Estimation of the origin of freshwater contained in Japan Sea Intermediate water using nutrient as a tracer

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1. Introduction

There is a salinity minimum layer between warm and saline Tsushima warm current and cold deep water (Japan Sea Proper Water) in the Japan Sea. This water mass was named as Japan Sea Intermediate Water (hereafter JSIW). The richness of dissolved oxygen indicates that JSIW is ventilated better and renewed faster than the deep waters below. Therefore, JSIW likely reflects the recent variation in the atmosphere and ocean.

There are two theories about the origin of the freshwater of JSIW. One possible source of freshwater is a discharge of the Amur river which is transported by Liman current [Yoshikawa et al., 1999; Yoon and Kawamura, 2002]. Park et al., [2017] suggested a new theory that freshwater flowing into the Japan Sea through the Tsushima Strait in summer is another possible origin of the freshness of JSIW. This water mass is known as Changjiang Diluted Water (CDW) as it mainly consists of the discharge of the Changjiang River.

We revealed the rapid decline in salinity of JSIW in the 2010s, based on the data from annual shipboard observations in the Japan Sea. In this previous research, CDW was suggested as a possible source of JSIW due to a positive correlation between the year-to-year decline in salinity of JSIW and the inflow of freshwater through the Tsushima Strait. However, there was little description of the Liman Current in the research. In this new research, we investigate which water mass caused the decline in the salinity of JSIW using biogeochemical tracers. The cause of the salinity decline is supported by the reanalysis of ocean and climate.

2. Data

We used the following data for our analysis.

Hydrographic measurements in the Japan Sea conducted by the Japan Meteorological Agency onboard R/Vs Ryofu-Maru, Keifu-Maru, and Seifu-Maru between 1997 and 2016

Hydrographic measurements in the Japan Sea conducted by the office of naval research in 2000 (Talley et al., 2006)

Japanese 55-year Reanalysis dataset (JRA-55)

Four-dimensional variational Ocean ReAnalysis for the western North Pacific (FORA-WNP30)

Advanced automatic QC Argo Data (Sato, 2014)

3. Results

To determine the reason for the decrease in salinity of the JSIW, biochemical parameters were used as tracers of water masses. Figure XX shows apparent oxygen utilization (hereafter AOU) and phosphate in the range of 1.0-5.0 °C corresponding to the temperature of JSIW in 2009 and 2016. AOU is close to zero when the water is at the surface as the air-sea gas exchange of oxygen is fast. AOU starts to increase by the degradation of organic matters after the water loses contact with the atmosphere. Simultaneously, phosphate is also generated along with the degradation. In this process, a good linear relationship between the AOU and phosphate should be obtained as the stoichiometric ratio of AOU to phosphate is almost stable. However, phosphate in JSIW indicated significant variation under the same AOU. This deviation of AOU occurred when the water was formed as the variation tended to be larger in lower AOU.

We compared phosphate of low salinity water in the Liman Current region with that in CDW during winter when JSIW was formed. Phosphate was higher in the Liman Current water (0.6-0.8 μmol kg^{-1}) than that in CDW (0.2-0.4 μmol kg^{-1}) when AOU was close to zero.
Many of the relationships between AOU and phosphate in 2009 were close to the extension line of Liman current water. Most of JSIW seemed to have been originated from Liman current water in 2009. As compared in 2009, phosphate was lower in 2016, especially in low AOU waters. This indicated that the contribution of CDW had increased. Furthermore, the salinity of water with similar levels of AOU and phosphate (e.g. AOU ≈50 μmol kg-1 and phosphate ≈1.0 μmol kg-1) was lower in 2016. CDW possibly not only increased its fraction in JSIW but also decreased its salinity. Most of the fresh JSIW with salinity below 34 was found in the water greatly affected by CDW. Therefore, the decline in salinity of JSIW between 2009 and 2016 was likely to be caused by the increase in the fraction of CDW with low salinity.

References

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Figure caption
AOU and phosphate in the range of 1.0-5.0°C in the Japan Sea in 2009 (left) and 2016 (right). The color indicates salinity. "Liman" and ” CDW” indicate winter AOU and phosphate of Liman current (salinity < 34; 41-45°N, west of 137°E) and Changjiang Diluted Water (salinity < 34; 36-39°N) respectively.

Keywords: Japan Sea Intermediate Water, Changjiang Diluted Water, Liman Current