Western Boundary Current Crossing a Ridge
—Barotropic and Equivalent Barotropic Models—*

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Abstract: Investigated is a possibility of two-dimensional model in the study of the dynamics of the western boundary current by a numerical experiment. Emphasis is laid on the effect of bottom barrier corresponding to the Izu Ridge.

The western boundary current in the model is formed by source and sink of the water prescribed at an artificial eastern wall (600 km offshore). The bottom topography consists of a continental slope parallel to the straight western coast, and a ridge protruding from the western coast to 500 km offshore (1,500 m deep and 400 km wide). The grid size of 12 km x 25 km (offshore and longshore directions, respectively) resolves both the western boundary current and the bottom topography.

The assumption of homogeneity of the water density makes the western boundary current detour along the isobath of the ridge.

A steady state solution is obtained under the assumptions that the horizontal velocity does not change direction vertically (equivalent barotropic), and that the geostrophic relationship holds at the bottom. Homogeneity of the water density is not assumed. The solution shows that most of the volume transport of the western boundary current cross the ridge and the current has cyclonic vorticity near the summit of the ridge. It seems to suggest that the investigation by three-dimensional models is necessary in order to study the complete dynamics of the western boundary current crossing the ridge.

1. Introduction

The present paper presents a numerical experimentation of the western boundary current by a barotropic model developed in ENDOH (1973)*** with a fine mesh (12 km x 25 km). Emphasis is laid on the effect of bottom barrier.

Since there has been almost no dynamical investigation so far made by a numerical experiment with a combined configuration of a fine mesh and the western boundary current crossing a ridge, the present study is aimed to know the fundamental dynamics of the barotropic mode of the boundary current with a variable bottom topography.

We investigate how the inclusion of the bottom barrier into the western boundary region would change the barotropic mode of the circulation and/or could represent the flow pattern of the Kuroshio current south of Japan. The Izu Ridge is modeled by a very simple ridge.

Next we study the significance of the vertical variation of the horizontal velocity by an equivalent barotropic model, in which the horizontal velocity is assumed to take the same direction vertically. The vertical shear may increase the Rossby number or the Reynolds number and may decrease the effect of the bottom topography. This is the second point of the present paper.

We treat four models. Model I is essentially an extension of model II in P1. The vorticity equation for the vertically averaged horizontal velocity of the homogeneous water is numerically integrated.

In model II, it is assumed that the horizontal velocity is vertically coherent in direction (equivalent barotropic), and that the vertical profile of the horizontal velocity is similar everywhere. This model enhances the non-linearity without

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*** ENDOH (1973) is referred to as P1 hereafter.
the decrease of the bottom topography.

Model III is also equivalent barotropic. Non-
homogeneity of the water density is implicitly
included into the model. Instead of the simi-
larly in velocity profile assumed in model II,
the shearing zone is limited in the upper level
above a fixed depth. This assumption causes
not only the increase of non-linearity but the
decrease of sensitivity of the model to the
bottom irregularity. In this model, the Rossby
number is not increased tentatively, and the
effect of the non-homogeneity of the water
density to the flow pattern is investigated.

In model IV, both the increase of non-line-
arity and the decrease of the bottom effect are
incorporated.

2. Steady barotropic current with a bottom
barrier

Figure 1 is a schematic view of the numerical
model. The latitudinal dimension of the model
is 3,500 km which covers the region between
the latitudes where the curl of the zonal wind
stress vanishes. The eastern wall of the model
is located 600 km offshore from the western
coast.

The bottom topography consists of a contin-
ental slope 120 km wide parallel to the straight
western coast, and of a ridge in the middle of

the domain. The latitudinal width of the ridge
is 150 km at the shallowest part (1,500 m deep)
and 400 km at the deepest part (400 m deep).
The top of the ridge is flat. There are north-
ward and southward linear slopes of 125 km
wide. East of the ridge, a narrow path of 84
km wide is opened in the flat bottom. Figure 2
shows the isopleths of the depth. Notice that
the isopleth around the ridge is not closed.

At the western coast, we impose the viscous
boundary condition. The northern and southern
boundaries are slippery. At the eastern bound-
dary (600 km offshore), we assume the Sverdrup
influx and efflux corresponding to the volume
transport due to the zonal wind stress of 0.6
dyne/cm² (see P1).

In this chapter a barotropic model is employed.
We integrate the following non-dimensional
vorticity equation for the vertically averaged
horizontal velocity of the homogeneous water.
The characteristic values for non-dimensionali-

\[ \frac{\partial \omega}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{\Omega}) \]

\[ \mathbf{v} = U \mathbf{e}_x + \mathbf{w} \]

\[ \mathbf{\Omega} = \mathbf{e}_y \times \mathbf{e}_z \]

\[ U = \frac{2}{\pi} \tan^{-1} \left( \frac{y}{x} \right) \]

\[ \mathbf{w} = \frac{2}{\pi} \frac{y}{x} \left( \cot \left( \frac{y}{x} \right) - 1 \right) \mathbf{e}_z \]

\[ \frac{\partial}{\partial t} \left( \frac{\omega}{\rho_0} \right) = \nabla \times \left( \mathbf{v} \times \mathbf{\Omega} \right) \]

Fig. 1. Schematic view of the model.

Fig. 2. Isopleths of the depth.