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Is the PDO a coupled Atmosphere-Ocean Process?

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14 January 2016

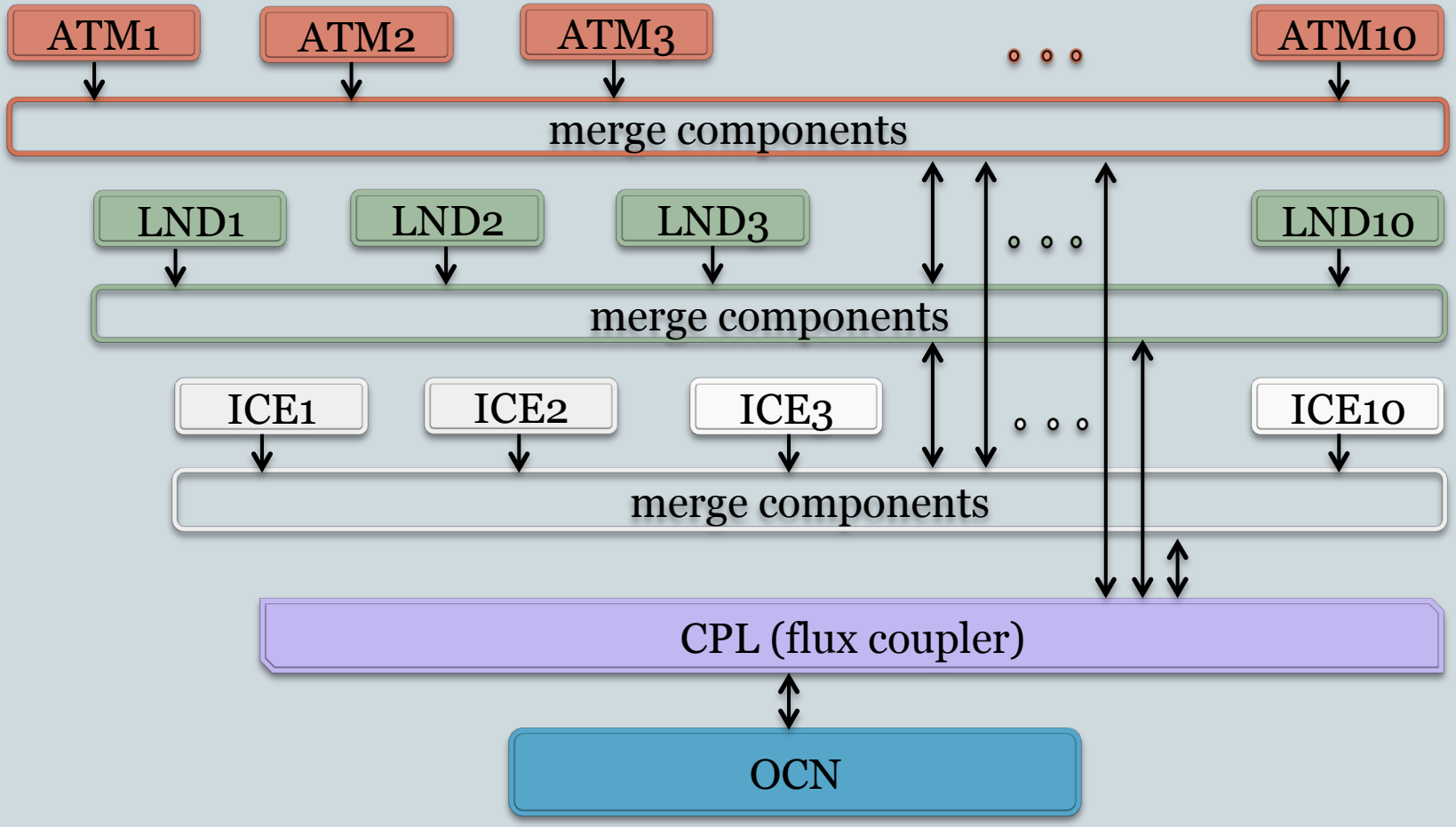
AMS 86th Annual Meeting 10-14 January 2016, New Orleans, LA

Is the PDO a coupled Atmosphere-Ocean Process?

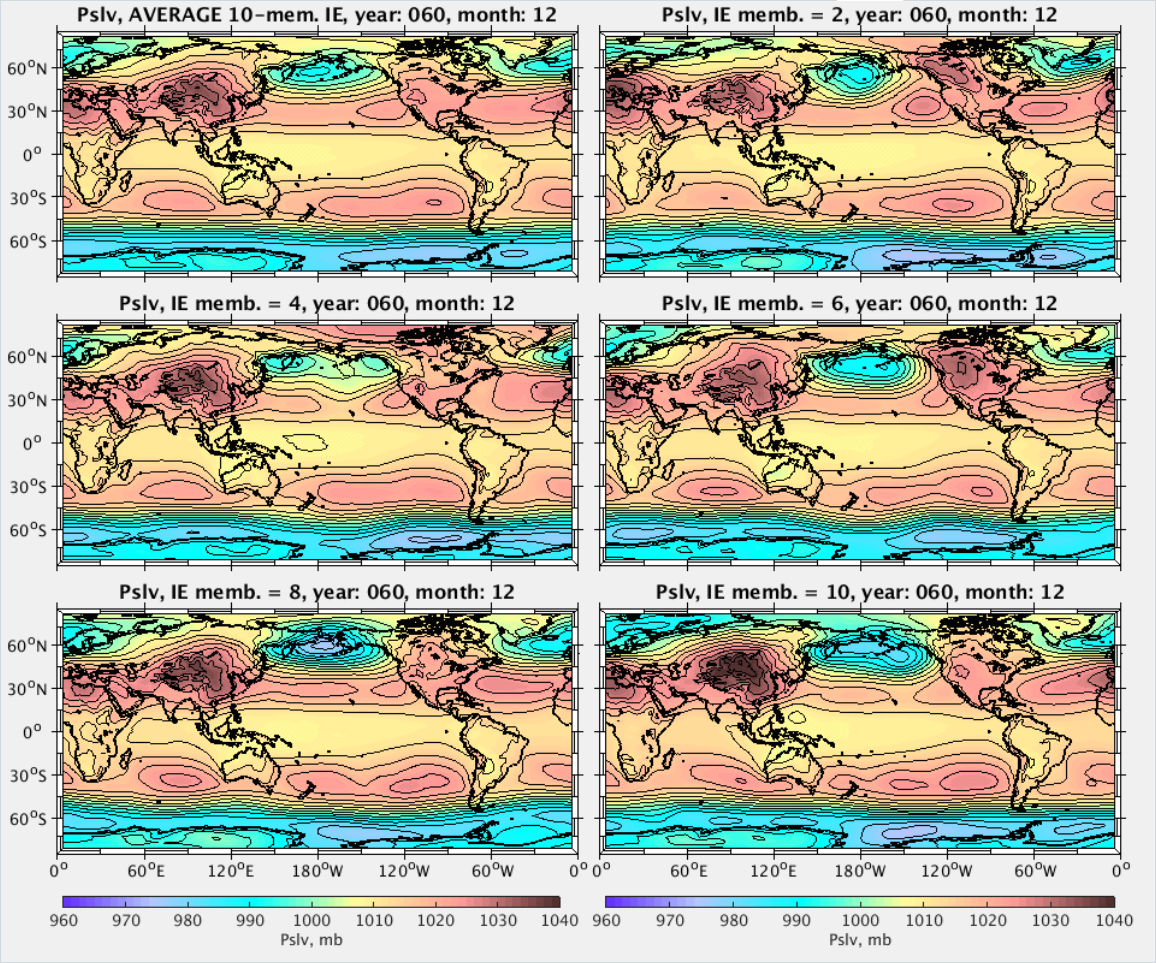
- Aim:
  - Examine coupled processes vs. stochastic forcing in multi-year North Pacific SST variability
- Approach:
  - Interactive Ensemble simulations (>100 years) based on the Community Climate System Model v.4, involving:
  - Ten (10) realizations of Global atmosphere/land/ice model components coupled to a single ocean model component
- Methods:
  - Separate coupled climatic signal from the stochastic weather variability: IE CCSM4 vs. control (single-component) CCSM4
  - Analyze the modes of variability in the North Pacific

Interactive Coupling (IE) CCSM4 approach

Temperature perturbations introduced to the atmospheric components at the initial time

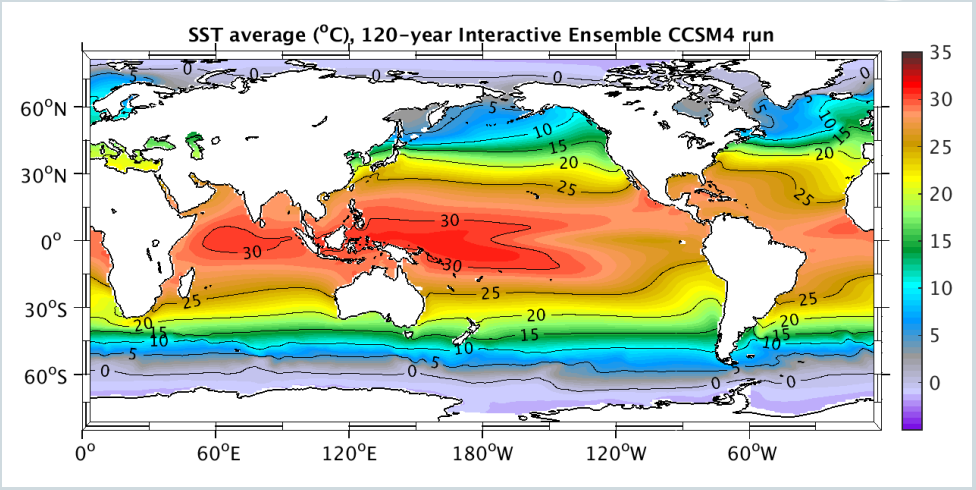


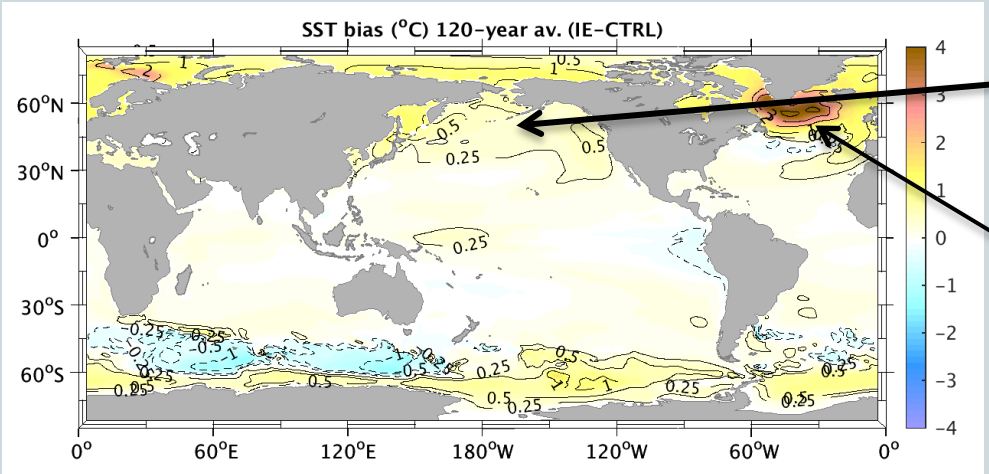
Interactive Ensemble spread in sea level pressure



- Example of monthly mean sea level pressure (Pslv, mb) in different realizations of the atmospheric components

Interactive Ensemble vs. control CCSM4





- ✓ Model output:
  monthly average fields (SST)
- ✓ Control CCSM4: single atmosphere/land/ice/ocean component
- ✓ 120 years analyzed following a 5-year spin-up period
- ✓ North Pacific – region of interest for the PDO
- ✓ NB: Strong warm bias in AMOC region

Null Hypotheses for the SST variability

- Original Null Hypothesis (Hasselman, 1976; Frankingnoul and Hasselman, 1977):
  - Stochastic weather variability (white noise) is integrated by the ocean to produce low-period oceanic response in the mid-lattitude upper ocean/ sea surface temperatures (red noise)
- Use the Ensemble mean X_E over the M ensemble members of the X_k to isolate the climate signal X_S from the stochastic weather noise N_k :

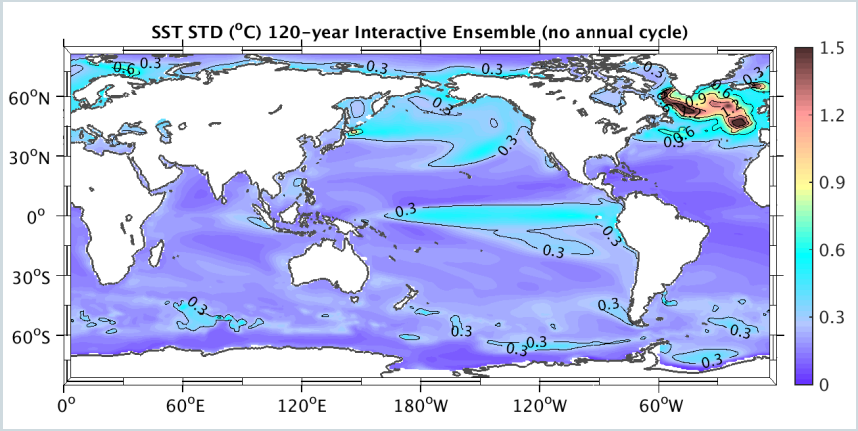
$$X_k = X_S + N_k$$

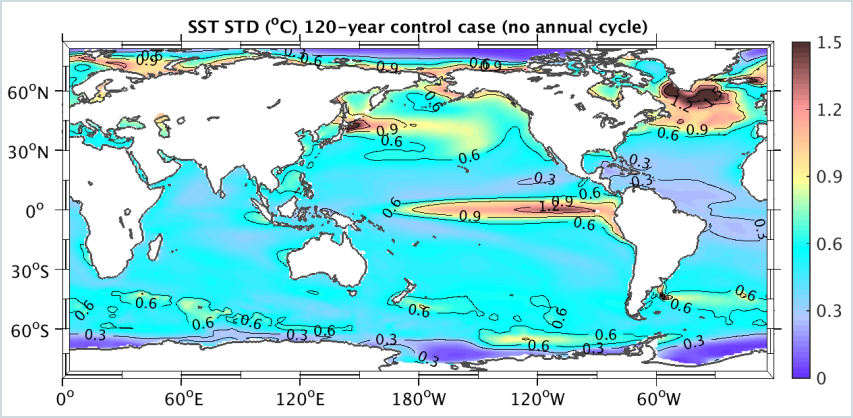
$$X_E = X_S + \frac{1}{M}\sum_{k=1}^{M} N_k, \quad \lim_{M\to\infty}(X_E) = X_S$$

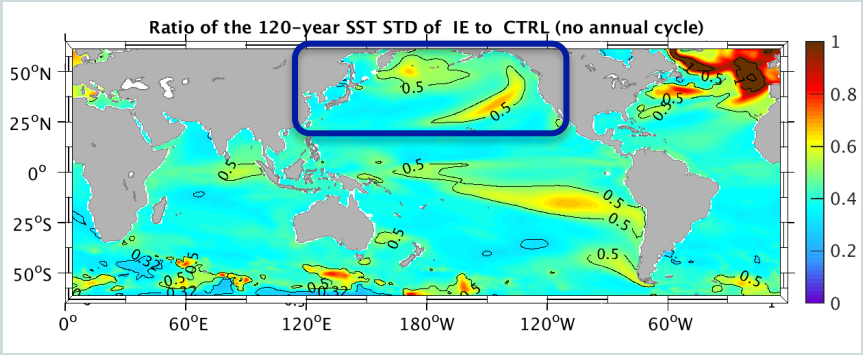
- Null Hypothesis for the Interactive Ensemble (Yeh and Kirtman, 2004):
  - Coupled air-sea interactions are viewed as stable feedbacks
  - If the ocean noise is small compared to the atmospheric noise, SST variance for the interactive ensemble of M members, σ^2_{IE}, is reduced compared to the single-member model σ^2_o:

$$\frac{\sigma^2_{IE}}{\sigma^2_o} \approx \frac{1}{M}, \qquad \frac{\sigma_{IE}}{\sigma_o} \approx \frac{1}{\sqrt{M}}$$

SST Variability for the Interactive Ensemble







Kirtman et al. (2005)

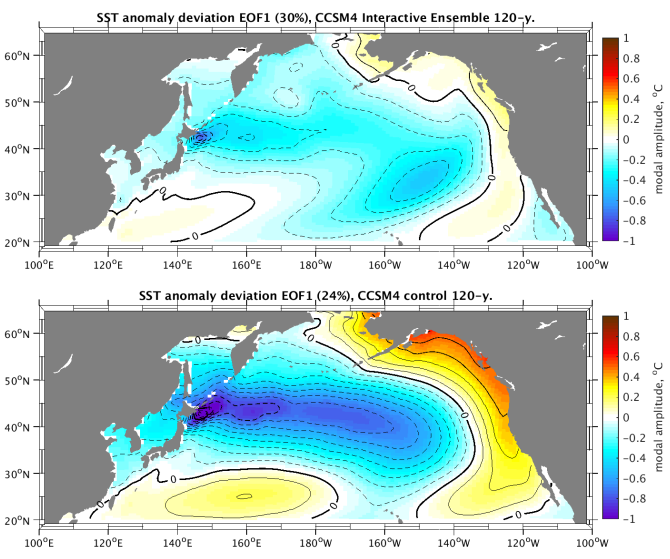
- Ratio is less than $1/\sqrt{M} = 1/\sqrt{10} \approx 0.32$:

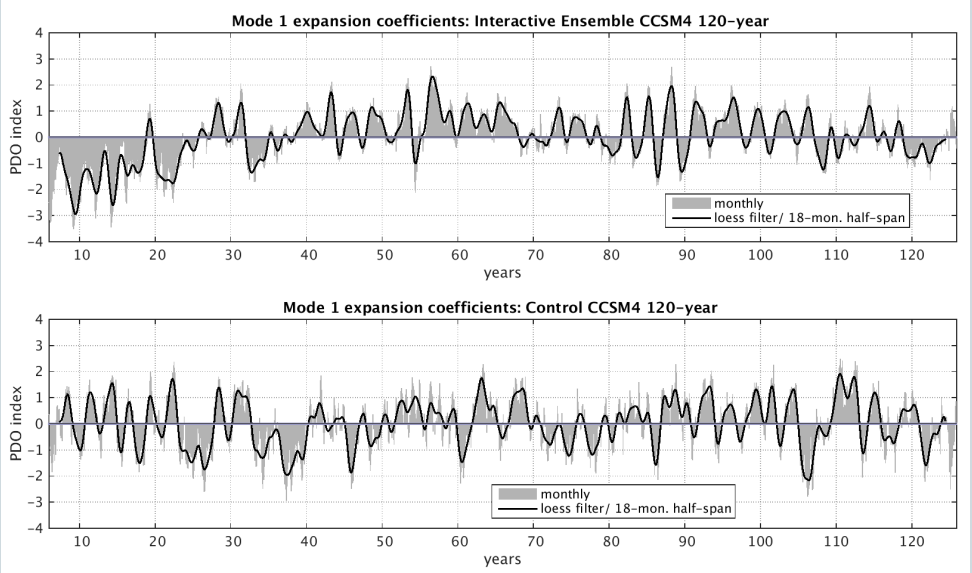
  largely integrated atm. noise

- Ratio is between $1/\sqrt{10}$ and 1:
  ocean dynamics, non-linearity, or unstable coupled feedbacks

- Ratio is greater than 1:
  unstable coupled feedbacks, non-linearity

PDO region: North Pacific SST anomalies





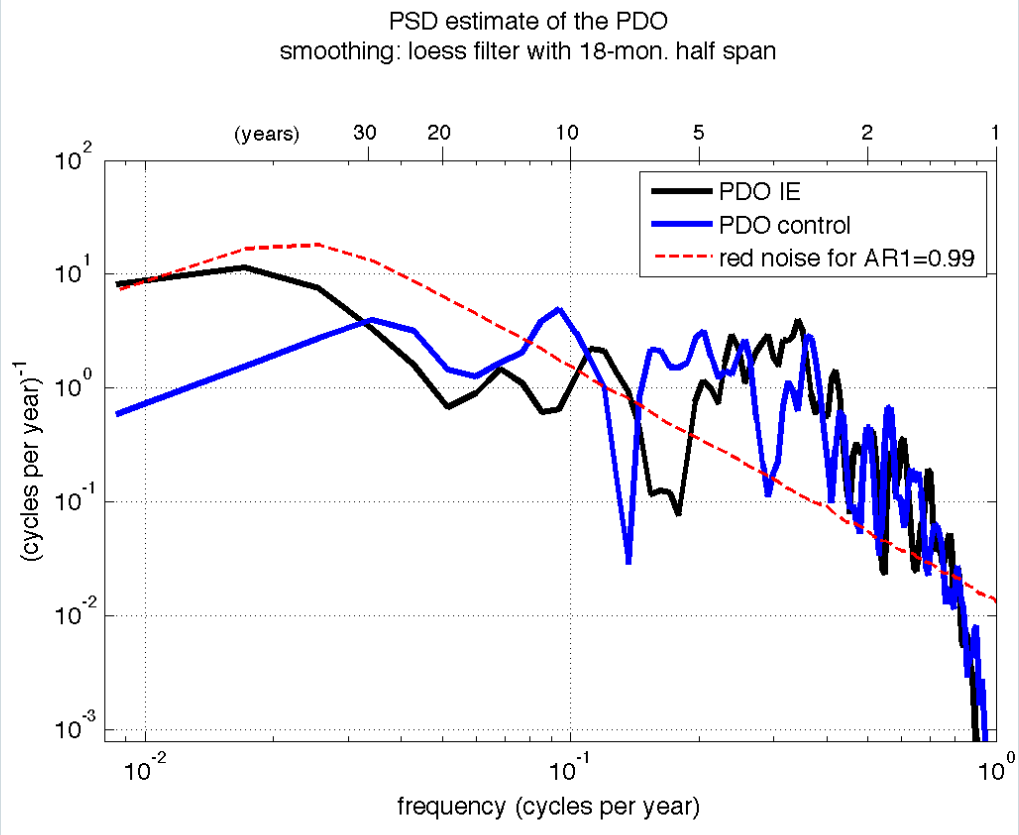
PDO index (Zhang et al., 1997):

PC1 (Principal Component) of the SST anomaly deviation for Pacific SST north of 20N

SST anomaly deviation: $SSTA^{*}_{x,y,t} = SSTA_{x,y,t} - [SSTA]_t$

(less global anomaly)

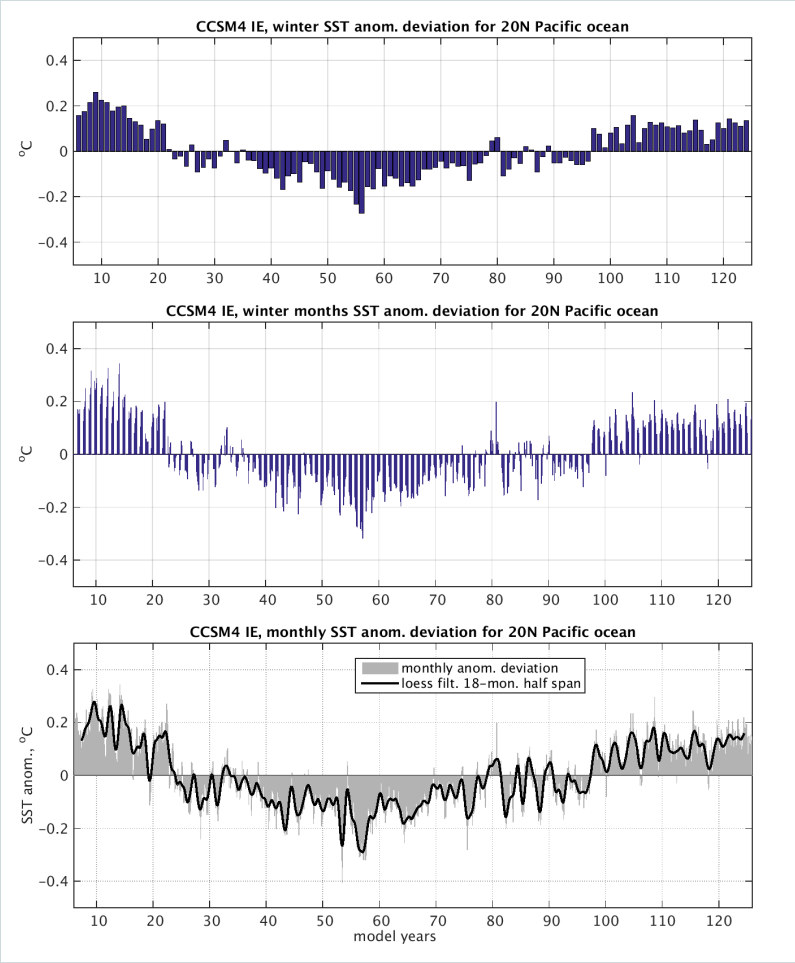
PDO index spectral analysis

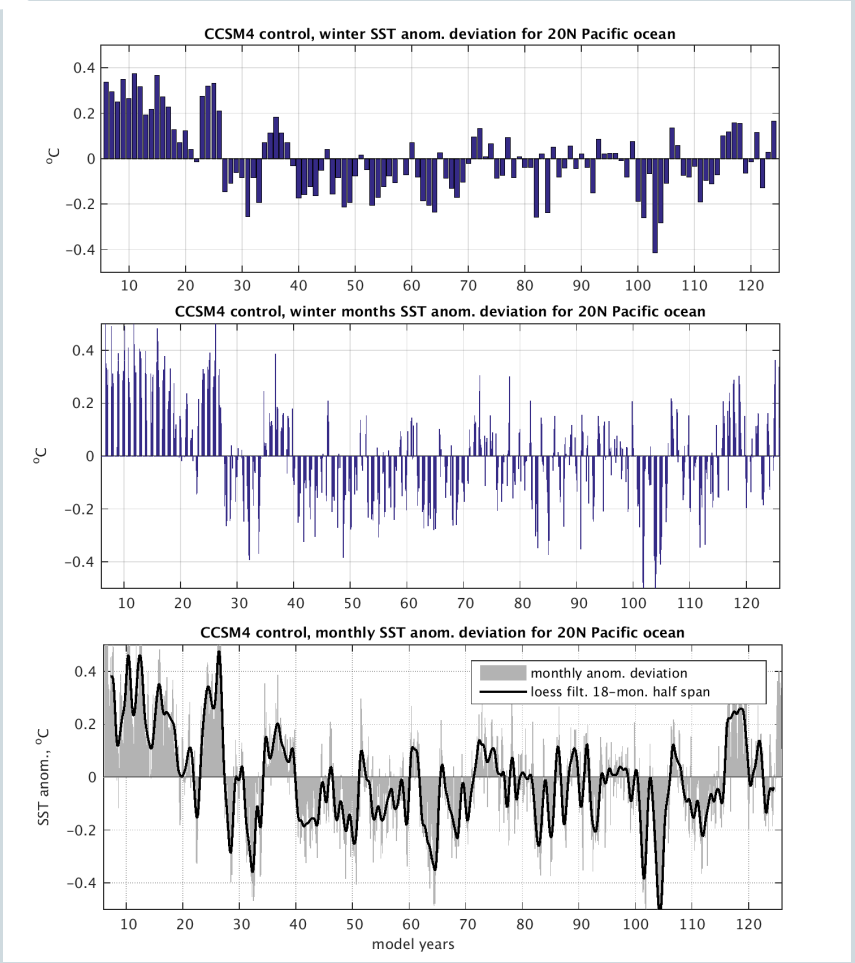


Autocorrelation with lag-1 for the filtered time series is AR1 ~0.99

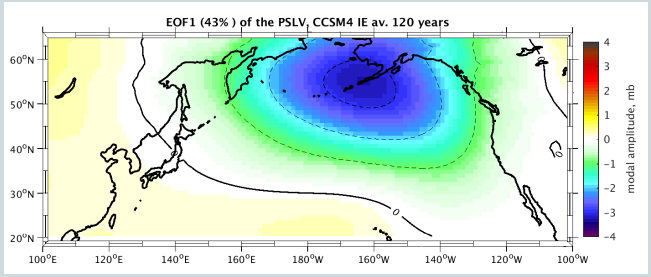
- Much variability is present at the ENSO time scale (2-7 years)
- Control simulation shows a notable peak at the decadal time scale
- Higher spectral estimates for the IE simulations result at lower frequencies

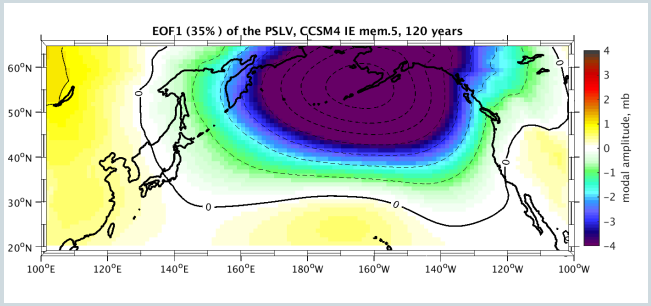
PDO index as spatial average of the SST anomaly for the N.Pacific (20N)

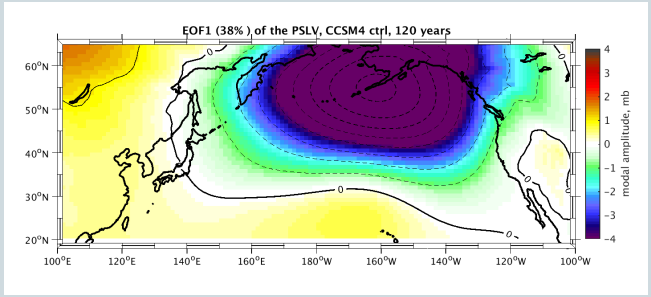


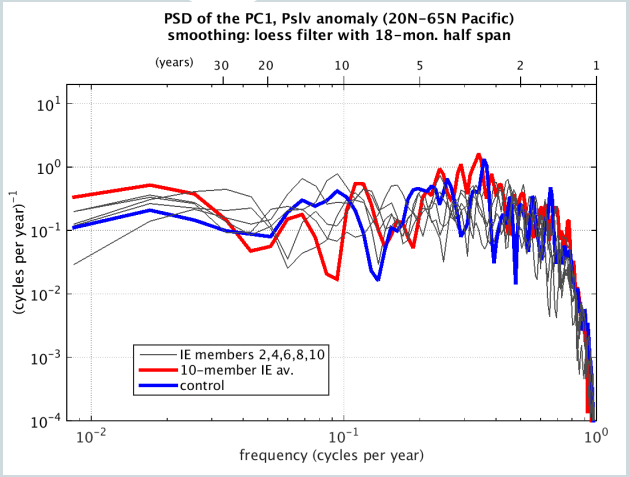


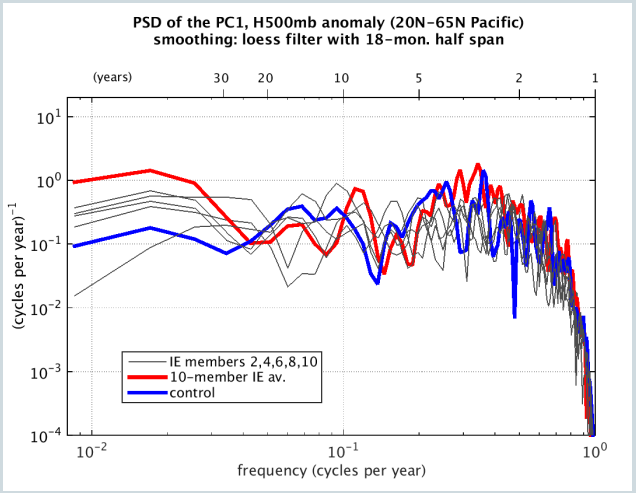
Atmospheric pressure systems variability for the North Pacific (20N -65N)





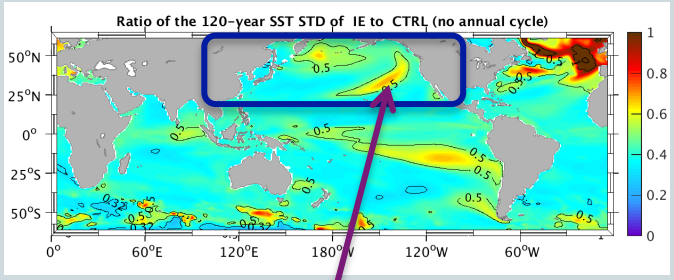




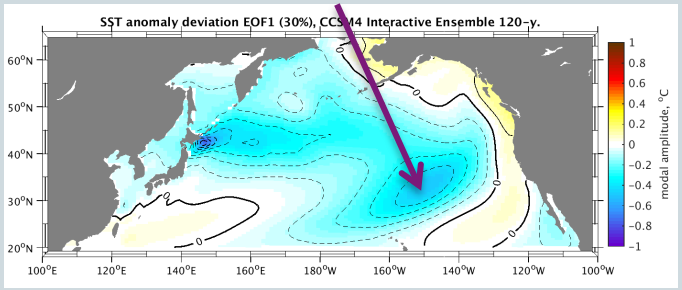


Individual ensemble members produce variations in atmospheric forcing (Pslv, H500mb) on a range of time scales

Summary for the PDO region SST variability



similar region

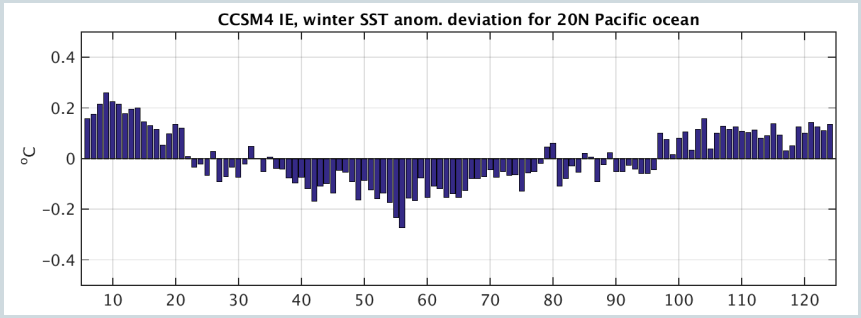


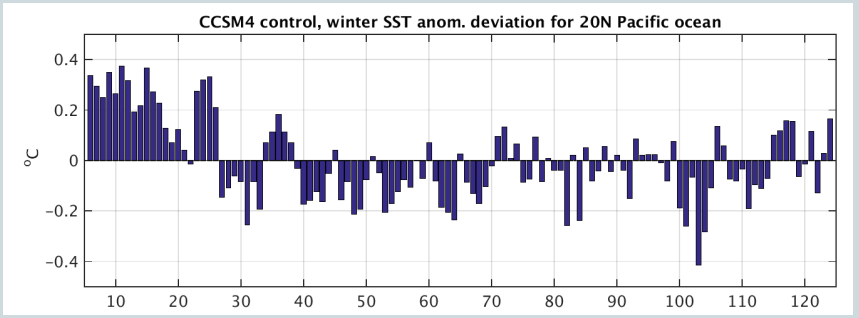
- ✓ SST σ_{IE}/σ_o ratio between 0.5 and 1 in two separate regions in N. Pacific:

  Possible indication of the two areas of enhanced air-sea interaction

- ✓ Two regions manifested in PDO spatial signature in the Interactive Ensemble simulations (also in Yeh and Kirtman, 2004)

- ✓ IE CCSM4 SST variability in the PDO region shows stronger lower-frequency variability (multi-decadal time scale) than the control run (~ decadal time scale)

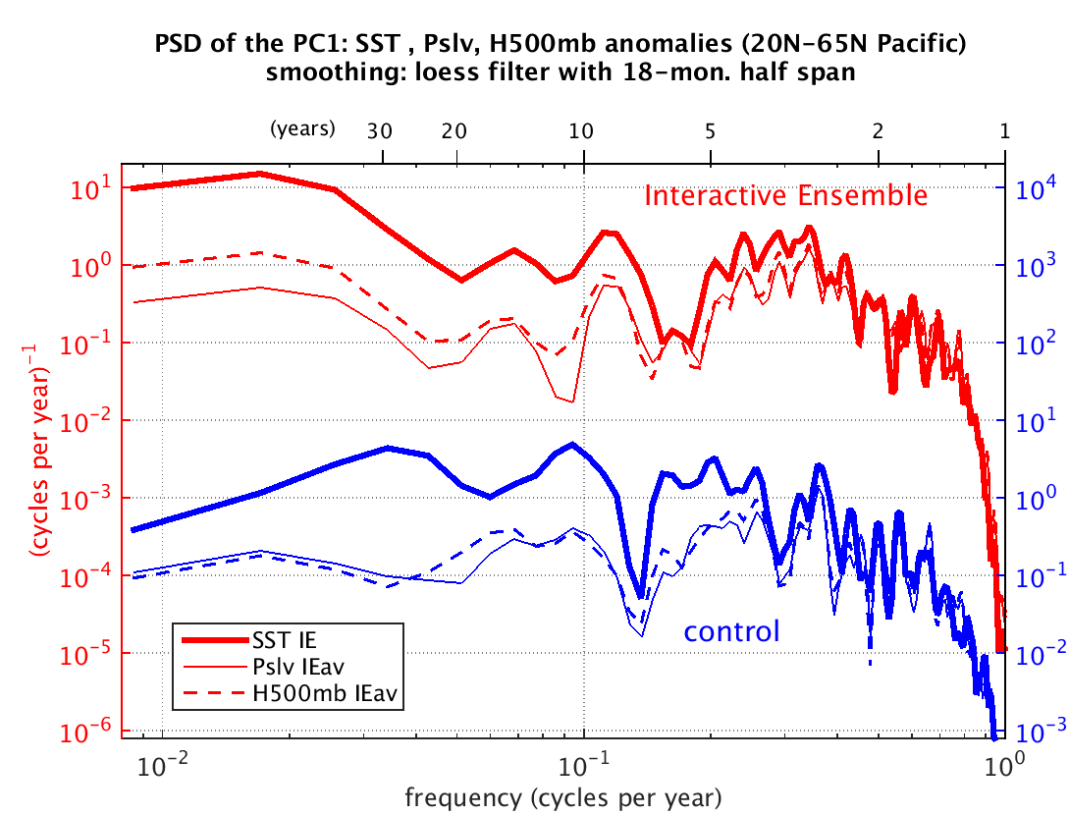




Thank you!

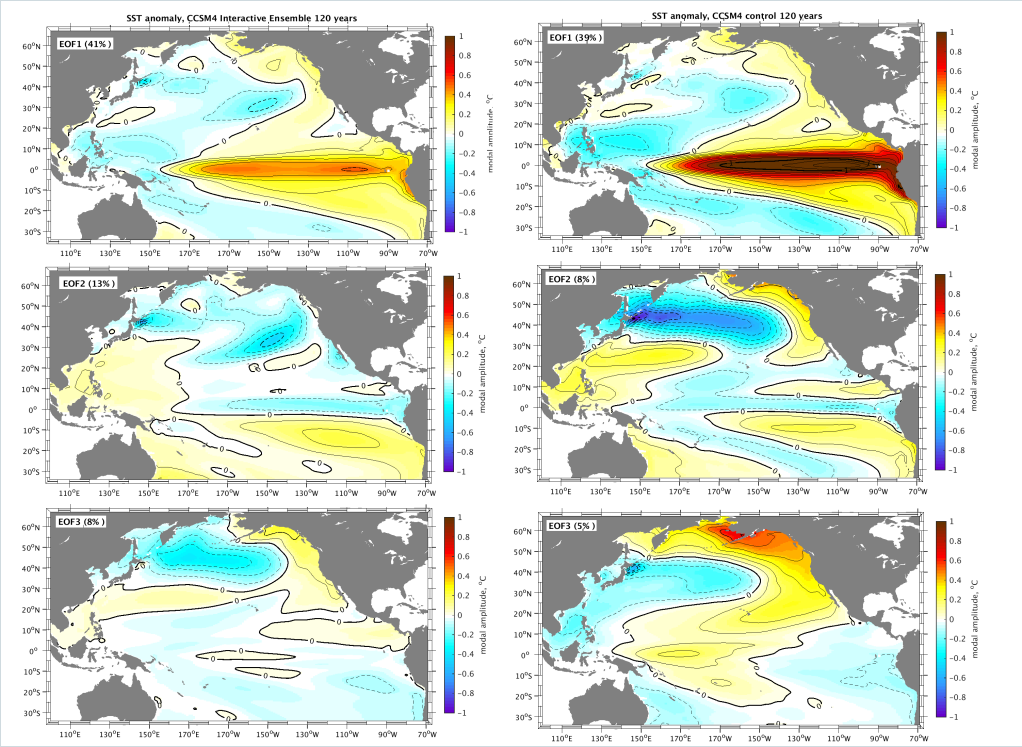
Correspondence of the PDO variability and the atmospheric forcing (Pslv, H500mb)

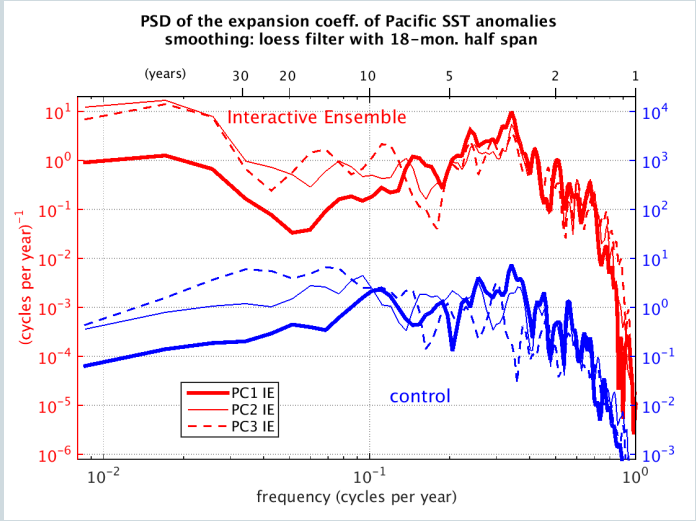
- Power Spectral Density estimates of the principal components (PC1) show similarities between the SST, Pslv, and H500mb in the PDO region



SST variability in the Pacific: IE and control SST

SST anomalies modal analysis:
Interactive Ensemble control CCSM4





Interactive Coupling (IE) CCSM4 approach

- Atmosphere (CAM2), Land (CLM):
  - Horizontal grid: 0.9 x 1.25 deg. grid (lat/lon), 192 x 288 grid points
  - Atmosphere: 26 vertical levels
  - Land: 10 vertical levels
- Ocean (POP2), Ice (CICE):
  - 320 x 384 grid points (gx1v5)
  - Ocean: 60 vertical levels
- Temperature perturbations introduced to the atmospheric components at the initial time to ensure the ensemble spread (!)
- 30 min. coupling time step
- 125-year simulations, startup run from a longer-term prior model integration