Observations of oceanic fronts and water-mass properties in the central Japan Sea: hydrographic surveys from gliders

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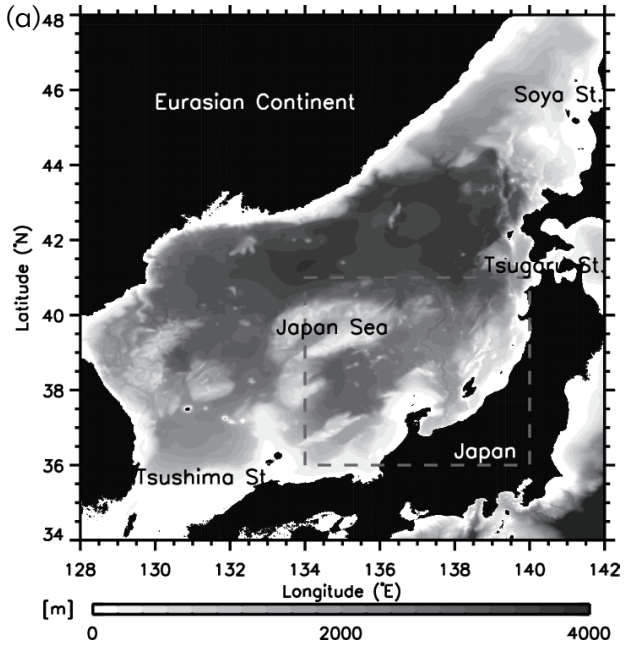
Outline

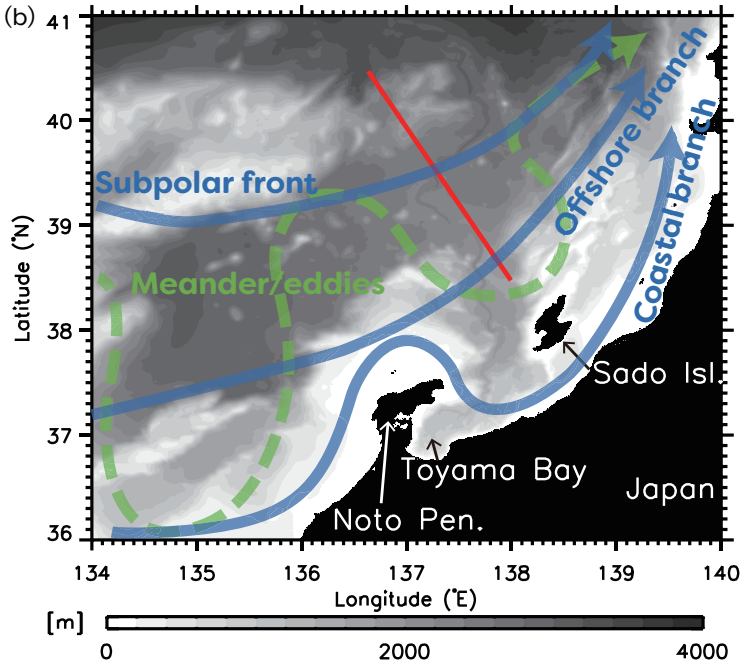
- Introduction
  - strong currents and eddies in the central Japan Sea
  - large spatiotemporal variabilities
- Methods
  - first glider observations in the central Japan Sea
- Results
  - intra-monthly variability of mesoscale frontal/eddy structures
  - detection of the Upper-layer Low Salinity Water

    Wagawa et al. (in revision of 2nd round; Journal of Marine Systems)

  - large turbulent below the negative vorticity pools
- Gliders in Japan
  - current and future

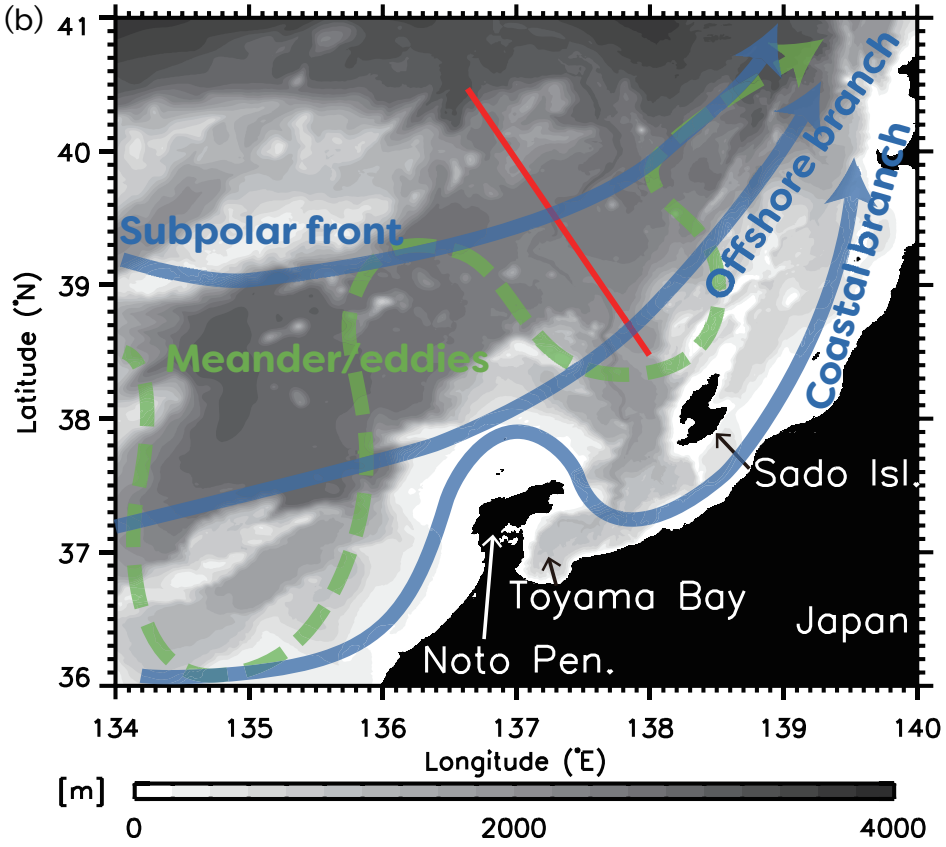
The central Japan Sea; strong currents and eddies





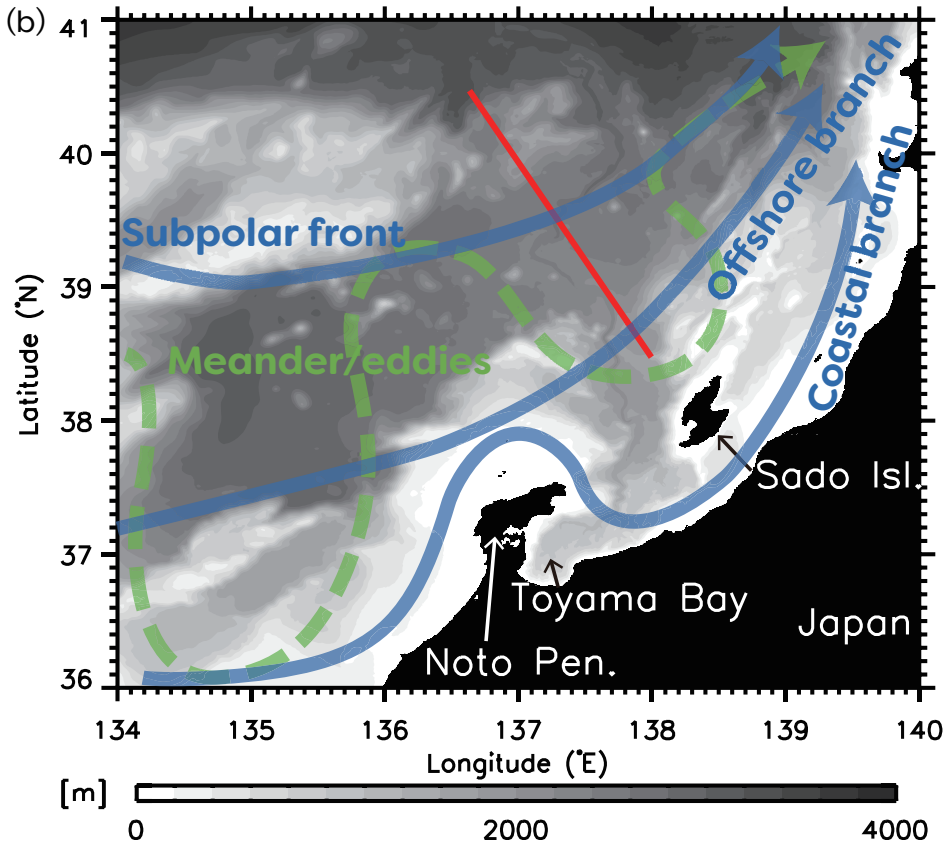
- The Japan Sea
  - a marginal sea bounded by the Asian landmass and the Japanese islands
  - warm/saline Kuroshio waters enter the Japan Sea: form the Tsushima Warm Current
- The region offshore of Sado Island
  - characterized by mesoscale northeastward flows
    - the subpolar front & Tsushima Warm Current, and mesoscale eddies
    - a surface-intensified jet with a lateral scale of O(10 km) and speeds exceeding 0.5 m s^{-1}

Large spatiotemporal variabilities; details remain unclear



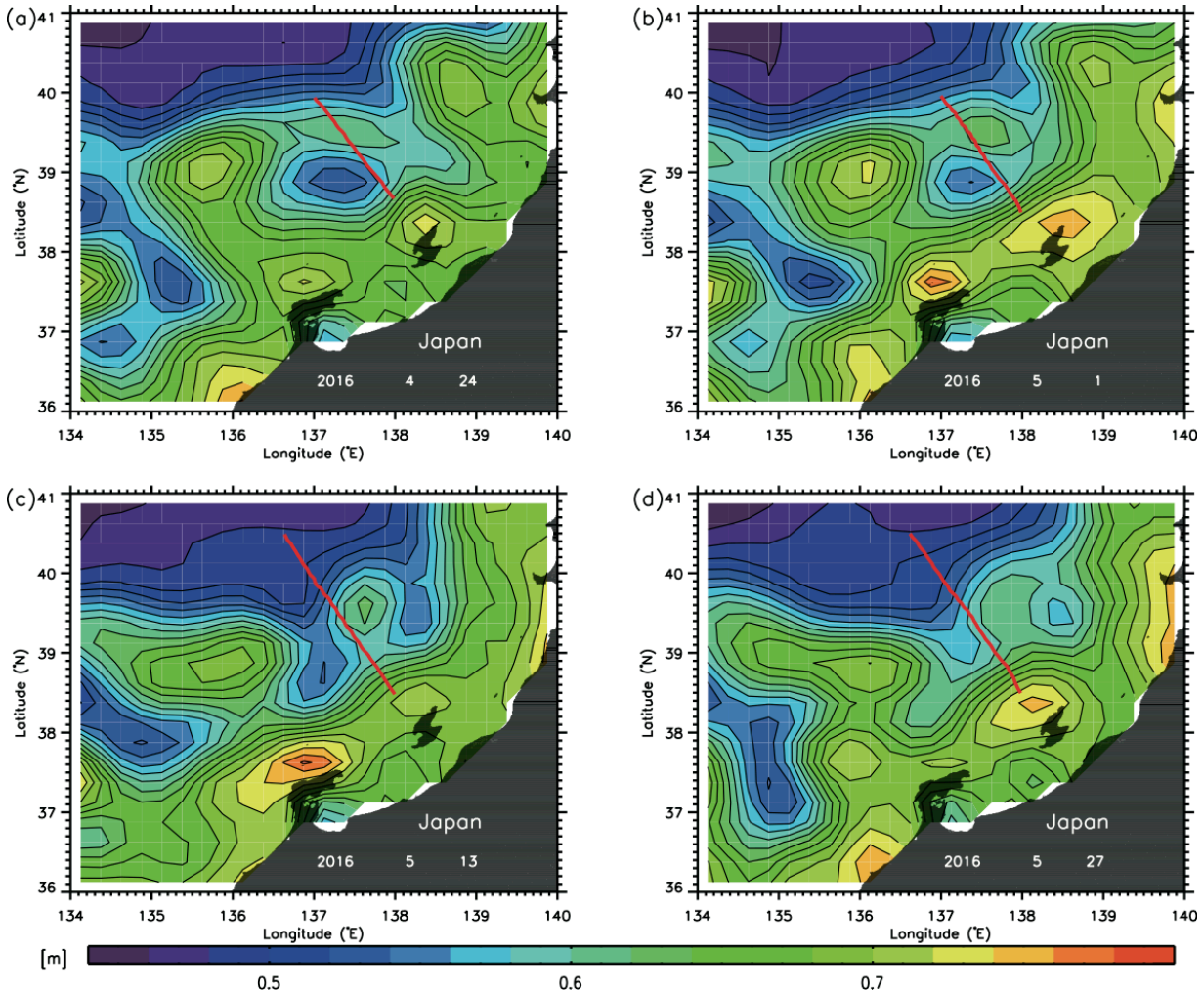
- The intrusion of such currents and eddies into this region cause fluctuations of T/S and flow field
  - impact primary production and the migration and recruitment of Japanese common squid (*Todarodes pacificus*) and yellowtail
  - raise serious concerns for the set-net fisheries and aquaculturists in the region
- Several studies have investigated those synoptic/mesoscale structures and their temporal variability
  - their detailed structures and variability remain unclear because of insufficient observational resolution

First glider observations in the central Japan Sea



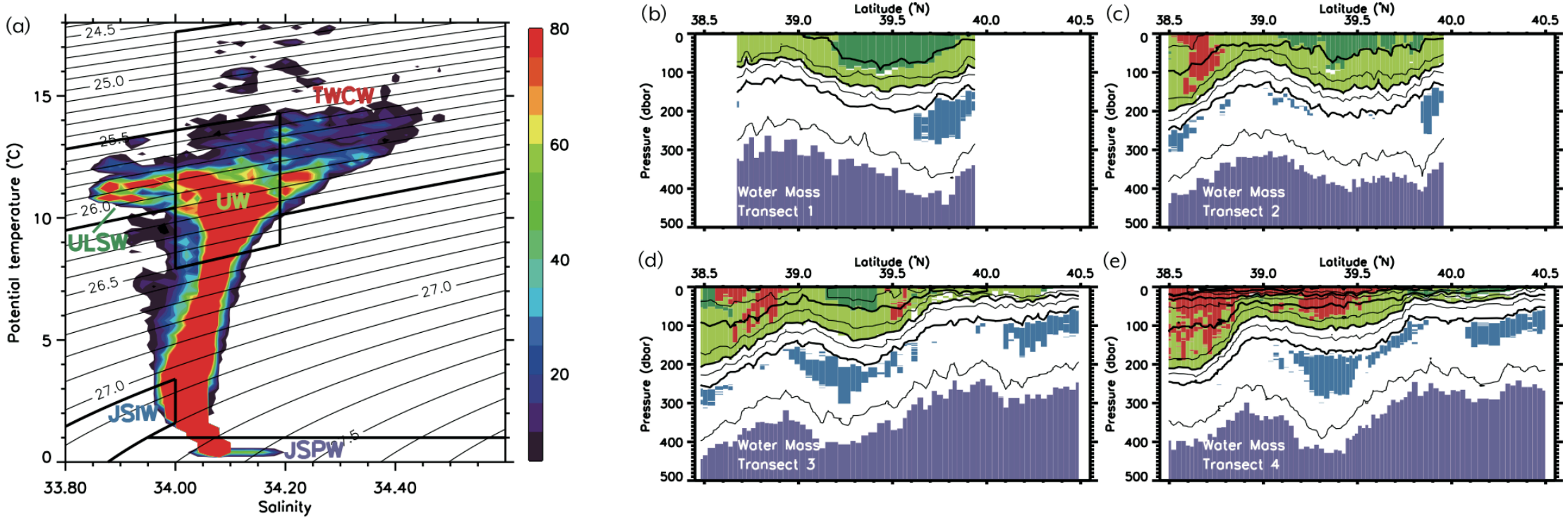
- We successfully completed for the first time a spatially high-resolution survey with an underwater glider
  - Seaglider (Kongsberg Underwater Technology Inc.)
  - along a Jason's track #86 off Sado Island from 20 April through 2 June 2016
- Glider repeatedly profiled T/S from the ocean surface to 900 m depth with an along-track profile separation 2–3 km (rd/6.5)
  - sufficient to resolve the mesoscale structures

Intra-monthly variability of mesoscale frontal/eddy structures



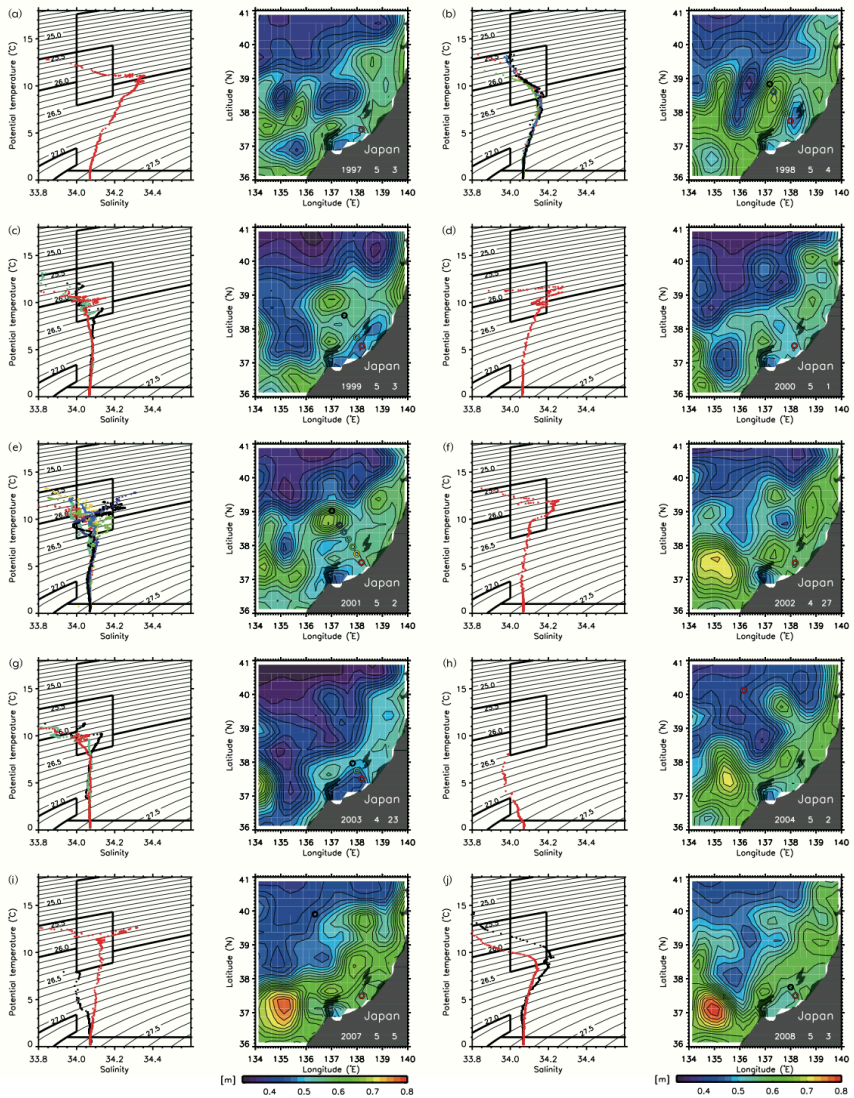
- The glider intersected sharp SSH contrasts across the fronts and eddies
- Large spatiotemporal variability of the mesoscale frontal/eddy structures
  - on a timescale of less than one month
  - Transects 1–4 were respectively characterized by
    - 1: cyclonic eddy
    - 2: vortex pair
    - 3: anticyclonic eddy
    - 4: baroclinic jets (no eddies)

Detection of the Upper-layer Low Salinity Water (ULSW)



- Classification of waters
  - Upper-layer Low Salinity (ULSW; green), Upper-layer (UW; yellow green), Tsushima Warm Current (TWCW; red), Japan Sea Intermediate (JSIW; blue), and Japan Sea Proper (JSPW; purple) Waters
- ULSW has never been detected in this season and area

Try to determine the origin of the ULSW; snowmelt

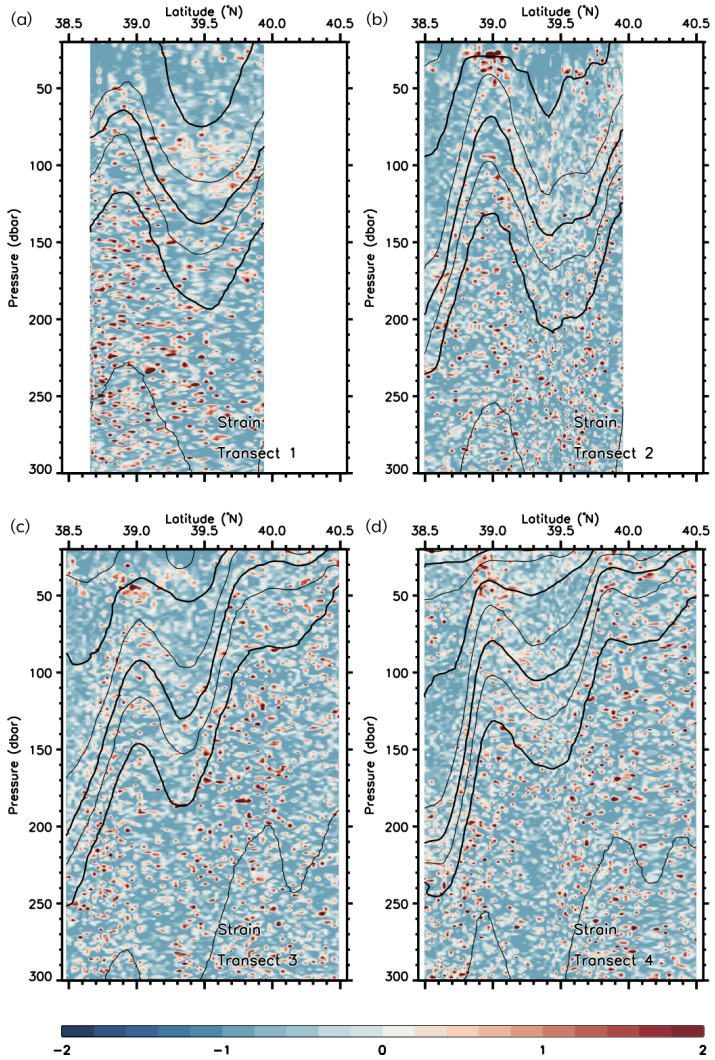


- Same water properties as ULSW
  - frequently observed in Toyama Bay
    - known to have a low salinity (< 34.0) due to snowmelt
- The offshore ULSW
  - form when there were anticyclonic eddies
    - similar to the case of the present study
  - impact on the biochemical environment
    - if it supplied freshwater and nutrients from land runoff into offshore regions
    - the mechanism were not clarified

      formation of the anticyclonic eddies

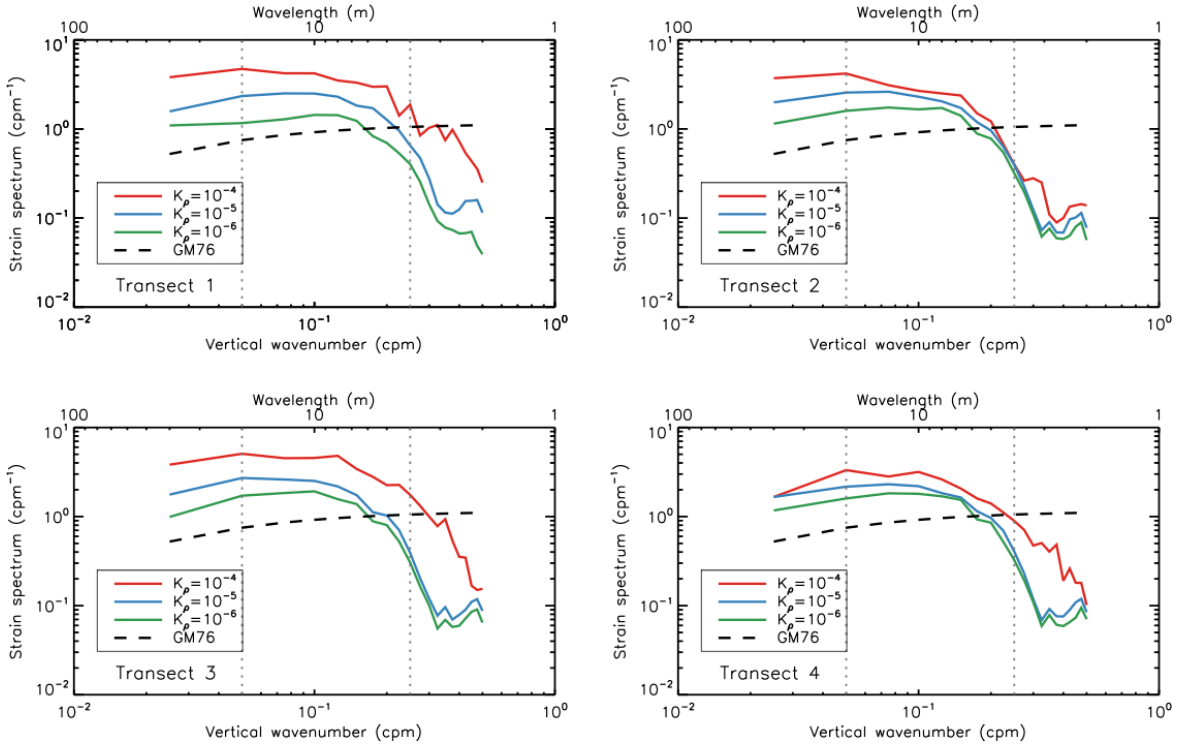
      the relationship between the spread of the ULSW from the coastal zone to the offshore area and to the eddies

Attempt to extract near inertial waves and mixing signals



- Strain and its SE-ward and NW-ward propagating components
- $\left(N^2 - N_0^2\right)/N_0^2$ defined by Kunze et al. (2006)
  - wavelike features on vertical and horizontal scales 5 m and 10 km
  - no difference between southeastward and northwestward propagating components

Spectral curves of 40-m binned strain representing $K\rho$



- Kunze et al. (2006)
  - K = 10^{-6}–10^{-4} m^2 s^{-1} (green, blue, and red lines, respectively)
  - The Garrett-Munk (GM76) internal wave spectrum for the canonical value (dashed curve)
  - Estimation of diffusivity $K\rho$
    - the spectra are integrated over m = 1/20 cpm and m = 1/4 cpm (dashed lines)

Large turbulent below the negative vorticity pools

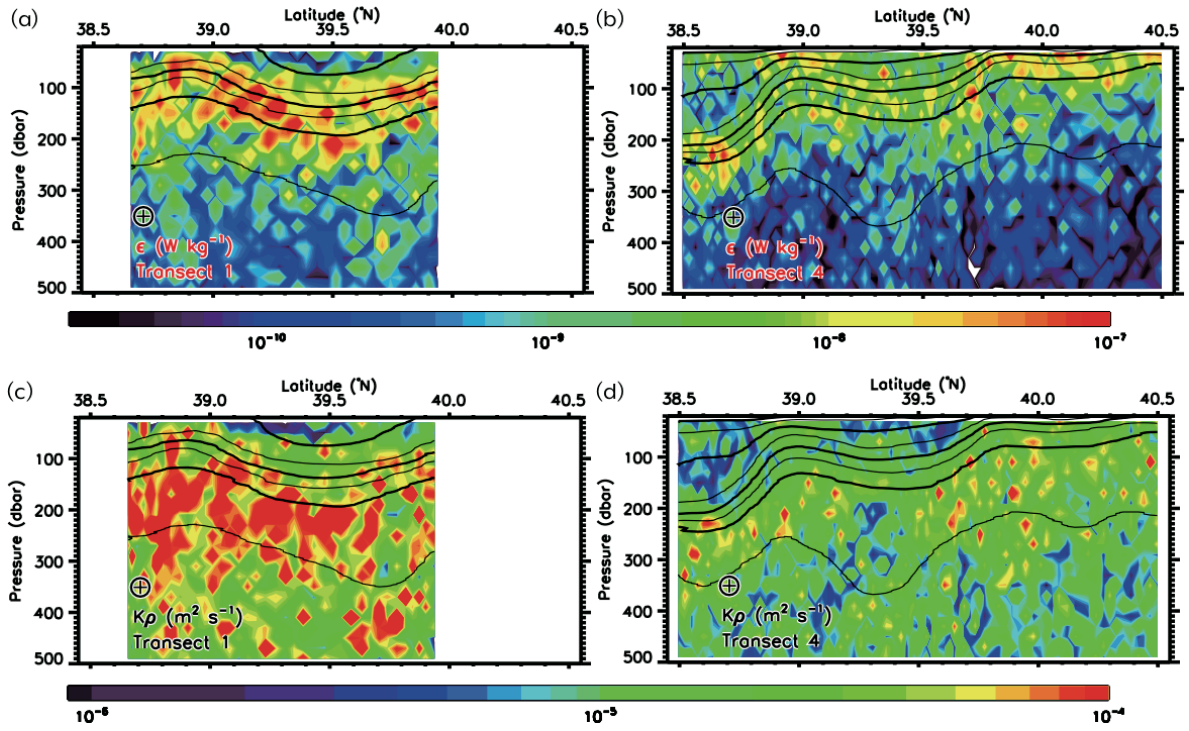


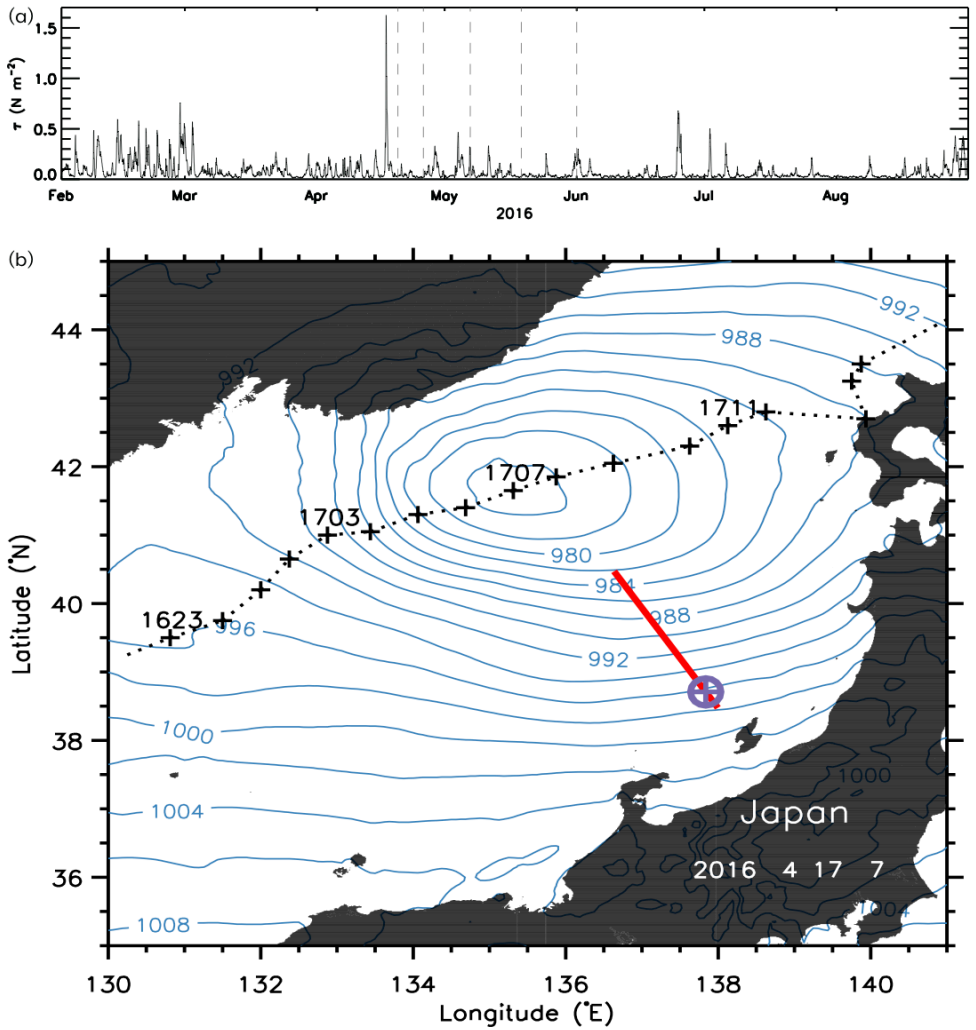
Table 2: The shear/strain variance ratio R_ω.

	Transect 1	Transect 2	Transect 3	Transect 4
$\langle V_z^2 \rangle^2 / \overline{N}^2$	265.0	377.1	225.2	175.8
$\langle \xi_z^2 \rangle^2$	45.33	147.0	103.1	70.75
R_ω	5.85	2.57	2.18	2.48

- Turbulent energy dissipation rates (ε) and vertical diffusivity ($K\rho$)
- Large ε
  - below the negative vorticity pools along Transect 1 ($\sim 2.9\times10^{-7}$ W kg^{-1})
    - wind-induced inertial oscillation ?

      Shcherbina et al. (2003)
- Corresponding $K\rho$
  - below the negative vorticity pools along Transect 1: 4.8×10^{-4} m^2 s^{-1}

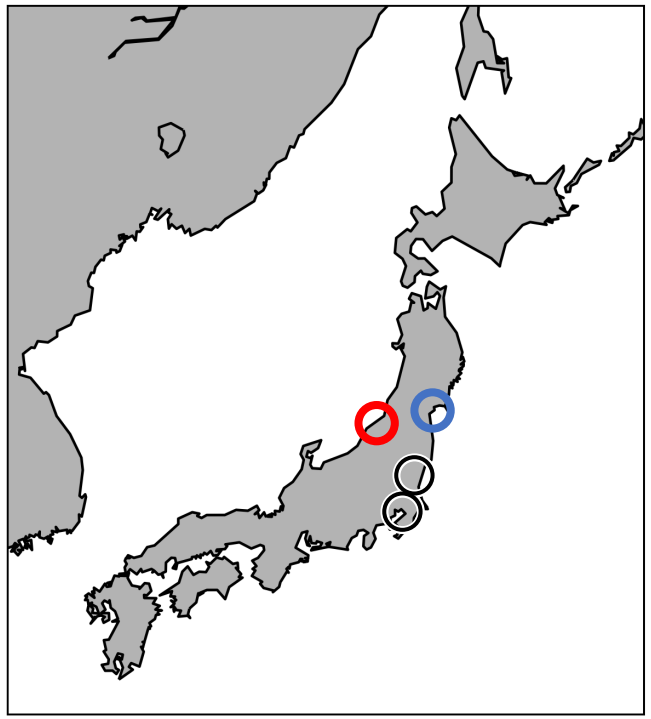
Strong wind-induced near inertial waves along Transect 1



- When bomb low pressure rapidly passed through the Japan Sea north of the glider observation lines April 16-18
  - fast migration of the low pressure system
    - generate the resonant inertial oscillations propagating to the interior water as the near inertial waves (e.g., Martini et al. 2014)
  - the detected large shear variance along Transect 1 observations
    - supported the strong wind-induced near inertial wave activities

Gliders in Japan; current and future

- Japan Fisheries Research and Education Agency (FRA): 7 gliders
  - Japan Sea National Fisheries Research Institute (JSNFRI): 1 glider
    - 1 Seaglider (our glider)
      working 150–180 days per year since 2016
  - Tohoku National Fisheries Research Institute (TNFRI): 6 gliders
    - 2 Seaglider and 1 Slocum
    - will get new 3 gliders in 2019
- Japan Meteorological Agency (JMA): 2 gliders
  - Meteorological Research Institute (MRI)
    - 2 Slocum
- The University of Tokyo: 2 gliders
  - Atmosphere and Ocean Research Institute (AORI)
    - 1 Slocum and 1 Seaexplorer



Summary

- To better understand the hydrographic structures and their fluctuations in the central Japan Sea,
  - we analyzed as a first step the mesoscale hydrographic structures and fine-scale water properties modulated by mesocale variability around the subpolar front and the Tsushima Warm Current.
  - we completed repeated glider surveys in the Japan Sea off Sado Island from 20 April through 2 June 2016.
    - we also attempted to extract mixing signals from fine-scale parameterizations based on the glider cross-sections.
    - a large intra-monthly variability of mesoscale frontal/eddy structures and water properties was revealed.
    - we classified water masses and found upper-layer, low-salinity water (ULSW) within an anticyclonic eddy.

      the low salinity may reflect the discharge of freshwater such as snowmelt from the Japanese coast.
    - we estimated the shear/strain variance ratio for the first time in the Japan Sea.

      high turbulent mixing activities and their intra-monthly variability estimated from density strain was possible evience of internal gravity waves.
  - we have taken an important first step by characterizing the hydrographic structures in the central Japan Sea.

Future works

- The water masses off Sado Island in spring could not be fully classified in the present study.
  - further data would help to refine the classifications in future.
  - numerical experiments will help to clarify the mechanisms responsible for formation of ULSW.
- To clearly understand the mechanisms responsible for generation and formation of the internal gravity waves,
  - it will be necessary to analyze both hydrographic and velocity observational data with high horizontal and vertical resolutions.
  - numerical experiments will also be useful for investigating such dynamics.
- We used the moored current meter data for estimating the shear/strain variance ratio in the present study
  - the detailed analyses of the data are left for another study in which strong NIWs and high turbulent diffusivity are likely after a fast-moving cyclone in fall.
    - Kawaguchi, Wagawa, and Igeta (submitted; Progress in Oceanography)