OS46Q-01 Variabilities of Upper-Ocean Heat Content in the North Pacific Subtropical Region

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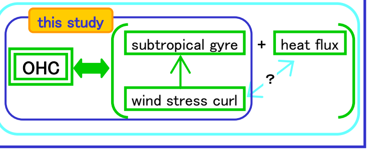
1. Introduction

Background

- Variability of subsurface temperature field in the North Pacific subtropical region has decadal time scale (Pacific Decadal Oscillation; PDO), associated with intensification of the Aleutian low (Nitta and Yamada, 1989; Deser et al., 1996; Yasuda and Hanawa, 1997; Yasunaka and Hanawa, 2002).
- Mechanisms of the decadal variations of subsurface temperature have also been proposed in several studies (e.g., Latif and Barnett, 1994, 1996; Gu and Philander, 1997; Schneider et al., 1999 etc.). However we have not reached the conclusion .
- In order to understand the mechanisms of these variations, it is necessary to consider the air-sea interaction in the North Pacific subtropical region.
- Thus, a study of the variability of the upper-ocean heat content (OHC) leads to an important step to understand the mechanisms of climate change.
- Recently, since subsurface temperature datasets for long-term period have been produced, it is possible to analyze the OHC field (eg., Zhang and Liu, 1999; Sugimoto et al., 2003; Hasegawa and Hanawa, 2003 etc.).
- On the other hand, properties of water masses in the North Pacific subtropical region (e.g., NPSTMW, NPTW and NPIW) have interannual and decadal time scales, associated with variabilities of the atmosphere and the subtropical gyre circulation (Yasuda and Hanawa, 1997; Suga et al., 2000; Nakano et al., 2005).
- It is important to reveal that a relationship among variabilities of OHC, subtropical gyre circulation, and atmospheric forcing.



Objectives

- Upper-ocean heat content (OHC) in the North Pacific subtropical region is investigated to reveal spatio-temporal variabilities.
- Possible causes of their variations are suggested by relationship with the variation of subtropical gyre and atmospheric field.
- To examine the mechanism of the variabilities of subsurface temperature field in the North Pacific subtropical region.

3. Spatio-temporal variation of OHC

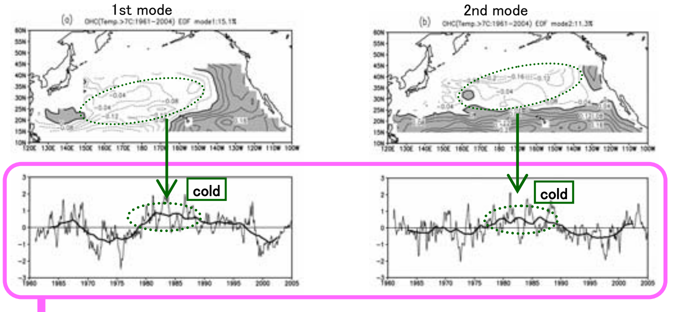


Fig. 1 (Top) spatial pattern and (bottom) time coefficients of (left) the first and (right) second EOF modes of monthly OHC anomaly. Thick line indicates 5-year running mean.

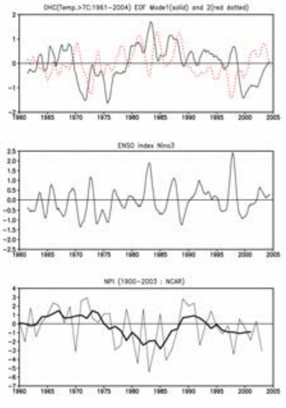


Fig. 2 Time coefficients of (top) the first (solid) and second (red dotted) EOF modes of OHC, (middle) time-series of Nino3 anomaly, and (bottom) time-series of the North Pacific Index. The line of top and middle figure shows 13-month running mean, the line of bottom figure shows the wintertime mean and thick line 5-year running mean.

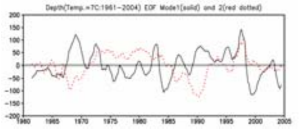


Fig. 3 Time coefficients of the first (solid) and second (red dotted) EOF modes of the depth of 7℃. The lines show 13-month running mean.

- The spatial patterns of the first (second) EOF mode indicate the subtropical gyre circulation structure (the north-south seesaw pattern).
- Two predominant periods at about 4 years associated with El Nino Southern Oscillation events, and about 20 years associated with the PDO.
- The phase difference has about 1 year between the first and second EOF modes.

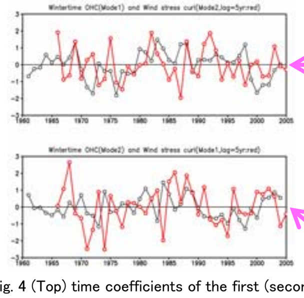


Fig. 4 (Top) time coefficients of the first (second) EOF mode for OHC and (bottom) the second (first) EOF mode for wintertime wind stress curl with time lead of 5 years.

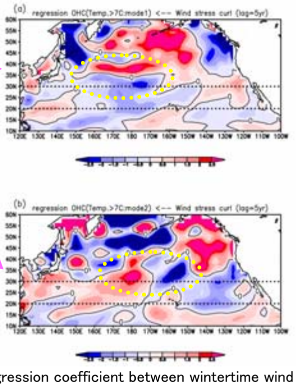


Fig. 5 Regression coefficient between wintertime wind stress curl and time coefficient of the (top) first (bottom ; second) EOF mode with time lead of 5 years.

4. Spatio-temporal variation of the depth at 7℃

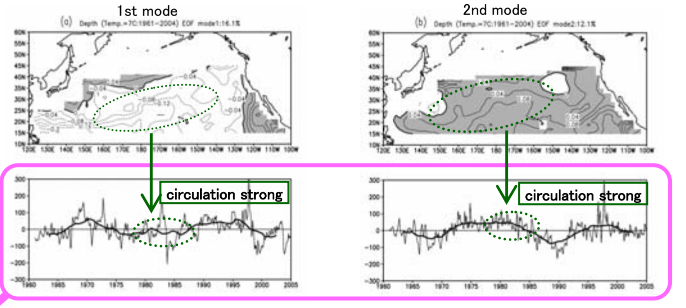


Fig. 6 (Top) spatial pattern and (bottom) time coefficients of (left) the first and (right) second EOF modes of monthly the depth of 7℃ anomaly. Thick line indicates 5-year running mean.

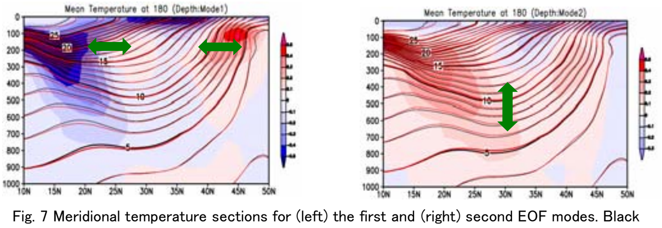


Fig. 7 Meridional temperature sections for (left) the first and (right) second EOF modes. Black (red) contours show time coefficients of positive (negative) period.

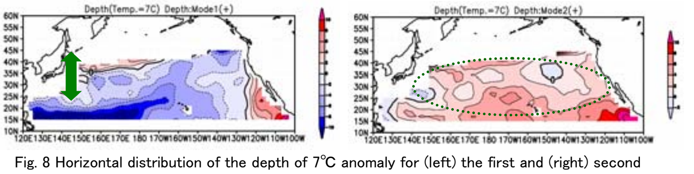


Fig. 8 Horizontal distribution of the depth of 7℃ anomaly for (left) the first and (right) second EOF modes at the time coefficients of positive period.

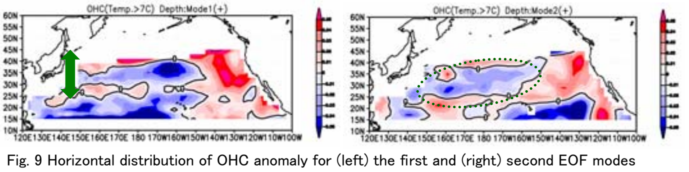


Fig. 9 Horizontal distribution of OHC anomaly for (left) the first and (right) second EOF modes at the time coefficients of positive period.

- The first EOF mode indicates north-south shift of the subtropical gyre that corresponds to the north-south shift of the westeries.
- The second EOF mode indicates vertical movement of the subtropical gyre that corresponds to the intensity of the westeries.

2. Data and Method of Analysis

Subsurface temperature dataset (Sugimoto et al., 2003)

- area : 29°S – 59°N, 111°E – 91°W
- resolution : 2° × 2° (lat.×long.), 26 standard levels (sea surface to 2000m depth)
- period : January 1961 – December 2004 (44years, 528months)

Objective Interpolated Method

- First guess : World Ocean Atlas 1994 (Levitus and Boyer, 1994)
- Spatio-temporal decorrelation scales : TOPEX/Poseidon altimeter data and the historical *in situ* data (Kuragano and Kamachi, 2000)
- Historical temperature profiles data : World Ocean Database 1998 (Levitus et al., 1998)
  Data set of Japan National Research Institute of Far Seas Fisheries (1966-1992)
  TRANSPAC XBT data co-operated on by JMA and NOAA (1997-)
  Ship/buoy data collected operationally by JMA (1986-)
  COADS data set (Woodruff et al., 1987)

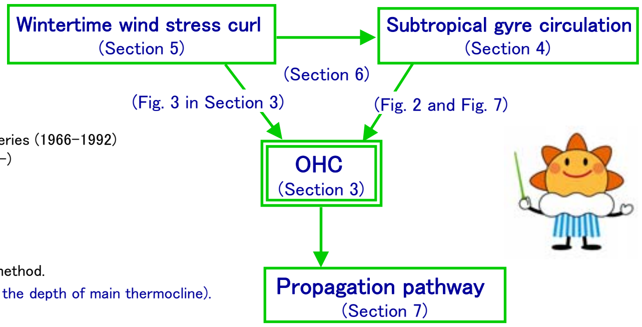
Definition of upper-ocean heat content (OHC)

- Temperature profile of the standard levels data interpolated into every 1m interval with the cubic spline method.
- OHC as vertically averaged temperature from the sea surface to the depth of 7℃ (equal to the depth of main thermocline).

Atmospheric dataset

- NCEP/NCAR reanalysis data : January 1949 – December 2004 (56years, 672months)

In order to examine spatio-temporal variabilities of OHC, the depth of 7℃ and wintertime wind stress curl, we used to the EOF analysis.



5. Spatio-temporal variation of wintertime wind stress curl

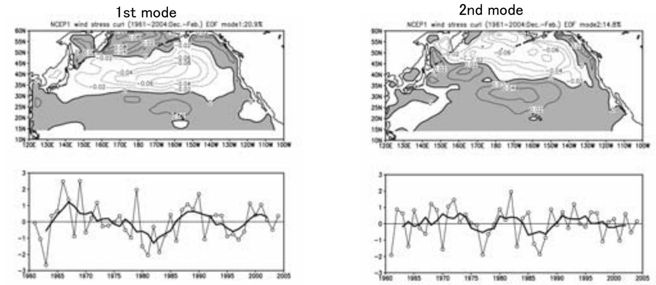


Fig. 10 (Top) spatial pattern and (bottom) time coefficients of (left) the first and (right) second EOF modes of wintertime (averaged from December to February) wind stress curl. Thick line indicates 5-year running mean.

- The first (second) EOF modes associated with north-south shift (intensity) of the westeries.

6. Relation between the depth of 7℃ and wintertime wind stress curl field

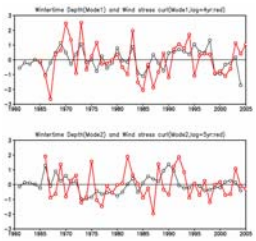


Fig. 11 (Top) time coefficients of the first (second) EOF mode for OHC and (bottom) the second (first) EOF mode for wintertime wind stress curl with time lead of 4 (5) years.

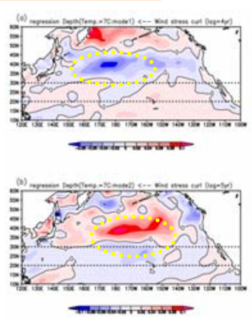


Fig. 12 Regression coefficient between wintertime wind stress curl and time coefficient of the (top) first (bottom; second) EOF mode with time lead of 4 years (5 years).

7. Propagation pathways of the OHC variabilities

Propagation pathways of the OHC variabilities decided time variation of horizontal distribution of OHC anomaly field.

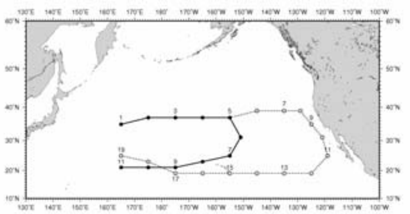


Fig. 13 Estimated propagation pathways of the OHC variabilities anomaly. Thick (dotted) line indicates pathway-1 (-2).

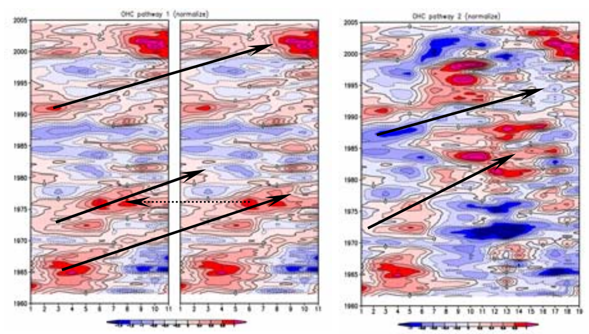


Fig. 14 Normalized OHC anomaly for 3-year running mean belong to (left) pathway-1 and (right) -2. Black arrows indicates propagation of OHC anomaly.

- Propagation pathways in this study are similar to the results of Zhang and Liu (1999) and Yukimoto et al., (2000).
- One pathway appears along the subtropical gyre circulation, and other pathway extends westward along about 20N from the west coast of North America.
- Pathway of along the subtropical gyre has been propagated about 5 years.

8. Summary

	Variabilities of OHC		Variabilities of the depth of 7℃		Variabilities of wintertime wind stress curl
1st EOF mode :	subtropical gyre structure	time lag?	north-south shift of the subtropical gyre	← 4 years time lag	north-south shift of the westeries
	↓ 1year time lag				↕ time lag ? ← difficult to separate both variations
2nd EOF mode :	north-south seesaw pattern		vertical movement of the subtropical gyre	← 5 years time lag	intensification of the westeries

Predominant periods :
4 years associated with ENSO events
20 years associated with PDO

Propagation pathways :
Pathway 1 : along the subtropical gyre circulation (about 5 years period ?).
Pathway 2 : extends westward along about 20N from the west coast of North America.

Future work

- Analysis of variabilities of heat flux in the subtropical region.
- Analysis of reanalysis dataset of the ocean data assimilation system (MOVE/MRI.COM).
- Examination of mechanism of variabilities of subsurface temperature field.
- Examination of relation between variation and propagation of OHC.

Results

- Variabilities of OHC in the North Pacific subtropical region corresponds to the intensity (north-south shift) of the subtropical gyre.
- Its variabilities associated with ENSO events and the PDO, and predominant periods are about 4 years and 20 years, respectively.
- Furthermore, its valiabilities associated with the variation of wind stress curl in the central North Pacific or the Kuroshio extension region with time lead of 4-5 years.
- We estimated the propagation pathways of the OHC variabilities, one pathway appears along the subtropical gyre circulation, and other pathway extends westward along about 20N from the west coast of North America.
- Since variabilities of OHC does not necessarily agree with the variabilities of the subtropical gyre, we should consider the heat flux variation in the subtropical gyre.