communications earth & environment

COMMENT

https://doi.org/10.1038/s43247-022-00646-9 OPEN

Inclusive science in the South Atlantic

Renellys Perez [1✉], Silvia Garzoli[2], Rebecca Hummels [3] & Isabelle Ansorge [4]

The South Atlantic Meridional Overturning Circulation initiative began as a grassroots effort to study the South Atlantic Ocean and its impact on climate. In striving towards this goal, it has also become a platform for the empowerment of women and international scientists.

In May 2007, a workshop was organized in Argentina to coordinate efforts to establish the basis for a system to observe the overturning circulation in the South Atlantic. Researchers attending this workshop hailed from Argentina, Brazil, France, Italy, Germany, Russia, the United Kingdom, the Netherlands, and the United States, and were instrumental in spinning up the South Atlantic Meridional Overturning Circulation (SAMOC) initiative. SAMOC goals included measuring the variability of heat, freshwater, and mass transports by the South Atlantic component of the overturning circulation, elucidating their connection to the interocean exchanges (i.e., exchange of South Atlantic waters with the Pacific Ocean and Indian Oceans), and studying water mass property changes and flow pathways.

Today the SAMOC initiative encompasses a range of distinct observing systems led by researchers from different countries, including trans-basin and boundary current moored arrays as well as ship-based hydrographic and expendable bathythermograph transects, all of which rely heavily on data from satellites and components of the global ocean observing system and depend on strong international partnerships[1–4]. The community is tied together, not by unified pools of funding, but by a shared vision, well-defined goals, and a grassroots-driven sharing of resources (e.g., research vessels, technological expertise, data, and personnel). More importantly, SAMOC has a culture of collaboration that has been fostered throughout the years via joint SAMOC workshops (Fig. 1), fieldwork (Fig. 2), and science sessions arranged at large scientific conferences.

A case for monitoring in the South Atlantic Ocean

Up until the mid-20th century, the majority of ocean observations were collected in the Northern Hemisphere, especially in the North Atlantic Ocean[5], due to oceanographic research being driven by more economically developed countries who invested their resources into observing waters near their coastlines and along shipping and navigational routes. The need to observe the whole globe to more fully understand the role of the oceans in climate, and in particular the importance of observing the South Atlantic Ocean, was first articulated in a pair of international conferences in the late 1990s, the Climate and Ocean Variability, Predictability and Change (CLIVAR) DecCen Planning Meeting and the OceanObs'99 Meeting[6,7]. While this need is true for many areas of oceanographic research, it is particularly true for studies of the global overturning circulation system, which drives much of the meridional (north-south) oceanic heat, salt, and carbon redistribution within basin and zonal (east-west) redistribution between basins. During these meetings, the idea of establishing a meridional overturning circulation (MOC) observing system

[1] National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida, USA. [2] Emeritus, National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida, USA. [3] GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany. [4] University of Cape Town, Cape Town, South Africa. ✉email: renellys.c.perez@noaa.gov

Fig. 1 SAMOC V Meeting Participants. Photo of the attendees at the fifth SAMOC workshop in Buenos Aires, Argentina (SAMOC V, December 2014) reproduced from SAMOC meeting reports and proceedings found on https://www.aoml.noaa.gov/phod/SAMOC_international/.

Fig. 2 South Atlantic research cruise in January 2017. A subset of the participants in the trans-basin cruise from Cape Town, South Africa to Montevideo, Uruguay aboard the German R/V Maria S. Merian in January 2017.

in the South Atlantic was proposed by several international scientists with a long history of studying the South Atlantic Ocean during field programs, including the World Ocean Circulation Experiment (WOCE) and CLIVAR hydrographic cruises[8–11], the South Atlantic Ventilation Experiment[12], the Benguela Sources and Transport Experiment[13,14], the WOCE Deep Basin Experiment[15], the Confluence project[16], International Southern Ocean Studies project[17,18], and the GoodHope project[19,20].

However, this South Atlantic MOC observing system idea was met with little enthusiasm at the time given the prevailing institutional preference for sampling in the North Atlantic Ocean, as well as the underappreciation of the impact of the South Atlantic Ocean on weather and climate in the Northern Hemisphere.

While much of the science community was focused on observing the MOC in the North Atlantic Ocean and its impact on the weather and climate of countries bounding the North Atlantic, a grassroots group of scientists studying the South Atlantic Ocean and its local and global impacts on society were continuing to champion the need for such research to commence in the South Atlantic Ocean. Through these efforts, two international CLIVAR workshops, the 2003 South Atlantic Climate Observing System (SACOS) and the 2004 Atlantic Climate Predictability workshop, documented the need for measurements of the MOC and meridional heat flux in the South Atlantic. In 2007, the U.S. Interagency Ocean Research Priorities Plan designated the study of the MOC as a key near-term priority[21], and the U.S. CLIVAR's Atlantic MOC (US AMOC) implementation panel identified improving the MOC observations in the South Atlantic as a critical need. This recognition provided the needed fuel to start the SAMOC initiative and begin developing the overturning observing system that the South Atlantic needed.

Towards an inclusive science culture

The first SAMOC executive committee (EC) was created with four scientists from Argentina, Brazil, France, and the United States. The equal participation from the northern and southern hemispheres on the committee was matched by an equal representation of male and female scientists. Having such a balanced EC from the outset made the SAMOC initiative somewhat unique amongst contemporaneous large-scale field programs and initiatives, which tended to be skewed towards male scientists from primarily Northern Hemisphere countries. It is testament to the diversity of the SAMOC initiative from the outset that this balance happened naturally as a result of who happened to be filling key leadership roles in existing observational and numerical modeling research teams in the South Atlantic at the time. As the initiative expanded over the years to encompass more observational components, the EC grew to include mid-career and senior scientists from South Africa, Germany, and Spain, thereby expanding membership to researchers from all four continents bounding the Atlantic Ocean. Present membership of the SAMOC EC includes fourteen scientists from seven countries, nine of whom are women.

The SAMOC community itself involves an even broader international network of scientists, and the demographics of that

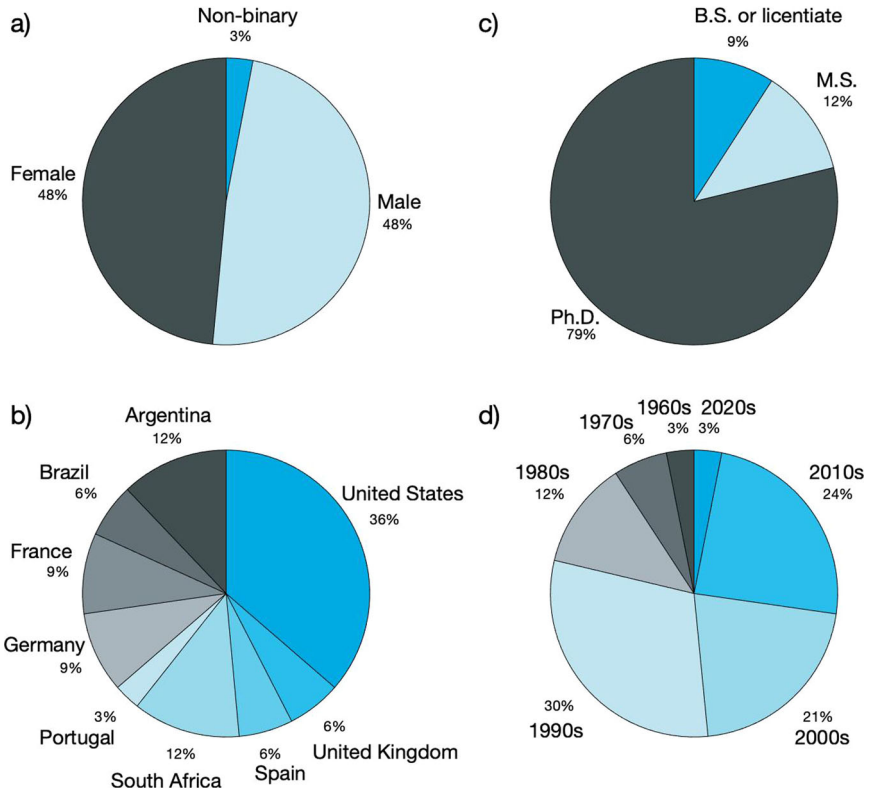

Fig. 3 SAMOC community survey. Responses from the voluntary census of the SAMOC community conducted in 2022: **a**) Gender that respondents self-identified as, **b**) country where they currently work, **c**) terminal, final, or latest degree obtained, and **d**) year terminal, final, or latest degree was obtained.

community have also changed over time to include more women. In early 2022, we conducted a voluntary census of the SAMOC community in the form of an online survey and received 33 responses (Fig. 3). Participants were given the option to opt-out of answering demographics questions, or use their own wording for their responses. To some questions, respondents were allowed to select multiple answers to allow for greater flexibility. Over 90% of the respondents identified physical oceanography as their research specialty. An equal number, 48.5%, of respondents identified themselves as male or female, with 3% identifying as non-binary or declining to respond (Fig. 3a). Respondents currently work in nine different countries: Argentina, Brazil, France, Germany, Portugal, South Africa, Spain, the United Kingdom, and the United States (Fig. 3b). When asked how they would best describe their race/ethnicity respondents self-identified as African, African American or Black; Biracial or Multi-racial; Cape Coloured; Caucasian or White; European; East Asian; or Hispanic, Latino, or South American. The majority of respondents have a doctorate (Ph.D.) as their terminal degree, with the remainder having a Masters of Science (M.S.) degree or equivalent or a Bachelors of Science (B.S.) or licentiate (Fig. 3c). Three-quarters of the respondents obtained their terminal degree in the 1990s, 2000s, and 2010s, with the remainder finishing their degrees in the 1960s to 1980s or in the 2020s reflecting a large generational diversity in the SAMOC community (Fig. 3d). While 88% of the respondents had a male supervisor/advisor during their terminal degree, only 48% responded that they are currently working on SAMOC related research for a male supervisor, reflecting a gender shift in the field possibly convolved with the gender shift in SAMOC leadership that have occurred over time.

With the growth of SAMOC, many students, postdoctoral researchers, and early career ocean professionals (ECOPs) joined the effort, participating in the data collection at sea, data processing and analysis in the lab, and research over the past two decades. An interesting spin-off from SAMOC cruises has been the creation of Floating Universities aimed at building capacity within the marine sciences - one such example being South Africa's annual SEAmester cruise onboard the SA Agulhas II. South Africa's SEAmester introduces marine science as an applied and cross-disciplinary field to students from all over the sub-Saharan continent, combining theoretical classroom learning with the application of this knowledge through hands-on research. While field work in the past involved predominantly male scientists hailing from the North Atlantic, on SAMOC cruises there is now more gender balance with researchers participating from the South and North Atlantic countries. For example, a trans-basin cruise[22] from Cape Town, South Africa to Montevideo, Uruguay aboard the R/V Maria S. Merian in January 2017 involved 21 scientists hailing from three North Atlantic and three South Atlantic countries, ~67% of whom were women (Fig. 2). Students and ECOPs have enhanced the human infrastructure of the SAMOC project and helped to expand the knowledge of the SAMOC community and reinvigorate the program. Some of these researchers have led papers listed on the SAMOC bibliography (https://www.aoml.noaa.gov/phod/SAMOC_international/samoc_publications.php) In a census of the SAMOC bibliography (as of December 2021), approximately 50% of the papers were led by a female first author and 64% of the papers regardless of the gender of the lead author had at least one female coauthor. Only 20% of the papers had only male authors.

A smaller subset of SAMOC scientists have led research cruises, become part of the leadership of the individual observing arrays, and joined the SAMOC EC. The overall demographics of those who have advanced in this fashion have skewed female, and this has led to a present-day SAMOC science team with a large fraction of women oceanographers in leadership or co-leadership positions that write influential papers. For example, the SAMOC observational review article

that appears in this Collection is led by eleven women scientists, most of whom are leading or co-leading SAMOC programs[23]. SAMOC is not a large community, and thus the sample size is relatively small, which makes it hard to be conclusive as to the reasons behind SAMOC's inclusive culture. From the survey we learned that 78.1% of the respondents view the SAMOC community to be "very inclusive" with regards to gender, with 6.3% responding "moderately inclusive" and 15.6% responding "no opinion/comment" which may indicate some dissenting viewpoints. In smaller numbers, 54.8% of the respondents view SAMOC as "very inclusive" with regards to race or ethnicity, with 22.6% saying "moderately inclusive", 6.5% saying "somewhat inclusive", and 16.1% respondents saying "no opinion/comment". However, in the open-ended comments provided by the respondents, we learned that not all countries and institutions involved in SAMOC have afforded the same opportunities to women. There are still barriers to advancement associated with gender and race/ethnicity in some countries and institutions that need to be overcome.

The future of SAMOC

The SAMOC initiative has created a unique space where scientists spanning several generations from different backgrounds and countries of origin can work together towards achieving a shared research mission while advancing in their careers. We may never be able to explain precisely how the SAMOC community has managed to create a culture that is generally viewed as inclusive towards women and international researchers. Perhaps the most important finding from our survey is that an overwhelming majority, over 84%, of the SAMOC science community responded that it was important for our community to be inclusive. It was also expressed in the open comments of the survey that the SAMOC community should strive to be more diverse with regards to ethnicity/race and physical ability and be more inclusive to ECOPs, researchers from countries not currently involved in SAMOC, researchers with new viewpoints about how to do SAMOC science, and the paleoclimate community. It was suggested that SAMOC should consider rotating leadership in the organization to seek out new points of view. Other suggestions included involving more underrepresented STEM groups in fieldwork, doing a better job of recruiting, and creating more training (i.e., summer schools) and leadership opportunities for ECOPs such as having an early career member on the SAMOC executive committee. The one clear message that has come across following this survey is the importance the SAMOC community places on developing a more balanced and inclusive approach to science. Whilst this goal has been successfully achieved in part, the SAMOC initiative will continue to strive towards balance and inclusivity as the program grows while creating new and exciting opportunities (such as Floating Universities) to build capacity in marine sciences.

Received: 15 August 2022; Accepted: 23 November 2022;
Published online: 19 January 2023

References

1. Speich, S., Garzoli, S., Piola, A., & SAMOC team. In Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Annex), Venice, Italy, 21-25 September 2009 (eds. Hall, J., Harrison, D. E., & Stammer, D.) (ESA Publication WPP-306, 2010).
2. Ansorge, I. J. et al. Basin-Wide Oceanographic Array Bridges the South Atlantic. *Eos Trans. AGU* **95**, 53–54 (2014).
3. Garzoli, S. L. & Matano, R. The South Atlantic and the Atlantic Meridional Overturning Circulation. *Deep Sea Research Part II: Topical Studies in Oceanography* **58**, 1837–1847 (2011).
4. Perez, R., Srokosz, M., & Danabasoglu, G. Atlantic overturning circulation questions abound, *Eos*, 100; https://doi.org/10.1029/2019EO114603 (2019).
5. Durack, P. J. et al. Ocean warming: From the surface to the deep in observations and models. *Oceanography* **31**, 41–51 (2018).
6. Campos, E. et al. The South Atlantic and the climate. OCEANOBS99: International Conference on the Ocean Observing System for Climate, Saint Raphael, France, October 18–22, 1999 (1999).
7. Garzoli, S. et al. COSTA: A climate observing system for the tropical Atlantic. OCEANOBS99: International Conference on the Ocean Observing System for Climate, Saint Raphael, France, October 18–22, 1999 (1999).
8. Ganachaud, A. & Wunsch, C. Large-Scale Ocean Heat and Freshwater Transports during the World Ocean Circulation Experiment. *J. Climate* **16**, 696–705 (2003).
9. Talley, L. D. Shallow, Intermediate, and Deep Overturning Components of the Global Heat Budget. *J. Phys. Oceanogr.* **33**, 530–560 (2003).
10. McDonagh, E. L. & King, B. A. Oceanic Fluxes in the South Atlantic. *J. Phys. Oceanogr.* **35**, 109–122 (2005).
11. Schott, F. A. et al. The Shallow and Deep Western Boundary Circulation of the South Atlantic at 5°–11°S. *J. Phys. Oceanogr.* **35**, 2031–2053 (2005).
12. Weiss, R. F. et al. South Atlantic Ventilation Experiment, SIO Chlorofluorocarbon Meas., 93, 9, Scripps Inst. of Oceanogr., La Jolla, Calif. (1993).
13. Garzoli, S. L. & Gordon, A. L. Origins and variability of the Benguela Current. *J. Geophys. Res.* **101**, 897–906 (1996).
14. Garzoli, S. L. et al. Variability and sources of the southeastern Atlantic circulation. *J. Mar. Res.* **54**, 1039–1107 (1996).
15. Hogg, N. G., Owens W. B., Siedler, G., & Zenk, W. Circulation in the Deep Brazil Basin. The South Atlantic: Present and Past Circulation, G. Wefer, W. H. Berger, G. Siedler, and D. Webb, Eds., Springer-Verlag, 249–260 (1996).
16. Garzoli, S. L. et al. CONFLUENCE 1988-1990: An Intensive Study of the Southwestern Atlantic. *EOS Transactions*, American Geophysical Union, 71, 1990 (1990).
17. Whitworth, T., Nowlin, W. D. & Worley, S. J. The Net Transport of the Antarctic Circumpolar Current through Drake Passage. *J. Phys. Oceanogr.* **12**, 960–971 (1982).
18. Whitworth, T. Monitoring the Transport of the Antarctic Circumpolar Current at Drake Passage. *J. Phys. Oceanogr.* **13**, 2045–2057 (1983).
19. Ansorge, I. J. et al. Monitoring the oceanic flow between Africa and Antarctica: Report of the first GoodHope cruise. *South African J. Sci.* 101, 29–35 (2005).
20. Speich, S. & Arhan, M. GOODHOPE/Southern Ocean: A study and monitoring of the Indo-Atlantic connections. (2007).
21. National Research Council. *A Review of the Ocean Research Priorities Plan and Implementation Strategy*. (Washington, DC: The National Academies Press. https://doi.org/10.17226/11984 2007).
22. Manta, G. et al. The South Atlantic Meridional Overturning Circulation and Mesoscale Eddies in the First GO-SHIP Section at 34.5°S. *J. Geophys. Res. Oceans* **126**, https://doi.org/10.1029/2020JC016962 (2021).
23. Chidichimo, M. P. et al. Energetic overturning flows, dynamic interocean exchanges, and ocean warming observed in the South Atlantic. *Comms. Earth Env.* **58**, 1837–1847 (2022).

Acknowledgements

The authors would like to acknowledge the SAMOC Executive Committee and the SAMOC scientists for their support in this endeavor and for participation in the voluntary survey. We also thank Shenfu Dong and Chris Meinen for their insightful comments on an early draft of the article, as well as Regina Rodrigues and the authors of a recent SAMOC review article[23] for discussions that helped broaden the viewpoints and perspectives expressed in this article. R.C.P. and S.G. acknowledge support from NOAA's Atlantic Oceanographic and Meteorological Laboratory, and R.C.P. acknowledges support from NOAA's Global Ocean Monitoring and Observing program (FundRef number 100007298) under the Southwest Atlantic Meridional Overturning Circulation (SAM) project. R.H. acknowledges support by the European Union's Horizon 2020 research and innovation program under grant agreement no. 817578 (TRIATLAS). I.A. acknowledges support from European Union Horizon 2020 research and innovation program under grant agreement 818123 (iAtlantic) and the NRF SANAP SAMOC-SA agreement UID 110733.

Author contributions

R.C.P. led the writing of the manuscript text, and S.G., R.H., and I.A. read and provided comments on the entire manuscript. S.G. performed the analysis of the SAMOC publications. R.H. provided information about the January 2017 Maria S. Merian cruise and I. A. provided information about the SEAmester program. R.C.P.,

I.A., R.H., and S.G. worked on composing the questions for the SAMOC demographics survey and interpreting the results. R.C.P. generated graphics summarizing some of the survey results.

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to Renellys Perez.

Reprints and permission information is available at http://www.nature.com/reprints

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

This is a U.S. Government work and not under copyright protection in the US; foreign copyright protection may apply 2023