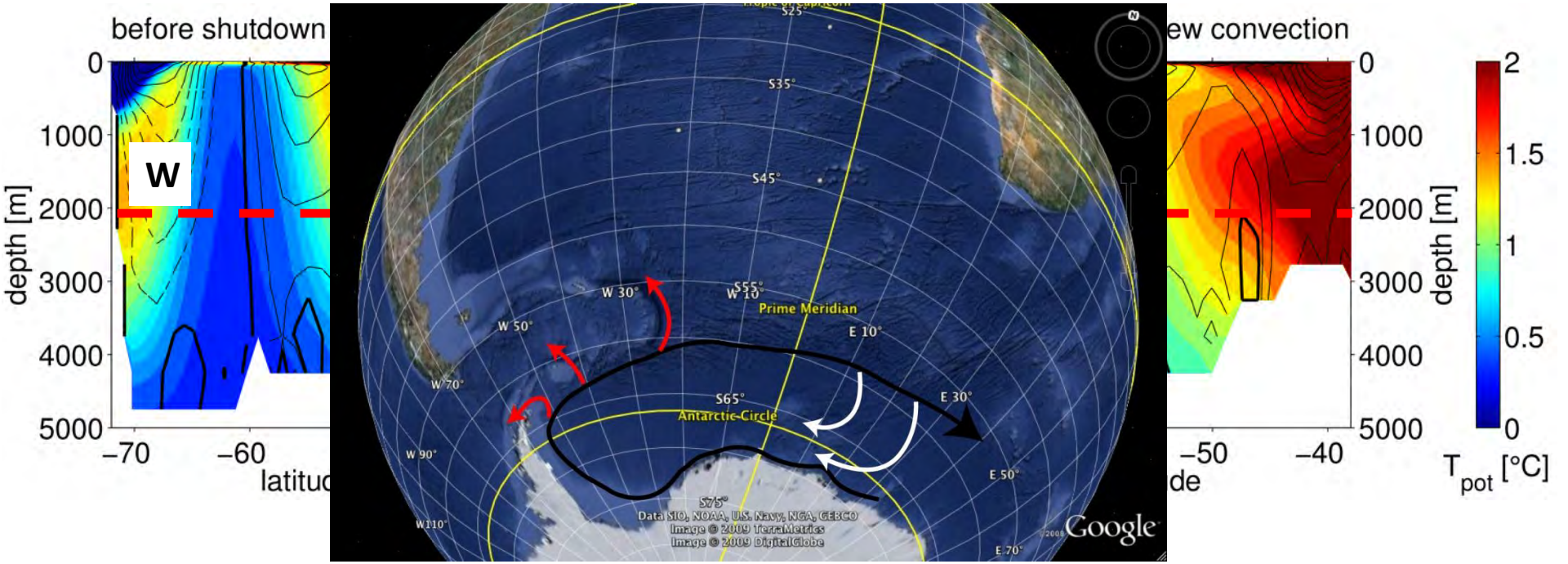
The Weddell Gyre plays an important role in the heat accumulation



the Weddell Gyre persists at mid-depth during both convective regimes (on, off) , enabling the heat accumulation in the Weddell Sea

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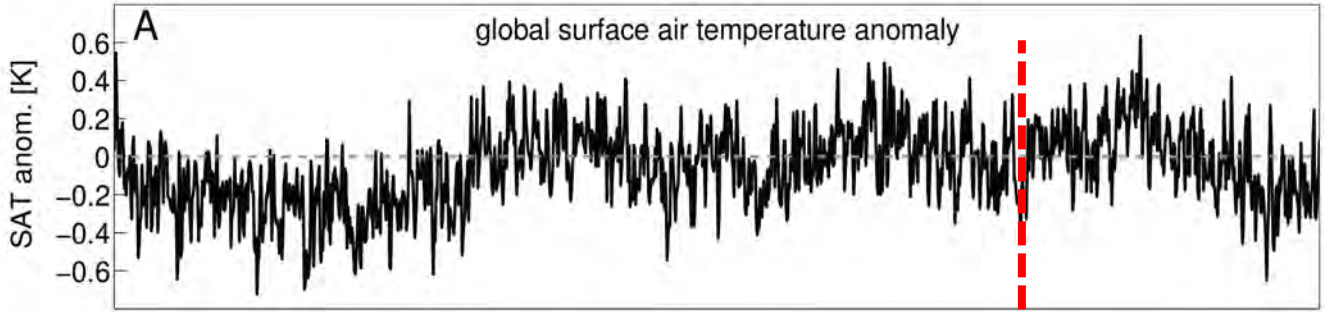
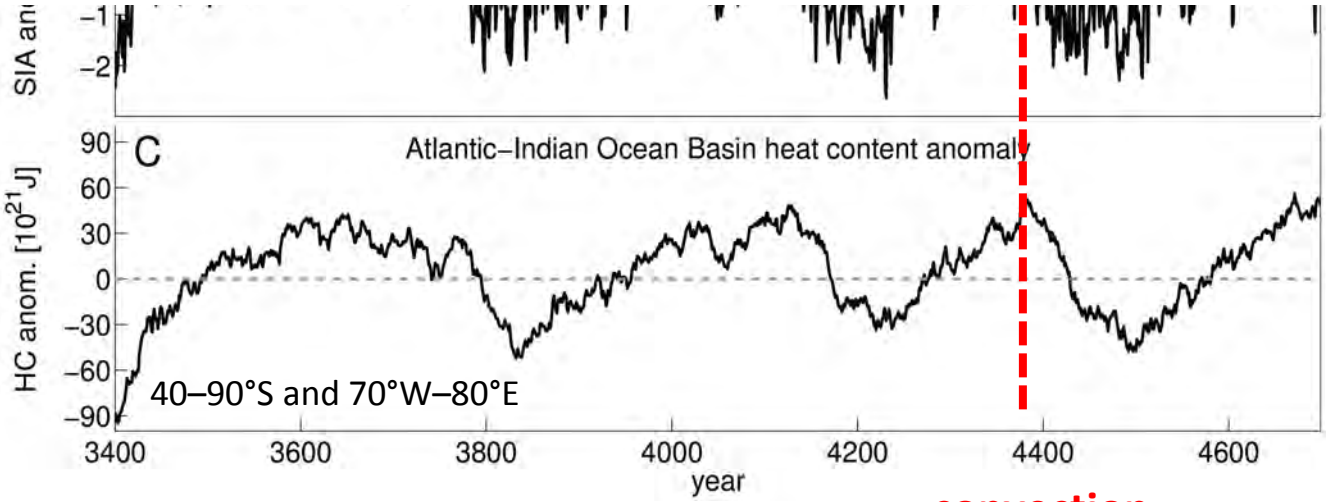
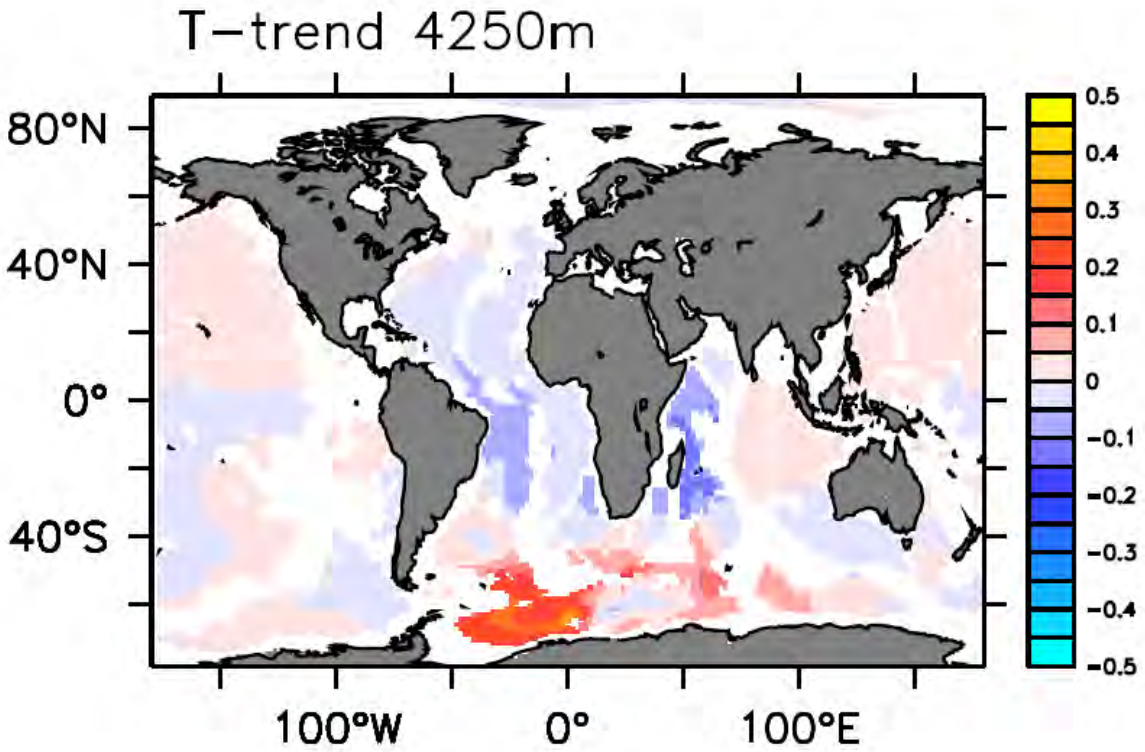
Heat accumulation at mid-depth in the Southern Ocean's Atlantic-Indian Ocean basin



Convection sets in after "enough" heat is accumulated, destabilizing the water column from below



Change in Southern Ocean temperature after convection halt



the subsurface Southern Ocean considerably warms after convection shutdown, consistent with the changes during the last decades

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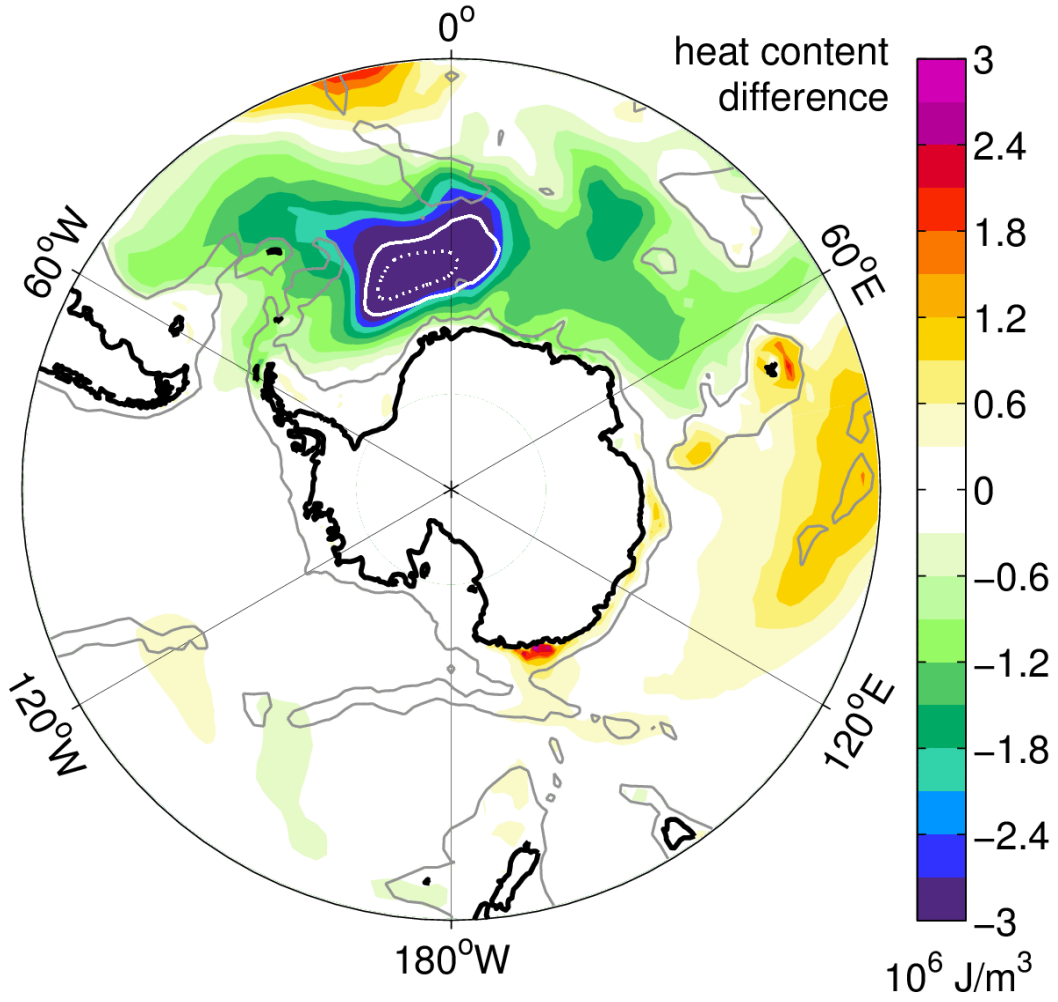
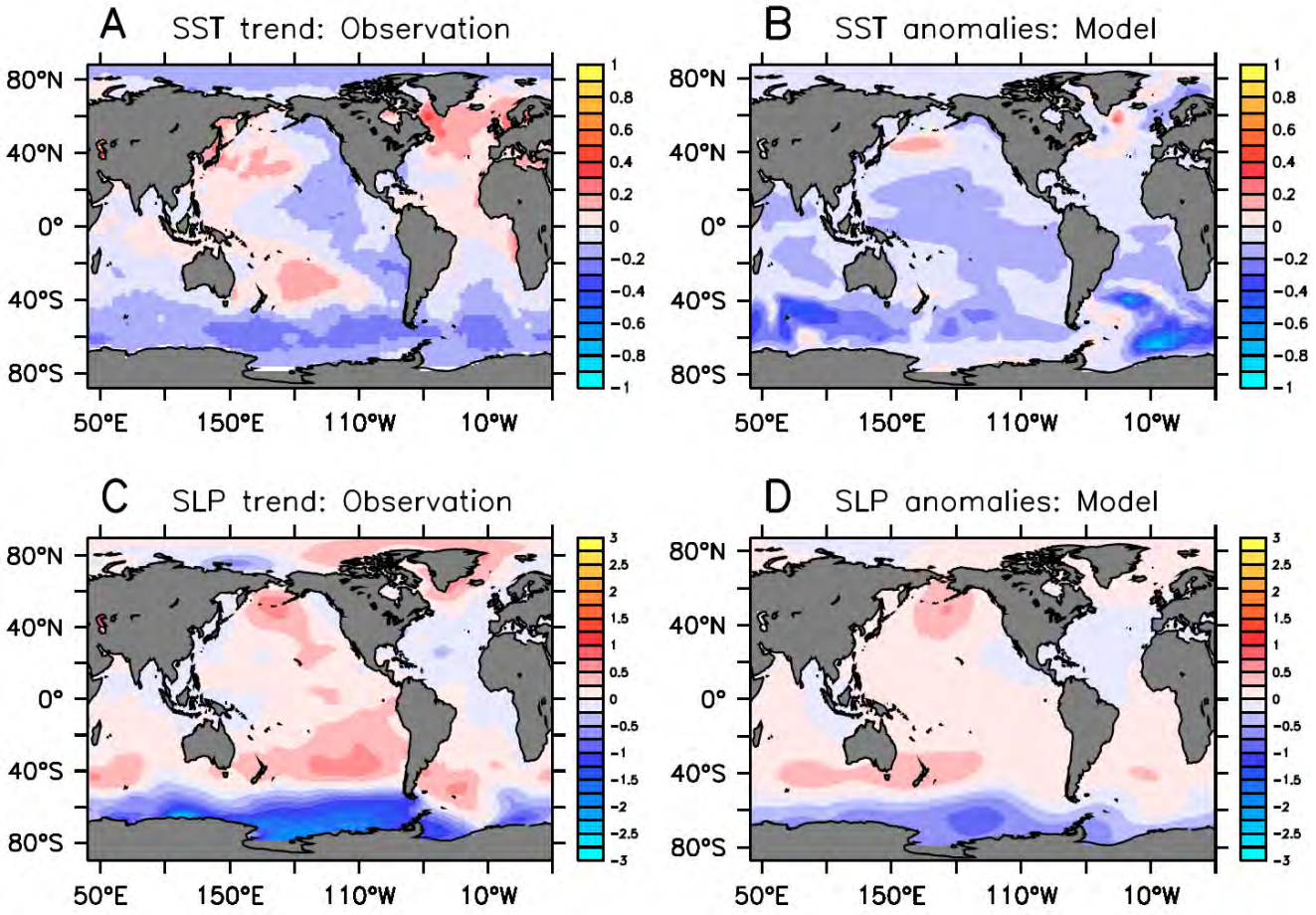
Heat content difference due to convection



Observed SST and SLP trends* 1975-2010 and model trends after convection halt



There is some similarity between KCM and the observations

*global mean trends have been removed

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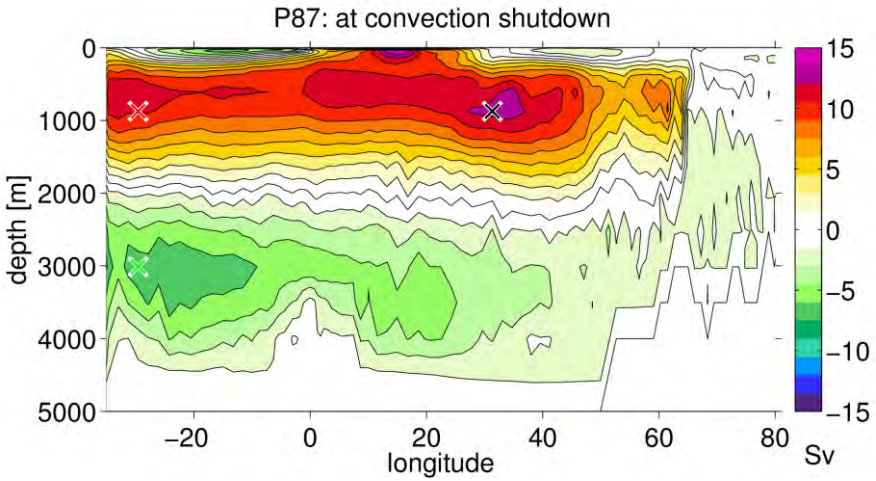
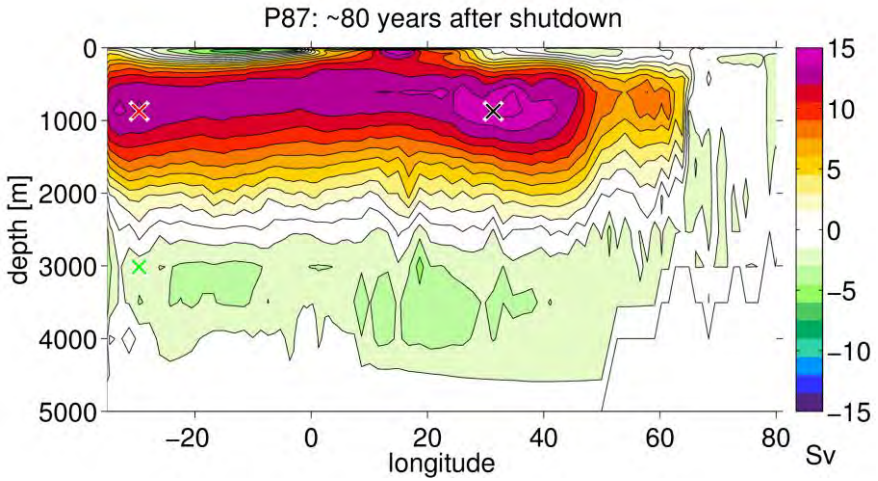
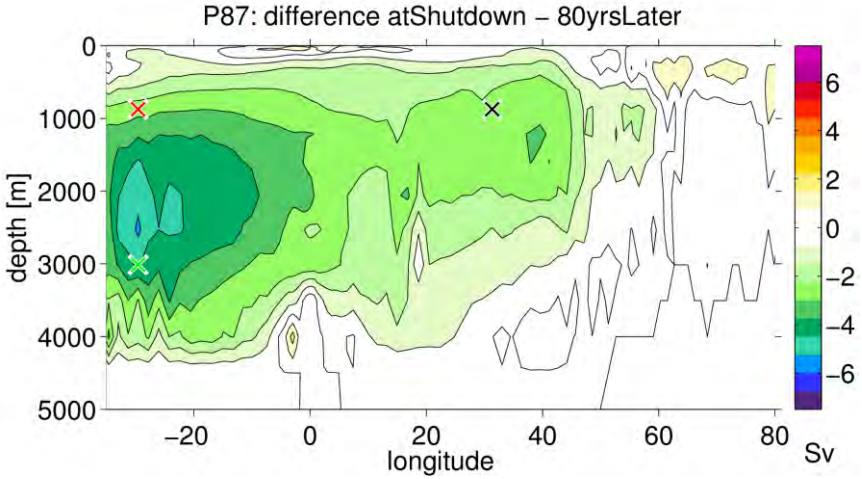
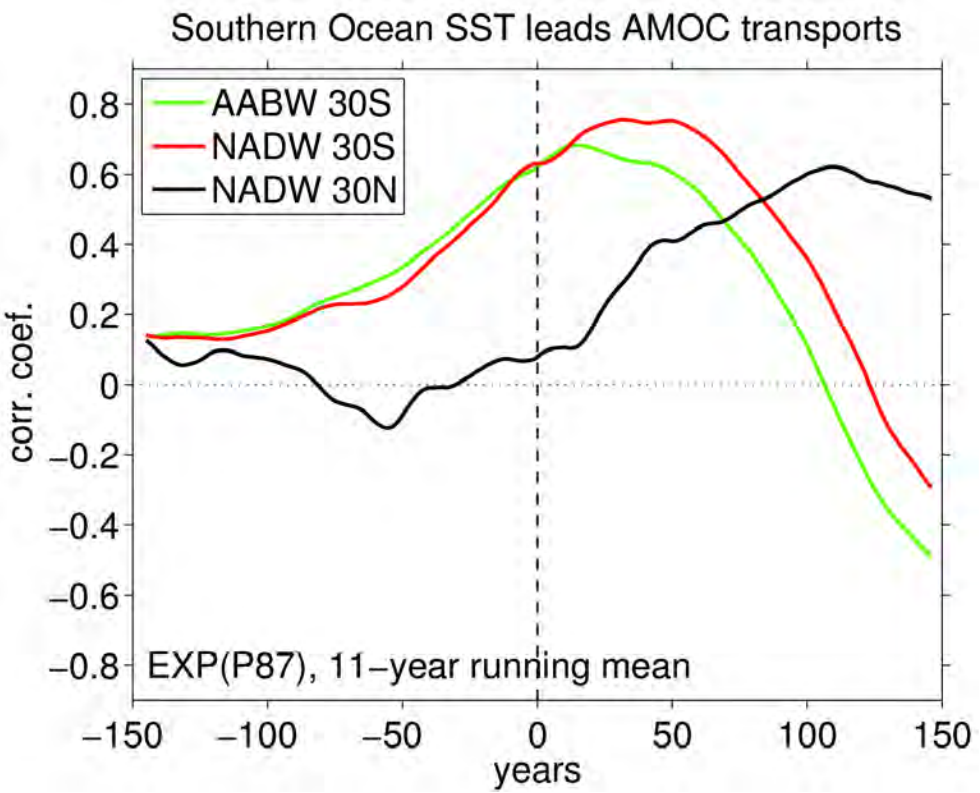
Stronger AMOC 80 years after convection shutdown in the Weddell Sea







AMOC follows Weddell Sea SST at convection site



the AMOC strength lags by several decades

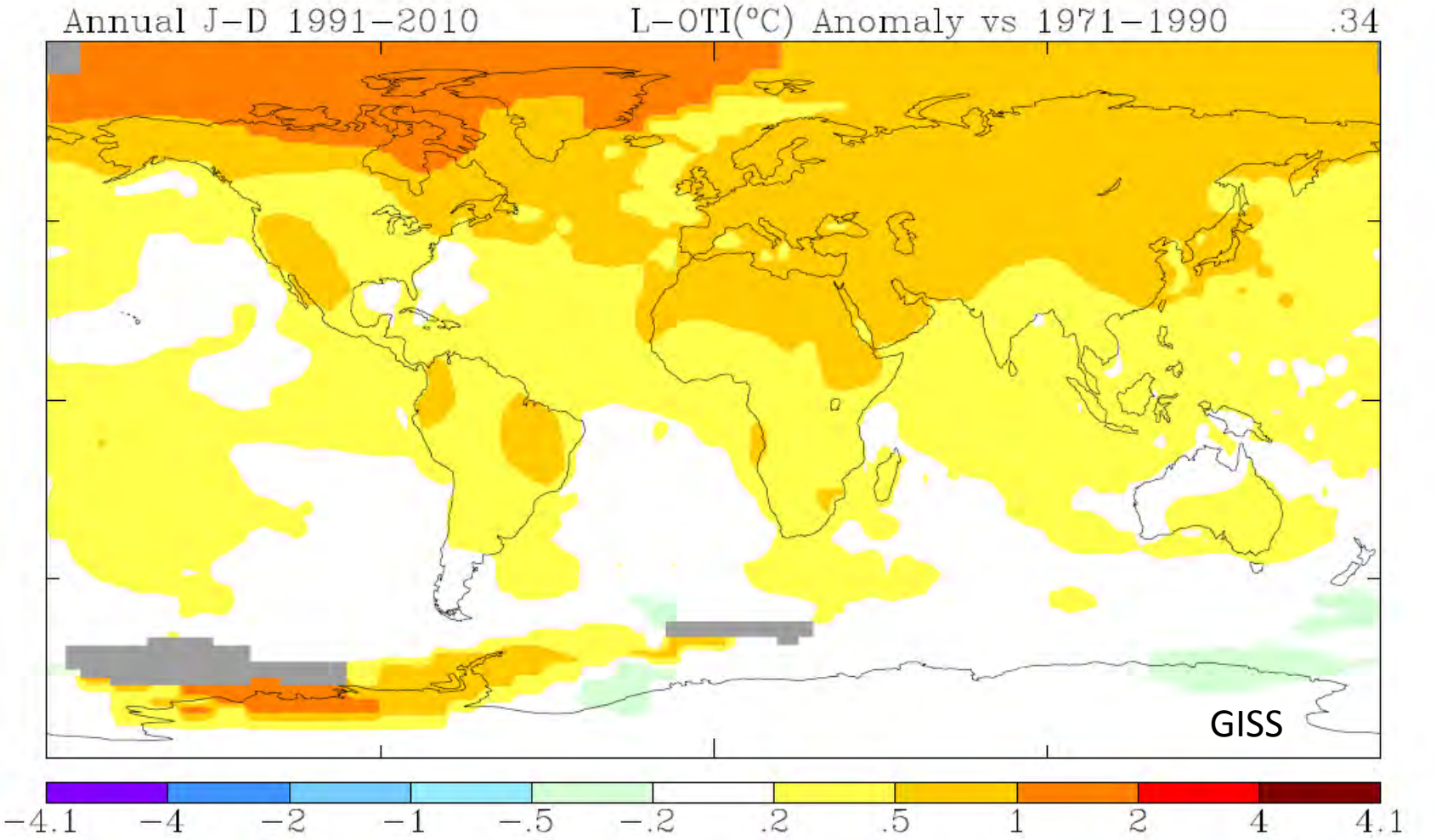
4. Conclusions

• Instrumental SST, tree ring data, and the KCM support the existence of a centennial mode in the Southern Ocean Sector
• The recent decades may have seen a phase reversal, from the positive to the negative phase of the centennial mode

Caution: climate models can only simulate gross features of and cannot simulate in detail the observations

• The AMOC responds to the changes in the Southern Ocean
• If real, the centennial mode would continue to retard global warming during the next decades

4. Potential implications for the next decades



The Southern Ocean did not participate in the warming of the recent decades (since 1971)

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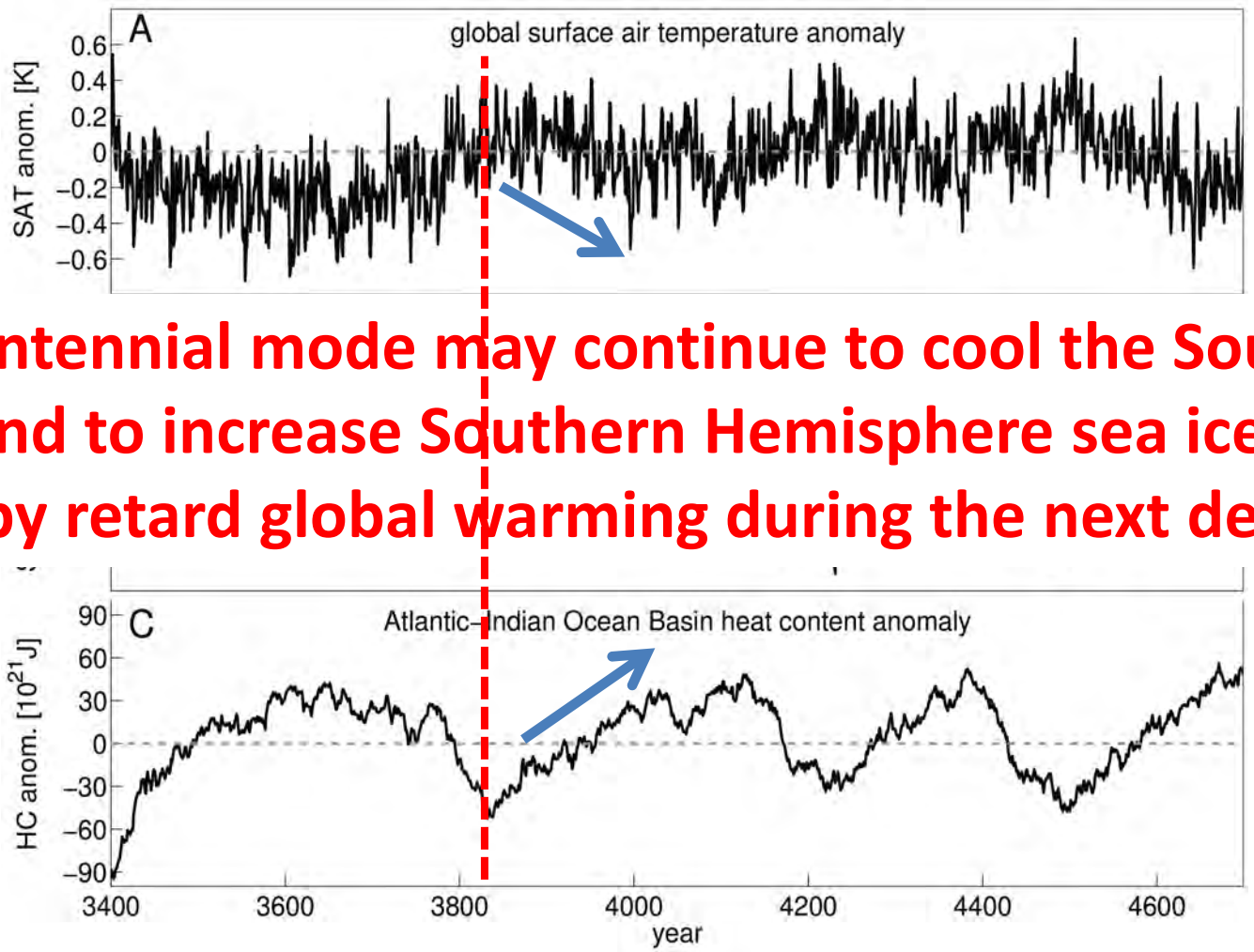
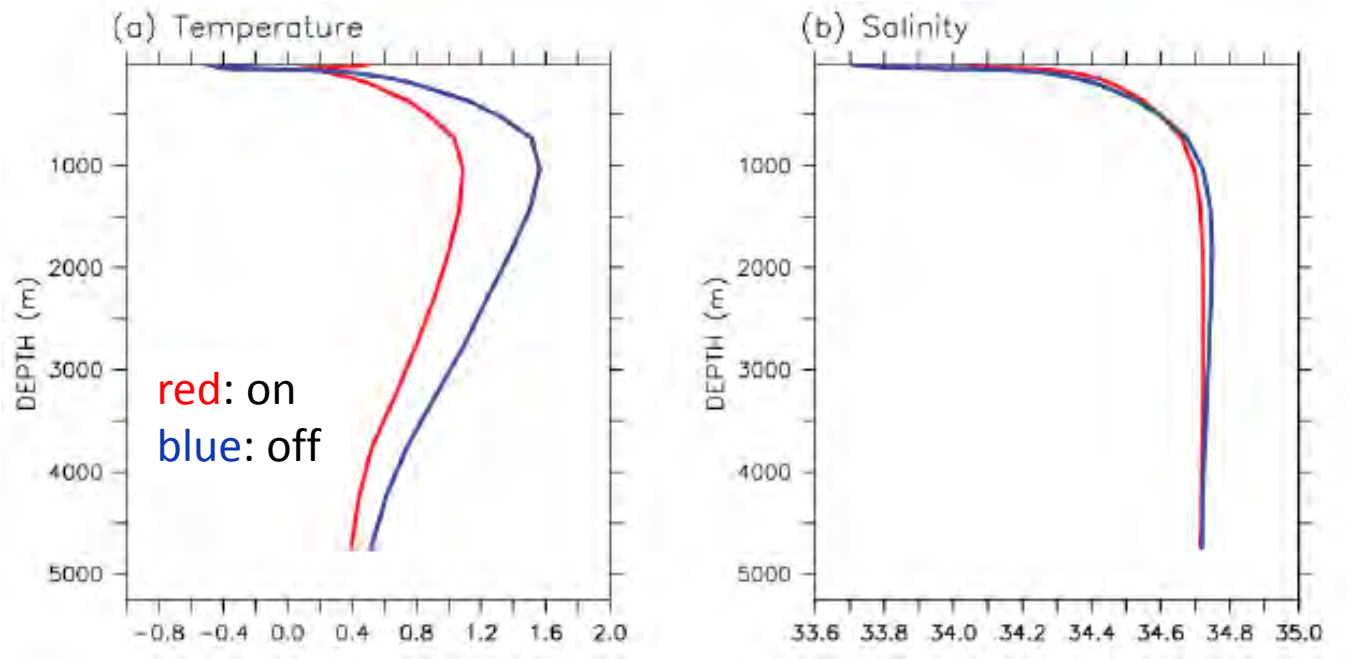
The observed trends may continue given the long timescale of the mode



The centennial mode may continue to cool the Southern Ocean and to increase Southern Hemisphere sea ice extent, thereby retard global warming during the next decades

Change in average Southern Ocean temperature and salinity after convection start

convection “on” versus convection “off”



the subsurface Southern Ocean gets considerably colder during convective activity and warms thereafter, consistent with evolution during the last decades

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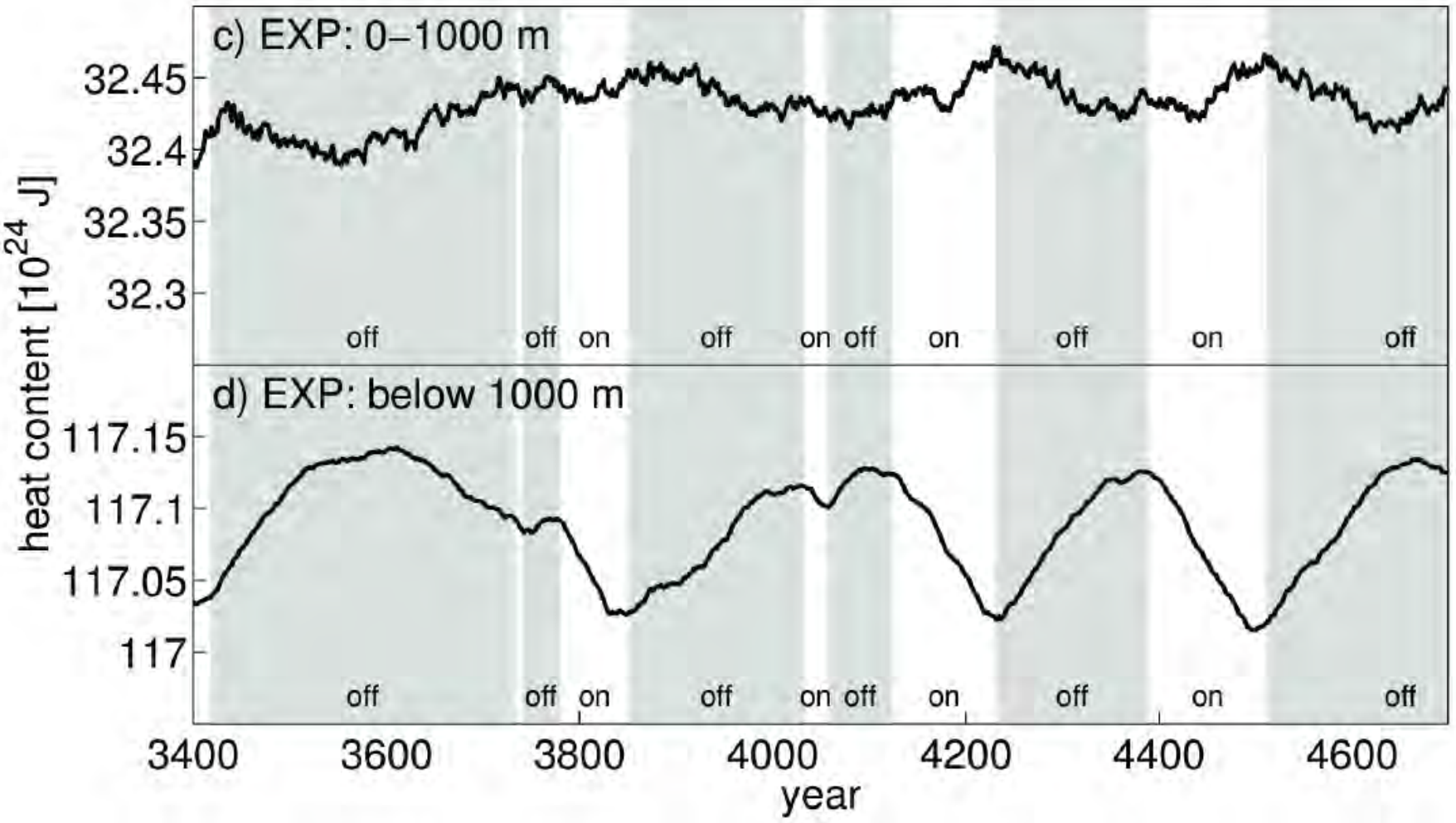
The heat accumulation takes place at mid-depth, below 1000m



this supports that NADW is the cause

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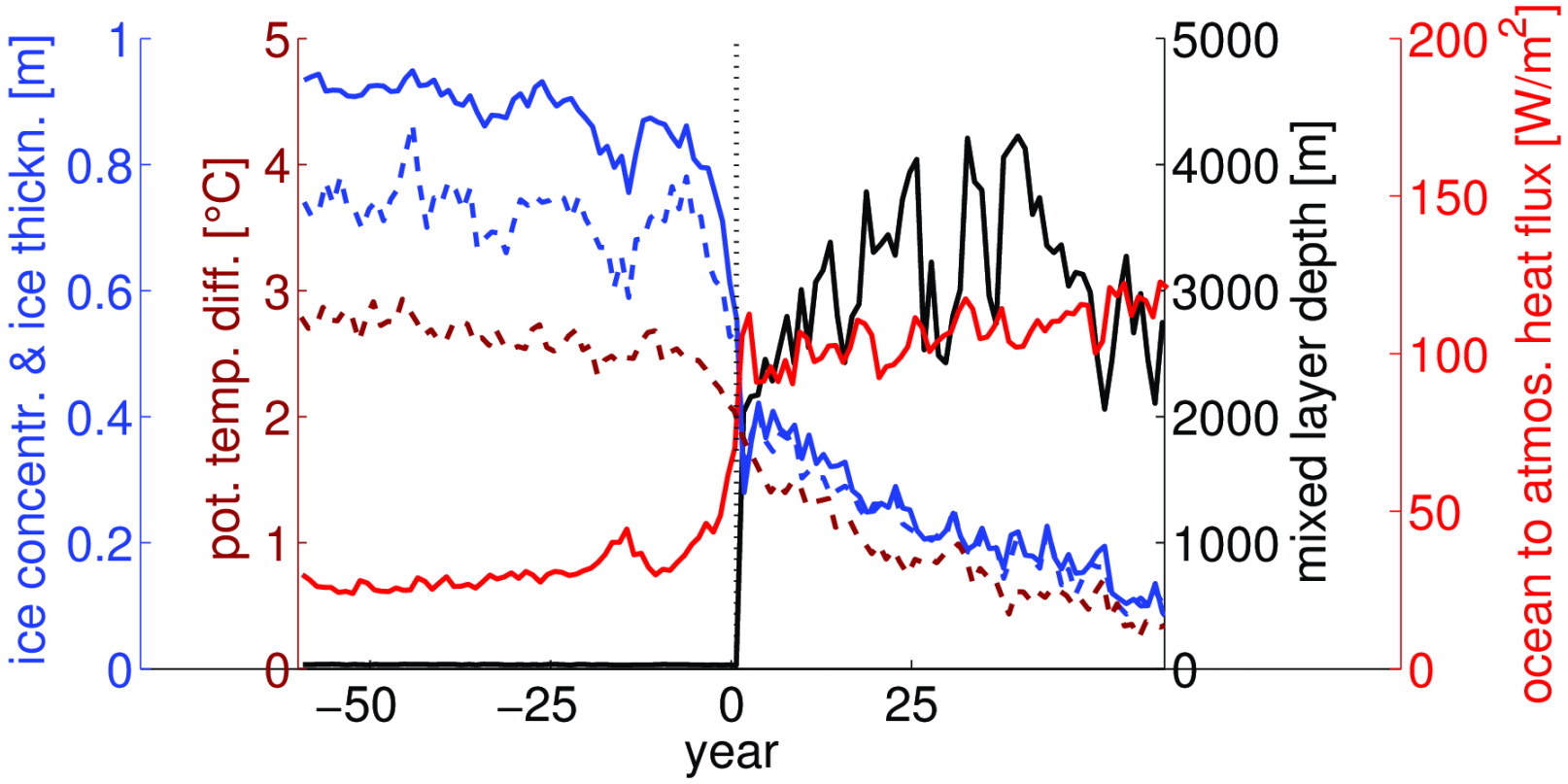
The onset of convection in the Weddell Sea: a more detailed description



convection sets in very rapidly

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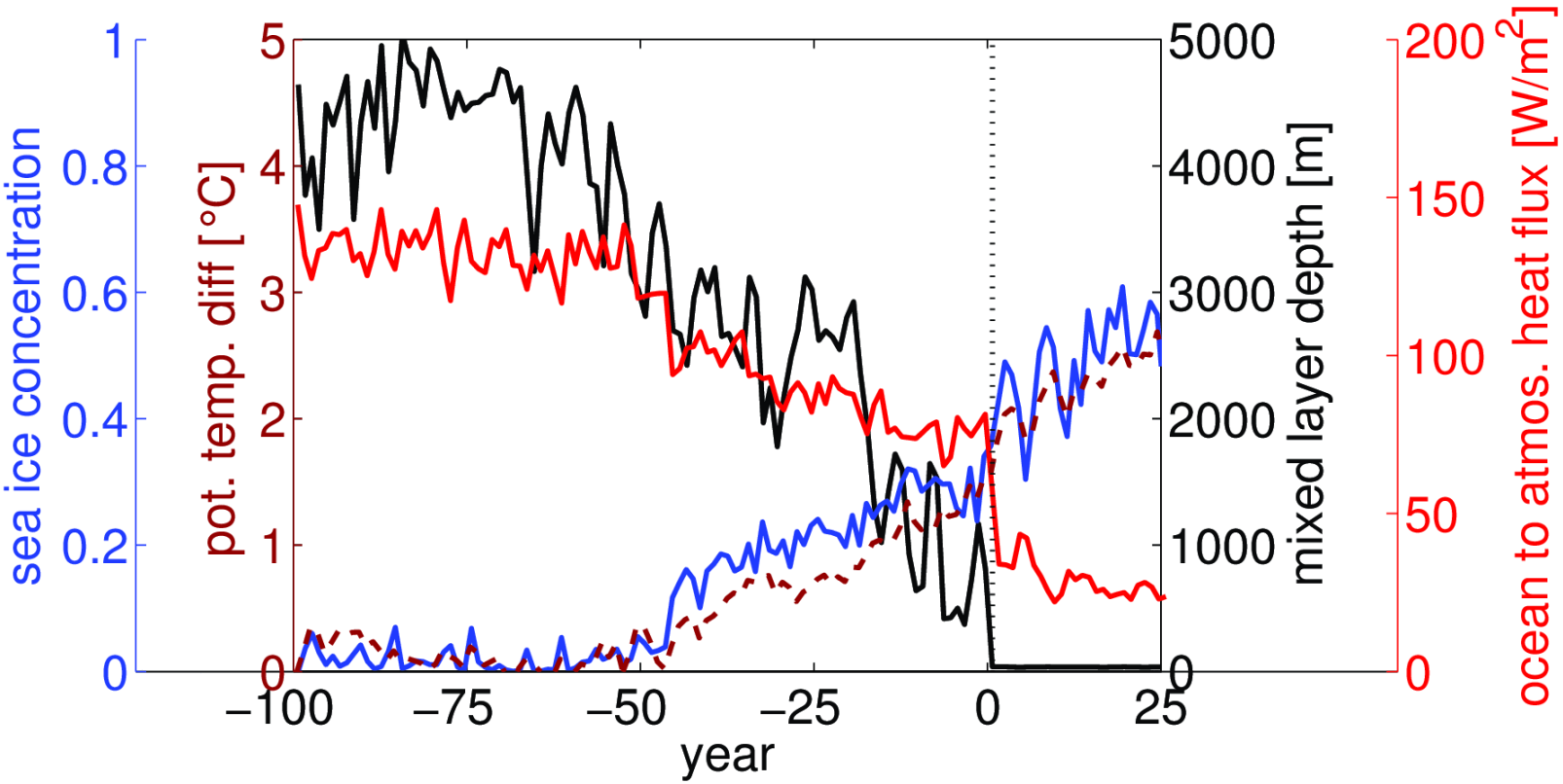
The halt of convection in the Weddell Sea: a more detailed description



convection stops after all heat is released to the atmosphere

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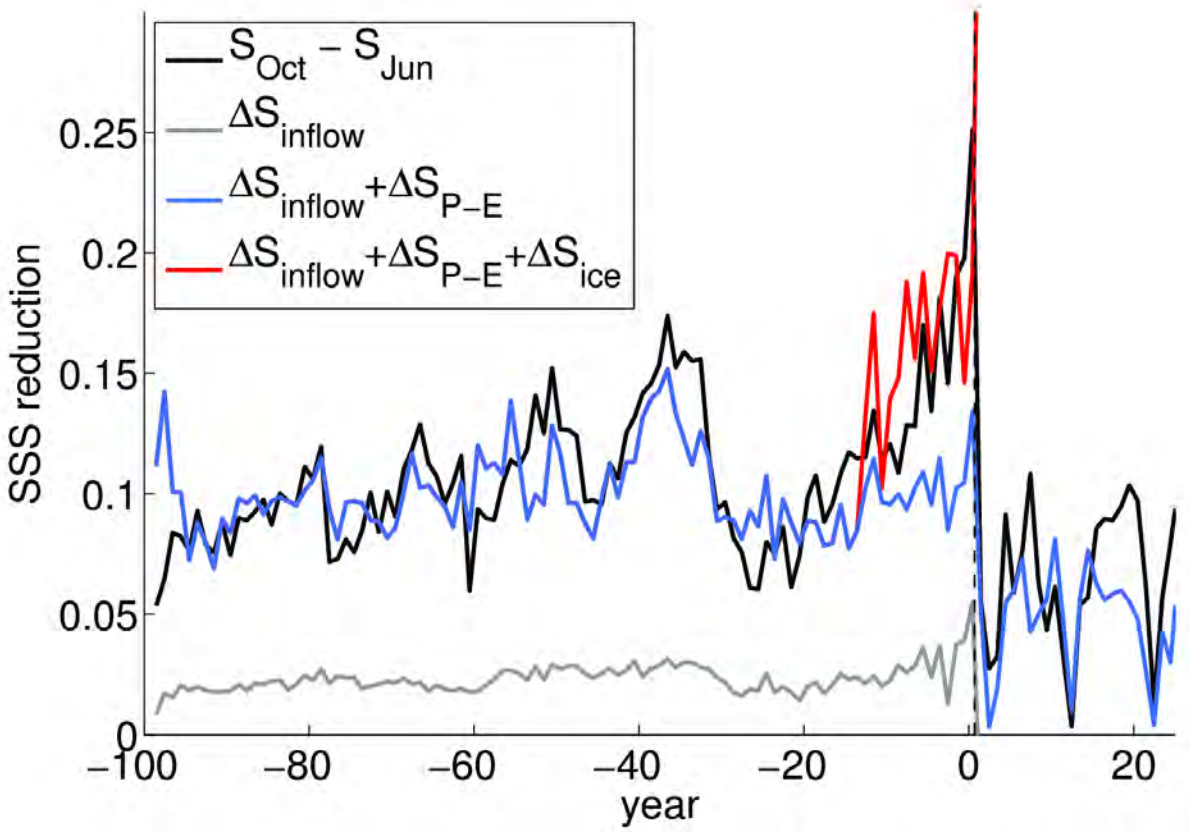
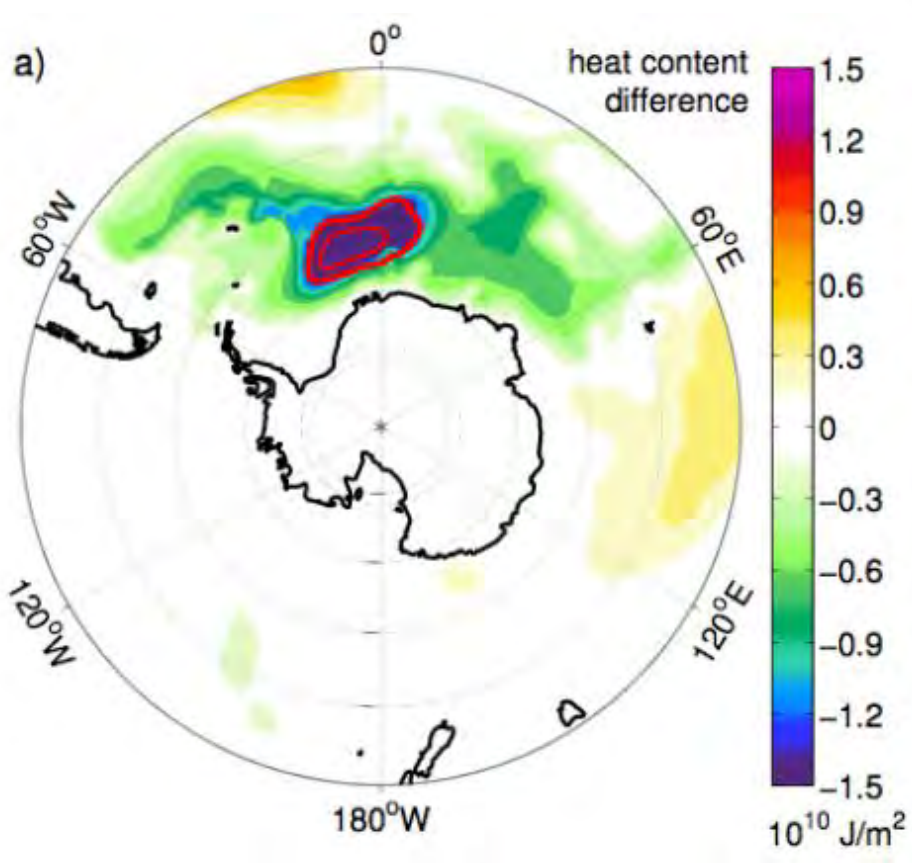
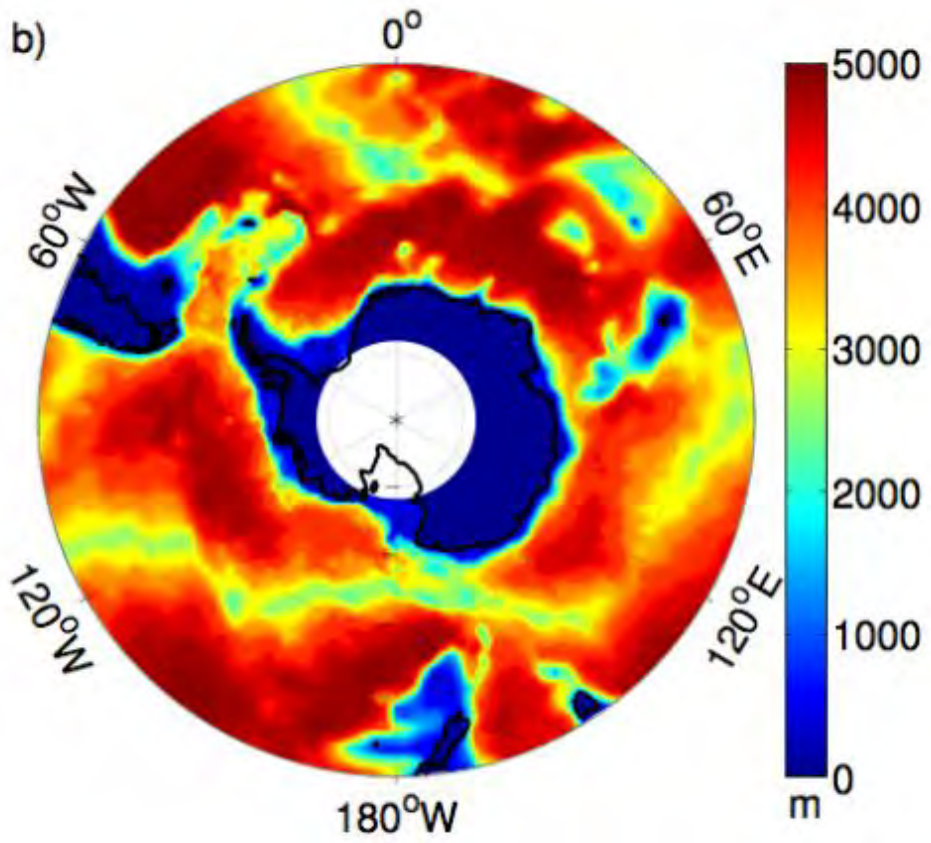
The halt of convection in the Weddell Sea and the surface freshwater budget



When the heat reservoir is depleted (the gun is loaded) a coincidental strong freshening shuts down the convection

Heat content difference and topography





a) Oceanic heat content depletion due to deep convection in the Weddell Sea. The difference is taken between 10–year averages from just before and at the end of a representative convection event. Red lines mark the 200 m (bold) and 1000 m (thin) MLD contours averaged over the entire convection period. b) Bathymetry.

Northern Hemisphere sea ice did strongly retreat during the last decades