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PTA Symposium@La Paz

Decadal-scale temperature variability in the subarctic-subtropical gyre boundary region in the North Pacific

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Introduction

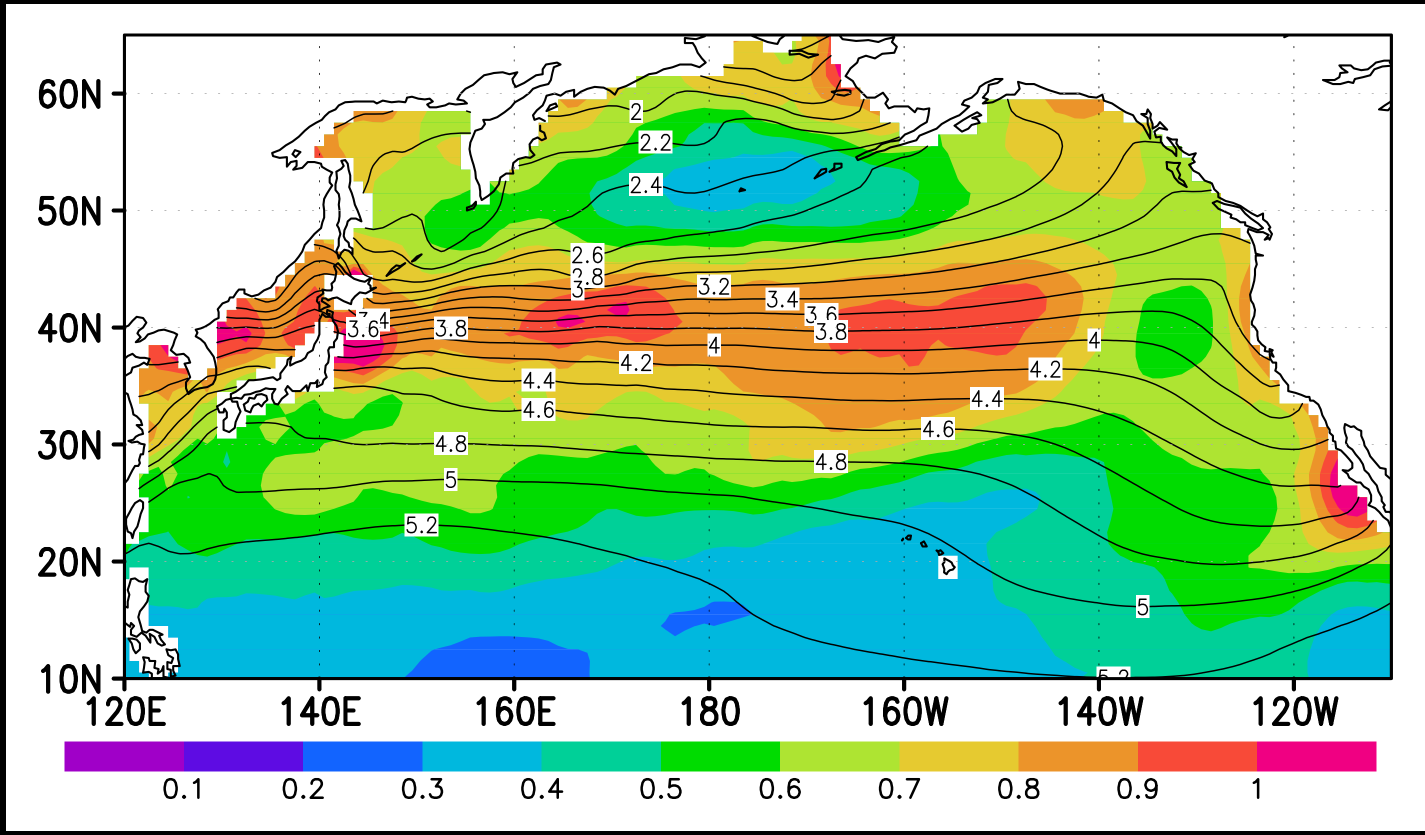
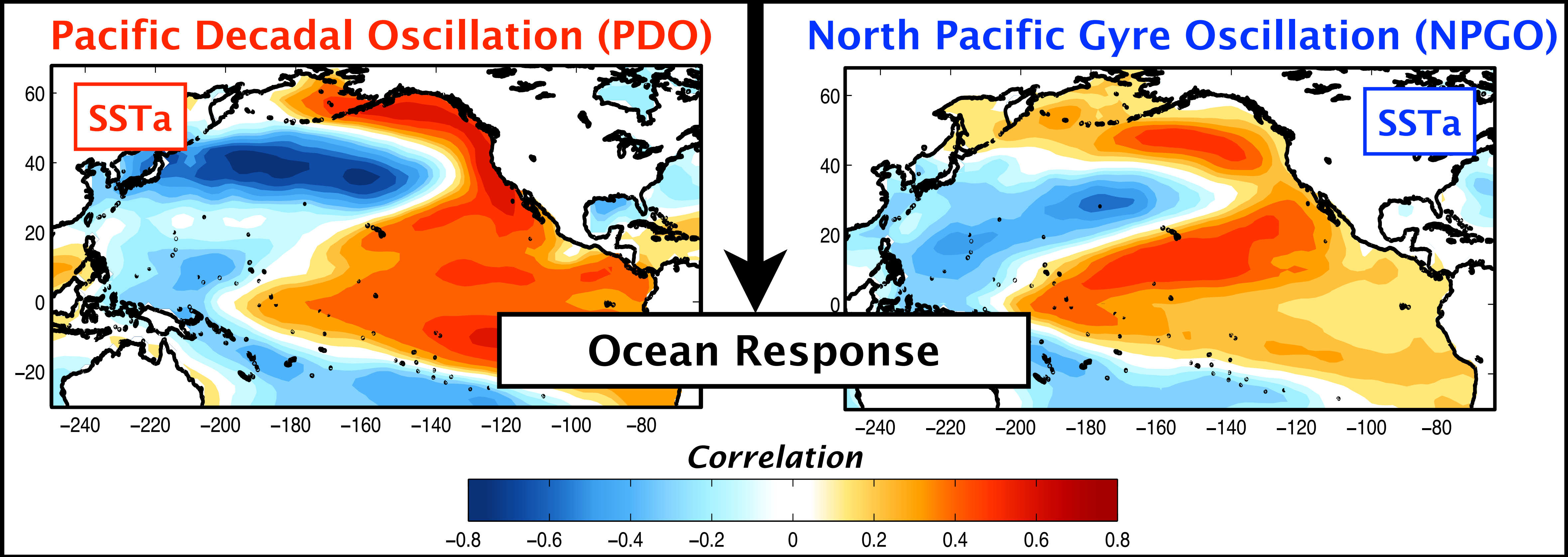


Fig.
Standard deviation (STD) of monthly SSTa deviated from monthly climatology. Contours denotes annual climatology

STD of monthly SSTa is large along the PTA along the subarctic-subtropical gyre boundary with relatively strong SST gradient

In this talk, I will …
- **review the studies about the relation between the monthly SSTa along this PTA and climate variabilities (PDO & NPGO)**
- **introduce my works on the SSTa along this PTA**

PDO & NPGO

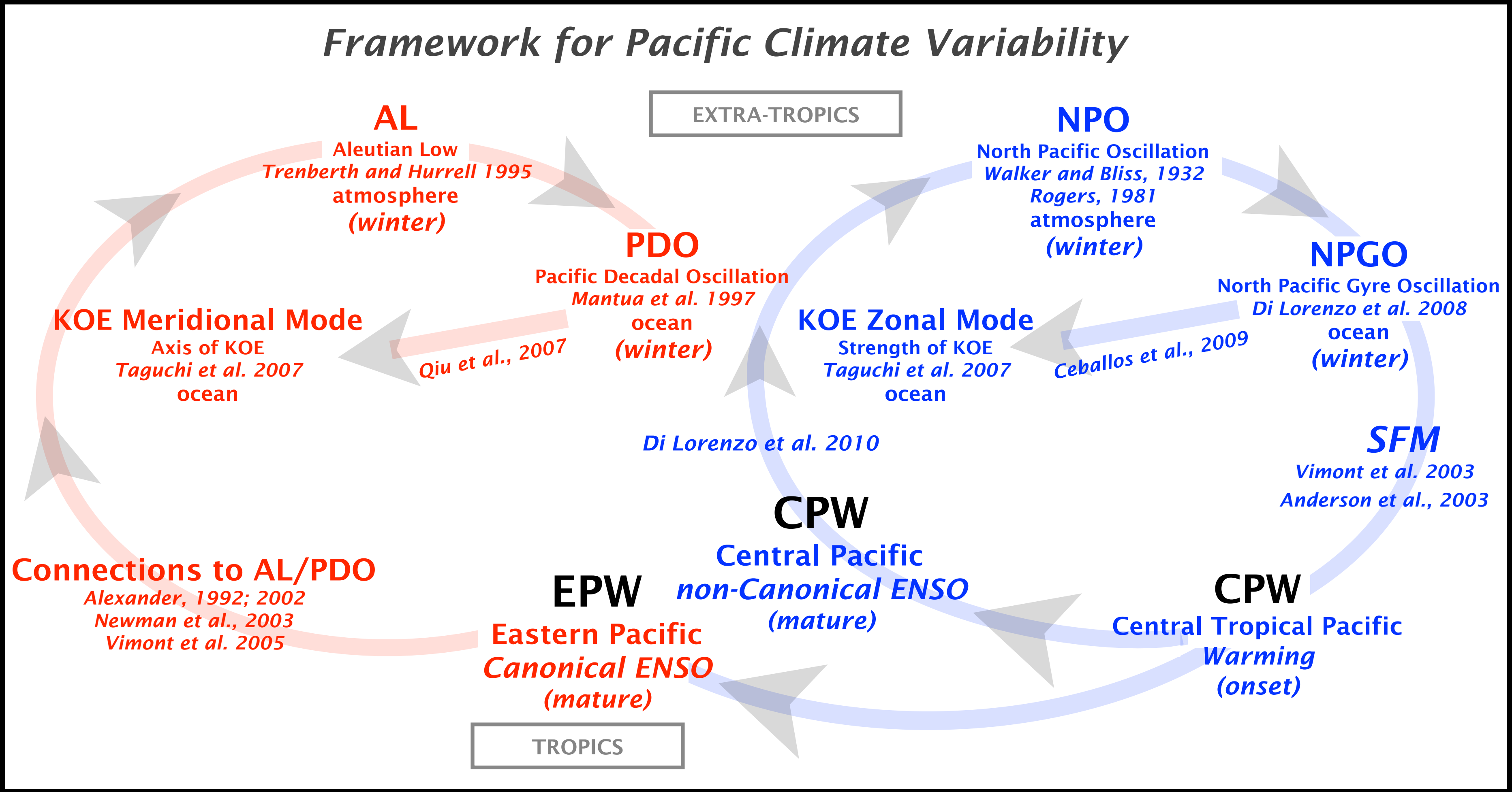


The SSTa correlation maps of the two dominant modes of SSTa variability.
“An overview of Pacific Climate Variability” (Di Lorenzo, Schneider et al.)

✦ The large SSTa variability along the PTA is largely explained by the two dominant modes of SSTa in the extratropical N. Pac.

Understanding SSTa along the PTA is closely related to understanding Pacific Climate Variability

How well do we know about the variability?



"An overview of Pacific Climate Variability" (Di Lorenzo, Schneider et al.)

By using PDO & NPGO as the keys, and
combining the studies to date based on observation, numerical model, etc.,
we can now draw the framework, by which we may understand the overall picture of the complicated Pacific Climate Variability

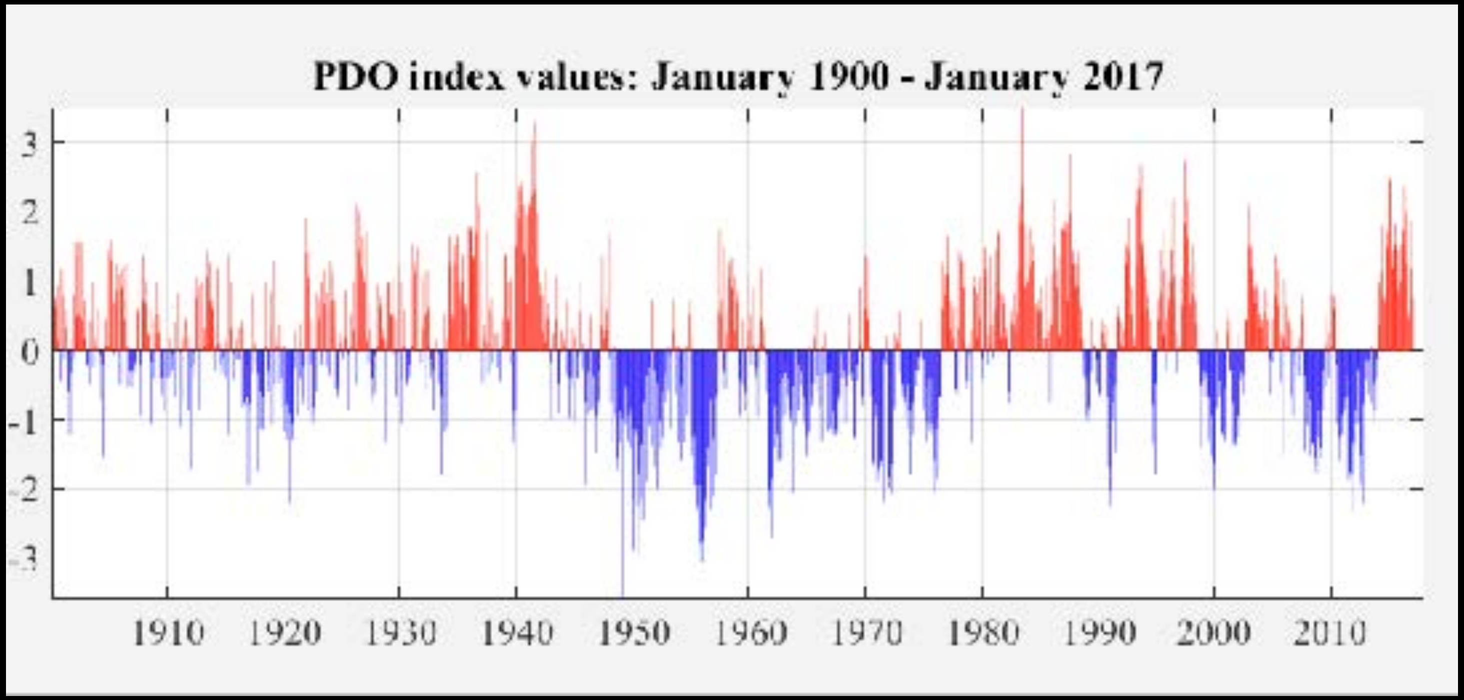
Most of these studies were published after 2002

→ **Research in this field made great progress after the last PTA symposium**

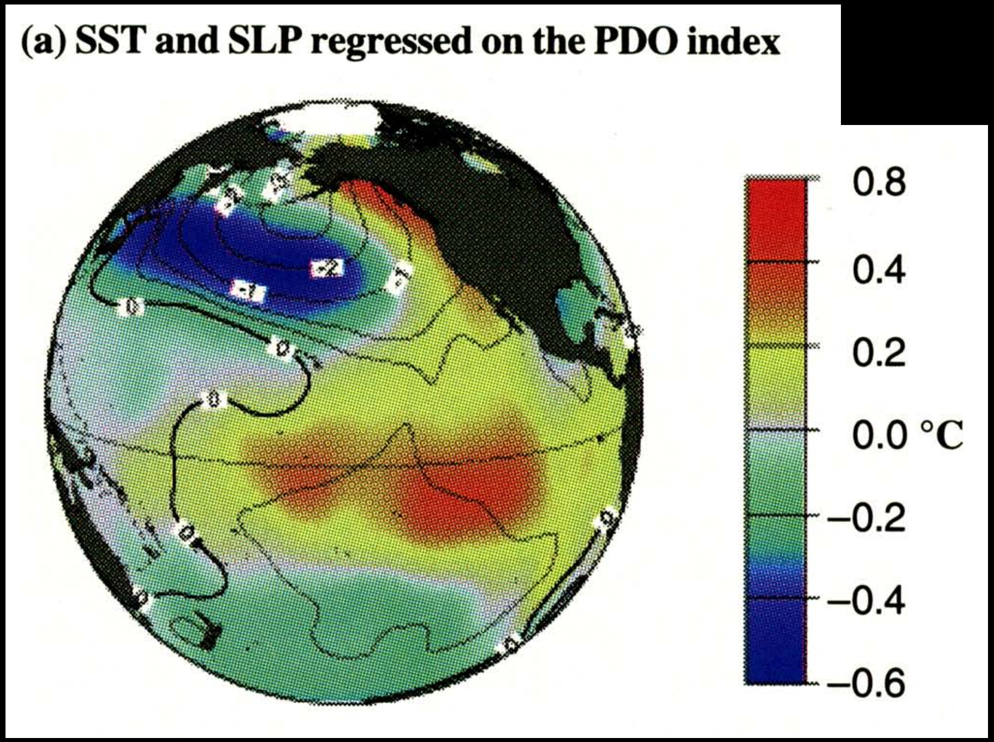
Pacific Decadal Oscillation (PDO)

✦Mantua et al. (1997) defined PDO as the EOF 1st mode of the monthly SSTa in the North Pacific (20°N-70°N)

- originally used to discuss the climate impact on Salmon Production



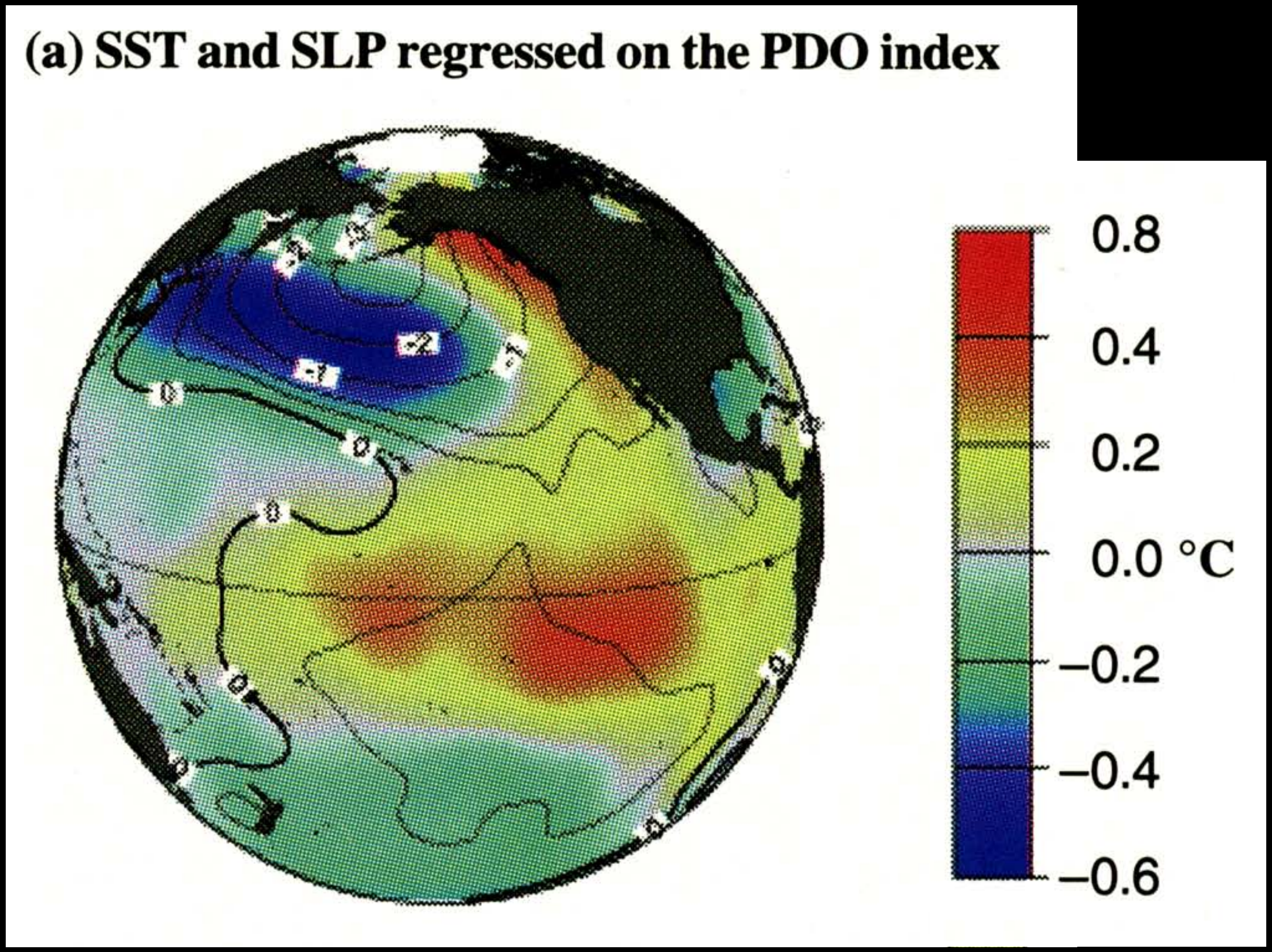
http://research.jisao.washington.edu/pdo/



Mantua et al. (1997)

Sea Level Pressure anomaly (SLPa) regressed on PDO suggests that, to first order, PDO is a forced response of the North Pacific ocean to atmospheric forcing by variability of the Aleutian Low (AL).

Aleutian Low <=> Westerly Wind <=> Ekman Transport



Mantua et al. (1997)

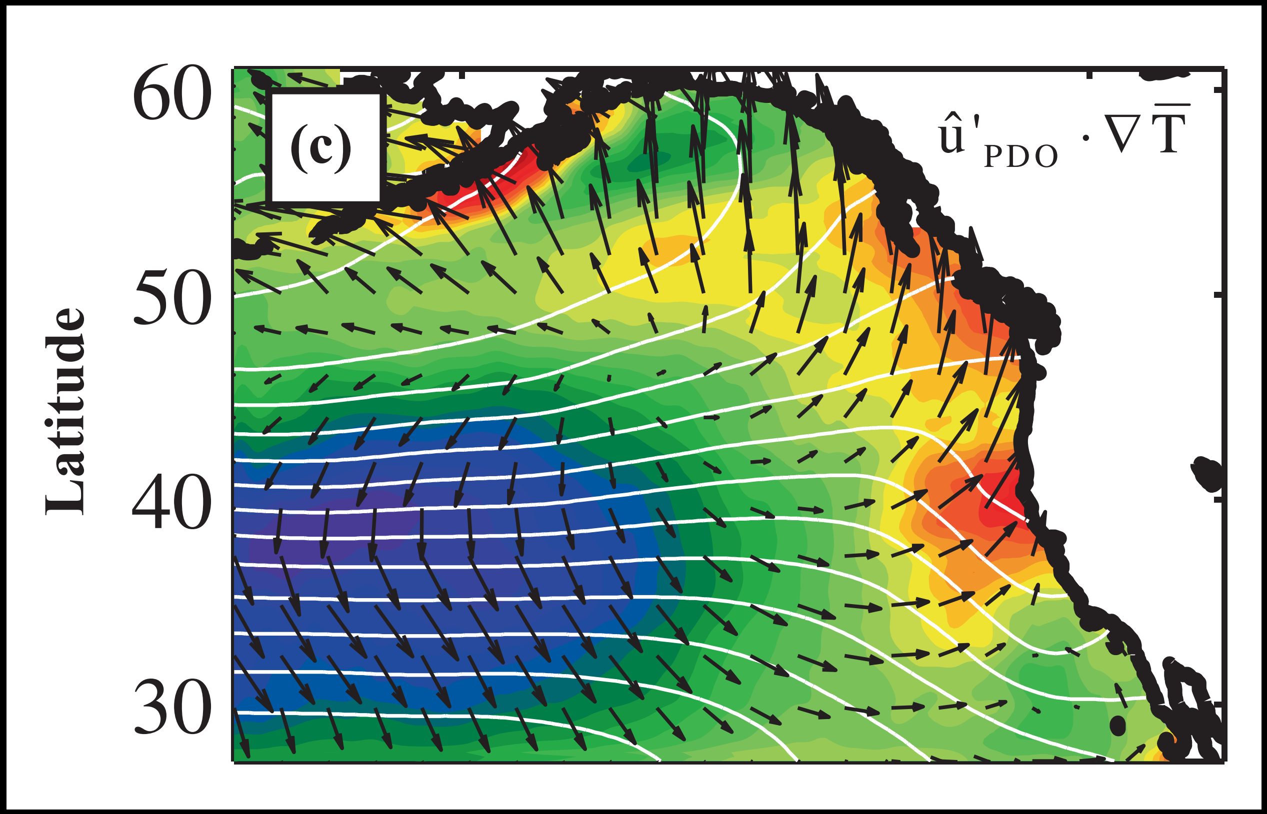


Fig. Contribution of $u'_{PDO} \cdot \nabla T$ estimated from a simplified SST budget by Chhak et al. (2009)

This first order explanation is confirmed quantitatively to some extent by using a numerical model & a simplified budget analysis (Chhak et al., 2009).

"The Pacific Decadal Oscillation, Revisited"

Newman et al. (2016, JPO)

✦The PDO is not a single phenomenon, but is instead the result of a combination of different physical processes that span tropics and extratropics.

➡The assessment of PDO-related regional climate impacts should accounts for the effects of these different processes.

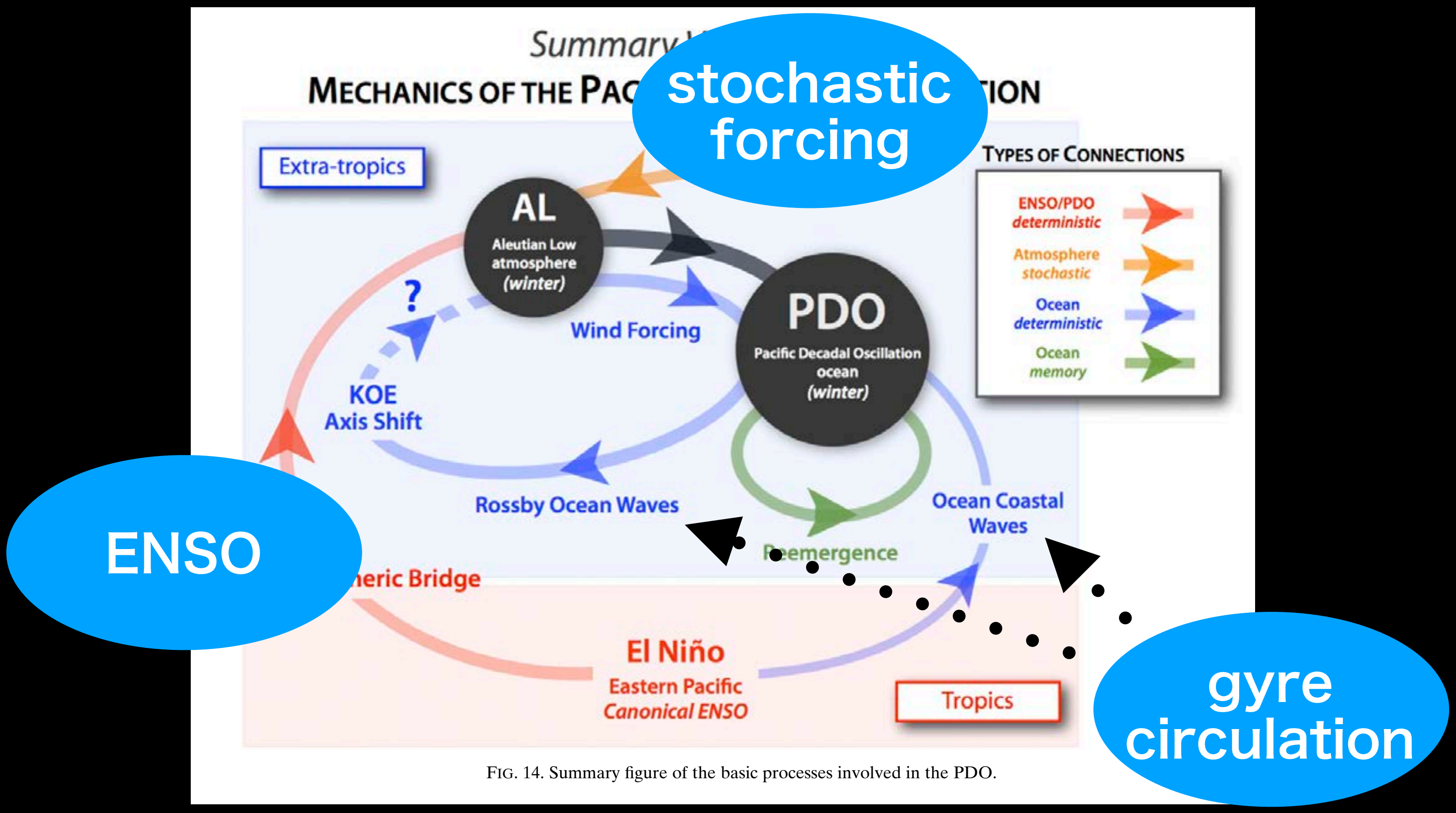


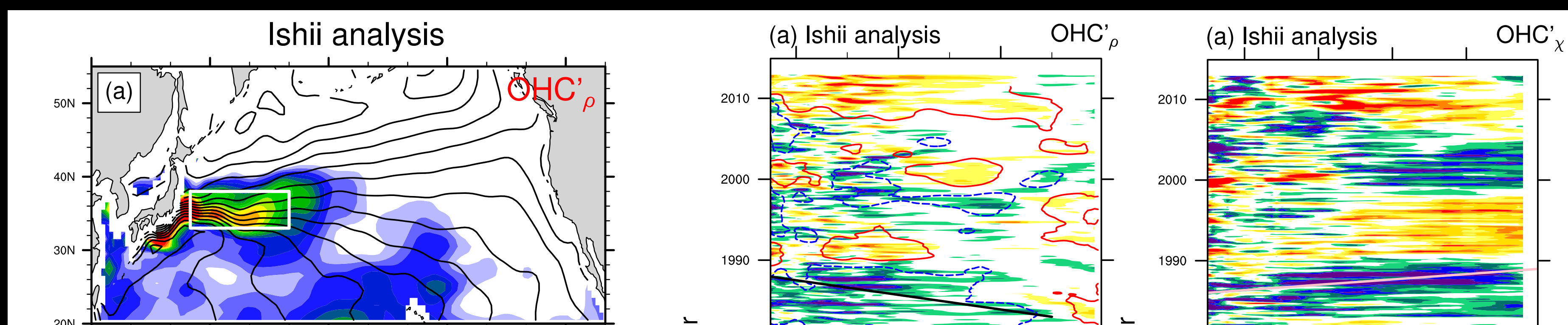
FIG. 14. Summary figure of the basic processes involved in the PDO.

- Schneider & Cornuelle (2005) suggested that contribution from changes in the gyre circulations is as important as stochastic forcing & ENSO on decadal time scales while it is negligible on interannual time scales

Effects of the Rossby waves on Heat Content (0-400m)

Taguchi et al. (2017) shows that

- T' moves westward along the Kuroshio Extension
  - the heaving of the thermocline related to the Rossby waves
- T' moves eastward along the subarctic frontal zone
  - generated by wave-related V' near the western boudary and passively advected by mean U



standard deviatio

longitude-time diagram

On decadal time scales, we must consider not only ocean response to local atmospheric forcings, but also remotely forced variabilities and/or delayed response, which are related to dynamical response of ocean

$$T' = T - \overline{T} \approx -\nabla\overline{T}(\mathbf{x}) \cdot (\delta\mathbf{x}_\rho + \delta\mathbf{x}_\chi) = T'_\rho + T'_\chi$$

$$T'_\rho = \frac{d\overline{T}}{d\overline{\rho}}\rho', \quad \text{with} \quad \frac{d\overline{T}}{d\overline{\rho}} = \frac{\nabla\overline{T} \cdot \nabla\overline{\rho}}{|\nabla\overline{\rho}|^2}$$

T'_ρ : dynamical component related to heaving

T'_χ : spiciness component ρ' compensating with S'

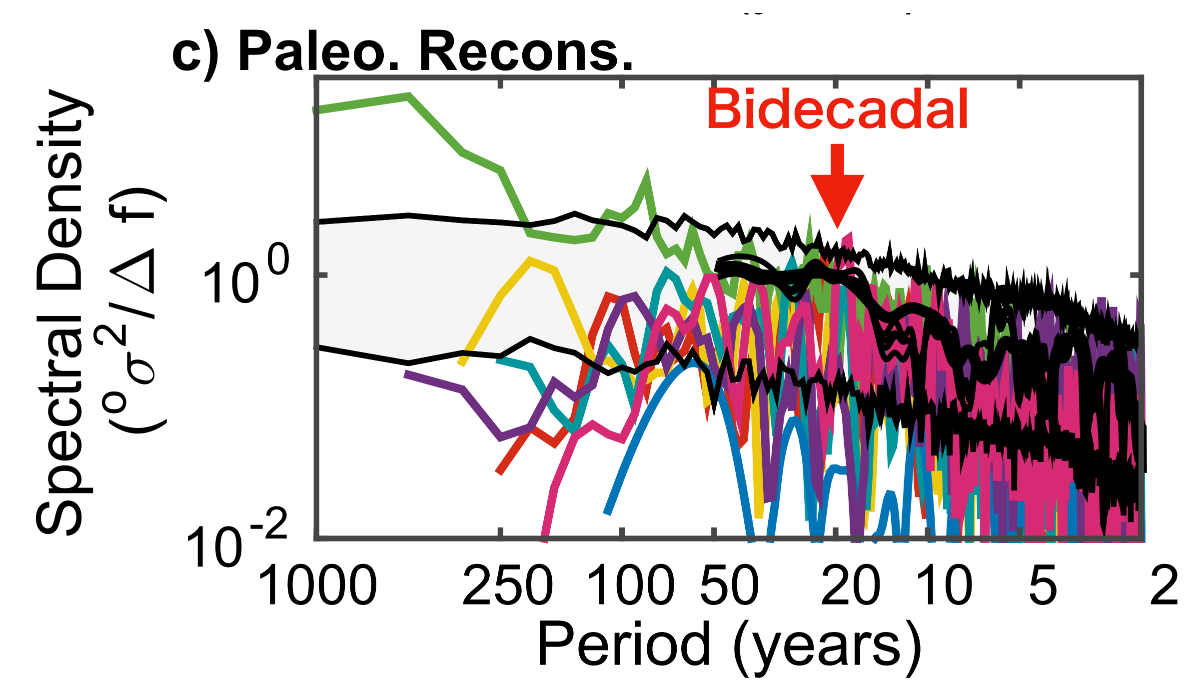
Bidecadal variability and the 18.6-year modulation of tide

Osafune et al. (2014 & submitted)

We show another possible mechanism, controlling eastward moving heat content anomaly along the PTA, which is related to a dynamical response of the ocean.

Bidecadal Variability

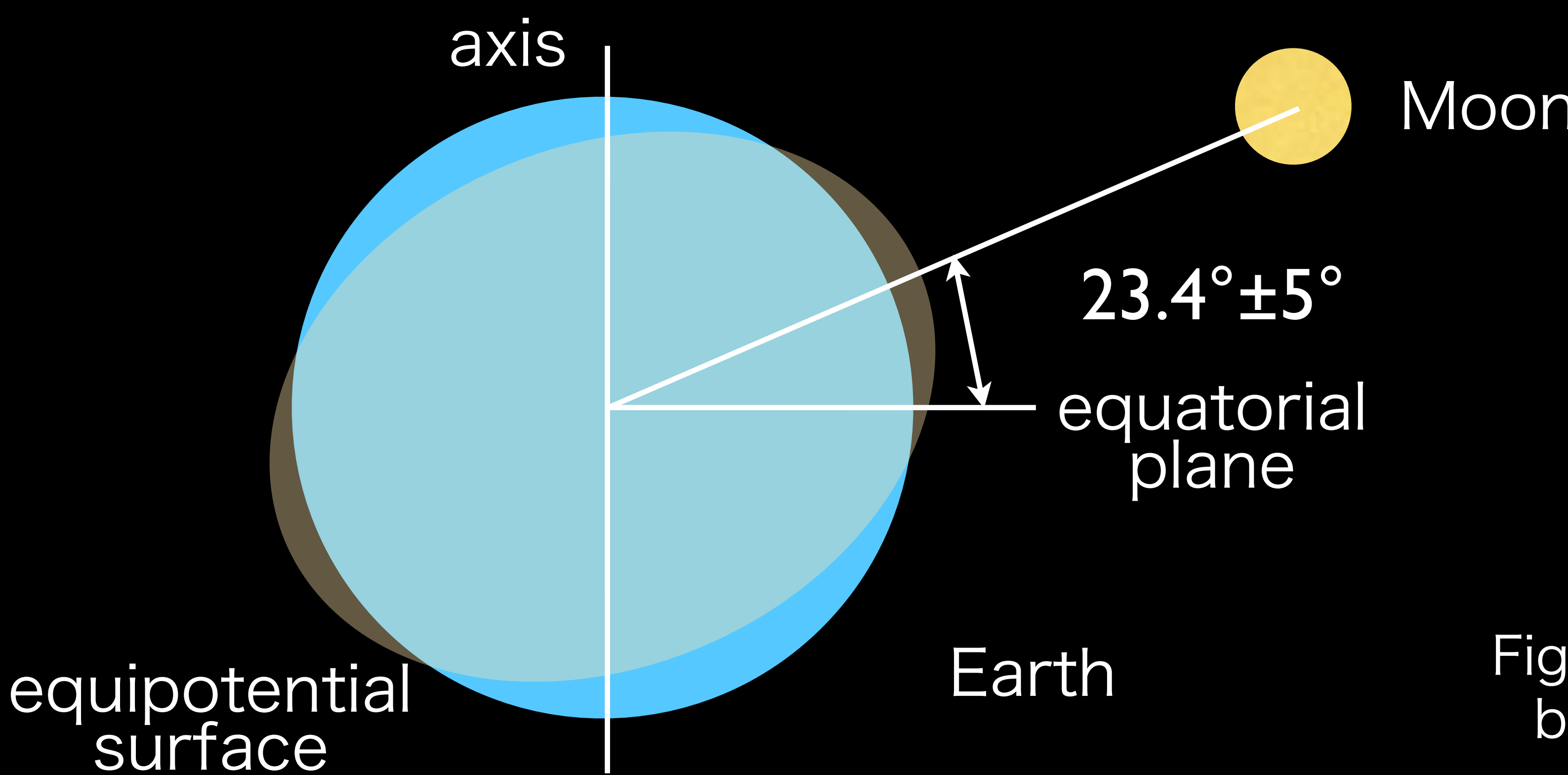
- ✦ Climate signal has a bidecadal peak (Man & Park, 1996)
- ✦ Bidecadal climate variability is prominent in the North Pacific
  (e.g. Cook et al., 1997; Minobe et al., 2002)
  - PDO has bidecadal component,
    although its spectral peak is not significant in OBS



Comparison of PDO spectra
(black) observational and
(colors) paleoclimate reconstructions
(Newman et al., 2016)

Is there actually bidecadal periodicity in large-scale SSTa / PDO?
If exists, what determines the periodicity?

Our hypothesis and its background



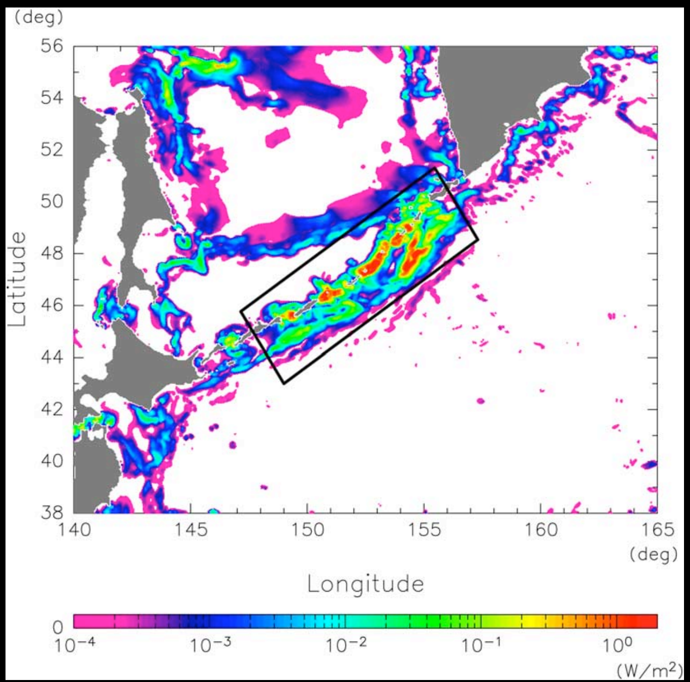


Fig. Energy conversion rate from the barotropic tides to internal waves (Tanaka et al., 2007)

- **The inclination of the lunar orbit varies in 18.6-year period. Diurnal and semi-diurnal tides are modulated largely (Godin, 1972).**
- **Large amount of diurnal tidal energy dissipates, and induces strong vertical mixing around steep topographies in the subarctic North Pacific, such as the Kuril Straits (Tanaka et al., 2010) the Aleutian Passes (Foreman et al., 2007).**
- **This localized strong mixing controls ocean circulation and water-mass formation in the North Pacific (e.g. Nakamura et al., 2006)**

↓

The 18.6-year modulation of localized strong tidal mixing could have an impact on climate (Yasuda et al., 2006).

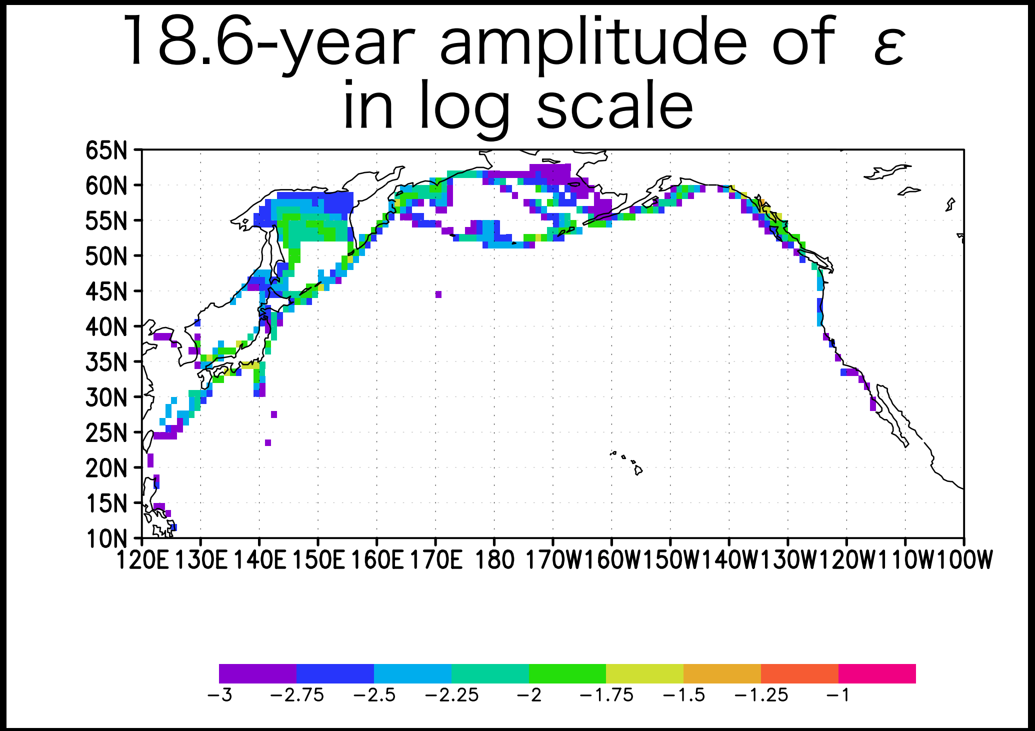
Verifying this hypothesis is a main topic in our project from 2015.

I will introduce my works in this line,
which investigated the impact of the 18.6-year modulation of mixing on large-scale SST though ocean-only mechanism

Data & Method

Ocean State Estimation (ESTOC) : Control Run (CTL)

- developed by JAMSTEC/K7
- model : GFDL/MOM3 (quasi-global, 1°× 1 °×45 levels)
- (… nt)



An OGCM simulation
using optimized initial condition
and atmospheric forcings,
which provide the best time-trajectory fit
to the observation

: TS (Ensembles ver. 3(including ARGO) + Mirai RV independent dataset)
OISST、AVISO SSH anomaly

: Climatology TS (WOA05; for parameter tuning by Green's Function Method)

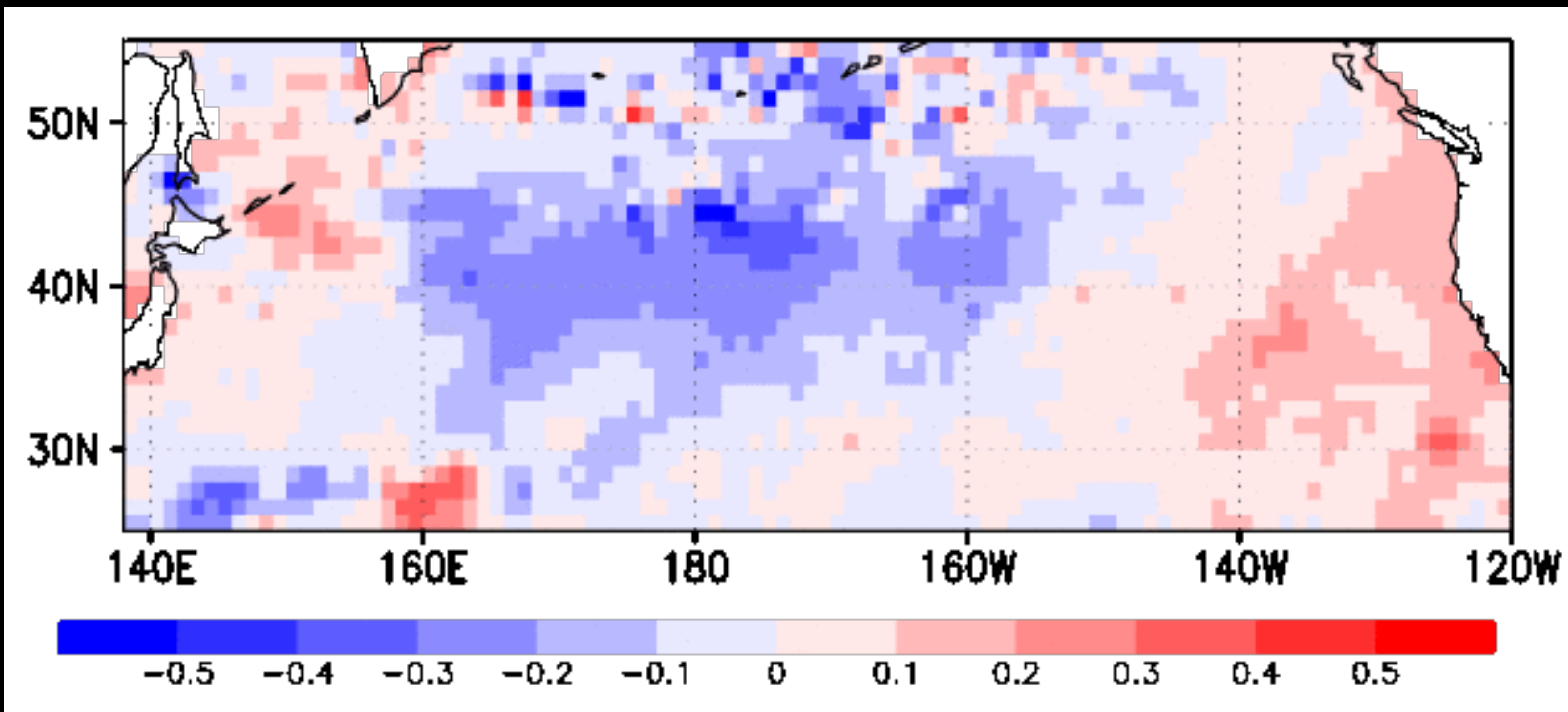
Numerical Experiment with 18.6-year modulation : Nodal Run (NODAL)

- initial condition & atmospheric forcings are same with CTL
- oscillating vertical diffusivity related to rough topography in 18.6-year period

Results

$\Delta SST = SST_{nodal} - SST_{ctl}$

1977-2009



ΔSST @ 40°N

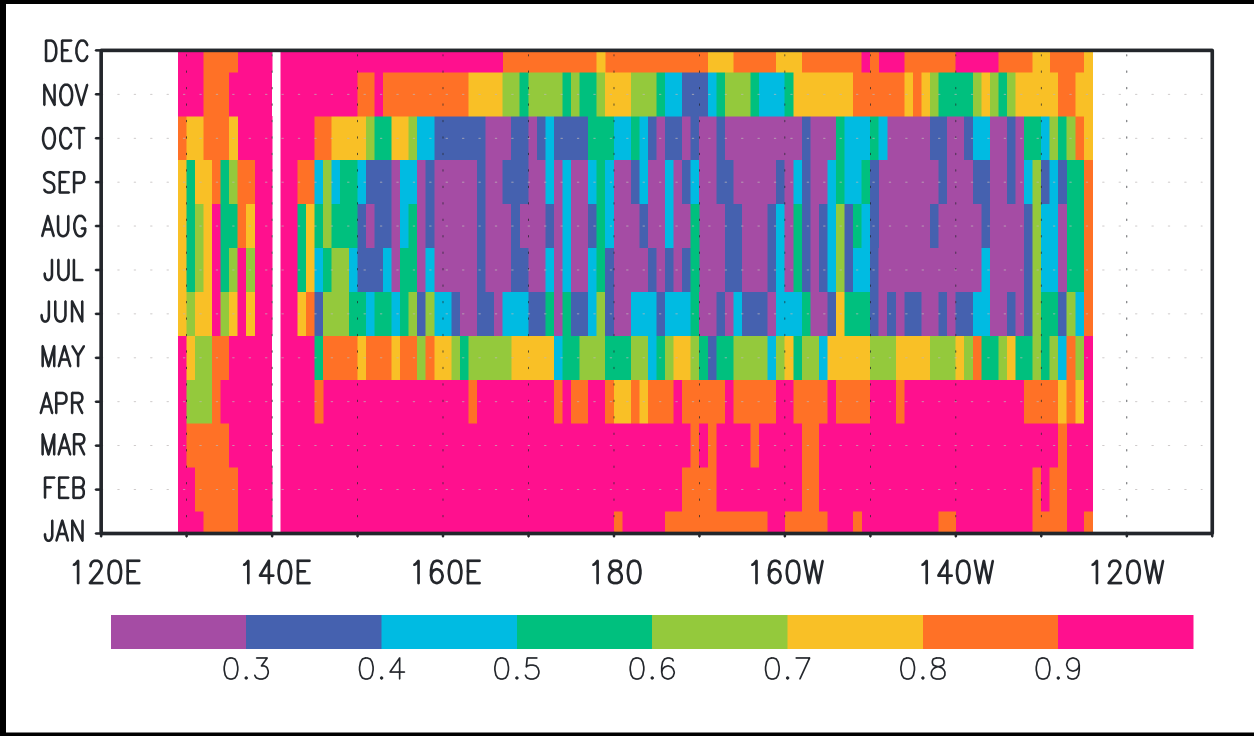
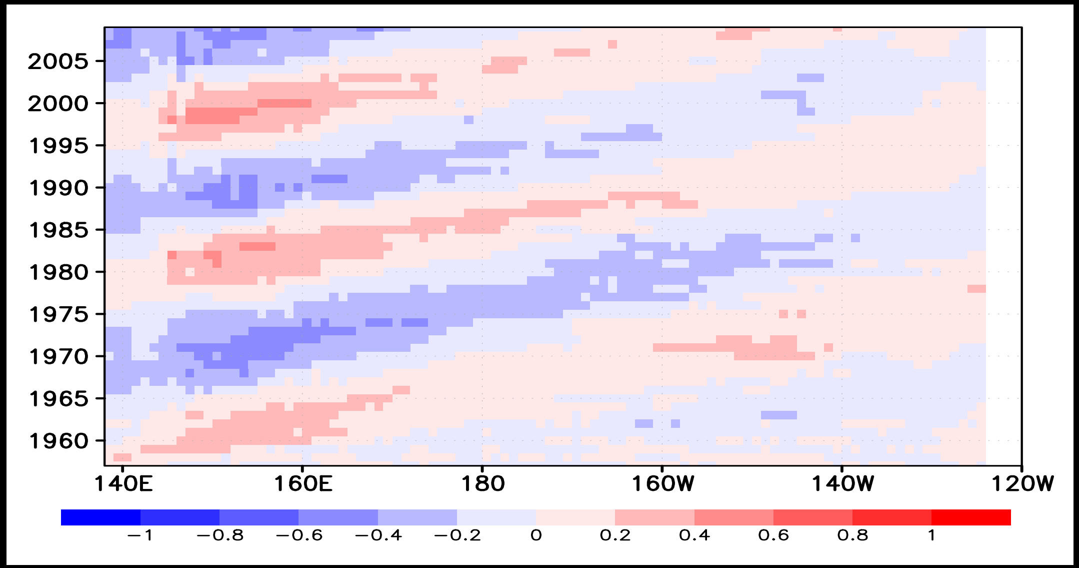


Fig. Correlation between ΔSST & 18.6-year cycle

Feb



Aug

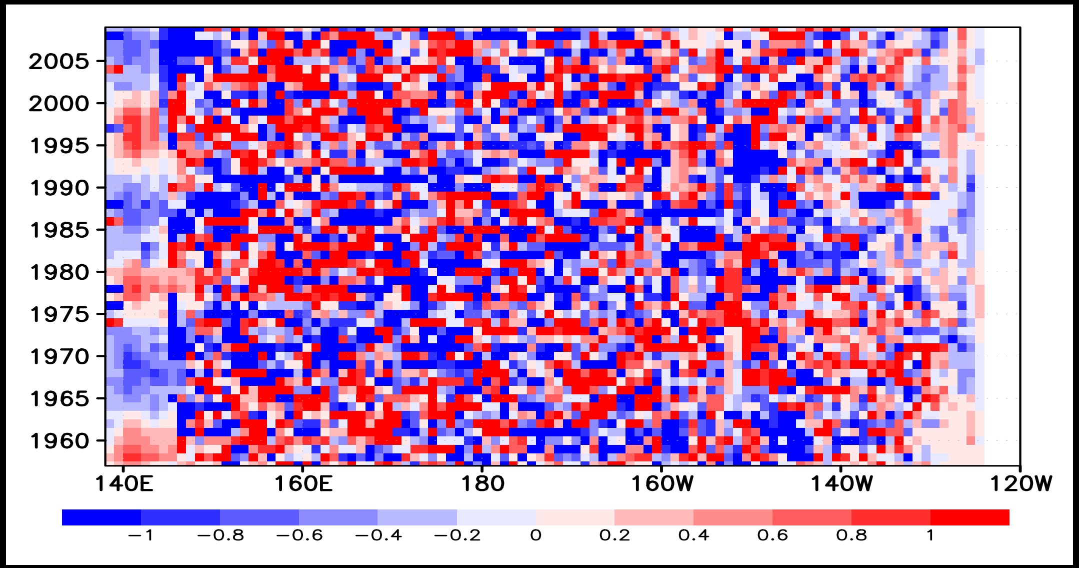


Fig. Time-longitude diagram of ΔSST along 40°N in Feb & Aug

- **Eastward moving 18.6-year signal has a clear seasonality, and is clear in winter, but not in summer.**

18.6-year ΔSST$_{feb}$ (NODAL-CTL)

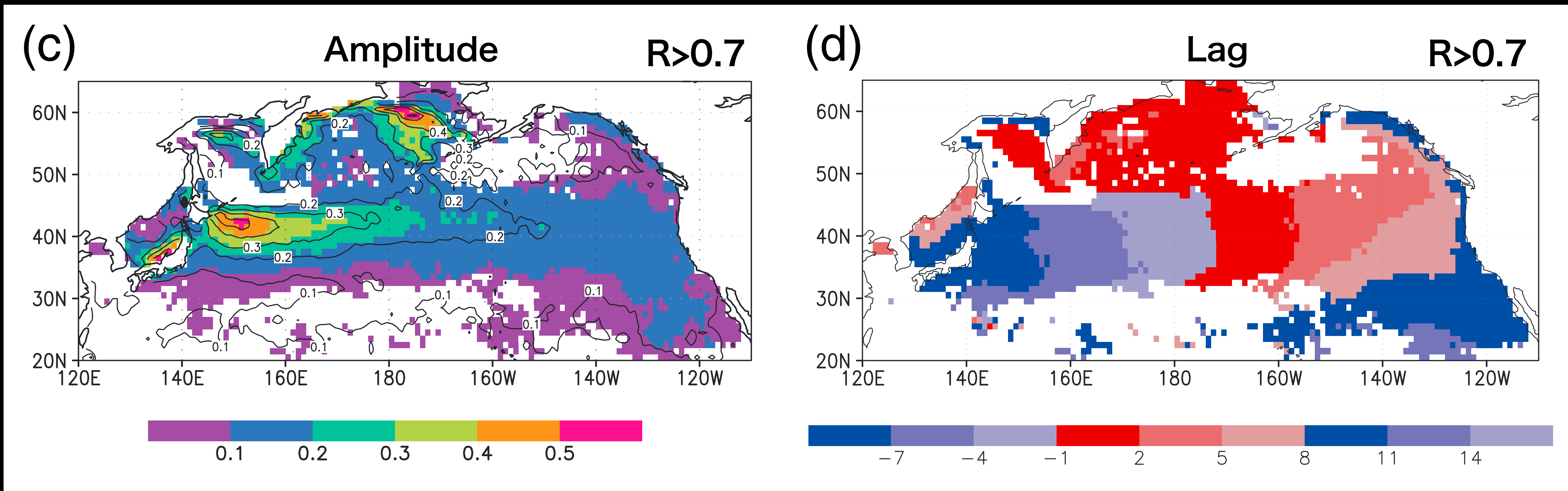


Fig. Amplitude and lag for the 18.6-year ΔSST$_{feb}$ estimated by regressing on 18.6-year cycle

- 18.6-year period ΔSST moves eastward along the PTA
  - ✓ This moving speed is slower than the mean current
- This ΔSST significantly contributes to the actual bidecadal SSTa near the center of action of the PDO
  - ΔSST is inphase with the actual SSTa
  - Amplitude of ΔSST is about 20% of that of the actual SSTa

Impact on PDO$_{Feb}$

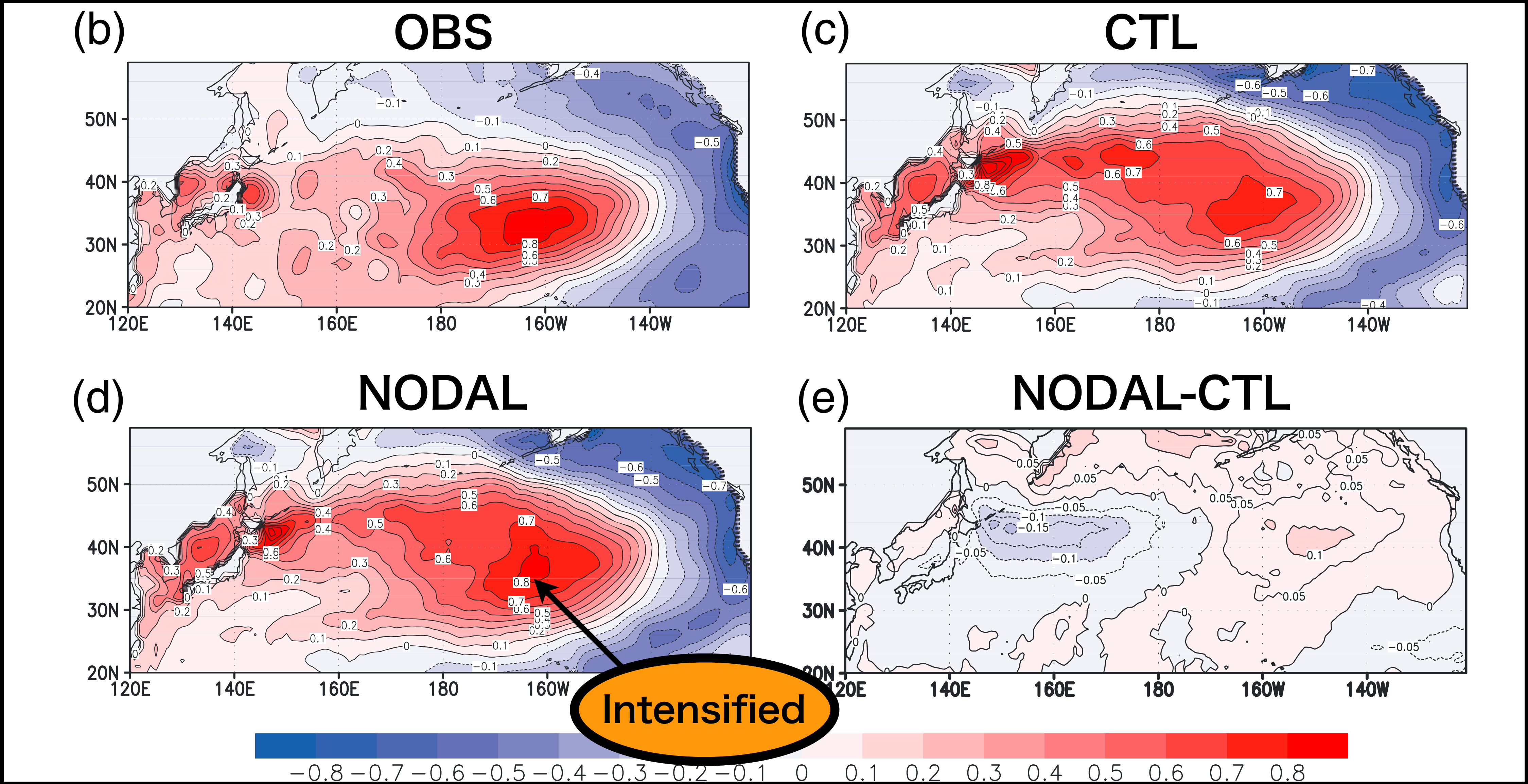


Fig. Regression of SSTa in Feb on PC1 for observed SSTa in Feb

- Spatial structure seems to be improved in NODAL

➡ The 18.6-year modulation of mixing may play a role in determining the spatial structure of the PDO

Dynamics of the eastward motion

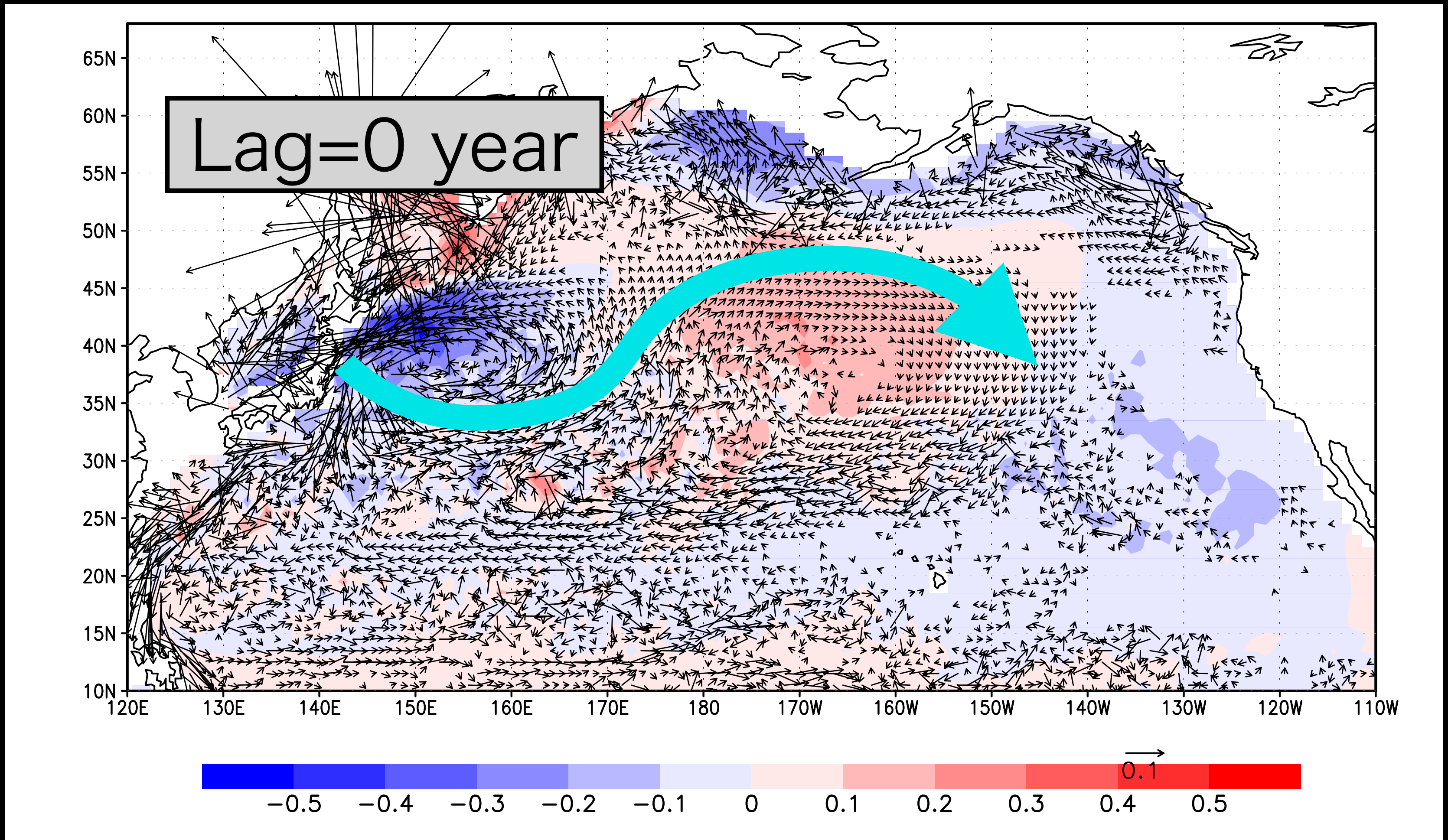


Fig. Reconstructed snapshots of 18.6-year Δu, Δv, ΔT at 100 m

- ✦ Large scale ocean circulation is distorted, and ΔT approximately reflects the meandering of the eastward current along the PTA
- ✦ Δu & Δv is coupled with the subsurface Δρ, corresponding to the intermediate layer thickness anomaly (not shown)

➡ The low-mode (2nd or higher) baroclinic long Rossby waves moving eastward along the PTA plays a substantial role
: What is essential in the western boundary region is not ΔT near the surface but subsurface Δρ

Summary & Discussion

- ✦ The 18.6-year modulation of tide-induced mixing in limited region can influence the large-scale SST, and possibly the PDO.
- ✦ Eastward moving low-mode (2nd or higher) baroclinic long Rossby waves play a role in the mechanism of this possible influence.
  - moving speed of T anomaly is slower than the passive advection
  - T anomaly is accompanied by subsurface density & circulation anomaly
- ✓ <u>This mechanism can work once density anomaly is generated, regardless of the cause and the periodicity.</u>
  - Clear bidecadal density anomaly has been observed in the subarctic region (Osafune & Yasuda, 2006; 2010).
- ▸ Does this mechanism actually work along the PTA?
  - We investigated data from Argo float array (Kouketsu’s Poster 12386)
  - I am analyzing ESTOC to evaluate the contribution on PDO
- ▸ This mechanism may help understanding the bidecadal variations not only physical properties, but also in biogeochemical properties (e.g. AOU, nutrient), plankton biomass, and marine resources (e.g. Ono et al., 2001; Tadokoro et al., 2009; Parker et al.,1995)
  - We are planing to investigate ESTOC and conduct similar impact experiment (biogeochemical component of ESTOC is introduced by Doi’s Poster 12392)

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