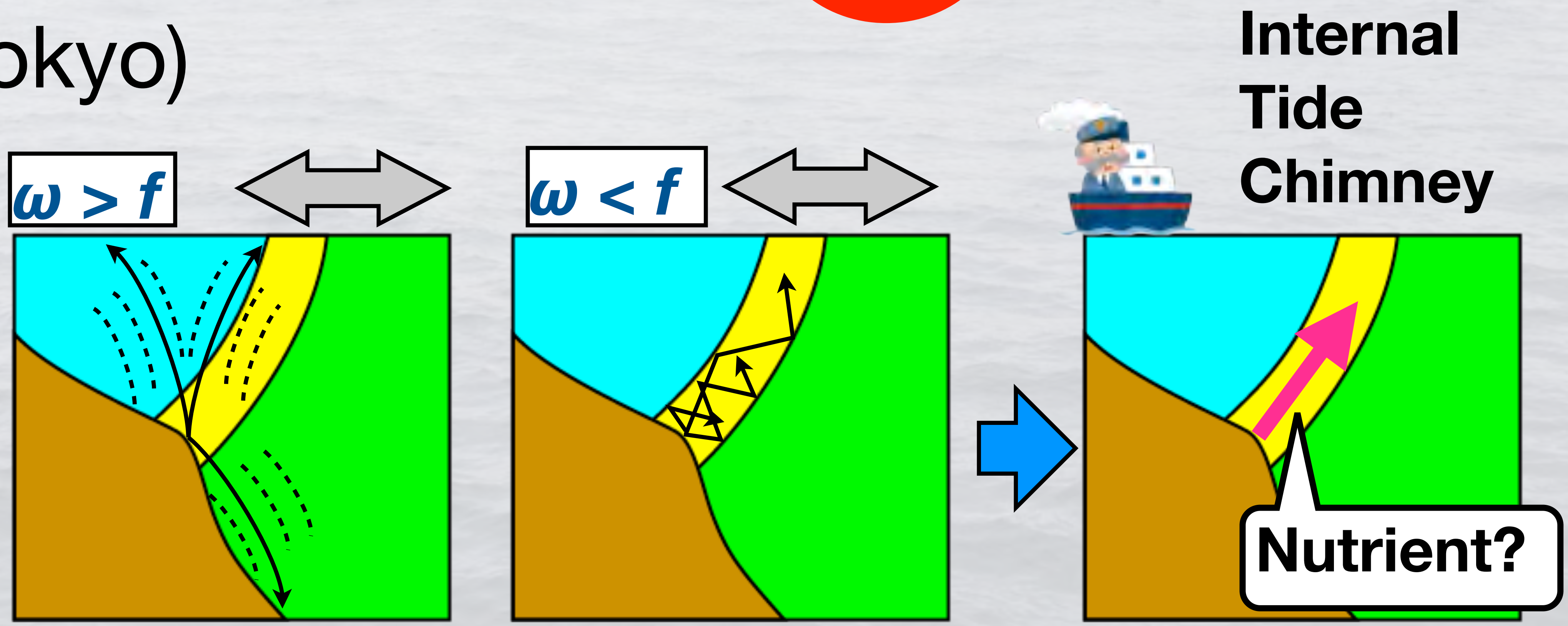
S5-13528

PICES2018 @Yokohama

Fine-scale structure & mixing across the front along the Sanriku Coast

Sachi Itoh *et al.*

(AORI, UTokyo)



Coauthors

Hitoshi Kaneko (AORI), Miho Ishizu (JAMSTEC), Daigo Yanagimoto (AORI), Takeshi Okunishi (TNFRI), Hajime Nishigaki (Oita Univ.) and Kiyoshi Tanaka (AORI)

Financial Support

TEAMS by MEXT

NEOPS by JSPS

Observation Support

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Ichiro Yasuda (AORI, UTokyo)
Hiroaki Kawahara (EMS)

General motivation: marine science support for fisheries in Sanriku areas

MEXT project

Diverse marine products in Sanriku areas

ミズダコ 5月～11月頃

ドンコ(エゾイソアイナメ) 4月～11月下旬頃

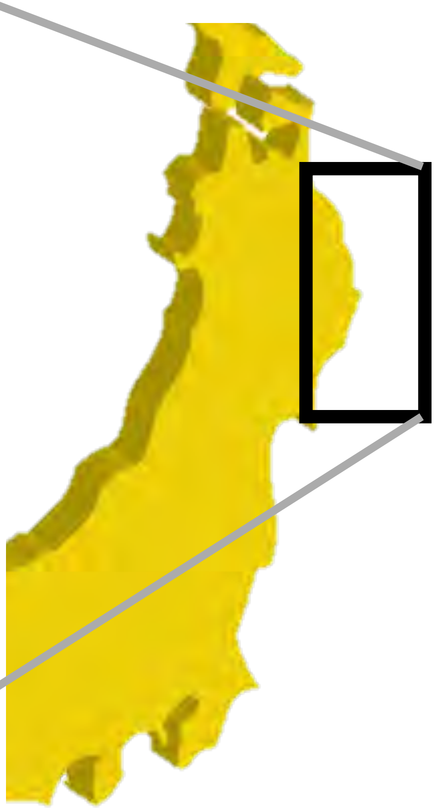
ウニ 6月～8月上旬頃

ツブ(トウダイツブ) 通年

マダラ 1月～4月頃

毛ガニ 1月～3月頃

アワビ 11月～12月頃



Seafood calendar

https://www.heiun.com

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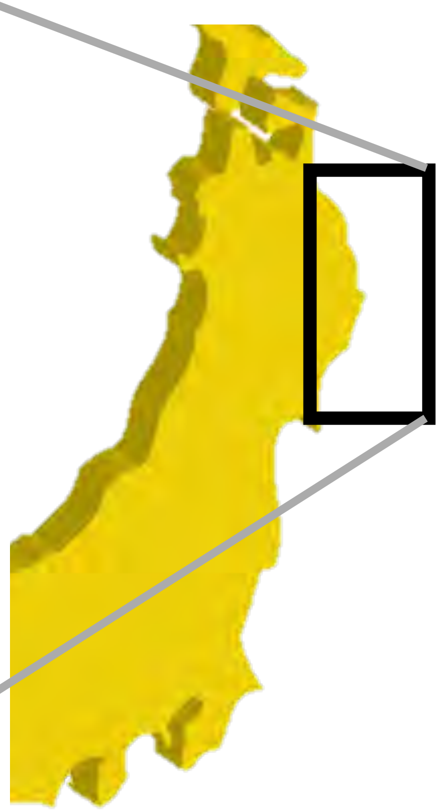
MEXT
project

2011
Tsunami

Diverse marine products in Sanriku areas



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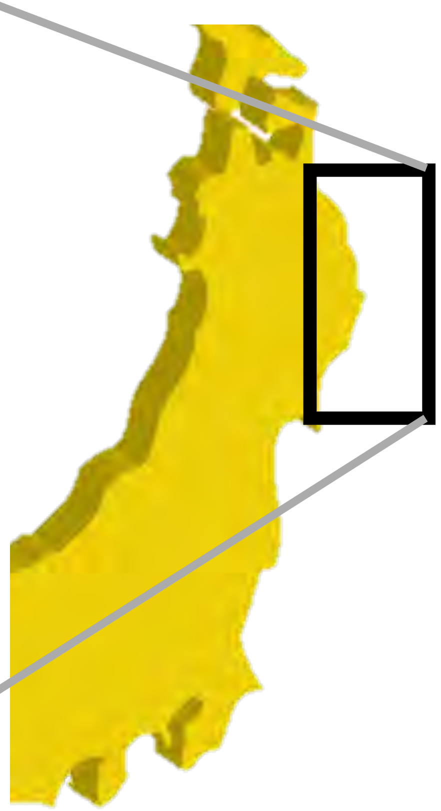


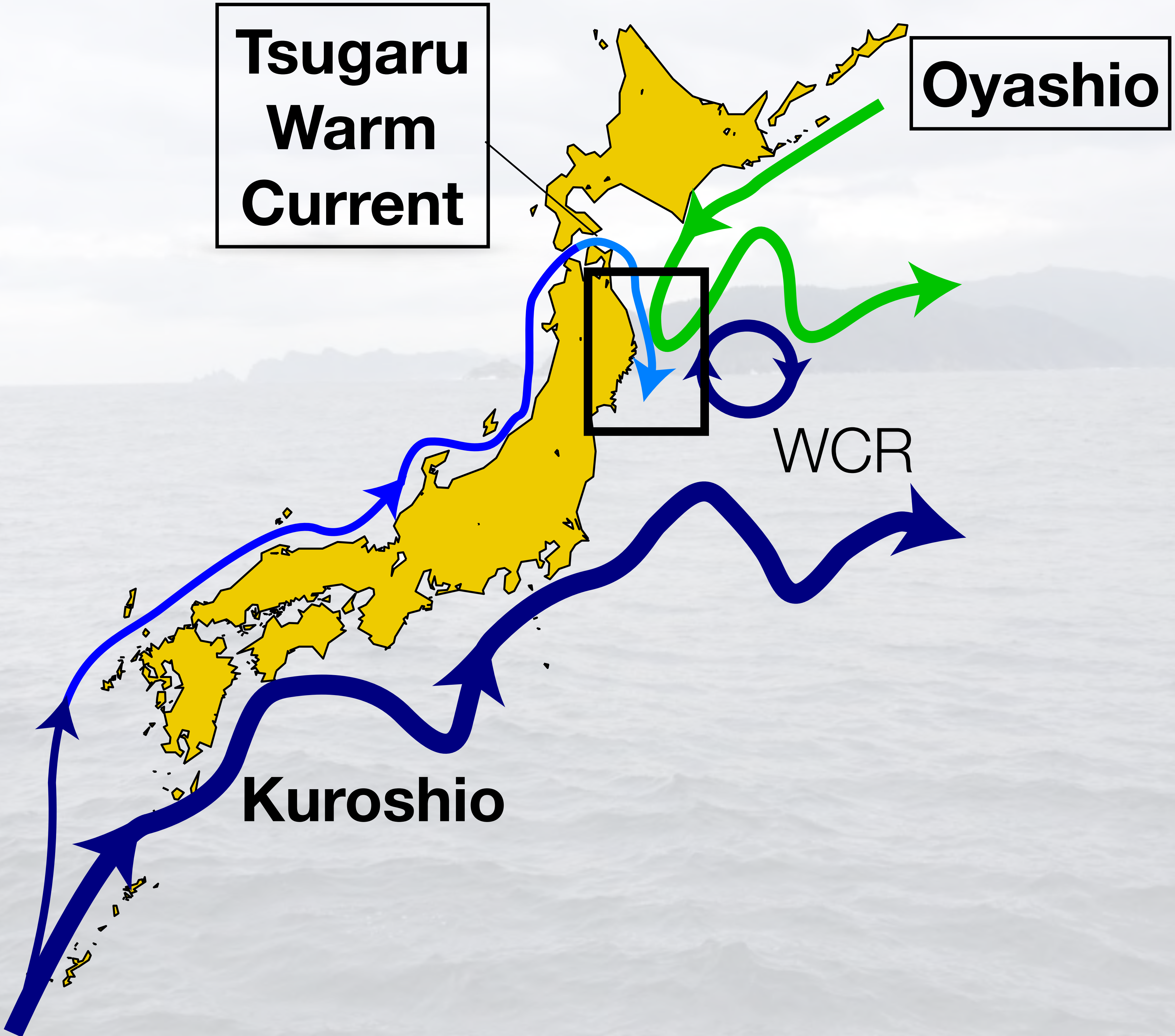
Post-tsunami difficulties

Infrastructure lost

Piled up debris

(Photos in 2012)

Productivity AND diversity are sustained by confluence of currents



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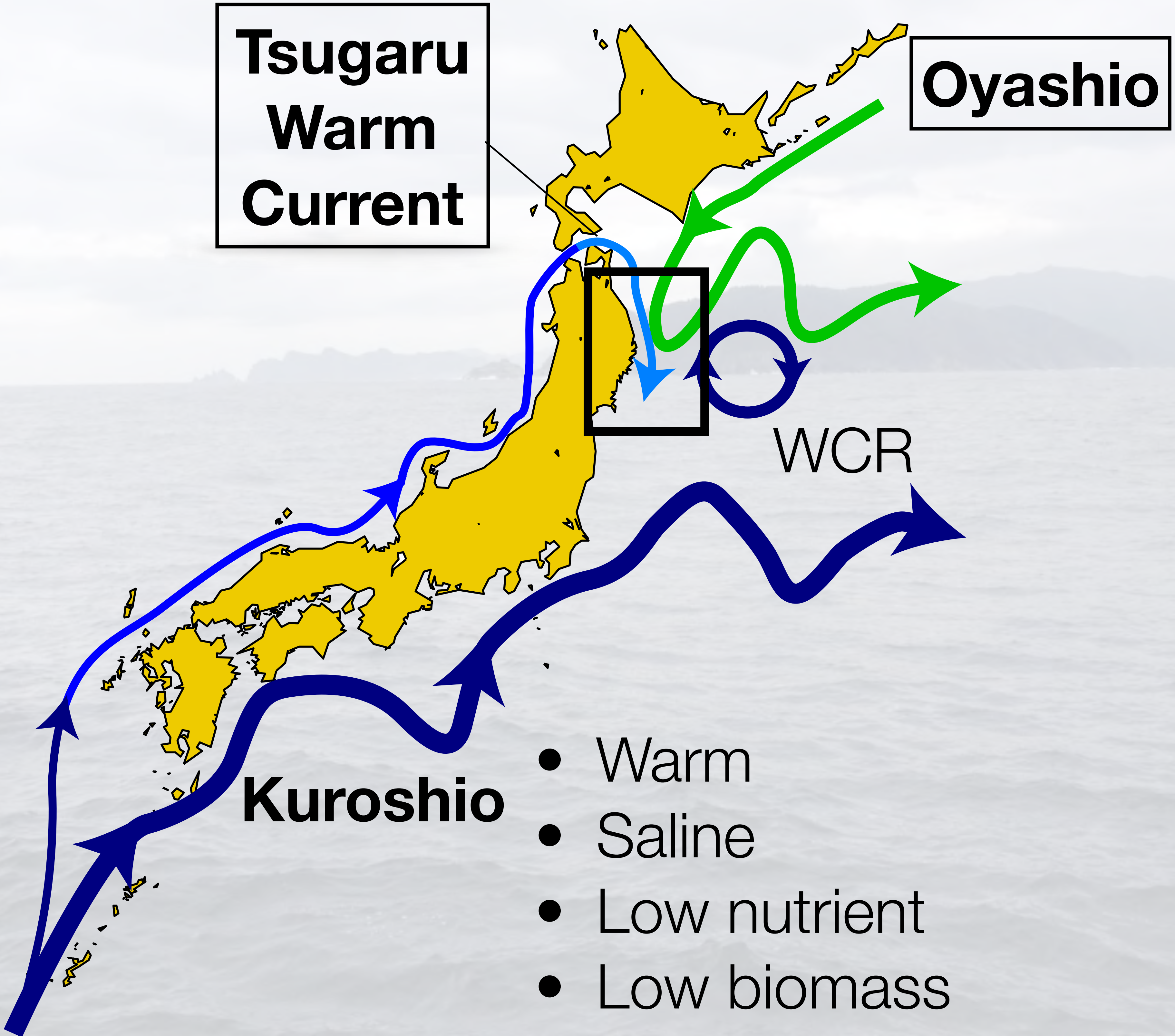

- Warm
- Saline
- Low nutrient
- Low biomass

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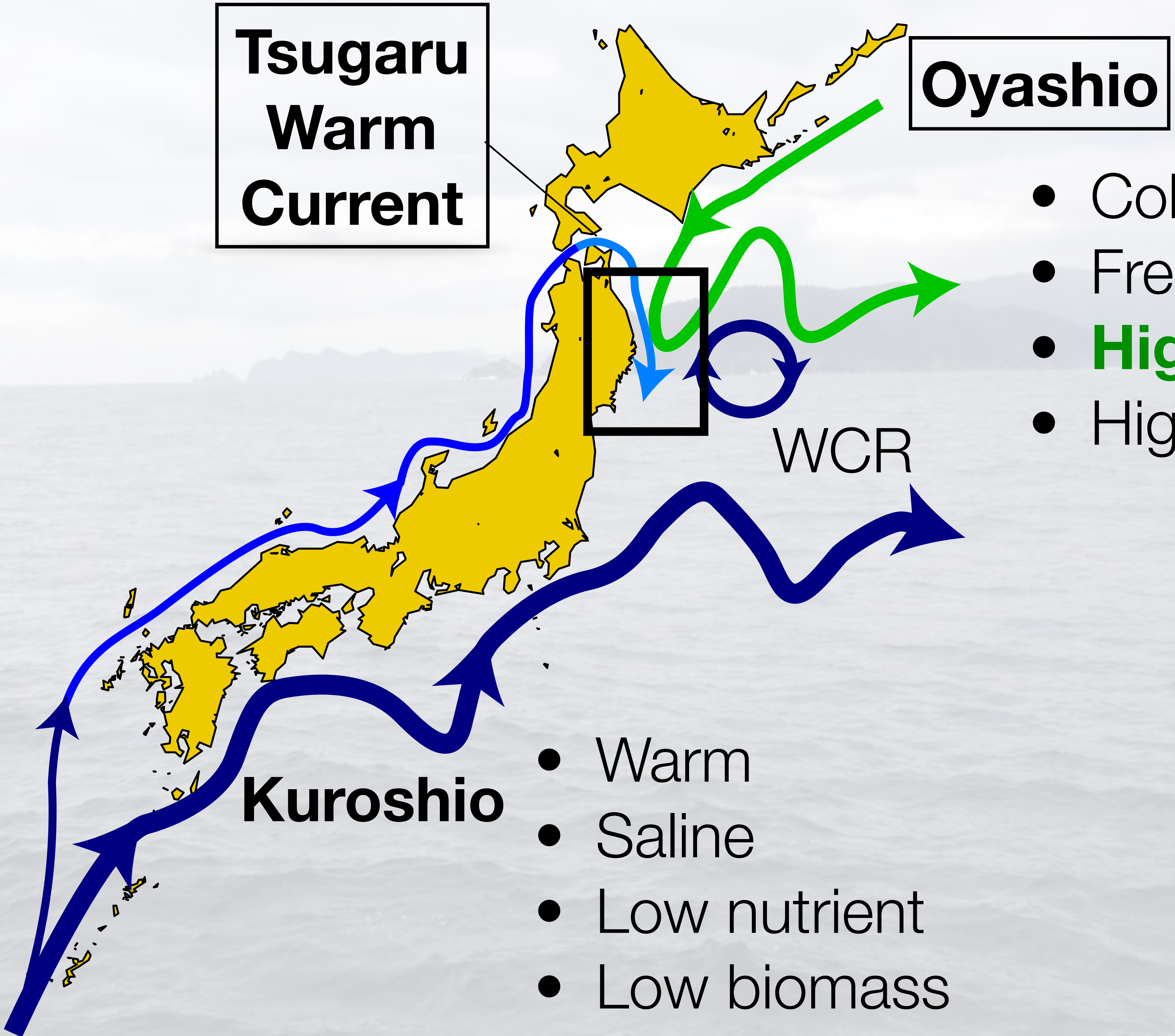

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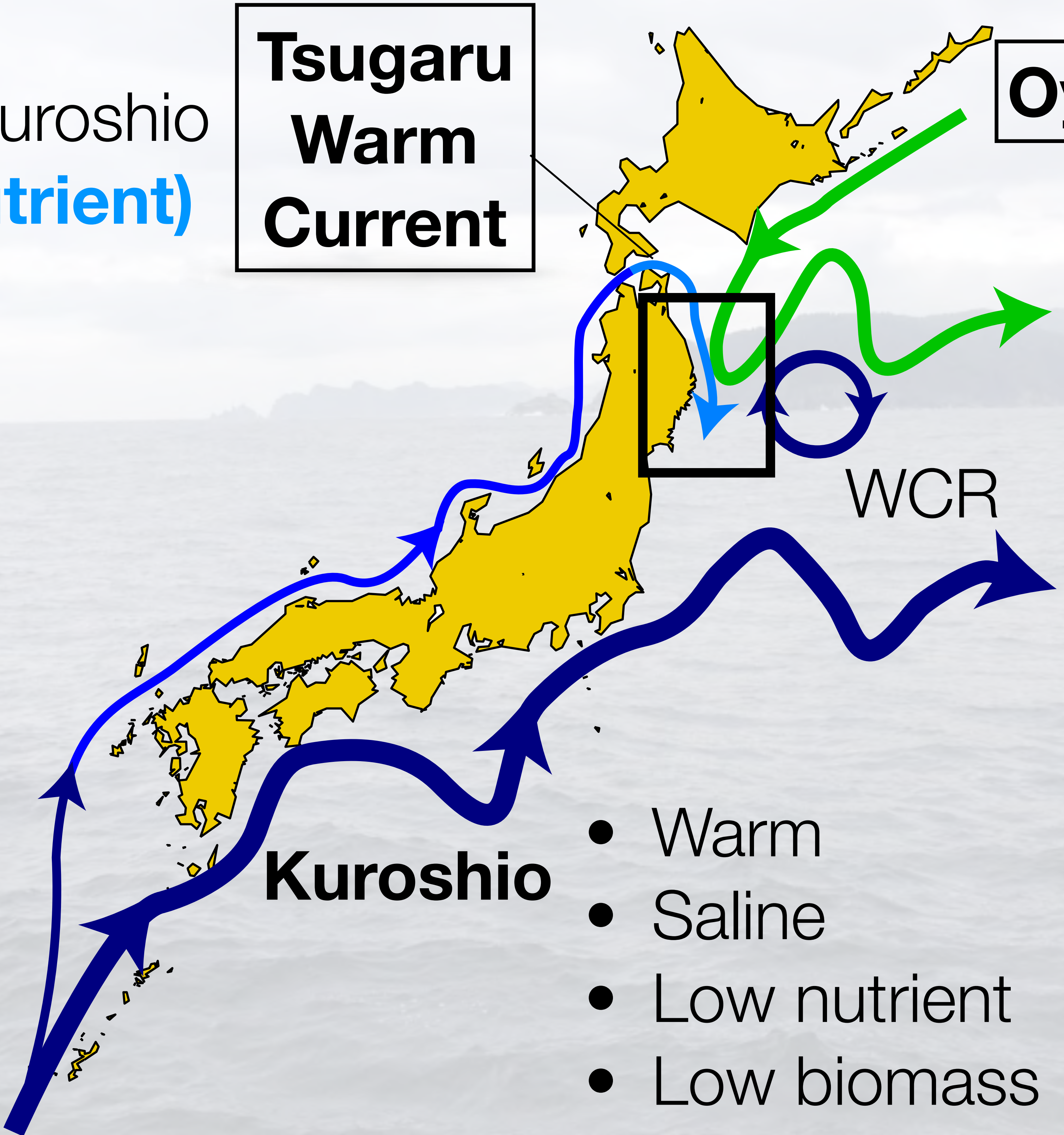

Origin: Kuroshio
(low-nutrient)

Tsugaru Warm Current

Oyashio

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WCR

Kuroshio

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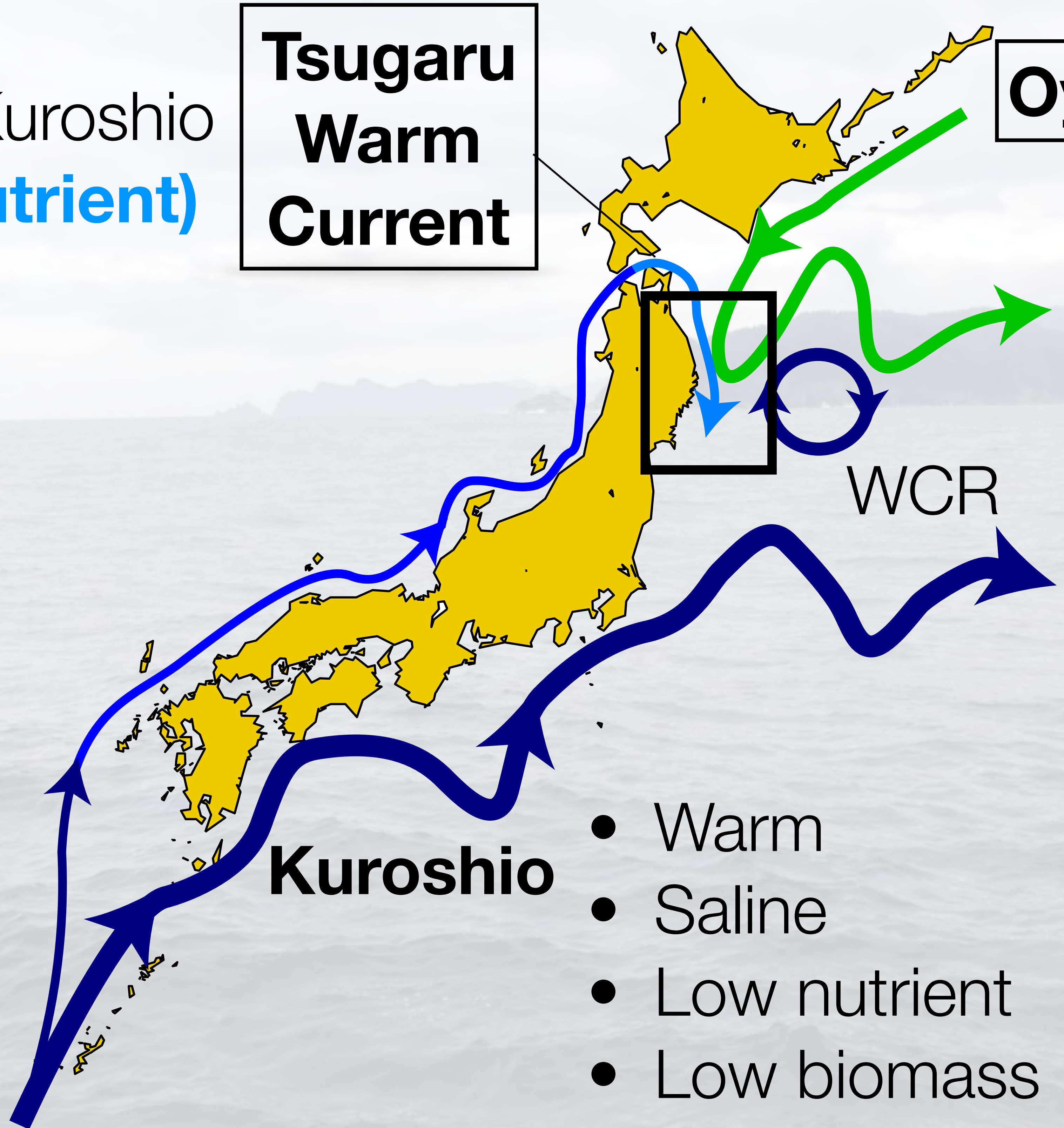

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Strong in
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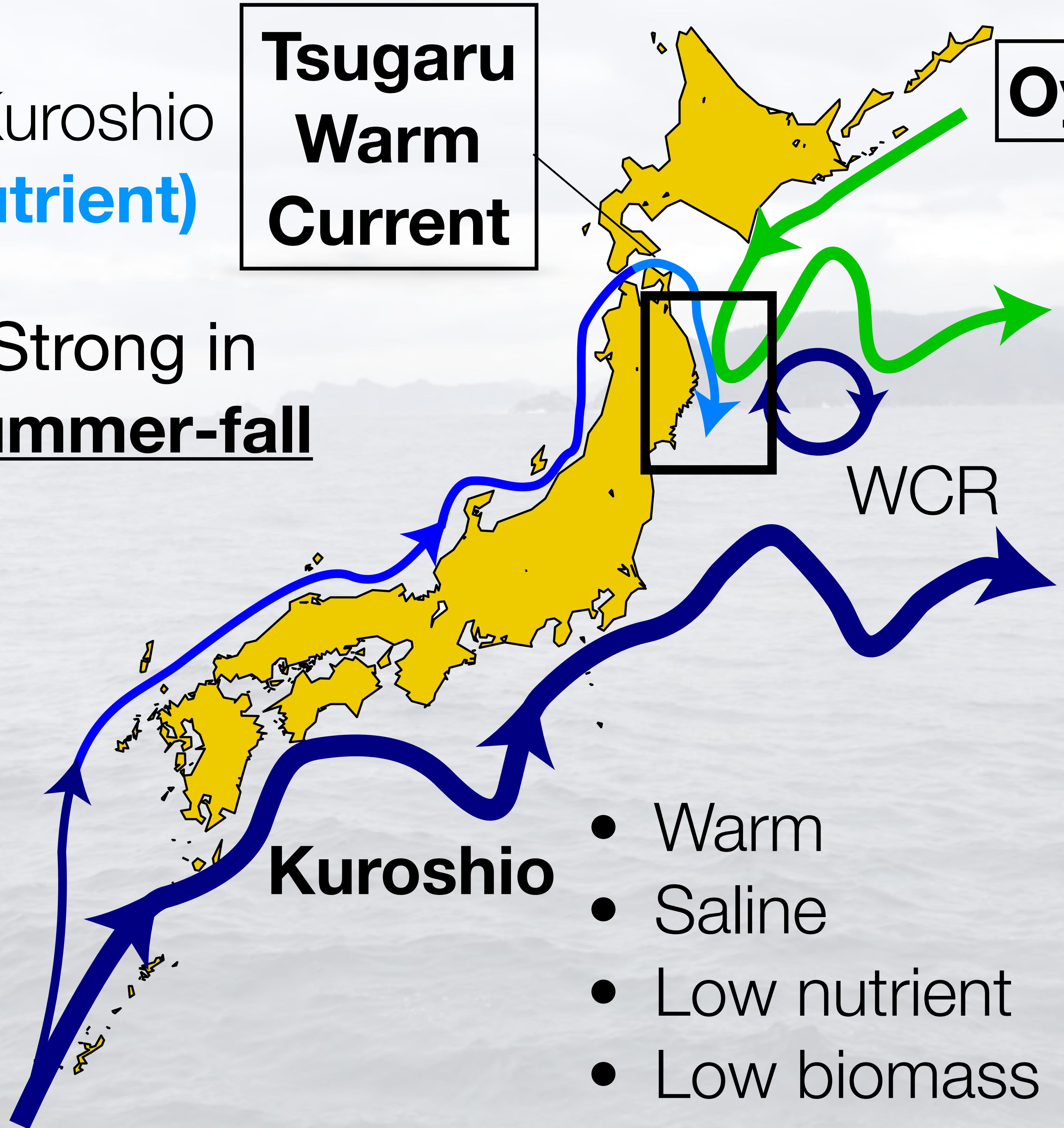

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Tsugaru Warm Current

Strong in
summer-fall

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- Fresh
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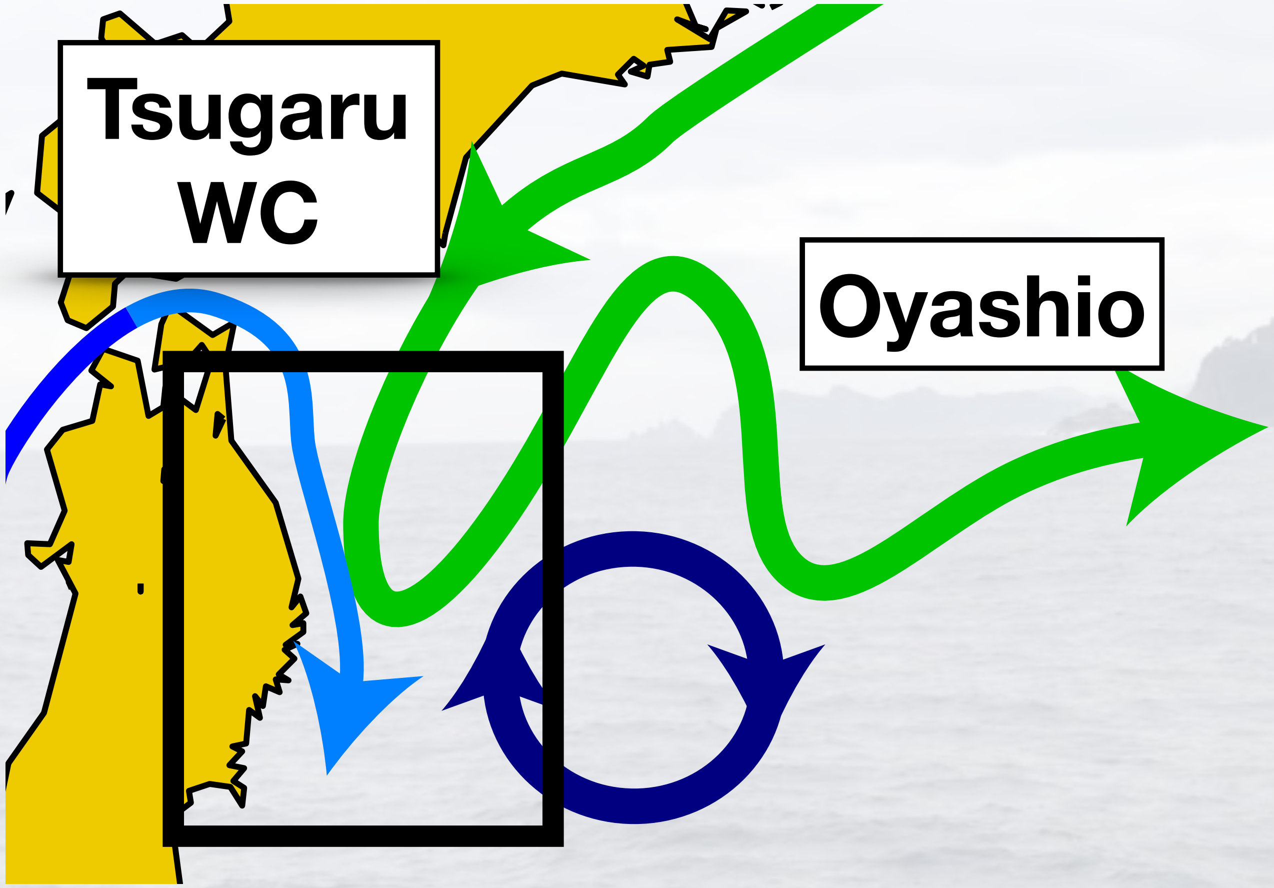
General Question:

How can Sanriku area be productive in summer?



Sanriku coastal areas are covered by nutrient-poor Tsugaru WC in summer

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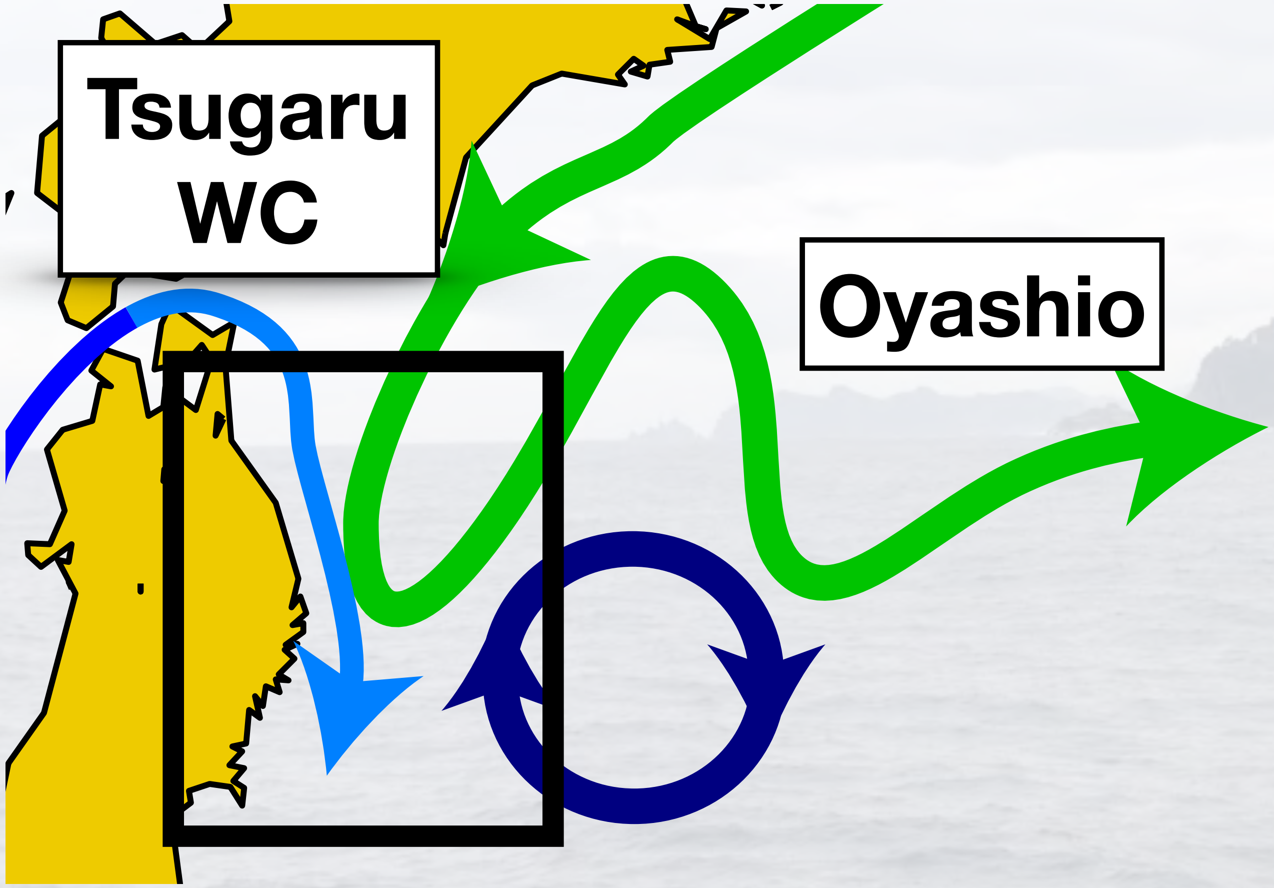

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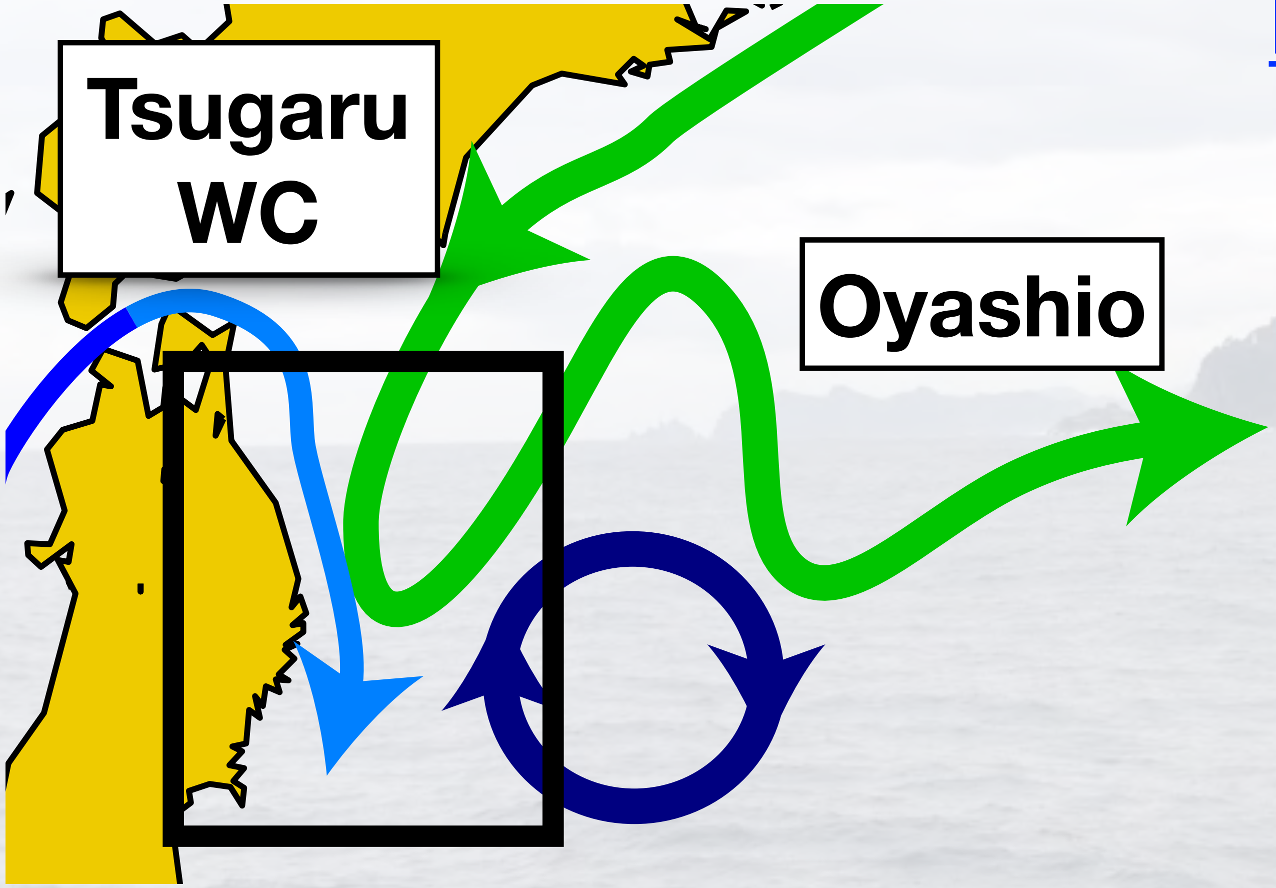

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- **Submesoscale** structure of the front b/w Tsugaru WC & Oyashio
- Internal waves & mixing processes across the front

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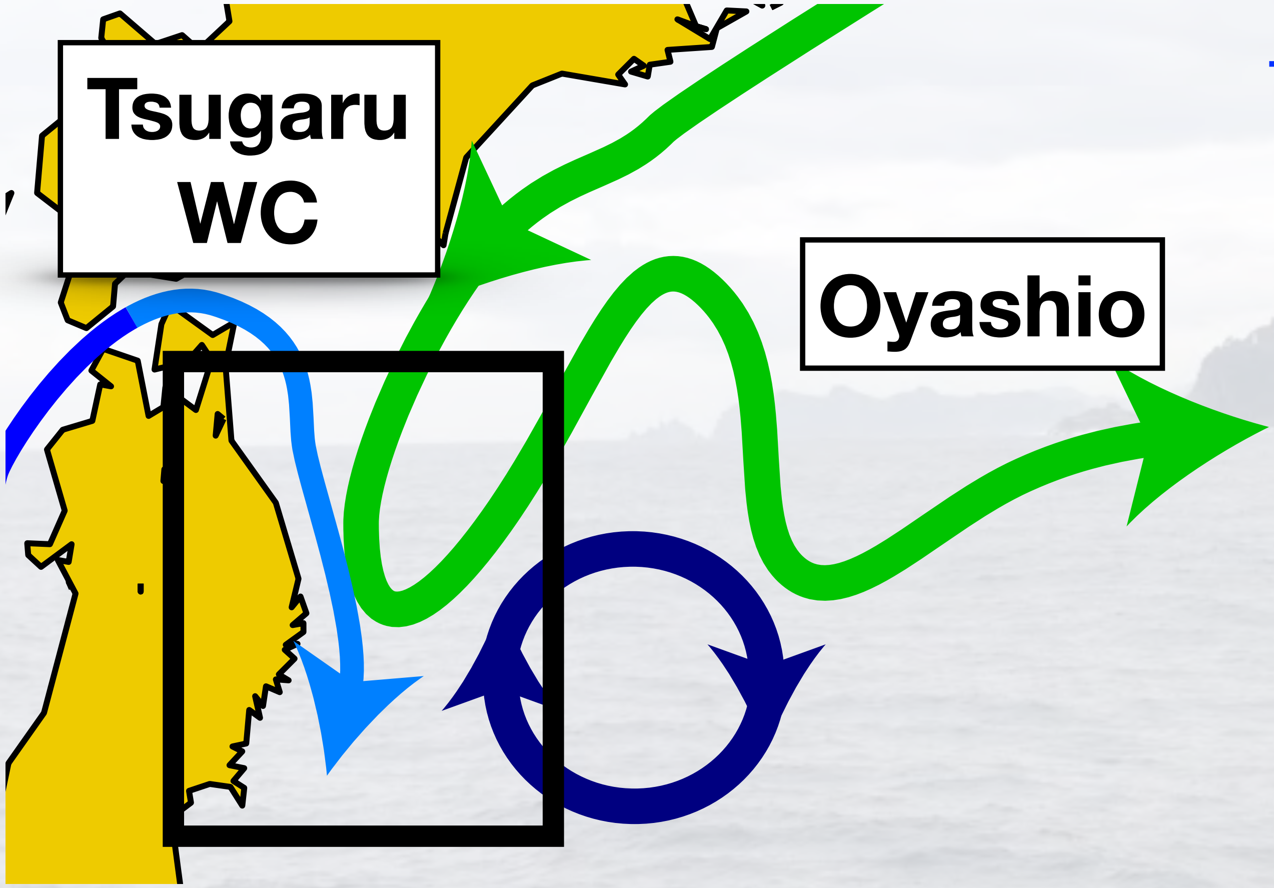

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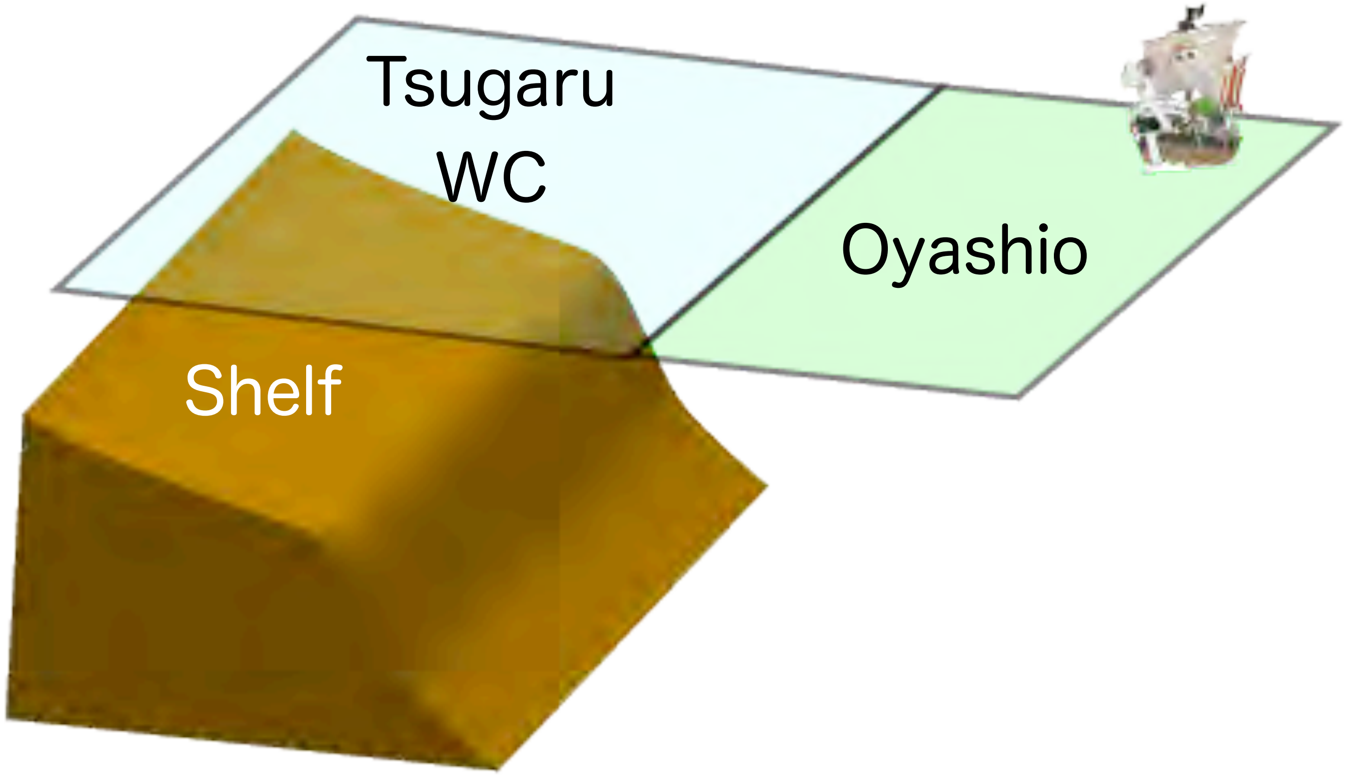
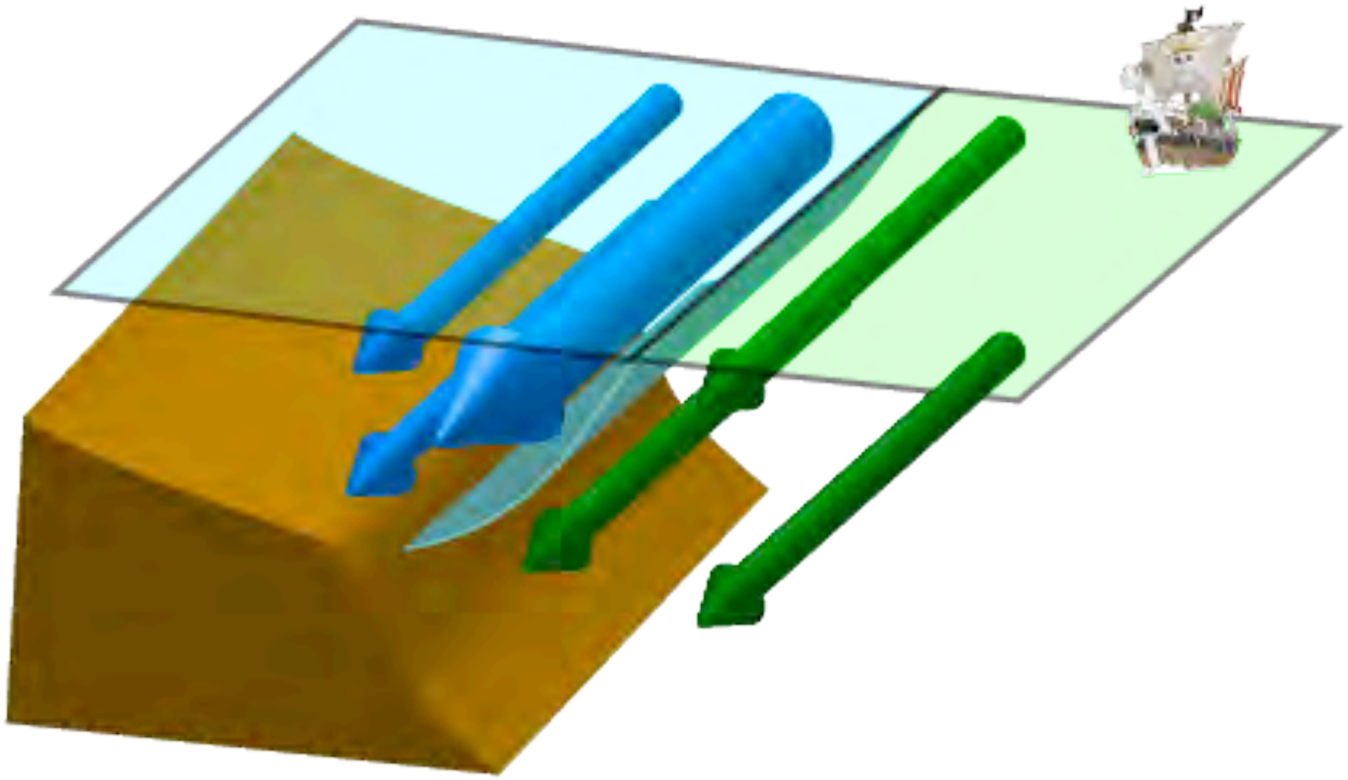
High-resolution observation

Dispersion relationship of IWs under the strong shear (Eqs by Whitt & Thomas 2013)



Dispersion relationship of IWs under the strong shear (Eqs by Whitt & Thomas 2013)

Latitudinally uniform geostrophic flows



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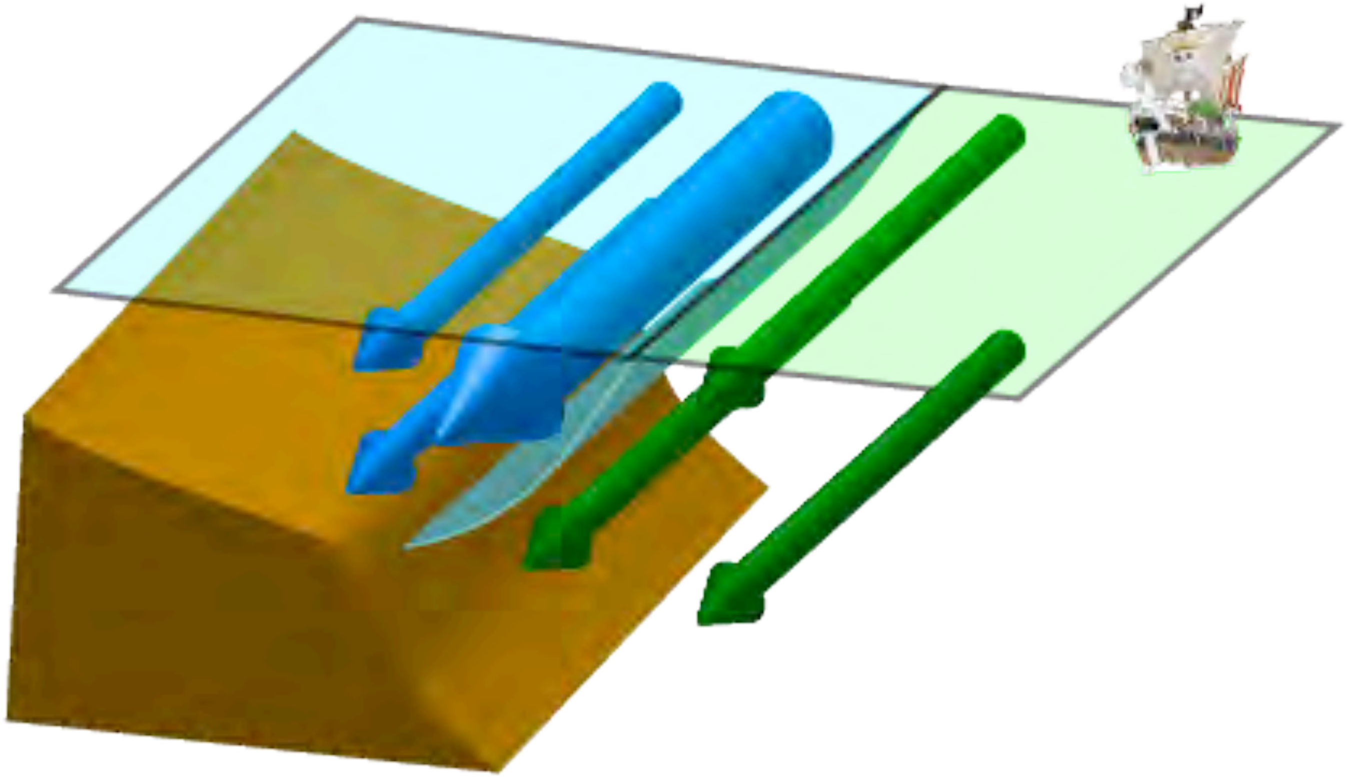

Equations of ageostrophic components (x-z plane)

$$\frac{\partial u_a}{\partial t} - f v_a = -\frac{1}{\rho_0}\frac{\partial p_a}{\partial x}$$

$$\frac{\partial v_a}{\partial t} + u_a\frac{\partial v_g}{\partial x} + w_a\frac{\partial v_g}{\partial z} + f u_a = 0$$

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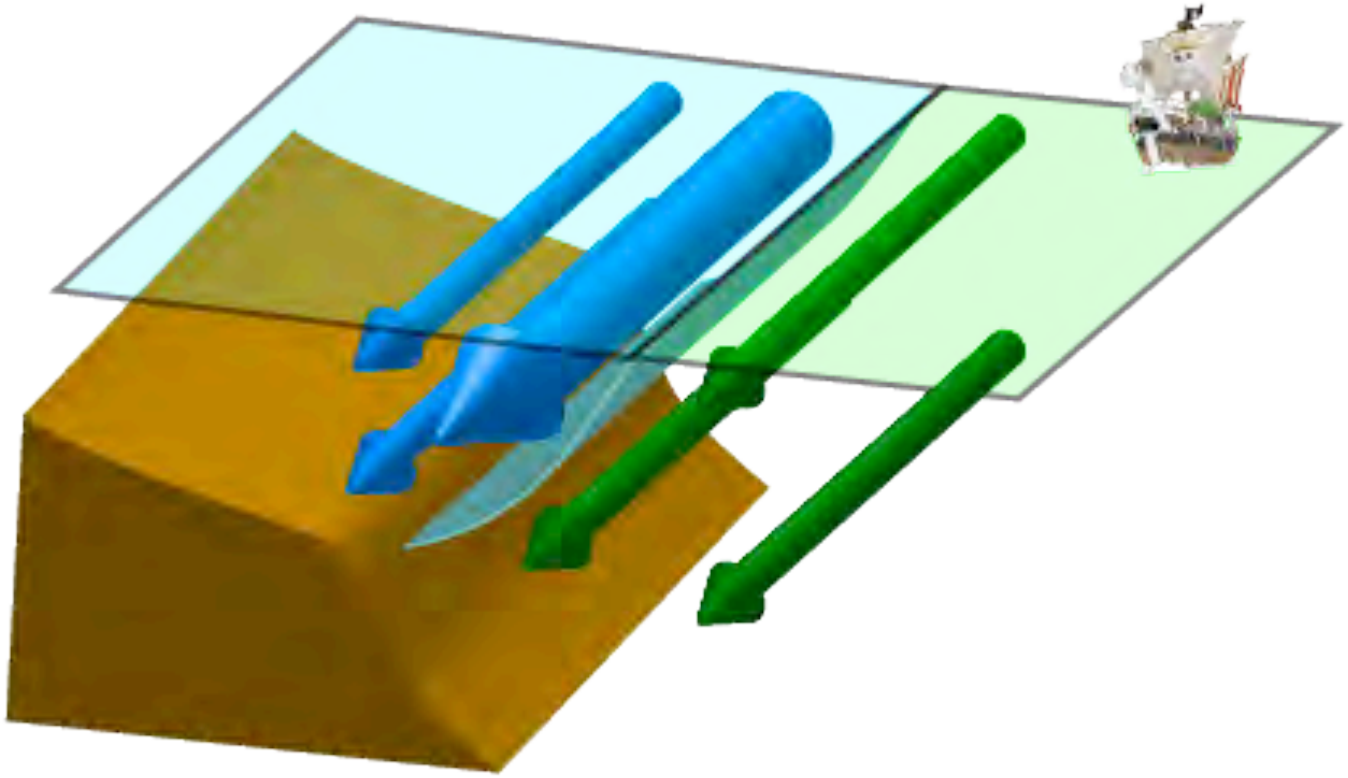

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and solve five algebraic equations

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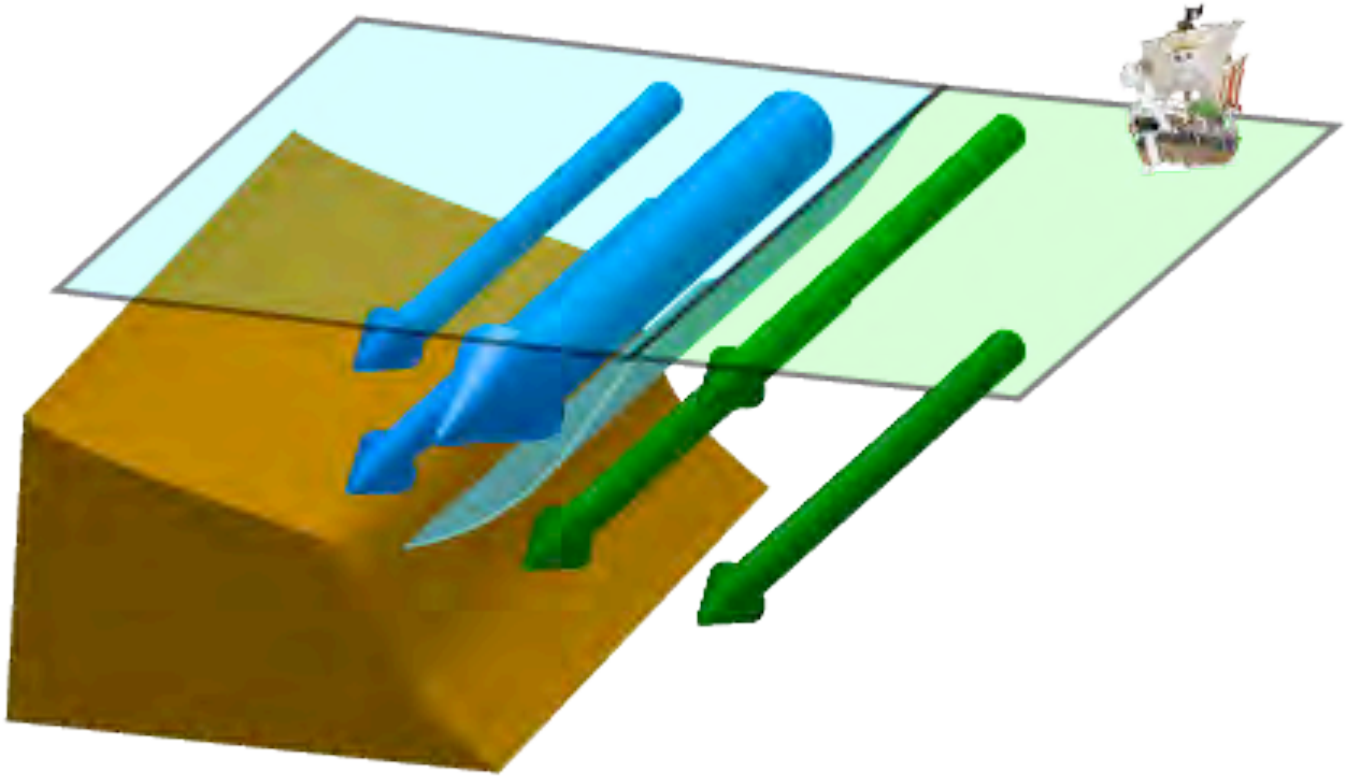

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Dispersion relationship

$$\omega = \sqrt{F^2 - 2f(\partial v_g/\partial z)(k/m) + N^2(k^2/m^2)}$$

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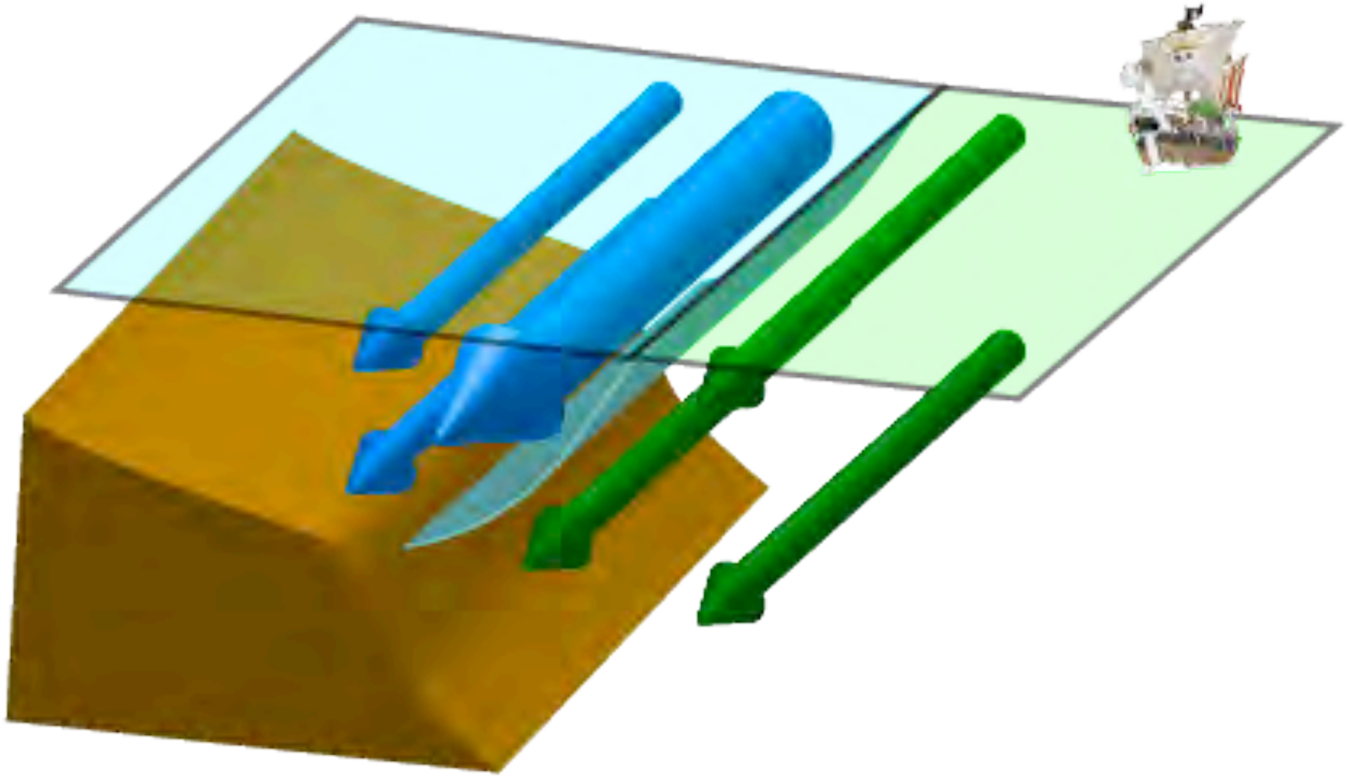

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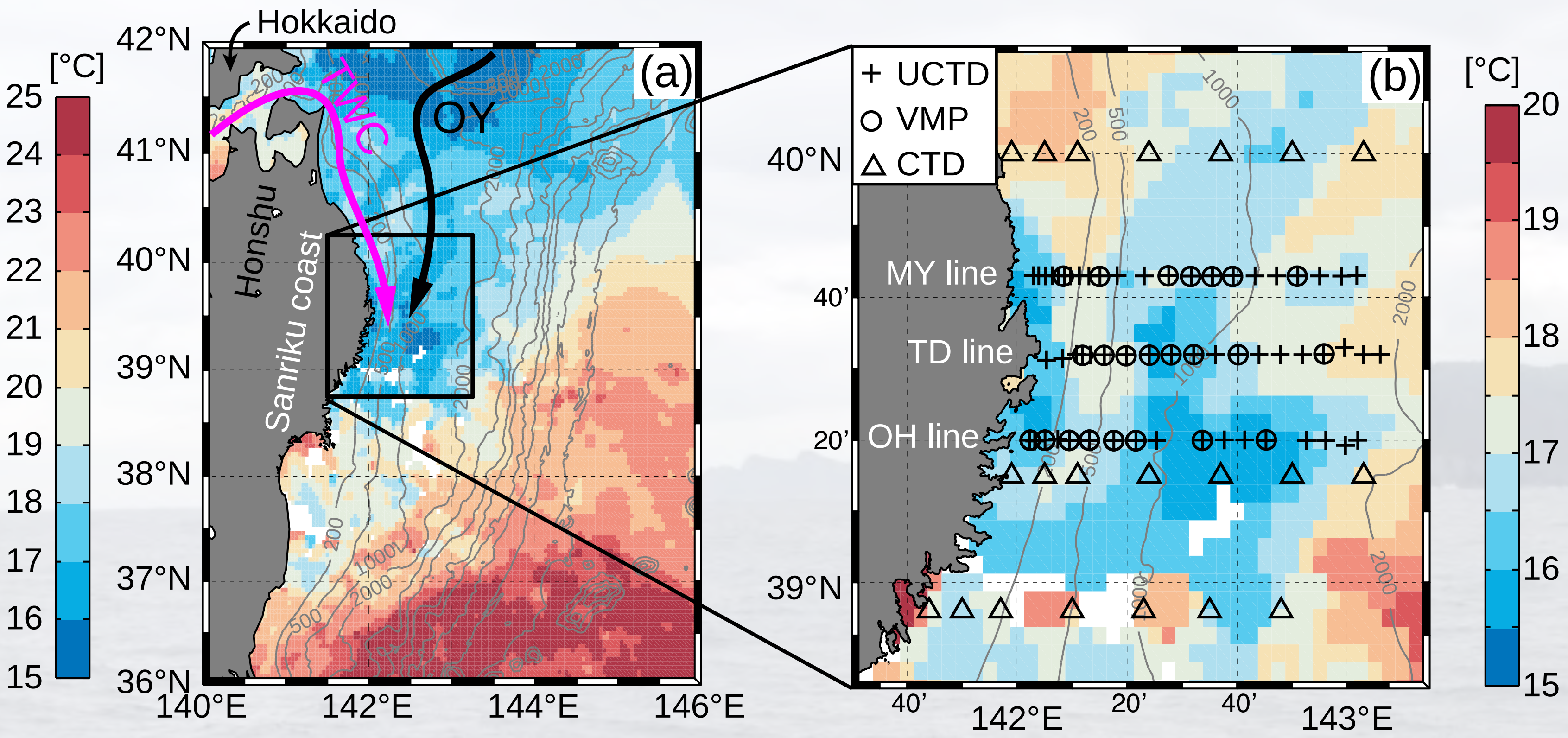
*Dispersion relationship is modified by horizontal & vertical shears, indicated by Rossby & Richardson numbers **Ro** and **Ri**

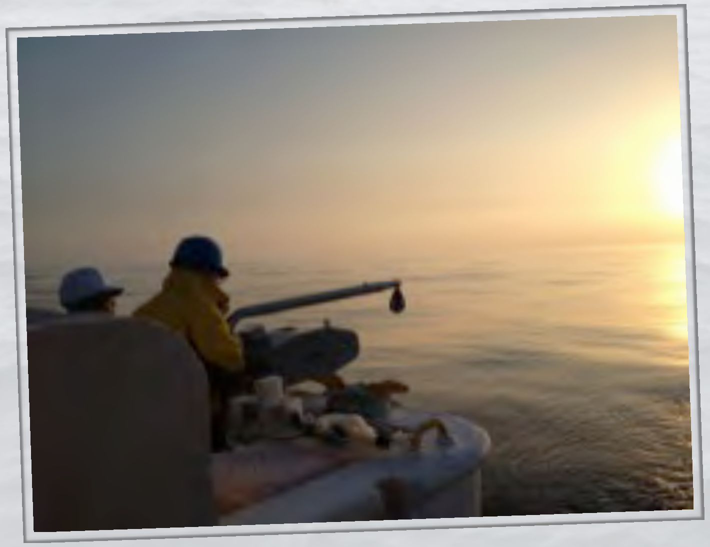
$$\mathrm{Ro} = \frac{1}{f}\frac{\partial v_g}{\partial x} \qquad \mathrm{Ri} = \frac{N^2}{\left(\frac{\partial v_g}{\partial z}\right)^2}$$

Observations:
R/V *Daisan Kaiyo maru* cruise in July 2013

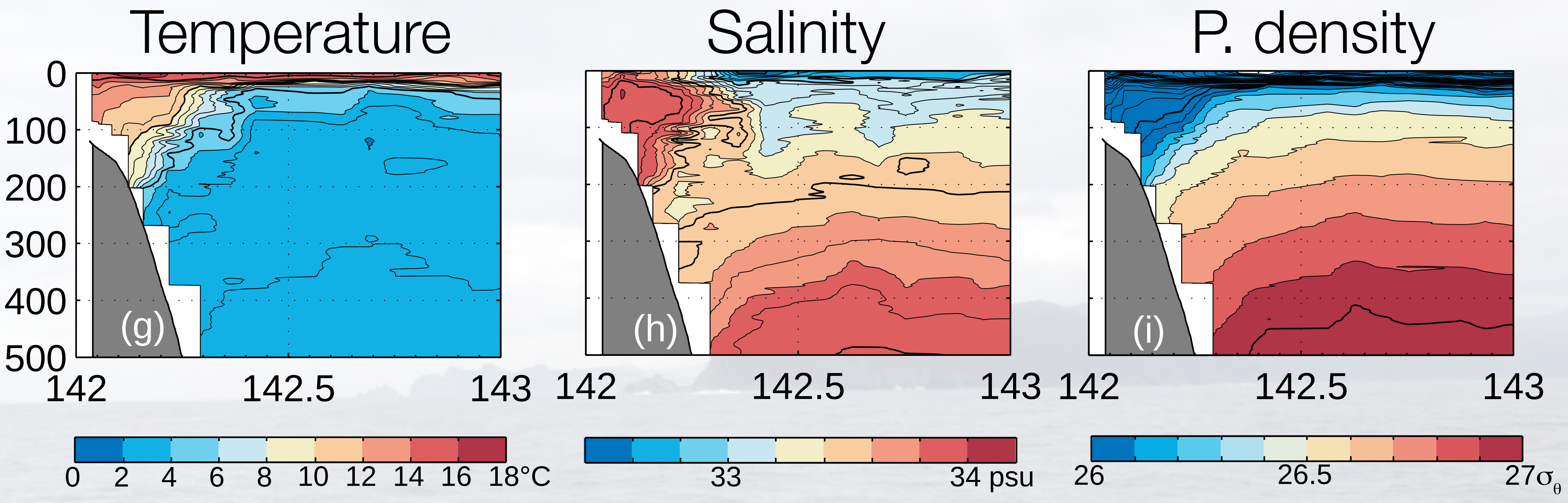


- Underway CTD (int. of 3–5 km)
- VMP (x3 casts) (vertical mixing)
- Shipboard ADCP

+: UCTD
o: VMP
^: CTD
surveys by Iwate pref.



Underway CTD transect (OH line)



- **Sharp front (10–30 km) on the shelf from subsurface to the bottom**
  (not resolved by past CTD observations of Δx~20 km)
- Complex interleaving structure of TS across the front
- Similar pattern for the other two transects

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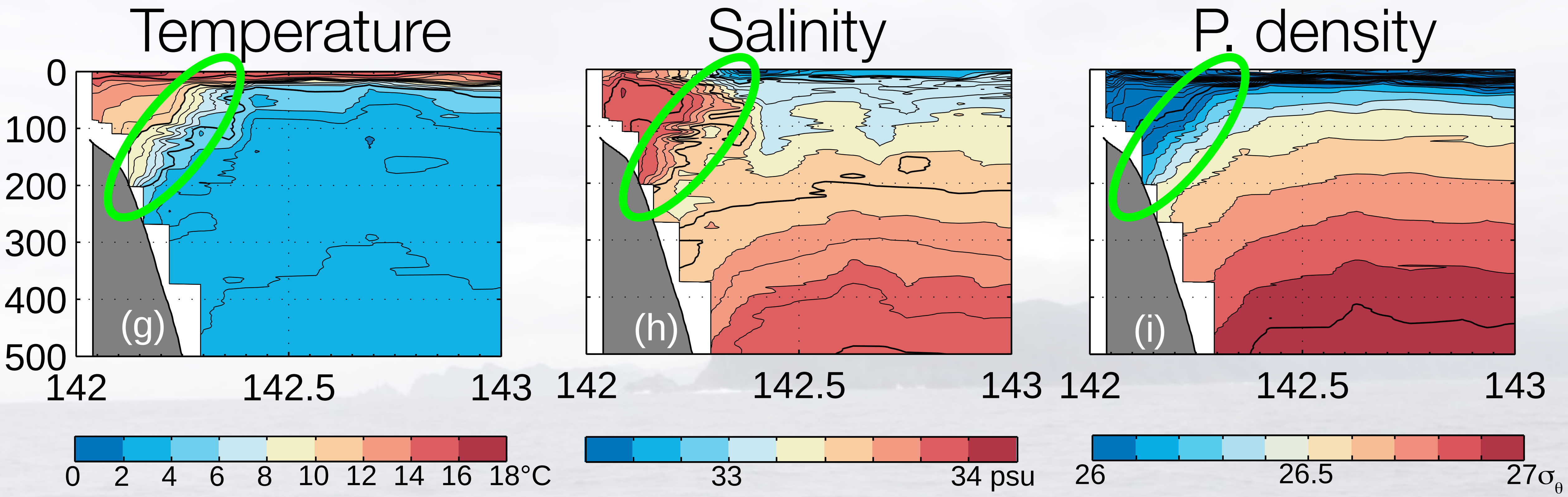

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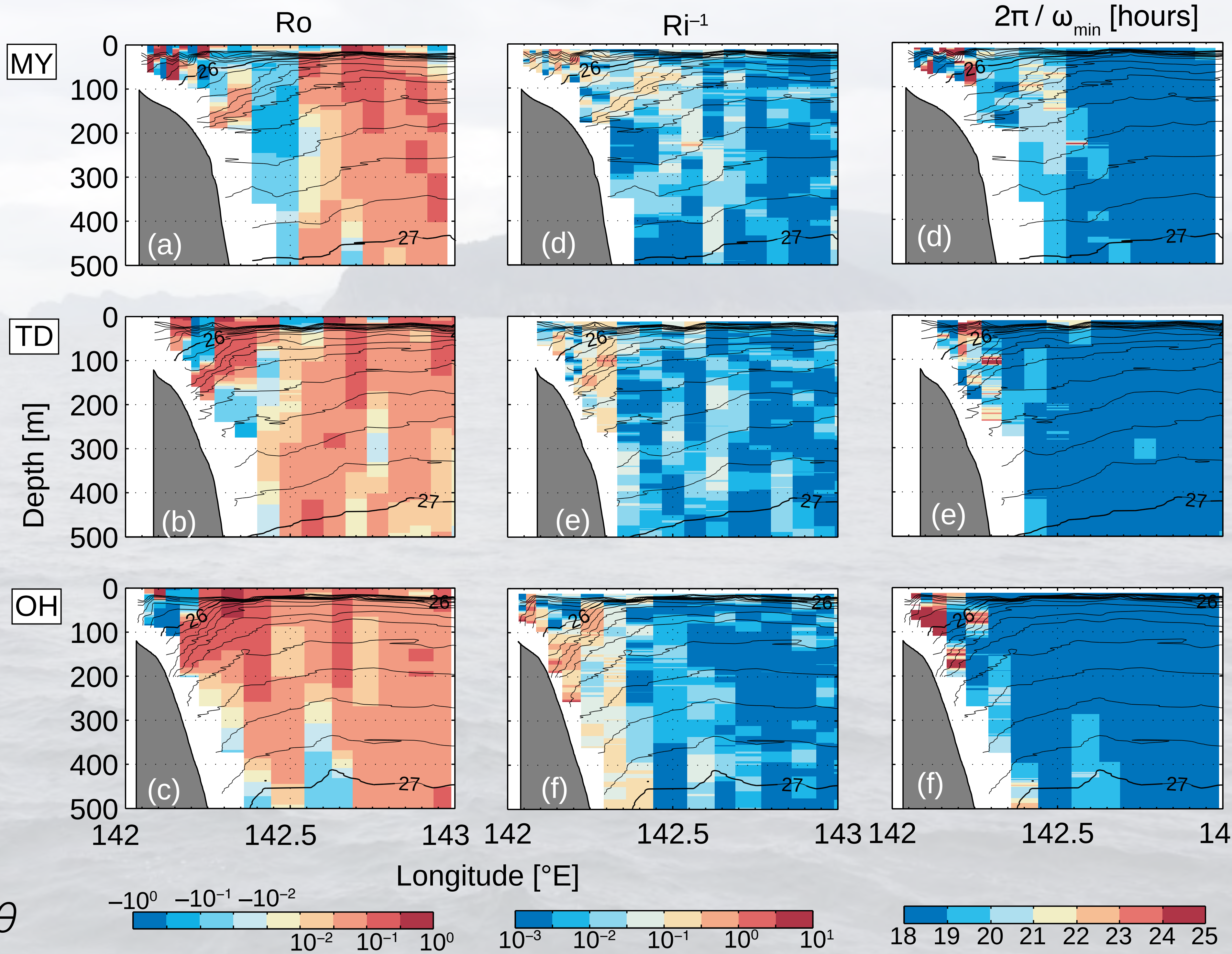
Drop in minimum frequency $\omega_{\min}$ for IWs

Ro h. shear **Ri** v. shear Max. period

$$\omega_{\min} = f\sqrt{1+\mathrm{Ro}-\mathrm{Ri}^{-1}}$$



Contour: σ_θ

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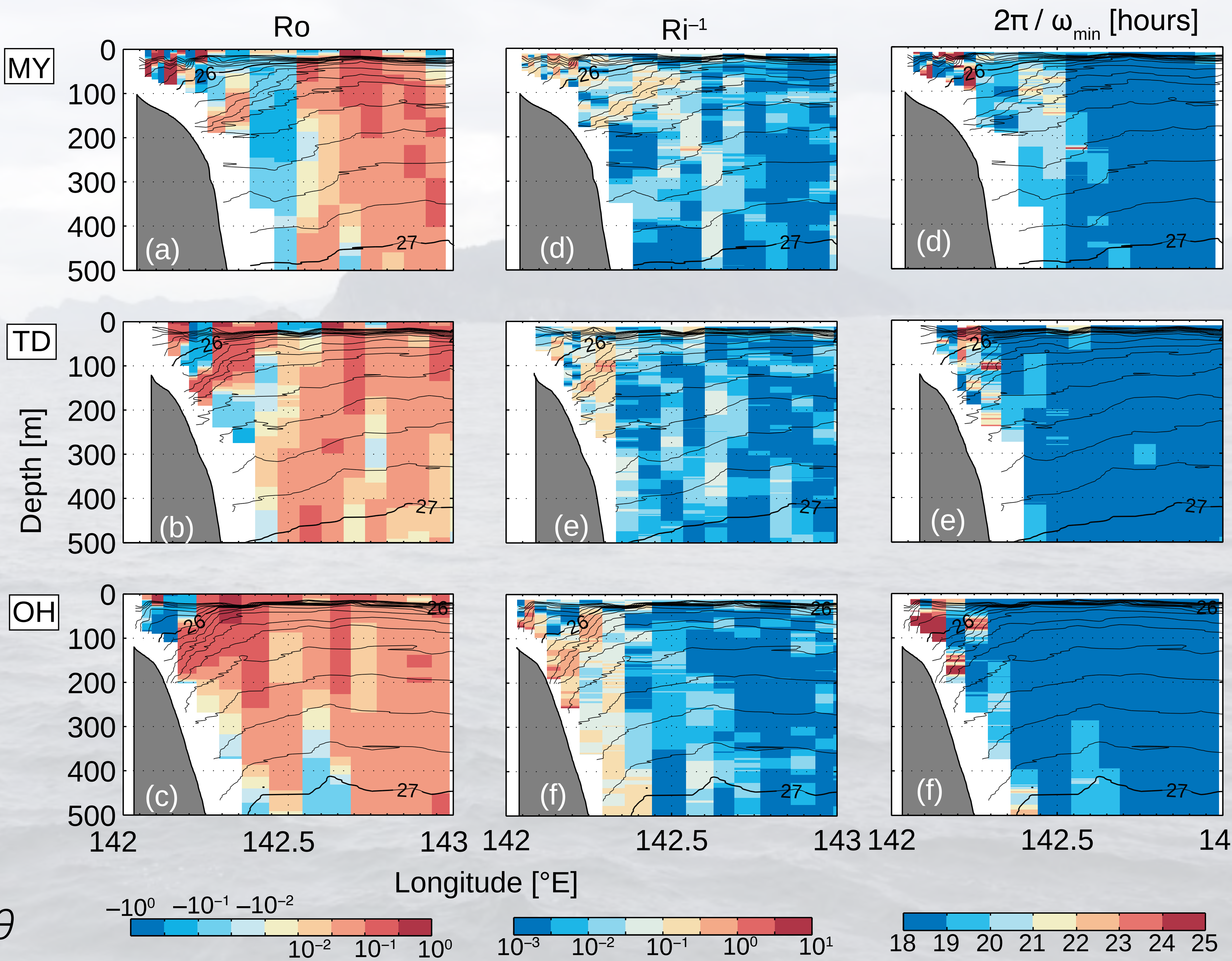

- **V. shear is high** along the front band
- **Minimum frequency was dropped** to ~ 2π/24 h

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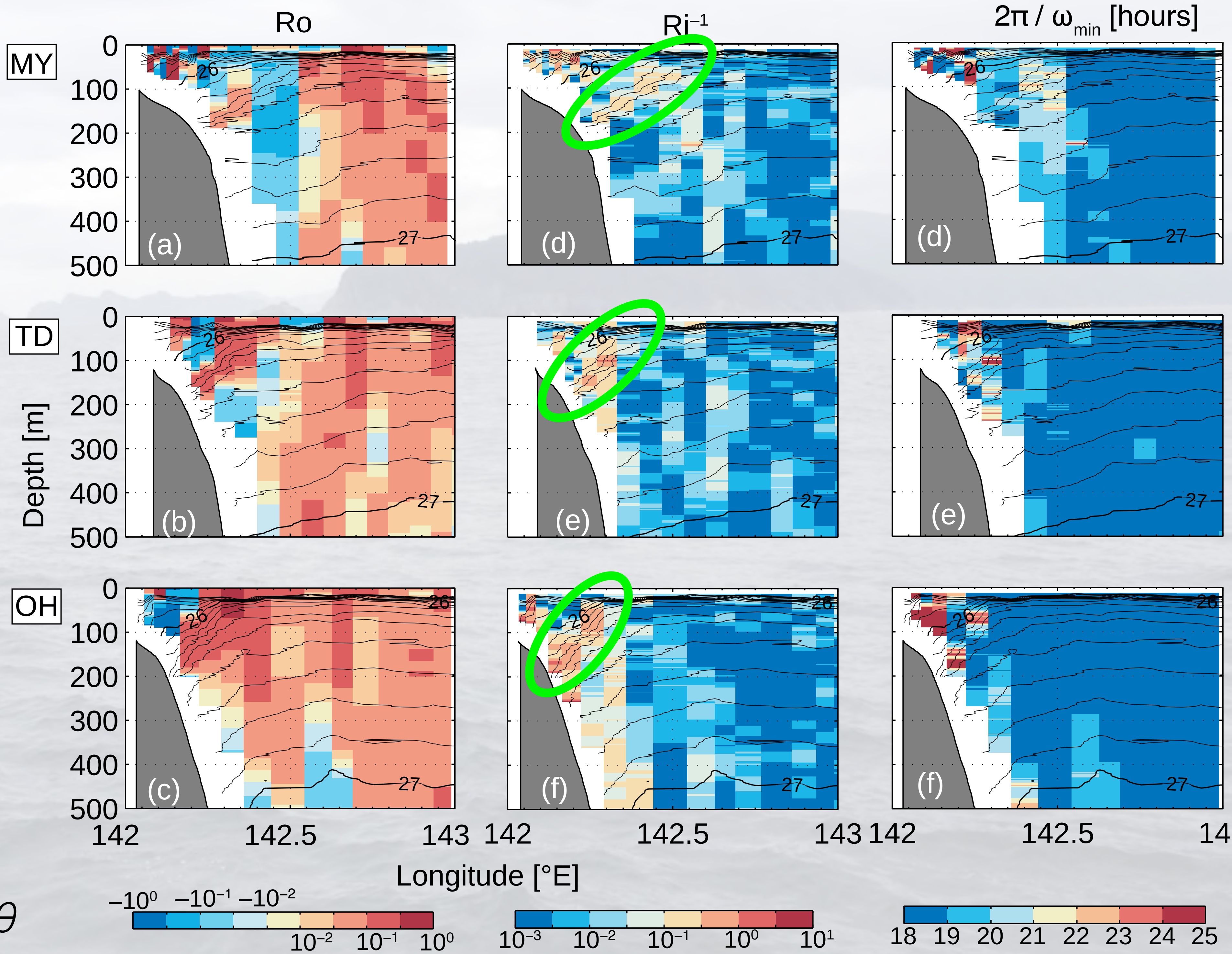

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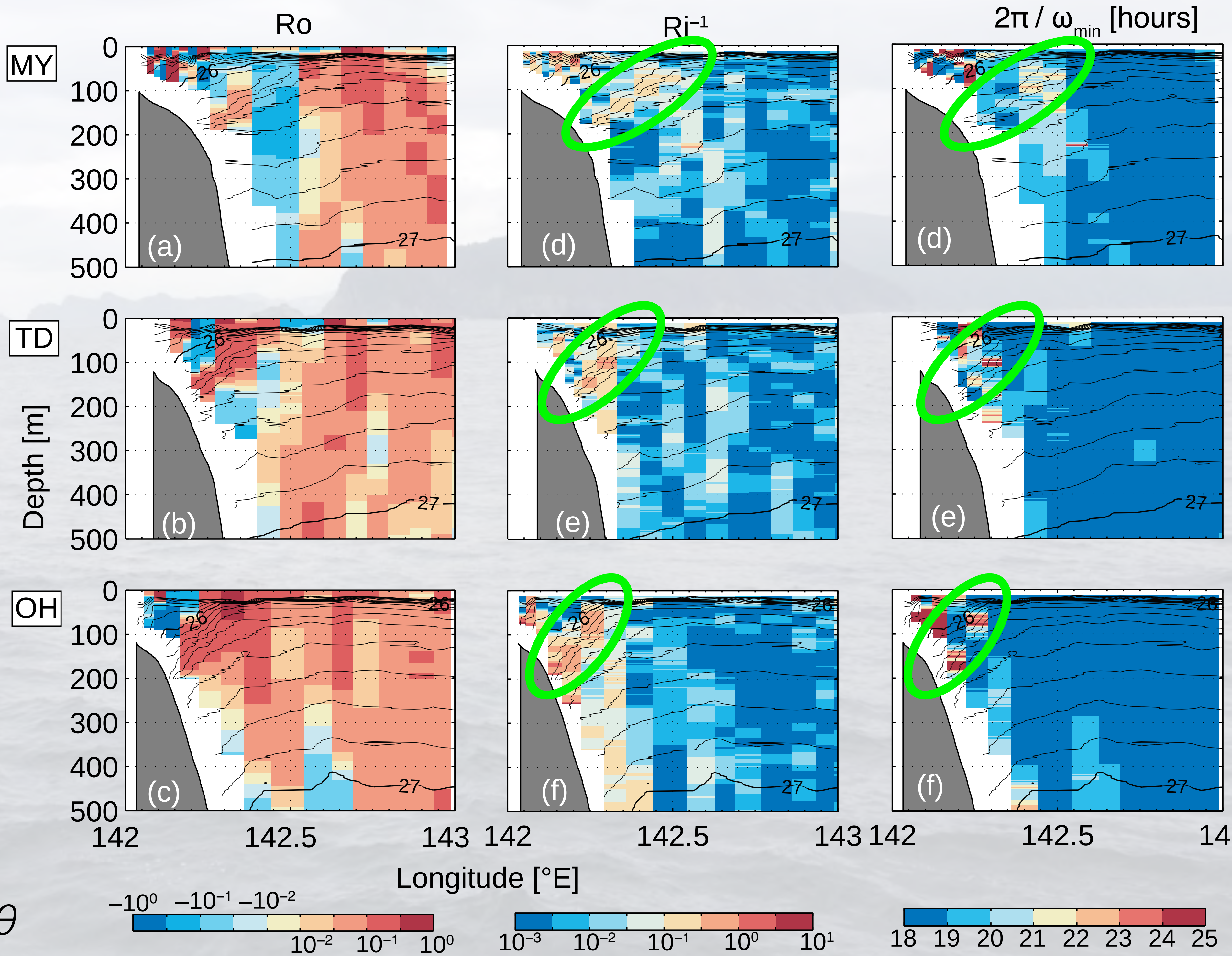

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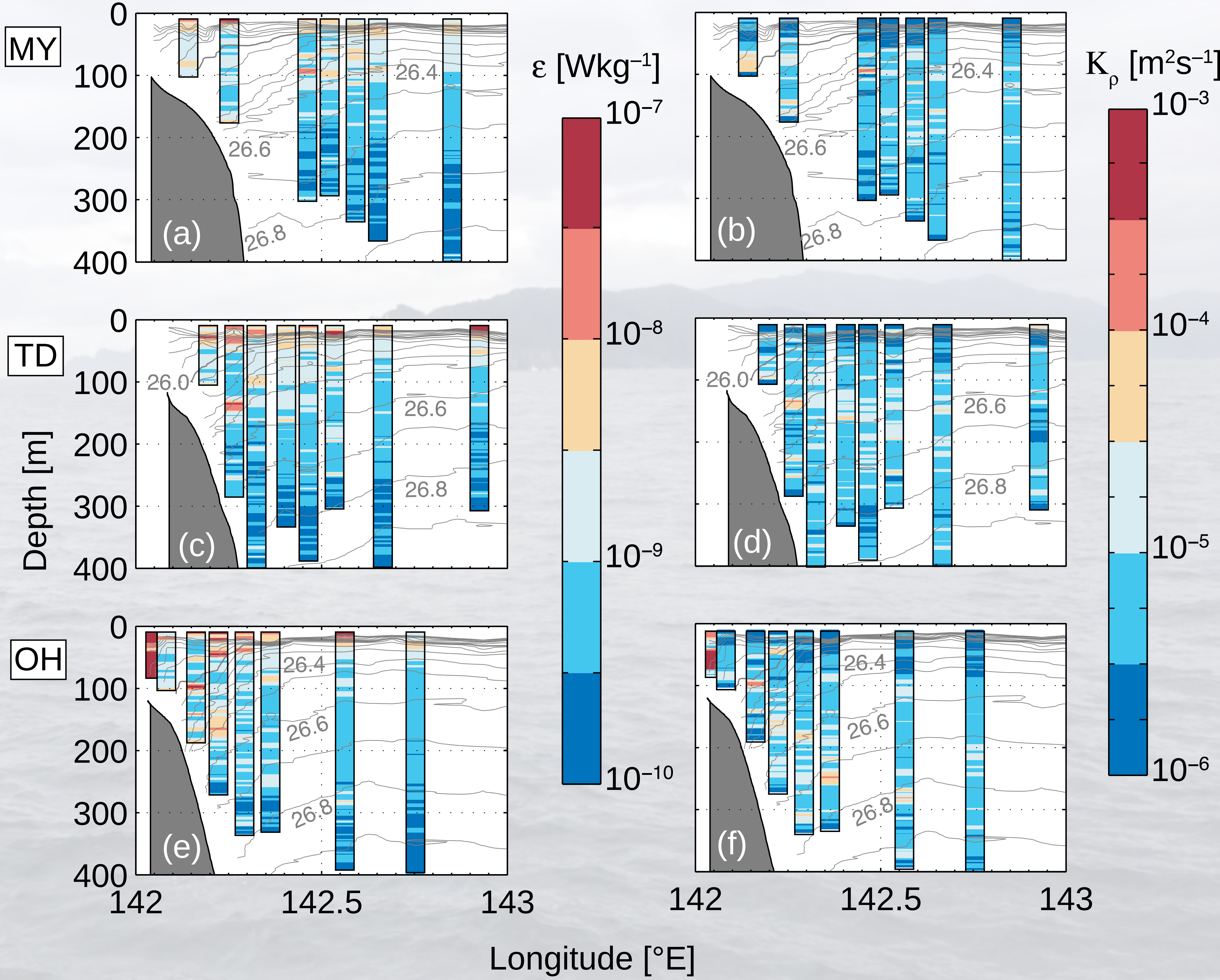
Vertical Mixing

Energy dissipation rate ε

Vertical diffusivity K_ρ



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Vertical Mixing

- **ε & K_ρ are elevated along the front**
- ε:
  front: ~10^{-8}
  bg: <10^{-9}
- K_ρ
  front: ~10^{-4}
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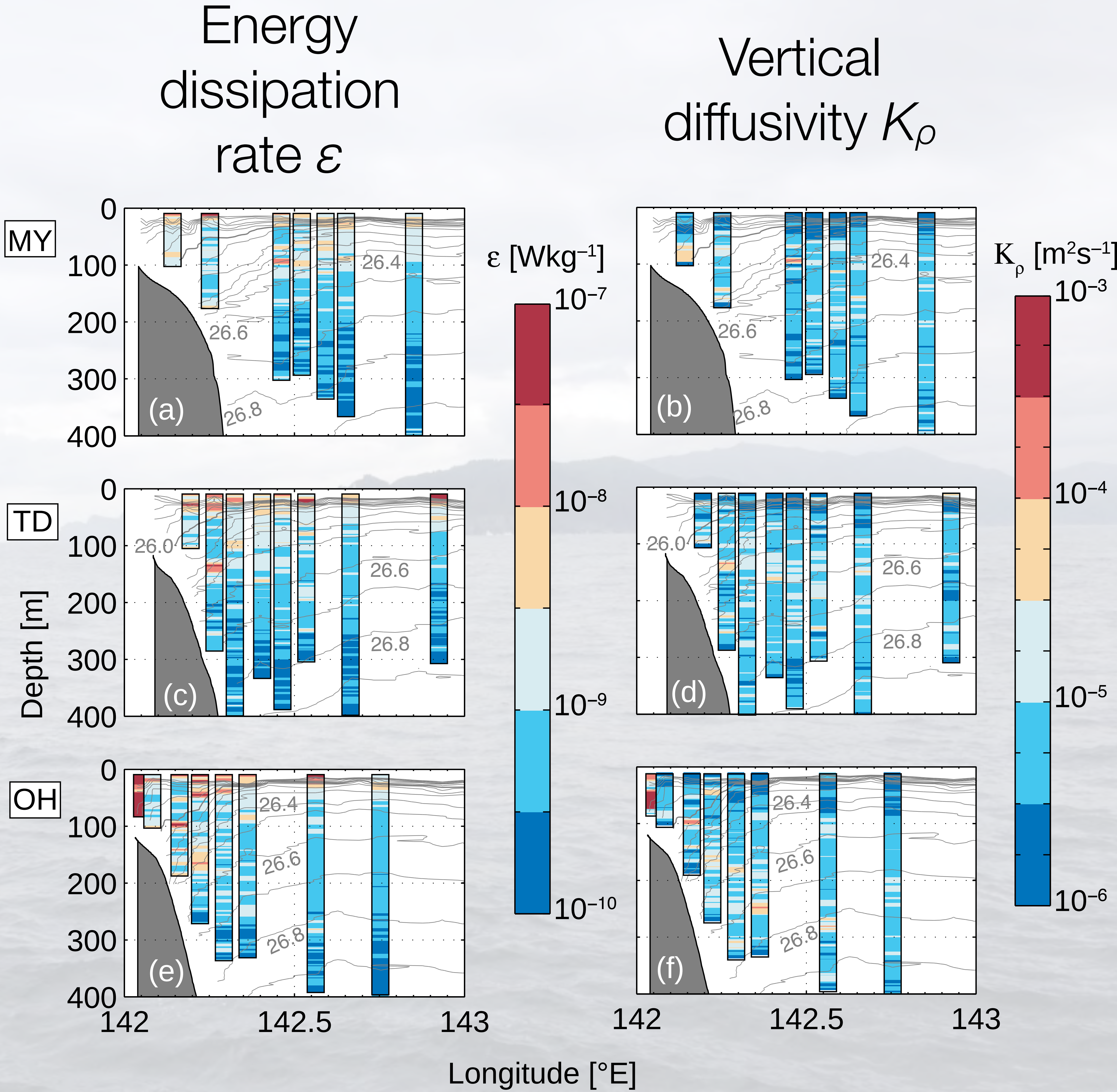
Contour: σ_θ



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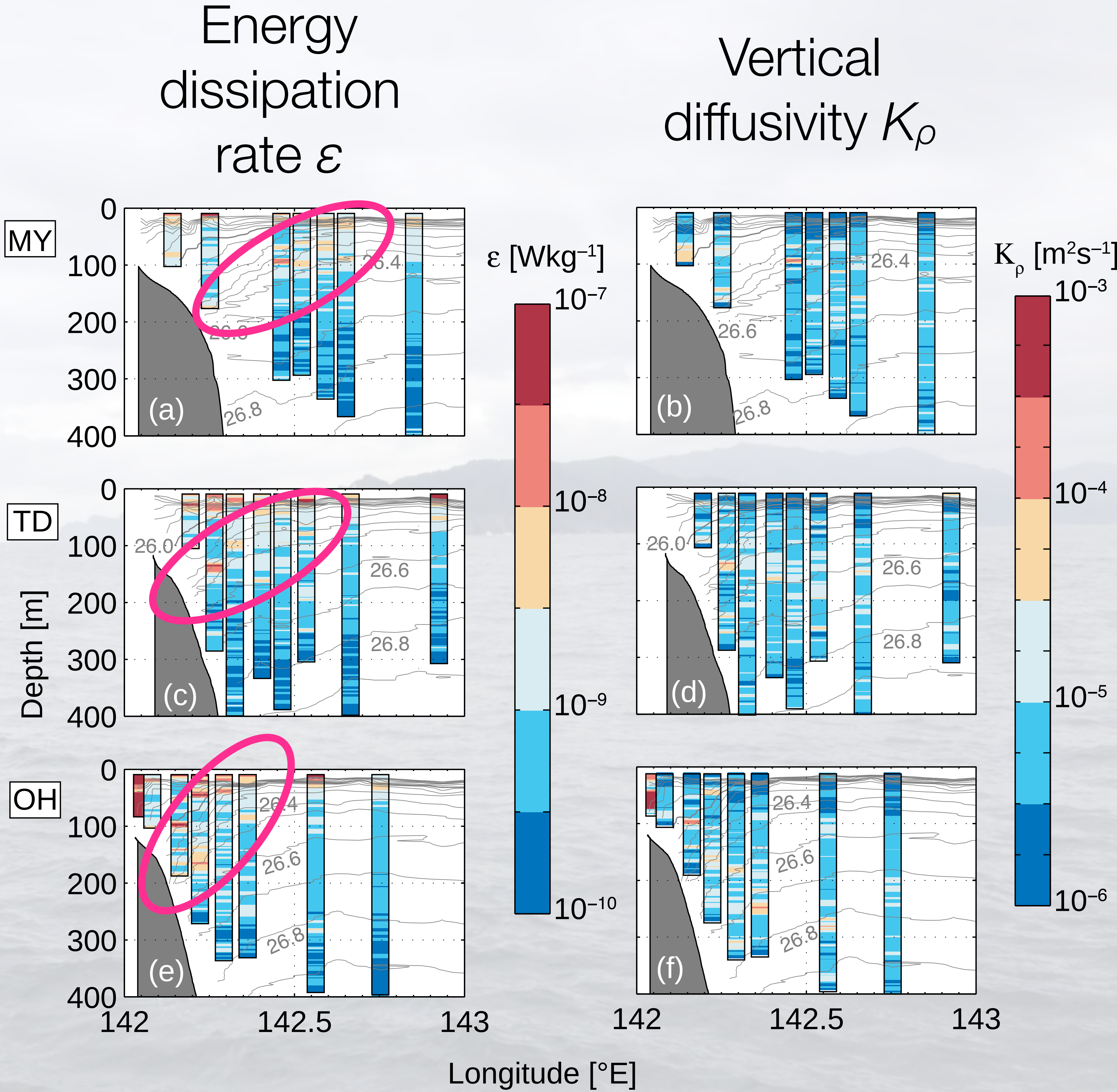

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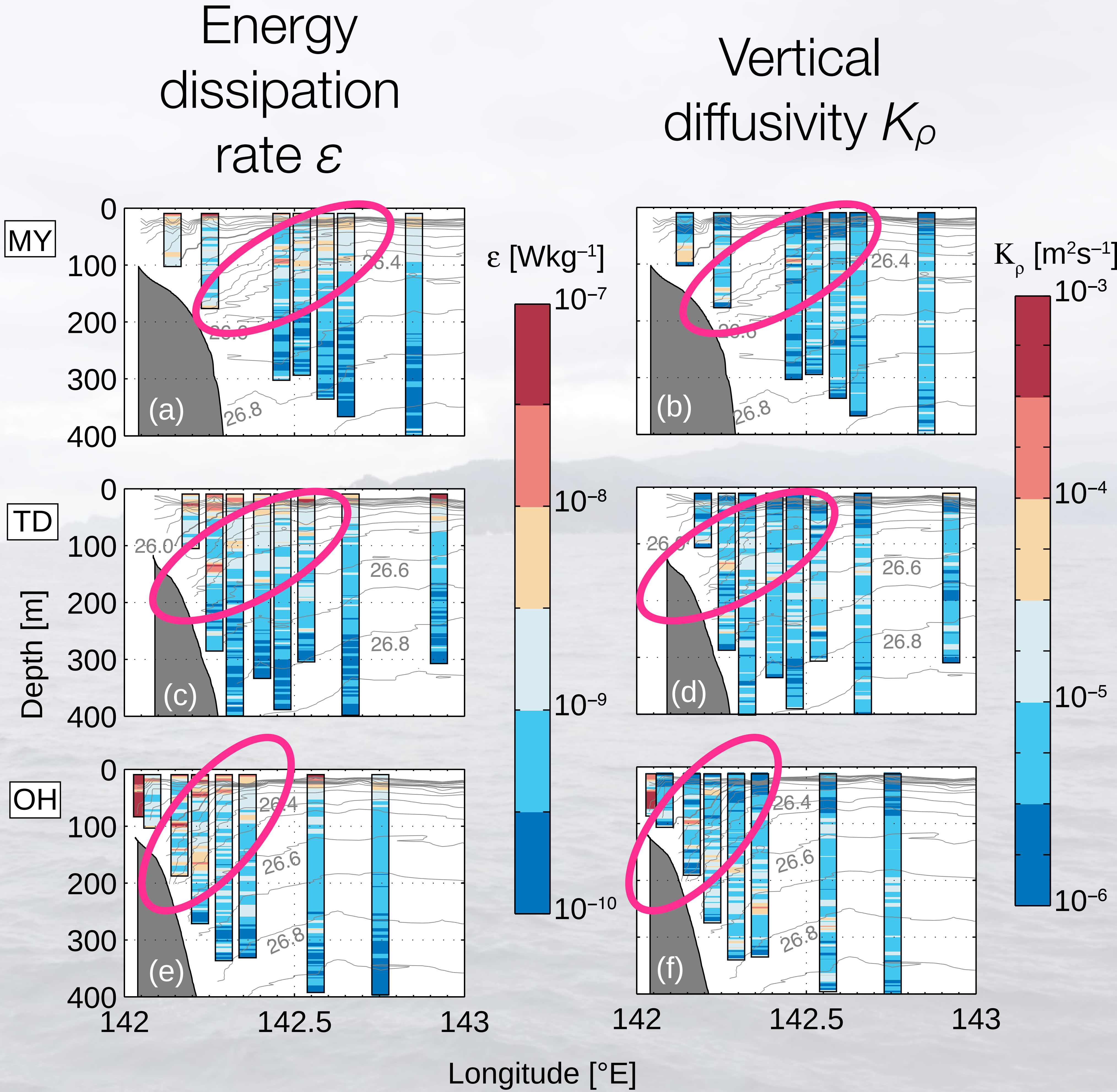
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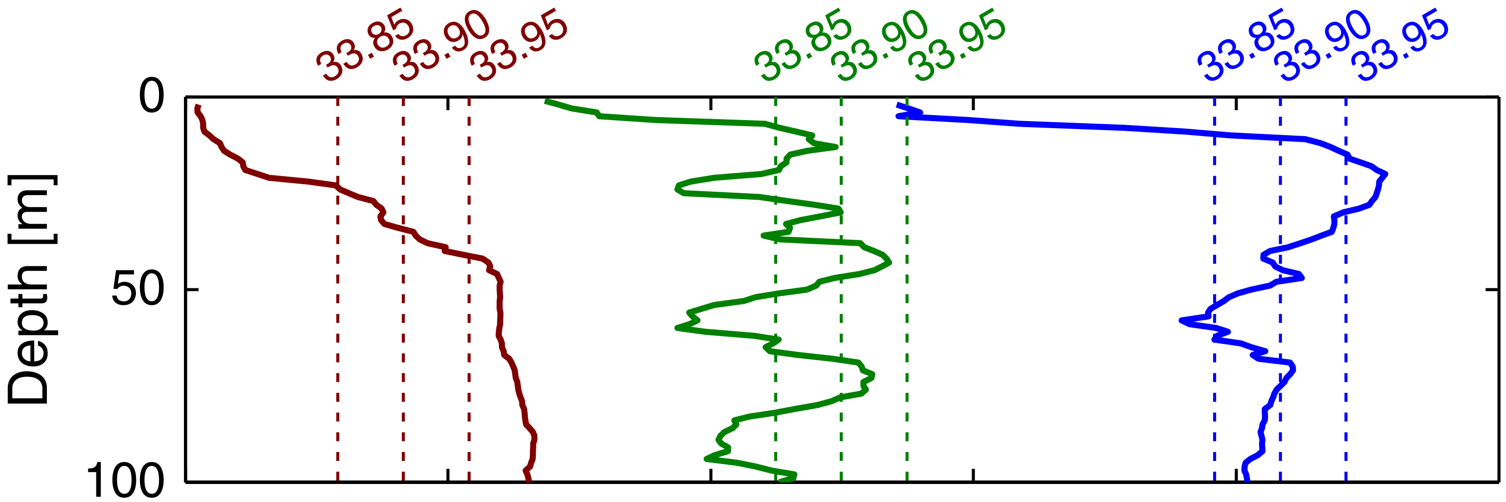
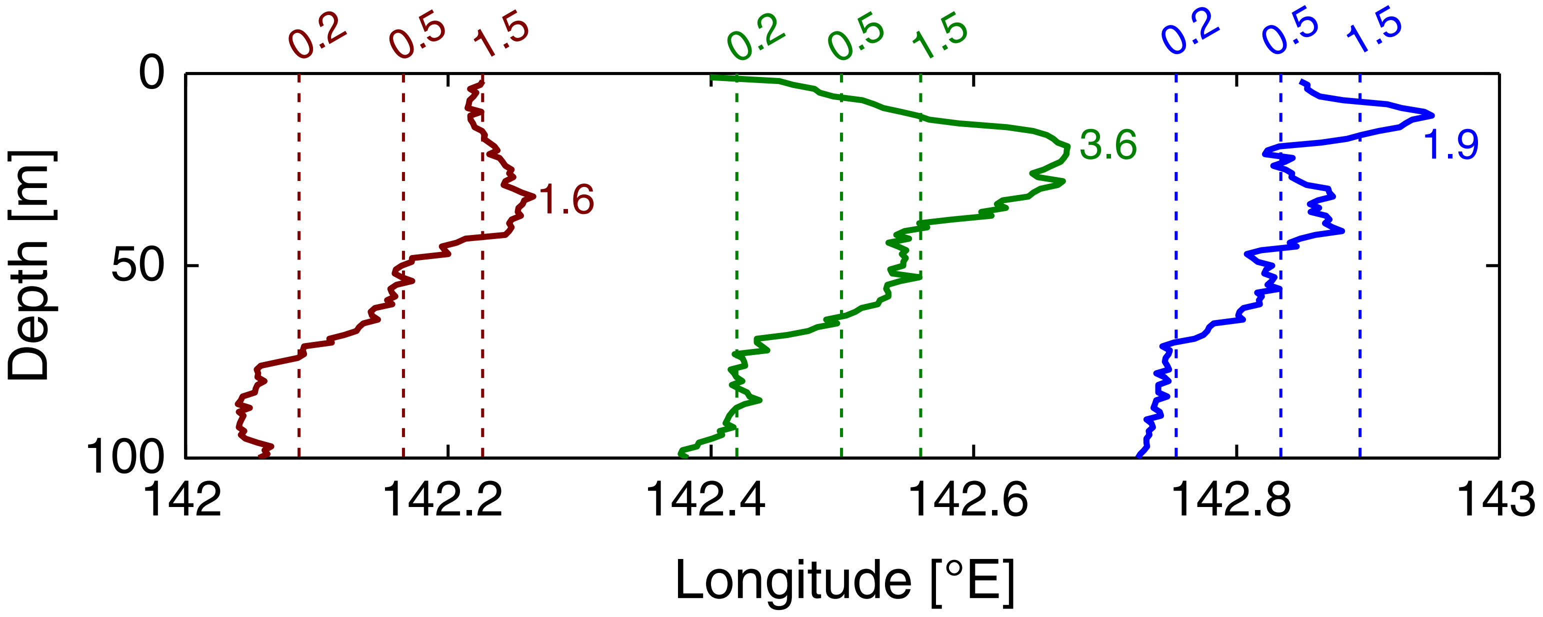
Enhancing biological production?

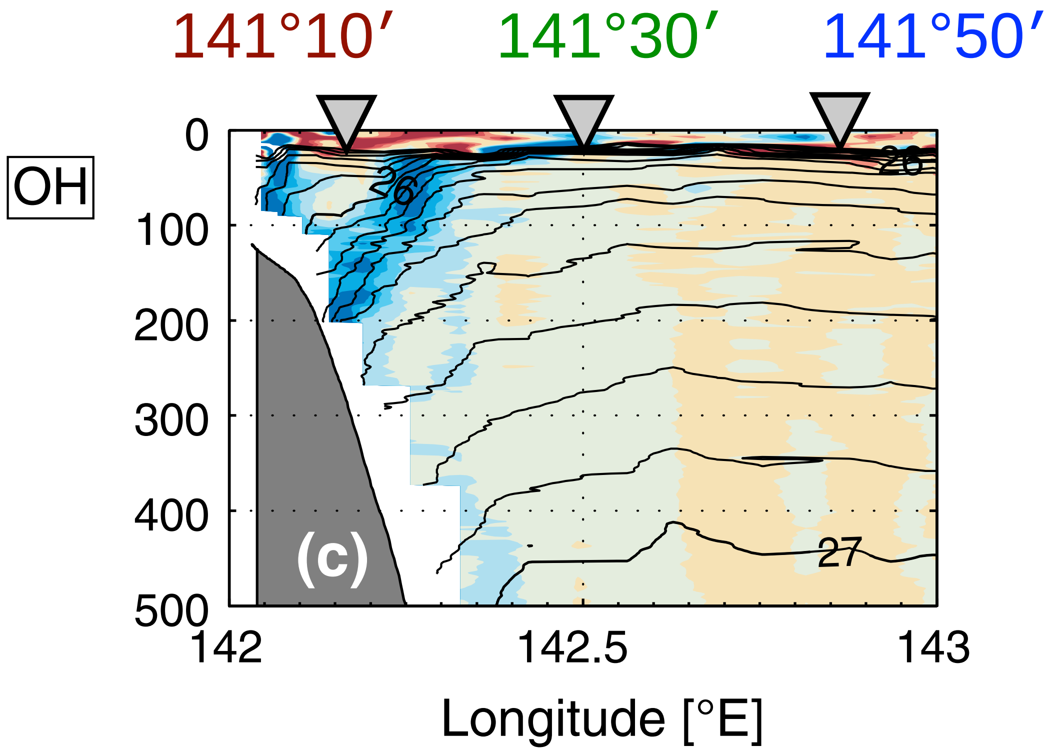
141°10′ 141°30′ 141°50′

(a) Salinity



(b) log$_{10}$(Chlorophyll a [mg m^{-3}])





Geostrophic shear

Observation in June
(2 weeks before)

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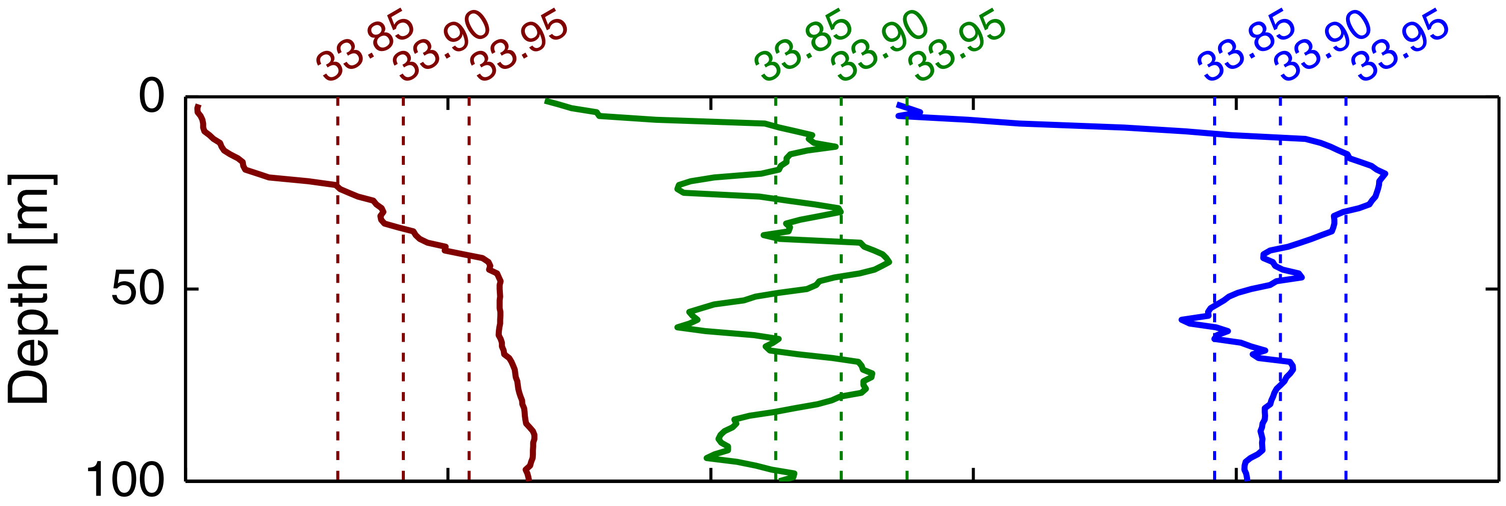

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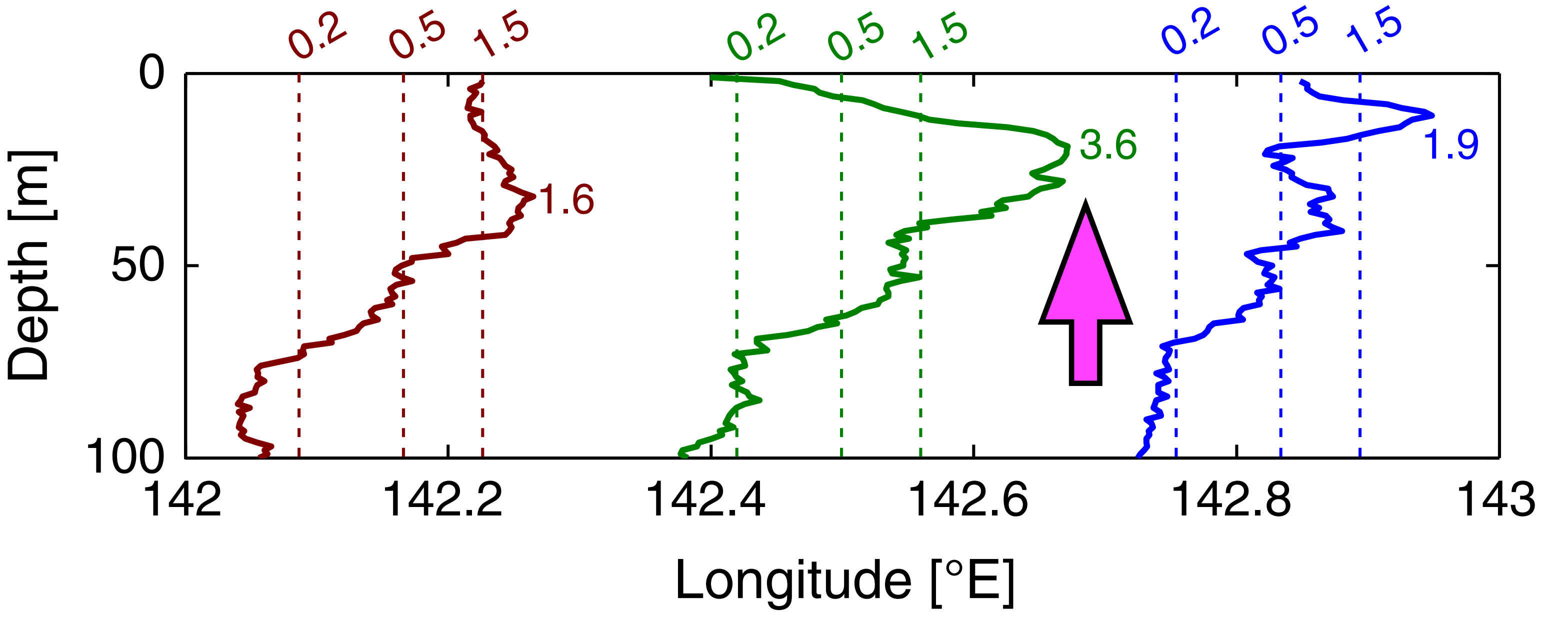

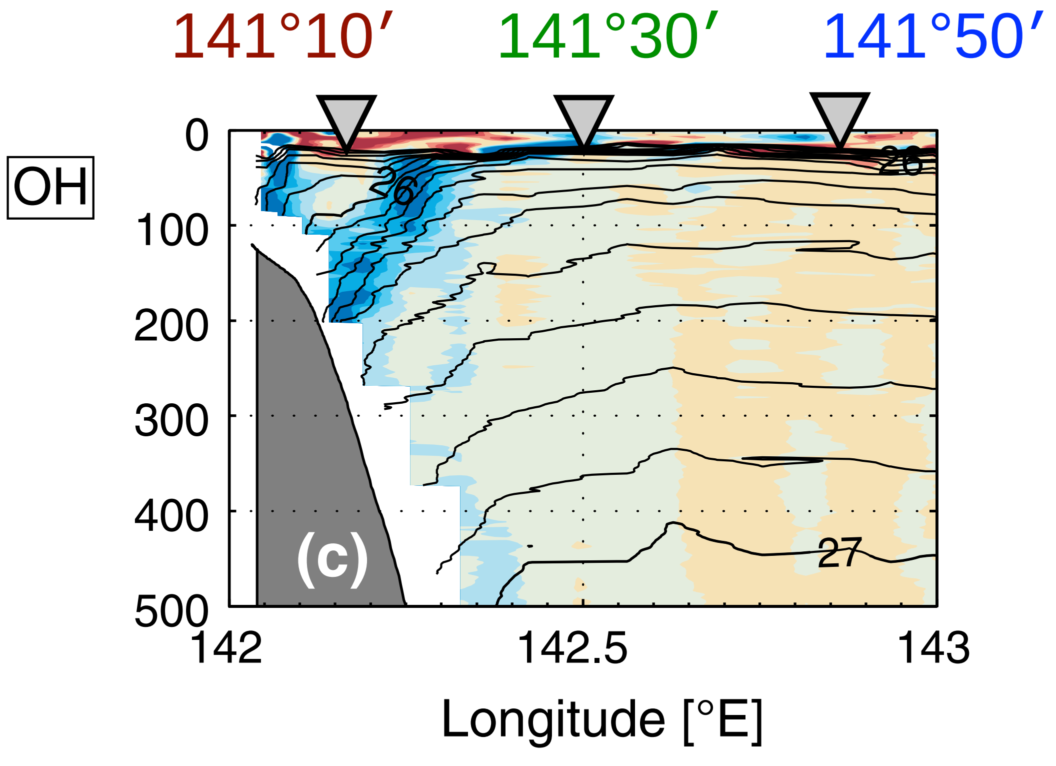

Geostrophic shear

Observation in June
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<u>Chl a is elevated along the front at subsurface</u>

Internal Tide Chimney

By analogy with “inertial chimney”
by Lee & Niiler (1998)

Dispersion relationship
(collected by k/m)

$$\omega = \sqrt{N^2\left(\frac{k}{m} - \frac{fv_z}{N^2}\right)^2 + F^2 - \frac{f^2 v_z^2}{N^2}}$$

Minimum $F^2 – f^2 v_z^2/N^2$
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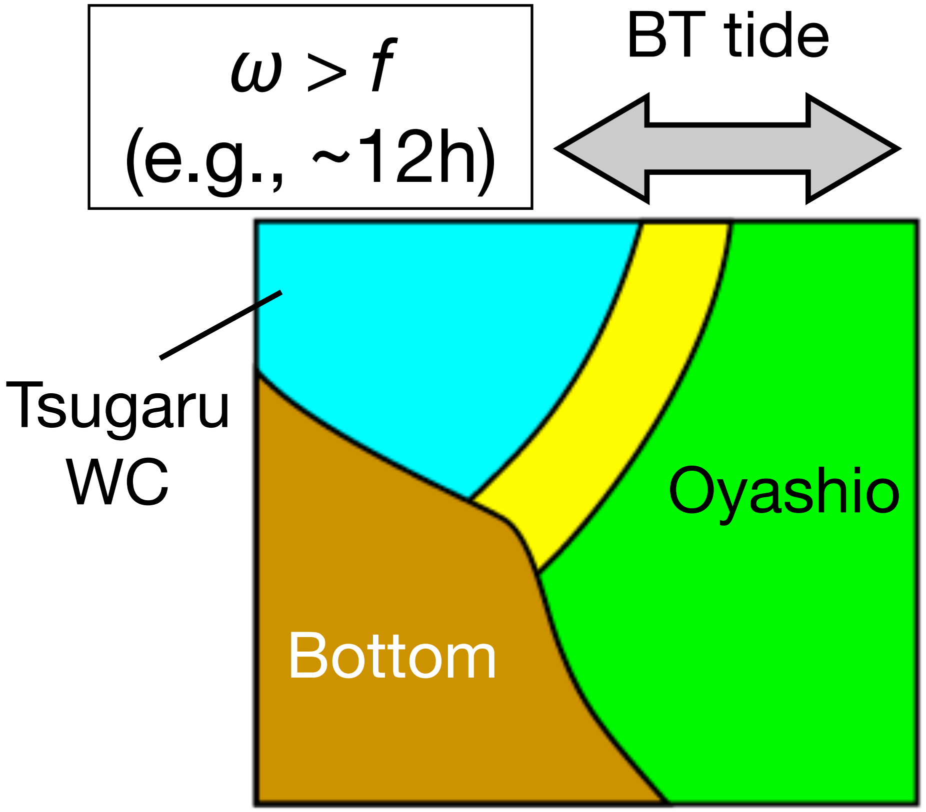

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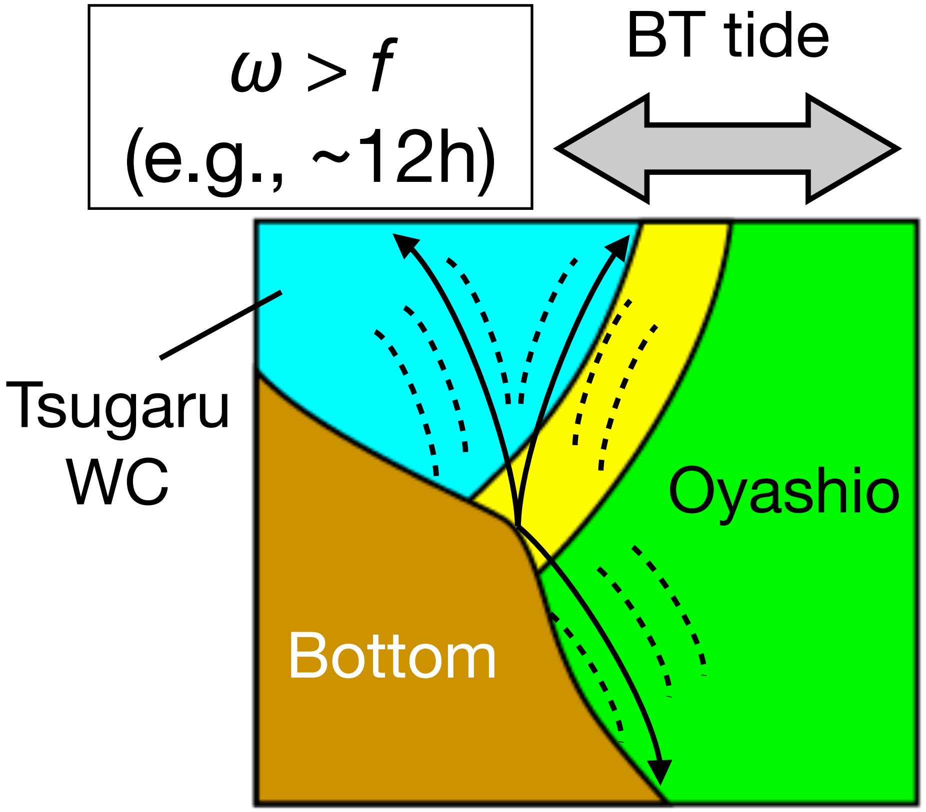
Minimum $F^2 - f^2 v_z^2 / N^2$
at $k/m = f v_z / N^2$ (<0)



(almost) free
propagation

Internal Tide Chimney

By analogy with “inertial chimney”
by Lee & Niiler (1998)

Dispersion relationship
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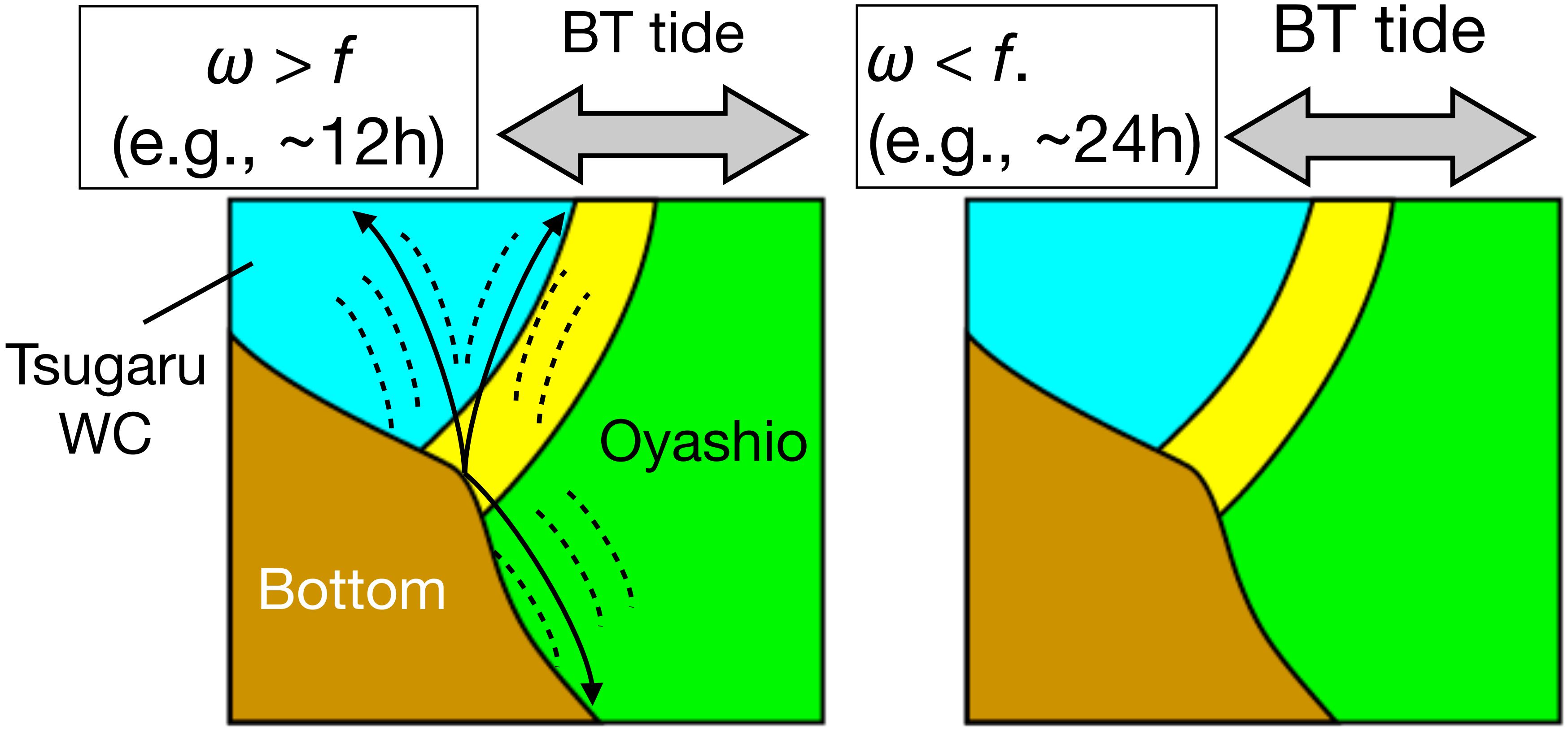

$\omega > f$
(e.g., ~12h)

BT tide

$\omega < f$.
(e.g., ~24h)

BT tide

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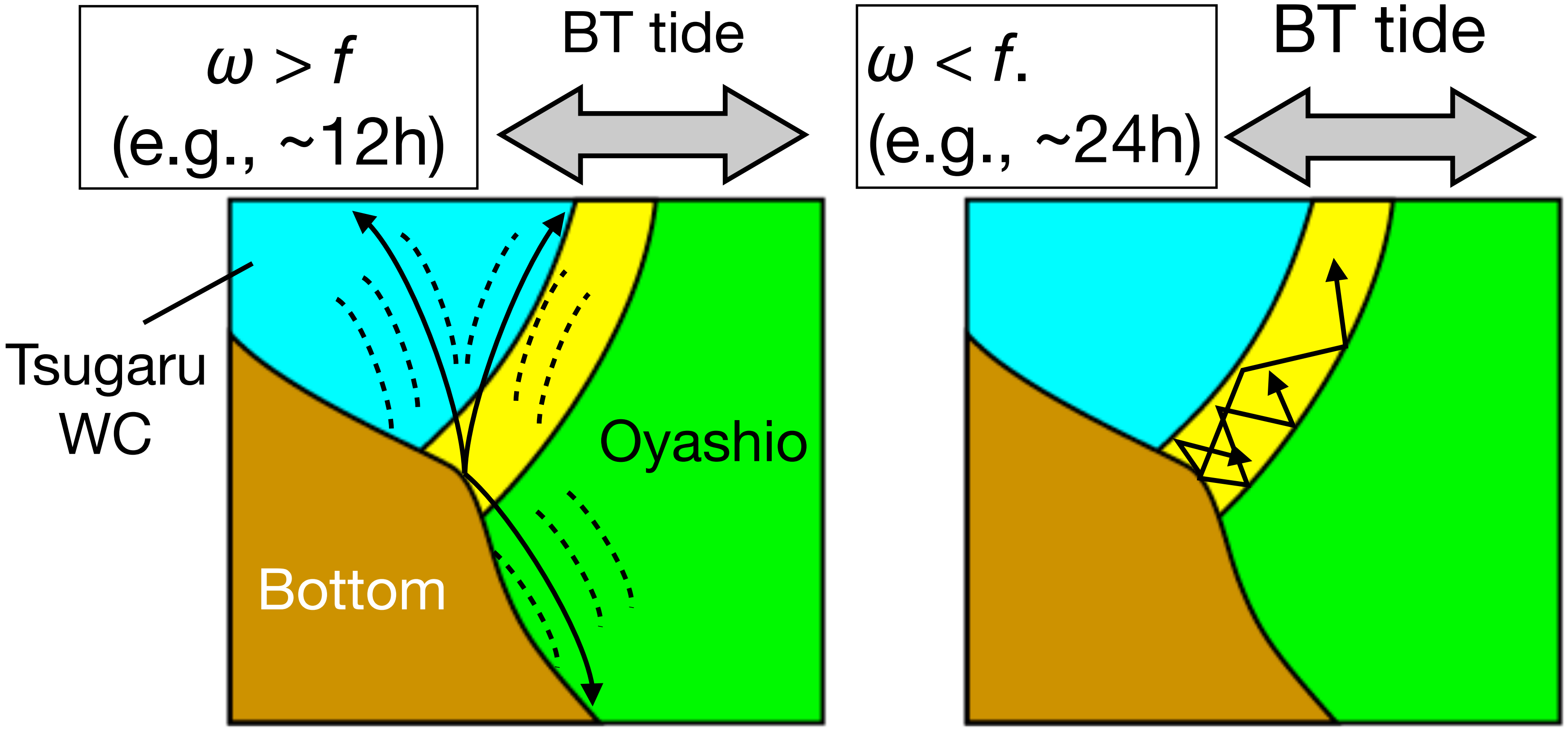

(almost) free propagation

- Offshore upward wave packet propagation
- **Trapped within frontal zone**; broken through reflection and interaction

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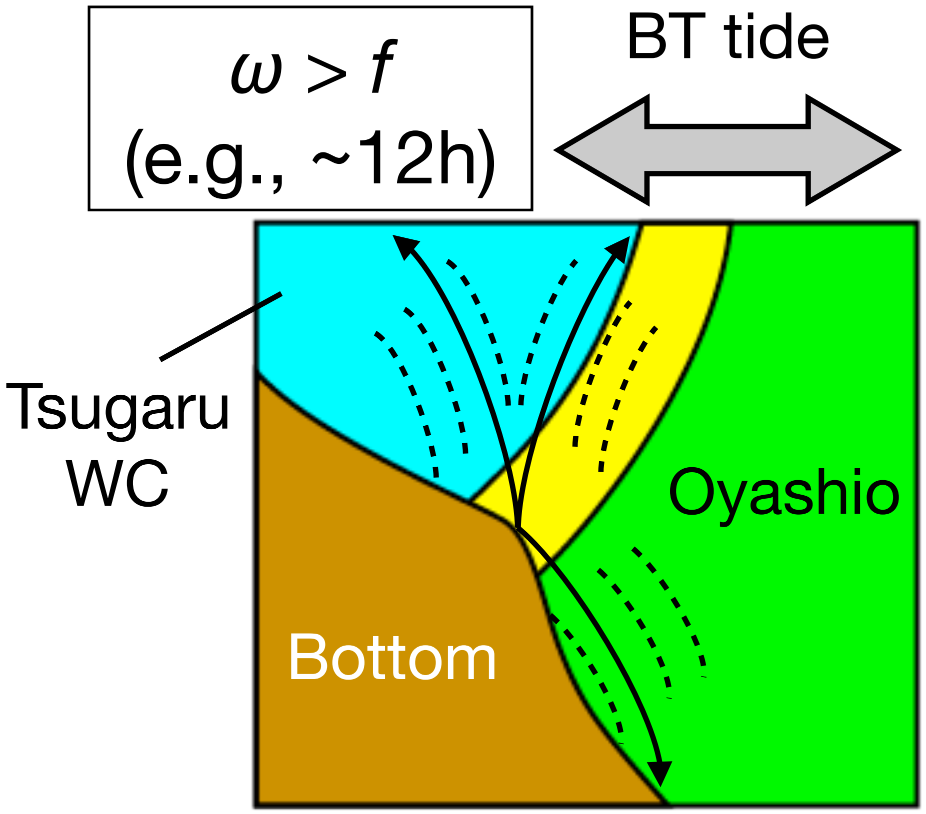

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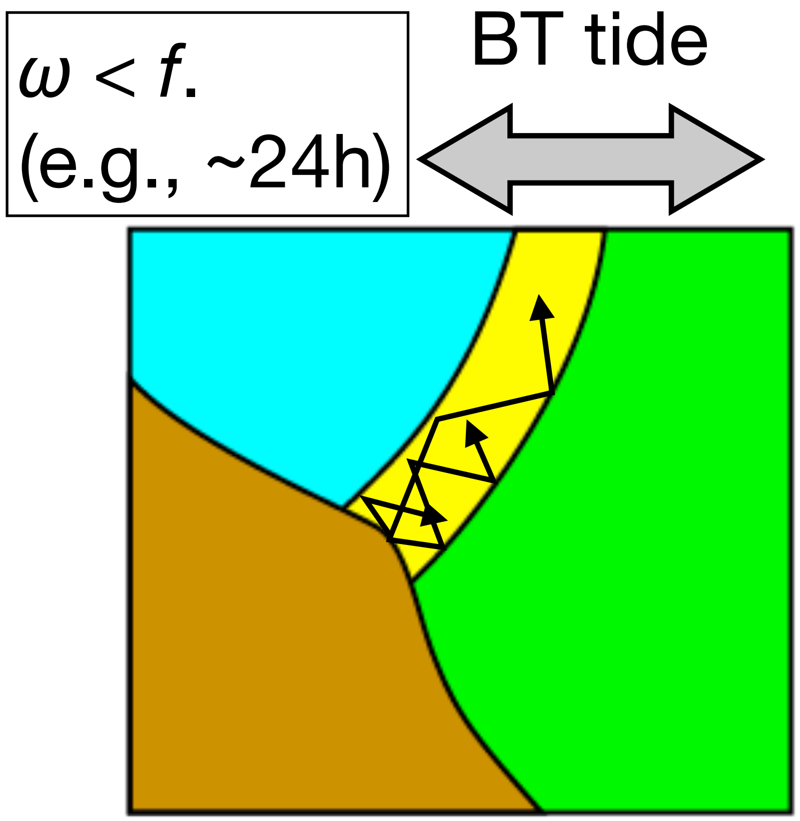

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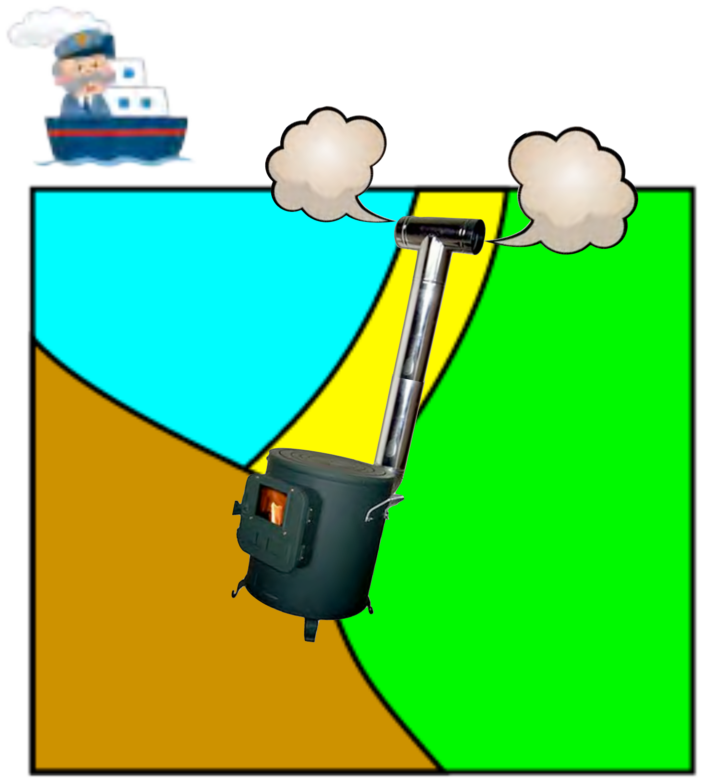
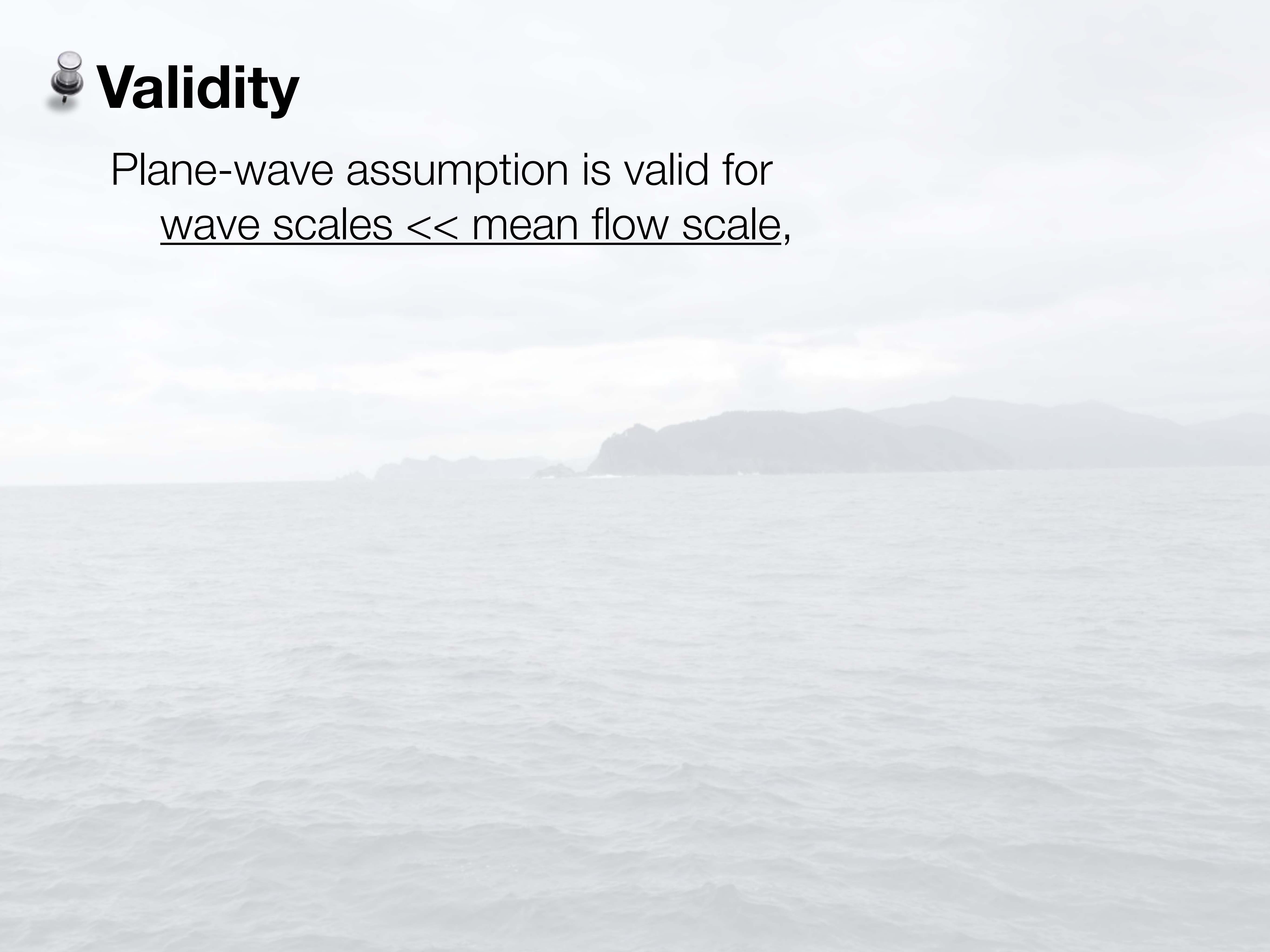
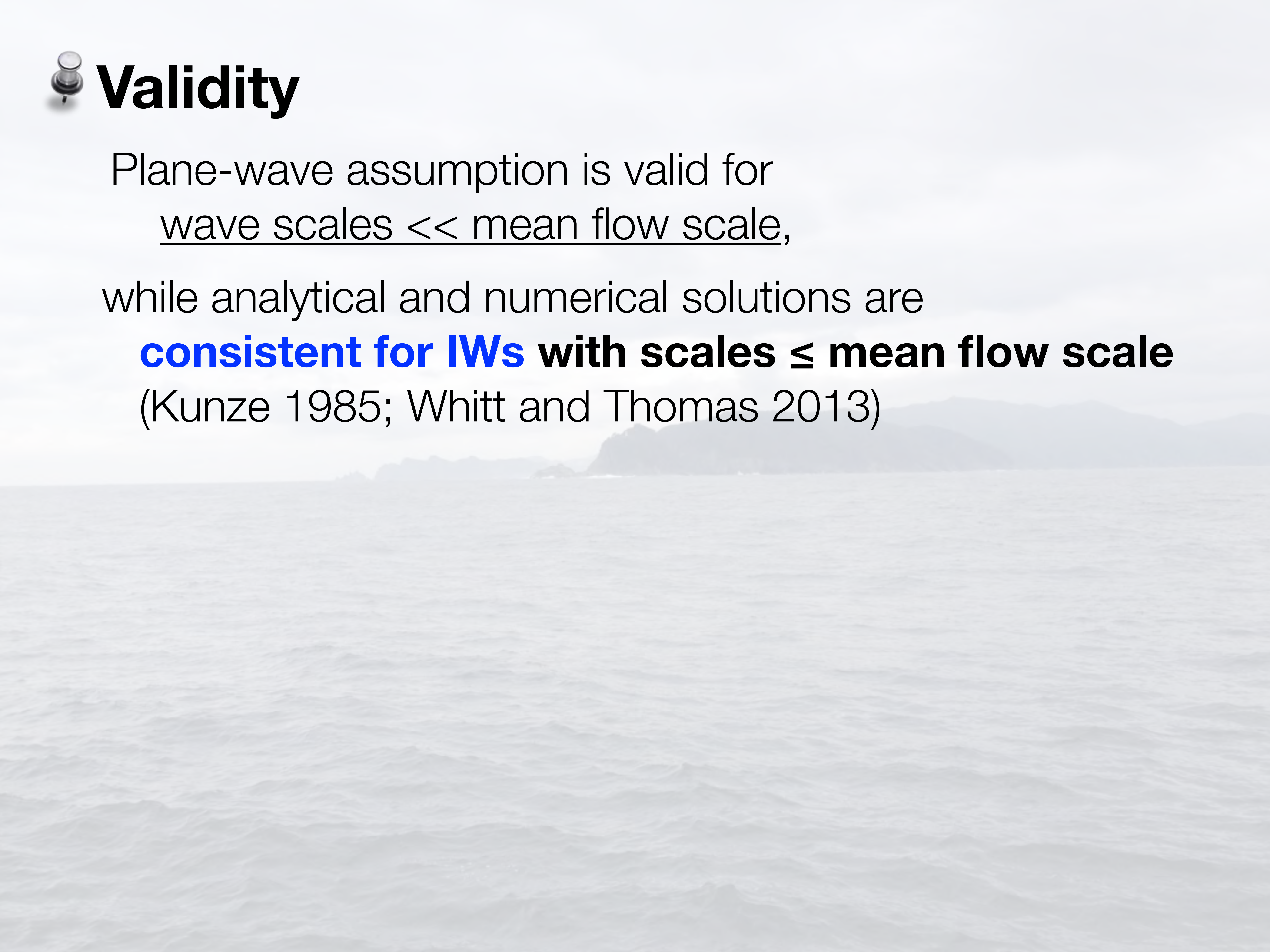


- Tidal energy is confined within the frontal band
- **Nutrient supply** at frontal zone by vertical mixing



Validity

Plane-wave assumption is valid for
wave scales << mean flow scale,



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→ **“Internal wave chimney”** processes may be
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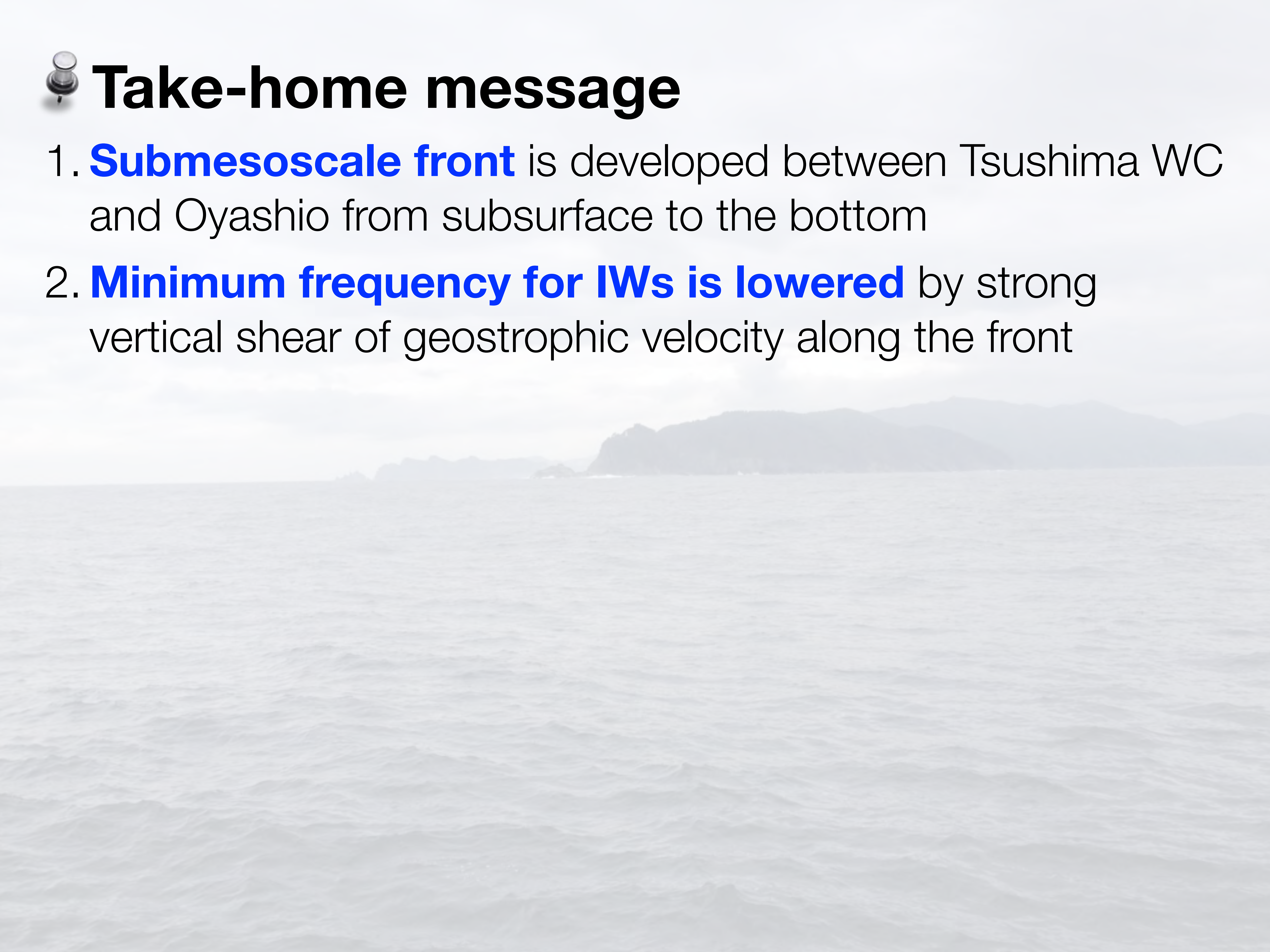
Applicability

Costal currents around the shelf edge with the coast
to their right (left) in the N. (S.) Hemisphere

Coastal currents in PICES region?

Take-home message

1. **Submesoscale front** is developed between Tsushima WC and Oyashio from subsurface to the bottom



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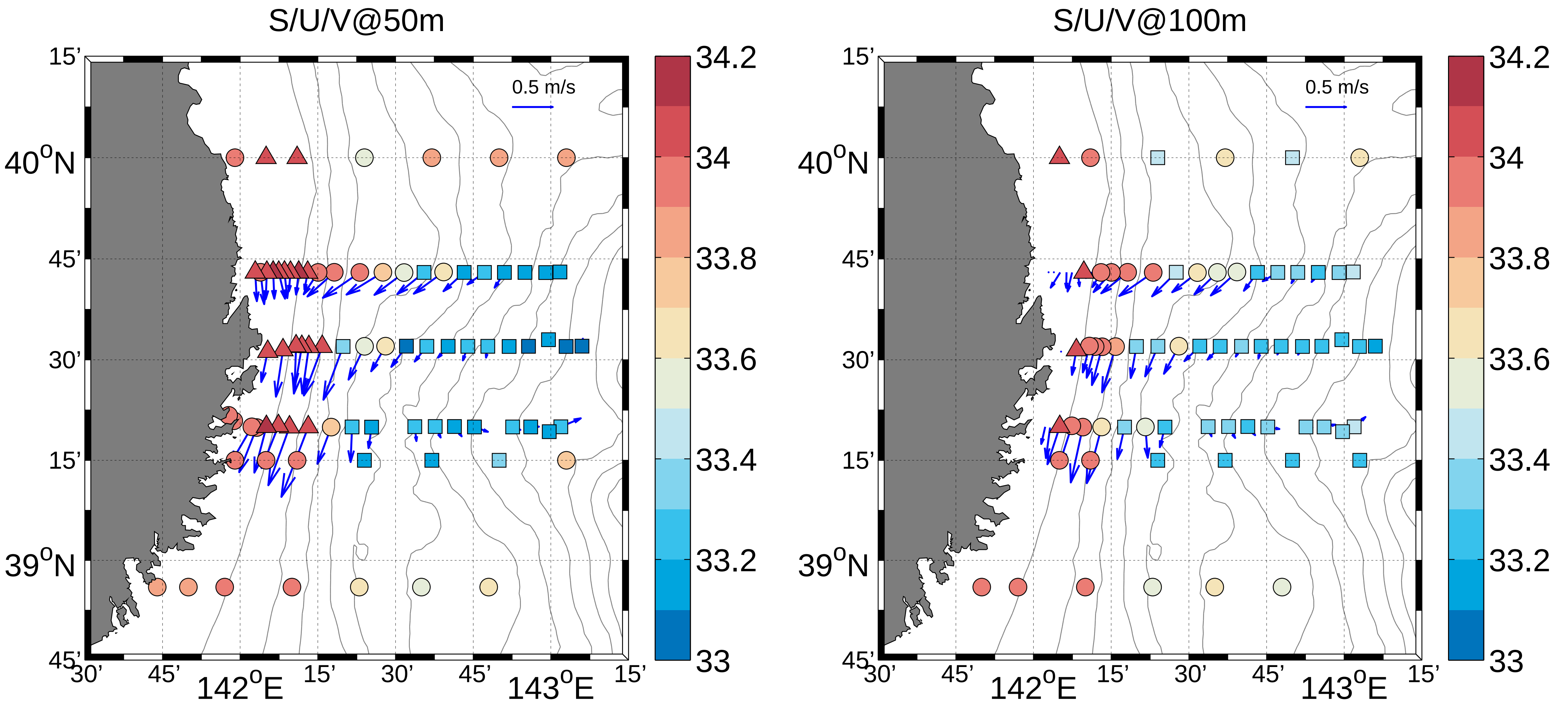
Reference

Itoh *et al* (**2016, Journal of Oceanography,** 72(1)
= Special section: *Oceanographic observations after the 2011 earthquake off the Pacific coast of Tohoku*)
https://rdcu.be/96fB

Salinity & velocity @50m & 100m



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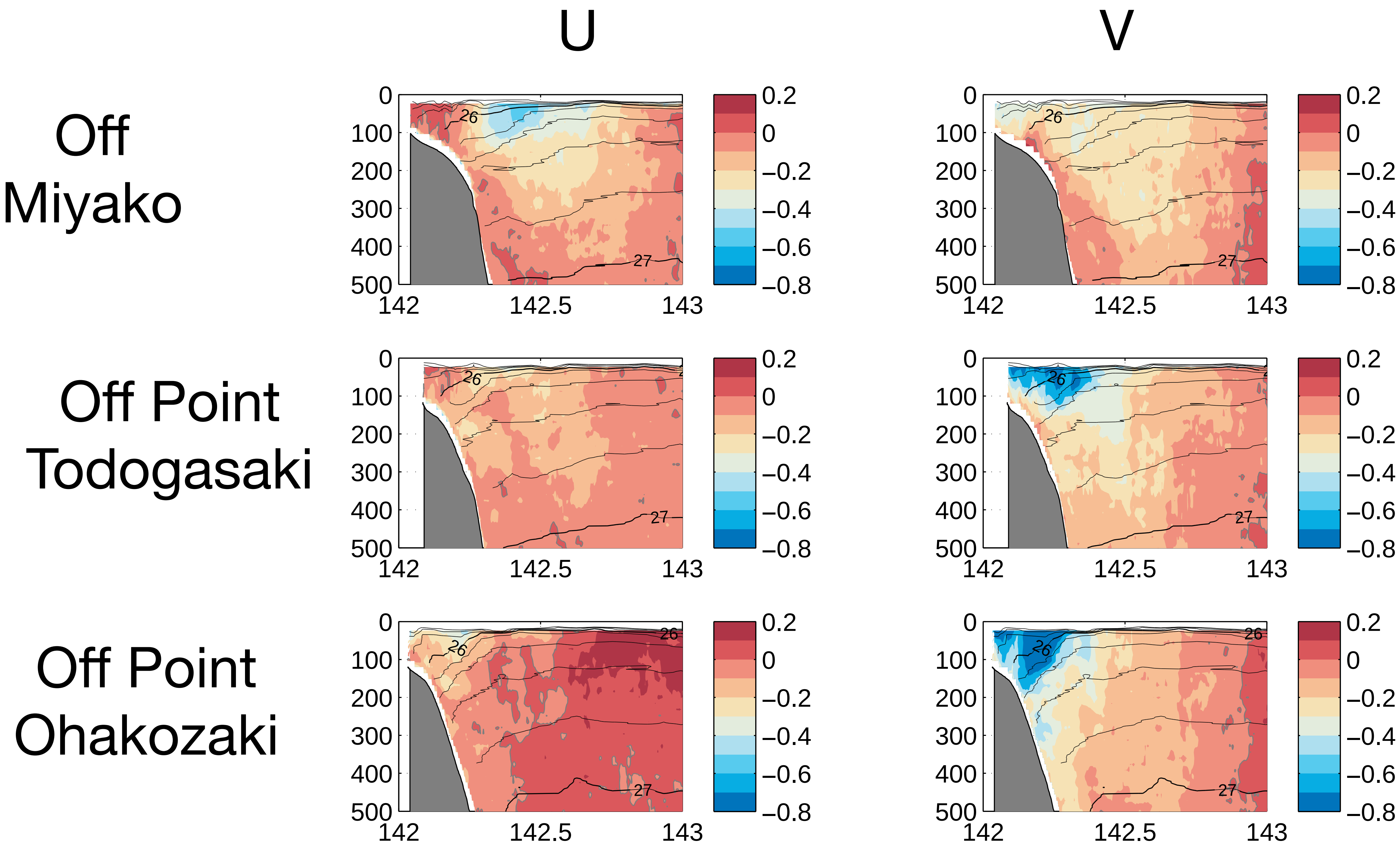
UV transect (shipboard ADCP)



U

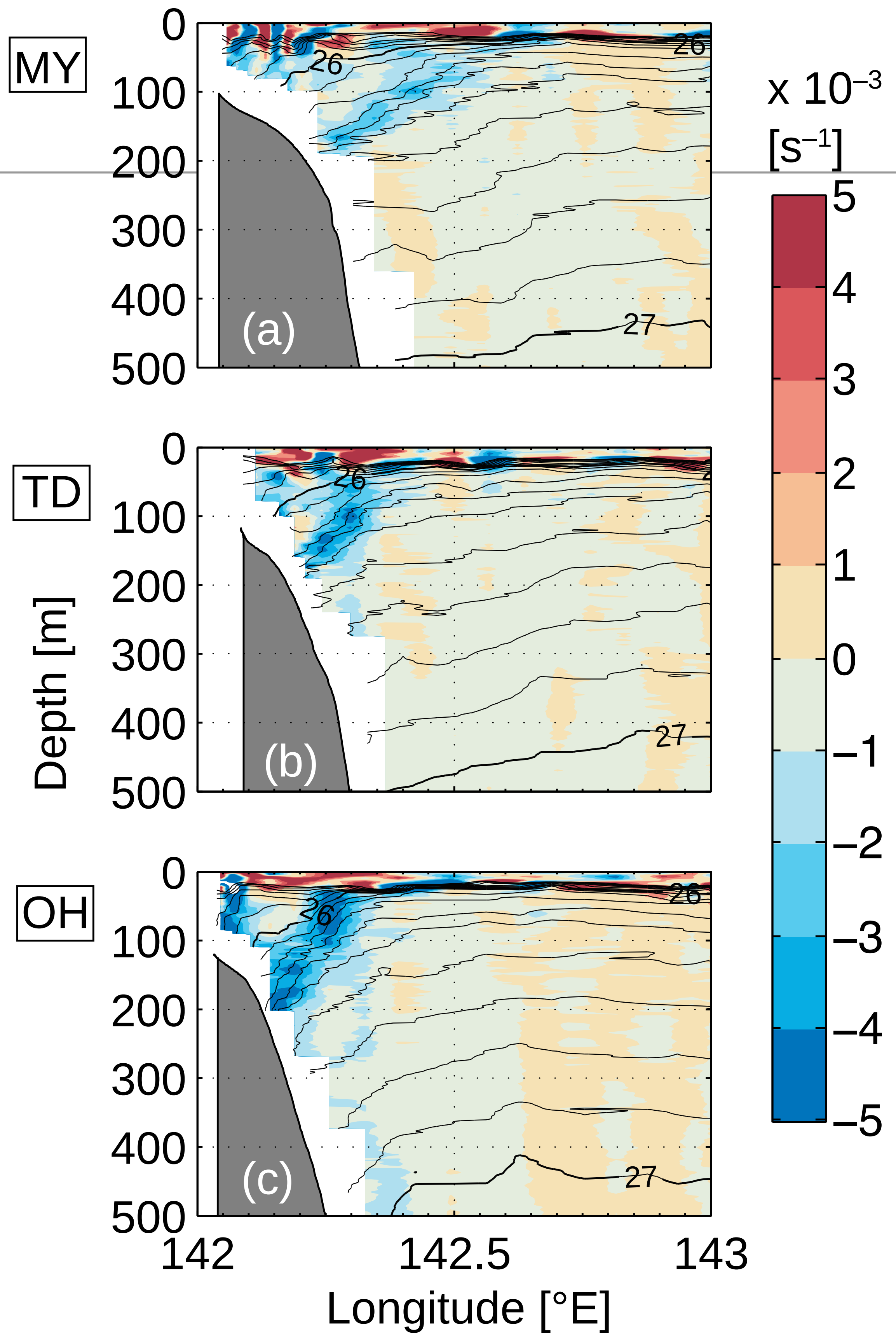
V

Off Miyako

Off Point Todogasaki

Off Point Ohakozaki

Vertical Shear of geostrophic velocity



ADCP Shear & characteristics of M2 IWs