Dr Andrew Coward is based at the Southampton Oceanography Centre and is a member of the Large-Scale Long-Term Ocean Circulation Consortium (n01).

A study of Agulhas rings in a high-resolution ocean model

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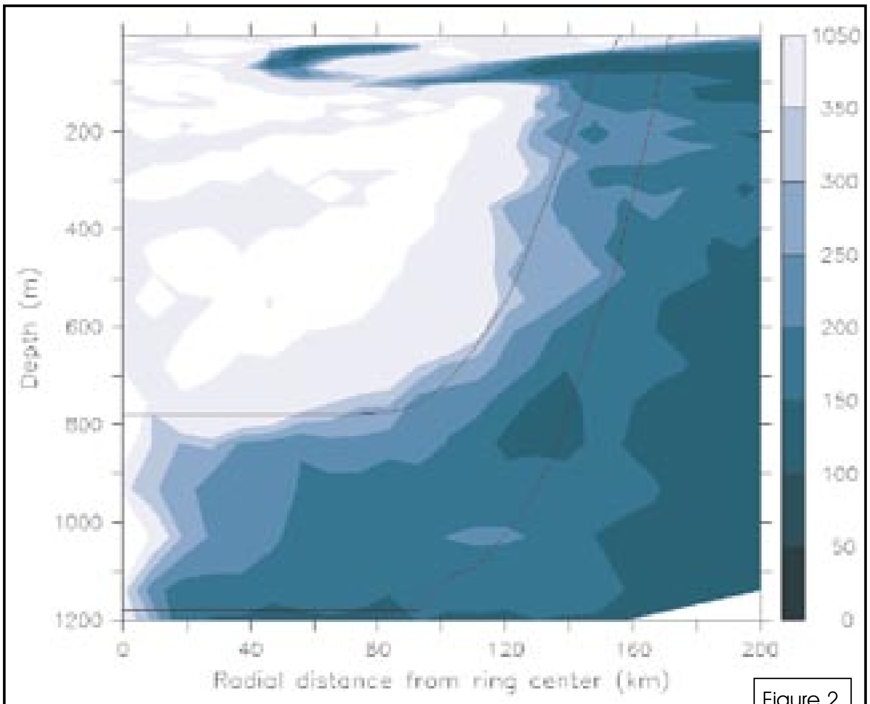

Figure 2

Introduction

The Agulhas Current is the strongest western boundary current of the southern hemisphere. It retroflects to the south of South Africa and flows back into the Indian Ocean as the Agulhas Return Current (ARC). Agulhas rings are shed off the retroflection loop irregularly and move into the South Atlantic Ocean in a north-westerly direction. Present estimates are that roughly six Agulhas rings are being formed each year. These rings form an important link between the subtropical gyres of the South Atlantic Ocean and the Indian Ocean. This link is also thought to play an important role in the upper branch of the global thermohaline circulation. These rings can be followed with satellite measurements of sea surface height (SSH). Such measurements show that the decay of the SSH is strongest during the first five months after the shedding of Agulhas rings. Observational studies of this important section of the thermohaline circulation are hampered by the episodic nature of the shedding process and the reliance on fortunate positioning of research vessels. Complimentary research using realistic ocean models is essential to improve our understanding of the regional processes and hence of any possible changes in a warming environment.

The UK's high resolution Ocean Circulation Model (OCCAM) is now being run at an eddy-resolving resolution of 1/12^o globally and has an effective grid size of approximately 7.5km in the Agulhas area. The model employs 66 depth levels, with 20 levels in the top 200 m and an explicit mixed layer. During the integration described here, the ocean surface is forced by a monthly wind stress climatology and a relaxation of temperature and salinity toward monthly climatological values. Integrating this model requires a capability machine such as HPCx and the model runs routinely on 352 processors of the Regatta system. Results from this model provide an ideal framework for investigating regional processes such as those described and this article briefly describes some analysis carried out in collaboration with colleagues from the Royal Netherlands Meteorological Institute (KNMI).For this analysis we used output from the second year of a two model-year integration.. The model provides three-day average values of all its state variables. Each such dataset is 8.5GB large which gives over 1TB of output per model year. These data were used to analyse the leakage of water from Agulhas rings using a novel, off-line, particle tracking approach developed by de Vries and Doos [2001] for the use with time-dependent flows. More than twenty thousand particles were used for the smallest Agulhas ring. Each trajectory was followed for the full second year of the model run. Particles were seeded in the top 2000m of the Agulhas rings wherever the SSH was above 25 cm. The center of the Agulhas ring was defined as the SSH maximum. The Agulhas rings were analyzed also in a two-dimensional, Eulerian framework. To this end, the data was azimuthally averaged around each ring centre and plotted as a function of radial distance and depth.

Figure 1 (on page 12) shows the SSH at the beginning of the year that has been used for the analysis. The Agulhas Current is centered at 24^{o}E. The heavy dashed lines indicate the regions within the three Agulhas rings where Lagrangian particles have been seeded. Also the path of the three rings has been indicated. The youngest (and largest) Agulhas ring is two weeks old. The ring in the middle was shed in mid-November, at the end of spring. The oldest ring was formed in midwinter of the first year.

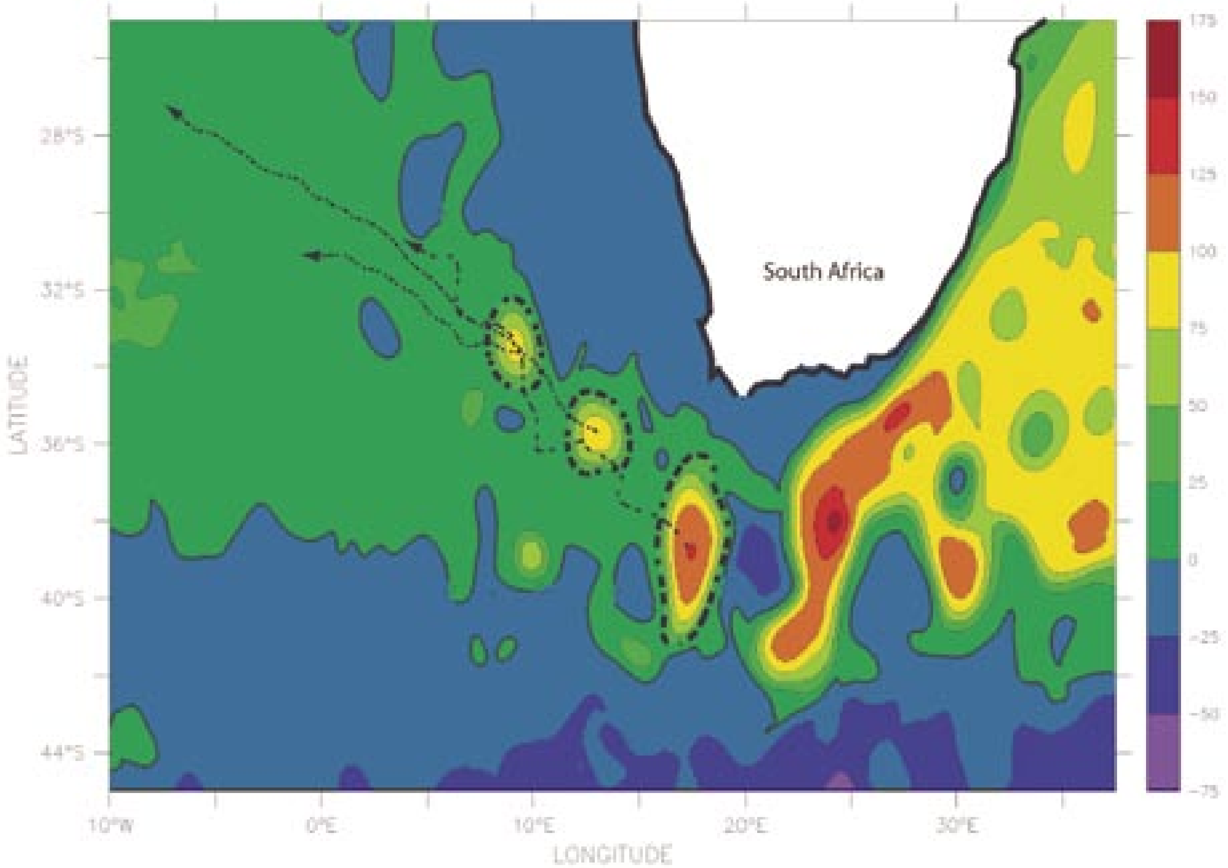

Figure 1

Figure 2 (on page 11) shows the average residence time (or e-folding time scale) of particles within the middle ring as a function of distance from the ring centre and depth. A clear, bowl- shaped division can be seen between particles that reside in the ring (white and light gray) and particles that leak into the environment (dark gray). The bowl-shape reaches to a distance of 140km and a depth of 800 m. The upper solid line in figure 2 shows the contour where the rotational velocity is at least twice the translational speed of the Agulhas ring. Note that the contour shallows at approximately 80km distance from the ring center, where the maximum azimuthal velocity is largest. At radii larger than 80km the criterion is a good indicator of the bowl-shaped ring boundary. The average residence time along the ring boundary is 250 days. In the upper 150m of the Agulhas ring a significantly stronger water mass exchange can be seen, in the form of a curl of water with a lower residence time. This suggests that the surrounding water is drawn into the ring at 100m depth, upwells within the ring and flows radially outward near the surface. This shallow overturning cell is the strongest circulation feature within the bowl shaped ring boundary and is confined to the mixed layer. The cell is present in all Agulhas rings during winter and spring, when heat loss is strong.

We have further analysed the model results to investigate the physical mechanisms behind this previously unobserved phenomenon. This analysis is the subject of an article (Donners et al., [2004]). Briefly, we were able to conclude that:

There is a sharp boundary between particles that stay within the Agulhas ring and particles that mix into the environment. The ring boundary is well predicted by a criterion that the azimuthal velocity is at least twice the translational velocity at any time.

Crucially, mixing with the environment is found to be enhanced when strong surface cooling generates a shallow overturning cell with radially outward flow near the surface and a compensating inward flow at depth. This circulation is limited to the mixed layer. The cell can be explained by Subinertial Mixed Layer theory: cooling creates vertically-sheared pressure gradients that induce vertically-sheared subinertial motions. Vertical mixing is balanced by restratification due to the sheared flow. The overturning cell forms an effective pathway between the edge and the inside of the Agulhas ring and it amplifies the dilution of the anomalous water properties of Agulhas rings near the surface. The surface water is not trapped in the core, but connected with the outside: the overturning cell amplifies this water mass exchange by constantly bringing new water to the edge, where it is mixed with the environment.

The model integrations are carried out as part of Southampton Oceanography Centre's core strategic research program, which is supported by the Natural Environment Research Council (NERC). This work is just one example of the environmental research carried out using the NERC share of HPCx. Realistic simulations of our natural environment will continue to require resources capable of integrating complex numerical models and analysing the large volumes of data generated by such models. The level of realism that can now be achieved is providing an invaluable complement to observational programmes.

References

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