Regional modeling of ocean-atmosphere interaction: from tropics to mid-latitude

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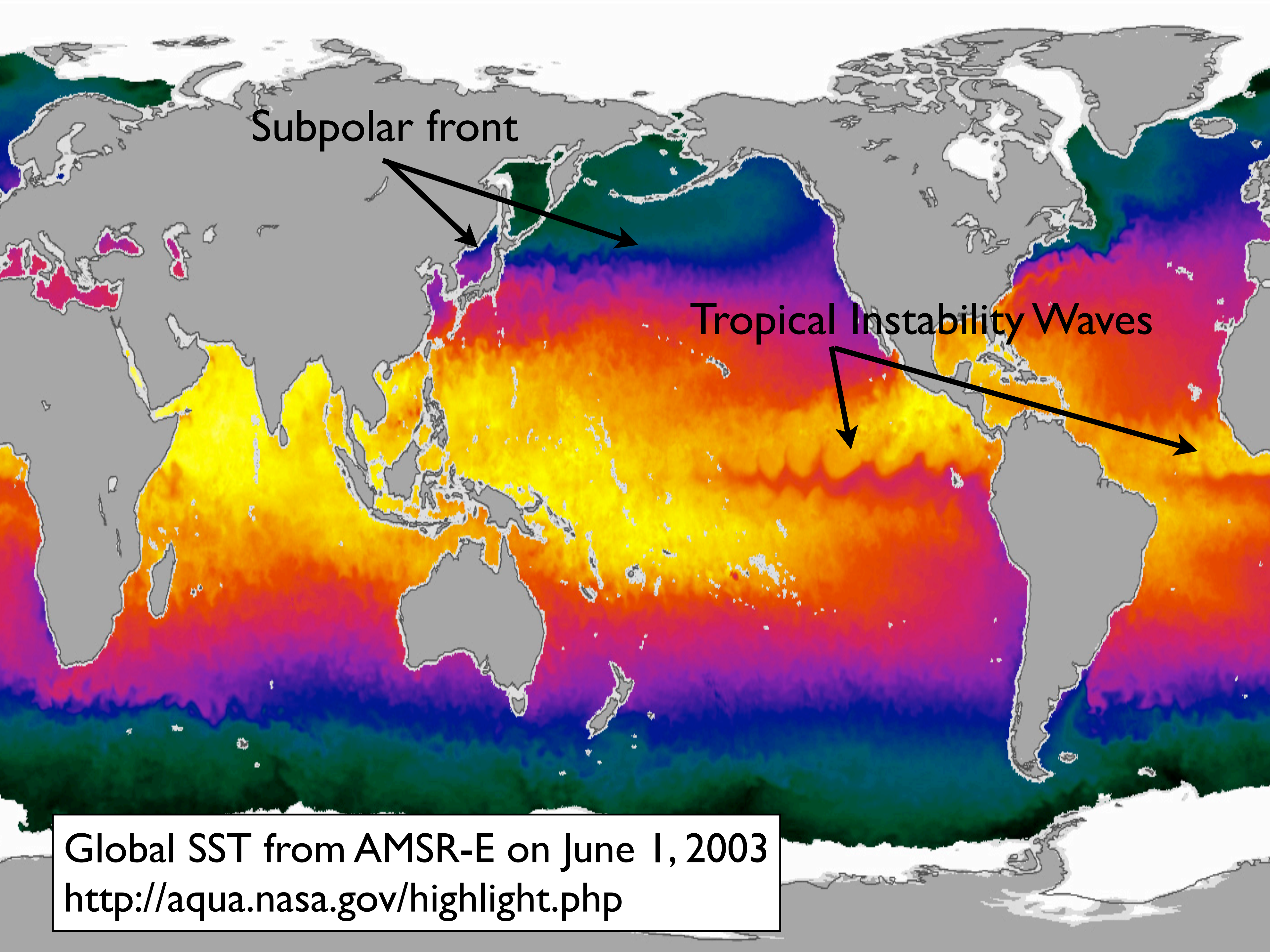
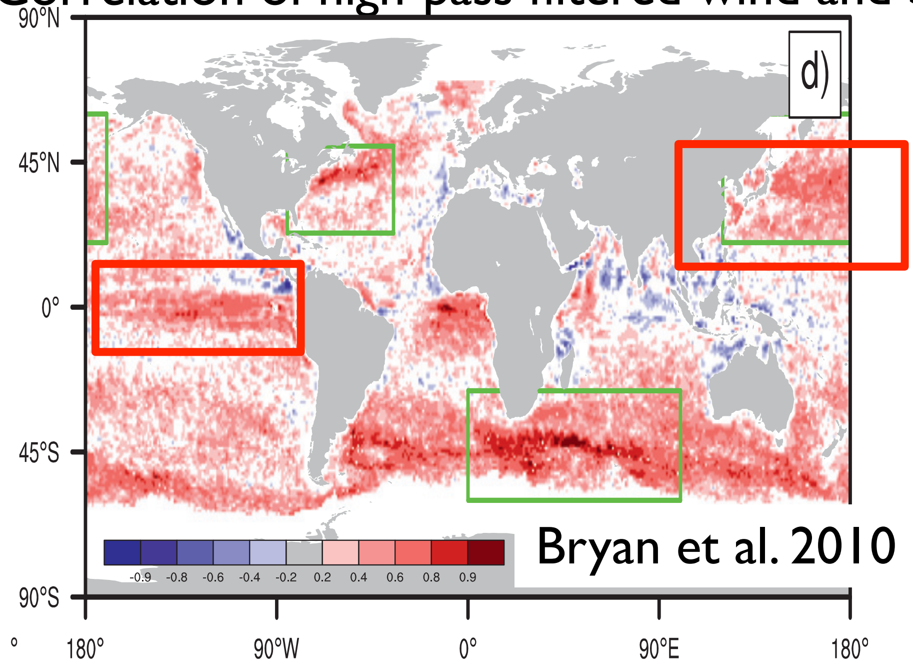

Subpolar front
Tropical Instability Waves
Global SST from AMSR-E on June 1, 2003
http://aqua.nasa.gov/highlight.php

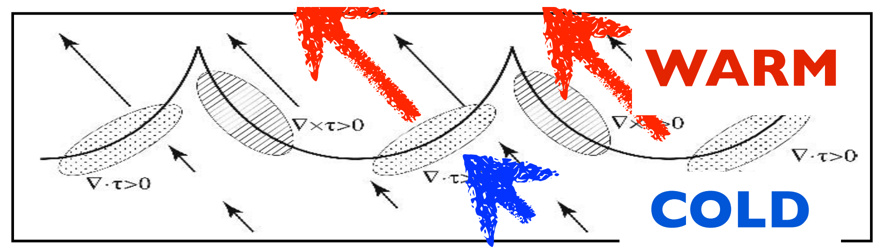
TIW High-frequency air-sea interactions

Correlation of high-pass filtered wind and SST

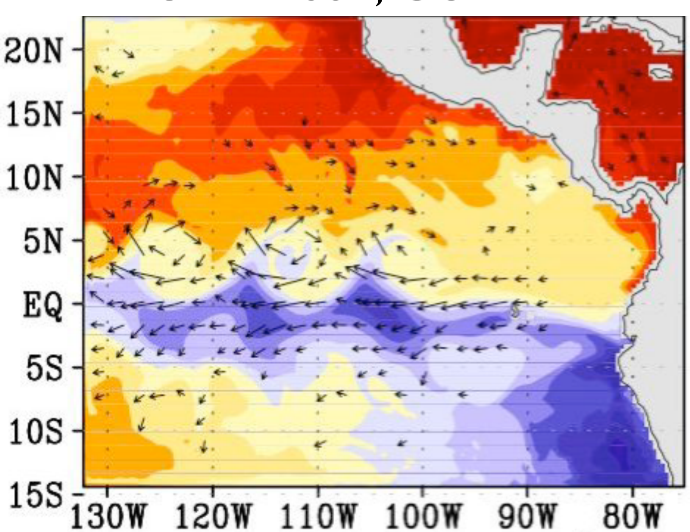


Bryan et al. 2010

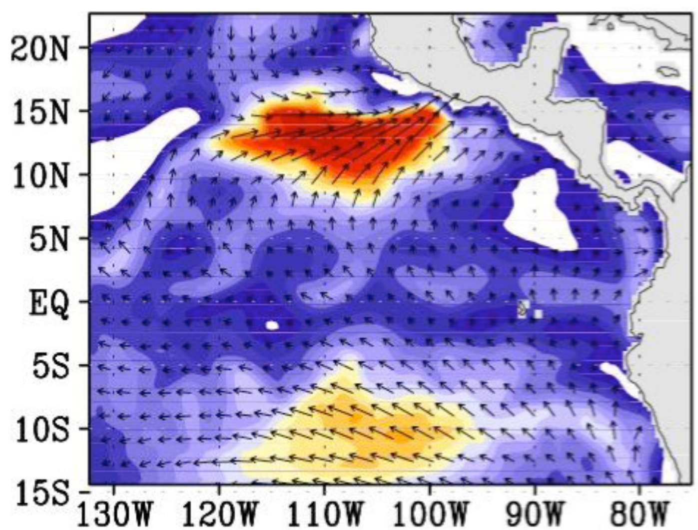
Chelton's schematic illustration of how the wind-stress responds over TIWs



MODEL SST, CURRENT



MODEL WIND STRESS



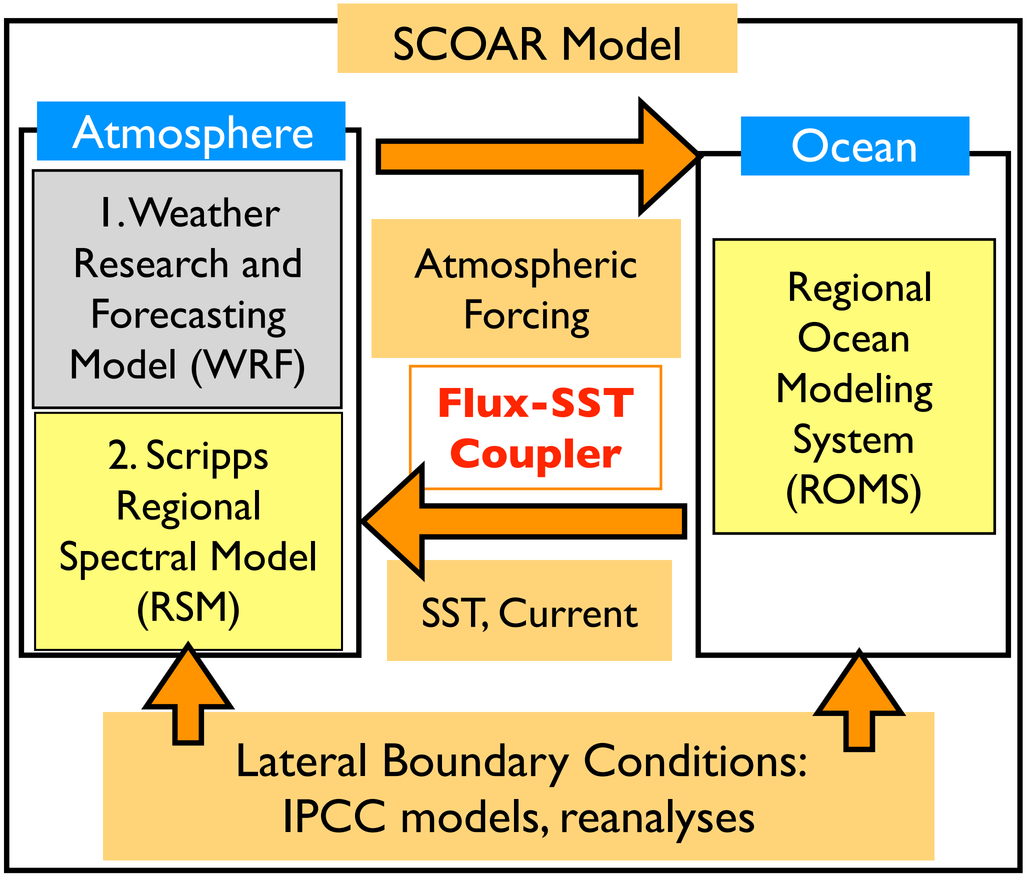
SCOAR Model

Motivation

- Small-scale oceanic processes (heat transport, mesocaele eddies, air-sea interactions) influence the atmosphere and climate through the impact on SST.
- The mechanisms for ocean-to-atmosphere forcing however significantly vary depending on the overlying large-scale circulation regimes, requiring a regional approach in climate modeling.

- Today, I will discuss how the oceanic processes would influence the regional atmosphere over the two regions.
    - Part I: Tropical Instability Waves in the Eq. Atlantic
    - Part II: East/Japan Sea SSTs

Scripps Coupled Ocean-Atmosphere Regional (SCOAR) Model



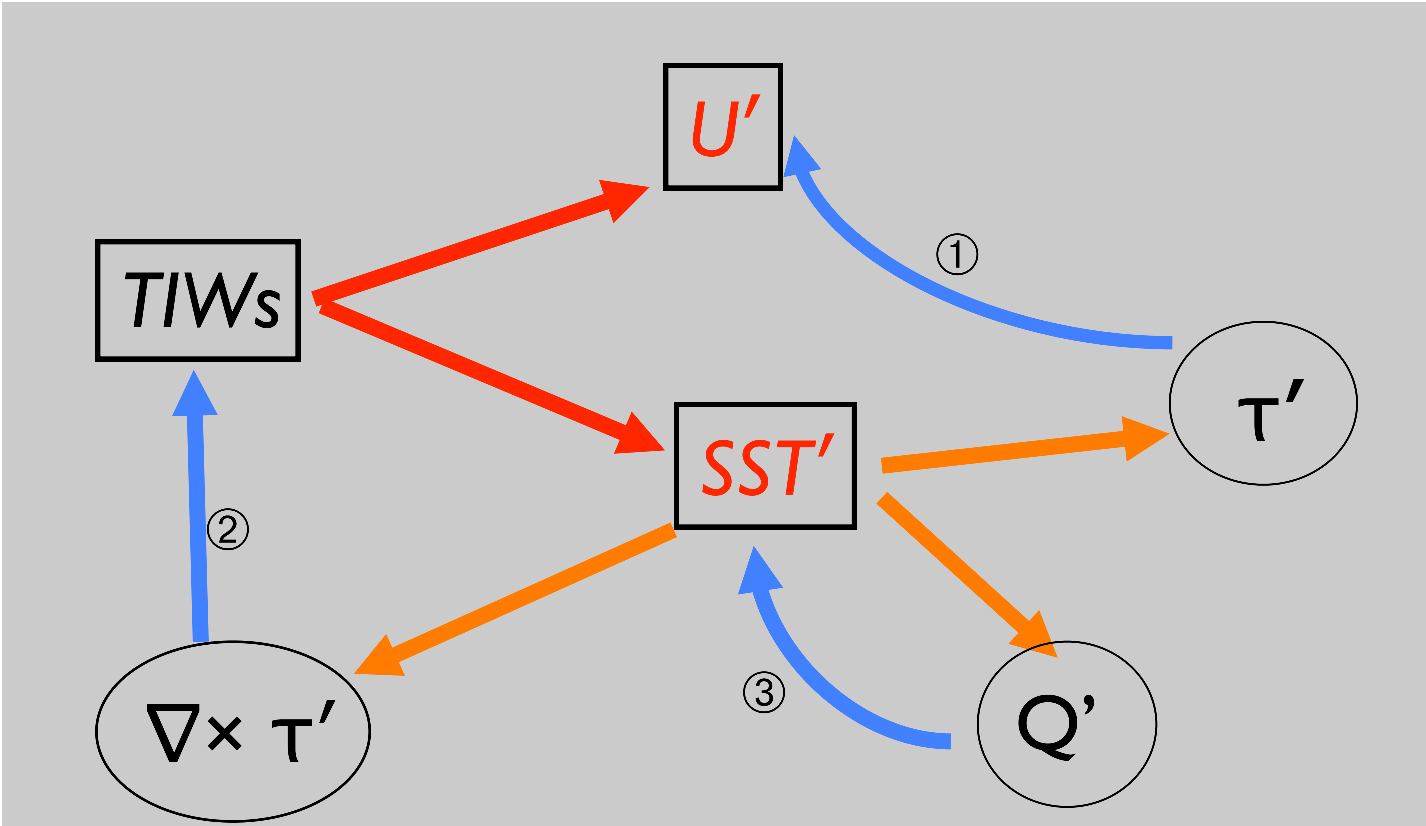
- Higher model resolution BOTH in the ocean and atmosphere.
- An input-output-based coupler and sequential coupling
- Greater portability and applicability

Seo, Miller and Roads, 2007:
The Scripps Coupled Ocean-Atmosphere Regional (SCOAR) model, with applications in the eastern Pacific sector. *Journal of Climate*

- Understanding the physical processes behind small-scale and large-scale climate dynamics
- Assess the regional aspects of global climate variability and change

Part I: TIWs-air-sea interaction

High-frequency TIW-atmosphere coupling processes to be studied



① Coupling of wind and current?

② Feedback of wind stress curls to TIW energetics?

③ Atmospheric heat flux response to TIWs?

① Energetics of TIWs: Eddy kinetic energy budget

Feedback to TIW energetics

EKE Equation

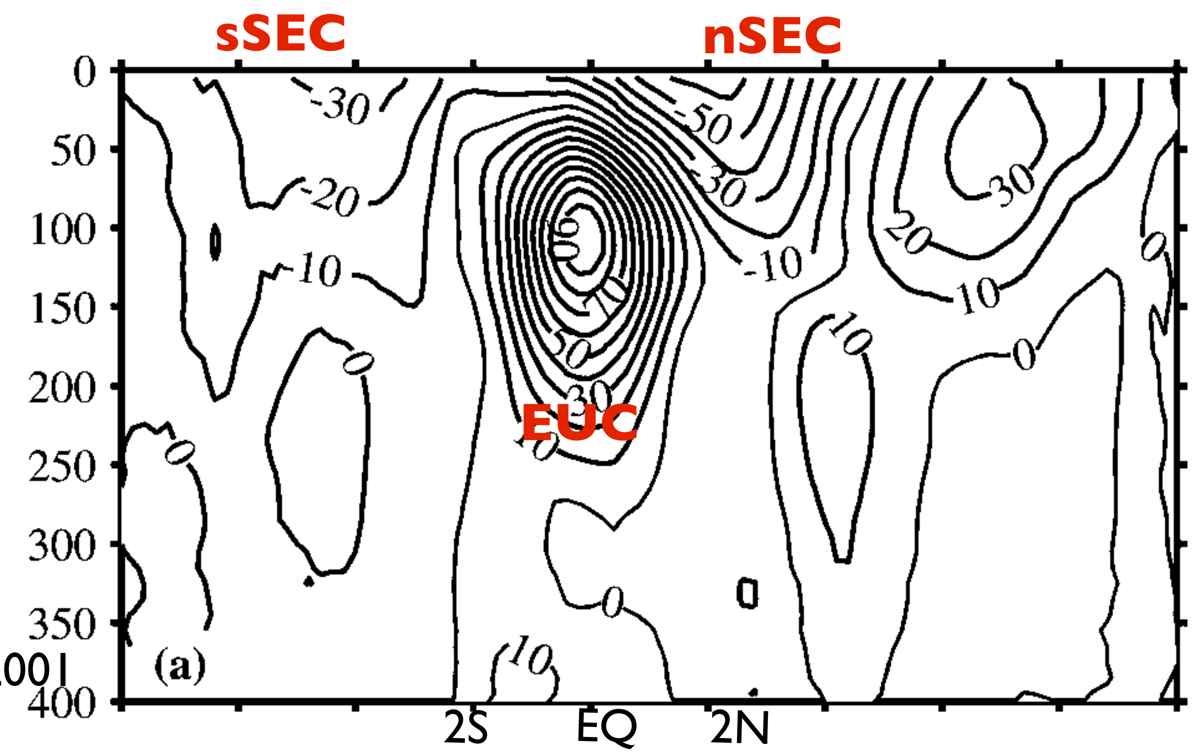
Baroclinic

Barotropic

$$\vec{U}\cdot\vec{\nabla}\vec{K}_e + \vec{u}'\cdot\vec{\nabla}\vec{K}_e = -\vec{\nabla}\cdot(\vec{u}'p') - g\rho'w' + \rho_o(-\vec{u}'\cdot(\vec{u}'\cdot\vec{\nabla}\vec{U}))$$
$$+\rho_o A_h \vec{u}'\cdot\nabla^2\vec{u}' + \rho_o\vec{u}'\cdot(A_v\vec{u}'_z)_z + \vec{u}'_{sfc}\cdot\vec{\tau}'_z$$

Correlation of wind stress and current

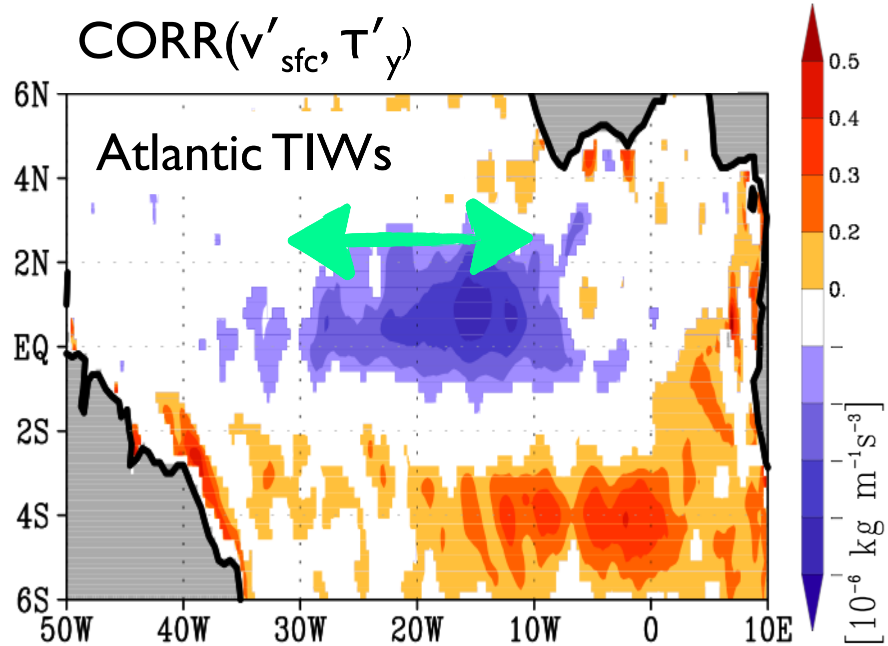
Lat-depth view of zonal current system in the equatorial Pacific

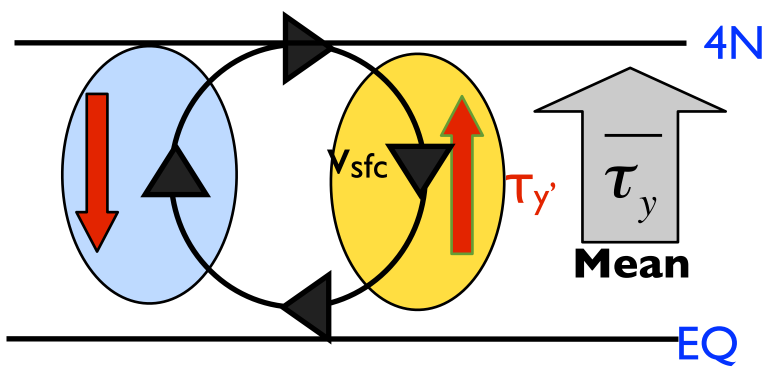


Johnson et al. 2001

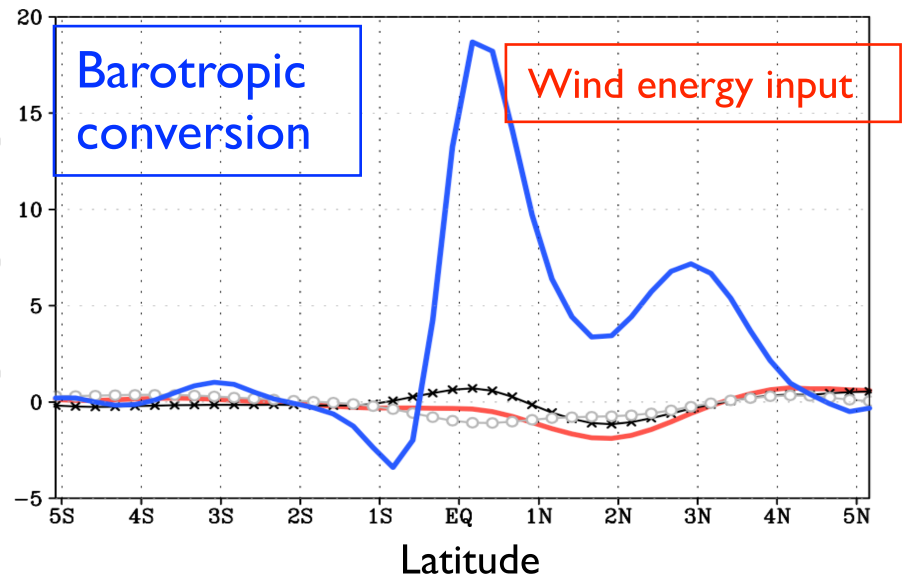
Anomalies in current and wind stress are opposite in direction.

CORR(v'_{sfc}, τ'_y)





- Wind and current are negatively correlated.
- Wind-current coupling ➔ energy sink

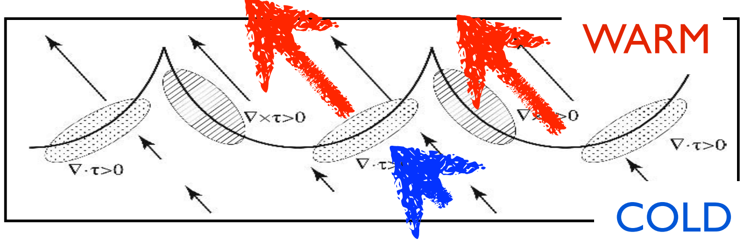


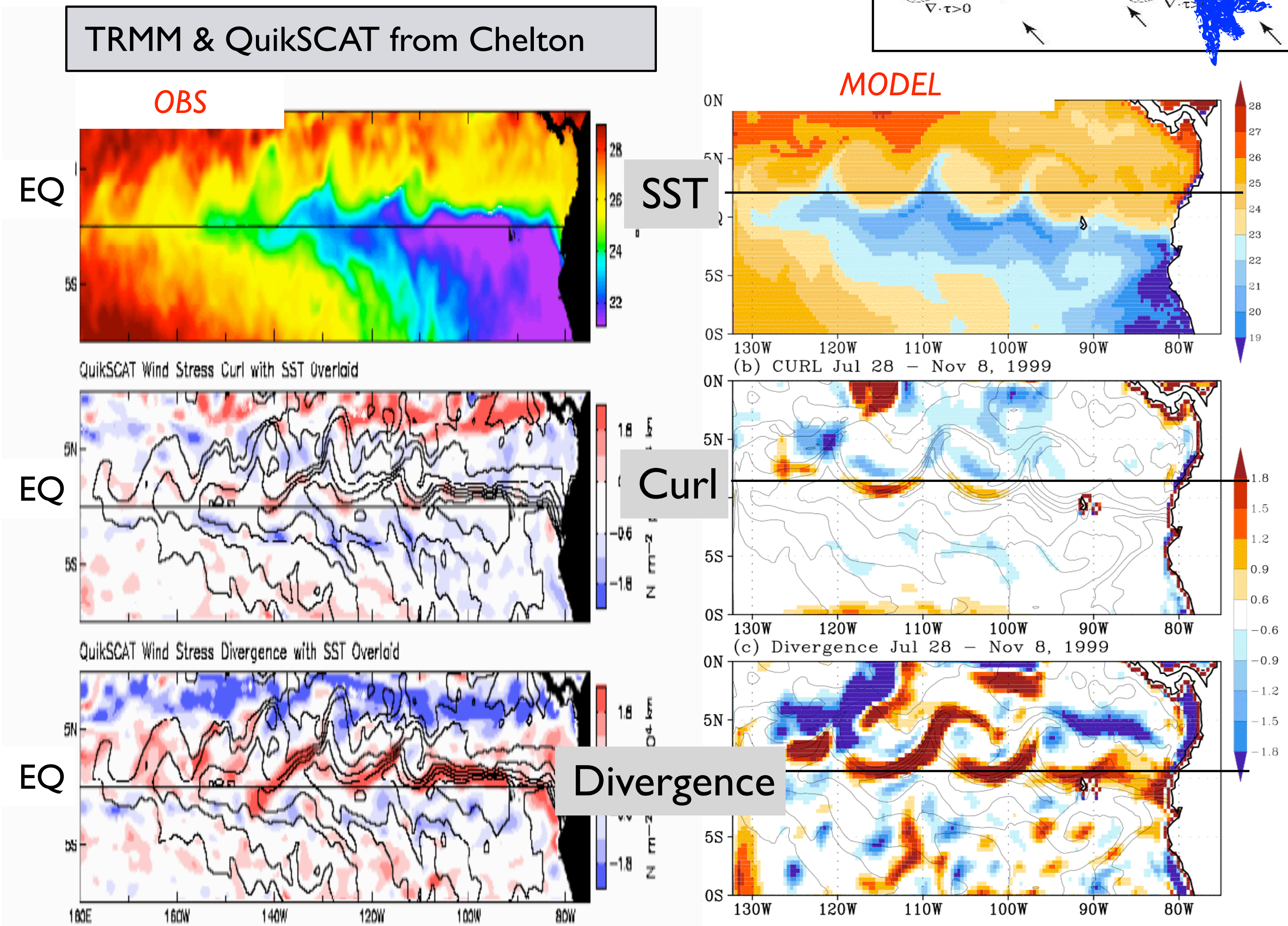
- Wind contribution to TIWs is ~10% of BT conversion rate.

Averages: 30W-10W, 1999-2004, 0-150 m

② Modification of wind stress curl by SST gradients:

SST gradients generate wind curl/div.





A quasi-linear relationship between the derivatives of wind stress and SST.
Curls tend to be largest on the equator!

Feedback of perturbation Ekman pumping to TIWs

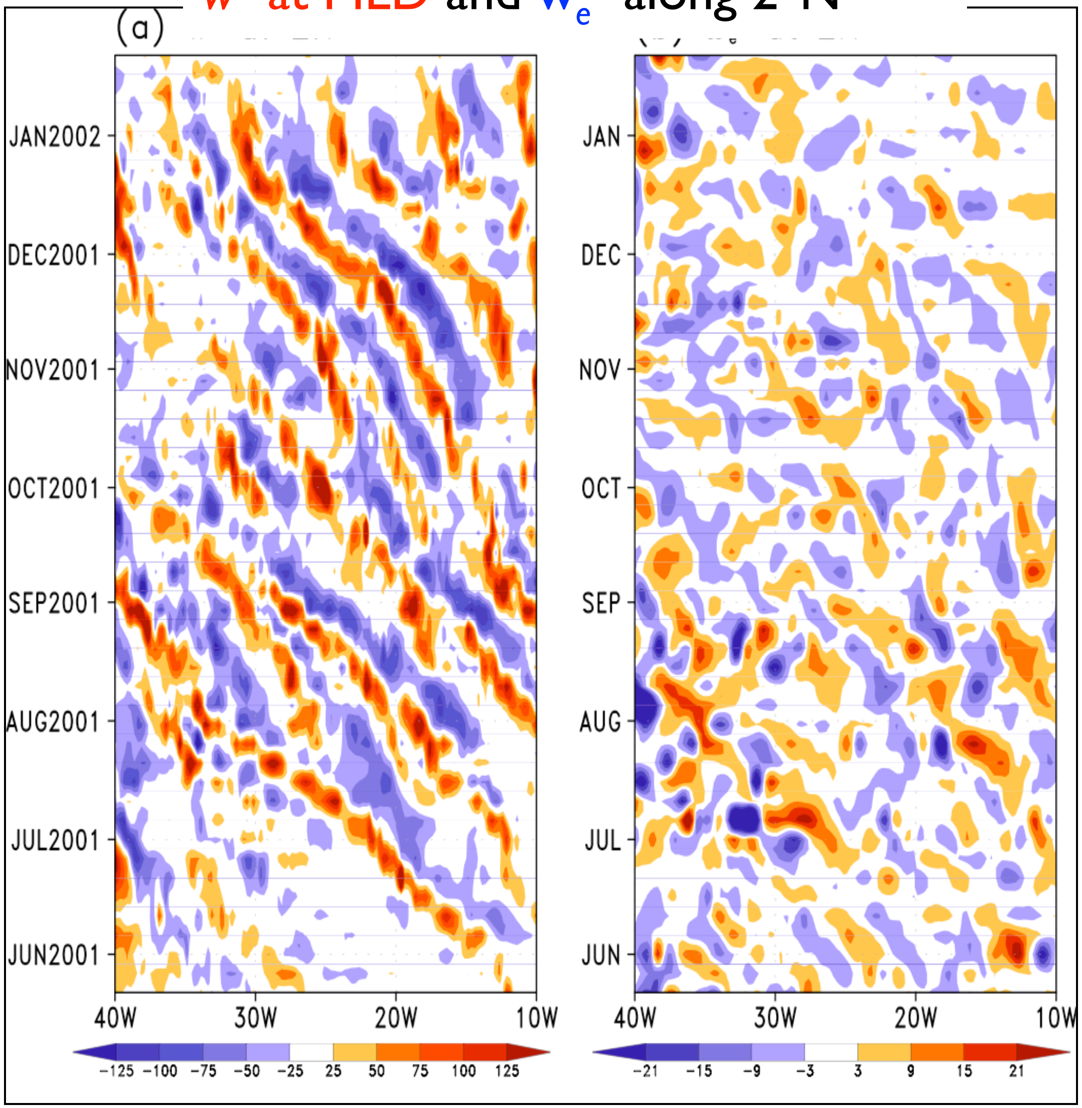
Perturbation Ekman pumping velocity (w_e') and perturbation vertical velocity (w') of $\boldsymbol{-g\rho' w'}$.

Overall, w_e' is much weaker than w'.

Caveat: Difficult to estimate Ekman pumping near the equator.

In other regions away from the equator effect, this may affect the evolution of mesoscale eddies. (e.g., Chelton et al. 2007, Spall 2007, Seo et al. 2007, 2008 etc)

w' at MLD and w_e' along 2°N



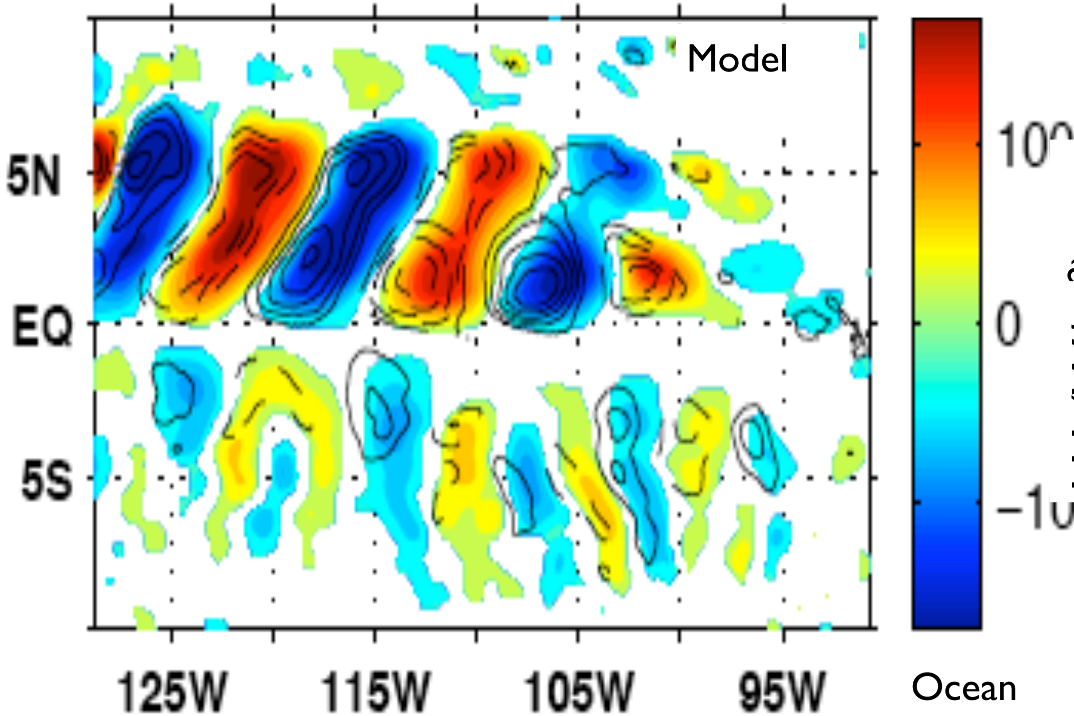
Unit: 10^{-6}m/s, Zonally highpass filtered, and averaged over 30W-10W

③ Response and feedback of heat flux

Turbulent heat flux response to TIWs

CEOF1: Latent heat flux and SST

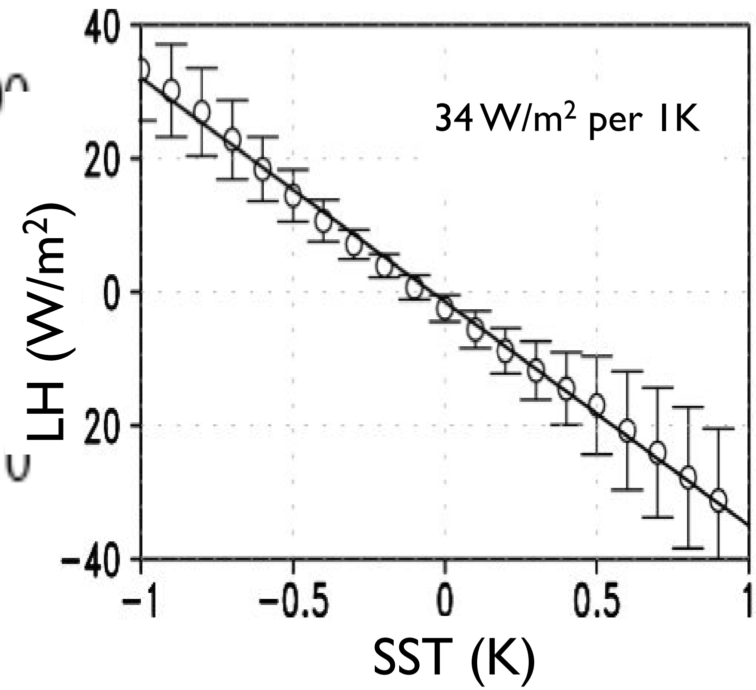
Ocean warming



Ocean cooling

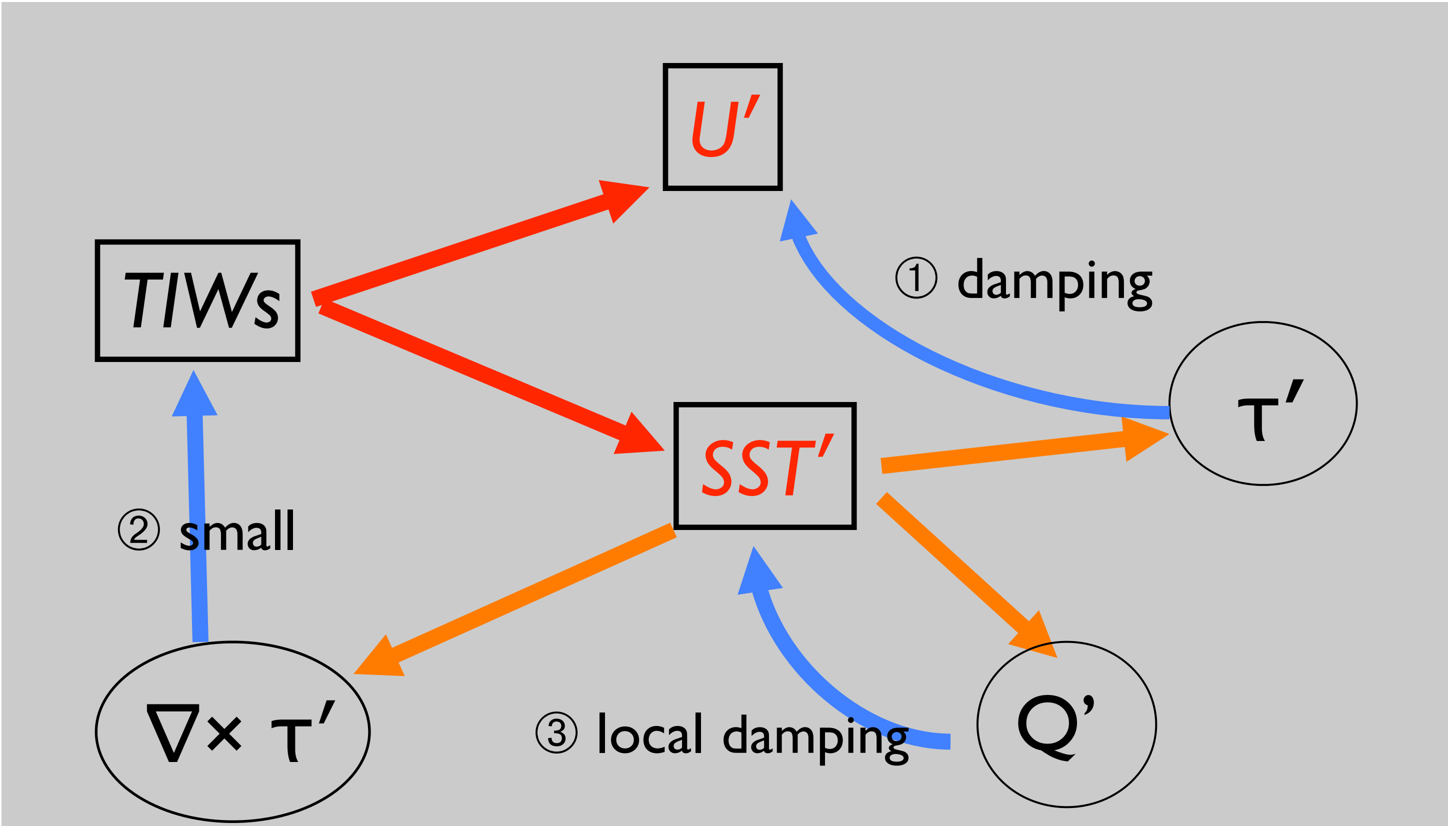
LH (shading) SST (contours)

A quasi-linear relationship



Instantaneous damping of local SST anomalies by perturbation heat flux

A summary for Part I: High-frequency TIW-atmosphere coupling



① Wind response damps TIW-current: Small but significant damping

② Negligible contribution at 2N (difficult to estimate near the equator)

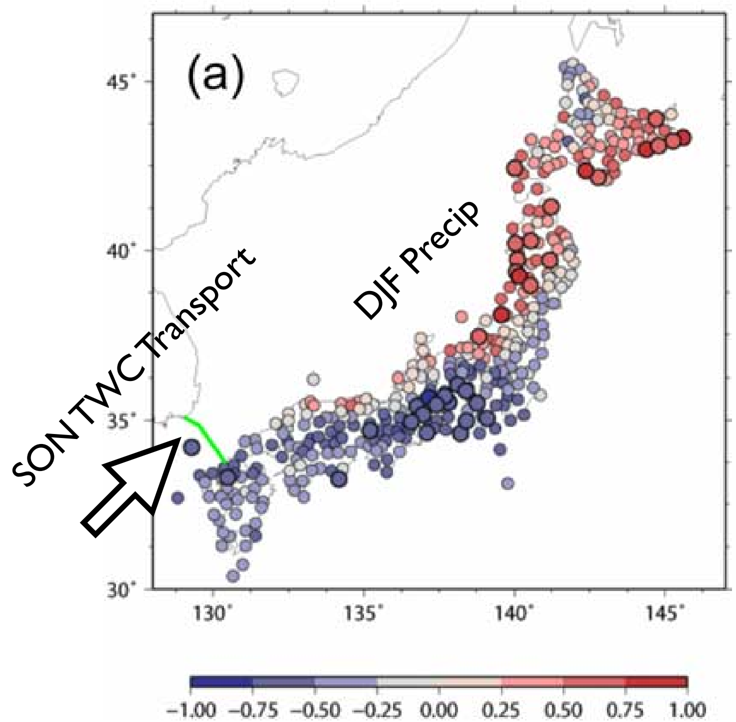
③ Damping of local SST (but small rectification to large-scale SST)

Part II:
Role of the East/Japan Sea SST in the regional weather and the downstream circulation

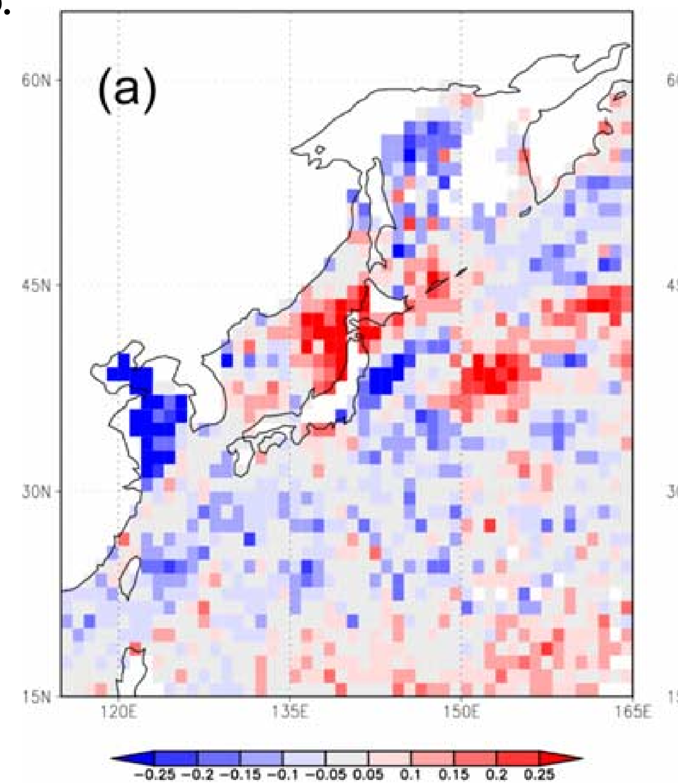
Winter SST variability in the East Asian Marginal Seas is important for regional weather variability.

In the East/Japan Sea, the ocean heat transport by the Tsushima Warm Current is known to impact the wintertime SST, hence the air-mass modification and precipitation.

Correlation
SON TWC Transport and DJF Precip.



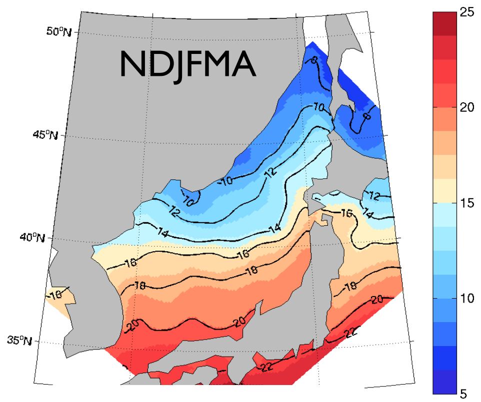
Correlation
SON TWC Transport and DJF SST.



Hirose et al. 2009

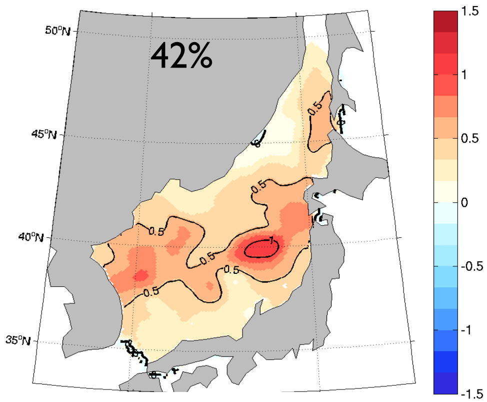
Dominant modes of the wintertime SST variability

Climatology

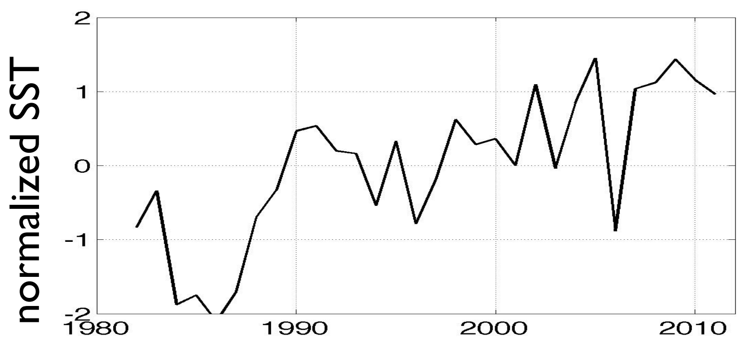


Data: NOAA OI SST 25 km, Daily, 1982-2010

EOF1

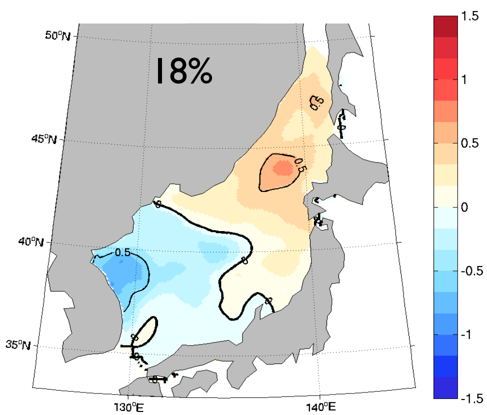


PC1

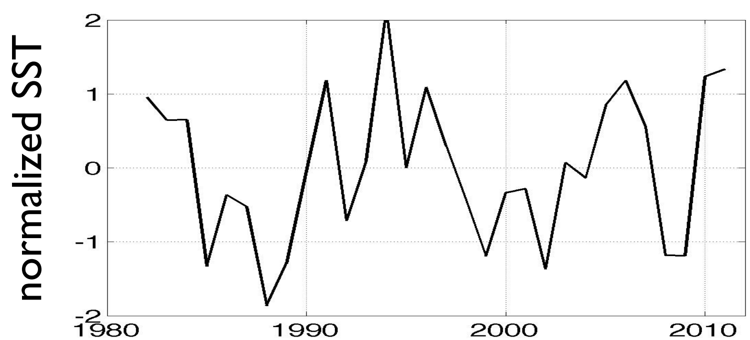


- Warming along the subpolar front with the mesoscale eddies
- ≈ **Interannual 1st CEOF** in Minobe (2004)

EOF2



PC2



- Dipolar pattern in SST anomalies across the subpolar front
- ≈ **Decadal 1st CEOF** in Minobe (2004)

Main question

How do these two types of SST anomalies patterns

1) Basin-wide warming and cooling
2) Northeast/southwest dipolar warming/cooling

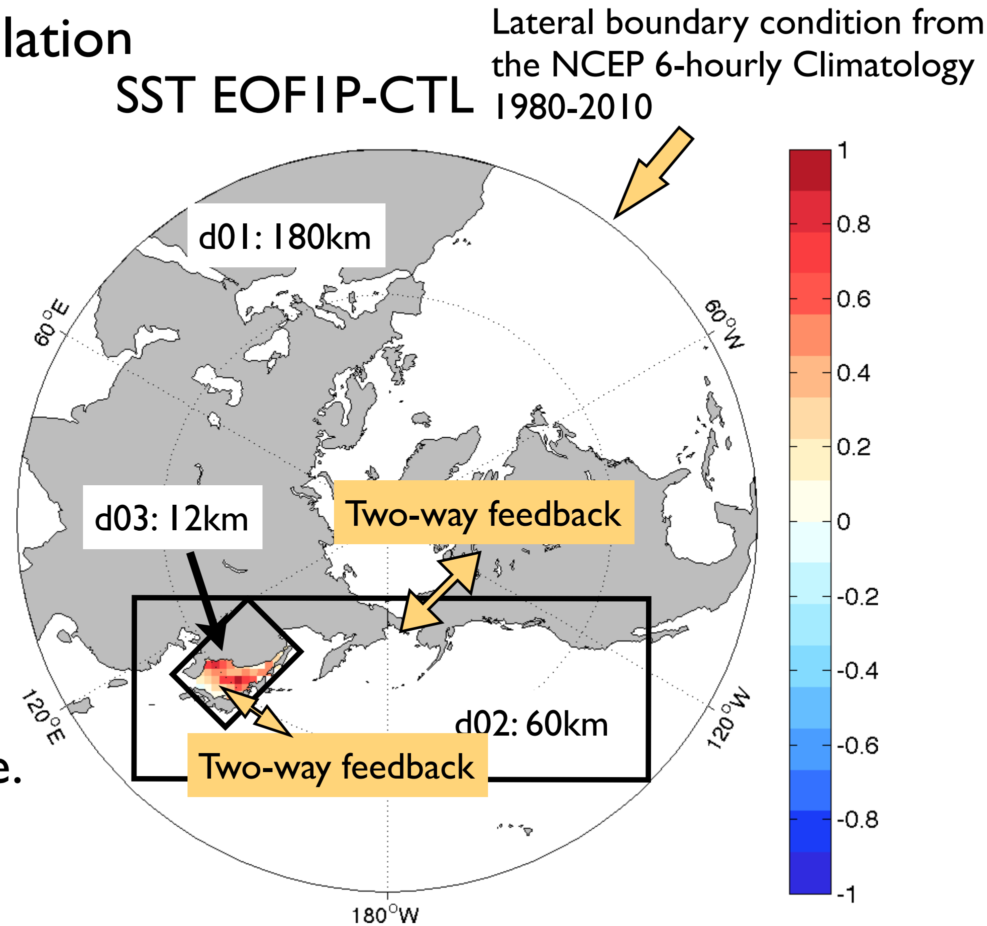
would impact the regional and large-scale circulation patterns?

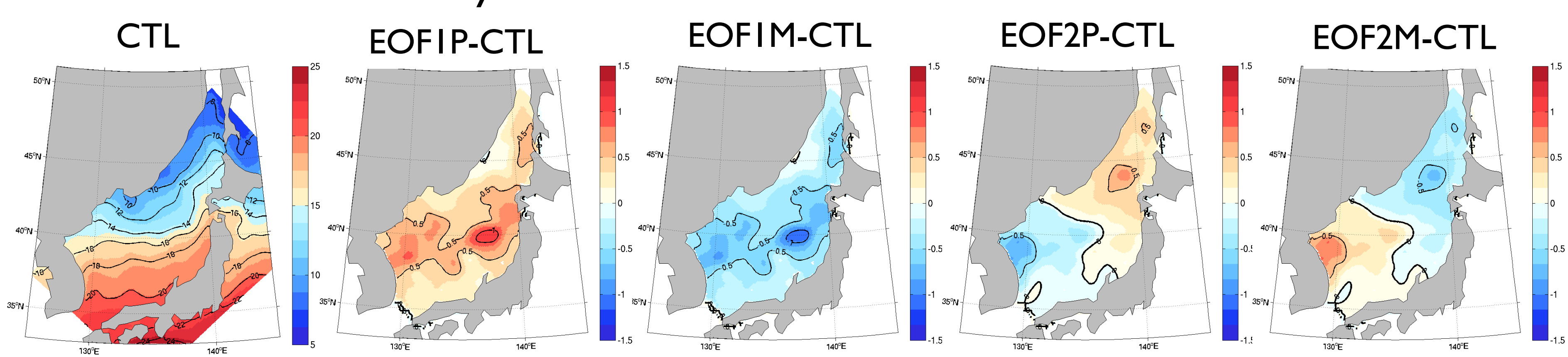
Regional atmospheric model simulation

- Model: **WRF 3.3**
- SST conditions: NOAA SST
- Integration: 6 months, Nov.-Apr.

• Five simulations:
• CTL, EOF1P and EOF1M (40-member ensemble)
• EOF2P and EOF2M (20-member ensemble)

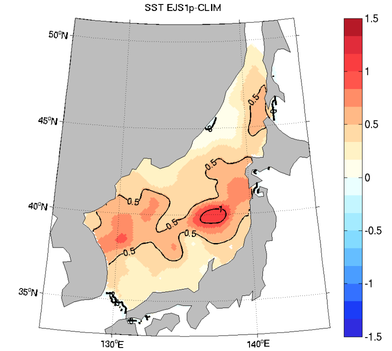
- Focus on November-January response.
  - First two weeks (1-14 days)
  - The rest of 77 days





1. Response to different time-scale and ensemble averaging

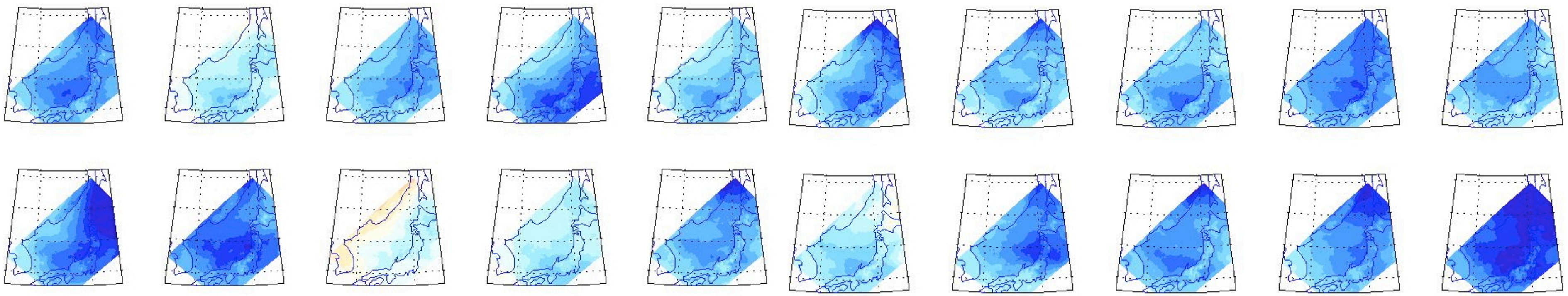
The deterministic SLP response to the diabatic forcing: **1-14 days**



EOF1P-CTL

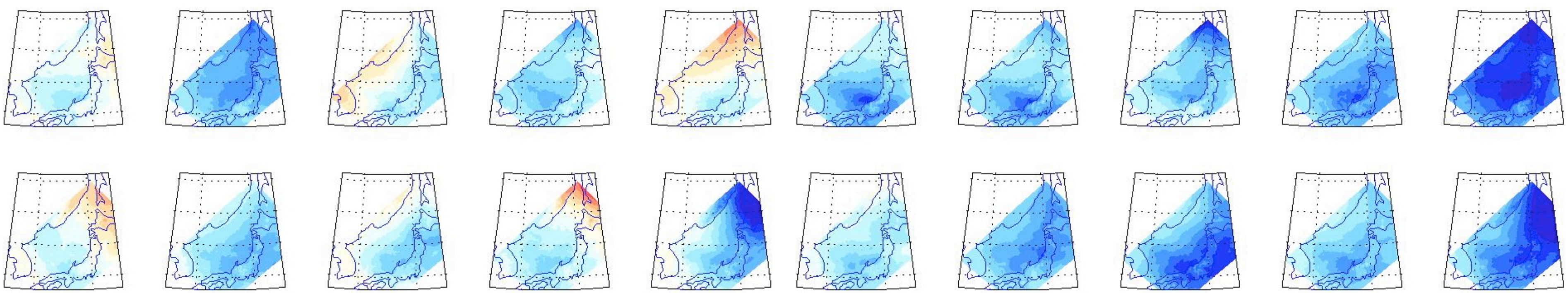
Ensemble member 1-10

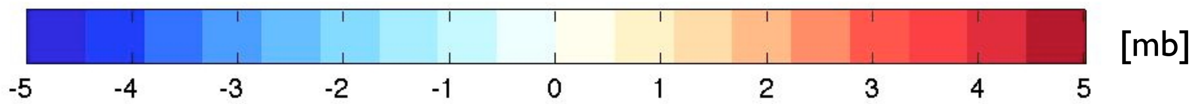
Ensemble member 11-20



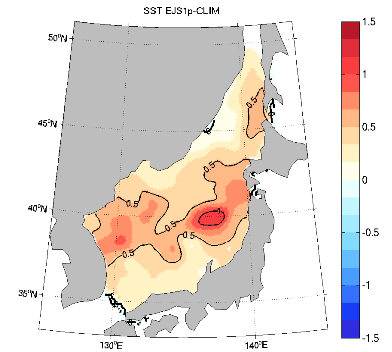
Ensemble member 21-30

Ensemble member 31-40





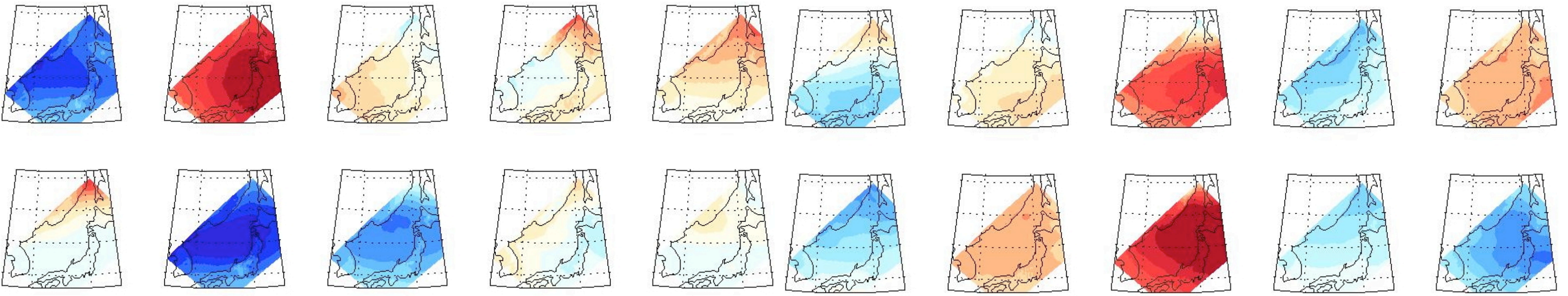
The quasi-equilibrium SLP response is chaotic. **15-91 days**



EOF1P-CTL

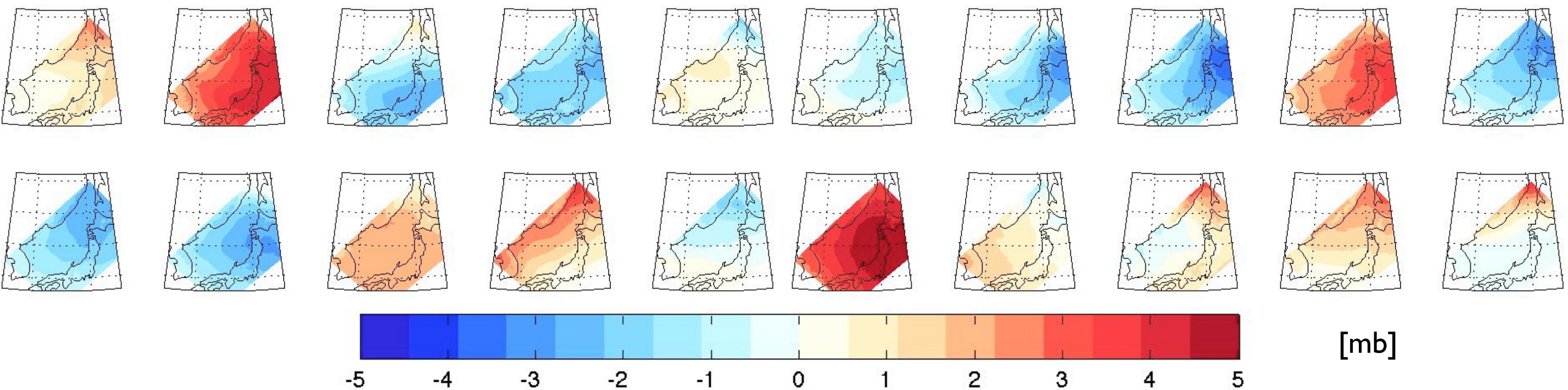
Ensemble member 1-10

Ensemble member 11-20



Ensemble member 21-30

Ensemble member 31-40

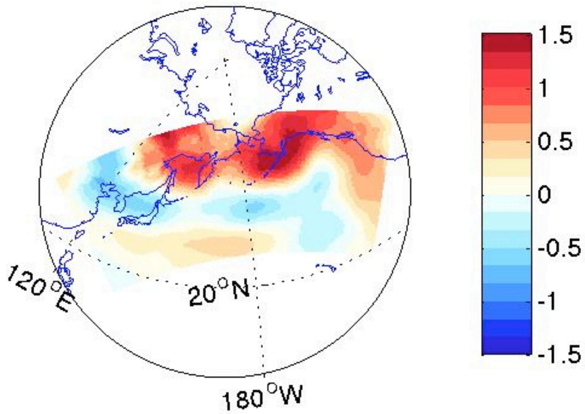


This chaotic response in SLP despite the prescribed diabatic forcing due to the change in large-scale circulation.

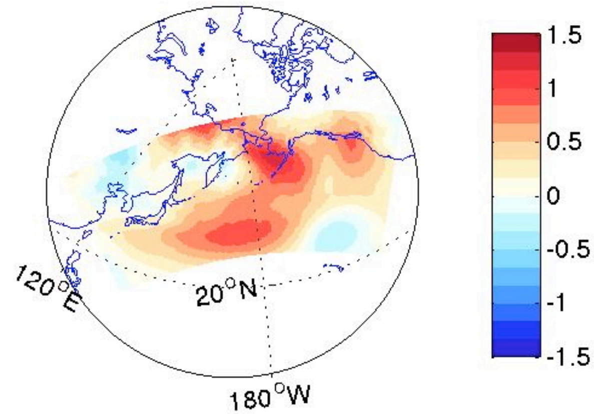
Sensitive to different number of ensemble averaging **15-91 day**

EOF1P-CTL

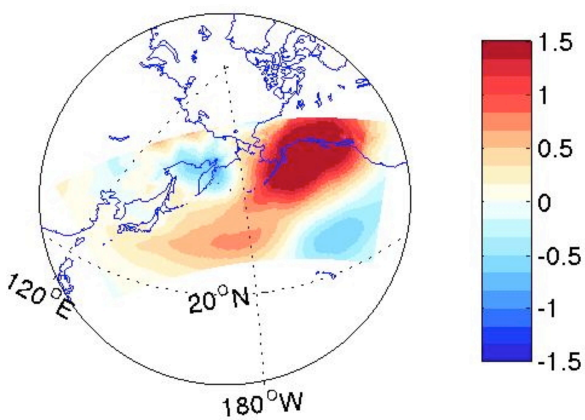
1-10 member mean



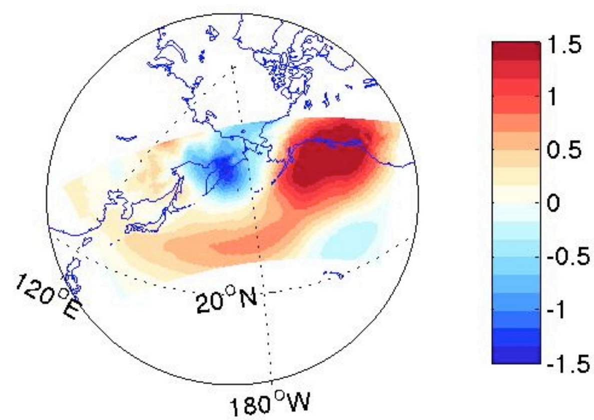
1-20-member mean



1-30 member mean



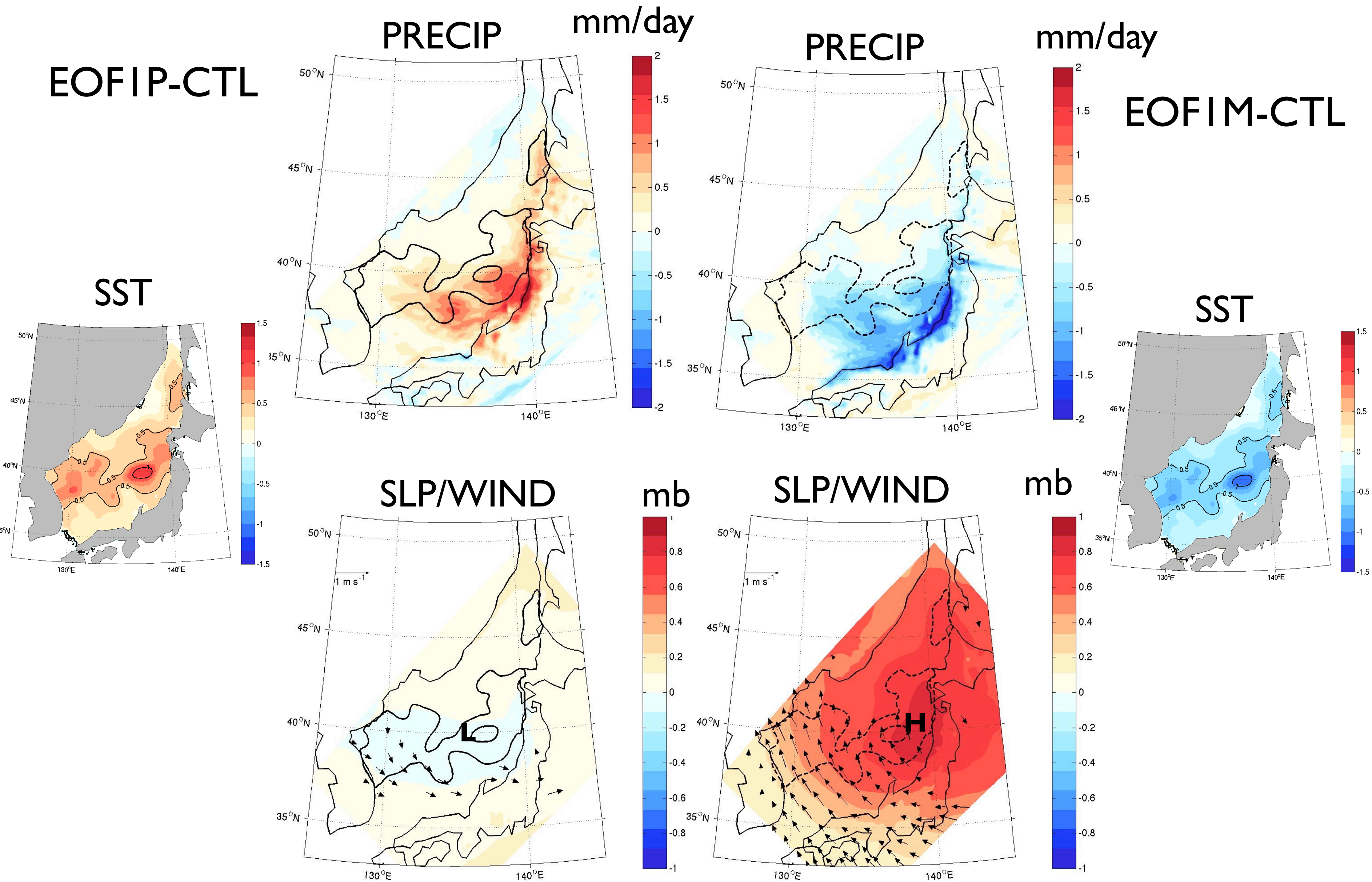
1-40 member mean



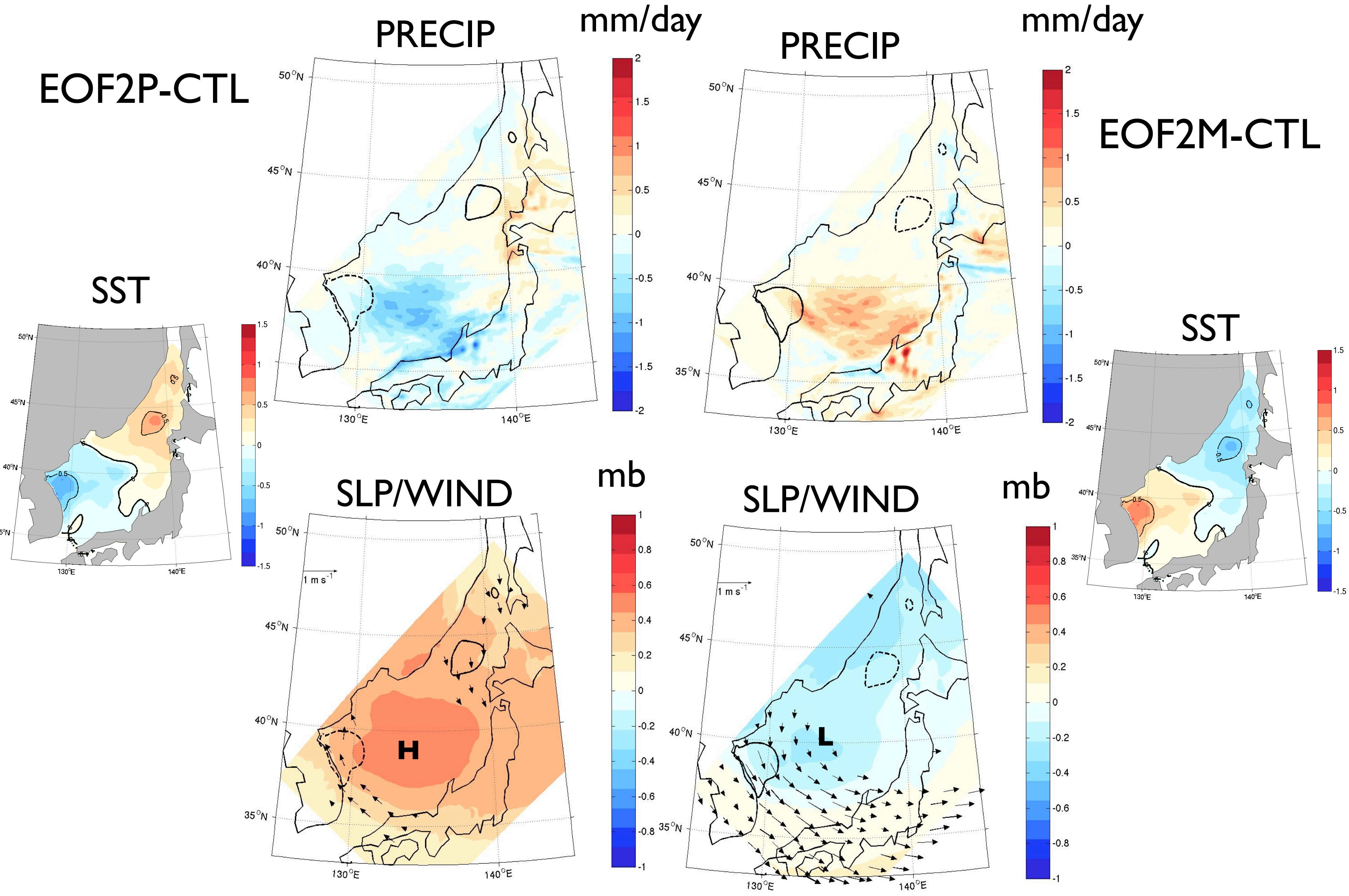
While 40-member ensemble average is not sufficient, some robust SLP responses begin to emerge in the downstream as more ensemble members are used for averaging.

2. Local responses
Precipitation and circulation in NDJ (15-91 day)

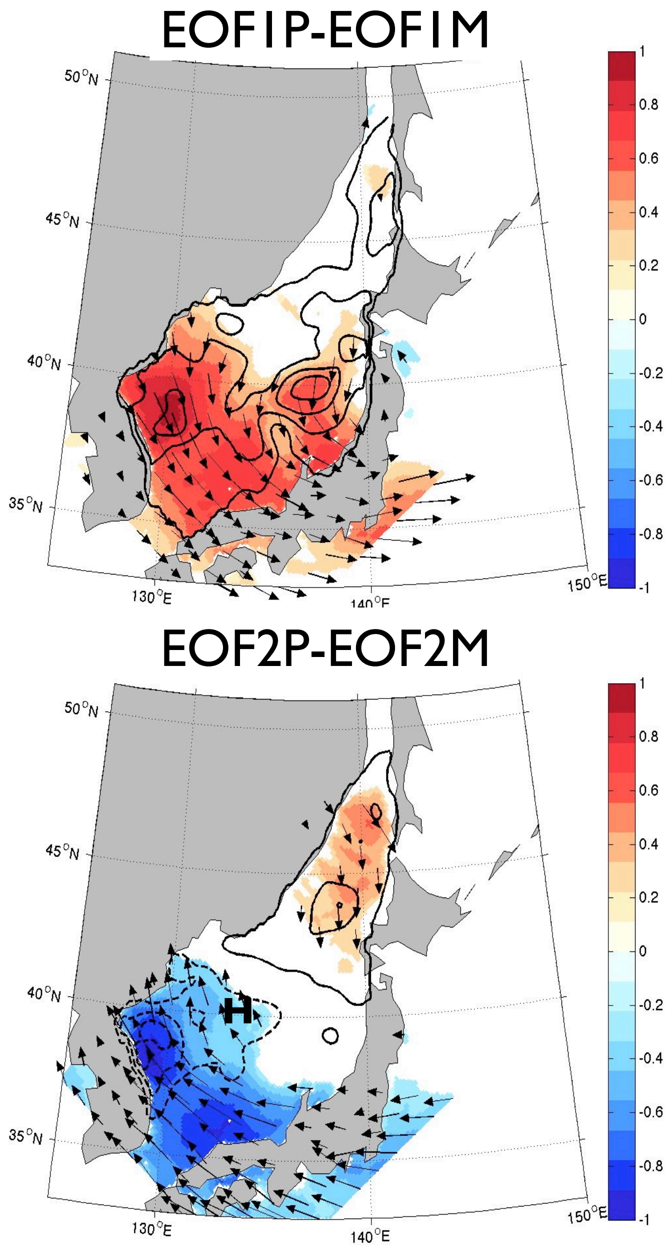
15-91 day averaged responses in precipitation, SLP, and surface wind

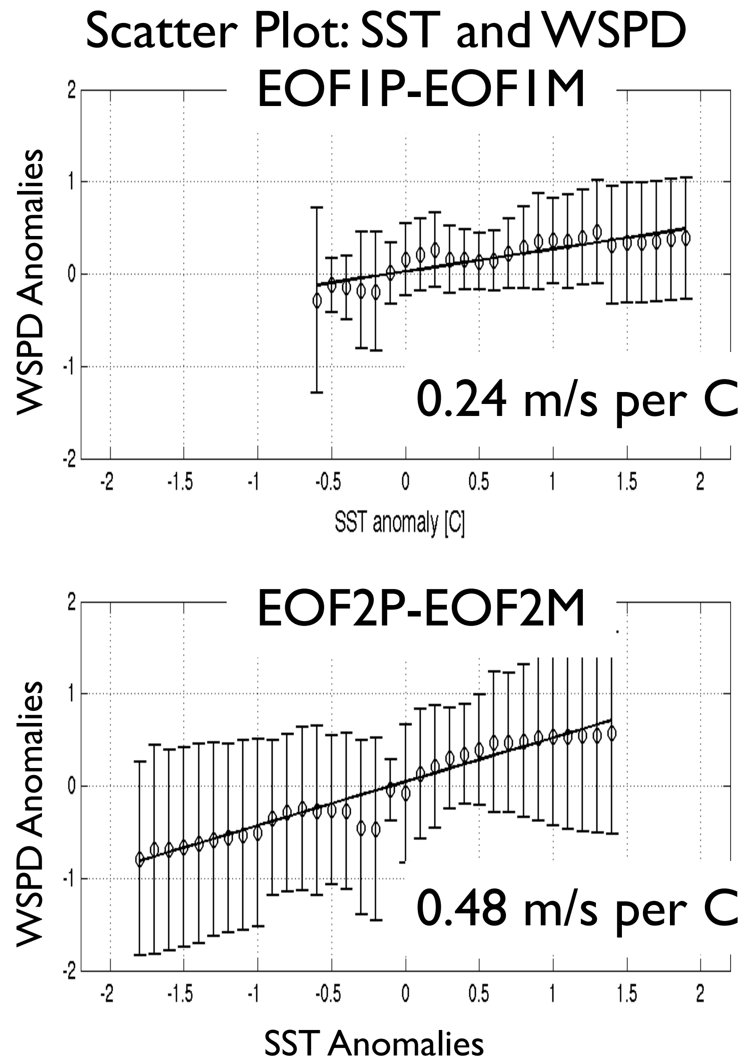


15-91 day averaged responses in precipitation, SLP, and surface wind



Patterns in anomaly of SST and wind speed are positively correlated.



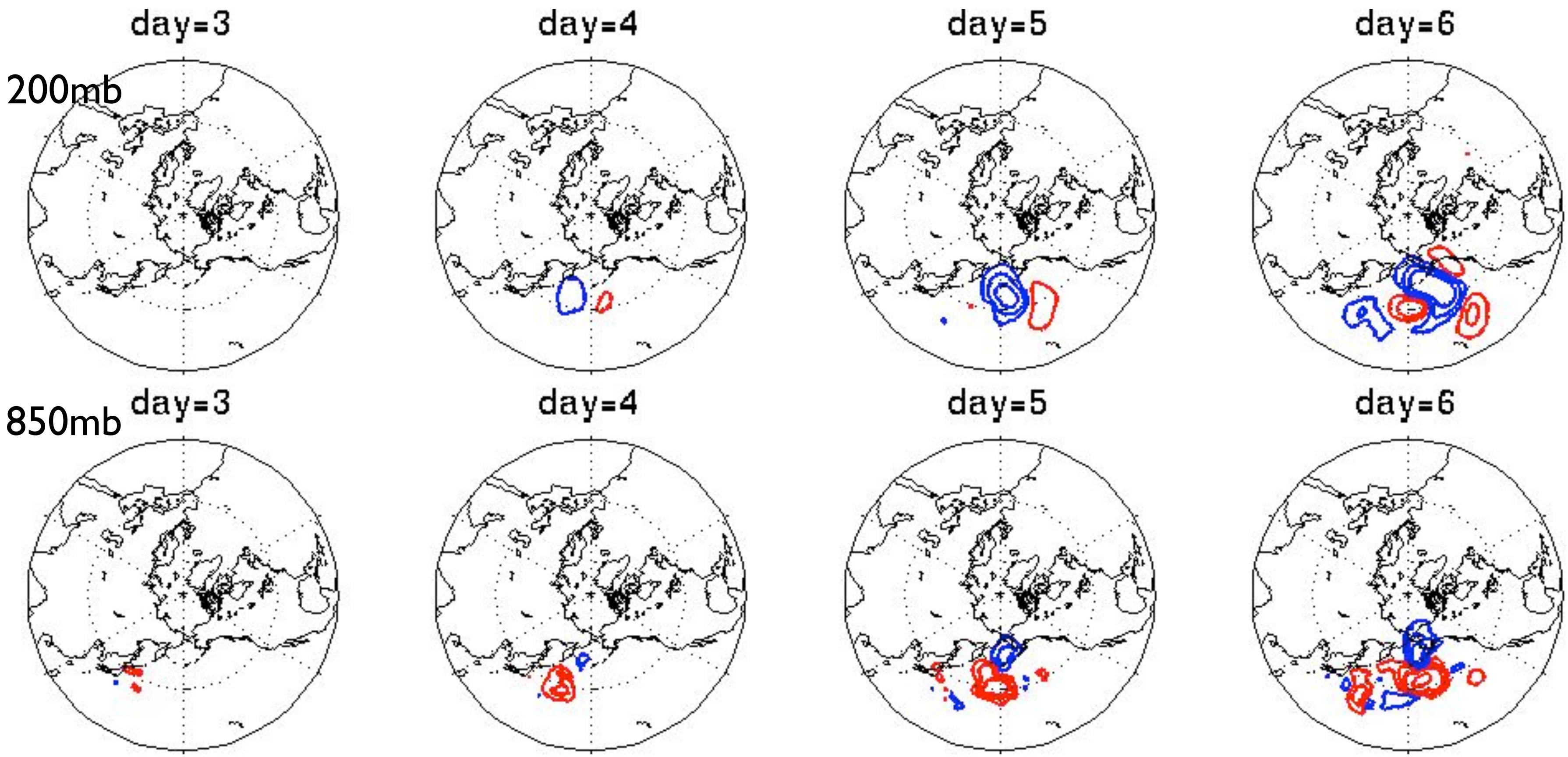


See Shimada and Kawamura (2006) s=0.31

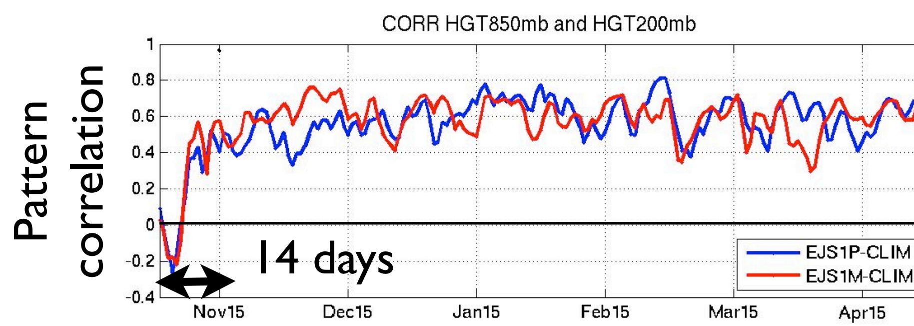
and also Yamamoto et al. (2011)

3. Downstream responses in atmospheric circulation

Baroclinic evolution to the SST anomalies in EJS during the first 6-days
EOF1P-CTL



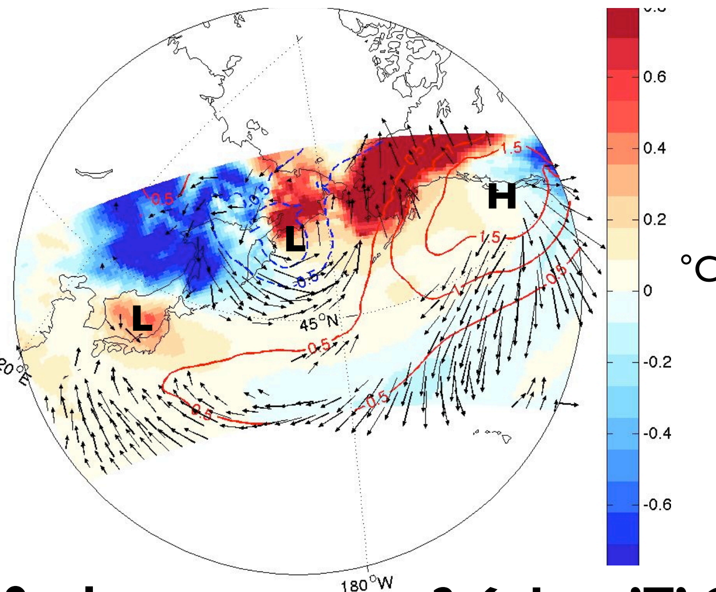
- A baroclinic height response for the initial 14 days
- Followed by the prominent barotropic structure.



Responses in baroclinicity and downstream storm track
EOF1P-CLIM

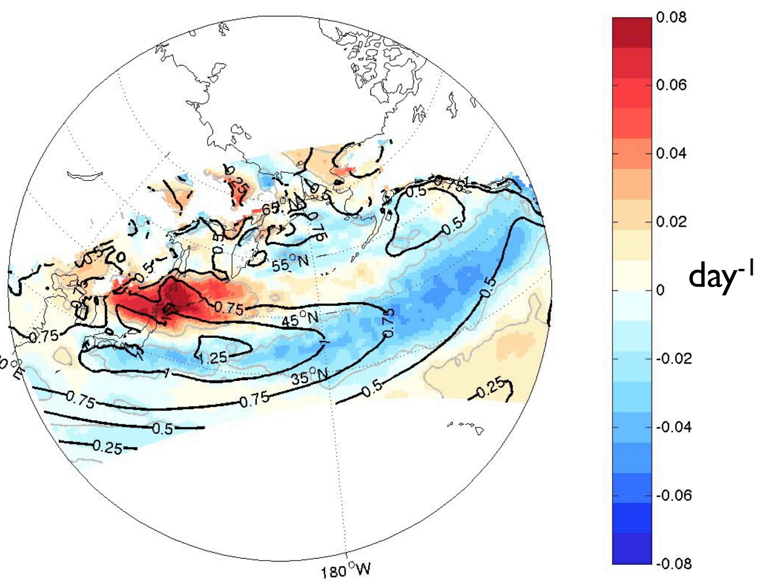
Air Temperature, SLP, wind

- Low centered over the Kamchatka Peninsula.
- High in the Pacific NW.
- Low-level baroclincitiy is enhanced in the northern EJS with the EOF1P pattern.

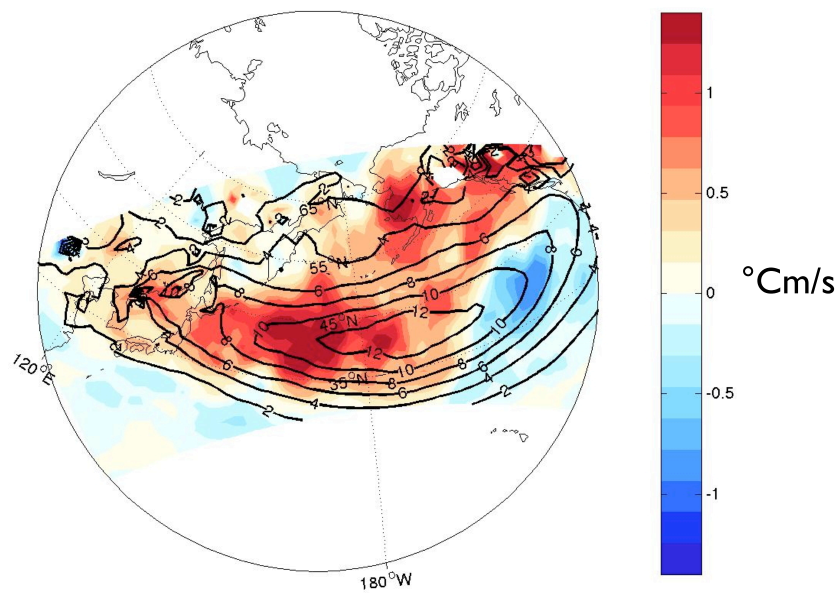


- Northward heat transport by synoptic eddies is enhanced in the W. Pac and shifted northward in the E. Pac.

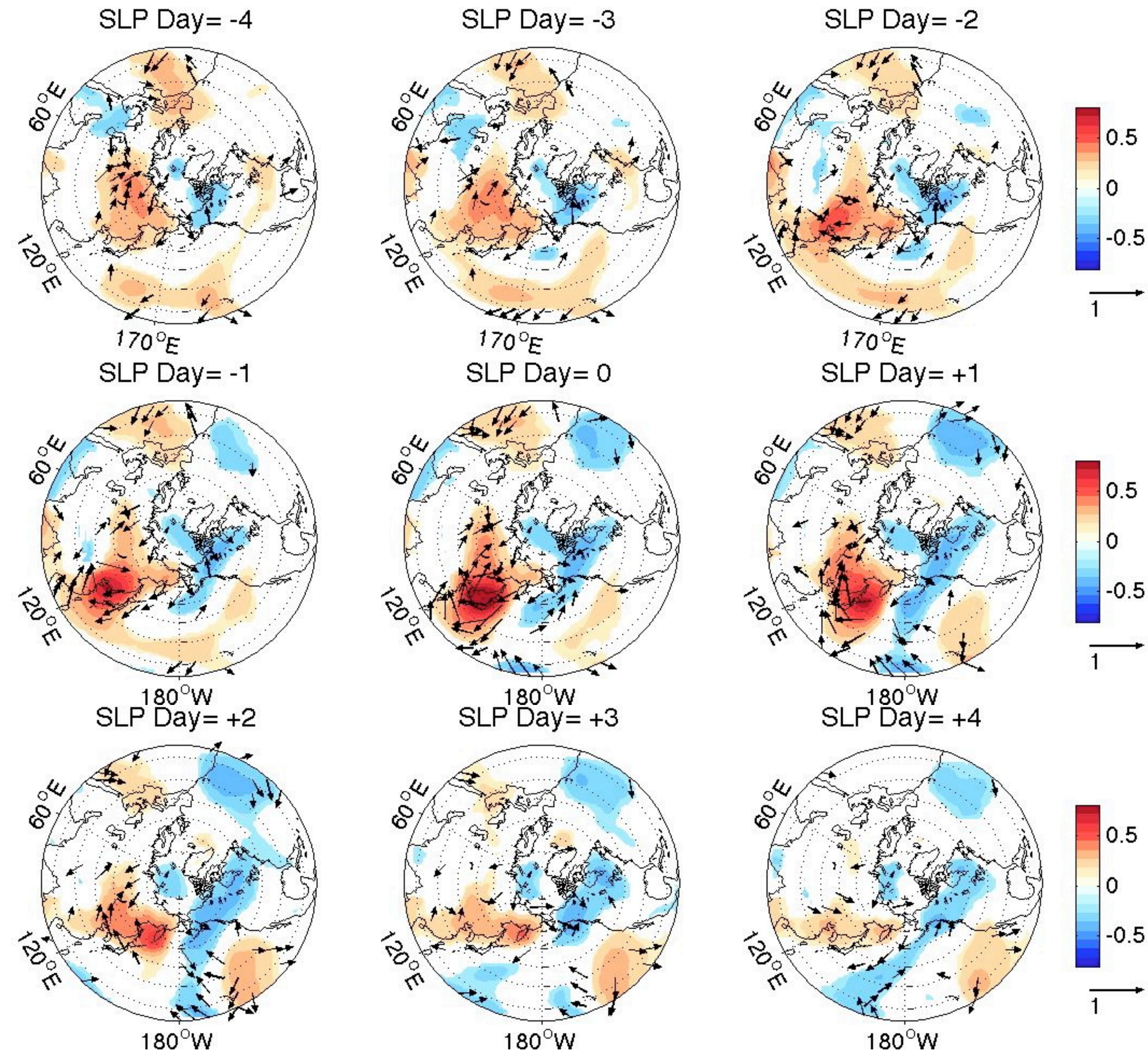
Eady Growth Rate σ_E @ 850 mb



2-6 day v'T' @ 850 mb



Lagged correlation coefficient of SLP: EOF1P-CTL



SLP (color) correlated with the index (SLP difference averaged EJS SLP)

Significant low and upper level ridges originate from Siberian High, passing over the marginal seas towards the Okhotsk Sea. Propagation of wave trains eastward and poleward.

Summary: Part II

- Two dominant modes of wintertime SST variability produce differing SLP responses during the periods of initial adjustment and quasi-equilibrium.
  - An initial deterministic and baroclinic response to a diabatic forcing
  - A quasi-equilibrium chaotic circulation response with an equivalent barotropic vertical stricture.
    - Some robust response can be identified after 40-member averaging, but it is uncertain as to the optimal number of ensemble.
- Precipitation response is largely symmetric with respect to the polarity of prescribed SST anomalies.
  - Vertical mixing mechanism over warm/cold SST appears to modulate the location of SLP extrema, especially with EJS2P and EJS2M.
- EJS1P (warm basin-wide SST anomaly) enhances the low-level baroclinicity north of the EJS, I
  - Leading to a strengthened storm track variability with a northward shift downstream.