Ocean Scale Interactions Symposium

A tribute to Bach Lien Hua

Response of atmosphere-ocean system to latitudinal shifts of the North Pacific western boundary current extensions in a coupled GCM

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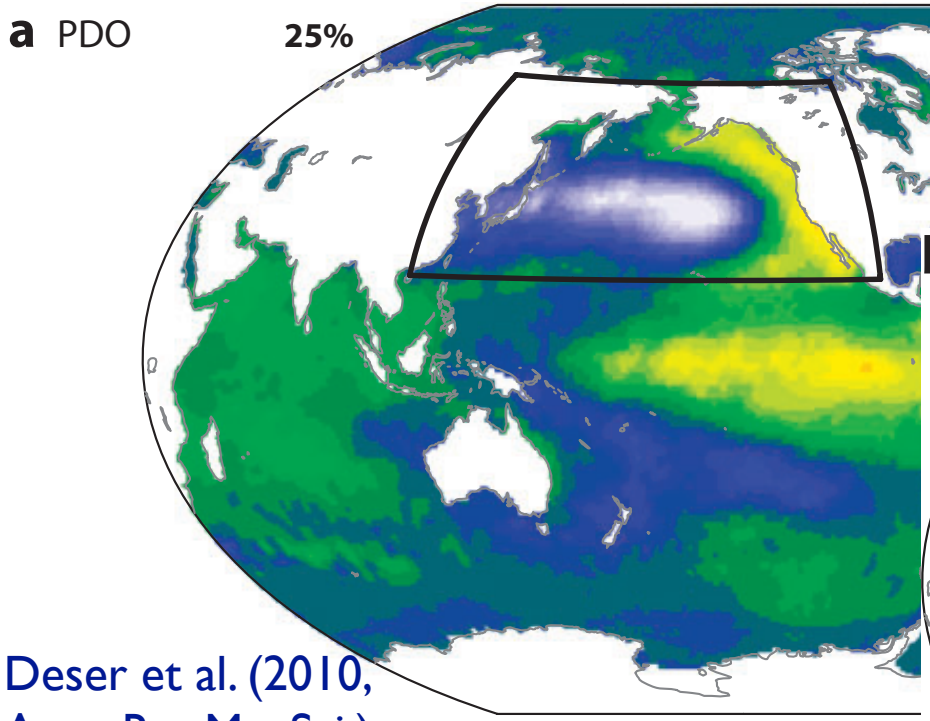
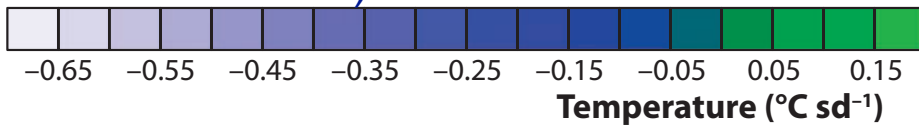
Pacific Decadal Variability

Basin-scale PDO pattern

✓Oceanic frontal-scale (~100km)
✓suggests roles of ocean dynamics.



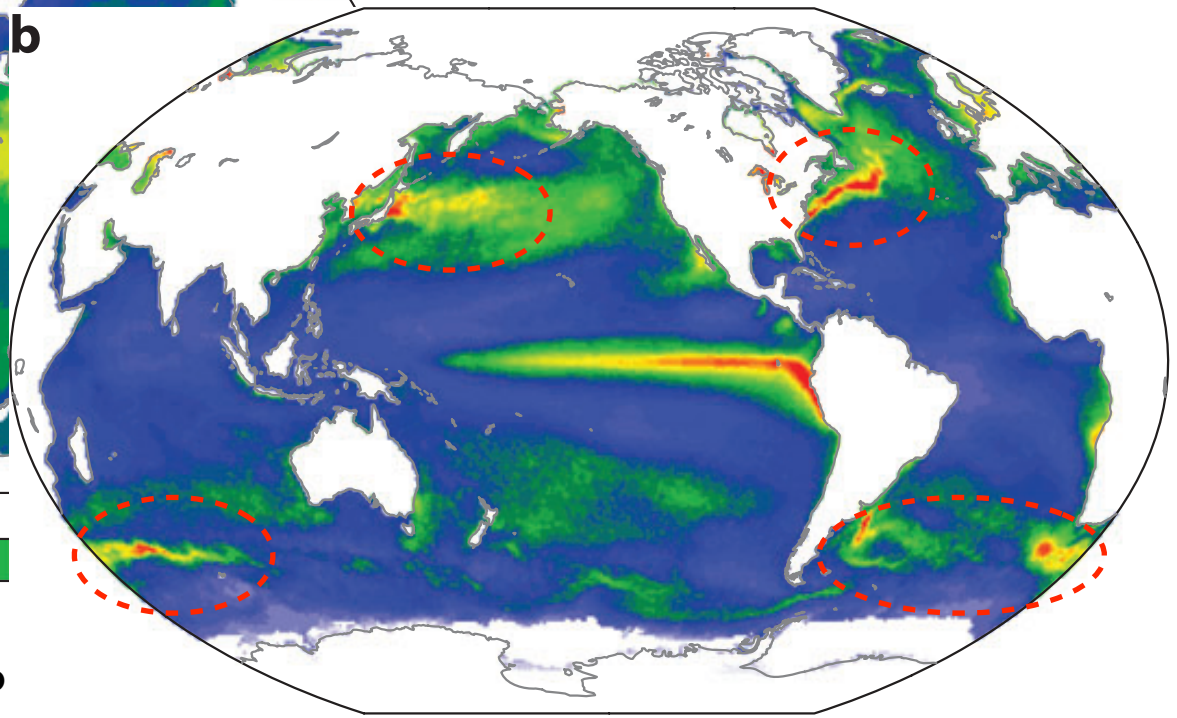
Deser et al. (2010, Annu.Rev.Mar.Sci.)

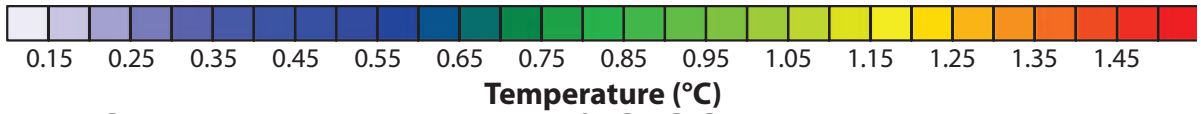


HadISST (1900-2008) regressed on P

Oceanic frontal-scale SST variability (>1year)

Standard deviation





Satellite-observed 1/4° OISST (1982-2008)

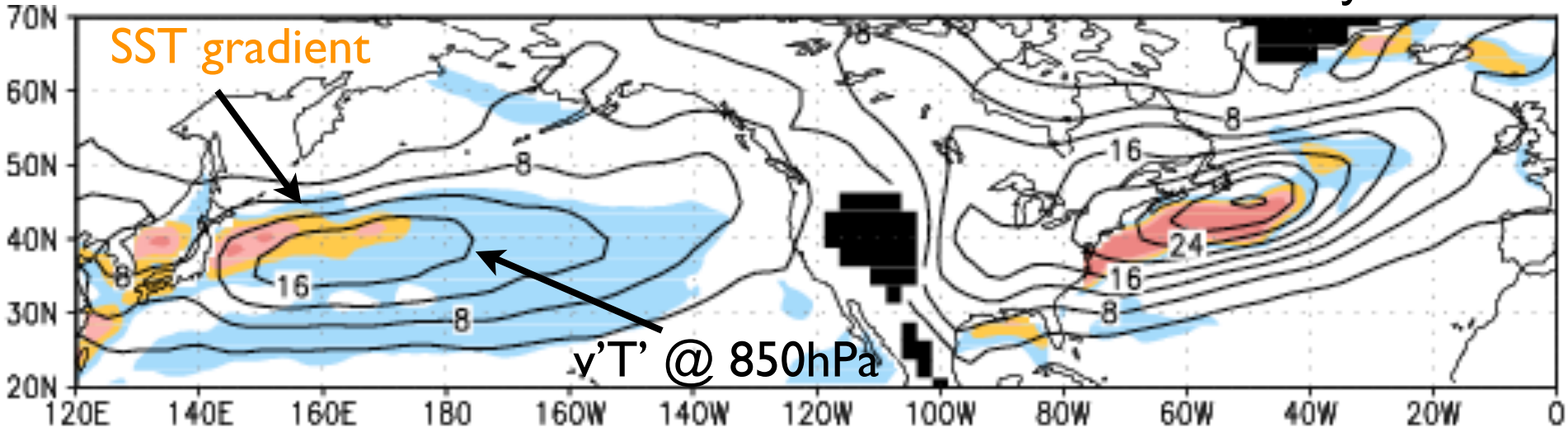
✓Ocean mixed layer integrates atmospheric forcing to generate large-scale PDV pattern.

see also Dommenget and Latif (2008, GRL)

✓ Large interannual to decadal SST variability in WBC regions.

WBCs influence on the large-scale atmospheric circulation

Observed collocation btw/ WBCs and storm track activity



✓ Differential air-sea heat exchanges across WBCs maintain near-surface baroclinicity and anchor storm track. (Nakamura et al. 2004, AGU monogr)

✓ Ocean frontal influence on *time-mean* atmospheric state is well established. (e.g., Minobe et al. 2008, Nature; Kwon et al. 2010, JC)

Questions

- Does WBC variability influence on *time-varying* atmospheric state?
- Does ocean-front induced atmospheric circulation change in turn feedback on the ocean and enhance N. Pac. decadal variability?

Objective

• To investigate two-way A-O interactions in the North Pacific between WBC variability and large-scale atmospheric circulation using a coupled GCM diagnosis/experiments.

Outline

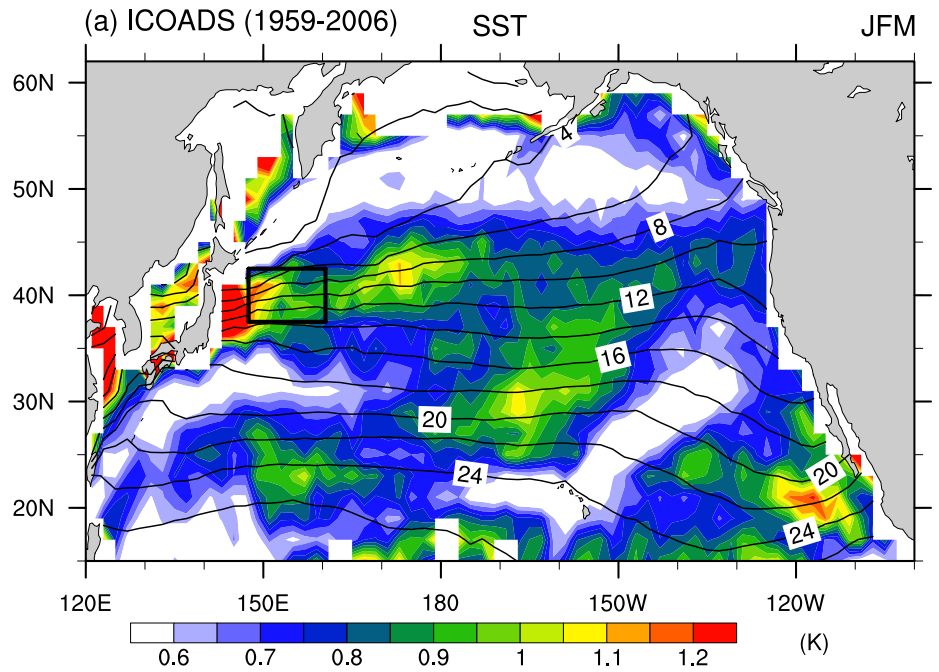
1. **Diagnostic analysis of CGCM and observation** of WBC variability influence on *time-varying* atmospheric state
2. **Idealized CGCM sensitivity experiments**: feedback on the ocean of atmospheric circulation response to WBC shifts

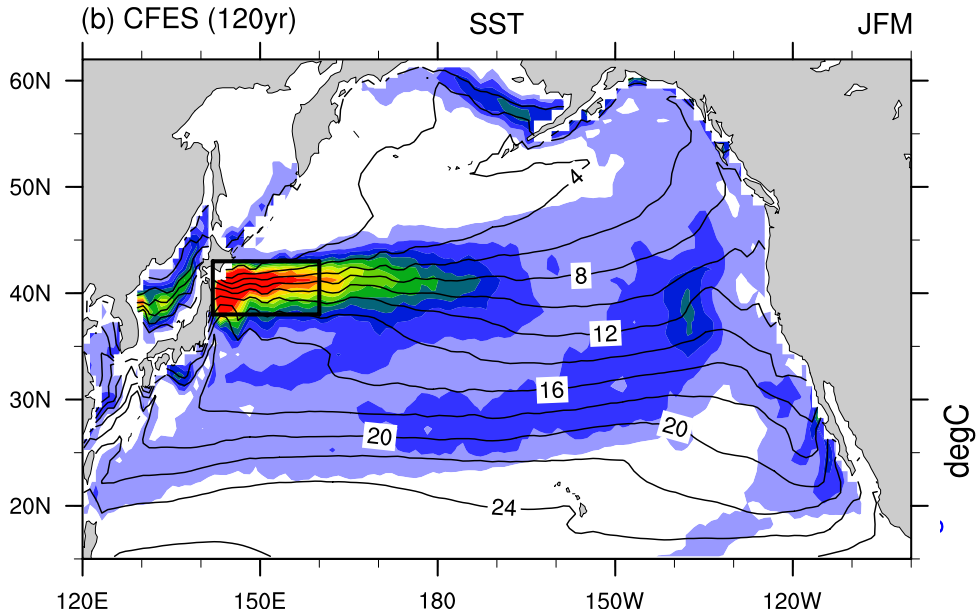
Model: CFES(Coupled GCM for the Earth Simulator)

Komori et al. (2008) "High Res. Num. Modeling on the Atmos. and Ocean", Hamilton & Ohfuchi (Eds.)

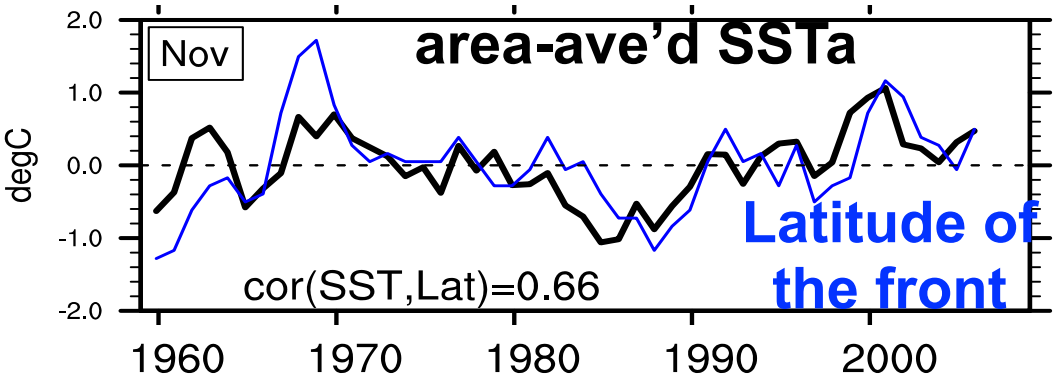
A:T119 (~100km) 48 σ-levels, O: 1/2°x1/2°, 54 z-levels
integrated for 150 years with present day GHG
"ocean-front permitting", to study interannual-decadal variability

Decadal SST variability in subarctic frontal zone: Observation vs CGCM



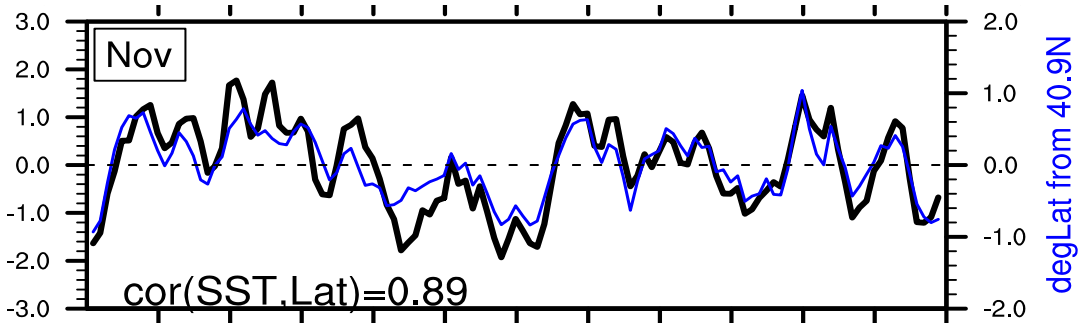


- **Historical Observation:**
  ICOADS SST (2ºx2º, 1959-2006)
  Courtesy of H. Tokinaga (Kyoto U)



- Latitudinal shift on decadal time scale (Nakamura & Kazumin, 2003) responding to basin-scale wind change (Seager et al. 2001)

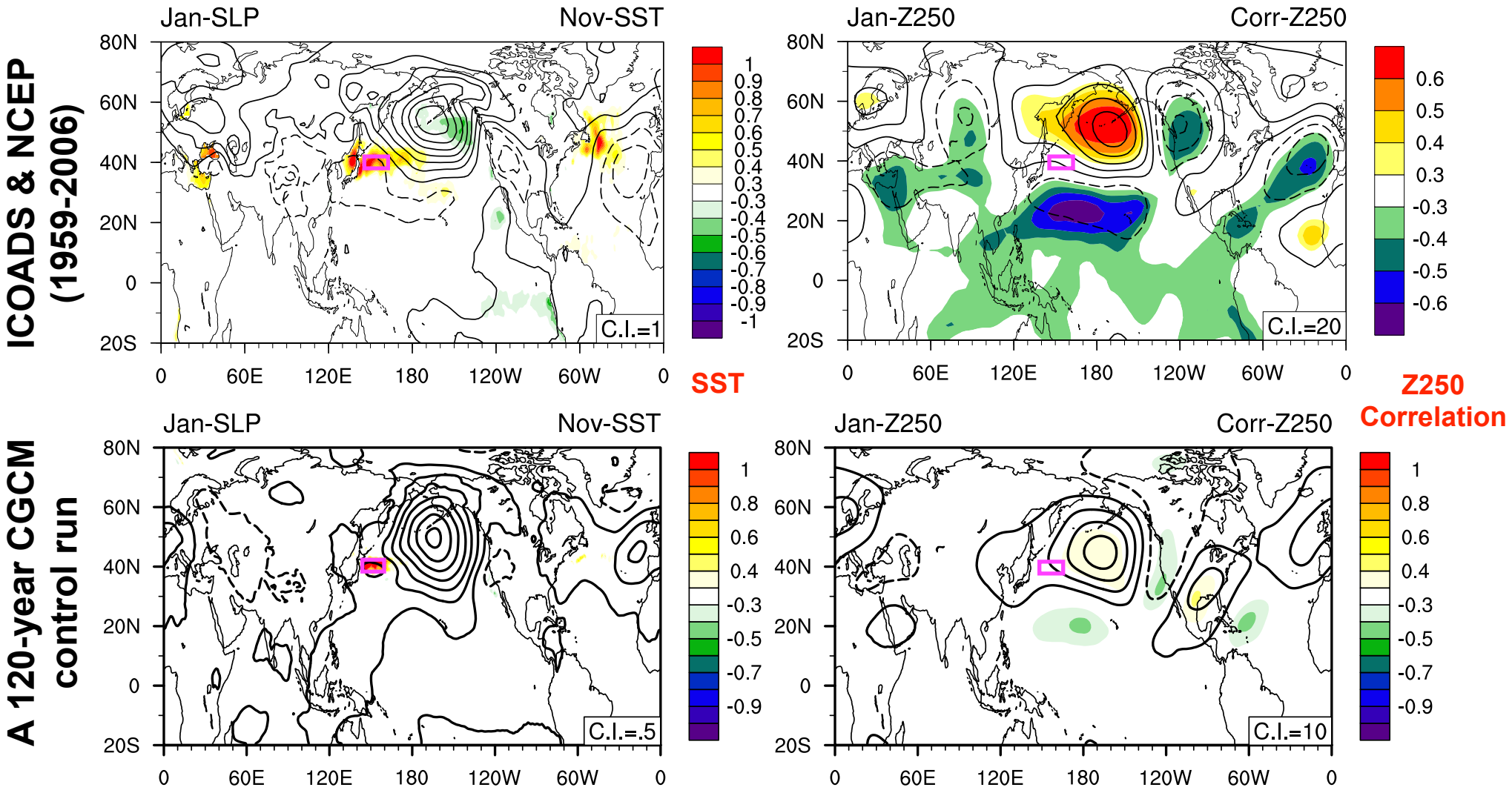
- **CFES:**



Does oceanic frontal variability influence on time-varying atmospheric state?

Atmospheric circulation response to decadal latitudinal shift of North Pacific subarctic front

Regressed SLP & Z250 anomalies in January on decadal SST anomalies in SAF in preceding November



✓warm SAFZ ➡ weakened Aleutian Low & PNA-like pattern in upper troposphere

Taguchi et al. (2012, JC), see also Frankignoul et al. (2011, JC)

Storm track activity and its feedback

storm track activity

$$\overline{v'T'}@850hPa$$

monthly mean of poleward eddy-flux due to synoptic (<8days) eddies

transient eddy feedback

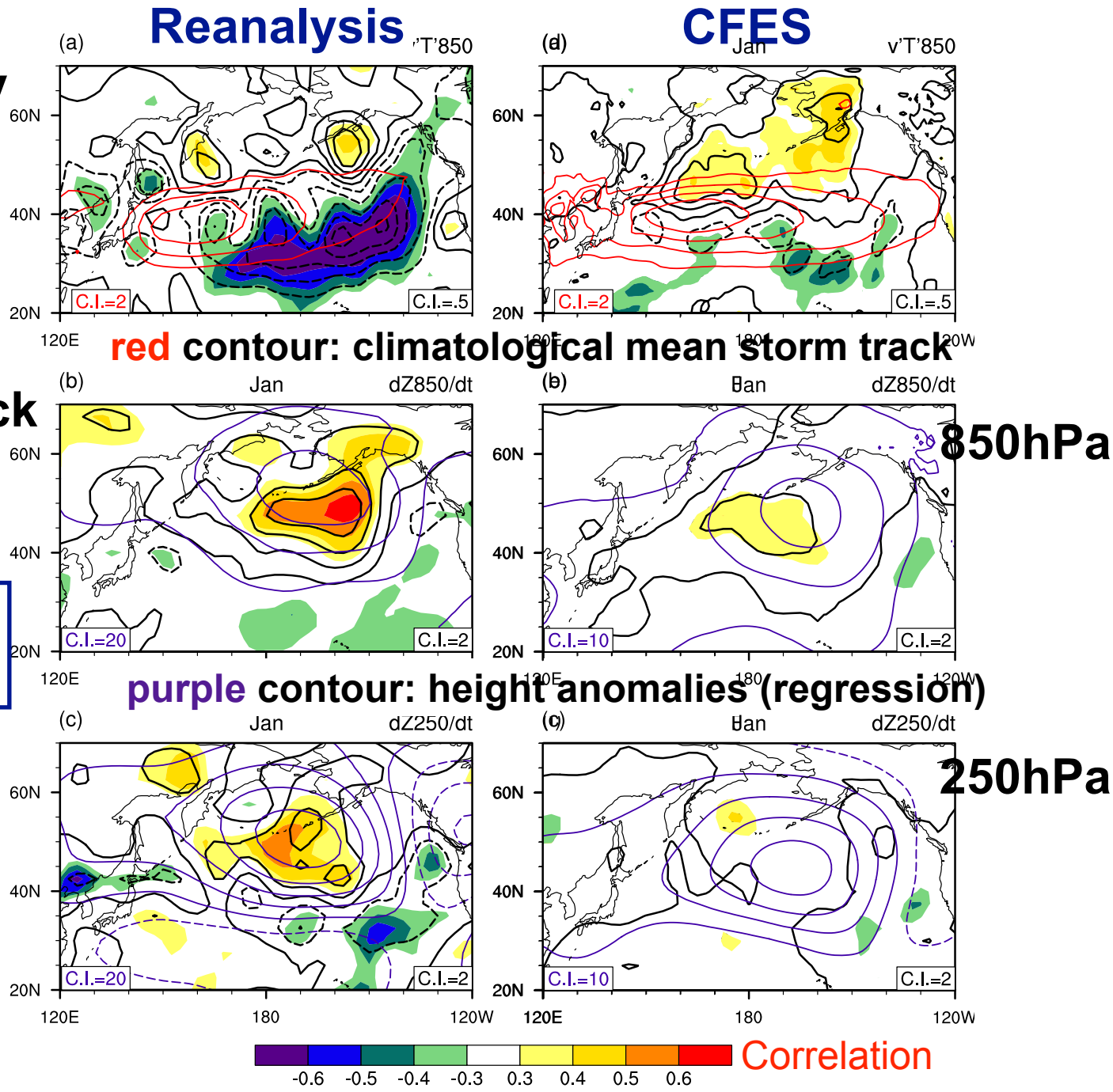
height tendency due to eddy heat&vorticity flux

$$\left[\nabla^2 + f^2 \frac{\partial}{\partial p}\left(\frac{1}{S}\frac{\partial}{\partial p}\right)\right]\boxed{\frac{\partial \overline{Z}}{\partial t}}$$

$$= -\frac{f}{g}\nabla \cdot \boxed{\overline{(\mathbf{v}'\zeta')}}$$

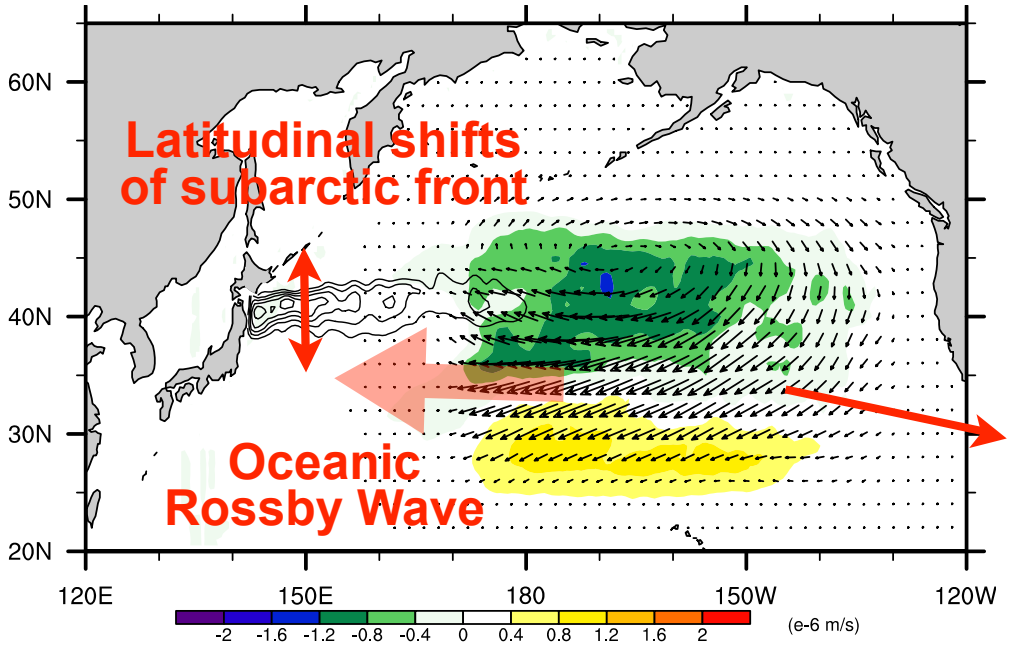
$$+\frac{f^2}{g}\frac{\partial}{\partial p}\left[\frac{\nabla \cdot \boxed{\overline{(\mathbf{v}'\theta')}}}{-(\partial\Theta/\partial p)}\right]$$

Taguchi et al. (2012, JC)

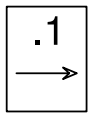


Coupled GCM sensitivity experiments imposing idealized wind stress anomalies

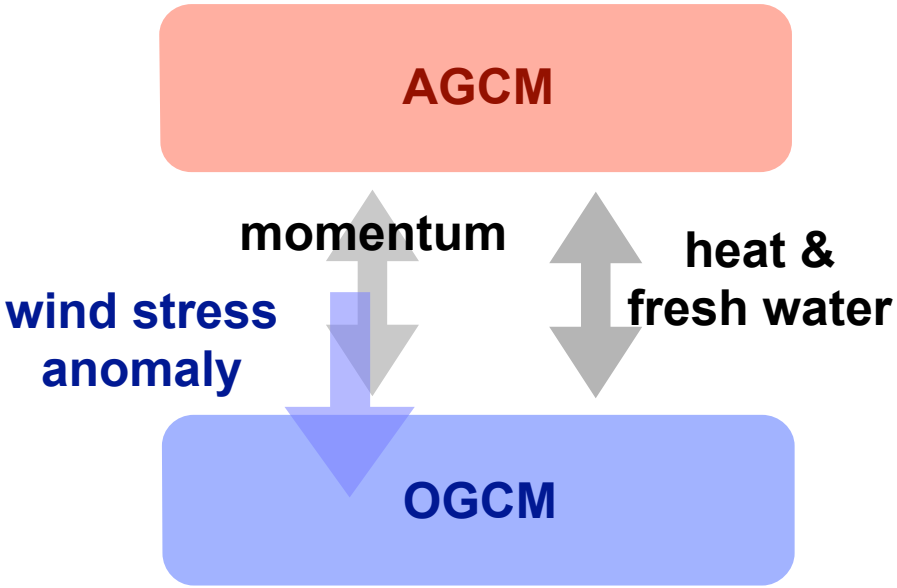
imposed wind stress anomaly pattern



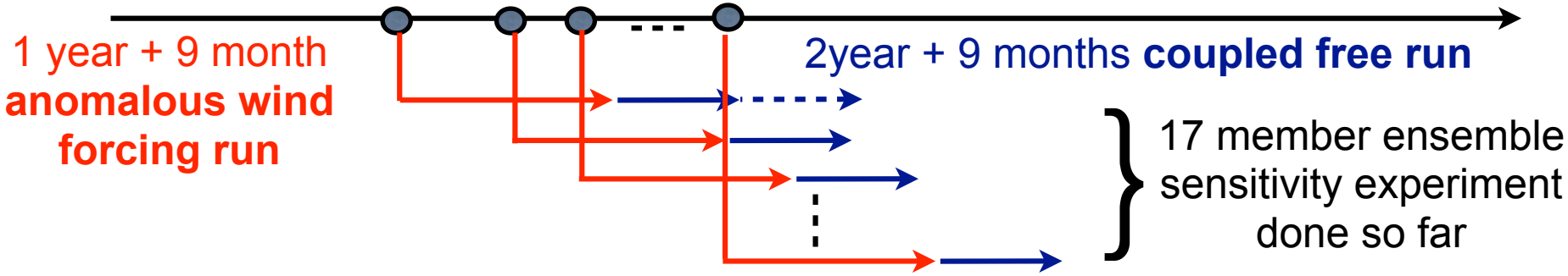
color: Ekman pumping velocity We
vector: wind stress(N/m^2)
contours: SST gradients



Anomalous wind stress forcing run

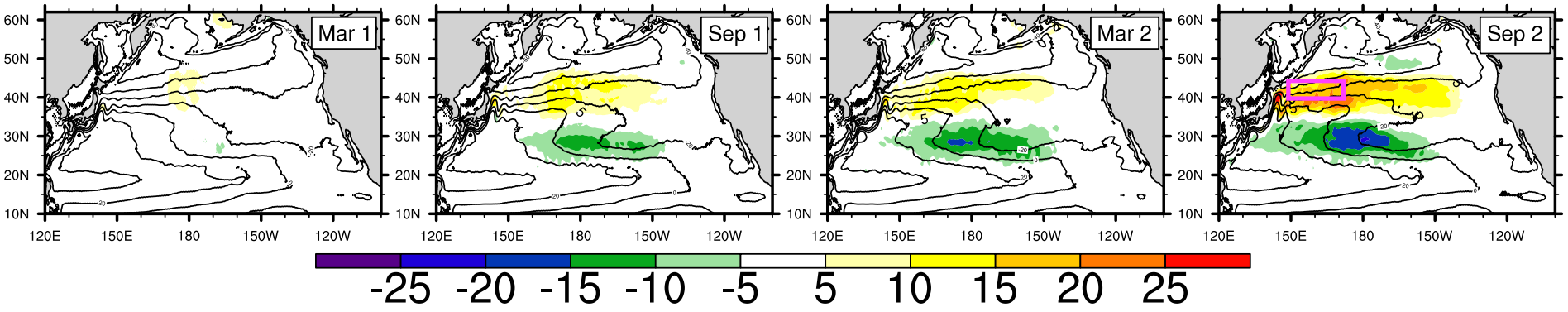


Initial conditions of the atmosphere and ocean take from **150-year control integration**

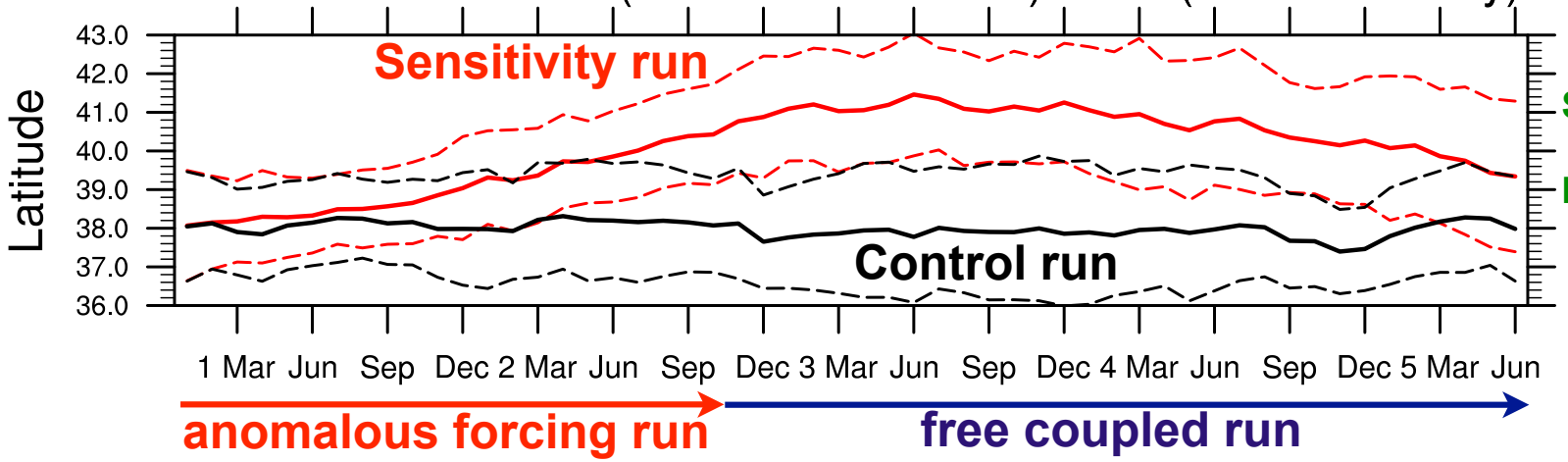


Oceanic response

Sea Surface Height (SSH): Ensemble mean difference (Sensitivity-Control runs)

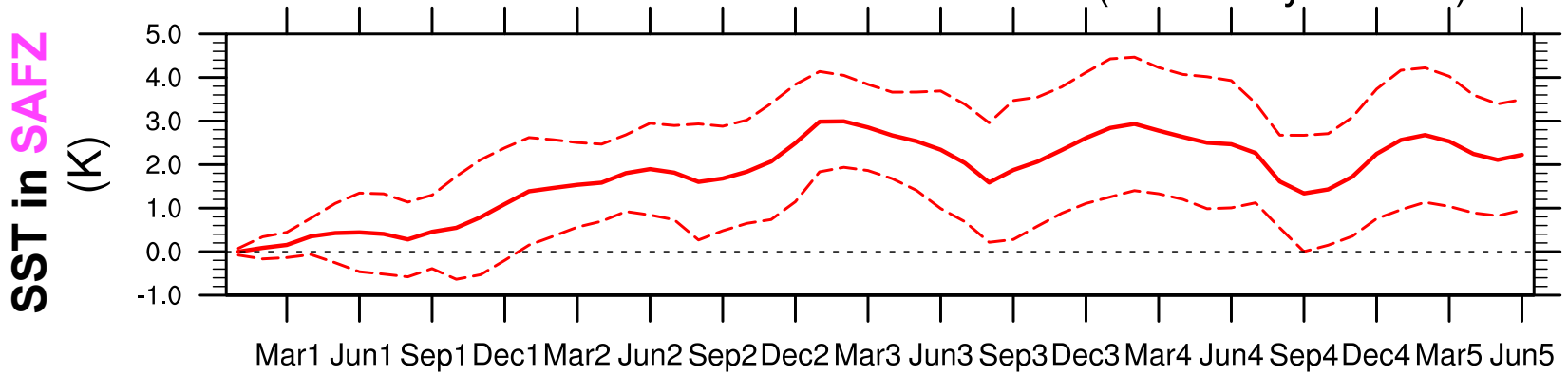


Latitude of Subarctic (Kuroshio extension) Front (max. -dSSH/dy)



Solid: Ensemble mean
Dashed: Ensemble spread

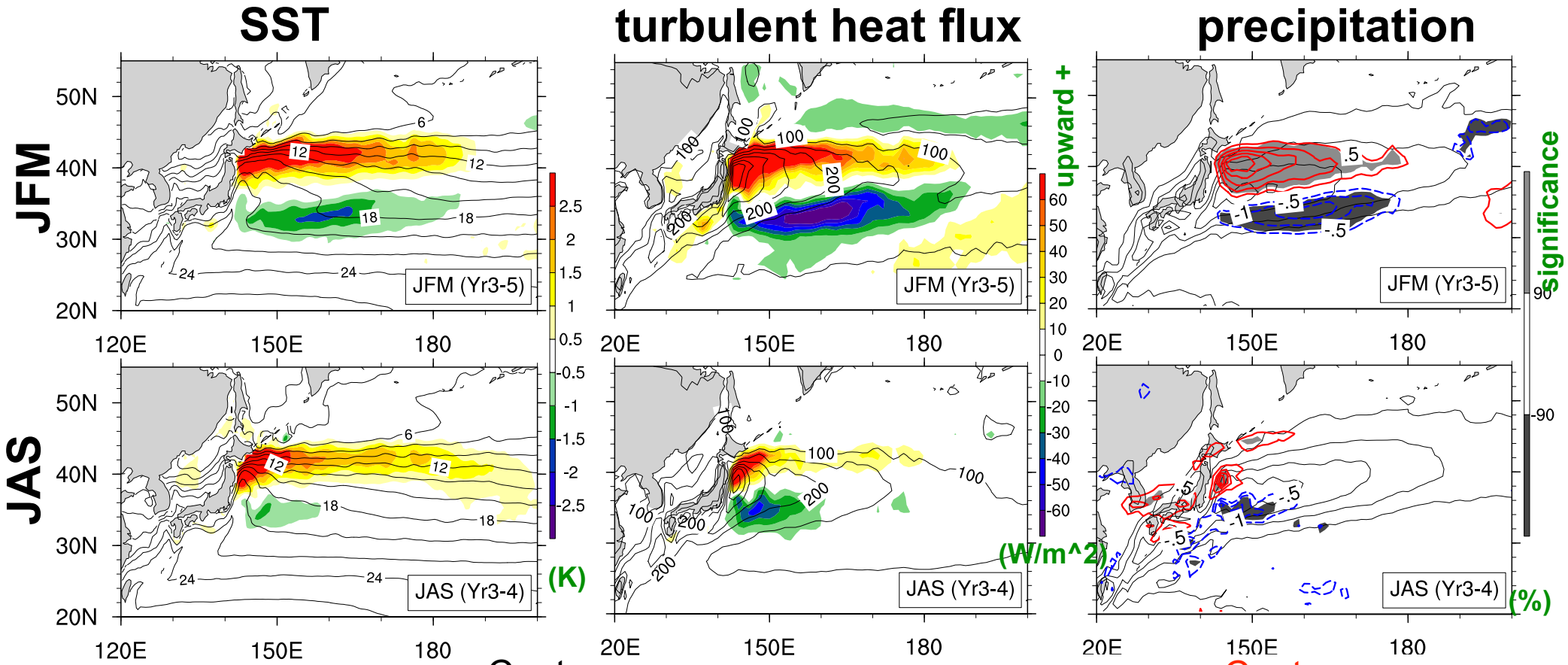
SST difference in Subarctic frontal zone (sensitivity-control)



✓ **Subpolar gyre spin-down → Northward shift of SAF → Warming in SAFZ**

Atmospheric local response

Ensemble mean difference (Sensitivity-Control runs) averaged over the free integration period



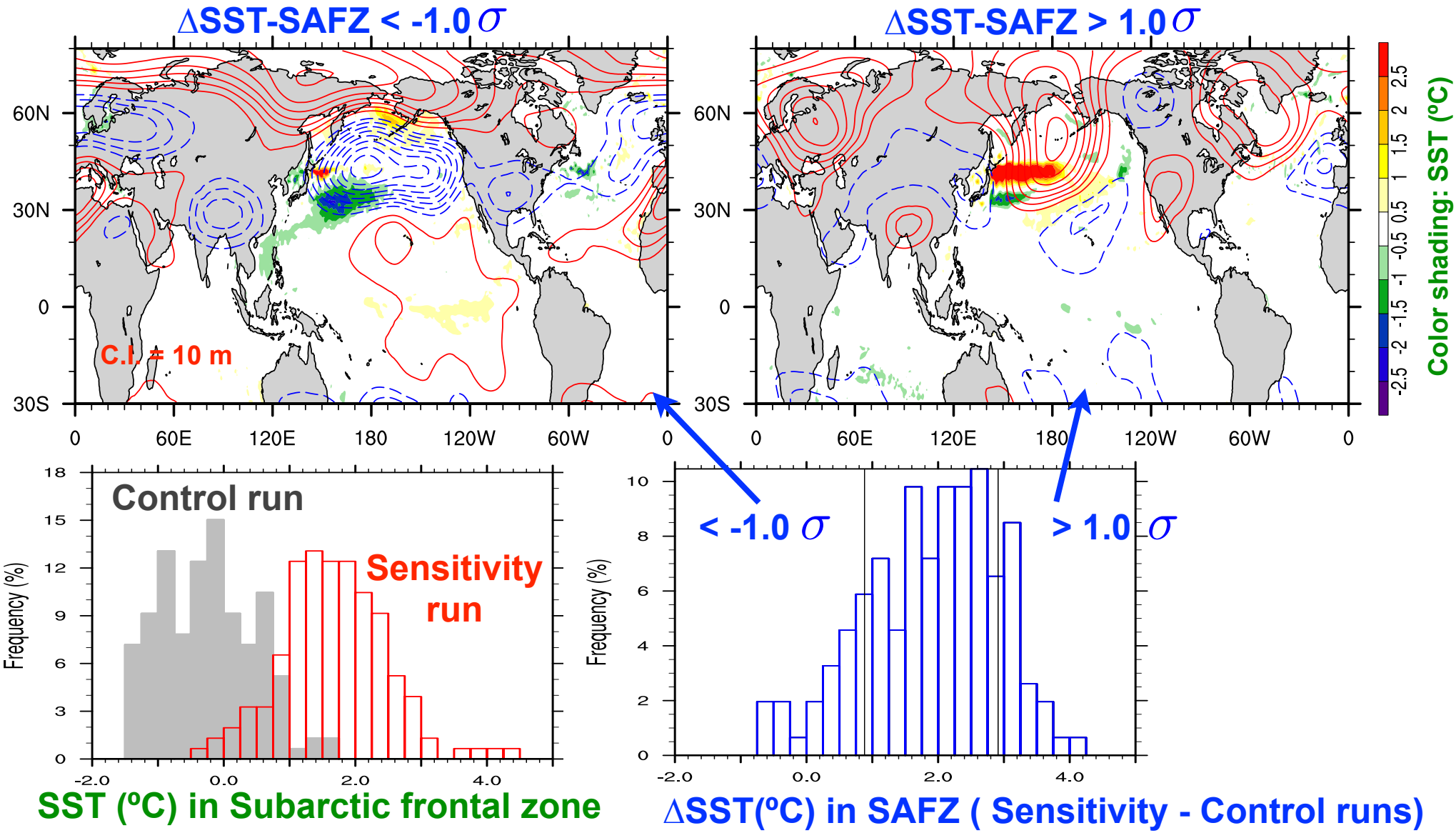
Contours:
Ensemble mean (Sensitivity run)

Contours:
Sensitivity-Control runs
(C.I.=1mm/day)

- ✓ **SST response persists overall throughout seasons.**
- ✓ **Significant local responses of upward heat flux and precipitation during winter.**
- ✓ **Precipitation response hints northward shift of storm track.**

Large-scale upper tropospheric response

ΔZ250 composite (contours) across ensemble members



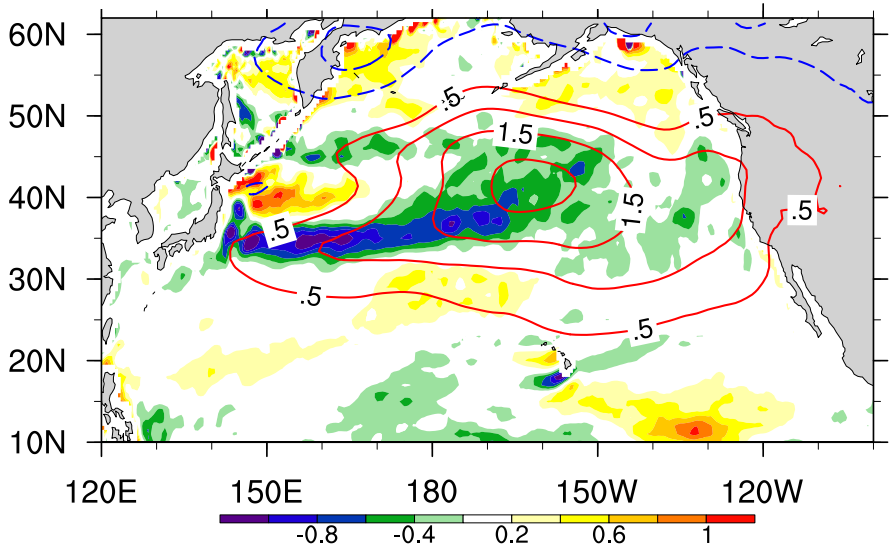
histogram based on 3 month (DJF) x 3 year x 17 = 153 members

✓ **Atmospheric response is sensitive to SST in SAFZ across ensemble members; the warmer the SST in SAFZ, the more anti-cyclonic circulation response.**

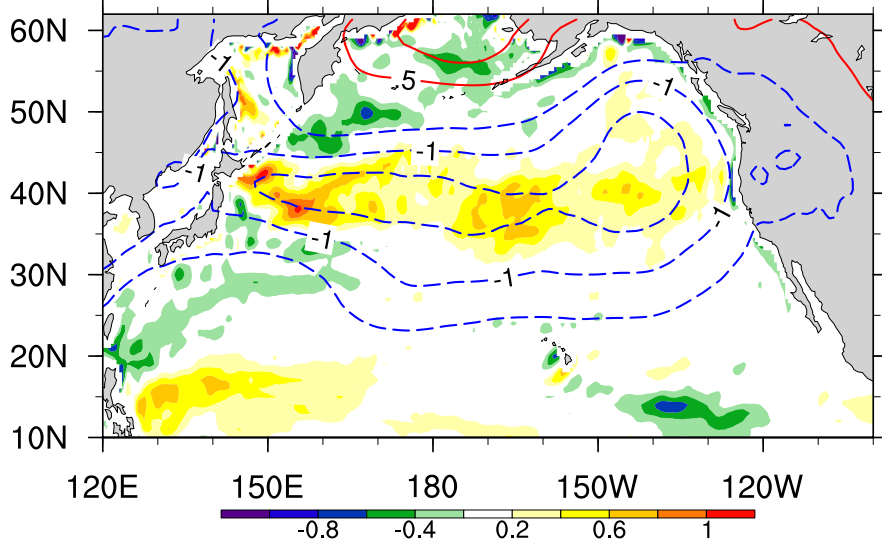
Feedback on the ocean

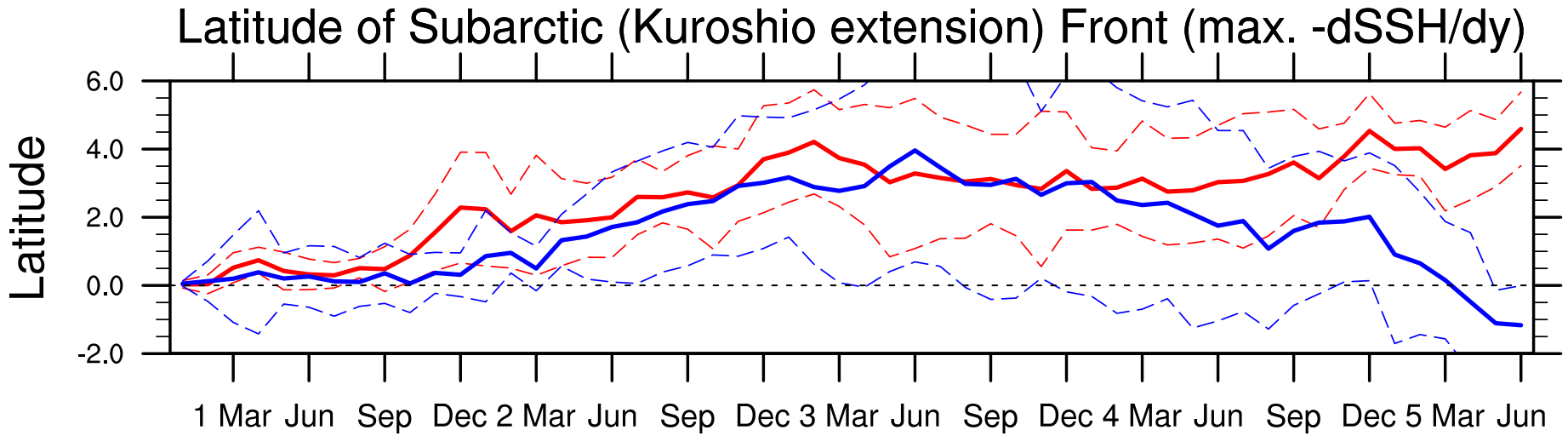
shading: Ekman pumping (x1.e-6 m/s), contours: SLP (CI=0.5hPa) **Sensitivity - Control (6members)**

Positive feedback ensemble Year 3-5



Negative feedback ensemble Year 3-5





✓ Anti-cyclonic (cyclonic) response exerts -ve (+ve) wind curl, keeping (shifting) the ocean front northward (southward).

✓ Two-way A-O interaction is extracted with ensemble composite.

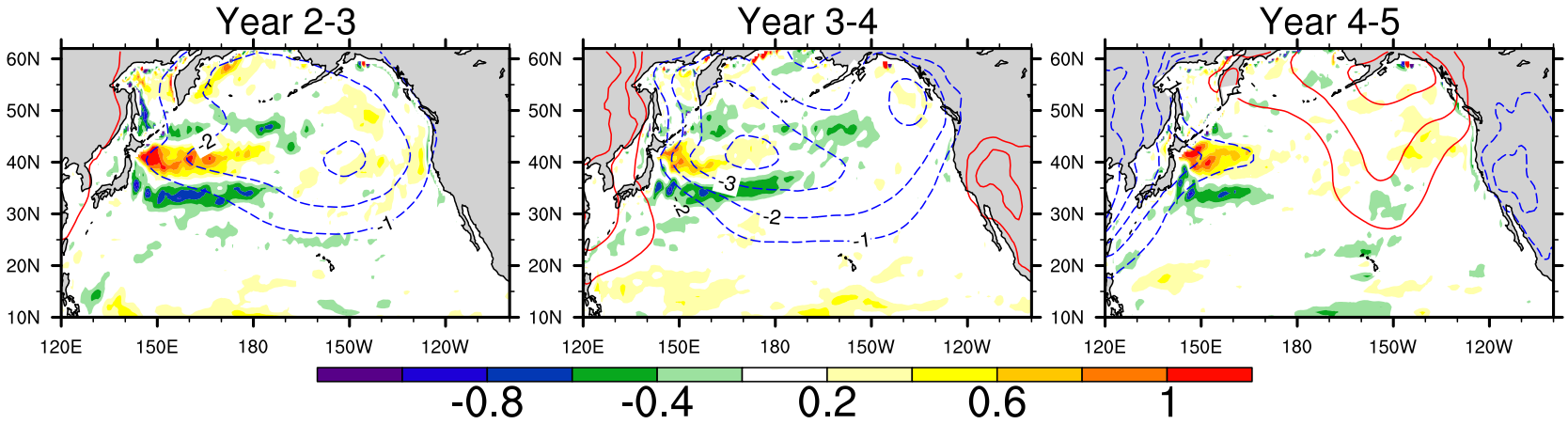
Summary

- Decadal-scale latitudinal shifts of the North Pacific WBCs can have significant impacts on the large-scale atmospheric circulation via modulation of storm track and their feedback forcing on the mean flow.
- CGCM Sensitivity experiments detect two regimes in feedback on the ocean of the ocean-induced atmospheric circulation change: warm-SAFZ/weakened Aleutian Low and cold-SAFZ/enhanced AL responses, leading to positive & negative A-O feedbacks, respectively.
- These two-way positive and negative feedbacks may contribute to persistence and delayed phase transition, respectively, of PDV.
- Atmospheric responses and preferred A-O feedbacks vary among different CGCMs, which need to be clarified to understand mechanisms for PDV.

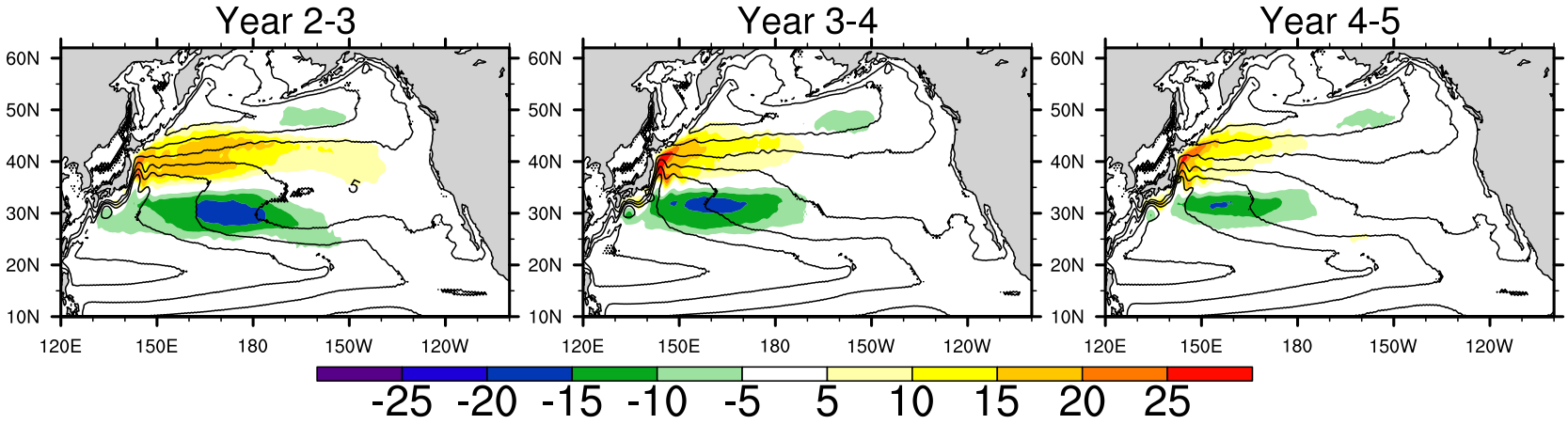
Feedback on the ocean

total 17 members

July-June annual mean We & SLP ensemble mean difference (Control-Sensitivity)



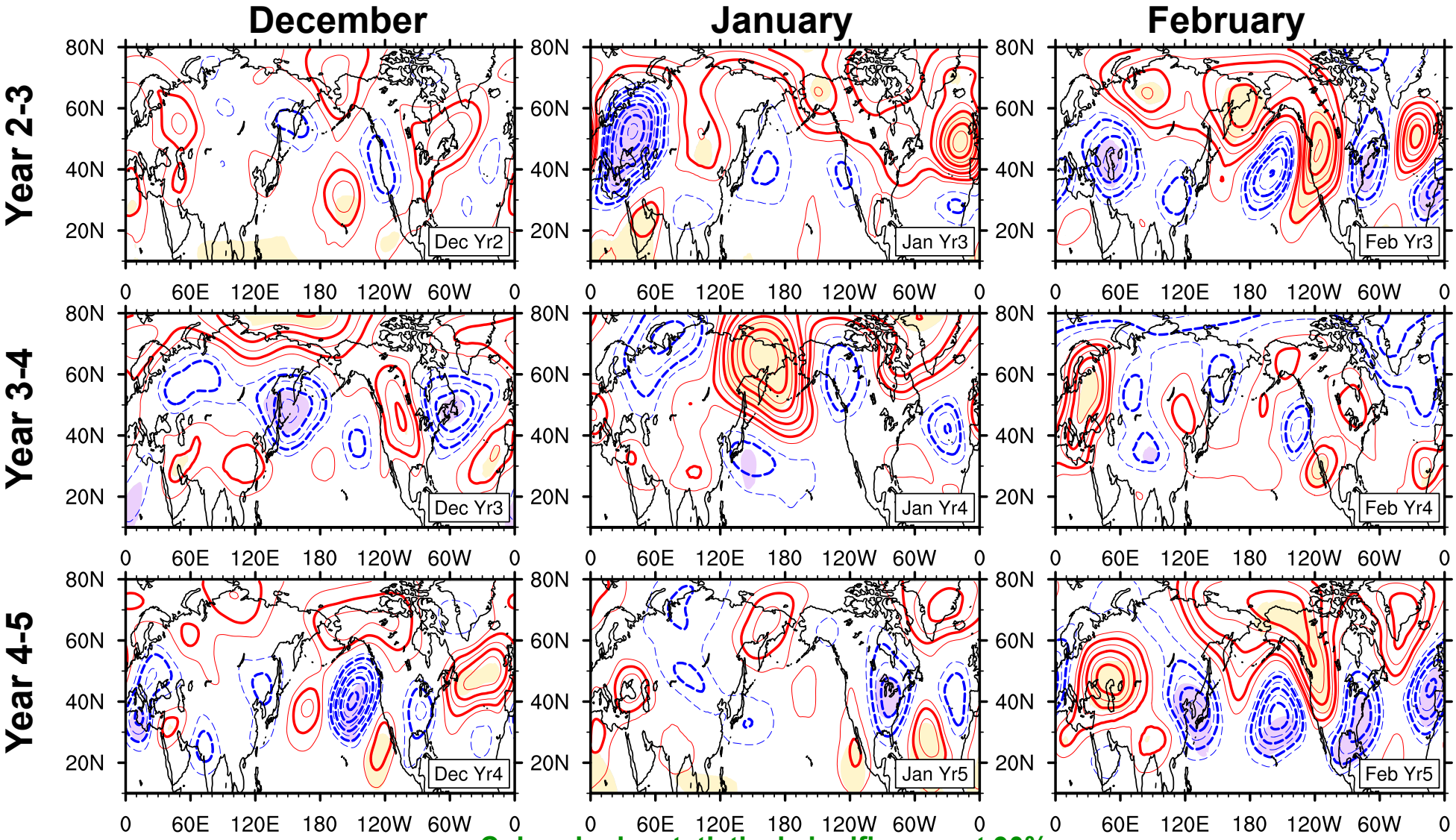
July-June annual mean SSH ensemble mean difference (Control-Sensitivity)



✓No obvious basin-scale Ekman pumping (We) feedback found. Positive We associated with local response may act to damp SST anomaly generated by SAF shift.

5. Upper tropospheric response

Z250: Ensemble mean difference (Control-Sensitivity runs)



Color shade: statistical significance at 90%

Contours: Ensemble mean difference C.I. = 10 m (thin), 20m (thick)

✓January 4-th year yields Pacific North American pattern-like anomaly, though large-scale atmospheric response is not coherent from mouth (year) to month (year).