Kuroshio and Oyashio current system: variability and impact on ecosystem

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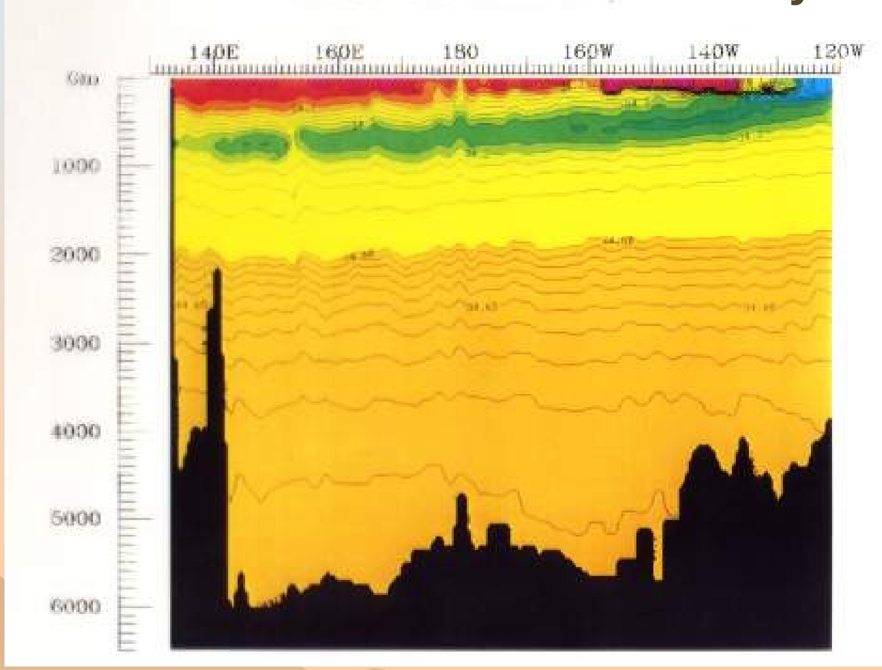
Recent progress of physical & fisheries oceanography in the Oyashio and Kuroshio Extension after the review of Yasuda (2003 JO PICES LaPaz symposium).

- NPIW/Oyashio and climate bi-decadal variations
- Kuroshio Extension and species replacement of small pelagic fishes

NPIW, Oyashio and Bi-decadal North Pacific variability

30N-Trans Pacific WOCE Salinity section



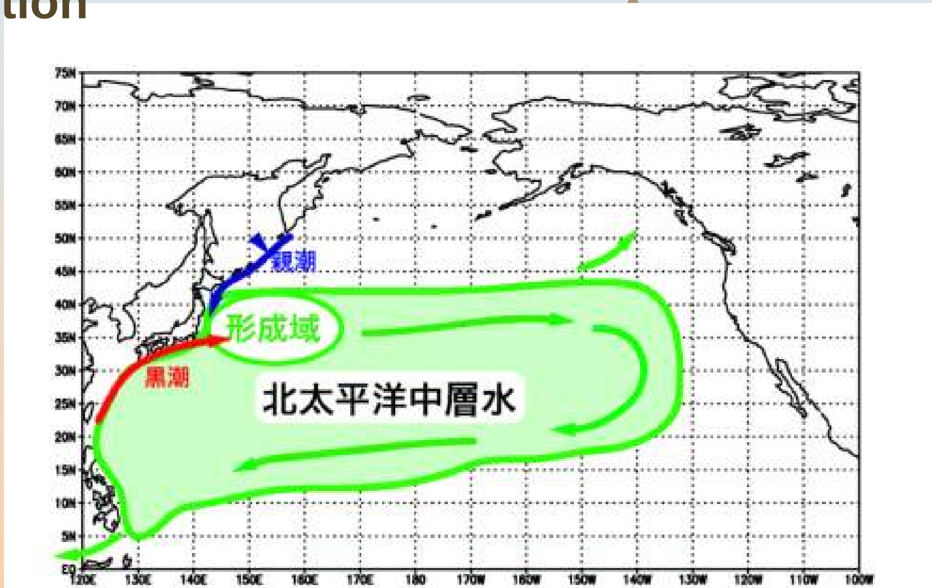
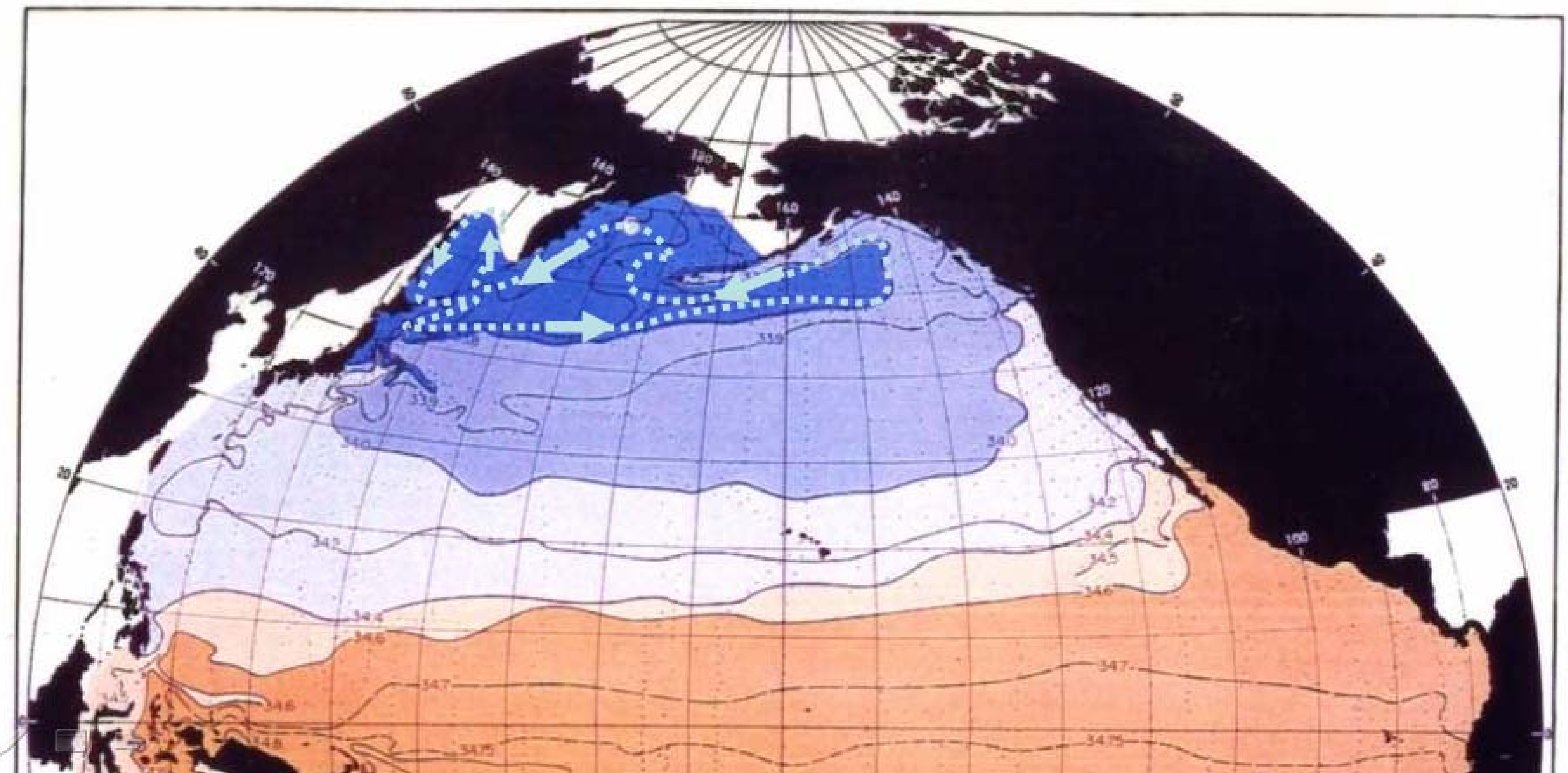


図３：北太平洋中層水の分布と循環

NPIW: is defined as intermediate-depth salinity minimum at 26.6-26.9 and its adjacent water and distributes in the mid-depth of North Pacific Subtropical Gyre

Reid (1965)-hypothesis :

1) freshening along the subarctic cyclonic path



Reid (1965)-hypothesis :

1) freshening along the subarctic cyclonic path

2) Lateral eddy diffusion/exchange along the subtropical/subarctic gyre boundary

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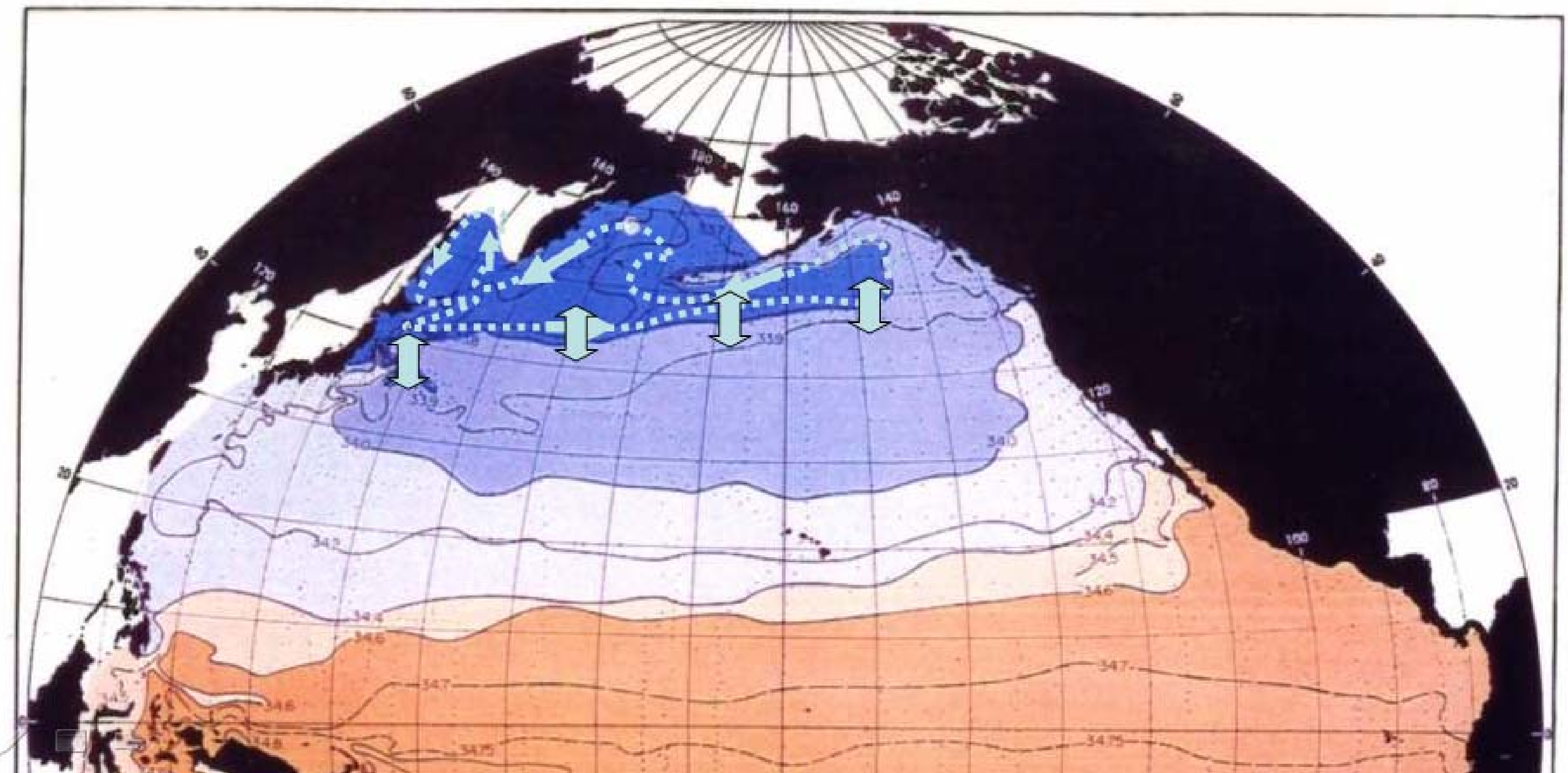

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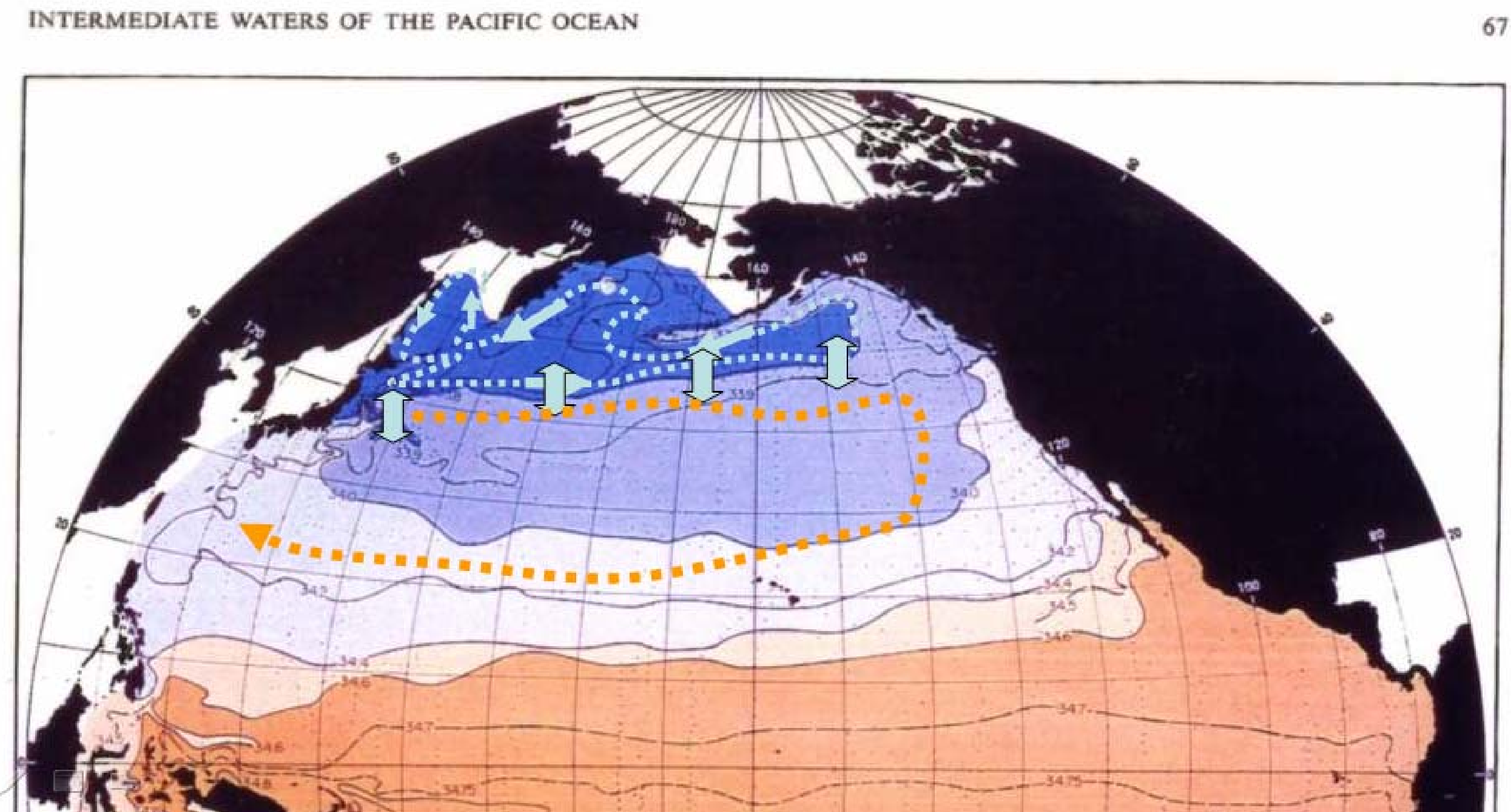
3)advection of subtropical gyre clockwise circulation



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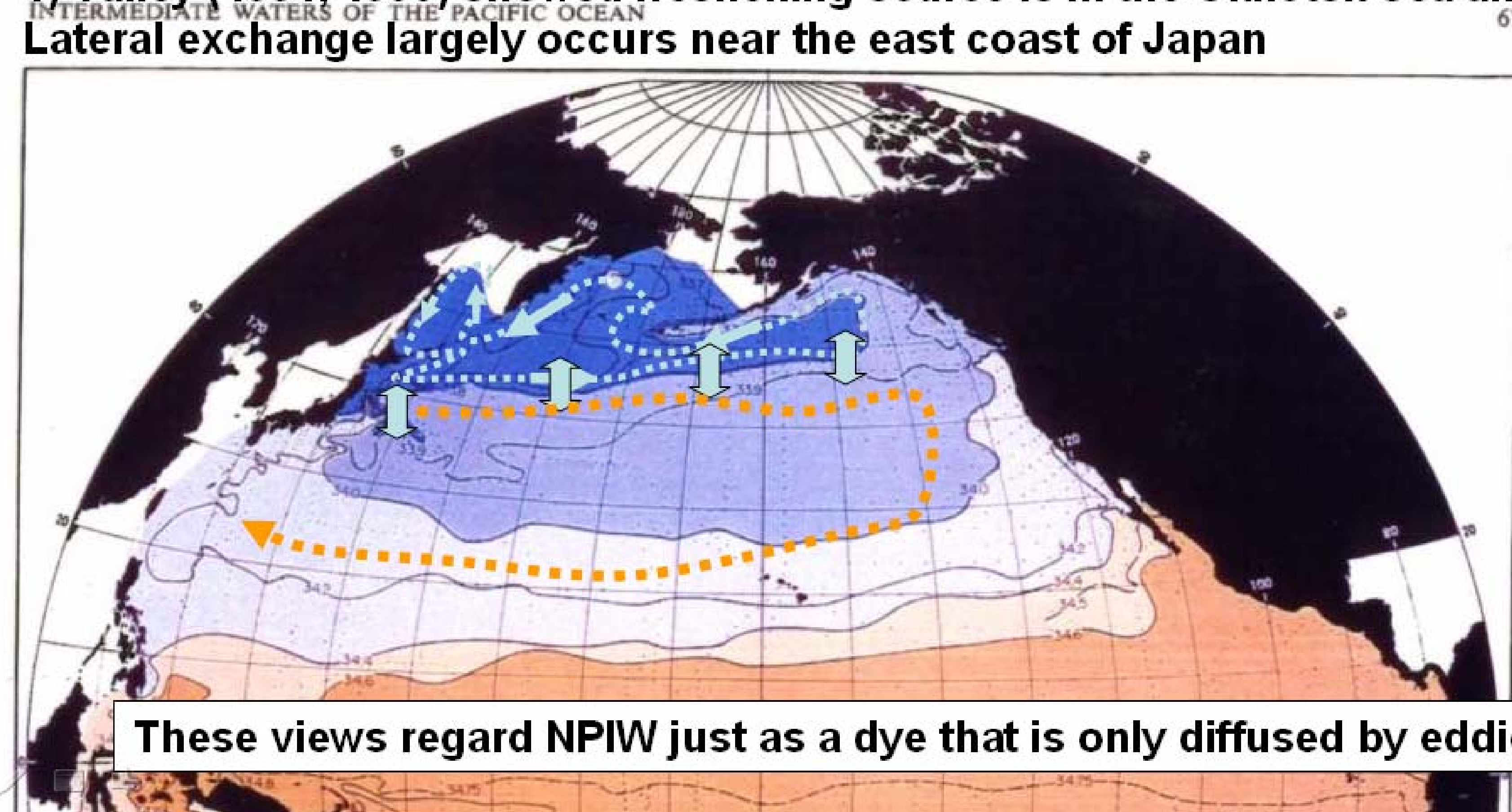
4) Talley (1991, 1993) showed freshening source is in the Okhotsk Sea and Lateral exchange largely occurs near the east coast of Japan

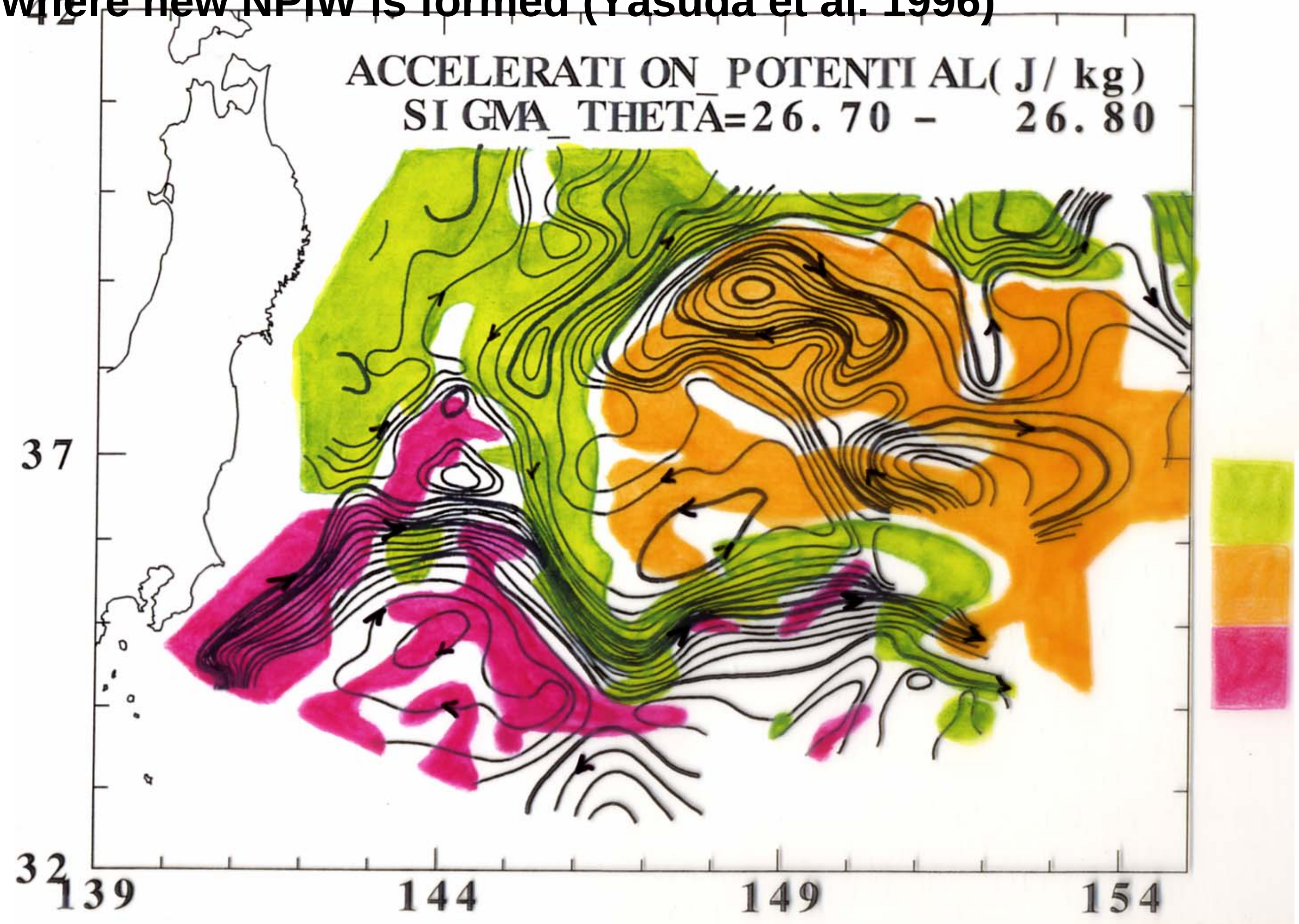


These views regard NPIW just as a dye that is only diffused by eddies

New hypothesis: Direct cross-gyre Oyashio transport produces NPIW

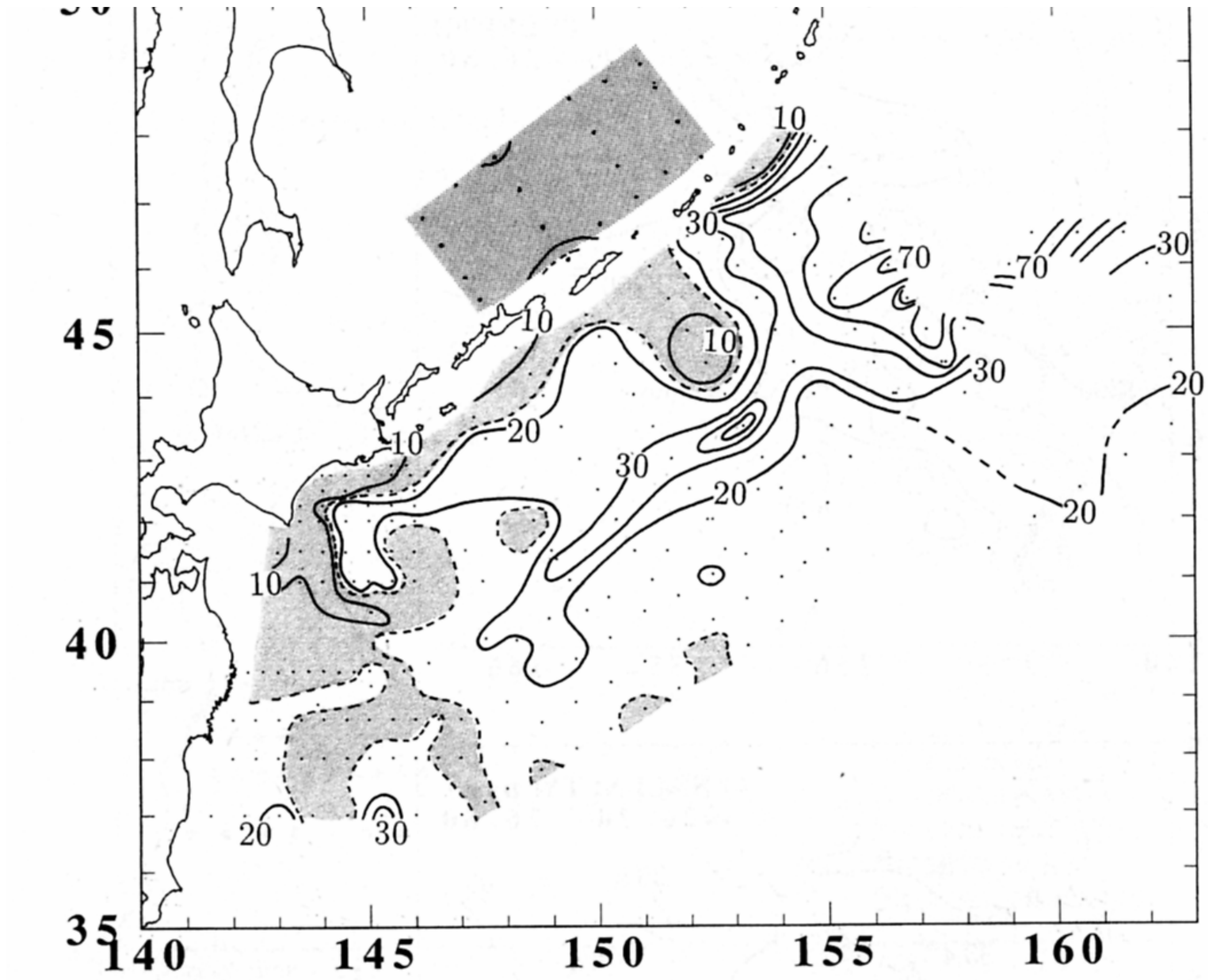
(Yasuda et al. 1996; Yasuda 1997)

Oyashio low-salinity and low-PV water reached the Kuroshio Extension where new NPIW is formed (Yasuda et al. 1996)

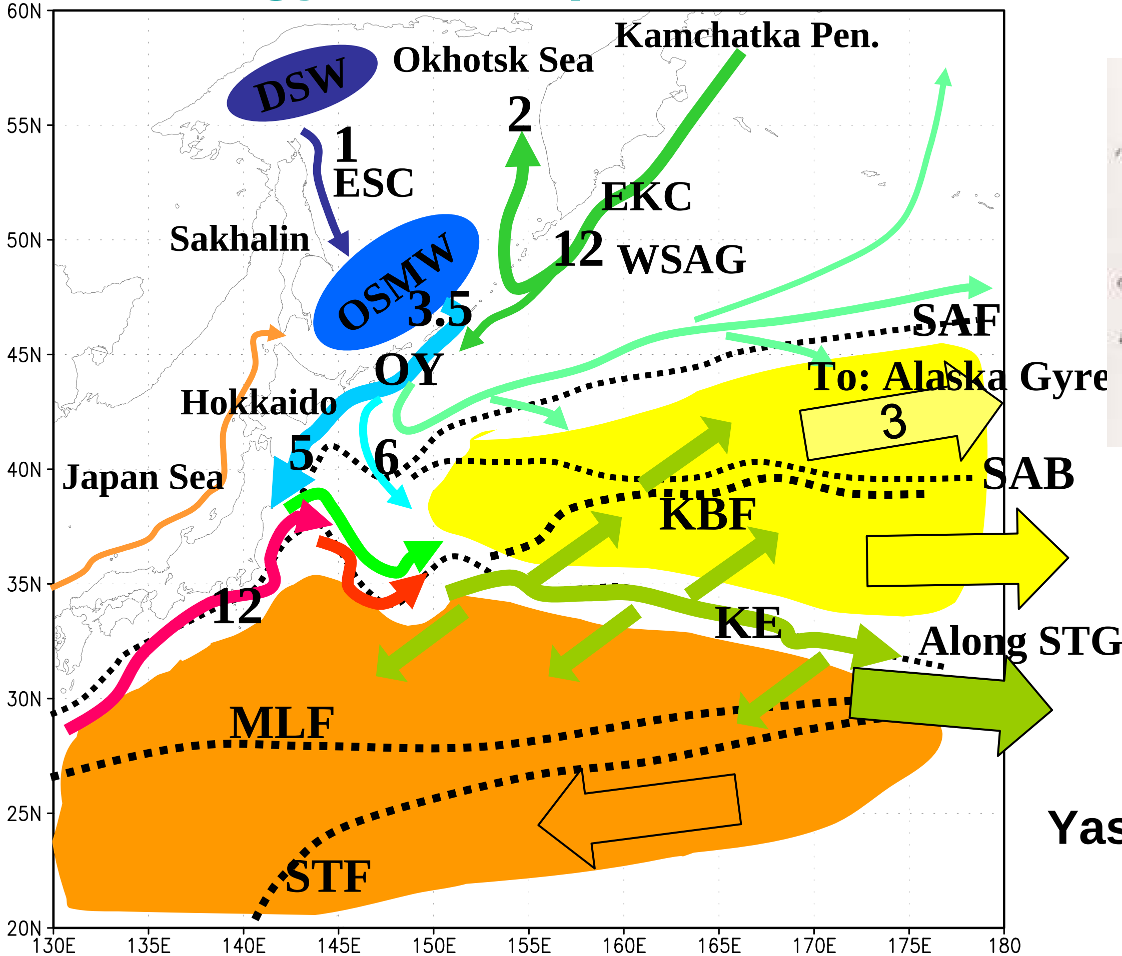


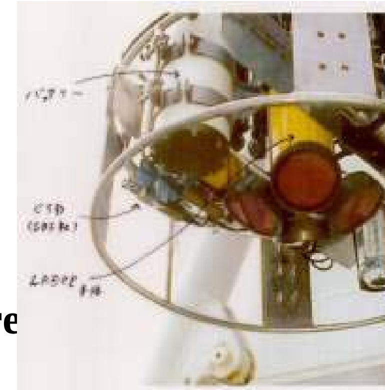
New hypothesis: Direct cross-gyre Oyashio transport produces NPIW
(Yasuda et al. 1996; Yasuda 1997)

The low-salinity and low-PV Oyashio water comes from the Okhotsk Sea (Yasuda 1997JGR)



SAGE(SubArctic Gyre Experiment：1997-2002) intensive observations confirmed and quantified the direct cross-gyre transport as about 5-7Sv





Yasuda (2004JO)

SAGE special issues in Journal of Oceanography (2004 and 2005)

Yasuda et al.2001JGR; Katsumata et al.2001GRL; Yoshinari et al.2001GRL
Hiroe et al. 2002DSR; Yasuda et al.2002JGR; Shimizu et al 2003JPO
Ono et al.2003JO Masujima et al. 2003JO; Iwao et al. 2003JO, Miyao&Ishikawa

New driving force for NPIW circulation: Strong tidal mixing around Kuril Straits

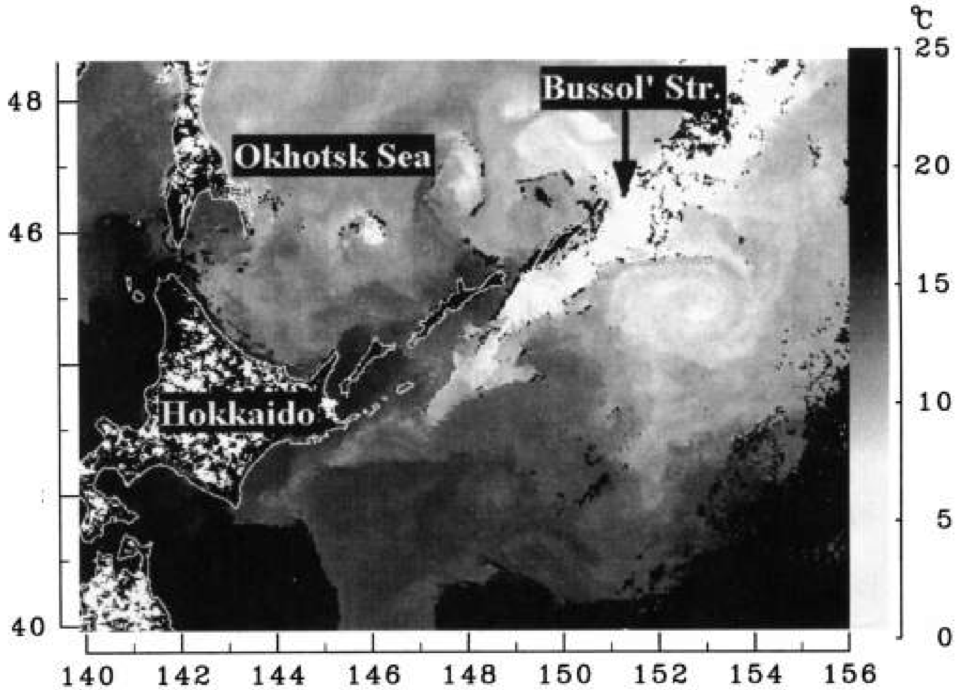
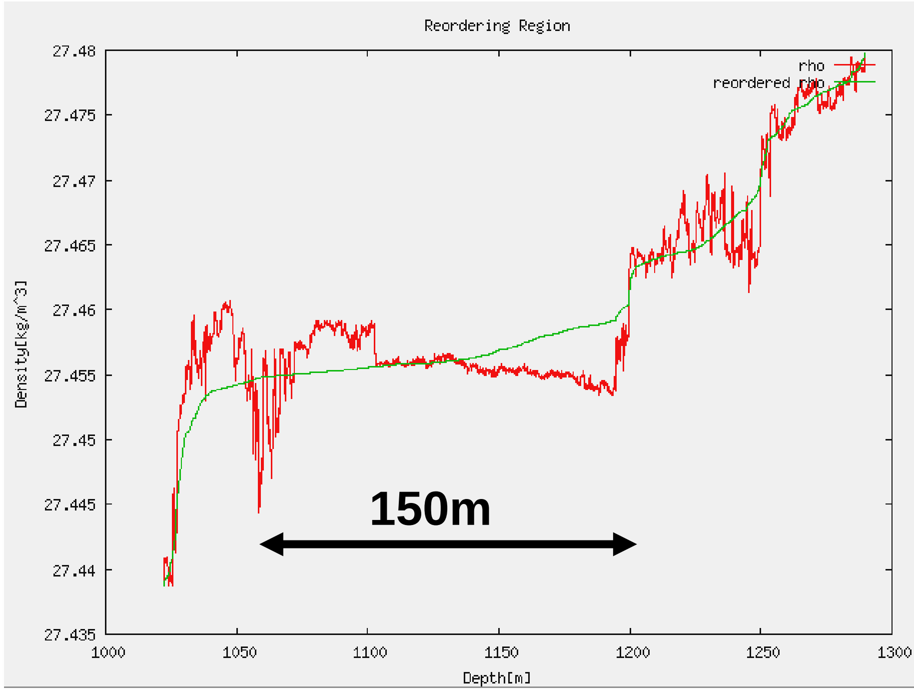
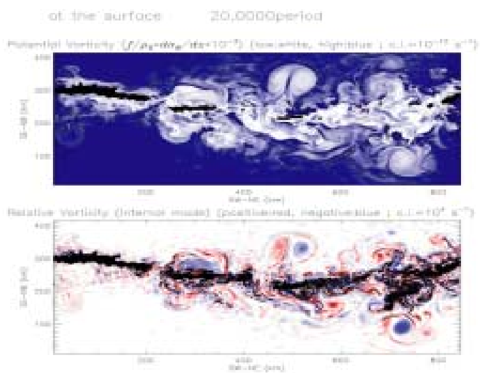


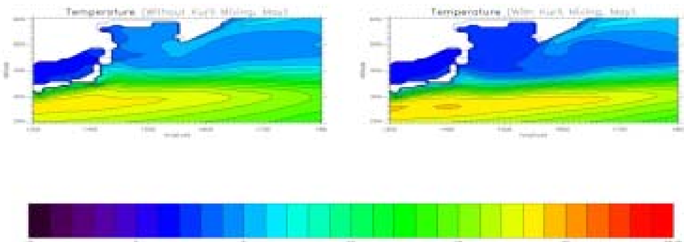
FIG. 1. NOAA AVHRR infrared image showing a large, cold-core anticyclonic eddy south of the Bussol' Strait on 10 October 1995.



Nakamura et. al (2000ab) suggested that strong diurnal tides induce large Vertical mixing of O(10^2) cm^2/s that is possible from the Thorpe-scale Analysis using density inversions (Yagi & Yasuda POC-Poster)

Modelling of NPIW considering large diapycnal mixing around the Kuril Straits
(Nakamura et al. 2004)





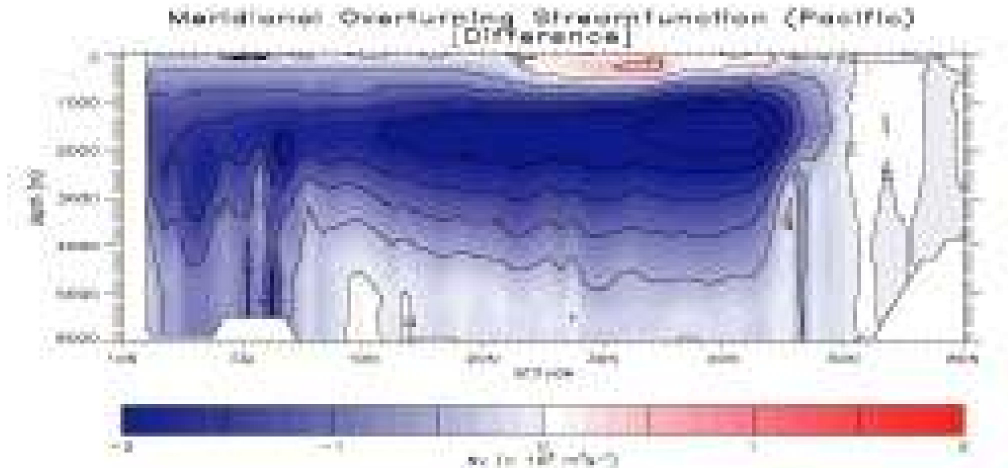


Fig. 13. Difference of the meridional overturning stream function in the North Pacific between the control and mixing cases. The values are averaged annually.

GCM of（Nakamura, Awaji et al. 2004JO) showed that the strong diapycnal mixing around the Kuril Straits (～200cm^2/s) [Nakamura et al. 2000] cause upwelling and make salinity high that enhances the dense shelf water production in the northwestern Okhotsk Sea shelf and promotes the Oyashio cross-gyre flow.

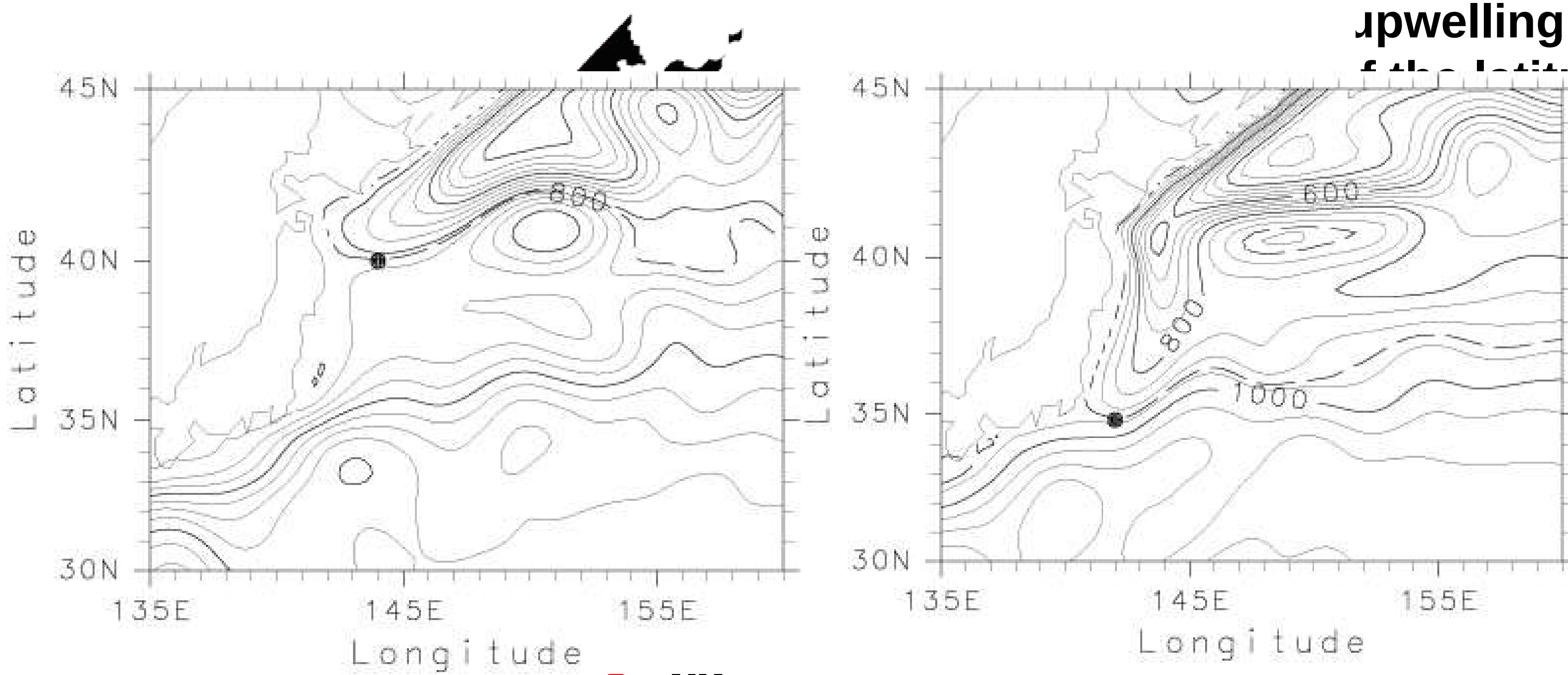
Theory of direct Oyashio cross-gyre transport

(Tatebe and Yasuda 2004JPO)

$$T_{WBC} = -\frac{1}{\rho_0 \beta}\int^{x_w} \boldsymbol{k} \bullet \nabla \times \boldsymbol{\tau}\, dx + \frac{f}{\beta}\int^{x_w} w_2\, dx - W_2$$

pwelling

de



■ w_2

Cross-gyre transport is proportional to diapycnal upwelling W_2

Oyashio southward extension enhances with the increase of W_2

New Hypothesis: Tide-induced NPIW

1) Strong tidal mixing makes surface salinity high

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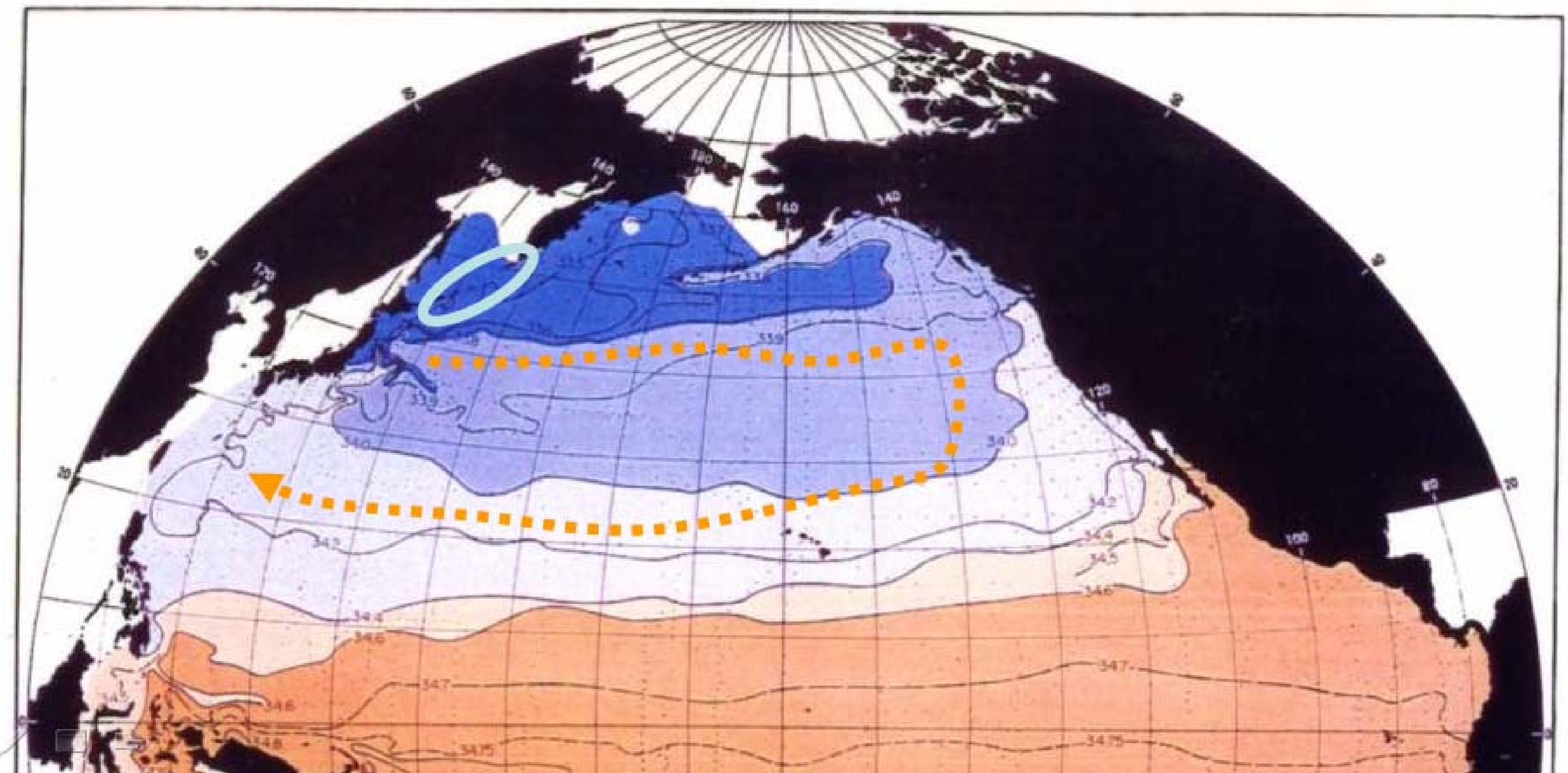

New Hypothesis: Tide-induced NPIW

1) Strong tidal mixing makes surface salinity high
2) The saline water is transported to the northwestern shelf region

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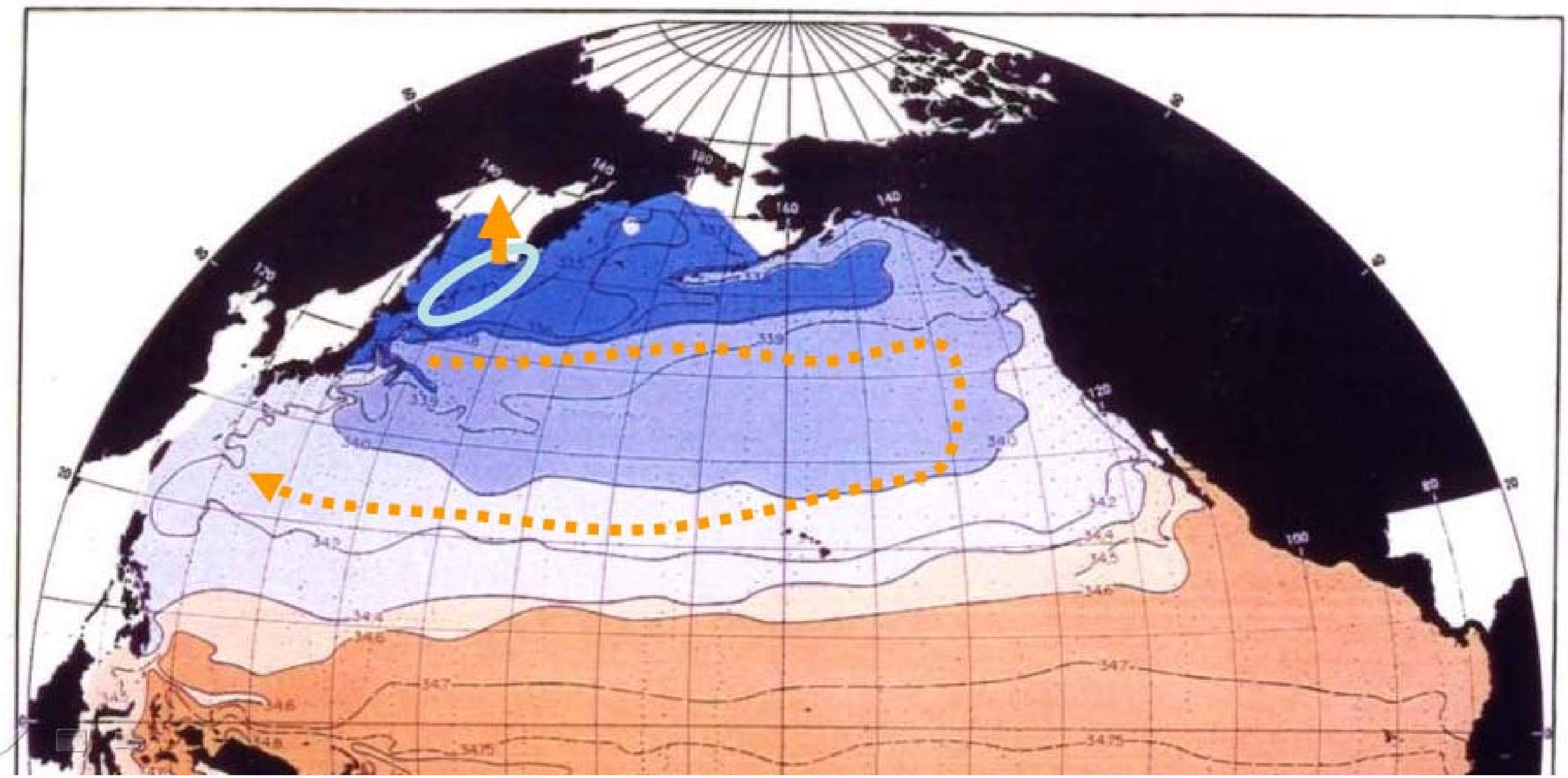

New Hypothesis: Tide-induced NPIW

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3) Sinking and formation of dense shelf water and mid-depth freshening

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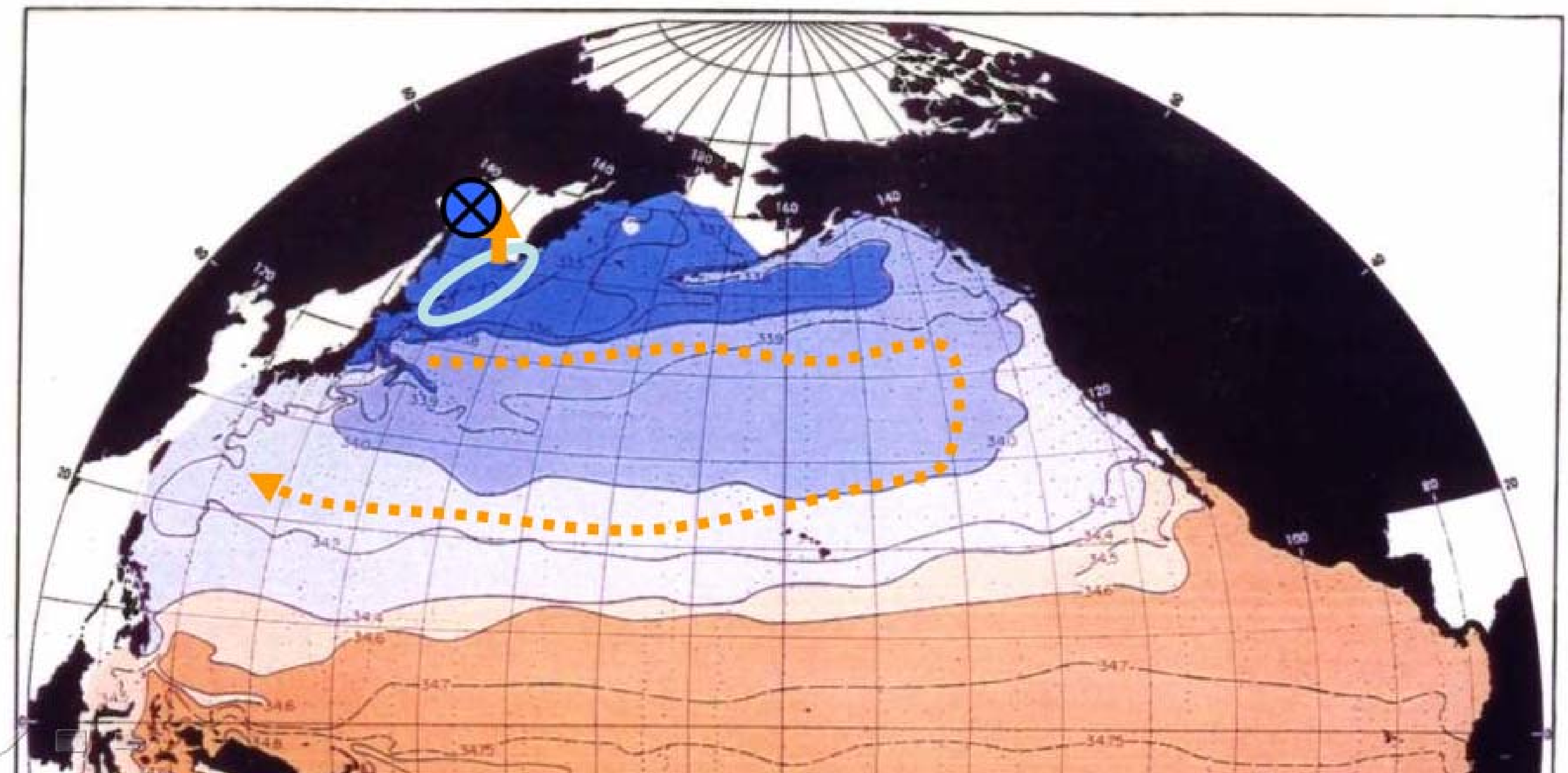

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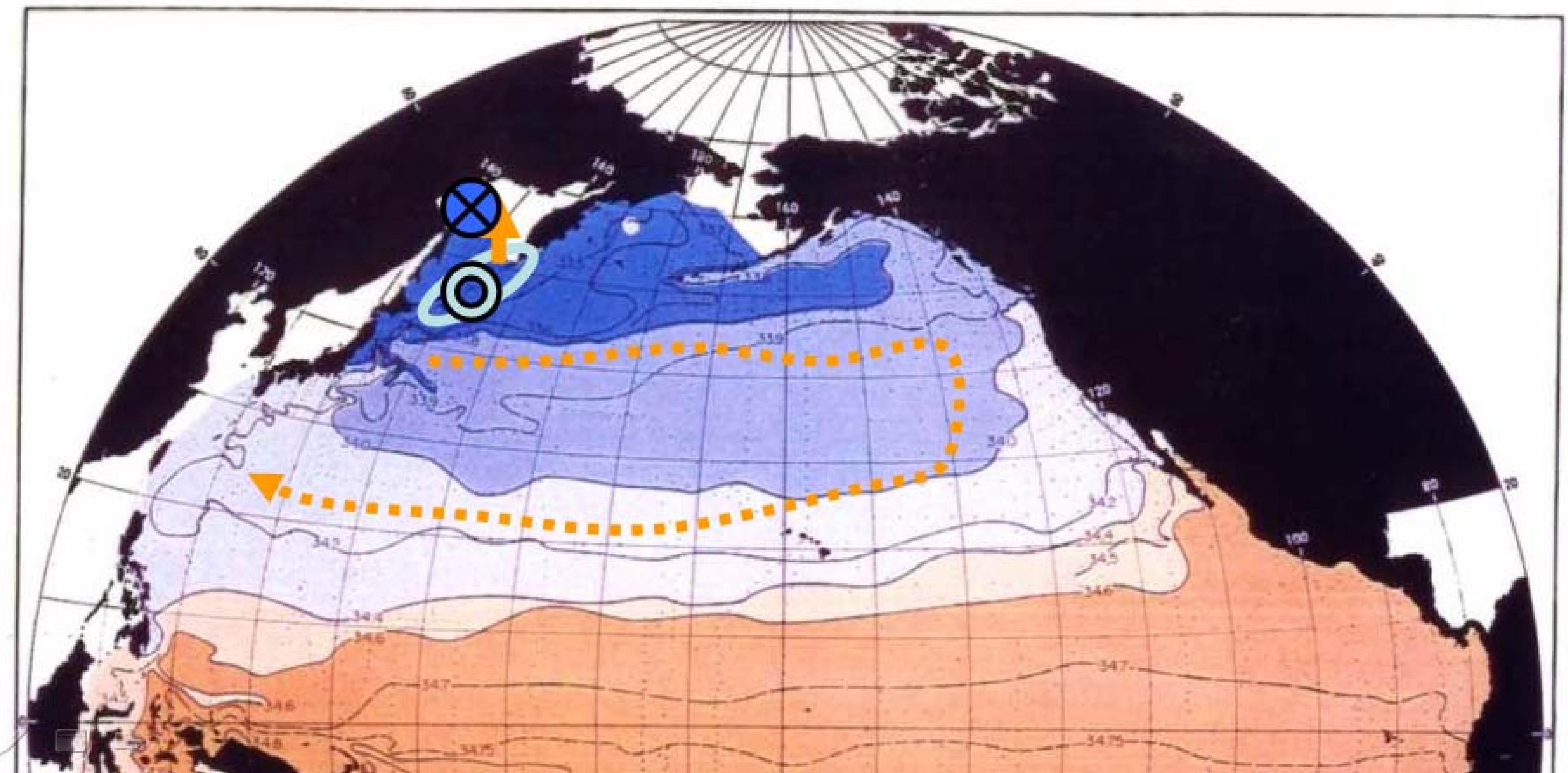
4) Diapycnal upwelling due to strong tidal mixing from deep to mid-depth



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3) Sinking and formation of dense shelf water and mid-depth freshening

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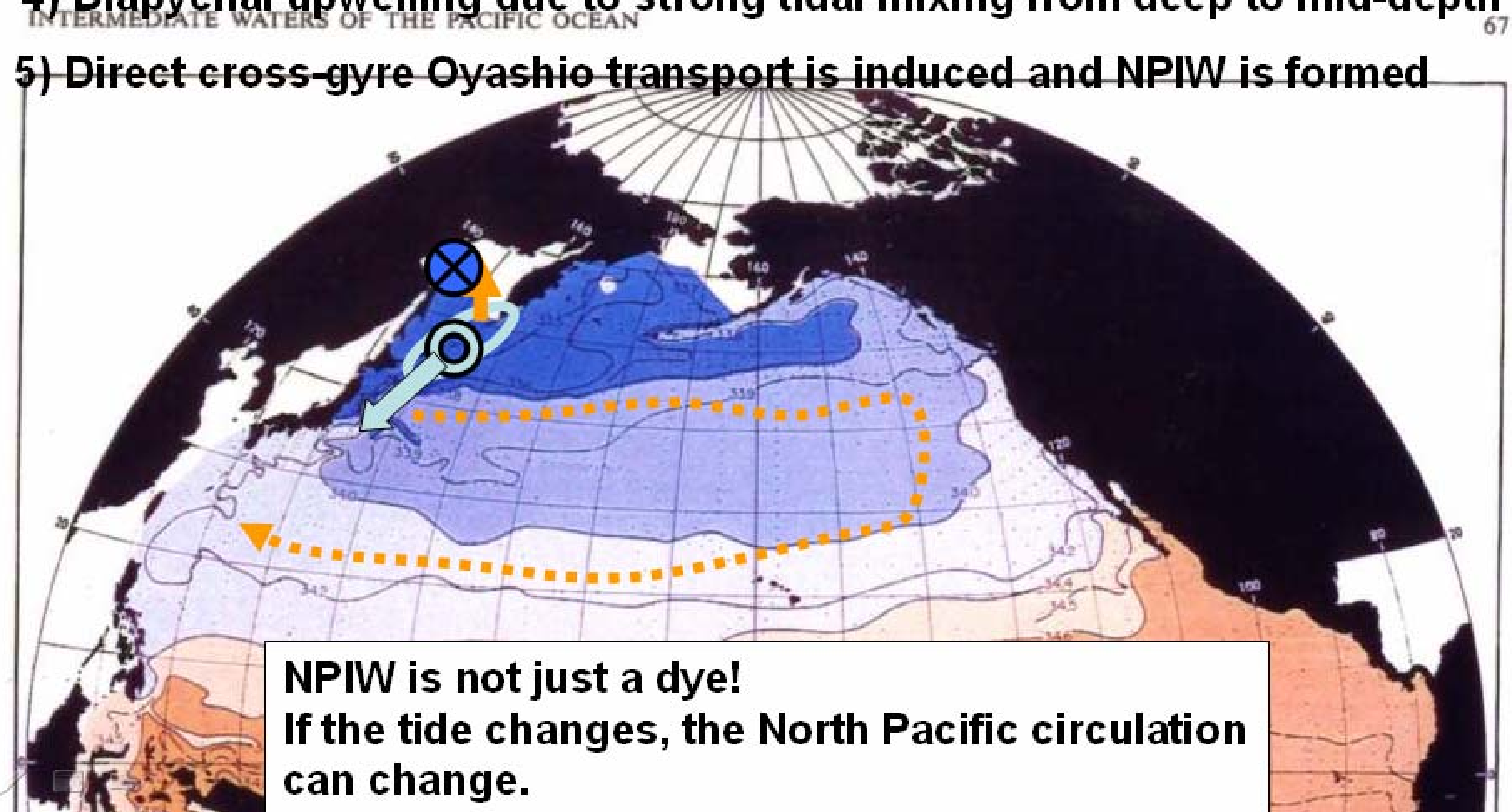
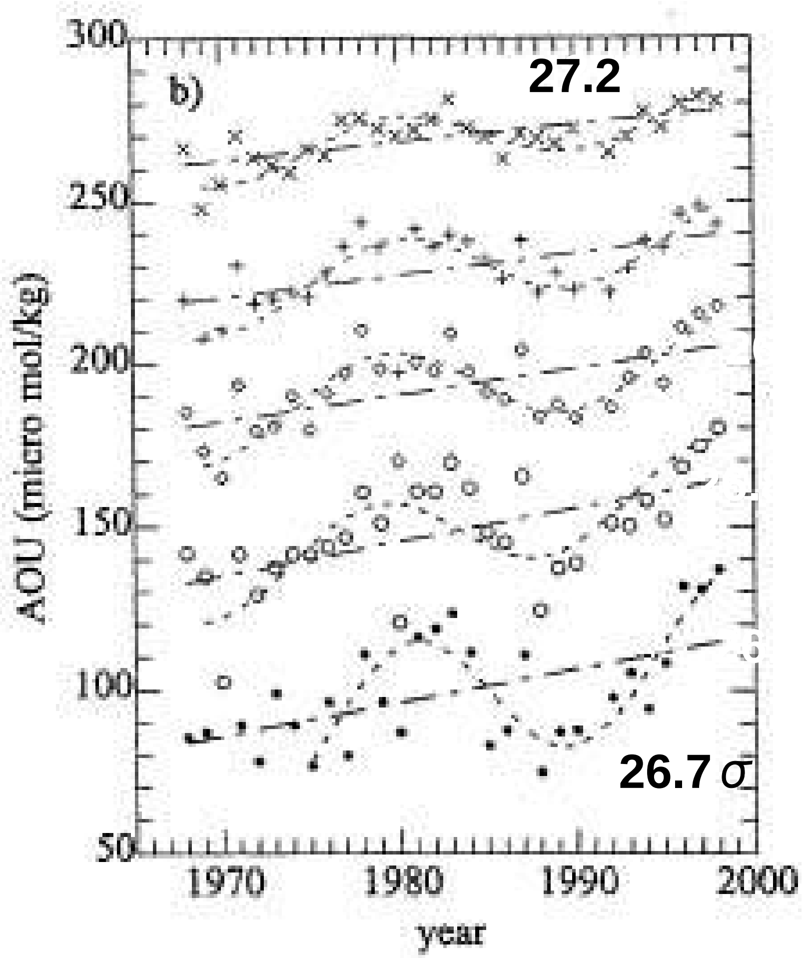
5) Direct cross-gyre Oyashio transport is induced and NPIW is formed



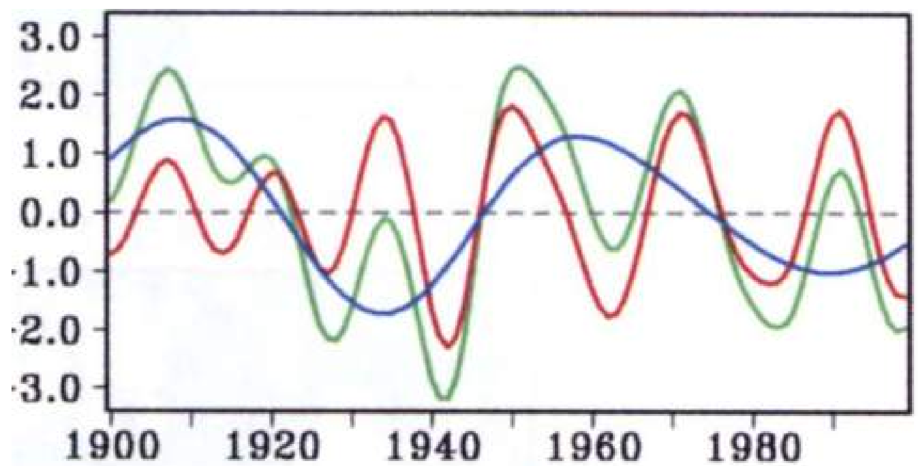
NPIW is not just a dye!
If the tide changes, the North Pacific circulation can change.

Bidecadal variations in Oyashio intermediate water and NPI & PDO



Ono et al. (2001)
Watanabe et al. (2001)

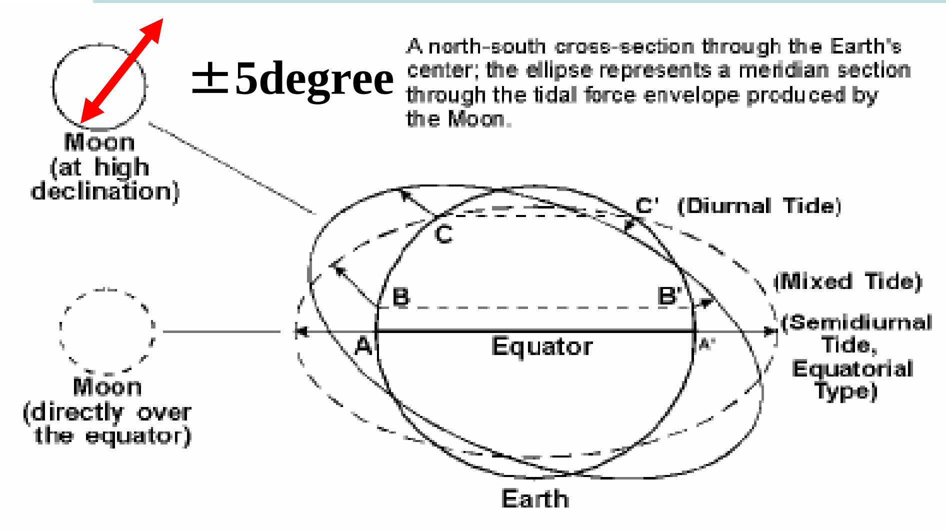
Winter-NPI Minobe (2000 PiO)

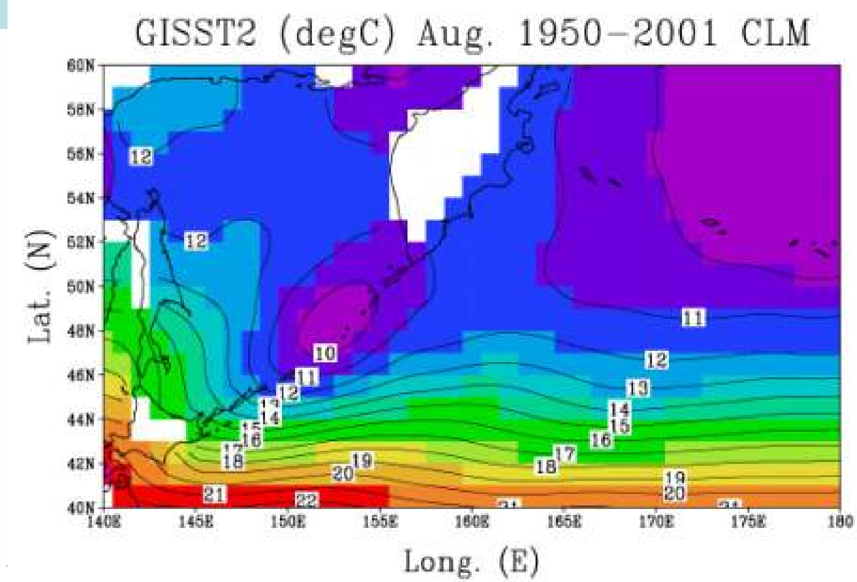


Bi-decadal period oscillation in Oyashio is synchronized with NPI bidecadal Osci.

However, this signal is not directly from atmosphere because the waters are not outcropped even in winter.

18.6-year period nodal tidal cycle





Inclination of moon orbit to the earth equatorial surface changes as 23.4±5deg with 18.6-year period（James Bradley, 1798）

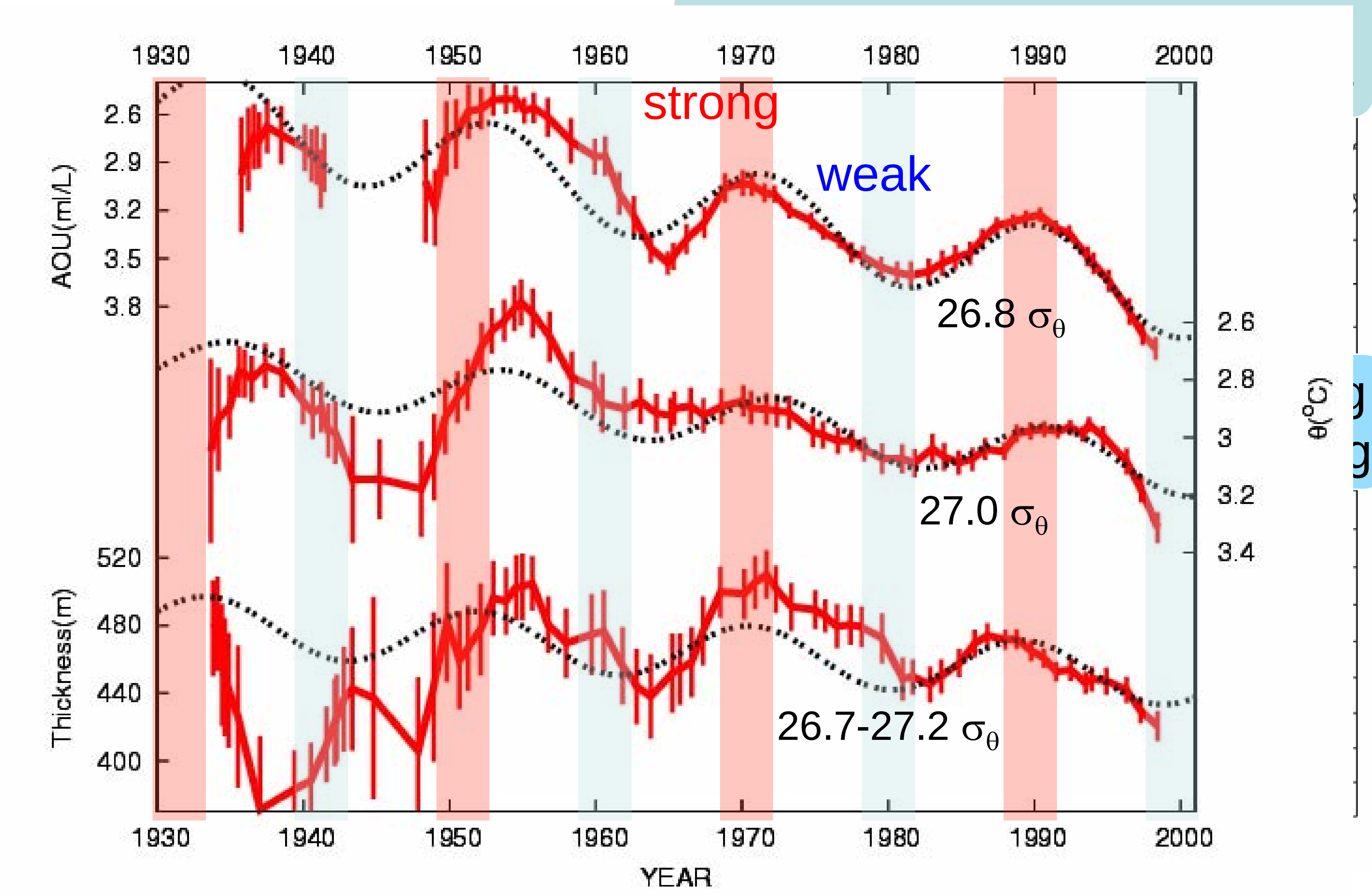
Strong tidal mixing around Kuril Islands up to Kv=O(100)cm2/s makes summer SST cooler.

Amplitude of the diurnal tides (K1,O1) modulates by max. 20%

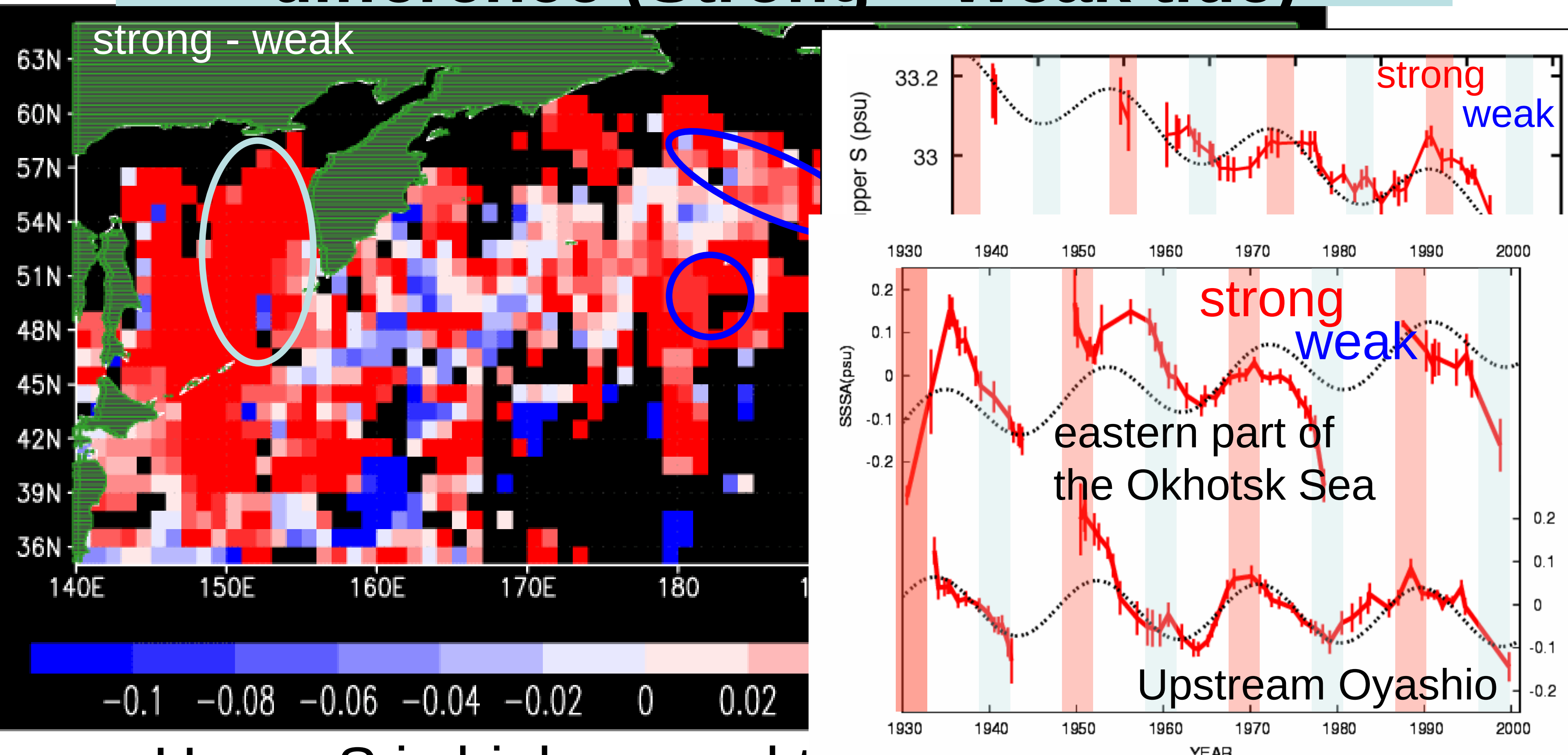
Many reports on the nodal cycle in the atmosphere and oceans (Maximov & Smirnov 1970; Currie 1984 etc.)
Loder & Garret (1978) Royer (1993) indicated the tidal mixing as a probable cause

Okhotsk-Oyashio bi-decadal oscillation and 18.6-year cycle

Osafune & Yasuda (2006JGR)



Upper-layer (0-100m) salinity difference (Strong – Weak tide)

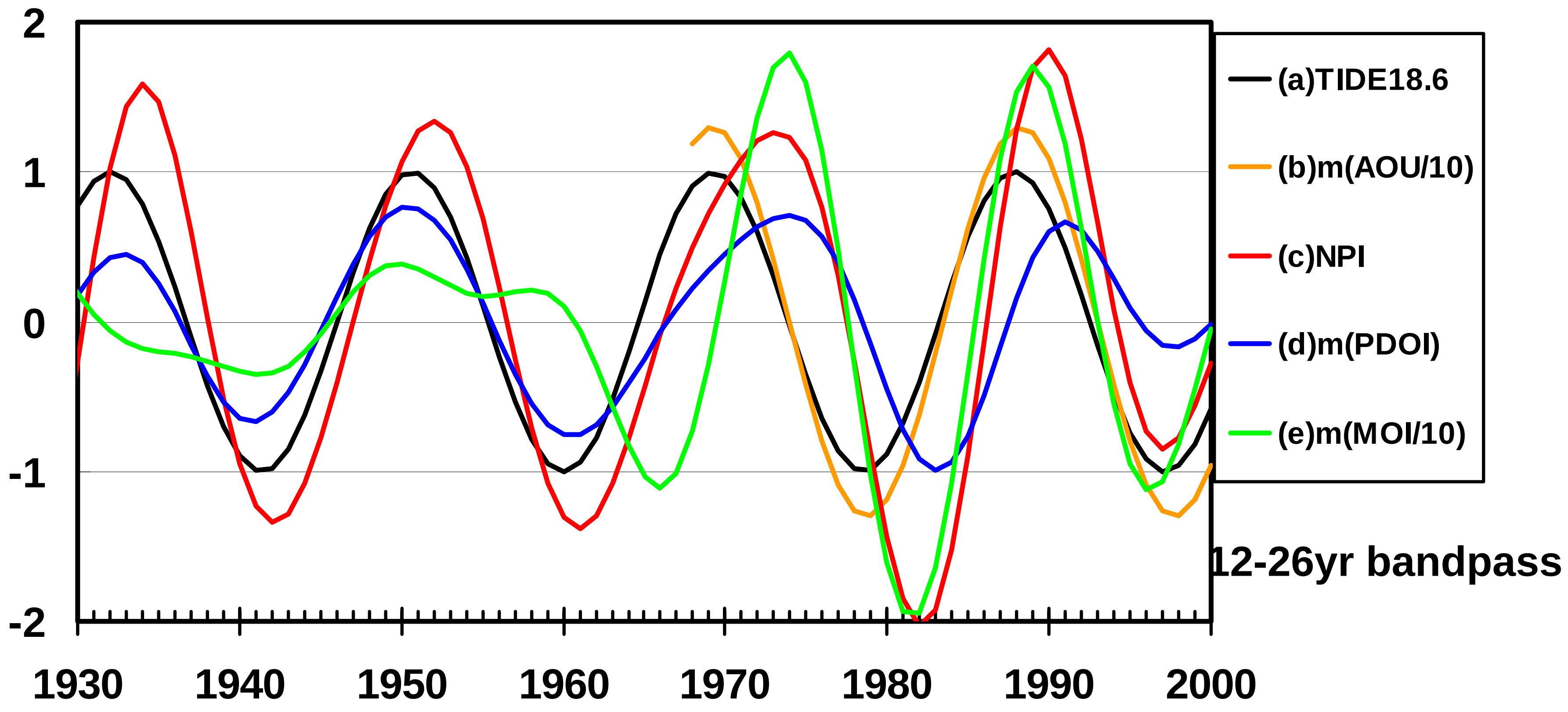


- Upper S is high around the strong tidal mixing region when the diurnal tide is strong
  – Aleutian Straits, Continental Shelves, Kuril Straits

(Osafune & Yasuda POC, Paper-3150)

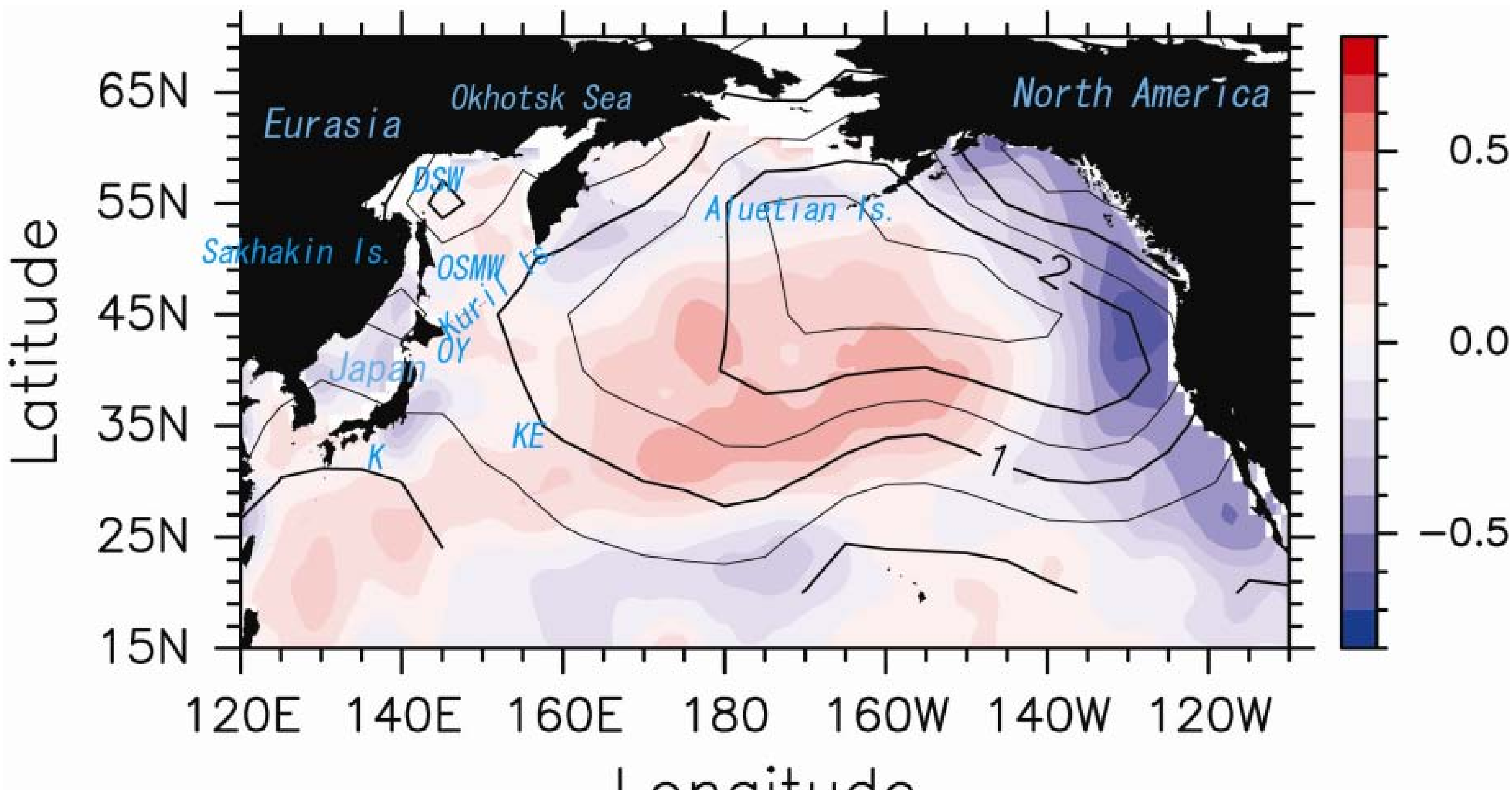
18.6-year tidal cycle is seen in the climate indices of winter-NPI/PDOI/MOI

(Yasuda et al. 2006GRL)



In the period of strong diurnal tide, negative-PDO, positive-NPI and Weak winter East Asian Monsoon. The phase looks delayed for the nodal Cycle, implying the influence from the ocean to the atmosphere.

Winter SST/SLP difference (Strong-Weak): warm KOE SST ←→weak winter-Aleutian Low & Monsoon (Yasuda et al. 2006GRL)

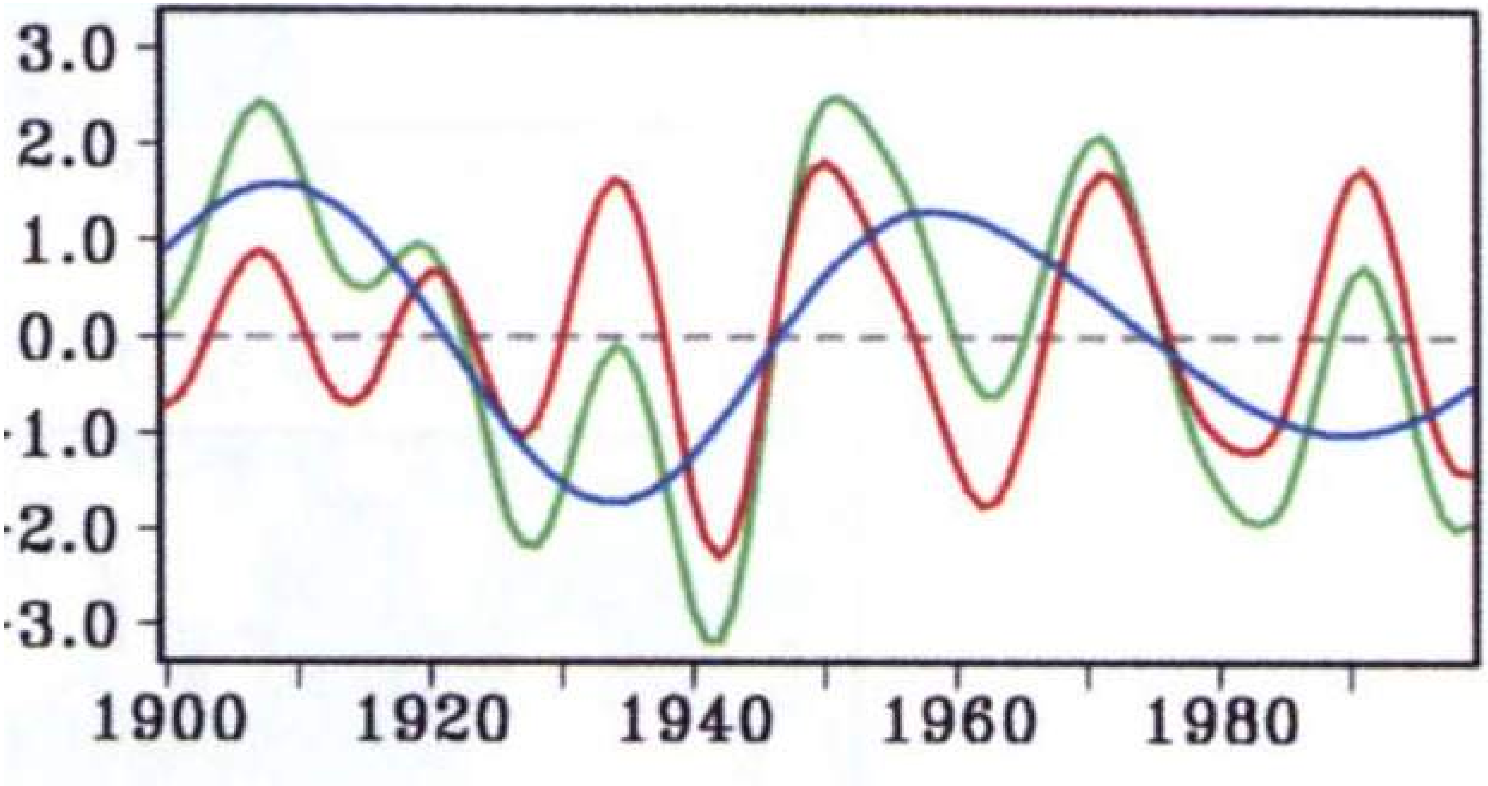


12-25-year bandpassed Feb-SST/SLP difference

18.6-year nodal cycle acts as a basic forcing for the bi-decadal ocean/climate
Air-sea coupled model experiment is going on with Prof. Hasumi in CCSR.

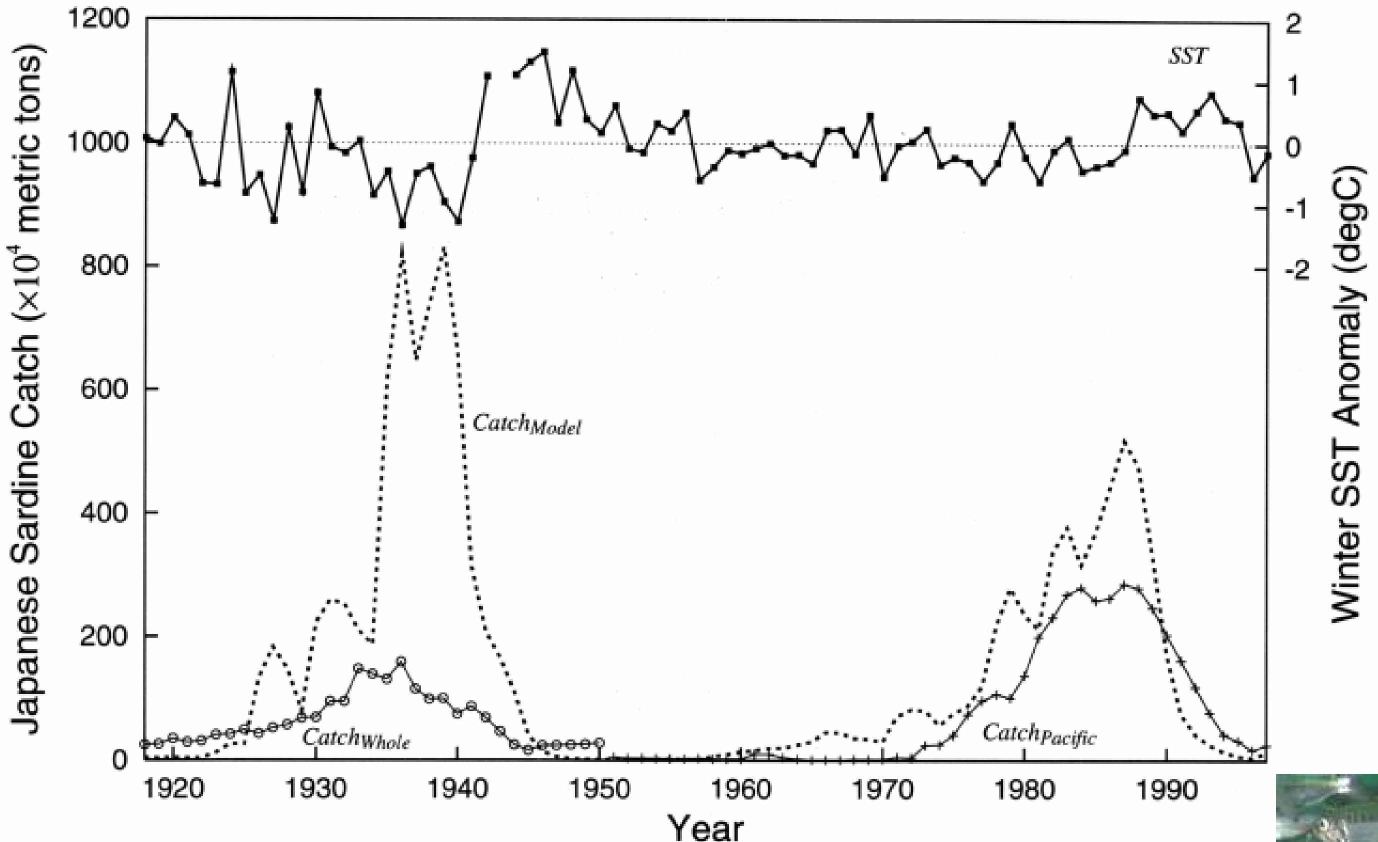
Bi-decadal and Penta-decadal North Pacific oscillations (Minobe 1997; 1999)

Winter-NPI Minobe (2000 PiO)



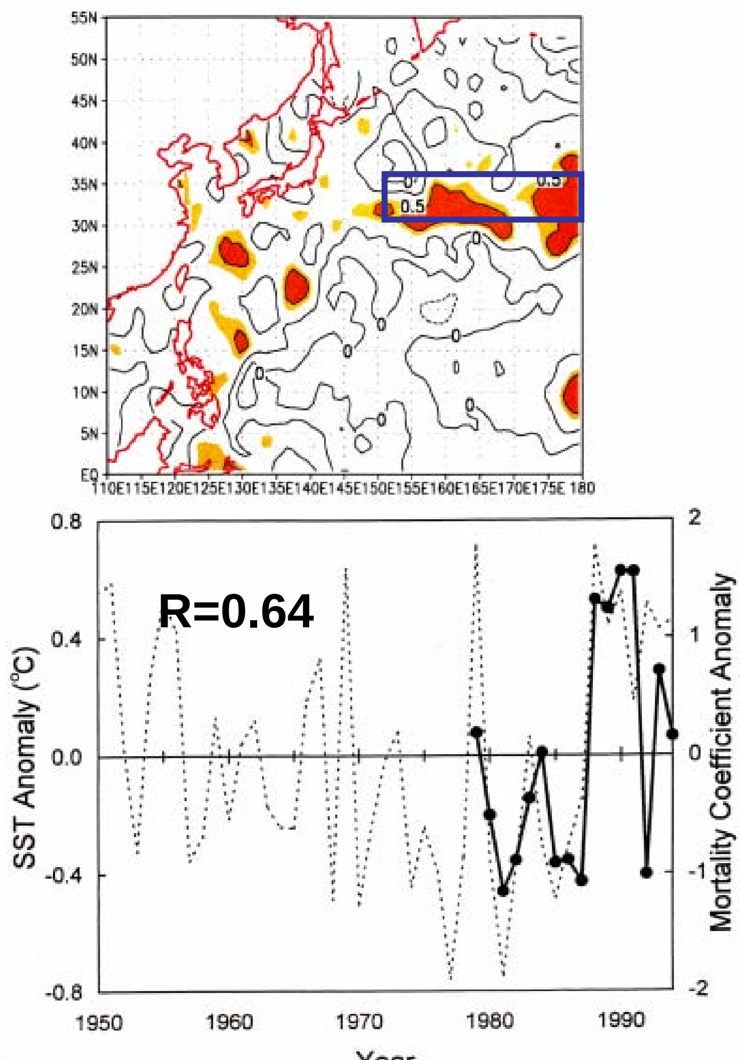
Bi-decadal and Penta-decadal oscillations in the North Pacific are Synchronized (Minobe 1999).
Penta-decadal oscillation can be excited by bi-decadal oscillation in a periodic-forced delayed-oscillator model (Minobe and Jin 2005)

Penta-decadal Oscillation in the Kuroshio Extension winter-SST and Japanese sardine (Noto & Yasuda 2006FO submitted)



Catch variation of Japanese sardine corresponds to 50-70year period SST variations in the Kuroshio Extension.

Survival rate of Japanese sardine and winter-spring SST in the Kuroshio Extension
(Noto & Yasuda 1999 CJFAS)



- Mortality coefficient of Japanese sardine from post-larvae to age-1 co-varied with winter-spring SST in the Kuroshio Extension and southern recirculation regions (KESA: 145-180E, 30-35N)

  on a year-to-year basis.
- High SST: high-mortality

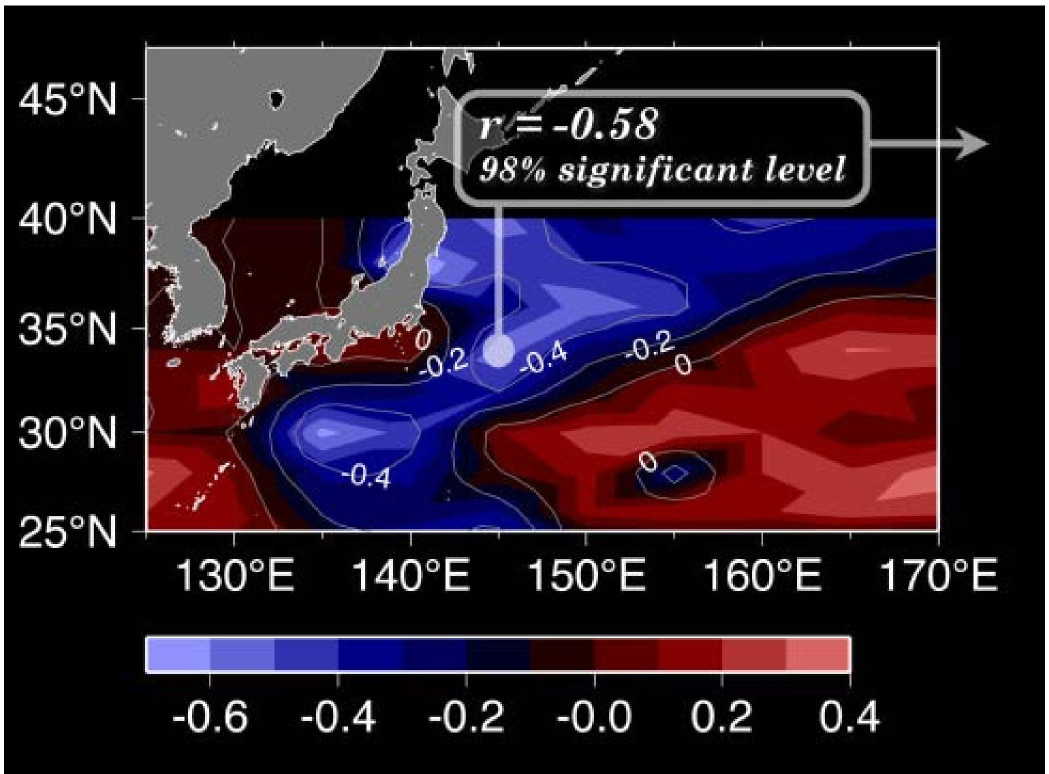
  Low SST: low-mortality
- SST-jump in 1988 and successive warm-SST may lead to sardine collapse
- Low-SST from 1970 to 1987 may lead to large peak.

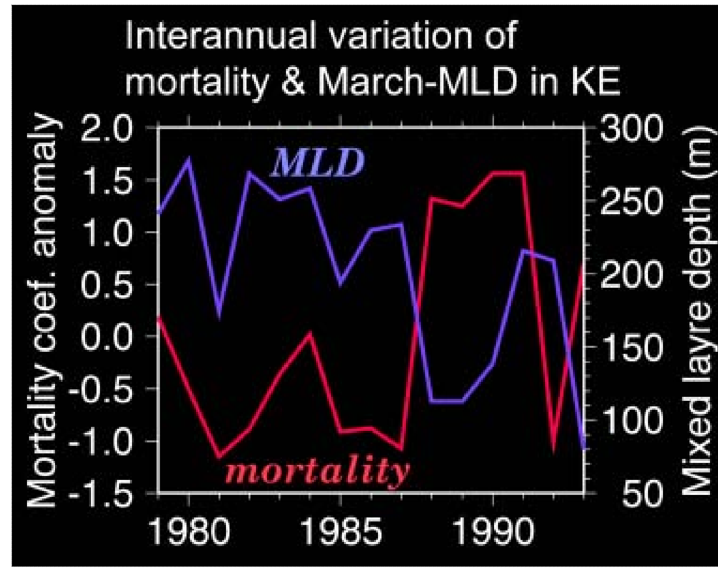
Mortality coefficient M: N=N0・exp(-M)

Mixed layer depth & sardine mortality

(Nishikawa & Yasuda 2006 submitted FO)

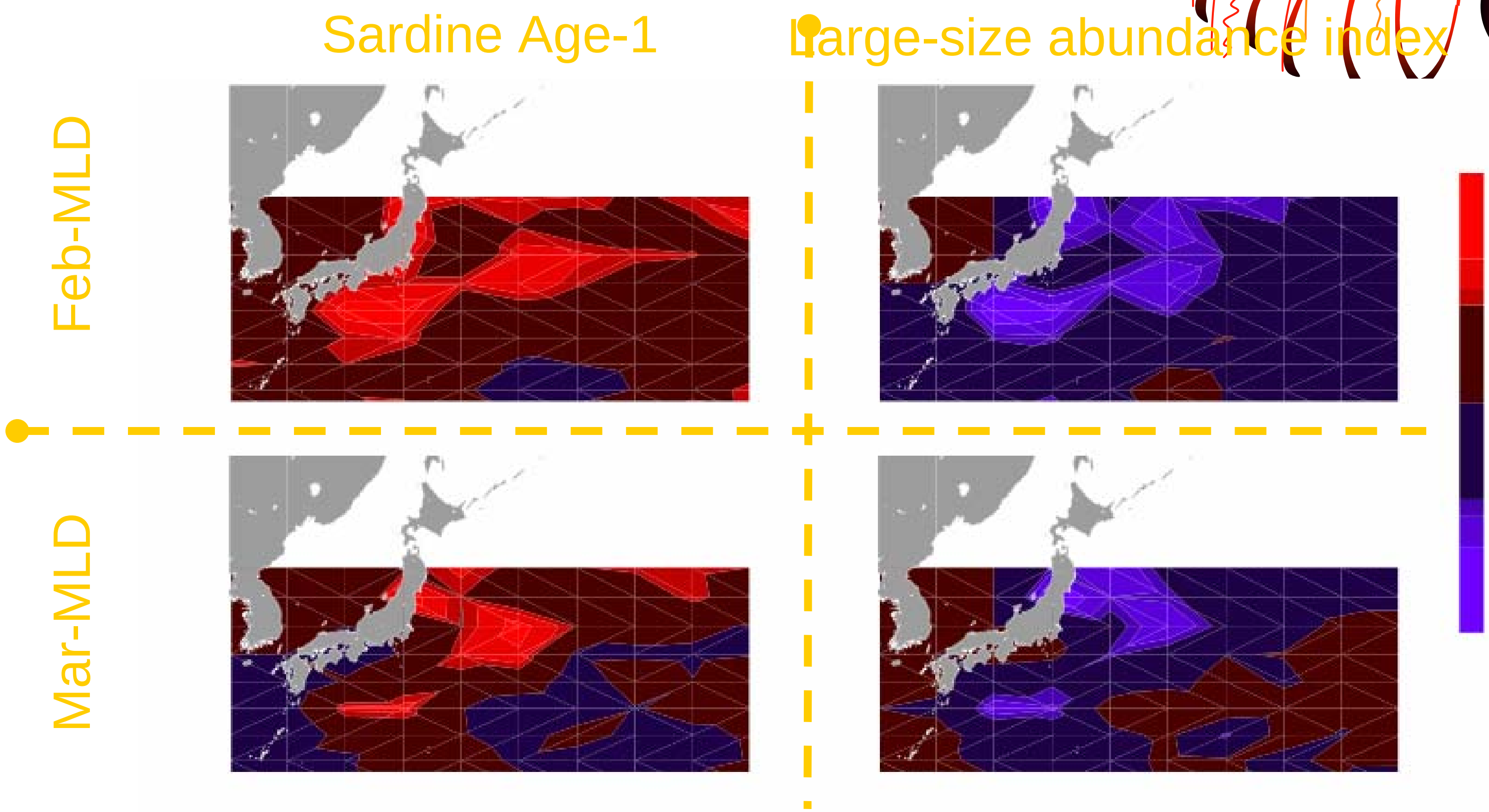
Correlation map of March-MLD & mortality (1979-1993)





Negative correlation between winter MLD and mortality

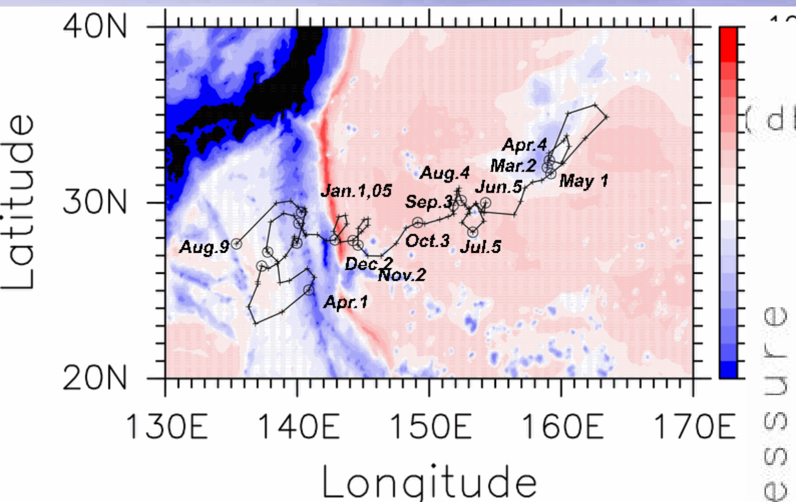
Large mortality occurred in year of shallow winter MLD

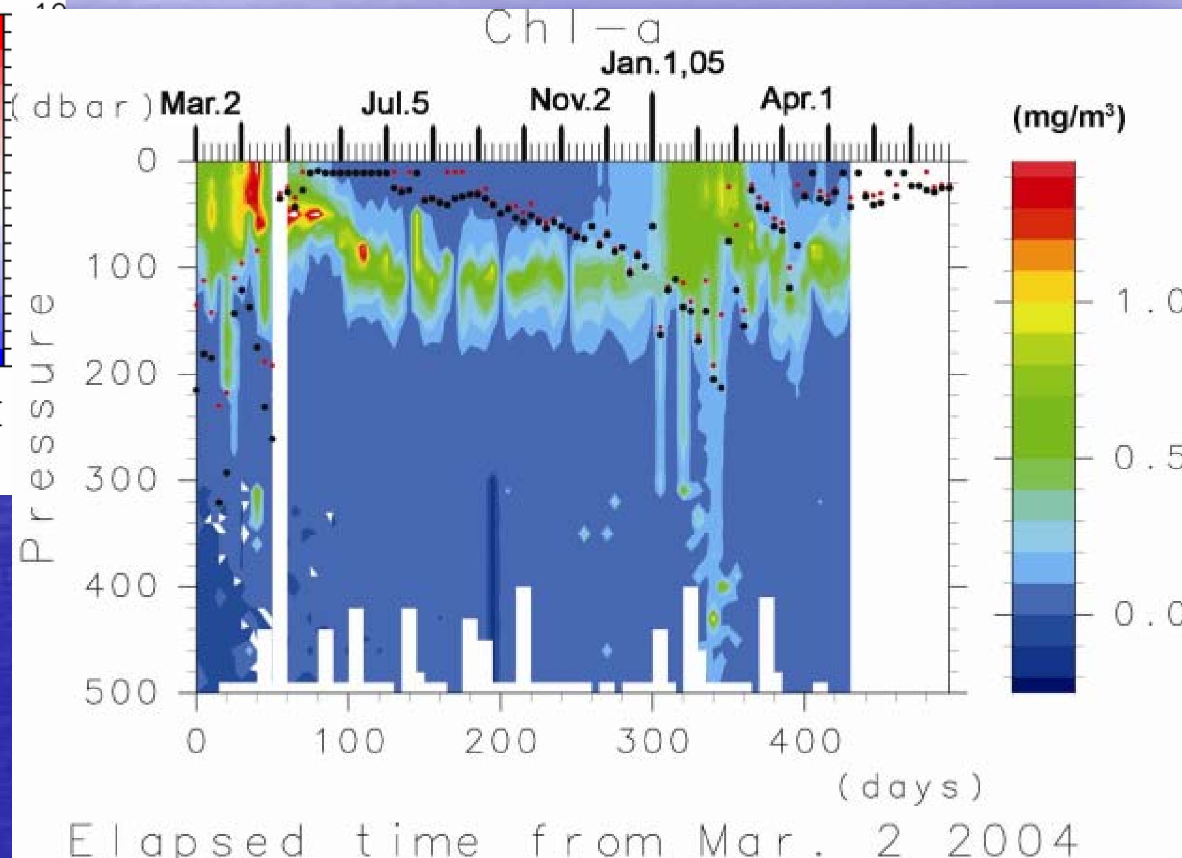


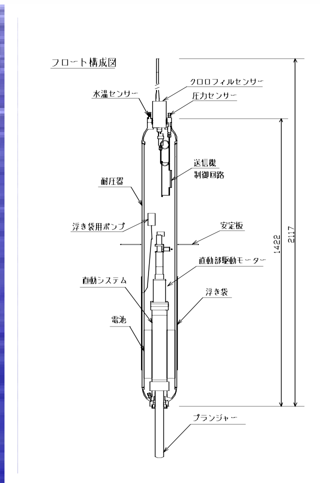
- Winter-deep MLD -→ better survival of sardine
- Winter-shallow MLD-→ abundant saury

Mixed-layer tracking profiling float with Chl-a sensor deployed in the Kuroshio Extension

(Mar. 2004- July 2005) (Yasuda & Watanabe 2006 FO submitted)

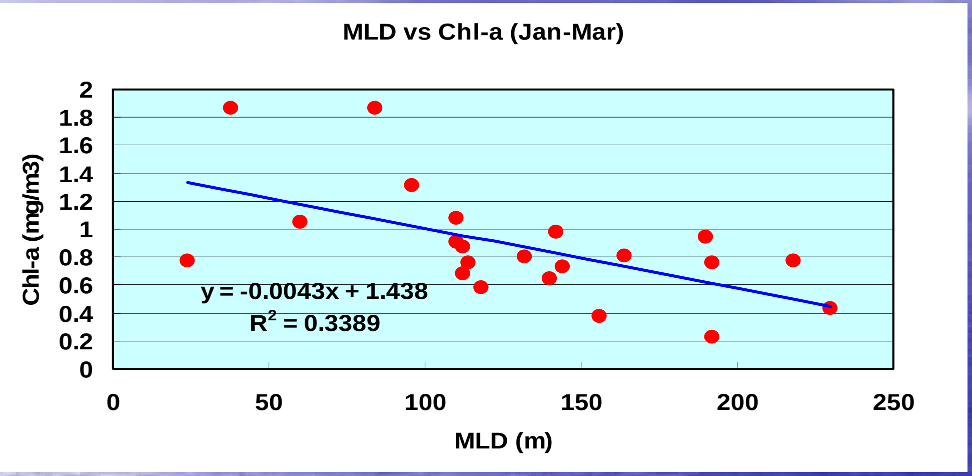






Phytoplankton bloom is found to occur in winter in the KE even though MLD is large compared with the other season.

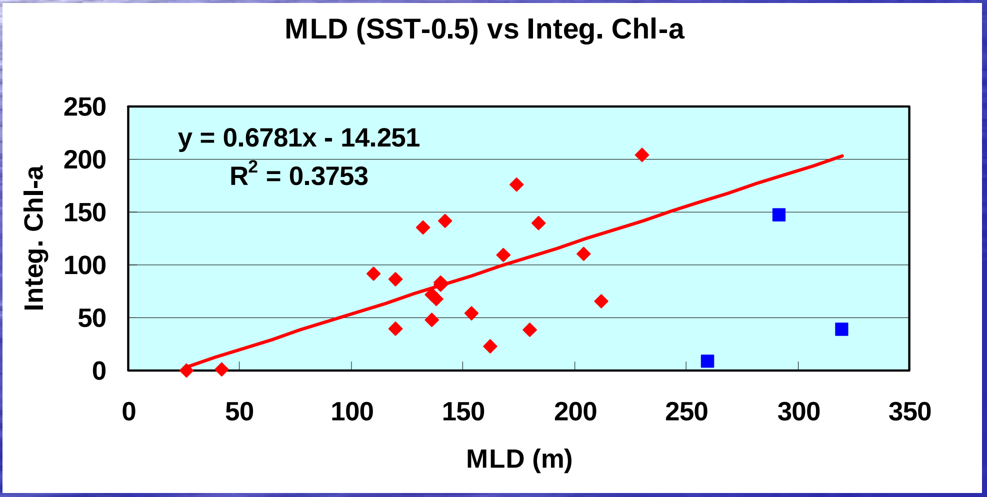
Relation of winter-MLD and Chl-a

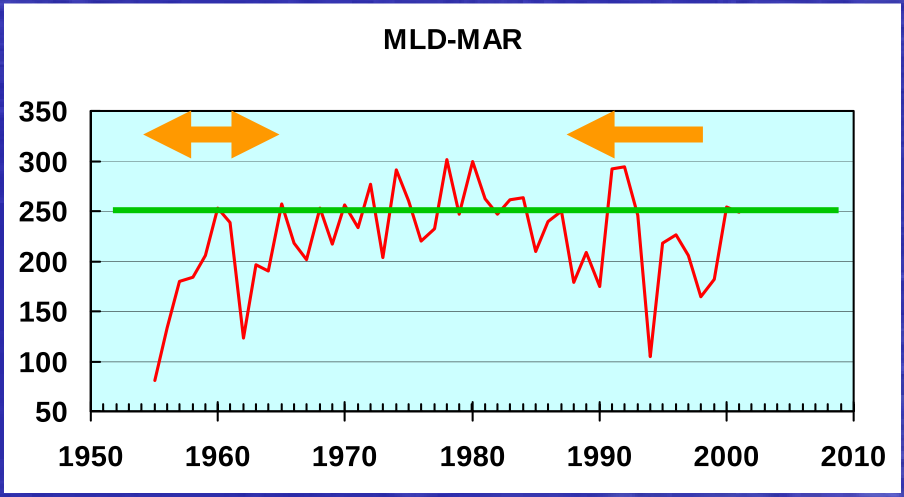


- In winter, Chl-a decreases with MLD
- Total Chl-a integrated in the mixed layer --

  increases with MLD for MLD<250m

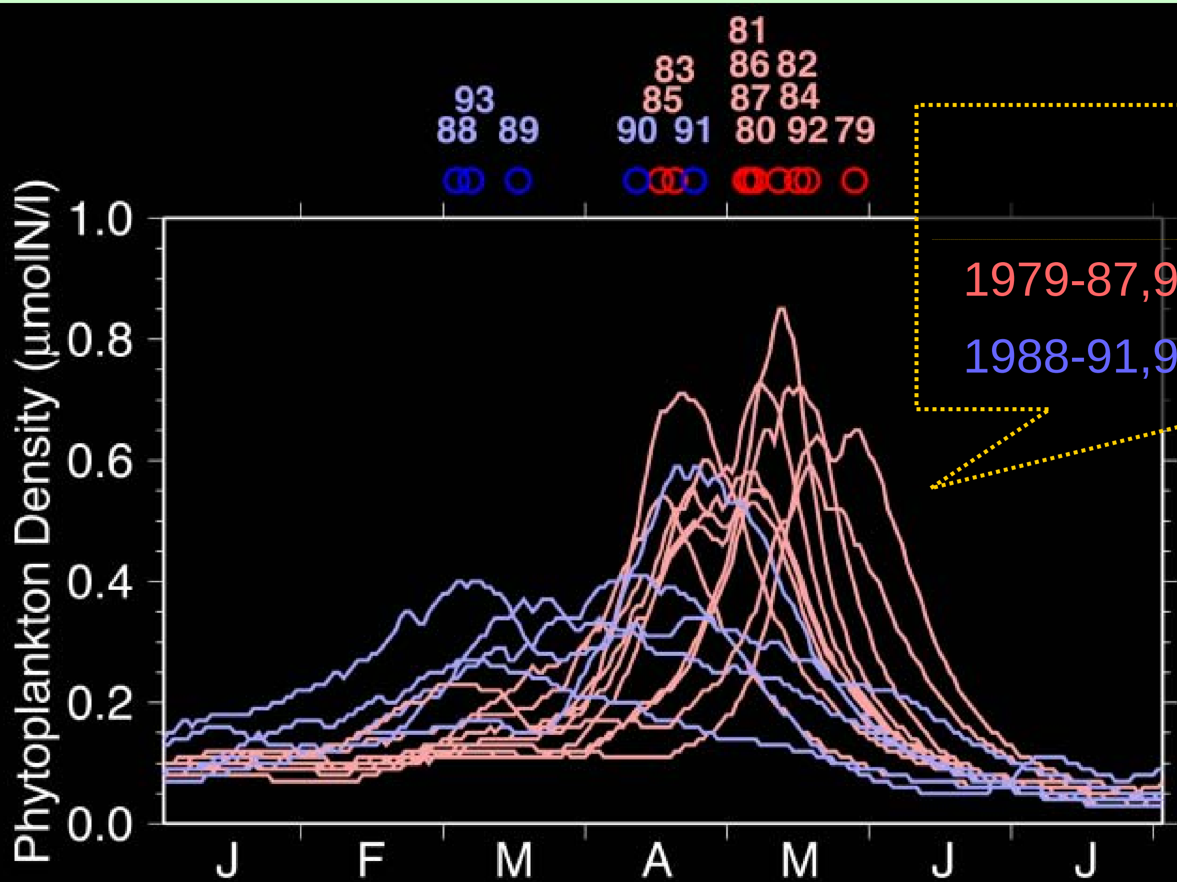
  almost disappears for MLD>250m
- In the period of MLD>250m, food density for winter saury larvae could be quite low.
- Deep-MLD period corresponds to low large-size saury population.





Mar-MLD time-series

Variability of plankton bloom using NEMURO model *(Nishikawa & Yasuda PICES-14)*



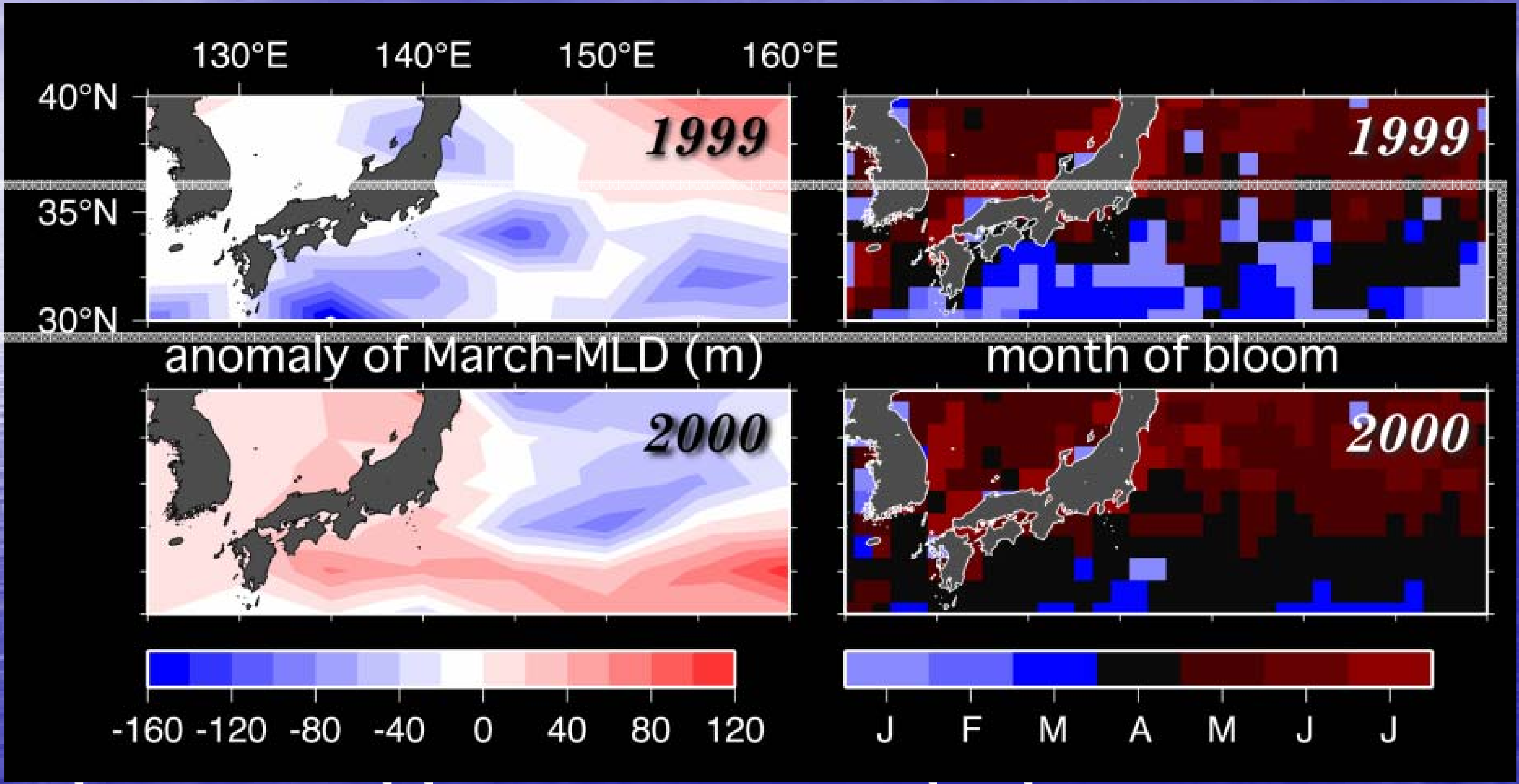
	morality anomaly	MLD
1979-87,92	negative	> 170m
1988-91,93	positive	< 170m

Deep winter MLD Phytoplankton bloom occur in late April - May

Shallow winter MLD Phytoplankton bloom occur in March - early April

- **Match-mismatch of plankton bloom to winter-saury and spring-sardine could determine the species replacement between sardine and saury.**

Plankton bloom & winter MLD from SeaWiFS ocean color (Nishikawa & Yasuda PICES-14)



Bloom occurred during January to March, when winter MLD was shallow as in 1999. Pacific saury can use this winter bloom; while Japanese sardine possibly needs big spring bloom

Final Remarks

- **Changing view of Northwestern Pacific circulation, long-term variability and ecosystem**

--- Vertical mixing and 18.6-year tidal cycle are important to explain the North Pacific inter-decadal variability

--- Timing of plankton bloom and related Mixed layer process and biological response are important to explain the species replacement of small pelagic fishes