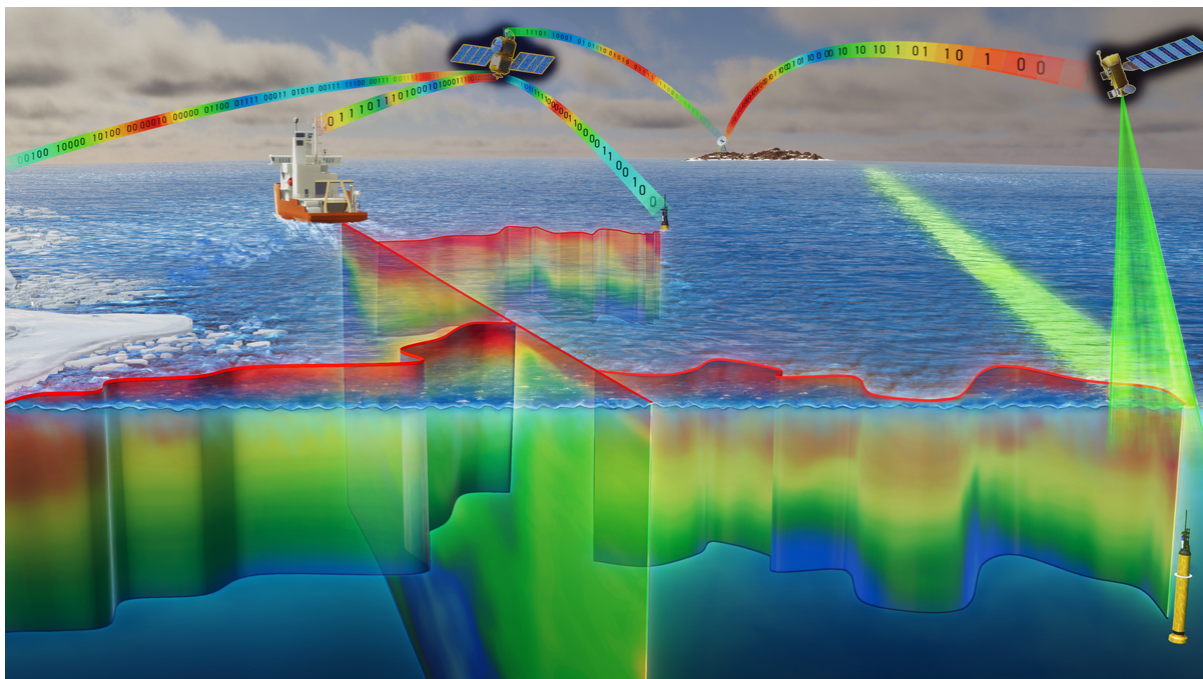


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A Global Ocean Biogeochemical Observatory Becomes a Reality

Building on the successful Argo network of seafaring temperature and salinity sensors, work is underway to deploy 1,000 floats equipped to study ocean biogeochemistry in greater detail than ever.

By Oscar Schofield, Andrea Fassbender, Maria Hood, Katherine Hill, and Ken Johnson
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This illustration of the Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) float system depicts trajectories of floats deployed from a ship as well as the communication of float data back to land via satellites. Credit: SOCCOM Project, Princeton University

The ocean is a central part of Earth's climate system. For example, it regulates temperatures and surface–atmosphere exchanges of gases around the planet. Yet the ocean is chronically undersampled, leaving vast gaps in

our knowledge of its behavior. This lack of data presents a fundamental barrier to understanding, predicting, managing, and adapting to [ongoing changes](#) in ocean physics, chemistry, and biology. These changes, among others, include warming of the ocean, declining oxygen content, and shifting dynamics in ocean carbon content, which have direct and indirect effects on open-ocean, nearshore, and even terrestrial ecosystems. These effects remain only loosely constrained but appear to be predominantly negative for life in the water—from keystone species like [coral](#) and [krill](#) to large mammals like [whales](#) and [walruses](#)—and on land by way of [degraded fisheries](#), for example.

The need to reduce gaps in global ocean observing is becoming increasingly urgent as we look to advance the science upon which mitigation and adaptation approaches are based. To meet this observing challenge, scientists have been developing a global array of hundreds of ocean-profiling floats that expands on existing observing resources. The floats, equipped with biogeochemical (BGC) sensors, constitute the [BGC-Argo](#) system, which will transform our ability to observe the ocean. Beyond serving needs for basic research, science advances and real-time observations from BGC-Argo will also inform a diverse range of stakeholders and facilitate solutions for sustainable ocean management.

Original Argo Network

Following the [World Ocean Circulation Experiment](#) (WOCE) in the 1990s, which involved the use of available tools at the time (i.e., ships, satellites, drifting buoys, and early-generation profiling floats), the international oceanographic research community focused on developing and deploying a global robotic network to observe the ocean. This interest [led to implementation](#), starting in 1999, of the Argo array: a global network of autonomous floats equipped with sensors for measuring physical ocean characteristics like temperature, salinity, and pressure.

Standard Argo floats descend as deep as 2,000 meters into the ocean and then return to the surface after 10 days, collecting data along the way to provide profiles of the water column. As of February 2022, the Argo array includes 3,894 active floats, each of which lasts for up to 5 years and communicates its data to shore via satellite transmission. The array collects

more than 150,000 vertical profiles per year on average—1,612,816 between 2011 and 2020—allowing quantitative description of the changing state of the upper ocean and of patterns of ocean climate variability, including with respect to [heat and freshwater storage](#) and transport, over months to decades.

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Prior to Argo, ship-based ocean observing strategies could not provide systematic global coverage and satellites could not provide information on the ocean interior. Since its inception, Argo has transformed oceanography and advanced ocean and weather forecasting. For example, Argo has been critical to showing that the deep ocean is warming and increasingly contributing to sea

level rise [[Johnson and Lyman](#), 2020]. Argo data are also increasingly critical in the ocean forecasting models that are vital decision tools for such marine operations as weather forecasting and fisheries management.

A key aspect of the Argo system is its transparency—it provides free, standardized, interoperable, and [open-access data](#) to the public in near-real time via [Global Data Assembly Centers](#) (GDACs) in [Brest, France](#), and Monterey, Calif. The data are served in two formats, one posted within 24 hours of collection after an automated quality control (QC) procedure, and another within 1 year of collection after more rigorous QC. The GDACs synchronize their data holdings to ensure that consistent data are available on both sites. In addition to charting the way forward for the global observing system in terms of near-real-time data delivery, the original [Core-Argo](#) array has facilitated seamless data integration with ocean models and development of useful data products, such as collections of profiles from the same depth in the ocean.

Expanding Argo's Mission

Many gaps in our understanding of ocean ecosystems reflect the limited spatial (horizontal and vertical) and temporal resolution of observations provided by traditional chemical and biological sampling approaches from ships, moorings, and satellites. The critical need to reduce uncertainties in estimates of ocean carbon and nutrient cycling, oxygen decline, and ecosystem health, together with the success of the Argo array, inspired the ocean sciences community to [extend the array's capabilities](#) by expanding the number and types of sensors carried by profiling floats [[Roemmich et al.](#), 2019].

Further motivation to build the BGC-Argo array stems from several international agreements that call for enhanced ocean biogeochemical observations to address global concerns about the ocean carbon cycle, acidification, deoxygenation, and sustainable management of marine ecosystems and living resources. These agreements include (among others) the [Convention on Biological Diversity](#), the [United Nations Sustainable Development Goals](#), and the United Nations Framework Convention on Climate Change, which includes the [global stocktake](#) of the Paris Agreement.

The development of low-power miniaturized chemical and bio-optical sensors has made it technically possible to implement BGC-Argo floats [[Johnson et al.](#), 2009; [Claustre et al.](#), 2020]. These floats are equipped to provide information about ocean oxygen and nitrate content, pH, [chlorophyll](#) fluorescence, particle abundance, light penetration, and other traits, as described in the [BGC-Argo Implementation Plan](#). Like the original Argo, BGC-Argo provides data publicly within 24 hours of collection after automated QC as well as within 1 year of collection after more rigorous QC [[Bittig et al.](#), 2019; [Maurer et al.](#), 2021].

Several pilot arrays of BGC profiling floats, deployed globally based on opportunistic ship availability, have already yielded valuable observations. The success of these small-scale arrays motivated the U.S. National Science Foundation to support deployment of a basin-scale array—the Southern Ocean Carbon and Climate Observations and Modeling project ([SOCCOM](#))—to observe a region that plays a disproportionately large role in the [cycling of carbon](#) and nutrients in the ocean. Over the past 6 years, SOCCOM has

deployed almost 200 floats, which provide an [unprecedented view of the Southern Ocean](#).



Researchers deploy a SOCCOM biogeochemical float during a 2016–2017 cruise of R/V *Palmer* to the Southern Ocean.

Credit: [SOCCOM Project](#), Princeton University, [CC BY 2.0](#)

SOCCOM, in concert with the BGC floats deployed in other regions, has affected marine science by

- motivating reconsideration of the magnitude of basin-scale air-sea carbon fluxes [[Gray et al.](#), 2018]
- revealing nuances of phytoplankton bloom dynamics [[Mignot et al.](#), 2018]
- allowing detailed quantifications of the [biological carbon pump](#) and its variability [[Estapa et al.](#), 2019]
- providing new evidence for novel pathways of ocean nitrogen cycling [[Johnson et al.](#), 2010]

- enabling basin-scale to global evaluations of primary productivity (through, e.g., photosynthesis and chemosynthesis) [[Arteaga et al.](#), 2020].

Each of these advances has yielded new insights about marine biogeochemical cycling and shed light on ecosystem health and the ocean's role in Earth's climate system.

BGC-Argo Goes Global

The success of BGC float pilot arrays and international cooperation around a coordinated data system has galvanized the international research community to build a global BGC-Argo array to address the goal of providing improved understanding and projections of how ocean ecosystems are responding to Earth's changing climate. In 2021, the United States committed to deploying 500 BGC floats throughout the ocean. This commitment is expected to be matched by partner countries to realize a vision of a global network of 1,000 BGC floats. Knowledge gained from the full BGC array will bring new insights to decisionmakers and resource planners, facilitating the development of informed mitigation and adaptation strategies for ocean change.

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The [G7 Future of the Seas and Oceans Initiative](#) (FSOI) has identified the implementation of the [full BGC-Argo array](#) by 2030 as a top priority. To engage potentially interested parties in envisioning societally beneficial applications of BGC-Argo beyond basic research, FSOI organized the virtual [Global BGC-Argo Fleet: Knowledge to Action Workshop](#), held in spring 2021. The event brought together marine scientists, policymakers, and

industry partners, including international stakeholders involved in fisheries management, ocean carbon budget verification, and environmental forecasting and modeling, to assess how best to leverage a global BGC-Argo array. On the basis of the recommendations of workshop participants, FSOI established a Resource Strategy Group (RSG) for BGC-Argo.

RSG serves as a mechanism for regular communications between the International Mission Team, a diverse group of Argo-sensor-data scientists as well as representatives of G7 government agencies, and the ministries that fund Argo. These groups regularly review progress toward implementation of the global BGC network, encourage new commitments from countries to achieve full implementation of the array, and work to identify promising innovations in cross-platform sensor integration and data interoperability that could be incorporated into the array. They also review the progress and lessons learned from other ocean observing networks.

The efforts of the International Mission Team and RSG will help foster links with countries to help develop data and information tools for BGC-Argo data as well as use cases and demonstrations. And they will create partnerships to develop sampling strategies for environments that have traditionally been difficult to sample, such as the deep sea, ice-covered zones, and continental shelf boundary systems. The groups also will work together to promote policy-relevant ocean information made possible by the BGC-Argo array to international federal agencies and environmental management entities.

Future of the BGC-Argo Array

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Given the past and planned investments in BGC-Argo, it is essential that its capabilities be fully used for both research and environmental management.

Given the past and planned investments of tens of millions of dollars in BGC-Argo, it is essential that its capabilities be fully used for both research and environmental management. The ocean science community has identified specific needs to maximize the utility of the array.

Some of these needs are being addressed through the combined efforts of the International Mission Team and RSG, including highlighting BGC-Argo's benefits and funding requirements to implementing agencies and ministries as well as fostering agreements with partners beyond the G7 to complete and sustain the array and coordinate the necessary data infrastructure.

The research community has also emphasized that BGC-Argo must continue providing data that conform to findable, accessible, interoperable, and reusable ([FAIR](#)) standards to meet the needs of diverse data applications and end users. To lower barriers for anyone to access and use float data, organizers have created [training workshops](#), freely available [code](#) to help synthesize and visualize data, and [online tools](#) for data discovery.

The development of this open-access BGC ocean observing network aligns with the key challenges raised by the United Nations [Decade of Ocean Science for Sustainable Development](#). This convening framework focuses on developing and implementing transformative ocean science solutions for sustainable development and for connecting people to the ocean. The Ocean Decade calls for an open-access, digital, integrated view of the ocean, with the goals of enabling the new [blue economy](#) and sustainable ocean management and restoration, and providing a new means to inspire society to value the ocean.

The BGC-Argo network represents a significant step toward meeting the grand challenges of the Ocean Decade by providing a foundation for understanding chemical and biological dynamics in the ocean. Results from the growing network will build on findings from the pilot arrays, helping reveal the disproportionately important role of the Southern Ocean in Earth's carbon cycle, for example, as well as how ecosystems from the tropics to the polar regions are shifting and many other vital insights about our changing ocean.

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