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Oceanic time variability near a large scale topographic circulation

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ABSTRACT

The oceanic circulation around a large scale topographic anomaly is studied using a numerical quasigeostrophic (QG) model. This simulation bears important similarities to a real ocean case, the Zapiola Anticyclone (ZA). The simple physics of the model allow the identification of two controlling parameters of the topographic circulation: bottom friction and eddy diffusivity. The role of these parameters was predicted in the theory proposed by Dewar [Dewar, W.K., 1998. Topography and barotropic transport control by bottom friction. J. Mar. Res. 56, 295–328] for the mean flow.

This paper focuses on the time variability of the simulated circulation. The topography energizes the low frequency band, due to variations of the topographic circulation and its collapses. A local mode varies the amplitude of the topographic circulation and is related to the eddy field activity. The model shows that the trapped circulation can be shed away from the topography due to an increased sensitivity to the background flow perturbations. In the mesoscale band, a mode one anticyclonic wave also appears. We compare these features with similar observations in the Zapiola region. The location and strength of the ZA raise the question of its role in the mean regional oceanic circulation. This work suggests that its variability on a variety of temporal scales may also be of importance.

1. Introduction

The unexpected discovery of the Zapiola Anticyclone (ZA) almost 15 years ago (Saunders and King, 1995) and of its intensity (transport near 100 Sv) revealed a lack of understanding about topographic mean flows. Since then a theory was suggested by Dewar (1998) that rationalized the existence of the ZA as the product of eddy interactions with bottom topography. Since its discovery, the ZA has been observed with various methods that revealed important variability in the mesoscale and interannual bands. Using a QG numerical model which captures important physics relevant to the ZA, we investigate here the variability of the oceanic circulation above a large scale isolated topography similar to the Zapiola Drift. Although simplified, the model reproduces variability features similar to the ones observed above the ZA.

The ZA is an intense barotropic closed circulation (Saunders and King, 1995). It is trapped above the Zapiola Drift (ZD), a sedimentary deposit located at (45°S, 42°W) in the center of the Argentine Basin (AB). The ZD reaches a maximum height of 1000 m above the 6000 m depth of the abyssal plain of the AB, and extends about 1000 km and 500 km in the zonal and meridional directions, respectively. Based on geologic evidence, Flood and Shor (1988) suggested the long-term presence of an anticyclonic circulation at the bottom of the AB.

The intense circulation of the ZA and its presence near the Confluence region in the AB render it an important feature of the South Atlantic ocean circulation and climate. There are mounting observations of the variability of the ZA. Indications of interannual variability and collapses of the ZA transports emerged from altimetry data (Saraceno, personal communication), whereas recent bottom pressure measurements (Hughes et al., 2007) indicated large transport variations of the barotropic circulation in the ZA as well as a slow trend that lasted longer than a year (see their Fig. 2). An anticyclonic wave, with a period of 20–25 days was also observed in the ZA region from altimetry (Fu et al., 2001), bottom current meters (Weatherly, 1993) and bottom pressure gauges (Hughes et al., 2007). Using numerical modeling and altimetry data, Weijer et al. (2007a,b) found multiple barotropic modes of variability near this high frequency band in the AB and traced them to flat bottom Rossby basin modes.

The limited temporal extent of available observations does not allow for the investigation of the interannual and interdecadal variability of the ZA. The goal of this paper is to explore this interdecadal variability using a QG numerical model and the theoretical framework introduced by Dewar (1998). Numerical simulations with high resolution and full primitive equations, being computationally demanding, are limited temporally as well and are sensitive to multiple parameters that further obscure the source of variability. In contrast, QG models can be integrated for long

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intervals on modern computers, thus allowing the study of long term variability. There is also strong evidence that QG physics capture the essential dynamics at play in the ZA. This was confirmed through comparison with a simulation of the South Atlantic using the Sigma-coordinate Primitive Equations Model (SPEM) by de Miranda et al. (1999).

We quickly review here the essential elements of the analytical mean flow theory that have been tested in numerical calculations. The theory predicts a linear relationship between potential vorticity (PV) and streamfunction in the bottom layer. The proportionality factor is the ratio C_b/κ of bottom friction C_b to eddy diffusivity κ. This theory also predicts a topographic transport that depends on a parameter $\chi = C_b R_d^2/\kappa$ where R_d is the Rossby deformation radius for the lower layer where the topographic anomaly is present. Using an eddy resolving QG numerical model (essentially the one used by Holland, 1978) with three layers, Dewar (1998) confirmed these predictions as well as the vertical structure of his analytical solution. Following a similar method, Bigorre (2005) confirmed the barotropization of the transport for small χ, quantified the eddy diffusivity κ, and computed directly the eddy PV fluxes, which were found to be downgradient, in accord with the theory's main assumption. The controlling effect of bottom friction and eddy diffusivity was also verified by de Miranda et al. (1999) using SPEM. In Béranger (2000), the use of a more realistic bathymetry on the continental slope in SPEM created a more turbulent front in the Confluence region, which led to an intensified ZA. Finally, in both QG (Bigorre, 2005) and SPEM (Barnier, personal communication) simulations, eddy transports were significantly nonzero in the forced layer near the surface and dissipative layer at the bottom but remained small at intermediate depths. A tendency for mixing of properties inside the closed topographic circulation was also observed in both models (Bigorre, 2005; Béranger, 2000). Although simplified, the theory in Dewar (1998) and the QG model appeared to capture important physics relevant to the ZA.

The present work deals mostly with the description and dynamical investigation of the low frequency variability in the topographic anomaly region. We argue the nature of this variability is dominated by the stability of the ZA which is, in turn, determined by the anticyclone strength. Strong transports resist perturbations more effectively than weak ones. An interannual time scale is selected by basin modes of the flow, but the response of the ZA to the ensuing perturbations is a sensitive function of the flow conditions. Last, the ultimate stability of the ZA is determined by very low frequency fluctuations of the eddy kinetic energy in the basin.

In this paper, Section 2 briefly presents the model and describes the low frequency variability of the basin circulation with flat bottom and the changes introduced by the presence of a bottom topography similar to the ZD. Section 3 discusses the effects of the controlling parameters on this variability. Section 4 describes a local mode of variation in the closed circulation above the seamount. Section 5 describes a high frequency mode one wave that shares similarities with observations. The paper concludes with a summary and discussion in Section 6.

2. Basin circulation

2.1. Numerical model

The numerical model is essentially the QG model from Holland (1978), with three layers. It is forced by a region of steady, downwelling Ekman pumping as a single gyre. The basin is rectangular (3000 and 2000 km in zonal and meridional directions, respectively). The spatial resolution is 10 km and the time step is 7200 s. Ekman pumping depends only on latitude, vanishes on the southern and northern boundaries and decreases linearly towards the basin center. It is uniform and minimum in a zonal band centered in the middle of the basin. No normal flow and free slip conditions are imposed on the side boundaries and the flow is spun-up from rest to a statistical steady state. The first 20 years of model spin-up are discarded. Numerical dissipation, which removes noise accumulated at the high wave numbers, is simulated by either Laplacian or biharmonic operators. The surface, intermediate and bottom layers are, respectively, 300, 700 and 4000 m thick. Associated reduced gravities are 0.014 and 0.007 ms^{-2} for top and bottom interfaces, respectively. Rossby radii of deformation are therefore 16 and 31 km. In comparison, Weatherly (1993) used hydrographic data and estimated the oceanic Rossby radii in the ZA region to be 11 and 22 km. When bottom topography is added to the flat bottom, it consists of a gaussian bump with slight asymmetry located in the interior of the rectangular basin, away from boundaries. The bump height is 800 m and gaussian decay length scales are 400 and 300 km in zonal and meridional directions, respectively. The topography used was slightly asymmetric, in keeping with the geometry of the ZD. We did not try a topography with azimuthal symmetry, but it should be noted that the β-effect breaks the symmetry of the circulation, which is centered poleward of the seamount's summit, as predicted by the theory of Dewar (1998). In our reference experiment, bottom friction $C_b = 10^{-8}$ s^{-1}, topography is centered at (1000 km,1000 km) with (0, 0) being the southwest corner of the basin and Laplacian dissipation is applied. Fig. 1 shows the mean streamfunction, averaged over 20 years, for this configuration. The upper layer has a western boundary current and inertial recirculation along the northern boundary of the basin. In the interior, a Sverdrup flow dominates except above the topographic anomaly. The lower layers exhibit very weak flow in the interior and a recirculating gyre in the southwest corner, similar to a Fofonoff mode. The topographic gyre is present in all layers.

2.2. Basin modes

Using long time series from a QG numerical model with parameters similar to Dewar (1998), we investigated the time dependence of the circulation and the influence of the topography on this variability. The model circulation variability indeed exhibited a clear sensitivity to the bottom topography. Fig. 2 shows the spectra of the streamfunctions in each layer, in the topographic gyre

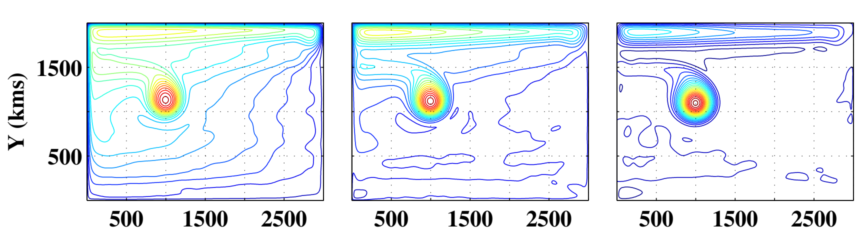

Fig. 1. Mean streamfunction (20 years average). Left: upper layer, (contour interval = 4×10^3 m^2 s^{-1}); center: intermediate layer, (contour interval = 2×10^3 m^2 s^{-1}); right: bottom layer, (contour interval = 1.5×10^3 m^2 s^{-1}). Run with Laplacian dissipation, 800 m seamount centered at (1000 km,1000 km) and bottom friction $C_b = 10^{-8}$ s^{-1}.