Decadal variability in the Kuroshio and Oyashio Extension frontal regions in an eddy-resolving OGCM

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Then, in this study, we examine oceanic variations in the KOE region to see the ocean's roles in the midlatitude air-sea interaction. If oceanic dynamics induce SSTAs as in the eastern equatorial Pacific, the ocean-to-atmosphere feedback, may be possible. While SSTAs are forced by atmospheric variability in the large parts of the North Pacific, in the KOE region, it has been suggested that SSTAs can be induced by ocean dynamics:

2. Vertical movement of thermocline (Schneider & Miller 2001)
3. Meridional migration of the KOE fronts (Seager et al. 2001)
4. Enhanced Oyashio current (Sekine 1989)

Possible importance of ocean-to-atmosphere feedback in the KOE region for the Pacific Decadal Variability has been debated. How are the SSTAs in the KOE region caused?

How do these oceanic frontal regions vary in association with the decadal SSTAs? Can we consider them as one unified front?

In these previous studies, the KOE region is considered as one unified frontal region. But, there are at least two distinct frontal regions.

Monthly mean SST in January 2003
Questions:

In the KOE region, there are at least two prominent fronts, the Kuroshio Extension front and the subarctic (Oyashio Extension) front.

- How each of these fronts changes in association with the large scale decadal SSTAs in the North Pacific?
- Are variations of these frontal regions coherent? Can we consider these fronts as an unified oceanic front as in the previous studies?

Analyse output of an eddy-resolving OGCM that can represent the two fronts separately.
Model: OFES (The Ocean model For the Earth Simulator)

Based on MOM3 (GFDL/NOAA), significantly modified on the parallelization procedures.

- Solve primitive equations in spherical coordinate.
- Boussinesq and hydrostatic approximations are adopted.
- Bi-harmonic horizontal mixing & the KPP vertical mixing scheme

Near-global model basin: 75S-75N, 0-360E.
0.1 degree horizontal resolution, 54 vertical levels (max 6065m)

Surface heat fluxes are given by the bulk formula.
Fresh water flux & SSS restoring to monthly climatology.
NCEP reanalysis fields are used for wind stress and all atmospheric fields for the fluxes.

After 50-year spin-up integration by monthly climatology fields, a hindcast integration for 1950-2005 with daily mean fields.
The two fronts in the KOE region

Two strong SST fronts, the Kuroshio Extension (KE) front and the subarctic (Oyashio Extension) front, are represented separately in the OFES simulation as in the satellite observation.

we can see an individual variability of the each front in the KOE region.
Meridional temperature gradients in climatology

JFM 145-160E mean latitude-depth sections of T climatology


Stronger meridional temperature gradient is found in the surface (subsurface) layer in the subarctic (KE) front. This structure is also found in the observed field.
Decadal variability in the KOE region

5-year running mean temperature in the KOE region (140-170E, 35-40N mean).

Surface and subsurface decadal temperature variabilities in the KOE region are represented well.

There is some negative trend in the OFES.

Examine decadal variability as [1984-88]-[1968-72].
Decadal SSTAs

Large scale distributions are well represented.

SSTAs in the OFES are most prominent along the SST fronts, especially along the subarctic front, suggesting importance of meridional migration of the fronts.
Changes in SST gradient

Much stronger SST gradient in the subarctic front than the KE front.

Both of the two fronts migrate southward in the cool period.

Larger SSTAs along the subarctic front.

How are subsurface changes?

JFM mean SST gradient in 1984-88 (top, shades in bottom) and 1968-72 (bottom).
T, S anomalies on meridional sections

T, S anomalies extend vertically associated with *meridional migration* of the fronts.

Max. of anomaly is found in the surface (subsurf.) layer in the subarctic (KE) frontal region.

JFM 145-160E mean latitude-depth sections of T, and S in 1968-72 (top), 1976-80 (middle), and 1984-88 (bottom).

Nonaka et al. (2006)
Surface heat flux anomalies


In the KOE region, cool SSTAs are associated with downward sea surface heat flux anomalies.

Atmospheric thermal forcing does NOT cause the SSTAs.

Cool SSTAs induce downward surface heat flux anomalies.
Temporal developments

At the KE front, westward propagating Rossby waves forced by Ekman pumping anomalies induce the changes.

Taguchi et al. (2007) further show that frontal scale changes are associated with large scale changes that induced by propagation of wind-induced Rossby waves.

Nonaka et al. (2006) propagating signals, and meet those from the eastern basin around 170E.

Longitude-time sections of JFM SSH (color) and Ekman pumping (contour). 5-year running-mean is applied and trends are removed. Nonaka et al. (2006)
Lagged correlation between Oyashio and SST

Lagged correlation (green contours) and regression (shades) of SST and 100-m depth area-mean Oyashio velocity based on Jan.-Mar (black curve of left-top panel). OFES hindcast fields. Solid contours show long-year mean fields.

Oyashio enhancement

Cooling off northern Japan

Cooling propagates/extends eastward along the subarctic front
Temporal developments

At the KE front, westward propagating Rossby waves forced by Ekman pumping anomalies induce the changes.

At the subarctic front, there seem to be also eastward propagating signals, and meet those from the eastern basin around 170E.

Signals appear earlier at the subarctic front.

Are the variations coherent in these two frontal regions?
Are changes in the two frontal regions synchronizing?

Simultaneous correlation of decadal JFM-mean SSTA with area-mean SSTA in the subarctic frontal region based on an observational data, JMA-SST.

The SST variations in the SAF region do not highly correlate with those in the KE frontal region.

Their variations need to be considered separately.
Summary

Decadal SSTAs are well represented in the OFES, and they have cores along the SST fronts, especially along the subarctic front.

Decadal SSTAs in the KOE region are mainly induced by *meridional migration* of the fronts. T/S anomalies extend vertically and vertical maximum is found in the surface (subsurface) layer in the subarctic (KE) frontal region.

Cool SSTAs are associated with downward SHF anomalies, suggesting ocean-to-atmosphere feedback.

Westward propagating Rossby waves are found at the fronts. KE frontal region: Rossby wave propagation and associated frontal scale variations induce the decadal variations (c.f. Taguchi et al. 2007, JC).

At the subarctic front, eastward propagations are also found. Advection of the signals by eastward current may be important. *Variability in the two fronts are not highly correlate.*

Higher resolution GCMs are necessary to represent them separately.
Much stronger SST gradient in the KE front than the subarctic front.

Both of the two fronts migrate southward in the cool period.

The KE front is intensified in the cold period.

How the subsurface fields change?
Impacts of changes in the Ekman advection induced by wind anomalies on the SSTAs are less than 1.5°C, inducing only a part of the SSTAs.
In both the OFES and observations, the KE front is intensified in the cool period (top). Upward displacement of the thermocline to the north of the KE front, and cool anomalies there.

While the KE current is also intensified, cool anomalies are found.
Interannual variability in the area-mean Oyashio

JFM area mean northward velocity in [40-45N, 143-151E]

Vertical mean velocity (STD=0.43 cm/s)
100m depth velocity (STD=1.12 cm/s)
[100m]-[vertical_mean]

Examine lagged correlations between the 100-m depth Oyashio index and SST field and so on to see influences of the Oyashio variations on the SAF region.

Oyashio is enhanced in winter, consistent with observations

Use mean velocity in the large area as an index to exclude influence of eddies.
Lagged correlation between isopycnal PV and Oyashio variations

Low PV waters extend eastward along the subarctic front after Oyashio enhancement.

Advection may induce changes in the frontal region.

\[ PV = \frac{1}{\rho_0} \frac{\partial \rho}{\partial z} \left( \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right) \]
Lagged correlation between Oyashio and SSH

Oyashio enhancement

Negative anomalies near northern Japan

Negative anomalies propagate/extend eastward along the subarctic front

SSTAs can be associated with changes in the subsurface ocean.

Lagged correlation (dashed contours) and regression (shades) of SST and 100-m depth area-mean Oyashio velocity based on Jan.-Mar. OFES hindcast fields. Solid contours show long-year mean fields.
Oyashio, Oyashio Extension, Kuroshio Extension currents are enhanced in 1984-88, cool period

Enhanced southward cool water transport may induce cool SSTAs.

JFM mean sea surface currents for 1984–88 (top) and for 1968–72 (bottom). Shadings show speeds.
Decadal variability is represented well in the OFES hindcast run, at least at the sea surface.
PADO in OFES and observations