Effects of deep bottom topography on the sea surface height field in the Kuroshio Extension region studied by a nested-grid OGCM

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**Meander and variability in Kuroshio Extension (KE) region**

KE is characterized by
- two quasi-stationary meander
- strong eddy activities

Because there is eddy activity, it is expected that momentum is transferred to abyssal ocean and KE jet interacts deep bottom topography.

Some setting of OGCMs only represent bottom topography shallower than around 5500m depth. Is it enough?

Hurlburt el al. (1996) pointed out that bottom topography in KE region including deeper one is important for formation of the KE quasi-stationary meander.

In this study, effect of deep bottom bottom topography is investigated by using a eddy-resolving OGCM.

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η: sea Surface height
\[ \bar{\eta} : \text{time-average (1993-2008)} \]
\[ \sqrt{\left(\eta'\right)^2} : \text{anomaly from time average} \]
Model

Two-way nested-grid OGCM (similar to Kurogi et al., 2013) based on COCO (Hasumi, 20006).

Nesting method is described later.

Model is integrated from 1950 to 2009 with CORE Ver. 2 Interannual forcing (Large and Yeager, 2009).
Experimental cases

EXA: Deep bottom topography (to the depth of 9200m) is represented.

EXB: Bottom topography shallower than 5450m is represented. Most region except Shatsky Rise is flat.

EXB1: Deeper bottom topography between east of trench and Shatsky Rize is added to EXB.

EXB2: Deeper bottom topography in EXB1 is reversed to 5450m and added to EXB.
Time-averaged SSH

● Compared to EXB, the amplitude of KE meander is roughly as two times larger in EXA.

● The amplitude is larger in other cases (EXB1, EXB2) with slopes in deep bottom topography.

KE axis defined by contour of $\overline{\eta} = \langle \overline{\eta} \rangle$ ($\langle \rangle$: horizontal average inside rectangular region).
Compared to EXB, RMS of SSHA in EXA is about 10% larger in horizontal average.

RMS of SSH is also larger in other cases (EXB1, EXB2) with slopes in deep bottom topography.

Hereafter, effects of deep bottom topography on KE quasi-stationary meander are focused on.

Time average: 1993-2008
Mechanism of interaction of KE-jet and bottom topography

The enhanced amplitude of KE meander is seems to be a result of following interaction between KE jet and bottom topography.

(1) Zonal momentum transferred is downward and absorbed at deep bottom topography.

(2) Rossby wave is excited in the seabed. Among them, modes which are effective to momentum transfer are retained (by positive feedback).

As an equilibrium state, potential density surface will be deformed in a way reflecting the slope of bottom topography.

We will show here that
① zonal momentum is absorbed in deep bottom topography and
② slopes of potential density surface reflect large scale bottom topography.
Other processes are under investigation.
Momentum absorption in deep bottom topography in EXA

Bottom topography between \([z, z+dz]\) absorbs zonal momentum of \((p_E - p_W)\)dz from fluid between them. Amount of zonal momentum which bottom topography deeper than \(z=z_0\) absorbs is

\[
\int_{z_B}^{z_0} \int_{x_W}^{x_E} \frac{\partial p}{\partial x} \, dx \, dz \approx \int_{z_B}^{z_0} \int_{x_W}^{x_E} \rho_0 f v \, dx \, dz = -\rho_0 f \psi(z_0)
\]

For region (box in middle figure),
- zonal extent \(L \sim 1.73 \times 10^6\) m,
- \(\psi(5450\text{m}) \sim -1.2 \times 10^6\) m\(^3\)s\(^{-1}\)
- \(\rho_0=10^3\) kgm\(^{-3}\),
- \(f \sim 0.8 \times 10^{-4}\),
- \(-\rho_0 f \psi(5450\text{m})/L \sim 0.055\) Nm\(^{-2}\)

Zonal momentum absorbed in topography deeper than 5450m in this region is 0.06Nm\(^{-2}\) per unit area. It is comparable to wind stress over the KE region.
Effects of deep bottom topography on potential density surface and KE jet

● Bottom topography is relatively deep around A and shallower around B.

● About 4200m depth, $\overline{z}_\rho$ is also deeper than zonal mean around A and shallower around B. This tendency also appears in the upper ocean.

● In regions with shallower (deeper) density surface, density is higher (lower) in the same depth. From thermal wind balance, KE jet tend to flows between them and meander amplitude is enhanced.

Anomaly of $\overline{z}_\rho$ from zonal average. $z_\rho$: depth of potential density surface

Bottom depth $z_b$ -5900(m)
It appears that only the effect of large scale bottom topography appears in the upper ocean.

Motions associated with bottom topography are expected to decay with e-holding scale of

\[ H_e = \frac{f}{NK} = \frac{f\lambda}{2\pi N} \]

(\(f\): Coriolis parameter, \(N\): Brunt–Väisälä frequency, \(\lambda\): wavelength, \(K\): horizontal wavenumber).

Rough estimates shows that wavelength of motions larger than about 500km will reach the upper ocean. In fact, the effect of larger scale topography (A, B) is larger than 500km.
In EXB, most regions are flat and effects of bottom slope hardly appears in the upper ocean. In other cases, the effect of large scale bottom slope penetrate to the upper ocean.
Summary

• By representing bottom topography deeper than 5450m, the amplitude of KE meander and RMS SSHA are enhanced. Simulated SSH is more realistic by including deep bottom topography.

• Topography deeper than 5450m absorbs zonal momentum.

• Slopes similar to large scale bottom topography appears in time-averaged depth of potential density surface. Small scale variation decays. In this situation, the amplitude of KE meander is enhanced (thermal wind relation).

• Enhanced meander seems to be a result of interaction between KE jet and bottom topography.
Higher resolution model (100m horizontal resolution around Japan) is planned to run in the next generation supercomputer.
**Nesting method**

- Both models are interactively coupled for all processes (baroclinic, barotropic, tracer, and sea-ice calculation). Only the data near the interface is transferred between the two models.

(1) **Outer → Inner**
Variables in the outer model are interpolated as a boundary condition of the inner model.

(2) **Inner → Outer**
Variables in the inner model are horizontally averaged and replace the outer model variables.

- Conservative method similar to Debreu et al. (2012) is implemented.
Flux of tracers, sea-ice for the outer model $F_O$ is replaced by the inner model one ($f_1 + f_2 + f_3$).
Integration

- RIKEN’s K computer is used.
- For 8 model day integration, 19,680 cores are used for 16.5 wall clock hour.

North Pacific (10km)  
WOA09 State of rest  
20yr and 7mon  
20th year  
8/1

North Pacific (2km)  
interpolation

Nested-grid model  
(2km North Pacific  
+ 400m around Japan)  
interpolation

8/2  
1 days  
8 days

8/10  
8 days
Relative vorticity of the surface current (8/9 18:00-24:00)

- In 1/250° (1/50°) model, eddy with diameter around 1/50° (1/10°) is permitted.
- In 1/250° model, smaller scale island, cape, and Kármán vortex behind them are represented.
Movie along southern coast of Japan is shown.
(6hr average×32 shots, repeated)
Thank you very much for your attention!
Figure 1. SAR image including Izu Islands detected by the PALSAR on 12 June 2006, retrieved from http://www.eorc.jaxa.jp/ALOS/new/I_pal_060612.jpg, Courtesy of JAXA/METI.
KE jet path length (Qiu and Chen, 2005) is calculated.

Upstream KE path length (141-153°E) KE axis: contour of SSH whose value is horizontally averaged SSH in upstream KE region (141-153°E, 30-40°N).
Hurlburt et al. (1996)
- Topographically steered mean abyssal currents steer surface currents.
SSH referenced point just south of the coast along 136.05°E

LM south of Japan
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<th>1/10°</th>
<th>1/50°</th>
<th>1/250° nest</th>
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<tbody>
<tr>
<td><strong>Horizontal viscosity</strong></td>
<td>Biharmonic Smagorinsky</td>
<td>outer: Smagorinsky</td>
<td>inner: Biharmonic Smagorinsky</td>
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<td><strong>Horizontal diffusion</strong></td>
<td>Biharmonic (10^8 m^4s^-1)</td>
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<td><strong>Vertical viscosity and diffusion</strong></td>
<td>Based on Noh and Kim (1999)</td>
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<td><strong>SSH diffusion</strong></td>
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<td>UTOPIA-QUICKEST (SOM is also implemented)</td>
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<td><strong>Forcing</strong></td>
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<td>CORE NYF</td>
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<td><strong>Body forcing</strong></td>
<td>SSS and T, S at near the horizontal boundary is restored to climatological monthly data.</td>
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<td><strong>Δt</strong></td>
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<td>2 minutes</td>
<td>30 seconds</td>
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<td><strong>Used nodes (K computer)</strong></td>
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<td>2460</td>
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<td><strong>Wall clock time for 1 model day integration</strong></td>
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<td>18 minutes</td>
<td>2 hours</td>
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