Direct breaking of large-amplitude internal waves in the Urup Strait, Kuril Islands

Sachi Itoh[1], Y. Tanaka, S. Osafune, I. Yasuda, M. Yagi, H. Kaneko, S. Konda, J. Nishioka and Y. N. Volkov

Urup Strait —Mixing Hotspot—

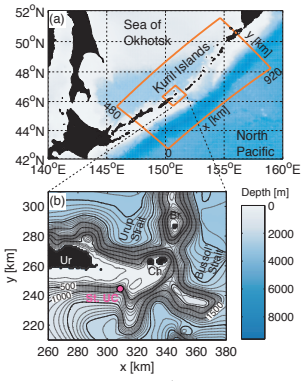


Fig. 1. Study site

- A shallow passage (~100 m) in Mid-Kuril
- Subinertial diurnal tide ($\omega_{tide} < f$)
- Extremely strong mixing on the lee-side of the sill (Itoh et al. 2010JGR, Itoh et al. 2011GRL; **Fig. 2**)

How can be the mixing so strong under the subinertial forcing?

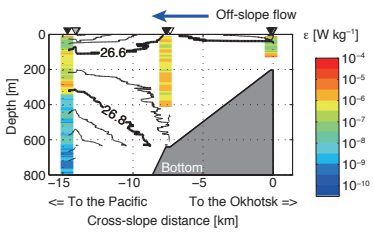
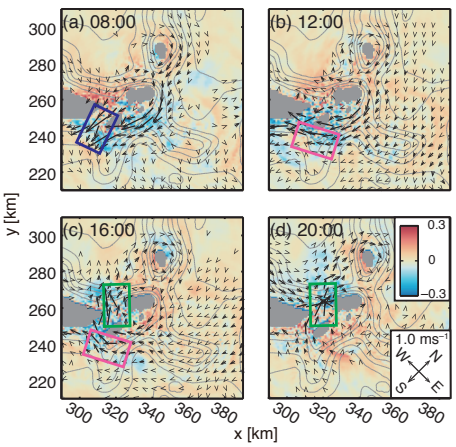


Fig. 2. Energy dissipation rate and potential density profiles on the Pacific flank of the Urup strait observed in 2007.

A 3D model



Model

- A hydrostatic model driven by the diurnal tide
- Resolution: 20 m (vertical), 1 km (horizontal)
- Energy dissipation estimation by viscosity terms

Flow field (Fig. 3)

- Topographically trapped internal tide with the diurnal frequency
- Negative density anomalies by off-sill flows (in areas within boxes)

Fig. 3. Model-predicted potential density anomalies [σ_θ] (color shading) and horizontal velocity (vectors) around the Urup Strait at 90 m.

Big wave and energy dissipation

- Deepening of isopycnal surfaces (> 200 m) during the Pacific-ward (off-sill) flow
- Enhanced energy dissipation after the deepening

Consistent with the observations

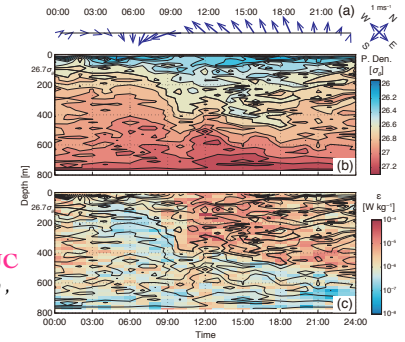


Fig. 4. Time variations at St. UC
(a) mean velocity above 26.7 σ_θ,
(b) potential density, and
(c) energy dissipation rates

Wave amplification mechanism

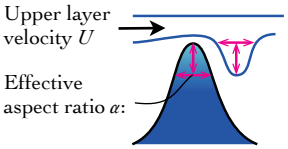


Fig. 5. Wave generation on the lee side of a tall sill

- Condition for the wave generation on the lee-side of a tall sill (**Fig. 5**; Klymak et al. 2010)

$\omega_{lee\text{-}side} = k\cdot U = \alpha N > \omega_{tide}$

- Effective amplification of the wave (Hibiya et al. 1986; **Fig. 6**)

Maximum Froude number ≥ 1

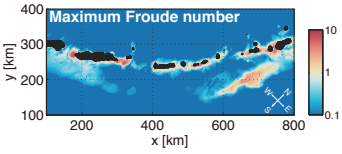
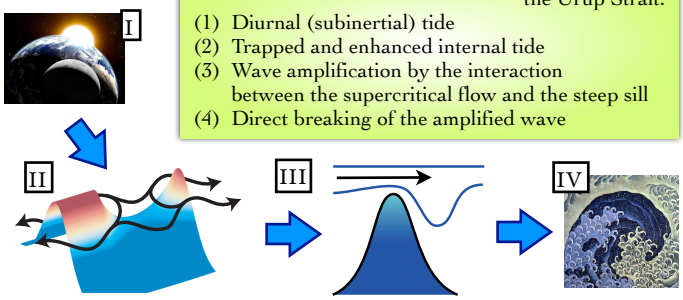


Fig. 6. Maximum Froude number estimated from the stratification and maximum barotropic velocity calculated in the model

Fig. 7. Four-step hypothesis for the strong mixing in the Urup Strait.
(1) Diurnal (subinertial) tide
(2) Trapped and enhanced internal tide
(3) Wave amplification by the interaction between the supercritical flow and the steep sill
(4) Direct breaking of the amplified wave



Reference

Itoh, S. et al., *JGR.*, **115**, doi:10.1029/2009JC005629, 2010 / Itoh, S. et al., *GRL.*, **38**, doi:10.1029/2011GL048507, 2011
Itoh, S. et al., *PiO*, special issue (Sea of Okhotsk), decision in process

[1]Atmosphere and Ocean Research Institute, The University of Tokyo; E-mail: itohsach@aori.u-tokyo.ac.jp