Nov. 1, 2018
14:40 – 15:00

Mixing and sediment transport induced by nonlinear internal wave breaking in coastal regions

○Eiji Masunaga
Ibaraki University

Robert S. Arthur
Lawrence Livermore
National Laboratory

Oliver B. Fringer
Stanford University

Hidekatsu Yamazaki
Tokyo Univ. of Mar. Sci. & Tech.

Acknowledgement

JST
科研費
KAKENHI

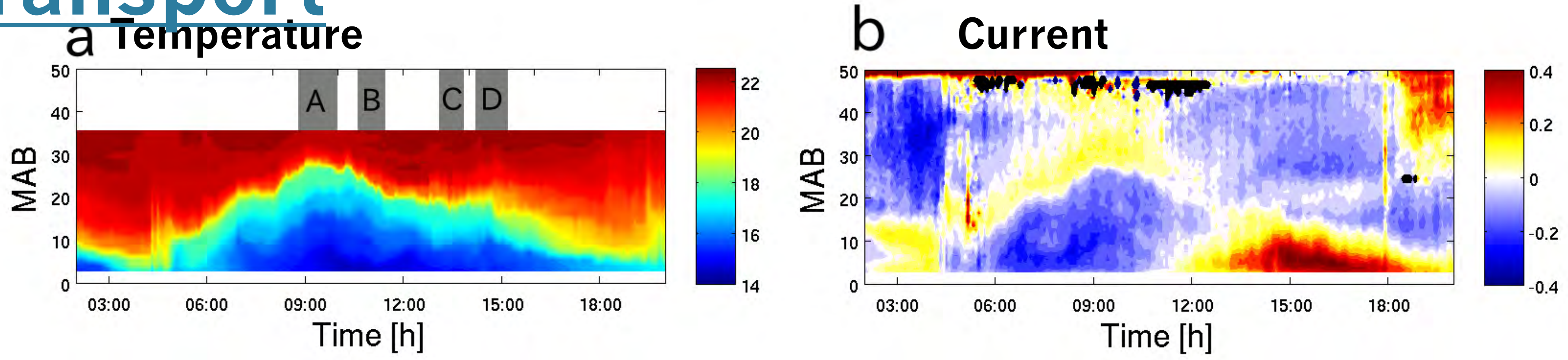
Internal tide breaking on a shallow slope

Masunaga et al. 2016 GRL

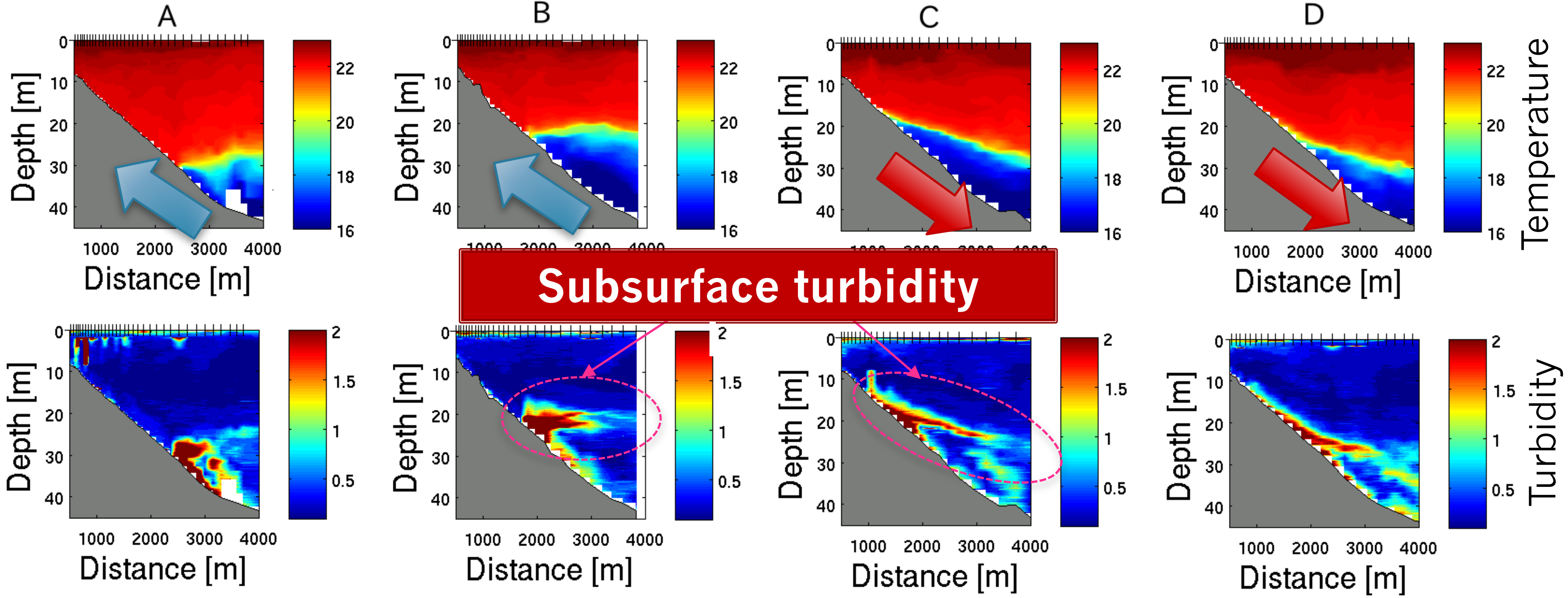
Internal waves and sediment transport

↓Mooring data at 50 m

Masunaga et al., 2015 (CSR

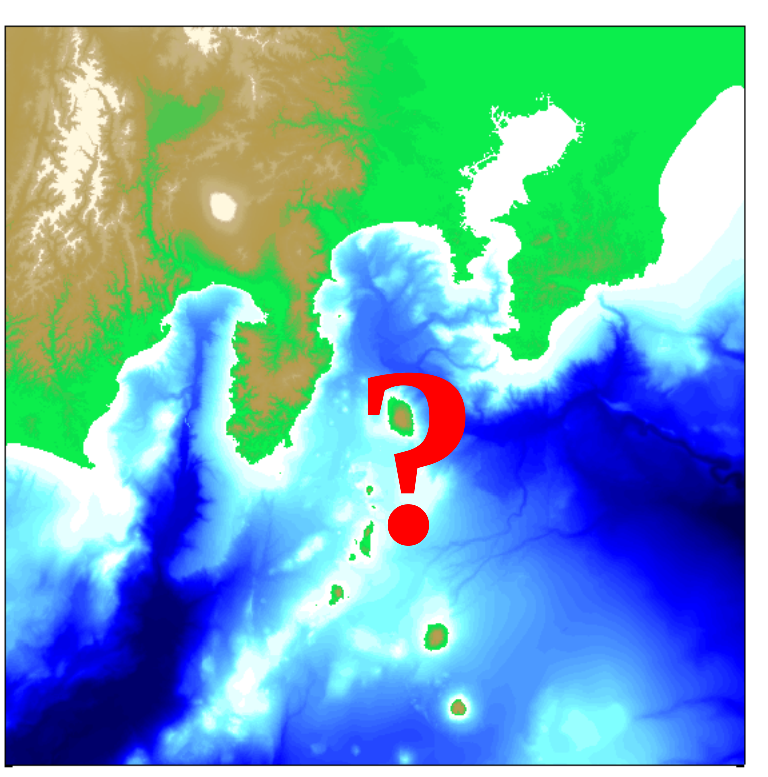


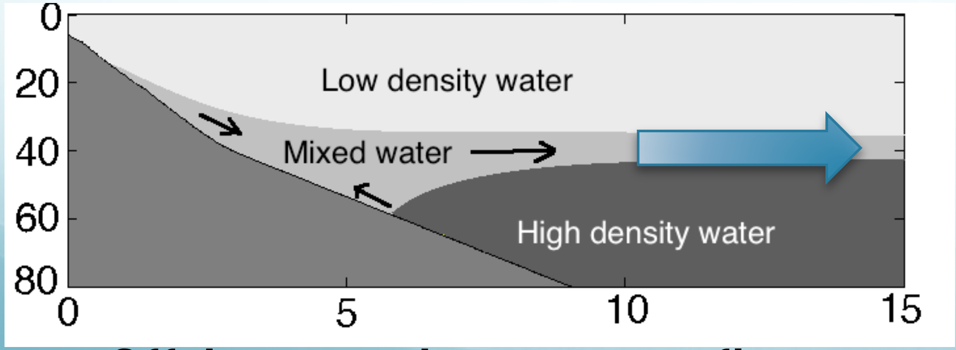
↓ Transect observation



Internal waves and sediment t

Masunaga et al., 2017JMS



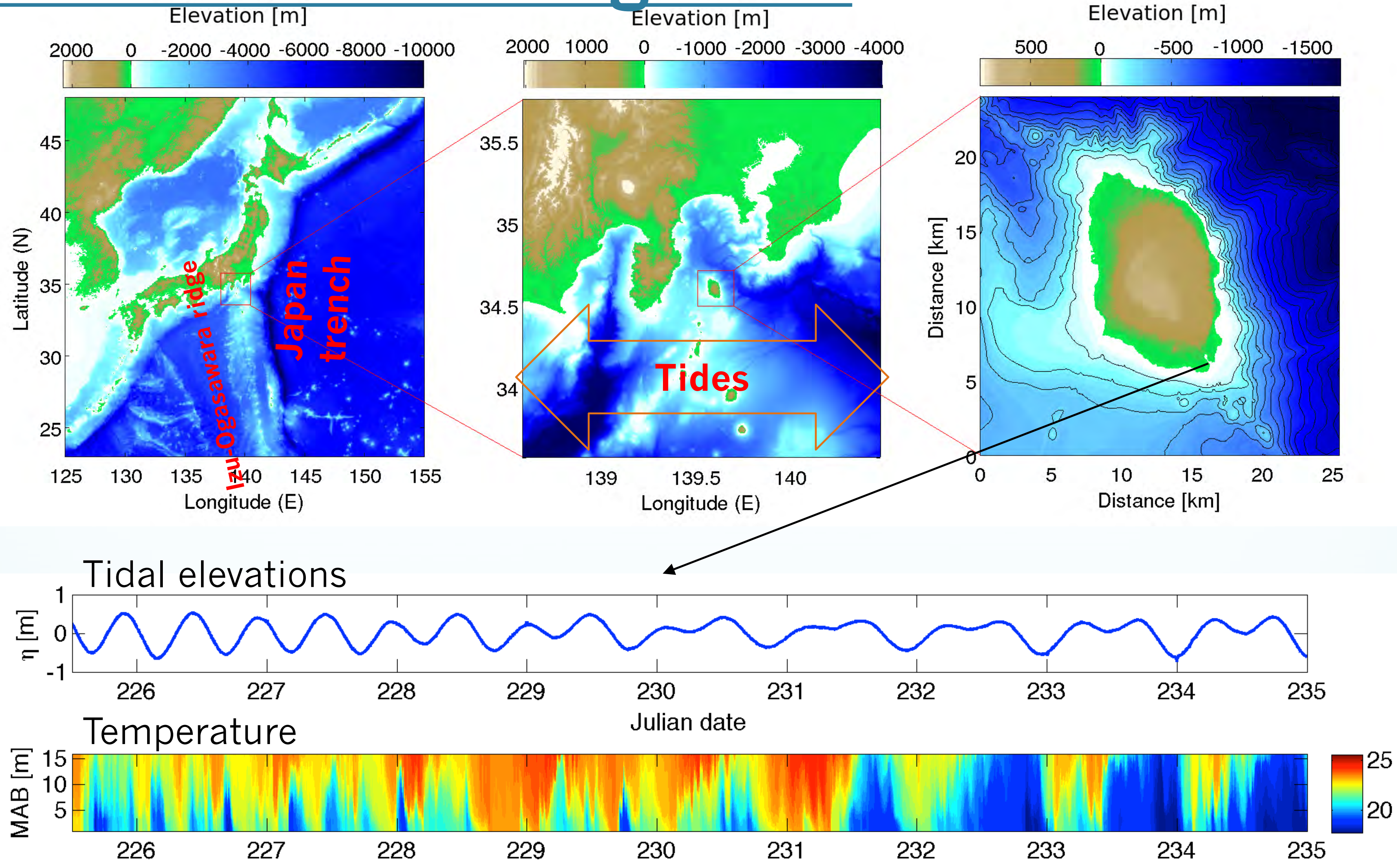


Offshore ward convergent flows are generated by IW breaking.

Question:

How nonlinear internal tides and their breaking influence mass and sediment transports in **3D** fields?

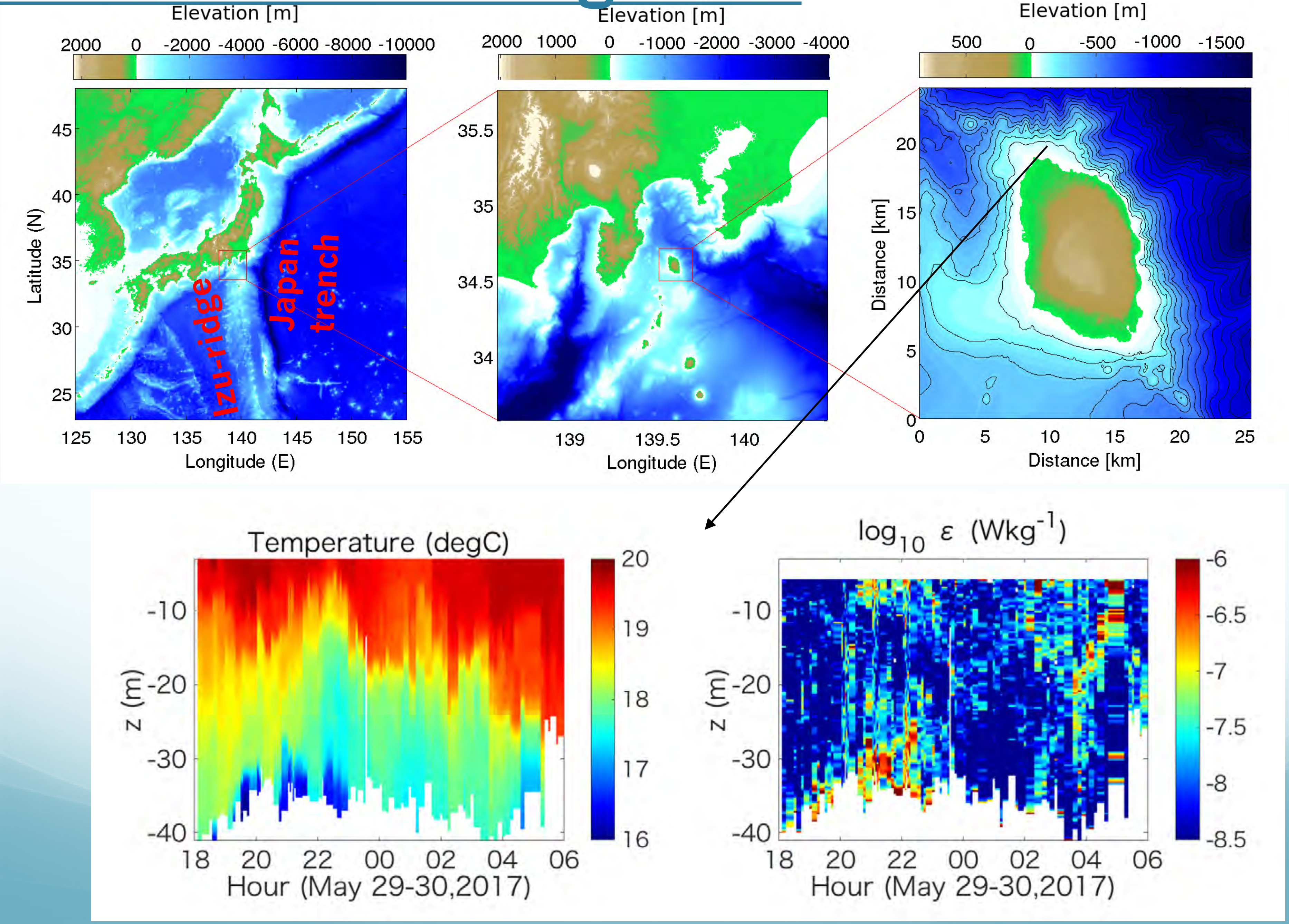
Location and background



Tidal elevations

Temperature

Location and background



3D Numerical setup (SUNTANS)

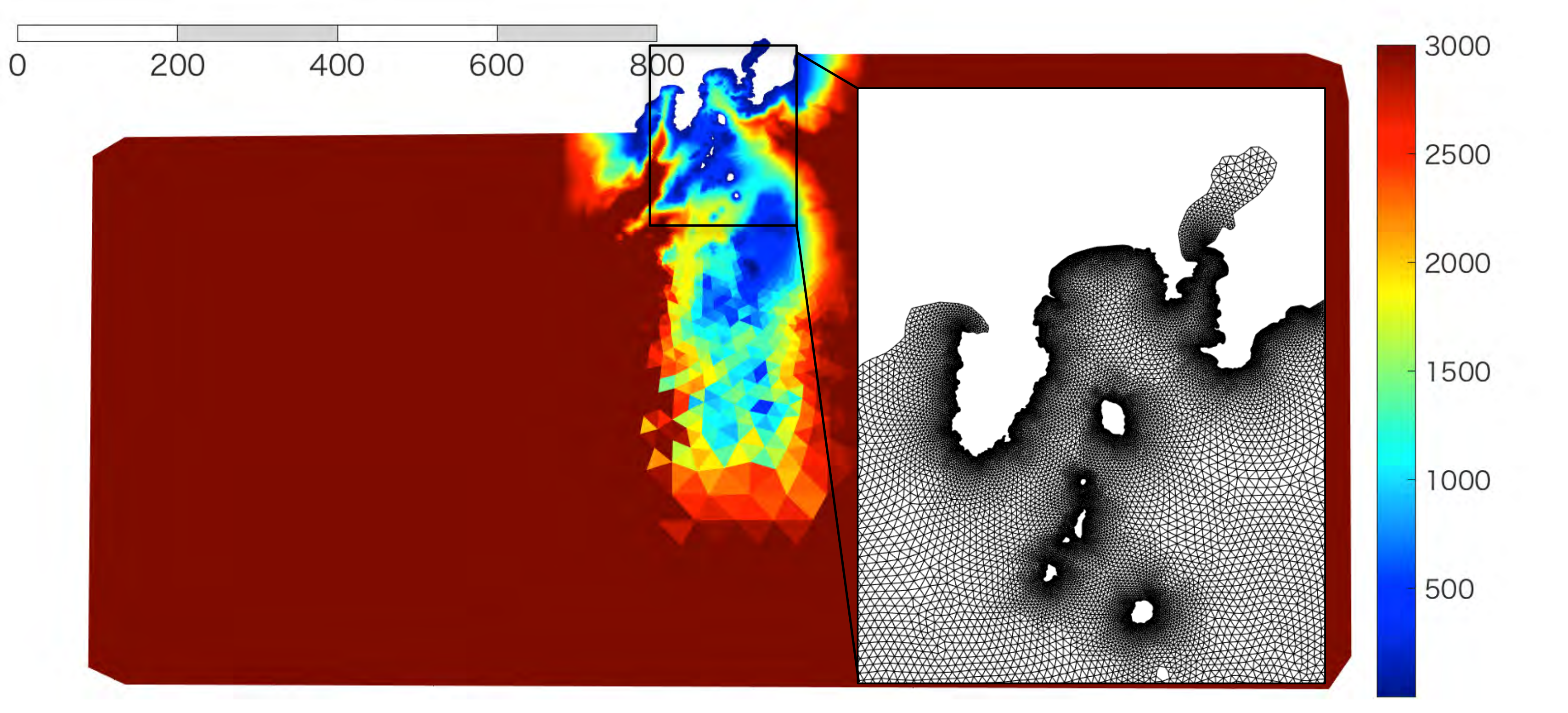
Model: SUNTANS (Fringer et al., 2006)

Grid: Unstructured grid. The maximum **Δx = 50 km** near the boundary and the minimum **Δx = 500 m** near the coast of Izu-chain Island.

Forcing: Barotropic tidal forcing using 4 main tidal constituents (S2, M2, K1, O1)

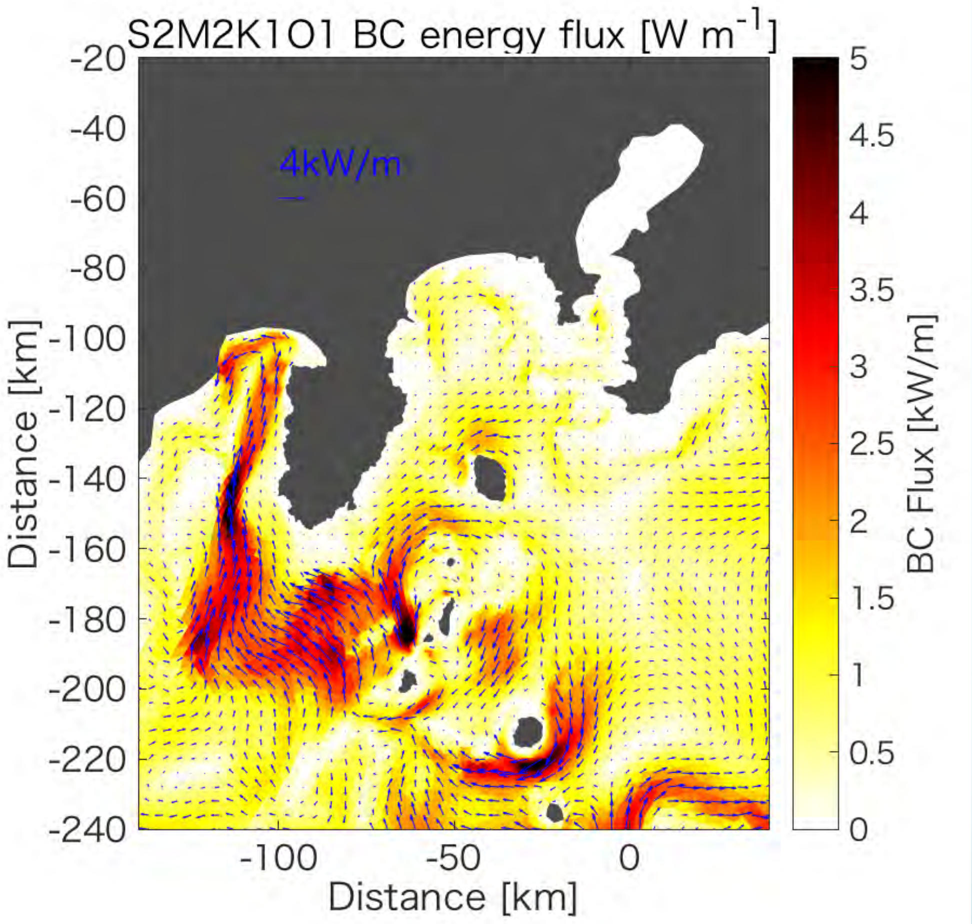
Initial condition: Data from World Ocean Atlas.

Sediment setup: The critical shear stress = 0.1 N/m^2.
Settling velocity: 1×10^{-4} m/s (8.64 m/day)
(Typical sinking velocity of silts and marine aggregates)



Internal tides

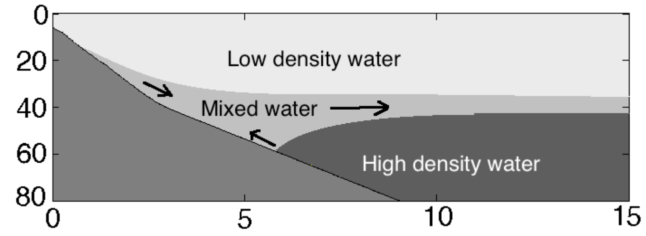
↑ Isotherm depth displacement



↑Internal wave energy flux

Sediment transports due to internal tides

Sediment: settle-able particles, sediments, planktons, aggregates, flocs (ws = 1×10^{-4} m/s)



↑ **SS in intermediate nepheloid layers**

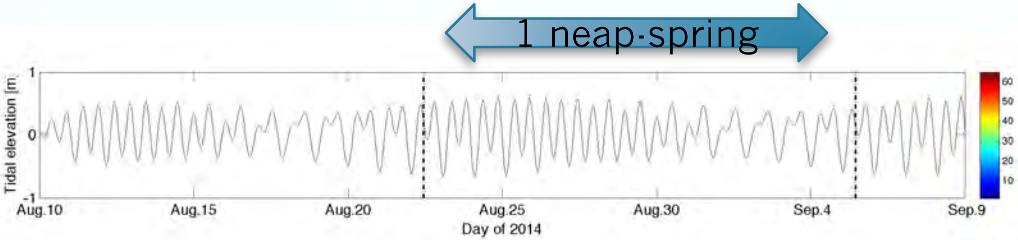
Sediment transports due to internal tides

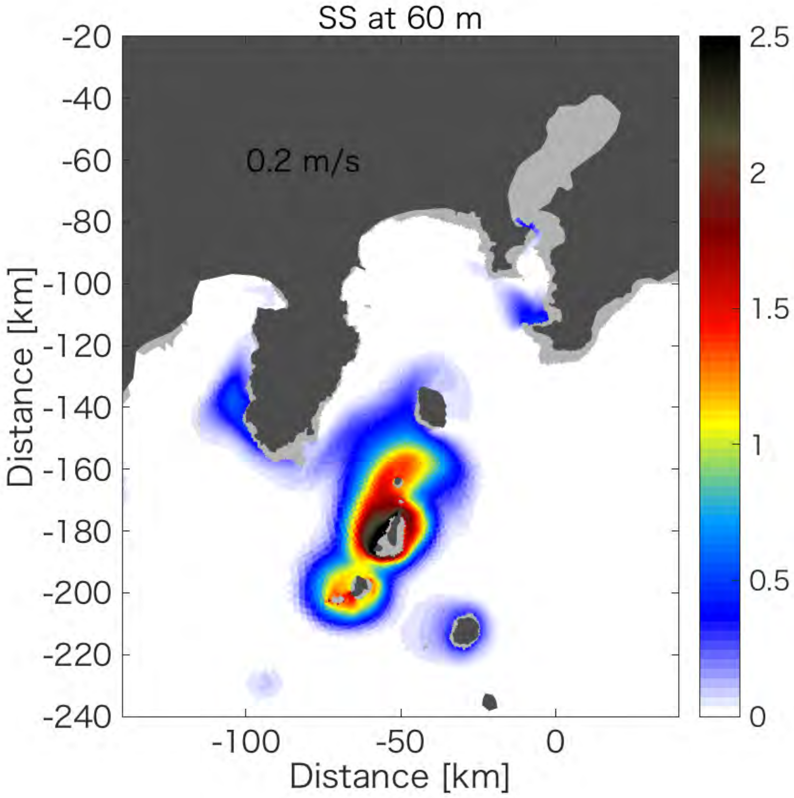
Simulation with a summer stratification

Simulation **without stratification**

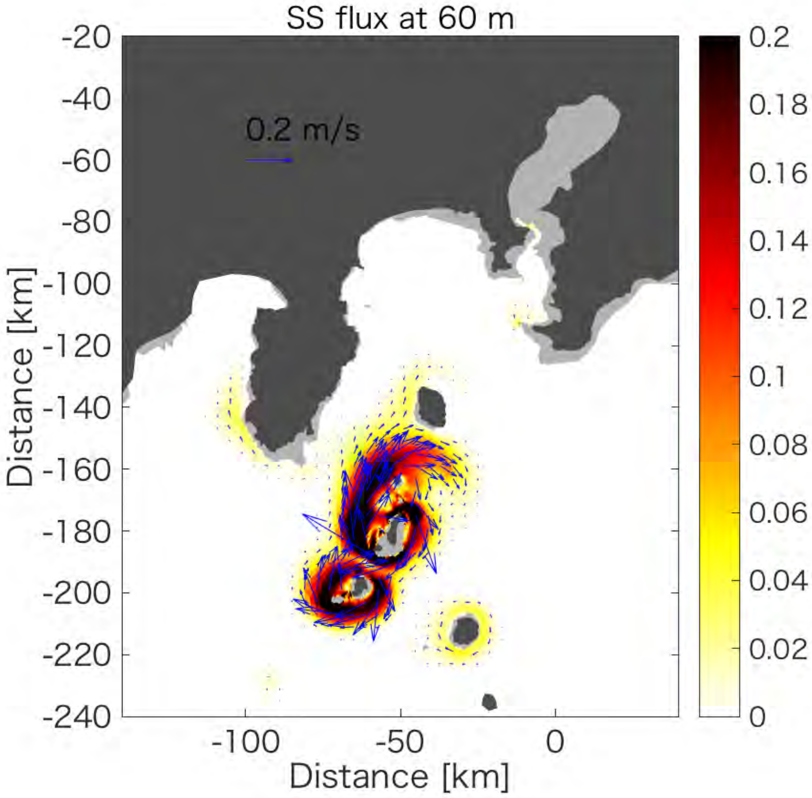
BC tides generates strong resuspension and INLs.
BT tides do not generate INLs.

Sediment transports due to internal tides



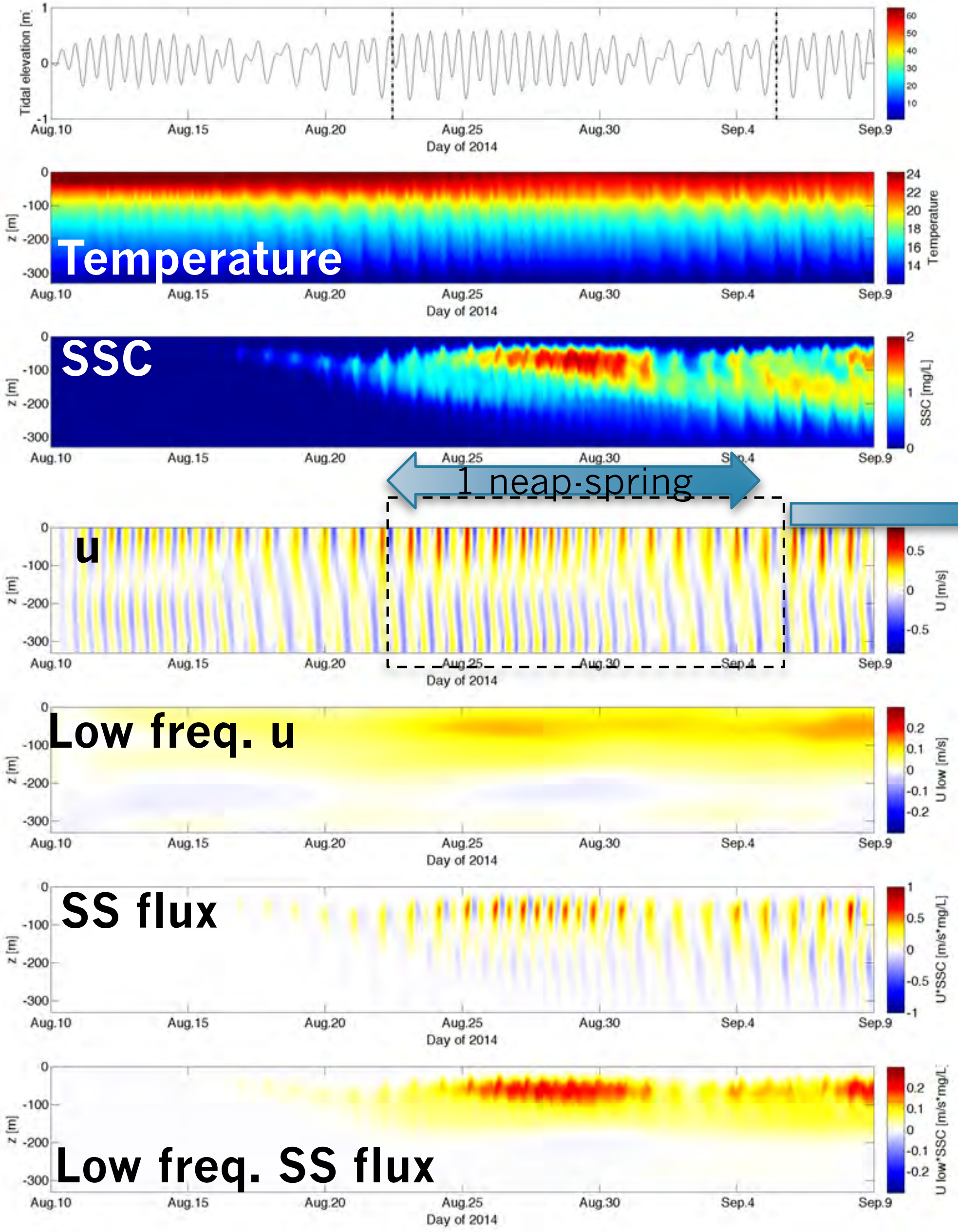


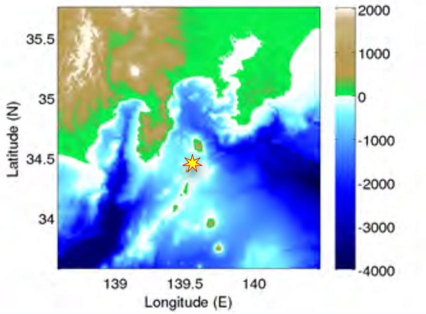
↑time averaged sediment at the depth of the main thermocline



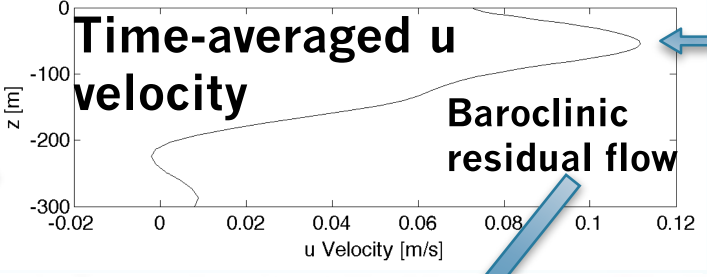
↑Sediment flux at the depth of the main thermocline

BC residual flows due to internal tides



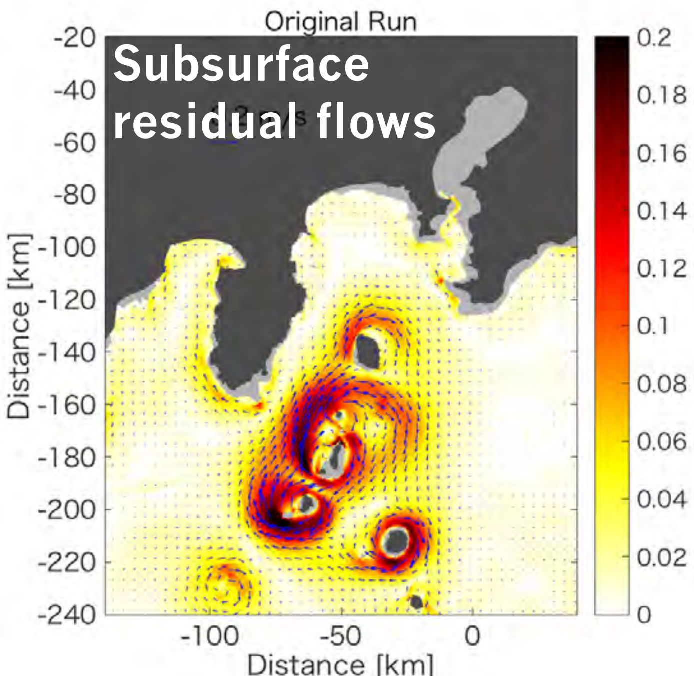


Subsurface flow maximum due to mixing?



Time-averaged u velocity

Baroclinic residual flow

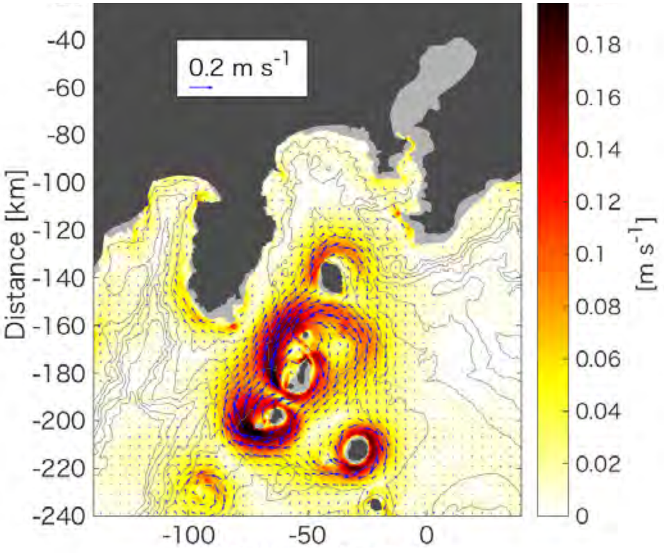


Original Run

Subsurface residual flows

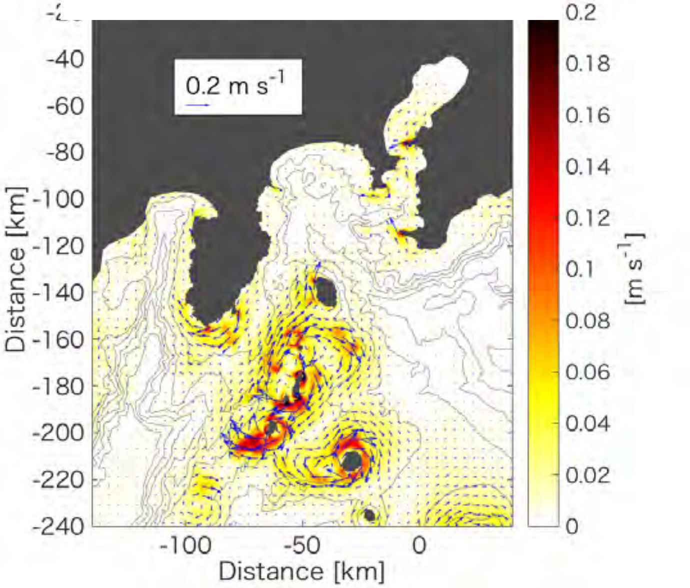
BC residual flows due to internal tides

Subsurface Residual flows (BT + BC)



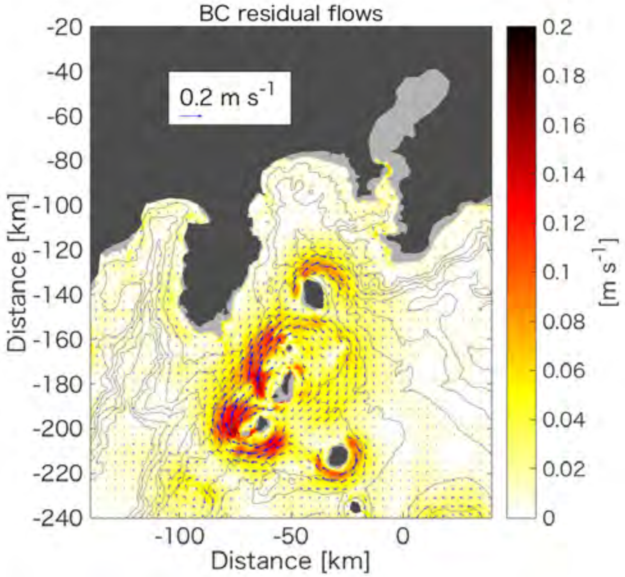
−

BT Residual Flows



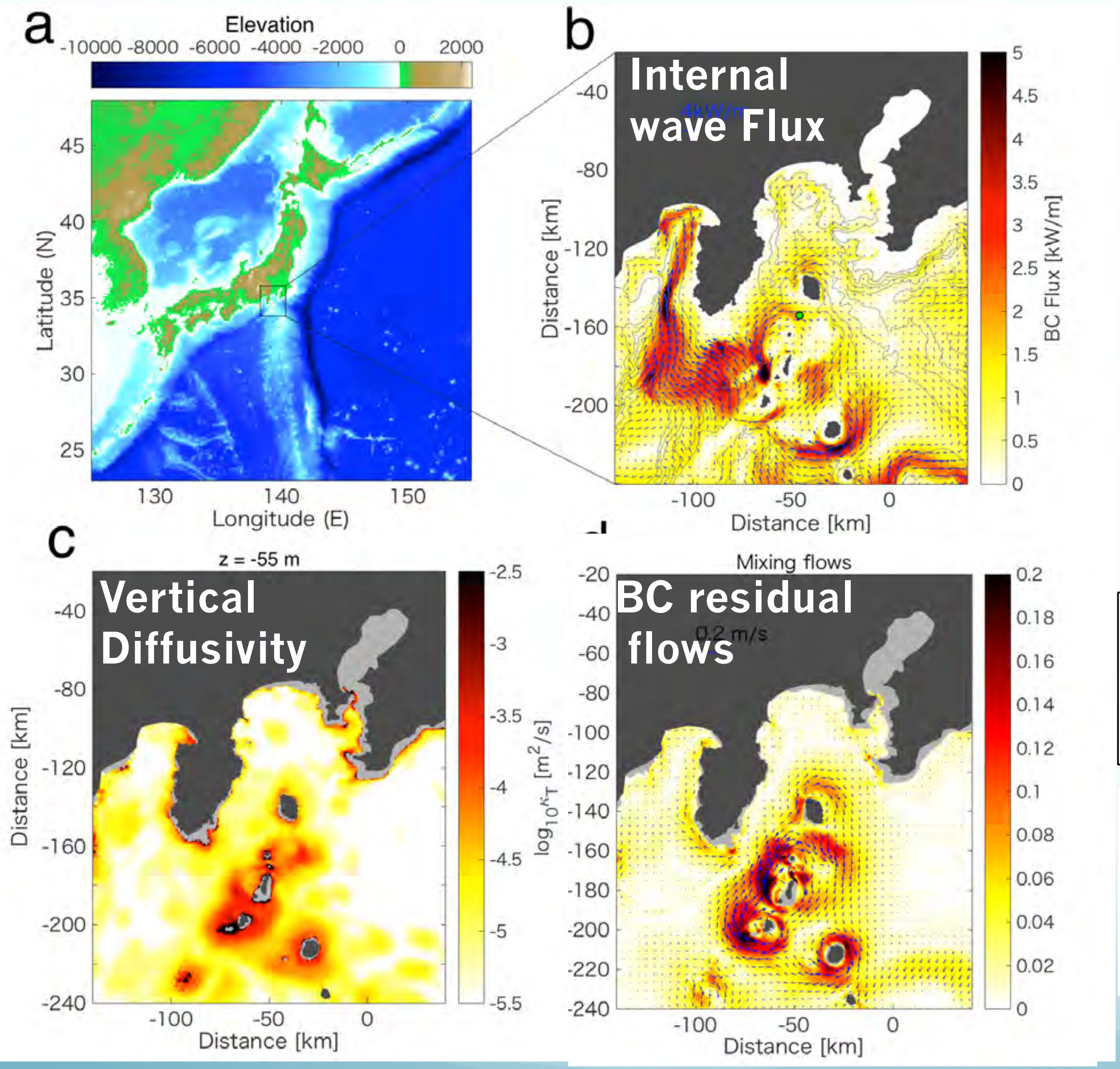
=

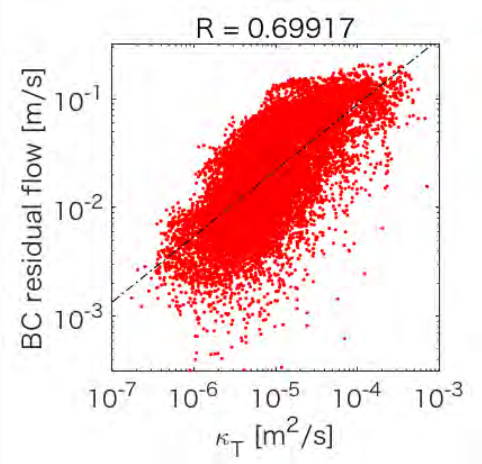
Subsurface BC Residual Flows



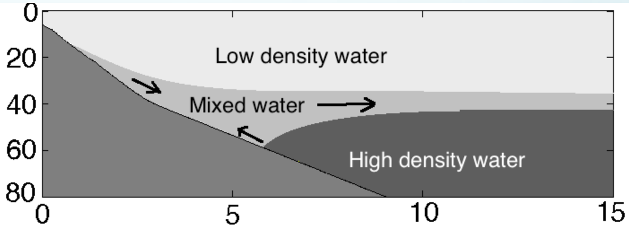
BC residual flows are higher than BT

BC residual flows due to internal wave breaking

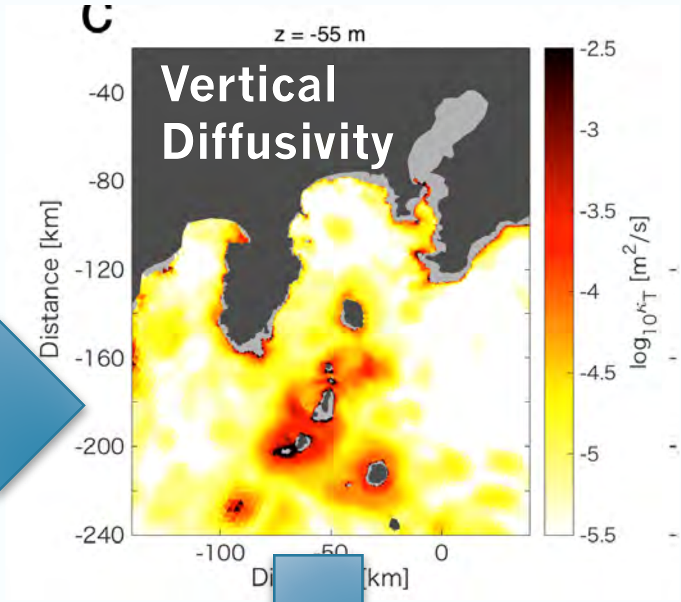


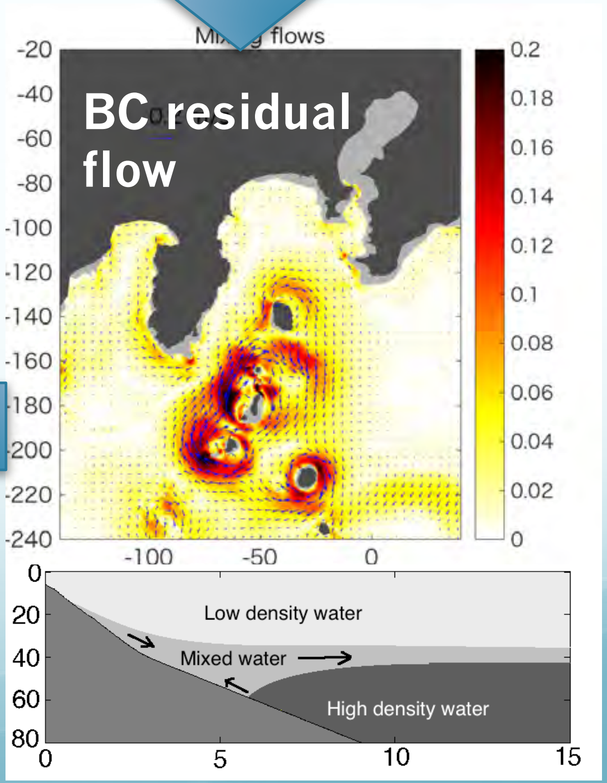


BC residual flow is generated by mixing due to IW breaking



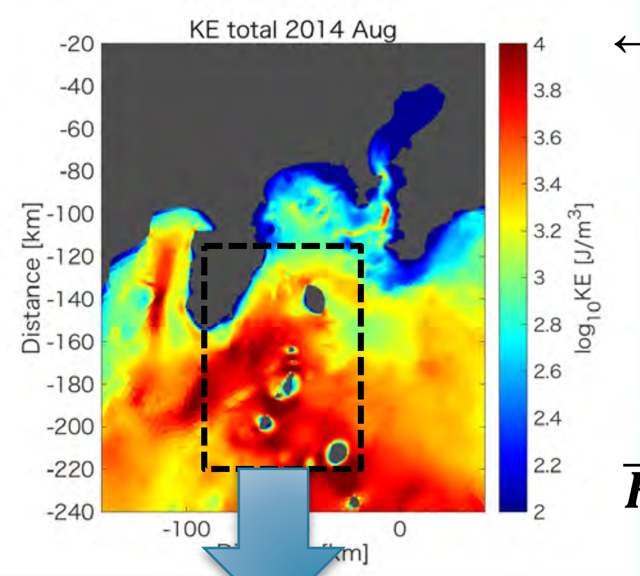
Breaking


Vertical Diffusivity


BC residual flow

Transport

Kinetic energy budget



←Time averaged vertically integrated KE

The total KE can be divided into BC and BT parts

$$KE_{Total} = KE_{BT} + KE_{BC} + \cancel{KE_{BTBC}}$$

Each part also can be divided into fluctuation and residual parts

$$\overline{KE_{Total}} = \overbrace{\overline{KE_{BThigh}} + \overline{KE_{BTR}}}^{Barotropic\ part} + \overbrace{\overline{KE_{BChigh}} + \overline{KE_{BCR}}}^{Baroclinic\ part}$$

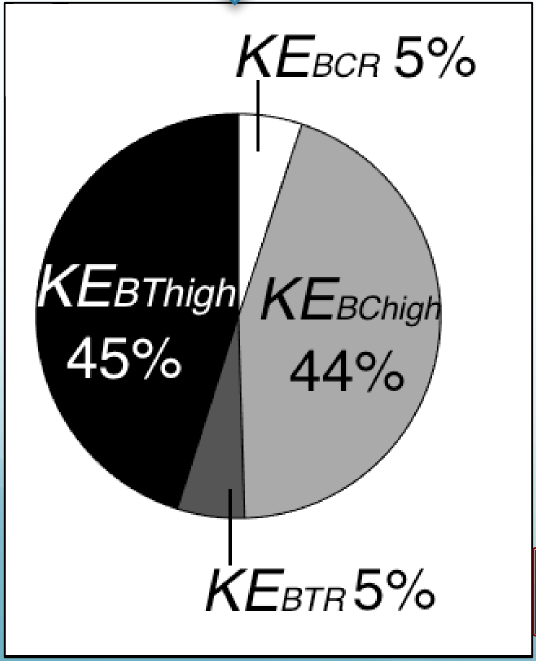
Overbar : time average

$$KE_{BTR} = 1/2\,\rho(\bar{u}_{BT}{}^2) \quad KE_{BCR} = 1/2\,\rho(\bar{u}_{BC}{}^2)$$

$$\bar{u}_{BT} = \frac{1}{\bar{H}}\int_{-d}^{\bar{\eta}} \bar{u}\,dz \quad \bar{u}_{BC} = \bar{u} - \bar{u}_{BT}$$

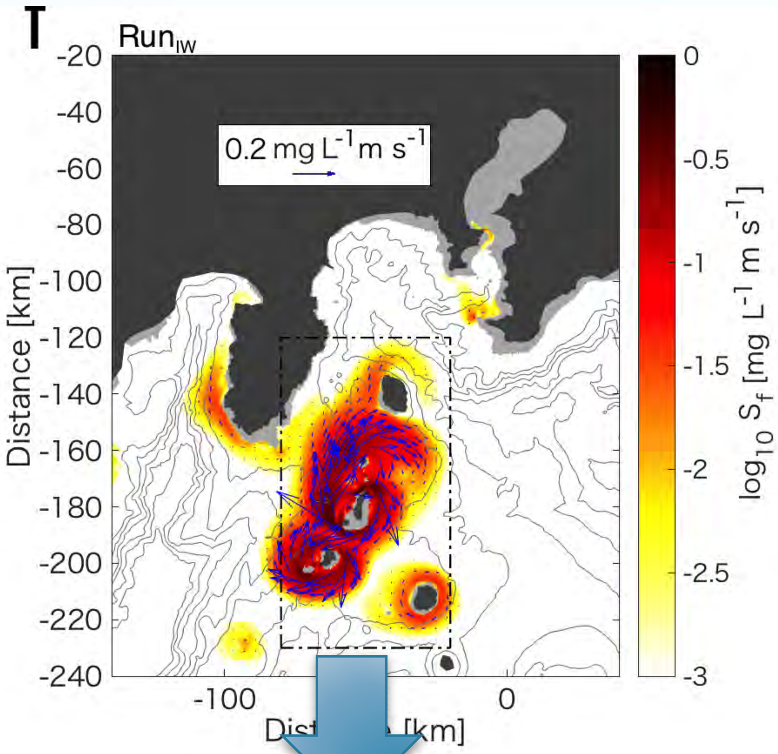
$$< \overline{KE_{BThigh}} > = < \overline{KE_{BT}} > - < \overline{KE_{BTR}} >$$

$$< \overline{KE_{BChigh}} > = < \overline{KE_{BC}} > - < \overline{KE_{BCR}} >$$



→BC residual part explains 5% of the total KE.

SS flux budget



SS flux can also be separated into four parts:

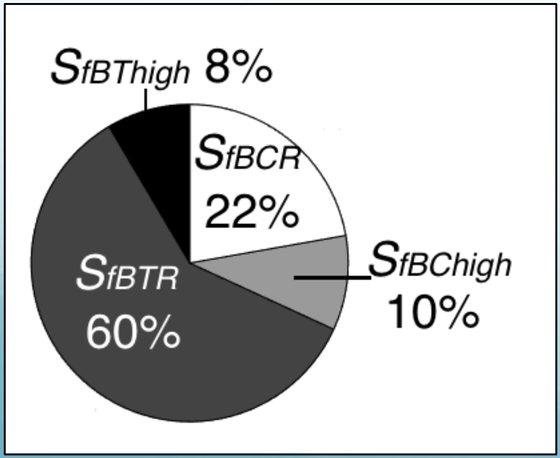
$$S_f = \overbrace{S_{fBThigh} + S_{fBTR}}^{Barotropic\ part} + \overbrace{S_{fBChigh} + S_{fBCR}}^{Baroclinic\ part}$$

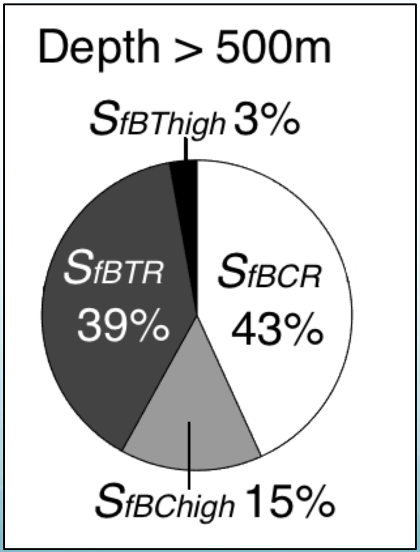
$$S_{fBThigh} = C(\mathbf{u}_{BT} - \bar{\mathbf{u}}_{BT}) \quad S_{fBTR} = C\bar{\mathbf{u}}_{BT}$$

$$S_{fBChigh} = C(\mathbf{u}_{BC} - \bar{\mathbf{u}}_{BC}) \quad S_{fBCR} = C\bar{\mathbf{u}}_{BC}$$

The residual part largely contributes to the SS flux (82%). → <u>opposite to KE.</u>

Tidal forcing transport SS back and forth, but it does not contribute to the net transport.





The contribution of S_{fBCR} becomes the largest contributor (43%) faraway from the coast (depth > 500 m).

Conclusions

1. **Mixing due to non-linear internal tides enhance baroclinic residual circulations along the thermocline.**

2. **The half of the residual KE is explained by the BC part.**

3. **BC residual circulations transport sediments from nearshore toward offshore, which results in intermediate turbidity layers.**

4. **High frequency tidal motions explain 90% of the KE, however, high frequency parts do not largely contribute to the net SS flux.**
   →<u>The net SS flux can be explained by residual circulation.</u>

Thank you,