**Project Title**

**SAMOC – FLOAT**:

Projet SAMOC : Déploiements de flotteurs profileurs en Atlantique Sud et dans le secteur Atlantique de l’Océan Austral.

**Years** 2011–2014

**PI**: Sabrina SPEICH LPO-IUEM (1011-2013) & LMD-IPSL (since 2014)

Participating Laboratories: LPO & LMI ICEMASA (Univ. of Cape Town, South Africa); CSIR, Cape Town, South Africa; NOAA.

Contribution to CLIVAR, SAMOC, ARGO International, SOCCO (South Africa), SOCLIM (BNP-ParisBas)

Other funding sources: ANR et Ifremer (F), FAPESP (Brazil), NOAA (USA), SANAP (South Africa)

### Objectives:

Earth’s climate, responding to the different thermo-dynamic properties of the land and ocean surfaces, is sensitive to the continental configuration. Indeed, because of the ocean-land configuration, each ocean basin is exposed to different atmospheric forcing, taking on correspondingly distinct property and circulation characteristics. These in turn provide feedback to the climate system through their effect on Sea Surface Temperature (SST) distribution, heat and freshwater fluxes and ocean overturning. Similarity between oceans is inhibited by their varied degrees of isolation from one another, and thus the coupled ocean-atmosphere system is influenced by the efficiency of interocean exchanges that link the ocean basins. The Southern Ocean and the South Atlantic are critical nexus for the global ocean circulation and climate. They connect efficiently North Atlantic and Arctic water masses with the rest of the world ocean. Limited observations suggest that the Southern Ocean and South Atlantic are changing. They are warming more rapidly than the global ocean average. However, the short and incomplete nature of existing data means that the causes and consequences of observed changes are difficult to assess. Sustained observations are required to detect, interpret and respond to changes. Within the South Atlantic Meridional Overturning Circulation (SAMOC) international initiative we have initiate a monitoring array experiment devoted to assess the capability of deep moored arrays together with Argo profiling floats and remote sensed data to 1) estimate the Meridional Overturning Circulation in the South Atlantic; 3) infer regional water masses transformation, pathways and variability 2) apprehend dynamical processes driving water masses exchanges and transformations. The profiling Argo floats obtained under the LEFE GMMC-Coriolis programme have been deployed within SAMOC to achieve such objectives. In addition, because of the knowledge on regional dynamics and water masses acquired since the Clivar GoodHope programme, we were able to start implement new method for Argo data validation and calibration.

### Main results

Variations in the Meridional Overturning Circulation (MOC) are known to have global implications to the climate system, however until recently most MOC observing programs have been focused in the North Atlantic. Recent model and data analyses have suggested that critical water mass changes to the upper and lower limbs of the MOC occur in the South Atlantic, and only limited latitudinal coherence has been found to date between the MOC observations made by the North Atlantic observing systems at different latitudes. As a result, a priority for a the ocean science community involved in field experiments has been the establishment of a MOC observing system in the South Atlantic, and recently the International CLIVAR panel endorsed a South Atlantic MOC ("SAMOC") Initiative to both strengthen existing programs seeking to study the MOC in the South Atlantic and to encourage further expansion of the MOC observing system in the region. The MOC is a primary mechanism for the transport and storage of heat, freshwater and carbon by the ocean and therefore has a large impact on climate variability and change. The MOC is a three-dimensional circulation pattern that links each of the basins and spans the full-depth of the global oceans. Given the complex, multibasin nature of the MOC, achieving a more complete understanding of its behaviour and changes requires a more comprehensive observing system,
one that extends across neighbouring ocean basins as the one we are developing for the South Atlantic within the CLIVAR SAMOC initiative.

Within the MOC, the South Atlantic Ocean plays a key role as a nexus for water masses formed elsewhere and en-route to remote regions of the global ocean. Because of this important interbasin exchanges, the South Atlantic Ocean is the only major ocean basin that transports heat from the pole towards the equator. However, the South Atlantic is not merely a passive conduit for remotely formed water masses. Indeed, within this basin water masses are significantly altered by local air-sea interactions and diapycnal/isopycnal fluxes, particularly in regions of intense mesoscale activity and steep topography. These contributions have been shown to have a crucial role in the strength of the MOC in paleoceanographic and modelling studies.

Here we will briefly summarize some of the results we obtained during these years. We will introduce first the preliminary results on estimates of the daily MOC strength and depth at 35°S during a ~20 month long pilot array of mooring as well as Argo data and model outputs. Then, we will summarize studies that focalized on water masses exchanges and transformation and related processes within the region as well as new developments in the use of the Argo data set and in the validation-calibration processing of Argo data. Last, we used the Argo data float to calibrate and characterize the 200 stations undertaken by TaraOceans during its journey across the world ocean basins.

35°S Meridional Overturning Circulation strength and variability (Meinen et al. 2013)

Here we discuss the preliminary results on estimates of the daily MOC strength at 34.5°S during a ~20 month long pilot array of mooring. Data from two boundary arrays deployed along 34.5°S and from Argo are combined to produce the first continuous in situ time series observations of the basin-wide MOC in the South Atlantic.

The MOC variability shows to be as large as that at 26N, with both eastern and western boundary flows contributing equally to the variance. Data Daily estimates of the MOC between March 2009 and December 2010 range between 3 Sv and 39 Sv (1 Sv = 10^6 m^3 s^-1) after a 10-day low-pass filter is applied. Much of the variability in this ~20 month record occurs at periods shorter than 100 days. Approximately two-thirds of the MOC variability is due to changes in the geostrophic (baroclinic plus barotropic) volume transport, with the remainder associated with the direct wind-forced Ekman transport. When low-pass filtered to match previously published analyses in the North Atlantic, the observed temporal standard deviation at 34.5°S matches or somewhat exceeds that observed by time series observations at 16°N, 26.5°N and 41°N. The higher standard deviation may be due to opposite-signed variability unobserved by the array inshore of the 1000 m isobath (e.g. partially observed eddies). For periods shorter than 20 days the basin-wide MOC variations are most strongly influenced by Ekman flows, while at periods between 20 and 90 days the geostrophic flows tend to exert slightly more control over the total transport variability of the MOC. The geostrophic shear variations are roughly equally controlled by density variations on the western and eastern boundaries at all time-scales captured in the record. The observed time-mean MOC vertical structure and temporal variability agree well with the limited independent observations available for confirmation (Meinen et al., 2013)

Three-dimensional fields from the Argo Array (work in progress in collaboration with E. Rusciano and B. Blanke; Blanke et al. 2014; Rusciano et al. 2015 in prep)

We developed a procedure to obtain three-dimensional climatological fields of T, S and absolute geostrophic velocities from Argo data available in the South Atlantic from 2004 to 2013. The 3-D velocity field extends from the surface to 2000 dbar with a vertical resolution of 10 dbar. These fields are derived by combining on a 1° by 1° spatial grid a total of more than 600 000 individual profiles of temperature and salinity located in the South Atlantic Ocean. By deriving the dynamic height from floats and combining the derived relative geostrophic velocity with the ANDRO world atlas (Argo New Displacements Rannou and Ollitrault) of deep displacements (Ollitrault and Rannou, 2013), we computed the absolute geostrophic velocity and transports down to 2000 m. We are now using this field to achieve various studies. The first one concerns the description of Intermediate Waters properties and circulation in the region. The second one try to apply Lagrangian estimates to the 3D climatological field we derived to investigate on the path and along path transformations of the upper 2000 m water column in the South Atlantic. While the first study is ready for submission, the latter is under development.
Intermediate water properties and circulation in the South Atlantic (Rusciano et al. 2012; Rusciano et al. 2015)

We combine the Argo measured variables and the ANDRO velocity data set to infer the absolute geostrophic velocities and to estimate the evolution of the dynamical properties of South Atlantic intermediate waters within the isoneutral layer (27.1 < γn < 27.6). We found four different regional types of Intermediate Waters converging in the area south of 15°S: Three Antarctic Intermediate Water (AAIW) varieties (the Atlantic, A-AAIW, characterized by S ≤ 34.2; the Indian, I-AAIW, 34.3 ≤ S ≤ 34.4; and the recently identified Indo-Atlantic, IA-AAIW, 34.2 < S < 34.3), and a saltier Tropical South Atlantic Intermediate Water (TSA-IW, 34.4 < S ≤ 34.6).

Across 17°S two veins of intermediate waters flows northward. One along the western boundary carrying 2.3 Sv of modified Indian AAIW (I-AAIW). The other along the eastern boundary carrying 4.5 Sv of tropical intermediate waters (TSA-IW). South, between the Subantarctic Front and 27°N, intermediate waters circulate around the South Atlantic subtropical gyre. The saltiest AAIW circulate at the northern edge of the gyre while the core is made of AAIW derived from a mixing of Indian and Atlantic AAIW. This mixing happens essentially at depth in the Cape Basin (Southeastern Atlantic) where the complex dynamics of the Agulhas Retroflection and Agulhas ring injections, the strong interaction with steep topography and the coming across of waters of remote origins (South African slope and the South Atlantic Current) enhance water masses stirring and therefore impact heat and salt exchanges. No fresh A-AAIW is observed to penetrate north of 30°S.


By taking advantage of the numerous repeat hydrographic CTD sections along the GoodHope line, the large number of Argo floats deployed in the area, and the available satellite altimetry data, an Altimetry Gravest Empirical Mode (AGEM) is developed for the ACC south of Africa. The AGEM has improved precision to comparable proxies and offers an ideal technique to investigate the thermohaline variability of the upper 2000dbar of the water column over the past two decades. In order to assess and attribute changes in ocean dynamics and water masses, we separate the diabatic and adiabatic components of the reconstructed trends. Integrated over the whole top 2000dbar of the ACC south of Africa, results show adiabatic changes of 0.016 ± 0.010°C.yr⁻¹ and 3.86x10⁻³ ± 1.30x10⁻³ yr⁻¹, and diabatic trends of 8.29x10⁻⁴ ± 9.20x10⁻³ °C.yr⁻¹ and -5.72x10⁻⁴ ± 1.0x10⁻³ yr⁻¹ for temperature and salinity respectively. By combining the original AGEM fields with the diabatic differences, a new AGEM (AD-AGEM) is created rendering mean property changes of 0.012 ± 0.011 °C.yr⁻¹ and -5.47x10⁻⁴ ± 1.60x10⁻³ yr⁻¹. The study focuses on the temporal evolution of the Antarctic Intermediate Water (AAIW), finding mean trends of -0.015 ± 0.096 °C.yr⁻¹ and -2.8 x10⁻³ ± 1.33 x10⁻² yr⁻¹ for the layer within the Subantarctic zone, and 0.029±0.12 °C.yr⁻¹ and 7.17x10⁻⁴ ± 5.90x10⁻³ yr⁻¹ for the Polar Frontal Zone. The results expose the uniqueness of the ACC south of Africa in its response to climate change.

Evolution of properties of Agulhas rings in the South Atlantic (Master2 thesis of Rémi Laxenaire; Laxenaire et al. 2015 in prep)

The Indo-Atlantic exchange achieved by mesoscale eddies formed in the region of the Agulhas Current Retroflection is investigated by combining daily satellite altimetry data, profiling floats. The eddy tracking algorithm developed by Alexis Chaigneau and Cori Pegliasco (Chaigneau and Pegliasco 2013 -not yet published-) is used and further developed in our study. This algorithm takes into account eddy shapes, merging and, thanks to this study, splitting events. The method is validated in a region characterized by a particularly high eddy activity, and where eddy formation, strong eddy-eddy interactions and influence of the bottom topography are observed.

The collocation of identified eddies and Argo profiles allows us to study isolated records of the internal structure of eddies in the water column.

The thermal contents anomalies associated with the eddies, and computed with the Argo profiles, are mapped over the area of study. The anticyclones (cyclones) show positive (negative) anomalies that vary from +10⁻¹⁰ J/m² (-10⁻¹⁰ J/m²) south of Africa to +4.10⁻⁹ J/m² (-4.10⁻⁹ J/m²) in the western part of the domain, in the South Atlantic. A continuous gradient exists between these two extremes. These Eulerian mappings highlight the importance of
both the cyclones and anticyclones for heat content.

One Agulhas ring is sampled on the vertical by 19 Argo profiles between the Cape Basin and the western part of the domain in the South Atlantic. We show the presence of a homogeneous surface layer down to 300 m that subducts when the Walvis Ridge is crossed. A reminiscence of this layer is found in the region of the Mid-Atlantic Ridge, but it is no more detectable west of it. An eddy with a similar behaviour was detected in the simulation. This comparative Lagrangian study highlights that Agulhas Rings can present a warm and salty layer up to the sea surface during more than 1 year, during which exchanges with atmosphere can occur, before the anticyclones subduct. Moreover, we show that the anticyclones can advect Indian water masses to the western part of the South Atlantic.

Delayed mode analysis of Argo floats: improvements of the method in the Southern Ocean (in collaboration with C. Cabanes and J. Lepesquer; Cabanes et al. 2014)

Argo floats conductivity sensors can be subject to drift and offset due to bio-fouling or other technical problems. Several approaches have been proposed to correct the float salinity measurements in delayed time. The method developed by Owens and Wong 2009 (OW, 2009) is now widely used by the Argo community. However, our experience has shown that it is sometimes difficult to detect a float salinity drift or offset in the Southern Ocean around southern Africa only on the basis of the results from OW method and it can be necessary to use complementary approaches. In our study we have shown that some modifications of the standard OW method are necessary to gain confidence in the results proposed by the method and to make it easier for the PI of the float the decide whether a salinity correction is necessary. We have followed Cabanes et al. (2014) and slightly modified the OW method in order to better take into account the large variability of the salinity field, which is assumed to be constant in the standard method. Indeed, this high variability is caused, in the Southern Ocean, by a complex ocean dynamics characterized by intense mesoscale features and various water masses varying at the same scale.

To take into account these complex variations, additional modifications have been implemented to better take into account the presence of fronts and large eddy variability. Particularly, in this area, we implemented a new methodology that takes into account in the comparison with historical data water-masses properties such as variable theta-related depths and the dynamic height of the Argo profile. The work is still in progress, however we hope to finalise this improvements to the Argo data delayed mode analyses this year.

Fig. 1: Transport time series of the MOC at 34.5°S (red line) with estimated daily error bars (grey shading) as derived in Meinen et al. 2013. Black vertical error bar at left illustrates the estimated bias accuracy. Also shown are five MOC estimates determined from trans-basin XBT sections where the horizontal length of the bar illustrates the start and end times of each trans-basin cruise.

Fig. 2: Isopycnic potential vorticity (10^{-11} m^3 s^{-1}) computed in the neutral density isopycnal layer (27.1 < \gamma_n < 27.6).
**Future of the project:**
The SAMOC international initiative is continuing. In particular, SAMOC has received much attention lately from the European Commission, USA and Canada within the Galway Agreement on Atlantic observing implementation. The participation of SAMOC community in the H2020 EU AtlantOS project will foster collaborations with Northern Hemisphere countries and the capability of the observing system will evaluated and possibly enhanced. Due to the new appointment of the French PI, Sabrina Speich, to the “Laboratoire de Meteorologie Dynamique” (LMD) of the “Institute Pierre-Simon Laplace” (IPSL) in Paris, has broke off momentarily the activity of SAMOC in terms of Coriolis Argo floats deployment.

**Bibliographic references linked with the project**

**Communications linked with the project**
Speich, S., Use of ARGO floats to study the ocean dynamics south of Africa: what we have learned from the GoodHope project and what we plan within the SAMOC international programme. "20 years of Progress in Radar Altimetry" symposium and 4th Argo Science Workshop - Venice, Italy. Sept. 2012
Speich, S., 2014 : Advances on the understanding of Indo-Atlantic exchanges from a complementary approach using model and observations within Good-Hope and SAMOC projects. Workshop : SAMOC V

Speich, S., 2015: South Atlantic MOC observations: past, present, future. Solicited presentation at the 26th General Assembly of the International Union of Geodesy and Geophysics (IUGG), 22nd June – 2nd July 2015, Prague, Czech Republic.


**Formation to scientific research linked with the project**

- Emanuela Ruscianto, 3 years of postdoctoral program (contracts from CNRS, ANR-UBo and ENS).
- Rémi Laxenaire, 5 months of Master 2 internship.
- Katherine Hutchinson, 12 months of Master 2 internship between Brest and cape Town.
- Jeremy Lepesquer, 4 months of Research Engineer contract.