# Divergent Pathways of anticyclonic and cyclonic ocean eddies

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## The Study

5 years of satellite altimetry data are used to study the propagation pathways of warm and cold ocean eddies in different ocean basins. We track eddies with a life span longer than 3 months, and we present three regional studies : in the southeast Indian, the southeast Atlantic, and the northeast Pacific Oceans. Under certain conditions, **anticyclonic** eddies propagate westward and **equatorward**; **cyclonic** eddies propagate westward and **poleward**.

## Defining cyclones and anticyclones

We track the A/C and C eddy cores using the 10-day T/P+ERS gridded data (DUACS). Following *Isern-Fontanet et al.* [2003], we define the eddy cores as regions in which the second invariant of the velocity gradient tensor is positive. We can express this in terms of a parameter, $Q$, :

$$Q = -\left(\frac{\partial u}{\partial x}\right)^2 - \left(\frac{\partial v}{\partial x}\right)\left(\frac{\partial u}{\partial y}\right) > 0$$

which is based on the 2D velocity field, ($u$,$v$) derived from the altimeter SLA maps assuming the geostrophic approximation. A vortex exists in regions where $Q$ is positive and large, $Q > Q_0$. $Q_0$ is set at 2.5 x $10^{-11} s^{-1}$ in the Agulhas region where the eddy energy is highest, and 1 x $10^{-11} s^{-1}$ elsewhere.

## Tracking the eddies in each basin

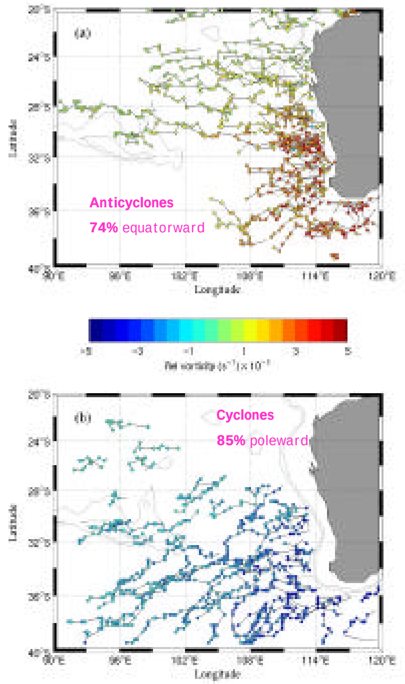
We developed an automatic tracking technique to monitor the eddy propagation. All eddies with $Q > Q_0$ and $|SLA| > H_0$ are identified in the initial map at time, $t_0$. We then search for the same eddy structure within a spatial radius, $R$, around our initial eddy position in the next map at time $t_0$+10 days. The final values for $Q_0$ and $H_0$ are summarized in Table 1 for our three case studies. The minimum eddy lifetime is > 90 days and > 120 days in the Agulhas. Sometimes eddies "disappear" in the gaps between groundtracks, To minimize this problem we keep searching for each eddy for 20 days after it "disappears".

**Table 1 : Selection criteria applied in the 3 study regions**

| Region | SE Indian | | SE Atlantic | | NE Pacific | |
|---|---|---|---|---|---|---|
| Rotation | A/C | Cyc | A/C | Cyc | A/C | Cyc |
| $Q_0$ ($10^{-11} s^{-2}$) | 1 | | 2.5 | | 1 | |
| $H_0$ (cm) | 20 | -20 | 30 | -25 | 8 | -8 |

## Case 1 : Southeast Indian Ocean :

high eddy energy, weak background flow, no bathymetric steering across deep Perth Basin

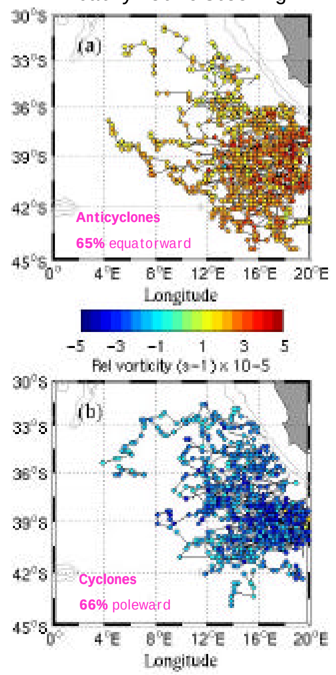



South of 25°S, 74% of the anti-cyclonic eddies tend WNW as they pass across the Perth Basin and are then channeled around the bathymetry west of 105°E. Their mean westward speed is 2.6 km/day, with a weak equatorward speed of 0.4 km/day. North of 25°S, their propagation is mainly zonal, and the SLA signal is dominated by Rossby waves [*Birol and Morrow, 2003*].

Cyclonic propagation is more distinctive; 84% show a clear poleward propagation, with faster meridional speeds (mean of 0.8 km/day) than for the anticyclones

## Case 2 : Southeast Atlantic Ocean :

high eddy energy, complex background flow and eddy interactions, some bathymetric steering

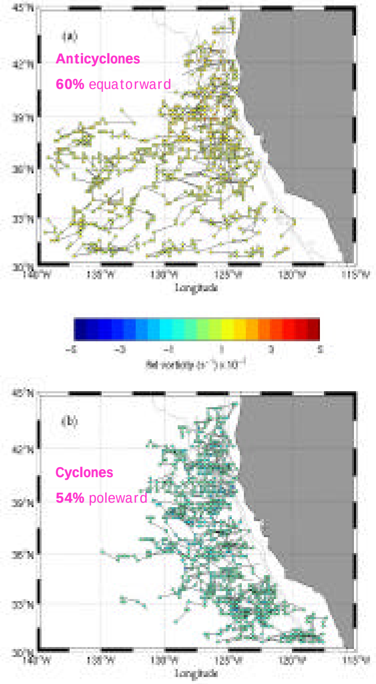



65% of the anticyclones propagate equatorward with meridional speeds around 0.2 km/day and 66% of the cyclones propagate poleward at 0.3 km/day.

Boebel et al. (2003) also studied cyclonic versus anticyclonic propagation using altimetry and RAFOS floats from 1997-1999, using a different tracking criteria. They identified 43 cyclones, with a mean poleward propagation of 0.3 km/day, with fewer, larger anticyclones (29) with a mean equatorward speed of 1.1 km/day. The different selection criteria and time periods of the two studies lead to slightly different propagation statistics, but both show consistent divergence in the eddy pathways.

## Case 3 : Northeast Pacific Ocean :

low eddy energy, weak background flow, little bathymetric steering



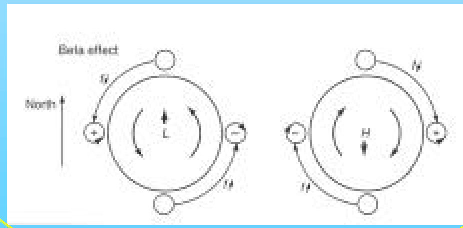

Cyclonic eddies decay below the 8 cm level within 1000 km of the coast, with no clear poleward propagation. In contrast, the anti-cyclonic eddies have a longer lifespan, propagate much farther west, and 60% have a clear equatorward propagation at 0.4 km/day.

## What causes this divergence in the eddy pathways?

- eddies have relatively large diameters > 100 km
- the β-effect influences their rotation.

The rotating eddies advect the surrounding fluid in the same direction : the surrounding fluid changes latitude and planetary vorticity, $f$, which induces small anticyclonic and cyclonic vortices on the flanks of the large vortex. These small secondary vortices combine with the large vortex to cause the drift as indicated in Figure 4,

***Figure 4.*** The different sign of relative vorticity on each flank of the eddy pushes a cyclonic eddy poleward, and an anticyclonic eddy equatorward, after *Cushman-Roisin* [*1994*].




## Conclusions

- Favourable conditions for observing these divergent eddy pathways are : **strong eddies** (tracked over long periods), **weak background flow and no bathymetric steering.**
- The reason why the SE Indian eddies have such a strong divergence is not clear.
- These divergent pathways of warm and cold ocean eddies may have repercussions on the global heat, salt and tracer budgets.
- Further studies are required to quantify whether divergent eddy transport in the eastern boundary regions provides a counter-balance to the poleward heat transport of the western boundary currents.

***References :***

Birol, F., and R., Morrow, Separation of quasi-semiannual Rossby waves from the eastern boundary of the Indian Ocean, *J. Mar. Res.*, 61, 707-723, 2003.,

Morrow et al., Divergent pathways of cyclonic and anti-cyclonic ocean eddies, *Geophys. Res. Lett.*, in press, 2004.

Boebel, O., et al. (2003), The Cape Cauldron : a regime of turbulent inter-ocean exchange. *Deep Sea Res. II*, *50*, 57-86.

Cushman-Roisin, B. (1994), *Introduction to geophysical fluid dynamics*. Prentice-Hall.