Birth, life and death of a cyclonic eddy in the Southern Ocean

PML Plymouth Marine Laboratory

SMILES PROJECT

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Introduction

The ACC is a climatically relevant frontal structure of global importance that regularly develops instabilities which grow into meanders that eventually evolve into long-lived cyclonic eddies. These eddies exhibit sustain primary productivity that can last several months fuelled by local resupply of nutrients. During April-May 2015 we conducted an intensive field experiment in the Southern Ocean (SMILES) where we sampled and tracked an ACC meander as it developed into an eddy and later vanished some 90 days later. The meander and later eddy physical characteristics were observed with a combination of high resolution hydrography, ADCP and turbulence observations in addition to surface and depth resolved biogeochemical observations of nutrients and phytoplankton. The life and death of the eddy was subsequently tracked through ARGO, BIO-ARGO and remote sensing.

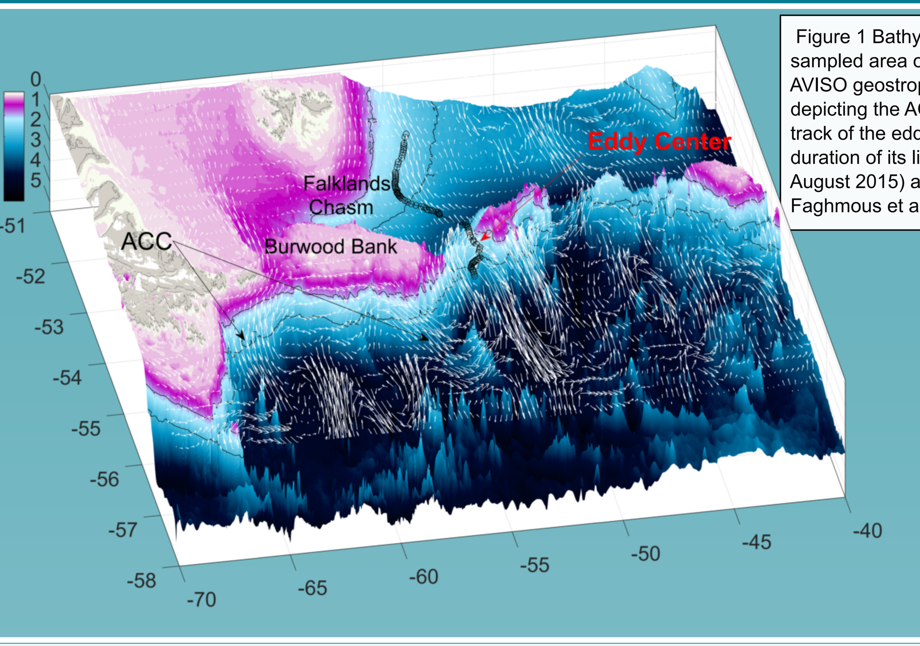


Figure 1 Bathymetry of the sampled area overlaid with the AVISO geostrophic currents depicting the ACC frontal jet. The track of the eddy center for the duration of its life (7 May to 7 August 2015) as estimated with Faghmous et al 2015 algorithm.

Background

On May 2015 an evolving meander of the ACC was sampled with a combination of ship observations and drifters. During the cruise (8 to 19 May), the 40km structure evolved into a drifting eddy that moved north west towards an opening in the Falklands ridge. At the initial time of the eddy formation the structure had associated surface frontal currents in excess of 1.1m/s. The cross section structure showed typical uplifting of fileds in the eddy center. The eddy drifted with a speed of roughly 5km/day. Before the eddy crossed the ridge the rotation period was 3 days as observed with surface drifters. The ARGO floats, which drift at a nominal depth of 1000m took an estimated 5 days to complete one rotation.

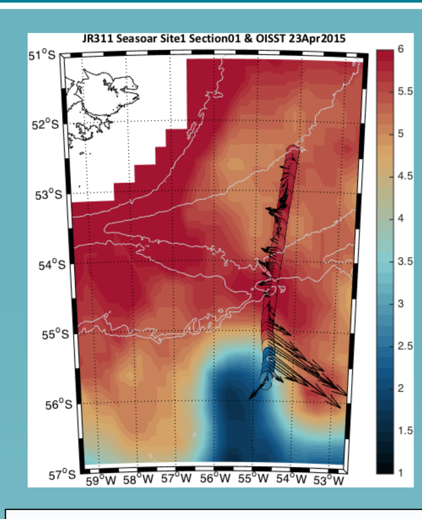


Figure 2 OISST product for 23 April showing the ACC front overlaid with the underway ADCP currents at 50m and sea surface temperature measured at the underway intake of the ship.

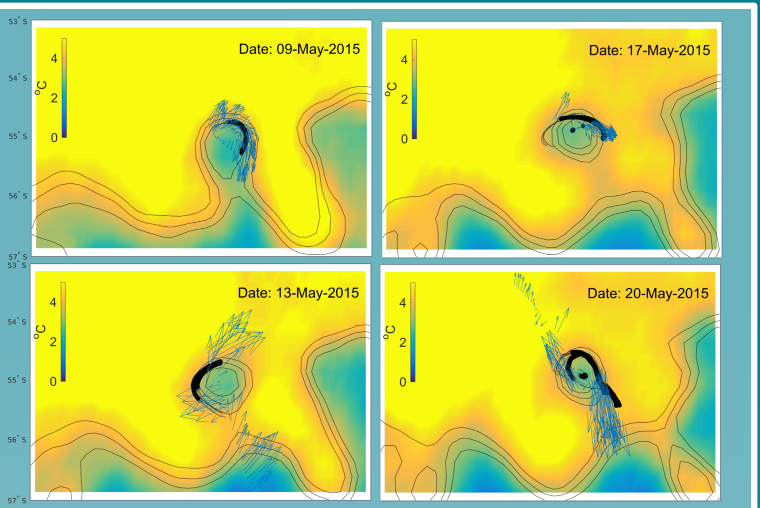


Figure 3 Eddy as identified by AVISO total dynamic sea surface elevation and merged SST data product (OISST) overlaid with ADCP 50m currents and drifter tracks for two days up to the nominal date for the AVISO data.

Eddy structure

The ACC meander was sampled with a combination of SeaSoar underway transects (locations shown in Figure 5) and CTD transects to resolve the 3D structure of this evolving feature in the ACC. Between the 8 and 11 May the structure was still recognisable as an ACC meander. The CTD transect performed on 13-14 May crossed N-S the newly formed Eddy (Figure 4). The eddy was characterised by uplifting of isolines visible to the full depth of the CTD casts (2000m) and sharp horizontal gradients at the eddy boundaries. The eddy core had colder temperatures and fresher salinities than the surrounding waters similar to the characteristics found in the ACC. Equally, chlorophyll-a concentrations were locally higher in the eddy. The core of the ACC was also sampled in the same transect some 150km south from the core of the eddy. In these early stages, the eddy was not symmetric and horizontal gradients were larger on the northern side than in the southern side where the separation process took place.

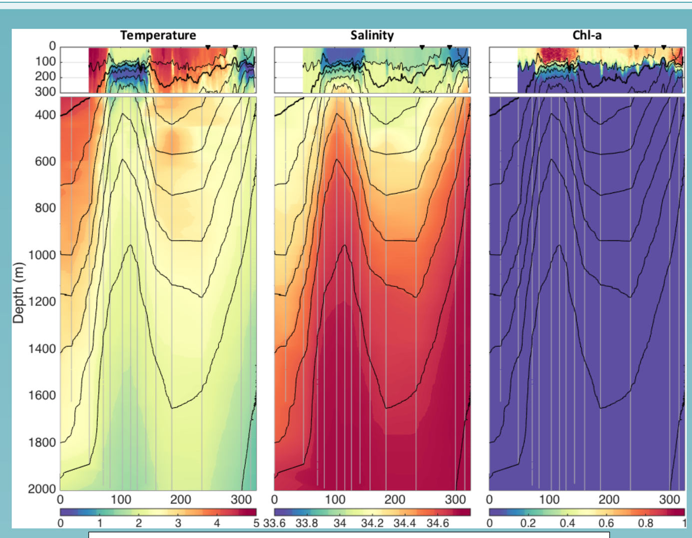


Figure 4. Combined CTD and SeaSoar transect of the newly formed eddy showing the vertical and horizontal distribution of temperature, salinity and chlorophyl.

The area was sampled with 25 underway SeaSoar transects (Figure 5) within a lagrangian frame of reference following a surface drifter drogued at 50m. The transects consistently showed colder temperatures, lower salinities, enhanced chlorophyll-a levels and high oxygen concentrations with sharp fronts occurring over length scales of a few kilometres. The frontal areas had associated along front velocities of 1m/s.

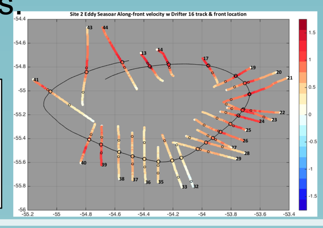


Figure 5. SeaSoar transects and surface Drifter track overlayed with the front position and along front current velocities. Notice the weaker velocities along the southern boundary of the meander.

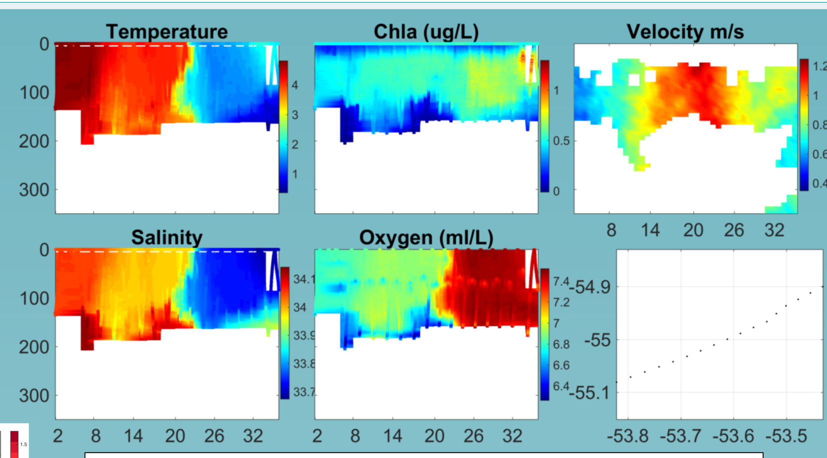


Figure 6: SeaSoar and ADCP transect number 21 with an orientation NorthEast - SouthWest. The inside of the eddy corresponds to the right hand side of the graphs. Enhanced subsurface chlorophyll-a levels are found in the inside of the eddy associated with high levels of oxygen concentrations. Maximum along front velocities coincide with the frontal position in temperature and salinity.

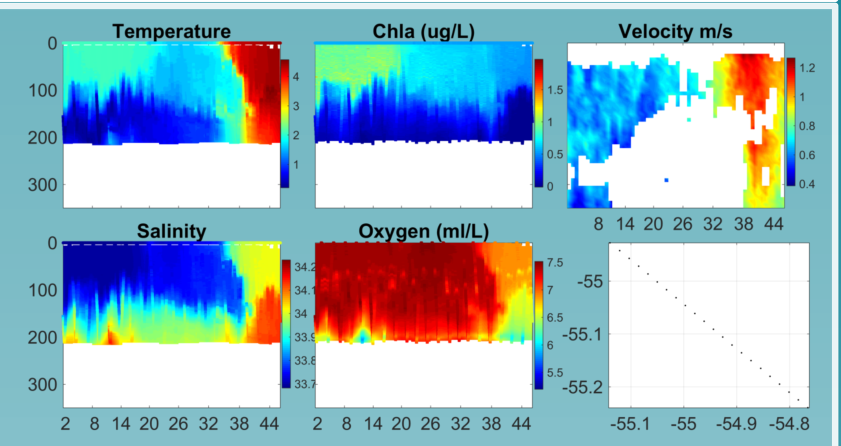


Figure 7: SeaSoar and ADCP transect number 41 with an orientation NorthWest - SouthEast. The inside of the eddy corresponds to the left hand side of the graphs. Enhanced surface chlorophyll-a levels are found in the inside of the eddy associated with high levels of oxygen concentrations. Maximum along front velocities again coincide with the frontal position in temperature and salinity.

Biogeochemical characterisation of eddy/meander

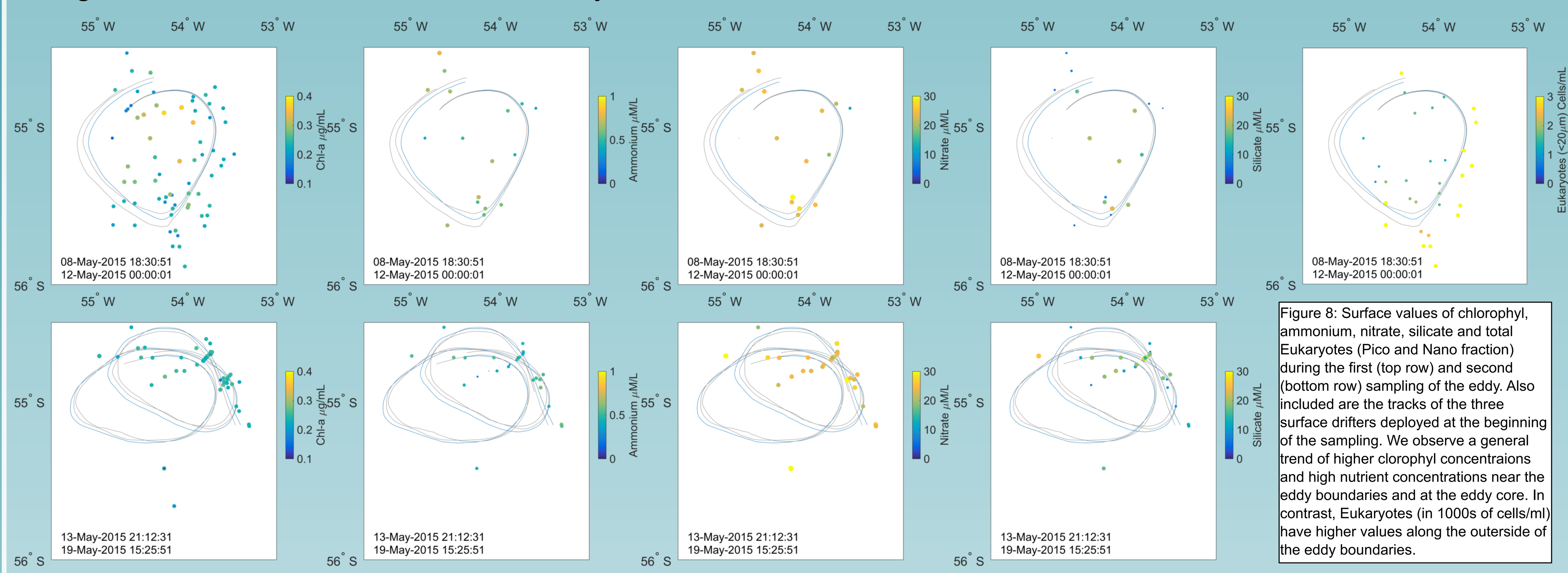


Figure 8: Surface values of chlorophyl, ammonium, nitrate, silicate and total Eukaryotes (Pico and Nano fraction) during the first (top row) and second (bottom row) sampling of the eddy. Also included are the tracks of the three surface drifters deployed at the beginning of the sampling. We observe a general trend of higher clorophyl concentraions and high nutrient concentrations near the eddy boundaries and at the eddy core. In contrast, Eukaryotes (in 1000s of cells/ml) have higher values along the outerside of the eddy boundaries.

Between 8 and 19 May we sampled the eddy, first during its formation stage (top) and subsequently during the NorthEast drift of the eddy. The drifters consistently experienced velocities between 0.8 - 1.3 m/s. While we are still processing the samples from the cruise, initial results indicate the core of the eddy and associated frontal areas had enhanced levels of nutrients and chlorophyll-a although these were not necessarily related to higher concentrations of Eukaryotes estimated as the sum of nano and pico eukaryotes analysed through flowcytometry.

Eddy evolution prior to ridge passage

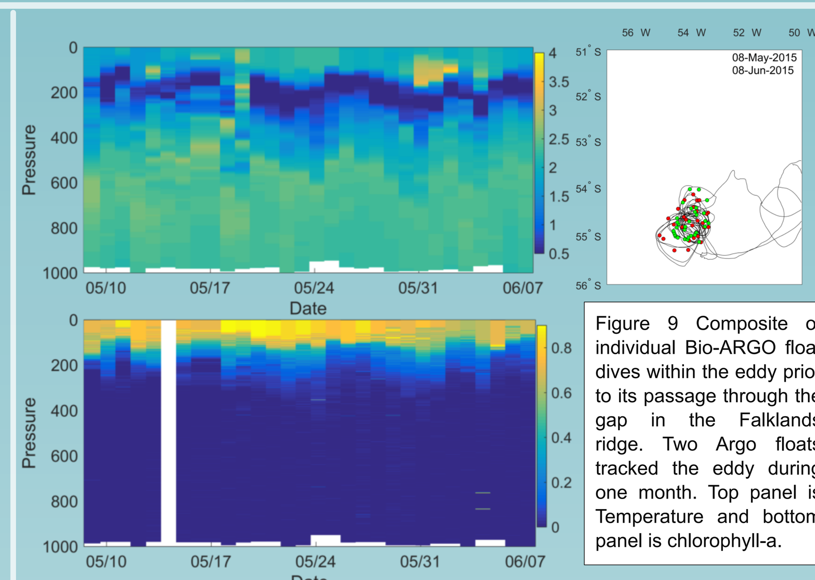


Figure 9 Composite of individual Bio-ARGO float dives within the eddy prior to its passage through the gap in the Falklands ridge. Two Argo floats tracked the eddy during one month. Top panel is Temperature and bottom panel is chlorophyll-a.

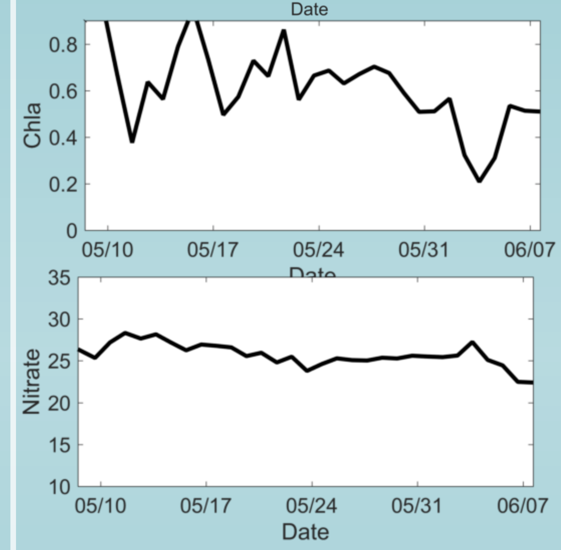


Figure 11 Time evoluation of the top 100m mean of chlorophyll-a and nitrate concentrations during 8-May until 8 June 2015. Both variables show a steady decline with time. Similar trends were observed in backscattering. Temperature showed a steady increase from 1.7C to 2.5 during the same period.

During the first month of the life of the eddy, two Bio-Argo floats sampled the area close to the interior boundaries performing daily profiles from their 1000m nominal drifting depth. The horizontal velicities at this depth were smaller than the observed surface ones which meant the floats took approximately 5 days to perform one eddy revolution instead of 3 days for the surface drifters. A total of 60 profiles were recorded (Figure 9). During this time, the eddy maintained its initial characteristics of surface intensified chlorophyll-a concentrations and a subsurface temperature minimum centred at 200m and extending 75-90m in the vertical (Figures 9 and 10). Initial concentrations of nitrate were similar to those sampled in-situ (~25 micromol/L, Figure 10). During this month, nitrate concentrations diminished and the nutricline deepened. At the same time, the mean chlorophyll-a in the top 100m also decreased (Figure 11) albeit with larger fluctuations than those observed in the nitrate data. The individual profiles suggest that the distribution of the chlorophyll-a maximum became narrower and shallower. A similar trend was observed in the backscatter data (Figure 10).

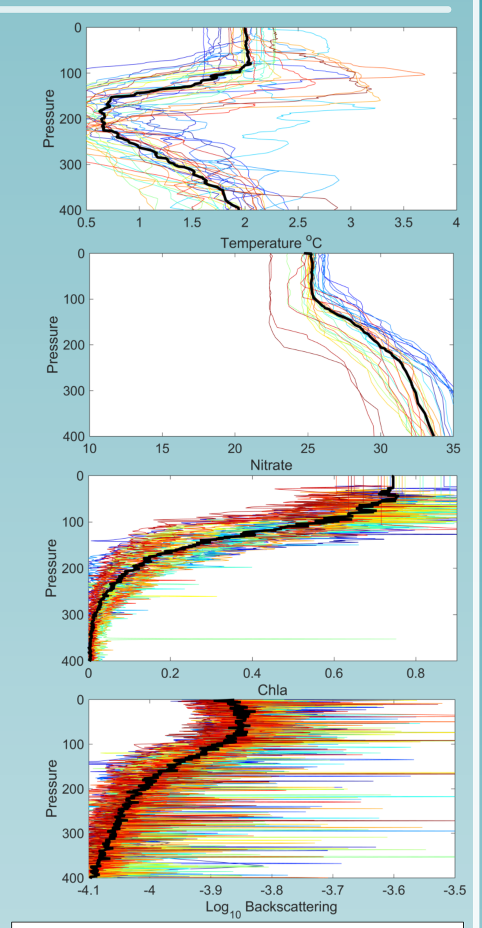
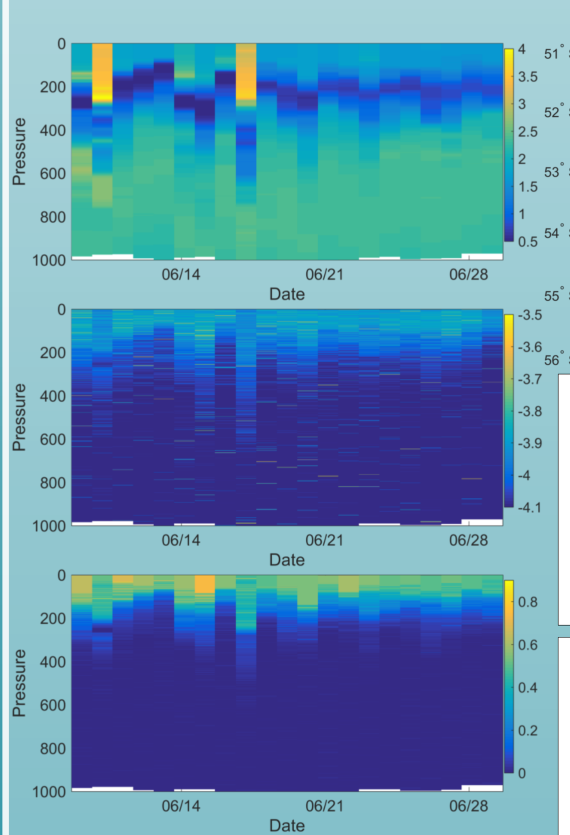


Figure 10 Top 400m of all individual Bio-Argo profiles colorcoded by time since deployment (blue is earlier while red correspond to the last profiles on 8 June). In bold is the averaged from all the individual profiles. Chlorophyll-a and backscattering at 700nm have not been filtered to remove spikes. Only the automated QC have been performed.

Eddy evolution during and inmediatly after the passage through the ridge



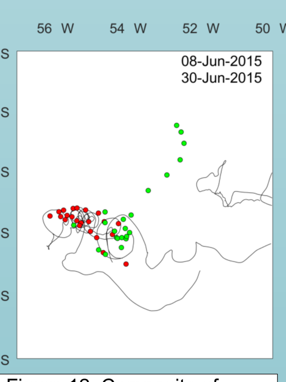
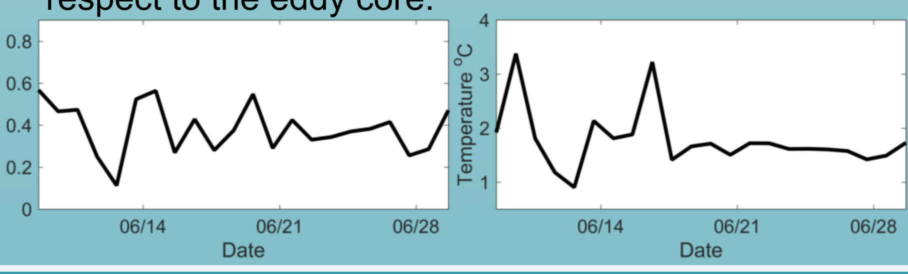


Figure 12. Composite of individual Bio-ARGO float dives within the eddy during and inmediately after its passage through the gap in the Falklands ridge. Top panel is Temperature, middle panel is log10 of backscatter signal at 700nm and bottom panel is chlorophyll-a.

Figure 14. Time evoluation of the top 100m mean of chlorophyll-a concentration and temperature during 8-30 June 2015. Both variables show a small decline with large fluctuations associated to the time of the passage.

The eddy took 4 days to cross the passage astimated to correspond to 11 June until 15 june. The eddy deformed and became briefly elongated. In those days there were significant variations in the vertical distribution of properties (Figure 12) with large oscillations (> 200m) of the subsurface temperature minimum (Figure 13) and strong vertical re-distribution of chlorophyll-a and backscattering fields. One of the floats did leave the eddy (unfortunately it was the one equiped with the nitrate sensor) although it returned to the eddy in July (see next panel). At this stage, it is difficult to assign the strong fluctuations to 1D vertical processes or to shifting of the floats location with respect to the eddy core.



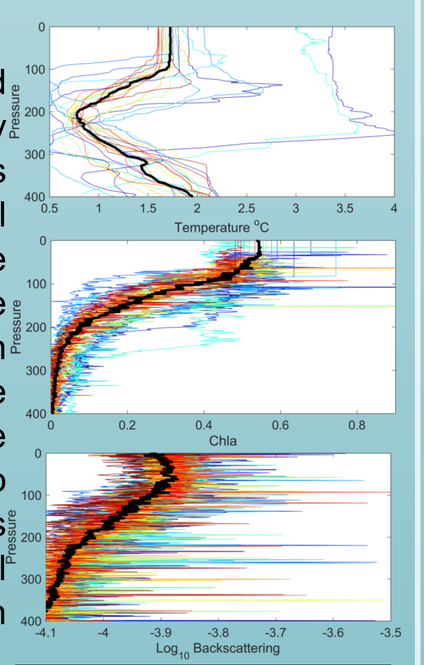


Figure 13 Top 400m of all individual Bio-Argo profiles colorcoded by time since 8 June (blue is earlier while red correspond to the last profiles on 30 June). In bold is the averaged from all the individual profiles. Chlorophyll-a and backscattering at 700nm have not been filtered to remove spikes.

Eddy evolution after the ridge passage

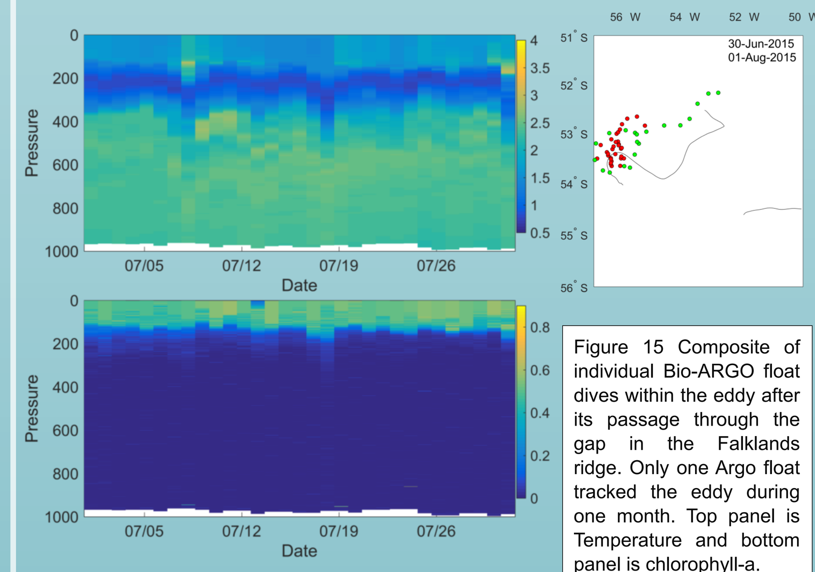


Figure 15 Composite of individual Bio-ARGO float dives within the eddy after its passage through the gap in the Falklands ridge. Only one Argo float tracked the eddy during one month. Top panel is Temperature and bottom panel is chlorophyll-a.

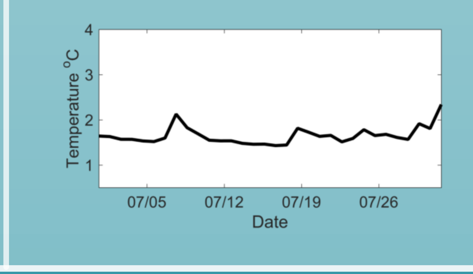


Figure 16. Time evoluation of the top 100m mean of temperature during July 2015. The observed changes are limited in time with little evidence of a constant rate of change in contrast with the observations from June.

After the passage the eddy was tracked for a further month from 30 June until 1 August (Figure 15). During this period only one float remained consistently within the eddy core while the other was briefly incorporated again, although it only sporadically sampled the subsurface temperature minimum and so has been ommitted from this analysis. Although the sampled period was of similar length to the first, the changes observed within the eddy correspond to sudden rather than gradual changes. For example, the temperature minima significantly broadened and became deeper than in the previous periods (Figure 16). Changes in the top 100m mean values where punctual in time with little evidence of a trend in either temperature or chlorophyll-a. The presence of a wider mixed layer corresponded to a narrower thermocline and a more abrupt attenuation of chlorophyll-a and backscattering values than previously observed.

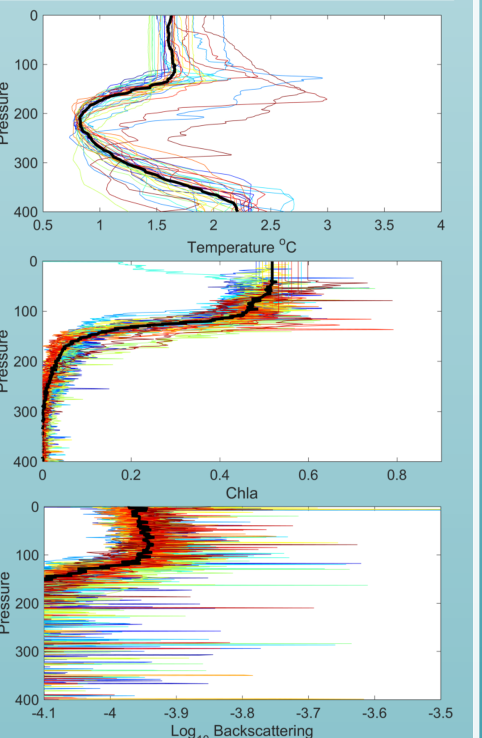
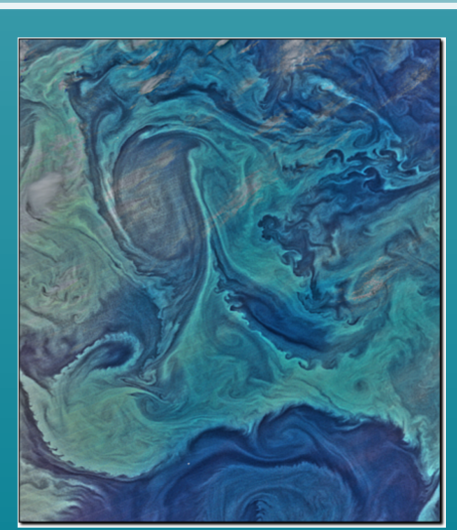


Figure 16 Top 400m of all individual Bio-Argo profiles colorcoded by time since 30 June (blue is earlier while red correspond to the last profiles on 1 August). In bold is the averaged from all the individual profiles. Chlorophyll-a and backscattering at 700nm have not been filtered to remove spikes. Only the automated QC have been performed.

CONCLUSIONS AND FUTURE WORK

We have presented preliminar results from the formation and evolution of a cyclonic eddy originated in the Southern Atlantic region of the ACC. The eddy formed from a meander in the ACC and later drifted away from it for 90 days. The eddy seemed to have a characteristic biogeochemical and hydrographical signature that was still apparent after 90 days. During its evolution, the eddy lost some of its original defining properties, some times in a gradual change, others in response to specific events like the passage of the eddy through a narrow gap in the Faulkland rigdge.

In the next stages of the project, we will finish analysing the rest of the nutrient and flowcytometry data and apply lagrangian approaches to the characterisation of the eddy (.e.g Lumpkin, R. Global characteristics of coherent vortices from surface drifter trajectories Journal of Geophysical Research: Oceans, 2016). Individual float's profiles will be analysed to look for evidence of submesoscale processes at the eddy boundaries.



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References and further information

www.smiles-project.org
PO21A-02 John Taylor, Submesoscale wiggles in the ACC
PO21A-01 Kate Adams, In situ subsmesoscale observations across the ACC during the formation of a mesoscale eddy.
PO21C-02 Megan Stamper

Faghmous, J. H. et al. A daily global mesoscale ocean eddy dataset from satellite altimetry. Sci. Data 2:150028 doi: 10.1038/sdata.2015.28 (2015).

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