Atlantic Regional Panel

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Panel overview

The CLIVAR Atlantic Regional Panel (ARP) is a part of the CLIVAR organization. The panel is in charge of implementing the CLIVAR science plan in the Atlantic sector. During the last 13 years, the primary function of the panel has been to promote, recommend and oversee the implementation of observational systems in the Atlantic Ocean sector and major research initiatives on Atlantic climate variability and predictability. The ARP works in close collaborations with other CLIVAR panels, regional and global programs. Important achievements have been made over the last three years in the development of an integrated Atlantic observing, ocean and climate modeling systems and interdisciplinary multinational climate research programs. In the following we highlight some of the major scientific and implementation accomplishments made by the CLIVAR international community within the Atlantic Ocean.

Achievements for 2017-18

Workshops

The CLIVAR panel or some of its member have organized three workshop and a conference session during the 2017-18 period:

1. CLIVAR has co-sponsored (together with US CLIVAR and the French CNRS) the first Tropical Atlantic Observing System (TAOS) Review Workshop, held February 8-9 2018, in Portland, Oregon, USA, immediately before the 12th Ocean Sciences Meeting. The meeting was chaired by W. Johns from RSMAS (Miami, FL) under the auspices of the Atlantic Regional CLIVAR Panel. The Review Committee was nominated. The Committee members and approximately 40 additional people participated in enabling the development of a TAOS rationale and to begin the very proactive construction of a Review report that is underway.
2. CLIVAR and US CLIVAR co-sponsored the Ocean Mesoscale Eddy Interactions with the Atmosphere Workshop, held February 17-18, 2018, in Portland, Oregon, USA, immediately following the 12th Ocean Sciences Meeting. More than 50 oceanographers and atmospheric scientists from ten nations came together to assess the current state of knowledge about ocean eddy-atmosphere interactions and to plan activities to address outstanding questions (Robinson *et al.,* 2018).
3. The Seventh SAMOC Workshop (SAMOC VII) was held back to back-to-back with the IAPSO Joint Assembly meeting in Cape Town, South Africa. September 4, 2017. Organizer: Isabelle Ansorge, University of Cape Town. The report can be found here: http://www.aoml.noaa.gov/phod/SAMOC_international/documents/SAMOC_VII_CapeTown_WorkshopReport.pdf

4. Session "Advances in our understanding of the Meridional Overturning Circulation in the South Atlantic", AGU/ASLO Ocean Sciences Meeting, Portland, Oregon, USA. Feb. 2018.
5. 2018 International AMOC Science Meeting, Miami, USA. 24 – 27 July 2018.

Scientific results from activities

New Action: Understanding atmospheric shallow convection and air-sea interactions at the ocean mesoscale: EUREC^{4}A-EUREC^{4}A_OA & ATOMIC

The CLIVAR ARP and CLIVAR SSG have endorsed two projects that are complementary to the existing international EUREC4A (http://www.eurec4a.eu; Bony et al. 2017): the US Atlantic Tradewind Ocean-Atmosphere Mesoscale Interaction (ATOMIC) project and the Ocean-Atmosphere component to EUREC4A (EUREC4A-OA). All three will take place during 6 weeks in January-February 2020 in the Tropical Nord Atlantic Ocean, near Barbados. ATOMIC and EURE4A-OA will address mesoscale Northwest Tropical Atlantic Ocean-atmosphere interactions and their relation to the regional oceanic barrier layer, air-sea interactions and atmospheric shallow-convection. The regional ocean structure is strongly influenced by outflow from the Amazon and Orinoco Rivers. These affect the surface energy budgets and thereby the atmospheric shallow convection, but in ways that are not fully understood.

ATOMIC and EUREC4A-OA provide linkages to operational Numerical Weather Predictions (NWP) centers and climate modeling centers. ATOMIC is slated to add the NOAA airborne (P-3 and G4) and shipborne (Ronald H. Brown) observing systems. EUREC4A-OA will add four ships. The shipborne work will focus on the role of eddies, barrier layers, and surface forcing on oceanic boundary-layer mixing. The ATOMIC & EUREC^{4}A-OA measurements will provide a benchmark data set for constraining a new generation of coupled models capable of resolving convective heat transport in the atmosphere, and meso- to sub-mesoscale variability in the ocean.

ATOMIC & EUREC^{4}A-OA contribute to the WCRP grand challenge on Clouds Circulation and Climate Sensitivity and are directly and/or indirectly related to numerous CLIVAR goals and activities. Specifically, CLIVAR is exploring a relevant initiative on *mesoscale oceanic eddies* (www.clivar.org/events/ocean-mesoscale-eddy-interactions-atmosphereworkshop). ATOMIC and EUREC^{4}A-OA, also have the potential to cooperate with CLIVAR PRP, IORP, OMDP and EBUS RF (as well as ARP) on the research of Ocean Mesoscale Eddy Interactions with the Atmosphere and which is considered important to address in the future *Tropical Atlantic Observing System (TAOS*) currently under review by ARP.

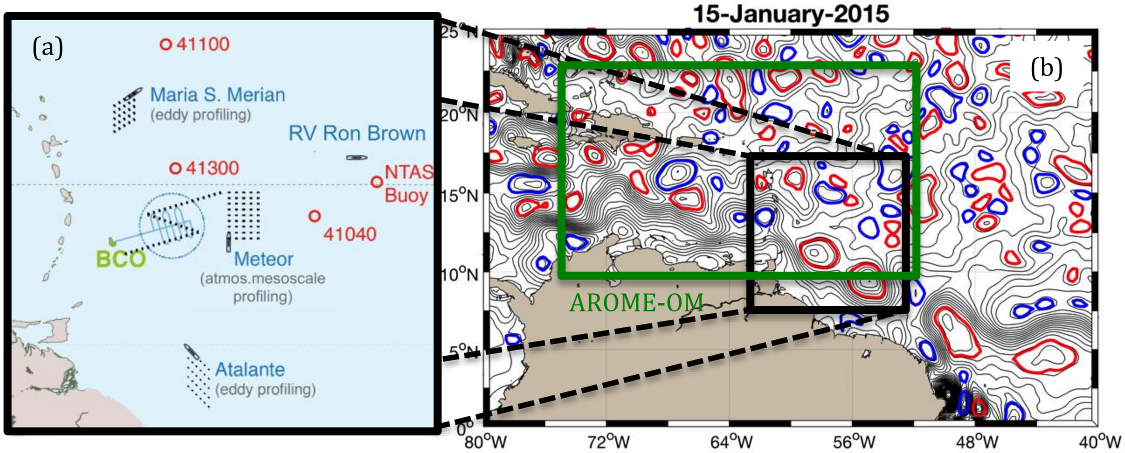


Figure 1. *(a) Observation strategy for EUREC⁴A core campaign (the 90km radius circle track of the Halo aircraft and the winding track of the ATR42 aircraft), EUREC⁴A ++ (RV Meteor and M. S. Merian), ATOMIC campaign (RV Ron Brown and NTAS buoy) and EUREC⁴A –OA (RV Atalante, this proposal), BCO stands for Barbados Cloud Observatory (b) Sea surface height (contours) and anticyclonic (red) and cyclonic (blue) contours of ocean mesoscale eddies derived by applying the novel automatic eddy-tracking method of Laxenaire et al. (2018) for 15 January 2015, the black box shows the EUREC⁴A region and the green box shows the french model AROME Outre Mer domain.*

Atlantic Ocean Observations developments

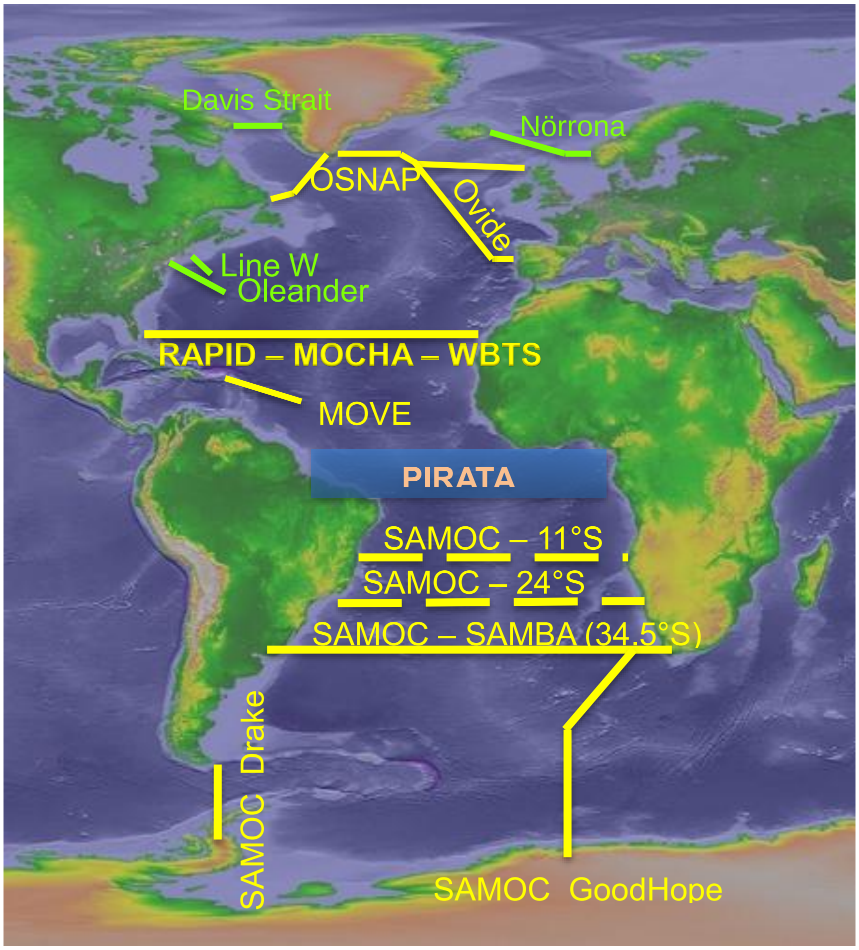
Atlantic Meridional Overturning Circulation (AMOC) observations

The Atlantic Meridional Overturning Circulation (AMOC) extends from the Southern Ocean to the northern North Atlantic, transporting heat northwards throughout the basin, and sinking carbon and nutrients into the deep ocean. Climate models indicate that changes to the AMOC both herald and drive climate shifts, so intensive trans-basin AMOC observational systems have been put in place to continuously monitor the strength and variability of meridional volume transport, and in some cases, heat, freshwater and carbon transport. These observational programs have been developing during the last 10 years and start to be, not only an essential source for monitoring AMOC variability, but also build upon knowledge and monitoring of climate change. It also constitutes one of the backbones of the Atlantic Ocean observing system. It provide the state and variability in terms of essential climate variables (ECVs) such as sea surface temperature, ocean heat content and coastal sea level. Approaches for observing the AMOC vary between the different systems (Figure 2), including trans-basin arrays (OSNAP 57°N, RAPID 26.5°N, 11°S, SAMBA 34.5°N) and arrays estimating the AMOC but concentrating on western boundaries (e.g., RAPID WAVE, MOVE 16°N).

Important activities have happened through the year around the AMOC observing system and achievements that have involved the ARP CLIVAR community. Among these are:

OSNAP: OSNAP comprises two legs: OSNAP West extends across the Labrador Sea from the Labrador shelf near 53°N to southwestern Greenland at 60°N; OSNAP East extends from southeastern Greenland at 60°N to the Scottish shelf at 56°N, crossing the Reykjanes Ridge and the Rockall plateau. The OSNAP observing system also includes RAFOS float deployments in the Irminger and Iceland basins and glider surveys over the Hatton Bank. The OSNAP observing system was fully deployed in the summer of 2014. The first full data recovery was 21 months later, in the summer of 2016 (Lozier et al., 2017; Li et al. 2017). A second full recovery was successfully completed in the summer of 2018. The observing system remains in place with funding through at least 2020.

Figure 2. *Observing arrays in the Atlantic with AMOC transport estimates (in yellow) as*



well as the PIRATA observing network and some other repeated lines and arrays that provides essential time series for the Atlantic Ocean observing system

OVIDE: Since 2002, the French-Spanish OVIDE project (https://wwz.ifremer.fr/lpo/La-recherche/Projets-en-cours/OVIDE) contributes to observations of both the circulation and the water mass properties along a section from Greenland to Portugal. Additional measurements are also conducted in the Irminger Sea and Iceland Sea (current meter mooring array, Argo float deployments, and surface measurements on voluntary observing ships). OVIDE occupies biennially the A25 Greenland to Portugal OVIDE section since 2002. It is a contribution to the GO‐SHIP (high frequency line) program. Last occupations were June‐July 2016 on the Spanish RV Sarmiento de Gambo (PI: F. Pérez) and June‐July 2018 (PI : H. Mercier). The data time-series is now 17 years long.

NOAC-47°N: This array consists of boundary current moorings (T/S sensors and acoustic current meters) on the western and eastern continental slopes. In the interior, Inverted Echo Sounders with pressure sensors (PIES) located along 47°N and along the western flank of the Mid Atlantic Ridge (MAR) from 47°N to 53°N provide estimates of the integrated flow fields (Breckenfelder et al., 2017). The deployment along the MAR (from 47°N40'W to 53°N) started in 2006 and is still on-going. Because of the importance of 47°N as a choke point for the inflow of subtropical water into the subpolar gyre, five PIES were deployed in the western Atlantic in 2011 between 42°W and 37°W to resolve the northbound and the southbound pathways of the NAC as well as the flow field west of 37°W. The deployment in the eastern basin (two PIES and two boundary current moorings) started in 2016. On some of the moorings upward looking Longranger ADCPs monitor the velocity profiles. Additionally, CTD/ADCP and CFC/SF6 measurements are carried out along the array and approximately every second year in the southern Irminger and Labrador Sea. PIES data are combined with Argo profiles and shipboard hydrography to calculate the geostrophic transport employing the Gravest Empirical Mode technique (Rhein et al., 2017). The NOAC array is funded mainly by the BMBF (German Ministry for Education and Research).

RAPID-MOC/MOCHA 26.5°N: It consists of a boundary array with current meters in the west (between 77°W and 76.75°W, east of the Bahamas), and tall moorings west and east of the MAR (at 24°N) and along the eastern boundary (towards the Canary islands at 28°N). In addition to the interior geostrophic, boundary and Ekman components, the Florida Straits transport is also included, with a mean northward transport of 31 Sv measured by a submarine cable. Over the April 2004 – February 2017 observational record, the mean and standard deviation of the overturning transport is 17.0 ± 4.35 Sv. The seasonal cycle has a peak-to-peak amplitude 4.3 Sv (peaks in October), and interannual variations include a notable dip in 2009/10, where the April 2009 – March 2010 period was 30% lower than average. Over the 10 year period, there is a declining tendency with the latter half on average 1.1 Sv less than the first half (Smeed et al., 2018).

MOVE 16°N: At 16°N, the observational approach uses full height moorings and boundary arrays but only over the region west of the MAR and east of Guadeloupe (MOVE3 east of Guadeloupe at 16.3°N, 60.5°W and MOVE1 west of the MAR at 15.5°N, 51.5°W), with direct velocity measurements on the continental slope (at MOVE4 just west of 60.5°W). Over the period January 2000 – December 2016, the mean and standard deviation of the monthly values are 19.4 ± 5.8 Sv. The seasonal cycle has a range of 4.9 Sv and peaks in July. Over this period, there is a strengthening tendency of 0.25 Sv/year (Send et al., 2011). The circulation changes at 16°N were found to be of an opposing sign to those at 26°N on long timescales (5+ years), due primarily to the treatment of the level of no motion in the geostrophic calculation (Frajka-Williams et al., 2018). The observed deep signatures of the change in baroclinic circulation (freshening on the western boundary of the Atlantic below 2000 m) were consistent between the two latitudes, demonstrating consistent changes in deep shear over the overlap period of April 2004 – December 2016.

SAMOC-TSAA 11°S: At 11°S the trans-basin Tropical South Atlantic Array (TSAA) at 11°S was deployed by Germany in 2013. It includes four tall current meter moorings off Brazil, bottom pressure sensors on both sides of the basin, and repeated ship-based observations (Hummels et al., 2015). Herrford et al. (2017) provided a comprehensive view of water mass distribution, pathways, along-path transformation and long-term temperature changes of North Atlantic Deep Water (NADW) and AABW in the western South and Equatorial Atlantic from historical and recent shipboard hydrographic and velocity measurements. Recent estimates of the transports at the western boundary at 11°S based on the reprocessed velocity time series (Hummels et al., 2015) yielded a mean southward transport for the DWBC of 17.5 ± 1.7 Sv and a northward transport of warm and intermediate waters within the North Brazil Under Current (NBUC) of 26 ± 1.1 Sv. The variability of the flow near Angola at the eastern edge of the 11°S array was analyzed by Kopte et al. (2017). The TSAA array at 11°S has recently been expanded to provide an AMOC estimate at that latitude (work in progress).

SAMOC-SAMBA 34.5°S: The "South Atlantic MOC Basin-wide Array" (SAMBA) along 34.5°S is one of the main components of the SAMOC initiative, an international collaboration between Argentina, Brazil, France, South Africa and the USA, with collaborators from Germany, Russia, Spain and the UK. SAMBA consists of arrays near the western and eastern boundaries of the South Atlantic (e.g., Ansorge et al. 2014). The western SAMBA array will be further extended by Brazil, including two additional moorings east of the Mid-Atlantic Ridge to track Antarctic Bottom Water (AABW) pathways. Meinen et al. (2017) estimated DWBC variability at 34.5°S between 2009 and 2014. The time-mean DWBC transport was -15 Sv (negative indicates southward flow) with a peak-to-peak range of -89 to +50 Sv and a large temporal standard deviation of 23 Sv. The AMOC strength at 34.5°S was 14.7 Sv with a peak-to-peak range of 55 Sv between 2009 and 2017 (with gaps in the record due to shortcomings in funding), with eastern boundary density changes dominating AMOC variations on interannual timescales, and the total variability at the eastern and western boundaries equally important on seasonal time scales (Meinen et al., 2018). Valla et al. (2018) analyzed the variability in water masses near the western boundary from hydrography. Kersalé et al. (2018) analyzed the characteristics of the water masses and mesoscale features from the mooring array near the eastern boundary. Laxenaire et al. (2018) showed that Agulhas Rings have a more complex behavior and far reaching impact than previously thought, clearly connecting the Indian and South Atlantic WBCs. Capuano et al. 2018a,b showed that small scale process are responsible of the water masses formation and transformation within Agulhas Rings.

SAMOC (general overview): With the main objective of quantifying and understanding the MOC and its associated Meridional Heat Transport (MHT), the CLIVAR-endorsed South Atlantic MOC (SAMOC) observational network has expanded dramatically over the past years (see also http://www.aoml.noaa.gov/phod/SAMOC_international/). Several modeling activities (e.g., Biastoch et al. 2018) have also been developed in addition to studies combining Argo floats and satellite-based altimetry observations (Schmid and Majumder, 2018; Majumder and Schmid, 2018). Additionally, Lopez et al. (2017) reconstructed a century-long SAMOC index, from 1870 to present, using sea surface temperature (SST) from 1993 to present. The reconstructed index is highly correlated to the observational-based SAMOC time series and provides a long historical estimate. These studies together with observations from the in situ arrays will provide better understanding of the meridional heat and volume transports in the South Atlantic.

PIRATA

The Prediction and Research moored Array in the Tropical Atlantic (PIRATA, https://www.pmel.noaa.gov/gtmba/pirata) project has continuously benefited from observing capability expansion.

The PIRATA-PNE 2017 cruise was conducted on the R/V Ron Brown from February 11st to March 25th, 2017 (Fig. 1(a)). As in 2016, the PIRATA-FR27 cruise was organized in one leg from Cabo-Verde without any call in continental West Africa (Fig. 1(b)). It was thus done from the R/V Thalassa and conducted from February 25th to April 3rd 2017. In the western boundary PIRATA-BR XVII cruise was conducted on the R/V Vital de Oliveira from October 25st 2017 to January 15th 2018. During these cruises seven new T-Flex systems (that progressively replace ATLAS) were installed at 20°N-38°W, 15°N-38°W, 4°N-38°W, 0°-35°W, 20°N-23°W, 4°N-23°W, and 6°S-8°E. Thus, ten T-Flex are now operating. No new T-Flex sites are scheduled for PIRATA in 2018 but additional sites will be converted in 2019. Enhancements also made possible through cooperation from several years, as: (a) 6 Flux Reference Sites (15°N-38°W, 19°S-34°W, 12°N-23°W, 0°-23°W, 10°S-10°W, 6°S-8°E), with the additional sensors: LWR, BP, CM, 2T and 4S sensors; (b) 3 Surface CO_2/O_2 (LOCEAN, France); (c) 8 Subsurface O_2 (GEOMAR), 6 in real-time; Plans for 8 real-time in 2018; (d) 1 Surface Pressure (BP) at 20°N, 38°W (Meteo France, France); (e) 2 Sites with 5 Thermal microstructure sensors (10 ChiPods total) (OSU, USA); (f) 18 Acoustic monitors (OTN, Dalhousie University, Canada); (g) AEROSE (Aerosols and Ocean Science Expeditions, NCAS); (h) 10 additional current meters at 4°N-23°W (Tropical Atlantic Currents Observations Study - TACOS, AOML); (i) 9 new T/C sensors planned for each of 3 sites (FUNCEME) at: 8°N-38°W, 4°N-38°W, and 0°-35°W; (j) and as part of that project a PIRATA NE Extension mooring at 4°N-23°W has been augmented with 10 additional Nortek Aquadopp current meters between 7 m and 87 m depth in March 2017, in order to resolve the circulation in and below the surface mixed layer.

The Tropical Atlantic Observing System (TAOS)

The tropical Atlantic observing system was last reviewed in 2006 by CLIVAR (Climate and Ocean: Variability, Predictability and Change) and GCOS-GOOS-WCRP through the OOPC (Ocean Observations Panel for Climate) with a primary focus on PIRATA (Prediction and Research Moored Array in the Tropical Atlantic). Since then, the CLIVAR Tropical Atlantic Climate Experiment (TACE) has been completed, and more recently the EU program Enhancing Prediction of Tropical Atlantic Climate and its Impacts (PREFACE) has also been completed; its final results together with a comprehensive assessment will soon be published. Scientific priorities and observational technologies have evolved since 2006, and in parallel, the observing system itself has evolved. For example, Argo is now fully developed and has been operating successfully for ten years. PIRATA has also expanded to new sites and has enhanced its measurement suite with higher vertical resolution in the mixed layer, and new CO_2 and O_2 measurements. It is therefore timely to systematically review the requirements for sustained observations in the tropical Atlantic, and to critically review the design of the sustained observing system in order to take advantage of what has been learned to date, to collectively identify new opportunities to build on past accomplishments, and to explore the possibility for expanded interdisciplinary initiatives with other communities, e.g. in biogeochemistry.

To that end, a Tropical Atlantic Observing System (TAOS) review was proposed by the CLIVAR ARP. CLIVAR ARP has taken the lead and coordinates the review, in close cooperation with the PIRATA consortium and the Ocean Observing Physics for Climate (OOPC) panel, and evaluates the scientific progress since the last review to recommend actions to advance sustained observing efforts in the tropical Atlantic. The ARP has sought to involve the International Ocean Carbon Coordination Project (IOCCP), the Integrated Marine Biosphere Research Program (IMBeR) and Surface Ocean - Lower Atmosphere Study (SOLAS), among others, as key partners in the review process. The review is meant to complement other reviews focusing on different elements of the Atlantic observing system to take place in the next several years (for example, RAPID-AMOC and OSNAP). It benefits from parallel efforts being carried out in the Pacific and Indian Oceans, namely the Tropical Pacific Observing System TPOS 2020 project, and the Indian Ocean Observing System (IndOOS) review. Results of the TAOS review are also expected to feed into the AtlantOS design strategy that is currently being formulated in advance of the OceanObs'19 conference.

The TAOS review is meant to be forward looking and strategic, and focus on possible changes to the observing system in the next decade. It is considering new observing technologies, observing system requirements from the user community (e.g. weather and climate forecasts), and observational products that will be delivered. The review is guided by the Framework for Ocean Observing (FOO) and makes recommendations toward an adequate governing mechanism. The review will try to be comprehensive across all relevant observing system networks, including satellite observations, but with the focus primarily on the *in situ* observing system; it will consider atmospheric parameters (e.g. winds, surface fluxes) as well as aerosols, biogeochemistry and biology within the framework of a single integrated observing system.

The first step of the actual TAOS review process was to organize a workshop in February 2018 (back-to-back with the AGU Ocean Sciences Conference) that gathered the TAOS review committee, presided by Prof. B. Johns from RSMAS (Miami, FL, USA), together with more than 40 external experts to establish and approve a strategic plan for TAOS and guide the review process. The TAOS Review Report is actually under construction. A second TAOS Review Workshop is organized in Marseille (France) at the end of October 2018 to complete the Review process and the Report that, once ready, will be submitted to a review process itself by the CLIVAR and OOPC panels.

Developments on the European H2020 project AtlantOS

The AtlantOS H2020 EU research and innovation project (https://www.atlantos-h2020.eu) pools the efforts of 57 European and 5 non-European partners from 18 countries to collaborate on optimizing and enhancing Atlantic Ocean observations. The overarching target of the AtlantOS initiative is to deliver an advanced framework for the development of an integrated Atlantic Ocean. The project has a budget of about € 21 Million for 4 years (April 2015 – June 2019) and is coordinated by GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany (Prof. Dr. Martin Visbeck).

AtlantOS has been very active again this year with many actions as in PIRATA, SAMOC, and OSNAP. AtlantOS actions cover a wide range of objectives and achievements. Information is regularly updated from the AtlantOS web page and Newsletters. AtlantOS has also been very active in the organization of international meetings for specific objectives and deeply involved in high-level international events, such as the Ocean Sciences conference in Portland (OR, USA) early this year and the Belem Statement anniversary in Salvador de Bahia, last July.

AtlantOS has initiated many capacity building efforts and processes to open the integration of the Atlantic Observing System to all countries bordering the basin. In particular, it has initiated the process of developing an Atlantic Ocean Observation System BluePrint. The BluePrint will present best practices to integrate existing ocean observing activities into a more sustainable, more efficient, and more fit-for-purpose Integrated Atlantic Ocean Observing System, with the ambition to be integrative, user-responsive, multi-national, multi-sectoral and purposeful. The team started its work in February 2017, and a draft outline has been developed. The overall goal is to present the BluePrint at the OceanObs 2019 and a white paper for OceanObs19 will be soon be submitted.

BluePrint towards an Integrated Atlantic Ocean Observation System

The *BluePrint for Ocean Observing in the Atlantic* is a strategic effort undertaken by the Atlantic observing and stakeholders communities aimed at providing a document that outlines the elements necessary for a more sustainable, coordinated, and comprehensive basin-scale ocean observing system delivering relevant ocean information for a wide range of societal benefit areas spanning ocean chang and near-real-time ocean state estimation. Such an observing system should support sustainable ocean use in the North and South Atlantic. The *BluePrint* team was assembled through an open nomination process to ensure adequate disciplinary and geographic representation. The team is led by Brad deYoung (Canada) and Martin Visbeck (Germany). It includes representation from Angola, Belgium, Brazil, Canada, France, Germany, Ireland, Portugal, South Africa, the United Kingdom, and the United States. The first meeting of the *BluePrint* Team was in New York following the Ocean Conference at the UN in June 2017 and the second was in Lisbon in July 2017. At the first meeting, the *BluePrint* Outline was finalized and writing the *BluePrint* began. The Lisbon meeting was a good opportunity to enhance the links among partners from the North and South Atlantic. The Team has agreed to develop two related documents that will be written in parallel: A shorter Vision Document (~ 20 pages), covering the key points and highlighting key steps for success as well as a longer Implementation Document (~ 100 pages), pointing to successful examples and reviewing best practices. The *BluePrint* team is meeting in Paris in October 2018 to finalize the Vision Document, to frame the Implementation Document and to prepare for the oceanObs’19 meeting. The Vision Document will be released in the winter of 2018/2019 and both documents will be presented at the final AtlantOS meeting in spring 2018, in Paris. The *BluePrint* will benefit from active engagement from all interested parties and partners. Information on the *BluePrint* will be available on the web site atlanticblueprint.net

Paleoceanography in the Atlantic basin

Efforts are continuing across the community to align palaeoceanography with modern oceanography, in particular with regard to integrating research methodologies and outputs across the different communities with the goal of generating long-term climate records for changes in the AMOC to present. Building on the US-CLIVAR paleo AMOC meeting (report: https://indd.adobe.com/view/b6e3e493-7c88-4bb5-bf13-3e8b4a1ff01b) this was a key theme and focus effort for the international AMOC meeting 2018 (July Florida. US CLIVAR has this year launched a PaleoAMOC Task Team (Task Team 5 of the US AMOC Science Team, funded by NSF, NOAA, NASA, DOE (https://usclivar.org/amoc/organization/task-team-5-paleo-amoc) to run for three years through the sunset of US AMOC in 2020. The team will focus on the variability of AMOC through the last two millennia and on AMOC-related events of the last glacial cycle, a period when the proxy signals are larger and can be resolved with more confidence. There remains no easy or quick solution to obtaining high [temporal] resolution paleo data to constrain AMOC variability on [sub-] decadal timescales. However, progress has been made in generating high-resolution surface climate data, for example using corals, a range of sedimentary archives such as sortable silt and geochemical signals, and palaeo-data compilation efforts. Consequently, publications are now emerging that relate past surface climate and deep ocean current data to AMOC variability on decadal-millennial timescales using a range of climate/ocean proxies and complex [general circulation and earth system] models.

One possible way forward continues to be the opportunity to link the past and present through transient modeling (e.g. the last Millennium and the new last deglaciation PMIP working groups). Efforts continue with the large task of producing these simulations and a 4D reanalysis product of the last 21 ka, combining models and geological archives using innovative statistical methods. This work will provide a tool for assessing past AMOC variability (UK EPSRC Past Earth Network). However, such research is costly, time-consuming and technically challenging with little support from model development centers. Therefore, it continues to require significant investment from palaeoclimate modelers to simulate the period (PMIP4 last deglaciation working group). Geochemical paleo-data compilation projects (e.g. PAGES OC3 and INQUA iPODS) have reached the end of their initial funding period, and the products will yield useful data for reconstructing and understanding past AMOC and carbon-cycle dynamics (including surface reservoir changes, ocean productivity, sources of atmospheric greenhouse gases). Although, the time-resolution of most of these records will prevent greater than multi-decadal to centennial scale resolution, especially if taken in a basin-wide to global context, our wider understanding of how many of these tracers operate, and thus how to interpret the data, continues to improve, especially with the increasing data produced by GEOTRACES, and climate models present a possible solution to filling in the temporal gaps. However, without greater uptake of isotope-enabled modeling by model developers, direct comparison between physical simulations and geochemical data (and hence reanalysis) remains difficult. It is anticipated that this will limit progress in the use of palaeo-archives and palaeoclimate modeling to extend the instrumental record of AMOC. One further outstanding technical challenge remains the ability of high resolution models to be adequately spun-up to simulate [past deep] ocean circulation. Overcoming this limitation (e.g. through adaptive mesh model grids, or advanced spin-up techniques) would present a paradigm changing opportunity in oceanography.

Of relevance, but not only relating to the Atlantic, the PMIP4 [including CMIP6] experiment protocols have been all been finalized (and published) for the last Millennium, mid-Holocene (6 ka), Last Glacial Maximum (21 ka), last deglaciation (26-0 ka), last interglacial (127 ka), mid-Pliocene (~3 Ma) and Eocene (~50 Ma). These represent a first port-of call for modeling efforts wishing to simulate past events or climates aligning with those time periods, and many include recommended sensitivity experiments with the possibility of adopting further such experiments. Coordinating new but compatible simulations to address AMOC variability would fit well with many of their overarching aims.

Ocean and Climate Modeling developments

High resolution modeling of the Atlantic

A recent paper by Hewitt et al. (2017) reviews the benefits from ocean horizontal and vertical resolution that have been seen in forced ocean/sea ice models and documents the impact of the small-scale ocean features on atmospheric simulations. It also presents the evidence for improved simulations from coupled models with an oceanic mesoscale eddy field and discusses to what extent these impacts can be captured by coarse-resolution ocean components with parameterized eddy effects. The following research priorities were highlighted:

1) While the balance of evidence suggests that increased resolution will improve both atmosphere and ocean simulations in coupled models, more systematic studies which make use of a traceable model resolution hierarchy are recommended. It is only in carefully constructed model frameworks such as these, that the relative contributions of resolution-related properties and parameterizations can be explored to produce a cross-model consensus. More specifically, further research is needed as follows: the most appropriate vertical resolution and coordinates for representing the effects of the ocean mesoscale and topographic interactions; the use of observations to evaluate simulations at different resolutions (which can be higher in resolution than the observations themselves); the development and assessment of scale-aware sub-gridscale parameterizations suitable for eddy-resolving resolutions and finer; the demonstration of numerical convergence as ocean resolution is increased; and the understanding of drifts, variability and response to forcing at different resolutions.

2) New paradigms in ocean-atmosphere interaction are leading to a greater understanding of the role of air-sea feedback in western boundary current dynamics and the role of vertical motions in the atmosphere allowing mesoscale features in the ocean surface to influence the atmospheric boundary layer and the upper troposphere. Further exploration of these paradigms and the impact on variability and change associated with large-scale climate modes such as ENSO and the NAO is important. This includes understanding to what extent the variability due to open ocean eddies is important as opposed to that due to western boundary currents. In terms of coupled prediction, a key question which remains unanswered is the relative importance of resolution in the atmosphere and ocean components to capture the essential processes.

3) While coupled models with ocean mesoscale eddying resolution remain expensive computationally, further effort is required to convince operational centers of the benefits of resolution, and to better gauge the relative benefits of resolution versus complexity/capability and ensemble size should be a priority. Development of modelling protocols to better quantify the benefits of resolution in a predictive setting would help to quantify the importance of resolution.

Atlantic variability and predictability : Model Biases

Within PREFACE extensive analysis and experimentation with regional and global ocean, atmosphere, and coupled models were performed. The conclusions on the bias are summarized in a key project deliverable:

D6.3 Best practices for simulating tropical Atlantic variability: https://www.dropbox.com/s/a6p5p07qc8ah2uc/PREFACE%20D06.3%20update%2020171106.pdf?dl=0 . It will become public once the EC reviewers have accepted it. Results from PREFACE will be published on a BAMS article on the tropical Atlantic, and perhaps also a perspective piece on the south-eastern Atlantic bias.

Concerning North Atlantic (NA) biases, some models (e.g., like FESOM-ECHAM6) have relatively weaker biases in the NA. We also know resolution can in some cases alleviate errors, but it is a not a universal solution. There is evidence that correcting the salinity field can alleviate model errors (Park et al. 2016). We also know that coupling with the atmosphere and resolving small scale process can be important (Ma et al. 2016). It would important to initiate a concerted effort with observations and suite of numerical model experiments to put these various pieces information into a consistent picture, and to also perform experiments and analysis to understand the impact of these biases on simulating and predicting climate (including climate change projections). This is basically the same approach as we followed in PREFACE. A Climate Process Team project on this topic is being intiated in the US. Perhaps something similar should also take place from the EU side.

Atlantic influence on climate system

Two review papers are in preparation on inter-basin teleconnections that emphasizes the growing recognition of the Atlantic's role in the climate system (Cai, lead, Keenlyside co-author) and book chapter on the same topic (Keenlyside).

Enhancement in International Collaborations

One of the main goals of ARP was to improve the pan-Atlantic collaboration. This goes beyond collaborations between the US and Europe and indeed concrete actions have been undertaken to initiate or strengthen northern and southern hemisphere collaborations. The development of the pan-Atlantic AMOC program described above or actions under TAOS and AtlantOS are excellent example of great collaborations between scientists and funding agencies from many countries that ensures the best use of available resources. Multinational efforts like SAMOC, RAPID-MOCHA, TAOS, OSNAP or AtlantOS require a distinct international coordination and ARP strongly aims to contribute to such efforts. Within this framework, ARP is in charge of the TAOS Review that started last February (2018). Also, great progresses have been made at high-political level to enforce collaborations all across the Atlantic with the signature, on July 12 2017, of the Belem Statement on Atlantic Ocean Research between the European Union, South Africa and Brazil (https://ec.europa.eu/research/iscp/pdf/belem_statement_2017_en.pdf) and his first year anniversary organized in Salvador de Bahia on July 2018 where many scientists across the Atlantic participate together with John Bell, Director of Marine Unit of the EC Directorate General of Research and his correspondent from Brazil, South Africa, Uruguay, and Argentina. S. Speich contributed to the Belem construction representing CLIVAR ARP.

Additional points on International Atlantic Ocean Projects

The Tropical and South Atlantic - climate-based marine ecosystem prediction for sustainable management (**TRIATLAS**) project has been submitted for EU H2020 funding. It requested a budget of 11 m EUR, it has 35 partners from Europe, Africa, and Brazil. TRIATLAS addresses sustainable management of human activities affecting Atlantic marine ecosystems. This topic is critical to maintain the ocean health and to support the development of the blue economy of the bordering countries. TRIATLAS will contribute to this by delivering knowledge of the current state and future changes of the Atlantic marine ecosystems. Our focus is on the South and Tropical Atlantic – the region of greatest uncertainty in the basin, and where impacts of global climate change and the pressures of growing economies and populations give urgency. We bring together an interdisciplinary team of marine ecologists, physical oceanographers, climate researchers, and social scientists from 35 different institutions in Europe, Africa, and South America, together with industrial and regional stakeholders. We will enhance knowledge of the Atlantic marine ecosystems in key areas of the South and Tropical Atlantic using existing and pivotal new (physical, biological, societal) observations. Earth system, ecological, and socio-economic models and observations will be used to assess the cumulative impacts of (climatic, pollution, and fishing) pressures driving fluctuations in the marine ecosystem, and the potential for tipping point behavior and regime shifts. We will develop the first predictions of the marine-ecosystem for the next 40 years for the region, by combining state-of-the-art climate prediction and ecosystem models, with Shared Socioeconomic Pathways, and by conducting socio- economic vulnerability assessments services, with stakeholder engagement. TRIATLAS will enhance capacity in marine ecosystems, oceanography, and climate research in countries bordering the South and Tropical Atlantic Ocean. There will be close cooperation and alignment with relevant European Commission services and the South-South Framework for Scientific and Technical Cooperation, as well as other relevant initiatives in the field. We will contribute to upscale cooperation around the Atlantic.

Scientific capacity building and career support

A first GO-SHIP SAMBA cruise along 34.5°S took place in January 2017 led by GEOMAR (D) and LMD (F) and partially funded by the EU AtlantOS H2020 project, with participants from seven countries (South Africa, Brazil, UK, Germany, France, Argentina, Sweden).

Plans for 2019 and beyond

Spring 2019 ARP meeting in Vienna back-to-back with the EGU 2019

During this new session of the Panel we plan to discuss about the progresses made on the “Action items” we defined during the last Panel meeting (February 2018)

We will make the point on the TAOS Review process and launch a reflection on an "Atlantic Basin-wide Science Enabled/Enhanced by A Reimagined TAOS"

In link with the work planned together with the CLIVAR Climate Dynamics Panel (CDP) we will discuss the availability and possible common work on the new Hi-Res atmospheric simulations (AMIP type) and Hi-Res CMIP simulations.

Future plans

We are planning to analyze the final results and benefits of AtlantOS and how we will bring it forward. Indeed AtlantOS will end in June 2019 and still there is much to do to organize and manage a fit-for-purpose Atlantic Observing System.

We will also discuss how to maximize the value of the EUREC^{4}A/EUREC^{4}A-OA/ATOMIC ocean-atmosphere observations by looking on involvement of additional modelers/theorists/etc.

ARP already discussed the possibility of organizing a short course (CLIVAR/FIO/ITCP) on meso- and submesoscale ocean dynamics and their relationship with the atmosphere (and possibly marine ecosystems). This point will be discussed during the ARP 2019 meeting.

Articles published in 2017/18 as part of panel activities (if any)

Robinson, W., S. Speich, and E. Chassignet (2018), Exploring the interplay between ocean eddies and the atmosphere, Eos, 99, https://doi.org/10.1029/2018EO100609.

Budget and other needs for 2019

We need the standard amount of funding to enable the venue and practical organization of a Panel meeting in Vienna (Austria) in April 2019.

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Annex A

Proforma for CLIVAR Panel requests
for SSG approval for meetings

1. **Panel or Working Group:**
2. **Title of meeting or workshop:**
3. **Proposed venue:**
4. **Proposed dates:**
5. **Proposed attendees, including likely number:**
6. **Rationale, motivation and justification, including: relevance to CLIVAR science & WCRP Grand Challenges, and any cross-panel/research foci links and interactions involved:**
7. **Specific objectives and key agenda items:**
8. **Anticipated outcomes (deliverables):**
9. **Format:**
10. **Science Organizing Committee (if relevant)**
11. **Local Organizing Committee (if relevant)**
12. **Proposed funding sources and anticipated funding requested from WCRP:**