Observing the Changing Southern Ocean and its Global Connections

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***Information paper submitted by the United States***

***Summary***

Despite the critical role of the Southern Ocean in the Earth’s climate system, observations of its properties have generally been sorely lacking due to challenges associated with conducting research in this remote and extreme environment. The Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) project was launched in 2014 with a vision to enable a transformative shift in scientific and public understanding of the role of the Southern Ocean in the world’s ocean and climate system. Since its initiation, the project, which involves U.S. scientists at eleven institutions and a number of international partners, has deployed over 130 robotic profiling floats equipped with chemical and biological sensors. These floats move up and down the water column collecting data. Once the floats resurface, these data are transmitted via satellite to the investigators and are publicly available.

The SOCCOM profiling float array has transformed the Southern Ocean from a poorly observed region into, perhaps, the best observed ocean for cycles of plankton biomass, carbon, oxygen, and nitrate. This work has laid the basis for a multi-decadal assessment of natural and anthropogenic climate effects on the Southern Ocean environment. Enhancing this system would include the systematic addition of bio-optical sensors to SOCCOM floats, as well as including regular deployment of floats which would collect long term data in Southern Ocean Marine Protected Areas (MPAs) established by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). Currently, there are two MPAs in the CCAMLR area (the South Orkney Islands southern shelf MPA and the Ross Sea region MPA) and three additional MPAs are in review by CCAMLR (one in East Antarctica, one in the Weddell Sea and one in the Western Antarctic Peninsula region).

***Background***

The open waters of the Southern Ocean have a profound influence that extends from the marginal seas of Antarctica to the global climate system. Near the continent, upwelling of the Circumpolar Deep Water (CDW), driven by an increase in winds, is melting ice shelves and stratifying the ocean. These processes have impacts on nutrient supply, phytoplankton biomass, and, ultimately, on upper trophic level organisms such as fish, seabirds and marine mammals.

The influence of the open waters of the Southern Ocean extends globally. The Southern Ocean is the primary gateway through which the intermediate, deep, and bottom waters of the ocean interact with the sea surface and the atmosphere. As a result, the majority of the oceanic uptake of anthropogenic carbon and heat occur within its domain. The Southern Ocean also has a profound influence on nutrient resupply from the abyss to the surface, regulating nutrient availability throughout the world ocean. Waters of the Southern Ocean are also particularly susceptible to ocean acidification, a phenomenon which is hypothesized have profound ecosystem impacts in the near future. Understanding the connections between the Southern Ocean and the rest of the globe is one of the primary research foci identified by the Scientific Committee for Antarctic Research.

Despite the importance of the Southern Ocean to global systems, it has been poorly observed due to its remote location and fierce weather conditions. However, two recent advances have transformed observation capabilities. The first is the development of new biogeochemical sensors mounted onto autonomous profiling floats used in the ocean-wide Argo system (<https://argo.ucsd.edu>). These sensors allow sampling of ocean biogeochemistry, including the indicators of ocean acidification, in 3-dimensional space with a data provided to investigators every five to ten days. Second, the climate modeling community now has the computational resources and the physical understanding required to develop climate models that can represent crucial mesoscale processes in the Southern Ocean. Advancements in biogeochemical sampling, combined with this new generation of models, provides investigators with tools that can vastly improve our understanding of Southern Ocean processes.

The SOCCOM project was designed to utilize both of these advancements and it is dramatically altering our understanding of Southern Ocean biogeochemistry (<https://soccom.princeton.edu>). Over 130 floats are operating in all three basins of the Southern Ocean. This includes routine operations under seasonal ice cover. Observations from the floats are uploaded to the Argo data system, made freely available in near-real time, and are being assimilated into the multi-basin biogeochemical state estimate developed as part of the SOCCOM project. These observations have become the dominant source of fundamental biogeochemical data, not just in the Southern Ocean, but globally (Table 1). These new observations and tools have allowed investigators to describe seasonal variability and major chemical fluxes throughout the Southern Ocean resulting in a fundamentally new understanding of the physical factors that underlie biogeochemical processes.

Profiling float operations extend into waters near the continent that are deeper than 2000 m and, in some cases, even shallower. A significant number of the profiling floats in the SOCCOM array are operating in current, or proposed, Marine Protected Areas (MPAs) in the Southern Ocean (Figure 1). These floats provide the only real-time biogeochemical observations in the MPAs, which are designed to protect and conserve the marine living resources in the waters surrounding Antarctica.  Biogeochemical floats operating in, or near, MPAs have been used by SOCCOM scientists in a variety of studies that are closely related to MPA ecosystem dynamics. Specifically, the SOCCOM project supports the recommendation in Resolution 5 (2017) which calls for identifying opportunities to conduct and support relevant research and monitoring activities that support the objectives and the forthcoming Research and Monitoring Plan of the Ross Sea Region MPA, in particular through international collaborations. The profiling float data are also being used widely by scientists from a variety of nations and the observations have become a major resource for their study of the Southern Ocean. A summary of publications arising from the SOCCOM project can be found at <https://soccom.princeton.edu/content/soccom-publications>.

Recent examples of research projects include:

* Effects of meltwater on long term oxygen, pH and nitrate changes)
* Effects of sea ice variability on blooms in the Weddell Sea
* Formation of super-cooled sea water from sea ice and ice shelves
* Seasonal modulation of phytoplankton biomass
* Effects of variable physics on phytoplankton bloom formation
* Polynya formation in the Weddell Sea
* Assessment of seasonal cycles in carbonate chemistry and projections of future acidification
* Net community production in Southern Ocean waters

***Future SOCCOM Program Goals***

* Continue operation of the SOCCOM array in the open waters of the Southern Ocean.
* Ensure SOCCOM floats are fitted with bio-optical sensors to enhance observations of biological processes.
* Assimilate data into operational models to enable predictions of future trends in ecosystem properties, including current and potential future MPAs.
* Enhance observations in current and projected Southern Ocean MPAs with additional floats, including enhanced international planning.
* Explore routine operation of floats in MPA waters between 2000 and 500 m depth

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| Table 1. Number of SOCCOM floats profiles and ship-based profiles for oxygen, nitrate, and pH per year, which illustrates the greatly increased (~10X) sampling available from floats. Source for ship data is the US National Oceanographic Data Center. Source for SOCCOM data is the Argo Global Data Assembly Center. | | | |
|  | Number of Profiles to >900 m per year | | |
| Property | SOCCOM floats  2014-2021 | Ships South of 30S  2010-2017 | Ships North of 30S 2010-2017 |
| Oxygen | 18,592 | 1,764 | 3,032 |
| Nitrate | 15,185 | 1,651 | 2,840 |
| pH | 8,505 | 1,054 | 1,976 |
|  | Figure 1 SOCCOM float trajectories (blue lines) and last position (black dots). |  |  |