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

Presented by Liping Zhang
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
- 2CO2 : 12 years
- 0.5CO2 : 34 years

Rossby wave speed

Zhang and Delworth, J Clim (2015, 2016)
Atlantic multidecadal oscillation (AMO)

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.

(Delworth et al. 2016)
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)

“Perfect Model” predictability run: SST predictability skill

SO internal SST predictability mainly arises from SO deep convection memory
Could SO internal variability play a role in explaining observed trends?

- Observed SST trend
- Observed Sea Ice trend (1979-2015)

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

SO internal variability in control run

Trend following active convection (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? 

**Ensemble simulations for 1979-2015:**

- **A:** Initialize from active phase of convective cycle
- **B:** Initialize from inactive phase
- **C:** Initialize from neutral phase

Reproduces observed trends!

Does NOT reproduce observed trends!

Does NOT reproduce observed trends!

Zhang et al. 2019 Nature climate change
Annual mean sea ice trends

Observation

Internal cycle in control run

Historical run start from active convection

Zhang et al. 2019 Nature climate change
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
MLD response in active convection

a Observed 1974–1976 mean SIC

b MLD in active convection
Observed and Modelled Weddell Polynya

b. Modelled SIC during strong convection phase
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

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

a generalized APT n

\[ \hat{X}_{t+\tau} = L_{\tau} x(t) + \epsilon(t) \]

The most predictable

(d) SST pattern associated with APT1
Observation

Internal cycle

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

MLD leads SLP leads

Lagged Maximum Covariance Analysis (MCA)

Annual MLD, seasonal SLP

Ocean feedback is very weak compared to atmosphere forcing

Sea ice/SLP trends

SLP trend:
~ 0.2 hPa/30yr

SLP trend:
~ 5 hPa/30yr