# Eddies and Chlorophyll in the Southern Ocean

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## Introduction

**Motivation:** The Southern Ocean (SO) is a region of intense mesoscale eddy activity (Fig.1). Eddies may impact phytoplankton by changing environmental conditions, such as nutrient and light availability or phytoplankton-grazer encounter rates e.g. by up- and downwelling and horizontal transport [1]. Our focus is on the contribution of these biophysical interactions to the total phytoplankton biomass and subsequently to carbon fluxes in the SO.

### Objective:

? **Do we see an effect of eddies on phytoplankton distribution in the SO? What is the contribution of eddies to the total phytoplankton biomass?**

## Data

### Satellite data for the period 1997 – 2010:

- Eddies were detected from **AVISO** [2] sea level anomalies (**SLA**, 1/3°, 7days);
- **GlobColour** [3] chlorophyll-a (**CHL-a**, 1/4°, 8days) was used as a proxy for phytoplankton biomass.

## Methods

### Eddy detection:

- Eddy where vorticity is greater than strain (see box);
- (Anti)cyclonic eddy: local (maximum)minimum;

**Okubo-Weiss parameter** [4,5]:

$$OW = s_n^2 + s_s^2 - \omega^2$$

With

| | |
|---|---|
| $s_n = u_x - v_y$ | normal strain |
| $s_s = v_x + u_y$ | shear strain |
| $\omega = v_x - u_y$ | relative vorticity |
| $u, v$ | geostrophic velocity components calculated from SLAs |
| subscript $x, y$ | partial derivatives in east- and westward direction, respectively |

**Eddy where** [e.g. 6]: $OW < -0.2\sigma_{OW}$

With $\sigma_{OW}$ spatial standard deviation of $OW$.

### Eddy tracking:

- Advection assumed: search ellipse for eddy in next time step using ocean current climatology **SODA** [7];
- If more than one eddy found in search ellipse, eddy matched with 'most similar eddy' (judged on amplitude and diameter).

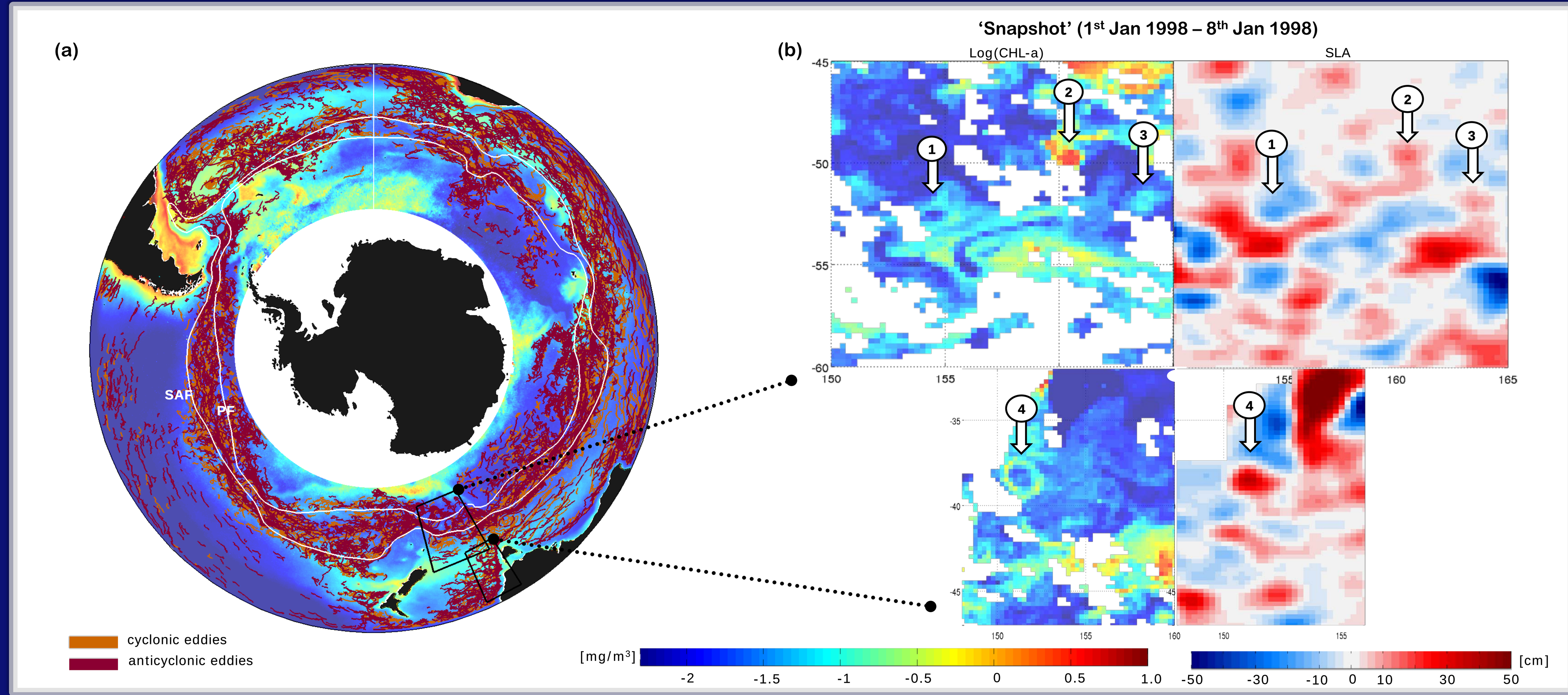


**Figure 1:** **(a)** Tracks of cyclonic (orange) and anticyclonic (red) eddies with life spans of 3 to 9 months plotted on top of the natural logarithm of the mean annual CHL-a (climatology of 1997 – 2010); the white lines mark the two main fronts of the SO, the Polar (PF) and the Subantarctic (SAF) Fronts, which comprise most of the transport of the Antactic Circumpolar Current (ACC); eddies frequently develop from instabilites of the ACC; the two black boxes denote the domains shown in **(b):** 'snapshots' (8-day period) of again Log(CHL-a) and the associated field of SLA; four examples where eddies show a signal in CHL-a are marked with arrows.

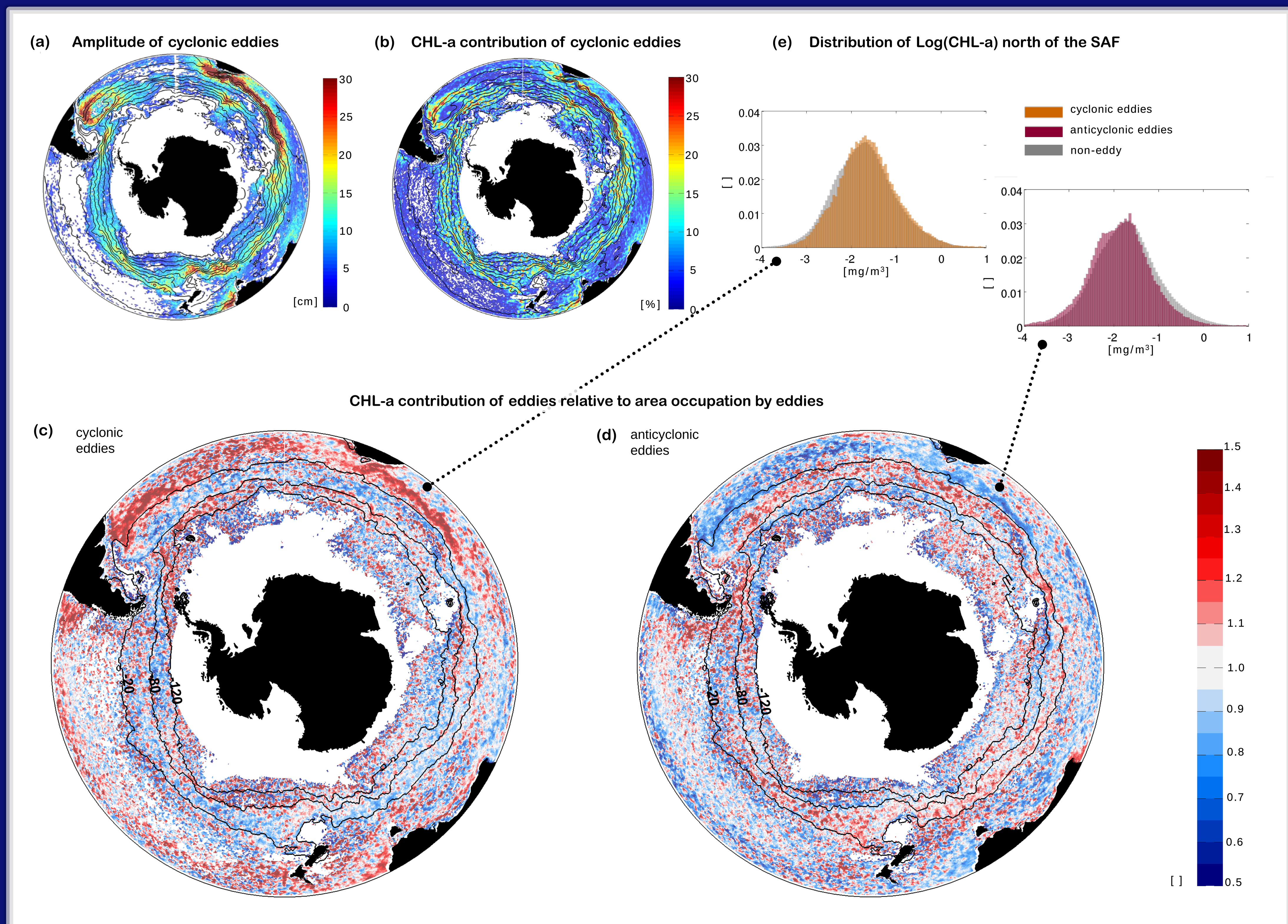


**Figure 2:** Time mean (1997 - 2010) **(a)** amplitude of cyclonic eddies; **(b)** contribution of cyclonic eddies to the total CHL-a; (a) and (b) exhibit a similar pattern for anticyclonic eddies (not shown); sea surface height (SSH)-contours (10 cm intervals) overlain in black;
Time mean (1997 – 2010) CHL-a contribution of eddies to total CHL-a [%] relative to area occupation by eddies [%] for **(c)** cyclonic and **(d)** anticyclonic eddies; selected SSH contours shown in black; **(e)** Log(CHL-a) distribution (normalized) for the area north of the SSH = -20 cm contour (approximately north of the SAF) for cyclonic and anticyclonic eddies as well as for the non-eddy CHL-a.

## Conclusions

### Summary:

! **Eddies have an effect on phytoplankton distribution in the SO (CHL-a anomalies up to 30 %), however, the impact can be both enhancing and inhibiting. Eddies contribute a substantial fraction (up to 40 %) to the total phytoplankton biomass.**

### Perspective:

Following this descriptive work, we plan to determine

1. the processes causing the impact of eddies on phytoplankton, and
2. the carbon fluxes resulting from this impact.

## Results

- **Over 120 000 eddies** were detected and tracked; nearly $^1/_3$ of the eddies existed for 1 month or more; average **amplitudes** and **diameters** of eddies in the **ACC** are **10-20 cm** and **100 km** respectively (Fig. 2a) and eddies may exist for more than 1 year; eddies occupy most of the ACC 20 – 40 % of the time (not shown);
- **Contribution** of (anti)cyclonic eddies **to the total CHL-a**:
  20 % in most of the ACC and 40 % in regions where eddies are largest (>200 km) and most intense (> 50 cm) (Fig. 2b);
- Eddies show a **CHL-a anomaly compared to the non-eddy background**:
  Cyclonic eddies show enhanced CHL-a e.g. north of the SAF, whereas they show suppressed CHL-a south of it (partly more than 30 %, Fig. 2c); accordingly, the distribution of absolute CHL-a e.g. north of the SAF shows a shift towards higher values for cyclonic and towards lower values for anticyclonic eddies relative to the non-eddy CHL-a (Fig. 2e).
- The effect of anticyclonic eddies shows a similar spatial pattern as the one of cyclonic eddies but of opposite sign mainly, thus **cyclonic eddies offset** the effect on phytoplankton distribution of **anticyclonic** eddies (Fig. 2d).

**References**: [1] Lévy, M. (2008). The modulation of biological production by oceanic mesoscale turbulence. *Lecture Notes in Physics.*, 744:219-261; [2] The altimeter products were produced by Ssalto/Duacs and distributed by **Aviso**, with support from **Cnes**: http://www.aviso.oceanobs.com/duacs/; [3] **GlobColour** Project: http://www.globcolour.info/; [4] Okubo, A. (1970). Horizontal dispersion of floatable particles in the vicinity of velocity singularities such as convergences. *Deep-Sea Res.*, 17:445-454; [5] Weiss, J. (1991). The dynamics of enstrophy transfer in two-dimensional hydrodynamics. *Physica D: Nonlinear Phen.*, 48:273-294; [6] D'Ovidio, F. et al (2009). Comparison between Eulerian diagnostics and finite-size Lyapunov exponents computed from altimetry in the Algerian basin. *Deep-Sea Res.*, 56:15-31; [7] Carton, J. A. and B. S. Giese (2008). A reanalysis of ocean climate using Simple Ocean Data Assimilation (**SODA**), *Mon. Weather Rev.*, 136, 2999-3017.