Decadal Variability and Predictability in the Pacific, Atlantic and Southern Oceans

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Geophysical Fluid Dynamics Laboratory Review

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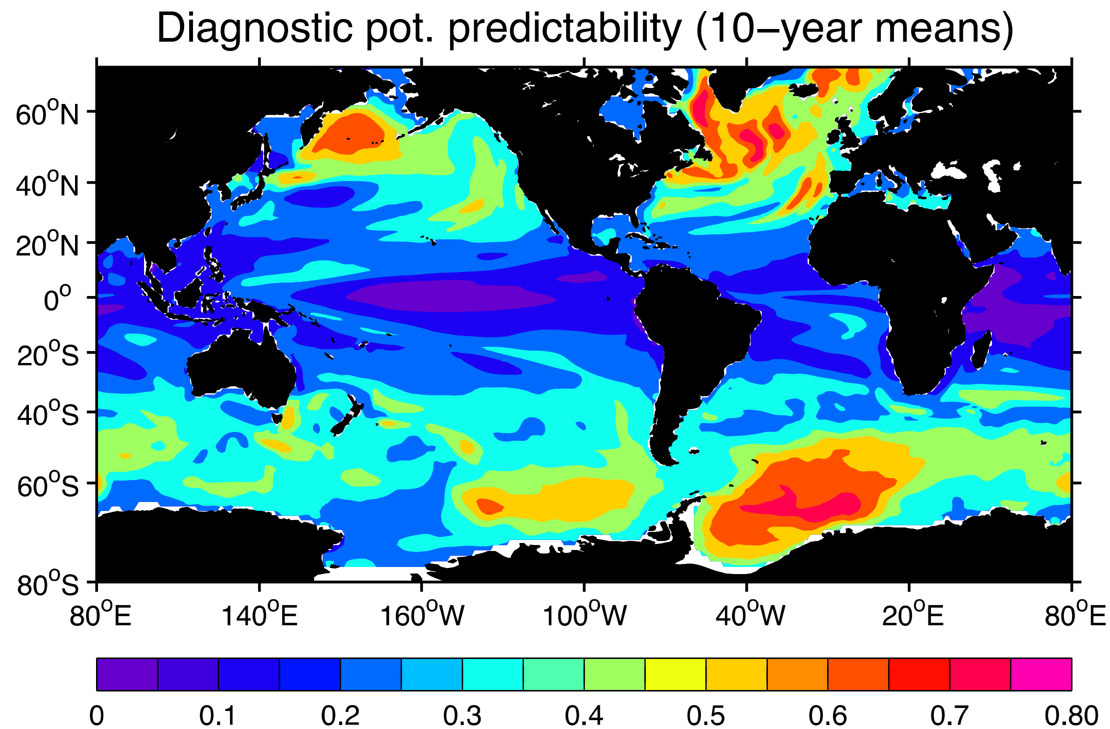
Decadal variability– impacts on climate, complicating climate change detection, sources of predictability

Potential predictability: Low frequency variance divided by total variance $\sigma_L{}^2/\sigma^2$

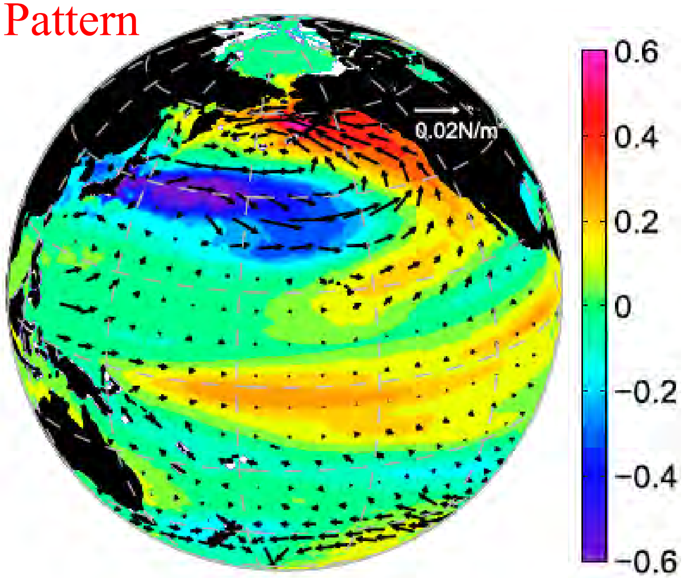
(Boer 2004)



GFDL has pursued vigorous research investigating low frequency variability in the North Pacific, North Atlantic and Southern Oceans

Pacific decadal oscillation (PDO)

Spatial Pattern



PDO impacts North American precipitation

PDO mechanism in GFDL FLOR model:

- Extratropical air-sea interaction
- Ocean Rossby wave propagation
- Teleconnection from tropical Pacific

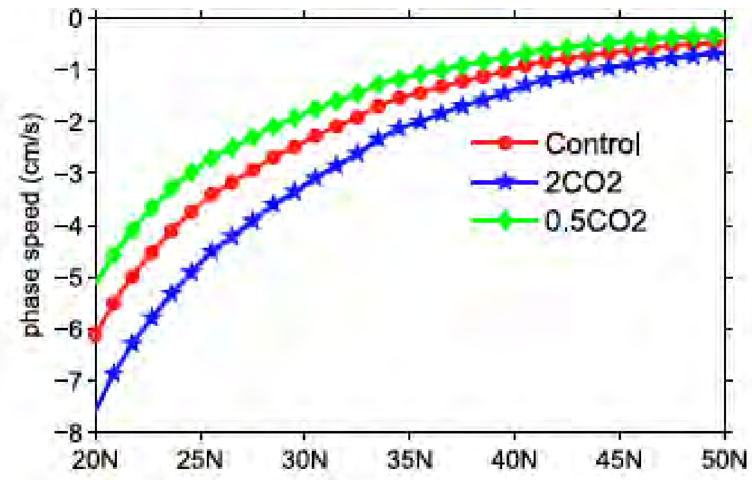
PDO has prediction skill ~1-2 years

In a changing climate

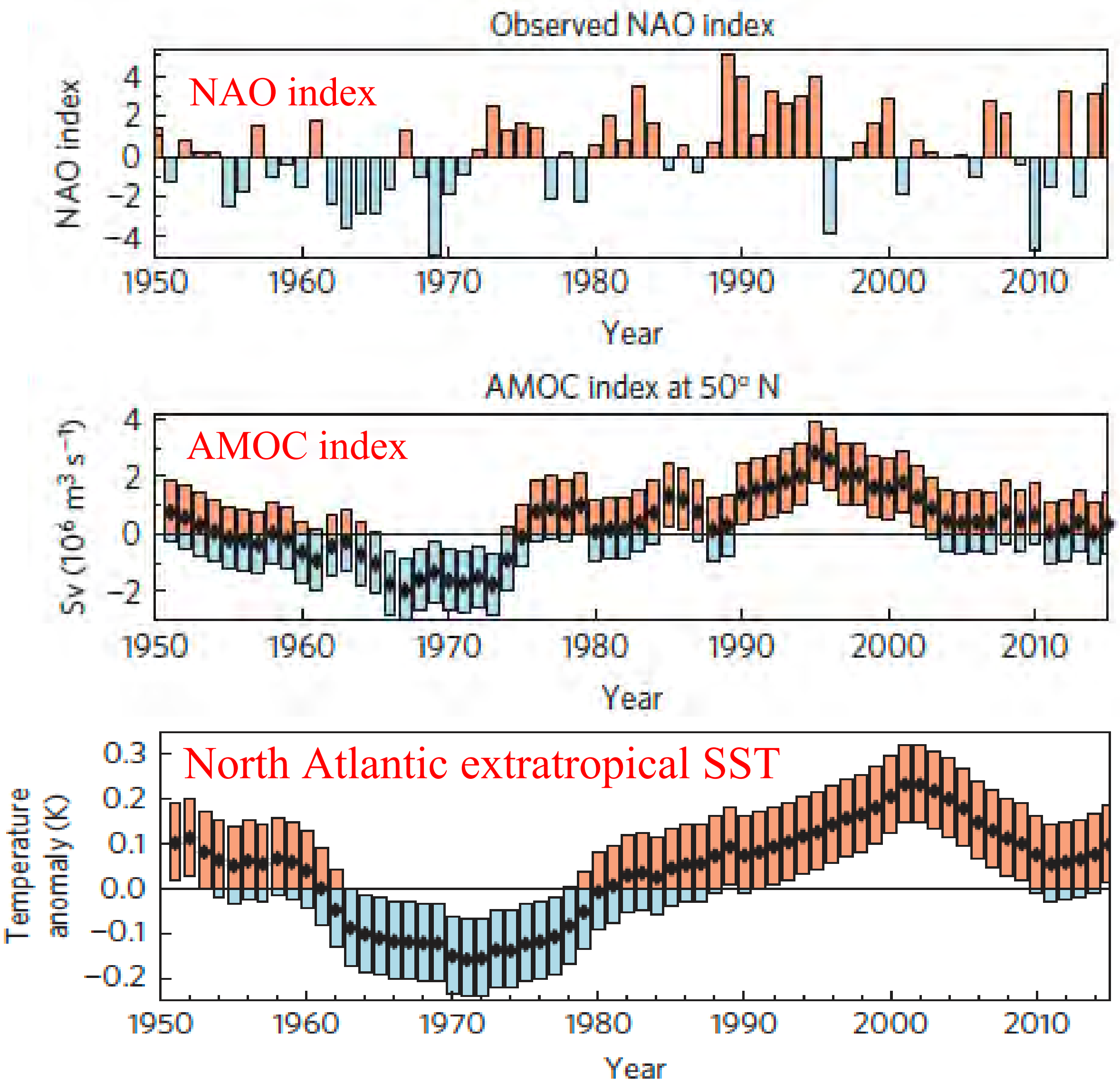
PDO period

- Control : 20 years
- $2CO_2$: 12 years
- $0.5CO_2$: 34 years

Rossby wave speed



Atlantic multidecadal oscillation (AMO)



(Delworth et al. 2016)

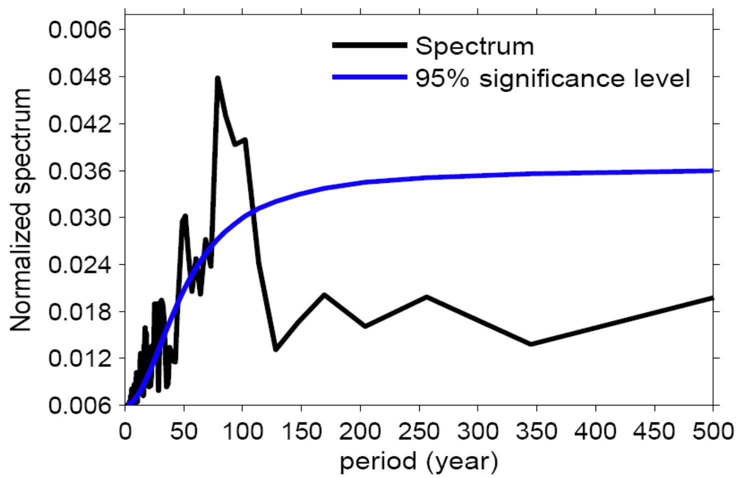
The North Atlantic Oscillation (NAO) is a major influence on subpolar North Atlantic variability through its influence on the AMOC

New initialization system for decadal Prediction: (Xiaosong's poster)

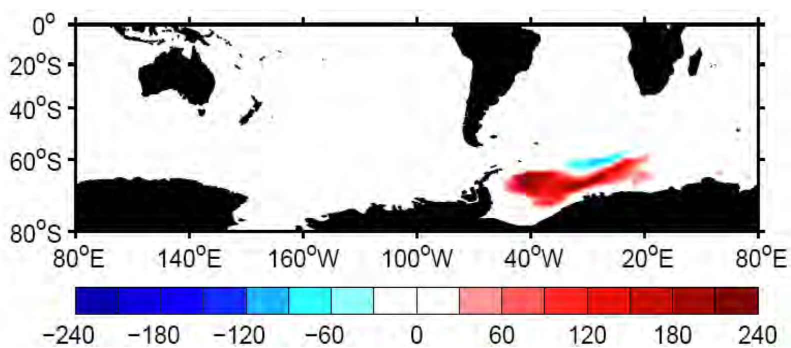
Send output to UKMO as part of an international collaborative effort

Southern Ocean (SO) multidecadal to centennial variability

Power spectrum of deep convection index (CM2.1)

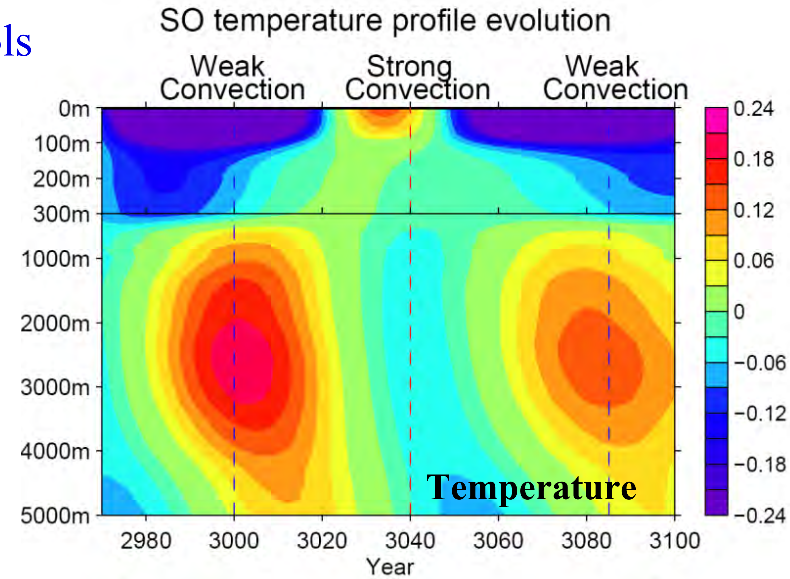


Mixed layer depth in strong convection phase

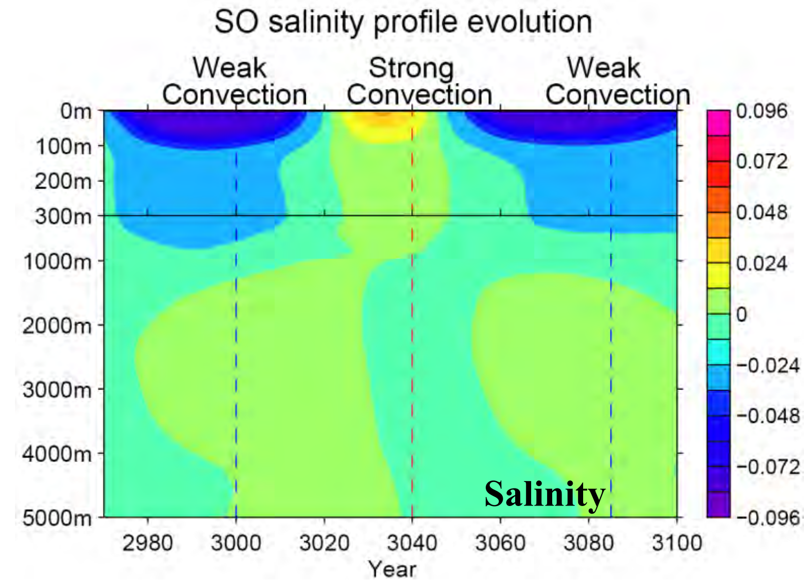


Physical controls of convection

Subsurface heat build up leads to strong convection



Surface freshening weakens convection

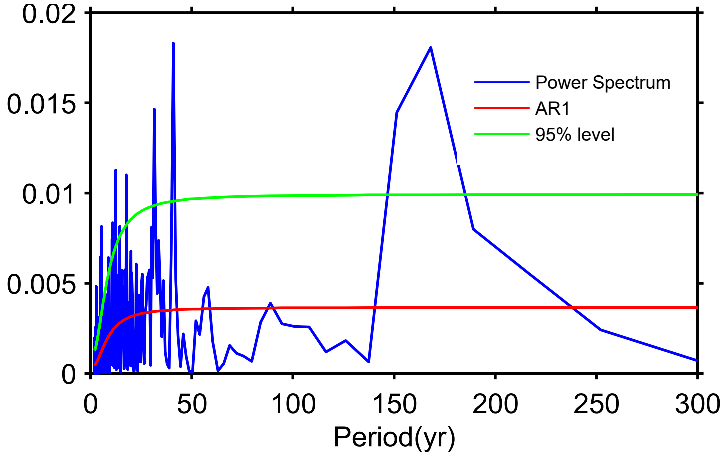


Zhang et al. 2016 JGR-Ocean; Zhang et al. 2017a,b J. Clim

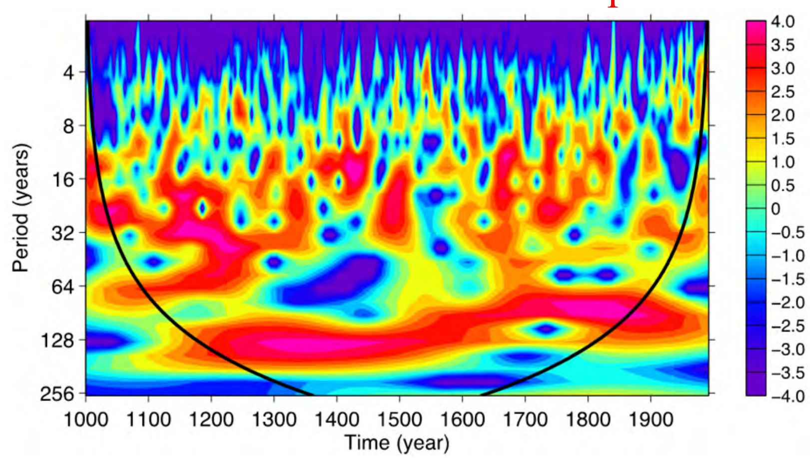
Is this low frequency variability realistic and predictable?

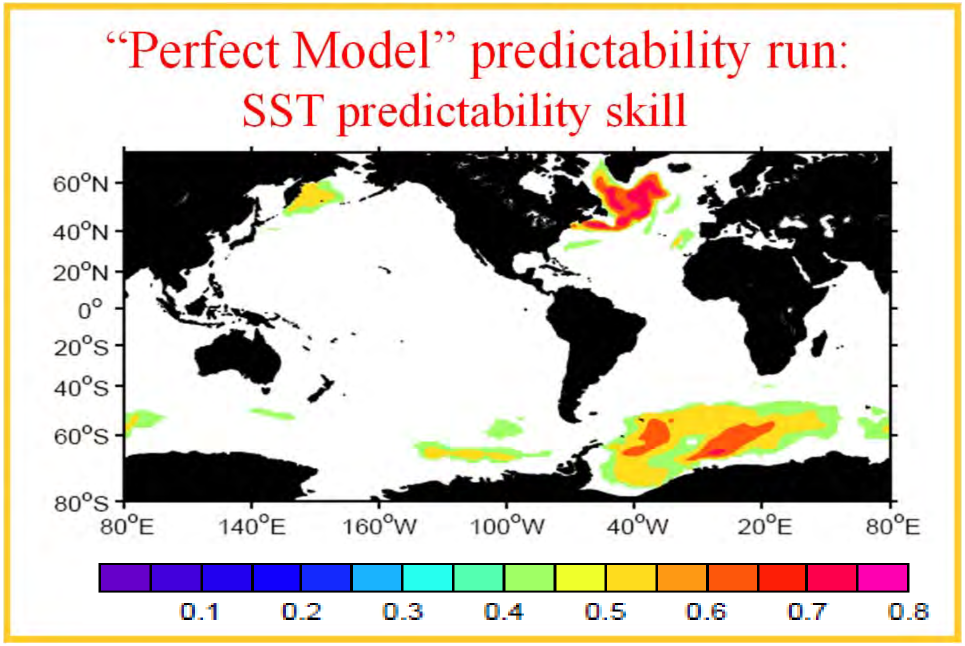
Ice core records over the Antarctic continent (PAGES Antarctica2k database)

Spectrum of whole Antarctic temperature



Wavelet of Weddell Coast temperature



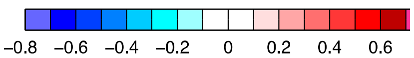


SO internal SST predictability mainly arises from SO deep convection memory

Observed SST trend

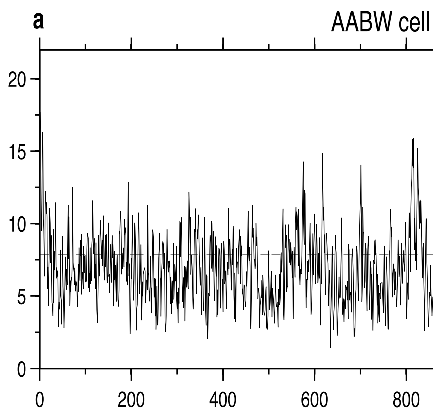
Observed Sea Ice trend (1979-2015)

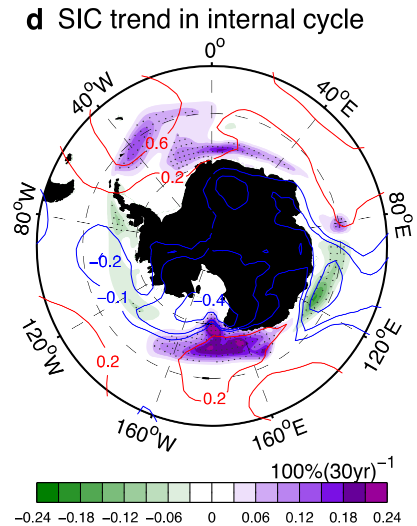
Observed SO surface cooling and sea ice expansion over the last several decades (1979-2015)



Trend following active convection (control run)

SO internal variability in control run

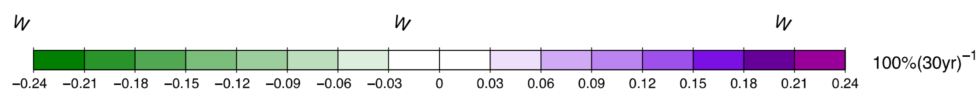




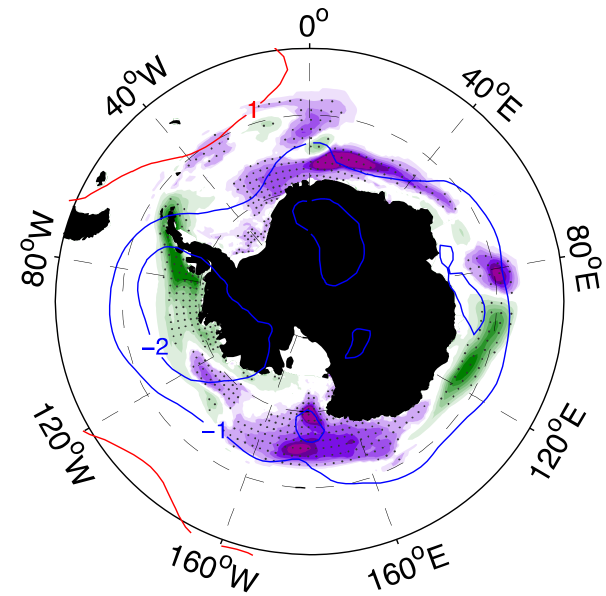
Zhang et al. 2019 Nature climate change

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?

Active inactive neutral



Historical run start from active convection



Summary and Challenges

- The westward propagating Rossby waves play a key role in the PDO mechanism and the PDO changes to climate change is related to the changing vertical stratification *(Zhang and Delworth J. Clim 2015, 2016)*

- The NAO is a major influence on North Atlantic variability through its influence on the AMOC *(Delworth et al. Nature Geoscience 2016a; Delworth et al. J. Clim 2016b, 2017)*

- The Southern Ocean internal variability can explain recent observed trends … and they may be predictable *(Zhang and Delworth JGR-Ocean 2016; Zhang et al. Clm. Dyn 2017a; Zhang et al. J Clim 2017b,c; Zhang et al. Nature climate change 2019)*

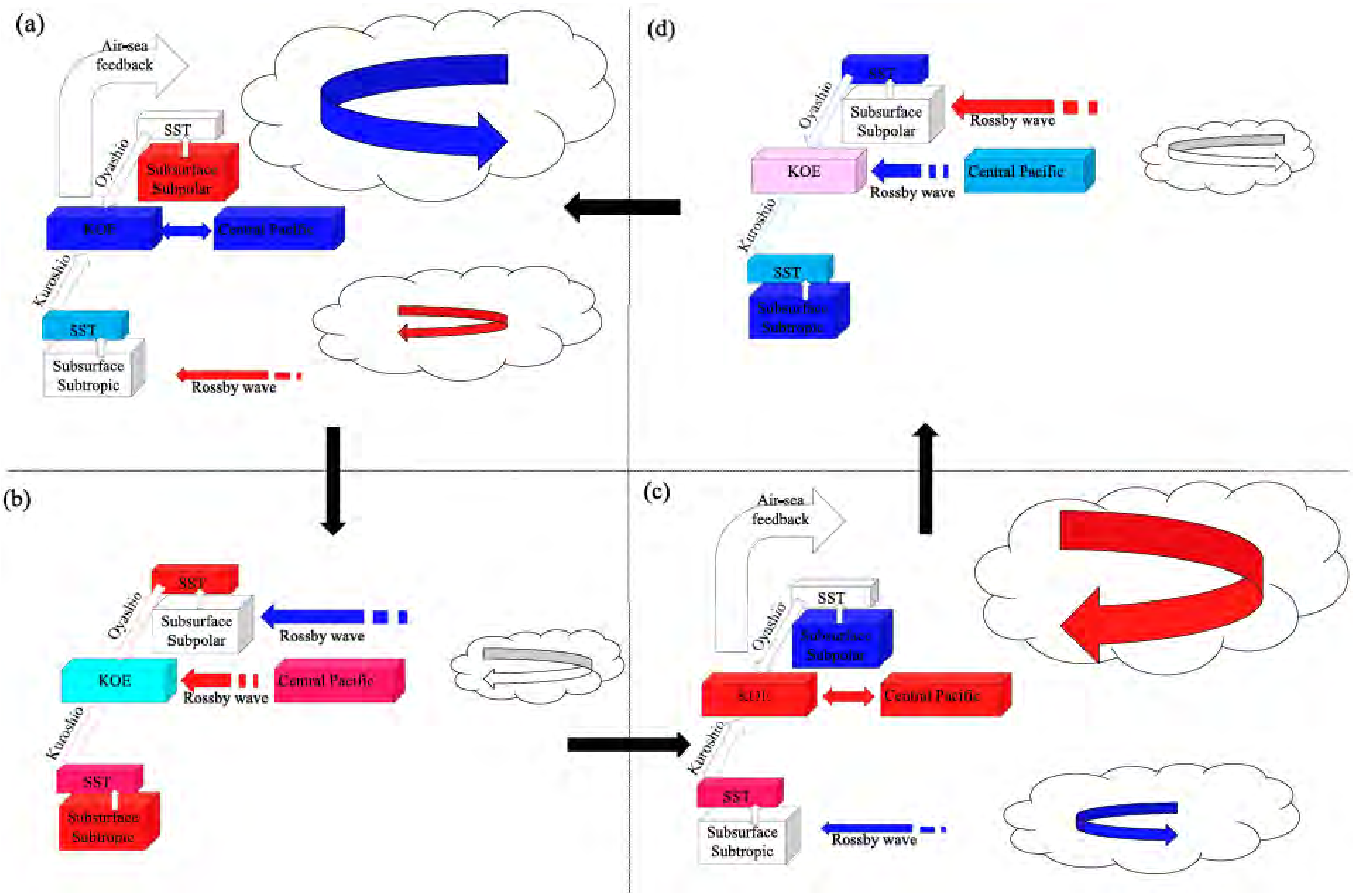
Challenges:

- Sparse observations
- Multiple processes are at work in each basin, and thus attribution to one set of processes can be difficult
- Model physics, especially ocean model (e.g., bias, resolution and mean state)

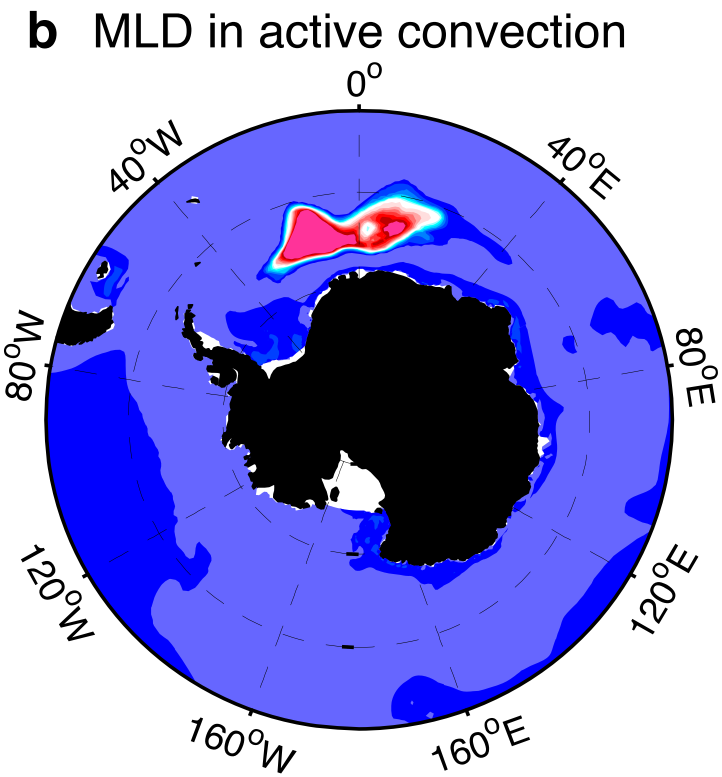
Backup slides for questions

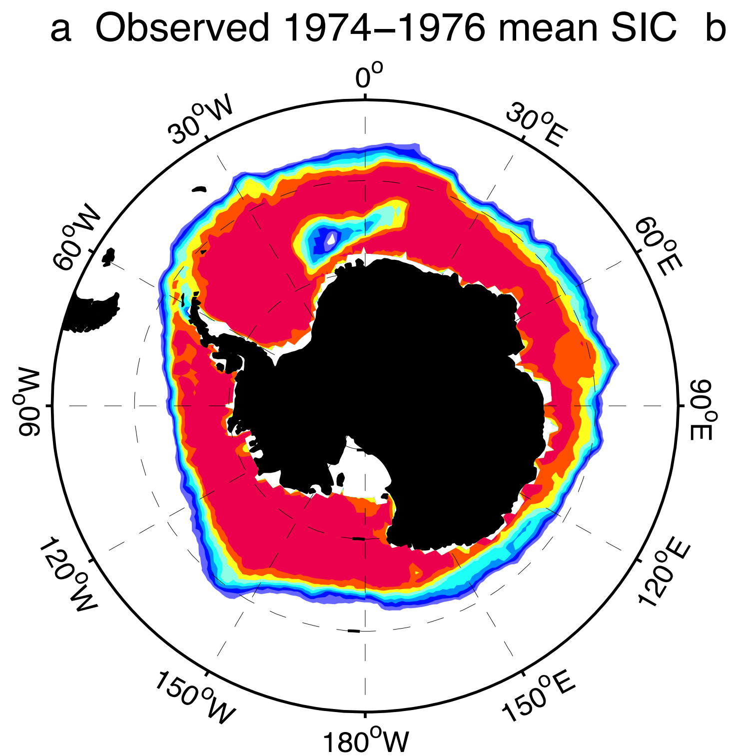
Schematic picture of the PDO full cycle

Peak warm phase

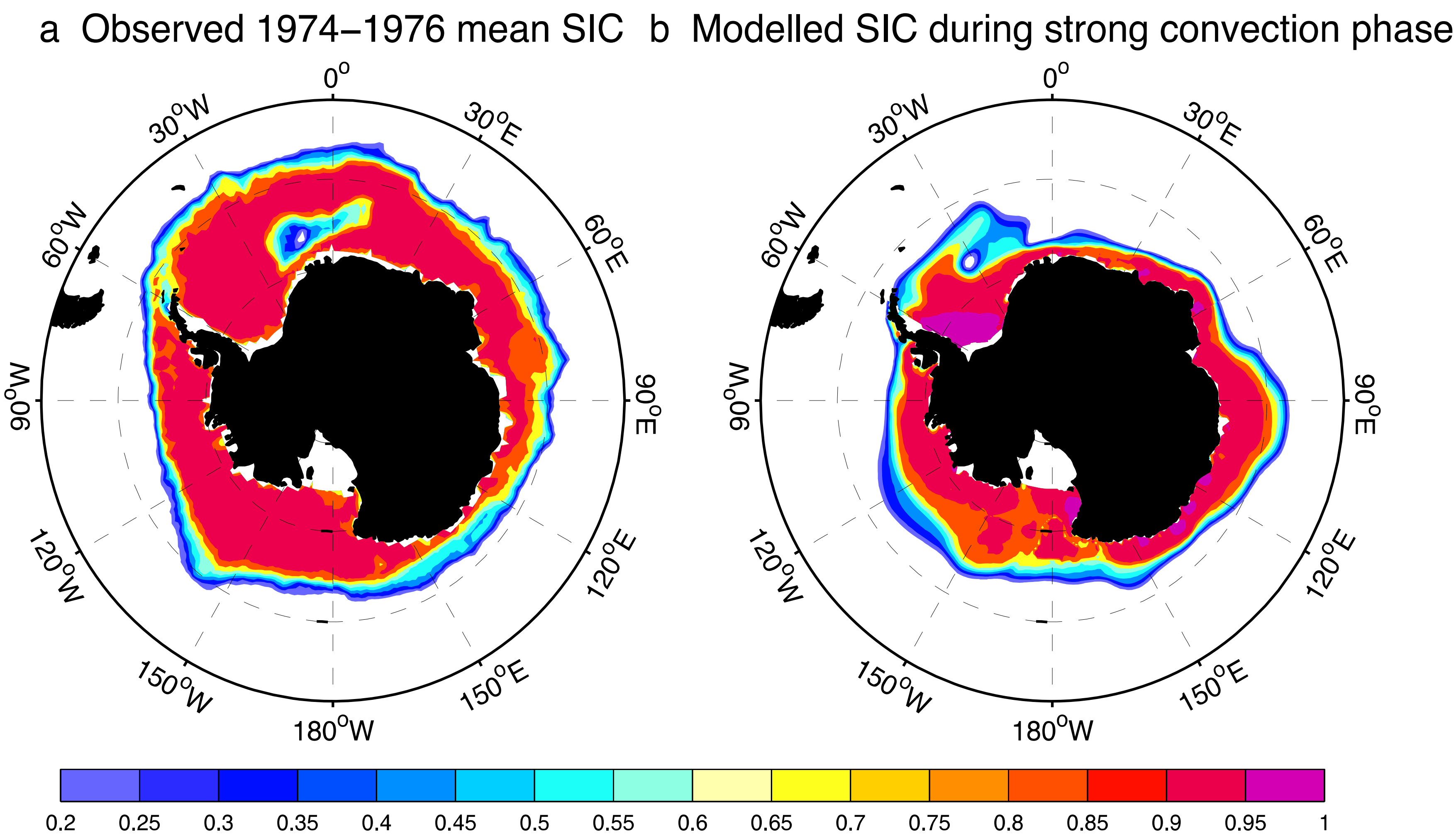


Peak cold phase

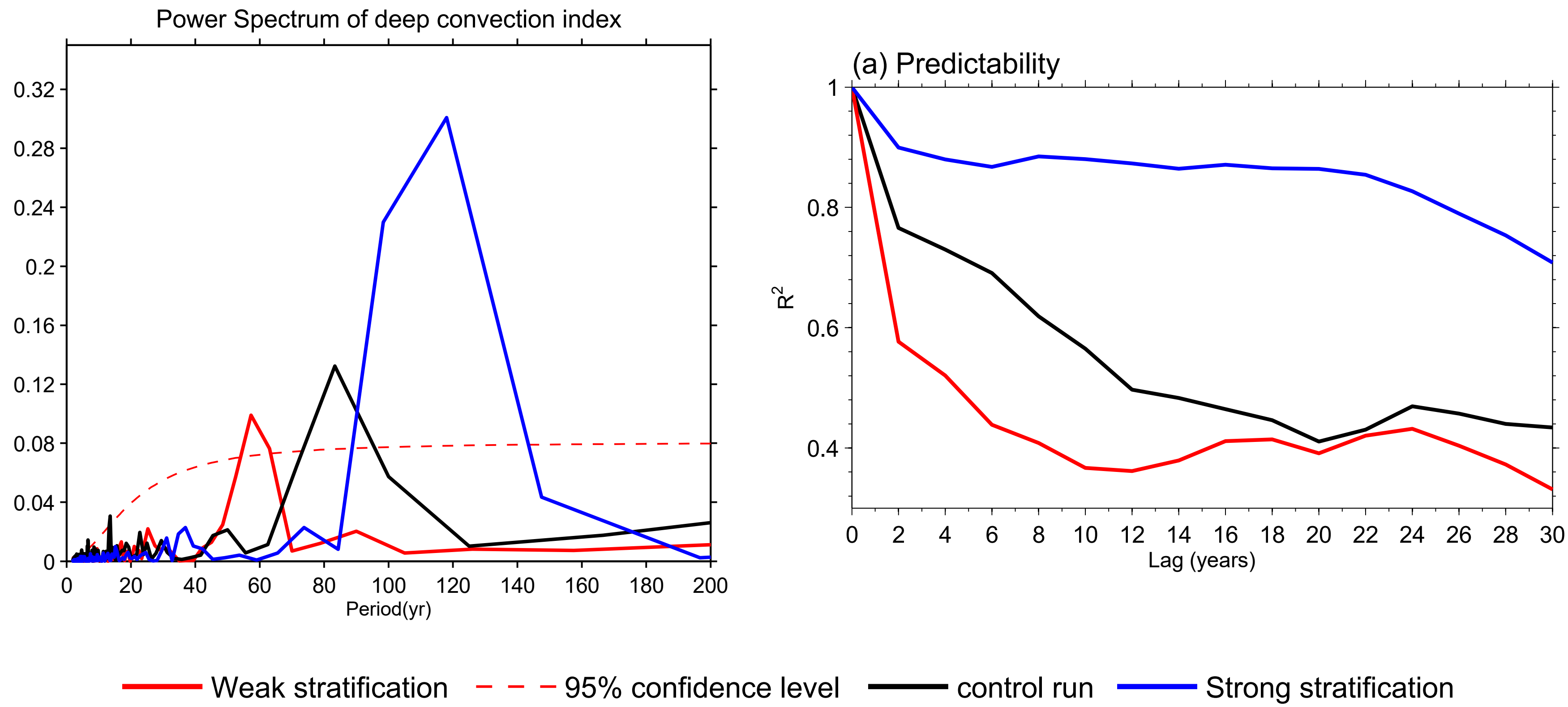

b MLD in active convection
0°
40°W
40°E
80°W
80°E
120°W
120°E
160°W
160°E


a Observed 1974–1976 mean SIC b
0°
30°W
30°E
60°W
60°E
90°W
90°E
120°W
120°E
150°W
150°E
180°W

Observed and Modelled Weddell Polynya



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



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

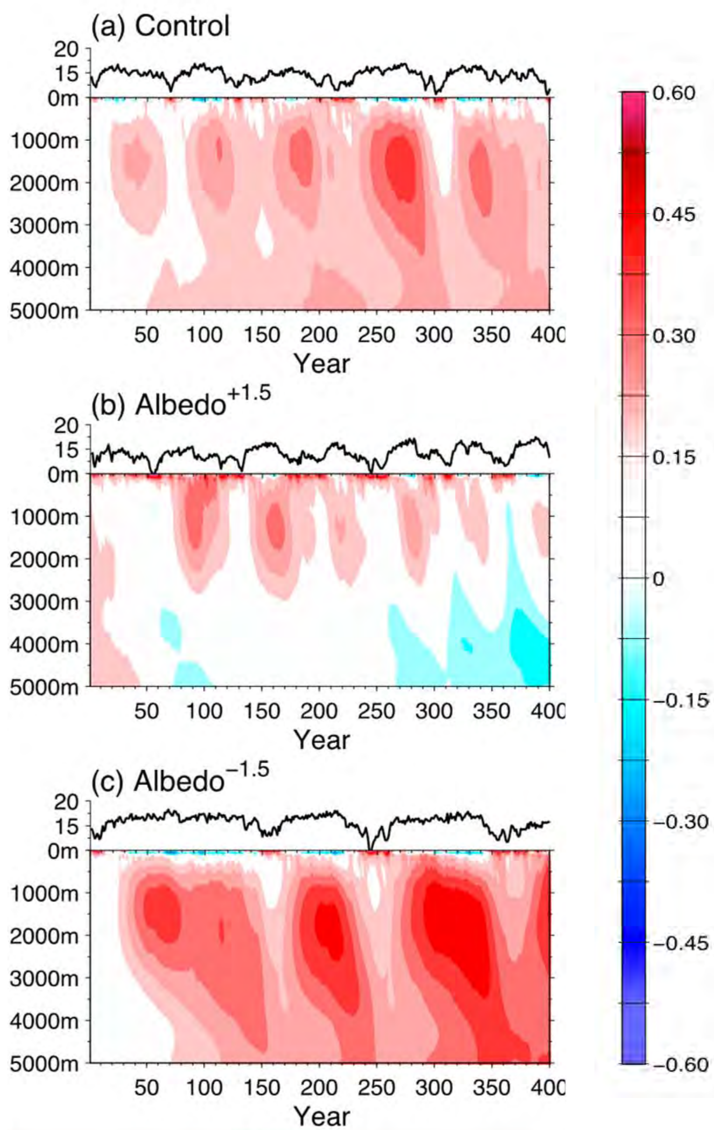
Zhang et al. (2019) to be submitted

Subsurface heat buildup

Control run

Weak stratification

Strong stratification

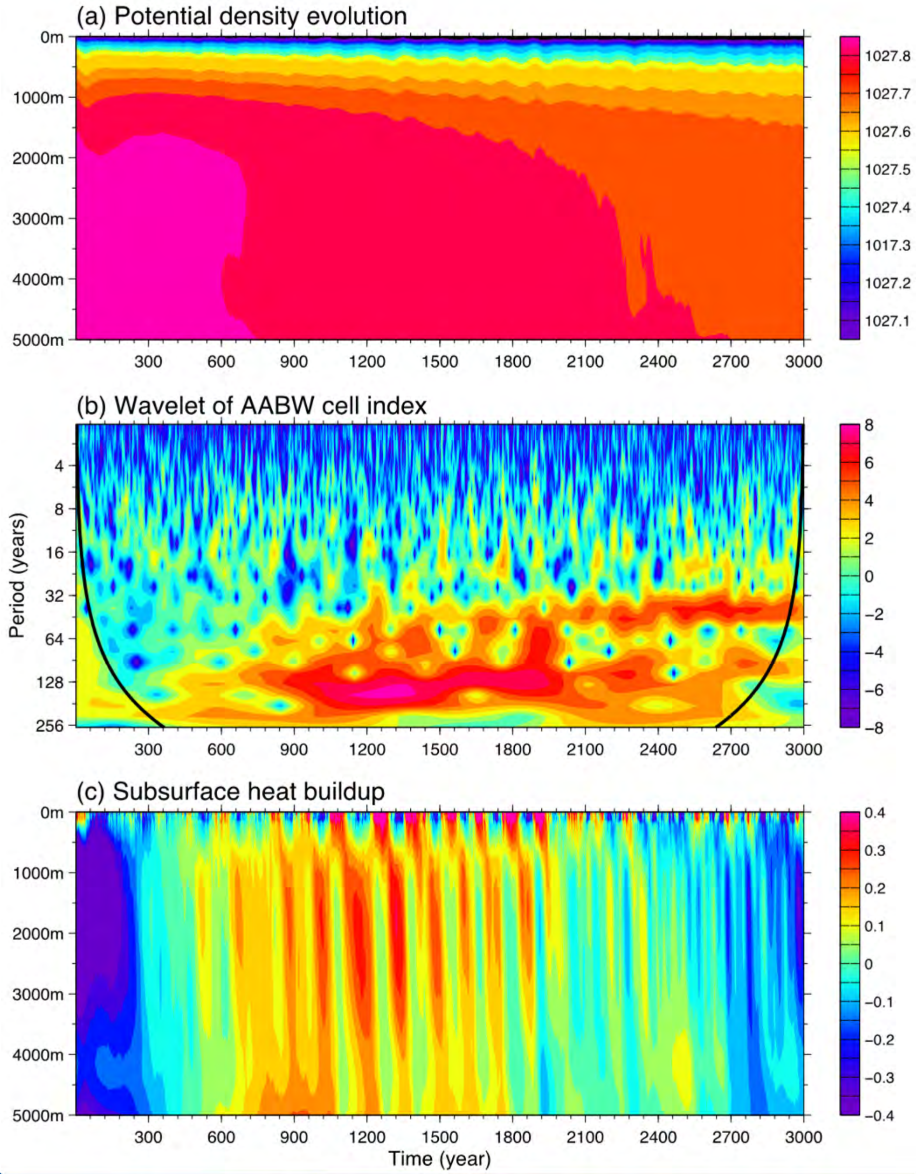


LOAR2 model

Stratification

Wavelet of
deep convection index

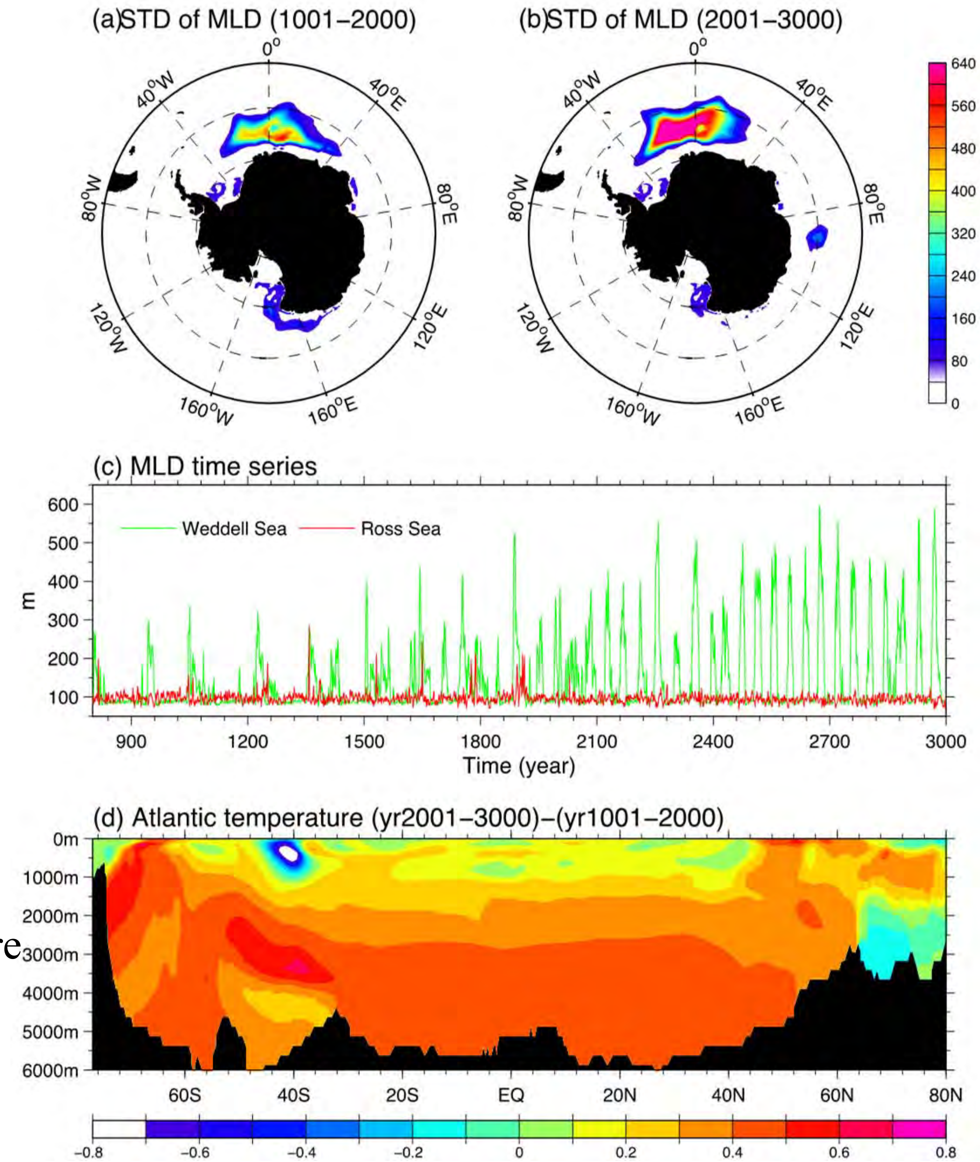
Subsurface heat buildup



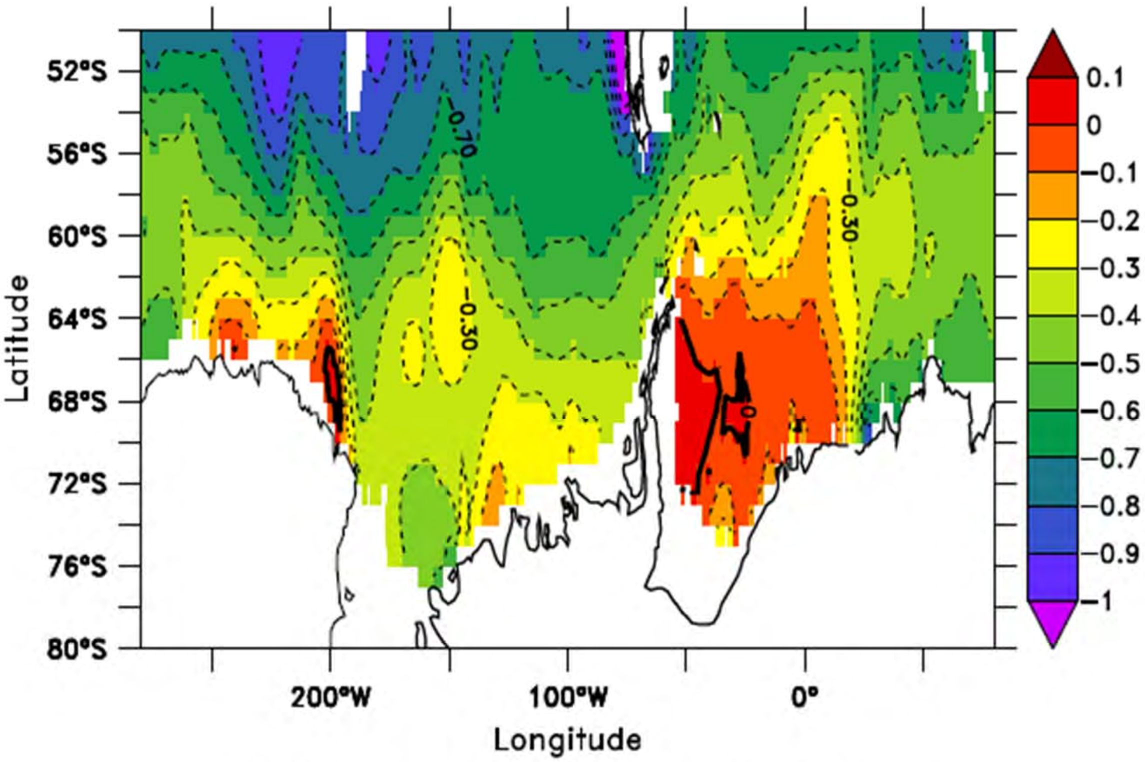
LOAR2 model

Mixed layer depth

Atlantic zonal mean temperature



Southern Ocean stability in wintertime



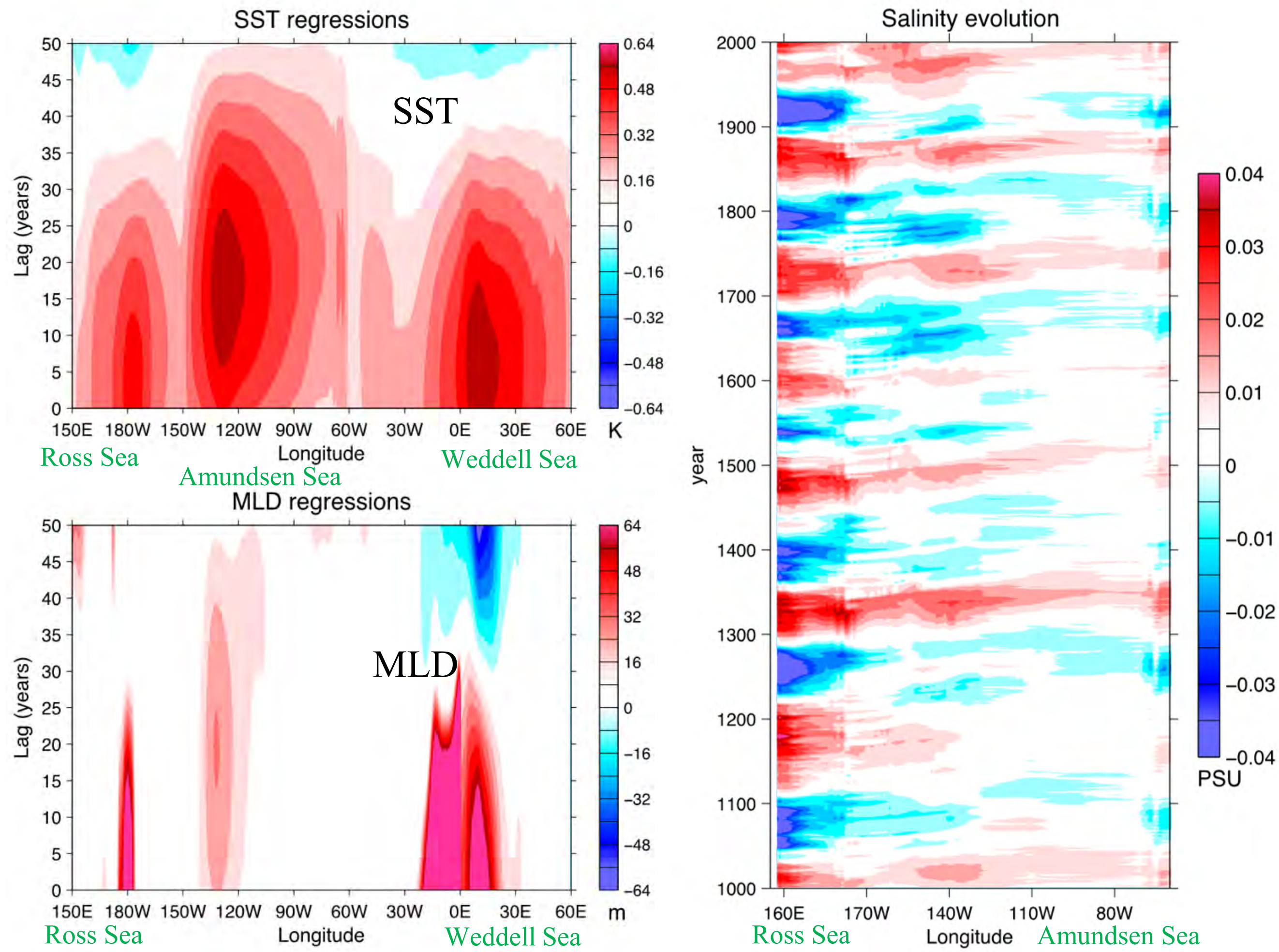
(a) Observed Sep $\Delta\sigma_{1.5}$ 0–1500m

Conditional instability of upper column defined as late wintertime difference between surface and 1500m potential density. Positive value means conditionally unstable

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

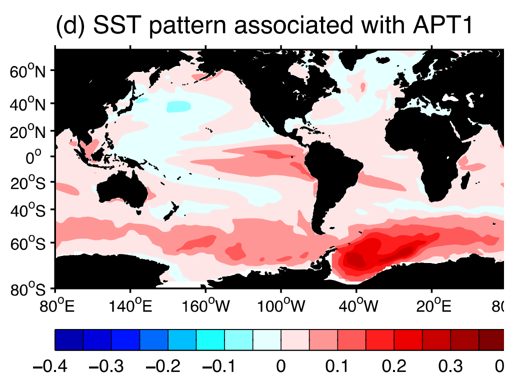


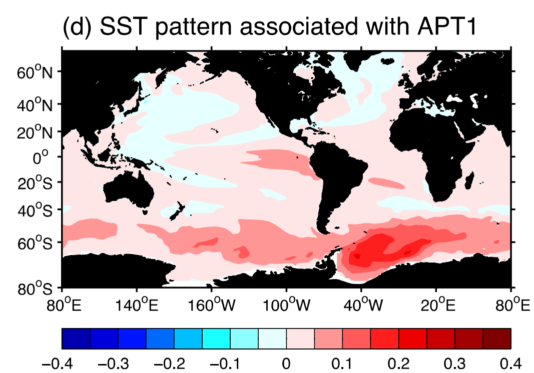
Climate impa

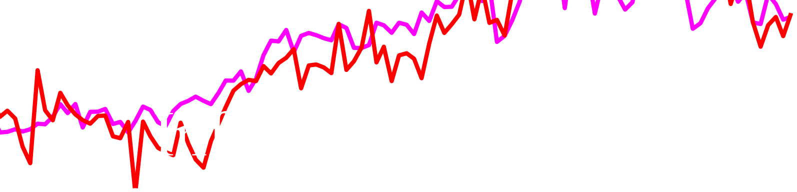
a generalized APT n

$\widehat{\boldsymbol{X}}_{t+\tau} = \boldsymbol{L}_{\tau}\, \mathbf{x}(\mathrm{t}) + \in (t)$

The most predictable





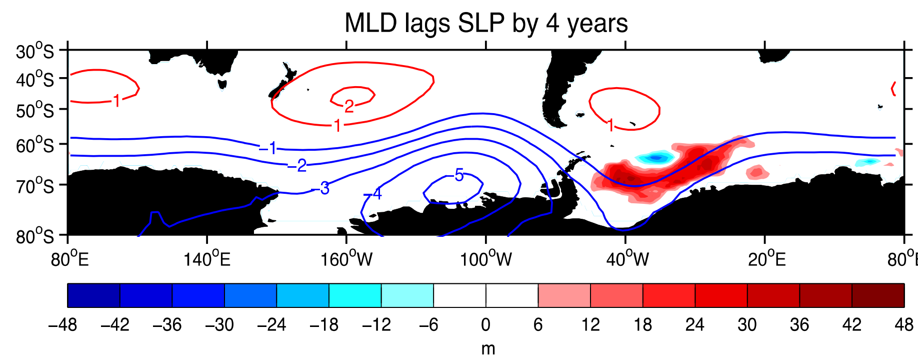


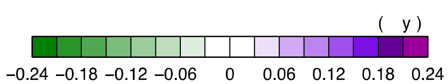
Internal cycle

Sea
ice/SLP
trends

SLP trend:
~ 0.2 hPa/30yr

SLP trend:
~ 5 hPa/30yr





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