Climate Variability of North Pacific Intermediate Water Analyzed with Ocean Reanalysis Data of MOVE/MRI.COM

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S5.17-033
GODAE final, 2008, Nice

1. Introduction

We conducted ocean analysis/reanalysis experiments for global ocean and the North Pacific. The MRI Multivariate Ocean Variational Estimation (MOVE) System was applied for these analyses. Resolutions are 1 degree for the global ocean (0.3 degree for meridional direction in the tropical region) and 0.5 degree for the North Pacific. Sea surface boundary condition for these analyses is an atmospheric reanalysis data, NCEP-R1. Assimilated observation data are *in situ* observations of temperature and salinity profile (World Ocean Database 2001, Global Temperature and Salinity Profile Project) and satellite altimetry sea surface height anomaly data (AVISO). (Please refer Dr. Cumming's presentation in the Session 4, Friday, Dr. Kamachi's poster S3.16-069, Soga's poster S5.27-034 for more information about MOVE system)

Using a global ocean reanalysis data (to which sea surface height anomaly data was not assimilated), the factors of North Pacific Intermediate Water (NPIW) variability are investigated. Figure 1 shows climatological map of salinity on $26.8\sigma_\theta$ surface. Salinity field is reproduced well in the ocean reanalysis.

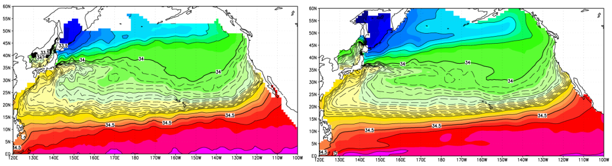


Fig.1 Climatological (1967～2005) maps of salinity on $26.8\sigma_\theta$ surface. Left panel: Hydrobase (Objective analysis of observation data on isopycnal surfaces), right panel: reanalysis.

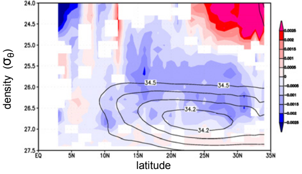
2. Freshening in mid-depth of the Western North Pacific (137° E section)

Freshening trend on isopycnal surfaces at the mid-depth along 137° E section have been shown by observation based analysis (Fig.2a; Nakano et al., 2007, GRL). The freshening rate of upper layer of NPIW core is about -0.0015 pss/year. Ocean reanalysis reproduces well the trend shown by observation (Fig.2b). Not only linear trend but also seasonal to decadal variabilities of salinity are reproduced well on reanalysis (Fig.3).

T-S curve shifts toward not only freshening but also warming direction at 21-25° N along 137° E section (Fig.4a and Fig.4d). Fig.4b and Fig.4e show freshening on isopycnal surfaces. Fig.4c and Fig.4f show deepening of isopycnal surfaces.

On isopycnal surfaces above the salinity minimum layer, the linear trend of freshening is affected by warming through the change (deepening) of isopycnal surface depth (Fig.5). To estimate how much freshening on isopycnal surface is due to warming, we calculated potential density by using temperature field for 2001-2005 and salinity field for 1971- 1975. Cross marks in Fig.4e show the warming effect in the upper layer is larger than lower layer. 59% of freshening is due to warming on $26.2\sigma_\theta$ surface. The effect is 44% for $26.4\sigma_\theta$ surface. This result is comparable to observation (Fig.4b; 70% for $26.2\sigma_\theta$ surface and 50% for $26.4\sigma_\theta$ surface).

(a) observation



(b) ocean reanalysis

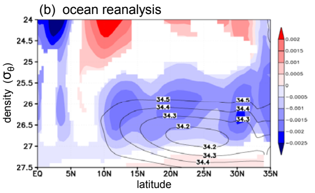


Fig.2 Linear trend of freshening (color; pss/year; over 95% significance level) and climatology of salinity of North Pacific Intermediate Water core (contour; pss) on isopycnal surfaces (σ_θ) for 1967 to 2005 along 137° E section. (a) observation, (b) ocean reanalysis

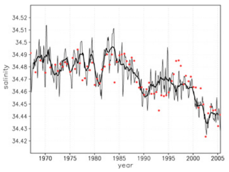


Fig.3 Time series of salinity on $25.2～27.0\sigma_\theta$ at 137° E 10～32° N. Line shows reanalysis. Thick line shows 13 month running mean data of reanalysis. Red dots show observation.

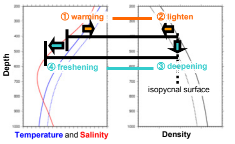
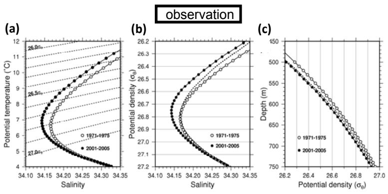


Fig.5 Schematic diagram of salinity change with warming (Nakano, 2008). Vertical profile of temperature and salinity (left) and density (right).

observation



ocean reanalysis

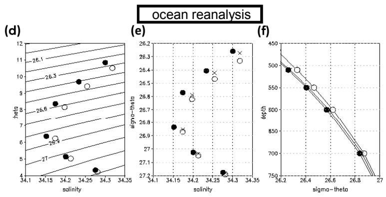


Fig.4 T-S property (left), salinity-density relation (center) and density-depth relation (right) for 1971-1975 (open circle) and for 2001-2005 (closed circle) at 137° E, 21-25° N. Cross mark on the center and right panel indicate density calculated from temperature field for 2001-2005 and salinity field for 1971-1975. It means the effect of warming.

3. A factor of NPIW freshening

Hereafter we mainly discuss about variabilities on $26.8\sigma_\theta$ isopycnal surface which is included in NPIW (e.g. Talley, 1993, JPO; $26.6～27.0\sigma_\theta$). Salinity minimum of NPIW itself freshens almost 0.02 pss for 35 years (Fig.4a,d). This freshening of salinity minimum is not able to explain by local warming. Therefore, this freshening is seems to be caused by variation of formation of salinity minimum. The origin area of salinity minimum is considered mixed water region (Yasuda, 1997, JGR) which is confluence zone of Oyashio (western boundary current of sub-polar gyre) and Kuroshio (western boundary current of sub-tropical gyre). There is a large freshening trend in the mixed water region (hereafter MWR) on $26.8\sigma_\theta$ surface (Fig.6).

Figure 7 shows variation of representative Oyashio water (151-152° E, 45-46° N) , Kuroshio water(34-35° N, 140-141° E) and MWR water (142-150° E, 4° width area north of Kuroshio extension current axis). Kuroshio water is freshening and cooling on $26.8\sigma_\theta$, but the trend is smaller than the trend of MWR water. Contrarily, Oyashio water is becoming saline and warming. Therefore, freshening of MWR water is not able to be explained by variations of Oyashio water and Kuroshio water. Oyashio-Kuroshio mixing ratio (e.g. Shimizu et al., 2001, JPO) of MWR water shows increasing proportion of Oyashio water on MWR water for 1967-2005 (Fig.8). Transport of Oyashio water into MWR is increasing for the same period (Fig.9). Sub-polar and sub-tropical circulation on $26.8\sigma_\theta$ are both intensified for the same period (Fig.10). Anti-clockwise circulation at MWR is also intensified (Fig.10). .Kuroshio extension is moving toward south (Fig.10). All of these changes of the circulations are consistent with increasing of Oyashio water transport into MWR.

From the above results, a factor of NPIW freshening is increasing of Oyashio water transport into MWR caused by variations of the circulations in the North Pacific.

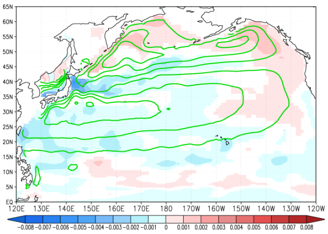


Fig.6 Freshening trend (pss/year) of reanalysis data on $26.8\sigma_\theta$ surface for 1967～2005 (over 95% significant level). Green lines show climatology of acceleration potential.

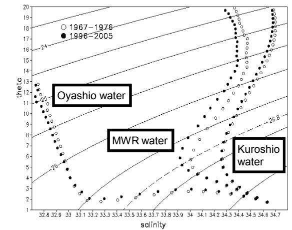


Fig.7 Variations of representative Oyashio water (151-152° E, 45-46° N) , Kuroshio water(34-35° N, 140-141° E) and MWR water (142-150° E, 4° width area northern Kuroshio extension current) of reanalysis data. ○ marks indicate mean value for 1967-1976, ● marks indicate mean value for 1996-2005.

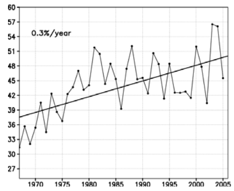


Fig.8 Yearly mean time series of Oyashio-Kuroshio mixing ratio (proportion of Oyashio water on MWR water) of reanalysis data. Strait line shows linear trend (0.3%/year, intercept is 37.5%).

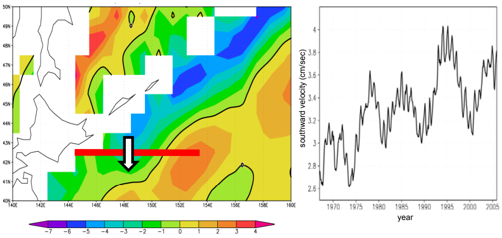


Fig.9 Southward transport of Oyashio water of reanalysis data. Left panel shows climatological (1967-2007) map of meridional velocity field at mid-depth (250m). Right panel shows time series of southward velocity (cm/sec) of Oyashio, 25 months running mean of zonal and vertical mean (144.5-153.5° E,150-400m) along 42.5° N.

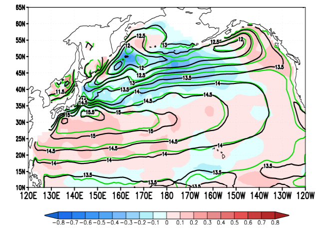
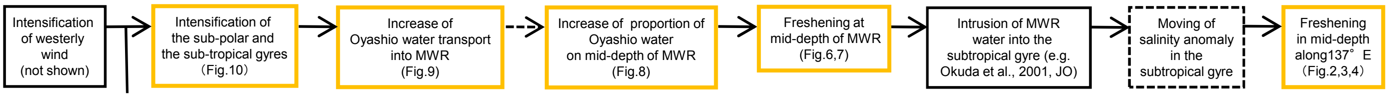


Fig.10 Acceleration potential (m^2/sec^2) on $26.8\sigma_\theta$ surface of reanalysis data. Green lines show temporal mean value for 1967～1976, black lines for 1996～2005. Colors of the background indicate difference between 1996～2005 and 1967～1976.

4. Summary

A scenario for freshening in mid-depth of the Western North Pacific



Intensification of westerly wind (not shown) → Intensification of the sub-polar and the sub-tropical gyres (Fig.10) → Increase of Oyashio water transport into MWR (Fig.9) --> Increase of proportion of Oyashio water on mid-depth of MWR (Fig.8) → Freshening at mid-depth of MWR (Fig.6,7) → Intrusion of MWR water into the subtropical gyre (e.g. Okuda et al., 2001, JO) → Moving of salinity anomaly in the subtropical gyre → Freshening in mid-depth along137° E (Fig.2,3,4)

Yasuda and Sakurai, 2006, GRL

Subjects

- Heat and salinity budgets in mid-depth of MWR
- Moving process of salinity anomaly in the sub-tropical gyre
- Influence of westward shift of low salinity tongue caused by intensification of sub-tropical gyre
- Freshening process caused by warming
- Influence of mid-depth freshening for ocean circulations and climate system

Future plan

- Detect most effective factor of the atmospheric forcing (wind stress, heat flux or E-P) by sensitivity experiments using ocean general circulation model (OGCM)
- Analysis of heat and salinity budgets using OGCM and ocean reanalysis data
- Search of salinity anomaly origin by adjoint model（e.g. Awaji et al.,2003, JO）