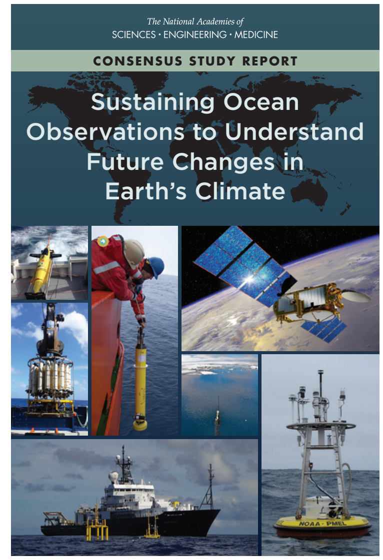
Consensus Study Report

November 2017

HIGHLIGHTS

# Sustaining Ocean Observations to Understand Future Changes in Earth's Climate




Earth's climate is changing more rapidly than at any time since the advent of human societies. Understanding climate dynamics is crucial to making informed decisions about how to mitigate and adapt to climate change impacts such as sea-level rise, ocean acidification, species loss, changing growing seasons, and extreme weather. While climate models reveal a great deal about the climate and how it will change in the coming decades, more data is needed to better predict and adapt to the changes ahead.

The richest data source for comprehending climate is also perhaps the least understood: the ocean. Covering more than 70 percent of Earth's surface, the ocean plays a large role in the fundamental physical and chemical processes that actively influence the planet's climate and weather. Currently, however, some key ocean properties are monitored insufficiently, both in their spatial coverage and on the many timescales that are important to understanding global climate.

## THE OCEAN'S CONNECTION TO CLIMATE

Whether or not $CO_2$ emissions follow their current trajectory or are curbed significantly, the Earth's climate system will continue to change because of the influence of the ocean. The ocean has absorbed more than 90% of the excess heat and more than 30% of the $CO_2$ associated with human activities. It also receives nearly 100% of the freshwater from melting land ice. These inputs enter the ocean surface and are transported into deeper layers of the ocean through complex mixing processes. It can take years to decades, or in the case of very deep water, millennia, for those inputs to resurface.

Given the complexity and duration of mixing in the ocean, long-term observations are needed to fully understand what is happening in the climate system and what will occur in the future. One of the more difficult challenges is the ability to discern long-term climate trends from shorter-term natural variability in the ocean. For example, as explained in Box 1, intermittent ocean measurements in the North Atlantic led to the erroneous conclusion that, over several years, the northward currents that transport warm surface water showed signs of slowing down. These currents play a major role in moderating the climate of northern Europe. However, a system of sensors installed in 2004, which provided the first continuous observations in that region, showed that the changes detected were within the range of annual variability, and hence not indicative of a long-term trend.

*The National Academies of*
SCIENCES · ENGINEERING · MEDICINE

## THREE BUDGETS FOR UNDERSTANDING CLIMATE

A good test of our understanding of the climate is whether or not we can reconcile all of the inputs to—and exchanges among—the components of the earth system, including the ocean, land, atmosphere, and cryosphere. In other words, can we produce a "budget" for a particular climate component? For example, does the sum of the measured heat increases of the atmosphere, land, and ocean correspond to the net energy from solar radiation? With sufficient observations, it should be possible to account for all the heat or other inputs and energy in the system.

Three different global budgets illustrate the importance of sustained ocean observations for climate: heat, carbon, and fresh water (see Box 2). Identified as priority areas by the international ocean observing community, those budgets can be used to inform climate model projections and to detect and attribute changes within the climate system. For example, the heat budget is central to understanding temporary delays in the warming of Earth's surface temperatures due to ocean heat uptake and storage. A thorough understanding of the carbon budget can be used to help predict future atmospheric $CO_2$ concentrations under various greenhouse gas emissions scenarios. Sea-level rise is a product of both the ocean heat budget—because water expands with heat—and the fresh water budget as land ice melts.

Quantifying and closing these budgets requires global ocean observing systems that provide ongoing, calibrated measurements to monitor short-and long-term changes in the ocean. For example, assessing the components of the heat and fresh water budgets that affect sea-level rise will require in situ measurements of temperature and salinity throughout the depth of the water column.

## ADDITIONAL BENEFITS OF OCEAN OBSERVATIONS

Modern weather forecasting, such as hurricane tracking and seasonal precipitation prediction, relies on the same satellites and in situ measurements used for observing the ocean for climate. Improving our ocean observing system will contribute to a wide range of weather forecasting and other services, such as living marine resource management and marine navigation.

## CHALLENGES OF OCEAN OBSERVING

Climate models cannot be evaluated, calibrated, and improved without sustained, high-quality observations with which to compare model predictions. While there are important ongoing efforts to collect ocean data, it has been challenging to establish the level of spatial coverage and temporal consistency that is needed to account for regional and short-term variation and provide a record of long-term change. Additionally, the uninterrupted observations needed to distinguish between natural variability and long-term climate trends cannot be made by one network of sensors but require multiple components with long-term, coordinated support and governance systems.

Because the ocean is a logistically and physically challenging environment, the majority of ocean observations to date have been conducted in the upper ocean and in areas of the world that are more readily accessible. A fleet of ships with global range will continue to be required to make direct observations and for platform deployment and maintenance. A workforce of scientists, engineers, and technical staff are required to manage operations of the observing system. However, the long-term nature of observing activities acts as a disincentive in fields where short term results are prioritized for career advancement.

### Box 1 Challenging the "Conveyor Belt": A Case Study in the Value of Observations

Until a few decades ago, it was thought that ocean water circulates in a regular pattern known as the global "conveyor belt" driven by differences in temperature and salinity. In this simplified system, scientists raised concerns that changes in climate could significantly affect these temperature and salinity driven processes and weaken ocean circulation, causing abrupt climate changes, such as a rapid cooling of the weather in northern Europe over a few years or decades. Indeed, some studies in the early 2000s identified trends in ocean currents suggesting the conveyor belt had already begun to slow down.

It turns out, however, that those concerns were based on insufficient information. A system of sensors was deployed across the Atlantic from Florida to Africa in 2004, providing the first continuous observations of the North Atlantic portion of the conveyor belt. The additional data provided by these sensors revealed that the apparent slowdown could be an artifact of natural variability. Their measurements showed, for example, that the strength of the Atlantic circulation can vary as much as 6-fold over a few months—a degree of variation that scientists had previously assumed could only happen over much longer time scales.

Insights from that observing network and others have subsequently led to a new understanding of ocean circulation that reflects a much more complex and variable pattern of movement than the older notion of the global conveyor belt. This new understanding would not have been possible without data reflecting a spatial and temporal scale that better reflects the processes occurring in the overturning circulation.

Continuity is essential, yet funding mechanisms that rely on annual budget approval or short-term grants put continuity at risk. Short-term funding also makes other parts of the ocean observation enterprise vulnerable, including the workforce, technological progress, and the support of the research fleet. Declining investments have threatened the development of new technology to facilitate more detailed or more reliable data collection.

## NATIONAL COORDINATION, PLANNING, AND FUNDING CHALLENGE

Within the United States, federal agencies are the primary supporters of ocean observing activities through funding for research, technology, and operations. This includes building and maintaining the research fleet; conducting research through federal laboratories and operational programs; and serving as coordinators on the international stage. Oceanographic institutions also operate a significant portion of the observing system with support from federal grants and conduct research that contributes to the state of knowledge of the ocean and its role in climate change. Some philanthropic and non-profit organizations provide funding for ocean conservation research and technological development.

Currently, the absence of an overarching long-term national plan with associated resource commitments and lack of strong leadership presents a challenge for sustaining U.S. contributions to ocean observing. National and international commitments and investments in technology and infrastructure are essential for sustaining, improving, and reducing the costs of ocean observations going forward. Because of the extended timeframe required for climate observations, a decadal plan for the U.S. ocean observing system would be the most effective approach for ensuring critical ocean information is available to understand future climate.

The United States is a leader in participation in the global observing system but issues related to flat or declining funding and reduced workforce capacity are already causing leadership in ocean observations to decline. A decadal plan could optimize and create a coordinated approach for continued contributions by the United States to sustain global ocean observing.

Raising awareness of the importance and value of sustained ocean climate observations could increase support for the observing system from multiple sectors, including philanthropic organizations. An Ocean-Climate Partnership organization would be an effective mechanism to increase engagement and coordination of the ocean observation science community with non-profits, philanthropic organizations, academia, U.S. federal agencies, and the commercial sector.

### Box 2 The Global Heat, Carbon, and Fresh Water Budgets

*Understanding climate change requires accounting for all the inputs, exchanges, and energy movement within Earth's climate system. Ocean observations are especially important in accounting for Earth's heat, carbon, and fresh water budgets.*

#### *The heat budget*

Human-induced increases in greenhouse gases have trapped heat in the atmosphere. While we have measured increased temperatures in the air and on land, about 90 percent of the net global heat gain is actually happening in the ocean. That heat is transported by currents and mixed into deeper water, where it may remain for many decades to centuries. This mixing does not occur evenly across all areas of the ocean. As a result, heat gain in one area of the ocean can look quite different from heat gain in another region. Thus, understanding global heat gain requires measurements at multiple depths and in many areas of the ocean.

#### *The carbon budget*

Since the Industrial Revolution, about 30 percent of the carbon dioxide released by human activities has been absorbed by the ocean. This has helped to lower the amount of carbon dioxide in the atmosphere and thus reduced the severity of the greenhouse effect. Dissolved $CO_2$ becomes a weak acid that lowers the pH of seawater, a phenomenon termed ocean acidification. Lower pH seawater absorbs less $CO_2$ thereby reducing the ocean's ability to moderate the effect of atmospheric $CO_2$ emissions. Quantifying the capacity of the ocean to absorb $CO_2$ from the atmosphere will be essential to predict future climate warming and changes in ocean chemistry.

Similar to heat, getting a complete picture of carbon absorption and storage in the ocean is dependent on observing processes that transport carbon to the deep ocean where it may be stored for a long time.

#### *The fresh water budget*

Fresh water inputs from melting glaciers and rainfall lower seawater's salinity, or salt content, in certain areas. Both salinity and temperature affect water's density, which in turn affects how ocean waters mix vertically. Freshwater inputs are also a primary cause of sea-level rise, along with the expansion of water as it absorbs heat. Thus, monitoring freshwater inputs can help us understand where the ocean is likely to store or lose heat, as well as help predict future sea-level rise.

Credit: Hans Graber, University of Miami

## Tools for observing the ocean

The instruments used to monitor the ocean fall into two main categories: those that are located within the water, and those that make observations remotely. Platforms located in the ocean ("in situ") include a variety of fixed and mobile platforms such as tide gauges, data buoys, moorings, ship-based observations, profiling floats, ocean gliders, and surface drifters. Remote sensing involves sensitive instruments, mounted on satellites or aircraft, capable of detecting reflected or emitted radiation that reveal properties of the ocean surface.

Ocean observations require multifaceted, integrated systems of sensing infrastructure, data management, information products, human capabilities, and planning and governance. This end-to-end approach to ocean observations is built upon sustained contributions from many entities, including governments, research institutions, non-profits, and the private sector.

## COMMITTEE ON SUSTAINING OCEAN OBSERVATIONS TO UNDERSTAND FUTURE CHANGES IN EARTH'S CLIMATE

**Mary M. Glackin** (*Co-Chair*), The Weather Company, an IBM Business, Washington, D.C.; **Robert A. Weller** (*Co-Chair*), Woods Hole Oceanographic Institution, MA; **Edward A. Boyle**, Massachusetts Institute of Technology, Cambridge; **Robert B. Dunbar**, Stanford University, CA; **Robert Hallberg**, NOAA's Geophysical Fluid Dynamics Laboratory, Princeton, NJ; **Patrick Heimbach**, University of Texas at Austin; **Mark Merrifield**, University of Hawaii at Manoa; **Dean Roemmich**, Scripps Institution of Oceanography, La Jolla, CA; **Lynne D. Talley**, Scripps Institution of Oceanography, La Jolla, CA; **Martin Visbeck**, GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany; **Susan Roberts** (*Director, Ocean Studies Board*), **Emily Twigg** (*Associate Program Officer, OSB*), **April Melvin** (*Associate Program Officer, Board on Atmospheric Sciences and Climate*), **Alexandra Phillips** (*Senior Program Assistant, OSB*), National Academies of Sciences, Engineering, and Medicine

For More Information . . . This Consensus Study Report Highlights was prepared by the Ocean Studies Board and the Board on Atmospheric Sciences and Climate based on the Consensus Study Report *Sustaining Ocean Observations to Understand Future Changes in Earth's Climates* (2017). The study was sponsored by the National Oceanic and Atmospheric Administration and the National Academy of Sciences' Arthur L. Day Fund. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project. Copies of the Consensus Study Report are available from the National Academies Press, (800) 624-6242; http://www.nap.edu or via the Ocean Studies Board web page at http://www.nationalacademies.org.

Division on Earth and Life Studies

*The National Academies of*
SCIENCES · ENGINEERING · MEDICINE

The nation turns to the National Academies of Sciences, Engineering, and Medicine for independent, objective advice on issues that affect people's lives worldwide.
**www.national-academies.org**