Aghullas ring Trajectories and Evolution from Altimeter data

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Abstract: Oceanic vortices have been the subject of several experimental and theoretical studies. They play a key role in the energy budget of the global ocean. A better understanding of their physics, (e.g. interaction with the mean currents) would improved our knowledge of the ocean circulation. Satellite altimetry and numerical models are used to detect, track and analyze the strong anticyclonic eddies generated by the Aghullas retroflection. These rings have a long lifetime and can cross the South Atlantic basin. They could play a key role in the exchanges between the Indian and South Atlantic oceans. The LEGI QG model is a high resolution (1/6°) eddy resolving model. By means of a simple nudging data assimilation procedure along track altimeter data are introduced into the model to control the simulation. Using a Gaussian eddy model and the smooth variation of eddy propagation speed, a method has been developed, based on the analysis of along track altimeter data in terms of eddy characteristics (amplitude, size) to estimate the eddy trajectory . This trajectory is then used as a frame of reference to estimate the bidimensional eddy structure. Three Aghullas rings, detected during a WOCE campaign are studied. Their trajectories, determined from altimetry, is compared to the numerical model ones. Their structure and their evolution are analyzed and compared to model and in situ data. The influence of bottom topography, mean currents, eddy/eddy interaction is analyzed.

INTRODUCTION

Since their discovery in the 70's, the oceanic vortices have been the subject of several experimental and theoretical studies. They play a key role in the energy budget of the global ocean. A better understanding of their physics, in particular their interaction with the mean currents would greatly improved our general knowledge of the ocean general circulation. The Aghullas current is the major western boundary current in the southern hemisphere. It flows along the coast of south Africa, then meanders while approaching the Cape of Good Hope. The current executes a rather abrupt anticyclonic turn (referred as the Aghullas Retroflection). This current loop regularly intercepts itself and forms anticyclonic rings that are the largest and most energetic in the world ocean. Around 6-7 rings (sometimes 9) are shedded each years [1]. They are advected north-west-wards by effect, then by the Benguela Current and finally by the South Atlantic subtropical gyre. By advection and dissipation they contribute significantly to the energy and freshwater flux between the Indian Ocean and the South Atlantic.

The trajectory of an Aghullas ring detected near the South Atlantic ridge (10°W, 32°S) during an at sea campaign [2] has been estimated using TOPEX/Poseidon and ERS-1 altimeter data [3][4]. The bidimensional structure of the eddy and its time evolution are presented and the results are compared with the output of a high resolution (1/6°) QG ocean circulation model, into which satellite altimeter data are assimilated using a simple nudging method.

RING TRACKING

The goal is to estimate the best possible eddy center track using the information provided by the along track Sea Level Anomaly altimeter data, the continuity of the track, and the rather small variations of the ring displacement speed. A first draft of the eddy center trajectory is obtained from Time/Longitude and Time/Latitude diagrams in different latitude and longitude bands. This first draft is then used to select the ERS and TOPEX/Poseidon orbits intersecting the ring. For each selected orbit, the along track SLA data are then analyzed using a bidimensional Gaussian eddy model of the form:

$$\zeta(x,y) = \zeta_0 \exp(-((x-x_0)^2 + (y-y_0)^2)/(2r^2)) \quad (1)$$

where x_0 and y_0 are the eddy center coordinates, ζ the SLA, and r the eddy radius. A satellite track can be considered as a straight line in the vicinity of the eddy center of the form $y = ax + b$. By simple algebra, it can be shown that the SLA has a Gaussian profile along the altimeter track of the form:

$$\zeta_{tr}(y) = \zeta_1 \exp(-(y-y_1)^2/(2r_1^2)) \quad (2)$$

where

$$r_1 = r / \sqrt{1+a^2} \quad (3)$$

$$y_1 = \frac{a(x_0-b)+y_0}{1+a^2} \quad (4)$$

$$\zeta_1 = \zeta_0 \exp(-\frac{(ay_0 - x_0 + b)^2}{2r^2(1+a^2)}) \quad (5)$$

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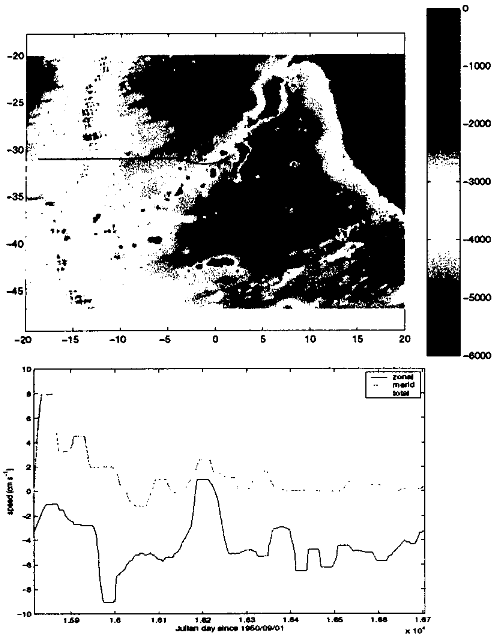

Fig. 1: (Top) Trajectory of the studied eddy determined from altimeter data. The color scale represents the bottom topography; (bottom) Moving speed of the eddy center. Zonal: blue line, meridian: red line, total: black line.

For each altimeter track, r_i and ζ_1 are estimated by least square fitting and the eddy amplitude ζ_0 and radius r are computed by inversion of (4) and (5) . The set of parameters obtained is then used to refine the eddy trajectory

For each segment of the trajectory for which the ring amplitude and radius are almost constant, the median and rms field of the SLA is computed in the frame of reference following the center trajectory. This allows, firstly to test the consistency and the accuracy of the trajectory and of the ring characteristics, secondly to obtain an estimate of the ring bidimensional structure

RESULTS

Fig. 1 presents the trajectory and moving speed of one of the Aghullas rings detected during a WOCE campaign [2]. This trajectory is determined from altimeter data analysis from April 1993 to September 1995. Several aspects of the eddy dynamics can be seen on Fig. 1, such as the influence of the bottom topography. The radius and amplitude of the eddy estimated from the analysis of 135 ERS and TOPEX/Poseidon altimeter tracks are presented in Fig. 2.

After its shedding from Aghullas retroflection, the eddy crosses the Aghullas ridge using a quite deep passage, then,

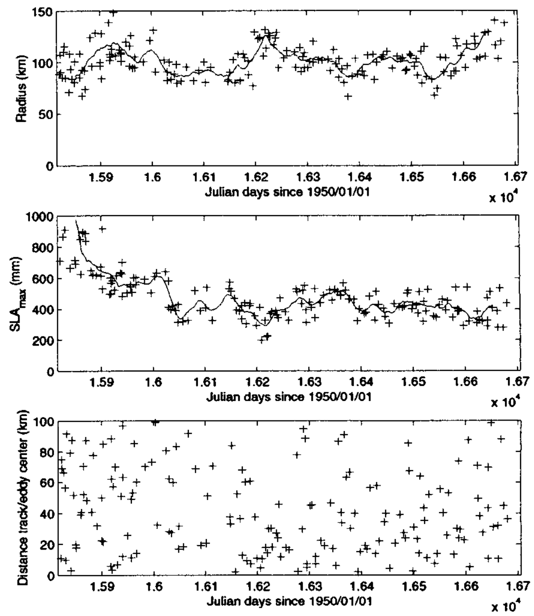

Figure 2: Eddy radius (top), amplitude (middle) and distance between the altimeter track and eddy center estimated from the ERS and TOPEX/Poseidon along track SLA data.

it moves north-westwards following quite remarkably the bottom topography. It is then advected by the subtropical gyre towards the Wallis ridge. Approaching the ridge, it turns abruptly to find a deeper passage within this complex topography [5]. The bottom topography strongly controls this part of the eddy trajectory [6], except during the zonal advection by the gyre where the topography is almost flat and where the eddy has a non negligible barotropic component [7]. Pass the Wallis ridge, the eddy follows an almost purely zonal trajectory until 18°W where it reaches the mid-Atlantic ridge. During the almost three year period, the radius is quite remarkably constant around 100 km. The amplitude rapidly declines in 2-3 month from ~1 m after the shedding to 0.4-0.5 m and remains quite constant. Thus, after a strong diffusion while following the South-West African Coast, the eddy remains almost unchanged (at least in surface) during more than 2 years.

The track has been divided into segments during which the eddy characteristics can be considered as constant. Fig. 3 presents the median of the eddy SLA for the last segment of the track (Sept. 1994 to Sept. 1995) as well as the rms of the SLA. The small values of the SLA rms (<5cm) near the center and the good centering of the median show the coherence of the eddy , the good consistency of the altimeter data and the good quality if the eddy center trajectory.

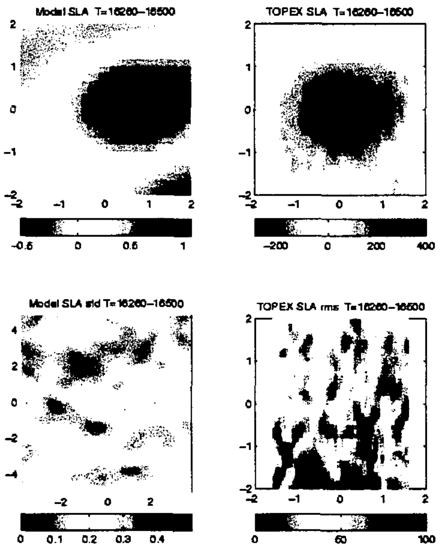

Figure 3: Median (top) and rms (bottom) of the sea level anomaly for the LEGI model (left) and altimeter data (right) in the moving frame of reference defined by the eddy center track for Sept. 1994 to Sept. 1995.

For each part of the trajectory, the bidimensional structure can thus be determined. This allows the study of the temporal evolution of the eddy which could give an new insight of the flux between the Indian Ocean and South Atlantic.

The eddy track can further be used to test the ability of numerical ocean circulation models to reproduce the eddy dynamics. The LEGI model [8] used in this study is a 4 layers quasi-geostrophic eddy resolving ocean circulation model of 1/6° resolution. The TOPEX/Poseidon and ERS dynamic height are assimilated using a simple nudging method presented in details in [8]. It should be noted that the reference level used in the model (mean sea surface estimated from the model) and the one used for the SLA are different, the comparison between the model and altimeter data is thus only qualitative. The median and rms of the model SLA in the frame of reference following the eddy center for the last segment of the track are also presented in Fig. 3. The agreement between the two median fields is good showing that the model reproduces quite well the eddy dynamics and displacement. However, the eddy center is misplaced by 0.7°. This might result from the tendency of the model to position the eddy center on the observed maximum SLA along a track or from the nudging method of assimilation. The smearing of the eddy to the East shows that the displacement speed of the eddy is underestimated within the model.

CONCLUSION

This analysis of one Aghullas eddy shows that the determination of the eddy trajectory and bidimensionnal structure is possible from the analysis of along track variation of the SLA measured by two altimeters. The trajectory is precise enough to clearly reveal the influence of bottom topography on the eddy dynamics. The trajectory of the eddy center and the estimate of the eddy radius and amplitude from the along track analysis are used to define periods during which the eddy characteristics are constant. The eddy structure is estimated by mapping the SLA in the moving frame of reference defined by the eddy center. The analysis of the median and rms of the SLA fields obtained shows that the eddy is remarkably coherent over long periods of time. This analysis can be refined in some regions (near seamounts for example) to study the influence of bottom topography on the eddy structure. The variation of the eddy characteristics estimated from the along track analysis shows an eddy flattening near seamounts. The eddy trajectory can be further used to analyze the results of ocean numerical models. The LEGI QG eddy resolving model which assimilates ERS and TOPEX/Poseidon dynamic height data reproduces quite well the eddy dynamics. However, the eddy center can be displaced by 100 km and some complex pattern of the trajectory near seamounts are not fully reproduced.

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