United Nations
Educational, Scientific and
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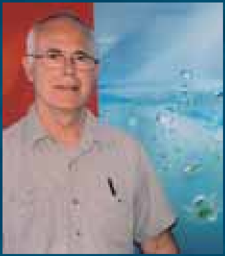
Intergovernmental
Oceanographic
Commission

GLOBAL OCEAN OBSERVING SYSTEM

GOOS



biography of the artist

Glynn Gorick, a former school teacher, investigates the complexity of ecosystems in his art through variations in scale. By adapting the scale to fit the subject, "I can draw molecules, cells, individuals, communities, ecosystems, and the biosphere in a way that may illustrate levels of organization," he says. Gorick's work often depicts Earth as a series of layers, beginning with the physical world and then adding different living systems, which, in turn, build upon each other. Humanity's part in these systems is regarded from a holistic perspective demonstrating through art how humans depend on and interact with the planet they call home.

Gorick's plan for this GOOS image started as a "simple flow diagram" from temperature measurements of the ocean using Argo floats (lower left in the image) to scientists constructing models of temperature changes (upper right). "This is possibly a picture of induction, where facts are built into theories of how things work," Gorick says. To complete this view of science in action and show the deduction that happens in science, "I imagine a line from top right to lower left, where the model is used to calculate future temperatures. If the prediction proves to be false, the model is modified, retested, and improved." Other themes in the image include the coastal city, "a picture-graph, where each part is scaled to its CO_2 emissions," explains Gorick. "I suggest that it is important for the city to be informed of its impact on the ocean, to fund the science, alter its strategy, and be able to observe how the ocean responds."

The GOOS office commissioned Gorick's artwork for this collage. He has also created images for the Natural Environment Research Council and International Geosphere-Biosphere Programme. Glynn Gorick's web page: http://www.gorick.co.uk/

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The Global Ocean Observing System

UNESCO Intergovernmental Oceanographic Commission

Glenn Gorick's artistic depiction of the Global Ocean Observing System, and the ocean that it serves to monitor, plays freely with spatial scales. The work sweeps effortlessly from the vast realm of the global oceans, through the human scales of oceanographic equipment and marine animals, to molecules. Fitting this range of scales on a single tableau required quite an artistic flight of fancy – but at its core, the work is not fantasy. In fact, the global ocean observing system is operating today, in the real world, across this same enormous range of scales.

While the artwork manages to beautifully capture many of the diverse elements of the observing system and the ocean, what unfortunately cannot be depicted, even with plenty of artistic license, is the daily delivery of societal benefits that routine ocean observations underpin. The system facilitates sustainable use of the many resources found at sea. From coast to coast, 70 percent by volume of the world trade moves across the surface of the ocean. The 100-billion-dollar-a-year fisheries industry supplies protein to millions of communities and is an essential export of many economies. Energy extraction from off-shore oil fields, as well as the advent of extensive off-shore wind turbines keeps the world's machinery moving. These industries depend on a robust ocean observing system in order to operate efficiently and sustainably.

A wide range of valuable predictions depends on ocean observations. These include for example forecasts of hurricane intensity and landfall, related storm surge heights, tsunami propagation and run-up, and seasonal climate variations such as the timing and strength of monsoon rains, and El Niño related seasonal droughts and floods. The oceans are both driving and responding to global anthropogenic change. Sea level rise, ocean acidification, ecosystem changes, and the impacts of pollution are all monitored by the system, and it is only by keeping this watchful eye on the changing ocean that humanity can mitigate and adapt to these dramatic changes.

Keith Alverson
Director, Global Ocean Observing System Secretariat,
and Head of Ocean Observations and Services Section,
Intergovernmental Oceanographic Commission of UNESCO

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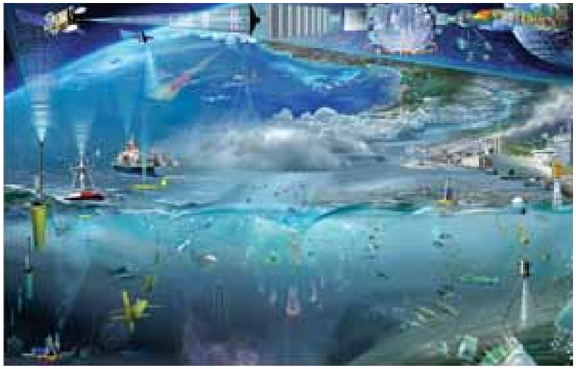
The Global Ocean Observing System



Monitoring and observing the global oceans requires an international effort and broad cooperation. The Intergovernmental Oceanographic Commission (IOC), the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), and the International Council for Science, (ICSU) sponsor and manage the Global Ocean Observing System (GOOS) to provide a coordinated approach to deployment of observation technologies; rapidly and universally disseminate data flows and delivery of marine information; to inform and aid marine management and decision makers; and to increase the appreciation of the general public of our changeable oceans.

The Global Ocean Observing System was originally envisioned in 1999 to serve the world through a unified global network that provides the information governments, industry, science, and the public need to deal with marine-related issues -- including environmental issues and the influence of the ocean upon climate. Oceanography has advanced from a science dealing mostly with local processes to one that is also studying ocean basin and global processes. As a result, researchers and a wide spectrum of users depend critically on the availability of an international exchange system to provide data and information from all available sources.

Today GOOS is more than a vision. Dozens of observation systems using sophisticated instrumentation, imaging the global oceans in dozens of ways at hundreds of locations across thousands of kilometers of oceans operate as GOOS. This booklet is a guide to these systems that marine illustrator Glynn Gorick elegantly portrayed in graphic design. The complexity of the image is a reflection of the complexity of the systems, but taken together we see that there is a flow of information, which starts as observations of nature and is transformed into unified knowledge about the global oceans.

UNESCO IOC WMO UNEP ICSU

Carbon Flux, Carbon Chemistry at Sea Surface

The interactions of atmospheric molecular compounds with the uppermost part of the ocean's surface have repercussions throughout the ocean and atmospheric system, as depicted here in this image. Indeed, the surface waters of the ocean have the greatest effect on controlling global climate change. Already the ocean has absorbed 82 percent of the total additional energy accumulated in the planet due to global warming. The ocean system also receives one-third of the industrial CO_2 emissions that humans produce. The added heat is warming the ocean while the added carbon is turning it more acidic. Coral reefs are therefore under double threat. Warmer water causes bleaching events that remove the colorful tissues of the animals from their structures, turning a reef into a grave of white skeletons. Acidic waters dissolve the skeletons.

GOOS is engaged with the task of delivering best possible data for the difficult science of 'ocean carbon tracking'. The ocean's ability to chemically absorb carbon dioxide from the atmosphere is tightly coupled to the biological uptake of dissolved carbon in seawater. As organisms uptake dissolved inorganic carbon from the ocean, the surface water draws more carbon dioxide from the atmosphere in order to maintain chemical equilibrium. These biological and solubility pumps however have feedback mechanisms that are complicated by the increasing CO_2 in the atmosphere. As seawater absorbs more carbon dioxide to maintain equilibrium with the atmosphere it increases the number of free hydrogen ions in the ocean, and, as a result, increases the ocean's acidity. Calcium carbonate buffers acidity and helps the ocean maintain chemical equilibrium, but at a cost to the skeletal structures of organisms that rely on calcium carbonate and cannot easily take advantage of the additional hydrogen ions.

Other feedback mechanisms of the carbon cycle include ocean temperature and circulation. Sinking water in the high latitudes transports CO_2-rich surface water into the deep ocean. But wind can cause upwelling along the coasts that bring these deep, cold, nutrient-enriched waters to the surface. The transported nutrients are important for phytoplankton growth, but sometimes these upwelling events lead to vast, albeit short-lived, algal blooms whose plant-like cells bacteria consume in a feeding frenzy that leaves the water column depleted of oxygen. For example, changes in wind patterns in recent years off the coast of Oregon have caused an increase in the extent and frequency of aptly-named dead zones where schools of fish turn belly-up and crabs lie dead on the seafloor. In other regions around the world the dead zones are the result of algal blooms and bacteria that proliferate due to an abundance of nutrient discharge from rivers laden with human pollution, sewage, and fertilizers.

Scientists have come together to study these large-scale and complex processes through global research programs such as SOLAS and IMBER, and are coordinating their observation platforms to develop a global observing network through the International Ocean Carbon Coordination Project (IOCCP). Ocean carbon studies require a multi-platform approach, including time series stations, decadal and high-frequency repeat hydrographic surveys, and surface observations made from ships of opportunity or drifting floats. New techniques such as gliders, wave-riders, and profiling floats are needed to provide spatial and temporal coverage not yet possible with existing techniques.

Coastal Ocean Observational Needs

From the population of nearly three billion who will live within 50 km of the coast within the next 15 years to those further inland who rely on the coastal services, the world's growing population is putting a great strain on existing coastal infrastructure and coastal marine ecosystems. The Global Ocean Observing System serves an important role in managing marine and estuarine resources. The GOOS coastal module promotes the needs and products required by coastal applications and member state's regional requests. The coastal module develops an integrated and holistic approach to addressing six goals for the health and prosperity of coastal communities:

- Improve the capacity to detect and predict the effects of global climate change on coastal ecosystems;
- Improve the safety and efficiency of marine operations;
- Control and mitigate the effects of natural hazards more effectively;
- Reduce public health risks;
- Protect and restore healthy ecosystems more effectively;
- Restore and sustain living marine resources more effectively.

The backbone of the GOOS coastal module are the GOOS Regional Alliances, groups of member states that share a strong interest in their shared part of the ocean. This regional interest emphasizes coastal processes and products which aid marine shipping industries, coastal development and sustainable use of coastal marine ecosystems. Through the alliances and their association with GOOS, national and regional observing networks are encouraged to adopt global standards for ocean observation methods, data storage and ocean product interoperability.

Oceanographic Research Vessels

Marine research has always involved going out to sea, sometimes for months and even for years, as was the case with the 19th-century sailing voyages of the *Challenger* and the *Beagle*. In spite of technological advances in robotic instruments and satellite observations, the primary measurements of ocean properties must still be made by lowering equipment over the side of a vessel. The POGO Ocean Going Research Vessel Database lists more than 100 Research Vessels between 60-90 m in length and 48 vessels over 90 m. The fleet includes ice-breakers capable of conducting studies in polar seas, deep-sea drilling ships which conduct geophysical studies of the seabed and tenders of the research submersibles, which take scientists directly to the ocean floor. Many ships are occupied with conducting acoustic hydrographic surveys and are equipped with computer systems capable of producing updated charts while still at sea. In addition to research vessels, many ships of opportunity volunteer to conduct research during their transits across the ocean. Together these vessels are essential for the deployment of many of GOOS's buoys, floats, and Argo drifters, and for obtaining high accuracy calibration data to verify the robotic systems and ground truth satellite missions.

The HMS Challenger preparing to sound in 1872. (NOAA Photo Library)

The direct sampling of ocean water by lowering bottles from a ship and returning water samples shipboard for analysis remains one of the fundamental tools of ocean observations. The workhorse of hydrography is the Niskin bottle which is often deployed in clusters on an instrumented rosette, which records Conductivity, Temperature, and Depth (CTD). The CTD rosette is lowered to its deepest point and then as it is winched up to the ship the bottles are closed, one at a time, capturing a profile of the water column along the way. The water can be filtered and sampled for CO_2, chlorophyll, microorganisms, biogeochemistry, and a wide variety of other uses. The IOCCP and CLIVAR organize and coordinate hydrography cruises and maintain databases of tens of thousands of hydrography profiles taken throughout the world's ocean. This program is an essential component of the ocean observing system as it is the only way to directly monitor the ocean's take-up of CO_2 and changes in ocean acidity levels caused by climate change.

Sea-level Monitoring

The Global Sea-Level Observing System, GLOSS, is an international programme overseeing the coordination of a network of sea level monitoring gauges installed along sea shores in over 70 countries. Each station is capable of accurately monitoring sea level changes with high accuracy and many are able to transmit information in real time via satellite links. The GLOSS network is incorporated into Tsunami warning systems. Real time measurements of water level changes can provide tsunami warnings for locations surrounding the affected sea basins. Sea-level observations are also useful for local navigation and continual refinement of tide table predictions. Tide gauges measure rising water levels from storms and extreme tides which can be responsible for billions of euros in damages and lost productivity every year. Sea level is rising as a consequence of melting glaciers and warming ocean temperatures due to climate change. With higher sea level comes an increase in the severity and frequency of flooding from storm inundation.

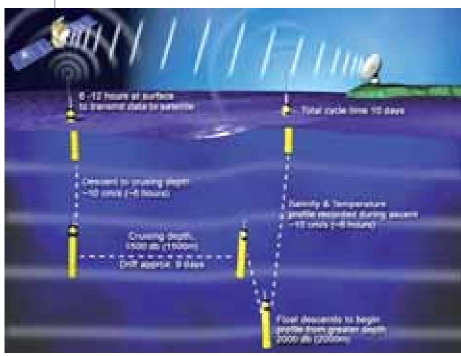
The Ott Radar Unit records sea level by acoustically measuring the distance from the transducer head to the water surface. (Proudman Oceanographic Laboratories)

Argo Profiling Floats

The Argo floats are autonomous observation systems which drift with ocean currents making detailed physical measurements of the upper 2 km of the water column. Every 10 days an Argo float changes its buoyancy by pumping fluid into an external bladder. During its journey through the water column, it records the conductivity of the seawater, its temperature, and depth pressure. Once at the surface the Argo finds its geographical position via GPS and transmits its recordings by satellite to Argo data centers where the information is joined with data from over 3,000 other Argo floats to form a synoptic 3-D view of the ocean in near real time.

This remarkable system has revolutionized oceanography since its inception in 1998 through the Climate Variability and Predictability (CLIVAR) program and the Global Ocean Data Assimilation Experiment (GODAE). Argo floats now number more than 3,000 and take more than 100,000 salinity and temperature profiles each year, more than 20 times the annual hydrography profiles taken from research ships. The Argo array is truly an international program with more than 23 different countries contributing floats and ship time for deployments. The project is overseen by the International Argo Steering Team and operations are overseen at the Argo Information Center, a part of the JCOMMOPS.

Argo data has transformed ocean circulation studies. Today Argo data is routinely assimilated into global circulation models giving accurate and timely global views of the circulation patterns and heat distribution of the ocean. This product has become an essential element of atmospheric forecast models and greatly improves seasonal climate, monsoon, El Niño forecasts, as well as tropical cyclone simulations. The value of subsurface heat content measurements to the study of global warming and climate change has made the Argo an invaluable component of 21st century environmental observation systems.



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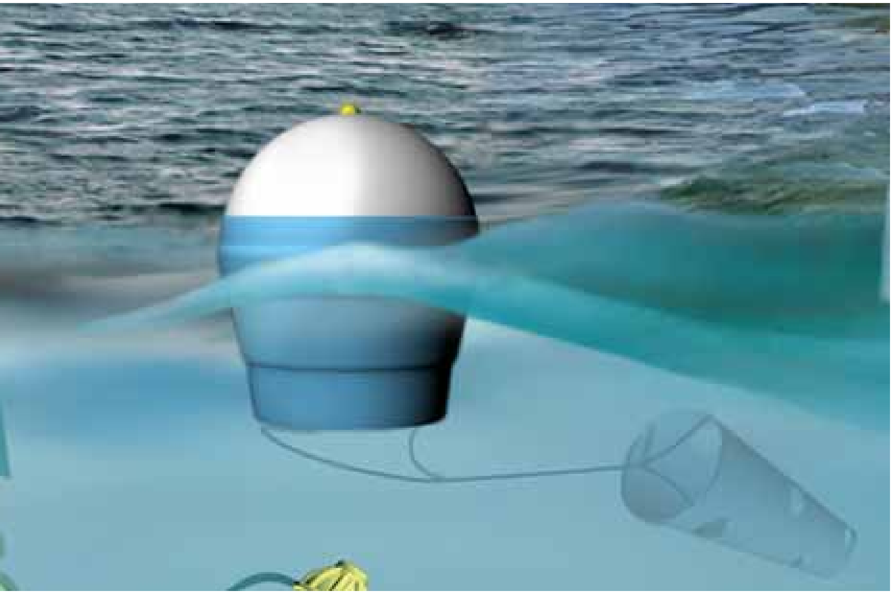
Buoyancy-Driven Gliders

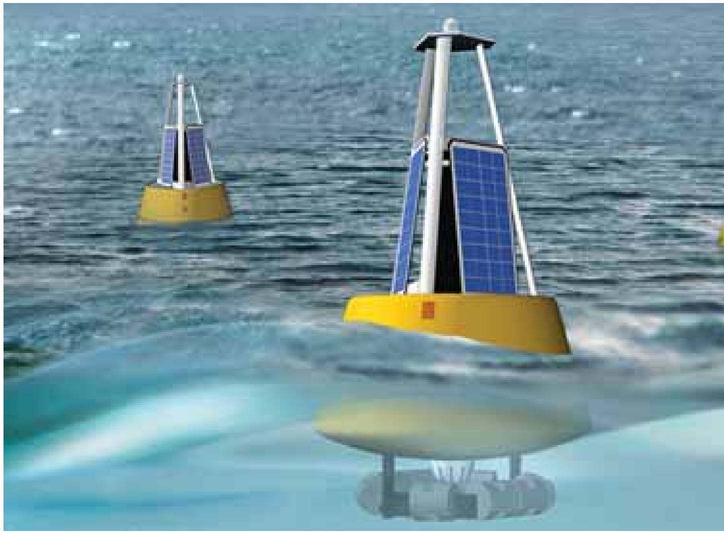
The Argo profilers have been a great success and have revolutionized our 3D view of the ocean. However, as drifters they can only take data where the ocean currents take them. An ability to control the location and sampling of data is needed for researchers to investigate specific oceanic phenomena, such as the downwelling of cold ocean water, the formation of ocean fronts, and the evolution of oceanic eddies. Today a new generation of Argo floats is in demand, ones that glide horizontally under control of computer guidance systems with two-way communications from the most remote parts of the ocean to land-based laboratories. The gliders adjust their buoyancy to sink and rise, just as the Argo floats, but by using wings and rudders the gliders can fly horizontally, turn, and control their positions in the water column. Recently, classrooms in Rutgers University had the opportunity to guide a glider across the Atlantic Ocean. The daily updates on the glider's position combined with the course alterations the students made based on anticipated and measured currents and eddies, provided a unique learning experience to see the dynamic physical interactions occurring within the Atlantic Ocean. Following the loss of the first trans-Atlantic glider in 2008, the students successfully guided a glider across the Atlantic to Spain in 2009. A dramatic demonstration that this technology is maturing and will soon be a basic component of the Global Ocean Observing System.

Surface Drifters



The JCOMM and Atlantic Oceanographic and Meteorological Laboratory Global Drifter Program manages the deployment of drifting buoys around the world. These simple buoys take measurements of surface seawater temperature and salinity and marine meteorological variables that are telemetered in real time through the World Meteorological Organization's Global Telecommunications System (GTS) to support global meteorological services as well as climate research and monitoring. The drifters are a flexible component of GOOS and can be deployed quickly for such tasks as monitoring an approaching typhoon. The global array is designed to use 1,250 buoys to cover the oceans at a resolution of one per 5° x 5°. The surface temperature data have been used to calibrate satellite temperature imagery, bringing bias errors down from 0.7 degree Celsius to less than 0.3 degree, allowing accurate climate change monitoring. Along with the Argo profilers the surface drifter programme has contributed to the success of a real-time monitoring system of the oceans, allowing much more accurate weather and climate forecasts.

Moored Buoys provide continuous monitoring of the ocean and atmosphere in locations far from land. A research vessel deploys and anchors the buoys at fixed locations. The buoys regularly collect observations from many different atmospheric and oceanographic sensors and usually supply their own power through the use of solar cells and rechargeable batteries. Because they provide their own power, the moored buoys can sample data at greater frequencies and can communicate longer streams of data to satellites and shore, than can the free-floating drifters or Argo profilers. Moored buoys are usually deployed to serve national forecasting needs, maritime safety needs or to observe regional climate patterns.



The Global Tropical Moored Buoy Array (GTMBA) is a multi-national effort to maintain a large system of fixed buoys for climate research and seasonal forecasting. Components of the global array include the Tropical Atmosphere Ocean/Triangle Trans-Ocean Buoy Network (TAO/TRITON) in the Pacific, the Prediction and Research Moored Array in the Tropical Atlantic (PIRATA), and the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) in the Indian Ocean. The array targets tropical phenomenon that impact the climate and seasonal variability, including:

- El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) in the Pacific
- The meridional gradient mode and equatorial warm events in the Atlantic
- The Indian Ocean Dipole and the Madden-Julian Oscillation in the Indian Ocean
- The mean seasonal cycle, including the Asian, African, Australian, and American monsoons

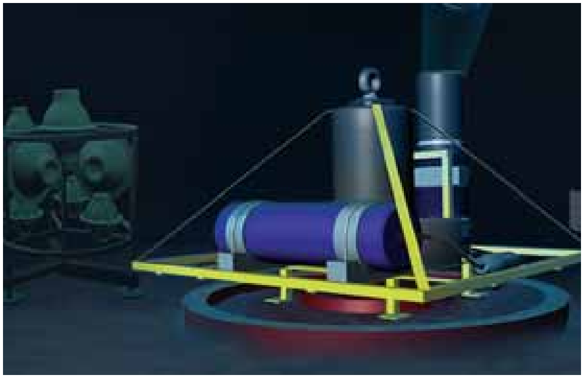
Deep Sea Moorings and Acoustic Doppler Current Profilers

Beneath the moored buoys, and sometimes deployed with no surface signature at all, are the observing instrumentation of the taut-line moorings. Commonly deployed in waters of more than 4 km, the moorings provide detailed data about the temperature, salinity, dissolved oxygen, chlorophyll, and water velocity changes through the water column. Dozens of yellow "hardhats", which contain hollow glass spheres, provide flotation to keep the mooring line taut and upright even in strong marine currents. Instruments such as thermistor chains, and conductivity and temperature sensors, are located along the line between the hardhat floats. The Acoustic Doppler Current Profiler (ADCP) measures the speed of the current as it passes by the instrument by recording the Doppler shift that occurs when sound pulses sent out into the water column bounce off of drifting marine particles. Sophisticated electronics can slice up the acoustic signal and provide a profile of the current velocity across hundreds of meters of depth.

Preparing for deployment of a mooring with hardhats, an ADCP, acoustic releases and the bottom anchor. (Fiamma Straneo, Woods Hole Oceanographic Institution)

The information collected by a network of DART® systems currently positioned at strategic locations in the Pacific, northwest Atlantic, and eastern Indian Oceans plays a critical role in tsunami forecasting. The first information available about the source of a tsunami comes from seismic monitors tracking disturbances along the seafloor. If the landslide or tectonic event is large enough to generate a tsunami wave, the DART® buoys, recording sea level measurements, will report the propagation of the wave to Tsunami Warning Centers. The result is an increasingly accurate forecast of the tsunami that can be used to issue watches, warnings, or evacuations.

The surface transmitter buoy on a Dart Mooring System communicates acoustically with a bottom pressure recorder and processes the signals of sea surface fluctuations. Near the seabed the noise from short-amplitude wind-driven waves are naturally filtered out, leaving the signal from the very long wavelength tsunami relatively easy to discern. Internal computers evaluate when a signal is worrisome and the data is transmitted on to the satellite communications system for final analysis at the Tsunami Warning Centers within minutes of a tsunami-generating seismic event. More often than not, the DART system discerns that an earthquake did not cause a dangerous tsunami, and thus avoids costly false alerts, which would degrade public trust in the warnings and assures prompt response to the tsunami alerts which are delivered.



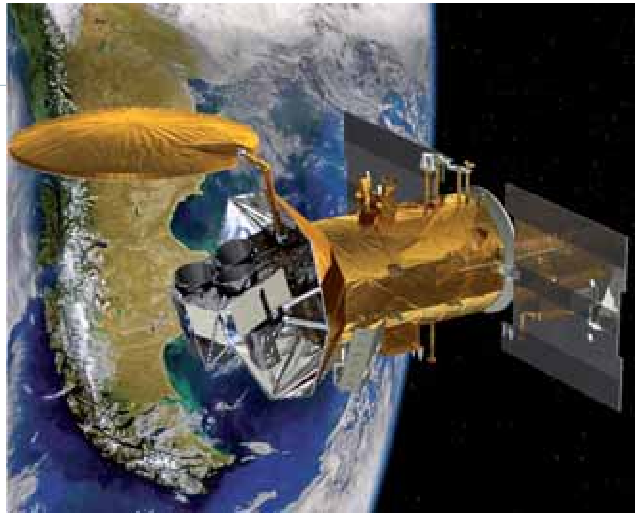
Satellite oceanography has become a routine part of global observation systems. Satellite imagery has given a new viewpoint to oceanographers, never imagined by early researchers confined between the deck of a ship and the horizon. Satellite imagery reveals swirls, eddies, vast streams and clouds of phytoplankton on scales from 100 m to several thousand kilometers. Over the years a wide variety of research and operational satellites have provided a view of the oceans from above the atmosphere.

TOPEX/POSEIDON and the Jason satellites use active radar altimeters to measure sea surface height and slopes, which can be interpreted as pressure gradients driving ocean currents below the surface. Fluctuations of sea-surface height are therefore associated with eddies and meanders of major currents such as the Gulf Stream, the Kuroshiro, and the Aghulos currents.
Satellites with the Advanced Very High Resolution Radiometer (AVHRR) routinely deliver 5 km resolution maps of the sea-surface temperature (SST). Sea-surface temperature maps are extremely useful for improving meteorological forecasting and have found civilian uses aiding fishing fleets and helping to predict the onset of harmful algal blooms.

The Aquarius/SAC-D spacecraft, due for launch in 2010, will use microwave radiation given off by the sea surface to observe seawater salinity. The Aquarius will be able to measure sea-surface salinity with an accuracy of 0.2 psu, carefully controlling the sensor temperature and making corrections for the roughness of the sea surface by using a scatterometer active radar. While shipboard laboratories can measure salinity with an accuracy of 0.001 psu, the satellite will surpass in volume what it lacks in precision, by making more measurements of salinity in two months than have been made in the last 125 years of research cruises.

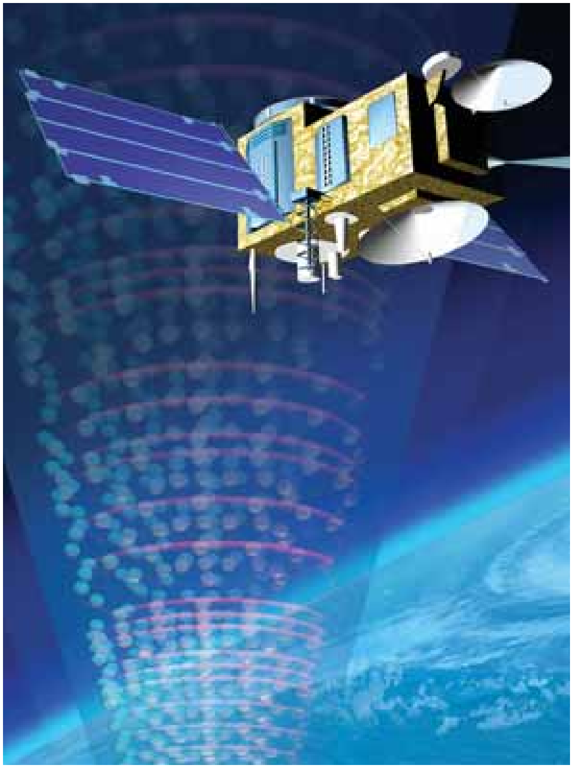
SeaWIFS, MODIS and MERIS satellites have provided ocean color by imaging the surface of the ocean at various wavelengths of light, selected for their importance to biological activity, such as chlorophyll absorption wavelengths and colored dissolved organic matter (CDOM). Scientists have learned to interpret the colors of the ocean to provide estimates of biological productivity, seasonal variation of carbon uptake, and the health of the surface waters.

The reliance upon satellite missions for fundamental ocean characterization concerns the climate community, which has seen worrisome reductions in support of future scientific satellite missions. The Committee for Earth Observation Satellites (CEOS) is coordinating the international "virtual constellation" of satellites, which working together form an intercalibration and also fill-in the gaps in observation schedules. Maintaining a continuous stream of data from overlapping satellite missions is essential to enable the satellite data to document climate change and ocean ecosystem response. Even so, the trends of climate change are small enough to require extremely accurate calibration. International cooperation to continue intercalibrations and compare satellite data will be a great and worthy challenge.



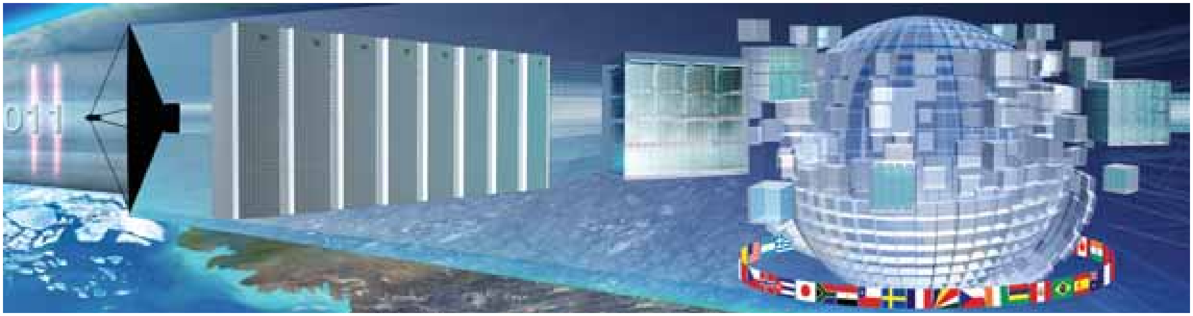
Artist's illustration of the Aquarius/SAC-D spacecraft, scheduled for launch in May 2010. It will be the first NASA instrument to measure sea salinity from space. (© Jet Propulsion Laboratories, NASA)

GOOS must be capable of delivering data from any location in the oceans to land-based scientists and data analysis centers. This is made possible by the constellation of communication satellites, which can receive data directly from the buoys, floats, and ships at sea. For 30 years the Argos system of polar orbiting satellites has provided complete coverage of the earth's surface, but until recently, low data rates, high power requirements and one-way communication limited its use to large moored buoys or shipboard systems. Current Argos systems have enhanced bandwidth and sensitivity allowing low-power data transmissions. By using Doppler shift data from the instrument transmitters the satellites can determine the position on the surface of the ocean to within 150m. In the late 1990's the Iridium and Globalstar systems were developed as commercial enterprises to deliver telephony across the globe. These systems offered many services that allowed ocean instrumentation to communicate larger data packets with lower energy expenditures. The advent of low cost and low-power communication has made it possible to develop systems such as the Argo expendable profiler system and the low cost drifter buoy network. Now simple, battery-powered devices may be launched into the ocean and left to drift and take data without a support research vessel nearby to pick up and transfer the data. Data instruments with satellite transmitters are even attached to marine animals and birds to track their behavior and health as they move about the world. Satellite communications have enabled GOOS to accomplish scientific observations not possible just 30 years ago when this type of satellite communication was just beginning.



Delta II was used to launch many of the Iridium satellites (© NASA/Regina Mitchell-Ryall & Jerry Cannon)

Data Control, Storage, and Dissemination

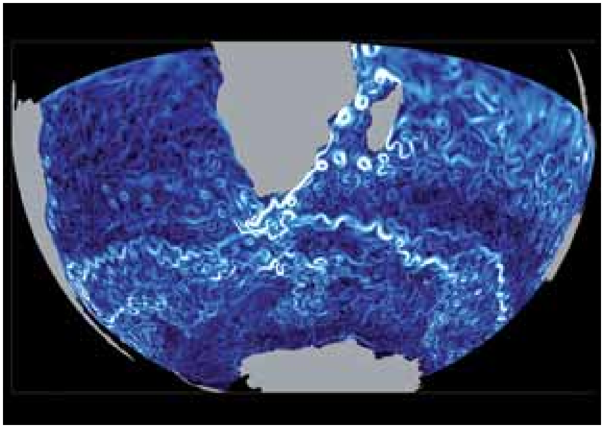


GOOS is a collection of ocean observing and information delivery systems providing near real-time measurements of the state of the oceans. The data from the many observing systems and instruments is received from the satellite transmissions and processed by many operational data centers. GOOS is an internationally distributed system, with numerous institutions and governments storing, serving, and processing data. GOOS seeks to leverage products off one another to create greater value and less duplication. The issue of combining and distributing disparate types of data has become extremely complicated. Can a thermometer measurement of temperature be combined with the IR emission imaged by a satellite? How does an investigator in Africa access biodiversity datasets stored in North America and a South American university model of ocean circulation for a single analysis? Effective quality control and quality assurance of data requires international agreements upon methodologies, calibration techniques, and naming conventions. A major accomplishment of GOOS is to provide the intergovernmental forum where these issues maybe explored and consensus reached. The result is a system of distributed data centers that communicate with one another to achieve interoperability of data storage, transmission, and analysis. Building the capacity to collect and use the data is a major objective of GOOS programmes. Education and training programmes are designed to teach the fundamentals of data management, while simultaneously promoting the use of standards amongst the data centers to help build an internationally integrated system.

Training classes are an important aspect of GOOS data management. The International Oceanographic Data and Information Exchange (IODE) trains users and data managers from around the world in techniques and standards to create the Ocean Data and Information Networks (ODIN) which are regional hubs of ocean data management. (IODE)

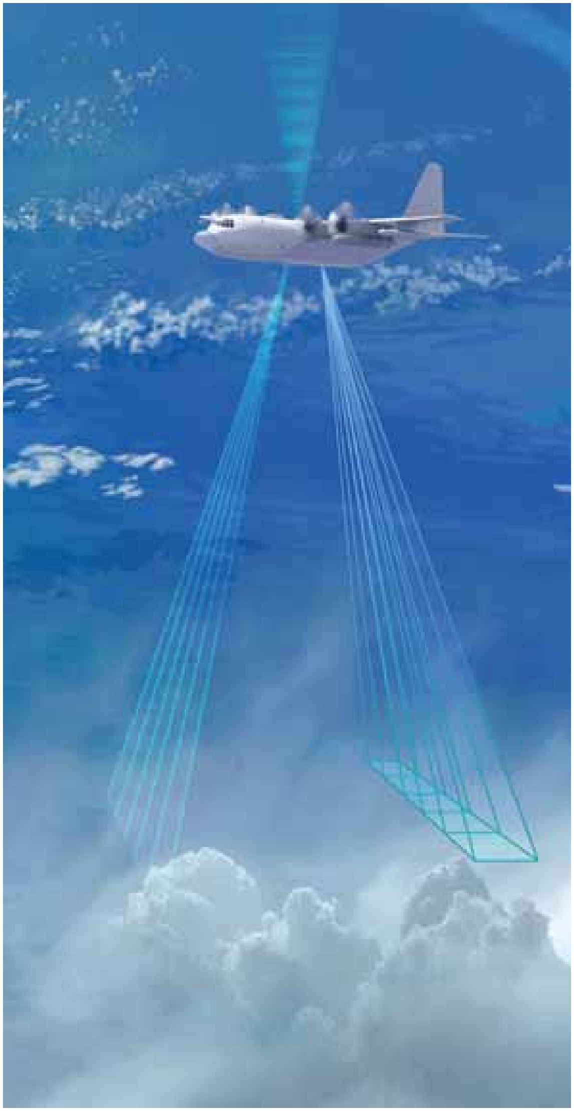
Ocean Process Modeling

The raw data from GOOS are alone of limited value. But when assembled together from across the globe, combined with different types of data, and assimilated into ocean modeling systems-- integrated views of the global ocean are created. The Global Ocean Data Assimilation Experiment, GODAE, has created a system that can ingest the GOOS data streams and produce detailed 3D circulation models of the ocean. Satellite altimetry data, Argo salinity and temperature profiles, ship hydrography, and coastal and DART measurements of sea level are all used to increase the accuracy and provide daily updates for forecasts of ocean conditions or tsunami propagation. Local, detailed modeling systems use the global results to provide boundary conditions for coastal models which resolve features as small as 100 m. Ecosystem modeling is beginning to use these methods to track nutrient and plankton growth, the creation and spread of harmful algae blooms and even to help predict fishery stocks to maintain sustainable industries. Analysts across the globe have rapid access to these model results via Internet exchange. Researchers and marine managers in developing countries without the large-scale computational resources are able to make use of these cutting edge technologies.



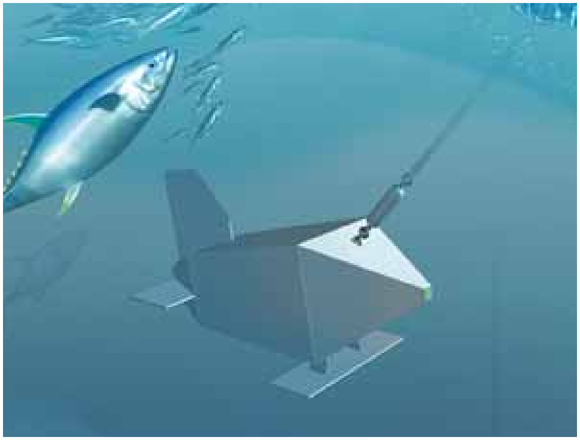
Aircraft Oceanography

Aircraft provide a platform for oceanographic observations with the aerial viewpoint of satellites, but with finer spatial and temporal resolution and greater flexibility to respond to transitory phenomenon of interest. A variety of aircraft-borne sensors and air-deployable sensors enable aircraft to quickly measure sea-surface properties, subsurface temperature, and salinity; define surface wave fields; and map bottom bathymetry. Aircraft monitor developing marine storm systems with a full suite of meteorological instrumentation, including expendable conductivity-temperature-current profilers that can measure ocean heat content below the sea surface. LiDAR (Light Detection and Ranging) uses an aircraft-mounted laser beam to penetrate coastal waters and return swaths of high-resolution bathymetric data. The technique can quickly chart areas which are inaccessible to shipborne acoustic swath methods. A quality data base of coastal bathymetry is a primary concern for developing countries managing their coastal resources and as a basis for developing numerical models of circulation and coastal inundation. The Airborne Oceanographic LIDAR Fluorosensor (AOLFL) is a laser fluorospectrometer used in phytoplankton and ocean color studies to measure dissolved organic materials and colored pigment concentrations for chlorophyll and phycoerythrin, a red-fluorescent protein. Ocean color measurements from aircraft and ships are required for in-situ calibration of satellite remote-sensing products. Aircraft oceanography and coastal mapping will be an important part of the Coastal GOOS strategy.



Sediment Traps

Tiny particles comprised of dead phytoplankton, dead zooplankton, and zooplankton feces, sink from sunlit surface waters where they are produced, through the deep ocean water column where light penetrates weakly, and into the dark abyss. The rain of this so-called «marine snow» provides the food supply for organisms in the depths. It also has a major impact on Earth's climate by transporting carbon to the deep sea and preventing it from re-entering the atmosphere as a greenhouse gas. Direct sampling of the marine snow is done with a variety of instruments known as particle traps. The one pictured here is part of a bottom-tethered mooring which includes current meters and other sensors. The trap simply collects falling particles in the large cone and concentrates them in a small cup. The samples are analyzed on retrieval and evaluated for type and quantities of marine snow that has accumulated over the duration of the deployment. Particle traps, such as this one, have been criticized for not providing quantitatively accurate flux rates. Horizontal currents, which can be at least 10 times as fast as the fall velocities, cause over or under sampling of the particles falling through the water column. However the traps remain quite valuable as they yield qualitative information about the type of particles and biogeochemical processes affecting marine snow in the mid-water column.

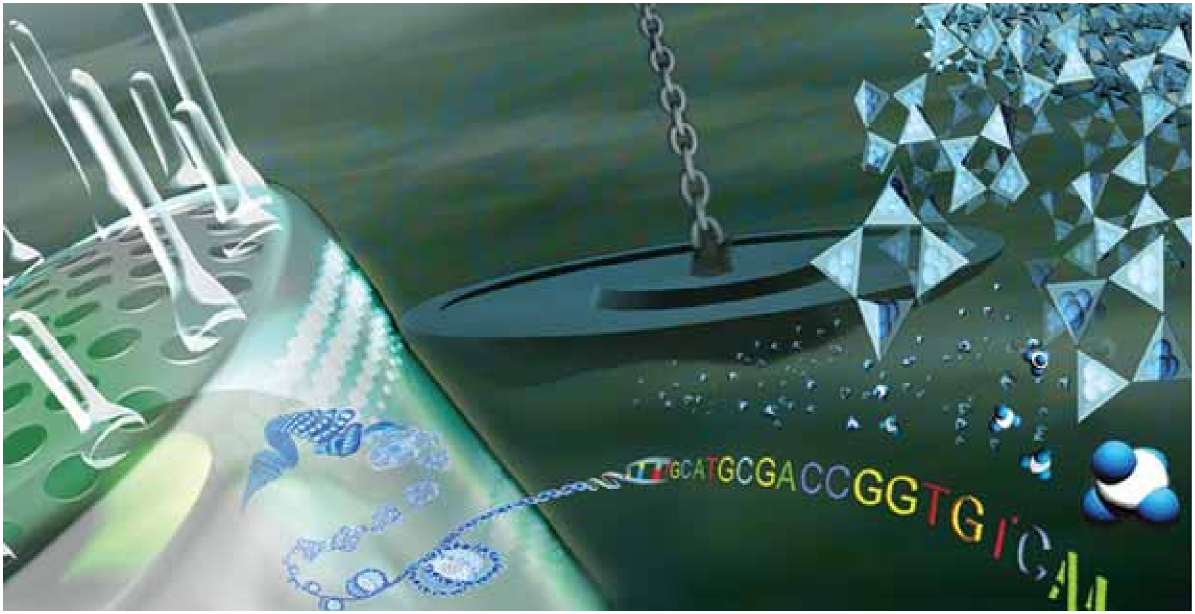


The CPR is about one meter in length. The body is made of gunmetal, (phosphor bronze), or stainless steel in later versions from 1997. The CPR has been operated successfully at speeds of up to 25 knots, and its robust design allows deployment in rough seas without fear of excessive damage. Successful tows have been conducted during sea states that are experiencing wind forces upwards of 11.

Launched over the side of a research vessel, merchant ship, or other vessel of opportunity, the Continuous Plankton Recorder (CPR) captures plankton from the near-surface waters as the boat tows the instrument during its normal sailing. British oceanographer Sir Alister Hardy developed the first prototype to sample krill in the Antarctic on the Discovery cruises of 1925-27. He modified the design for use in the North Sea and started collecting plankton in the 1930s. Since 1946, the CPR has been regularly deployed in the North Sea on a number of routes. The CPR is a critical component of GOOS and monitors the near-surface plankton in the North Atlantic and North Sea over a monthly basis from a network of shipping routes.

The CPR works by filtering plankton from the water over long distances (up to 500 nautical miles) on a moving filter band of silk (270 micron mesh size). The filter silk band is wound through the CPR on rollers turned by gears, which are powered by an impeller. On return to the laboratory, the silk is removed from the mechanism and divided into samples (known as blocks) representing 10 nautical miles of towing. The amounts and types of phytoplankton and zooplankton captured upon the silk are analyzed at the lab. After analysis, the counts are checked and added to the CPR database, which contains details of the plankton found on over 170,000 samples taken since 1946 in the North Sea and North Atlantic Ocean.

Census for Marine Life DNA Barcode of Life



Few modern oceanographers would like to write *mare incognitum* on their charts. But 10 years ago a group of scientists did just that and emphasized how little we know about the biodiversity of the oceans. Thousands, maybe millions of marine plant and animal species have yet to be discovered or cataloged, and thousands more will become extinct before scientists have a chance to identify them. The Census of Marine Life, CoML, was created to fill this void in ocean understanding. CoML is a global network of more than 70 nations which are describing the biodiversity, distribution, and abundance of life in the oceans and providing a baseline for future studies of changes in biodiversity. Since CoML began in 2000, molecular and traditional taxonomists working together have identified more than 5,600 new species and compiled a database of over 16 million records describing more than 260,000 species. A large number of species have been discovered at all levels in the animal and plant kingdoms, and it has become logistically very complicated to catalog and uniquely identify individual organisms. Modern genetic methodologies have been deployed to uniquely "barcode" species by developing simple analytic techniques to differentiate species based upon DNA sequence analysis of a unique target gene. Using these techniques researchers have already barcoded over 6,000 species and are continuing to expand the databases of marine diversity.

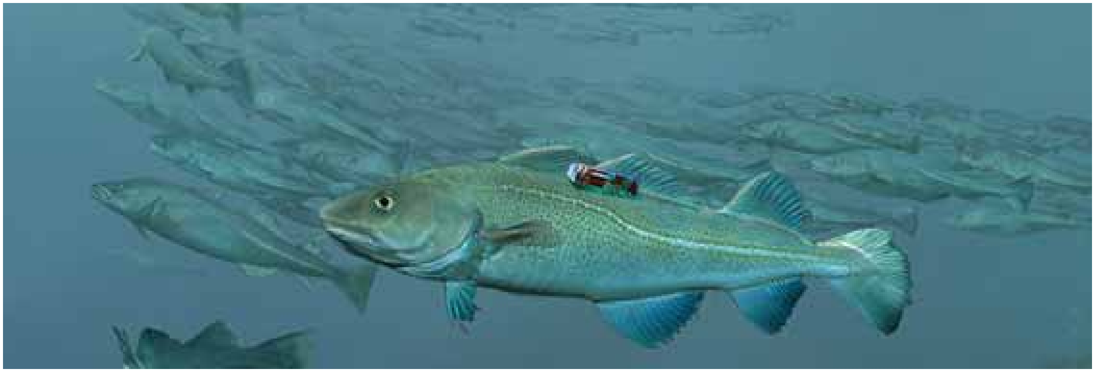
Atlantic Cod, Gadus morhua

World fisheries catch more than 100 million tons of fish per year, feeding millions in both developed and developing countries. Monitoring fish stocks and documenting changes in geographic distribution and ecosystems is an essential observational requirement to sustain and improve this vital industry.

Atlantic cod fish and their main food source, the copepod Calanus finmarchicus are the most studied species in the oceans. Fertilized cod eggs, as illustrated in this image, float to the surface and hatch. The life cycles of the fish and the copepod are synchronized with the cod feeding on Calanus larvae and later adults as the fish grows. Both species however are susceptible to ocean warming. Monitoring ecosystem changes is a large part of fisheries research. Juvenile cod disperse to possibly feed on sea bed (benthic) animals. Observing this part of the life cycle may reveal other clues as to which factors affect the size of the breeding fish population. As young adults the cod migrate back to their origins to pair up in column formations and spawn. Cod research provides theoretical models to share and compare with models for many other fish species.

Animal Oceanographers

A new innovation in oceanographic data collection is the smart tag, which when harmlessly attached to a marine animal can record cardiac rhythms, body temperature, as well as ambient seawater temperature, salinity, and depth. Equipped with a satellite transmitter the tags can send their data to scientists describing the location and recent behavior of the animal. Valuable biological information about feeding behaviors, energy use, diving behavior, and even mating habits are possible. The Tagging of Top Predators Programme, TOPP, monitors hundreds of tagged marine animals and tracks them in real time on their educational web pages. Some animals dive deep below the Antarctic ice shelves and are returning information on deep water conditions below the ice which has never been available before. These data are now blended with the Argo profiler data to include the whole of the Southern Seas and are of great value to GOOS physical oceanographic researchers.



The Ocean Tracking Network (OTN) has moved the technique of fish tagging into the 21st century by tagging fish with tiny acoustic transponders that can identify individual fish, or any equipped marine animal, each time they swim near one of several hundred acoustic receivers deployed along "Listening Lines". Researchers are tracking Greenland shark migration patterns in the Canadian Arctic, movements of king penguins as they feed in Antarctic waters and migration routes of salmon. The data allows a first time look at the migration patterns throughout a target species lifetime.

The information will become an invaluable resource for fisheries management, allowing direct monitoring of the population, health and location of each year's cohorts, which can be used to guide fishing regulation strategies and maintain sustainable and healthy fisheries.

The OTN is a GOOS pilot project, generously funded by the Canadian government. The project is being deployed off all seven continents and used by dozens of GOOS countries. The distribution of OTN technology and data collection is a global effort that has become an integral component of the GOOS coordination and cooperation.

Preparing to deploy a deep water mooring receiver assembly in Australian waters. (Stephane Kirchhoff, OTN Headquarters, Dalhousie University)

For more Information

These web pages provide a wealth of information for GOOS ocean services.

Argo	Argo Project Office http:/www.argo.net
CoML	Census of Marine Life http://www.coml.org
CPR	Continuous Plankton Recorder http://www.sahfos.ac.uk/cpr_survey.htm
DART	Deep-ocean Assessment and Reporting of Tsunamis http://nctr.pmel.noaa.gov/Dart/
GDP	Global Drifter Program http://www.aoml.noaa.gov/phod/dac/gdp.html
GLOSS	Global Sea Level Observing System http://www.gloss-sealevel.org/
GODAE	Global Ocean Data Assimilation Experiment http://www.godae.org
GOOS	Global Ocean Observing System http://www.ioc-goos.org
GRA	GOOS Regional Alliances http://www.ioc-goos.org/content/view/159/89/
GTMBA	Global Tropical Moored Buoy Array, http://www.pmel.noaa.gov/tao/global/global.html
IOC	Intergovernmental Oceanographic Commission http://ioc-unesco.org/
IOCCP	International Ocean Carbon Coordination Project http://www.ioccp.org
IODE	International Oceanographic Data and Information Exchange http://www.iode.org/
JCOMM	Joint WMO-IOC Commission for Oceanography and Marine Meteorology http://www.jcomm.info
Mercator	Mercator Operational Oceanography http://www.mercator-ocean.fr
OTN	Ocean Tracking Network http://oceantrackingnetwork.org
POGO	Partnership for Observation of the Global Oceans http://www.ocean-partners.org
RUCOOL	Rutgers University Glider Site http://rucool.marine.rutgers.edu/atlantic/
Satellites	NASA Climate Change and Earth Science Satellites http://climate.nasa.gov/missions
TOPP	Tagging of Top Predators http://topp.org
Tsunami	IOC Tsunami Information http://www.ioc-tsunami.org/

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