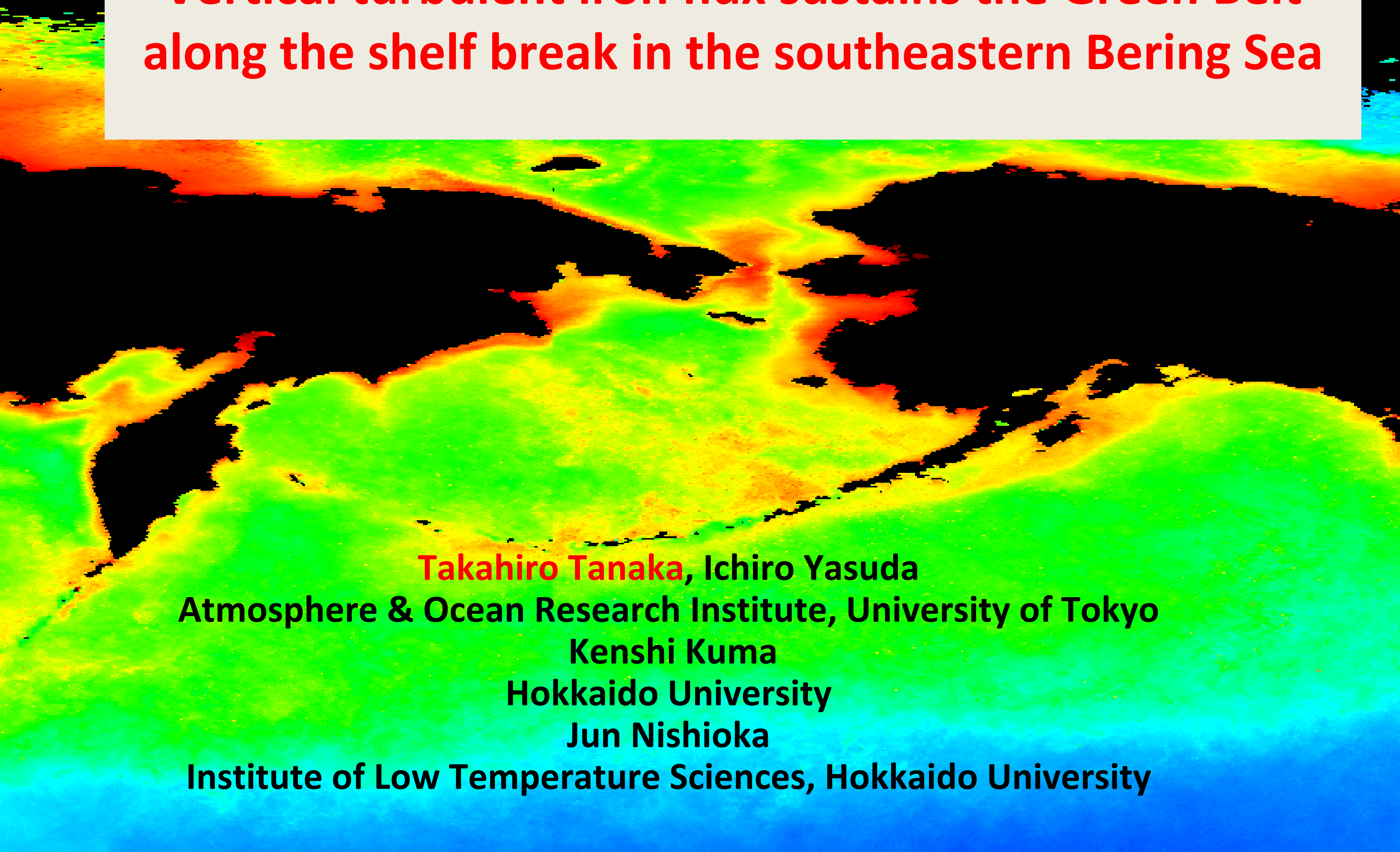
PICES-POC-P-8746 2012/10/16 Hiroshima

SeaWiFS Seasonal climatology Chl.
http://oceancolor.gsfc.nasa.gov/cgi/l3

Vertical turbulent iron flux sustains the Green Belt along the shelf break in the southeastern Bering Sea



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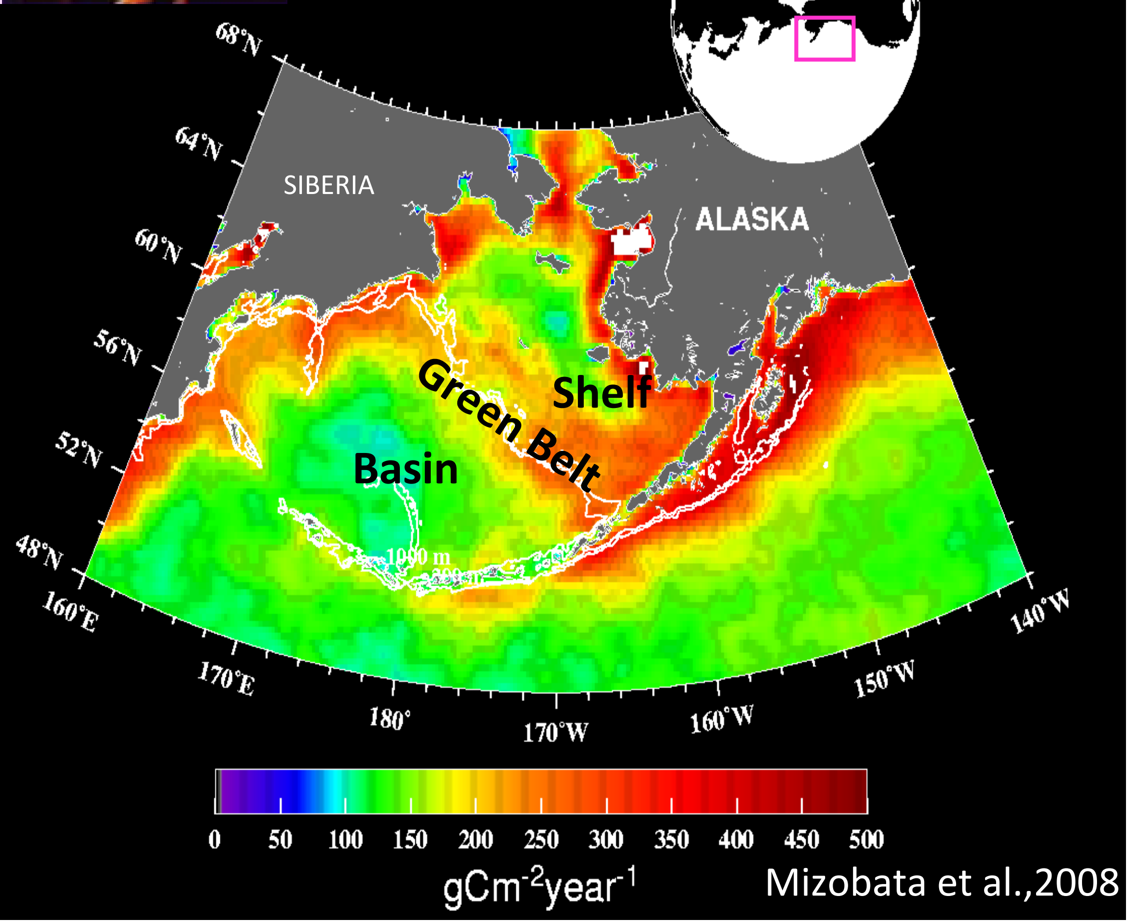


Annual primary production in the Bering Sea

- **Green Belt** (Springer et al., 1996)

✓ Highly biologically productive area along the shelf-edge

→ high productivity is maintained even in summer

- **Basin**

- Typical High Nutrient Low Chl. (HNLC). Nitrate remains in summer but chlorophyl is low

↓

- Iron depletion in summer is thought to be the reason for HNLC(e.g. Martin et al., 1988)

- **Shelf**

- Rapid consumption of nutrients(nitrate,NO3) by phytoplankton in spring (spring bloom)

↓

- Nitrate depletion at surface in summer (Aguilar-Islas et al., 2007)

→Why Green Belt is highly productive even in summer?

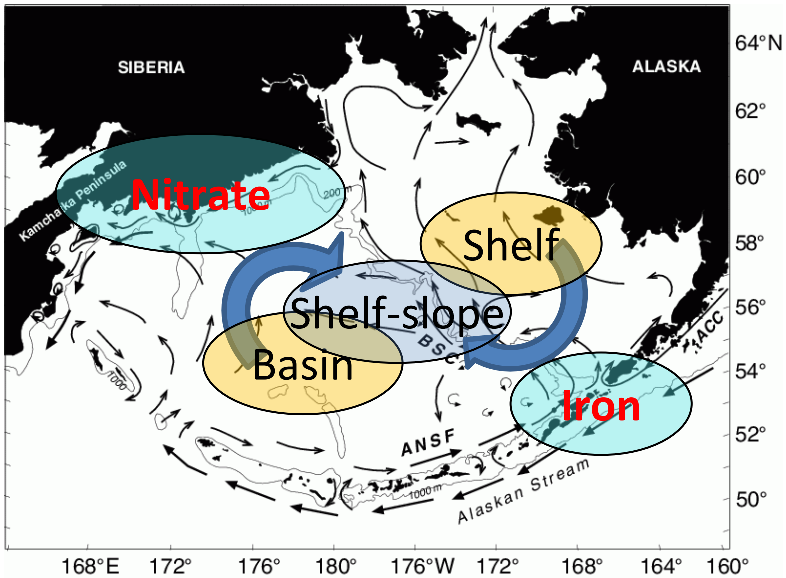
Why Green Belt is so productive even in summer?

1. Horizontal mixing

(e.g. Okkonen et al., 2004; Mizobata and Saitoh, 2004)

✓Eddy induced frontal processes along the Bering Slope Current (BSC)

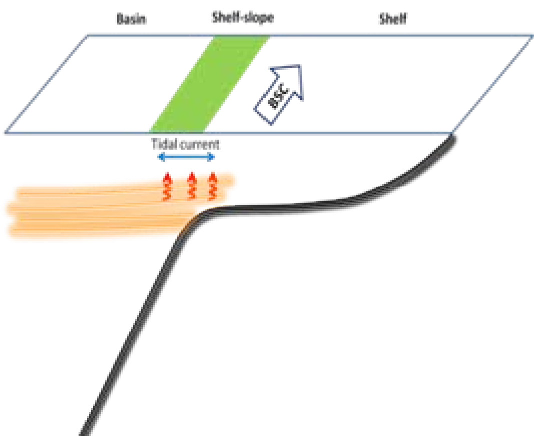
✓Mix nitrate-rich basin water & iron-rich shelf water



Stabeno et al. 2006

2. Vertical mixing (e.g. Springer et al. 1996)

✓Promote mixing of the outer-shelf waters into the surface just off the shelf break



However, no in-situ observations of mixing intensity

➢Concurrent Fe and turbulence measurement to show the importance of turbulent vertical iron fluxes from iron-rich subsurface thick layer along the shelf break

Data and Methods

➢ World Ocean Database (WOD) 2009

- 0.5° ×0.5° grid, climatological dataset
- Individual temperature and salinity data interpolated on the isopycnal surfaces (0.1σ_θ interval)
- Potential temperature(θ), Potential thickness(H) are analysed

※Potential thickness (H, e.g. Kubokawa (1999), hereafter "thickness")

$H \equiv \Delta h \times f_{45}/f$

Δh: layer thickness between isopycnals

f: Coriolis parameter($=2\Omega \sin\phi$) (ϕ:latitude)

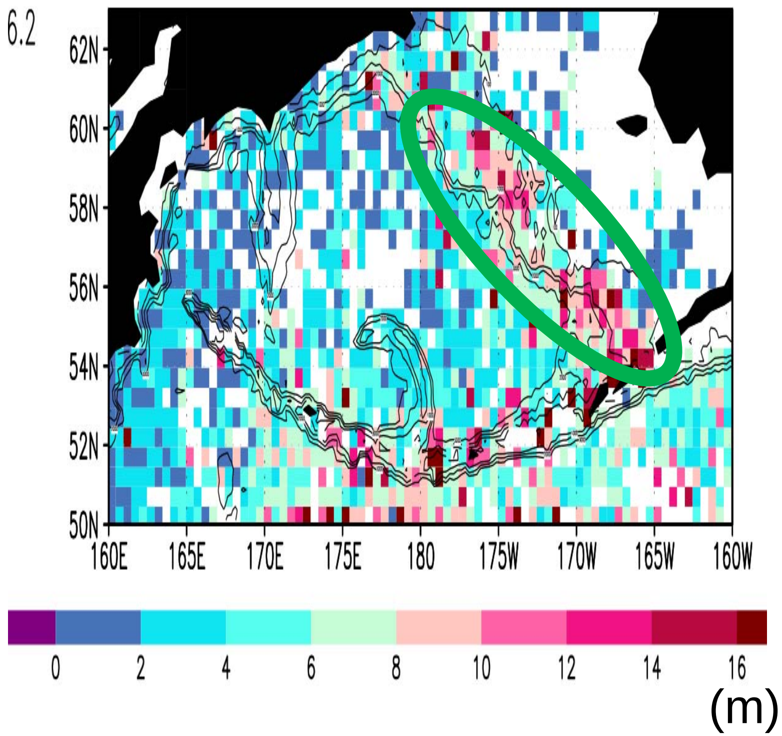
$f_{45} = 2\Omega \sin(45°)$

(Ω:angular velocity of the Earth)

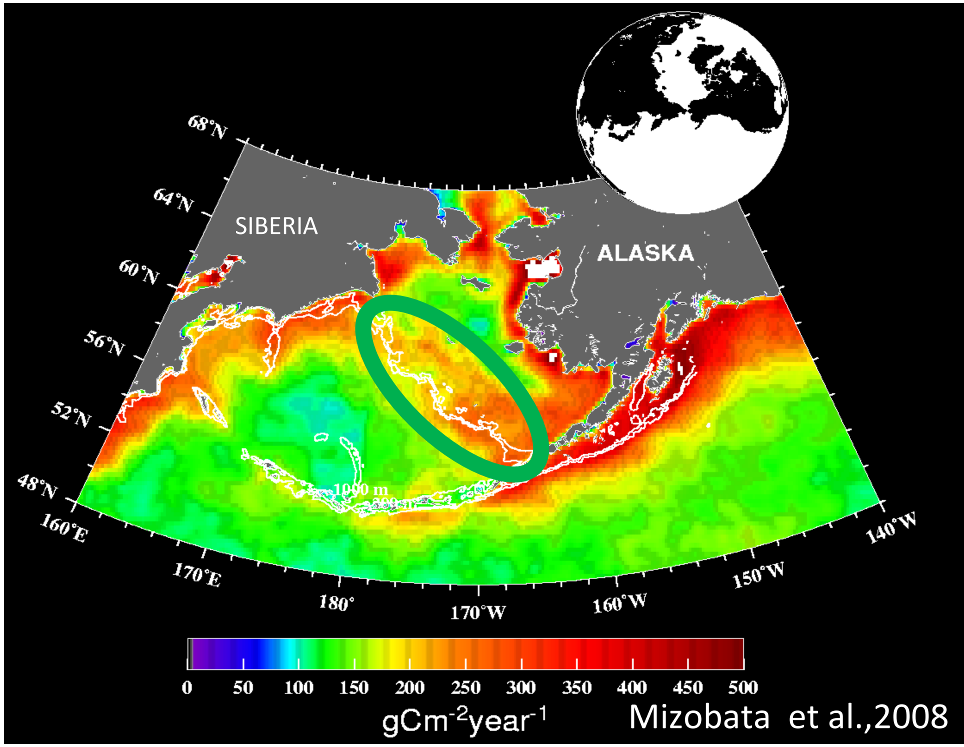
- If relative vorticity is small, H is the inverse of potential vorticity
- If strong vertical mixing occurs on an isopycnal, the thickness around the isopycnal get larger.
- No dynamiclal force exerted, H will conserve along the stream line

Thick layer along the Green Belt

Distribution of Thickness in summer (Jul. ~Sep.)@26.2 σ_θ ±0.03 σ_θ



Annual Primary Production

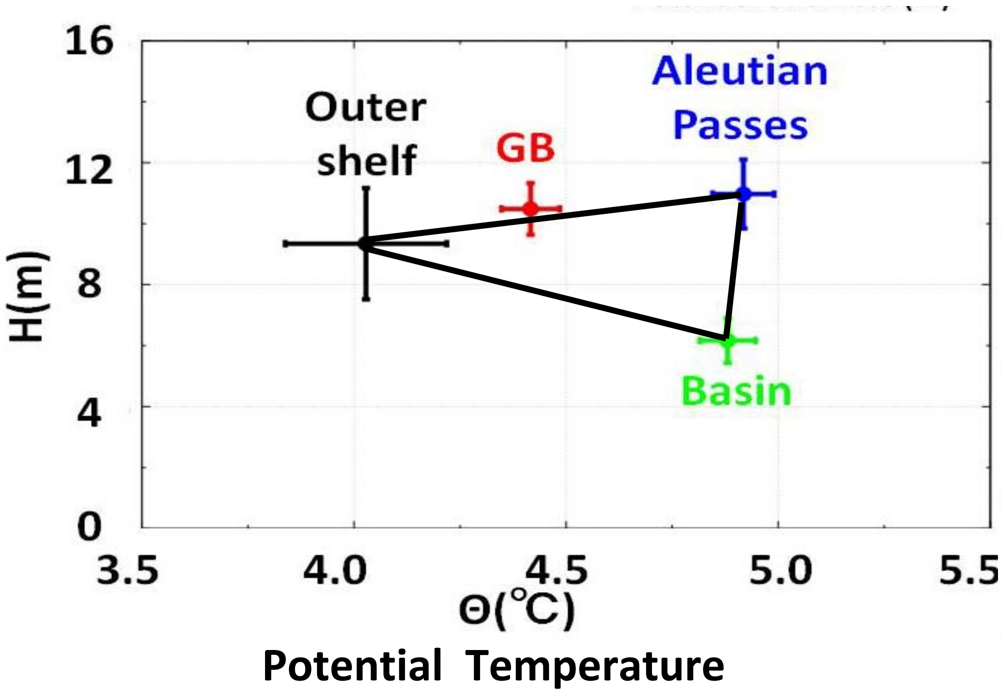


- Climatological distribution of H on 0.5° ×0.5° grid
- Thick layer along the shelf-slope on 26.0～26.3 σ_θ isopycnals.

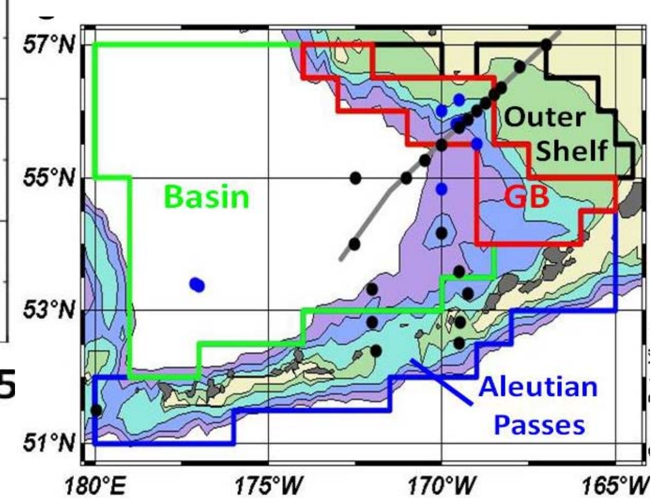
✓Thick layer location is almost identical to the Green Belt

Formation of Subsurface water at 26.2 σ_θ

Potential Thickness at 26.2 σ_θ $\pm$0.03 σ_θ



※bars denote 99% Confidence Interval



✓ Large H in the Aleutian Passes, GB, and shelf

・This may be the result of strong vertical mixing in the Aleutian Passes (e.g. Stabeno et al., 2005, Ladd et al., 2005) & over the shelf bottom (e.g. Coachman, 1986)

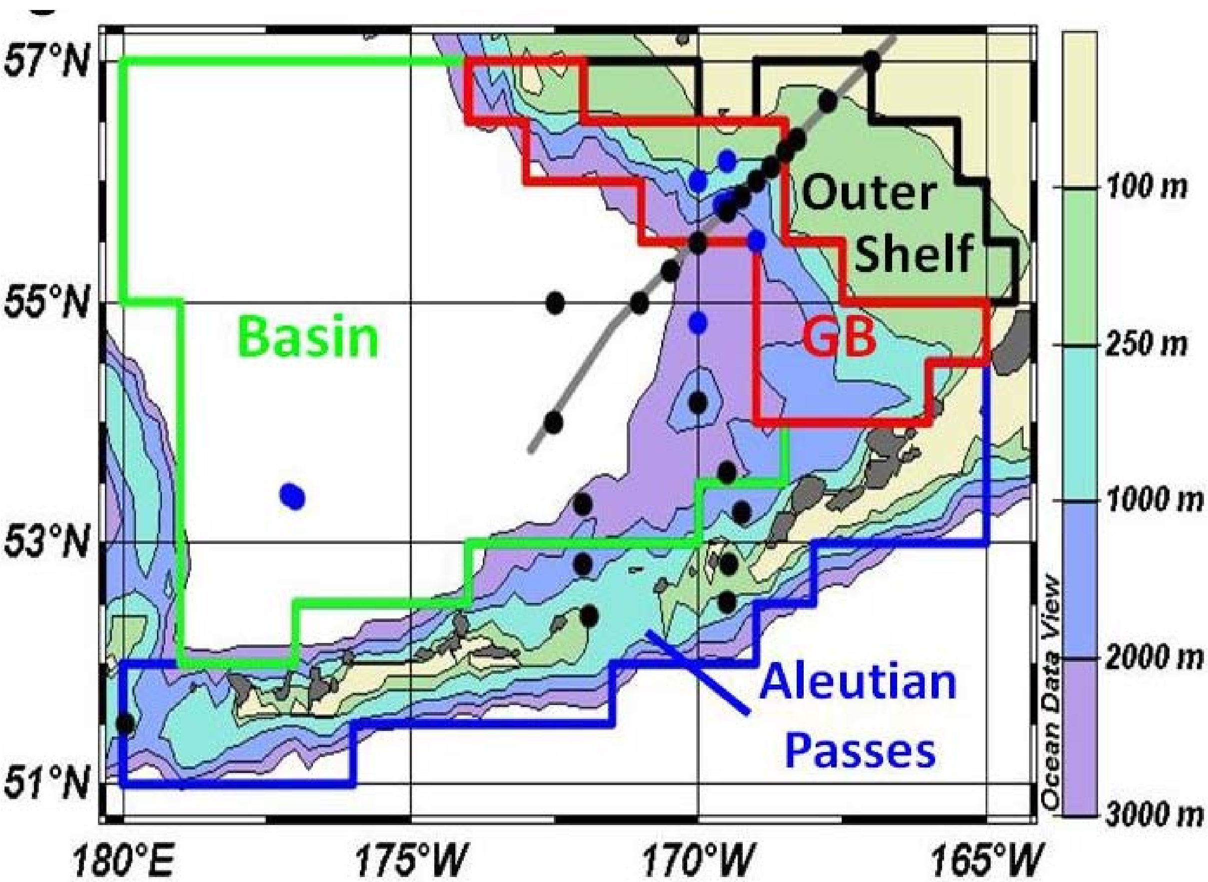
→ Consistent with the results from direct turbulent measurements (will be shown)

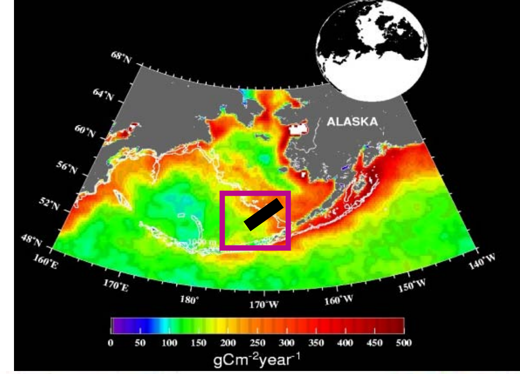
✓ Water along the Green Belt is suggested to be the mixture between cold outer-shelf water and warm water from the Aleutian Passes (55:45)

In-situ obs. of turbulence, iron and nitrate

- R/V Hakuho-maru cruise (KH09-4)
- ✓ Aug.25～Aug.29, 2009
- ✓ Temperature, Salinity, Nitrate + Nitrite (Nitrates)･dissolved iron (D-Fe) concentrations, Chl-a, vertical mixing intensity

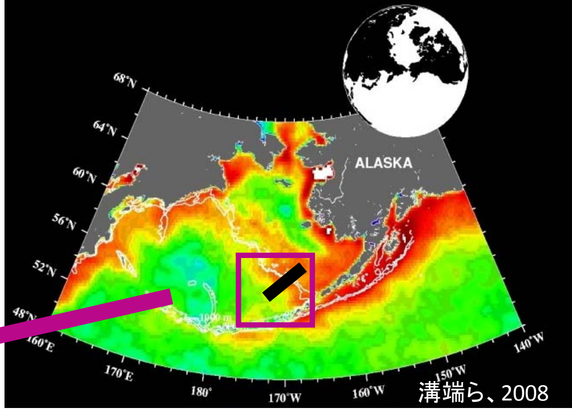
✓ Iron measurement by the T/S Oshoro-maru cruises (2004, 2005, 2007) are also compiled (blue dots)

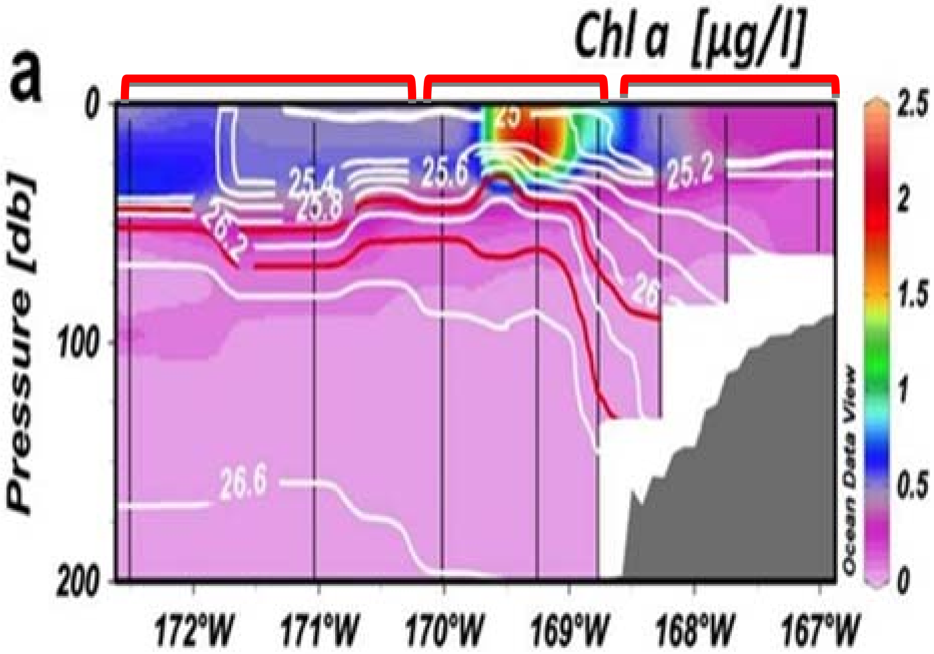




Vertical Microstructure Profiler(VMP) 2000

Chl-a vertical cross-section



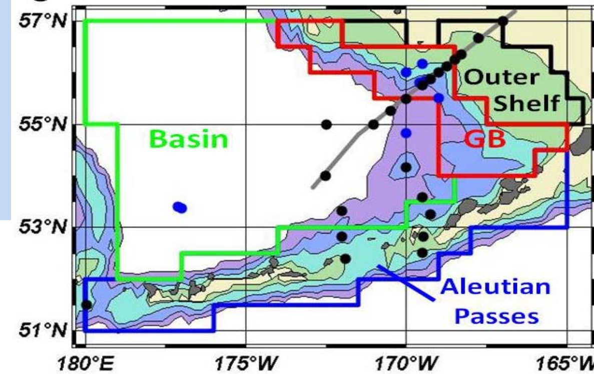


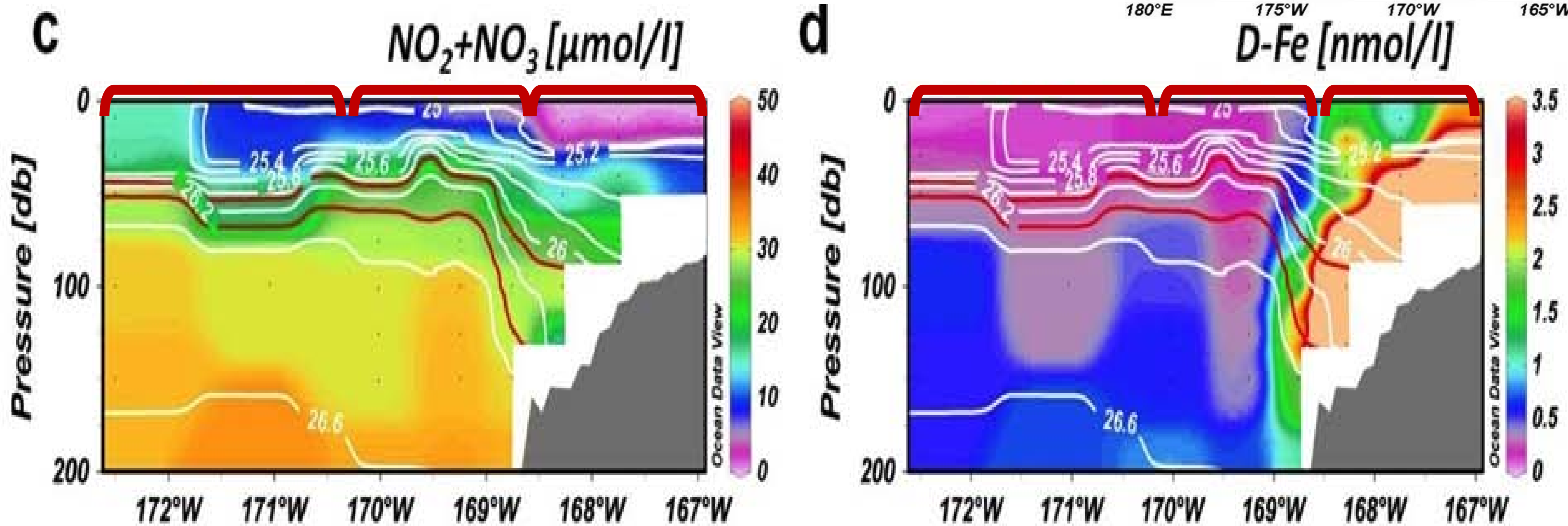
- Chlorophyll-a concentration

→ Green Belt was observed during the Hakuho-maru cruise.

Vertical transect of Chlorophyll-a concentration observed in Hakuho-maru cruise(KH09-4)
(contours: potential density(σ_{θ}))

Nitrate and Dissolved Iron Distribution





(contours: potential density)

➢Nitrates and Dissolved iron(D-Fe) concentration

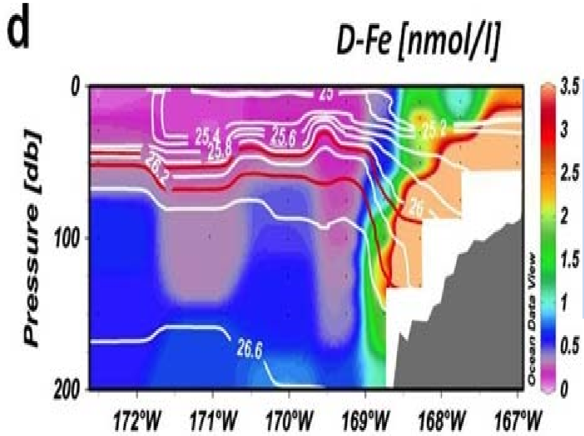
•Nitrates: generally uniform along isopycnals & higher with greater potential density

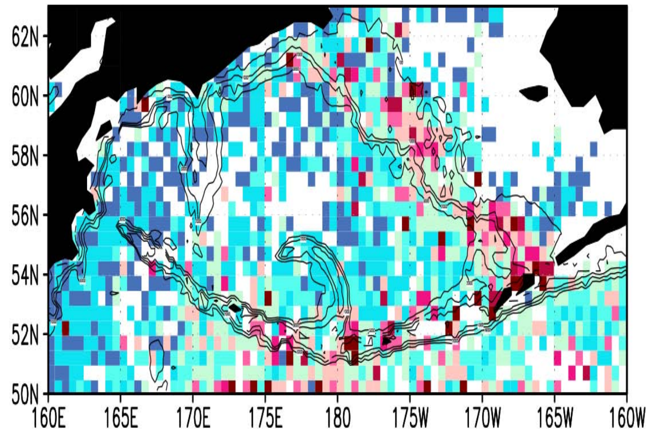
•D-Fe: ･High over Shelf

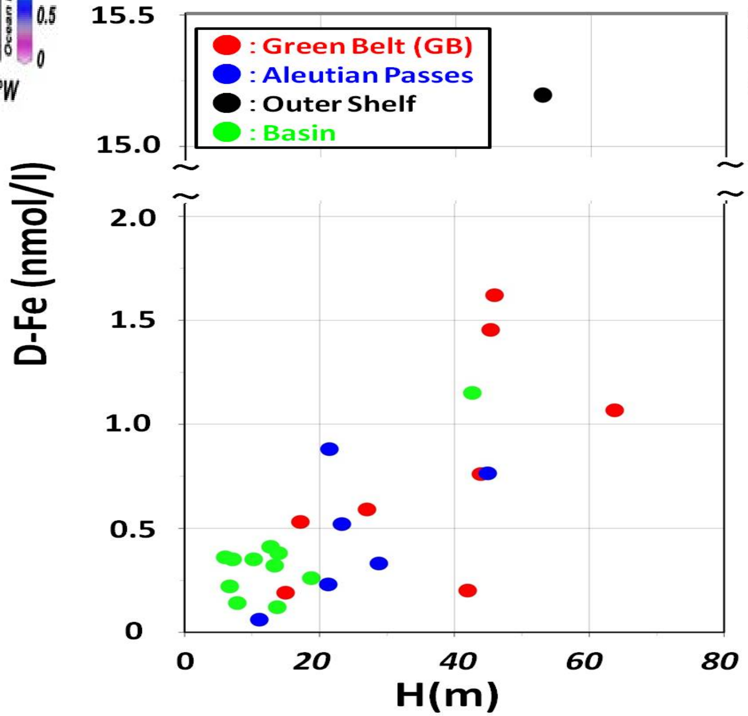
→ from Shelf bottom sediment (Johnson et al., 1999）

･Vertical maximum over the shelf-break

Potential thickness & D-Fe







➢ Potential thickness (H) and D-Fe relation @26.1-26.3 σ_θ

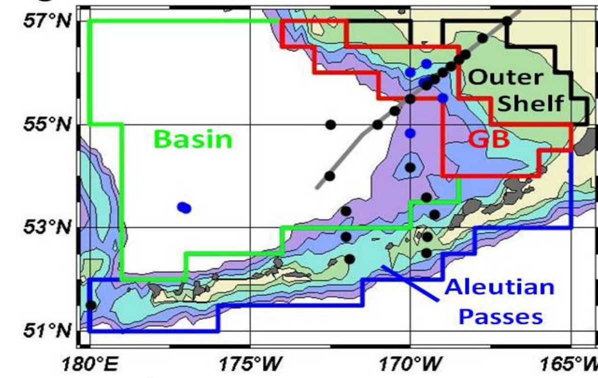
（including 3 years (2004,2005,2007)of data obtained by Oshoro-maru cruise in summer）

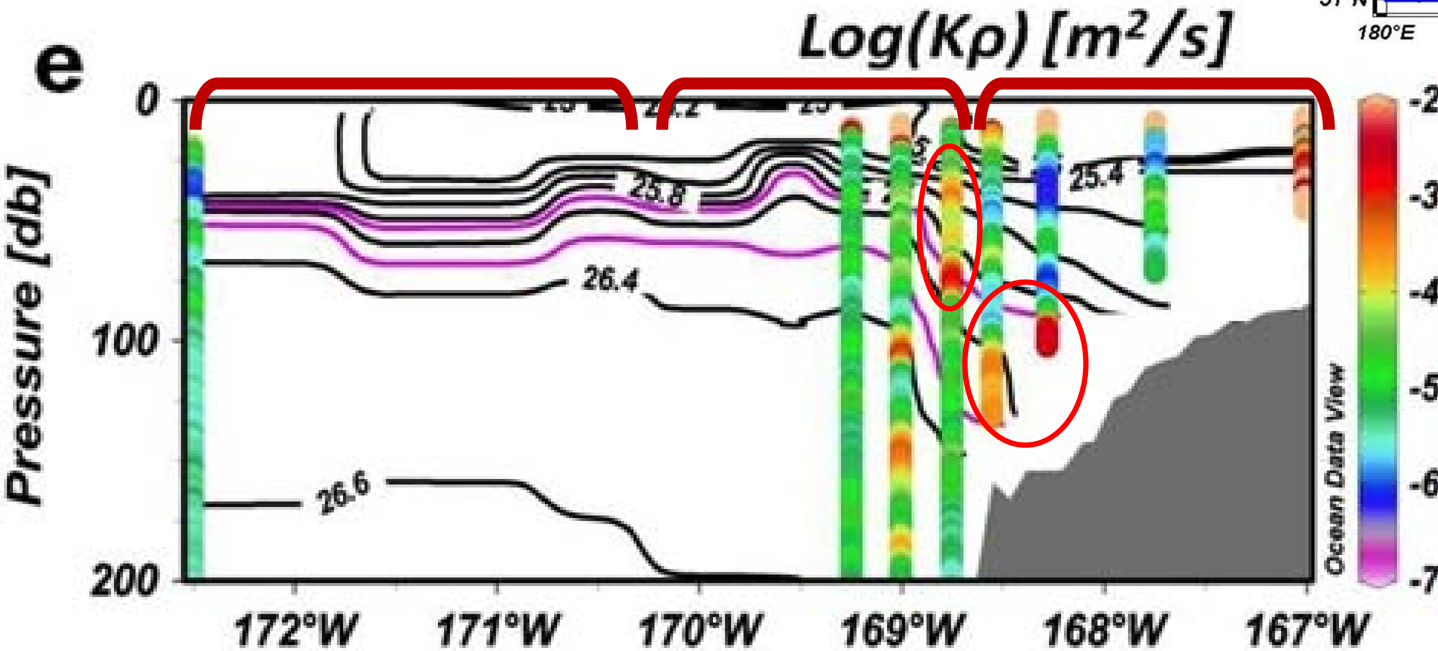
① Water with large H contains high concentrations of D-Fe in this layer

② D-Fe @Shelf bottom >> D-Fe @GB > D-Fe @Aleutian Pass & Basin

→suggesting that the subsurface D-Fe in the GB is elevated by the iron from the shelf

Vertical diffusivity (K_ρ)



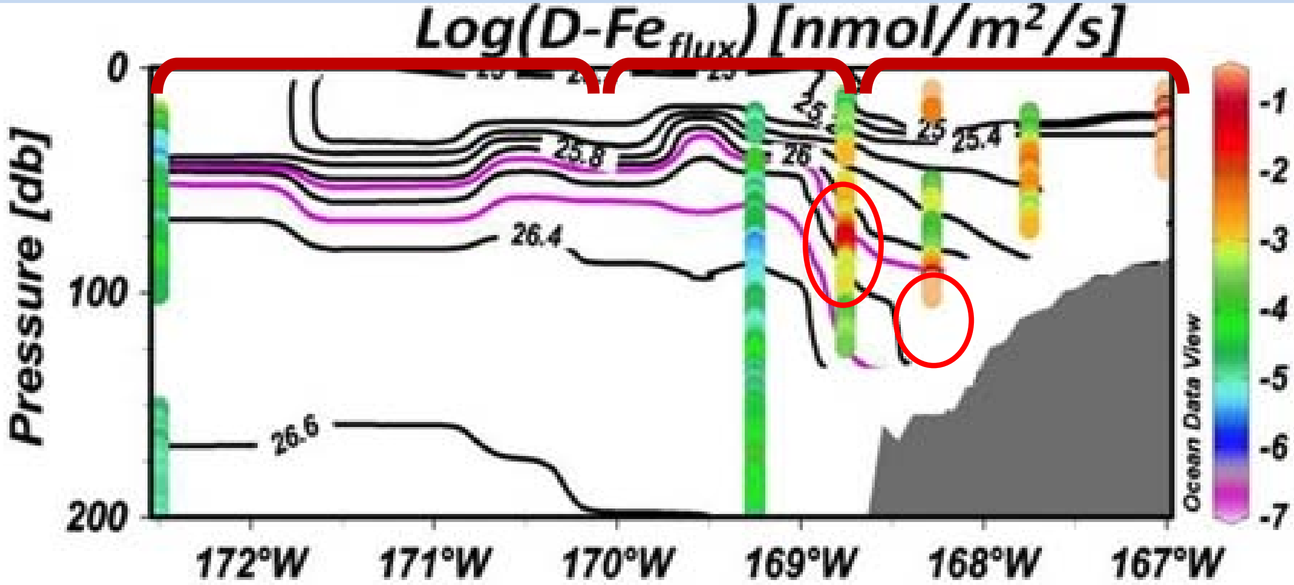


Vertical transect of Vertical diffusivity Coefficient(log scale)

➢ Vertical diffusivity coefficient (K_ρ) profiles

- $K_\rho \sim 10^{-4}$ - 10^{-3} m^2/s was observed at Shelf-break subsurface and over outer-Shelf bottom
- K_ρ is low (~ $10^{-5} m^2/s$) at the depth of ~50 -100m in the shelf, basin, & slope except for just off the shelf break

Can the vertical iron flux at the shelf break sustain biological productivity in the Green Belt?



Upward vertical turbulent Iron flux profiles

$D\text{-}Fe_{flux} = -K\rho \times \partial(D\text{-}Fe)/$

（$K\rho$: Vertical diffusivity coefficient）

➢ $D\text{-}Fe_{flux}$ through vertical turbulent mixing

•Strong on the subsurface just off the shelf break & over the shelf bottom

→D-Fe is efficiently transported from the iron-replete water

・Daily iron consumption ：150~3000nmolFe/m^2/day (Prev. studies)

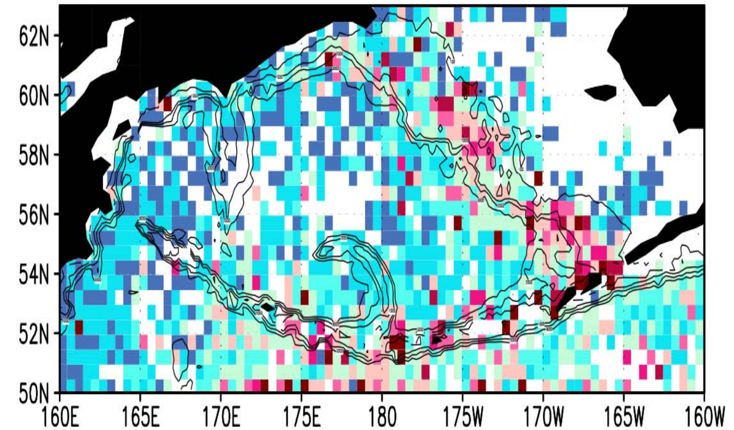
for the new production of 500~1000(mgC/m^2/day) and the iron-carbon intake ratio of 16~36 μ molFe:1molC

（Aguilar-Islas et al., 2007,Sambrotto et al., 2008）

・$D\text{-}Fe_{flux}$ from the subsurface Fe max. ：~280nmolFe/m^2/day (This study)

→Although there is a big uncertainty, there is a possibility for the vertical flux to sustain the biological productivity in the Green Belt

Summary : the formation of the water masses on subsurface(~26.2 σ_θ) based on this study



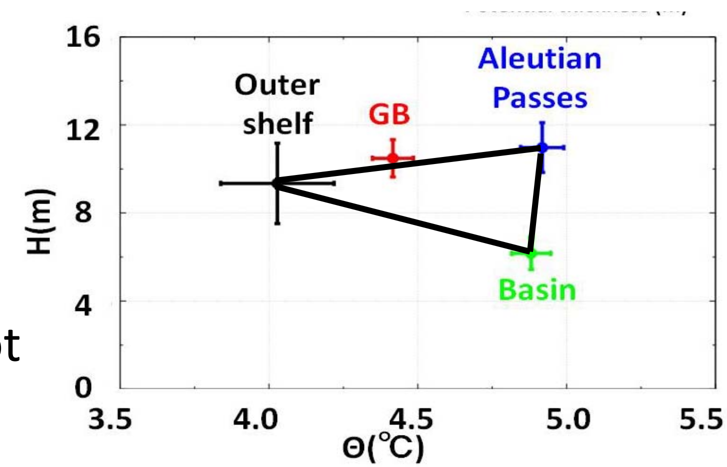
- Strong vertical mixing

①over the shelf bottom

→producing extremely iron-rich water with large H

②in the Aleutian Passes

→producing thick layer with moderate D-Fe



- Horizontal mixing

③ along the shelf break between the shelf water & water from the Aleutian Passes

→ producing iron-rich water with large H

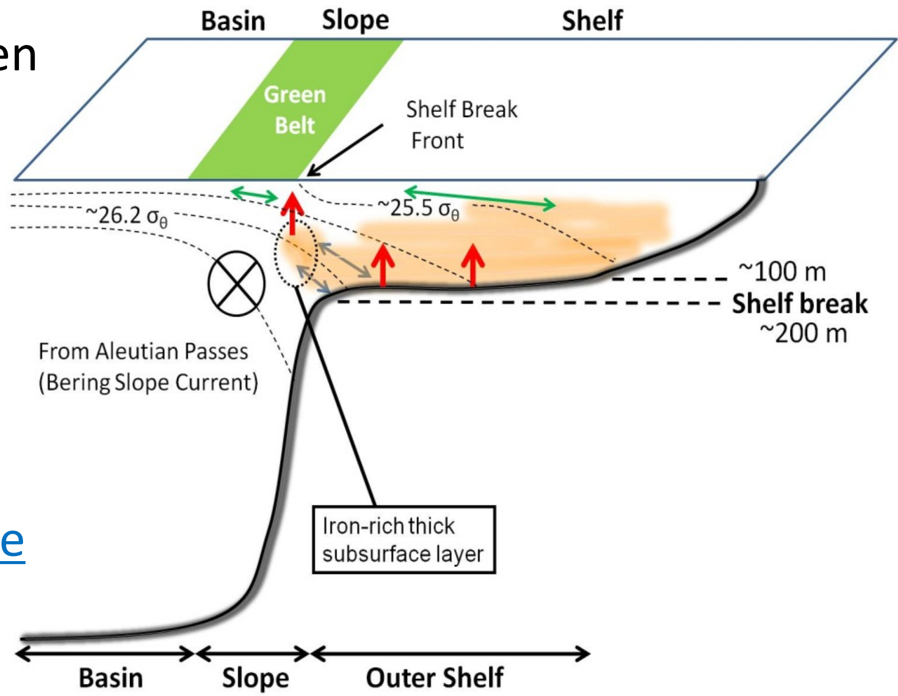
✓ Local vertical mixing along the shelf break may not be necessary to form the GB subsurface water

Summary: Mechanisms for sustaining high biological productivity in the Green Belt

①Strong vertical mixing over the shelf bottom producing iron-rich water with large H

②Isopycnal mixing at around 26.2 σ_θ between this iron-rich shelf water with oceanic water (probably from the Aleutian Passses)

→Producing Iron-rich thick subsurface layer around the shelf break



• Turbulent mixing around the shelf break subsurface efficiently transport D-Fe to surface along the Green Belt