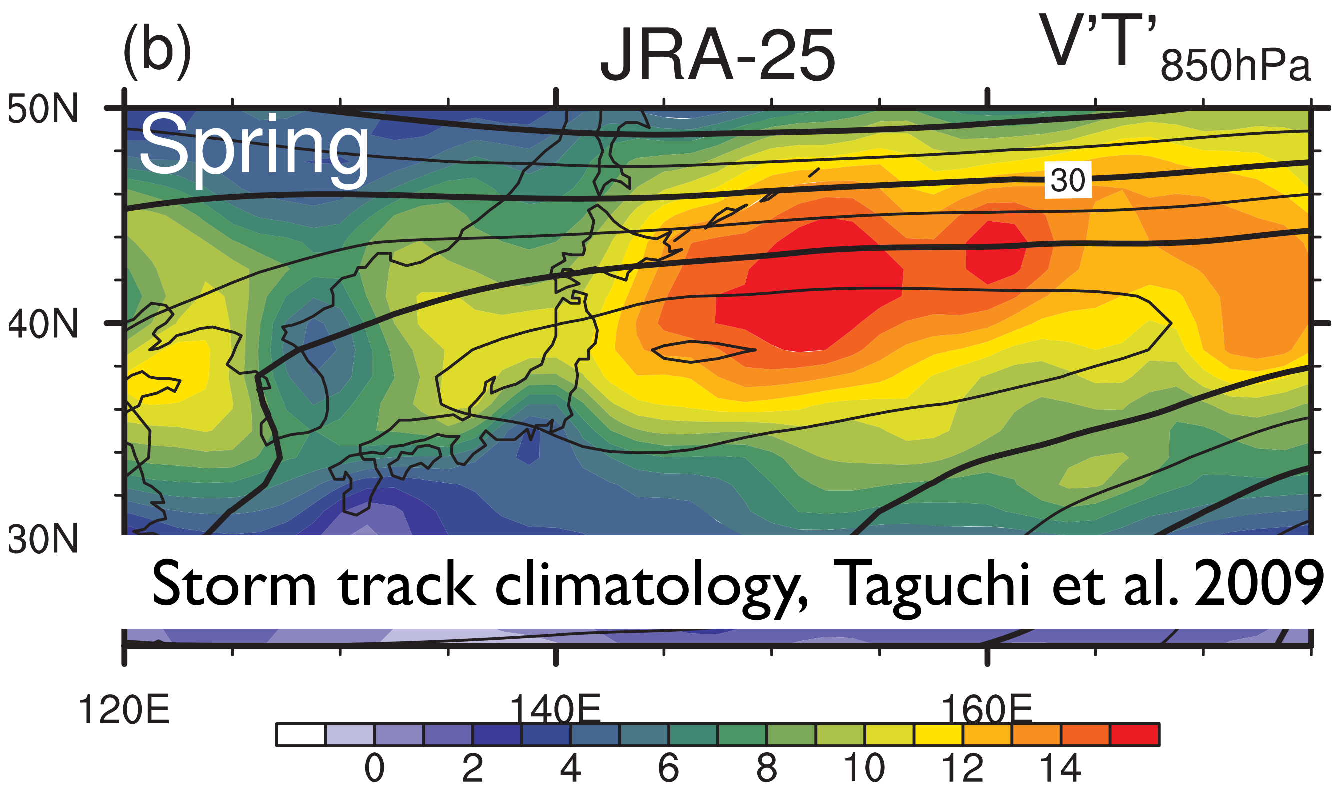
Effect of East/Japan Sea SST variability on the North Pacific atmospheric circulation

Hyodae Seo
Woods Hole Oceanographic Institution

Young-On Kwon (WHOI) and Jong-Jin Park (KNU)

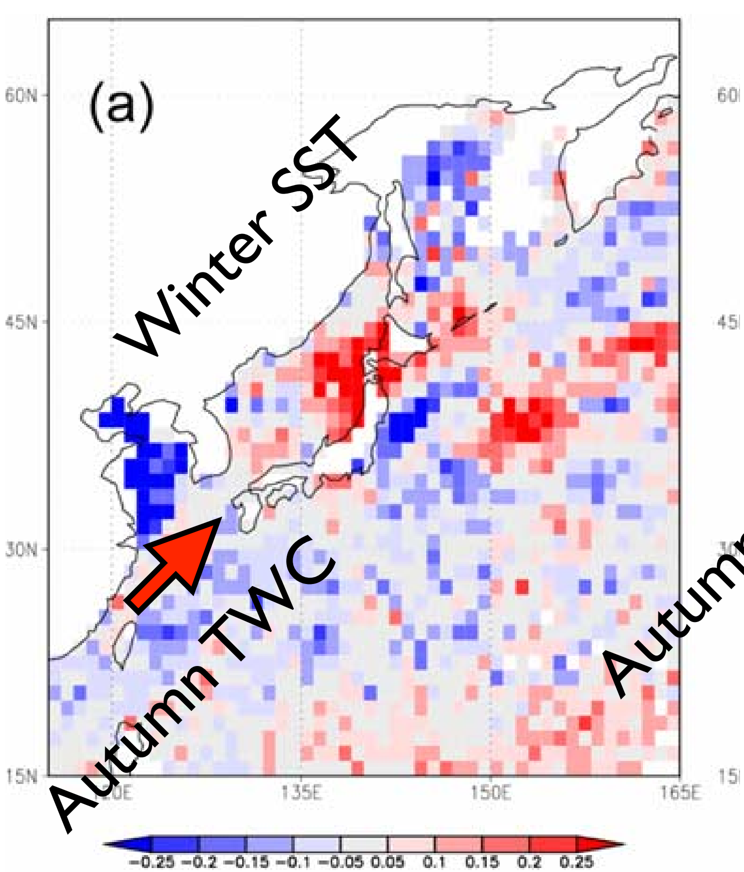
International Workshop on
Development and Application of Regional Climate Models-II
Busan, Korea, September 10-12, 2013

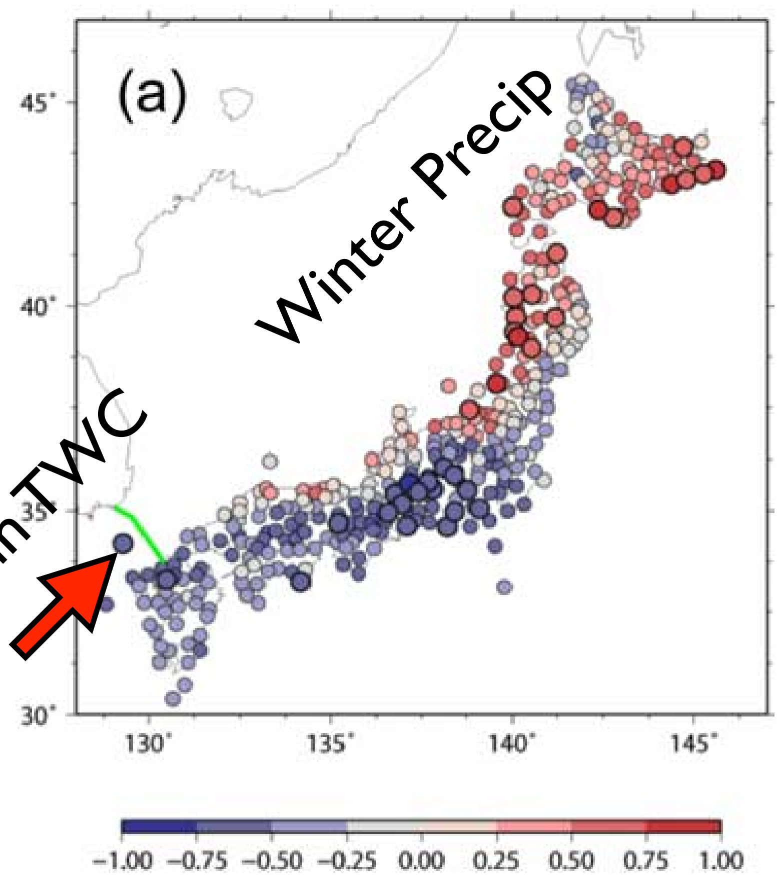
The East/Japan Sea: A semi-enclosed marginal sea in the Northwest Pacific



Storm track climatology, Taguchi et al. 2009

- Located upstream of the winter climatological storm track
- EJS SST is influenced by the greater WBC system and the East Asian monsoon systems.





Hirose et al. 2009

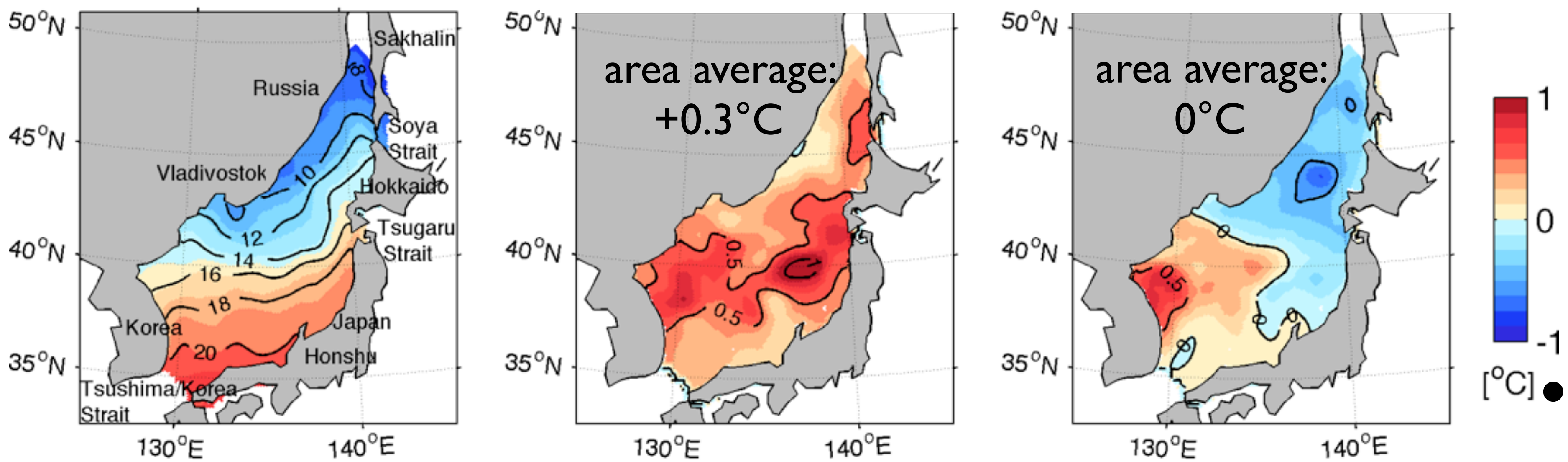
- Winter EJS SST variability is highly correlated the autumn volume transport by the Tsushima Warm Current.
- Important for predictability of regional weather pattern

Possible linkage between the EJS and the large-scale coupled system in the North Pacific?

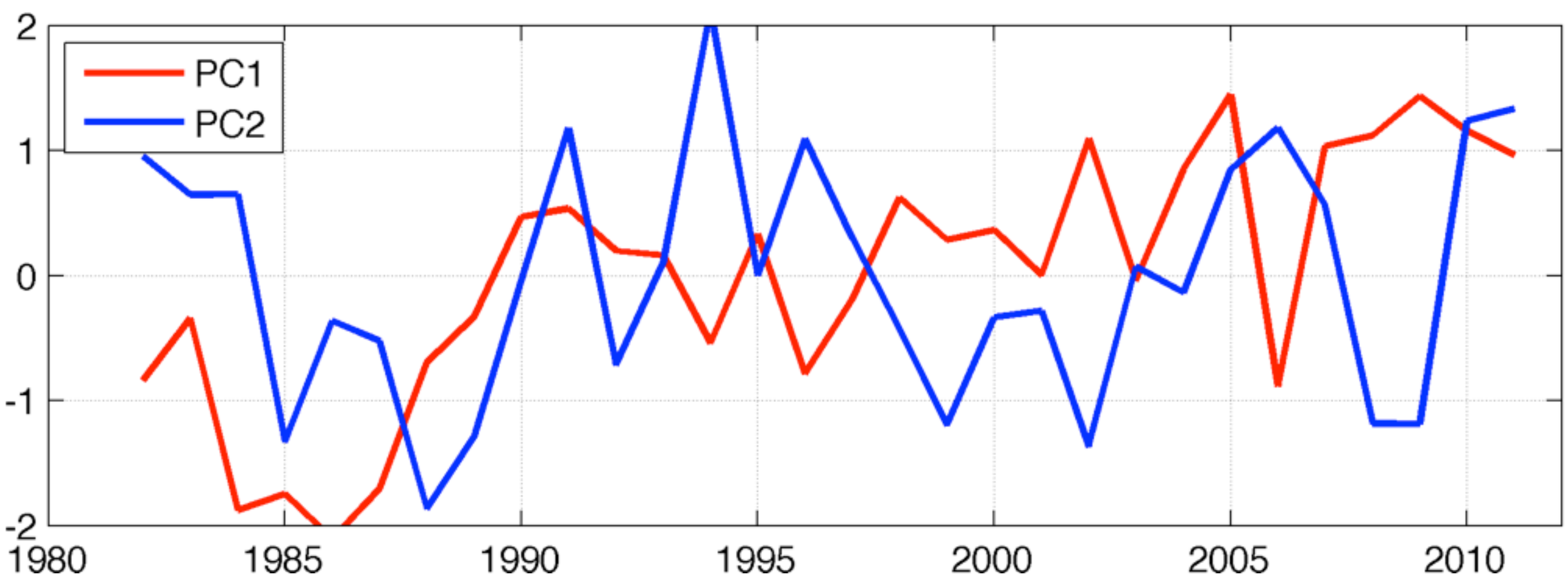
Climatology and dominant modes of variability of winter EJS SST

Optimally Interpolated AVHRR infrared satellite SST
blended with in situ data, daily and 1/4°

1982-2010 NDJFMA SST Climatology | EOF1 42% | EOF2 18%



PC Time-series



- Warm south /southwest and cold north / northeast water masses separated by the subpolar front
- The 1st EOF: Basin-wide warming and cooling centered on the subploar front ≈ **Interannual 1st CEOF** in Minobe (2004) + Linear trend
- 2nd EOF: NE/SW dipolar pattern ≈ **Decadal 1st CEOF** in Minobe (2004)

Key Research Questions

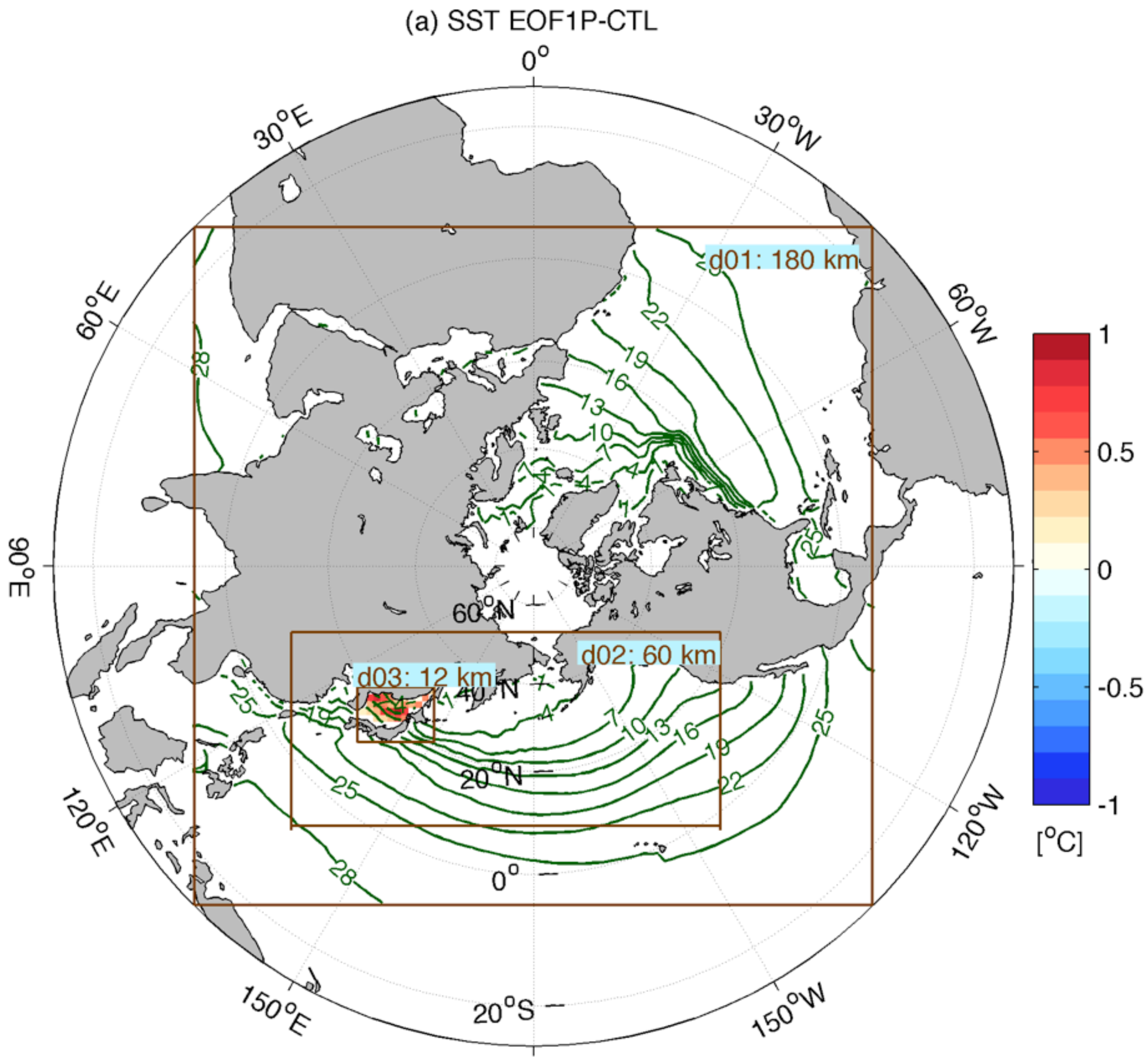
What is the *characteristic response pattern* in local and remote atmospheric circulation to these EJS SSTAs?

What physical and dynamical mechanisms are responsible for the response?

What aspect of such response is sensitive to intra-basin structures of SSTA... and what is not?

A hemispheric WRF model with multiple two-way nesting

as a way to study large-scale impact of marginal sea process



- Challenges in this type of study:
  - Weak SSTA (<0.3°C)
  - Small spatial extent (~10°X10°)
  - Strong atmospheric intrinsic variability

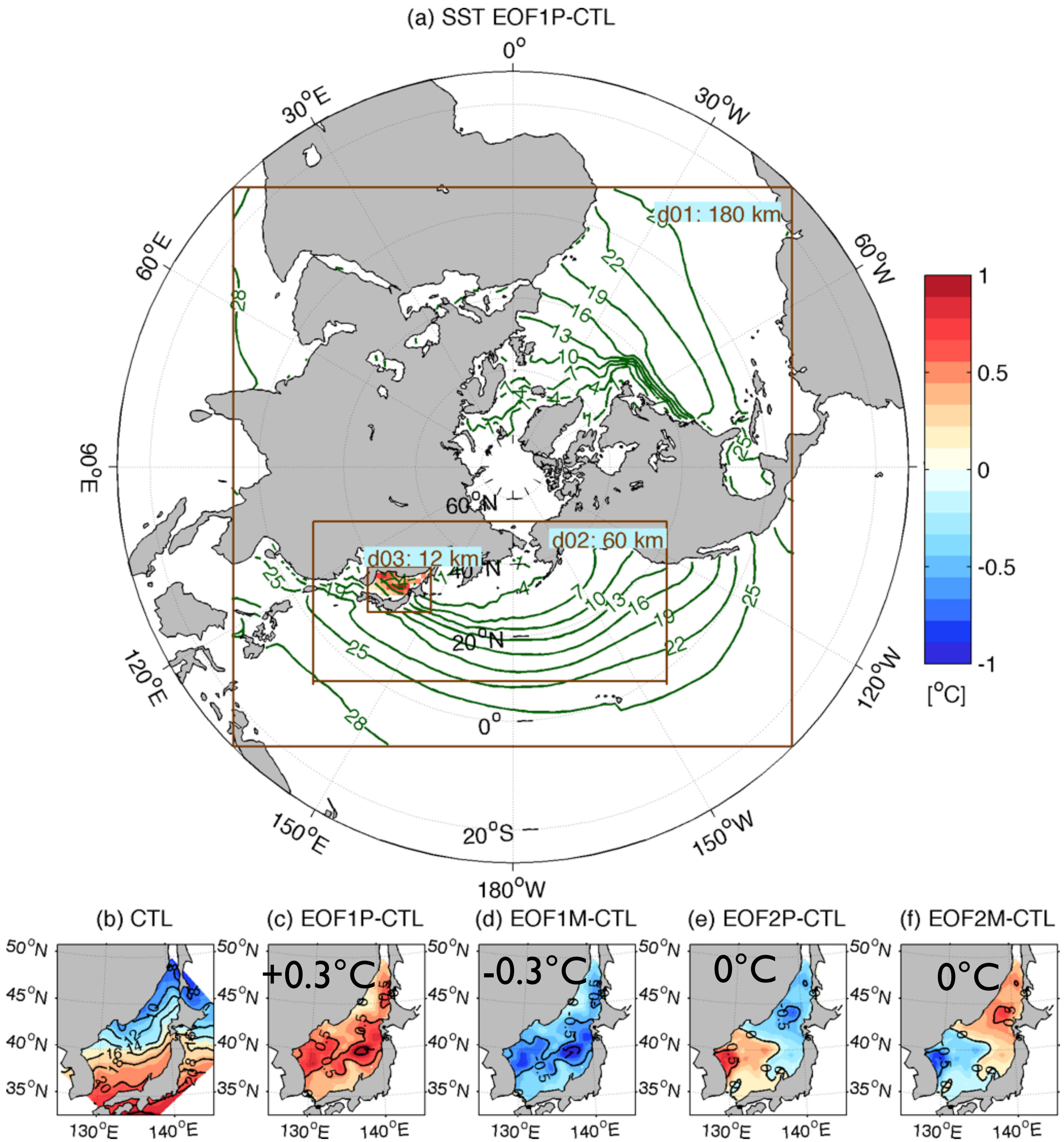
- Need to resolve fine-scale marginal sea process and non-linear feedback leading to large-scale circulation

- Hemispheric WRF with multi-nesting
  - *Downscaling*: Large-scale ➜ EJS
  - *Upscaling*: EJS ➜ Large-scale

  For robust signal detection:
  - Longer simulations (NDJFMA)
  - Large member of ensembles (40)

Experimental setup

to test the effect of anomalous diabatic heating by EJS on the atmosphere



SSTA added to climatology

- Five sets of ensemble simulations:
- **CTL** forced with clim. EJS SST
- Four perturbation experiments with different types of SSTA
  - **EJS1P**, **EJS1M**
  - **EJS2P**, **EJS2M**
- (+) and (-) SSTA forcing to assess symmetricity in response

- Daily climatology in NOAA OI SST and NCEP reanalysis
- To remove influence fro the interannual variability in the tropics and outside the EJS.

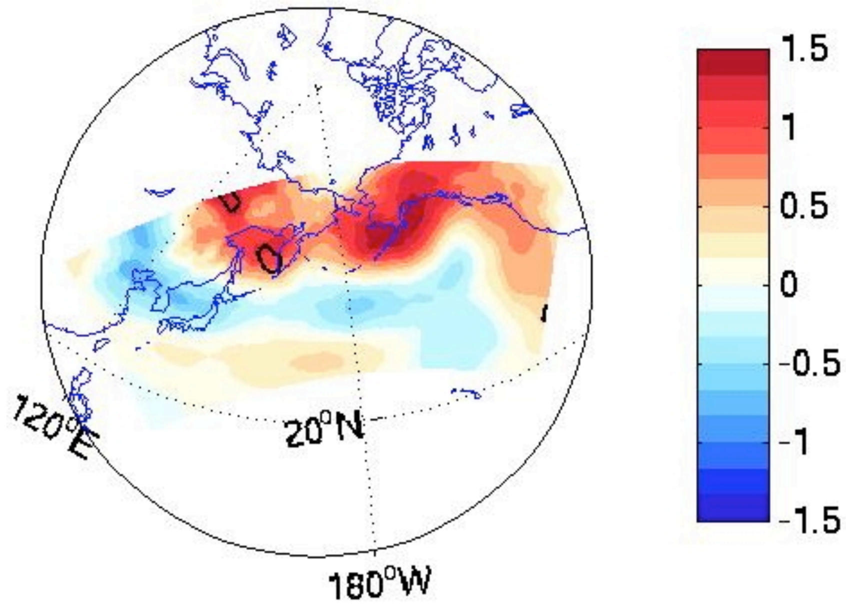
Response is defined as
EJS1P-CTL, EJS1M-CTL
EJS2P-CTL, EJS2M-CTL

Sensitivity of response to the different number of ensemble averaging

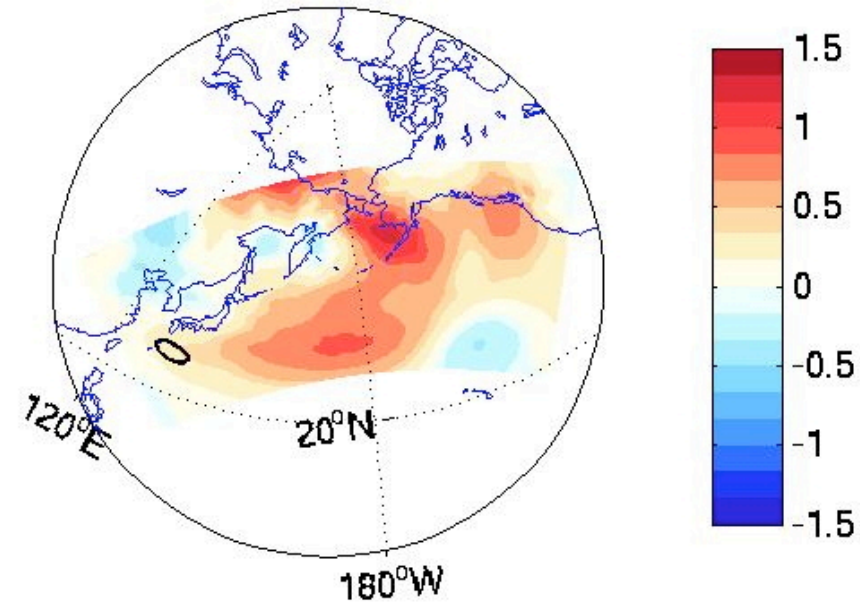
EOF1P-CTL

15-91 day

1-10 member mean

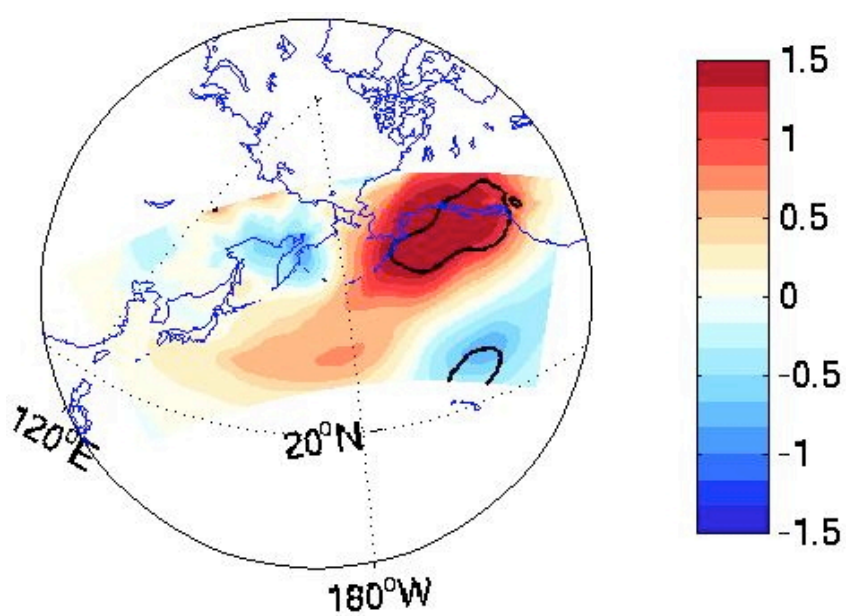


1-20-member mean

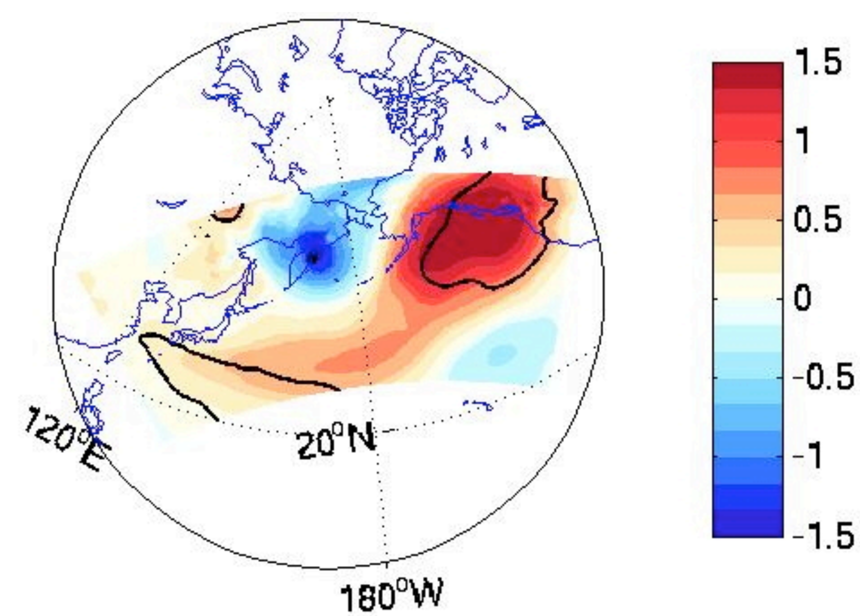


Black contours: significant at 95%

1-30 member mean

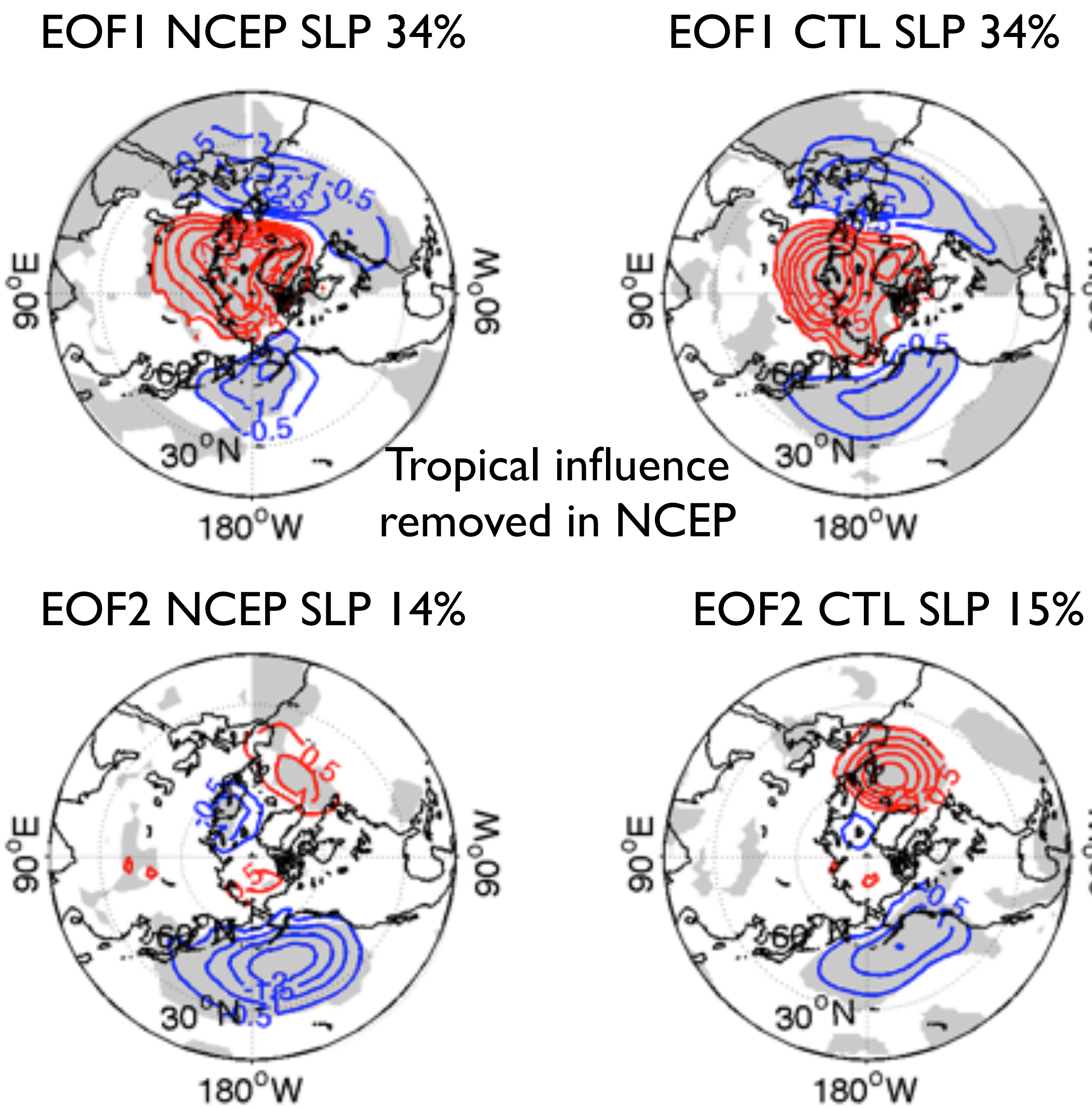


1-40 member mean



Some robust and significant SLP response emerge as more ensemble members are used for averaging.

Does the model capture dominant modes of NH winter atmospheric variability?



- The atmospheric response to extra-tropical SSA is projected onto the dominant intrinsic variability.

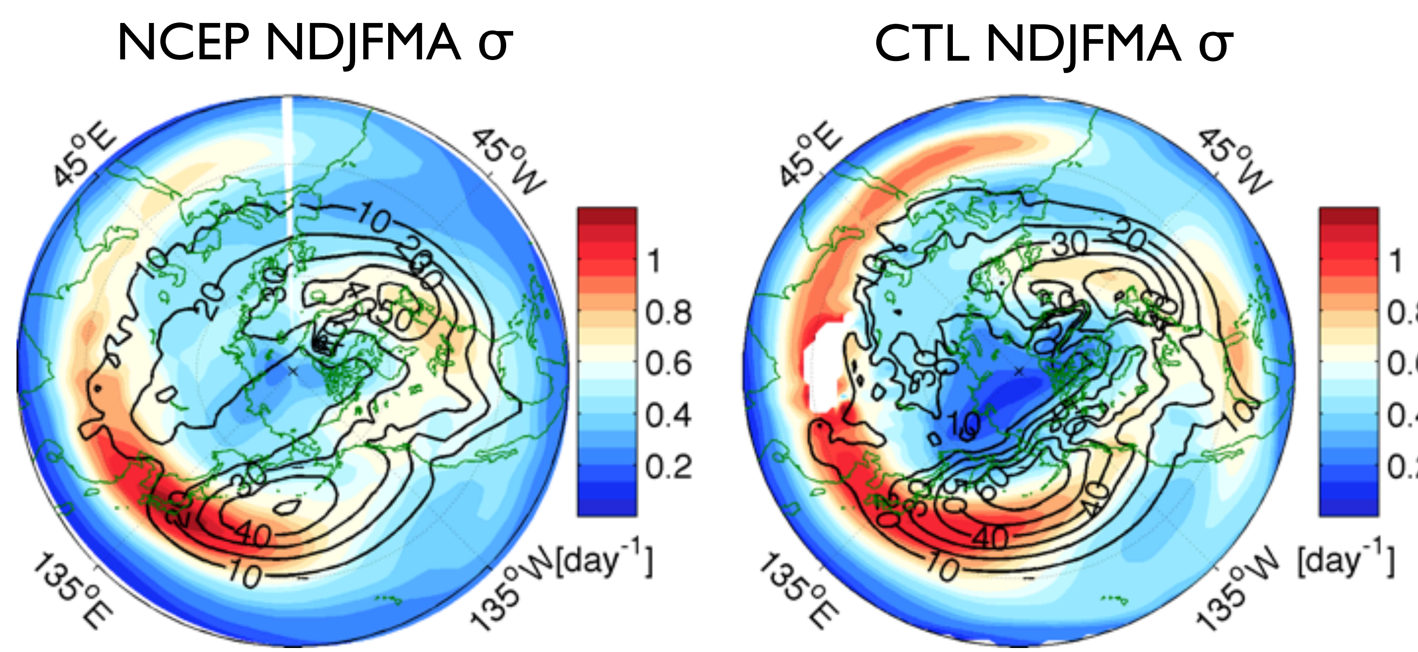
- Internal modes of variability is represented reasonably well in CTL.

- In the absence of tropical influence, both NCEP and CTL reveal the Arctic Oscillation as the 1st mode.

- The 2nd mode showing the Aleutian Low mode.

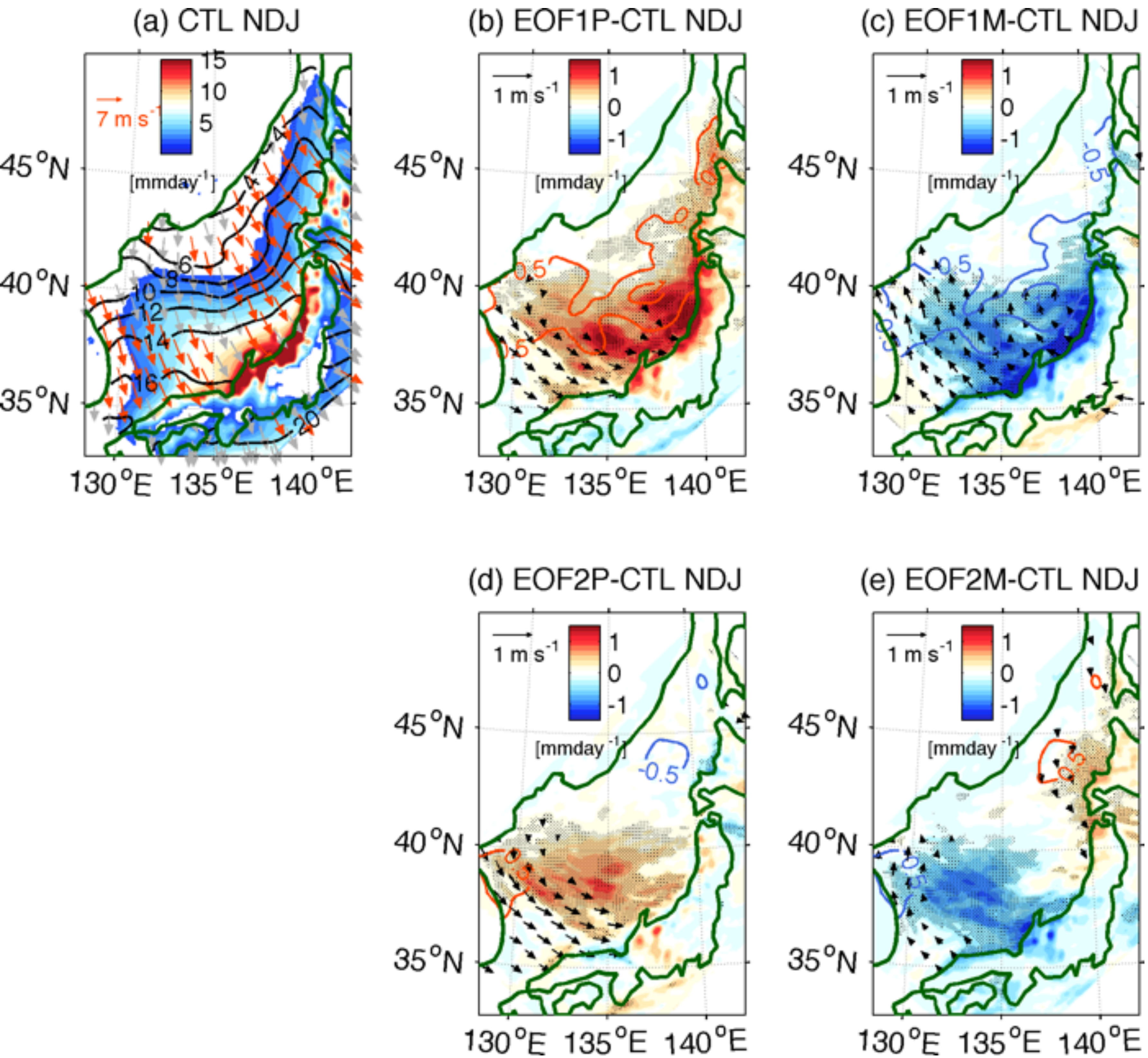
- The simulated climatological *Eady growth rate* (σ) and the storm track (2-8 day SLP variance) are reasonably realistic.

$$\sigma = 0.31 f \left| \frac{\partial \vec{v}}{\partial z} \right| \frac{1}{N},$$



Local atmospheric response is *linear*, *symmetric*, and *deterministic*.

Intra-basin SSTA pattern is critical to the *LOCAL* atmospheric response pattern.



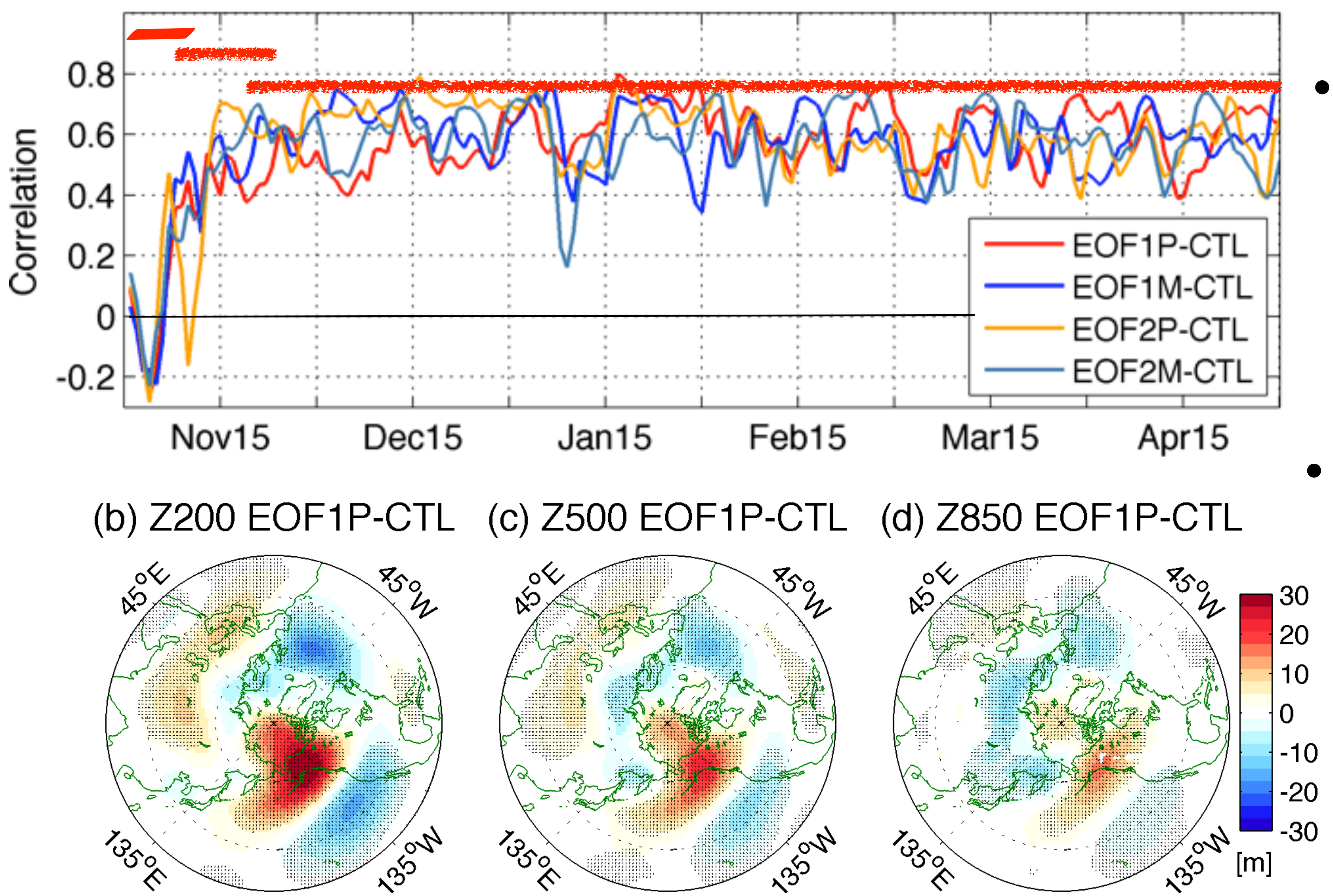
- Higher precipitation and accelerated wind associated with warm SSTA.
- Reduced precipitation and weaker wind associated with cold SSTA
- Response is *symmetric* with respect to the polarity of SSTA:

  ➡ A quasi-deterministic response in the vicinity of diabatic forcing

Remote atmospheric response:

How does it emerge and evolve with time?

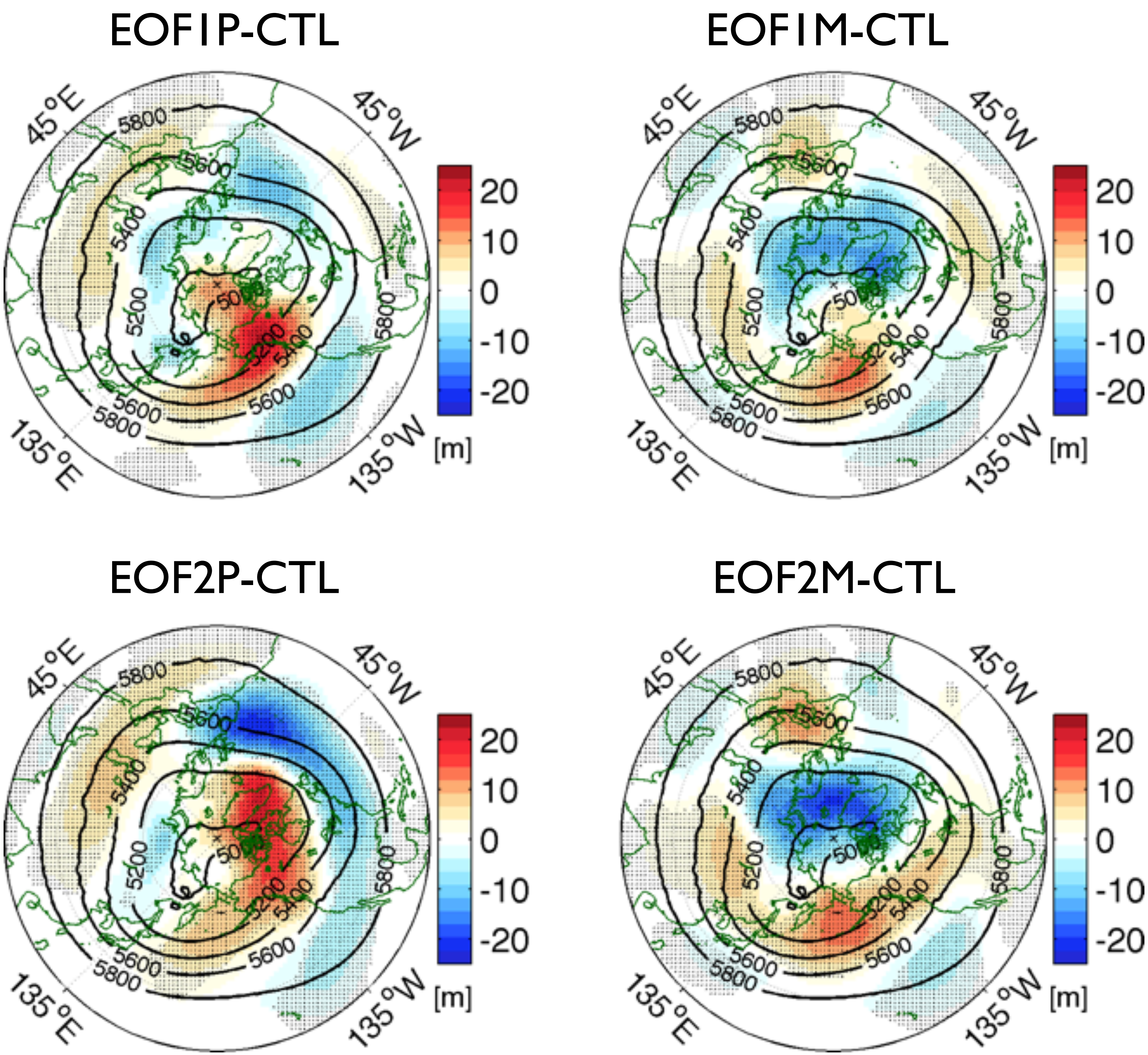
Time-series of pattern correlation of Z200 and Z850



- Initial response is short-lived and baroclinic
  ➡Negative correlation in low and upper level height anomalies.
- A rapid transition to a positive correlation.
- A quasi-steady response with an equivalent barotropic structure

Equilibrium response in remote circulation is *NOT linear*.

Response pattern in mean Z500

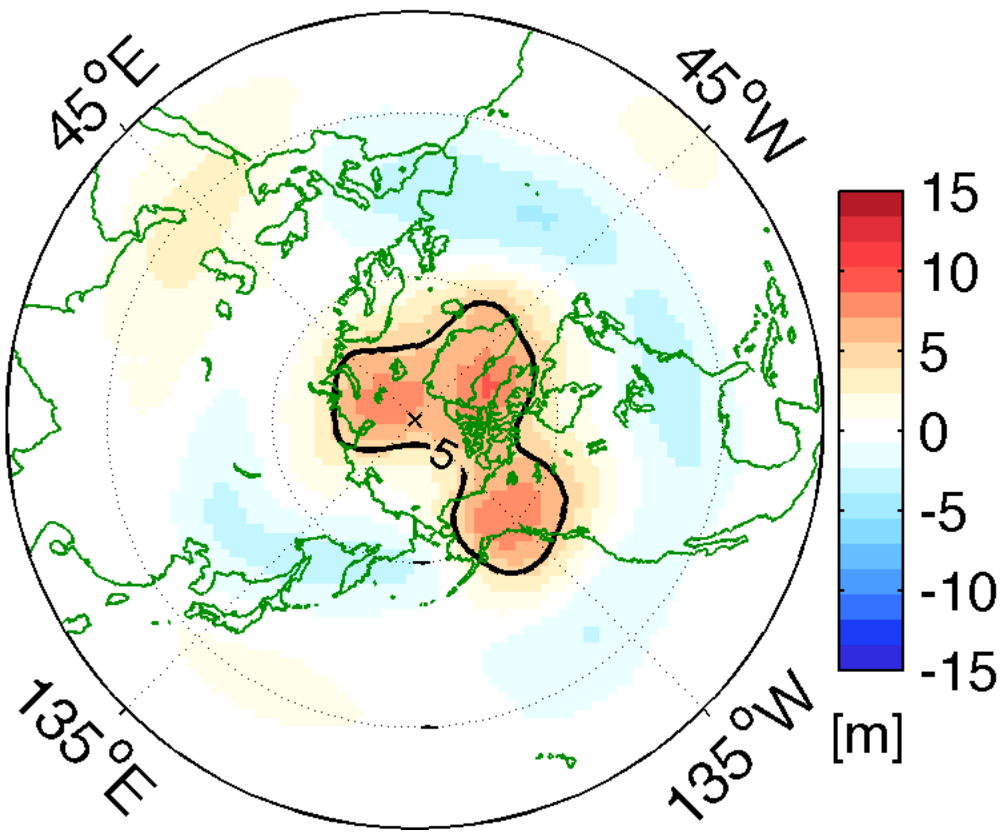


- Anomalous GoA ridge is a characteristic equilibrium response pattern **independent of** EJS SSTA.
- Response of O(20m) is comparable to the classical AGCM studies forced with basin-scale SSTA of 2-3°C.

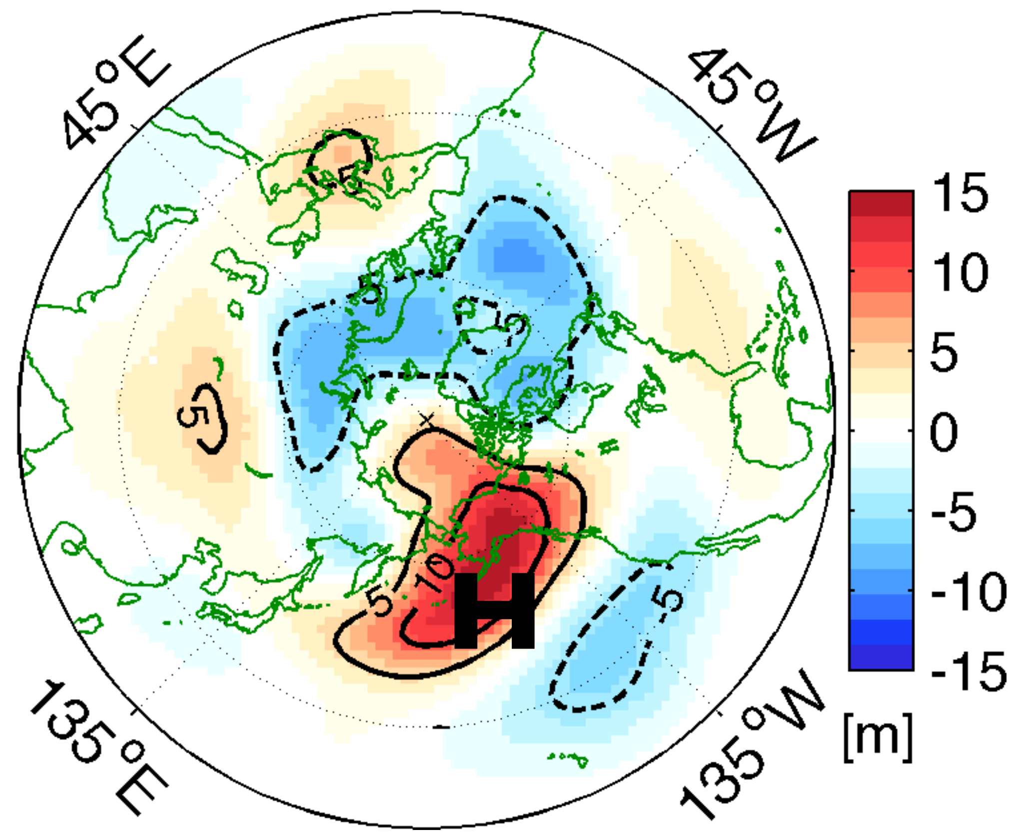
Confirming that the anomalous GoA ridge is a nonlinear response

- The total response is partitioned into
  - *Symmetric* response = ½ × (EOF1P - EOF1M)
  - *Anti-symmetric* response = ½ × [(EOF1P-CTL) + (EOF1M-CTL)]

EOF1 Symmetric Z500



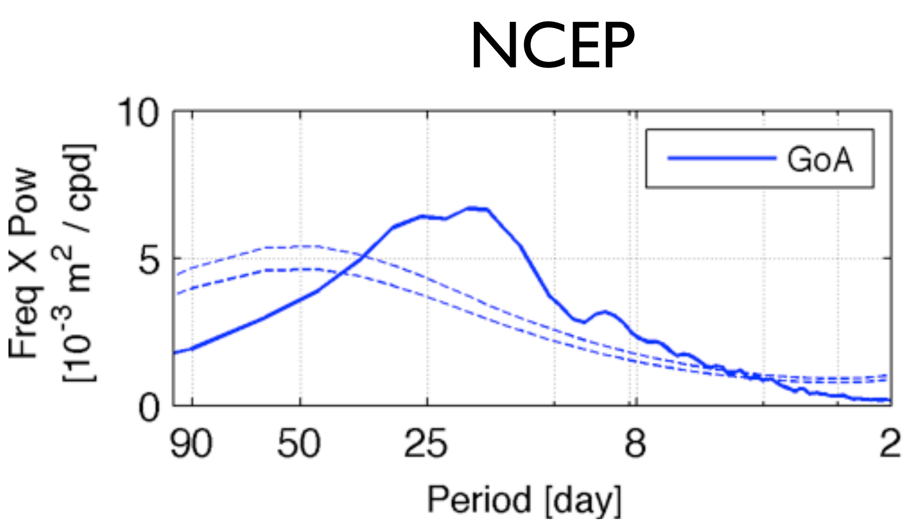
EOF1 Anti-symmetric Z500

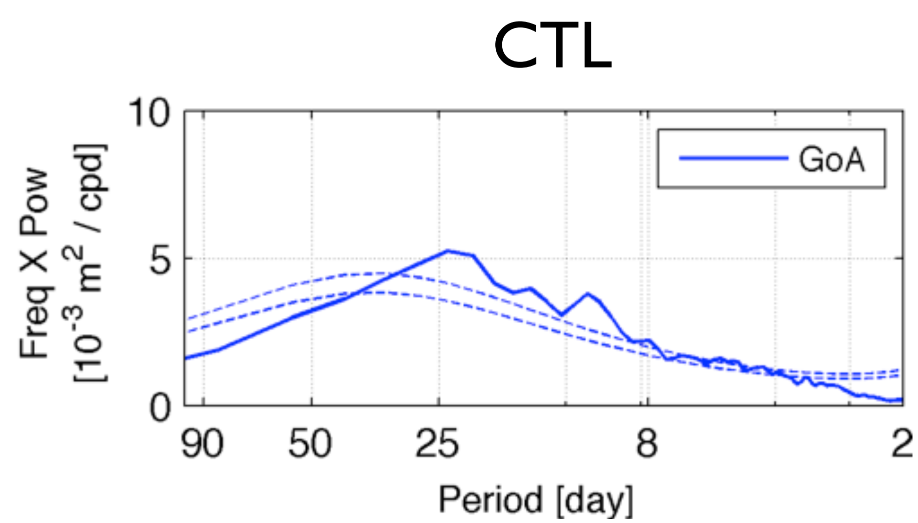


- The GoA ridge response bears a strong resemblance to the anti-symmetric component.
- Independent of SSTA, an equivalent barotropic ridge in GoA emerges as the dominant response pattern.

What is the dominant time-scale of this nonlinear response?

Spectral analysis of Z500 in **GoA**

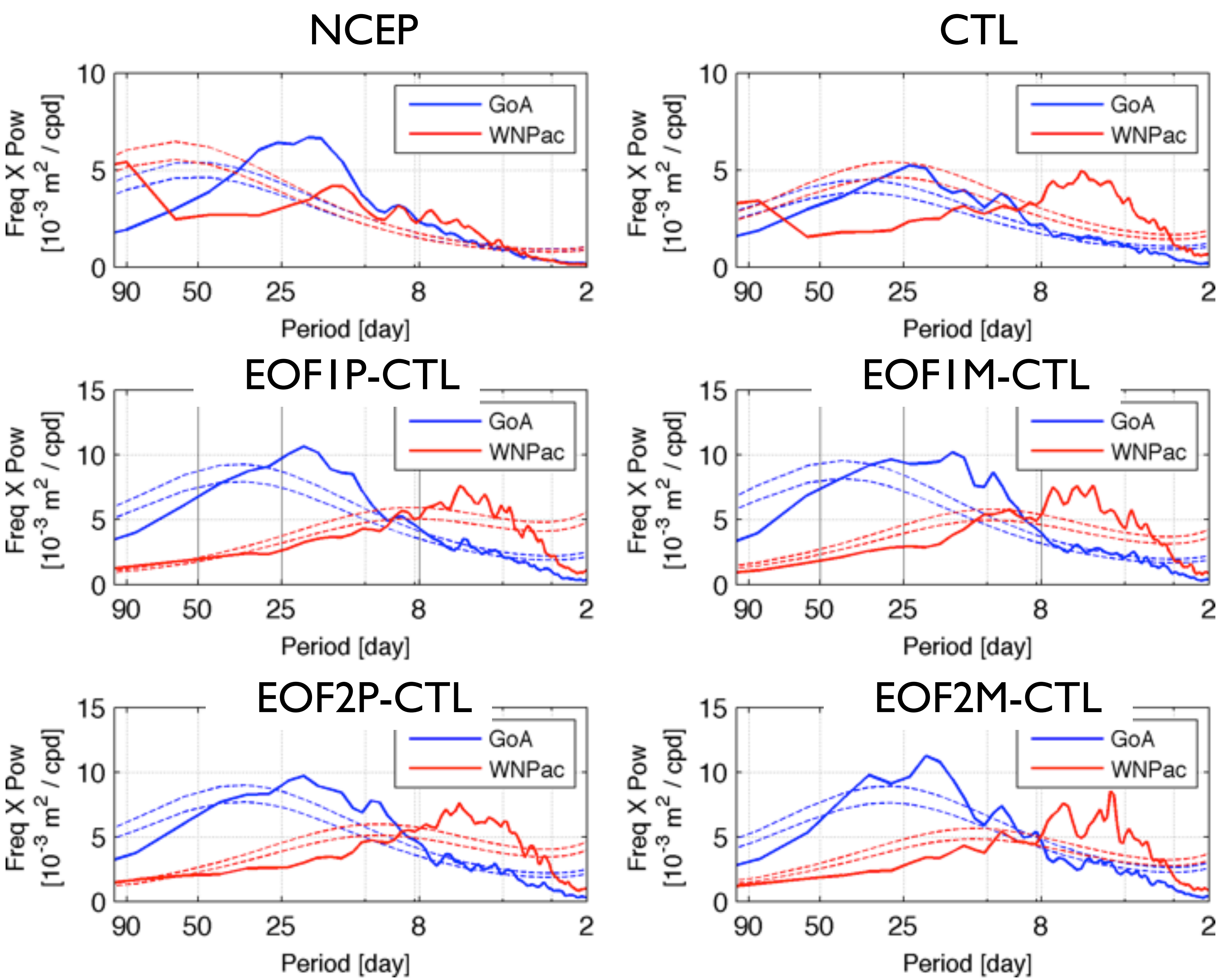




- **In GoA** (downstream storm track), transient intra-seasonal (8-90 day) variability is pronounced
  - enhanced intra-seasonal blocking activity

What is the dominant time-scale of this nonlinear response?

Spectral analysis of Z500 in **GoA** and **Western North Pacific**

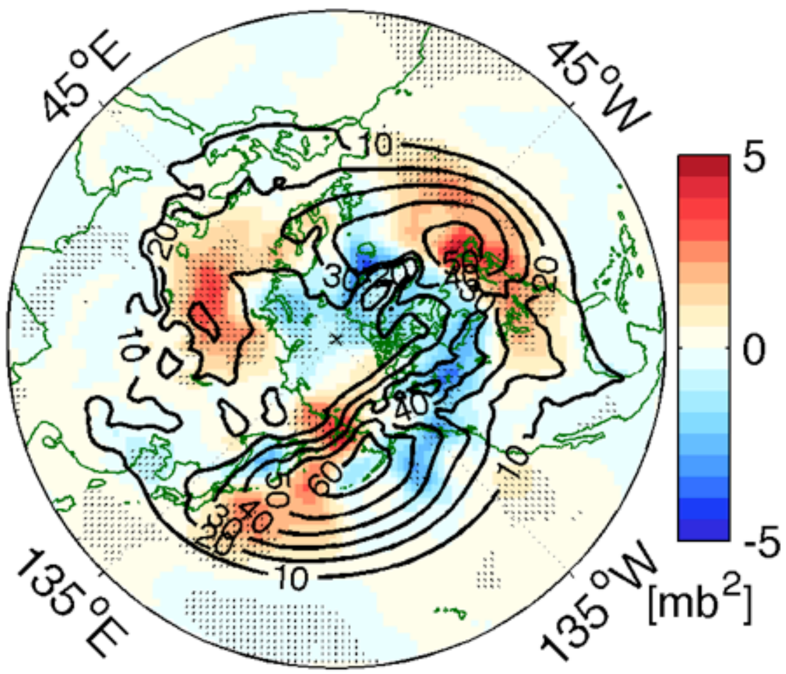


- **In GoA** (downstream storm track), transient intra-seasonal (8-90 day) variability is pronounced
  - enhanced intra-seasonal blocking activity
- **In the NW Pacific** (upstream storm track), dominance of transient synoptic variability (2-8 day)
- Responses denote strengthened storm track variability!

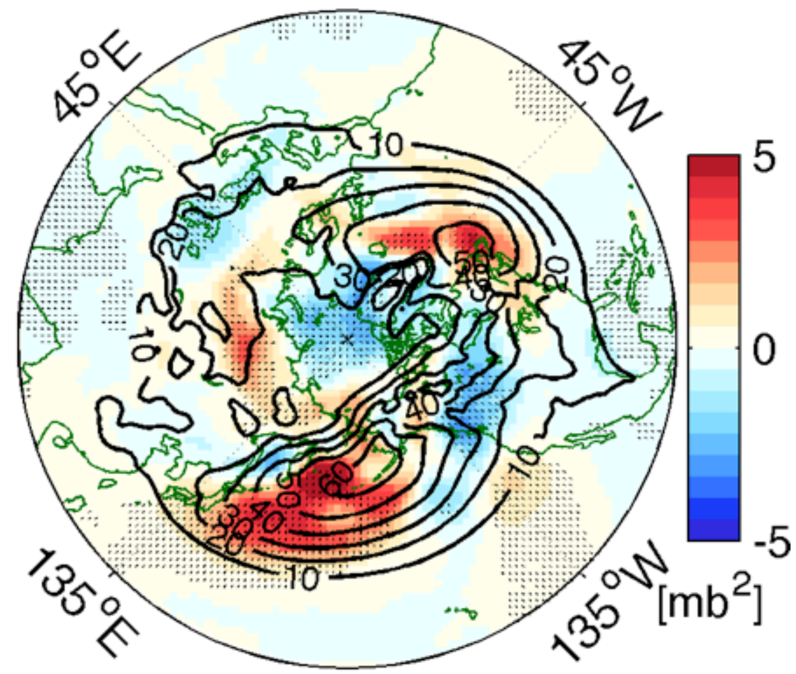
Enhanced blocking response is accompanied by storm track response

Response of the 2-8 day filtered SLP variance

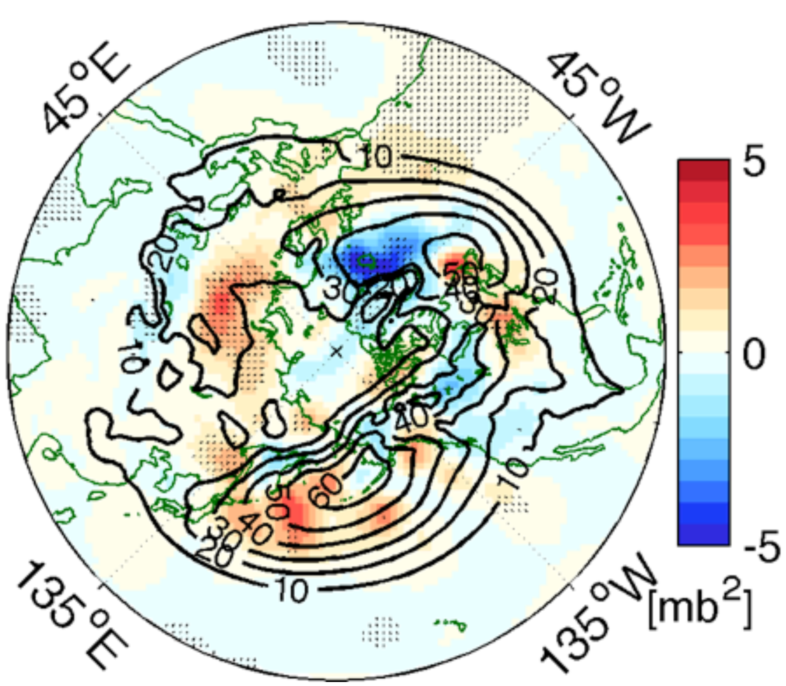
EOF1P-CTL



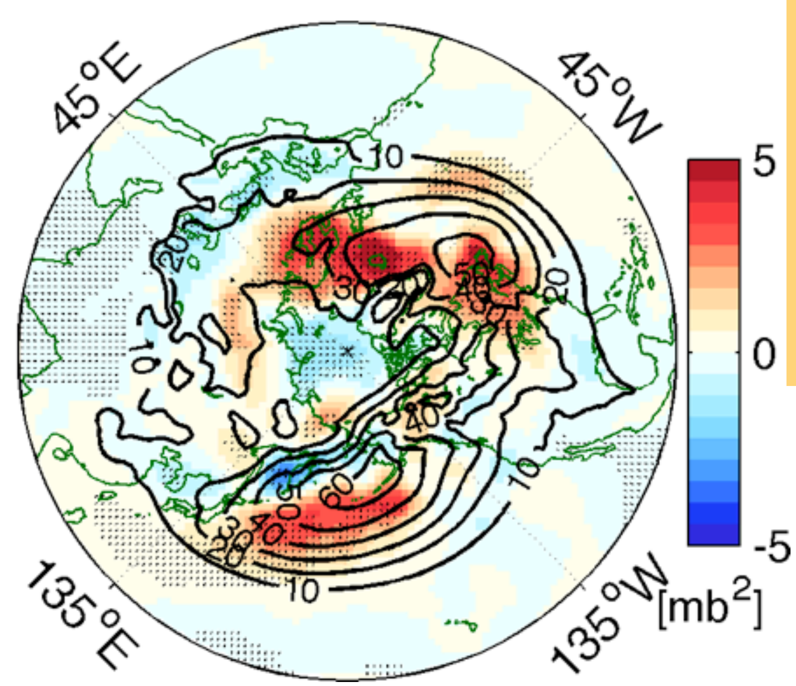
EOF1M-CTL



EOF2P-CTL



EOF2M-CTL



- Anomalously enhanced synoptic (2-8 day) storm track variability
- To the upstream half of the climatological storm track in the northwest Pacific

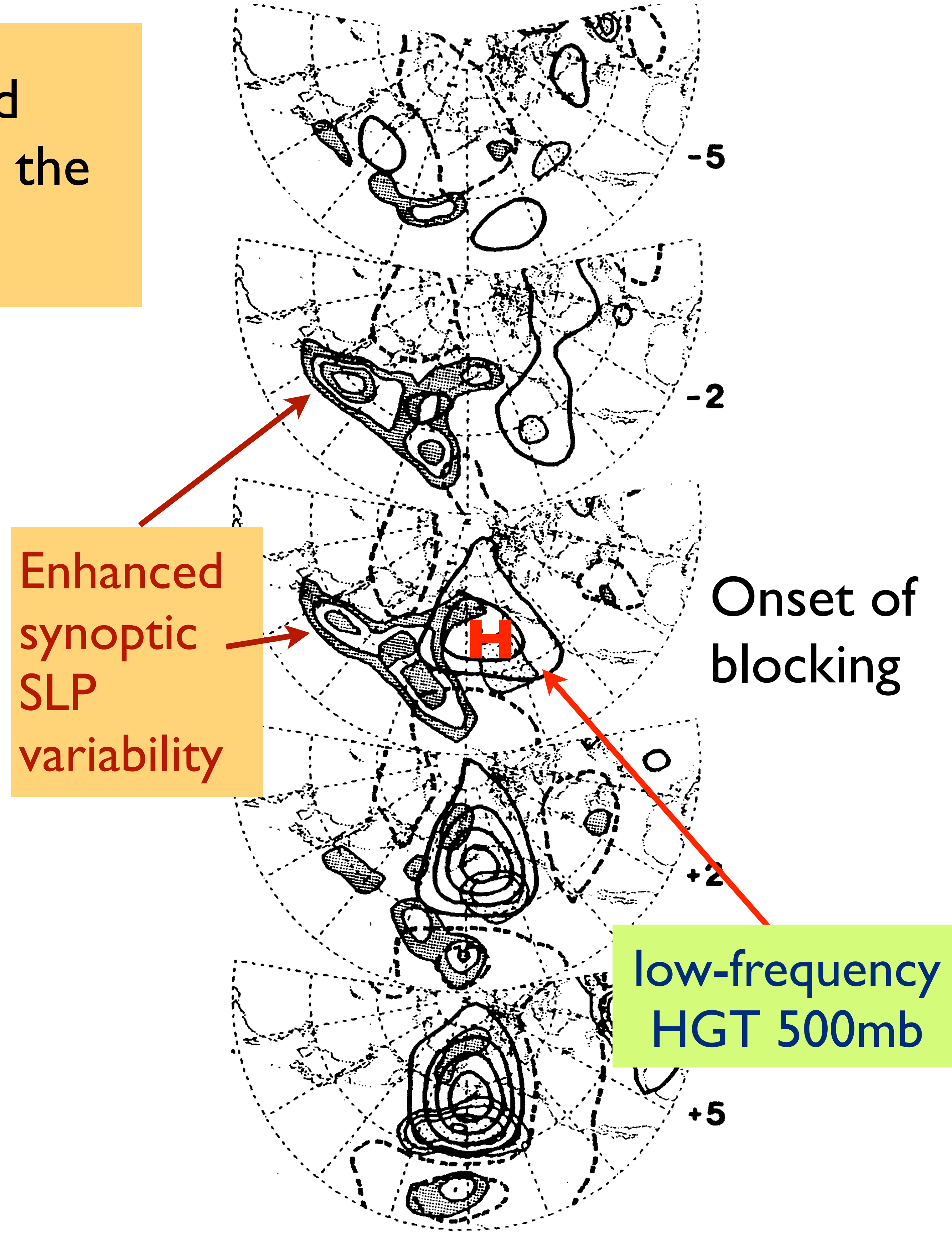
So what is the connection between the storm track response and the blocking response?

Intensified synoptic storm activity **prior to** the onset of GoA blocking

Composite evolution of synoptic and intraseasonal variability associated with the GOA blocking index

Envelope function (shading) represents the variance anomaly time-series associated with the transient baroclinic wave activity.

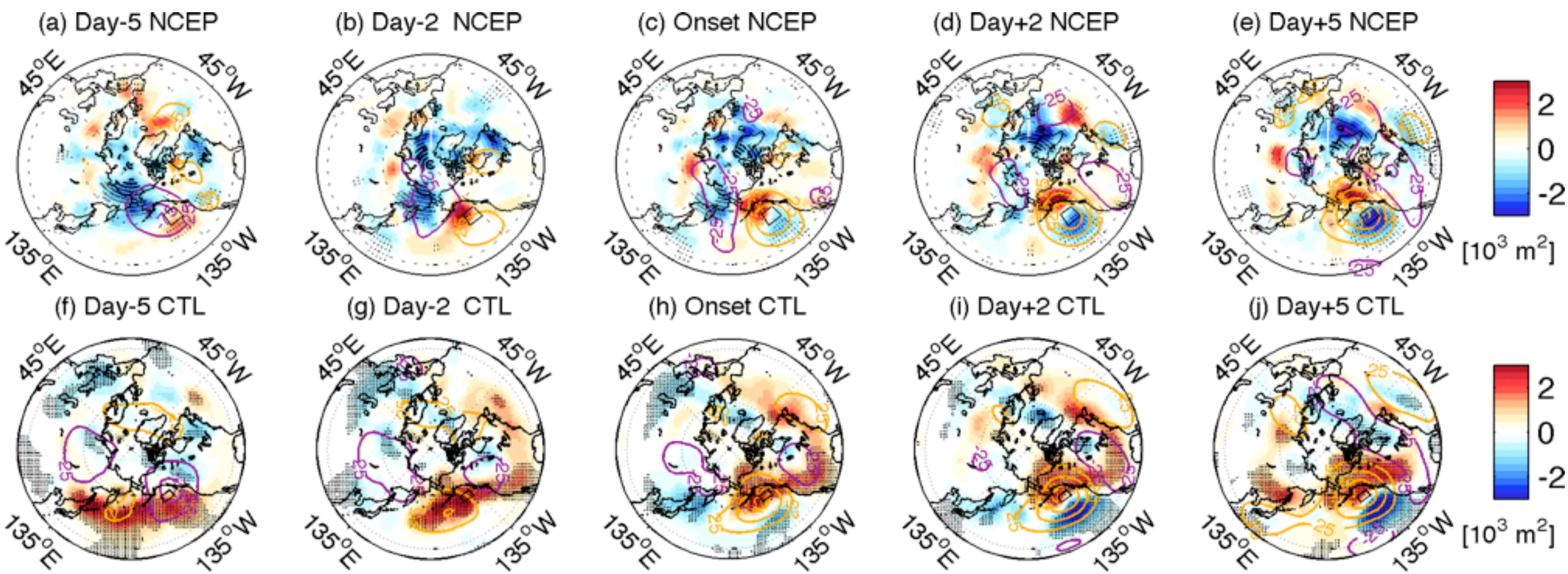
Enhanced baroclinic wave activity in the upstream storm track, which is primarily a manifestation of deeper cyclones at the surface.



Nakamura and Wallace 1990

Intensified synoptic storm activity **prior to** the onset of GoA blocking In NCEP and CTL

NCEP

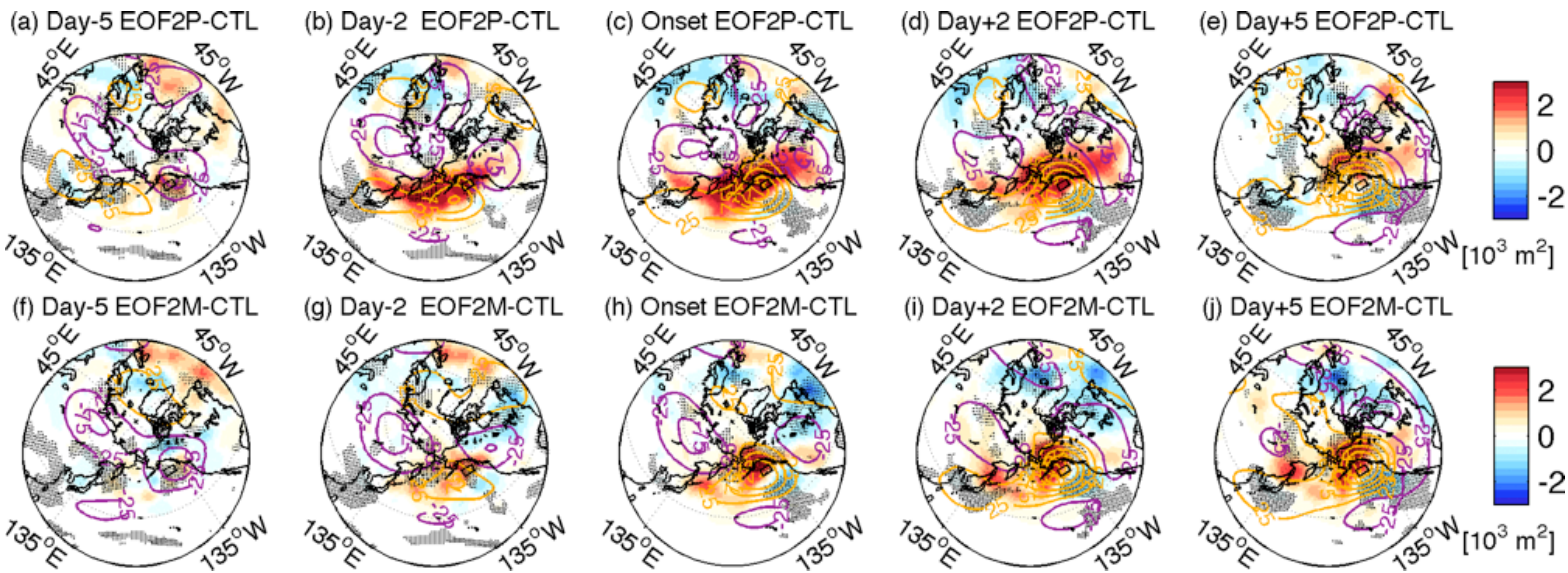


CTL

- The anomalously intensified synoptic transient eddy variability in the upstream of the Pacific storm track precedes the anomalous ridge in the downstream.

Intensified synoptic storm activity **prior to** the onset of GoA blocking:
This is the case with the responses too!
EOF2P-CTL and EOF2M-CTL

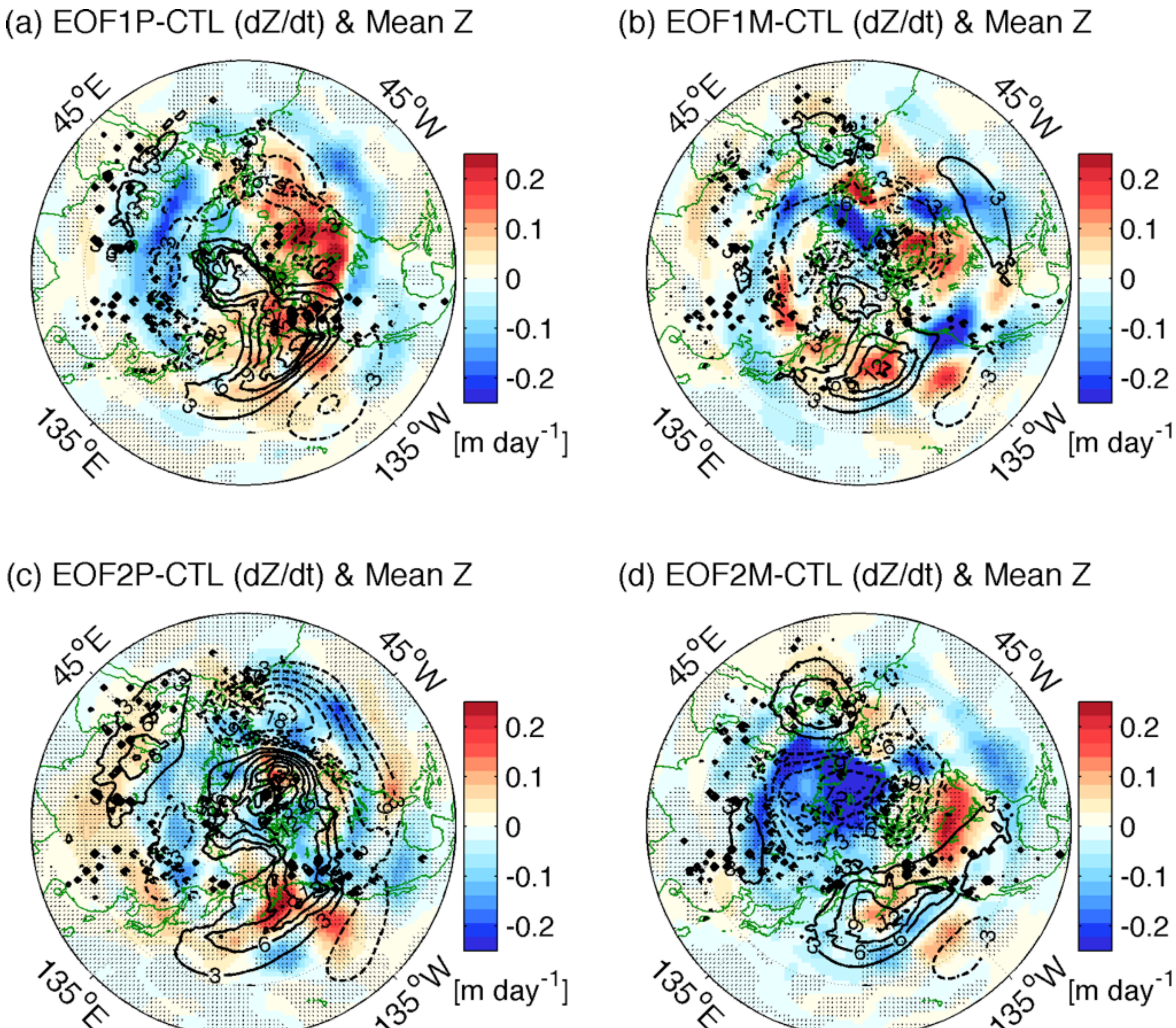
EOF2P-CTL



EOF2M-CTL Can we tell the causality of this covariability?

- The onset of blocking response is sandwiched by the anomalously amplified baroclinic wave activity in the northern Alaska and the suppressed one in the south.

Synoptic eddy vorticity flux reinforcing blocking ridge response via convergence of transient eddy vorticity flux



- Solve the vorticity equation at 500 hPa.

$$\boxed{Z_t = (f/g)\nabla^{-2}\left[-\nabla(\overline{v'\zeta'})\right]}$$

- Z_t spatially well corresponds to low-frequency blocking circulation.

- $-\nabla(\overline{v'\zeta'})$ is the key mechanism for maintenance of low-frequency circulation anomaly.

Consistent with the AGCM studies forced with basin-scale SSTA (e.g., Kushnir et al. 2002)

Discussion

- What is the characteristic response pattern, and its generating mechanism, to EJS SST anomalies?

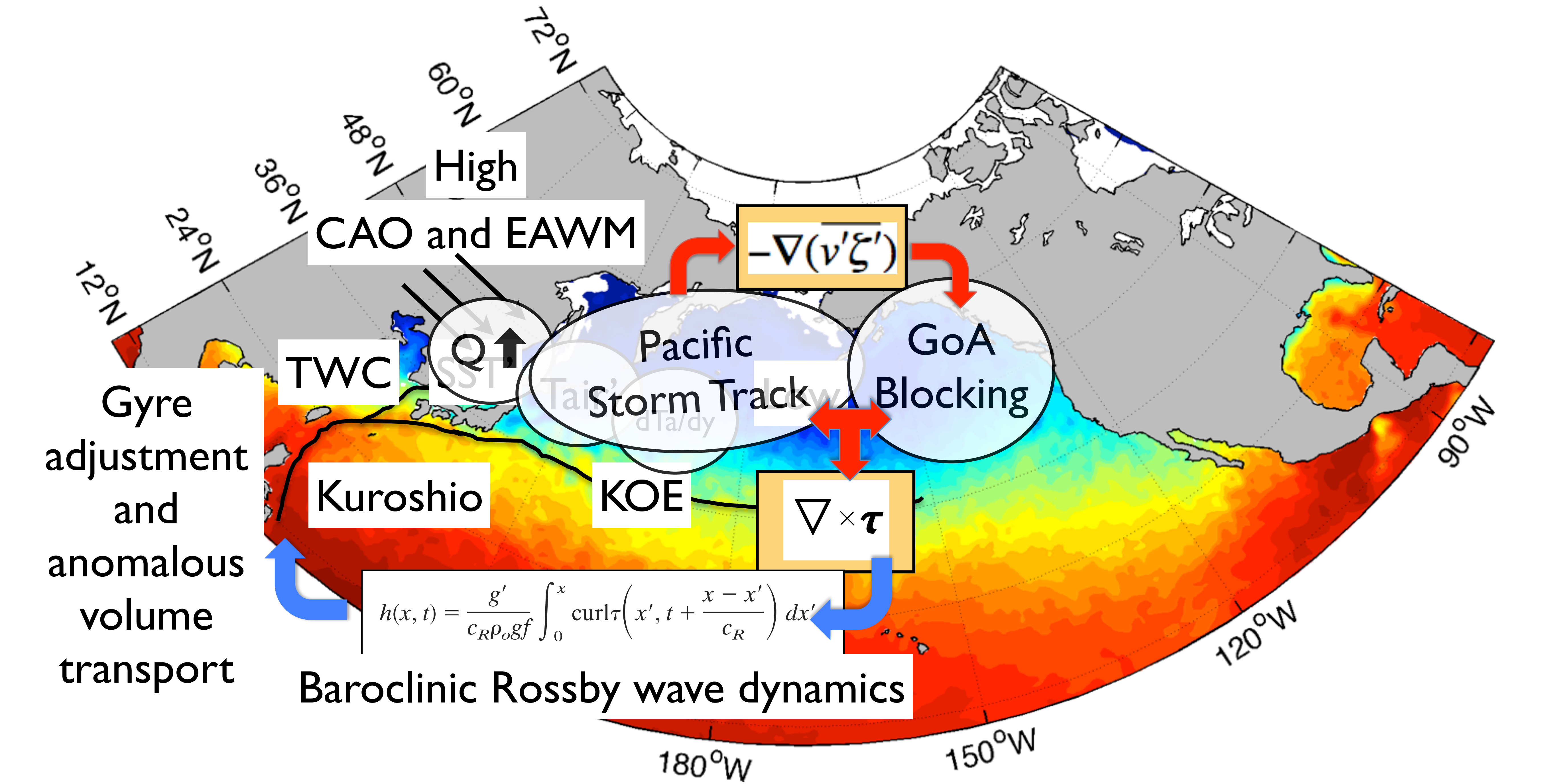
  - ***Local response*** is linear and symmetric with respect to pattern and sign of SSTA

    - Accelerated (decelerated) winds and increased (decreased) precipitation located with diabatic heating (cooling)
    - *Critical role* of the intra-basin structure of the EJS SSTA on the simulation of the wintertime regional atmospheric conditions.

  - ***Remote response***: Highly nonlinear response *independent of SSTA.*

    - Mid-latitude atmospheric transient eddy feedback produce an equivalent barotropic ridge in the Gulf of Alaska.
    - Intra-basin structure of the EJS SST pattern *may not be important* for the pattern of remote response given a strong nonlinearity.

A possible two-way coupling between the North Pacific Ocean and its marginal seas via extra-tropical multi-scale ocean-atmosphere interactions?



- Low-frequency feedback mechanisms might exist involving East Asian Marginal Seas, East China Sea Kuroshio Current, Tsushima Warm Current and the open ocean large-scale atmospheric circulation and Kuroshio Extension via dynamic coupled modes of variability.

Sessions

All Sessions

044 - East Asian Marginal Seas: sea surface temperature variability and ocean-atmosphere process

Encompassing complex interplay among the ocean, atmosphere, continents, and cryosphere, sea surface temperature variability in East Asian marginal seas, including South and East China, Yellow, Japan/East and Okhotsk Seas, plays a critical role in the coupled ocean- atmosphere system in the region. Substantial progress has been made for recent decades in furthering the understanding of rich physical processes determining the spatio- temporal variability of SSTs with far-reaching climatic impacts. This session provides a forum for both oceanographers and meteorologists, and observationalists and modelers to review the recent progress in marginal sea studies, and to identify areas of future collaborative research. Papers are solicited using observations, models and theories to address important physical processes in the East Asian marginal seas: the effect of shelf and coastal circulation and upper ocean mixing, the surface heat and momentum flux, and the ocean and atmosphere circulations and interactions; the influence of bathymetry, continents, rivers, and sea ice; interactions between the marginal seas and open oceans and with the atmosphere, including the Asian monsoons, storm track and teleconnections. Contributions are also welcome on the effects on the marine ecosystem and biogeochemical processes.

Organizers

Hyodae Seo , Woods Hole Oceanographic Institution
hseo@whoi.edu

Shang-Ping Xie , Scripps Institution of Oceanography
sxie@ucsd.edu

Glen Gawarkiewicz , Woods Hole Oceanographic Institution
ggawarkiewicz@whoi.edu

Naoki Hirose , hirose@riam.kyushu-u.ac.jp
Kyushu University

Category

K - Physical Oceanography/Ocean Circulation

Thanks

hseo@whoi.edu

Seo, Kwon and Park, On the effect of marginal sea SST variability on the North Pacific atmospheric circulation. JGR-Atmos. Under revision

Woods Hole Oceanographic Institution