

THE MIXING OF AGULHAS RINGS EXPERIMENT (MARE)

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One of the major oceanic contributions to the global climate system is the oceanic thermohaline circulation (THC). In this global circulation system the inter-ocean exchange of mass, heat and fresh water plays an important role. Around South Africa the exchange of warm saline water between the Indian and Atlantic Ocean takes place as the so-called Agulhas leakage, whereby large oceanic rings (~300 km) shed from the retroflexion of the Agulhas Current near 38°S, 17°E (Figure 1). Computations with general circulation models have shown that the strength of the THC is very sensitive to the magnitude of the Agulhas leakage, determined by the annual number of Agulhas rings and the exchange of heat and salt between the rings and their surroundings. To study all aspects of the Agulhas leakage a national research programme was initiated by NIOZ in cooperation with Utrecht University (IMAU) and the Royal Netherlands Meteorological Institute (KNMI). The research programme was named Mixing of Agulhas Rings Experiment (MARE) in order to emphasize that the role of the Agulhas Rings in climate was the central issue.

The MARE programme consisted of 5 sub-projects: - observing the decay of a single Agulhas ring, - modelling of the evolution of these rings, - modelling the effects of the rings in the hydrography of the Atlantic Ocean, - studying the effects of variations of the Agulhas Leakage on the North Atlantic and - European Climate, and performing a paleoceanographic study of the Agulhas leakage and the occurrence of Agulhas rings in past climatic periods. The observational field programme of MARE took place in 2000 and 2001.

NIOZ was the lead institution for the observational and paleoceanographic sub-projects. RV Pelagia carried out a hydrographic survey of a single Agulhas Ring, named Astrid, in March 2000 and February 2001 during research cruises around Africa. In July/August 2000 the same ring was surveyed by the South African vessel SA Agulhas, with a scientific

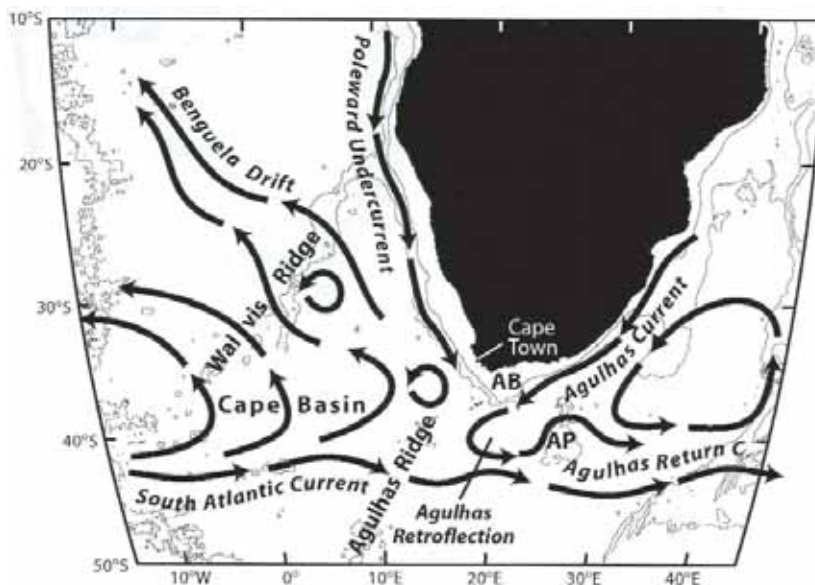


Fig. 1. Circulation scheme for the south-eastern South Atlantic and the south-western South Indian Ocean, where the Agulhas leakage takes place. In this process large rings, filled with warm and saline Indian Ocean water, drift from the Agulhas retroflexion into the Atlantic Ocean.

crew from NIOZ, IMAU, KNMI and the University of Cape Town. Observations were carried out with a CTD, measuring the salinity and temperature distribution. Water samples were taken for chemical analysis. The velocity field of the

ring could be measured by means of a lowered Acoustic Doppler Current Profiler (ADCP) as well as a hull-mounted ADCP on board RV Pelagia. During the first survey also a towed undulating CTD system was used to determine the

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temperature and salinity field in the upper 200 m in detail. During these three surveys also paleoceanographic observations were carried out.

Ring Astrid had been formed in December 1999 at the Agulhas Retroflection in the south-eastern Atlantic Ocean, and was quite young when it was surveyed in the austral autumn, March 2000. Then it was a nearly circular counter-clockwise rotating ring (Figure 2). The core of the ring consisted of warm and saline Indian Ocean Water, brought around South Africa by the Agulhas Current. The ring's diameter was about 275 km. The tangential velocity around the core of the ring reached maximum values of over 1.5 m/s. The high rotating velocity field of the ring was mainly confined to the upper 1000 m, although co-rotating velocities of about 10 cm/s were observed near the bottom at a depth of ~5000 m (Figure 3). During this survey the young ring already had started to decay. Especially below a depth of 200 m cold and relatively fresh water from the surrounding ocean had started to intrude into the ring, replacing the ring's warm Indian Ocean Water.

Already during the March survey the ring was losing huge amounts of heat to the overlying cold atmosphere. That heat loss increased in the following winter and during the survey in August 2000, the sea surface temperature in the centre had decreased with about 4.5°C, while the surface mixed layer had

reached a depth of over 150 m. Due to the seasonal cooling of the ring it was no longer visible in infrared satellite images, although its surface elevation could be followed by means of satellite altimetry. During this survey it was found that Ring Astrid had collided with another Agulhas ring, thereby

had decreased further, but the ring was still visible in satellite altimetry observations. During the second and third survey the ring had changed from nearly circular to strongly elliptical, similar to model predictions. In its first year of existence Astrid drifted slowly westward along an irregular path, inter-

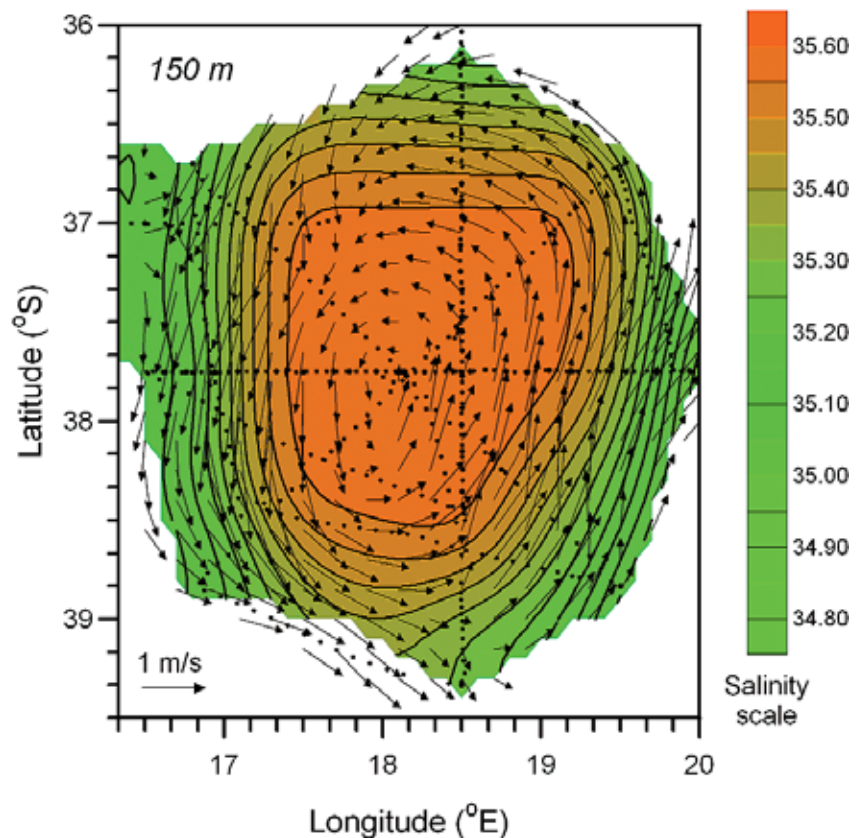


Fig. 2. The salinity distribution (coloured) and velocity field (arrows) at a depth of 150 m in Ring Astrid, observed in March 2000 during a survey with RV Pelagia.

exchanging a considerable amount of their contents.

In the following spring and summer the sea surface of the ring and its surroundings was heated again, while the salinity increased due to an evaporation excess. The sea surface height anomaly of the ring

was dispersed with short periods of fast motion. Analysis of the observed decay process of ring Astrid, and comparison with ring observations reported in literature, have led to the conclusion that heat loss to the atmosphere and intrusion of colder water from the surrounding ocean

are both important processes for the decay of Agulhas rings, diminishing its excess heat content and rotations rate. Their contributions to the heat loss of the ring are of about equal magnitude. When the ring drift speeds up, as occasionally occurs, Agulhas rings lose considerable parts of their deeper water.

In 2004 and 2005 the MARE programme has resulted in 3 academic promotions. It was funded by NWO-ALW as a Dutch contribution to the international CLIVAR programme.

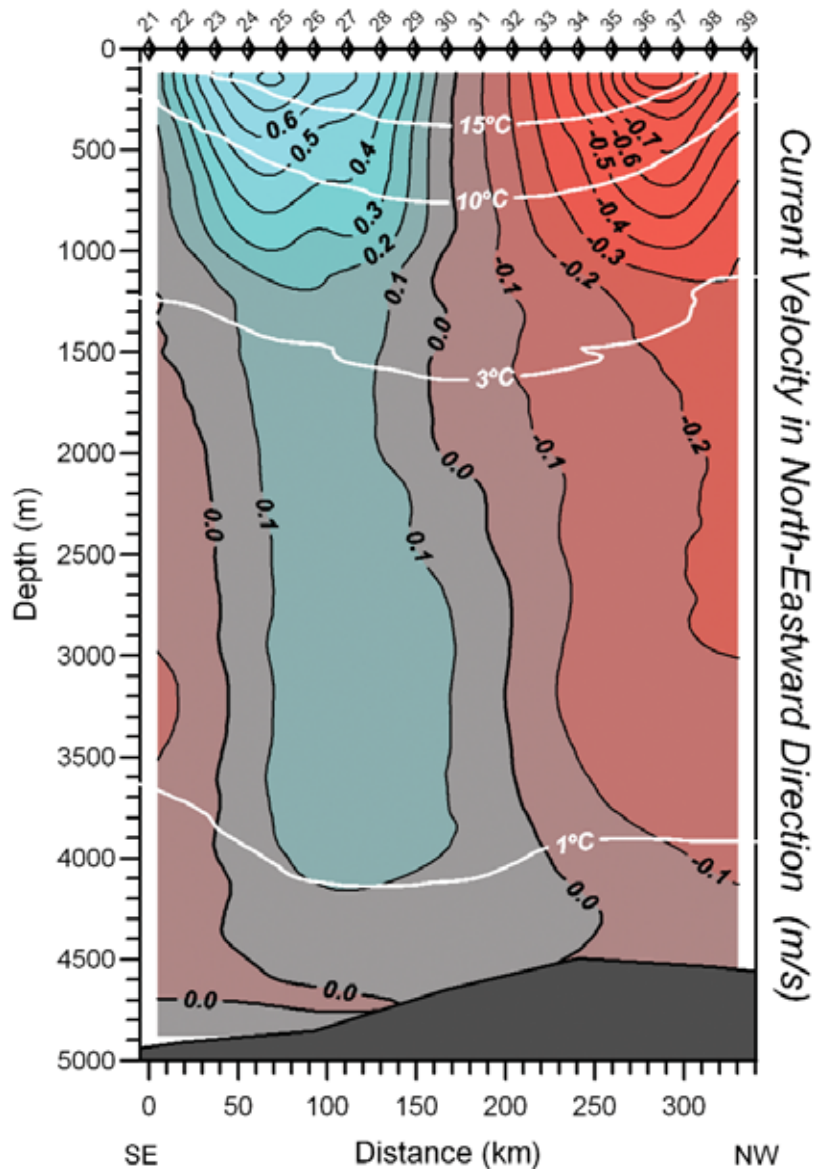


Fig. 3. Section of the northeastward velocity component (m/s) through ring Astrid, perpendicular to the southeast-northwest hydrographic section from station 21 to station 39. The red area shows the positive velocities (towards northeast). On top of the velocity distribution some isotherms are shown in white. Station numbers are indicated at the top.