Recent deoxygenation in the Japan Sea Proper Water in the northeastern Japan Basin

Toshiya NAKANO[1, 2] (nakano_t@met.kishou.go.jp), Daisuke SASANO[1, 2], Takahiro KITAGAWA[1], Naoki NAGAI[1], Yoshiteru KITAMURA[1], Michio AOYAMA[3], Masao ISHII[2, 1]
(1: Japan Meteorological Agency, 2: Meteorological Research Institute, 3: JAMSTEC/Fukushima Univ.)

➢ Background, Motivation and Objectives

A gradual warming and deoxygenation in the Japan Sea Proper Water (JSPW) have been observed since 1950s. The cause of this warming and deoxygenation is potentially the weakening of winter cooling associated with the climate change in the northwestern region of the Japan Sea where the JSPW is formed (e.g. Gamo et al.,1986; Minami et al., 1999; IPCC AR4, 2007).

※ Are causes of the warming and deoxygenation in the JSPW the only weakening of winter cooling ?

- To clarify the spatiotemporal variability in the water properties of the JSPW in the northeastern Japan Basin (NEJB).
- To understand the causes of these variabilities.

➢ Summary

- Recent deoxygenation rate in the Upper JSPW of the NEJB is higher than that in the Yamato Basin.
- O_2 minimum layer emerged at 1000 m in 2013 and is being developed to date.
- The deoxygenation in the NEJB is hard to explain by the variability of the surface/subsurface oceanic conditions of the JSPW formation region off Vladivostok.
- It is important for the recent deoxygenation in the Upper JSPW in the NEJB to understand the spatiotemporal variability of biological activity.
- There is a possibility that the formation and disappearance of shallow O_2 minimum layer as part of decadal/interdecadal variability.
- The results of this study are helpful in understanding the difference of circulation structure in the NEJB, the formation of JSPW, and mixing and biological process.
- Further examination is also necessary to reveal the variability and its mechanism of warming and deoxygenation in the JSPW by analysis of a comparable high-quality hydrographic observation data in the Japan Sea.
- High-quality O_2 sensor data is very useful and necessary to understand the spatiotemporal variability of fine structure.

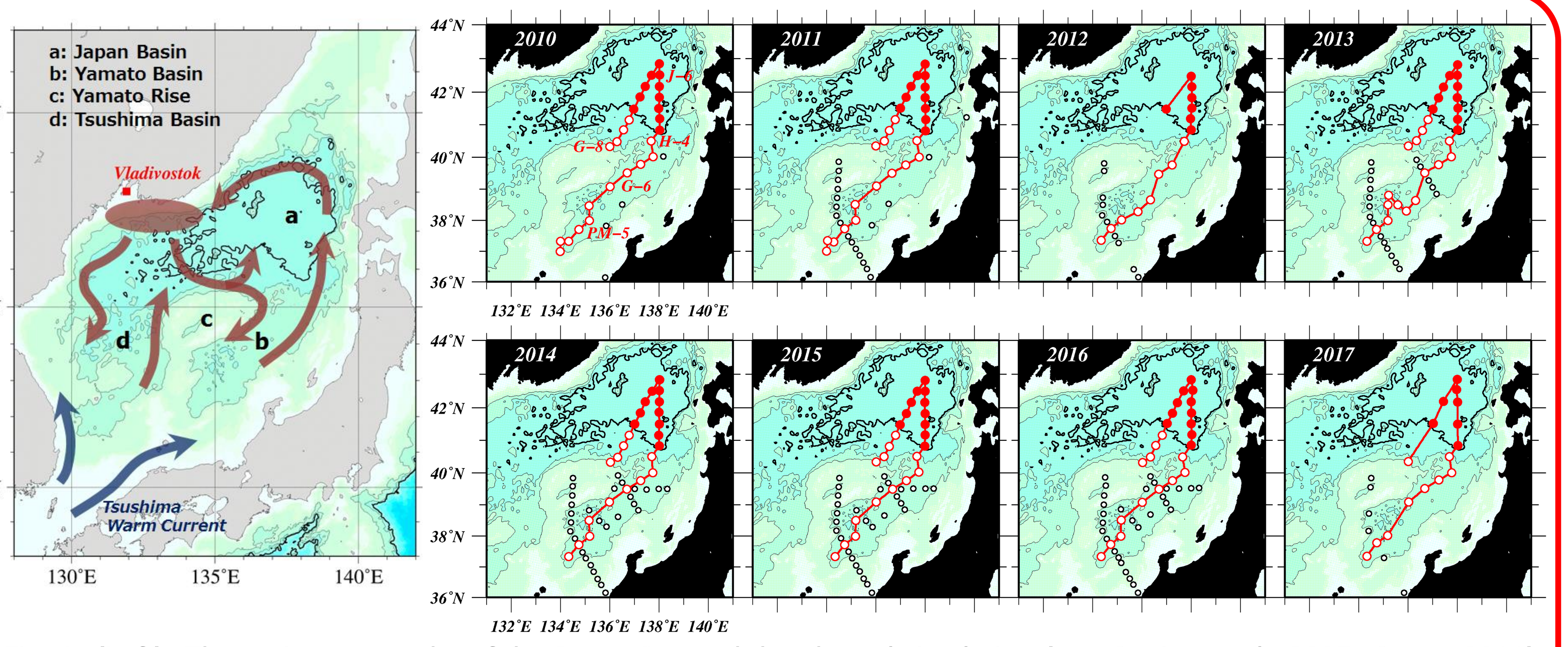

Fig. 1: (Left): The major geography of the Japan Sea and the abyssal circulation (e.g. Senjyu et al., 2005; Gamo, 2011)
(Right): The location of $CTDO_2$ stations (●: averaged stations (>3500m depth) in the NEJB)

Cruise designation and observation date:
KS1007: 2010/10/21–10/29, KS1109: 011/10/28–11/06, KS1208: 2012/10/24–11/07, KS1308: 2013/10/30–11/24, KS1406: 2014/09/21–10/12, KS1508: 2015/10/24–11/13, RF1608: 2016/10/25–11/19, KS1708: 2017/11/07–11/26
(All data is available from "http://www.data.jma.go.jp/gmd/kaiyou/db/vessel_obs/data-report/html/ship/ship_e.php")

➢ Results: Temporal variability in the water properties of the JSPW in the northeastern Japan Basin (NEJB) and Yamato Basin

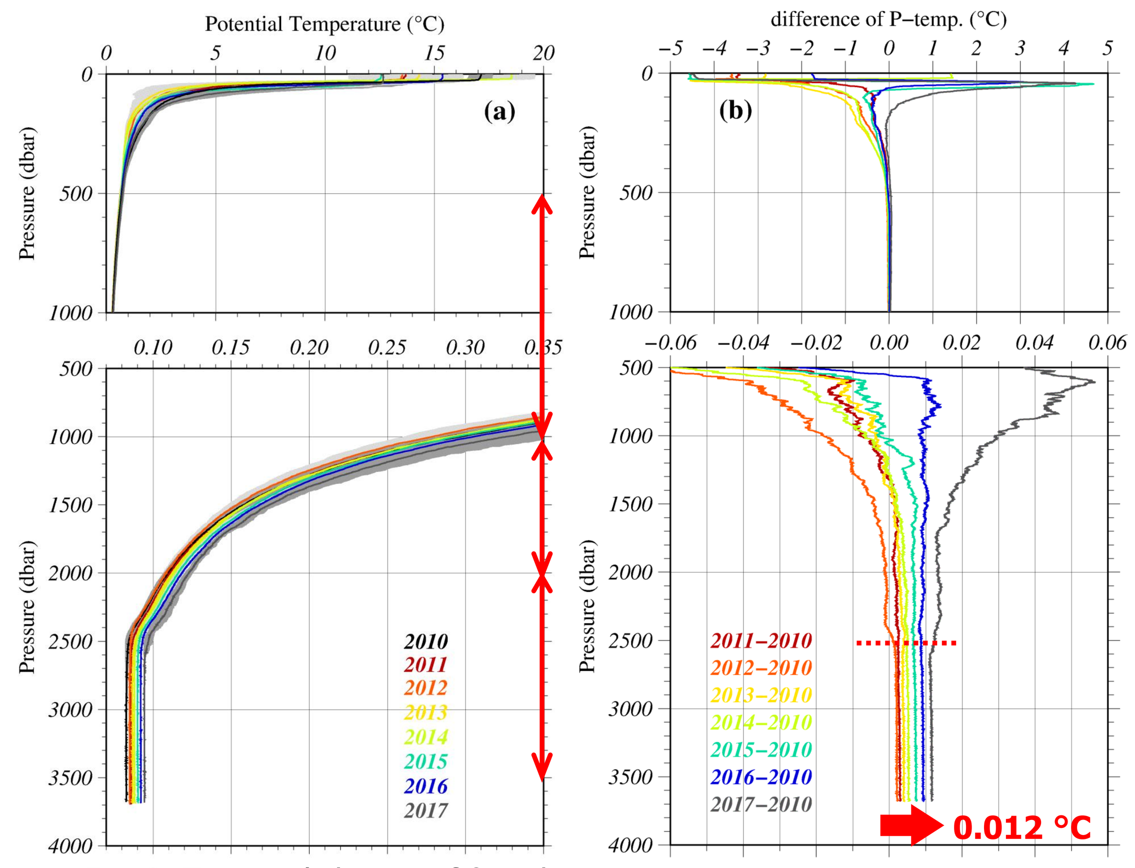

Fig. 2: Temporal change of θ in the NEJB during 2010–2017.
(a) averaged vertical profile (shade: ±1σ) and (b) difference from 2010.

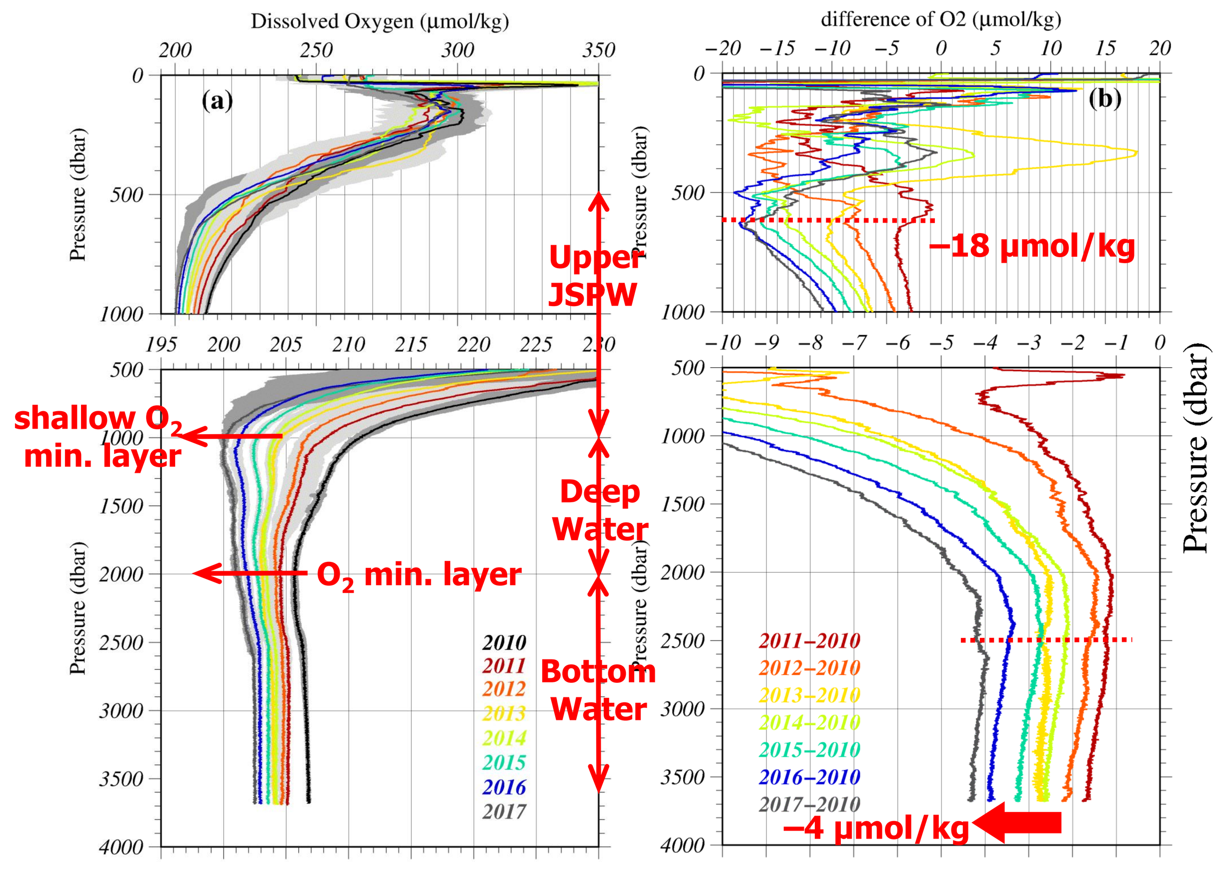

Fig. 3: Temporal change of O_2 in the NEJB during 2010–2017.
(a) averaged vertical profile (shade: ±1σ) and (b) difference from 2010.

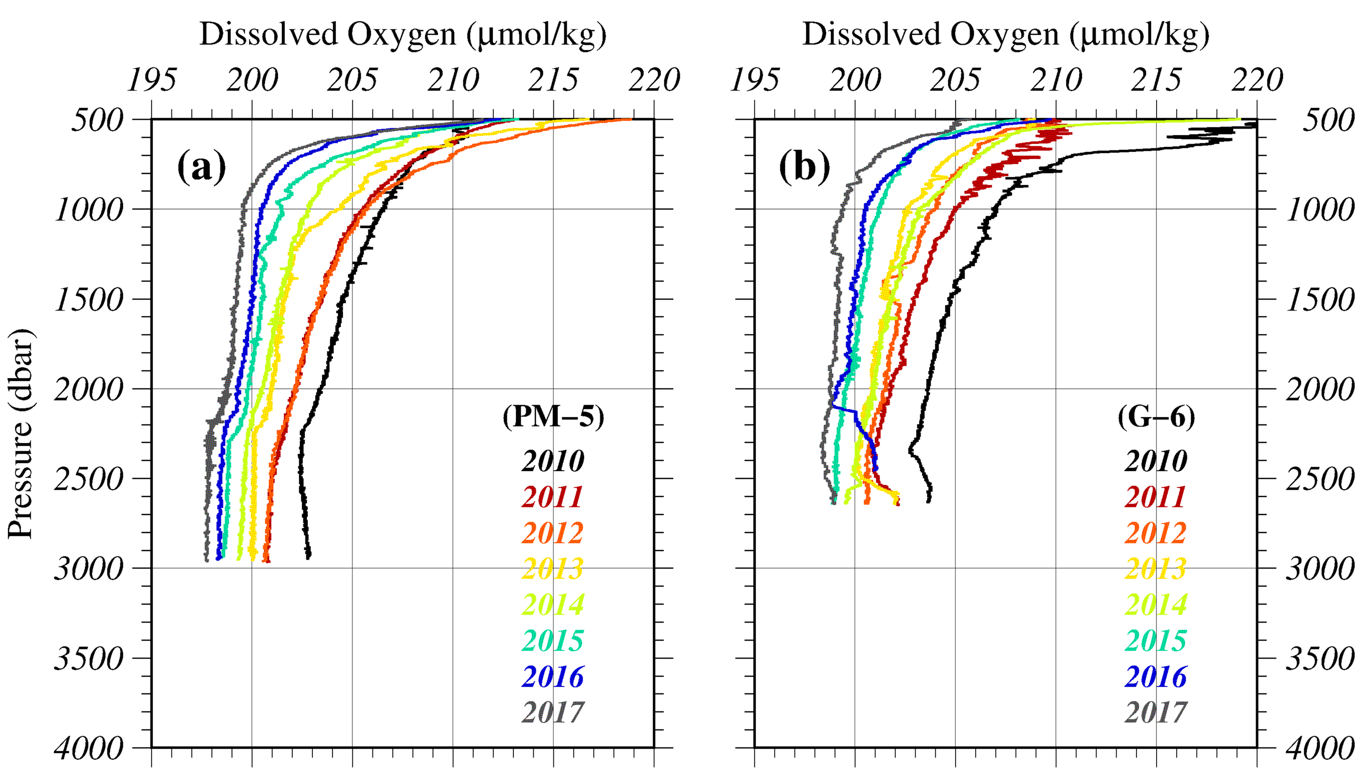

Fig. 4: Temporal change of O_2 in the Yamato Basin (a: PM-5 and b: G-6) during 2010–2017.

☐ JSPW in the NEJB is classified into three distinctive layers. (the same as previous studies)

Upper JSPW at 500–1000m (σ_θ=27.340 kg/m³) : −11 to 18 µmol/kg for 2010–2017.
→ The decrease of O_2 for 2010–2017 was faster than in Deep Water and Bottom Water. (Fig.2&3)
→ **O_2 minimum layer emerged at 1000m in 2013 and is being developed to date. (Fig.3&5)**

Deep Water at 1000–2000m (σ_θ=27.347 kg/m³): −5 to 11 µmol/kg for 2010–2017.
→ Deeper O_2 minimum layer appeared at 2000 m between Deep Water and Bottom water. (Fig.3&5)
(O_2 minimum layer not appeared in the Yamato Basin. (Fig.4&5))

Bottom Water (below 2000 m)
→ Vertically most uniform below 2500 m (σ_θ=27.349 kg/m³) (Fig. 3)
→ Deoxygenation and warming below 2500 m were 4 µmol/kg and 0.012 °C for 2010–2017. (Fig.2&3)

☐ Recent deoxygenation rate in the Upper JSPW of the NEJB is higher than that in the Yamato Basin. (Fig. 3,4&5)

☐ O_2 concentration over the slope in the NEJB, located near the JSPW formation region off Vladivostok, is lower than in the deeper area of NEJB. (Fig. 5)

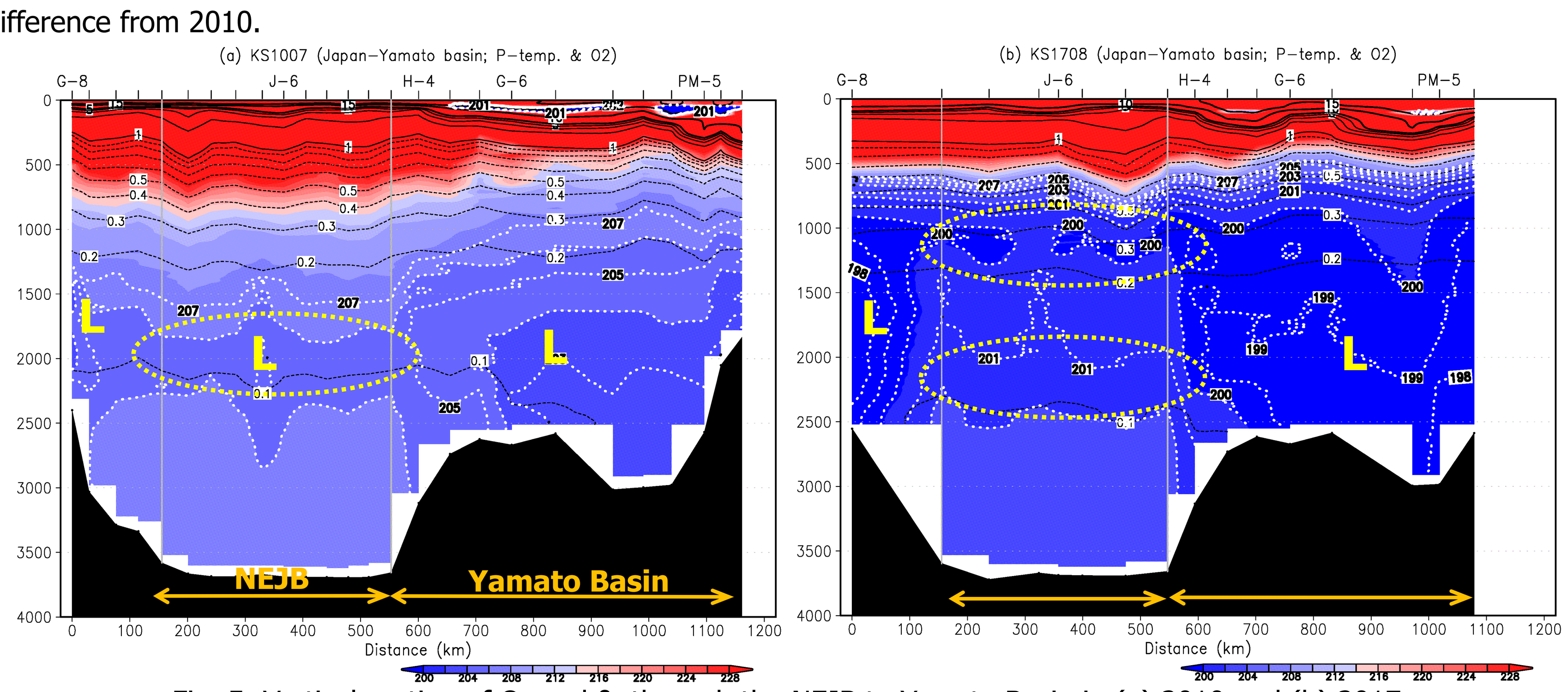

Fig. 5: Vertical section of O_2 and θ through the NEJB to Yamato Basin in (a) 2010 and (b) 2017.
(Color and white contour indicates O2, and Black contour indicates θ)

➢ Discussion: Possible causes of recent accelerated deoxygenation and the formation of shallow O_2 minimum layer in the Upper JSPW in the NEJB

☐ Long-term variability of surface/subsurface oceanic conditions such as warming, freshening, and weakening of wind stress curl in the JSPW formation region

→ The variability of decreasing of O_2 solubility, lighting of density, weakening of subduction, and slowdown of circulation would cause deoxygenation.
- Recent notable change in surface/subsurface oceanic conditions and wintertime air temperature in Vladivostok are unclear.

☐ Influence of biological activity (organics decomposition)

→ This variability has the potential for increasing of nutrients (nitrate and nitrite (nitrate) and phosphate) were related to decreasing of O_2.
- Nitrate increase between 500–900 m depth is statistically significant, which is consistent with O_2 decrease.
- Phosphate did not indicate significant increase considering the accuracy and uncertainty.

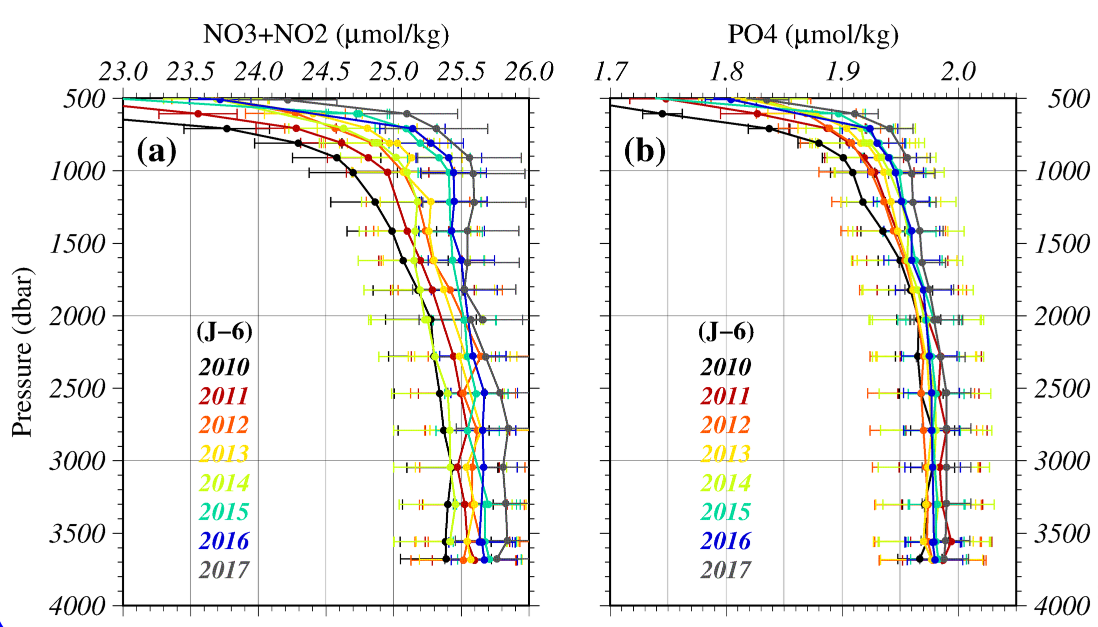

Fig. 6: Temporal change in vertical profile of (a) Nitrate and (b) Phosphate at station J-6 in the NEJB. The error bars indicate uncertainty.

☐ As part of decadal/interdecadal variability

→ In the past, shallow O_2 minimum layer was formed in the late-1960s, and deepening of the depth, finally O_2 minimum layer disappeared.
- There is an incomplete understanding of causes and its mechanisms of the formation and disappearance in shallow O_2 minimum.

■ Additional Questions

✓ Where is the formation region of the shallow O_2 minimum water over the slope of NEJB ?
✓ How the shallow O_2 minimum water in the NEJB formed ?
✓ What is a cause and its mechanisms of decadal/interdecadal variability in the JSPW ?

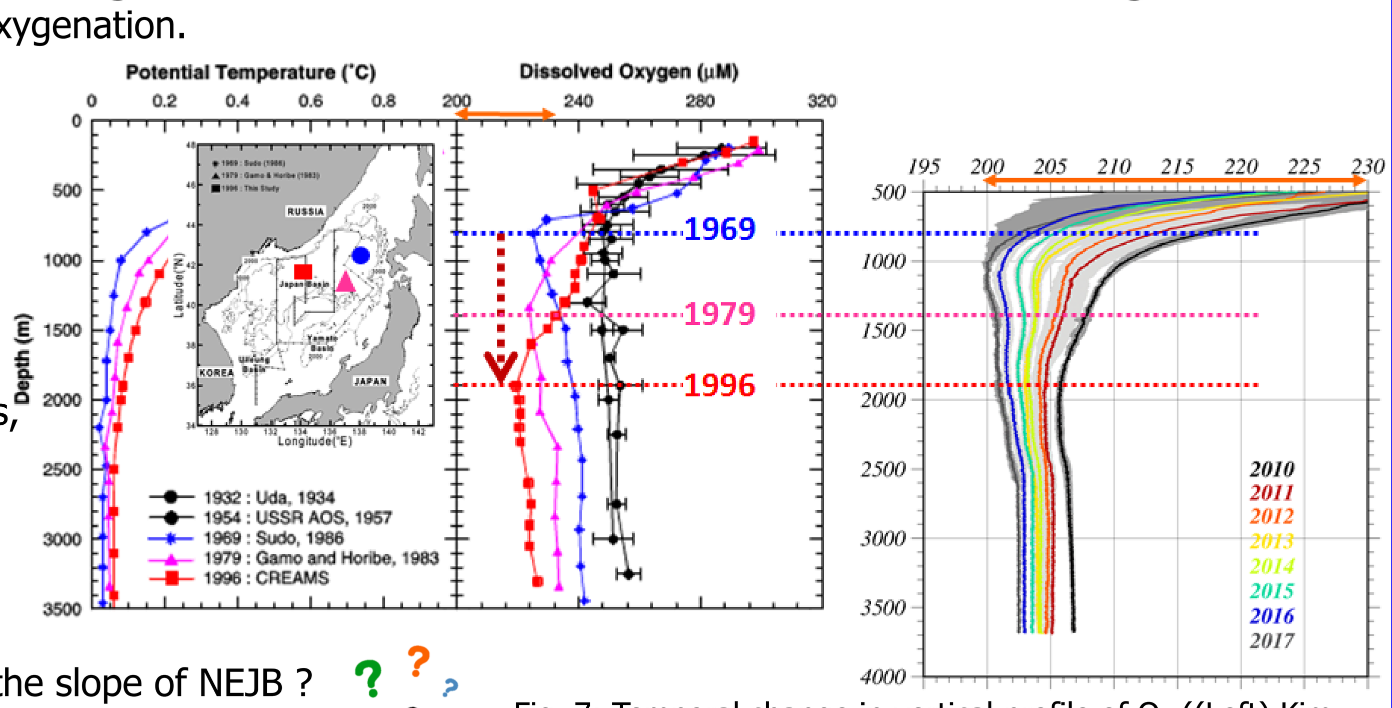

Fig. 7: Temporal change in vertical profile of O_2 ((Left) Kim et al. (2001) and Kang et al. (2004)) and (right) this study.

➢ Geography of Japan Sea and Japan Sea Proper Water (JSPW)

- Japan Sea is a semi-closed marginal sea surrounded by Japan, Russia and Korea and connected with the East China Sea, the North Pacific and the Okhotsk Sea through four shallow sills (<150m) at Tsushima, Tsugaru, Soya and Mamiya Straits.
- The deep part of the sea consists of the Japan Basin, Yamato Basin, and Tsushima Basin around the Yamato Rise.

✓A homogeneous water mass (potential temperature (θ): 0–1 °C, Salinity (S): 33.96–34.14 and dissolved oxygen (O_2): >200 µmol/kg) has been found below the main thermocline (Uda 1934; Yasui et al., 1967).
✓The water column is classified into three distinctive layers, i.e., the Upper JSPW, the Deep Water and the Bottom Water (Sudo 1986).
✓A gradual warming and deoxygenation rates after 1990 are 0.02 °C/10yr and 8 µmol/kg/10yr at 2000 m depth at stations of J-6, H-4, G-6 and PM-5 on the average (e.g. Gamo et al.,1986; Minami et al., 1999).

➢ Data: High-quality hydrographic data with established comparability collected by JMA on board R/Vs Keifu Maru and Ryofu Maru during 2010–2017

- **$CTDO_2$**: SBE 911plus system (Sea-Bird Electronics, Inc., USA) with 10-liter Niskin bottles/36-position SBE35 Deep Ocean Standards Thermometer (Sea-Bird Electronics, Inc., USA) → θ < ±0.001 °C RINKO III dissolved oxygen sensors (JFE Advantech Co., Ltd., Japan) → O_2 < ±1 µmol/kg
- **Bottle Salinity**: AUTOSAL 8400B (Guildline, Canada) → IAPSO SSW → S < ±0.002
- **Bottle O_2**: DOT–01X (Kimoto Electric Co., Ltd., Japan) → KIO_3 solution compared with JAMSTEC
- **Nutrients**: Auto AnalyzerIII (BL TEC K.K., Japan) → KANSO RMNS/CRM

※Uncertainty of nutrients concentration was estimated to be around 1.5 % for nitrate, and phosphate, and 0.23% for dissolved oxygen at typical concentrations in the NEJB.

$CTDO_2$ system

Acknowledgement: We also thank Prof. I. Yasuda and Ms. N. Kobayashi of the University of Tokyo, and Dr. Y. Yoshikawa of Kyoto University. This study is partially supported by "Ocean Mixing Processes: Impact on Biogeochemistry, Climate and Ecosystem (MEXT KAKENHI JP15H05817, JP15H05818 and JP15K21710)".