



1. Introduction

Background:

- The global surface temperature change is a 0.6°C increase in the 20th century (IPCC, 2001).
- The long-term trend of subsurface temperature and salinity (S) are
- **Warming** (Levitus et al., 2005) : differences in the regions (increasing (decreasing) trend in the North Pacific subtropical gyre (in the east of Honshu))
- Freshening** (Wong et al., 1999; Joyce et al., 2003; Boyer et al., 2005) : What is the spatio-temporal scales of the trend (variation) ? What causes the freshening trend ?
- ✳ **In the subtropical region, subsurface density is lighter → weakening of vertical mixing and ventilation → impacts on carbon dioxide absorption and biological activity**
- Intermediate water (salinity minimum layer) in the subtropical gyre: NPIW) transports heat and carbon dioxide southward to the ocean interior and is believed to play an important role in moderating climate change (Tsunogai et al., 1993).
- ✳ **A study of the long-term variability of salinity between surface and mid-depth layer leads to monitor and predict climate changes.**
- The mechanism of salinity minimum core variation in interannual time scale has been ascribed to the result of the zonal shift at the salinity minimum core which is controlled by the variation of the recirculation intensity and associated with the propagation of the first baroclinic Rossby waves excited by the variation of the wind stress curl field in the central North Pacific (Nakano et al., 2005; Figure 1).
- The cross-sectional area of $S < 34.2$ has a positive trend. ... **Does this trend associate with freshening ?**

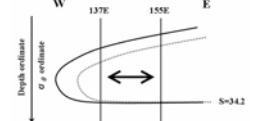


Fig. 1 Schematic representation for the mechanism of salinity minimum core variability (Nakano et al., 2005).

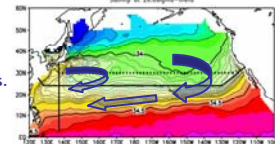


Fig. 2 Climatological map of salinity on $26.8 \sigma_{\theta}$ surface. Meridional line: 137E section by JMA. Dotted Zonal line: WHP-P2. Thick Zonal line: WHP-P3

Objective: To describe a situation of freshening in the mid-depth layer over the North Pacific subtropical gyre.

2. Data (Figure 2)

- The meridional repeat hydrographic section along 137E by Japan Meteorological Agency (JMA) from 1967 to 2005.
- Interpolated into every 1 dbar interval by an objective analysis (Roemmich, 1983).
- First guess is averaged 20 cruises from 1991 in winter to 2000 in summer by CTD, weight function of decay scale is chosen the exponential function (horizontal:300km and vertical:100dbar)
- WHP-P2 (along 30N) ... from January to February 1994 (Fisheries Agency, Japan), from June to August 2004 (Scripps Institution of Oceanography)
- WHP-P3 (along 24N) ... from March to June 1985 (Scripps Institution of Oceanography)

3. Results

3.1 Long-term variability of salinity minimum core at the 137E repeat section (Figure 3)

- Cross-sectional area of $S < 34.2$ and $S < 34.3$... **interannual (3-5 years) and decadal variations, and positive trend**
- Thickness of $S < 34.2$... **positive trend and spreads toward north and south**

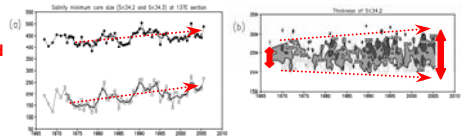


Fig. 3 Variation of salinity minimum core at 137E section. (a) cross-sectional area of $S < 34.2$ (C) and $S < 34.3$ (O). (b) thickness of $S < 34.2$

3.2 Linear trend in salinity at the 137E section

(1) Linear trend with depth ordinate (Figure 4a)

- The region of salinity minimum core ... **0.001 psu/yr**, southern region is **0.0015 psu/yr** (17N, 500-600m)
- The region of Kuroshio axis (30N, 600-1000m) ... **0.0015 psu/yr** → In recent year, the large meander does not occur ?
- 10-15N, 300-400m (difference in the origin of NPIW) ... **0.0015 psu/yr**

✳ **Problem: Salinity changes by the vertical movement of water column due to strengthening of the subtropical gyre.**

(2) Linear trend with σ_{θ} ordinate (Figure 5a)

- In order to remove the variation of strengthening of the subtropical gyre.
- The region of salinity minimum core from the main thermocline to $26.8 \sigma_{\theta}$ surface at 15-30N ... **0.0015 psu/yr**
- In particular, $26.5 \sigma_{\theta}$ surface between 25 and 30N, and between 25.5 and $26.0 \sigma_{\theta}$ surfaces at 15N (difference in the origin of NPIW) ... **> 0.002 psu/yr**

✳ **Problem: Salinity changes by the vertical movement of isopycnal surface due to temperature change.**
 ... If salinity does not change and isopycnal surface is deepened by warming of subsurface temperature, salinity has freshening on isopycnal surface.

→ There is a possibility that the trend of freshening on isopycnal surface indicates the warming signal.

(3) Linear trend of depth on isopycnal surface (Figure 4b and Figure 5b)

- Comparison with vertical gradient of salinity profile in the depth of salinity minimum core.
- The region of freshening trend ... **> 0.5 m/yr** (The linear trend of depth at the Kuroshio axis at 30N is more than 2 m/yr)
- The center of Salinity minimum core at 25N ... about 1 m/yr
- averaged vertical gradient of salinity ... about 0.15 psu/100m (= **0.0015 psu/m**)

✳ **Result: The linear trend of freshening on isopycnal surfaces is comparable to the variation of salinity by isopycnal surface deepened by the warming of subsurface temperature.**

(4) Depth of the trend of freshening (Figure 6)

- There is a possibility of the variation of density is small according to cancel by the effect of warming and freshening below salinity minimum layer.
- To examine the long-term variation of relationship between potential temperature (θ) and S, θ and S are reconstructed based on the coefficients (gradient and slope) of linear trend, and averaged 22-25N in the center of the latitude of salinity minimum core every 5 years.
- ✳ **The trend of warming and freshening has been appeared until the depth of 5°C deeper than the salinity minimum layer.**
- Remarkable trend of freshening appears in the upper layer of salinity minimum.

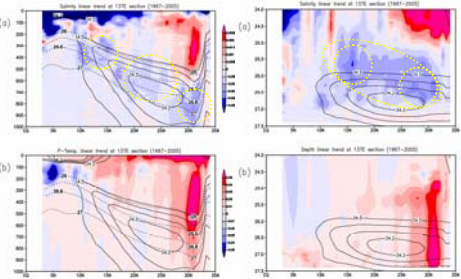


Fig. 4 Linear trend of (a) salinity and (b) potential temperature with depth ordinate. (thick (dotted) line: averaged salinity (isopycnal surface))

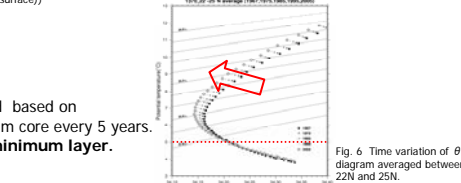


Fig. 5 Linear trend of (a) salinity and (b) depth with σ_{θ} ordinate. (thick line: averaged salinity)

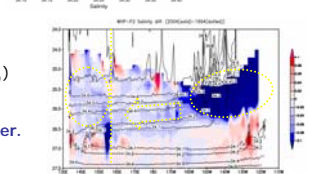


Fig. 6 Time variation of θ -S diagram averaged between 22N and 25N.

3.3 Freshening of zonal hydrographic section (WHP-P2) along 30N (Figure 7) ... Comparison with zonal hydrographic section.

- Difference between 1994 and 2004 at the same position with σ_{θ} ordinate (omit the effect of meso-scale eddy and seasonal variability)
- Freshening above salinity minimum layer ($26.8 \sigma_{\theta}$)
- The linear trend of freshening is more than 0.1 psu upper $26.0 \sigma_{\theta}$ layer from off California to 170W → freshening spread to 170E (26.0 - $26.5 \sigma_{\theta}$)
- Are these results related to the freshening in the Gulf of Alaska? (Freeland and Whitney, 1997; Overland et al., 1999)
- Freshening trend is different at 160E.
- ✳ **There is a possibility difference in formation process of salinity minimum water and circulation pathways of intermediate water.**
- supported the results of Nishina (1997)

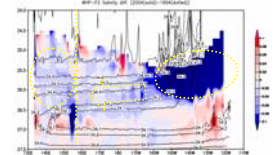


Fig. 7 Difference of salinity between 1994 and 2004 on σ_{θ} ordinate at the WHP-P2 section.

3.4 Causes of freshening of the mid-depth in the North Pacific

- (1) The variation in depth of isopycnal surface by warming in the subsurface layer ... effect by warming ?
- (2) Possibility of westward shifts of NPIW salinity minimum tongue due to strengthening of the subtropical gyre
 - The result of EOF analysis of wintertime wind stress curl field, the second mode related to strengthening of the subtropical gyre has a positive trend (Yasuda and Sakurai, 2006).
 - Comparison with between the zonal variation of θ -S diagram of WHP-P3 section along 24N and the time variation of θ -S diagram at 137E section (Figure 8).
 - ✳ Time change of θ -S diagram at the 137E section within the range of zonal change of θ -S diagram in the WHP-P3 section. ... **It does not deny the possibility of strengthening of subtropical gyre.**
- (3) The variation of long-term water property changes in the formation region with increased fresh water flux.
 - discussion to section 4

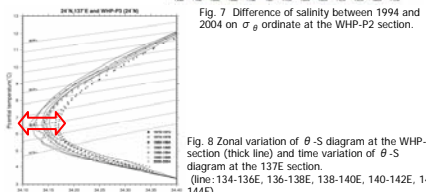


Fig. 8 Zonal variation of θ -S diagram at the WHP-P3 section (thick line) and time variation of θ -S diagram at the 137E section. (line: 134-136E, 136-138E, 138-140E, 140-142E, 142-144E)

4. Summary

✳ **The trend of freshening from the main thermocline to the salinity minimum layer is 0.0015 psu/yr in the mid-depth of the North Pacific subtropical gyre.**

✳ **Causes of freshening**

- (1) **Warming of subsurface temperature** ... deepening of isopycnal surface
- (2) **Strengthening of the subtropical gyre** ... possibility of westward shifts of NPIW salinity minimum
- (3) **Long-term variation of water property** → **Future work**

• Minobe and Nakanowatari (2002) reported relationship between the strengthening of the Aleutian low (North Pacific Index: NPI) and the long-term variability of global precipitation. → They suggested a relationship with long-term variation of subsurface salinity (Freeland and Whitney, 1997; Overland et al., 1999; Suga et al., 1999; Lukas, 2001).

✳ **Analysis of atmospheric field (evaporation-precipitation and wind stress curl field)**
 Historical experiment with high resolution numerical model (MRI.COM; Ishikawa et al., 2005)

Understanding of circulation in the mid-depth of North Pacific, formation process of intermediate water and mechanism of variability.

