Agulhas 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 improve our knowledge of the ocean circulation. Satellite altimeter data are used to detect, track and analyze the strong anti-cyclonic eddies generated by the Agulhas retroflection. These rings have a long lifetime and can cross the entire South Atlantic basin. They could play a key role in the exchanges between the Indian and South Atlantic oceans. Using a Gaussian eddy model and the smooth variation of eddy propagation speed, a method has been developed, based on an along track analysis of 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. An Agulhas rings; detected during a WOCE campaign is studied. Its trajectory, its structure and its evolution are presented.

Keywords: altimetry, anticyclonic rings, trajectory, bidimensional structure

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 improve our general knowledge of the ocean general circulation. The Agulhas current is the major western boundary current in the southern hemisphere. It flows along the coast of South Africa, and then meanders while approaching the Cape of Good Hope. The current executes a rather abrupt anti-cyclonic turn (referred as the Agulhas 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 β 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 Agulhas 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]. This particular eddy had a time life of more than 4 years and crossed the entire South Atlantic basin. Its bidimensional structure and its time evolution are presented.

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

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

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

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

For each altimeter track, r_1 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 from this analysis is then used to iteratively 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 testing the consistency and the accuracy of the trajectory and of the ring characteristics, secondly to obtain an estimate of the ring bidimensional structure

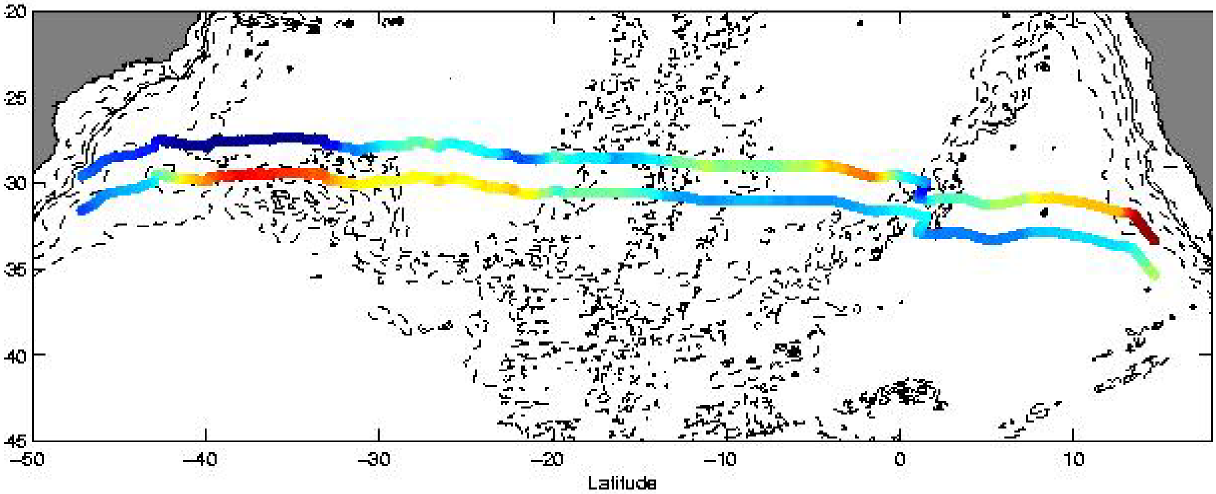

Fig.1: Trajectory of the studied eddy determined from altimeter data. The bottom topography is represented by dashed lines. The southern line represents the eddy trajectory with the eddy radius color-coded (blue-small to red-large), the eddy amplitude is color-coded over the northern line (displaced 2° North).

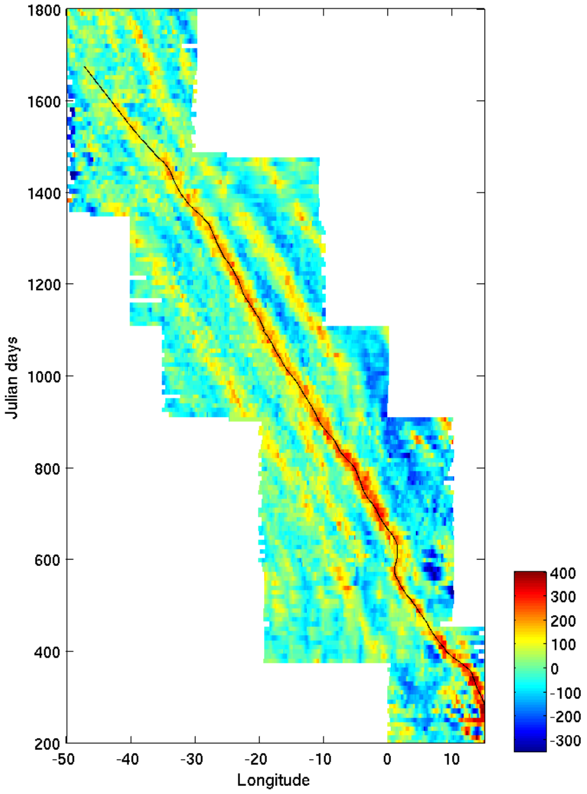

Figure 2: Time/longitude SLA diagram in a 1° latitude band following the eddy center.

RESULTS

Fig. 1 presents the trajectory of the Agulhas rings detected during a WOCE campaign [2]. This trajectory is determined from altimeter data analysis from April 1993 to October 1997. During this more than 4 years period the ring shedded in April 1993 from the Agulhas current retroflection cross this entire South Atlantic basin. It appears to remarkably conserve its structure. 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 450 ERS1n ERS-2 and TOPEX/Poseidon altimeter tracks are presented in Fig. 3.

After its shedding from Agulhas retroflection, the eddy crosses the Agulhas ridge using a quite deep passage, then, it moves northwestwards 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. Although the ridge is deeper than 2000 m, the trajectory is still slightly deflected to the North toward a deeper passage. Pass the ridge, the trajectory is again almost purely zonal until the Rio Grande ridge. This ridge has a complex pattern and culminates at –683 m. The eddy turns around the deeper eastern part of the ridge then hit the main seamount where it almost split into two eddies. It then regains some coherence before being absorbed near 47°W by the Brazil Current.

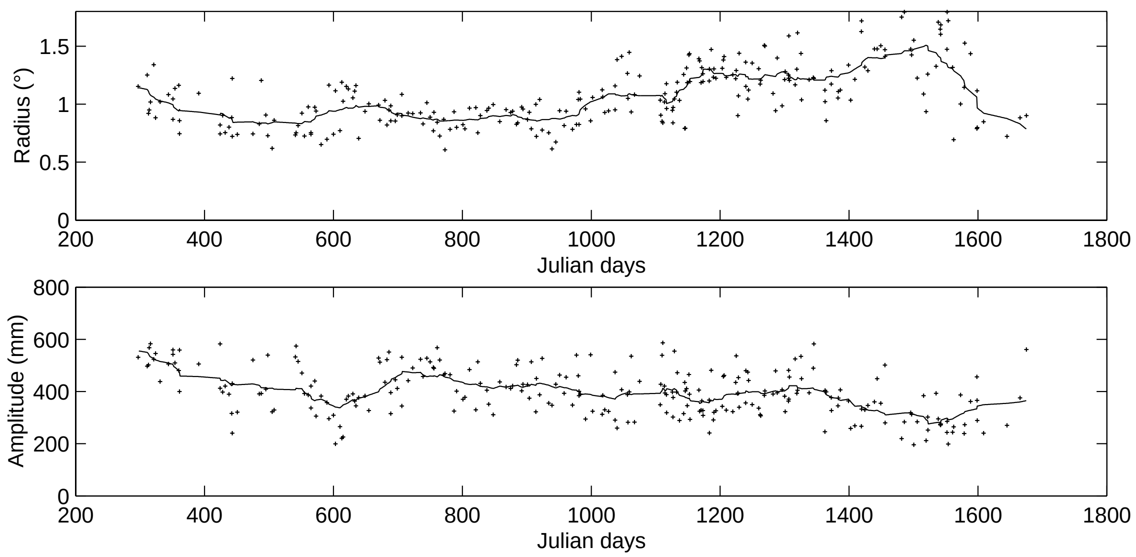

Figure 3: Eddy radius (top), amplitude (middle) estimated from the ERS and TOPEX/Poseidon along track SLA data

During its longer than 4 year lifetime, the eddy remains remarkably stable as it can be seen in fig. 2 which presents the time and zonal evolution of the Sea Level Anomaly in a 1° latitude band following the eddy center. This coherence makes this type of eddy one of the more coherent structures in the world ocean.

The eddy radius, after a rapid decline during the first 2 month after shedding is almost constant around 100 km for 2 years (until the eddy reaches the mid-Atlantic ridge (MAR)). It then slowly increases to reaches 150 km near the Rio Grande ridge (RGR).

The amplitude rapidly declines in 2-3 month from ~1 m after the shedding to 0.4-0.5 m and remains quite constant around 40 cm until the MAR, it then slowly decreases to 20 cm near the RGR. Thus, after a strong diffusion while following the Southwest African Coast, the eddy remains almost unchanged (at least in surface) during more than 2 years until the MAR it then slowly losses its rotation speed and slowly diffused before being almost destroyed by hitting the RAR and being absorbed by the Brazil Current.

A detailed analysis of the eddy track and characteristics reveals interesting features of eddy-topography interactions which should be studied in details. For example, when turning around some of the Wallis seamounts, the eddy displacement speed decreases whilst its radius increases and its amplitude decreases.

Following this along track analysis, the eddy trajectory has been divided into segments for which the eddy characteristics can be considered as constant. Eight segments have been identified. They correspond to the initial period (first 2 months) during which the eddy follows the South-West Africa, the East basin until the Wallis ridge, the Wallis ridge zone, the East basin from Wallis to the MAR, the MAR, from the MAR to the RGR, the eastern RGR, above the RGR. Fig. 4 presents the median of the eddy SLA for the eight segments 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.

Table 1 presents the parameters of the Gaussian fit to the mean profile as well as the maximum speed within the eddy.

Table 1 = Eddy characteristics for the 8 segments of the trajectory

segment	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Radius (°)	0.80	0.59	0.85	0.84	0.98	0.90	0.94	1.45
Ampl (m)	0.45	0.33	0.24	0.33	0.26	0.29	0.25	0.18
V (m/s)	0.46	0.39	0.23	0.28	0.22	0.22	0.19	0.16

Because of averaging the values of the radius and amplitude are smaller than the ones obtained from the along track analysis. However the relative variations are similar. The radius slowly increases with time, except for small period of strong eddy – topography interaction. For segment 4, corresponding to the Wallis ridge crossing the speed of rotation increases while the radius decreases and the amplitude increases.

For each part of the trajectory, the bidimensional structure (at least for the surface signature) can thus be precisely determined. Compared to mean SLA fields the structure of the eddy is better reproduced because the averaging process is conducted in a frame of reference moving with the eddy. During a 10 day period typically used to estimate mean SLA field this particular eddy moves in general by more than 40-50 km, i.e. more than its solid rotation core. This implies that although the eddy can easily be detected its structure will be strongly smoothed out. Its trajectory can also not be precisely defined from mean fields in particular in region of strong eddy-topography interactions.

CONCLUSION

This analysis of one Agulhas 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 (three) 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). The variation of the eddy characteristics estimated from the along track analysis clearly reveals strong eddy-topography interactions that should be analyzed in details. The eddy trajectory could also be further used to analyze the results of ocean numerical models.

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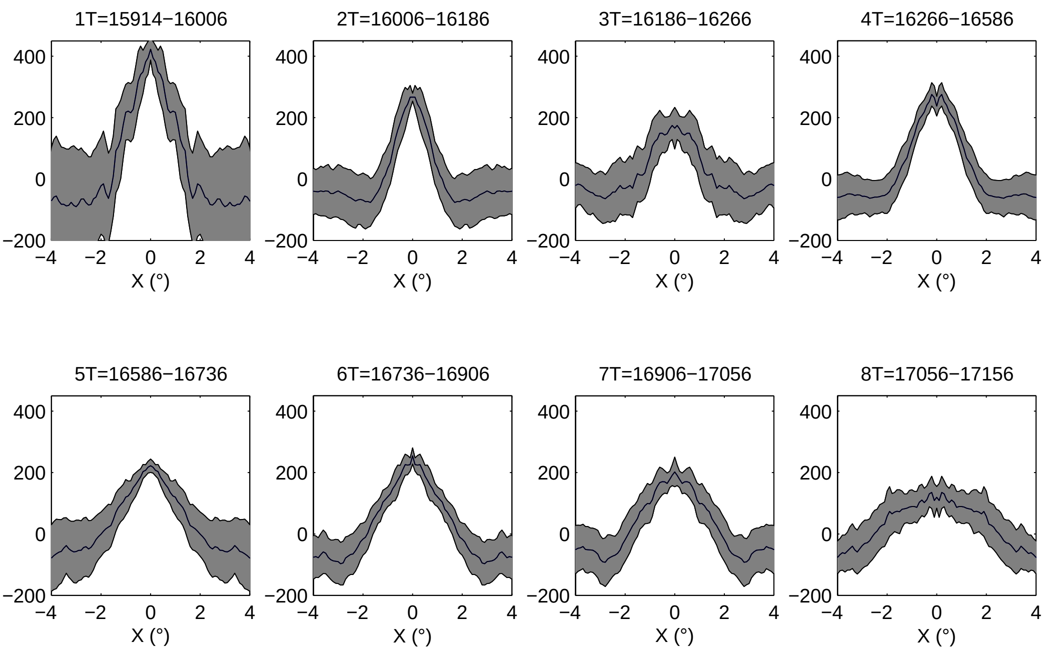

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Figure 4 : Mean (radially averaged) profile of the eddy for the 8 different segments of the trajectory (see text). The shaded area represents +-1 rms around the mean profile.