Seasonal to interannual variations of the western boundary current of the subarctic North Pacific using altimeter data

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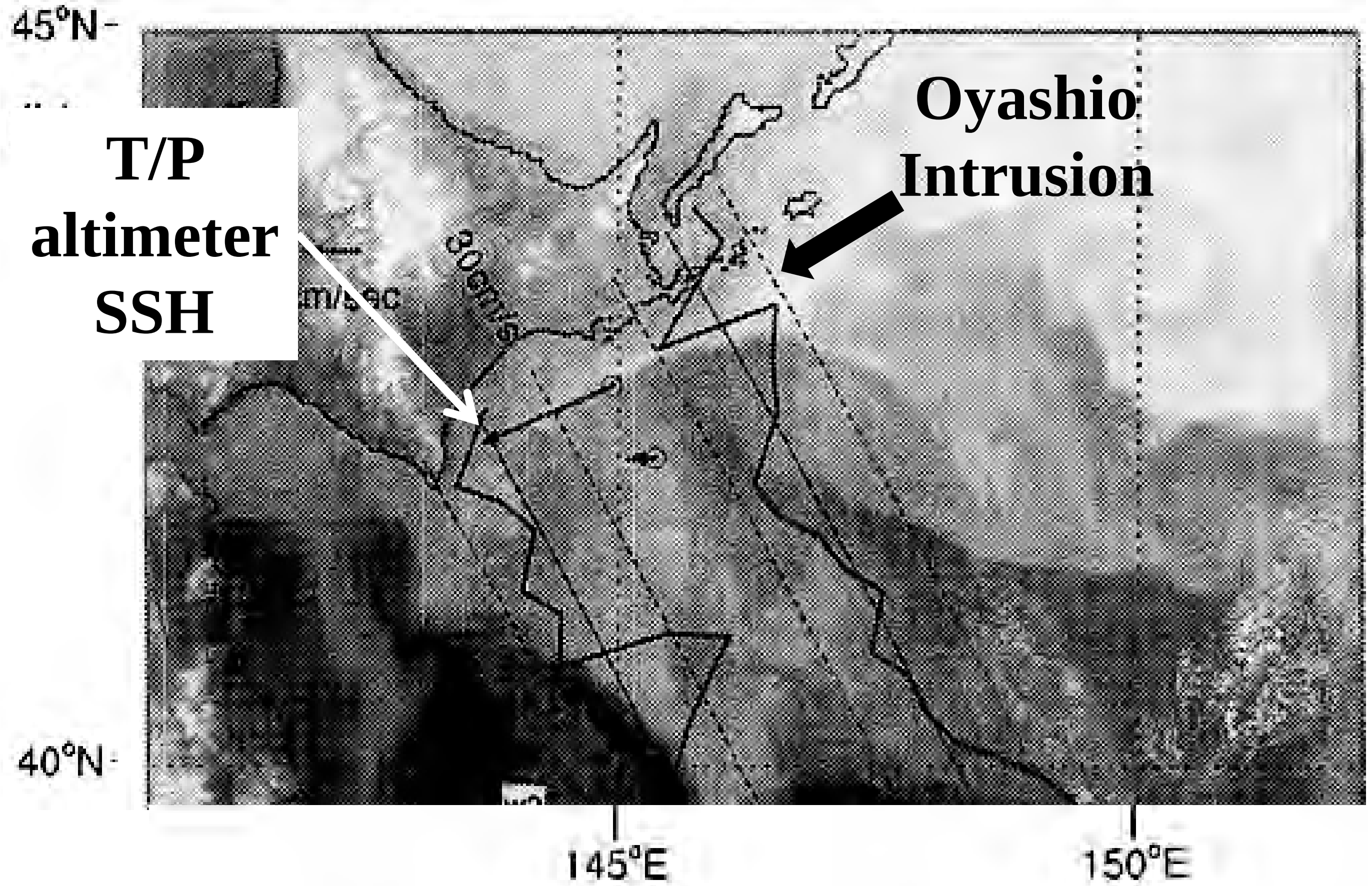
Isoguchi, O., H. Kawamura and T. Kono (1997): A study on wind-driven circulation in the subarctic North Pacific using TOPEX/POSEIDON altimeter data, J. Geophys. Res., 102, 12457-12468. Master thesis

Isoguchi, O. and H. Kawamura (2003): Eddies advected by time-dependent Sverdrup circulation in the western boundary of the subarctic North Pacific, Geophysical Research Letters, 30, doi:10.1029/2003GL017652. A part of Ph.D thesis

Isoguchi, O. and H. Kawamura (2006): Seasonal to interannual variations of the western boundary current of the subarctic North Pacific by a combination of the altimeter and tide gauge sea levels, J. Geophys. Res., 111, C04013.

Isoguchi, O., and H. Kawamura (2006), Oyashio seasonal intensification and its effect on subsurface temperature variation off the Sanriku coast, J. Geophys. Res., 111, C10006, doi:10.1029/2006JC003628.



磯口治, 川村宏，河野時廣, 川崎康寛(1995): 海面高度計と海洋観測データを用いた北海道南沖合域の海況変動，海の研究，4，163-174.

Isoguchi, O., H. Kawamura, T. Kono and Y. Kawasaki (1995): Oceanic variations observed by combining altimeter and hydrographic observations, Umi-no-Kenkyu, Vol.4, 163-174. **Bachelar thesis**

A study on wind-driven circulation in the subarctic North Pacific using TOPEX/POSEIDON altimeter data

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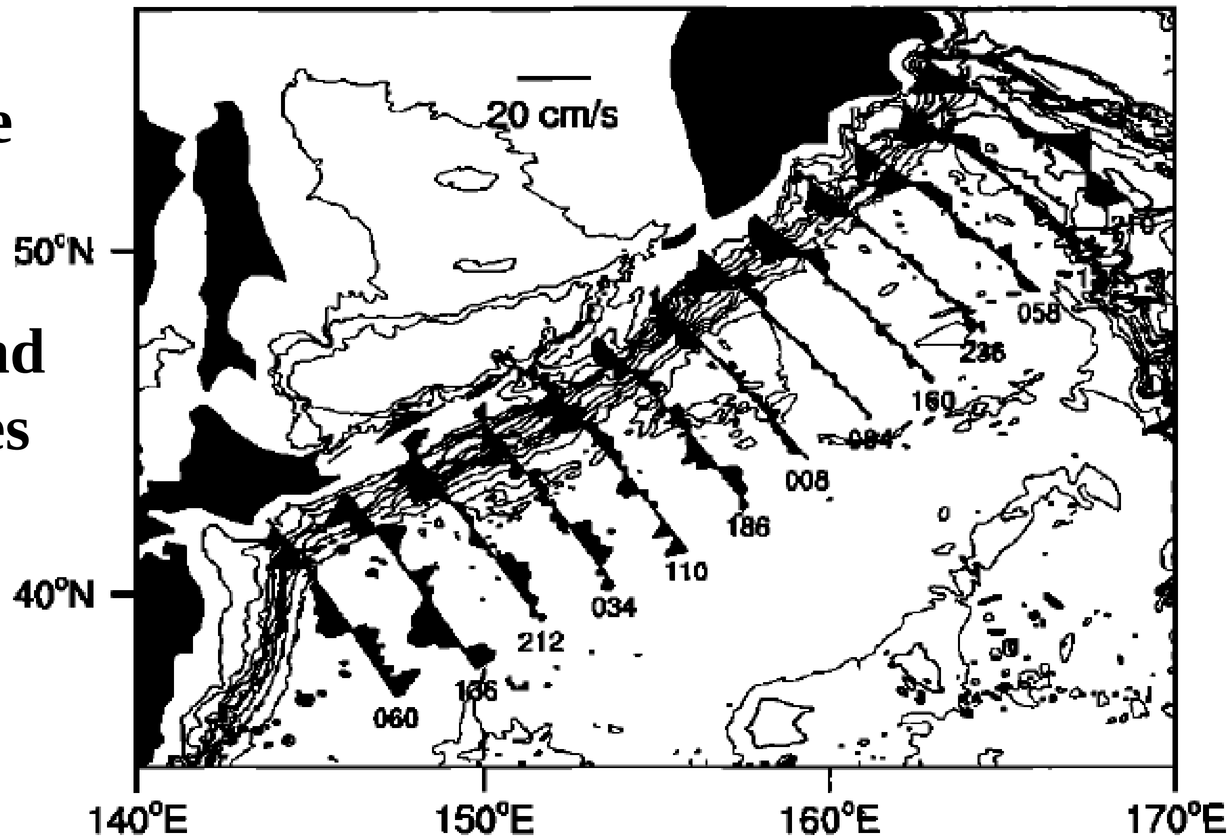
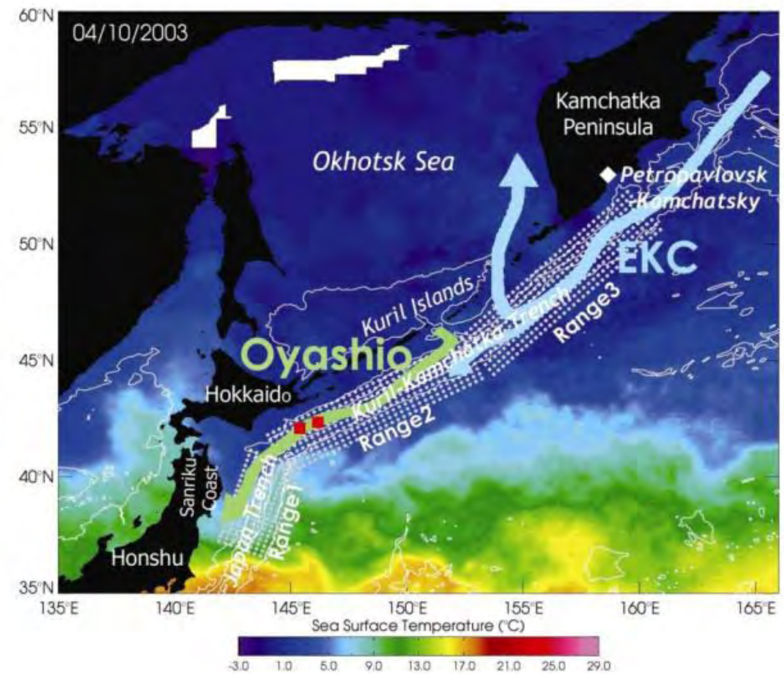
Covariance between the time series of the first EOF of the SLA (Sveldrup transport) and the cross-track velocities



JGR (1997)

Previous works about Oyahio/East Kamchatka Current variations



Interannual variation

✓Southward shift of Oyashio water (subsurface temperature field) shows a good correlation with wintertime atmospheric forcing (Aleutian low and related Sverdrup transport) (Sekine 1988; Hanawa1995)

Seasonal variation

✓Hydrographic and moored buoy observations: strong (weak) current/transport in winter/spring (summer/fall)

Present study

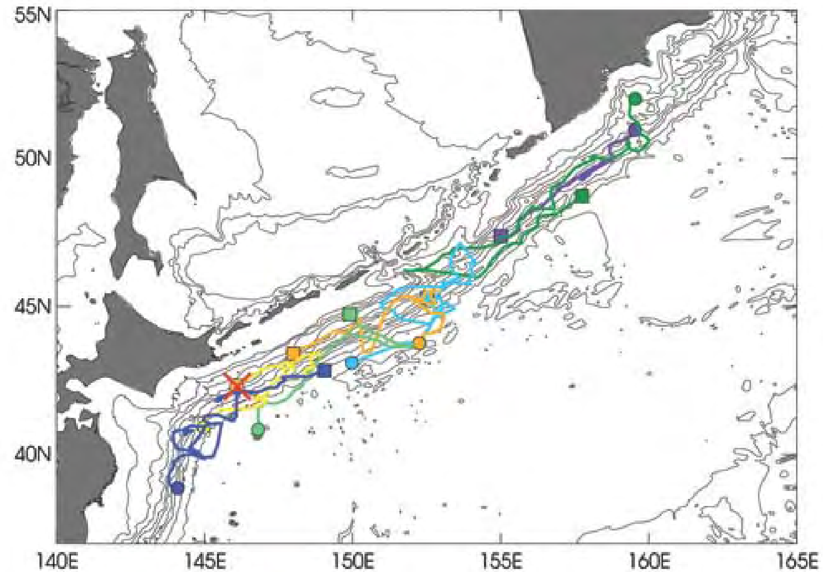
✓We demonstrate that altimeter and tide gauge sea levels are **good indices** of Oyashio/EKC variations, which could connect dynamically the relationship between atmospheric forcing and subsurface temperature fields in the previous studies.

✓We investigate in detail **seasonal/intraseasonal evolution** of Oyashio current and its effect on sea surface/subsurface temperature fields off the Sanriku coast of Japan using derived indices.

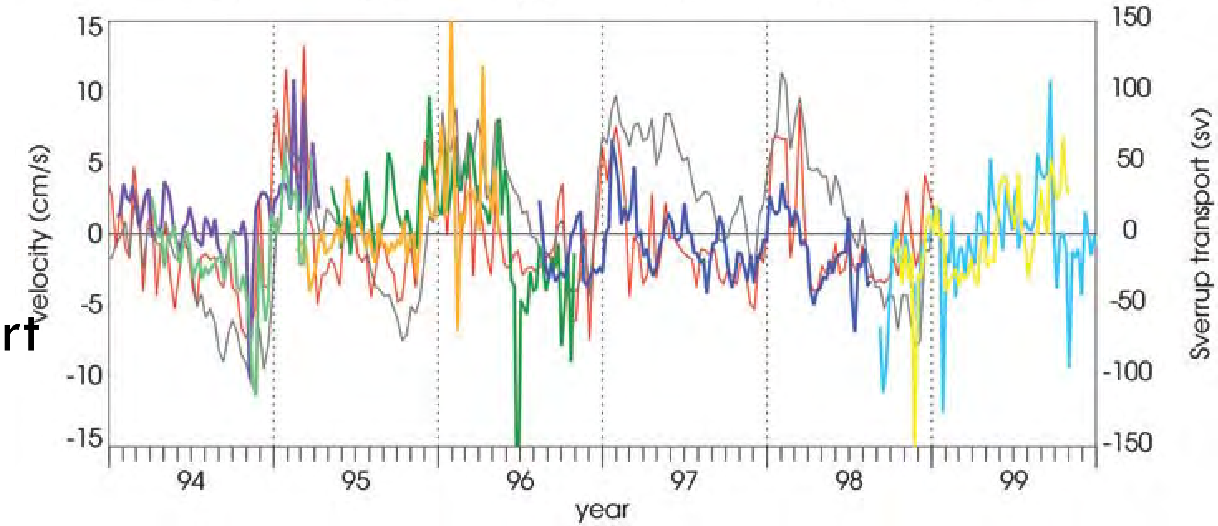
- **Indices of Oyashio/EKC variations**
  - Altimeter-derived Eddy Drifting Velocity (EDV) and Geostrophic Current Anomaly (GCA)
  - Tide gauge sea levels
- **Seasonal/intraseasonal variation**
- **Interannual variation**

Indices of Oyahio/EKC variations

Trajectories of eddies

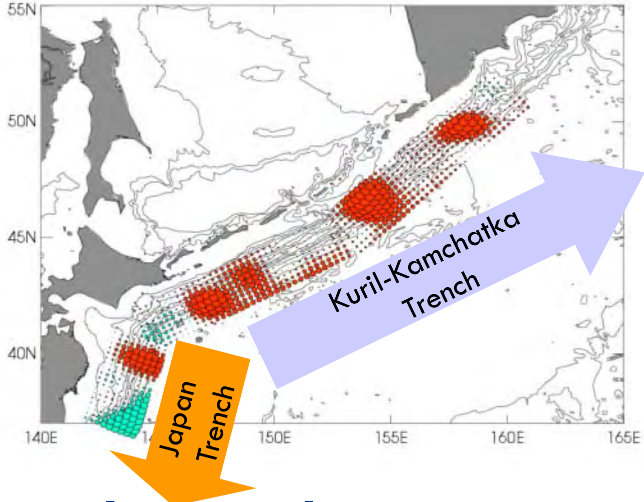


Comparison between eddies propagating velocity and Sverdrup transport



✓Movement of eddies over Japan Trench and Kuril-Kamchatka Trench could be a good index of Oyashio and EKC short term variation [Isoguchi and Kawamura ,2006]

1) Eddy Drifting Velocity (EDV)



Sea Level Anomaly

-Maps of SLA provided by AVISO

-Merged data from Jason-1,Envisat,Topex/Poseidon,GFO

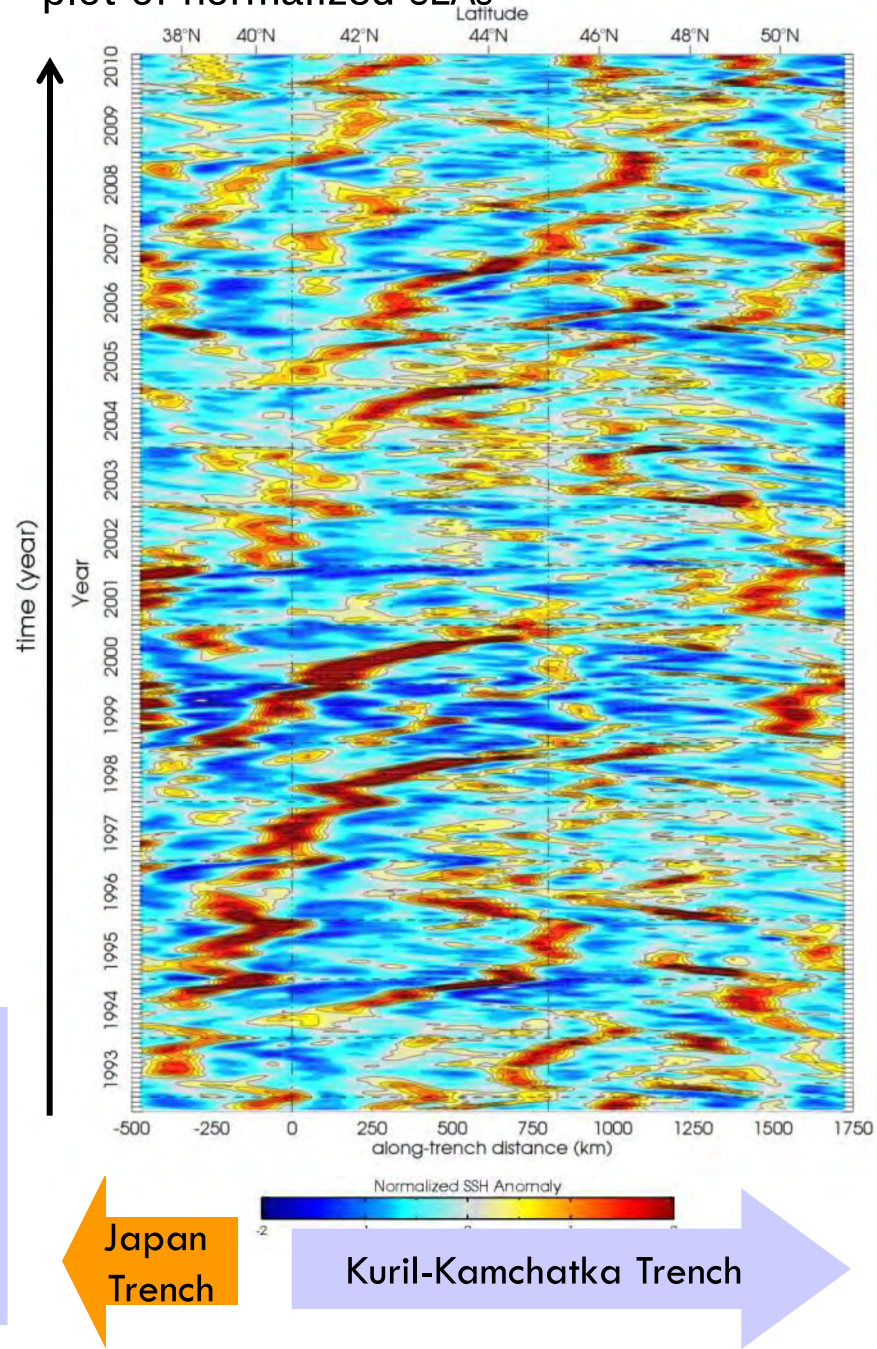
- time: Oct 1992 – Aug 2010
- 1/3 deg gridded SLAs every 7 day

EDV= Δx/ Δt

Δx: Lag distance in which cross-correlation has a maximum

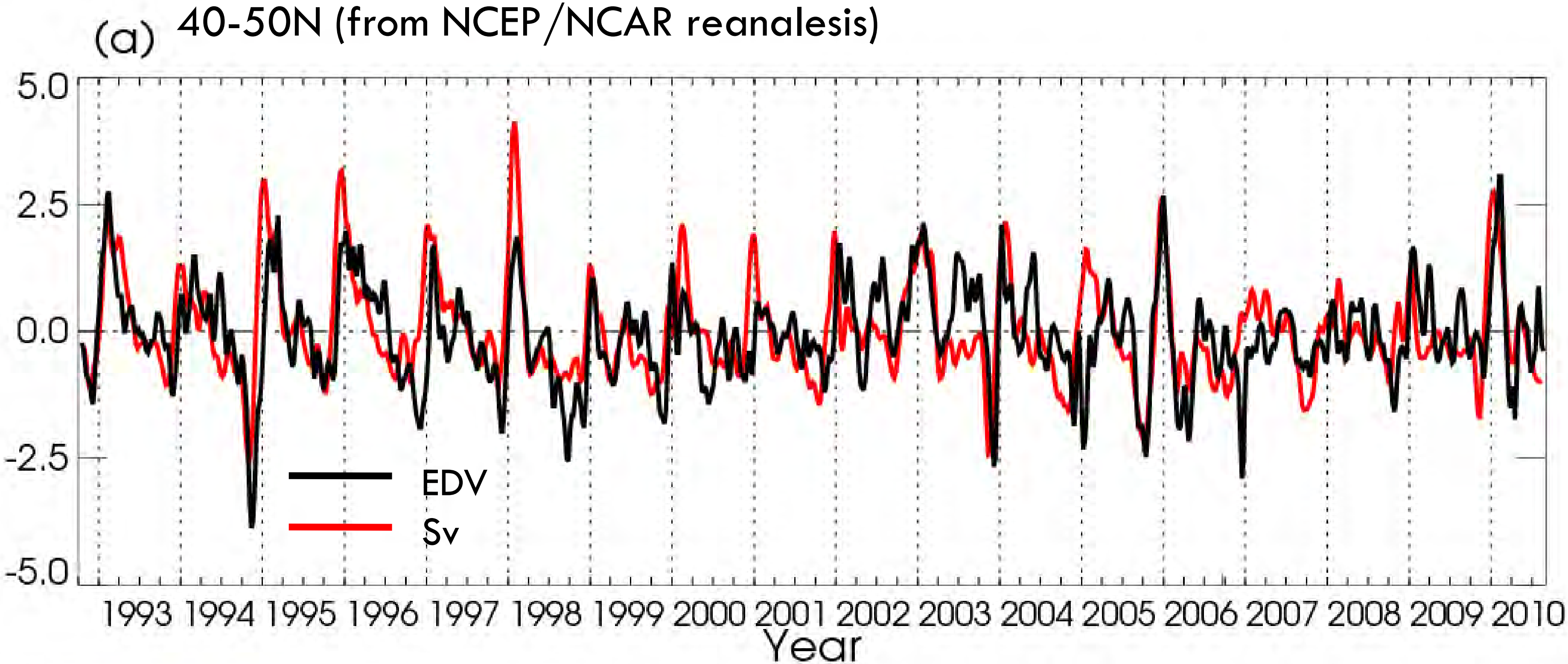
Δt: temporal distance of SLAs

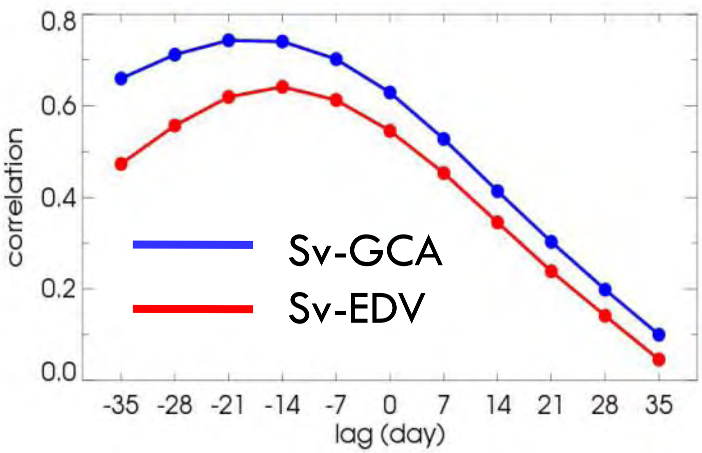
Along-trench distance (x-axis)-time (y-axis) plot of normalized SLAs



1) Eddy Drifting Velocity (EDV)

Time series of normalized EDV and Sverdrup transport (Sv) averaged for 40-50N (from NCEP/NCAR reanalesis)





Correlation: **0.64** when **14-day lag**

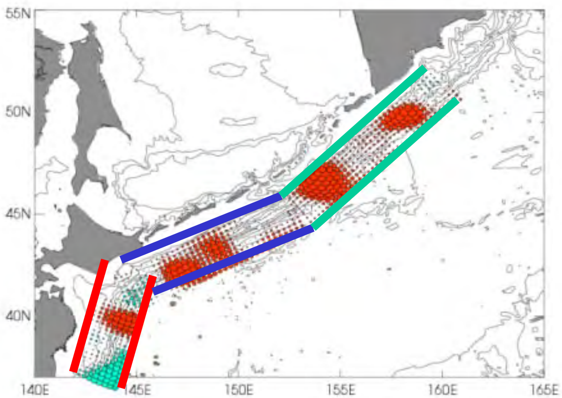
2) Geostorophic current anomaly (GCA)

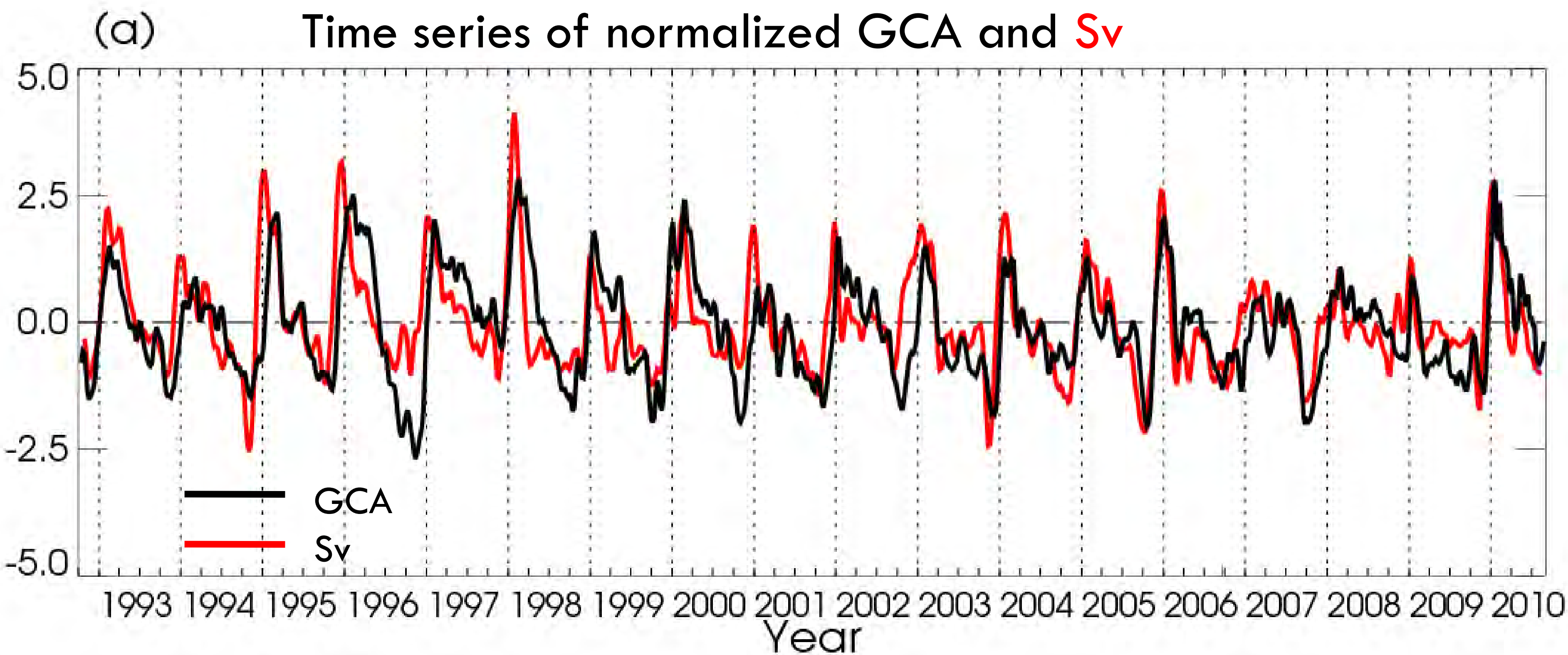
✓from Sea level difference across 200km width grids over the trenches

GCA= Δh/ Δs

Δh: sea level difference

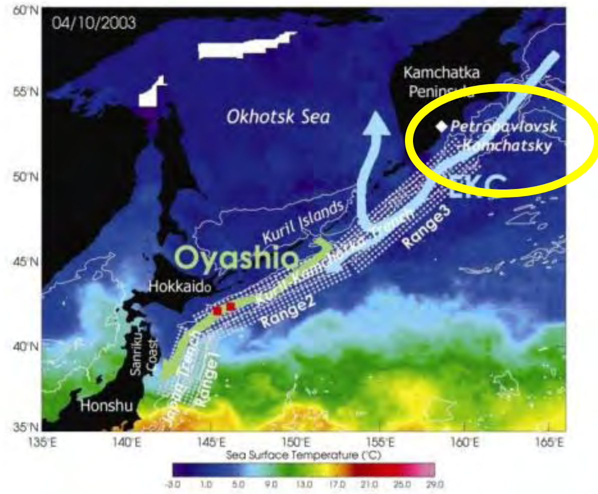
Δs: cross trench distance (200km)





Correlation: **0.74** when **21-day lag**

3) Tide sea levels at Petropavlovsk-Kamchatsky (PK-Tide)

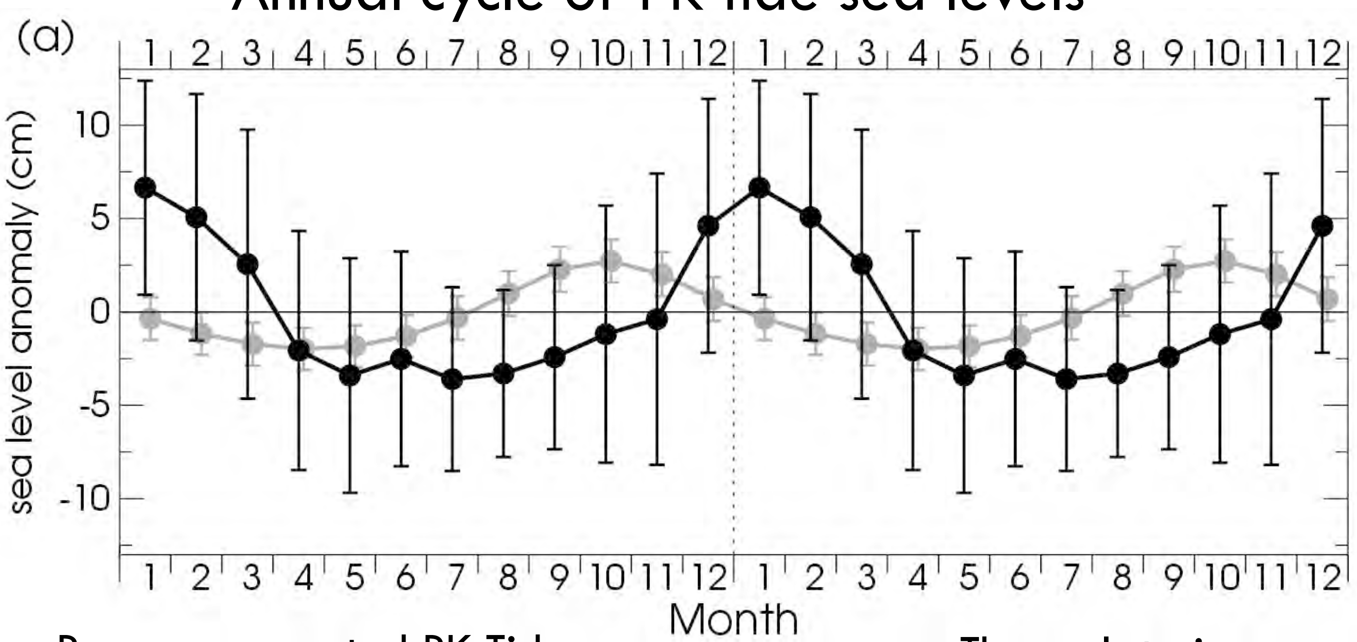


- ✓from Permanent Service for Mean Sea Level (PSMSL: *Woodworth*, 1991)
- ✓Period: July 1957 to Nov 2008
- ✓Correction for atmospheric Pressure
- ✓Removal of thermal steric component

$$\eta'_{heat}(t) \approx \eta'_{heat}(t_0) + \frac{1}{\rho_o c_p}\int_{t_0}^{t} \alpha_T (Q_{net} - \langle Q_{net} \rangle) dt',$$

ρ_o: Reference density,
Cp: Specific heat of sea water
α_T: thermal expansion coefficient
$Q(t)$: Net surface heat flux

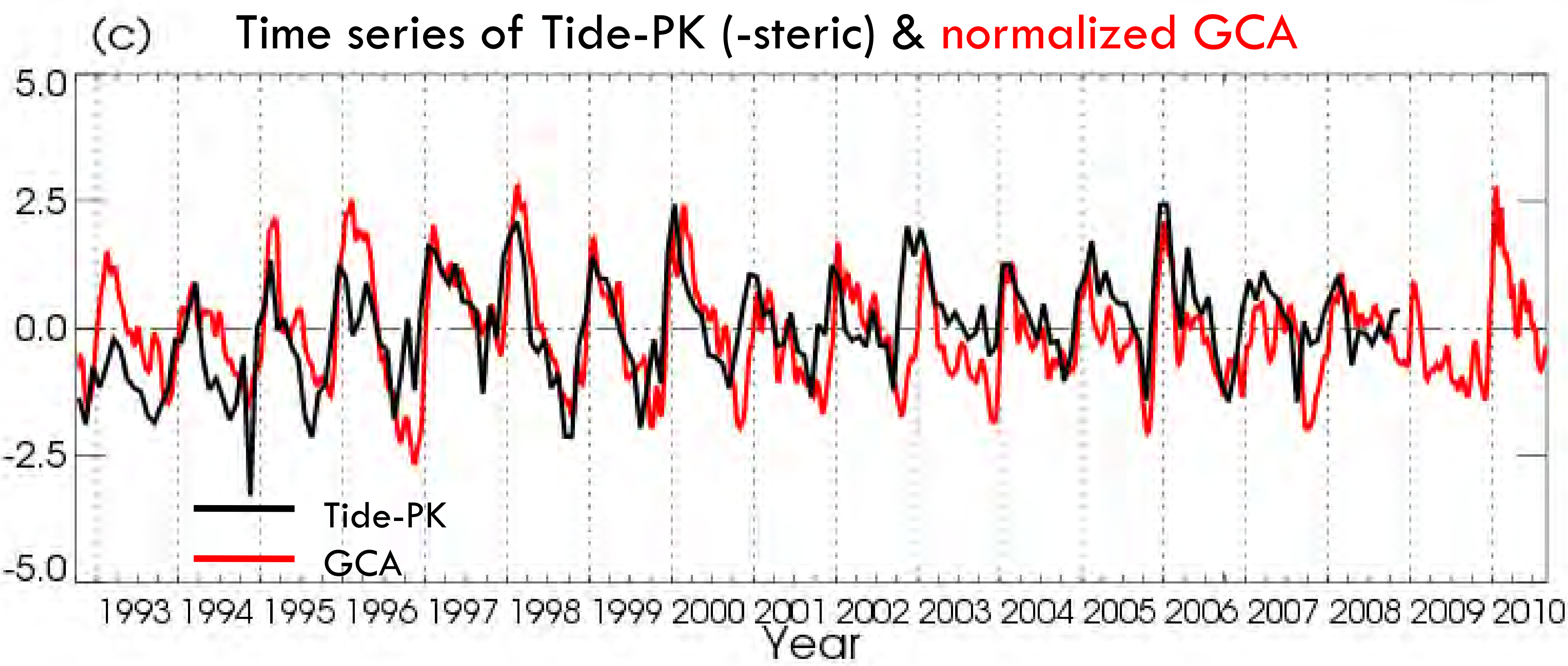
Annual cycle of PK tide sea levels



Pressure-corrected PK Tide

Thermal steric comp. at PK

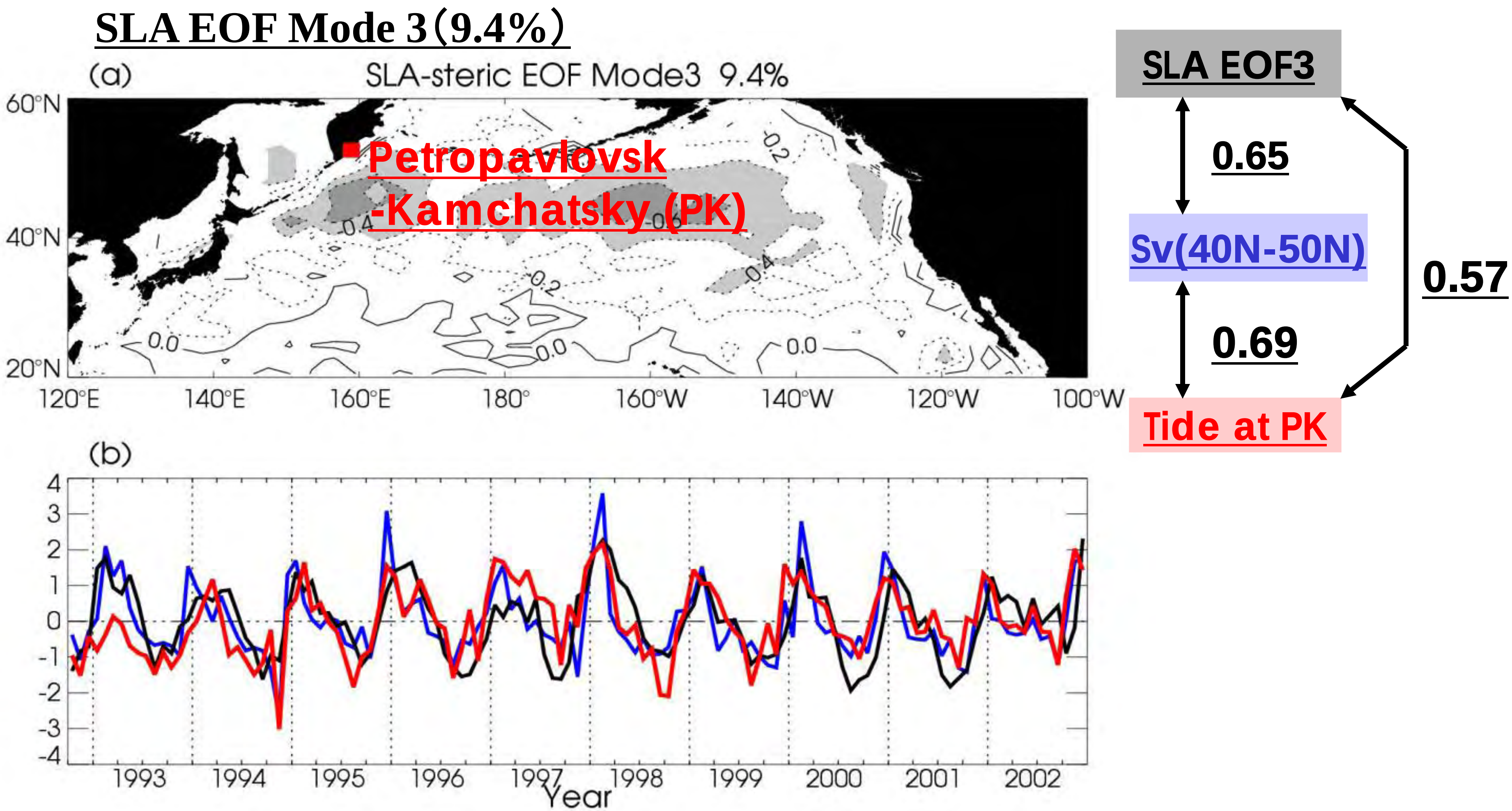
3) Tide sea levels at Petropavlovsk-Kamchatsky (Tide-PK)



Correlation: **0.60** when **1-month lag**

3) Tide sea levels at Petropavlovsk-Kamchatsky (PK-Tide)

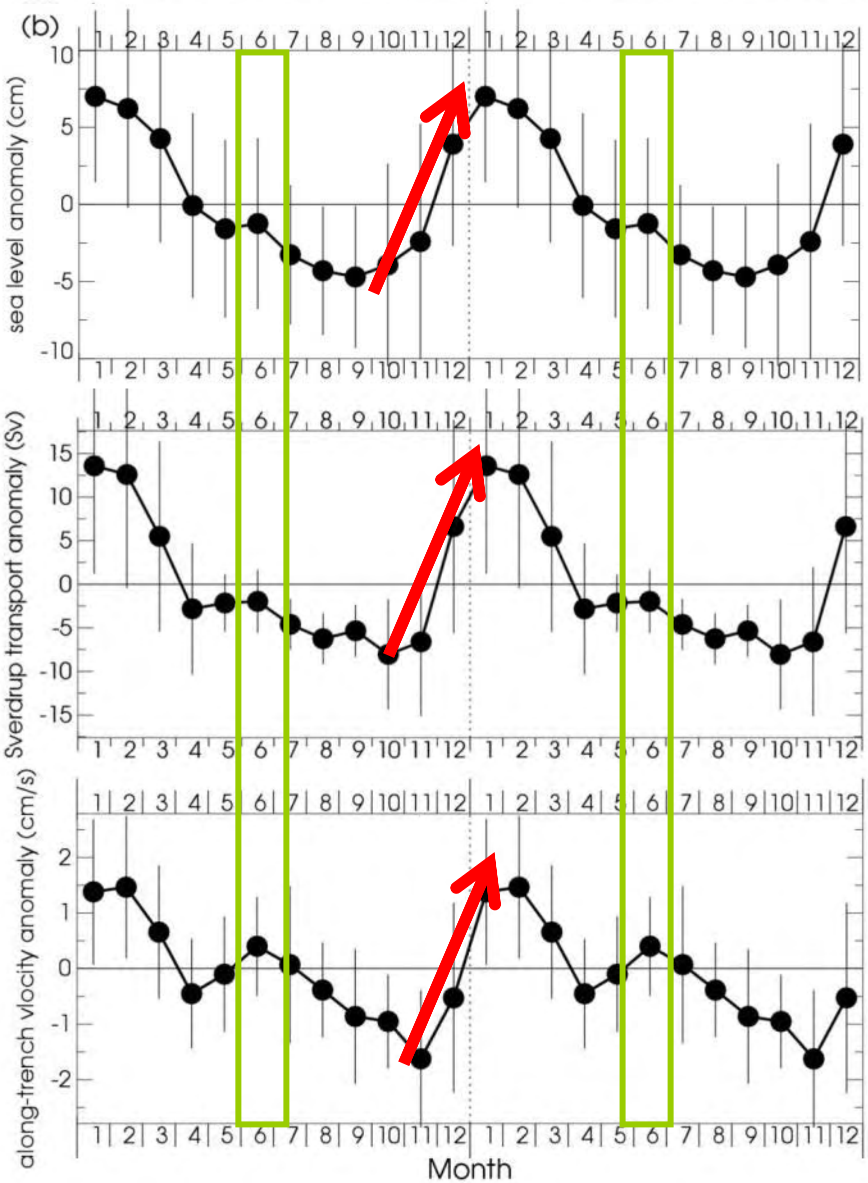
Why Tide-PK ?



✓**PK Tide** is representative of **sea level gradients** across the KK Trench which is related to **large scale Sverdrup circulation.**

- ✓ Indices of Oyashio/EKC variations
  - ✓Altimeter-derived Eddy Drifting Velocity (EDV) and Geostrophic Current Anomaly (GCA)
  - ✓Tide gauge sea levels
- ✓ **Seasonal/intraseasonal variation**
- ✓ Interannual variation

Annual cycles of Tide-PK , Sv, EDV



Tide-PK

PSMSL

1957/7-2002/12(45.5 years)

Removal of thermal steric

Sverdrup (40-50N)

NCEP/NCAR reanalyses

1957/7-2002/12(45.5 years)

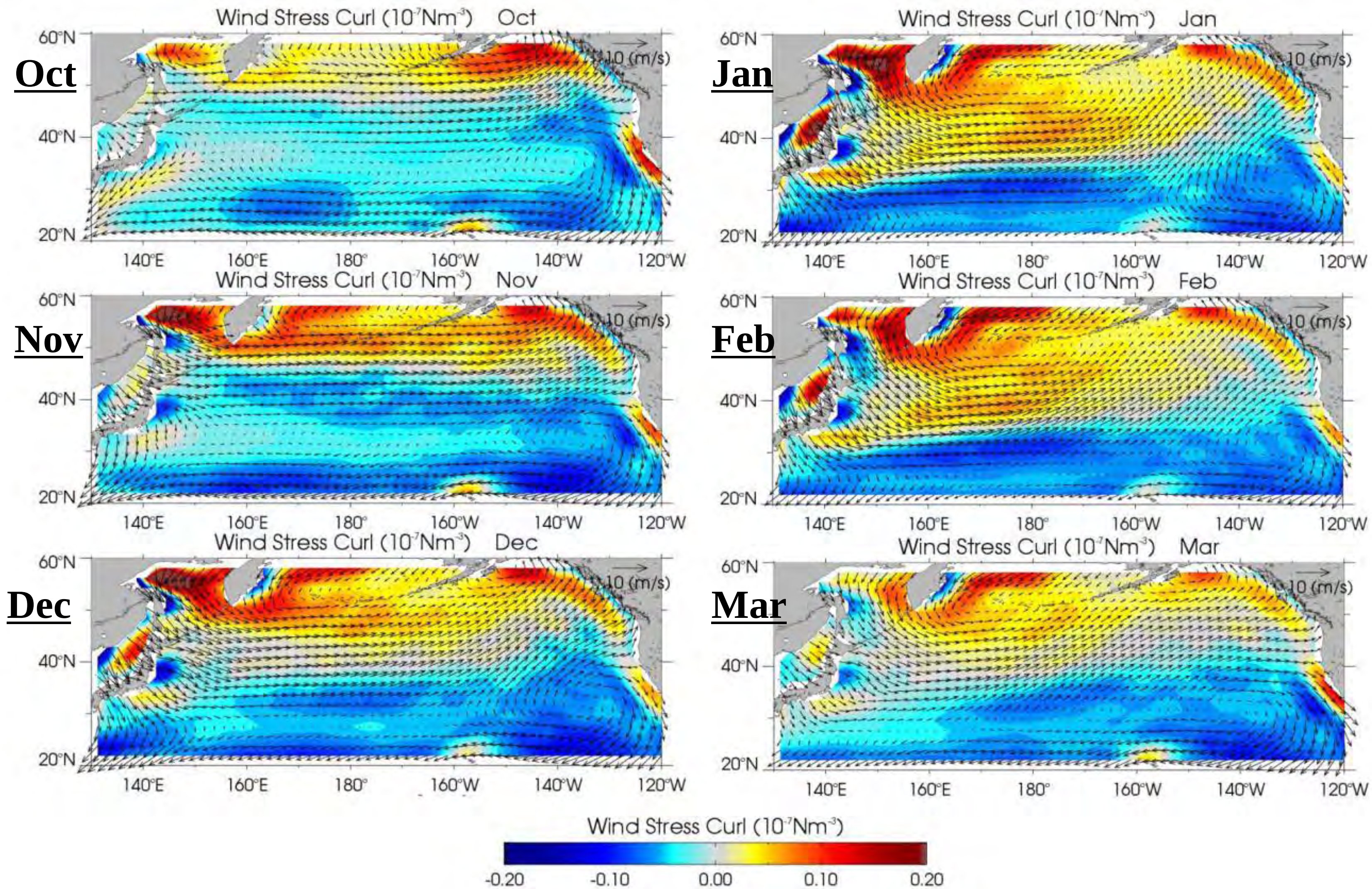
Eddy drifting velocity

1992/10-2003/9(11years)

- ✓ **Wintertime abrupt intensification (from minimum in late fall to max in winter)**
- ✓ **Secondary peak in early summer (in June)**

✓Wintertime abrupt intensification

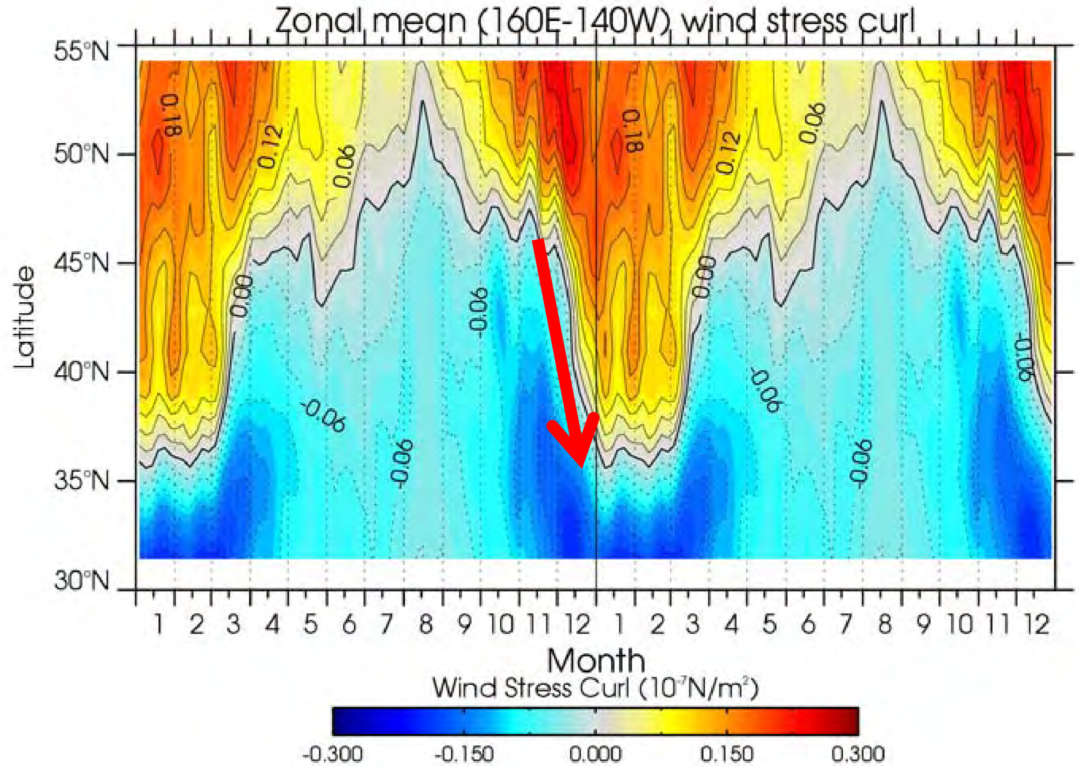
Climatology of Wind & Wind stress curl (October-March)



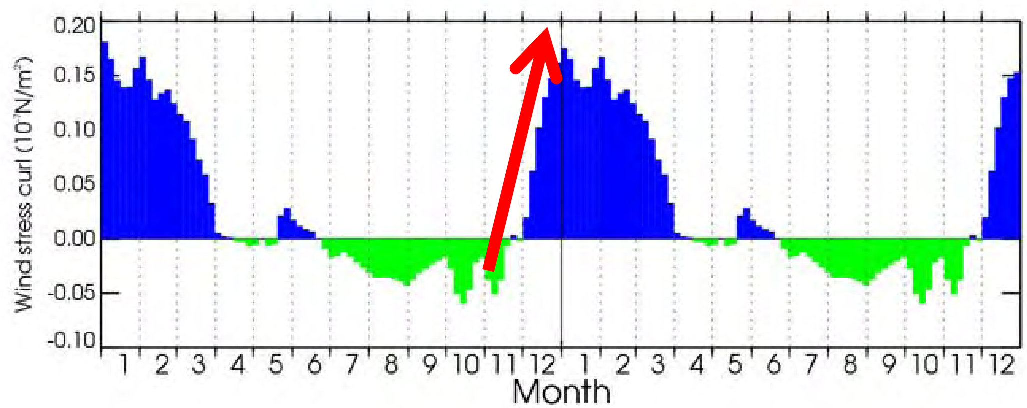
Westerlies rapidly shift southward from late fall to winter.

✓Wintertime abrupt intensification

Annual cycles of zonal mean wind stress curl based on NCEP 5-day climatology



Annual cycles of area-averaged (160E-140W, 40-50N) curl

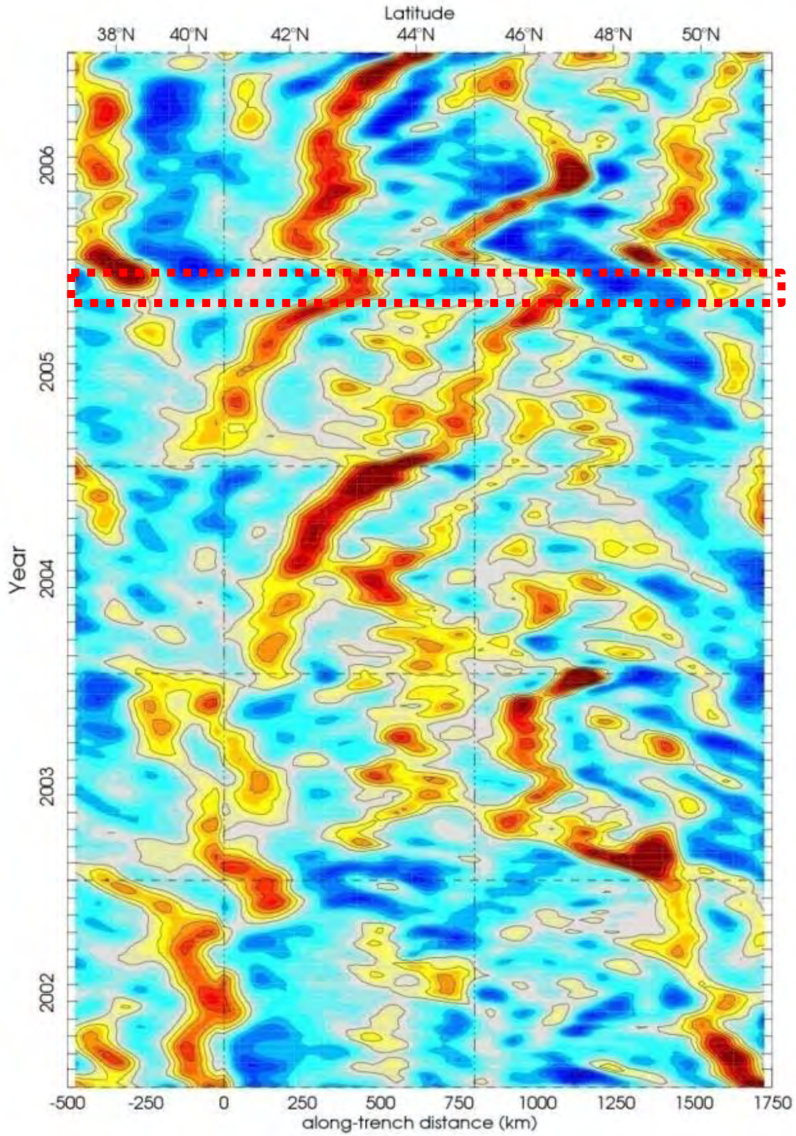


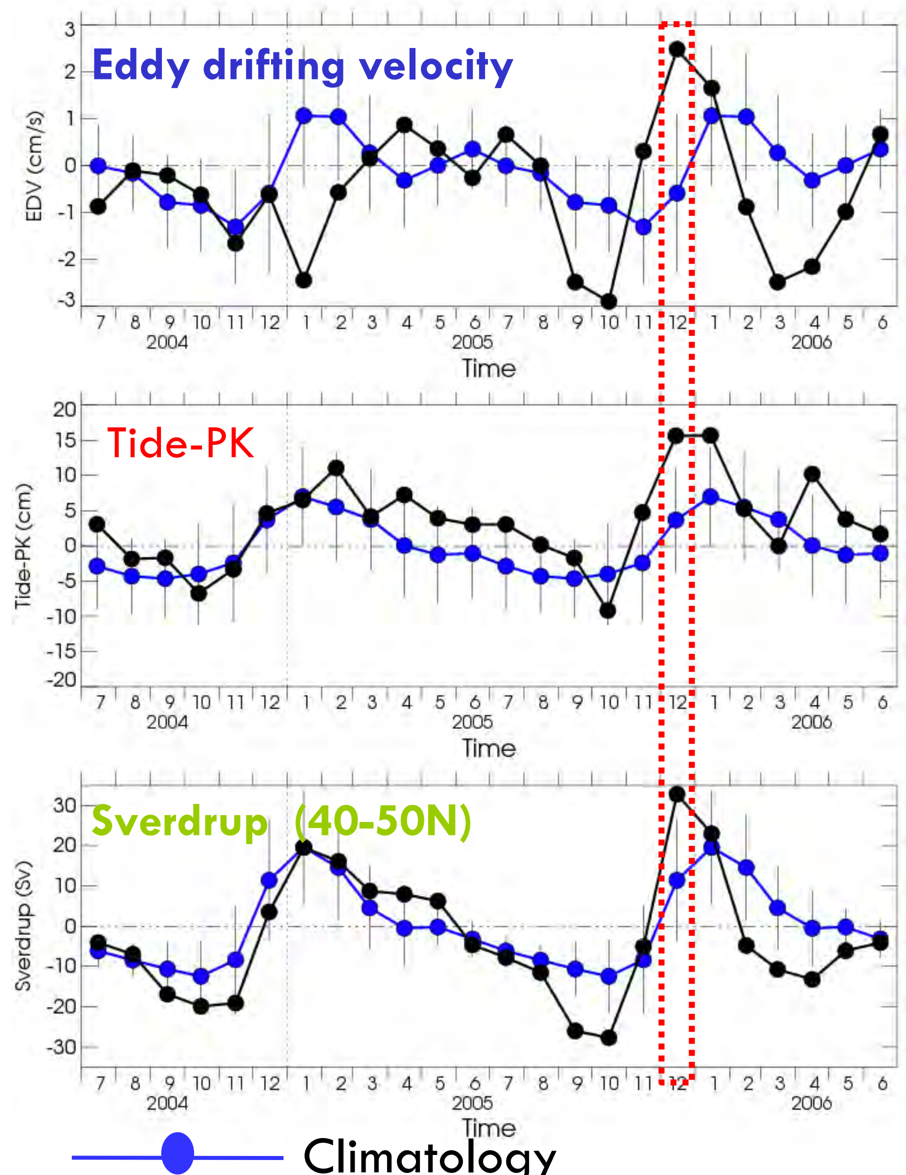
✓Abrupt intensification caused by rapid southward migration of westerlies

✓Wintertime abrupt intensification

Timing of onset of wintertime intensification, which is represented by turnaround of eddy propagation, have a large impact on late fall condition in Japan.

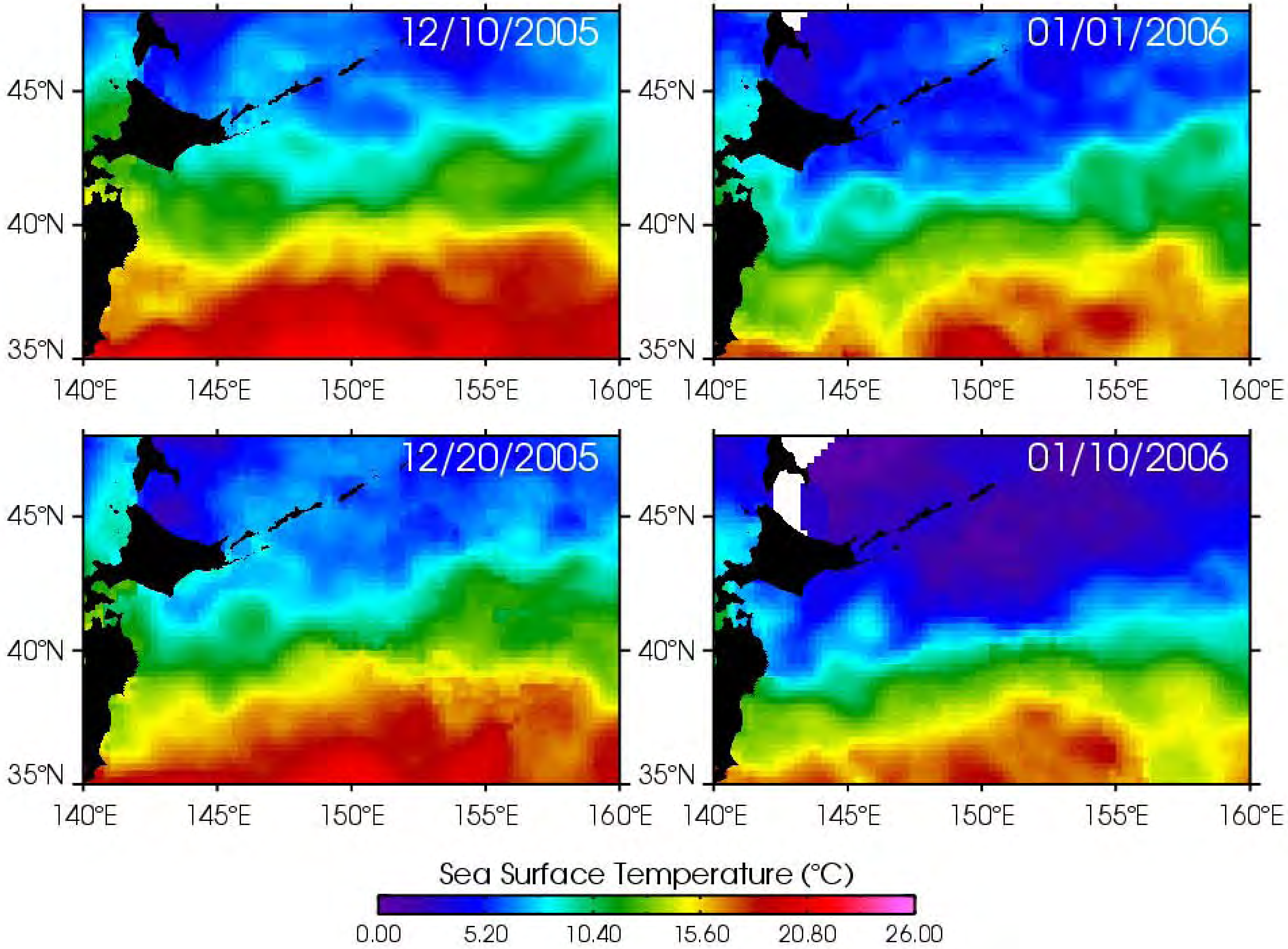
Early onset in December 2005





✓Wintertime abrupt intensification

NGSST 2005/12/10-2006/1/10 10-day interval



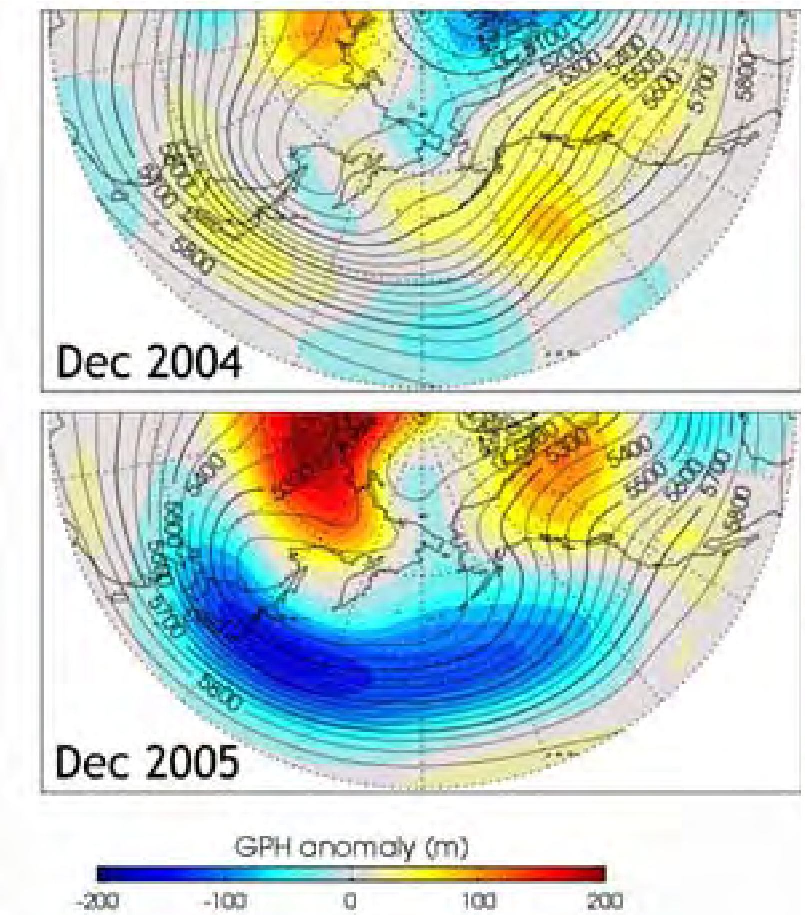
Short-term penetration of cold water due to the intensification of Oyashio

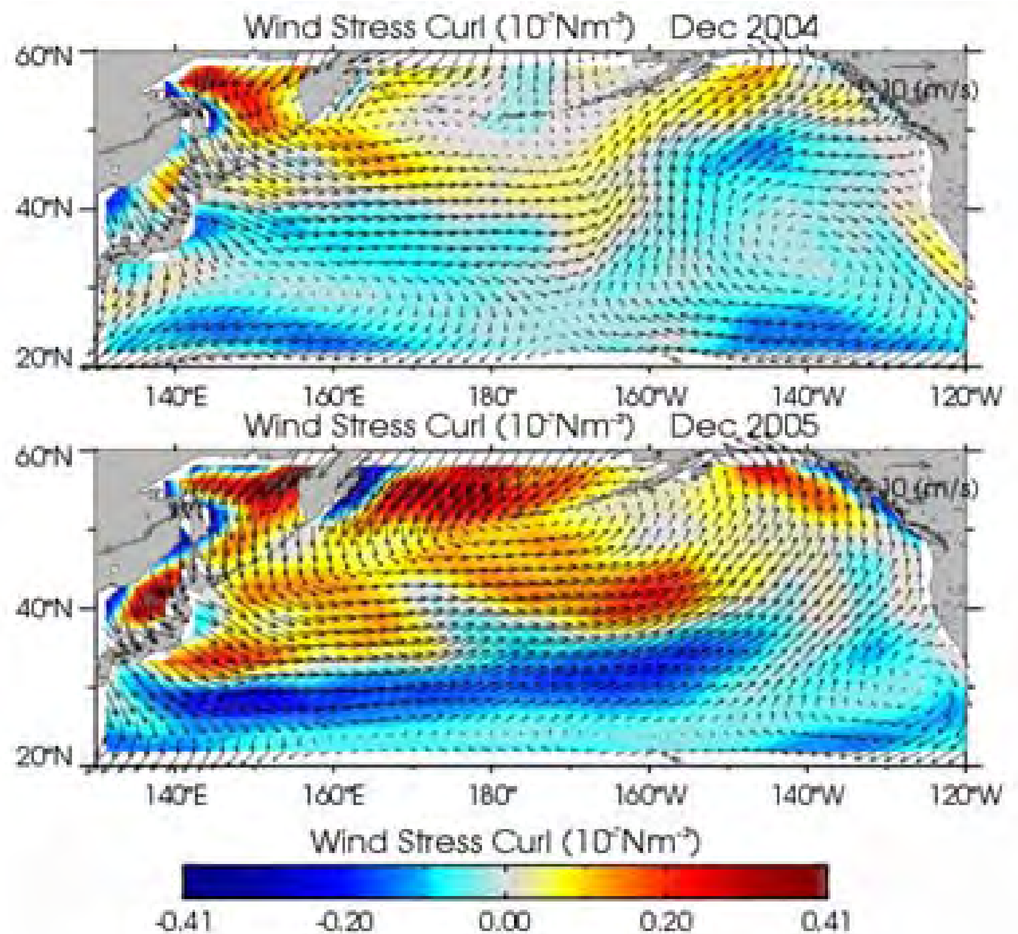
✓Wintertime abrupt intensification

Early onset in December 2005

Geopotential height at 500hPa (contour) and its anomaly from climatology (color)

10m winds (arrows) and wind stress curl (color)



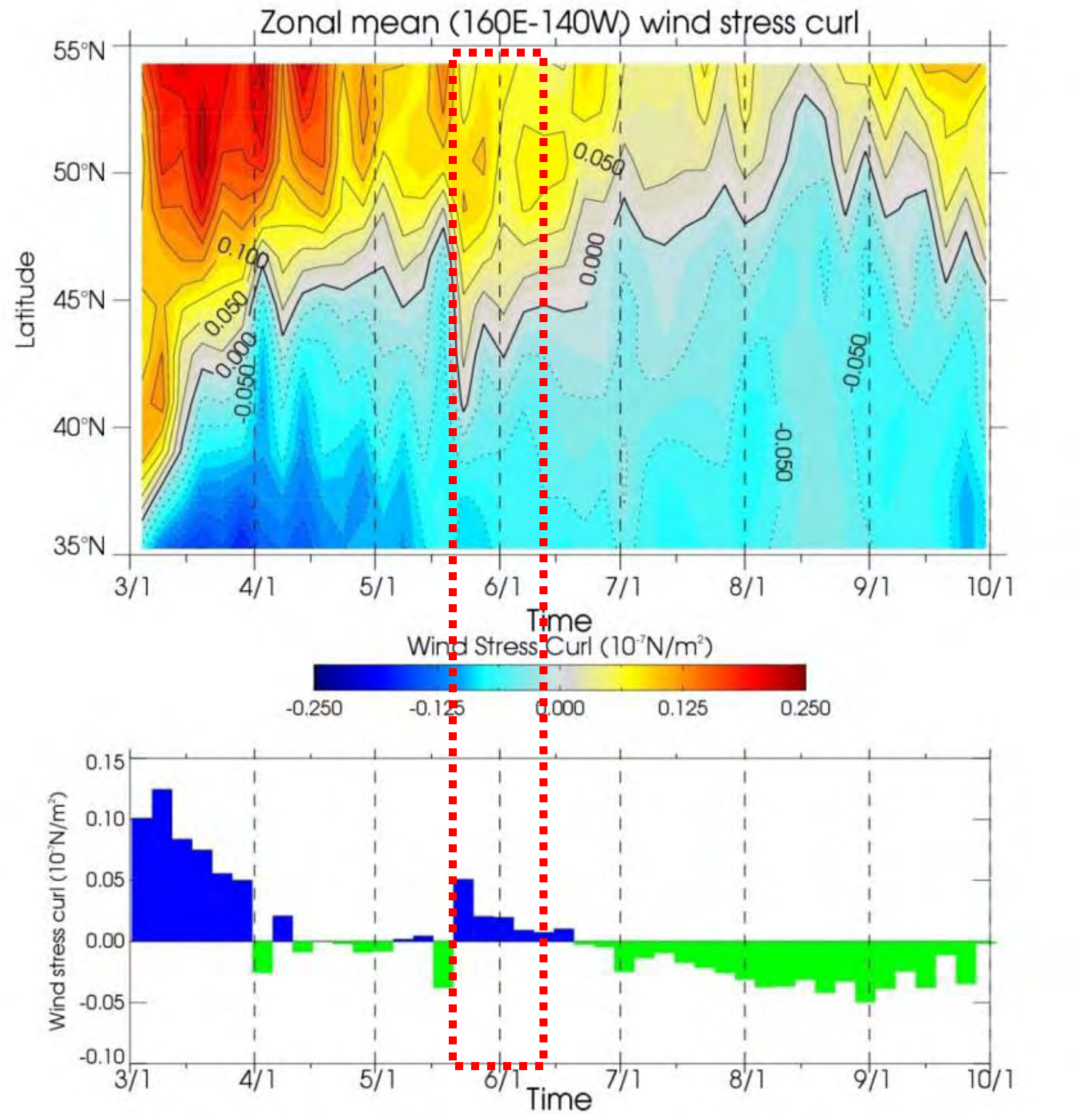


Anomalous southward shift of wetelies produced strong positive wind stress curl .

✓**Secondary peak in early summer (June)**

Climatology of zonal mean wind stress curl in summer

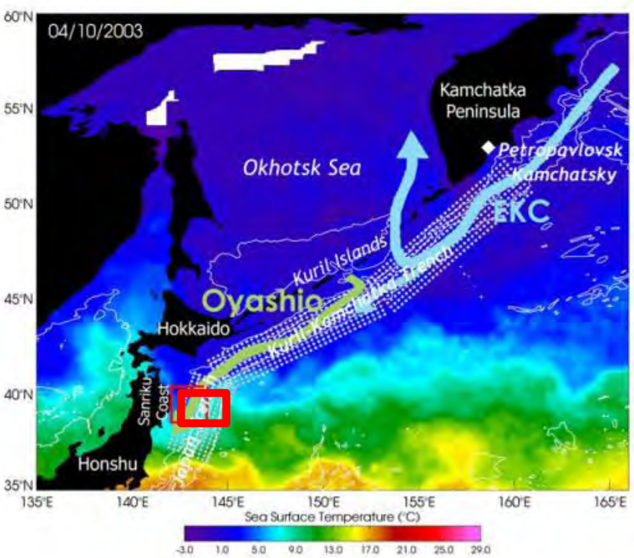
Area-averaged (160E-140W, 40-50N) curl



✓**North Pacific Index**(based on SLP: Trenberth and Hurrell, 1994) shows small peak in June.

✓Barotropic response to **intraseasonal atmospheric variation** seems to induce Oyashio variation.

✓Effect on subsurface temperature off the Sanriku coast (red square)



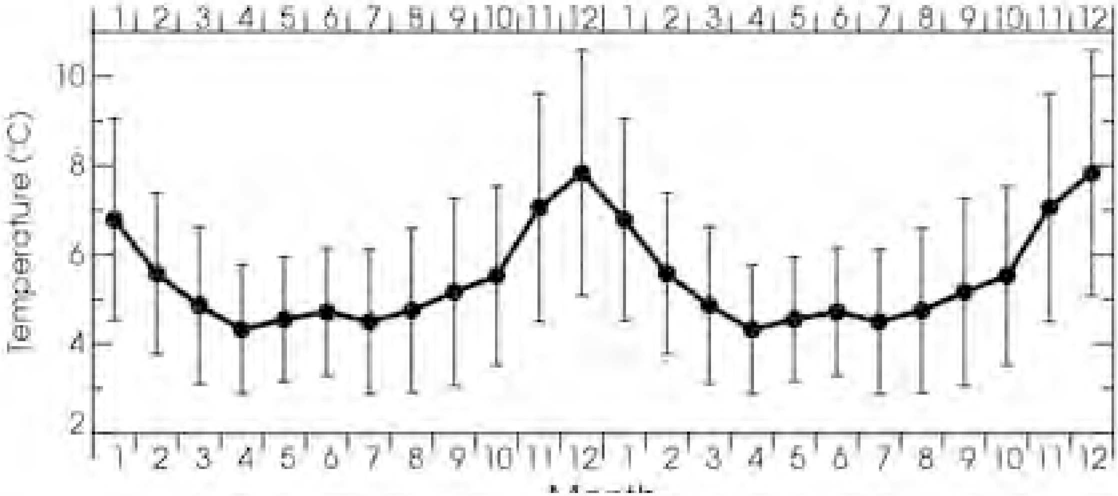
Estimation of **meridional velocity (v)** based on an assumption that temperature (*T*) variation is induced by **meridional heat advection;**

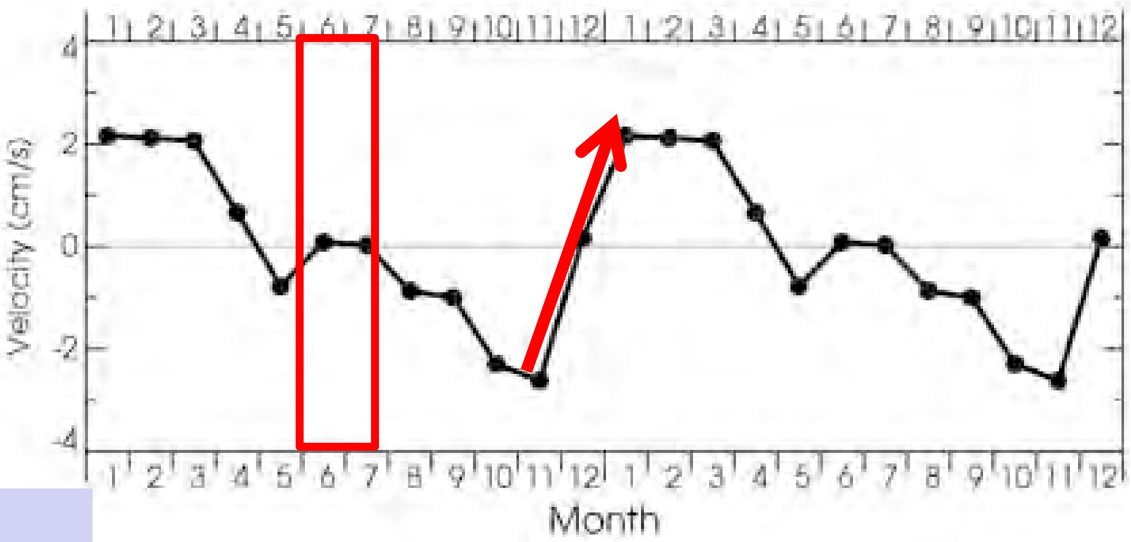
$$\frac{\partial T}{\partial t} = -v\frac{\partial T}{\partial y}$$

✓Wintertime abrupt intensification
✓Secondary peak in early summer

✓Seasonal variation

Annual cycle of subsurface (200m) temperature
- from SAGE (JMA,2001) from 1990 to 2000

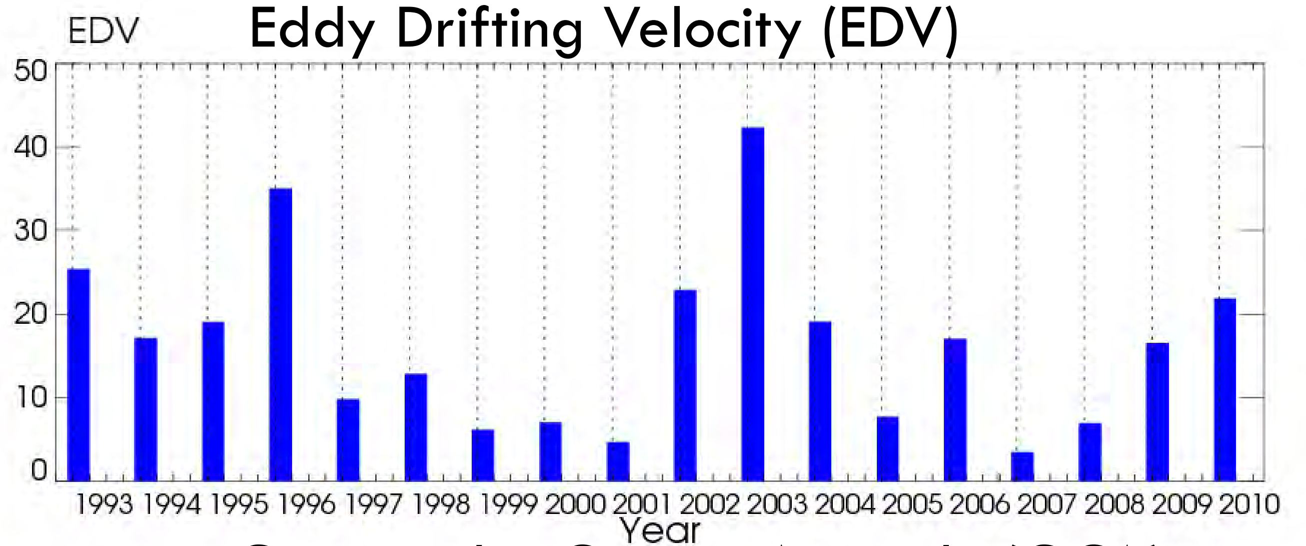


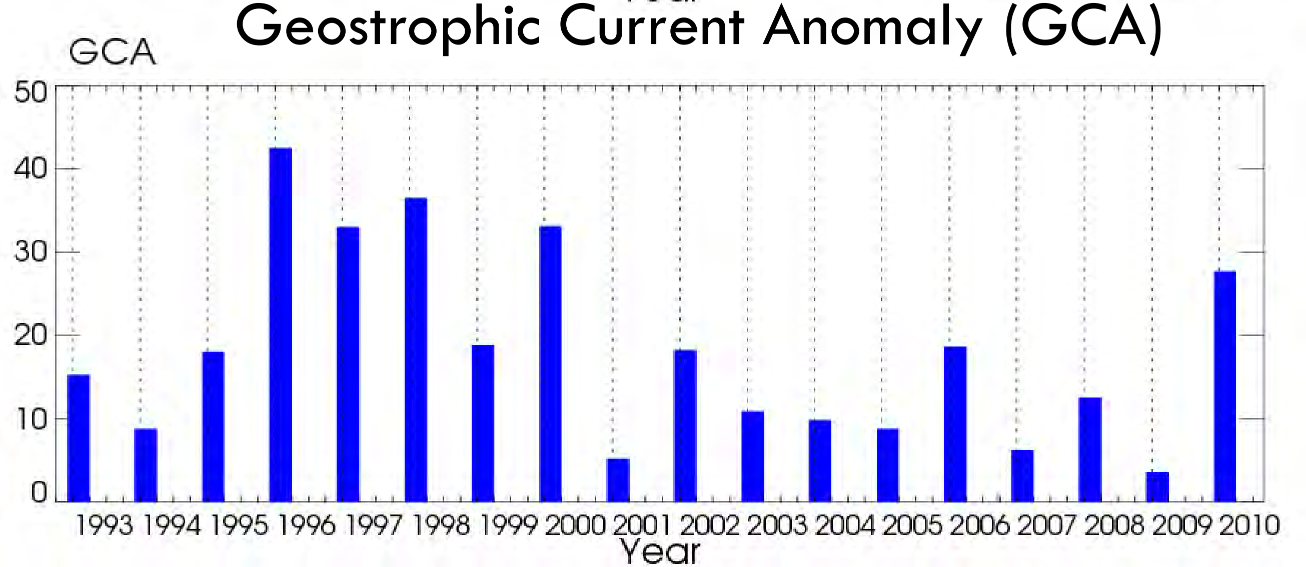


- ✓ **Indices of Oyashio/EKC variations**
  - ✓Altimeter-derived Eddy Drifting Velocity (EDV) and Geostrophic Current Anomaly (GCA)
  - ✓Tide gauge sea levels
- ✓ **Seasonal/intraseasonal variation**
- ✓ **Interannual variation**

✓Interannual variation

Integration of positive values

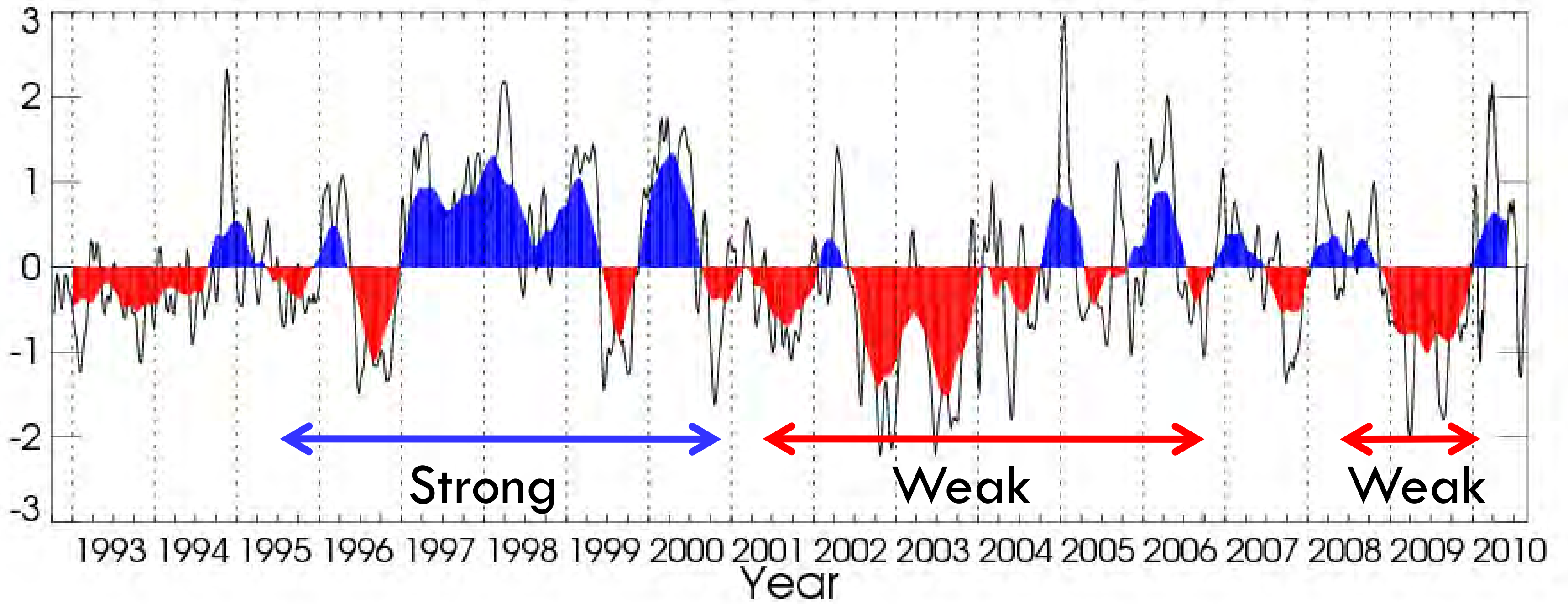




- ✓**Whereas integrated GCA is strong in the late 1990s, it is relatively weak in the 2000s.**
- ✓Though there are some strong winter peaks in the 2000s (2005/06 and 2009/10), they decayed rapidly (didn’t keep up by spring).
- ✓Hypothesis: minor effects on springtime temperature fields off the Sanriku Coast

✓Interannual variation

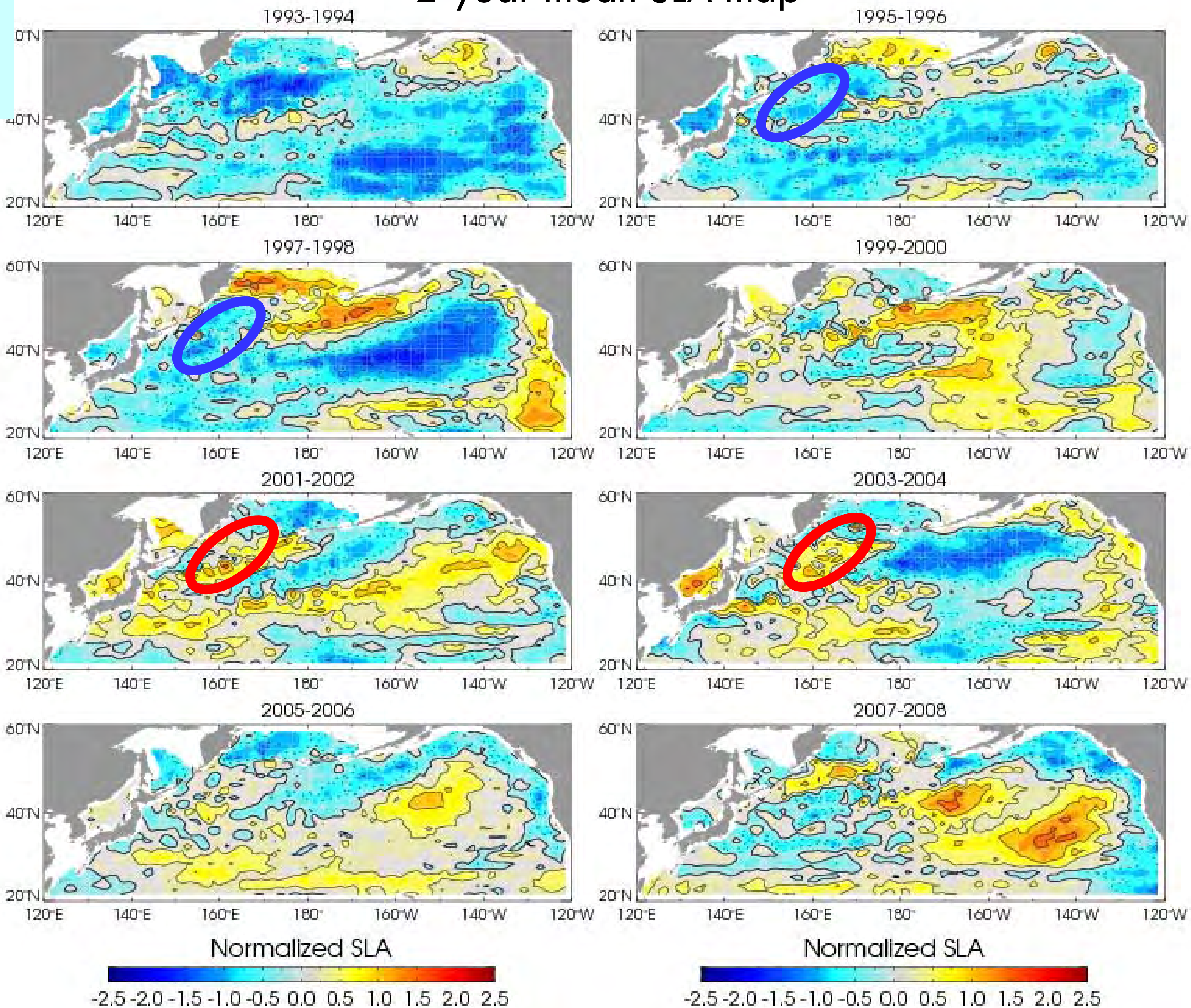
Time series of normalized GCA-EDV (6-month running mean)



- ✓GCA (Geostrophic current anomaly): barotropic + baroclinic components
- ✓EDV (Eddy Drifting Velocity) : mainly barotropic component
- ✓**GCA-EDV: baroclinic component ?**

✓Interannual variation

2-year mean SLA map

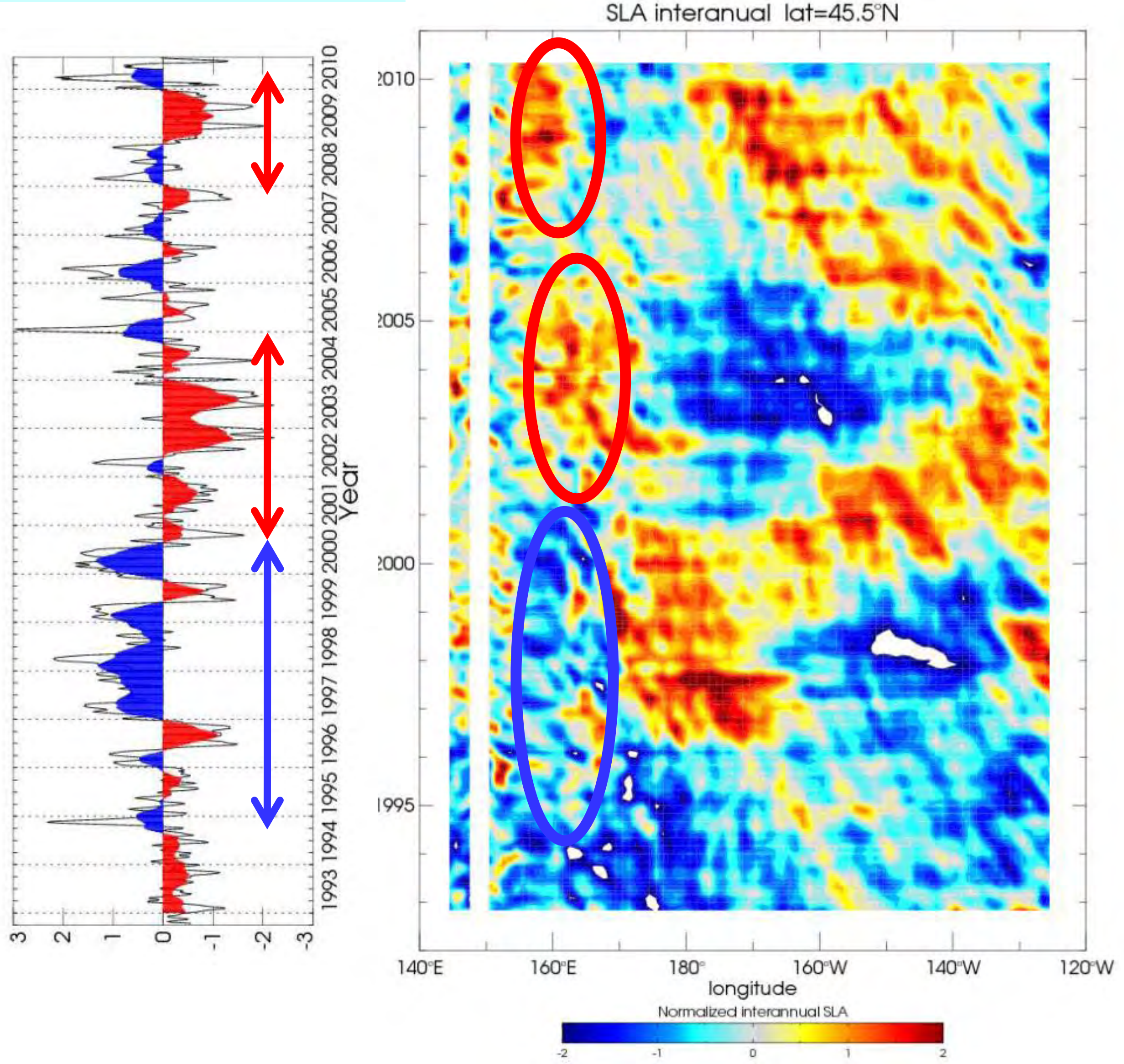


✓Strong phase (**95-00**): negative SLA over the western subarctic gyre in the North Pacific

✓Negative phase (**01-04**) : positive SLA

✓Interannual variation

SLA time-longitude plots at 45.5N

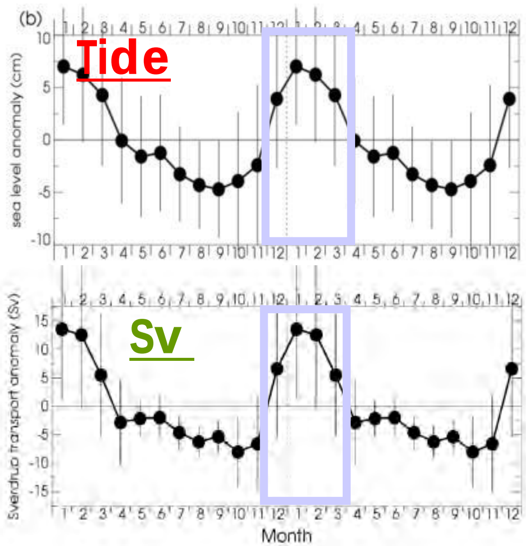


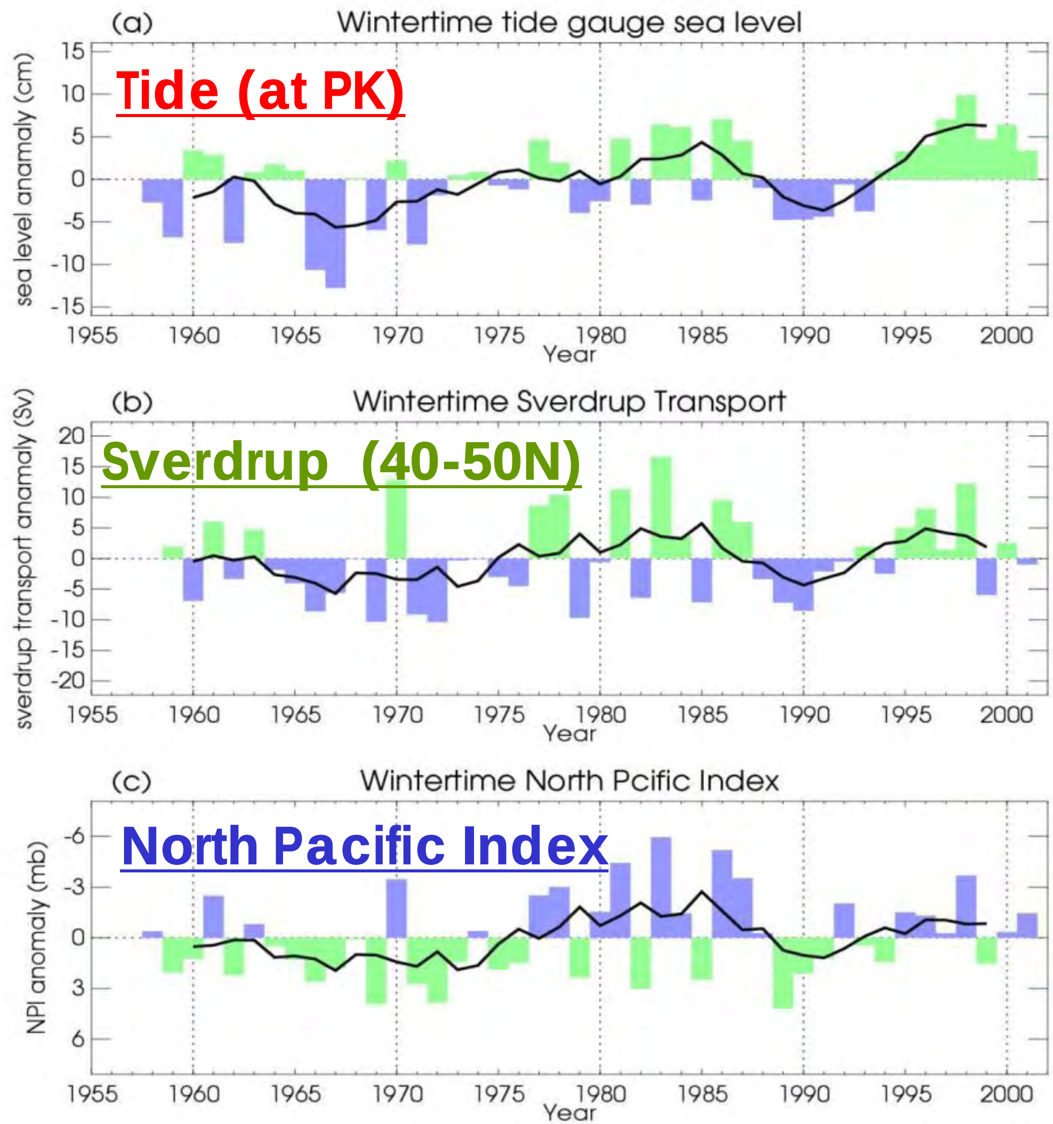
✓Westward propagation of Rossby waves induce Interannaul variation (except year-to-year variability of barotoropic response) ?

✓Interannual variation

✓Decadal variation using **PK tide gauge records**

Time series of Wintertime (Dec-Mar) Tide-PK, Sv40, NPI

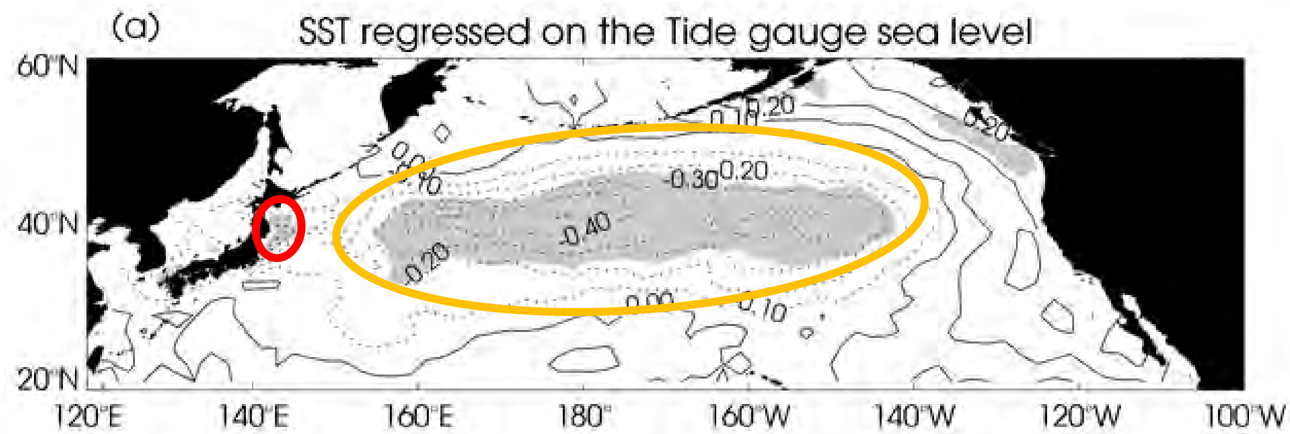




- ✓**Correspondence on**
  - ✓**2-3 year cycle**
  - ✓**Decadal scale**

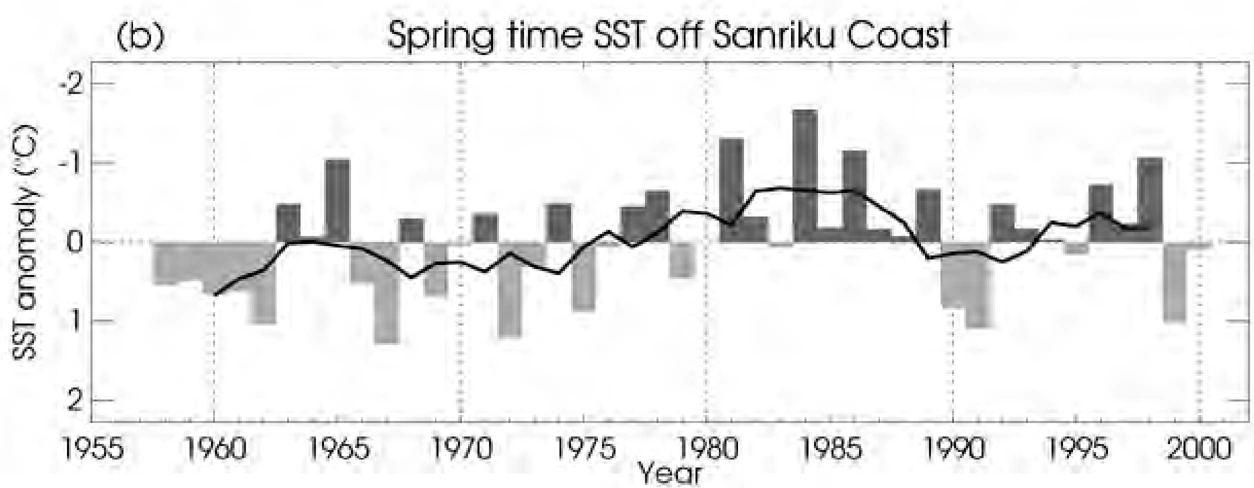
✓Interannual variation

✓Effect of decadal variation on SST off the Sanriku coast



by advection (Oyashio)

Remnant of atmospheric forcing



Summary (1)

✓ **Sea-level related Indices** about variations of western boundary currents (Oyashio/EKC) in the subarctic North Pacific and related large-scale sea level variation

- ✓_Eddy Drifting Velocity (EDV) (barotropic component)
- ✓Geostrophic Current Anoamly (GCA)
- ✓Tide gauge sea level at PK (thermal steric removed)
- ✓They correlate well each other and with Sverdrup transport at 40-50N

✓**<u>Seasonal variation</u>**

- ✓1) **Rapid wintertime intensification** (minimum in late fall to maximum in early winter) and 2) **Secondary peak in early summer** (in June) are:
- ✓explained by **barotropic response** to seasonal and intraseasonal atmospheric forcing (latitudinal migration of westerly)
- ✓Their thermal advection induces subsurface temperature variations off the Sanriku coast
- ✓ Early onset of wintertime intensification (in Dec 2005)
  - ✓due to anomalous southward shift of westeries
  - ✓causes rapid cold water (low SST) penetration
  - ✓being associated with cold weather in Japan

Summary (2)

✓<u>Interannual variation</u>

- ✓Low frequency variation (except year-to-year barotropic variability) seem to be attributed to westward propagation of Rossby waves
- ✓ Long-term PK tide gauge record shows decadal scale wintertime intensification responding to atmospheric forcing on decadal scales.
- ✓Wintertime current intensification induces springtime cold SST condition off the Sanriku coast on decadal scales.