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Decline and bidecadal oscillation of dissolved oxygen in the Oyashio region and their propagation to the western North Pacific

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1. Introduction

Dissolved O_2 is decreasing in the North Pacific, especially in the Oyashio region.

Found between $26.7\sigma_\theta$ and $27.2\sigma_\theta$ due to the reduction of ventilation. (Ono et al., 2001)

The decline of O_2 propagates along the NPIW pathway. (Takatani et al., 2012; Sasano et al., 2015)

However, the depth of the $27.2\sigma_\theta$ isopycnal horizon is much deeper than that of $26.7\sigma_\theta$.

the water does not outcrop at the surface in winter in the western North Pacific

→ Necessary to improve our understanding of these controlling factors.

Bidecadal oscillations in O_2 are found in the Oyashio region. (Ono et al., 2001)

However, the extent of the bidecadal oscillations in the North Pacific is still unclear.

Through the comparison of trends and oscillations with those along the 165°E section, their propagation from the Oyashio region to the wide range of the western North Pacific was evaluated.

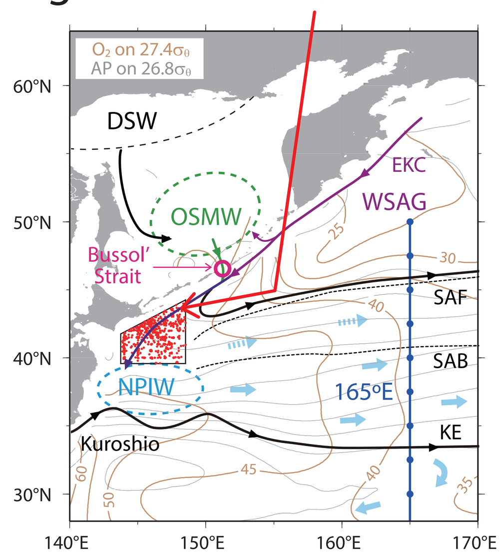


Fig. 1 Schematic representation of the currents, fronts, and distributions of water masses in the western North Pacific.

2. Data

In the Oyashio region, data from a total of 1332 stations between 1954 and 2014 were used.

Remove outliers by a statistical method.

Annual mean is basically used for analysis.

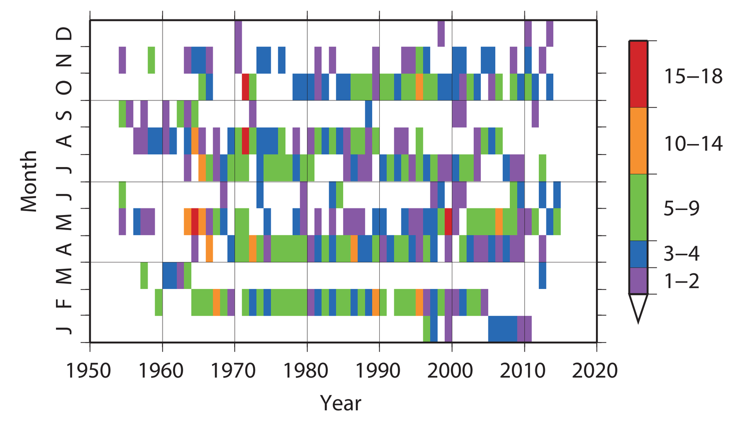
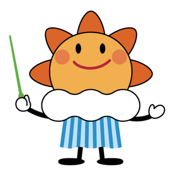


Fig. 2 Year-month distributions of number of hydrographic stations in the Oyashio region.

Along the 165°E section, data between 30°N and 50°N from 1987 to 2014 were used.

Annual mean in each 2.5° band from anomalies of the mean value at intervals of 1° for the entire period.



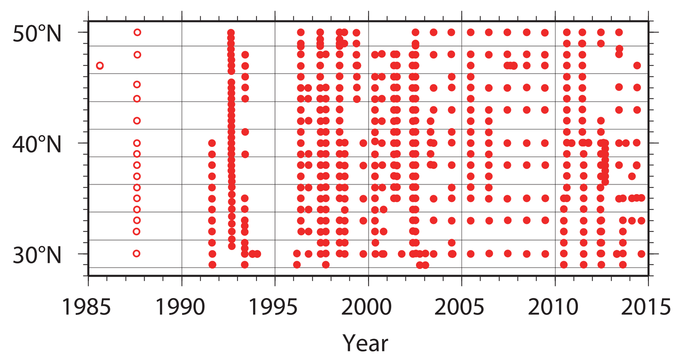


Fig. 3 Year-latitude distributions of hydrographic stations along the 165°E section.

3. Results

In the Oyashio region, **O_2 declined** and **O_2 bidecadally oscillated.**

vertically synchronized within 1 year

Fitted to the equation of $X = A \cdot yr + B + C \cdot \sin\{2\pi(yr-D)/E\}$

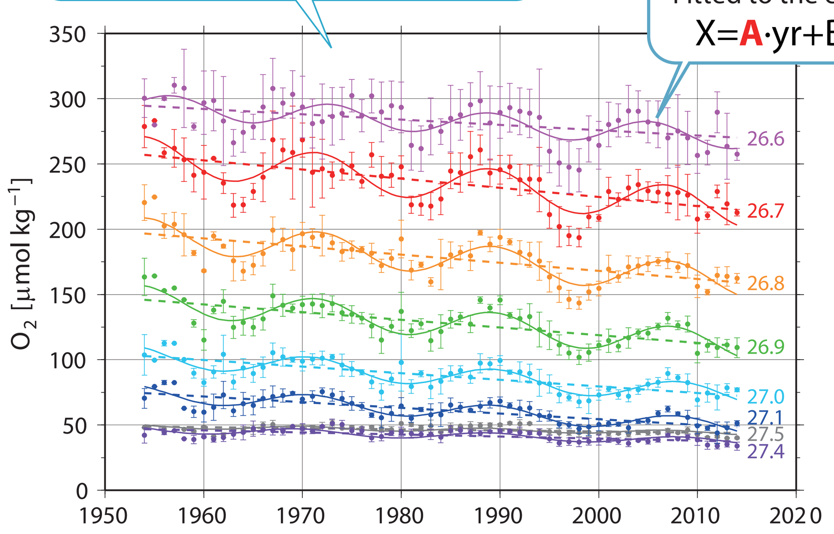


Fig. 4 Time series of dissolved O_2 in the Oyashio region.

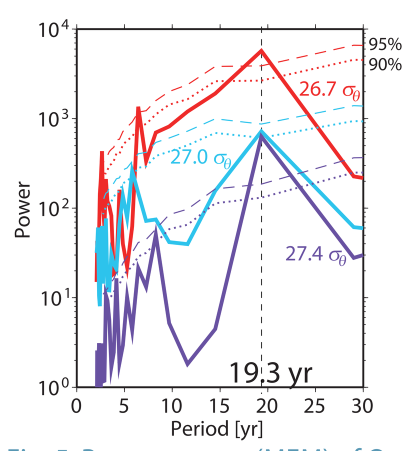


Fig. 5 Power spectra (MEM) of O_2 in the Oyashio region.

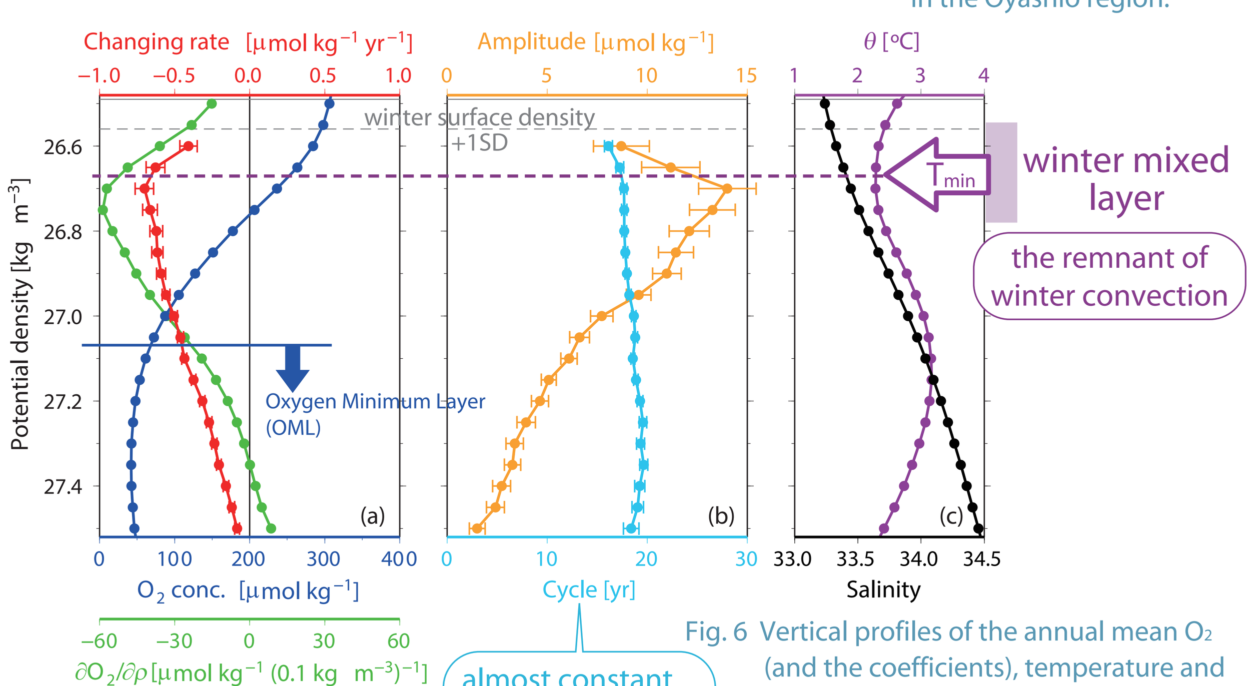


Fig. 6 Vertical profiles of the annual mean O_2 (and the coefficients), temperature and salinity in the Oyashio region.

4. O_2 decline

❶ Ventilation

The largest decreasing rate was found on $26.7\sigma_\theta$ (-0.70 ± 0.11 μmol kg^{-1} yr^{-1}).

The density corresponds to ... the temperature minimum layer (T_{min}) = the remnant of winter convection

Surface density in winter has been lightened significantly.

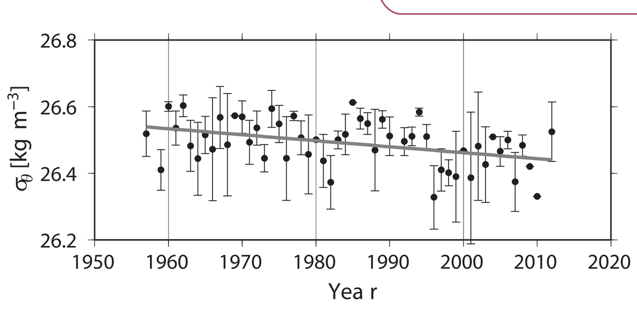


Fig. 7 Time series in potential density in 10 m during winter in the Oyashio region.

The decrease in O_2 would be attributed to **the reduction of ventilation in winter above $26.7\sigma_\theta$.**

However, the signals of winter mixed layer would not reach below T_{min} down to $27.5\sigma_\theta$.

❷ DSW+diapycnal mixing

The Sea of Okhotsk is a key!

Dense shelf water (DSW) is important as a ventilation source of the North Pacific. Cold and O_2-rich water ($26.8\sigma_\theta$–$27.0\sigma_\theta$) (Warner et al., 1996)

Ventilation in two ways (Yamamoto-Kawai et al., 2004)

1st Sea ice is actively produced in winter.
↓ DSW is produced due to brine rejection.
↓ Supplying O_2-rich water down to $27.0\sigma_\theta$.

+

2nd Around the Bussol' Strait, diapycnal mixing is induced by tidal currents.
↓ Transporting O_2-rich water down to $27.5\sigma_\theta$.

Strong mixing is observed around the Bussol' Strait (Yagi and Yasuda, 2012).

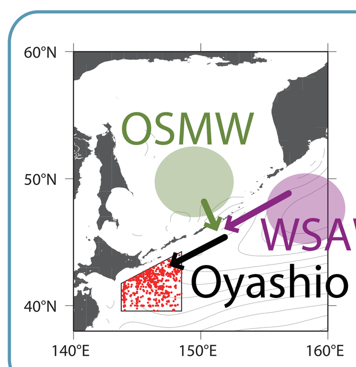
The mixing controls biogeochemical properties within intermediate water (Nishioka et al., 2013).

In the Sea of Okhotsk, O_2 declined down to $27.4\sigma_\theta$. (Nakanowatari et al., 2007)

because DSW production has been reduced by 30% through sea ice decline. (Ohshima et al., 2014)

The tidal mixing around the Bussol' Strait conveys the signal of O_2 decline vertically to deeper layers.

5. Oscillations



Oyashio = OSMW + WSAW

OSMW	WSAW
Okhotsk Sea Mode Water	Western Subarctic Gyre Water
High O_2, Low PV, θ, S	Low O_2, High PV, θ, S

Bicecadal oscillation in the Oyashio region is related to ...

the strength of the Aleutian Low (Ono et al., 2001)
- Change in the ocean circulation around the WSAG
- ↓ Change in the volume transport of the **WSAW** to the Oyashio

and/or

the 18.6-year period nodal tidal cycle (Osafune and Yasuda, 2006)
- Upward salt flux around the Bussol' Strait
- ↓ DSW formation in the Sea of Okhotsk
- ↓ OSMW formation
- ↓ Change in **OSMW** outflow to the Pacific side

However, the oscillations above $26.7\sigma_\theta$ (The amplitude is the largest) cannot be attributed solely by their mixing ratio

because mean O_2 concentrations in OSMW are comparable to, or rather lower than, those in WSAW above the isopycnal surface. (Yasuda et al., 2002; Itoh et al., 2003)

Other controlling factors?

Diapycnal mixing, similar to the Bering Sea (Osafune and Yasuda, 2010)

→ cannot explain oscillations of O_2 above $26.7\sigma_\theta$ because of O_2 gradient

Variation in the source water *(dominant?)* (Osafune and Yasuda, 2006)

Oyashio → 165°E section

The oscillations in dissolved O_2 have been determined horizontally and vertically in the region of influence of subarctic water.

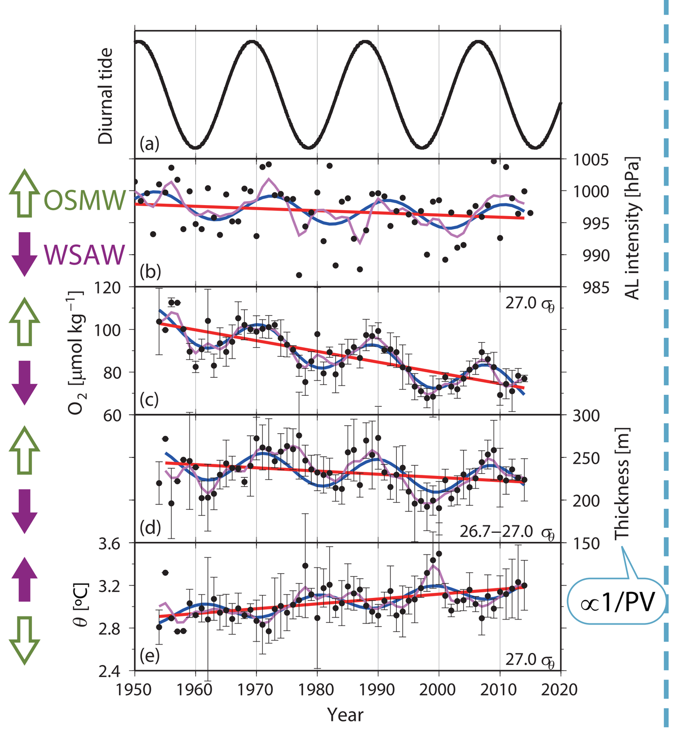


Fig. 8 Time series of various parameters in the Oyashio region.

Horizontally on $26.8\sigma_\theta$

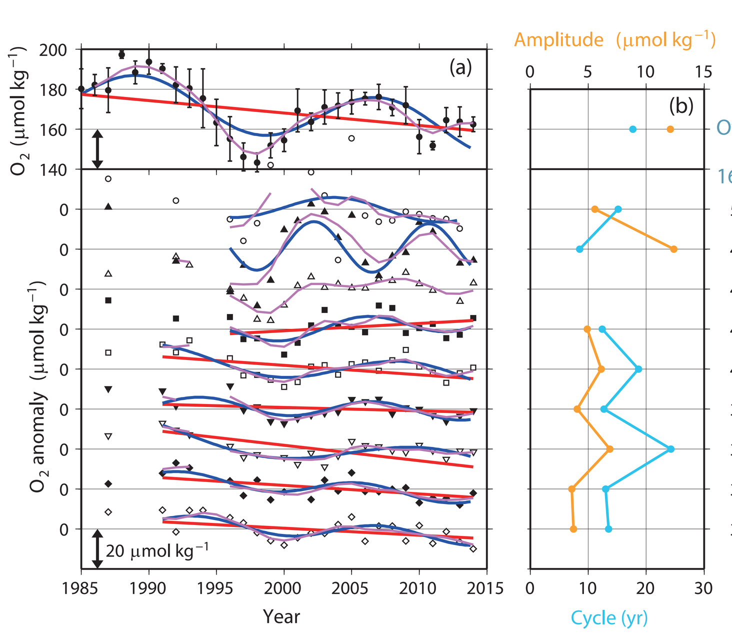


Fig. 9 (a) Time series of O_2 on $26.8\sigma_\theta$ in the Oyashio region and along the 165°E section. (b) Meridional distributions of coefficients of amplitude and cycle shown in (a).

Vertically at 40°N

Located just in the downstream of the Oyashio region

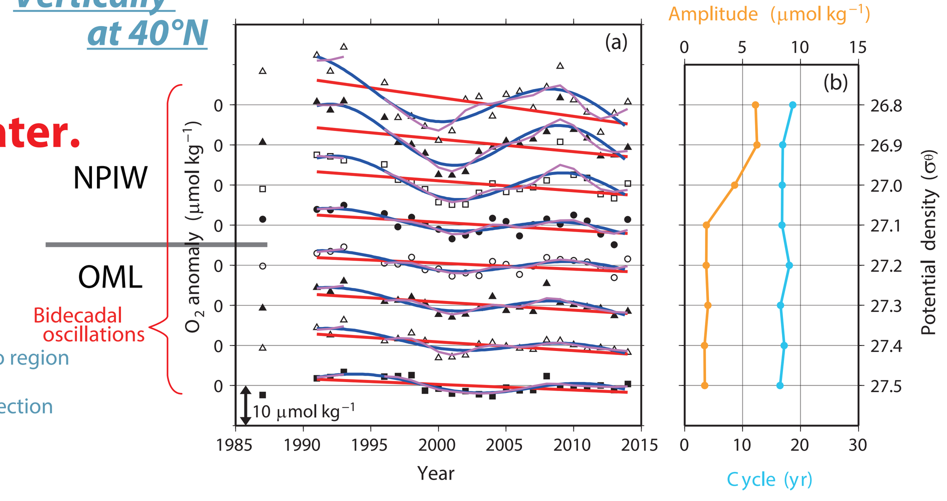


Fig. 10 Same as Fig. 9, but for dissolved O_2 on $26.8\sigma_\theta$–$27.5\sigma_\theta$ in 40°N.

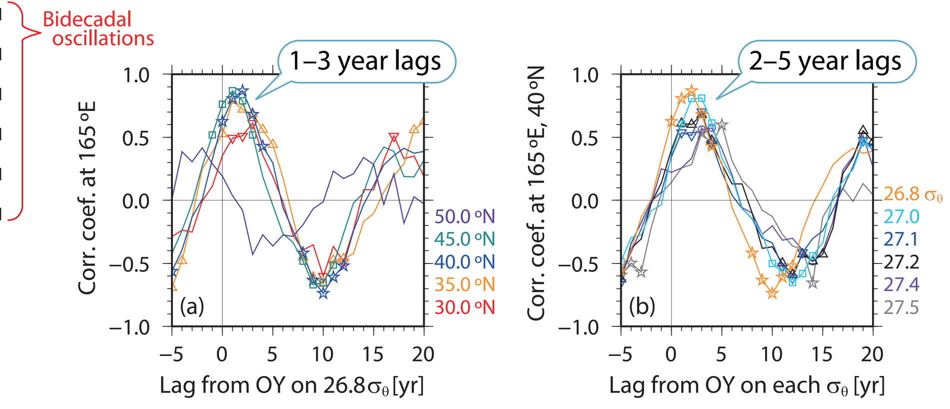


Fig. 11 Time-lag correlations of dissolved O_2 of from the Oyashio region (OY)

SUMMARY

For details, see Sasano et al. (2018), GBC.

1. Significant trends toward decreasing O_2 were detected between $26.6\sigma_\theta$ and $27.5\sigma_\theta$ in the Oyashio region during 1954–2014.
2. A variety of drivers contribute to O_2 decreases, varying by density.
3. The bidecadal oscillations in O_2 extended horizontally and vertically to the regions where the subarctic water influences in the North Pacific.

Acknowledgement

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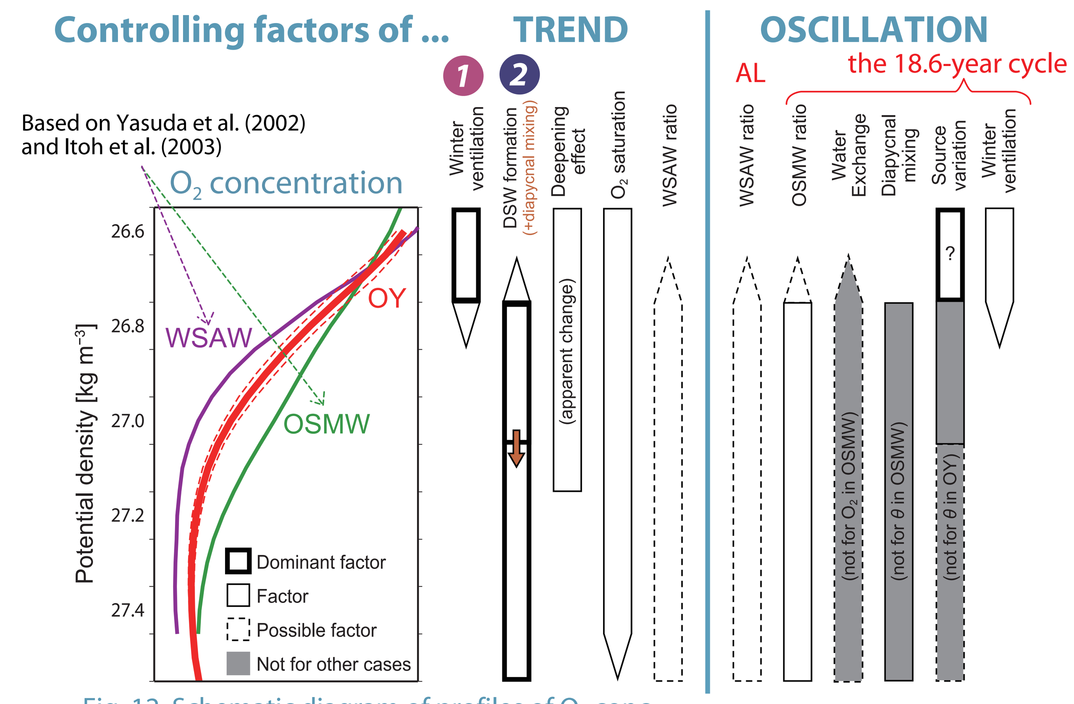

Fig. 12 Schematic diagram of profiles of O_2 conc., and factors controlling O_2 trend and oscillation in the Oyashio region.