Congressional Research Service
Informing the legislative debate since 1914

Federal Involvement in Ocean-Based Research and Development

Updated December 7, 2022

Congressional Research Service
https://crsreports.congress.gov
R47021

CRS REPORT
Prepared for Members and
Committees of Congress

Congressional Research Service
Informing the legislative debate since 1914

Federal Involvement in Ocean-Based Research and Development

SUMMARY

R47021

December 7, 2022

Caitlin Keating-Bitonti
Analyst in Natural Resources Policy

Multiple federal departments and agencies conduct ocean-based research and monitoring and/or technological development. The interpretation of oceanographic data collected and studied by these federal departments and agencies—and the academic, commercial, nonprofit research the federal government helps support—provide information to domestic policymakers, including Members of Congress, on relevant societal issues and needs that extend beyond coastal communities and island states, such as climate change and characterization of the deep-sea for geohazard prediction, environmental protection, and natural resource management.

The federal government generally is involved in ocean-based research, monitoring, and technological development to increase knowledge and understanding of the ocean. International interests also frame federal ocean work, as the ocean supports global trade and recreation. The federal departments and agencies involved in ocean-based research, monitoring, and technological development include the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, the U.S. Geological Survey, the Bureau of Ocean Energy Management, the National Science Foundation, and the Office of Naval Research of the Department of the Navy, among others.

Federal ocean data collection efforts are varied and make use of many different types of tools and technology. The federal government uses satellites, deployed instruments (e.g., buoys, floats), stationary monitoring (e.g., tide gauges), ship-based equipment (e.g., multibeam sonar sensors), and sampling (e.g., sediment corers) of targeted site locations, among other approaches. Technology such as autonomous underwater vehicles, launched from land or ships, has the capability to collect and automatically send large volumes of data to nearby shore facilities or back to the vessel. In addition, remote or human-operated vehicles and human technical divers can be used for exploration (including data collection and sampling) and visualization of the ocean. Some departments and agencies also fund extramural research, such as through grants for projects where nonfederal entities carry out various types of ocean-based research and analysis efforts.

Congress may be interested in the potential of federal ocean-based research to inform the nation's evolving understanding of the physical ocean and its resources. Some scientists and environmental and climate advocates argue that continuous, systematic ocean observations (e.g., temperature, salinity) may help identify climate impacts that contribute to ocean change (e.g., warming, sea ice melt) and, in turn, may affect society. Additionally, some experts note that using scientific knowledge of the ocean's current state to inform federal policy has both economic and environmental benefits. For example, federally collected and monitored ocean-based weather, climate, and physical Earth (i.e., seismic) data are used for early warning alerts for severe events (e.g., hurricanes, tsunamis) headed for the United States and its territories. At the same time, ocean-based research can be costly and time consuming, and some may question the relative priority of individual efforts, compared to both other ocean-based efforts and other federal activities.

Contents

Figures

Tables

Appendixes

Contacts

Introduction

The Atlantic, Indian, Pacific, Arctic, and Southern Oceans (collectively, the *global ocean*) are interconnected and comprise 71% of Earth's surface. The global ocean provides societal resources (e.g., coastal protection, storage of carbon) and affects various economic sectors (e.g., fisheries, marine transportation). For example, the ocean influences Earth's weather and so can affect things such as the amount of snowpack and spring melt, the strength and intensity of hurricanes making landfall, and seasonal crop yields.

The ocean is also a major component of the global climate system, as it absorbs, retains, and transports heat, water, and carbon. Scientists estimate with high confidence that the global ocean has absorbed more than 90% of the atmosphere's human-induced excess heat; since the 1980s, it has very likely absorbed between 20% and 30% of total anthropogenic (human-related) carbon dioxide (CO_2) emissions.[1] Climate change impacts on the ocean (e.g., warming) have affected marine fisheries, the marine tourism and recreation sector, and global food security.[2] Many view the continued observation and monitoring of the global ocean as important tools for assessing natural resources and related ecosystems in the face of these impacts.

Selected federal departments and agencies pursuing mission-based, long-term data collection and monitoring of the ocean include the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA); the National Aeronautics and Space Administration (NASA); the Department of the Interior's United States Geological Survey (USGS) and Bureau of Ocean Energy Management (BOEM); and the Department of the Navy's (DON's) Office of Naval Research (ONR). The National Science Foundation (NSF) is an independent agency that provides grant funding for short-term ocean research projects that investigate specific hypotheses and research questions. The NSF also supports research infrastructure (e.g., research facilities, vessels, equipment and instruments, and other resources). Oceanographic data collected and studied by these federal departments and agencies—and the academic, commercial, and nonprofit research the federal government helps support—provide information to domestic policymakers, including Members of Congress.

Congressional interest in federal ocean data collection and research is multifold and includes issues related to authorizing and funding specific ocean research activities and performing oversight on the implementation of federal ocean research. Congressional funding for federal departments and agencies that conduct ocean-based research allows for the continued monitoring of the ocean and the development of novel technologies to do so. In turn, Congress may use the data and knowledge gained by these federal departments and agencies to inform legislation and oversight. Ocean research may provide other benefits, such as supporting ocean-based private-sector economic activities innovation and protecting sensitive marine habitats and their wildlife. At the same time, the collection and monitoring of ocean data by the federal government can be time consuming and costly, and some may question the relative priority of individual efforts, compared to both other ocean-based efforts and other federal activities.

This report provides an overview of the U.S. federal government's efforts to collect ocean-based data through observations and monitoring and to conduct and support federal and U.S-based extramural ocean-based scientific research. It also discusses selected federal grant making efforts

[1] Intergovernmental Panel on Climate Change (IPCC), "Summary for Policymakers," in *The Ocean and Cryosphere in a Changing Climate: A Special Report of the Intergovernmental Panel on Climate Change*, eds. Hans-Otto Pörtner et al., 2019, p. 9. Hereinafter referred to as IPCC, *Ocean and Cryosphere*.

[2] National Oceanic and Atmospheric Administration (NOAA) Fisheries, "Understanding Our Changing Climates," at https://www.fisheries.noaa.gov/insight/understanding-our-changing-climate.

for these purposes. The report further explores the how ocean-based data may illuminate the impacts of climate change (e.g., data collected through NOAA's Argo Program) and how interagency collaboration and research on the seafloor and its environments may inform federal policy on deep-sea geohazards and natural resources.

Federal Ocean Research Infrastructure and Equipment

Research infrastructure contributes to the U.S. leadership role in ocean science. Federal research infrastructure and equipment used to collect and monitor ocean data form the basis for much ocean research. The analysis of these data has the potential to elucidate threats (anthropogenic and natural) to the ocean and its changing nature, contribute to marine resource (offshore energy) exploitation, maximize commercial fisheries yields, and provide warnings for marine geohazard and storm events. The information gained from these analyses may inform federal policy on the protection of the ocean, economic sectors that depend on marine resources, and coastal communities.

Federal departments and agencies have established programs and projects to collect ocean data, using federal and nonfederal assets for observations. These data are collected through various equipment, such as satellites (NOAA, NASA, USGS); ships (NOAA, USGS, BOEM, ONR); aircraft (NOAA, NASA); and various deployed objects, such as buoys and floats (NOAA). In addition, federal agencies may use ocean data collected by international, regional, and private-sector partnerships and integrate these data into federal databases; for example, the European Organisation for the Exploitation of Meteorological Satellites' polar satellite system contributes to NOAA's Joint Polar System.[3] Stationary coastal equipment, such as tide and water-quality gauges (USGS), collect and monitor local oceanographic data. Ship-based equipment allows for detailed mapping (e.g., multibeam sonar sensors);[4] exploration (e.g., human technical divers); visualization (e.g., remote or human operated vehicles); and sampling (e.g., nets, tows, grab samplers, sediment corers) of targeted site locations. Autonomous underwater vehicles (AUVs), routinely launched from ships, collect and automatically send large volumes of data to a nearby shore facility or back to the vessel.

Ocean data collection generally requires investment in time and resources. Lack of federal funding support can halt ongoing data collection. The below sections provide examples of individual U.S. federal department and agency ocean research efforts. The sections below do not provide an exhaustive list of all the departments and agencies and their respective programs that conduct ocean-based research.

National Oceanic and Atmospheric Administration

NOAA's mission includes to better understand the natural world (ocean, climate, space, and weather), help protect its resources, and monitor global weather and climate. To study the ocean, NOAA uses satellites, ships, remotely operated vehicles (ROVs), AUVs, aircraft, and other smaller deployed instruments (e.g., buoys). NOAA is structured in six line offices that cover

[3] European Organisation for the Exploitation of Meteorological Satellites, "Metop Series," at https://www.eumetsat.int/our-satellites/metop-series.

[4] A *multibeam sonar* sends out simultaneous sonar beams (sound waves) in a fan-shaped pattern to collect seafloor information surrounding the ship. For more information, see the Seafloor Bathymetry section in **Appendix A**.

various aspects of the natural world.[5] Four of NOAA's six line offices are applicable to this report: National Environmental Satellite, Data and Information Service (NESDIS); Office of Marine and Aviation Operations (OMAO); National Ocean Service (NOS); and Office of Oceanic and Atmospheric Research (OAR). The line offices and their program offices described below are not an exhaustive list of all ocean research carried out by NOAA but rather an illustration of the variety of research conducted.

NESDIS manages the nation's operational environmental satellites and makes the environmental data collected by these satellites accessible to sources for research purposes and to enhance the nation's economy and security.[6] Selected NOAA satellites (i.e., NOAA-20, Suomi National Polar-Orbiting Partnership, and Jason-3) are discussed in greater detail in the "National Aeronautics and Space Administration, below."[7]

OMAO operates specialized aircraft and ships and oversees small boat and underwater activities (including human technical diving) that help achieve NOAA's environmental and scientific missions. It operates 15 ships, including the *Okeanos Explorer*; four manned aircraft; and several unmanned aircraft systems.[8]

NOS leads NOAA's navigation and charting efforts and coordinates a federal interagency program dedicated to coastal and ocean observations and research. NOS's U.S. Integrated Ocean Observing System (IOOS) provides support, funding, guidance, and advice for tracking, predicting, managing, and adapting to environmental changes in the ocean, coastal system, and Great Lakes.[9] In addition to managing some federal ocean data and modeling systems, IOOS integrates certain nonfederal information into these systems, which can inform decisionmaking on coastal monitoring, coastal and ocean development, and changes in the Arctic.[10]

OAR conducts various aspects of ocean research across at least four offices.

- The Office of Ocean Exploration and Research is the only federal organization dedicated to exploring the deep ocean.[11] NOAA's *Okeanos Explorer* is outfitted with the necessary technology to map the seafloor during research expeditions.[12] NOAA uses other infrastructure, such as aircraft equipped with remote sensing technology and submersible ROVs, to map the depth and shape of the seafloor, complementing multibeam sonar data. This office also funds non-NOAA, U.S.-

[5] NOAA, "NOAA Line Offices," at https://www.corporateservices.noaa.gov/public/lineoffices.html.

[6] NOAA, "Our Mission," at https://www.nesdis.noaa.gov/about/our-mission.

[7] NOAA, "Currently Flying," at https://www.nesdis.noaa.gov/current-satellite-missions/currently-flying.

[8] NOAA, "Fleet," at https://www.omao.noaa.gov/find/fleet.

[9] The Integrated Coastal and Ocean Observation System Act of 2009 (49 U.S.C. §§3601 et seq.) established the U.S. Integrated Ocean Observing System. Prior to the passing of the 2009 act, no coordinated approach to coastal and ocean observing existed; instead, nonuniform data was collected by multiple federal, tribal, state, and local agencies. Integrated Ocean Observing System, "Senate Passing ICOOS Reauthorization," at http://www.ioosassociation.org/senate-passing-icoos-reauthorization-2016; NOAA, "IOOS by the Numbers," at https://ioos.noaa.gov/about/ioos-by-the-numbers/.

[10] NOAA, "Societal Benefits," at https://ioos.noaa.gov/about/societal-benefits/.

[11] NOAA, "About NOAA Ocean Exploration," at https://oceanexplorer.noaa.gov/about/welcome.html.

[12] While the mission equipment onboard Okeanos Explorer is operated by NOAA's Office of Ocean Exploration and Research within OAR, the ship is managed by NOAA's OMAO. NOAA, "NOAA Ship *Okeanos Explorer*: Meet the Team," at https://oceanexplorer.noaa.gov/okeanos/explorers/explorers.html.

based researchers conducting ocean exploration to better document and understand U.S. waters.[13]

- The Climate Program Office manages a competitive grant program to fund high-priority climate science research on Earth's climate system, including its atmosphere, ocean, land, and ice components. These grants support activities related to climate observations; Earth system science; climate and societal interactions; and modeling, analysis, predictions, and projections. Research results funded by these grants aim to enable scientists to quantify the amount of heat and CO_2 uptake by the global ocean, to estimate rates of sea level rise, and to provide adaptation tools for fisheries threatened by warming ocean waters, among other findings.
- The Ocean Acidification Program coordinates research and activities to better understand the ocean's chemistry; how it is changing; its rate of change; how change varies regionally; and how marine life (e.g., coral reefs), people, and the economy (e.g., the marine tourism and recreation sectors) are impacted. This program also provides funds for extramural research and ensures data collected by funded projects are archived and accessible for future research use.[14]
- The objective of the Global Ocean Monitoring and Observing Program (GOMO), funded under OAR's Sustained Ocean Observing and Monitoring (SOOM),[15] is to conduct continuous, in situ observations for ocean-based research, monitoring, and prediction. The GOMO supports more than 1 million oceanographic observations per day,[16] through various activities such as the Global Ocean Carbon Network and the Argo Program, among others. The Global Ocean Carbon Network aims to help researchers better understand the ocean's role in the global carbon cycle, including how the ocean absorbs atmospheric CO_2 and distributes carbon throughout the global ocean. The Argo Program is composed of nearly 4,000 Argo Profiling Floats (**Figure 1**). These floats drift with currents across the global ocean, capturing over time a near-global record of ocean temperature, salinity, dissolved oxygen, and pH data.[17] The Agro Program is international, with participation and program funding from over 25 countries; NOAA maintains about half of the global fleet.[18]

[13] NOAA, "Federal Funding Opportunity," at https://oceanexplorer.noaa.gov/about/funding-opps/welcome.html.

[14] NOAA, "Data Collection and Management," at https://oceanacidification.noaa.gov/WhatWeDo/Data.aspx. For more information on ocean acidification, see CRS Report R47300, *Ocean Acidification: Frequently Asked Questions*, by Caitlin Keating-Bitonti and Eva Lipiec.

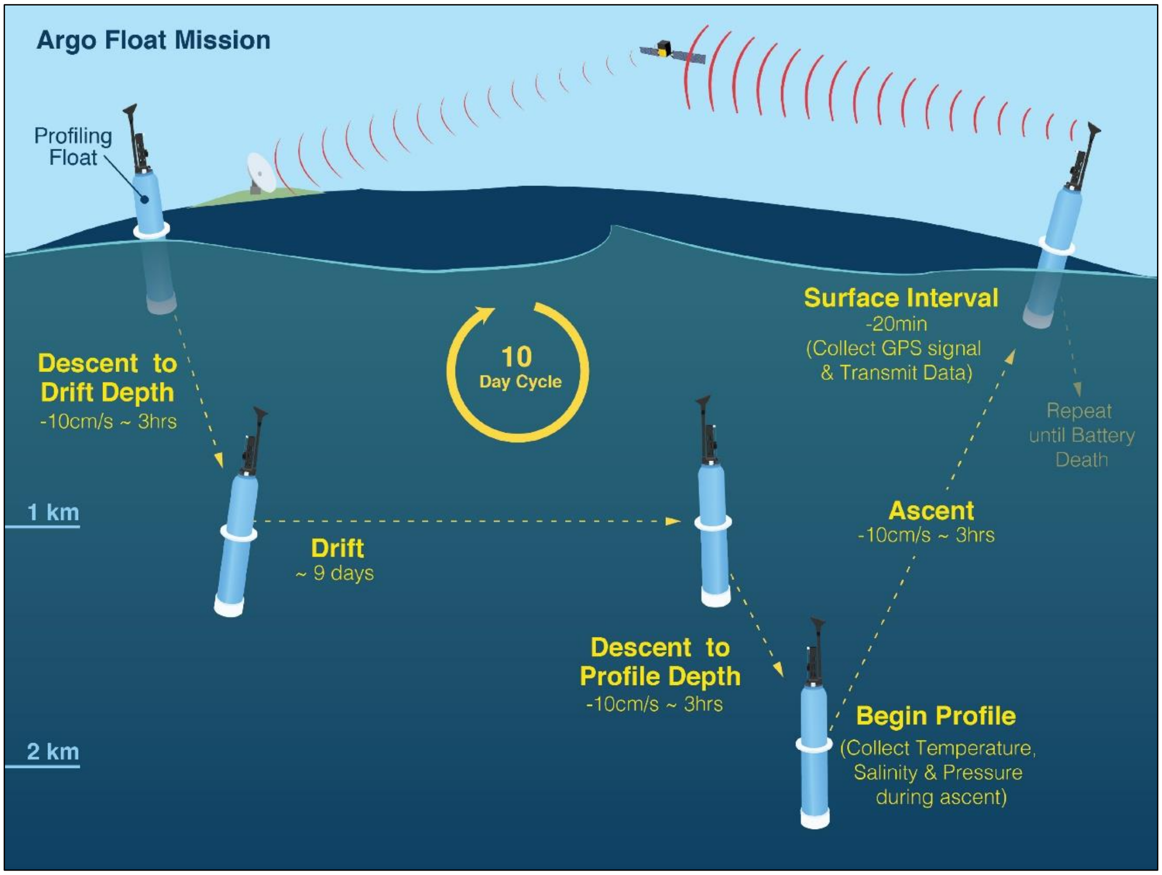
[15] NOAA's Sustained Ocean Observations and Monitoring (SOOM) Program, Project Activity (PPA) is a funding line in NOAA's budget. GOMO is the NOAA program that receives the initial allocation of the SOOM PPA; but SOOM is not GOMO's sole funding source. GOMO may use SOOM funds to support other programs which contribute to the overall priorities set by GOMO. Email correspondence with NOAA, Congressional Affairs Specialist, Office of Legislative and Intergovernmental Affairs, December 13, 2021.

[16] NOAA, "Global Ocean Monitoring and Observing," at https://globalocean.noaa.gov/About-Us.

[17]. NOAA, "NOAA Updates Sea Surface Temperature Dataset," at https://www.ncei.noaa.gov/news/noaa-updates-sea-surface-temperature-dataset.

[18] NOAA, "Argo Program Achieves Milestone with Two Million Ocean Measurements," at https://research.noaa.gov/article/ArtMID/587/ArticleID/2398/Argo-Program-Achieves-Milestone-with-Two-Million-Ocean-Measurements.

Figure 1. NOAA Argo Profiling Float 10-Day Data Collection Cycle



Source: National Oceanic and Atmospheric Administration (NOAA), "The Argo Program," at https://globalocean.noaa.gov/Research/Argo-Program.

Notes: At the end of the 10-day cycle, Argo floats transmit data to satellites from which it is collected and processed for public use. Abbreviations included in the figure include kilometers = km, centimeters per second = cm/s, minutes = min, and hours = hrs.

National Aeronautics and Space Administration

NASA studies the Earth, including its ocean and climate, the sun, and the solar system and beyond. In the 1960s, NASA began launching satellites to monitor Earth's weather. NASA has since expanded the types of Earth-observing data it collects with satellites to study Earth's climate system.

NASA's Earth Science Division plans, develops, and operates missions that support the science of Earth's atmosphere, land cover and vegetation, ocean currents and upper-ocean life, and continental and sea ice.[19] The bulleted list below is not an exhaustive list of all ocean research missions carried out by NASA but describes selected satellites that support NASA's Earth observing missions and supply ocean data to researchers.

- **Aqua.** This satellite's mission is to collect information about Earth's global water cycle, including sea surface temperature (SST) and ocean color. The satellite has

[19] NASA, "NASA Earth Science Division Mission," October 18, 2021, at https://svs.gsfc.nasa.gov/30065.

four operating instruments that collect and transmit high-quality data to inform weather forecasts, carbon management, coastal management, disaster management, and water management.[20]

- **OCO-2.** This satellite is the first satellite to collect space-based measurements of atmospheric CO_2.[21] These measurements help identify areas that are natural CO_2 sinks, such as the ocean.
- **Terra.** This satellite is equipped with five instruments that are capable of comparing different aspects of Earth over time, including SST and ocean color.[22]
- **Jason-3.** This NASA and NOAA partnership satellite is equipped with technology to collect detailed sea level measurements (altimetry) to gain insight into ocean circulation and climate change.[23]
- **Sentinel-6.** This NASA and NOAA partnership satellite is equipped with technology capable of collecting sea level measurements within 1 centimeter of precision.[24]
- **GRACE-FO.** This satellite broadly tracks Earth's water, including ice sheets and glaciers, and sea level changes due water additions to the ocean.[25]
- **ICESat-2.** This satellite measures Earth's ice coverage within 4 millimeters of precision using its only onboard instrument, the Advanced Topographic Laser Altimeter System.[26]
- **Landsat 8 and 9**. These satellites are a collaboration between NASA and USGS that primarily collect data on Earth's land surface (i.e., not the ocean) but also provide information on shallow coastal seafloor bathymetry.[27]
- **Suomi National Polar-Orbiting Partnership (NPP).** This satellite was developed by NASA for NOAA's Joint Polar Satellite System to provide data for weather forecasts and extreme storm events. Suomi NPP carries five research instruments to monitor the climate system (e.g., ocean color) while collecting the operational requirements for weather forecasting (e.g., SST), demonstrating the multifunctional nature of satellite technology.[28]
- **NOAA-20.** This satellite, Suomi NPP's successor and also built by NASA for NOAA's Joint Polar Satellite System, collects data on SST and ocean color.[29]

---

[20] NASA, "Aqua Earth-Observing Satellite Mission," at https://aqua.nasa.gov/.

[21] NASA, "Quick Facts," at https://ocov2.jpl.nasa.gov/mission/quick-facts/.

[22] NASA, "Terra Instruments," at https://terra.nasa.gov/about/terra-instruments.

[23] NASA, "Jason-3," at https://www.jpl.nasa.gov/missions/jason-3.

[24] NASA, "Sentinel-6 Mission Overview," at https://www.nasa.gov/sentinel-6/overview.

[25] NASA, "Mission," at https://gracefo.jpl.nasa.gov/mission/overview/.

[26] Anna Heiney, "ICESat-2 Successfully Launched on Final Flight of Delta II Rocket," NASA ICESat-2 blog, September 15, 2018, at https://blogs.nasa.gov/icesat2/.

[27] NASA, "Landsat 8 Mission Details," at https://landsat.gsfc.nasa.gov/satellites/landsat-8/landsat-8-mission-details/. For more information, see CRS Report R46560, *Landsat 9 and the Future of the Sustainable Land Imaging Program*, by Anna E. Normand.

[28] NASA, "NPP Mission Overview," at https://www.nasa.gov/mission_pages/NPP/mission_overview/index.html. For more information on NOAA's polar-orbiting weather satellites, see CRS Report R44335, *Minding the Data Gap: NOAA's Polar-Orbiting Weather Satellites and Strategies for Data Continuity*, by Peter Folger.

[29] NOAA, "Joint Polar Satellite System (JPSS) Program Office," at https://www.jpss.noaa.gov/.

United States Geological Survey

The USGS is a scientific agency within the Department of the Interior (DOI).[30] USGS scientists monitor, analyze, and predict the current and evolving dynamics of the Earth. A core USGS mission is mapping, which includes coastal maps generated from bathymetric surveys;[31] generally, NOAA is the primary federal source for ocean bathymetric data. The USGS also collects, monitors, and analyzes natural resources data, including for resources found in the ocean, such as sand and gravel for construction and minerals required for emerging technologies.[32]

At least three selected USGS programs are engaged in ocean-based research.

- The Coastal/Marine Hazards and Resources Program, within the Natural Hazards Mission Area, collects and manages data, such as information about gas hydrates, hydrothermal vent deposits, and rare Earth minerals.[33] This program also supports other ocean science topics, such as mapping the extent of the continental shelf; studying factors related to sea level rise; and conducting research on ocean ecosystems, including benthic ecosystems (i.e., organisms living on or in seafloor sediments).
- The Groundwater and Streamflow Information Program, within the Water Resources Mission, deploys, operates, and retrieves sensors for coastal storm events, including tide gauges and other water sensors (see **Table 1** and **Table 2**). The Coastal/Marine Hazards and Resources Program augments data collection and other activities associated with storm events as needed.[34]
- The Climate Research and Development Program, within the Ecosystems Mission Area, supports monitoring of the Arctic, sea ice, and sea level rise. This program also collects and analyzes deep-sea sediments to reconstruct changes in past climate and oceanographic conditions.

Bureau of Ocean Energy Management

BOEM, an agency within DOI, manages the development of the nation's energy and mineral resources on the outer continental shelf (OCS), which includes submerged lands, subsoil, and seabeds under U.S. jurisdiction.[35] BOEM conducts geological and geophysical (G&G) surveys to

---

[30] For more background on the USGS, see CRS In Focus IF11433, *The U.S. Geological Survey (USGS): FY2021 Appropriations Process and Background*, by Anna E. Normand.

[31] U.S. Geological Survey (USGS), "Sea Floor Mapping Group," at https://www.usgs.gov/centers/whcmsc/science/sea-floor-mapping-group?qt-science_center_objects=0#qt-science_center_objects.

[32] USGS, "Ocean Resources," at https://www.usgs.gov/centers/whcmsc/science/ocean-resources; USGS, "Celebrate June as Oceans Month," June 2, 2016, at https://www.usgs.gov/news/featured-story/celebrate-june-oceans-month.

[33] USGS, "Coastal and Marine Hazards and Resources Program," at https://www.usgs.gov/natural-hazards/coastal-marine-hazards-and-resources/science/ocean-resources.

[34] USGS funding for these activities primarily comes from reimbursable partners (typically the Federal Emergency Management Agency) as storm events occur. Email correspondence with USGS, Congressional Liaison, Congressional Liaison Office, on January 7, 2022.

[35] The Outer Continental Shelf Lands Act of 1953 (43 U.S.C. §§1331-1356b) defines the outer continental shelf (OCS) as all federally controlled submerged lands, subsoil, and seabed. The OCS generally begins 3 nautical miles (international nautical mile = 6,076.1 feet) off the coastline and extends for at least 200 nautical miles to the edge of the exclusive economic zone, or farther if the continental shelf extends beyond 200 nautical miles. For more information, see CRS Report RL33404, *Offshore Oil and Gas Development: Legal Framework*, by Adam Vann.

obtain data on oil and gas reserves located on the OCS, identify sites for offshore renewable energy structures, and locate marine mineral resources.[36]

BOEM conducts two types of G&G surveys: deep penetration airgun surveys and high-resolution geophysical (HRG) surveys to characterize the subsurface of the seafloor (i.e., different layers of rock beneath the seafloor).[37] Deep penetration airgun surveys are also used for oil and gas exploration. HRG surveys can be used for oil and gas exploration, siting for renewable energy structures, and sand and gravel identification. HRG equipment can include multibeam sonars, sidescan sonars, and sub-bottom profilers. These surveys typically operate at higher frequencies and image smaller structures at higher levels of detail as compared with airgun surveys.

BOEM has four programs, among other activities, that involve ocean-based studies and the management of related scientific research and data.

- The Conventional Energy Program, among other activities, conducts assessments of the oil and gas resource potential on the OCS, including G&G surveys to obtain data useful for oil and gas exploration, inventories of oil and gas reserves, and economic evaluations.
- The Renewable Energy Program, among other activities, funds and manages scientific research related to renewable energy projects on the OCS (e.g., potential environmental and ecological stressors during the construction and operation of offshore renewable energy facilities).
- The Environmental Program funds and manages relevant environmental studies including, but not limited to, physical oceanography, protected species, economics, and cultural resources.
- The Marine Minerals Program, among other activities, conducts environmental studies and assessments, performs resource evaluation studies, and contributes data for *bathymetric maps*.[38] Initiatives include the National Offshore Critical Mineral Inventory, the National Offshore Sand Inventory, and the Marine Minerals Information System (with information on OCS sand and gravel resources).

National Science Foundation

NSF promotes the progress of science by funding extramural research, largely through grants awarded in support of academic research.[39] The types of data collected, and the modes of data collection and observation, depend on the awarded research project. Funding duration for NSF grants generally ranges from one to five years, with an average of three years for research grants.[40]

---

[36] Bureau of Ocean Energy Management (BOEM), "Fact Sheet: Geological and Geophysical (G&G) Surveys," at https://www.boem.gov/sites/default/files/about-boem/BOEM-Regions/Atlantic-Region/GandG-Overview.pdf.

[37] Bureau of Ocean Energy Management (BOEM), "Fact Sheet: Geological and Geophysical (G&G) Surveys," at https://www.boem.gov/sites/default/files/about-boem/BOEM-Regions/Atlantic-Region/GandG-Overview.pdf.

[38] *Bathymetric maps* give the ocean's depth relative to sea level and show the three-dimensional features of the seafloor (similar to topographic maps). NOAA, "What Is Bathymetry," at https://oceanservice.noaa.gov/facts/bathymetry.html.

[39] For more information on the National Science Foundation (NSF), see CRS Report R46753, *The National Science Foundation: An Overview*, by Laurie A. Harris.

[40] NSF, *Merit Review Process: Fiscal Year 2019 Digest*, December 2020, pp. 7, 20, https://www.nsf.gov/nsb/.publications/2020/merit_review/FY-2019/nsb202038.pdf.

The Division of Ocean Sciences (OCE) within the NSF Directorate for Geosciences, provides funding support to advance understanding of all aspects of the global ocean (including human interactions),[41] and gives the nation's academic community the opportunity to obtain funds to work toward advancing this understanding through competitive grants. Aspects of ocean research may also be supported by other NSF Directorates (e.g., Directorate for Biological Sciences, Directorate for Mathematical and Physical Sciences). In general, about 30% of OCE's funding each year goes to new research grants, with the remaining 70% supporting grants made in previous years and research infrastructure.[42] Also within NSF's Directorate for Geosciences is the Office of Polar Programs (OPP), which includes research funding for scientists supported by NSF and by other U.S. departments and agencies studying the polar regions, including the Southern and Arctic Oceans. OPP leverages both interagency and international partnerships.

Both OCE and OPP support the U.S. Global Change Research Program (USGCRP),[43] including infrastructure programs that focus on observing today's changing ocean while better understanding past climate events to inform future climate change. For FY2022, the USGCRP established five research themes, including the Ocean's Role in Climate Change.[44]

NSF is part of the University-National Oceanographic Laboratory System (UNOLS),[45] which provides a forum for the research and education community and the federal government to work cooperatively on oceanographic research while coordinating a federally supported Academic Research Fleet (ARF).[46] For example, the R/V *Sikuliaq* is a research vessel owned by the NSF and operated by the College of Fisheries and Ocean Sciences at the University of Alaska Fairbanks, specializing in polar-focused ocean research. OCE also oversees the Regional Class Research Vessel (RCRV) project, which is currently funding the construction of three ships for inclusion in the ARF to support the needs of researchers in coastal zones.[47] The transition of these three new ships from construction to operations is estimated for Fall 2022.[48]

NSF also provides support to the International Ocean Discovery Program (IODP), an international marine research collaboration that uses research platforms to drill and recover seafloor sediments that can be used to study the dynamics of the sub-seafloor and the past 200 million years of Earth's history.[49] Seafloor sediments can be used to reconstruct the extent of sea

[41] NSF, "About the Division of Ocean Sciences (OCE)," at https://www.nsf.gov/geo/oce/about.jsp.

[42] NSF, "FY 2022 NSF Budget Response to Congress—Geosciences," p. GEO-11, at https://www.nsf.gov/about/budget/fy2022/pdf/49_fy2022.pdf. Hereinafter referred to as "FY2022 NSF GEO Budget Response."

[43] The U.S. Global Change Research Program (USGCRP) was mandated by Congress in the Global Change Research Act of 1990 (P.L. 101-606) to coordinate federal research and investments across 13 departments and agencies to advance understanding of the changing Earth system. USGCRP, "About USGCRP," at https://www.globalchange.gov/about.

[44] FY2022 NSF GEO Budget Response, p. GEO-10.

[45] University-National Oceanographic Laboratory System (UNOLS), "UNOLS Charter," at https://www.unols.org/sites/default/files/UNOLS_Charter_2019.pdf.

[46] ARF vessels support the needs of all federal oceanographic research stakeholders, particularly NSF, NOAA, and ONR. NSF, "FY 2022 NSF Budget Response to Congress—Major Research Equipment and Facilities Construction," p. MREFC-35, at https://www.nsf.gov/about/budget/fy2022/pdf/58f_fy2022.pdf.

[47] Regional Class Research Vessels (RCRV) was designed to support the eight high-priority science questions identified in the 2015 National Academies report on sea change. The National Academies, "Sea Change: 2015-2025 Decadal Survey of Ocean Sciences," 2015, at http://www.nap.edu/read/21655/chapter /1.

[48] The total appropriated RCRV funds are $358.97 million, which is $16.03 million below the authorized total project cost of $356 million. NSF, "FY 2022 NSF Budget Response to Congress—Major Research Equipment and Facilities Construction," p. MREFC-35, at https://www.nsf.gov/about/budget/fy2022/pdf/58f_fy2022.pdf.

[49] Jason Daley, "This 340-Million-Year-Old Ocean Crust Could Date Back to Pangaea," *Smithsonian Magazine*,

ice during past glaciation events. The sediments also reflect past changes in deep-sea circulation patterns, which help distribute and sequester (or bury) atmospheric CO_2 in the deep sea.

Office of Naval Research

ONR within the DON aims to provide science- and technology-based solutions for current and future naval challenges. ONR oversees the execution of the science and technology (S&T) portion of DON's overall research and development account. ONR addresses a wide range of potential S&T issues of interest to the Navy. A portion of those issues are ocean-based, including ocean engineering, maritime sensing, undersea and remote sensing system development, ocean acoustics, Arctic changes, and physical oceanography monitoring.

ONR and NSF are the two primary federal support agencies of the UNOLS fleet of academic research vessels. ONR owns three UNOLS academic research vessels and, together with the operating institutions, coordinates their research missions and ship schedules.

The Department of the Navy's Naval Oceanographic Office (NAVOCEANO) collects and analyzes oceanographic data to support national security and provide knowledge of the maritime battlespace. Civilian and military members of NAVOCEANO are generally qualified as hydrographers and survey technicians capable of hydrographic surveys (descriptions of seafloor features) anywhere in the world.[50]

Oceanographic Data

Oceanographic data consist of measurements of the physical state of the ocean (e.g., sea level is a physical variable) and the amount of chemical elements in the seawater (e.g., dissolved oxygen is a biogeochemical variable). Oceanographic data provide a basis for insights into the ocean ecosystem and its changing environment, aspects of climate change, and the distribution and availability of marine resources. Physical oceanographic data (**Table 1**) also can provide information on oceanographic processes, such as ocean upwelling (**Figure 2**) and ocean current and circulation patterns.[51] Whereas an oceanographic variable can provide insight into various characteristics of the ocean, the combination of more than one physical or biogeochemical variable often can provide additional confidence about the scientific interpretations of the ocean's current and future state through scientific modeling studies. Select common physical oceanographic data are summarized below in **Table 1**. These data are discussed in more detail in **Appendix A**.

August 17, 2016, at https://www.smithsonianmag.com/smart-news/oldest-bit-seafloor-discovered-mediterranean-180960153/.

[50] NAVOCEANO, "Fleet Survey Team," at https://www.cnmoc.usff.navy.mil/Organization/Naval-Oceanographic-Office/Fleet-Survey-Team/.

[51] Ocean upwelling occurs when wind energy pushes sea surface water in a specific direction, allowing for deep water to move to the surface. Upwelled waters are rich in nutrients and ocean upwelling is a natural fertilization process for the surface ocean, stimulating the base of the marine food web. For more information on ocean upwelling, see text box entitled "Ocean Upwelling" in **Appendix A**. NOAA, "What Is Upwelling?" https://oceanexplorer.noaa.gov/facts/upwelling.html.

Table 1. Selected Physical Oceanographic Variables

(common physical oceanographic data collected and studied by federal departments and agencies)

Physical Oceanographic Variable	Instrumentation and Equipment Examples	Selected Uses/Purposes
Ocean Temperature	Argo Profiling Floats (NOAA);[a] Unmanned Surface Wave Gliders (NOAA);[b] CTD Sensors (NOAA/USGS);[c] Research Vessels (NOAA);[d] Submersible ROVs (NOAA);[e] Earth-Observing Satellites (NOAA/NASA);[f] Water-Quality Gauge (USGS)[g]	• Forecast and track pending short- and mid-term weather events (including storms and hurricanes) and long-term climate patterns, such as the El Niño Southern Oscillation;[h] • Track ocean circulation patterns, such as the Gulf Stream;[i] • Monitor ocean upwelling,[j] which can be applied to track the occurrence of specific marine species
Ice	Earth-Observing Satellites (NOAA/NASA);[k] Research Vessels (NSF);[l] Moored (Stationary) Buoys (NOAA);[m] Aircraft (NASA)[n]	• Understand impact of climate change on polar regions;[o] • Predict and quantify rate of sea level rise;[o] • Predict freshening (salinity decline) of surface ocean water in polar regions[o]
Sea Level	Earth-Observing Satellites (NOAA/NASA);[p] Tide Gauges (NOAA/USGS);[q] Water-Level Sensors (USGS)[g]	• Predict coastal sea level trends and flooding;[i] • Quantify the rate of sea level rise;[o] • Inform safe vessel navigation[r]
Chlorophyll (ocean color)	Earth-Observing Satellites (NOAA/NASA)[j]	• Monitor ocean upwelling and provide an estimate for living phytoplankton in the near-surface water[j]
Seafloor Bathymetry	Research Vessels Equipped with Geological and Geophysical Survey Equipment (NOAA/BOEM/USGS);[s] Submersible ROVs (NOAA);[e] Aircraft Equipped with lidar (NOAA);[t] Earth-Observing Satellites (NASA/USGS)[i]	• Quantify water depth;[u] • Provide information on seafloor sediment type that could aid siting of natural resources;[v] • Identify seafloor geologic features (faults or subduction zones) that could produce natural hazards (earthquakes or tsunamis);[u] • Determine the extent of the U.S. continental shelf;[w] • Inform safe vessel navigation[u]

Source: For additional information and source data, refer to **Appendix A**.

Notes: BOEM = Bureau of Ocean Energy Management; CTD Sensors = Conductivity, Temperature, and Depth Sensors; lidar = light detection and ranging; NASA = National Aeronautics and Space Administration; NOAA = National Oceanic and Atmospheric Administration; National Science Foundation = NSF; ONR = Office of Naval Research; ROV = remote-operated vehicle; USGS = U.S. Geological Survey.

a. NOAA, "Argo Center," at https://www.aoml.noaa.gov/phod/argo/.

b. Wave gliders are inexpensive surfboard-looking autonomous vehicles that collect surface ocean data. NOAA, "Surface Wave Gliders," at https://www.pmel.noaa.gov/edd/surface-wave-gliders.

c. A Conductivity, Depth, and Temperature (CDT) sensor detects how the conductivity and temperature of the seawater changes with water depth, which can be used to derive salinity. NOAA, "What Does "CDT" Stand For?" at https://oceanexplorer.noaa.gov/facts/ctd.html.

d. NOAA, "Observation Platforms: Vessels," at https://oceanexplorer.noaa.gov/technology/vessels/vessels.html.

e. NOAA, "Remotely Operated Vehicle Deep Discoverer," at https://oceanexplorer.noaa.gov/technology/subs/deep-discoverer/deep-discoverer.html.

f. NASA, "Ocean Temperature," https://podaac.jpl.nasa.gov/SeaSurfaceTemperature; NOAA, "How Are Satellites Used to Observe the Ocean?" at https://oceanservice.noaa.gov/facts/satellites-ocean.html.

g. USGS, "Storm-Tide Monitoring," June 9, 2018, at https://www.usgs.gov/special-topics/water-science-school/science/storm-tide-monitoring.

h. NOAA; "SST—Sea Surface Temperature," at https://www.climate.gov/maps-data/data-snapshots/data-source/sst-sea-surface-temperature; NASA, "Recipe for a Hurricane," at https://www.nasa.gov/vision/earth/environment/HURRICANE_RECIPE.html.

i. NOAA, "How Are Satellites Used to Observe the Ocean?" at https://oceanservice.noaa.gov/facts/satellites-ocean.html.

j. Ocean upwelling occurs when wind energy pushes sea surface water in a specific direction, allowing for deep water to move to the surface. For more information on ocean upwelling, see text box entitled "Ocean Upwelling" in **Appendix A**. NASA, "Remote Sensing," at https://science.nasa.gov/earth-science/oceanography/living-ocean/remote-sensing; NASA, "VIRRS Single-Sensor S-NPP and NOAA-20 Anomaly Products," at https://coastwatch.noaa.gov/cw/satellite-data-products/ocean-color/anomaly.html.

k. NASA, "Our Mission," at https://icesat-2.gsfc.nasa.gov/mission; NASA, "GRACE, GRACE-FO Satellite Data Track Ice Loss at the Poles," March 18, 2020, https://climate.nasa.gov/news/2959/grace-grace-fo-satellite-data-track-ice-loss-at-the-poles/; NASA, "VIIRS—Sea Ice Concentration, Ice Thickness, Ice Surface Temperature," https://coastwatch.noaa.gov/cw/satellite-data-products/sea-ice/viirs-sea-ice-concentration-ice-thickness-ice-surface-temperature.html.

l. NSF, "USAP Ships," at https://www.nsf.gov/geo/opp/support/ships.jsp.

m. NOAA, "Meet 5 NOAA Buoys that Help Scientists Understand Our Weather, Climate and Ocean Health," at https://research.noaa.gov/article/ArtMID/587/ArticleID/2762/Meet-5-NOAA-Buoys-that-help-scientists-understand-our-weather-climate-and-ocean-health.

n. NASA, "IceBridge—Aircraft, Instruments, Satellites," at https://www.nasa.gov/mission_pages/icebridge/instruments/index.html.

o. NASA, "Understanding Sea Level," at https://sealevel.nasa.gov/understanding-sea level/global-sea level/overview.

p. NASA, "NASA, US, European Partner Satellite Returns First Sea Level Measurements," at https://climate.nasa.gov/news/3052/nasa-us-european-partner-satellite-returns-first-sea level-measurements/.

q. NOAA, "What Is a Tide Gauge?" at https://oceanservice.noaa.gov/facts/tide-gauge.html.

r. NOAA, "Maritime Services," at https://tidesandcurrents.noaa.gov/maritime.html.

s. NOAA, "Ten Years of Collecting Ocean Exploration Data from NOAA Ship Okeanos Explorer," at https://oceanexplorer.noaa.gov/ex10years/welcome.html; BOEM, "Geological and Geophysical (G&G) Surveys," at https://www.boem.gov/sites/default/files/about-boem/BOEM-Regions/Atlantic-Region/GandG-Overview.pdf; USGS, "Marine Seismic Imaging" at https://www.usgs.gov/programs/coastal-and-marine-hazards-and-resources-program/science/marine-seismic-imaging.

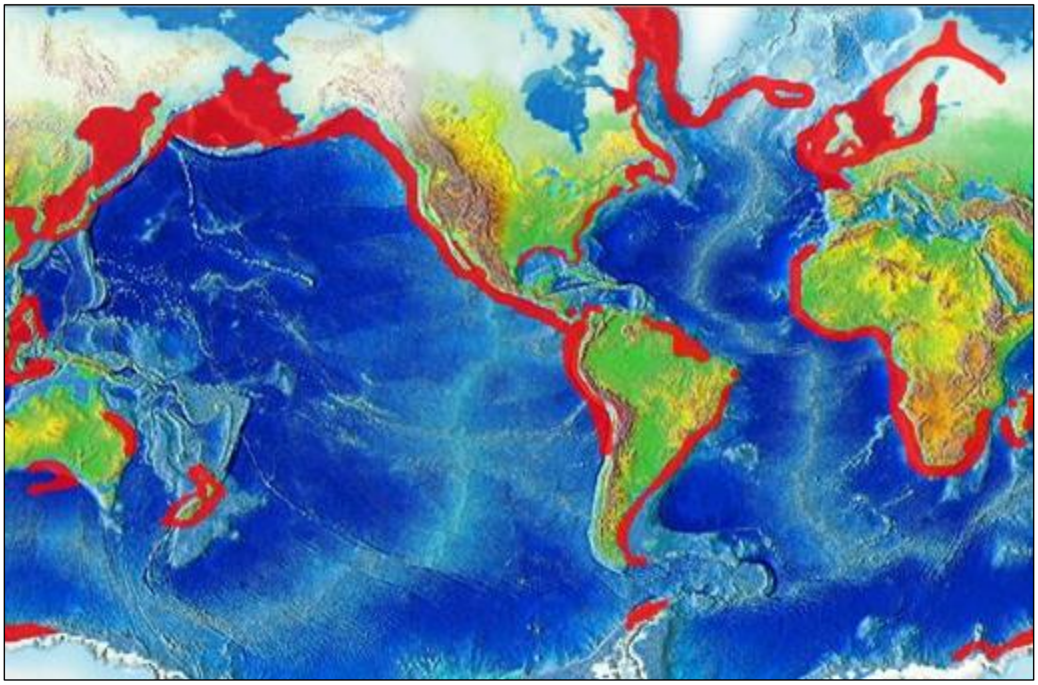
t. NOAA, "What Is Lidar," at https://oceanservice.noaa.gov/facts/lidar.html.

u. NOAA, "How Is Bathymetric Data Used?" at https://oceanservice.noaa.gov/facts/bathyuses.html.

v. NOAA, "Sea Floor Mapping," at https://oceanexplorer.noaa.gov/explorations/lewis_clark01/background/seafloormapping/seafloormapping.html.

w. NOAA, "NOAA's Participation in the U.S. Extended Continental Shelf Project," at https://oceanexplorer.noaa.gov/okeanos/explorations/ex1810/ecs/welcome.html. For more information, see CRS Report R41153, *Changes in the Arctic: Background and Issues for Congress*, coordinated by Ronald O'Rourke.

Figure 2. Major Areas of Coastal Upwelling



Source: National Oceanic and Atmospheric Administration (NOAA), "Upwelling," at https://oceanservice.noaa.gov/education/tutorial_currents/03coastal4.html.

Notes: Areas of major coastal upwelling are shown in red. For additional information on ocean upwelling, see text box entitled "Ocean Upwelling" in **Appendix A**.

The concentrations of biogeochemical variables (**Table 2**) in seawater are influenced by mixing of waters with different concentrations (e.g., upwelled deep-sea water mixing with near-surface water), biogeochemical processes (e.g., marine carbon cycle), and atmospheric inputs (e.g., diffusion of dissolved oxygen across the atmosphere-surface water interface), among other factors. Anthropogenic CO_2 emissions and agricultural or wastewater discharge have also altered biogeochemical variables (e.g., pH and dissolved oxygen).[52] Selected common biogeochemical oceanographic data are summarized below in **Table 2**. These data are discussed in more detail in **Appendix B**.

Table 2. Selected Biogeochemical Oceanographic Variables

(common biogeochemical oceanographic data collected and studied by federal departments and agencies)

Biogeochemical Oceanographic Variable	Instrumentation and Equipment Examples	Selected Use/Purpose
Salinity	Argo Profiling Floats (NOAA);[a] Unmanned Wave Gliders (NOAA);[b] Submersible ROVs (NOAA);[c] CTD Sensors (NOAA/USGS);[d] Water-Quality Gauge (USGS)[e]	• Provide insight into the water cycle;[f] • Trace ocean circulation patterns;[f] • Monitor runoff from land or ice melt;[f] • Predict hurricane intensity[g]

[52] For information on the effects of human-associated discharge on coastal ocean waters, see CRS Report R46921, *Marine Harmful Algal Blooms (HABs): Background, Statutory Authorities, and Issues for Congress*, by Eva Lipiec.

Biogeochemical Oceanographic Variable	Instrumentation and Equipment Examples	Selected Use/Purpose
Dissolved Oxygen	Argo Profiling Floats (NOAA);[a] Unmanned Wave Gliders (NOAA);[b] Submersible ROVs (NOAA);[c] Water-Quality Gauge (USGS)[e]	• Serve as indicator of the health of the marine ecosystem;[h] • Correlate with surface ocean temperature[h]
pH	Argo Profiling Floats (NOAA);[a] Unmanned Wave Gliders (NOAA);[b] Moored Buoys Equipped with CO_2 Sensors (NOAA);[i] Earth-Observing Satellites (NASA/NOAA);[j]	• Quantify rate of anthropogenic carbon uptake by the ocean;[k] • Serve as indicator for ocean acidification[k]

Source: For additional background information and source data refer to **Appendix B**.

Notes: CO_2 = carbon dioxide; CTD Sensors = Conductivity, Temperature, and Depth Sensors; NASA = National Aeronautics and Space Administration; NOAA = National Oceanic and Atmospheric Administration; USGS = U.S. Geological Survey.

a. NOAA, "Argo Center," at https://www.aoml.noaa.gov/phod/argo/.

b. NOAA, "Surface Wave Gliders," at https://www.pmel.noaa.gov/edd/surface-wave-gliders; NOAA, "Autonomous Surface Vehicles," at https://www.pmel.noaa.gov/co2/story/Autonomous+Surface+Vehicles.

c. NOAA, "Remotely Operated Vehicle Deep Discoverer," at https://oceanexplorer.noaa.gov/technology/subs/deep-discoverer/deep-discoverer.html.

d. A Conductivity, Temperature, and Depth (CDT) sensor detects how the conductivity and temperature of the seawater changes with water depth, which can be used to derive salinity. NOAA, "What Does 'CDT' Stand For?" at https://oceanexplorer.noaa.gov/facts/ctd.html.

e. USGS, "Storm-Tide Monitoring," June 9, 2018, at https://www.usgs.gov/special-topics/water-science-school/science/storm-tide-monitoring.

f. NASA, "Salinity/Density," at https://podaac.jpl.nasa.gov/SeaSurfaceSalinity.

g. NOAA, "Measuring Salt in the Ocean May Be Key to Predicting Hurricane Intensity," December 16, 2021, at https://research.noaa.gov/article/ArtMID/587/ArticleID/2819/Measuring-salt-in-the-ocean-may-be-key-to-predicting-how-hurricanes-strengthen.

h. USGS, "Dissolved Oxygen and Water," at https://www.usgs.gov/special-topics/water-science-school/science/dissolved-oxygen-and-water.

i. NOAA, "Buoys and Other Autonomous Systems," at https://www.pmel.noaa.gov/co2/story/Buoys+and+Autonomous+Systems.

j. Joseph Salisbury et al., "How Can Present and Future Satellite Missions Support Scientific Studies that Address Ocean Acidification?" *Oceanography*, vol. 28 (October 2015); NOAA, "Ocean Acidification from Space," June 2, 2016, at https://carbon.nasa.gov/pdfs/20160602%20NASA%20SSAI%20Gledhill.pdf.

k. Environmental Protection Agency, "Climate Change Indicators: Ocean Acidity," at https://www.epa.gov/climate-indicators/climate-change-indicators-ocean-acidity.

Ocean Data Trends and Climate Change

Ocean data and observation trends over time have informed scientific reports that have highlighted the nature and rate of change the global ocean has experienced, as well as the potential impacts of these changes.

- **Ocean Temperature.** Warming surface ocean waters affect weather patterns and storms, including hurricanes. The 2019 Intergovernmental Panel on Climate Change (IPCC) *Special Report on the Ocean and Cryosphere in a Changing Climate* found evidence for an increase in the global proportion of category 4-5 tropical cyclones in recent decades and the proportion of tropical cyclones are projected to increase with continued warming.[53]

- **Ice.** Warming near-surface air temperatures in the Arctic are melting continental ice (ice sheet and glacier) across the region.[54] The climate modeling results for the mid- and high greenhouse gas emissions scenarios published in the 2021 IPCC *Sixth Assessment Report* project the Arctic to be "practically" sea-ice free during the month of September between 2050-2100.[55]
- **Sea level.** Continental ice melt and thermal expansion of ocean water are contributing to rising sea levels.[56] From 2006 to 2018, continental ice melt was the dominant contributor to global sea level rise.[57] Continuous data on variations in sea level inform scientists on the rate of sea level rise and the regions most susceptible to coastal flooding. The average global sea level rise from 2006 to 2018 was 3.7 millimeters per year.[58]
- **Dissolved Oxygen.** Declining oxygen levels in seawater correlate with warming ocean waters. Warmer water holds less dissolved gases (e.g., oxygen) than colder water. Trends published in the physical science report of the 2021 IPCC *Sixth Assessment Report* showed a decline in surface dissolved oxygen levels (deoxygenation) in all ocean basins. The IPCC attributed this decline, with medium confidence, to surface ocean warming.[59]
- **pH.** Declining seawater pH levels are attributed to the global ocean's increased absorption of anthropogenic atmospheric CO_2. Since the beginning of the Industrial Revolution, the pH of global surface ocean has decreased by 0.1 pH units (from an average pH of 8.2 to 8.1), equivalent to a 25%-30% increase in ocean acidity.[60]

Selected Issues for Congress

Research and analysis of ocean processes, resources, and potential future changes to these processes and resources have the potential to inform congressional deliberations regarding ocean policy and ocean management. Congress also may be interested in these efforts for their potential to support public and private sector economic activities that rely on the ocean or facilitate the protection sensitive habitats and their wildlife.

A potential issue facing Congress is to what extent, if any, to support and direct federal ocean science research and development and, if so, which efforts to emphasize and how to guide departments and agencies in this work. Scientific knowledge of the ocean evolves as new

---

[53] "Summary for Policymakers," in IPCC, *Ocean and Cryosphere*, p. 11. NOAA, "Global Warming and Hurricanes," August 2021, at https://www.gfdl.noaa.gov/global-warming-and-hurricanes/#summary-statement.

[54] T. J. Ballinger et al., "Surface Air Temperature," in NOAA, *2020 Arctic Report Card*, December 2020, p. 21.

[55] IPCC, "Summary for Policymakers," in *Changing Climate 2021: The Physical Science Basis*, eds. V. Masson-Delmotte et al., 2021, pp. SMP-29-SMP-30. Hereinafter referred to as IPCC, *AR6 Physical Science Basis*.

[56] Because water expands as it warms (thermal expansion), warming ocean water will cause sea level rise.

[57] "Summary for Policymakers," in IPCC, *AR6 Physical Science Basis*, p. SMP-14.

[58] "Summary for Policymakers," in IPCC, *AR6 Physical Science Basis*, p. SMP-6.

[59] "Summary for Policymakers," in IPCC, *AR6 Physical Science Basis*, p. SMP-6.

[60] NOAA, "Ocean Acidification," at https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification; Environmental Protection Agency (EPA), "Understanding the Science of Ocean and Coastal Acidification," at https://www.epa.gov/ocean-acidification/understanding-science-ocean-and-coastal-acidification.

information and exploration technology becomes available. Thus, some scientists and environmental and climate advocates call for continuous, systematic ocean research observations and monitoring by federal government, as well as funding for new endeavors. Supporters of these efforts frame the modern challenges of ocean management and the opportunities the ocean presents to address environmental and societal issues. At the same time, funding for ocean research can be costly; thus, some may question the relative priority of some work, compared to both other ocean-based efforts and other federal activities.

Another set of issues Congress may consider is related to what extent existing ocean research efforts are sufficient to address climate change impacts. This includes to what extent, if any, Congress might change any specific ocean research programs or projects to improve data collection and monitoring for the purpose of understanding the ocean's role in the climate system. Relatedly, Congress may consider whether additional investments in certain federal programs are necessary, such as improving Argo float technology to expand the program's coverage of the ocean. Further, another set of issues relates to whether—and if so, how—to incorporate ocean research findings into existing ocean programs or other policies.

Technological advances in deep-sea infrastructure have led to increased interest in deep-sea exploration and the extraction of deep-sea resources. Thus, the application of deep-sea data for geohazard prediction, environmental protection, and natural resource management comprise another set of issues related to ocean research that Congress may consider. Congress may consider issues related to federal coordination, environmental concerns, development of renewable technologies and energy for anthropogenic CO_2 mitigation, and national security needs.

Ocean Data and Research Needs Related to Climate Change

Congress may consider a range of issues related to ocean research and climate change. Potential issues include whether the current investment is sufficient to provide adequate information on the potential impacts of climate change on the global ocean and its resources and, conversely, the ways in which ocean processes influence global climate. P.L. 117-169, a budget reconciliation measure commonly referred to as the "Inflation Reduction Act of 2022" (IRA), appropriated $150 million in FY2022 (available through FY2026) to NOAA, with the goal of accelerating advances and improvements in research of atmospheric and ocean processes that relate to climate and weather, among others.[61] In addition, Section 40004 of the IRA appropriated $50 million in FY2022 (available through FY2026) to NOAA for climate research competitive grants relating to ocean and other processes and associated impacts to marine species and coastal habitat. Some scientists and environmental advocates view the ocean as having a key role in mitigating climate change,[62] and they view federal spending in ocean monitoring and observational technologies as one means to better understand the ocean-climate nexus. Congress also may consider policy implications related to the ocean's role in mitigating rising atmospheric CO_2.

NOAA's Argo Program has collected over two decades' worth of oceanographic data that have helped scientists understand the ways in which climate change has affected the global ocean. Technological advancement since the Argo Program's establishment in 1998 has led scientists to call for additional Argo floats to utilize these technological enhancements.[63] Examples include

[61] Section 40004 of P.L. 117-169.

[62] The global ocean absorbs CO_2 emissions from human activities (i.e., the combustion of fossil fuels), helping to offset the buildup of anthropogenic CO_2 in the atmosphere.

[63] Dean Roemmich et al., "On the Future of Argo: A Global, Full-Depth, Multi-Disciplinary Array," *Frontiers in*

developing and deploying a fleet of floats that extend the typical profiling depth of 2,000 meters to 6,000 meters (Deep Argo) and a fleet that includes additional biogeochemical sensors to study carbon and nutrient cycling in the ocean (Biogeochemical Argo).[64]

Congress funds NOAA's Sustained Ocean Observing and Monitoring Program (SOOM) programs, projects, and activities on a year-to-year basis, from which NOAA determines and allocates the amount of funds to the Argo Program (**Table 3**). Funding support for the Argo Program has remained relatively constant since 2004 (with variations), with funding priority directed to sustaining the current fleet of Argo floats.[65] Some Members of Congress have proposed increases for Argo funding; for example, in FY2022, Congress directed NOAA to expand coverage of the Biogeochemical Argo fleet.[66]

Table 3. Congressional Appropriations Applied to NOAA Argo Program

Program	FY2020 Enacted Appropriations (Thousands of $)	FY2021 Enacted Appropriations (Thousands of $)	Description
Argo Program	$11,491	$11,495	Amount directed toward Argo Program from total SOOM appropriations[a]
Other Argo Initiatives	$3,600	$3,780	Amount appropriated to other programs, projects, and activities that was used for Deep Argo and Biogeochemical Argo
Total Argo Funding	**$15,091**	**$15,275**	—

Source: Email correspondence with NOAA, Congressional Affairs Specialist, Office of Legislative and Intergovernmental Affairs, November 18, 2021.

Notes: NOAA = National Oceanic and Atmospheric Administration; SOOM = Sustained Ocean Observing and Monitoring Program.

a. SOOM enacted appropriations for FY2020 and FY2021 were $45,000,000 and $45,408,000, respectively.

Data collected by Argo floats show a warming trend of average global ocean temperature that can have policy applications. For instance, many marine species are moving toward the poles to remain in waters within their temperature tolerance.[67] These shifts in species' geographic distributions can cause economic disruptions if a fish population becomes less productive in its new environment or moves out of range for fishermen. Some Members have introduced legislation that would amend the Magnuson-Stevens Fishery Conservation and Management Act

Marine Science, vol. 6 (August 2019), p. 2.

[64] Successful prototype float deployments of Deep Argo floats took place in 2013-2015. These prototypes were able to reach approximately 6,000 meters below sea level. Testing of Biogeochemical Argo floats equipped with sensors for dissolved oxygen, nitrate, pH, chlorophyll fluorescence, and particulate backscatter began in 2012. Scripps Institution of Oceanography Argo Program Office, "Frequently Asked Questions," at https://argo.ucsd.edu/faq/#who; NOAA Research News, "NOAA Invests in New Tools to Measure the Ocean," at https://research.noaa.gov/article/ArtMID/587/ArticleID/2561.

[65] Scripps Institution of Oceanography Argo Program Office, *U.S. Argo National Report to Argo Steering Team-22*, March 2021, at https://argo.ucsd.edu/wp-content/uploads/sites/361/2021/03/USA_national_report_AST22v1.pdf.

[66] H.Rept. 117-97 referenced by the explanatory statement accompanying the FY2022 Consolidated Appropriations Act (P.L. 117-103).

[67] NOAA Fisheries, "Understanding Our Changing Climates," at https://www.fisheries.noaa.gov/insight/understanding-our-changing-climate.

(MSA) to take into account changing environmental conditions.[68] The primary objectives of the MSA,[69] for example, are to prevent overfishing and to rebuild overfished stocks; issues of migrating and dwindling fish stocks due to ocean warming were not considered (or foreseen) when the bill was originally enacted in 1977. Furthermore, the MSA requires fishing management procedures to be based on the best scientific information available to rebuild overfished stocks where needed.[70] Additional oceanographic data available through a more technologically advanced Argo profiling fleet included as part of the best scientific information available would be one tool with the potential to inform the management of marine fisheries and other resources.

Applications for Deep-Sea Exploration and Bathymetric Data

Technological advances have allowed for greater and more detailed exploration of the deep sea, which has raised several related issues for Congress to consider. Improved deep-sea exploration (including bathymetric and G&G surveys) has provided scientists with the data necessary to better characterize the deep-sea environment. Geologic features on the seafloor, deep-sea habitats and its organisms, and natural resources occurring on or beneath the seafloor can be derived from these data. Decisionmakers may consider ocean policies related to geologic hazards, environmental protection, and national security issues, such as the establishment of a domestic supply of marine natural resources of economic value.

Deep-Sea Geologic Hazards

Motion along seafloor geologic features, such as faults and subduction zones, has produced a complex seafloor landscape of volcanic islands, seamounts, trenches, and ridges. The prediction of geohazard events (e.g., earthquakes, tsunamis, marine landslides) associated with geologic features helps safeguard coastal communities and marine infrastructure (e.g., pipelines, undersea cables). For example, the Cascadia subduction zone off the coast of the northwestern United States has the potential for very large earthquakes, which could cause destructive tsunamis that would strike the coastlines of Washington, Oregon, and Northern California. Knowledge of this subduction zone allows for the implementation of early warnings and the enforcement of construction standards for marine infrastructure that can withstand seafloor movement, which aims to save lives and mitigate potential damage and the need for costly repairs.

Seafloor mapping is a primary tool used for seafloor geohazard assessments. Many major active marine fault zones in U.S. waters have been identified—about 40% of the U.S. exclusive economic zone (EEZ) has been mapped.[71] The unmapped 60% of the U.S. EEZ (approximately 2.0 million square nautical miles, or 2.7 million square miles[72]) likely includes unknown seafloor

[68] H.R. 4690, Sustaining America's Fisheries for the Future Act of 2021, would amend the MSA to include "changing environmental conditions, including those associated with climate change" as one of the causes for declining fish stocks for certain species.

[69] 16 U.S.C. §§1801 et seq. For more information on the Magnuson-Stevens Fishery Conservation and Management, see CRS Report R43565, *Reauthorization Issues for the Magnuson Stevens Fishery Conservation and Management Act*.

[70] For an overview of "best available science," see CRS Report RL32992, *The Endangered Species Act and "Sound Science"*, by Pervaze A. Sheikh.

[71] The exclusive economic zone is the zone where the U.S. and other coastal nations have jurisdiction over natural resources. It extends no more than 200 nautical miles from the shore (territorial sea baseline). Executive Office of the President, "Ocean Mapping of the United States Exclusive Economic Zone and the Shoreline and Nearshore of Alaska," 84 *Federal Register* 64699, November 22, 2019.

[72] Rounded to the nearest 100,000. NOAA, "The United States Is an Ocean Nation," at https://www.gc.noaa.gov/

features that may present geohazard risks. In 2009, Congress established the Interagency Committee on Ocean and Coastal Mapping (IWG-OCM), a working group of the National Science and Technology Council Subcommittee on Ocean Science and Technology, to coordinate ocean and coastal mapping activities across federal agencies (including BOEM, NASA, NOAA, NSF, USGS, and others) as well as with state, industry, academic, and nongovernmental mapping interests.[73] While the IWG-OCM continues to operate and assist in achieving national mapping priorities,[74] funding for the Ocean and Coastal Mapping Integration Act of 2009 was authorized through 2015.[75] In 2021, NOAA announced a matching fund program to encourage nonfederal entities to partner with NOAA to acquire more ocean and coastal survey data.[76] The reauthorization of the Ocean and Coastal Mapping Integration Act by Congress would be one means of ensuring continued authorization of funds to this program, which provide the data and information necessary for safe navigation, climate preparedness, geohazard prediction, and coastal zone management.[77]

Environmental Protection of the Deep Sea

An estimated 80% of the ocean remains unexplored,[78] presenting the opportunity to study and document deep-sea life and habitats. In 2017, NOAA's *Okeanos Explorer* concluded a three-year field campaign mapping approximately 600,000 square kilometers of the Pacific seafloor (about 61% within U.S. waters) and documenting its biodiversity.[79] The documentation of these Pacific deep-sea habitats provided baselines for understanding whether and how vulnerable and resilient they might be to disturbance or change. Such information may allow the United States to take a more holistic approach in the conservation of deep-sea habitats and biodiversity and the management and extraction of marine resources.

Deep-sea biodiversity is potentially threatened by resource exploitation activities (e.g., drilling, dredging, mining) that can disturb the seafloor environment by removing habitats and fragmenting populations.[80] In addition, habitat disruptions could impact services derived from marine species—some marine invertebrates (e.g., deep-sea sponges) have been shown to produce

documents/2011/012711_gcil_maritime_eez_map.pdf.

[73] 33 U.S.C. §§3507 defines *ocean and coastal mapping* as "the acquisition, processing, and management of physical, biological, geological, chemical, and archaeological characteristics and boundaries of ocean and coastal areas, resources, and sea beds through the use of acoustics, satellites, aerial photogrammetry, light and imaging, direct sampling, and other mapping technologies." NOAA, "IWG-OCM," at https://iocm.noaa.gov/about/iwg-ocm.html.

[74] As outlined in Presidential Memorandum on "Ocean Mapping of the United States Exclusive Economic Zone and the Shoreline and Nearshore of Alaska," IWG-OCM, along with other councils and interagency working groups, will review and update the Implementation Plan for the National Strategy for Ocean Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone as well as facilitate the management of data for the Alaska Coastal Mapping Strategy.

[75] P.L. 111-11.

[76] NOAA, "Notice of Matching Fund Opportunity for Ocean and Coastal Mapping and Request for Partnership Proposals," 86 *Federal Register* 40197, July 27, 2021.

[77] The National Ocean Exploration Act (S. 381) would authorize $60 million annually from FY2021 through FY2026 for NOAA's Ocean Exploration Program as well as $45 million annually for cooperative agreements and $15 million annually for grants as part of NOAA's Ocean and Coastal Mapping Program, over the same period.

[78] NOAA, "How Much of the Ocean Have We Explored?" February 26, 2021, at https://oceanservice.noaa.gov/facts/exploration.html.

[79] Brian R.C. Kennedy et al., "The Unknown and the Unexplored: Insights into the Pacific Deep-Sea Following NOAA CAPSTONE Expeditions," in *Frontiers in Marine Sciences*, vol. 6 (August 2019), p. 2.

[80] Travis Washburn et al., "Ecological Risk Assessment of Deep-Sea Mining," *Ocean & Coastal Management*, vol. 176 (June 2019).

antibiotic, anti-cancer, and anti-inflammatory substances.[81] Both environmental advocates and international fora have called for environmental safeguards to be put in place before deep-sea activities are permitted.[82] Article 145 of United Nations Convention on the Law of the Sea calls on parties to take necessary measures to protect of the marine environment and organisms from waste effects of activities, such as drilling, dredging, and excavation, among other activities.[83]

Knowledge and understanding of the U.S. deep sea through exploration and scientific research may allow for protection of sensitive habitats and their wildlife and establishment of a domestic supply of marine natural resources, such as minerals, located in the U.S. EEZ. In 2015, NOAA launched a three-year field campaign of the *Okeanos Explorer* to map and explore the Pacific U.S. EEZ, the first modern-era exploration of the deep sea of this scope. Scientists found that this field campaign (partially funded by NOAA's Office of Ocean Exploration and Research) "represented a model of systematic exploration that is critical to understanding one of the earth's largest ecosystems."[84] Congress may consider the level of funding to support NOAA's Office of Marine and Aviation Operations and Office of Oceanic and Atmospheric Research Deep-Sea, which houses the Office of Ocean Exploration and Research, to allow for additional deep-sea exploration campaigns designed to better document and characterize other areas of the U.S. EEZ.

Deep-Sea Natural Resources

Knowledge of seafloor features and environments can be used to locate potential offshore oil and gas reserves, sand and gravel deposits, and minerals of economic value. For example, bathymetric and G&G survey data can help identify hard surfaces on the seafloor, such as exposed rock. These sites can be conducive sites for locating ferromanganese crusts. Ferromanganese crusts typically are enriched in cobalt, manganese, and rare earth elements that are used in renewable energy technologies (including electric vehicles).[85]

The International Seabed Authority (ISA), an autonomous organization established under the United Nations Convention on the Law of the Sea, regulates and controls all mineral-related activities in international waters.[86] Coastal nations regulate seabed mining activities occurring in their national waters. Environmental advocacy organizations argue that the ISA and national governments lack the regulatory frameworks and decisionmaking tools to weigh the potential impacts seabed mining might have on deep-sea ecosystems, given that much of the deep sea

[81] NOAA, "Do Medicines Come from the Sea," at https://oceanexplorer.noaa.gov/facts/medicinesfromsea.html.

[82] International Union for Conservation of Nature, "Deep-Sea Mining," July 2018, at https://www.iucn.org/sites/dev/files/deep-sea_mining_issues_brief.pdf.

[83] Although the United States is not a party to the United Nations Convention on the Law of the Sea (UNCLOS), it abides by its principles. United Nations, "United Nations Convention on the Law of the Sea of 10 December 1982, Overview and full text," updated February 11, 2020, at https://www.un.org/depts/los/convention_agreements/convention_overview_convention.htm.

[84] Brian R. C. Kennedy et al., "The Unknown and the Unexplored: Insights into the Pacific Deep-Sea Following NOAA CAPSTONE Expeditions," *Frontiers in Marine Science,* vol. 6 (August 2019), p. 18.

[85] USGS, "Global Marine Mineral Resources," at https://www.usgs.gov/centers/pcmsc/science/global-marine-mineral-resources?qt-science_center_objects=0#qt-science_center_objects.

[86] For more information on seabed mining in areas beyond national jurisdiction, see CRS Report R47324, *Seabed Mining in Areas Beyond National Jurisdiction: Issues for Congress*, by Caitlin Keating-Bitonti. International Seabed Authority, "About ISA," at https://www.isa.org.jm/about-isa.

remains unexplored and unknown.[87] By contrast, mining industry proponents argue that seabed mining is more environmentally friendly than terrestrial-based mining.[88]

Congress has shown interest in securing and enhancing the domestic supply of critical minerals through proposed legislation.[89] Multiple departments and agencies estimate the occurrence of and environmental impact of extracting deep-sea minerals within the U.S. EEZ. The Global Marine Mineral Resources Project, based out of the USGS Pacific Coastal and Marine Science Center, "provide[s] stakeholders with the best available science regarding potential resources and environmental impacts associated with accessing [marine mineral deposits]."[90] BOEM also considers the environmental impact of marine mineral extraction from the U.S. outer continental shelf. BOEM scientists use the results of environmental studies to characterize the effects of proposed mineral extraction and design mitigation measure to minimize or avoid adverse effects.[91] The Deep Seabed Hard Mineral Resources Act,[92] which became law in 1980, governs seabed mining activities in areas beyond national jurisdiction and is implemented by NOAA. The Ocean-Based Climate Solutions Act of 2021, introduced in the 117th Congress, would call on the NOAA Administrator to seek "an agreement with the National Academies to conduct a comprehensive assessment of the environmental impacts of deep-sea mining."[93] Congress may be interested in interagency coordination of seabed mining research activities by NOAA, USGS, and BOEM, among others, to better document the distribution and location of deep-sea natural resources of economic value and to understand the potential economic and environmental impacts of extraction activities.

[87] Earthworks, Deep Sea Mining Campaign et al., "World's First Deep Sea Mining Proposal Ignores Consequences of Its Impacts on Oceans," media release, September 2015 at https://earthworks.org/media-releases/worlds_first_deep_sea_mining_proposal_ignores_consequences_of_its_impacts_o/#.Vvw4tz_UTaY.

[88] The Metals Company, "A Battery in a Rock. Polymetallic Nodules are the Cleanest Path toward Electric Vehicles," at https://metals.co/nodules/.

[89] For more information, see CRS Report R46618, *An Overview of Rare Earth Elements and Related Issues for Congress*, by Brandon S. Tracy.

[90] USGS, "Global Marine Mineral Resources," at https://www.usgs.gov/centers/pcmsc/science/global-marine-mineral-resources?qt-science_center_objects=0#qt-science_center_objects.

[91] BOEM, "Research and Studies," at https://www.boem.gov/marine-minerals/research-and-studies.

[92] P.L. 96-283; 30 U.S.C. §§1401-1473.

[93] H.R. 3764.

Appendix A. Background on Selected Physical Oceanographic Variables

Ocean Temperature

Ocean temperature varies predictably—colder water occurs at higher latitudes and at greater depths, as well as in regions where wind energy pushes sea surface water in a specific direction, allowing for deep water to move to the surface (*ocean upwelling;* see text box entitled "Ocean Upwelling"). Sea surface temperatures (SSTs) and temperatures for water depths up to 2,000 meters are primarily collected by National Oceanic and Atmospheric Administration (NOAA) Argo Profiling Floats.[94] As Argo floats drift in the ocean and submerge to new pressure levels at different water depths, they collect data on the water's temperature profile (**Figure 1**). When Argo floats return to the surface, they transmit temperature data via satellites to scientists for processing and analysis.

Various instruments other than Argo floats also collect and transmit ocean temperature data. Research vessels can collect ocean temperature and other data using deployable vehicles or devices. For example, unmanned wave gliders are remotely operated vehicles that collect SST data. Research vessels can also deploy Conductivity, Temperature, and Depth (CTD) sensors that collect water temperatures at various water depths. Wave gliders and CTD sensors, however, are limited to the path taken by the ship; gliders and CTD sensors provide detailed data for specific sites.

The satellites Aqua, Terra, Suomi National Polar-Orbiting Partnership (NPP), and NOAA-20 are equipped with instruments that collect near-global SST data from space. Unlike sensors deployed in the ocean, they collect data from the top 1 millimeter of the ocean.

Over the 20th century and continuing today, global SSTs have increased as the ocean absorbs more heat.[95] Ocean temperature impacts global climate. For example, warm waters increase the amount of water vapor over the ocean that can influence weather systems (e.g., precipitation patterns, storm events).[96] Warming SSTs also have the potential to affect marine ecosystems by altering where species can live and when species migrate and reproduce, and causing loss of life for species that cannot migrate to new waters.[97] Additionally, ocean temperature influences other ocean variables, such as ice, sea level (because of thermal expansion of ocean water),[98] chlorophyll, dissolved oxygen, and pH.

---

[94] Sea surface temperatures (SSTs) are considered as depths up to 5 meters below the surface ocean. National Oceanic and Atmospheric Administration (NOAA), "Argo Center," at https://www.aoml.noaa.gov/phod/argo/.

[95] EPA, "Climate Change Indicators: Sea Surface Temperature," at https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature.

[96] NASA, "Sea Surface Temperature & Water Vapor," at https://earthobservatory.nasa.gov/global-maps/MYD28M/MYDAL2_M_SKY_WV.

[97] "Chapter 5. Changing Ocean, Marine Ecosystems, and Dependent Communities," in IPCC, *Ocean and Cryosphere*.

[98] Because water expands as it warms (thermal expansion), warming ocean water will cause sea level rise.

Ocean Upwelling

There are two types of ocean upwelling.

- **Coastal upwelling** is the most common type of upwelling and generally occurs along the western coast of North America in the winter and year-round along the western coasts of South America and Africa. In the winter, strong winds typically blow north to south along the west coast of the United States. Due to Earth's rotation, these strong winds cause surface waters along the western U.S. coast to be pushed offshore, allowing for deep, colder ocean waters to replace them. This path of air deflection is called the *Coriolis Effect*. Because of the *Coriolis Effect*, surface ocean water is also deflected, moving at about 90-degrees to the right of the wind direction in the Northern Hemisphere and about 90-degrees to the left of the wind direction in the Southern Hemisphere. This movement of water is called *Ekman Transport* (or *Ekman Spiral*).
- **Equatorial upwelling** occurs along the equator. Surface water in the Northern Hemisphere diverges northward along the equator (to the right) and southward in the Southern Hemisphere (to the left) due to the *Coriolis Effect*. Where these two surface water masses diverge away from each other along the equator, deep, colder waters rise to the surface. Trade winds in the Indian Ocean make equatorial upwelling less prevalent in this ocean basin compared to the Atlantic and Pacific Oceans.

Sources: National Oceanic and Atmospheric Administration (NOAA), "The Coriolis Effect," at https://oceanservice.noaa.gov/education/tutorial_currents/04currents1.html; NOAA, "The Ekman Spiral," at https://oceanservice.noaa.gov/education/tutorial_currents/04currents4.html.

Ice

Continental ice and sea ice cover vast swaths of the Antarctic and Arctic regions, including Greenland. Extreme weather, ice-covered terrain, and thick sea ice can pose challenges to research vessel polar scientific expeditions. Satellite and aircraft remote sensing allow for more continuous and broad monitoring of these regions, including aspects such as ice thickness and areal extent. Sea-ice concentration data are derived from the Advanced Topographic Laser Altimeter System on the IceSat-2 and the Special Sensor Microwave/Imager and Special Sensor Microwave Imager/Sounder on Defense Meteorological Satellite Programs satellites.[99] The VIIRS instrument onboard both the Suomi NPP and NOAA-20 also collects data used to monitor the amount of ice at the poles. The GRACE-FO satellite measures changes to Earth's gravitational pull, which reflect changes in Earth's distribution of mass (including water and ice).[100] As ice melts and redistributes water across the planet, it alters Earth's gravitational pull allowing scientists to use the satellite data to measure these water mass and ice mass changes.

Continental and sea-ice melt add freshwater to the surface ocean. Freshwater is less dense than seawater and consequently tends to layer with the underlying seawater, leading to the stratification of ocean water in regions with increased ice melt. Cold, salty polar surface waters are dense enough to sink to depth in the ocean and fuel global deep-sea circulation. Because cold water also holds more dissolved gasses than warm water, polar regions play an important role in absorbing atmospheric CO_2 and then sinking this carbon into the deep ocean.

---

[99] Initiated by the Department of Defense in the mid-1960s, the Defense Meteorological Satellite Program is composed of low, Earth-orbiting satellites that provide the military with environmental information. These satellites provide global coverage twice per day. Meteorologists interpret the data (e.g., cloud type, land and water temperatures, water currents) for U.S. military operations worldwide.

[100] NASA, "GRACE, GRACE-FO Satellite Data Track Ice Loss at the Poles," March 18, 2020, at https://climate.nasa.gov/news/2959/grace-grace-fo-satellite-data-track-ice-loss-at-the-poles/.

Sea Level

The surface height (elevation) of the ocean can naturally vary in places due to gravitational pull from the moon and sun, Earth's rotation, atmospheric pressure, and gravitational forces from continental land mass.[101] At the same time, the global average sea level is slowly rising because of melting continental ice and thermal expansion of ocean water due to its warming.

Satellite-based radar altimeters measure variations in the surface height of the ocean by sending pulses of microwaves toward the ocean that bounce off its surface and return to the satellite. Similar to sonar sensor systems, the amount of time it takes for the signal to return to the satellite corresponds to the height of the sea surface. Both Jason-3 and Sentinel-6 Michael Freilich are altimetry satellites. The Jason-3 satellite is a shared partnership between NASA, NOAA, France's Centre National d'Etudes Spatiales, the European Organisation for the Exploitation of Meteorological Satellites, and the European Space Agency.[102] The Sentinel-6 Michael Freilich satellite is a collaborative partnership between the European Space Agency, European Commission, European Organisation for the Exploitation of Meteorological Satellites, SpaceX, NASA, and NOAA.[103] The GRACE-FO satellite measures changes to Earth's gravitational pull, which can provide information about the amount of sea level rise as the distribution of water and ice changes across Earth's surface.[104]

Prior to altimetry satellites, tide gauges were used to continuously collect tidal wave heights. This recorded the height of the surrounding water relative to a reference point, taking into account land elevation changes. Modern gauges use a microprocessor-based technology to collect sea level data every six minutes and are synchronized with Geostationary Operational Environmental Satellites.[105]

Heating of Earth's climate system has led to both continental ice melt and thermal expansion of the ocean, leading to global mean sea level rise.[106] Due to sea level rise, low-lying areas are susceptible to more frequent and severe coastal flooding events and sandy coastlines more susceptible to coastal erosion. The 2021 IPCC *Sixth Assessment Report* also projects that with high confidence that extreme sea level events that previously occurred once per century at least annually at more than half of all tide gauge locations by 2100.[107]

---

[101] NASA, "Sea Level 101: What Determines the Level of the Sea?," June 3, 2020, at https://climate.nasa.gov/ask-nasa-climate/2990/sea-level-101-what-determines-the-level-of-the-sea/.

[102] NOAA Earth Observatory, "Taking a Measure of Sea Level Rise: Ocean Altimetry," at https://earthobservatory.nasa.gov/images/147435/taking-a-measure-of-sea level-rise-ocean-altimetry.

[103] Linda Herridge, "Sentinel-6 Michael Freilich Satellite in Earth Orbit, Mission Begins to Map Sea Levels," *NASA Blogs*, November 21, 2020, at https://blogs.nasa.gov/sentinel-6/.

[104] NASA, "Sea Level," at https://gracefo.jpl.nasa.gov/science/sea-level/.

[105] Geostationary Operational Environmental Satellites (GOES) track the same position on Earth's surface as the planet rotates, thereby providing constant surveillance over the specified area. These satellites can provide information on weather conditions (e.g., tornados, floods, hurricanes). NASA, "GOES Satellite Network," at https://www.nasa.gov/content/goes; and NOAA, "What Is a Tide Gauge?" at https://oceanservice.noaa.gov/facts/tide-gauge.html. For more information, see CRS Report R44632, *Sea-Level Rise and U.S. Coasts: Science and Policy Considerations*, by Peter Folger and Nicole T. Carter.

[106] "Summary for Policymakers," in IPCC, *AR6 Physical Science Basis*, p. SPM-14.

[107] "Summary for Policymakers," in IPCC, *AR6 Physical Science Basis*, p. SPM-33.

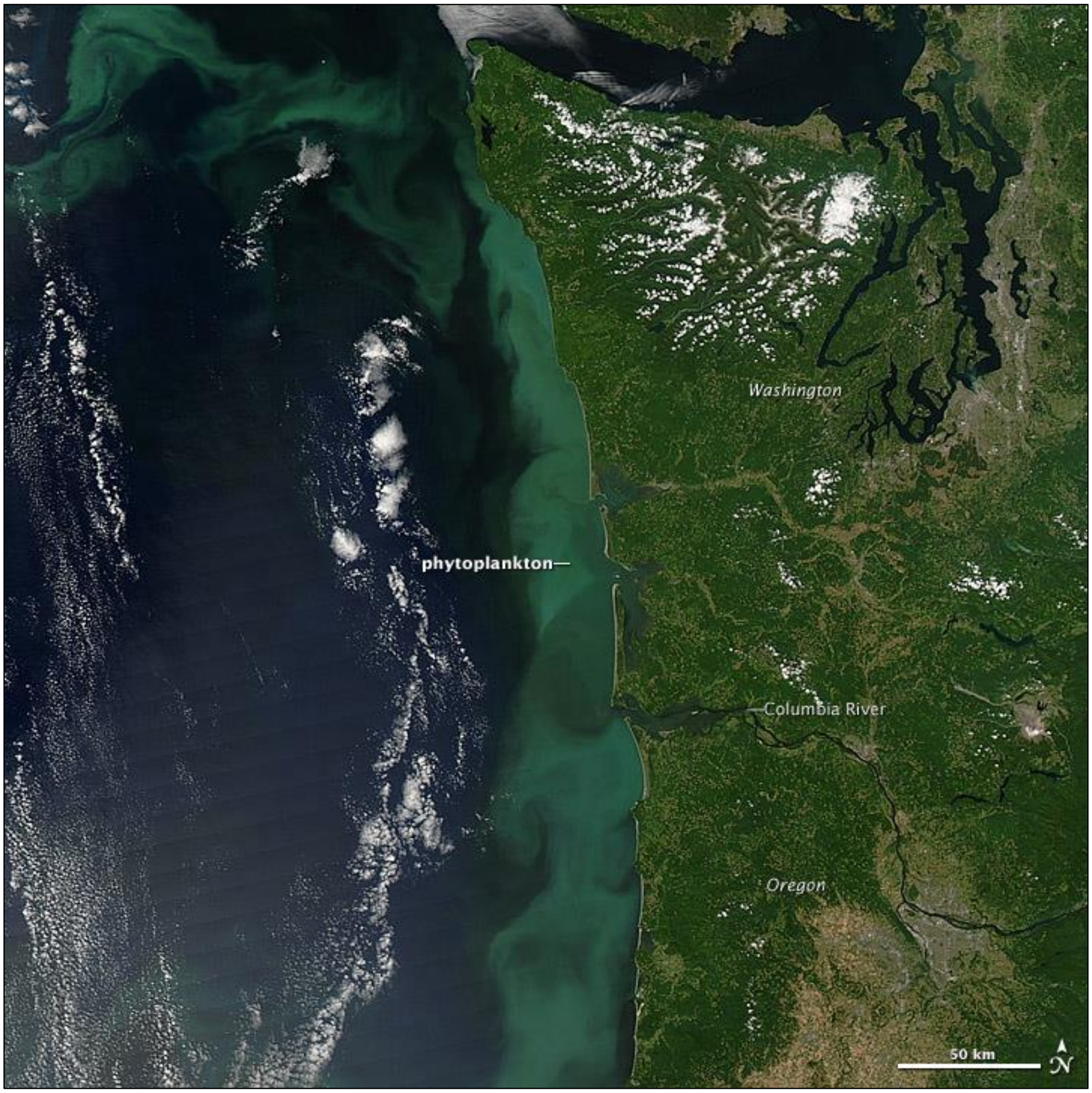
Chlorophyll (Ocean Color)

The chlorophyll concentration of the surface ocean provides an estimate for living phytoplankton in the near-surface water and is inversely correlated with temperature (i.e., dense populations of phytoplankton occur in cold surface waters where ocean upwelling has occurred).[108] Phytoplankton use photosynthetic green pigments (chlorophyll) to convert the solar energy they capture into organic matter. When phytoplankton occur in dense populations, the color of the ocean appears greener (**Figure A-1**). The MODIS instrument on the Aqua and Terra satellites and the VIIRS instrument on the Suomi NPP and NOAA-20 satellites collect chlorophyll data.

Chlorophyll concentrations provide information about ocean health and primary productivity in surface waters. Deep, cold waters tend be nutrient-rich; when these waters are exposed to sunlight, marine phytoplankton absorb solar energy and atmospheric CO_2 to form organic matter, forming the base of the marine food chain for larger organisms to feed on them. Phytoplankton are composed of organic (flesh) and inorganic (shell) carbon; thus, when phytoplankton die, the inorganic shell of the organism sinks to depth in the ocean, removing carbon from the surface waters. This process provides a natural atmospheric CO_2 sink.

[108] NASA Earth Observations, "Chlorophyll Concentration (1 Month—Aqua/Modis)," at https://neo.sci.gsfc.nasa.gov/view.php?datasetId=MY1DMM_CHLORA.

Figure A-1. Phytoplankton Bloom off the Washington Coast



Source: NASA Earth Observatory, at https://earthobservatory.nasa.gov/images/84095/phytoplankton-bloom-off-the-pacific-northwest.

Notes: NASA's Aqua satellite captured this image of coastal upwelling on July 26, 2014. Upwelling currents and summer weather promoted this large phytoplankton bloom off the Pacific Northwest making the coastal ocean waters appear green.

Seafloor Bathymetry

Approximately 80% of the global ocean floor is unmapped,[109] and less than 10% has been mapped in detail using modern sonar technology.[110] The primary instrument used for mapping the

[109] NOAA, "How Much of the Ocean Have We Explored?," February 26, 2021, at https://oceanservice.noaa.gov/facts/exploration.html.

[110] NOAA, "Chapter Two: How Much of the Seafloor Is Left to Explore?," at https://oceanexplorer.noaa.gov/world-

seafloor is a multibeam sonar sensor, which attaches directly to a ship's hull. A multibeam sonar sensor sends out simultaneous sonar beams (sound waves) in a fan-shaped pattern to collect seafloor information surrounding the ship.[111] The amount of time it takes for the sonar sound wave to return back to the sensor corresponds to the depth of the seafloor. Multibeam sonar sensors also can collect backscatter measurements, which correspond to the return beam's intensity. The return signal's intensity provides information about the seafloor's composition; for example, a mud surface will absorb most of the sound pulse, returning a weak signal to the receiver, whereas a rocky surface will absorb little of the sound pulse, returning a strong signal.[112]

A sidescan sonar also provides information on the composition of the seafloor sediment. This equipment, which is towed off of vessels on long cables, sends and receives sound signals across the seafloor, recording the return signal's intensity.

Satellite-based remote sensing technology can also be used for shallow seafloor mapping, especially in areas inaccessible to research vessels. The Landsat 8 and Landsat 9 satellites provide near-shore bathymetric data, but the satellite primarily collects land-based observations for a variety of governmental and nongovernmental applications.[113] The ICESat-2 satellite is equipped with lidar technology that can be used to map coastal waters.[114]

Knowledge of seafloor bathymetry serves several navigation, economic (natural resource), and ocean science purposes. Nautical charts are based on bathymetric data. Characteristics of the seafloor partially derived from bathymetric data can help identify and locate natural resources of economic value (e.g., sand and gravel, critical minerals, oil and gas reserves). In addition, seafloor characteristics can help study changing coastlines (e.g., erosion, land sinking), geologic hazards (e.g., earthquake faults), and the habitats of benthic organisms (i.e., organisms living on or in seafloor sediments).

oceans-day-2015/how-much-of-the-seafloor-is-left-to-explore.html.

[111] A single-beam sonar uses only one sonar beam aimed directly beneath the ship to collect bathymetric data.

[112] NOAA, "Sea Floor Mapping," at https://oceanexplorer.noaa.gov/explorations/lewis_clark01/background/seafloormapping/seafloormapping.html.

[113] U.S. Geological Survey, "Satellite-Derived Bathymetry," at https://www.usgs.gov/special-topics/coastal-national-elevation-database-%28coned%29-applications-project/science/satellite#overview; NASA, "Landsat 8 Mission Details," at https://landsat.gsfc.nasa.gov/satellites/landsat-8/landsat-8-mission-details/. For more information, see CRS Report R46560, *Landsat 9 and the Future of the Sustainable Land Imaging Program*, by Anna E. Normand.

[114] NASA, "Sounding the Seafloor with Light," at https://earthobservatory.nasa.gov/images/148246/sounding-the-seafloor-with-light.

Appendix B. Background on Selected Biogeochemical Oceanographic Variables

Salinity

Salinity (saltiness) is a measure of the dissolved salt ions in seawater. The two most common ions in seawater are chloride and sodium. They make up over 90% of all dissolved ions in seawater. Dissolved ions can be washed from land into the ocean via rivers or can be mixed into seawater by submarine hydrothermal vents or undersea volcanoes.[115] Salinity can be measured using Argo floats, unmanned wave gliders, Conductivity, Temperature, and Depth (CTD) sensors, and water quality gauges.

Salinity and sea surface temperature determine the density of surface ocean water. Density differences between water masses (e.g., surface water versus deep-sea water) drive ocean circulation, which is the primary mechanism for transporting heat across and within the global ocean. Scientists use the salinity of ocean water to trace ocean circulation patterns and to monitor freshwater input from land or melting ice. Both increased precipitation over land and continental and sea-ice melt are freshening near-surface ocean waters,[116] which may contribute to weaker ocean circulation.

Dissolved Oxygen

Dissolved oxygen is the amount of oxygen that is present in water.[117] The amount of dissolved oxygen is affected by seawater temperature, patterns of ocean circulation, ocean mixing (driven by wind energy and ocean stratification), aerobic biological activity (i.e., respiration), and distance from oxygen source (e.g., depth from the interface between the surface water and the atmospheric). Continental runoff with increased nutrient loads (e.g., fertilizer) or pollution (e.g., wastewater) can lead to excessive richness of nutrients in the water. This may stimulate marine algal blooms that lower the amount of dissolved oxygen.[118] Dissolved oxygen concentrations can be measured using Argo floats, unmanned wave gliders, and water quality gauges.

Because warm water holds less dissolved gas compared to cold water, the ocean is holding less dissolved oxygen as a result of global ocean warming.[119] Many marine species have undergone shifts in geographic range and seasonal changes in response to oxygen loss, in addition to other oceanographic changes, which may affect the aquaculture sector.[120]

---

[115] U.S. Geological Survey (USGS), "Why Is the Ocean Salty?" at https://www.usgs.gov/special-topic/water-science-school/science/why-ocean-salty?qt-science_center_objects=0#qt-science_center_objects.

[116] "Summary for Policymakers," in IPCC, *AR6 Physical Science Basis*, p. SPM-6.

[117] Environmental Protection Agency (EPA), "Indicators: Dissolved Oxygen," at https://www.epa.gov/national-aquatic-resource-surveys/indicators-dissolved-oxygen#:~:text=Dissolved%20oxygen%20(DO)%20is%20the,of%20a%20pond%20or%20lake.

[118] For more information on harmful algal blooms, see CRS Report R46921, *Marine Harmful Algal Blooms (HABs): Background, Statutory Authorities, and Issues for Congress*, by Eva Lipiec.

[119] T.L. Frölicher et al., "Contrasting Upper and Deep Ocean Oxygen Responses to Protracted Global Warming," *Global Biogeochemical Cycles*, vol. 34 (August 2020), p. 1.

[120] "Summary for Policymakers," in IPCC, *Ocean and Cryosphere*, p. SPM-12.

pH

The ocean's surface is in chemical equilibrium with Earth's atmosphere—as atmospheric CO_2 concentrations increase, surface ocean water absorbs more CO_2. When atmospheric CO_2 dissolves into the ocean, it forms carbonic acid (H_2CO_3). Some of the carbonic acid dissociates in ocean waters, producing hydrogen ions (H^+). As the number of hydrogen ions increases, the pH of seawater decreases and the seawater becomes more acidic, a process known as *ocean acidification*.[121] The NOAA Ocean Acidification Program uses two types of floating devices—moored (stationary) buoys and wave gliders—that measure the concentration of dissolved CO_2 every three hours.[122] Scientists use the data collected by these devices to study the rate of carbon uptake by the ocean.

More acidic waters can physiologically stress some marine invertebrate organisms (e.g., clams, snails, crabs) that use carbonate ions to create their shells, which result in a less robust carbonate shell and might make the organisms more susceptible to predation and death.[123]

Author Information

Caitlin Keating-Bitonti
Analyst in Natural Resources Policy

Disclaimer

[121] For more information on ocean acidification, see CRS Report R47300, *Ocean Acidification: Frequently Asked Questions*, by Caitlin Keating-Bitonti and Eva Lipiec.

[122] NOAA, Ocean Acidification Program, "Monitoring," at https://oceanacidification.noaa.gov/WhatWeDo/Monitoring.aspx

[123] Smithsonian, "Ocean Acidification," at https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification.