Decadal variability and predictability studies in GFDL - Southern Ocean and North Atlantic

main focus — Slightly mention

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Motivations for the Southern Ocean work:

- **Observed decadal scale cooling and sea ice increase in the Southern Ocean**

- **Simulated multidecadal variability in the Southern Ocean, related to deep ocean convection, with impacts on temperature and sea ice (e.g. GFDL CM2.1 and SPEAR models)**

Goals:

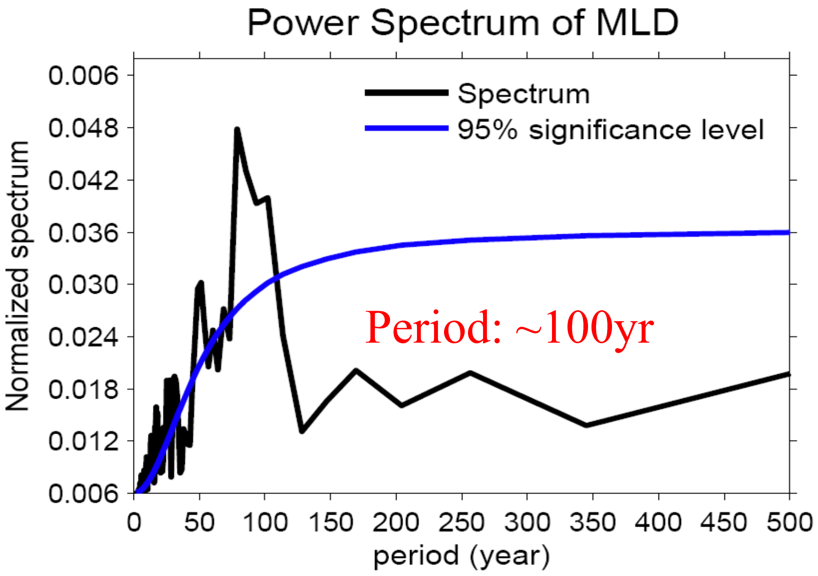
- **Better understand the mechanism of the simulated variability**

- **Assess the predictability of the simulated variability**

- **Assess whether this type of variability could play a role in the recent observed trends**

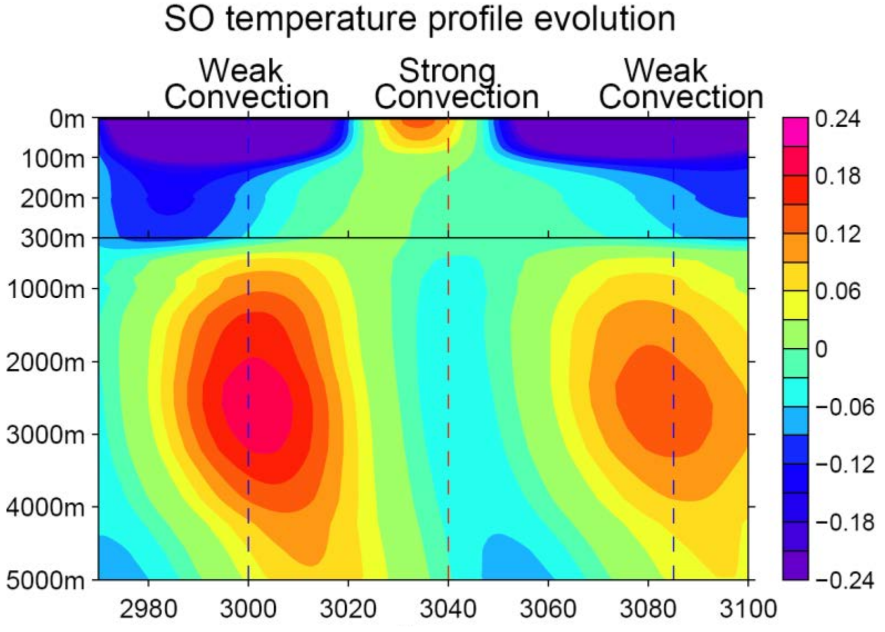
Simulated low frequency climate variability over the Southern Ocean in GFDL CM2.1 control run

Weddell Sea deep convection

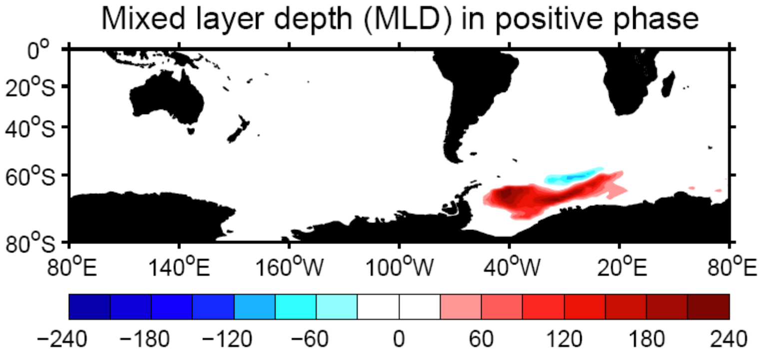


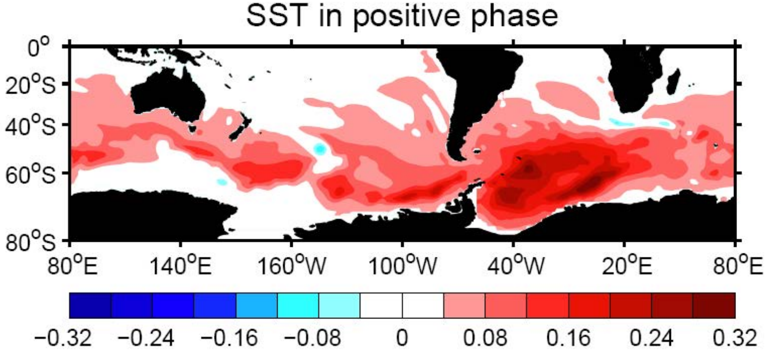
Physical controls of convection

Subsurface heat build up leads to strong convection

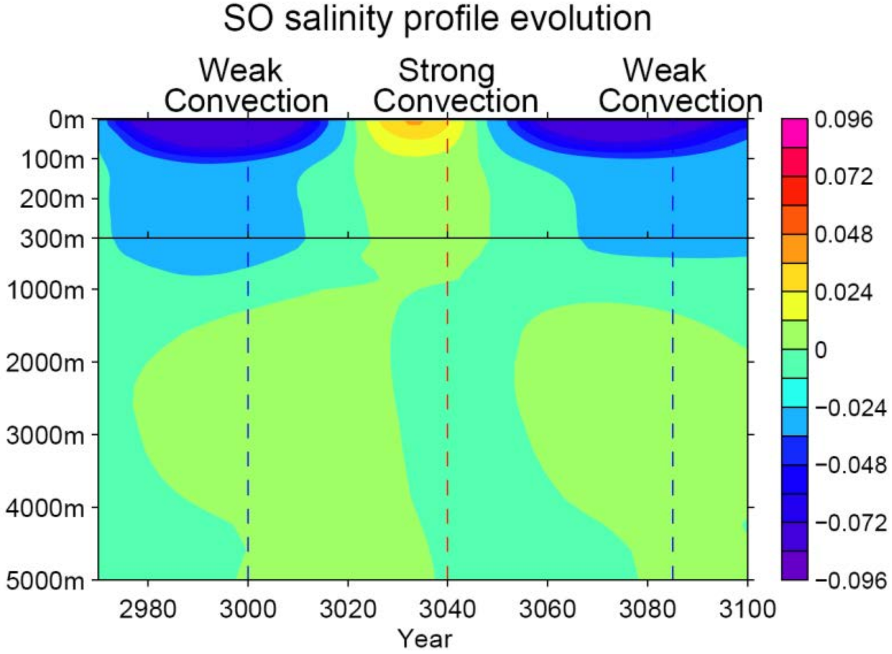


MLD and SST in strong convection phase





Surface freshening weakens convection



Zhang and Delworth 2016 JGR-ocean; Zhang et al. 2017a, J.Clim

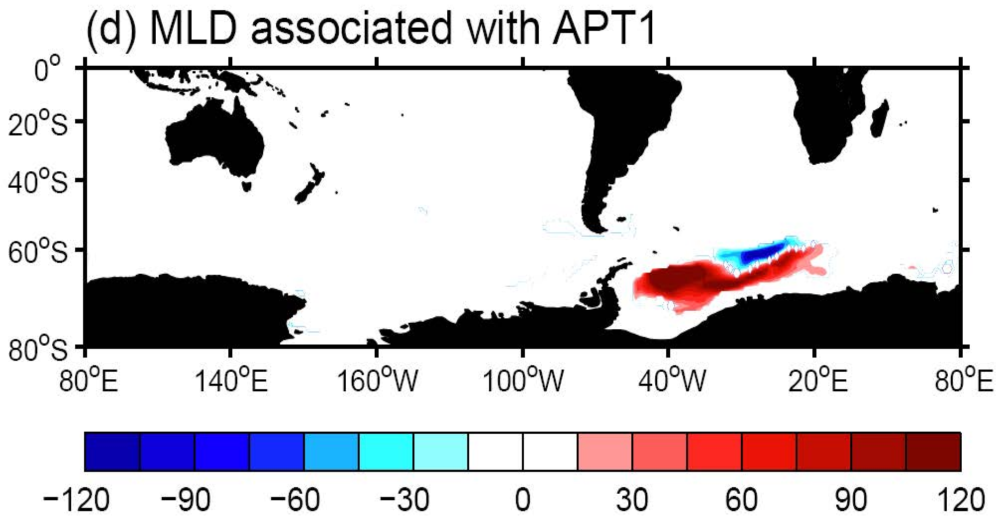
Is this low frequency variability predictable? Step 1: diagnostic analysis in CM2.1 control run

Average predictability time (APT) method, similar to EOF, but decompose predictability instead of variance

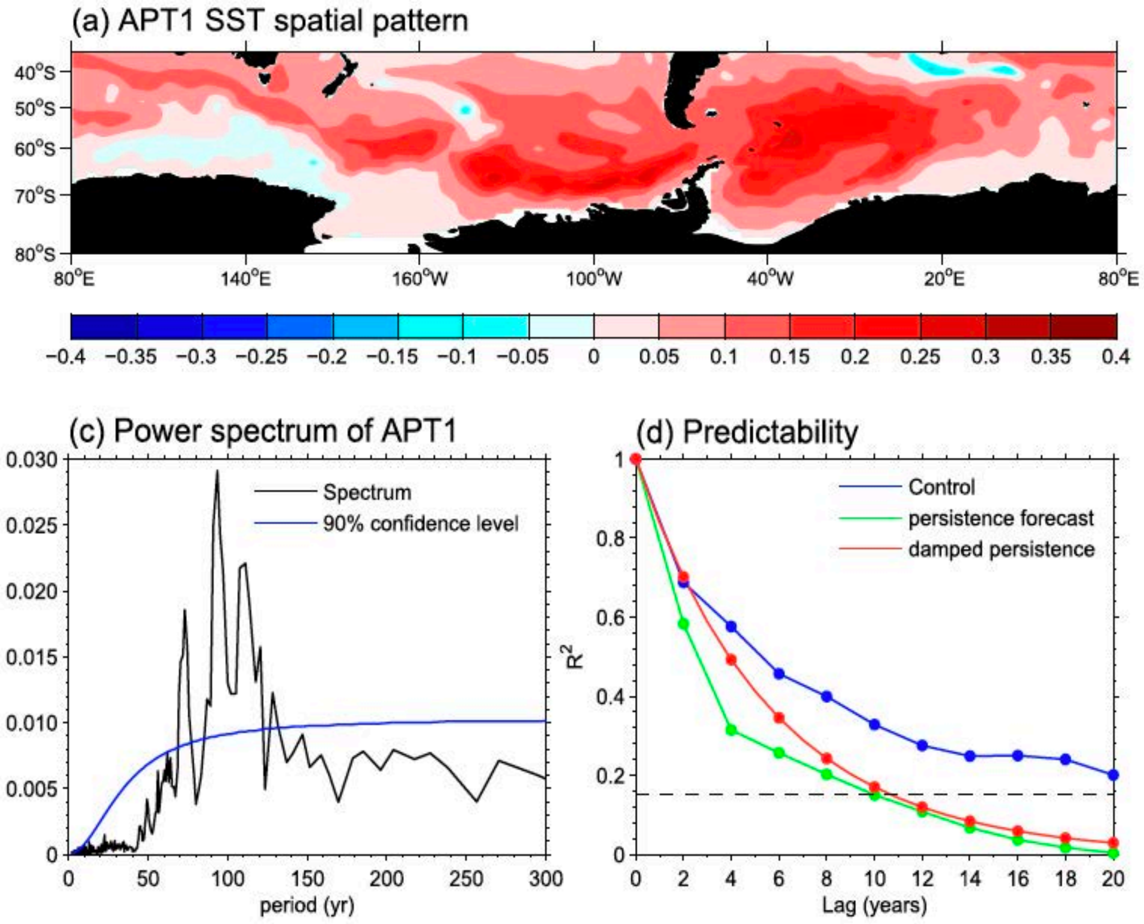
$$APT = 2\sum_{\tau=1}^{\infty}\left(\frac{\sigma_\infty^2 - \sigma_\tau^2}{\sigma_\infty^2}\right)$$ DelSole and Tippett (2009a,b)

Source of skill

MLD regression on the APT1 time series



The most predictable patterns (APT1)



The most predictable pattern is closely related to the SO deep convection memory

Zhang et al. 2017a, J.Clim

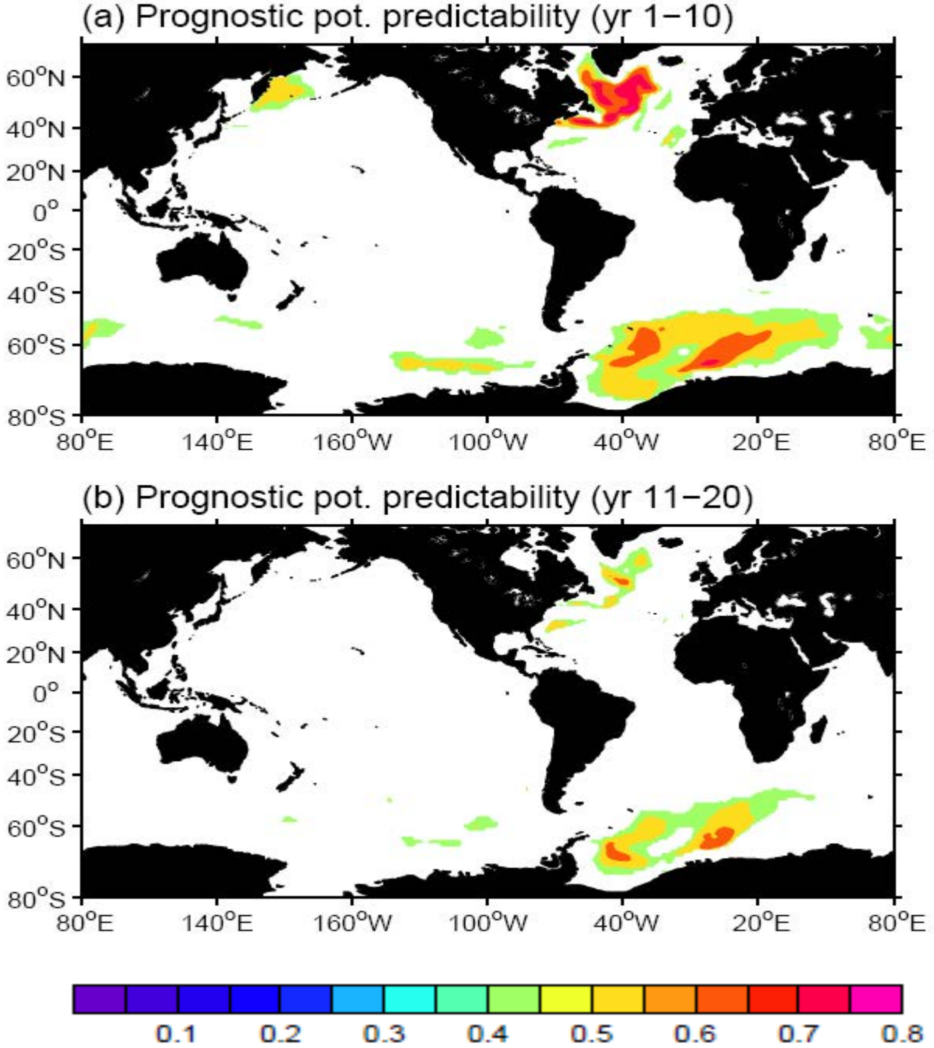
Is this low frequency variability predictable? Step 2: "perfect model" experiments

"Perfect Model" predictability run:
Each ensemble consists of ten members with perturbed atmospheric states but with the same oceanic initial conditions

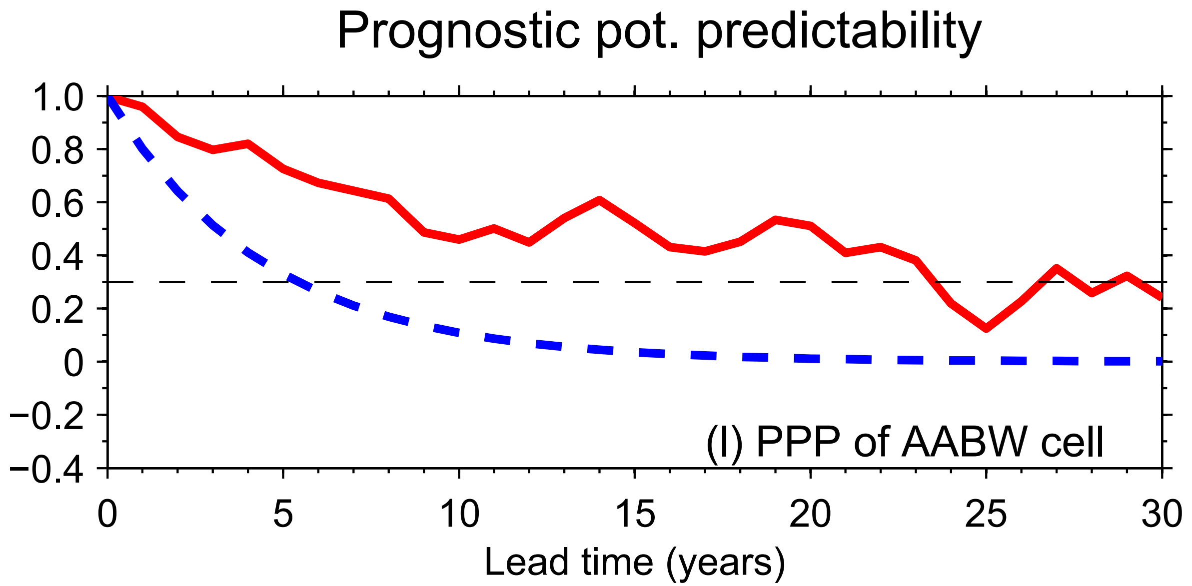
Ensemble spread can be interpreted as the predictability skill

Prognostic potential Predictability (PPP): Large PPP value means small ensemble spread and high predictability

PPP Spatial Pattern averaged in the first and second decades



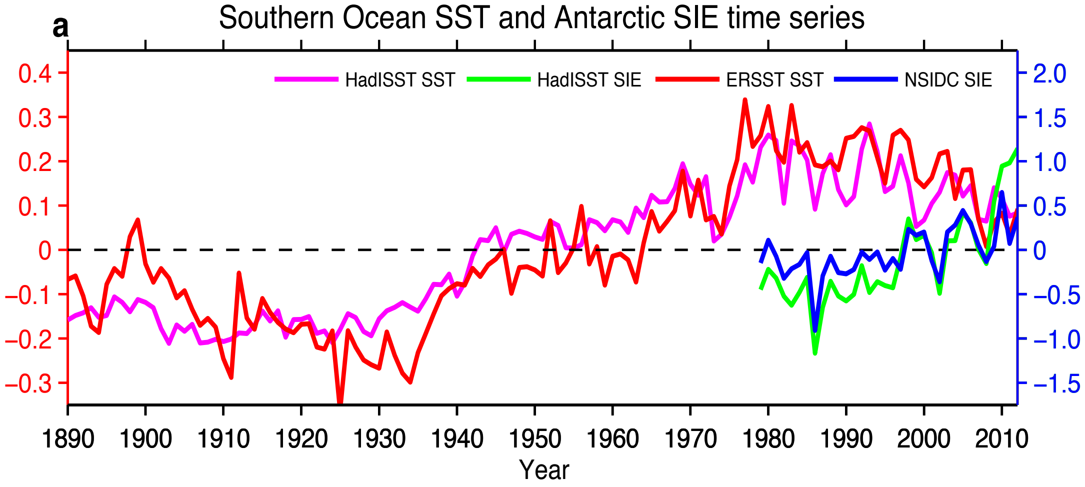
PPP of Southern Ocean deep convection

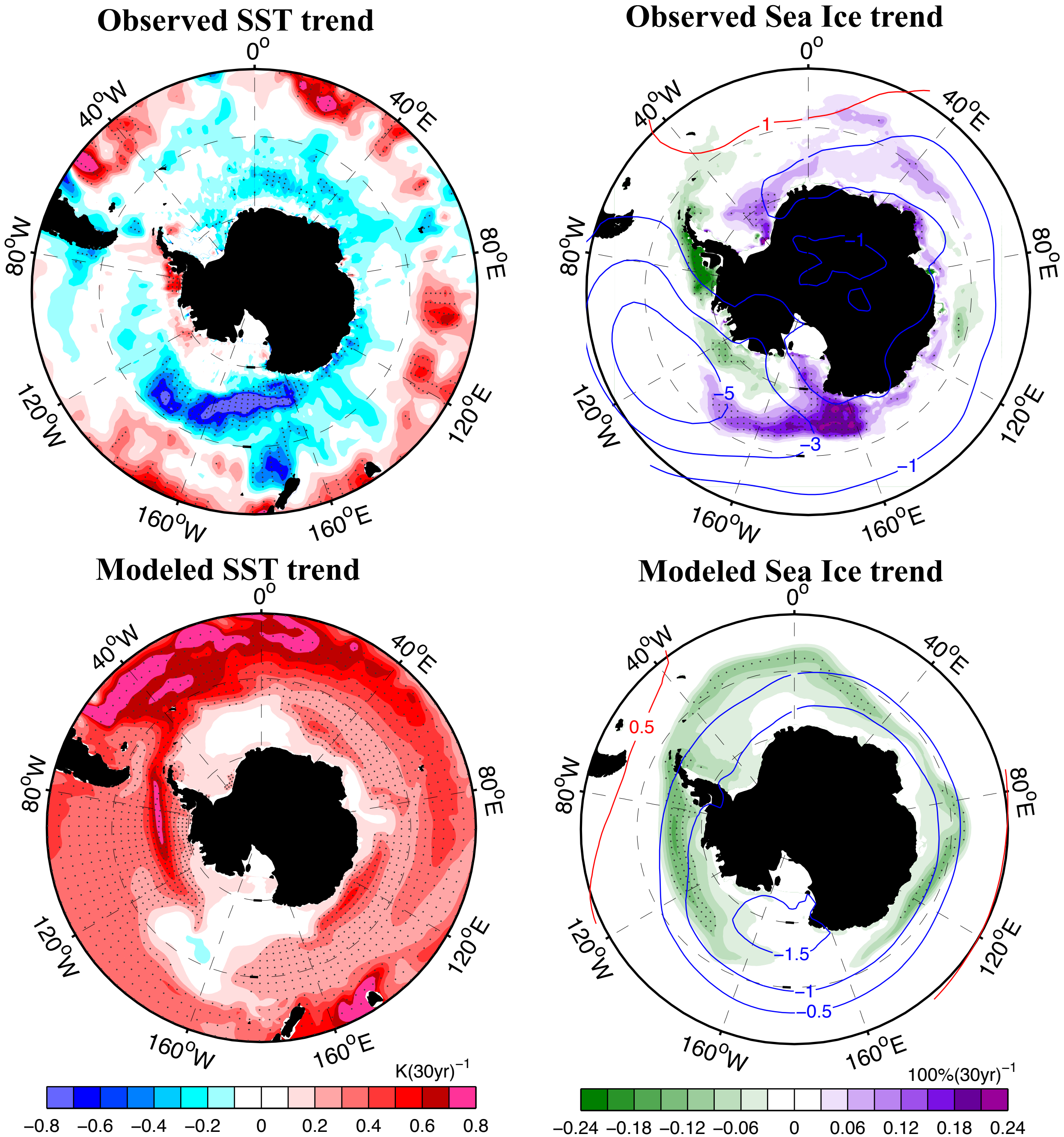


Zhang et al. 2017b, J.Clim

Could such low frequency climate variability play a role in explaining observed trends?

Observed SO surface cooling and sea ice expansion over the last several decades (1979-2015)





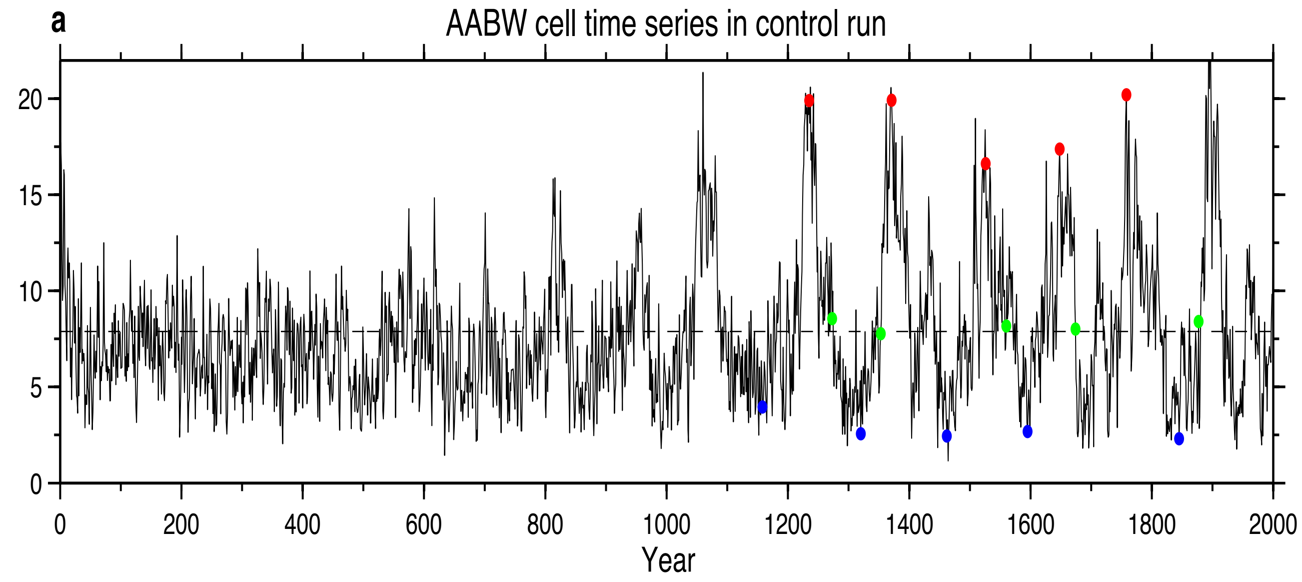
The model simulation (SPEAR_AM2) does not reproduce the observed trends around the Antarctic.

Instead, the model simulates a steady warming and Antarctic sea ice loss.

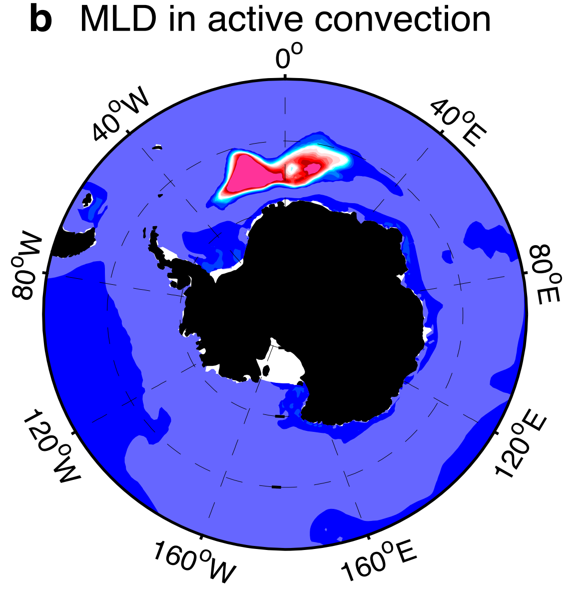
Zhang et al. 2019 Nature climate change

Southern Ocean(SO) internal variability in SPEAR model control run

Southern Ocean deep convection variability

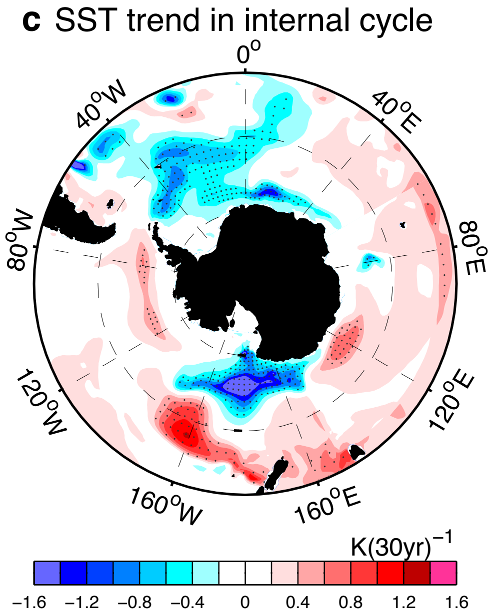


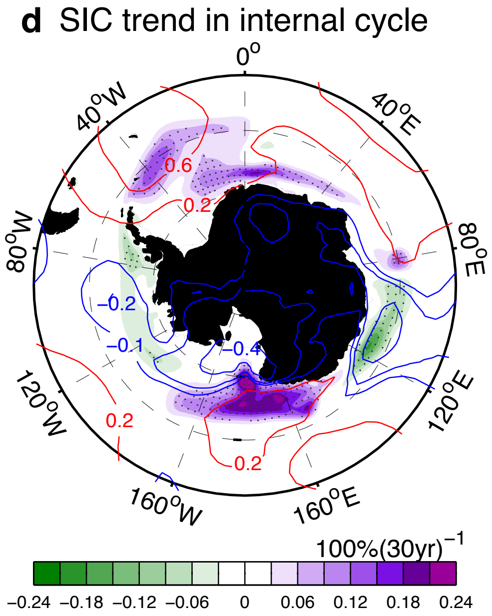
MLD response in active convection resembles Observed 1974-1976 Weddell Polynya



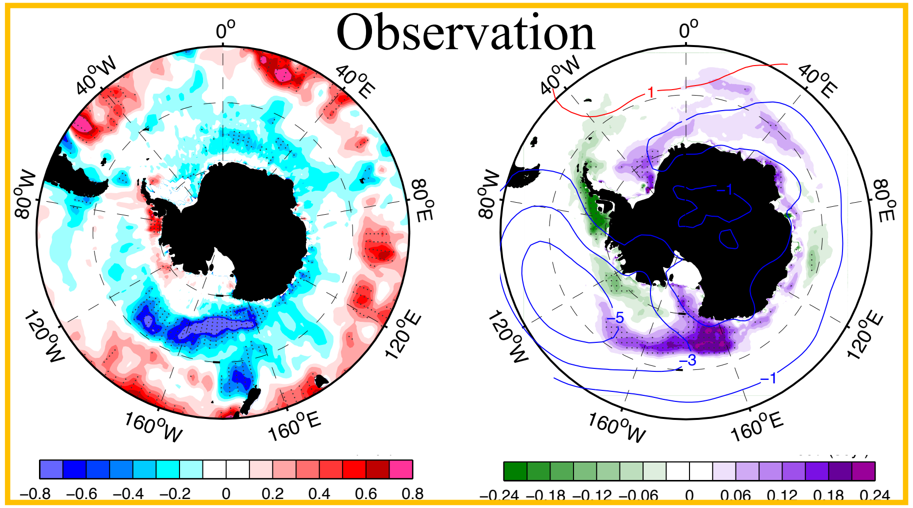
SST trend following active convection

Sea ice trend





This natural variability can produce ~30-yr trends in SST and SIC that resemble the observations.



If we initialize a coupled model from a strong phase of the convective cycle, does the model reproduce the observed trends over the period 1979-2015?

<u>Ensemble simulations for 1979-2015:</u>

A: Initialize from active phase of convective cycle

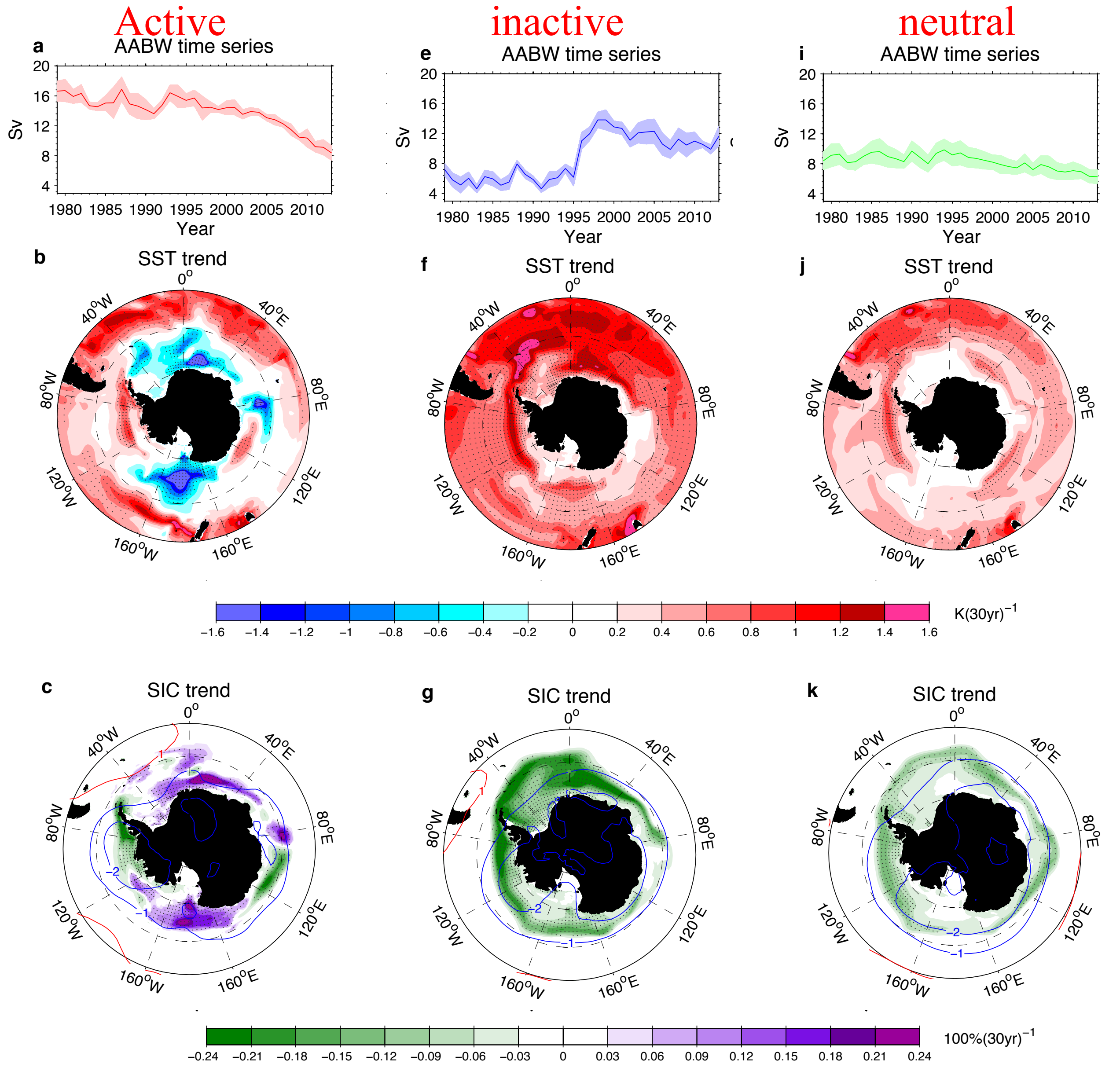
Reproduces observed trends!

B: Initialize from inactive phase

Does NOT reproduce observed trends!

C: Initialize from neutral phase

Does NOT reproduce observed trends!

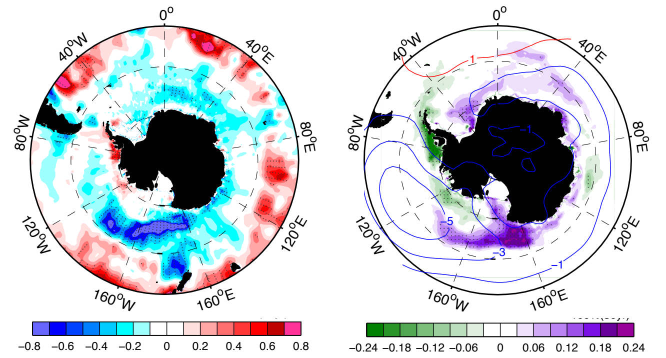


AABW cell

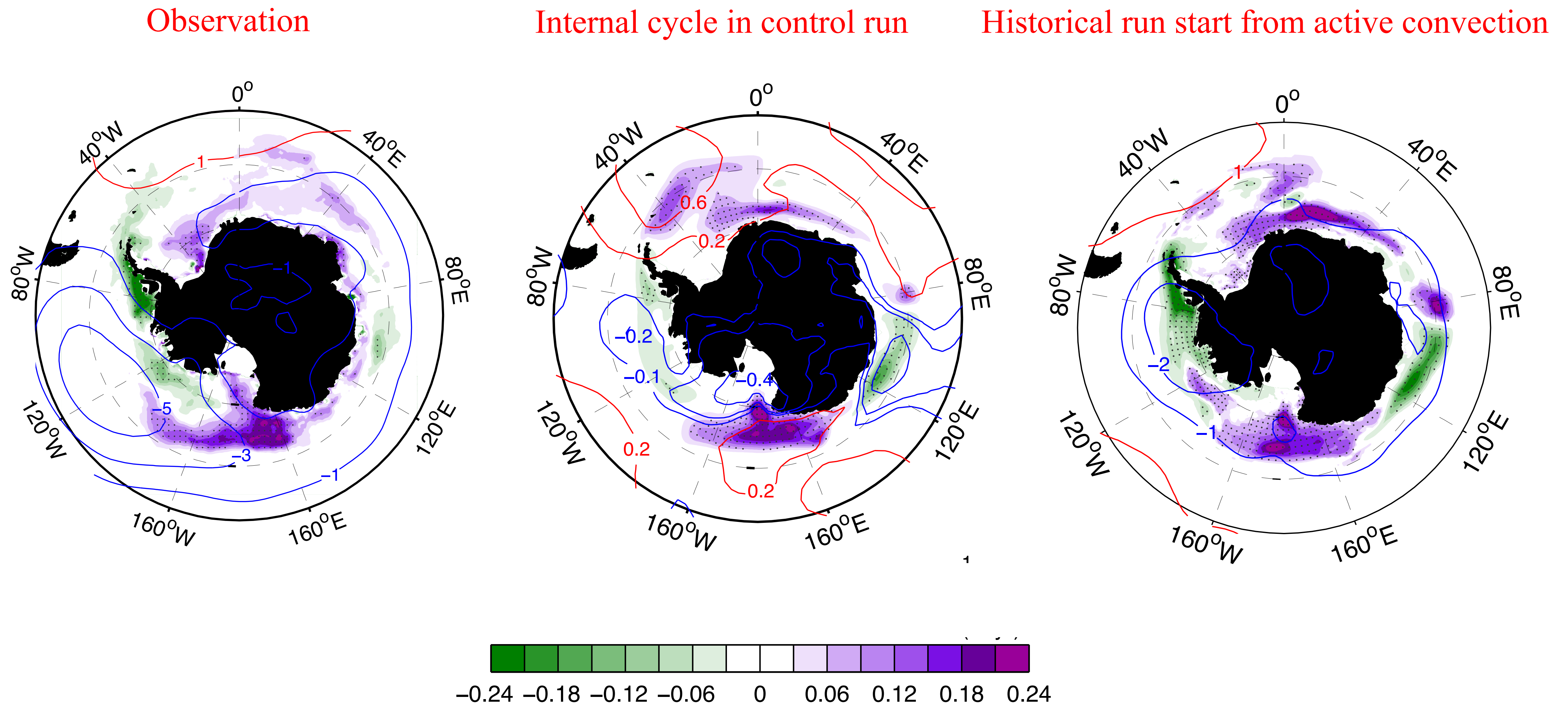
SST

Sea ice

Observation



Annual mean sea ice trends



Zhang et al. 2019 Nature climate change

Summary and Discussion

- Pronounced multidecadal model variability in the Southern Ocean is related to a buildup of heat in the deep ocean and freshening in the surface

- This variability is highly predictable on decadal scales

- Simulations initialized from a phase of this variability (with active convection) can reproduce observed trends in the Southern Ocean

- These results suggest a strong role for internal variability in explaining observed trends … and with good observations and models they may be predictable

Caveats:

- Sparse observations in Southern Ocean

- Internally generated SO deep convection likely not the only driver

- Model physics, especially ocean model (e.g., bias, resolution and mean state)

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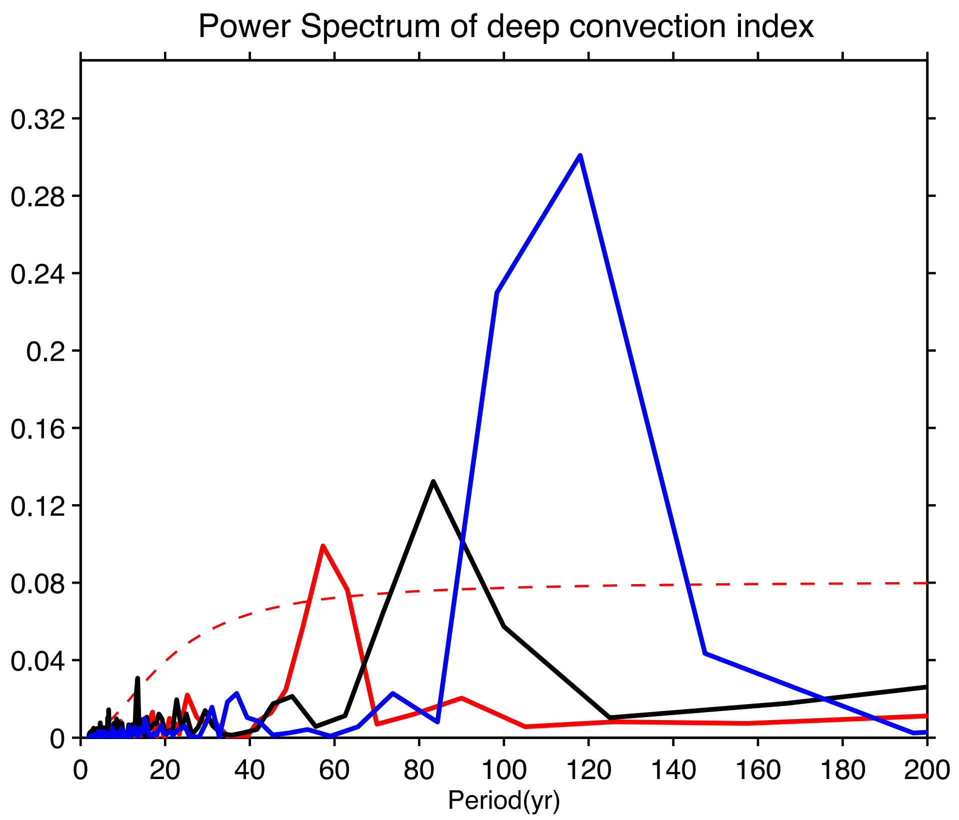
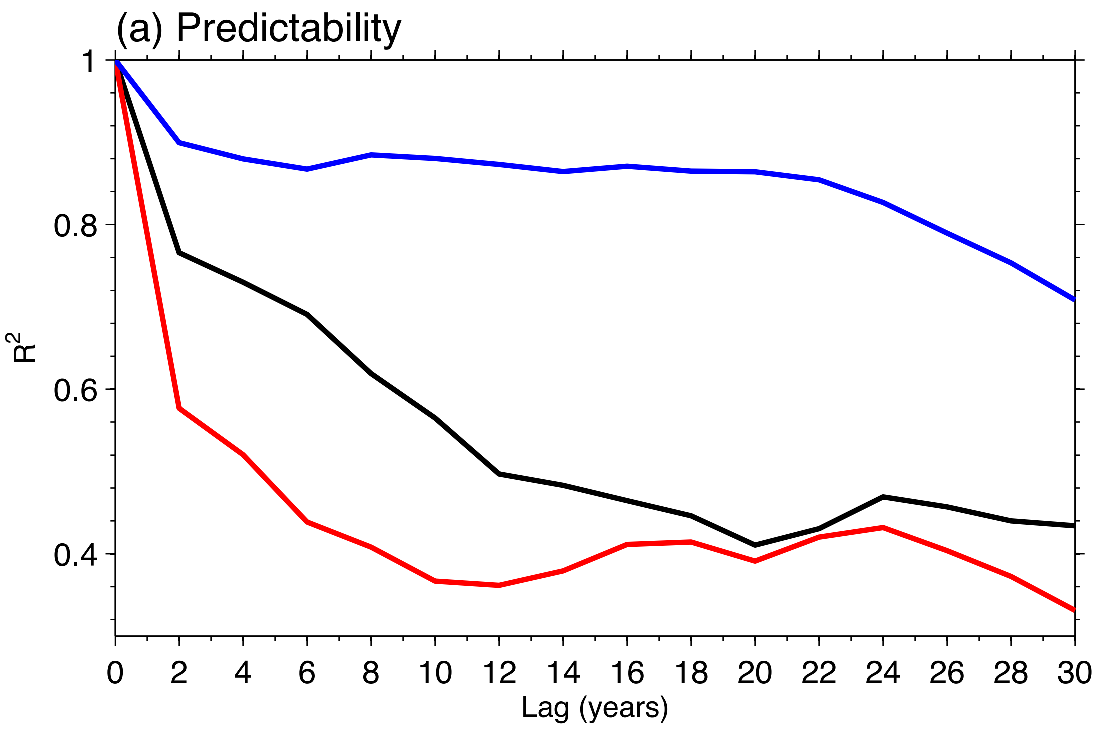
Ocean stratification strongly impacts the amplitude and period of Southern ocean internal variability





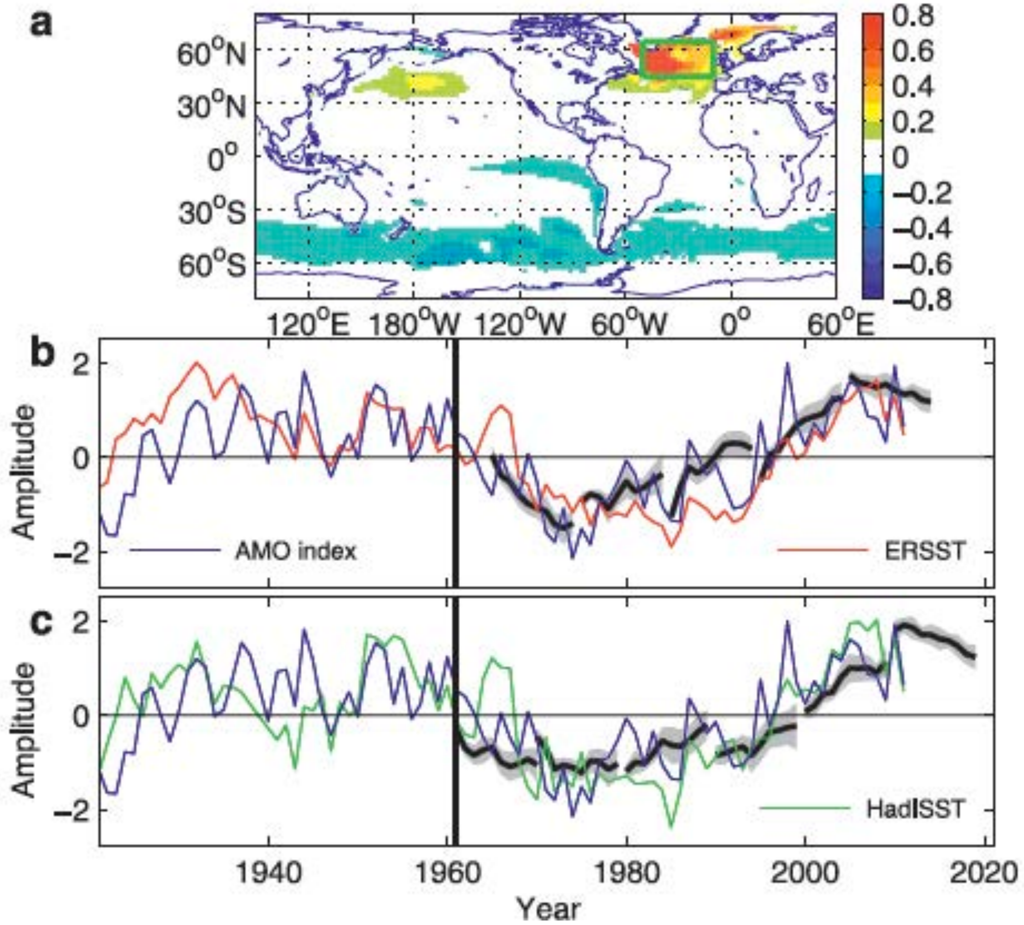
Weak stratification — 95% confidence level — control run — Strong stratification

Weak (strong) ocean stratification corresponds to higher (lower) frequency and smaller (larger) amplitude of internal variability and lower (higher) predictability

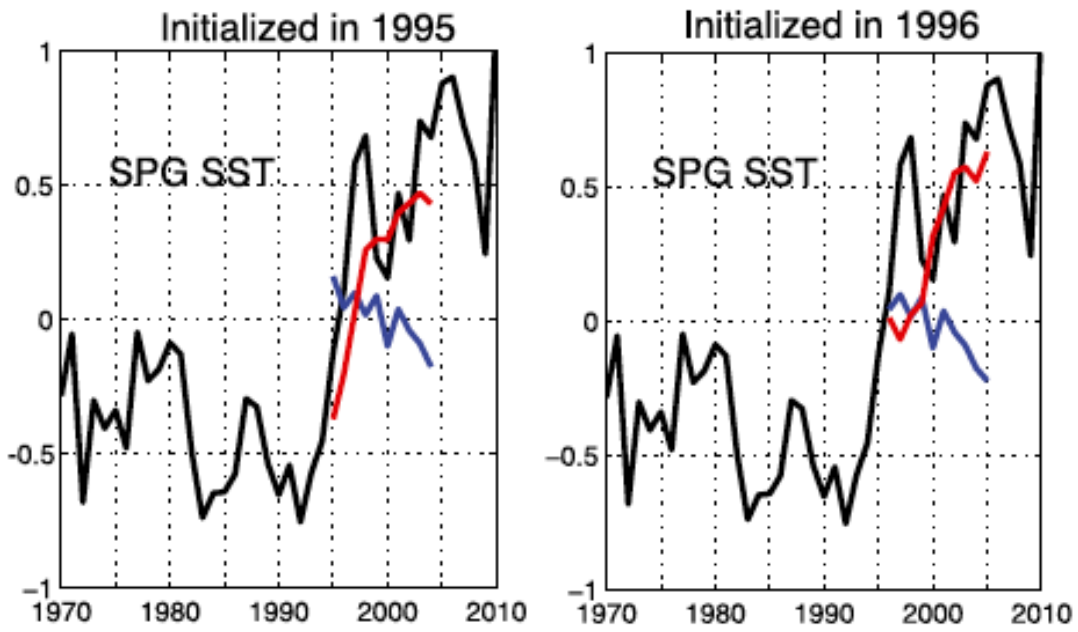
Zhang et al. (2019) to be submitted

North Atlantic Prediction

Decadal prediction initialized from ECDA reanalysis. ECDA: assimilates both atmospheric and ocean observation



Yang et al. (2013)



Msadek et al. (2014)

However, this technique appears to have difficulty in initializing the AMOC in what we think are physically meaningful ways

Explore a different initialization strategy for decadal prediction system

The GFDL is developing a new data assimilation system to be used for decadal prediction experiments. We called it SLP assimilation (lead by Xiaosong Yang and Tom Delworth).

This new assimilation data applies the ensemble adjustment Kalman filter to the fully coupled climate model SPEAR, in which the atmosphere assimilates the station-based SLP data used in the 20CRv2 atmospheric reanalysis.

The SLP assimilation at each time step produces an increment term for the winds. Thus, the winds (U, V) (e.g, the North Atlantic Oscillation (NAO)) and therefore the AMOC in the assimilation are broadly consistent with the observation.


Thank you

Potential questions to discuss

1. GFDL models have frequent Southern Ocean deep convection variability, while NCAR models are not. Why? Is it related to ocean stratification mean state? Which one is more realistic? How to improve background ocean stratification in model?

2. What determines the Southern Ocean open ocean deep convection location? The open ocean deep convection occurs in Weddell Sea in some models, while occurs in the Ross Sea in others.

3. How to initialize models for decadal prediction? e.g, the initial condition from ECDA we used in the hindcast have considerable uncertainties, especially arising from changing observational net works.

4. Given the importance of ocean circulation initialization in the hindcast skills, the North Atlantic and the Southern Ocean predictability is very likely dependent on the ocean model resolution.

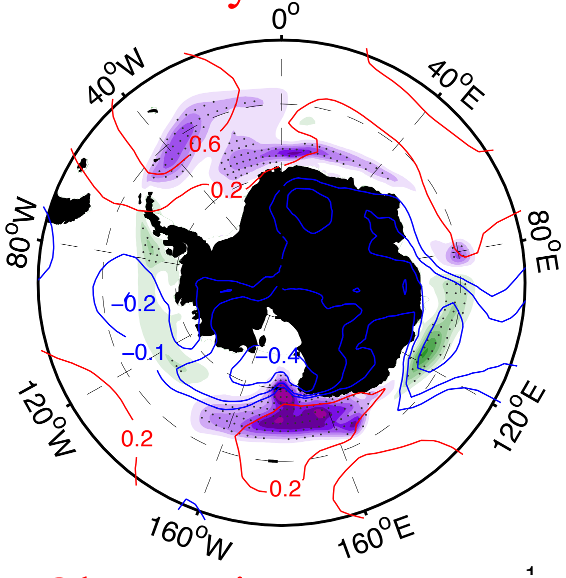
5. Call for more observation, especially the subsurface ocean

Influence of the natural variability of Southern Ocean deep convection on the atmosphere

Sea ice/SLP trends

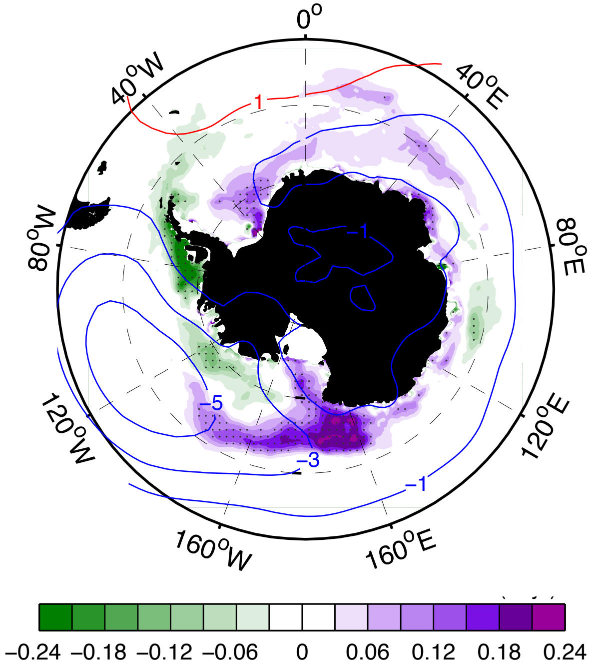
Internal cycle

SLP trend: ~ 0.2 hPa/30yr

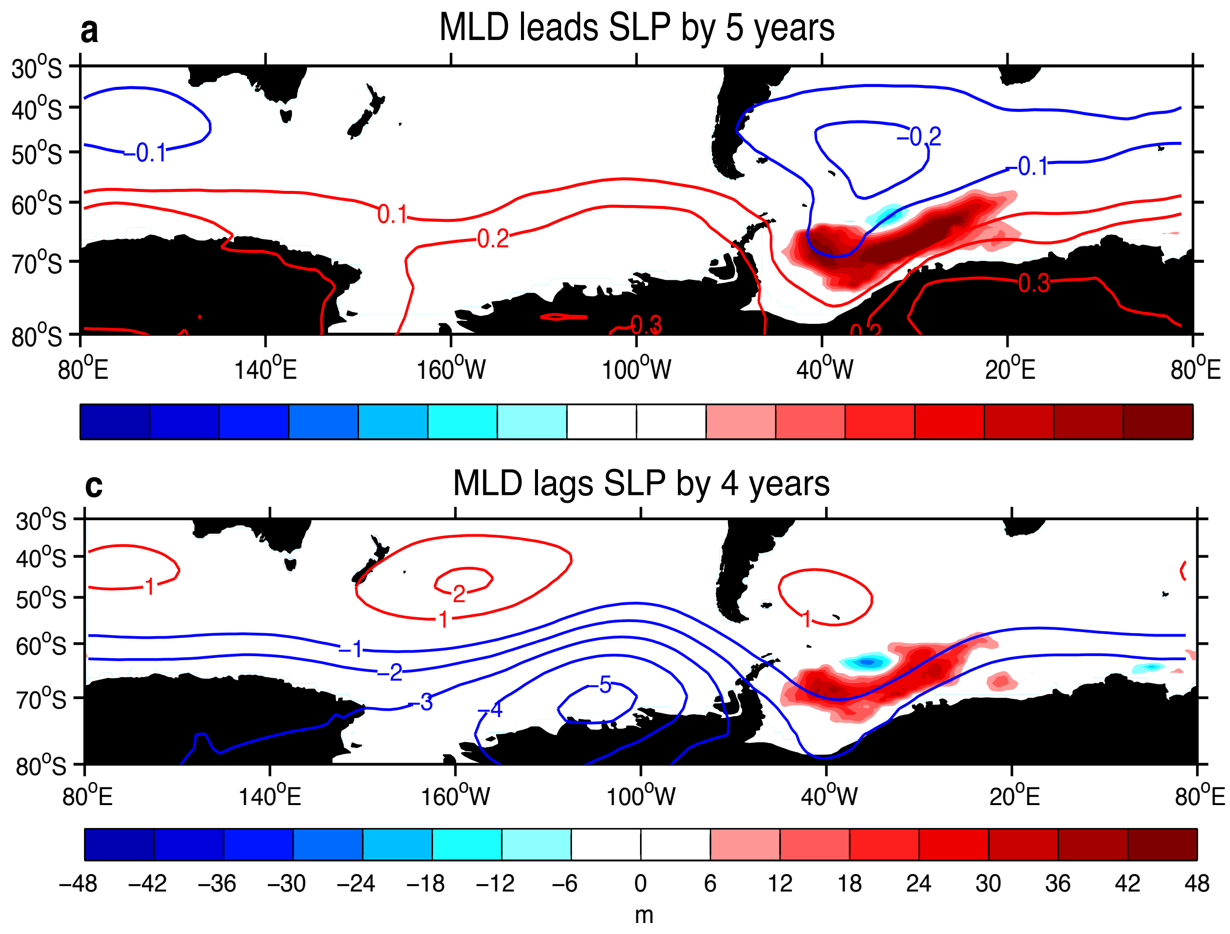


Observation

SLP trend: ~ 5 hPa/30yr



Lagged Maximum Covariance Analysis (MCA)
Annual MLD, seasonal SLP

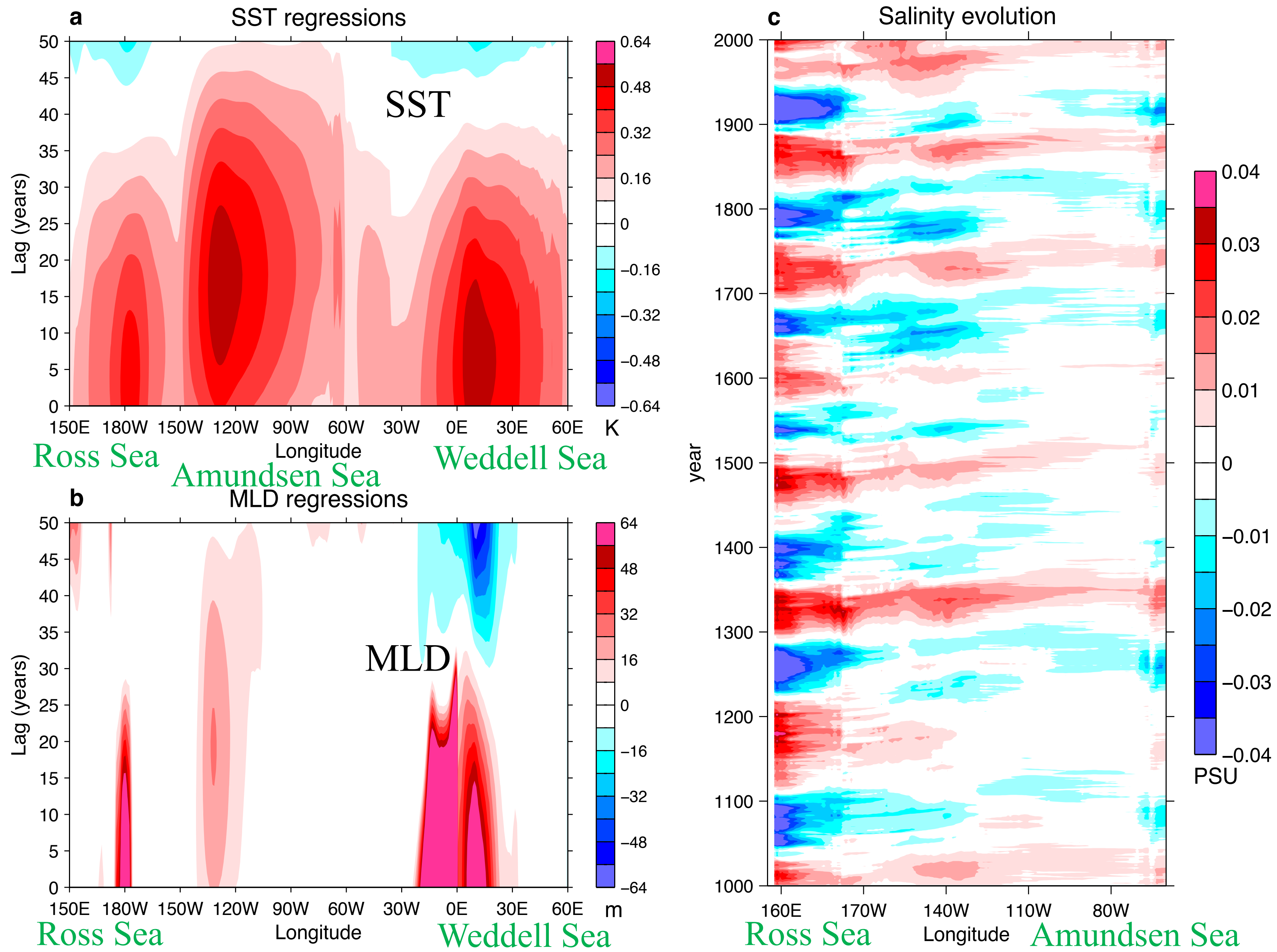


Ocean feedback is very weak compared to atmosphere forcing

Delayed response over the Amundsen-Bellingshausen Seas

The SST anomalies over the Amundsen-Bellingshausen Seas lag the SST (MLD) anomalies over the Weddell and west Ross Seas

The delayed convection over the Amundsen-Bellingshausen Seas is due to the advection time of salinity anomaly from the Ross Sea

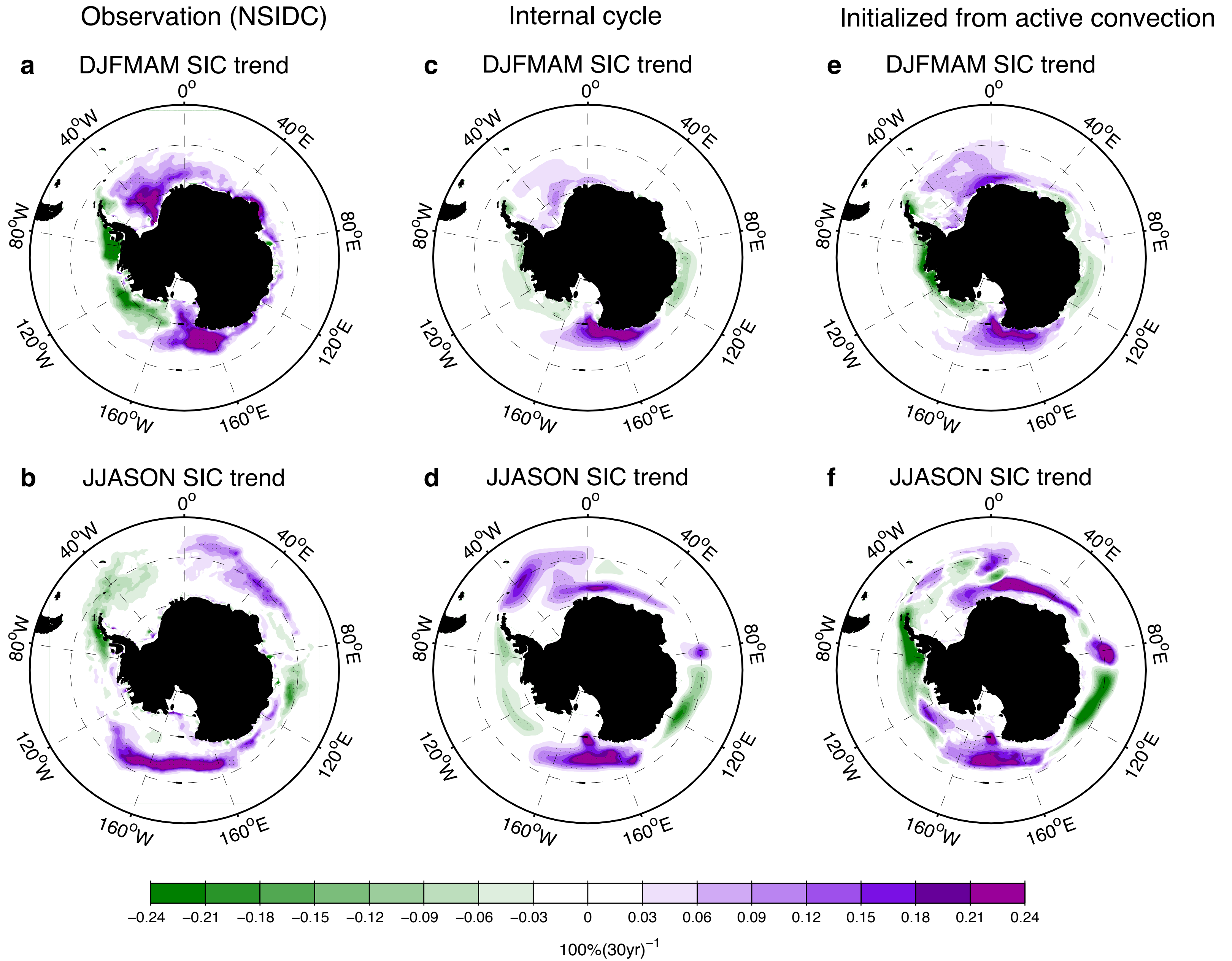


Seasonality of sea ice trends

Observation | Internal cycle | Historical run start from active convection

Warm season

Cold season



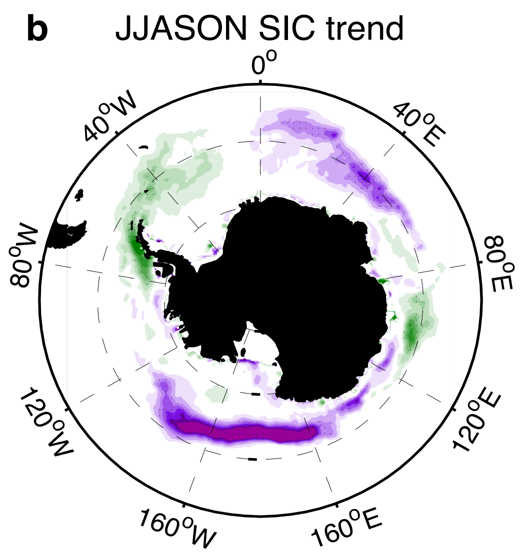
Southern Ocean responses in SLP assimilation

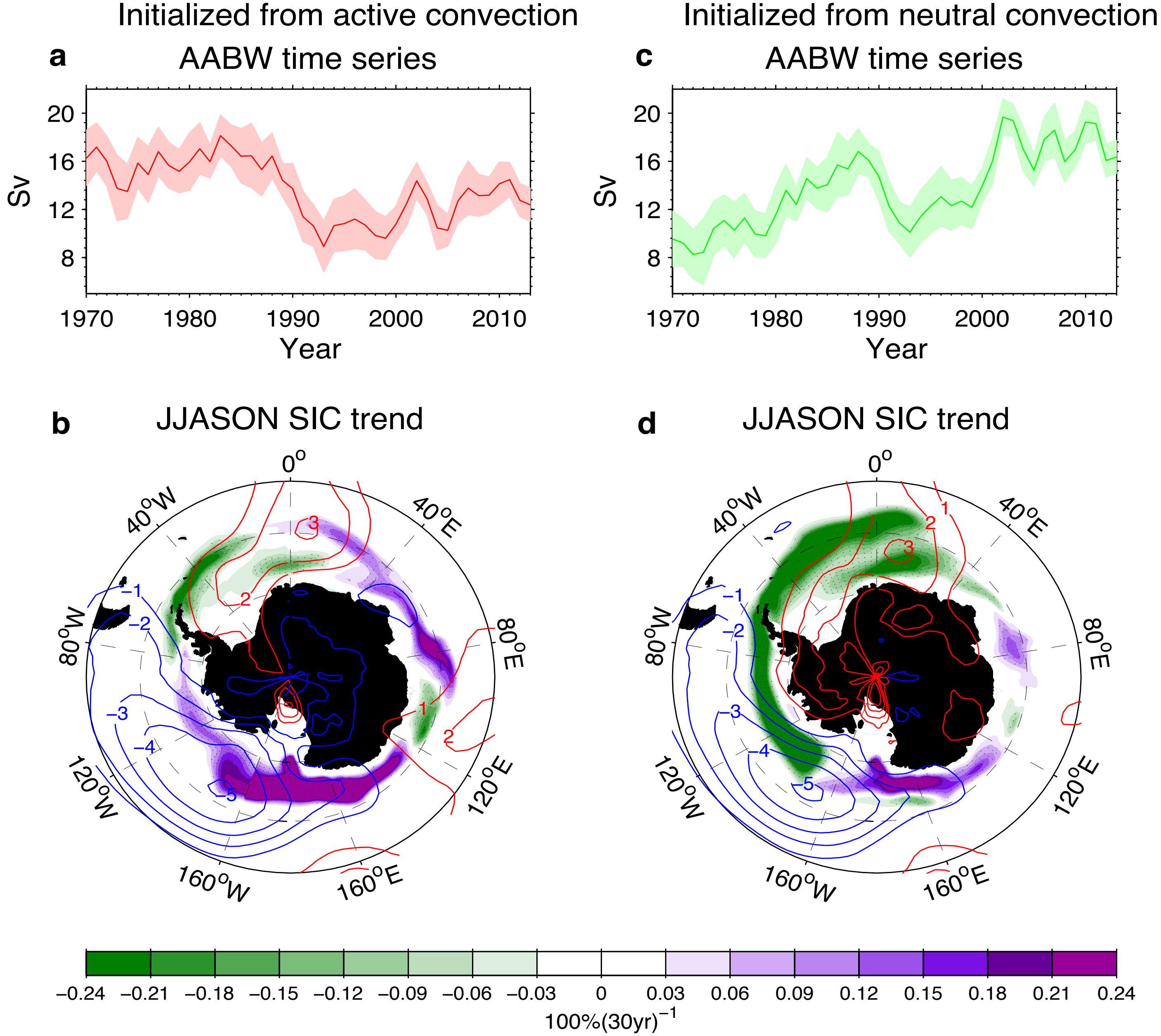
Initialized from active convection state | neutral convection state

SLP assimilation constrains the time series of model winds to resemble the time series of observed winds

Wind trend is similar in these two runs, but the ocean initial condition is different

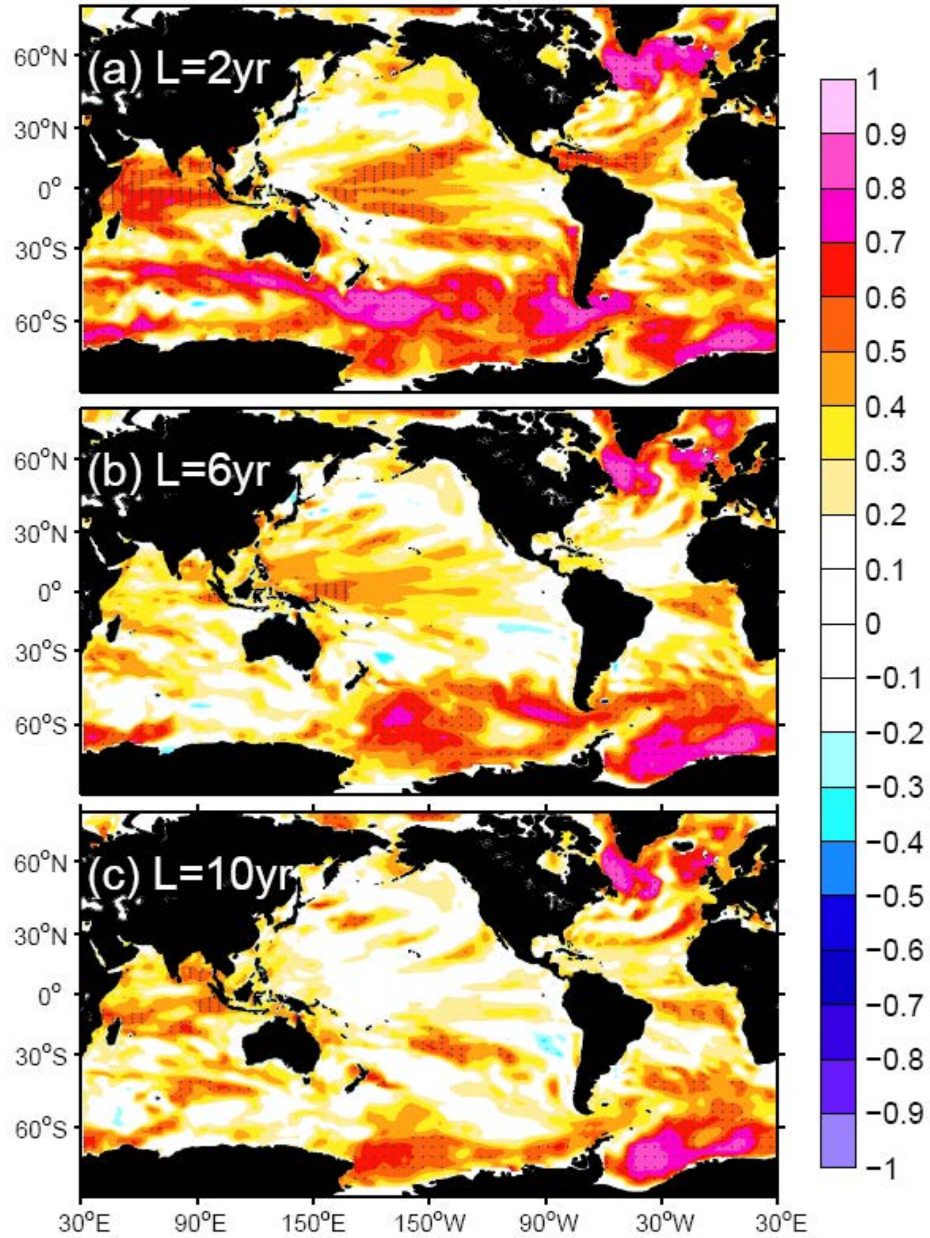
Observation





Is this low frequency variability predictable? Step 3: decadal hindcasts/forecasts initialized from ECDA

SST Correlation: hindcast data VS ECDA

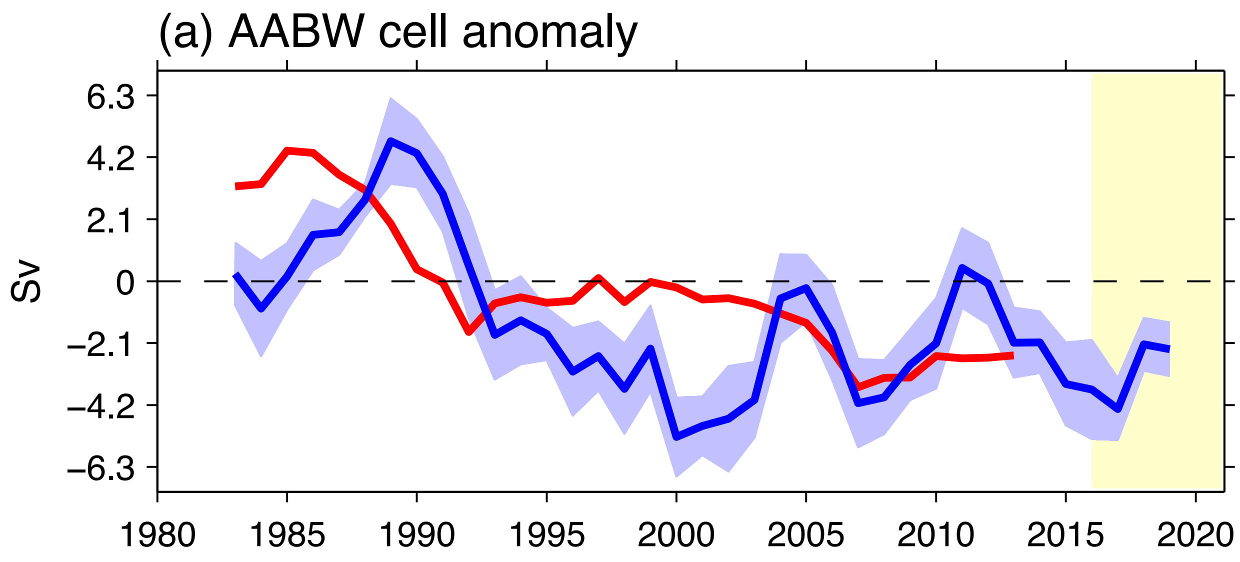


The success of SST prediction over the SO appears related to initialization of the SO deep convection internal variability into the model

Blue line: lead 1-10yr mean Hindcast/forecast (shading is ensemble spread)

Red line: ECDA

Yellow: forecast period



Sparse observations over the Southern Ocean create large uncertainties in prediction