The importance of the greater Agulhas Current is increasingly being recognised

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In February 2010, the annual Ocean Science meeting was held in Portland, Oregon, USA. For the first time in the history of this conference at least two sessions were aimed at aspects of the Agulhas Current system. In conjunction with the conference, the first meeting of a Scientific Committee on Oceanic Research (SCOR) Working Group on the global influence of the Agulhas Current[1] was held, attracting representatives of 13 countries. In addition, towards the end of 2009 a new EU research programme was approved called GATEWAYS[2] to study mainly the palaeoceanographic implications of the Agulhas Current. In the meantime, the Dutch are maintaining an expensive array of current meter moorings in the Mozambique Channel called Long-term Ocean Climate Observations (LOCO),[3] while the University of Miami will be placing a similar set of moorings across the Agulhas Current near East London[4] in April 2010. Why this sudden explosion of international interest in the greater Agulhas Current?

Each large ocean basin on the globe has a basin-wide, wind-driven circulation. These circulations are not longitudinally symmetric, but each has an intensified, strong current on its western side: a western boundary current. In the North Atlantic Ocean this is the Gulf Stream and in the South Indian Ocean it is the Agulhas Current[5] adjacent to the east coast of South Africa (Figure 1). All of these currents eventually feed all their water back directly into their respective subtropical gyres, with the exception of the Agulhas Current. Since the land mass of Africa does not extend very far south, a significant amount of Agulhas water can leak into the South Atlantic Ocean. This leakage comes about predominantly by the shedding of large current rings at the Agulhas Retroflection (Figure 1) south of Africa.[5] It turns out that the flux of heat and salt that is injected into the Atlantic by the shedding of these Agulhas rings has the potential to affect the meridional overturning of the whole Atlantic, and this in turn can have a major impact on global climate.

Models have, in fact, shown that recent shifts in the wind patterns of the Southern Hemisphere – probably anthropogenically induced – have led to a greater input of Agulhas water into the Atlantic.[6] This may inhibit the effect of the climatically important freshening of the North Atlantic due to the increased melting of the icecap of Greenland. Furthermore, palaeoceanographic studies have indicated[7] that fluctuations in this leakage are closely correlated with substantial changes in global climate, such as glaciations and even decadal changes.[8] Therefore, it is clear that this process of ring shedding south of Africa is worthy of considerably more than just local interest – hence the growing international interest.

It is immediately evident that the dynamic processes that mediate this Agulhas leakage, (i.e. the shedding of Agulhas rings) are also important to understand. This is where the upstream sources of the Agulhas Current proper (Figure 1), and particularly perturbations in these sources, play a decisive role. These include eddies formed in the Mozambique Channel and to the south of Madagascar. Hence there is a growing interest in the formation of these features and their respective frequencies of formation.[3]

The reason for the growing international interest is, therefore, clearly the key role of the greater Agulhas Current system in the global climate. Having recognised this role, one may want to identify the most important dynamical processes that now need to be understood. To this end, a number of major programmes are currently investigating the greater Agulhas Current system.

Large Marine Ecosystems (LMEs) are programmes instituted by the Global Environmental Facility to help countries manage marine ecosystems across political boundaries. In the Agulhas and Somali Current Large Marine Ecosystem (ASCLME) project, two ecosystems have been combined[9] and the ocean region in question, therefore, covers the whole western Indian Ocean (Figure 2). Whereas other LME projects have been based on a solid knowledge foundation[10] from many previous investigations, this has not been possible for the ASCLME because this ocean region is one of the least explored. This has meant that the ASCLME has had to be designed[11] to fill the most glaring knowledge gaps. This has, to a large extent, been accomplished during the last three years (Figure 2) and is continuing. Ocean systems that have never been observed adequately, such as the East Madagascar Current and the deep-sea environment of the island of Mauritius, have been studied in a multidisciplinary way for the first time, using the Norwegian research vessel *Dr. Fridtjof Nansen*. A remarkable new discovery has been that the deep-sea circulation at Mauritius is strongly influenced by passing mesoscale eddies. Regions in the Mozambique Channel, the Comores Gyre and the Mascarene Plateau have also been explored. The results are still being analysed. Furthermore, the ASCLME has helped in deploying current meter moorings (Figure 1) and deep-sea weather buoys for other projects (see below). In short, the western Indian Ocean has never before seen such an extensive research effort. Regrettably, the scourge of piracy has, up until now, prevented work off Somalia and, currently, a zone of exclusion has been defined north of the 10 °S latitude (Figure 2).

The African Coelacanth Ecosystem Programme (ACEP II)[12] is the major contribution by South Africa to the ASCLME. Its activities are concentrated along the east coast of South Africa and, in particular, in the Natal Bight. Cruises include a first study of the landward edge of the Agulhas Current along its full length and coverage of the Agulhas Bank, the continental shelf south of Africa (Figures 1 and 2). The latter will include the unusual upwelling cell at Port Alfred[13] at the eastern extremity of the Agulhas Bank. Once again, these investigations are bound to add substantially to the existing knowledge of these ocean regions.

With the advent of global warming, it has been become imperative that long-term monitoring of the ocean be carried out at crucial locations. Such monitoring, by the Dutch, is being carried out with current meter moorings in the narrows of the Mozambique Channel (*vide* Figure 1).[3] It has previously been shown that the volume transport through the Channel may be an important contributor to the greater Agulhas Current system, and this has now been carefully quantified to be $14 \times 10^6\,m^3/s$ on average, with a seasonal signal of $5 \times 10^6\,m^3/s$. The maintenance of this array is crucial for a proper understanding

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ACT, Agulhas Current Time-series.
UTR, underwater temperature recorder.
ARC, Agulhas Return Current reference station.
ADCP, acoustic Doppler current profiler.

Figure 1: Some of the major currents in the western Indian Ocean, indicated schematically, with the existing mooring locations, as well as some of those planned for future deployment, shown in orange

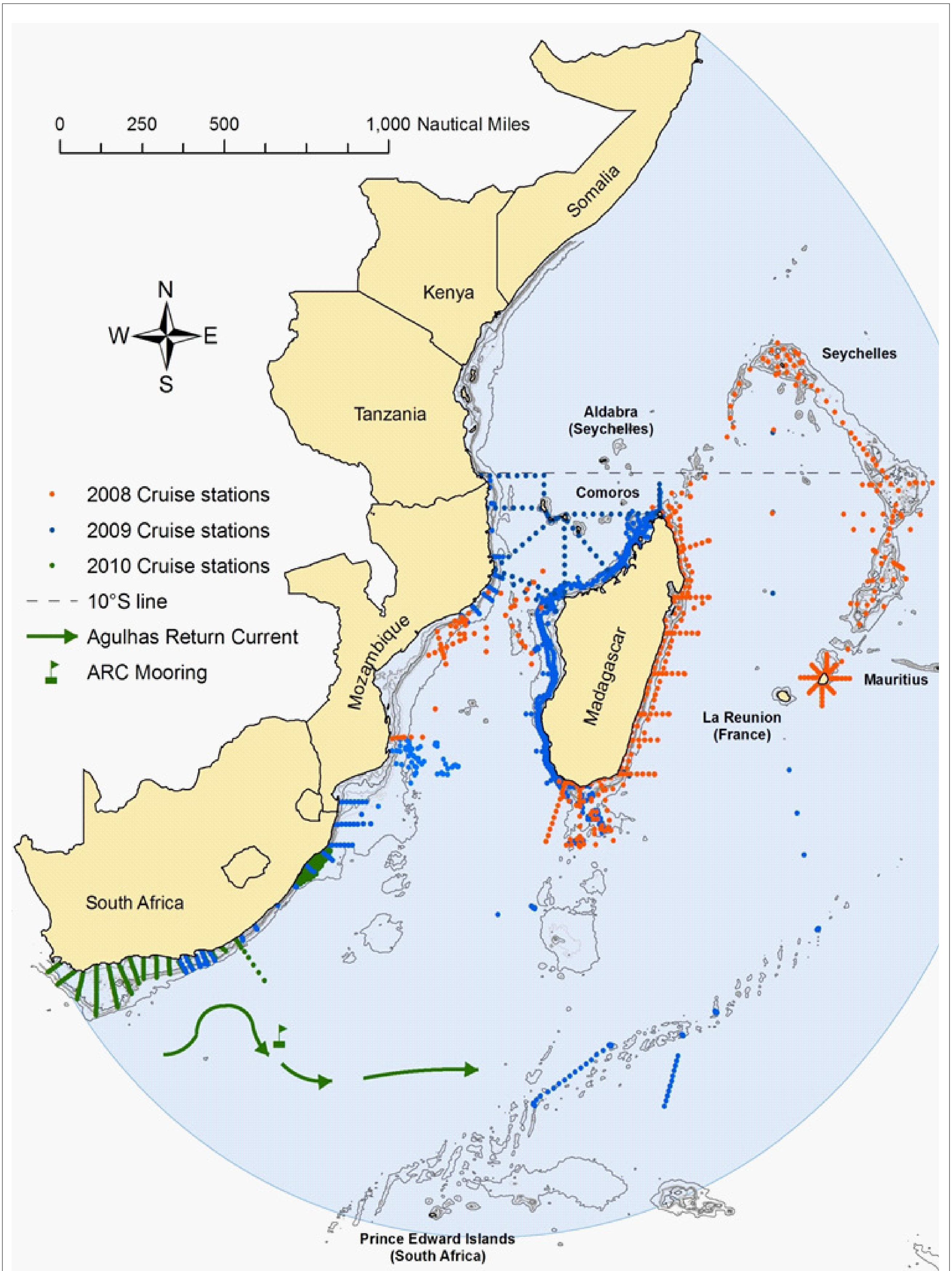

Figure 2: The western Indian Ocean with the hydrographic station positions indicated for 3 years of the ASCLME (Agulhas and Somali Current Large Marine Ecosystem) programme and other cruises. Note the exclusion zone that is now in place owing to piracy to the north of 10 °S latitude and how the 2009 cruises skirted the border of this zone at Tanzania. Note also the manner in which the East Madagascar Current (see Figure 1) and the deep-sea environment of Mauritius have been extensively covered for the first time.

of long-term changes to the Agulhas Current system, but the logistics to accomplish this have not been easy. The moorings will soon be extended to include an array in the southern branch of the East Madagascar Current (Figure 1).

One of the most prominent mooring arrays in the global ocean has been the Tropical Atmosphere Ocean programme along the equator over the full width of the Pacific Ocean. This array has been maintained since 1985 and has been essential in monitoring and predicting the El Niño phenomenon. These successes have led to attempts to build a similar array in the tropics of the Indian Ocean.[14] This will clearly have a great impact on a better understanding of the monsoon system over the Indian Ocean and its predictability, weather prediction for east Africa and in long-term climate studies. The first ATLAS moorings[11] have been placed along the 55 °E longitude in 2008 (*vide* Figure 1).

One of the key elements for a proper understanding of the Agulhas system is detailed knowledge of the volume, heat and salt fluxes of the Agulhas Current and their possible variations. Since the fluxes in the Mozambique Channel exhibit seasonality, as do the atmospheric driving forces of the South Indian Ocean, the question that arises is: are these and other variations reflected in the fluxes of the Agulhas Current? If so, this might have a direct effect on the Agulhas leakage since it has been suggested that a weaker Agulhas Current might lead to more leakage while others maintain that, on the contrary, it will lead to less leakage. To address this important question, an array of current meter moorings is to be placed across the current in 2010. This project, called Agulhas Current Time-series,[4] is building on a very successful past deployment, during which the volume flux of the current was established accurately for the first time and the Agulhas undercurrent was discovered. The line of current meter moorings off East London, on the east coast of South Africa, will be along a ground track of satellite altimetry observations (Figures 1 and 2). It is hoped that if it can be shown that there is a firm relationship between the volume transport of the current and the sea surface gradient as measured by altimetry, records of the temporal variations of the fluxes may be extended backward as far as the altimetric record allows.

Once the water in the Agulhas Current has passed through the retroflection loop, that part of it that has not been taken up by the formation of Agulhas rings flows eastward along the Subtropical Convergence (see Figures 1 and 2) as the Agulhas Return Current. This juxtaposition of front and warm current creates one of the most intense horizontal thermal gradients in the world's oceans.[5] It is also known for its very high ocean-to-atmosphere heat fluxes. The Agulhas Return Current reference station project, therefore, will aim at monitoring of the ocean-atmosphere interactions here,[15] by placing a specialised mooring (*vide* Figures 1 and 2).

Notwithstanding all these sophisticated observations, predicting future climate change, including the potential role of the Agulhas Current in this, remains fraught with obvious difficulties. However, palaeoceanographic records spanning the last several 100 000 years demonstrate the sensitivity of the Agulhas Current system to varying climatic factors. Integrating the complex circulation processes with palaeoceanographic reconstructions and numerical ocean modelling may be the only way to fully understand the system and its climatic variations and, to this end, the GATEWAYS project[2] has been designed. New sediment cores have been collected from sites with high sediment accumulation rates, located in a number of sectors of the Agulhas regime. The analysis of these has recently started.

Of all the ocean basins, the North Atlantic has a particularly special role in the global overturning circulation. It is here that salty surface water is cooled in the Labrador Sea and sinks down to form the deep water mass of most of the world's oceans. It has been noted in some palaeoceanographic studies that this overturning circulation has, at times, been stopped, with considerable climatic impacts. At a time when the global climate is changing due to anthropogenic forcing, knowledge of any changes in the oceanic overturning circulation is crucial. To this end, an optimal monitoring array needs to be designed to study the influence of the South Atlantic on meridional overturning, a task taken up by an international group under the auspices of the South Atlantic Meridional Overturning Circulation.[16]

To the uninitiated, this veritable letter soup of project acronyms may be thoroughly confusing and disheartening. Not only that, but the question may legitimately be asked if elements of this large collection of individual projects do not overlap and if all this, therefore, optimal use of funds and equipment. Building appropriate links between all oceanographers working in the south-west Indian Ocean is one of the main aims of the new SCOR Working Group 136: *Climatic importance of the greater Agulhas Current system*.[1] This working group includes formal participants from seven countries that are carrying out research in the region as well as a host of volunteers from many others countries.

It would seem abundantly clear that the greater Agulhas Current system is the subject of an unprecedented international research effort. It also seems clear that by the time most of these projects are completed, the level of knowledge and understanding of the system may well have increased significantly. All this research is bound to leave a legacy of better educated scientists in the region and also a broader base of understanding of the ecosystems to inform decision makers. ■

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