GDRI-CROCO Report 2021

Student particulars:
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Degree: PhD Physical Oceanography
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Thesis title:
The life-cycle and fine-scale dynamics of the Durban Eddy.

Project description:
The Agulhas Current is the western boundary current of the Indian Ocean subtropical gyre and the dominant oceanographic feature along the east coast of South Africa. Carrying 76 Sv (1 Sv = $10^6 m^3 s^{-1}$) at 32°S (Gunn et al., 2020), extending to more than 3000 m depth, and showing maximum surface velocities greater than 2 $m.s^{-1}$ (Beal et al., 2015). The fast flowing upstream section (27°S and 34°S) of the Agulhas Current follows the steep and straight continental shelf closely, forming a narrow jet stream that is episodically disrupted by the propagation of Natal pulses (Rouault and Penven, 2011) and solitary meanders (Tedesco et al., 2019) that develops near the Natal Bight (31° 01'E, 29° 51'S, Figure 1). The latter, better known as the Durban Eddy, is a semi-permanent, cyclonic vortex, stuck between the east coast of South Africa and the poleward flowing Agulhas Current. Located at the interface between two very contrasting environments both in terms of their physical (temperature and salinity) and their biogeochemical (nutrients and phytoplankton) properties. This mesoscale eddy (~50 km) strongly influences coastal exchanges and water enrichment processes in the area (Roberts & Nieuwenhuys, 2016). At the coast, a very productive (rich in phytoplankton) environment exists that is characterised by cold waters; whereas in the open ocean an oligotrophic environment exists that is characterised by warmer waters (those of the Agulhas Current). The strong thermal gradients of the Agulhas Current generate instabilities that are fine-scale and extremely intense. Strong horizontal and vertical speeds associated with this turbulence could redistribute nutrients and organic matter horizontally and vertically in the heart of the eddy and around its edges. This highlights the main objective of the CYCLOPS project, which is to better understand the life-cycle and physical characteristics of the Durban Eddy, its coastal enrichment processes and its fine-scale dynamics.

The Scientific questions for this project are:

- What is the life-cycle (generation to decay) of the Durban Eddy?
- What are the water masses trapped within the Durban Eddy?
- What are the coastal exchanges generated by the Durban Eddy?
- What are the fine-scale (< 10 km) dynamics that will emerge from the Durban Eddy?

Tasks during visit:

1. Configure 1 km horizontal grid resolution numerical simulation for the project.
2. Develop the tools for the evaluation of the model.
3. Configure 300 m horizontal grid resolution numerical simulation for the development of the sampling strategy during the RESILIENCE oceanographic campaign.

Results

1. <u>**Configure 1 km horizontal grid resolution numerical simulation for the project.**</u>

The model configured for this project, the DURBan eddy Simulation (DURBS-1km), is a high-resolution (1 km horizontal grid size), realistic model that was simulated for the years 2003-2010, including a 3 years spin-up. The model domain stretches from 22°E to 40°E and 37°S to 27.5°S and is centred over the Agulhas Current (Fig. 1).

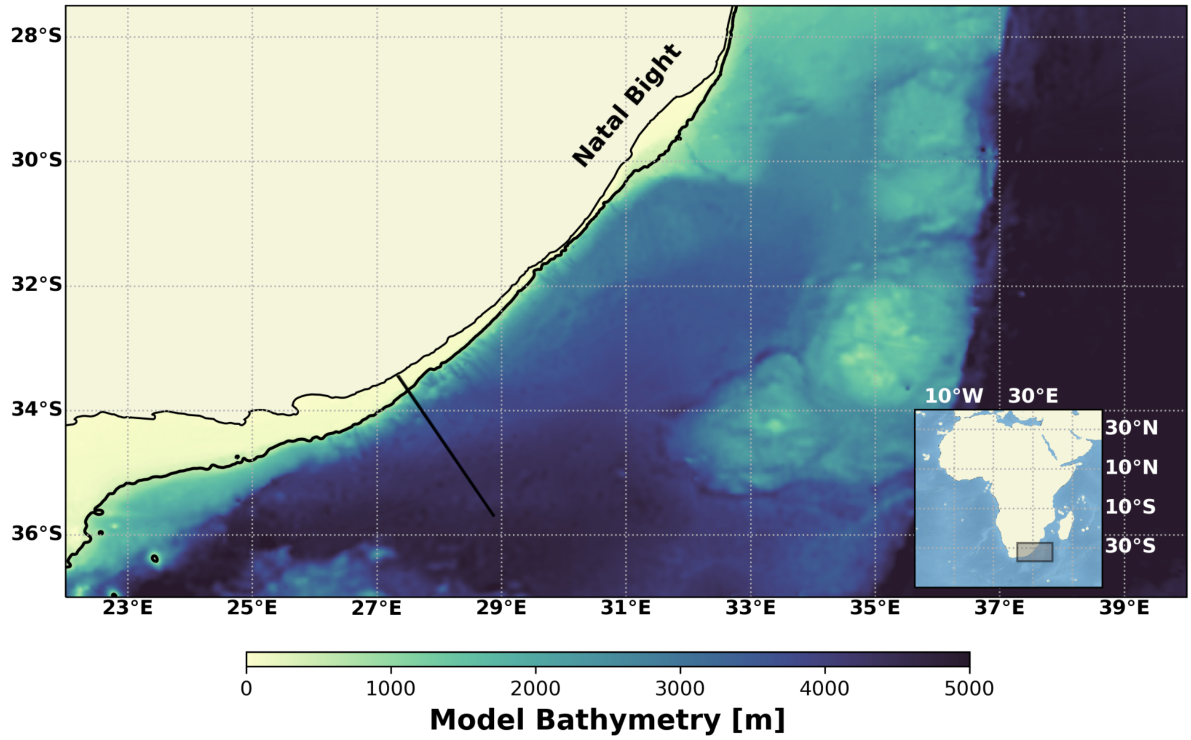

Figure 1: DURBS-1km model domain and bathymetry in colour. Black contour line showcases the narrow bathymetry along the east coast of South Africa, and the widening of the shelf at the Natal bight. Black line indicates position of ASCA (Agulhas System Climate Array) transect. Inset figure shows the geographical location of the model domain shaded in grey.

DURBS-1km was downscaled using an offline, one-way nested approach from a 3 km simulation that used GLORYS and ERA interim for its lateral and atmospheric boundary conditions respectively. At the bottom, the model uses the SRTM-30 bathymetric dataset (Fig. 1). This simulation includes 1729 x 1082 x 75 nodes and a time-step of 90 seconds and were saved in monthly files at daily intervals.

Early investigations on whether the model simulated the Durban Eddy satisfactory seems promising. This is evident in the snapshot of 14 January 2006 of the relative vorticity and surface velocity components shown in Figure 2, showing the presence of the Durban Eddy (negative vorticity) and its clockwise rotation.

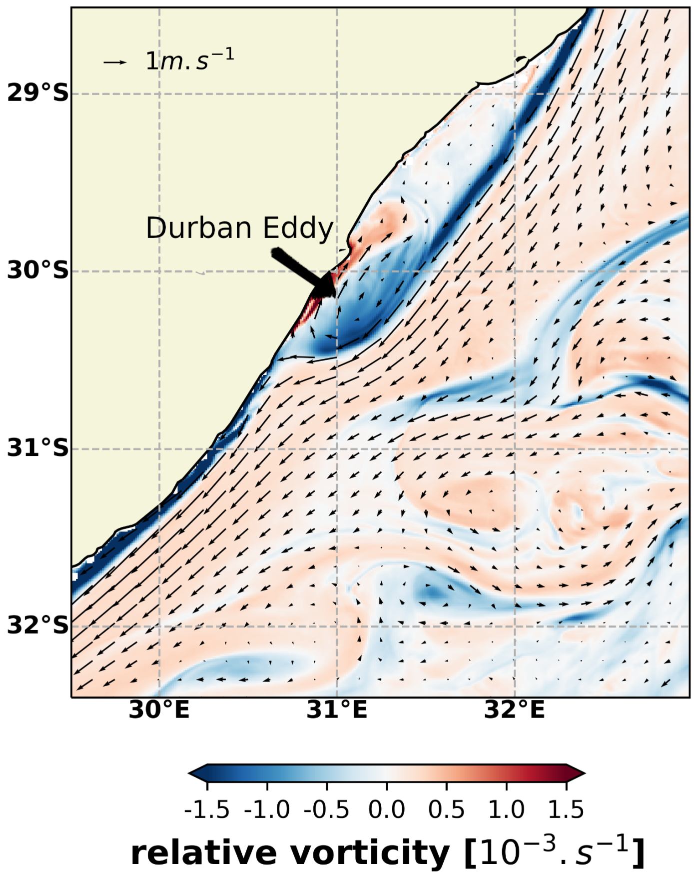

Figure 2: Surface relative vorticity (in colour) and velocity components (black vectors) of DURBS-1km on 14 January 2006 representing development of the Durban Eddy.

2. Develop the tools for the evaluation of the model.

It is important for DURBS-1km to resolve the Agulhas Current satisfactorily as it is the dominant oceanographic feature in the region that greatly influences inshore and coastal areas, and in this particular case, the Durban Eddy. To investigate if the simulation resolves this region satisfactorily, climatologies of the surface and interior of the model were made and compared to satellite observations and in-situ measurements of the ASCA transect - position of ASCA transect shown on Figure 1. For the evaluation, temperature, salinity, geostrophic currents, eddy kinetic energy and volume transport are investigated; however, for this report, we only show the most important findings - the representation of the Agulhas Current and how it behaves.

Results from the alongshore velocities indicate that the Agulhas Current is present in the model and behaves with a good degree of realism when compared to the ASCA mooring line (Fig. 3). The only noticeable difference is that the Agulhas Current in the model tends to be closer to the shelf and not extend as far offshore as observed in the ASCA line. Furthermore, the model is not able to reproduce the Agulhas Return Current (situated below the Agulhas current at > 1500 m depth) which is normal for models due to the difficulty of reproducing it.

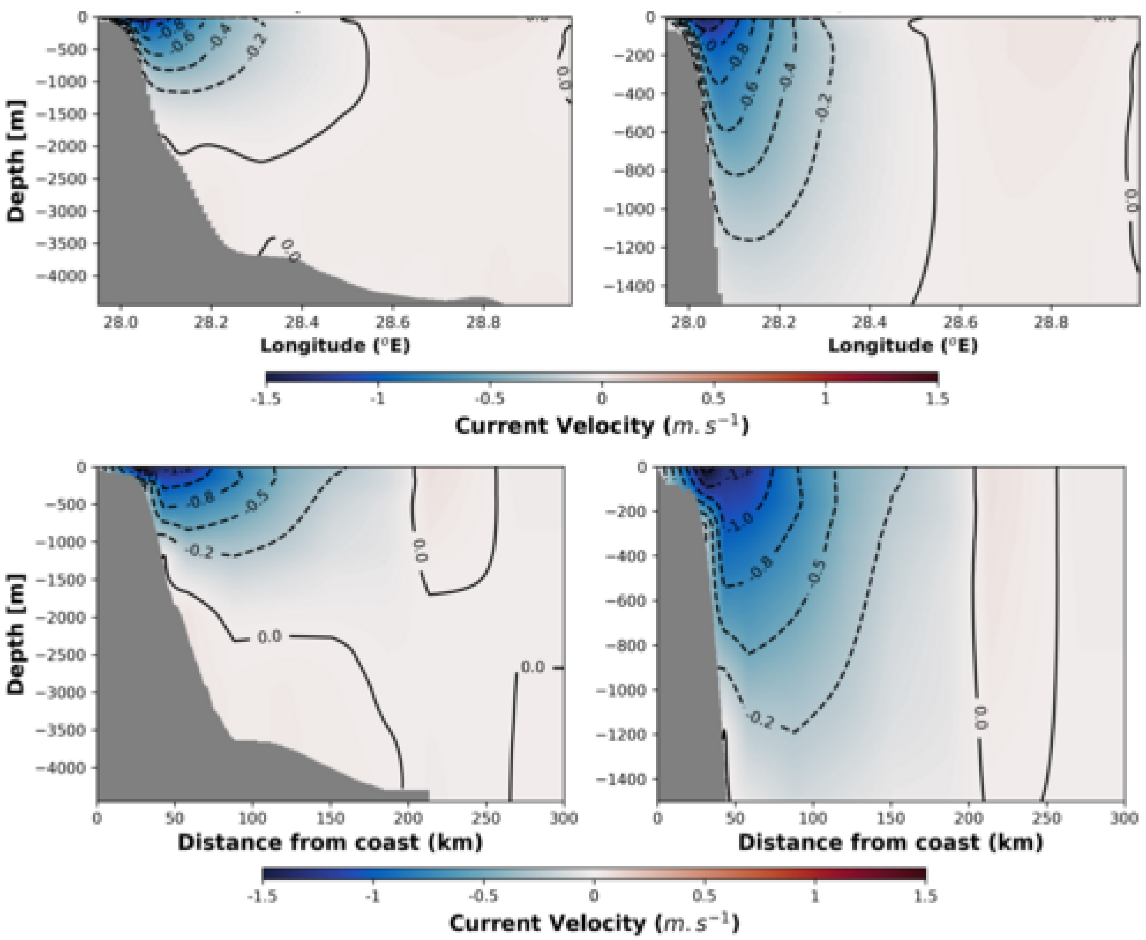

Figure 3: Mean alongshore velocities of DURBS-1km (top) and the ASCA transect (bottom). Figures on the right zooms in on the Agulhas Current. Contours show current velocity, where dashed contours shows polewards flow and solid contours equatorward flow.

The volume transport was calculated and compared to previous literature to determine if the Agulhas Current is behaving properly (Fig. 4). The mean volume transport calculated in the model along the ASCA transect was -85.74 Sv. This is relatively close to Gunn et al. (2020), -76 Sv (∓ 11), and Beal et al. (2015), -84 Sv (∓ 2), calculated along the ASCA transect. To add to this, when comparing the volume transport climatologies there are some degree of similarity between the trends observed in the in-situ and the model, and that is that both the in-situ and the model shows a stronger Agulhas Currents (more negative Sv values) during summer months compared to the winter months. These results combined give us confidence that the Agulhas Current in DURBS-1km is reproduced and behaves well.

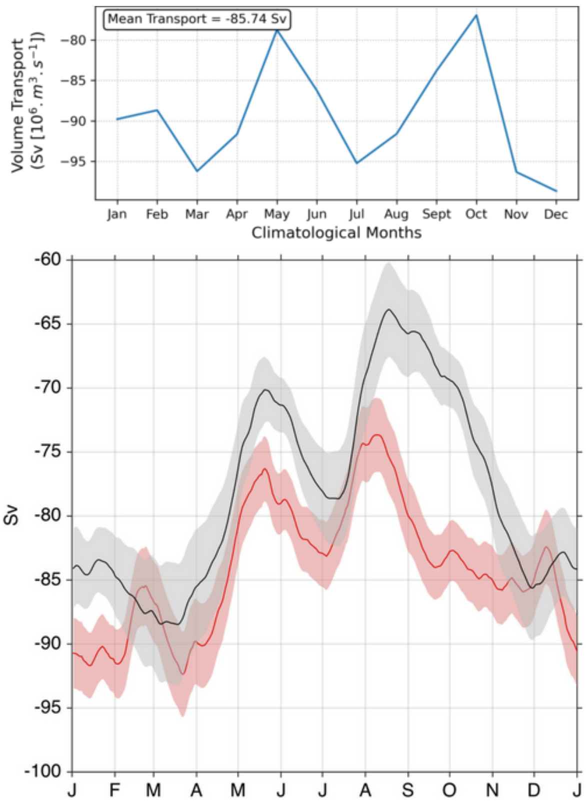

Figure 4: Climatological volume transport of DURBS-1km (top) compared to the ASCA line (bottom image; from Beal ei at., 2015). The grey line in the bottom figure is the more traditional method of calculating the volume transport to which we compare our values with. Stronger (more negative) Sverdrup (Sv) observed in summer months (December, January & February) compared to winter months (June, July & August)

3. <u>Configure 300 m horizontal grid resolution numerical simulation for the development of the sampling strategy during the RESILIENCE oceanographic campaign.</u>

A 300 m horizontal grid resolution simulation was developed to aid with the sampling strategy for the RESILIENCE oceanographic campaign taking place on 17 April 2022 - 20 May 2022. Even though only a short simulation of a month was made the outputs were saved hourly, thus increasing the temporal resolution substantially. This simulation proved to be useful as it can simulate the Durban Eddy (negative vorticity on the south western border of the model domain) and the fine scale dynamics inshore of the Durban Eddy (Fig. 5). This simulation still needs some tweaking, which is noticeable in the bathymetry observed on the eastern edge of the model domain (Fig. 5). However, a similar setup will also be used to make a longer simulation for the third chapter of the thesis to investigate the fine-scale dynamics of the Durban Eddy.

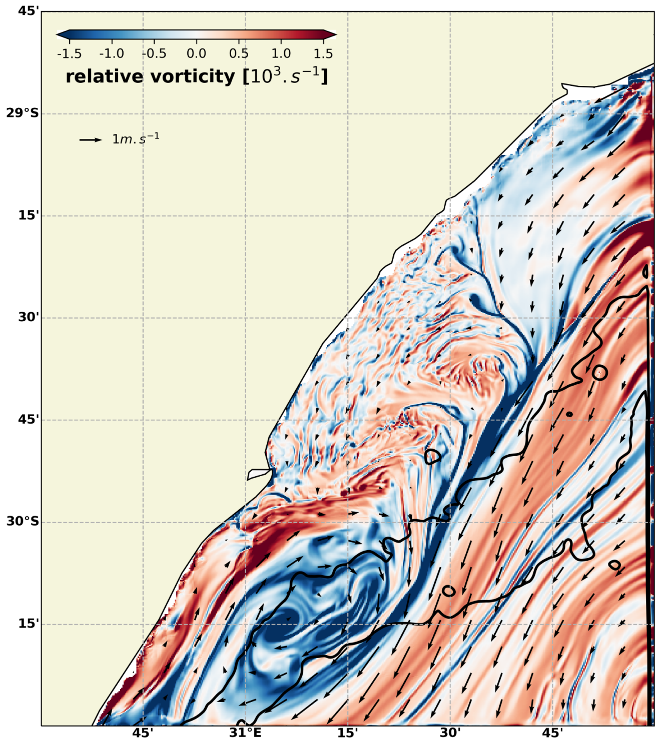

Figure 5: Snapshot of the relative vorticity (colour) and surface velocity components (black quivers) of DURBS-300m at midnight (24:00 hours) on 14 January 2003.

Conclusion:

During this trip to the University of Western Brittany (UBO) in Brest, France, the DURBS-1km was configured and simulated for the PhD titled: *The life-cycle and fine-scale dynamics of the Durban Eddy*. Furthermore, all the tools were developed that are required for the evaluation of DURBS-1km. Results have shown that the model can reproduce the Agulhas Current satisfactorily. Additionally, the higher resolution DURBS-300m was simulated to help develop a sampling strategy for the RESILIENCE oceanographic campaign, as well as provide guidance on the model setup for the final chapter of this thesis.

Even though this trip was short (2.5 months), a lot was achieved and this trip has really kick-started this PhD thesis. It was a great experience during which I learnt a lot of technical and oceanographic knowledge which is crucial for the development of the PhD thesis. Many thanks to the support I gained from GDRI and my supervisors Mike Roberts, Steven Herbette, Jenny Veitch, Gildas Cambon and Pierrick Penven to whom this would not have been possible.

References:

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