Projet ANR-11- IS56-0004

South Atlantic Meridional Overturning Circulation

SAMOC

Programme BLANC International 2012

A IDENTIFICATION

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B RÉSUMÉ CONSOLIDÉ PUBLIC

B.1 RÉSUMÉ CONSOLIDÉ PUBLIC EN FRANÇAIS

Mettre l'océan sous écoute pour en suivre ses battements : Conception d'une stratégie d'observation efficace du pulse de la circulation océanique

L'océan par sa capacité à absorber la chaleur et le CO2 d'origine anthropique et à les distribuer via sa circulation globale, constitue le cœur du système climatique terrestre et est le majeur régulateur de ses changements. Appréhender son état et mesurer ses changements constituent donc des éléments clé pour connaître l'état du système climatique actuel et futur. Malheureusement l'océan est un milieu encore très peu connu et si pendant les deux dernières décennies notre connaissance de l'océan de surface a énormément progressé beaucoup rester à faire pour évaluer de manière quantitative les courants marins et les propriétés (chaleur, sel, oxygène, carbone, éléments nutritifs) qu'ils transportent sur toutes les profondeurs. Notre projet a contribué à démontrer la faisabilité et la mise en œuvre d'un système d'observation efficace et innovant de l'océan. Des études de modélisation numériques effectuées en parallèle nous ont permis d'appréhender de nouveaux phénomènes. Ce projet a concouru à la mise en place d'un partenariat international très important qui a débuché sur un accord international, la mise en œuvre d'un projet Européen d'ampleur et l'ouverture de nouveaux appels à projets Européens.

Reconstruction de la circulation océanique par optimisation des nouvelles technologies d'observation et de modélisation numérique

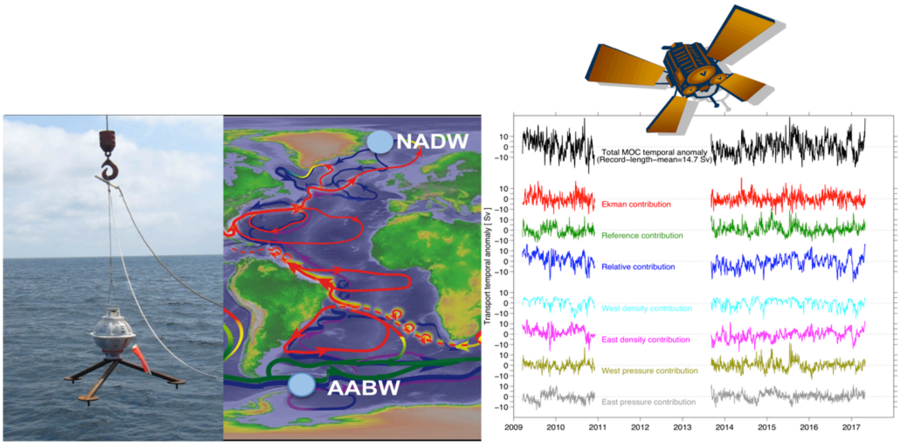
Le projet ANR SAMOC nous a permis de tester régionalement un réseau d'observation de l'océan qui, à un coût modéré, permet de mesurer le transport des propriétés de l'océan à très haute fréquence (journalière) et de caractériser les événements responsables de ses variations. Pour cela nous avons déployé en mer des outils de mesure innovants: des mouillages posés au fond de la mer (jusqu'à 4200 m) qui mesurant en même temps les courants, la pression et la vitesse du son ; des bouées profilantes Argo, robots submersibles autonomes qui mesurent les propriétés physiques (et plus récemment des paramètres biochimiques) de l'océan. Nous avons aussi effectué des campagnes océanographiques avec la mise en œuvre de nouvelles technologies de mesures embarquées, qui permettent des mesurer de manière plus fréquente et automatique la structure en température et salinité de la colonne d'eau ou, encore, une caméra sous-marine capable de mesurer les particules (de matière vivante ou non) contenues dans l'eau de mer. Ces mesures que nous avons associé à d'autres observations (essentiellement satellitaires ou robotisées) nous ont permis d'accéder à des résultats novateur.

Résultats majeurs

Parmi différents résultats du projet, nous avons pu estimer pour la première fois le transport des courants marins dans la région d'étude. Ces résultats nous montrent que les écoulements de surface et profonds de l'océan sont extrêmement variables et cela à toutes les fréquences observées (de la journée à quelques années). Ce résultat, qui nous donne une vision de la dynamique océanique très différente de celle que nous pouvions avoir avant l'issue du projet, est important car ces courants, qui se dévoilent à nous, influencent le climat de la planète et les écosystèmes marin. Un réseau d'observations tel que celui que nous avons mis en œuvre s'est ainsi révélé essentiel pour une surveillance de l'océan sur toute sa profondeur. Le projet a acquis une très grande visibilité internationale, il a fortement contribué à la mise en œuvre d'un projet Européen de grande ampleur et il a abouti à un partenariat international inédit, avec la signature d'un accord international de collaboration scientifique sur l'observation de l'océan.

Production scientifique

Nous avons produit une importante série de nouvelles observations qui sont accessible par la communauté scientifique internationale et contribuent à la surveillance de l'état de l'océan et du climat. Dans le cadre du projet ont été effectuées 4 thèses et trois études postdoctorales. Nous avons publié une vingtaine de publications scientifiques dans des journaux internationaux qui présentent nos résultats. Nous avons organisé 5 workshops et plusieurs sessions dans des conférences internationales.



Le projet SAMOC est un projet de recherche fondamentale coordonné par Sabrina Speich. Il associe aussi des chercheurs du LPO-Ifremer, ainsi que des laboratoires internationaux. En fait il a été conçu avec Edmo Campos de l'Université Fédérale de Sao Paolo (Brésil) et co-financé par l'agence Brésilienne FAPESP. Il a réuni ensuite un partenariat plus large qui regroupe la *National Ocean and Atmosphere Administration* (NOAA, Etats Unis), l'Université du Cap (Afrique du Sud), le *Department of Environmental Affairs* (Afrique du Sud), l'Université RSMAS (Miami, Floride, Etats Unis), l'Université de Buenos Aires (Argentine), l'institut GEOMAR (Kiel, Allemagne) et le *National Oceanic Centre* (NOC, Royaume Uni). Le projet a commencé en mars 2012 et a duré 48 mois. Il a bénéficié d'une aide ANR de 700 000 € pour un coût global de l'ordre de 10 000 000 €

B.2 RÉSUMÉ CONSOLIDÉ PUBLIC EN ANGLAIS

Listening to the ocean to monitor its beat: Designing an effective ocean circulation observing strategy

The ocean's ability to absorb anthropogenic heat and CO2 and distribute it through its global circulation constitutes the core of the Earth's climate system and the major regulator of its changes. Apprehending its state and measuring its changes are therefore key elements to assess the state of the current and the future climate system. Unfortunately, the ocean is an environment that is still underdetermined and, if during the last two decades our knowledge of the surface ocean has progressed enormously, much remain to be done to quantitatively evaluate the ocean currents and properties (heat, salt, oxygen, carbon, nutrients) that they transport to all depths. Our project has helped to demonstrate the feasibility and implementation of an effective and innovative ocean observing system. Numerical modeling studies carried out in parallel have allowed us to understand new phenomena. This project has contributed to the establishment of a very important international partnership which has led to an international agreement, the implementation of a major European project and the opening of new European calls for projects.

Reconstructing the ocean circulation by optimizing new observations and numerical modeling technologies

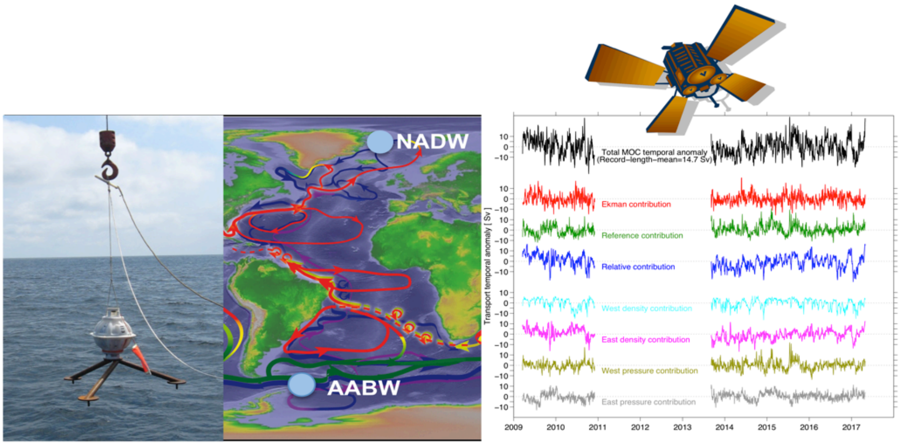
The ANR SAMOC project has allowed us to test regionally an ocean observing network that, at a moderate cost, makes it possible to measure the transport of the ocean properties at very high frequency (daily) and to characterize the events responsible of such variations. To this end, we have deployed innovative measuring tools at sea: moorings placed at the bottom of the sea (up to 4200 m) which simultaneously measure currents, pressure and the speed of sound and many Argo profiling buoys, that are autonomous submersible robots that measure the physical (and more recently biochemical) properties of the ocean. We have also carried out oceanographic cruises with the implementation of new onboard measurement technologies, which allow to measure more frequently and automatically the temperature and salinity structure of the water column as well as an underwater camera, capable of measuring particles (of living matter or not) contained in the seawater. These measurements that we associated with other observations (mainly satellite or robotized) allowed us to reach innovative results.

Major achievements

Among the different results of the project, we were able to estimate for the first time the transport of marine currents in the study area. These results show us that surface and deep ocean flows are extremely variable at all observed frequencies (from day to a few years). This result, which gives us a vision of ocean dynamics very different from what we could have before the end of the project, is important because these currents, which are revealed to us, influence the climate of the planet and marine ecosystems. An observation network such as the one we implemented proved to be essential for monitoring the ocean in all its depth. The project has gained a great international visibility, it has strongly contributed to the implementation of a large-scale European project and it has resulted in an unprecedented international partnership, with the signing of an international agreement for scientific collaboration on the subject.

Scientific outcomes

We have produced an important series of new observations that are accessible by the international scientific community and contribute to monitoring the state of the ocean and the climate. As part of the project, 4 PhDs and 3 postdoctoral studies were completed. We have published more 20 scientific publications in international journals presenting the achieved results. We organized 5 workshops and several sessions in international conferences.



The SAMOC project is a fundamental research project coordinated by Sabrina Speich (IUEM and LMD). It also associates researchers from LPO-Ifremer, as well as international laboratories. In fact it was designed together with Edmo Campos of the Federal University of Sao Paolo (Brazil) and co-financed by the Brazilian agency FAPESP. We then extended the project across a broader international partnership that includes researchers from the National Ocean and Atmosphere Administration (NOAA, USA), the University of Cape Town (South Africa), the Department of Environmental Affairs (South Africa), RSMAS University (Miami, Florida, USA), the University of Buenos Aires (Argentina), the GEOMAR Institute (Kiel, Germany) and the National Oceanic Center (NOC, United Kingdom). The project started in March 2012 and lasted 48 months. It benefited from an ANR funding of 700 000 € for a total cost of about 10 000 000 €

C MÉMOIRE SCIENTIFIQUE

Mémoire scientifique confidentiel : non

C.1 SUMMARY

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Among the different results of the project, we were able to estimate for the first time the transport of marine currents in the study area. These results show us that surface and deep ocean flows are extremely variable at all observed frequencies (from day to a few years). This result, which gives us a vision of ocean dynamics very different from what we could have before the end of the project, is important because these currents, which are revealed to us, influence the climate of the planet and marine ecosystems. An observation network such as the one we implemented proved to be essential for monitoring the ocean in all its depth. The project has gained a great international visibility, it has strongly contributed to the implementation of a large-scale European project and it has resulted in an unprecedented international partnership, with the signing of an international agreement for scientific collaboration on the subject.

C.2 STAKES, PROBLEMATIC AND STATE OF THE ART

Climate change and variability are major societal challenges, and the ocean is an integral part of this complex and variable system. Key to the understanding of the ocean's role in the Earth's climate system is the study of ocean physical processes, including its interactions with the atmosphere, cryosphere, and ecosystems. These processes include, those linked to ocean circulation; the distribution and transport of heat, salt and other water properties; exchanges of heat, momentum, freshwater, and gasses between the ocean, atmosphere, land and cryosphere. Ocean physical observations are fundamental to reliable earth system forecast and prediction systems for a range of applications and users. In addition knowledge of the physical environment is fundamental to growing understanding of the ocean’s biogeochemistry and biological/ecosystem variability and function.

In this framework, the global ocean circulation, often defined as the global ocean Meridional Overturning Circulation (MOC, Figure 1), is of capital importance for the Earth climate and society. Indeed, variability in the MOC is correlated with important worldwide climate variations, including changes sea-level, rainfall patterns and intensity, inter-hemispheric temperature contrasts, atmospheric temperature gradients, diversity and biogeography of ecosystems such as cold-water corals and commercial fisheries (e.g. Vellinga and Wood, 2002; Stouffer et al., 2006; Latif et al., 2007; McCarthy et al., 2015a; Lopez et al., 2016). A slowing MOC is one of the fundamental predictions of anthropogenic-forced climate change in the 21st Century. Observing, predicting and understanding the causes and consequences of this slowing is therefore a preeminent scientific problem.

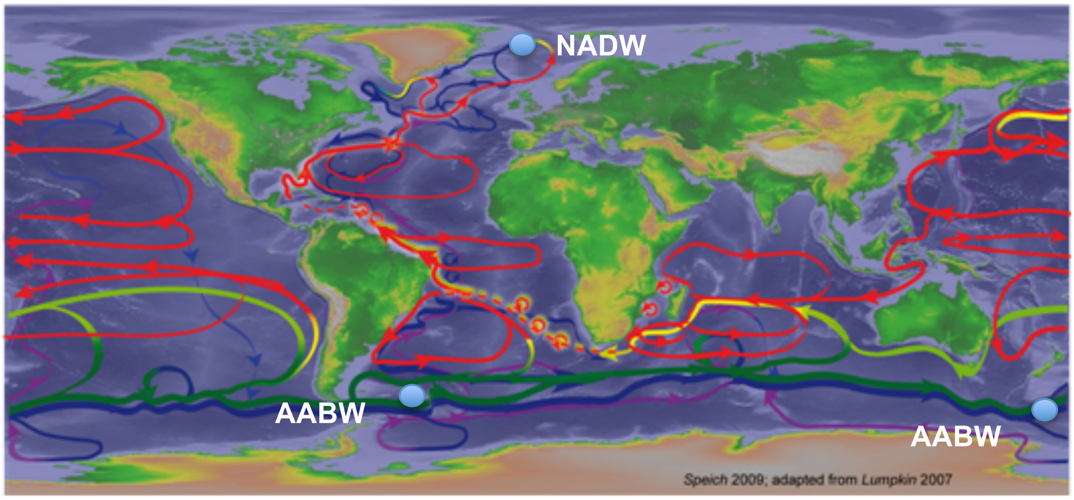

Figure 1*. Schematic diagram of the global overturning circulation that represents the large-scale conversion of surface waters (red arrows) to deep waters (blue arrows in the Southern Ocean; dashed blue line arrows for the North Atlantic Deep Water), adapted from Speich et al. 2010 and "charting and course of the Ocean Science in the United States for the next decade", 2007, R. Lumpkin, NOAA/AOML. The South Atlantic circulation includes water mass transformations including intermediate water (yellow and green arrows) and considerable uncertainty in the mean pathways (dashed lines) and eddy processes (red and blue circular rings).*

Theoretical and observational studies of the mechanisms controlling the MOC in the Atlantic have suggested that the MOC is presently bistable, with on and off states, and that MOC stability is controlled by interocean exchange between the South Atlantic and Southern Oceans (e.g. Dijkstra, 2007; Huismann et al., 2010; Drijfhout et al., 2011; Garzoli et al., 2013). While continuous, daily, observations of the MOC have been ongoing for 13+ years in the North Atlantic at 26.5°N (e.g. Kanzow et al., 2007; McCarthy et al., 2015b; Frajka-Williams et al., 2016; Smeed et al., 2018), observations of the MOC in the South Atlantic have been limited mainly to repeated quasi-synoptic snapshot ship sections using either expendable bathythermograph (XBT) probes (e.g. Garzoli and Baringer, 2007; Dong et al., 2009) or full-depth conductivity-temperature-depth (CTD) profiles (e.g. Lumpkin and Speer, 2007; Bryden et al., 2011; McCarthy et al., 2011), and to indirect estimates combining satellite observations with irregularly spaced (in time and space) hydrographic data (e.g. Dong et al., 2015; Majumder et al., 2016). While these studies have greatly improved our understanding of the MOC structure and dynamics (e.g. Garzoli and Matano, 2011; Buckley and Marshall, 2016), the daily MOC observations at 26.5°N have illustrated the importance of continuous observations to avoid aliasing highly energetic short period variations (e.g., Kanzow et al., 2010).

The successes of the trans-basin array at 26.5°N and the other North Atlantic MOC observing systems have provided many insights, but they have also raised several new questions, such as the degree to which MOC fluctuations are correlated meridionally as well as the mechanisms associated with the complex phasing between atmospheric forcing and intrinsic variability (e.g. Zhang, 2010; Zhang et al., 2011). Furthermore during the decade when these observations have been collected, a wide range of theoretical and numerical modeling studies have demonstrated that the variability in the subtropical North Atlantic is only one facet of a complex circulation system, with significant variability and forcing introduced in the South Atlantic, for example (e.g. Garzoli and Matano, 2011, and references therein). Within the South Atlantic itself, regular trans-basin hydrographic and expendable bathythermograph (XBT) section observations have been collected at selected latitudes such as 24°S (e.g. Bryden et al., 2011; McCarthy et al., 2011), 30°S (McDonagh and King, 2005), and 34.5°S (e.g. Baringer and Garzoli, 2007; Garzoli and Baringer, 2007; Dong et al., 2009; Garzoli et al., 2013).

Key objectives of SAMOC include the need to characterize the temporal variability of the MOC and the mechanisms controlling that variability, to provide a means to observe the changes in the ventilation characteristics and relative contributions of different water masses to the MOC, and perhaps more importantly to monitor the nature of exchange between the Indian and Atlantic Oceans and beyond. The SAMOC ANR project has addressed these gaps in understanding through new observations, leveraging on an international partnership going beyond the initial agreement between the ANR (France) and FAPESP (Brazil) components. The SAMOC partnership has led to build a fit-for-purpose observing network particularly efficient in terms of observing capability and cost. Its conception has been based on careful system evaluation undertaken at the beginning of the project. The data obtained and their analyses, including the *ad hoc* modeling studies developed during the project, have provided groundbreaking results enabling a critical ground truth of numerical simulations of these processes for climate models.

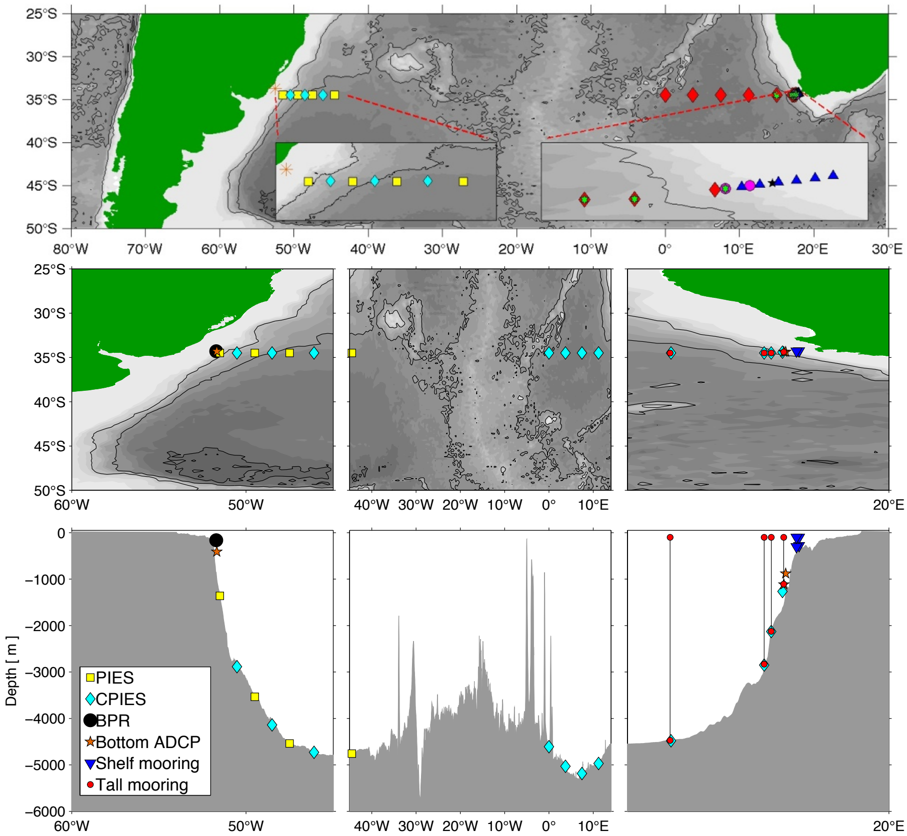

Figure 2 Maps showing the SAMOC moored instrument locations, in the west and in the east along the 34.5°S line; (b) a zoomed version of the mooring array to enhance the view of moorings on the continental slopes; (c) The distribution of the SAMOC 34.5°S mooring array along the vertical. Topography in the top panel (gray shading with 500 m intervals; every 2000 m contour shown as black contour) is from Smith and Sandwell (1997).

C.3 Scientific and Technical Approaches

At the beginning of the SAMOC project, we undertook observing system design studies (also generally referred to as Observing System Experiment – OSE) to locate the best site and observing configuration enabling a high-frequency sampling of the MOC. These studies have suggested that, of the South Atlantic latitudes, 34.5°S would be ideal for capturing MOC variability at the 'mouth' of the Atlantic basin (Perez et al., 2011). This location was also well supported by theoretical analyses that suggest that crucial MOC stability evaluations would be best applied as far from the equator in the South Atlantic as possible (e.g. Dijkstra, 2007; Drijfhout et al., 2011).

In the subtropical South Atlantic the character of the MOC is somewhat different than at 26.5 N in the North Atlantic in that at 34.5°S the northward flowing warm upper limb of the MOC is primarily found near to the eastern boundary in the Benguela Current and Agulhas Rings, while in the North Atlantic at 26.5°N the upper limb of the MOC is primarily found near to the western boundary. As such, it is more critical in the South Atlantic to have detailed, well resolved measurements near both, the eastern and western boundaries.

We therefore tested the potential of the designed SAMOC observing system using, in the first phase of the SAMOC project, data from the SAMOC initial pilot array, that consisted of 6 bottom Current Pressure Inverted Echo Sounders (CPIES) deployed at each end of the South Atlantic Basin at 34.5°S. Towards the mid-phase of the SAMOC ANR project, we developed further the SAMOC observing system that, today, includes 20-30 deep ocean moorings, a combination of tall moorings and CPIES on the shelf and continental slopes on either side of the basin (Fig. 2). Funds are also being sought to augment the trans-basin array through the addition of more moored instruments, for example to better sample transport streams by the different water masses on the western boundary continental shelf and slope. This has been achieved at the eastern boundary, where South African colleagues who joined the SAMOC project, deployed four tall moorings. These measurements have been analyzed in concert with data from the wider SAMOC observational network which includes moored arrays at other latitudes, repeat shipboard (XBT and CTD) transects, Argo profiling floats, surface drifting buoys, and satellites.

We in particular used Argo profiling floats to recover the mean horizontal and vertical structure from the upper layers to the base of the thermocline in the South Atlantic.

Besides the OSE modeling studies, we also used numerical simulations to interpret observations and assess the physical process governing the observed circulation and variability.

C.4 Major Results

During the preliminary phase of the SAMOC ANR project we undertook efforts to estimate the MOC at 34.5°S and to try to assess the related processes governing its mean state and variability. We worked on the preliminary data obtained from the SAMOC pilot phase moorings network, Argo floats and we also developed modeling strategies to understand the observations. The results (e.g., Rusciano et al., 2012 ; Rimaud et al., 2012 ; Meinen et al., 2013) proved to be groundbreaking and showed the need for the monitoring of the ocean and climate states and variability at different latitudes (and hemispheres) than at 26.5°N in the North Atlantic.

This led us into the second phase (started in 2013) where we enhanced the observing effort in order to build as long as possible time series with, thanks to the SAMOC ANR levearaging, a significant enhancements of the observing network and new partners (e.g. Ansorge et al., 2014; von Schukmann et al., 2014; Kersalé et al., 2018; Laxenaire et al. 2018a,b; Meinen et al. 2018). The observing effort has been accompanied by modelling experiments devoted to the understanding of the involved processes governing the ocean dynamics and variability and to help the efforts on numerical parametrization of small-scale processes for global ocean and climate models (e.g., Rimaud et al., 2012; Blanke et al., 2014; Capuano et al., 2018a,b).

In particular, the SAMOC results reveal a highly energetic MOC record with a temporal standard deviation of 8.3 Sv (1 Sv = 10^6 m^3 s^{-1}), and strong variations at time scales ranging from a few days to years (peak-to-peak range = 54.6 Sv). Much of the variability occurs at periods shorter than 100 days (Figure 3). Approximately two-thirds of the MOC variability is due to changes in the density related volume transport (what we call the geostrophic part), with the remainder associated with the direct forcing by the local wind (the 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. By contrast with 26.5°N, where the non-Ekman components of MOC variability appear to be primarily driven by western boundary changes at all time scales aside from seasonal (e.g. Chidichimo et al., 2010; McCarthy et al., 2015), at 34.5°S MOC variability appears to be more complicated. At 34.5°S, eastern boundary density variations are the most important at the interannual time scales during the observed period (2009-2017), but the western boundary density contributions are still significant, and barotropic changes dominate in some years.

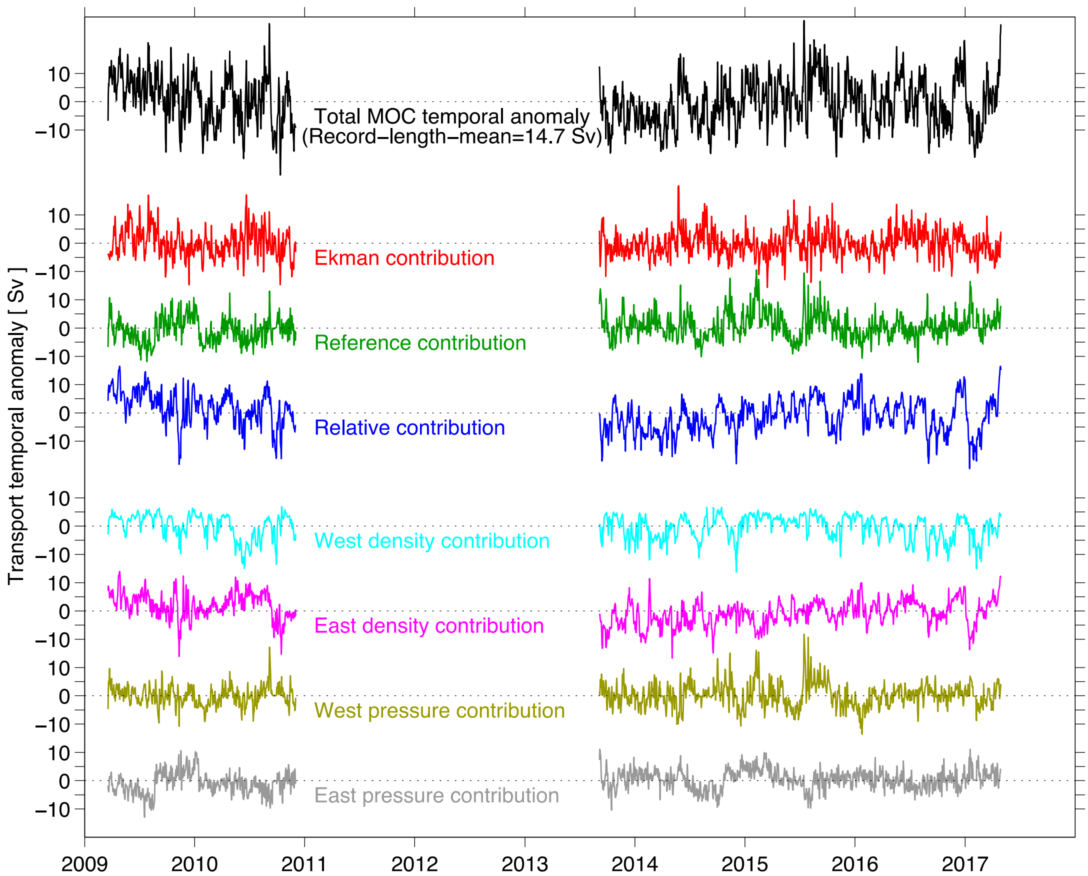

Figure 3: Time series (temporal anomaly relative to the record-length mean) of the basin-wide MOC volume transport across 34.5°S calculated as described in the text. The total (net) transport anomaly is shown in black. The record-length mean total MOC value that has been removed to create the anomaly is noted on the figure. Also shown are the contributions of Ekman, geostrophic reference flow, and geostrophic relative flow components; the geostrophic relative and reference flow components are further broken down into the contributions from variations in the western and eastern density or pressure contributions, respectively. For all components, the 'contribution' is estimated as the difference between the total MOC (black line) and the MOC calculated while holding the term in question constant (i.e. the reference contribution is the difference between the total MOC and the MOC that was calculated holding the bottom pressure values on both sides of the basin constant).

Baroclinic (density-driven) and barotropic (bottom pressure-driven) changes at both boundaries are clearly important at seasonal time scales. At time scales shorter than semi-annual, variations at the western boundary meet or exceed those of the eastern boundary, although this may solely be a function of where the mooring locations are relative to the Brazil and Benguela Currents. Planned augmented observations on the continental shelves and upper slopes will aid in the future in evaluating the sensitivity of the estimated MOC by better capturing the near-shore transports, and will improve the overall accuracy of these MOC estimates. The observations presented here demonstrate unequivocally that the dynamical control of the MOC flows at 34.5°S is more broadly spread across the basin than at 26.5°N. This is likely due to the South Atlantic basin's role as a 'mixing pot' for exchange with the Indian and Pacific basins. This is also what results from our analyses of Argo floats in the South Atlantic (Rusciano et al. 2012; Rusciano and Speich, 2018). These measurements also illustrate the essentiality of continuous daily observations to avoid aliasing of highly energetic short period variations, and the strong need to independently observe both the baroclinic (density gradient driven) and barotropic components of the MOC flow at both boundaries.

C.5 RESULTS EXPLOITATION

The experimental results of SAMOC have been exploited at three levels:

Advancing knowledge: Data were presented annually throughout the project to international conferences and ocean and climate international organizations (*e.g.*, CLIVAR, WCRP, GCOS, OOPC). All the data and results have been publically released and can be used by the wider scientific community or any other stakeholder.

Advancing research: We have released a significant number of international refereed publications that provided new knowledge to the broader scientific community. SAMOC results have been integrated in various "state of climate" assessments, in the global ocean monitoring systems and are repeatedly used to understand natural versus anthropogenic forced climate variability as well to assess the skill of numerical model simulations. SAMOC has been key in leveraging international scientific cooperation in Europe, North America, Africa and South America.

Advancing international cooperation: SAMOC highly contributed and still contributes to the wider AtlantOS H2020 Eu project and consortium and has constituted the base element of the recently signed Bélem Statement between the European Commission, South Africa and Brazil on the Atlantic Research and Innovation Cooperation.

C.6 DISCUSSION

The SAMOC project has benefited from a very good group dynamic and numerous collaborations and exchanges between all partners associated officially by the consortium agreement and those that joined the project in route with in-kind funding. The organization and implementation of the observations, analyses, numerical simulations, publications and communications were particularly well managed, which contributed to the success of the project. This allowed the academic work initially envisaged in SAMOC to go somewhat beyond and may be depart slightly (but by opening new perspectives) from the initial objectives.

The SAMOC project had three fundamental objectives:

1. **To measure the capability of a cost effective observing array to "observe" the *South Atlantic MOC*, as well as, its variability and changes.**

   We have achieved this objective and even surpassed it quantitatively and qualitatively. We will continue to try to maintain the full SAMOC observing system in place by taking advantage of the large international collaborations that this project has leveraged. We now count in SAMOC participation in the observing and modeling aspects with seven countries and 13 institutions. Funding for maintaining the network will be looked at national and international level. Indeed, this time series has revealed essential in measuring and understanding the South Atlantic segment of the MOC but it reveals to be one of the few existing time-series able to capture changes in the ocean dynamics. Its existence and continuation will contribute to arousing the oceanographic and climate communities with ground-truth observations needed for climate monitoring and seasonal-to-decadal forecasts.

2. **To improve our knowledge on dynamical processes responsible of the MOC and its variation.**

   We have conducted different studies, using observations and numerical models or both at the same time to enhance our understanding the MOC and its variability. We were able to identify the interannual to daily scales of MOC variations that showed to be extremely energetics and evolving at frequencies much higher than ever suggested in the literature. We have been also able to isolate many dynamical processes. All studies suggest that the local action of the wind stress is important but so is the remote forcing from the Indian and Pacific oceans. Also, the SAMOC achieved studies clearly indicates the importance of mesoscale and smaller scale processes (eddies, filaments and submesoscale) in achieving the South Atlantic MOC transport of properties (mass, heat, freshwater). These processes are responsible of advecting water properties as well as of capital importance for water masses formation, subduction and mixing. We were also able to assess clearly how numerical simulations could be improved in order to resolve properly these processes.

3. **To improve our understanding on how ocean dynamics intervenes on air-sea exchanges and biogeochemistry tracer transports and budget.**

   This objective has been only partially fulfilled. Indeed it is too large to be achieved within a single, and limited in time, project. However, we have shown that air-sea interactions take place at the ocean mesoscale and they are responsible of huge heat (and water vapor) release to the atmosphere, ocean heat uptake as well as that of carbon and other properties. They also strongly shape marine ecosystems (from nutrients, oxygen and the lower level of the trophic system to top predators). We will continue to investigate on this aspects within the H2020 TRIATLAS European Project if accepted (it passed phase 1 of evaluation) within a very large “South Atlantic” consortium.

C.7 Conclusions

Thanks to the scientific support represented by its selection under the 2011 International call for projects and thanks to the induced funding, the SAMOC project was able to achieve its ambitious objectives. The results of this project have greatly improved our knowledge on the MOC revealing highly energetic and highly variable behavior unexpected and never documented in previous studies. The SAMOC project has allowed us to test regionally an ocean-observing network that, at a moderate cost, makes it possible to measure the transport of the ocean properties at very high frequency (daily) and to characterize the events responsible of such variations.

The various, seminars, workshops, conferences organizations during the project made it possible to disseminate the knowledge acquired and led to create a very active international dynamic around this fundamental element of our climate system. It has leveraged new projects and collaborations that federate now in a large scientific community.

C.8 References

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D LISTE DES LIVRABLES

Date de livraison	N°	Titre	Nature (rapport, logiciel, prototype, données, …)	Partenaires (souligner le responsable)	Commentaires
01.01.2014	**T1.1**	Operational web site with set up of a data base	Web page and data base	IUEM, Ifremer, FAPESP, NOAA	http://www.aoml.noaa.gov/phod/SAMOC_international/index.php
One meeting every year since the beginning of the project	**T1.2**	SAMOC Meetings 5, 6, 7, 8	Meetings	IUEM, ifremer, Fapesp, NOAA, Argentine, UCT, DEA	http://www.aoml.noaa.gov/phod/SAMOC_international/samoc_background2.php
One report every year since the beginning of the project and cruises, operations at sea reports at every operation at sea	**T1.3**	SAMOC Reports 1, 2, 3, 4	Project reports, Cruises reports, Technical reports	IUEM, ifremer, Fapesp, NOAA, Argentine, UCT, DEA	http://www.aoml.noaa.gov/phod/SAMOC_international/samoc_background2.php
Many of them, practically every year.	**T2.1**	Full depth cruises and SAMOC (western, eastern and GoodHope) moorings deployment	Oceanographic cruises, Instruments (moorings and Argo floats) deployment, full depth CTDs, cruises reports	IUEM, ifremer, Fapesp, NOAA, Argentine, UCT, DEA, GEOMAR	The deployment and cruises are still ongoing to try to maintain the observing network and the precious time series
2012, 2013, 2014, 2015, 2016, 2017, 2018	**T2.2**	SAMBA/SAMOC Mooring turnover	Mooring turnover	IUEM, ifremer, Fapesp, NOAA, Argentine, UCT, DEA, GEOMAR	
2013, 2015, 2018	**T2.2**	GoodHope/SAMOC Mooring turnover	Mooring turnover	IUEM, ifremer, Fapesp, NOAA, Argentine, UCT, DEA, GEOMAR	
2013, 2018	**T2.3**	SAMOC Data deliveries	Data delivered	IUEM, ifremer, Fapesp, NOAA, Argentine, UCT, DEA, GEOMAR	
2013	**T3.1**	First estimate of regional dynamics and SAMOC variability from the pilot project	Paper published in J. Geophys. Research	IUEM, ifremer, Fapesp, NOAA, Argentine, UCT, DEA,	
2013, 2018	**T3.2**	Development of appropriate indicators	Various indicators developped	IUEM, FAPESP, NOAA	
2015, 2018	**T3.3**	Modelling processes studies	Three papers published in J. Geophys. Res.	IUEM, ifremer, Fapesp, NOAA, Argentine, UCT, DEA,	
2015, 2018	**T3.4**	Regional air-sea numerical coupled systems and data analyses : processes studies and régional downscaling	A 2-year study that is now reconsidered. A workshop has been organized	IUEM	

E IMPACT DU PROJET

Ce rapport rassemble des éléments nécessaires au bilan du projet et plus globalement permettant d'apprécier l'impact du programme à différents niveaux.

E.1 INDICATEURS D'IMPACT

Nombre de publications et de communications (à détailler en E.2)

		Publications multipartenaires	Publications monopartenaires
International	Revues à comité de lecture	17	
	Ouvrages ou chapitres d'ouvrage		
	Communications (conférence)	30 + 3 Workshops organisés	
France	Revues à comité de lecture		
	Ouvrages ou chapitres d'ouvrage		1
	Communications (conférence)		
Actions de diffusion	Articles vulgarisation		
	Conférences vulgarisation		
	Autres		

Autres valorisations scientifiques (à détailler en E.3)

	Nombre, années et commentaires (valorisations avérées ou probables)
Brevets internationaux obtenus	
Brevet internationaux en cours d'obtention	
Brevets nationaux obtenus	
Brevet nationaux en cours d'obtention	
Licences d'exploitation (obtention / cession)	
Créations d'entreprises ou essaimage	
Nouveaux projets collaboratifs	AtlantOS EU H2020, TRIATLAS EU H2020 (en cours de soumission)
Colloques scientifiques	5
Autres (préciser)	

E.2 LISTE DES PUBLICATIONS ET COMMUNICATIONS

REFEREED ARTICLES

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Speich, S., and P. Klein, Satellite and in situ fields experimentation in a turbulent ocean, ESA/GlobCurrent User Consultation Meeting, 7-9 March 2012, Ifremer, Brest (France)

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

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Hutchinson, K., S. Speich, S Swart, I. Ansorge, A. Meijers, 2014 : Thermohaline variability of AAIW in the Atlantic sector of the Southern Ocean investigated using an Altimetry Gravest Empirical Mode. SCAR XXXIII Assembly, Aukland, New Zealand., 25-28 August 2014.

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 MEETING, ICTP-CONICET, Buenos Aires, Argentina, 1 – 5 December 2014.

Speich, S., 2015 : A highly turbulent interocean exchange South of Africa, SYNBIOS Workshop, Ecole normale supérieure, 8-10 July 2015, Paris, France.

Visbeck, M., A. S Fischer, P.-Y. Le Traon, M. C Mowlem, S. Speich, K. Larkin, 2015 : Are Global In-Situ Ocean Observations Fit-for-purpose? Applying the Framework for Ocean Observing in the Atlantic. Fall Meeting of the American Geophysical Union, San Francisco, California, December 2015.

Speich, S., C. Meinen, E. Campos, A. Piola, S. Garzoli, M. Roberts, I. Ansorge, R. Perez, S. Dong, T. Terre, M. Van van den Berg, M. Kersalé, 2016, Recent daily MOC variability estimates at 34.5°S from in situ observations and comparisons with estimates at 26.5°N . Ocean Sciences, American Geophysical Union, New Orleans, Louisiana, USA, February 2016.

Blanke, B., S. Sabrina, E. Rusciano, 2016, Tracking AAIW properties, transformations and paths in the South Atlantic from Argo floats data and a global ocean model. Ocean

Sciences, American Geophysical Union, New Orleans, Louisiana, USA, February 2016.

Chichidimo, M.-P., A. Piola, C. Meinen, E. Campos, S. Garzoli, R. Perez, S. Speich, S. Dong, R. Matano, V. Combes, 2016 : Intraseasonal to Interannual Variability of the Brazil Current Transport Measured at 34.5°S - Baroclinic and Barotropic Contributions. Ocean Sciences, American Geophysical Union, New Orleans, Louisiana, USA, February 2016.

Capuano, T., S. Speich, X. Carton, 2016 : Small scale ocean dynamics in the Cape Basin, south of Africa, and the impact on the ocean circulation. Ocean Sciences, American Geophysical Union, New Orleans, Louisiana, USA, February 2016.

Laxenaire, R., S. Speich, 2016 : A New Insight on the Indo-Atlantic Exchange Achieved by Indian Ocean Eddies Assessed by Satellite Altimetry and Argo Profiling Float Data. . Ocean Sciences, American Geophysical Union, New Orleans, Louisiana, USA, February 2016.

Speich, S., J. Karstensen, R. Laxenaire, F. Schütte, M. Körner, 2016 : Eddy high-way connecting boundary currents – Long-lived Mesoscale Eddies in the South Atlantic. Clivar Open Science Conference, Quindao, China, 20-25 September 2016.

Speich, S., C. Meinen, A. Piola, E. Campos, S. Garzoli, M. Roberts, I. Ansorge, R. Perez, S. Dong, M.P. Chichidimo, M. van der Berg, M. Kersalé, G. Goni, and T. Terre, 2016 : The South Atlantic MOC international initiative: Status and preliminary results.Clivar Open Science Conference, Quindao, China, 20-25 September 2016.

Chichidimo, M.-P., A. Piola, C. Meinen, E. Campos, S. Garzoli, R. Perez, S. Speich, S. Dong, R. Matano, V. Combes, 2016 : Absolute Brazil Current transport: Five year observations at 34.5°S. Clivar Open Science Conference, Quindao, China, 20-25 September 2016.

SCIENTIFIC EXPOSURE

2016 Speich, S., Collaboration avec Oceanopolis (Brest) sur un projet de visite virtuelle de l'océan centré sur les impacts du changement climatique.

2016 Speich, S., Interview sur les enjeux de l'océan dans le cadre du changement climatique pour Universcience.

2016 Speich, S., Organisation d'une conférence à l'ENS sur « Tout ce que vous voulez savoir sur le climat » dans le cadre de la Participation de l'ENS à la Nuit des débats, organisée par la Mairie de Paris.

2015 Speich, S., Conférence à Océanopolis sur l'Océan et le Climat.

2015 Speich, S., Participation à la réalisation de l'exposition « Climat à 360° » à la Cité des Sciences et de l'Industrie à la Villette, Paris, en collaboration avec Valérie Masson-Delmotte et Universcience.

2015 Speich, S., Participation à la réalisation d'un film documentaire pour CNRS-Image Images sur l'océan et le réchauffement climatique.

2012 Speich, S., Participation à la réalisation d'un film documentaire pour Océanopolis Images sur la petite échelle océanique.

2012 Speich, S., Participation à la réalisation d'un film documentaire pour la chaîne télévisuelle ARTE sur les courants océaniques.

2012 Speich, S., Participation à la réalisation de la restitution scolaire et grand publique de l'Europôle Mer (présentation d'un livret et d'un document multimédia), janvier 2012.

2012 Speich, S., Interviews pour le hors-série de Science & Vie : *Antarctique : Le continent du futur*. N. 257, pp 144, janvier 2012.

E.3 LISTE DES ÉLÉMENTS DE VALORISATION

NEW PARTNERSHIPS

2012 New SAMOC partnership with University of Cape Town and the Department of Environmental Affair in South Africa;

2012 New SAMOC partnership with the University of Buenos Aires, Argentina;;

2015 New SAMOC partnership with GEOMAR, Germany and the realization in January 2017 of the first transatlantic full depth GO-SHIP section along 34°5S.

2016 New SAMOC partnership with NOC, UK.

NEW PROJECTS

2015 Participation to represent the South Atlantic observing system community in the AtlantOS European H2020 project;

2017 Participation to represent the South Atlantic observing system community in the TRIATLAS European H2020 project at the BG08 2018 call; It has passed the evaluation phase 1.

2018 Conception of the EUREC4A_OA-ATOMIC project recently endorsed by CLIVAR

INTERNATIONAL OPENESS

2013 Endorsement by International CLIVAR of SAMOC

2015 S. Speich nominated co-chair of the CLIVAR Atlantic Regional Panel of the World Climate Research Programme (WCRP)

2017 S. Speich nominated as member of the Ocean Observations Physics and Climate Panel (OOPC) of the Global Climate Observing System program (GCOS)

2018 S. Speich nominated as co-chair of the OceanObs'19 Programme Committee

WORKSHOP AND CONFERENCES ORGANIZATION

2012 Advanced International Workshop on *Conceiving a Submesoscale Experiment South of Africa*, ACCESS, Cape Town, South Africa, June 2012

2012 International Workshop *Diagnosis of vertical exchanges at submesoscales - and their impacts on ecosystems - from satellite and in-situ observations*, Brest, Ifremer, 27 et 28 November 2012.

2015 International Symposium on "Submesoscale Dynamics and biogeochemistry on steep slopes" Ecole Normale Supérieure, Paris, 6-8 juillet 2015.

2016 International Workshop on "Building an integrated South Atlantic observing system" GEOMAR, Kiel, Germany, 28 et 29 juin 2016.

2017 Second International Workshop on "Building an integrated South Atlantic observing system" Lisbon, Portugal, 12 July 2017.

E.4 Bilan et suivi des personnels recrutés en CDD (hors stagiaires)

Identification				Avant le recrutement sur le projet			Recrutement sur le projet				Après le projet				
Nom et prénom	Sexe H/F	Adresse email (1)	Date des dernières nouvelles	Dernier diplôme obtenu au moment du recrutement	Lieu d'études (France, UE, hors UE)	Expérience prof. Antérieure, y compris post-docs (ans)	Partenaire ayant embauché la personne	Poste dans le projet (2)	Durée missions (mois) (3)	Date de fin de mission sur le projet	Devenir professionnel (4)	Type d'employeur (5)	Type d'emploi (6)	Lien au projet ANR (7)	Valorisation expérience (8)
Rusciano Emanuela	F	erusciano @cls.fr	Avril 2018	PhD	Italie	Post-doc	IUEM	Post-doc	2 ans	Décembre 2014	Recrutement par JCOMMOPS	ingénieur	CDI	non	Oui, très directement
Kersalé Marion	F	marion.kersale@noaa.gov	Mai 2018	PhD	France	Post-doc	UCT puis NOAA	Post-doc	3 ans	Juin 2018	Research Associate	chercheur	CDD	oui	Oui, très directement
Laxenaire Remi	M	rlaxe@lmd.ens.fr	Mai 2018	Master	France et Canada	Étudiant Master	ENS	AI	3 ans et 6 mois	Décembre 2019	Post-doc	chercheur	CDD	oui	Oui, très directement
Capuano Tonia	F	toniacapuano@yahoo.it	Mai 2018	PhD	Italie, Espagne, UK	Étudiant Master	IUEM	doctorant	3 ans et 6 mois	Décembre 2018	Post-doc	chercheur	CDD	oui	Oui, très directement

Aide pour le remplissage

(1) Adresse email : indiquer une adresse email la plus pérenne possible

(2) Poste dans le projet : post-doc, doctorant, ingénieur ou niveau ingénieur, technicien, vacataire, autre (préciser)

(3) Durée missions : indiquer en mois la durée totale des missions (y compris celles non financées par l'ANR) effectuées sur le projet

(4) Devenir professionnel : CDI, CDD, chef d'entreprise, encore sur le projet, post-doc France, post-doc étranger, étudiant, recherche d'emploi, sans nouvelles

(5) Type d'employeur : enseignement et recherche publique, EPIC de recherche, grande entreprise, PME/TPE, création d'entreprise, autre public, autre privé, libéral, autre (préciser)

(6) Type d'emploi : ingénieur, chercheur, enseignant-chercheur, cadre, technicien, autre (préciser)

(7) Lien au projet ANR : préciser si l'employeur est ou non un partenaire du projet

(8) Valorisation expérience : préciser si le poste occupé valorise l'expérience acquise pendant le projet.

Les informations personnelles recueillies feront l'objet d'un traitement de données informatisées pour les seuls besoins de l'étude anonymisée sur le devenir professionnel des personnes recrutées sur les projets ANR. Elles ne feront l'objet d'aucune cession et seront conservées par l'ANR pendant une durée maximale de 5 ans après la fin du projet concerné. Conformément à la loi n° 78-17 du 6 janvier 1978 modifiée, relative à l'Informatique, aux Fichiers et aux Libertés, les personnes concernées disposent d'un droit d'accès, de rectification et de suppression des données personnelles les concernant. Les personnes concernées seront informées directement de ce droit lorsque leurs coordonnées sont renseignées. Elles peuvent exercer ce droit en s'adressant l'ANR (http://www.agence-nationale-recherche.fr/Contact).