A modeling study of the North Pacific shallow overturning circulation

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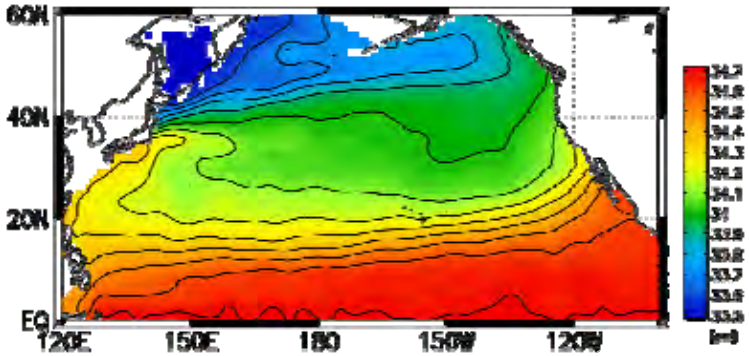
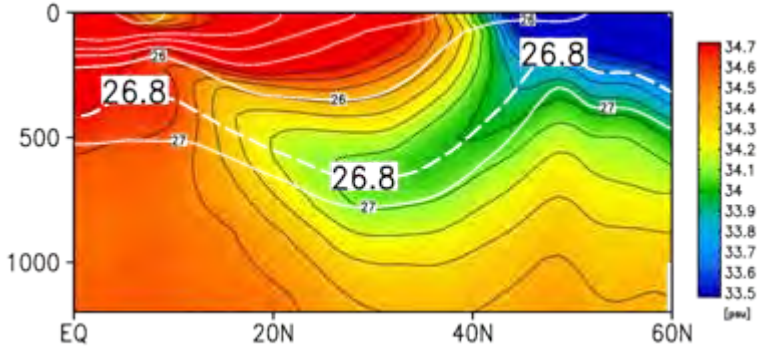
Kawasaki, T., and H. Hasumi (2010):
“Role of localized mixing around the Kuril Straits in the Pacific thermohaline circulation”, J. Geophys. Res. Oceans., 115, C11002, doi:10.1029/2010JC006130.

North Pacific Intermediate Water (NPIW)

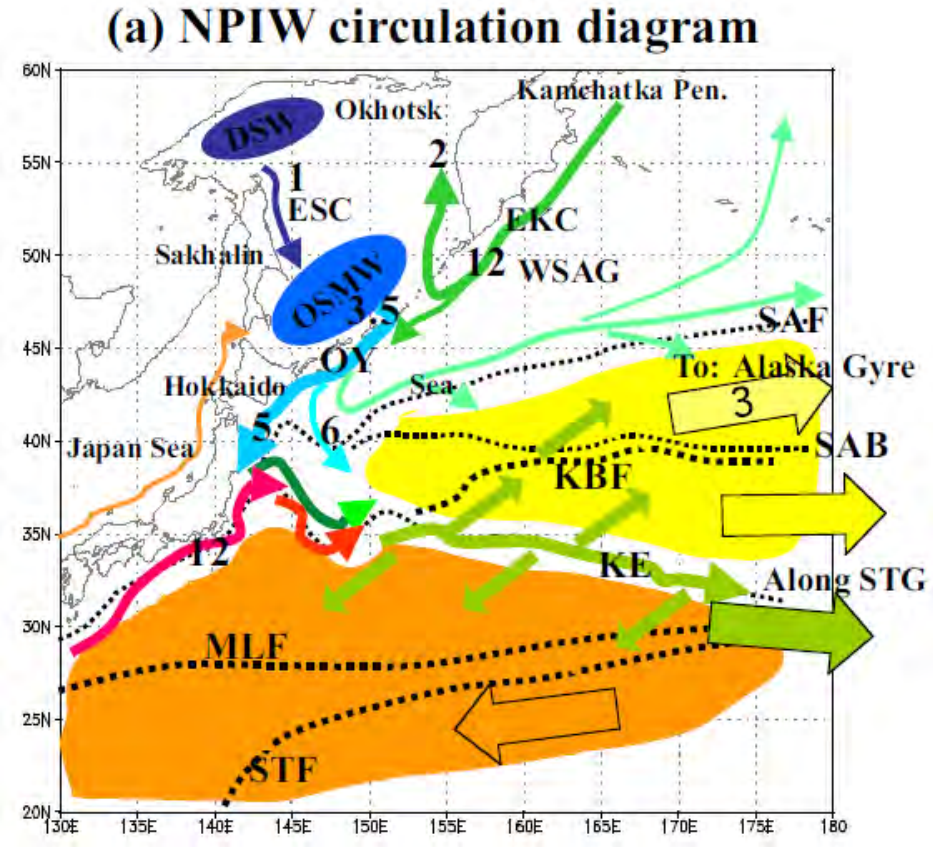
Salinity (26.8 σ_θ)



Salinity & Density (Longitude = 180)



World Ocean Atlas (2001)



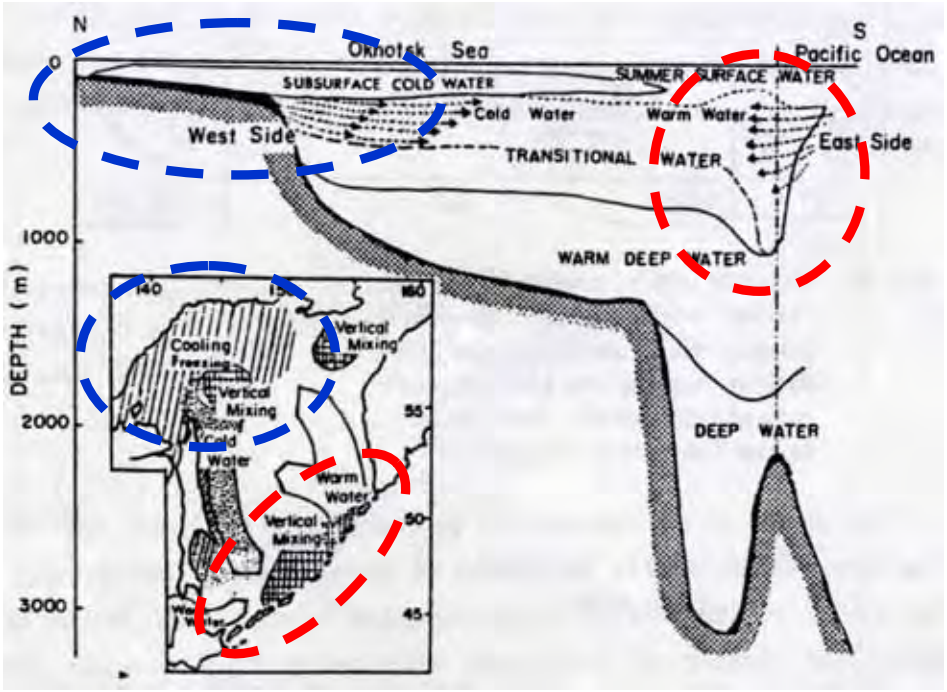
Yasuda (2004)

NPIW: Low potential vorticity water in North Pacific Ocean

- Originated in the Okhotsk Sea
- Low salinity water around 26.8 σ_θ (Intermediate layer)
- High nutrient and iron → effect on biological productivity

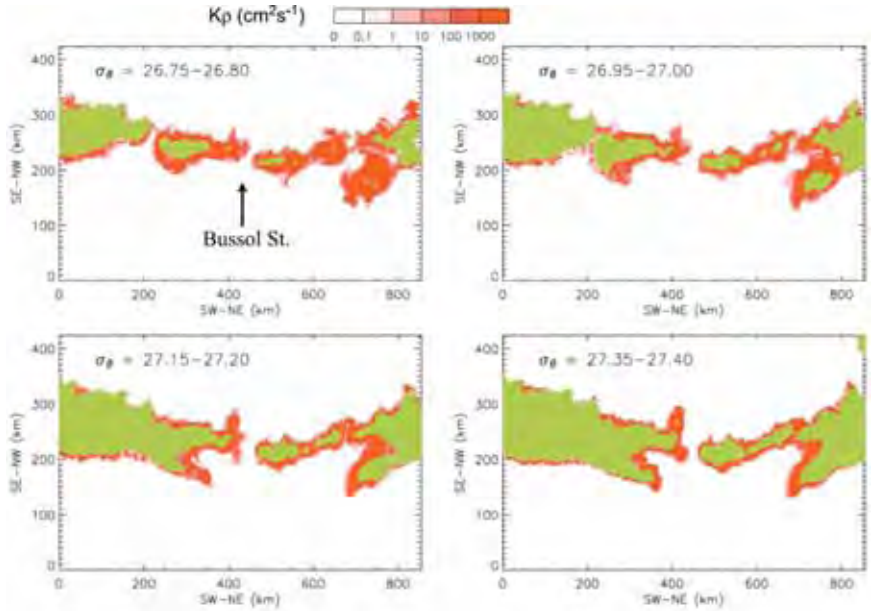
North Pacific Intermediate Water (NPIW) & Strong Mixing around Kuril Islands

Schematic of NPIW formation in Okhotsk



Kitani (1973)

Vertical diffusivity around Kuril Straits (modeling estimation)



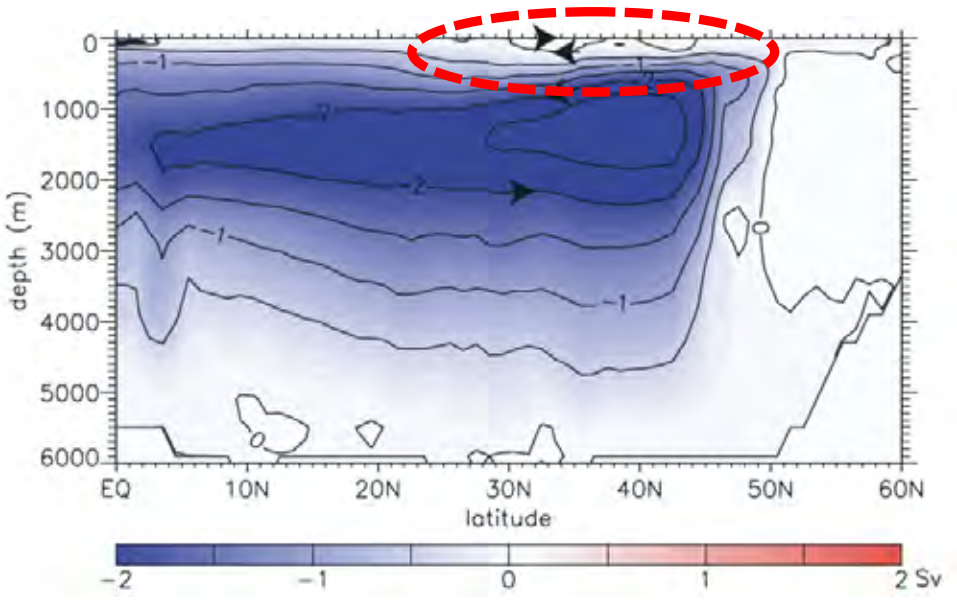
Nakamura and Awaji (2004)

Dense Shelf Water(26.8 σ_θ) modification at σ_θ=26.8-27.6 is due to vertical mixing around the Kuril Islands (Kitani, 1973; Talley, 1991)

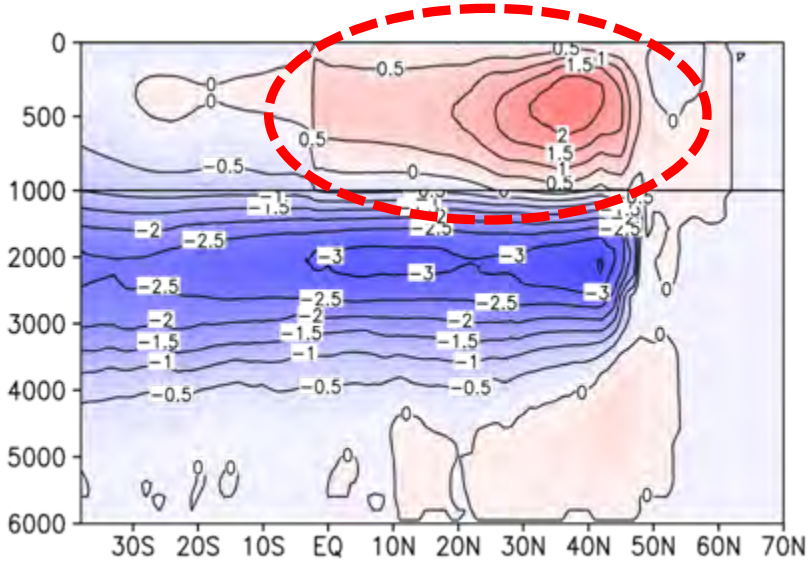
Dense Shelf Water formation (sea surface cooling) and vertical mixing are expected to induce the North Pacific thermohaline circulation (meridional overturning circulation)

Strong mixing around Kuril Straits & North Pacific shallow overturn

Anomaly (with mixing - no mixing) of meridional stream function



Nakamura et al. (2006)



Kawasaki and Hasumi (2010)

- The vertical mixing around the Kuril Straits enhances the North Pacific “shallow overturning circulation”
- Southward flow at intermediate depth = pathway of Okhotsk Sea water to the North Pacific Ocean (spreading of NPIW)

Motivation

The shallow overturn circulation should be obtained, since they transport the nutrient-rich Okhotsk Sea water to the North Pacific Ocean

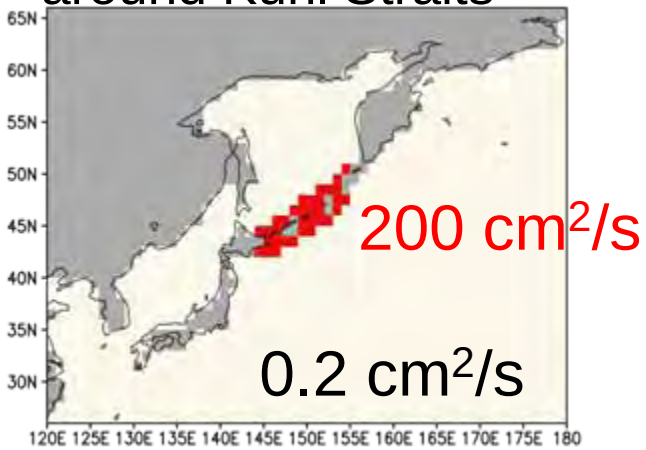
It is difficult to obtain the over view of the North Pacific shallow overturning circulation by observations

We describe the North Pacific shallow overturning circulation in an ocean general circulation model (non-eddy-resolving)

Model Description

- COCO ver. 4.2 (an OGCM developed by AORI & JAMSTEC)
- Bathymetry: Global (without the Arctic Sea)
- Resolution: Hor. 1x1 degree, Vert. 45 levels (layer thickness: 5-200m)
- Wind stress: Monthly mean climatology (Roske, 2001)
- Restoring sea surface temperature and salinity toward monthly mean climatology (Levitus)
- Body forcing of temperature and salinity is applied at except for the Pacific Ocean
- Isopycnal diffusion: $10^3 m^2/s$
- Isopycnal thickness diffusion (GM): $7.0 \times 10^2 m^2/s$
- Surface mixed layer: Noh and Kim(1999, JGR), $\alpha = 3$
- Integrate 6000 years for steady state

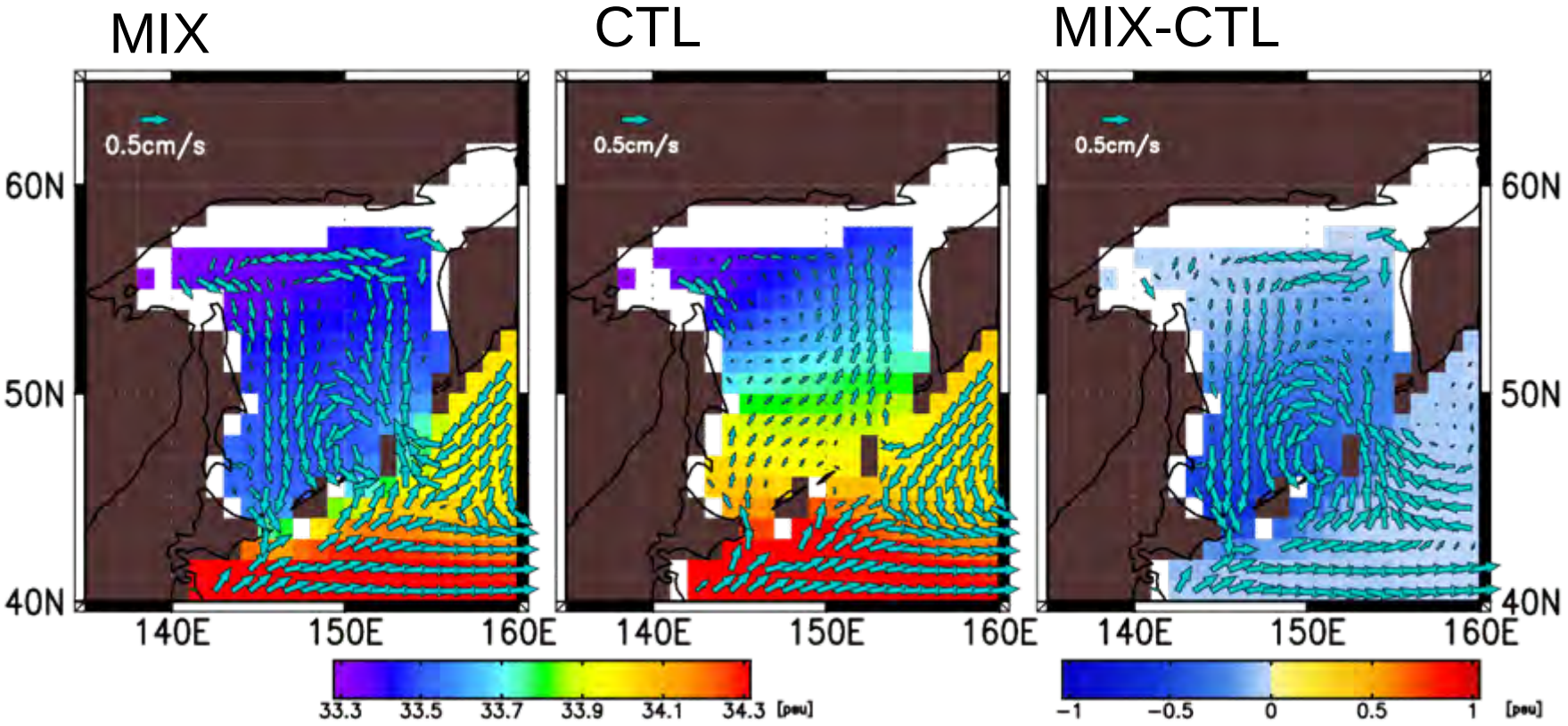
Strong vertical mixing around Kuril Straits



CTL: No Kuril mixing (vert. diffusivity: 0.2 cm^2/s; constant)
MIX: With Kuril mixing (vert. diffusivity: 200 cm^2/s around Kuril)

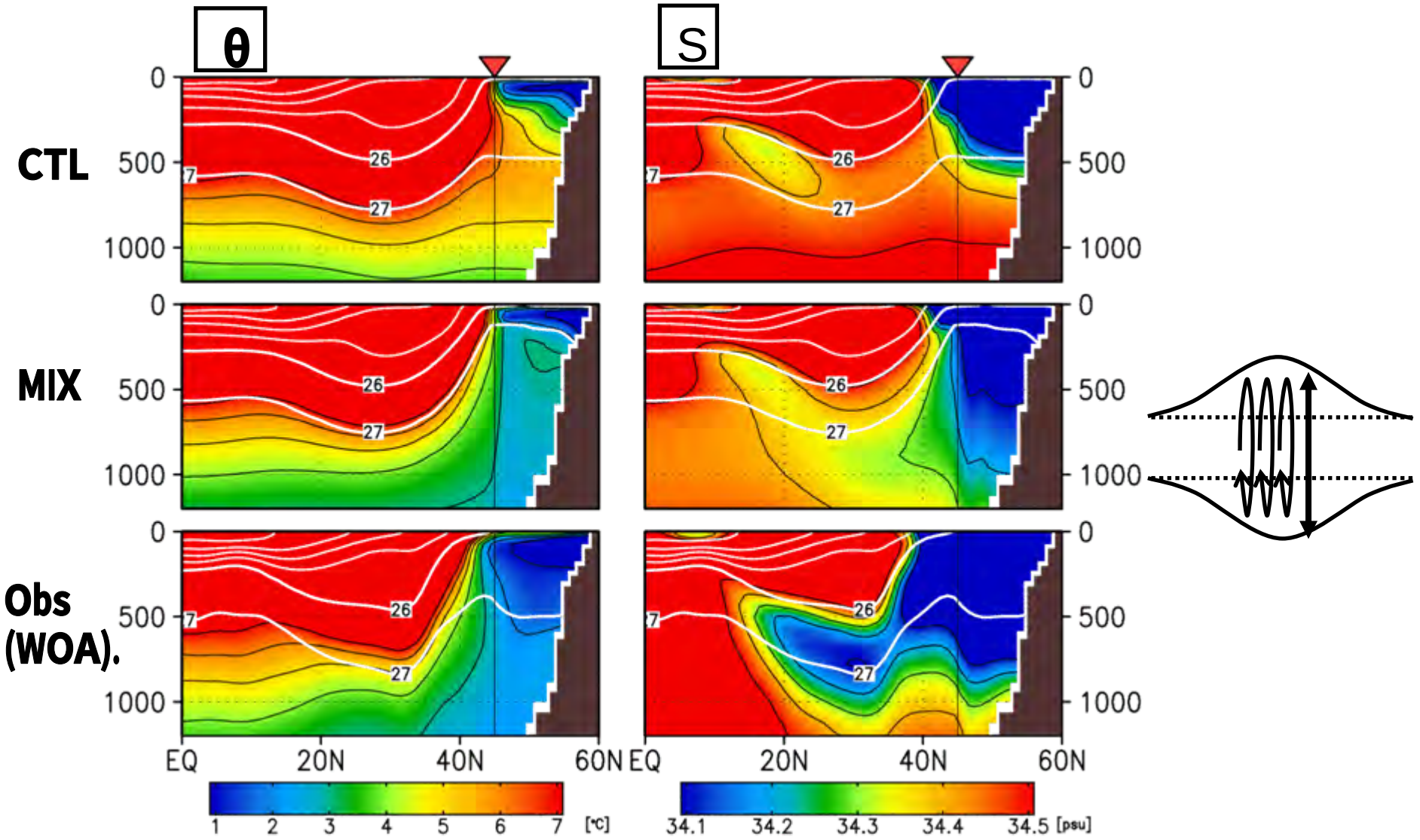
The difference of results in two cases is expected to show the structure of the North Pacific shallow overturning circulation

Salinity & Horizontal Velocity (at 26.8 σ_θ)



- The dense shelf water transported southward in CTL and MIX
- The vertical mixing intensifies the southward current in the Okhotsk Sea and the eastward flow in the open ocean
- The intermediate water is freshened by the vertical mixing

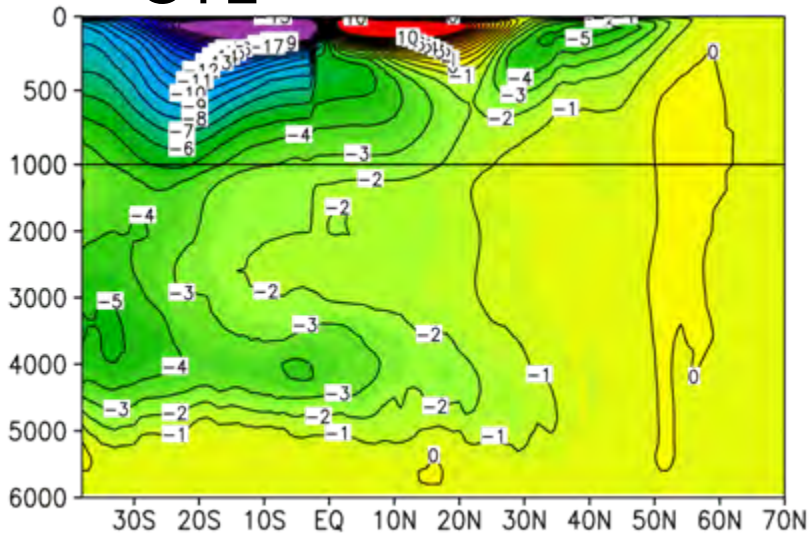
Potential Temperature & Saliniy (150E)



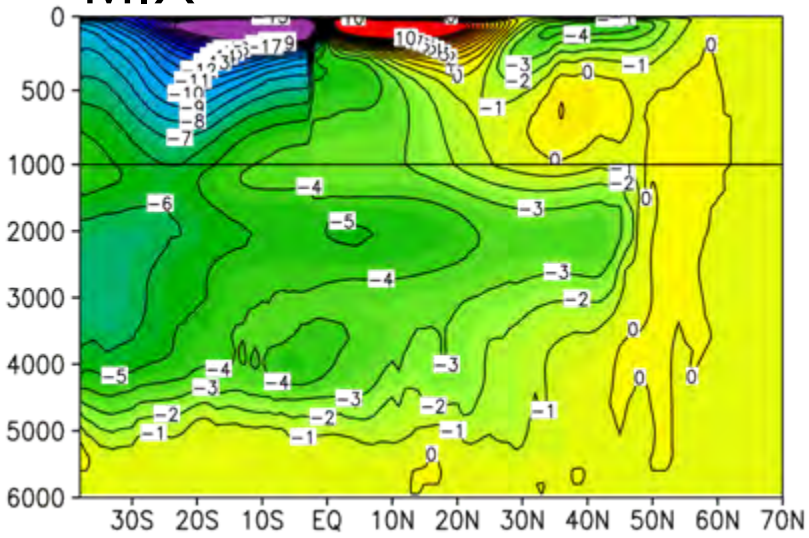
- The vertical mixing forms the low PV water around the Kuril
- The NPIW is fresher in MIX than in CTL

Pacific Meridional Overturning Circulation (Sv)

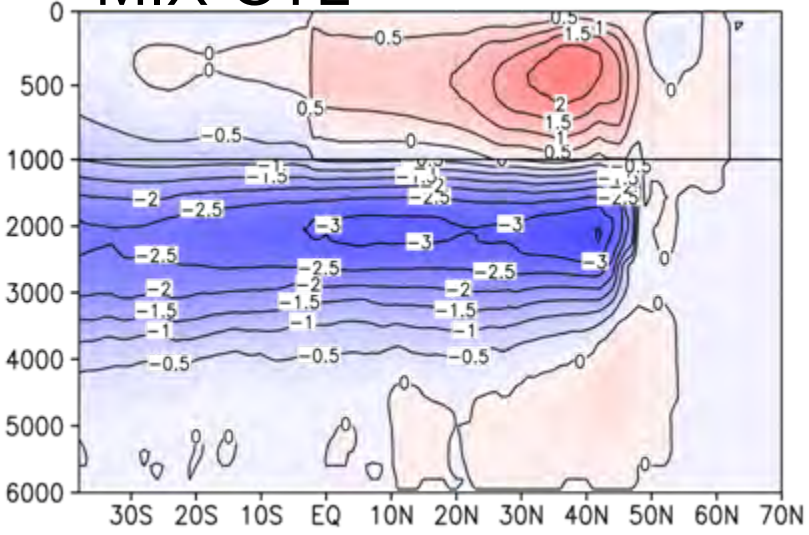
CTL



MIX



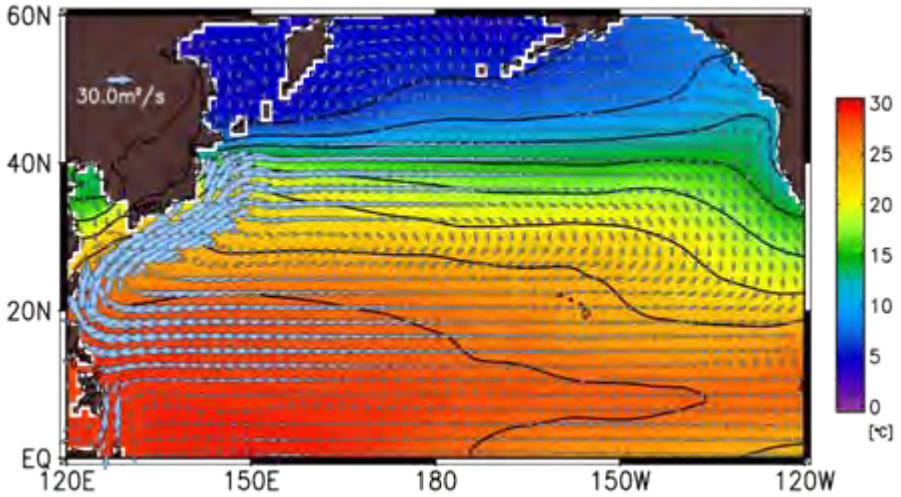
MIX-CTL

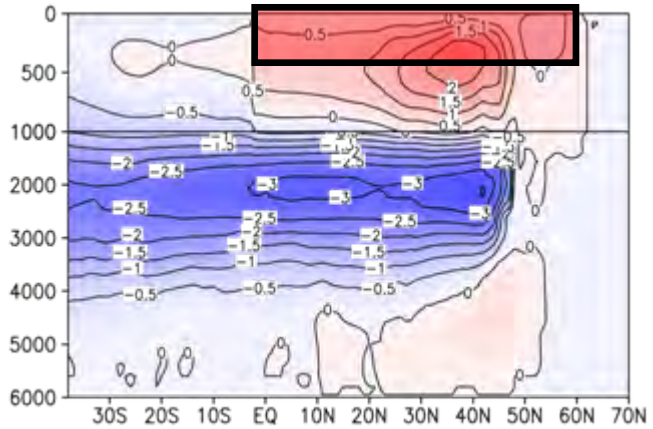


- Ekman upwelling/downwelling in shallow layer
- The vertical mixing induces the downwelling around Kuril Straits in shallow and intermediate layers
- The northward and southward flows are induced in shallow and intermediate layers, respectively.

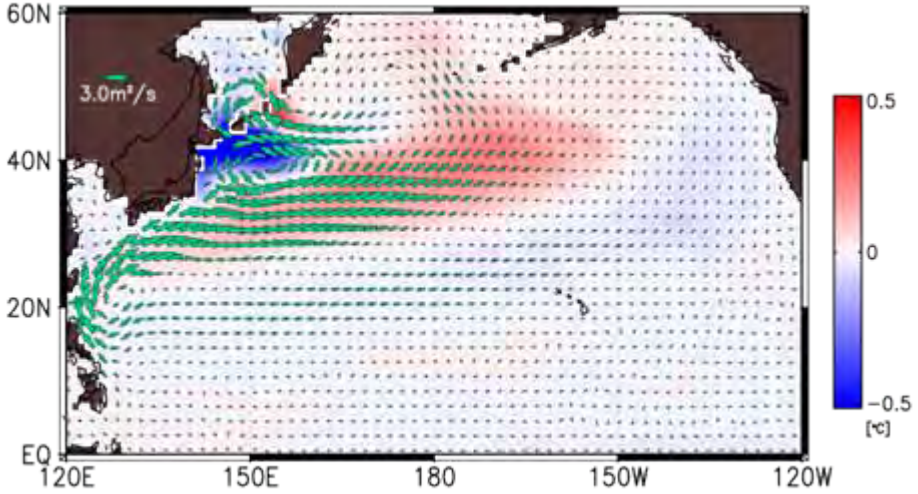
Sea Surface Temperature & Hor. Flow at Shallow (0-390m)

CTL

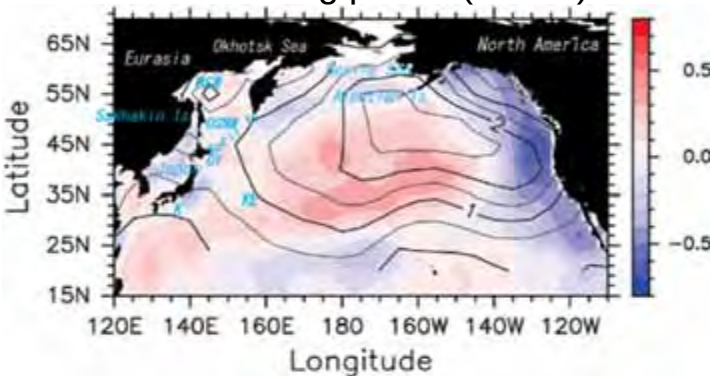




MIX-CTL



Difference of SST between strong and weak mixing phase (NCEP)

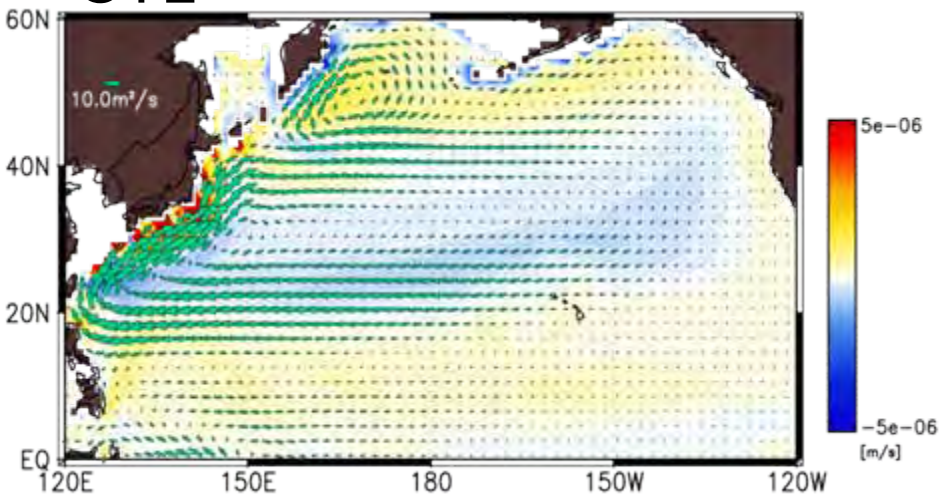


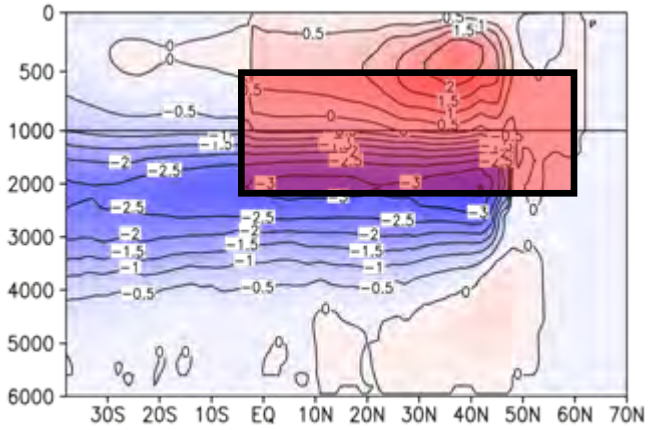
Yasuda et al. (2006)

- The Kuroshio and its extension and subarctic gyre is intensified by the vertical mixing
- SST is warmer in Kuroshio extension region in MIX than in CTL

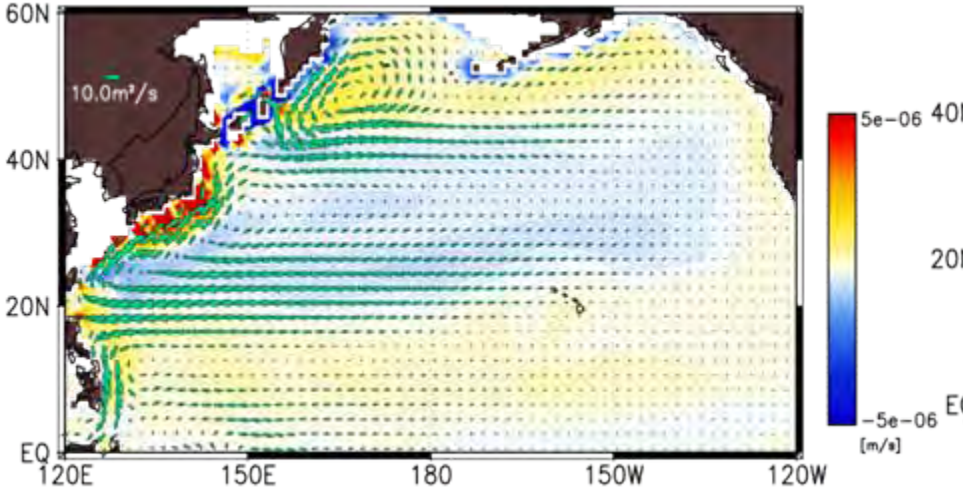
Vertical Velocity (390m) & Hor. Flow at intermediate(390-2130m)

CTL

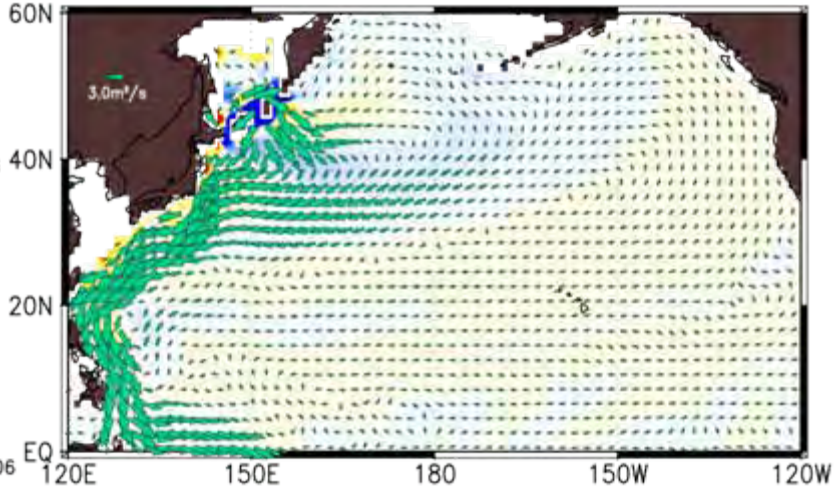




MIX



Anomaly (MIX-CTL)

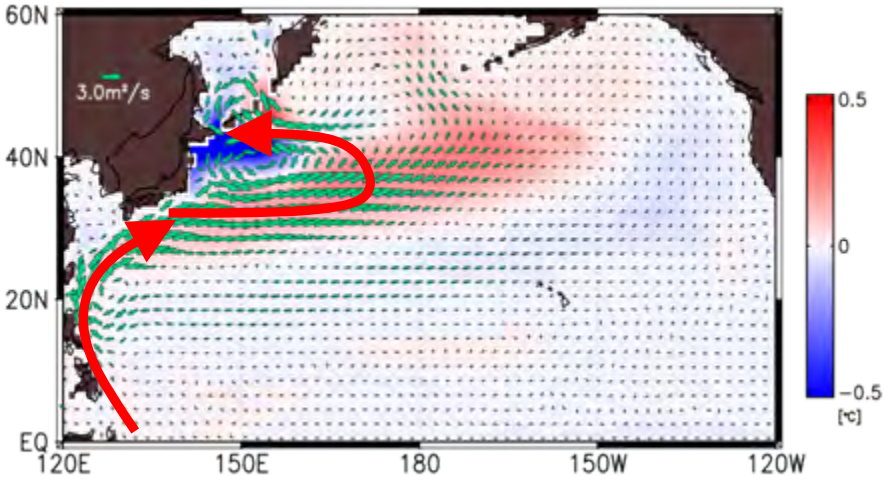


- The strong downwelling is induced by the vertical mixing around Kuril Straits
- Gyre-cross southward flow in Kuroshio Extension region is increased and southward western boundary current in south of 20N are induced in MIX

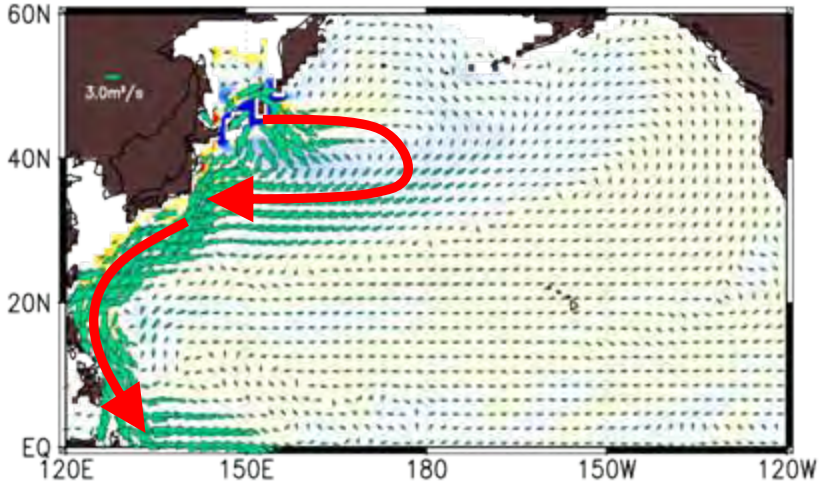
Horizontal currents induced by the Kuril mixing

Vertically integrated horizontal velocity (MIX-CTL)

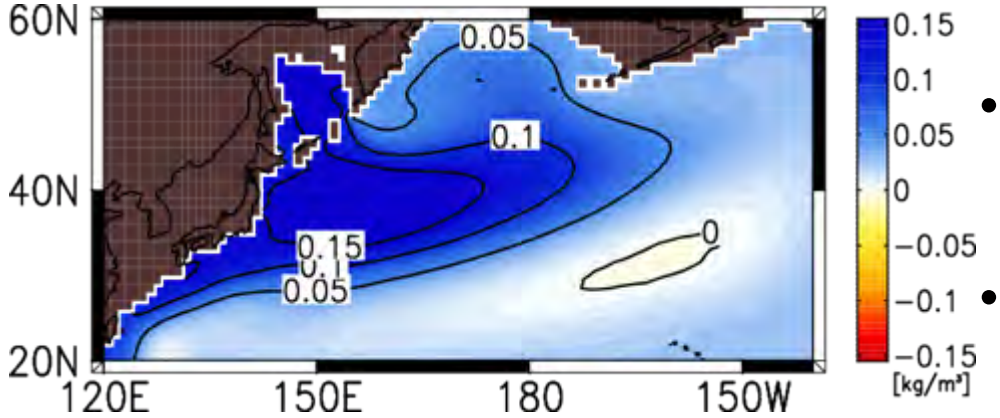
Shallow layer (0-390m)



Intermediate & upper deep layers (390-2130m)



Potential density at 500m (MIX-CTL)



- Horizontal structure in shallow and intermediate layers are mirror image
- The high density water formed in Kuril is transported by Kuroshio extension
- The horizontal currents are formed along the edge of the high density water

The horizontal current structure is influenced by wind-driven circulation

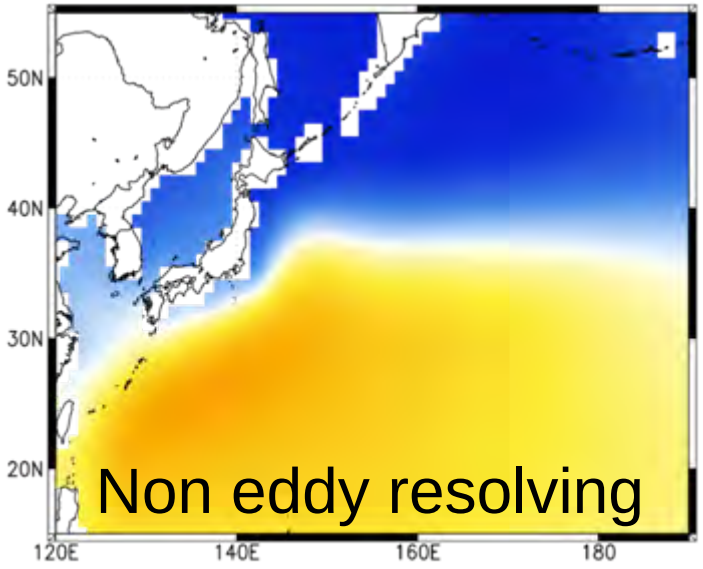
Summary

- We investigate the structure of the North Pacifc shallow overturning circulation by using an OGCM
- The strong vertical mixing around the Kuril Straits intensifies the shallow overturning circulation (southward and Northward flow are intensified in intermediate and shallow layers, respectively)
- The northward flows are Kuroshio and its extension and subarctic gyre in shallow layer
- The southward flow is the cross-gyre current of NPIW around the Kuroshio-extension region in intermediate layer
- The horizontal structure of mixing-inducing shallow overturn is influenced by the wind-driven circulation

Future Work

- Tracer experiment
  - to obtain the effect on the biological activity
  - to validate the result of model
- Low resolution (non-eddy-resolving) model cannot reproduce the Kuroshio separation (over-shoot) and gyre-cross flow induced by mesoscale eddies explicitly → eddy-resolving model

Sea Surface Height
(this study)



Sea Surface Height in nested model