Evidence of a semi – permanent cyclonic circulation on the edge of the Eastern Agulhas Bank

Niel Engelbrecht B-Tech Dissertation Cape Technikon

Ample research has been conducted on the powerful Agulhas Current and it's associated phenomena eg. eddies, meanders *etc.* However, the interaction between the Agulhas Current and the triangular extention off the South Coast of southern Africa, known as the Agulhas Bank, has not been extensively researched.

Boyd *et.al.* (1994), analyzed current measurements recorded by a ship-borne ADCP from November 1989 until October 1991.A total of 13 cruises were studied and current vectors from depths 30m and 50m on the South African south and west coasts were analyzed. The results in Boyd *et.al.* (1994) showed a southwestward flow along the Eastern Agulhas Bank. Furthermore, Boyd *et.al.* (1994) noted that reversals in the current flow were due to the presence of cyclonic eddies on the landward side of the Agulhas Current. Eddies are short-term oceanographic phenomena that last a maximum of 2-4 days.

Smook (Unpublished data, 1998) examined data from 2 Aanderaa Recording Current Meters (ARCM'S) deployed along the 200m isobath of the Eastern Agulhas Bank, one 60 km south of Cape St.Francis and the other 100 km south of Plettenberg Bay (Project L). The aim of Project L was to look at the mechanisms for shelf edge upwelling and the bottom layer on the Eastern Agulhas Bank.

The Plettenberg Bay temperature record also showed some temperature depressions of longer than 2-3 days, which could not have been caused by transient eddies. CTD temperature data collected on a research cruise during 1992 showed shelf edge upwelling to depths of 1000m. The dynamics of Agulhas Current border eddies formed on the landward side do not go this deep. This deep upwelling was thought to be caused by Ekman Veering. In strong flowing Western Boundary Currents, drag created by friction in the bottom layer of the current flowing against the shelf, causes it to slow down. At this lowered speed, Coriolus force does not affect the flow of the bottom layers and the cold, bottom water moves up the slope due to "Bottom Ekman Transport".

The current meter results from Project L showed dominant bottom eastward flow at the Plettenberg Bay and St.Francis Bay sites, which is counter to the Agulhas Current. Therefore, the depressed temperatures were not due to Ekman Veering. This bottom flow, opposing the Agulhas Current, was thought to be part of a recently observed undercurrent first reported by Toole and Warren (1993), and later confirmed by Beal and Bryden (1997) while conducting a transect spanning 230 km across the Agulhas Current off Port Alfred using a Lowered Acoustic Doppler Current Profiler. The undercurrent was found close to the continental slope with it's core at a depth of 1200m.

During April 2000 Pioneer Natural Resources (PNR) deployed two Acoustic Doppler Current Profilers (ADCP's) and a Waverider buoy at a depth of 240m off Mossel Bay. The data was to provide information on whether the current speed and direction would be conducive for oil drilling during the majority of the year. However, the analysis of the data yielded some very interesting results, and coupled with the previously unexplainable data from Project L suggested the presence of a semi-permanent bottom cyclonic gyre that could be dependant on the bathymetry of the Agulhas Bank and the dynamics of the Agulhas Current. A Regional Ocean Modeling System (ROMS) has confirmed the presence of this gyre. Such a bottom feature can have major implications on fish resources that utilize the area for spawning such as squid (*Loligo vulgaris reynaudii)*.

The ADCP data obtained from PNR, showed intermittent eastward flow superimposed on a dominant westward flowing current. Also, the surface and bottom flows were almost identical (near - barotrophic flow). So how is it possible to have an opposite semi – permanent flows on the shelf edge at the same depth within a distance of 300 km. A possible explanation for the sudden and extensive reversals in the current flow could be a semi-permanent bottom cyclonic gyre. In the Southern Hemisphere a cyclonic circulation causes divergence. A cyclonic feature such as the semi-permanent bottom gyre would cause a loss of water at the surface due to divergence and this would result in cold water being pulled up to replace the surface water losses.

A newly implemented three dimensional hydrodynamic modeling system known as ROMS (Regional Oceanographic Modeling System), has been used to identify specific oceanographic features in the Southern Benguela (Penven *et al.*, 2001 a.) as well as the formation of eddies in the Agulhas Current (Penven *et.al.*2001 b., Lutjeharmse *et.al.*2001). ROMS is a regional ocean circulation model solving the free surface, hydrostatic, primitive equations over a varying topography. The ROMS model was developed at the University of California in Los Angeles, and is based on the S-coordinate Rutgers University Model (SCRUM Model) described by Song and Haidvogel (1994). The modeling system is a very useful tool for studying both complex coastal ocean problems and basin-scale ocean circulation. This is in contrast to other ocean models that are designed to study either coastal or basin-scale ocean circulation.

Ocean modeling plays an important role in both understanding the current environmental conditions and predicting future change. *In-situ* oceanographic instruments provide only sparse measurements over the world oceans. Although remotely sensed data from satellites cover the globe, it only provides information on the ocean surface. Synoptic information, in 3-D, covering a large area can be obtained using ocean models. One major drawback of modeling is that it is not absolutely accurate as it is based on assumptions, approximations, boundary conditions *etc*. that can all add various errors. Although the ROMS model has been tested with various situations to prove its ability to give near - accurate forecasting predictions, some oceanographic phenomena have not been resolved by the model.

The ROMS model consist of 144 by 65 grid mesh with the resolution ranging from 9 km to 16 km, with the highest resolution being at the coast. The grid is pie-shaped and has three open boundaries and one solid coastline The model consists of 20 vertical levels, with the highest resolution at the surface. The results of these modeling studies exemplified a semi-permanent cyclonic circulation in the area 22°E and 25 °E. The formation of this semi-permanent circulation was considered due to the interaction between the Agulhas Current and the topography of the Agulhas Bank (Lutjeharmse *et.al.*2001). When studying monthly averaged results of the ROMS model, the circulation in question undergoes contraction and expansion. It is the expansion of the semi-permanent circulation that causes the major current reversals as observed in the ADCP data presented here. When the gyre contracted, the current was seen to flow in the regular direction of the Agulhas Current dominated flow. By implication, the measurements made during Project L is assumed to be during a period when the gyre was expanded for a substantial time period, hence explaining the persistent eastward flow.

Ship-mounted ADCP transects on the South Coast, have also intermittently shown a reverse flow in the study area, over a distance of ~150km, even though ship borne ADCP data are non-synoptic snapshots and not a continuous data source.

Importance of a semi-permanent cyclonic gyre

The Agulhas Bank is the main habitat of the chokka squid (*Loligo vulgaris reynaudii).* Previously it was believed that chokka squid exclusively spawned in the shallow regions of the Eastern Agulhas Bank (Augustyn, 1990). However, recently Roberts *et.al.* (In press) demonstrated that chokka squid also spawn on the mid-shelf in the depth range of 60-120m. This zone has been defined as the deep spawning grounds (FIG 4.12). Eggs deposited in this region are subjected to temperatures between 9° – 12° C. Laboratory studies by Oosthuizen (1999) has shown that squid egg development is highly temperature dependent with optimal growth at temperatures between 15° – 19° C. Hatching does occur at temperatures lower than 12° C, but there is a high percentage of abnormal embryonic development (>30%). At temperatures lower than 7°C, 100% abnormalities occur.

The area in which this semi-permanent circulation occurs overlaps with squid deep spawning area. The semi-permanent bottom circulation was shown to be a major upwelling mechanism and the low bottom temperatures would suggest that large numbers of paralarvae are lost as a result of abnormal egg development. The gyre also plays a role in transportation of paralarvae and eggs in that it could either entrain the paralarvae and eggs or cause substantial losses to the ecosystem. This could have serious implications for recruitment as the chokka squid has a short life span of 15 months (*pers.comm.* M.Roberts).

REFERENCES

AUGUSTYN, C.J. 1990 – Biological studies on the chokker squid *Loligo vulgaris reynaudii* (Cephalopoda: Myopsida) on spawning grounds off the south-east coast of South Africa. *S.Afr. J.Mar.Sci.* 9: 11-26.

BEAL, L.M. and H.L.BRYDEN 1997 – Observations of an Agulhas Undercurrent. *Deep-sea Res.*44: 1715 – 1724.

BOYD, A.J. and F.A. SHILLINGTON 1994 – Physical forcing and circulation patterns on the Agulhas Bank. *S. Afr.J.Sci.* 90:114 – 122.

LUTJEHARMSE, J.R.E. 2001 – Agulhas Current. In *Encyclopedia of Ocean Sciences.* 5.104-114.Steele, J.H, Turekan.K.K, and Thorpe, S.A. (Eds.) Academic Press.

PENVEN, P., LUTJEHARMSE, J.R.E., MARCHESIELLO, P., ROY, C., WEEKS, S.J. 2001 – Generation of cyclonic eddies by the Agulhas Current in the lee of the Agulhas Bank. *Geophysical Research Letters.*7: 1055 – 1058.

PENVEN, P., C.ROY, G.BRUNDIT, A.COLIN de VERIERE, P.FREON, A.S.JOHNSON, J.R.E.LUTJEHARMSE and F.A.SHILLINGTON 2001- A regional hydrodynamic model of upwelling in the Southern Benguela. *S.Afr.J.Sci.* 97: 472 – 475.

SMOOK, A. 1998 – Eastern Agulhas Bank Shelf Edge Upwelling. *N.Dip. Report.* Cape Technikon.35pp.

SONG.Y.T and D.HAIDVOGEL 1994 – A semi – implicit ocean circulation model using a generalized topography following coordinate system.*Jour.Comp.Phys.*115: 228 – 248.

TOOLE, J.M. and B.A. WARREN 1993 – A hydrographic section across the subtropical South Indian Ocean. *Deep – sea Res.* 40: 1973-2019.