The Southern Ocean absorbs a great deal of heat and carbon dioxide (CO₂) from the atmosphere, helping to shape the global climate. This oceanic service comes at a cost: the Southern Ocean is becoming warmer, fresher, less oxygenated, and more acidic—in effect heating up, losing breath, and becoming corrosive. The consequences of these changes are difficult to monitor and remain poorly understood.

With observations collected by the longest biogeochemical moored time series in the Southern Ocean, we are making an integrated and ongoing assessment of the processes that control the carbon cycle in the Subantarctic Southern Ocean (47°S, 142°E, Figure 1)—now recognized as globally important in the uptake and storage of anthropogenic CO₂.

The Southern Ocean Time Series (SOTS) consists of two deep-water moorings: the Subantarctic Zone (SAZ) sediment trap mooring and the Southern Ocean Flux Station (SOFS) air-sea flux and biogeochemistry mooring, both supported by the Australian Integrated Marine Observing System (IMOS; https://imos.org.au/). Mooring data from the surface ocean and the atmosphere are transmitted in near-real time, while data logged at depth are collected when the moorings are retrieved. Automated samplers on the moorings provide precious samples year-round, and annual research voyages are essential for turn-around of the moorings, sensor calibration, and process studies. All data streams combine to deliver a suite of autonomous, year-round, multitrophic observations, providing an unparalleled multyear record of the Southern Ocean. Data collected at SOTS are freely available from the Australian Ocean Data Network (AODN; https://portal.aodn.org.au/).

Changes in Southern Ocean Biogeochemistry and the Potential Impact on pH-Sensitive Planktonic Organisms


The goal of SOTS is to assess air-sea exchange, biological production, and carbon uptake and export in the Subantarctic Zone. Because these exchanges occur over many spatial and temporal scales, for example, from daily insolation cycles to seasonal cycles in biological production and decadal oscillations over whole ocean basins, high-frequency observations collected over many years are required. The current context of relentless anthropogenic forcing of rapid climate change increases the urgency of this work.

CHANGING OCEAN CHEMISTRY AT SOTS

Measuring the amounts of CO₂ (in parts per million or ppm) in the air and the ocean provides key indicators of climate change. Sensor records from SOTS show an increase of atmospheric CO₂ from roughly 375 ppm in 2012 to 390 ppm in 2019 (Figure 2a); this change of approximately 15 ppm over seven years, or ~2.14 ppm/yr, is consistent with observations from the Cape Grim Baseline Air Pollution Station in northwestern Tasmania (Figure 1). By contrast, in the 1960s, the rate of increase of atmospheric CO₂ was much smaller, only 0.5 ppm/yr; not only are the atmospheric CO₂ concentrations much higher today, the rate of increase has continued to grow.

Measurements of surface ocean CO₂ at SOTS show an increase from an average winter (June–August in the Southern Hemisphere) concentration of ~360 ppm in 2012 to ~388 ppm in 2019 (Figure 2a); this change of approximately 15 ppm over seven years, or ~2.14 ppm/yr, is consistent with observations from the Cape Grim Baseline Air Pollution Station in northwestern Tasmania (Figure 1). By contrast, in the 1960s, the rate of increase of atmospheric CO₂ was much smaller, only 0.5 ppm/yr; not only are the atmospheric CO₂ concentrations much higher today, the rate of increase has continued to grow.

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FIGURE 1. Location of the Southern Ocean Time Series (SOTS), which includes the Subantarctic Zone (SAZ) sediment trap mooring and the Southern Ocean Flux Station (SOFS) air-sea flux and biogeochemistry mooring, and the Cape Grim observatory in relation to major oceanographic zones and fronts. Redrawn from original by L. Armand
It's likely that the extended seasonality of calcification in *Emiliania huxleyi* was most abundant in the winter months, when the more heavily calcified forms of the dominant species, *Algirosphaera cucullata*, were particularly challenging. The longer-term changes described above are not just about changes in the physical environment, but also about changes in the biology of the organisms that live in that environment. The variation in calcification rate among different species and populations can be significant. For example, in the Southern Ocean, two species, *Emiliania huxleyi* and *Gephyrocapsa oceanica*, dominate the phytoplankton community, but their calcification rates differ significantly. *Emiliania huxleyi* is known for its ability to produce large, calcified cocoliths, while *Gephyrocapsa oceanica* produces smaller, less calcified cocoliths.

Consequently, the health of the Southern Ocean ecosystem depends not only on the physical environment but also on the biology of the organisms that live there. Disentangling natural variability and climate change requires observations collected over all seasons and many years. The SOTS observatory provides an important baseline for understanding the evolution of the physical, chemical, and biological processes in the Subantarctic region. These observations are essential to provide advice about how climate variability is affecting us now and is likely to affect us in the future.
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