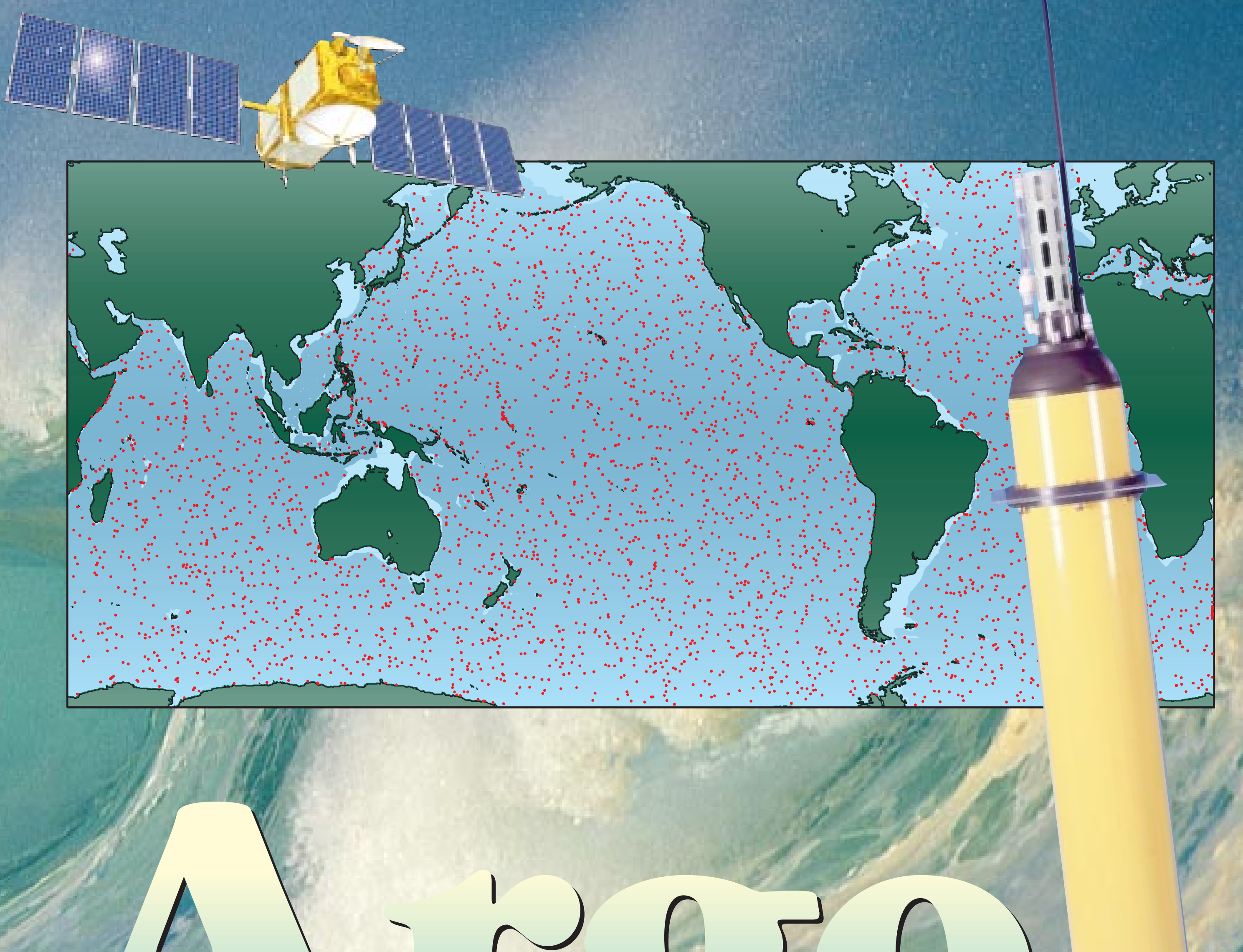
Observing the Ocean

...in Real Time



Argo

A Global Array of Profiling Floats

The Argo Program will collect upper

Profiles of temperature and salinity are necessary for improved climate forecasts

Hurricanes. Tornadoes. Ice storms. Record rainfall. Floods. Droughts. Unprecedented warm spells in winter. Over the past two years, extreme events like these have shown the dramatic impact of short-term climate variability throughout the world.

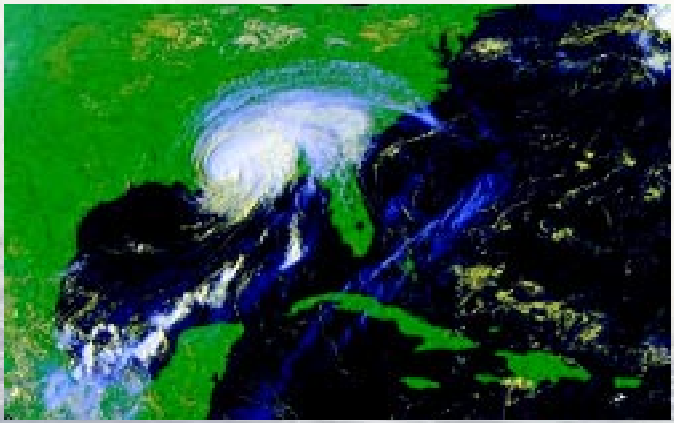
To forecast individual storms, warm periods, and other day-to-day events that comprise the weather, meteorologists use observations from an extensive atmospheric observing system: a network of land and ocean surface measurements, and a sparser network of balloon-borne sensors that collect profiles of temperature, humidity, and winds at least once a day. These networks enable accurate three- to five-day weather forecasts. Predicting climate, the broad pattern of weather over seasons and years, requires additional observations—temperature, salinity, and currents within the upper layer of the ocean.

The familiar El Niño and its less well-known sister La Niña cause a significant amount of climate variability. Every few years, the upper layer of the eastern Tropical Pacific Ocean heats up, and remains warm for months. This warming, termed El Niño, alters the global atmospheric circulation, and changes the likelihood that many types of extreme weather conditions will occur. La Niña, a cooling of those same waters

Argo, a program proposed by an international team of scientists, will employ a global array of 3,000 profiling floats to observe the ocean's upper layer in real time. Along with satellites, the Argo array will initiate the oceanic equivalent of today's operational observing system for the global atmosphere. The combined ocean/atmosphere observing systems will collect necessary data to understand and predict phenomena that influence our global climate.

President Clinton has proposed a U.S. contribution of 1,000 floats for this array. We are working with our international partners to secure commitments for the remaining floats.

This brochure describes the U.S. effort in support of the Argo Program.



NOAA

Hurricane Georges, September 1998

AP Photo by J. Pat Carter

Tornado damage, Winter Garden, Florida, February 1998

On the cover: An Argo profiling float and the Jason-1 altimetric satellite appear with a map showing the proposed global array of 3,000 Argo floats. The name Argo stresses the close connection between observations from the floats and the Jason-1 satellite. Jason was a mythological Greek hero and Argo his ship. Together, the modern Argo and Jason will improve the scientific basis for climate observation and forecasting. Photo of float: Tom Kleindinst, WHOI; Jason-1: NASA/JPL; map: Jay Shriver, NRL.

layer profiles of the global ocean

that sometimes follows an El Niño episode, causes a different set of weather conditions to become more likely. Each affects weather around the world.

To forecast the development, strength and duration of El Niños and La Niñas, the National Oceanic and Atmospheric Administration (NOAA) implemented and operates an extensive network to monitor the Tropical Pacific. The oceanic component of this El Niño Southern Oscillation (ENSO) Observing System, fully in place in November, 1994, makes measurements from the ocean surface and its subsurface layers, and reports this information back to forecast centers in real time. Data gathered by the system, complemented by measurements from space, led to successful seasonal climate forecasts for the United States during the 1997/98 El Niño—six months in advance.

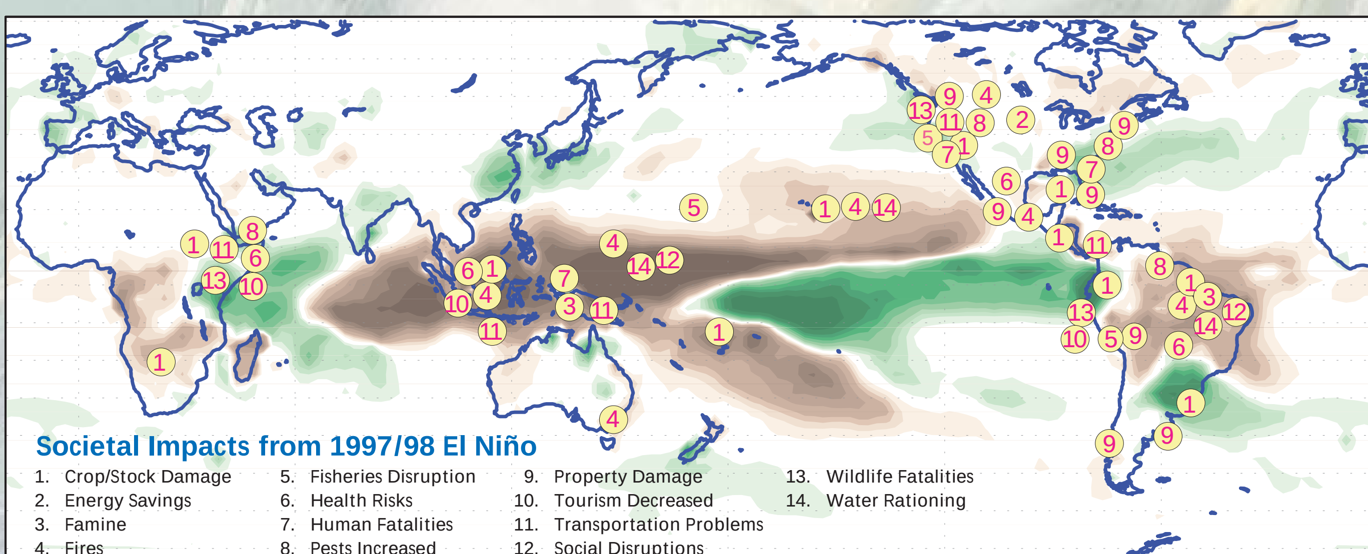
John Ferguson, NOAA/National Weather

Ice Storm, Mooers, New York, January 1998

Research has revealed that phenomena in addition to El Niño and La Niña occur in other parts of the global ocean. These also influence year-to-year climate variations. Predicting these additional phenomena requires observations of the ocean well beyond the Tropical Pacific. We need a global observing system, operating both from space and within the ocean. The space component is already in place. Profiling float technology necessary for observations within the ocean has been demonstrated. To complete the global observing system, oceanographers have proposed an array of 3,000 floats, to be deployed globally. Called Argo, it will greatly improve our ability to understand the fluctuating climate system and to provide reliable forecasts worldwide.

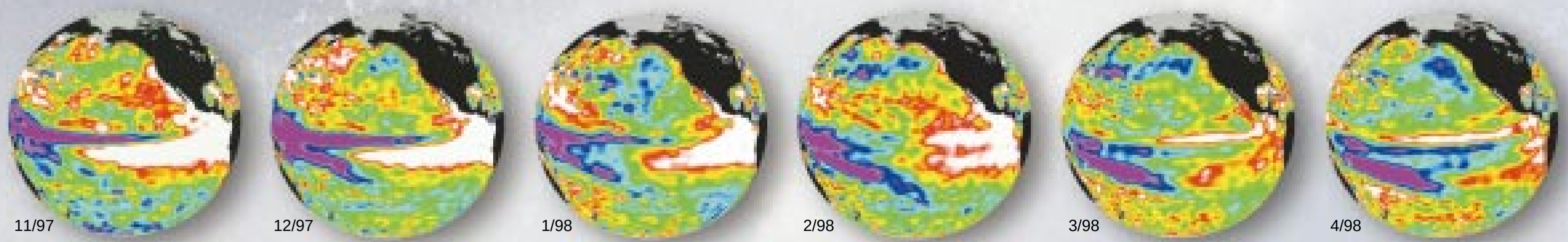
Sarah Zimmerman, WHOI

An early version of an Argo float. At present, there are two float suppliers in the U.S., and at least two suppliers of float sensor modules. Individual floats shown in this brochure differ according to supplier and model.



NOAA

The latest El Niño had global consequences, both positive and negative. Over a six-month period, the darkest green areas received at least 30 inches more rain than normal; darkest brown areas received at least 30 inches less. During the winter of 1997-98, the United States used 15 percent less energy for heating, owing to the warmer than normal temperatures, thus saving about $5 billion.



We routinely observe the Tropical Pacific

To forecast El Niño/La Niña and their influence on climate

NOAA

Forecasting the strength and duration of El Niño and La Niña requires advance knowledge of conditions in the Tropical Pacific, particularly sea surface temperatures. Since changes in sea surface temperature depend not only on surface atmospheric conditions—such as the wind field—but also on the ocean's subsurface characteristics—such as currents, temperature, and salinity—it is necessary to have advance knowledge of those oceanic variables. The ENSO Observing System, illustrated in the chart to the right, collects such data.

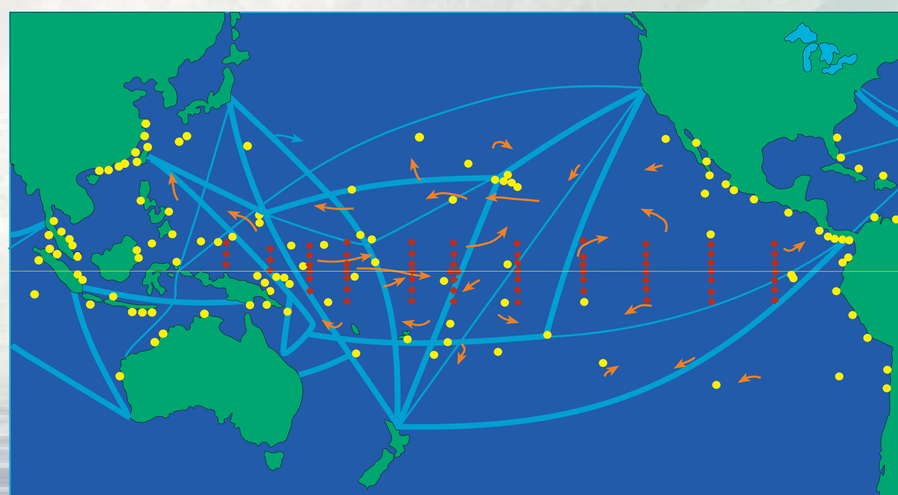
Collated and fed into computer models of the ocean, these data enabled NOAA's Climate Prediction Center to forecast the temperature of the sea surface in the Eastern Pacific half a year ahead. These predicted surface temperatures were key to the Center's corresponding forecasts of extreme weather conditions associated with the 1997/98 El Niño event. While El Niño caused losses of $15 billion in the U.S., the advance warning helped to save an estimated $1 billion in California alone.

The U.S. is not alone in experiencing such extreme weather. El Niño's effects in 1997/98 ranged from violent hurricanes off Mexico's West Coast to crop-destroying rains in East Africa and widespread fires in Indonesia. Worldwide, more than $30 billion in damage occurred during the 1997/98 event. Thus, a reliable means of predicting El Niños and La Niñas has global implications.

A global monitoring network that includes Argo will enable scientists not only to extend their El Niño/La Niña forecasts, but also to predict the effects of other phenomena. This will improve the overall accuracy of climate forecasts, and thus will contribute to the economic well-being of the world.

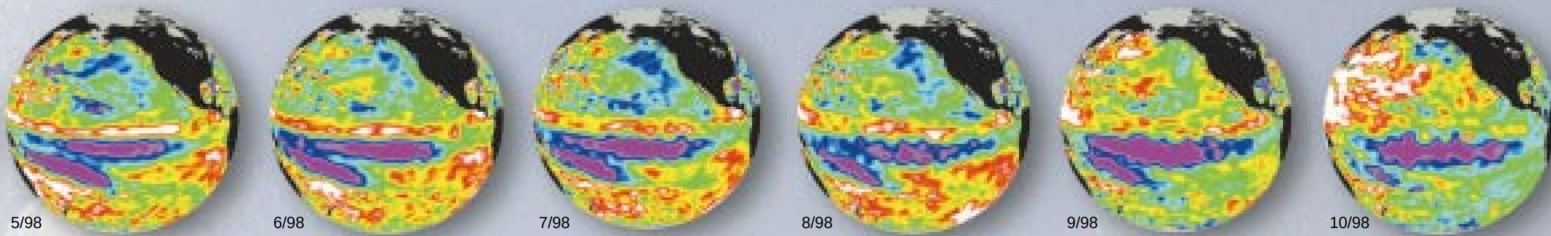
NASA/Jet Propulsion Laboratory

Jason 1, an altimetric satellite scheduled for launch in 2000, will measure global sea level, continuing the observations begun by TOPEX/Poseidon in 1992. These data will complement measurements collected by the ENSO Observing System. Both are joint NASA/CNES missions.



NOAA

The ENSO Observing System collects observations of the atmosphere, the sea surface, and the upper ocean to help forecast short-term climate changes associated with El Niño and La Niña. It consists of moored buoys (red) such as the one pictured above left; coastal sea level stations (yellow); surface drifting buoys (pink arrows); and expendable bathythermographs deployed along the routes taken by volunteer observing ships (blue lines).



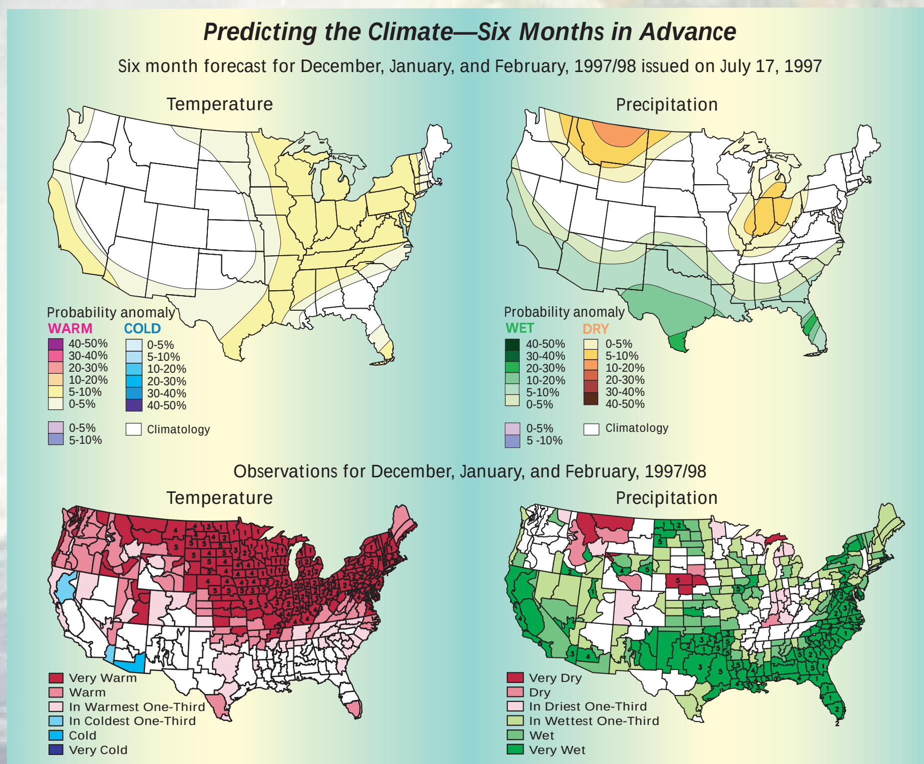
NASA/JPL

From El Niño to La Niña. TOPEX/Poseidon images (above) show that sea level in the Eastern Tropical Pacific fell by about a foot between November 1997 and October 1998, as the warm upper layer associated with El Niño gave way to cold waters associated with La Niña. White patches indicate that local sea level is 5-10 inches higher than mean sea level (green); purple patches indicate that it is 5 inches lower. NASA/JPL

Fritz Heide, WHOI

El Niño, La Niña, and American winters. A typical El Niño involves a weakening of the Trade Winds and warming of the waters of the eastern Tropical Pacific with associated heavy rainfall. There is a more intense Aleutian Low, and the Pacific Jet Stream directs storms toward Southern California, and brings wetter, colder than normal conditions to the southern tier of states. The region from the Great Lakes to Alaska experiences a milder winter than usual. La Niña, on the other hand, involves stronger Trade Winds, cooler waters in the eastern Tropical Pacific, and a weakened Aleutian Low. The Jet Stream crosses into the U.S. farther north, bringing wetter than normal weather to the Pacific Northwest. The region from the Prairie states to Alaska experiences colder weather, while the southern tier states are warmer and drier than usual. Source: Dave Thompson, John M. Wallace, and Kay Dewar. University of Washington.

How predictions match reality. Top charts show forecasts—issued on July 17, 1997—for the December 1997 to February 1998 period. For the rainfall forecast (top right), yellow/orange indicates a high likelihood of drier than normal weather and green an above-normal chance of wet weather; the darker the color, the greater the likelihood of extremes. For the temperature forecast (top left), yellow indicates a warmer season than normal. Bottom charts show actual rainfall and temperatures for the same period. For more information, see: http://www.cpc.ncep.noaa.gov.



NOAA/Climate Prediction Center

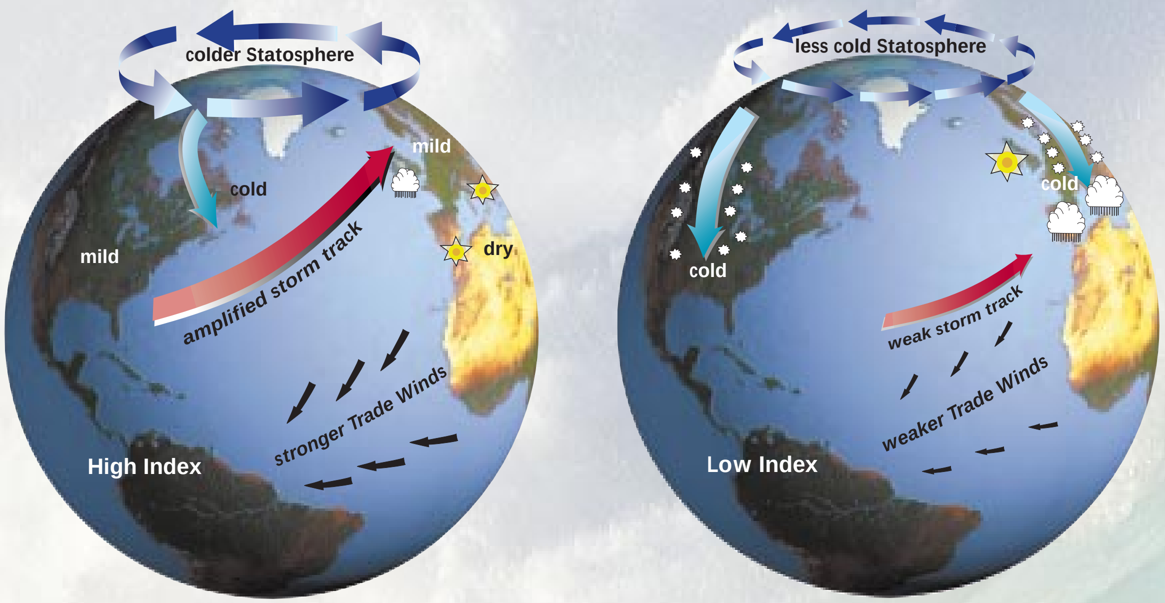
Additional phenomena influence our climate

To forecast their impact, we need global subsurface observations

Building on their success in predicting El Niño and La Niña, meteorologists and oceanographers are ready to take the next steps. They seek to understand decade-scale, global phenomena that are correlated with weather anomalies over the U.S. and elsewhere.

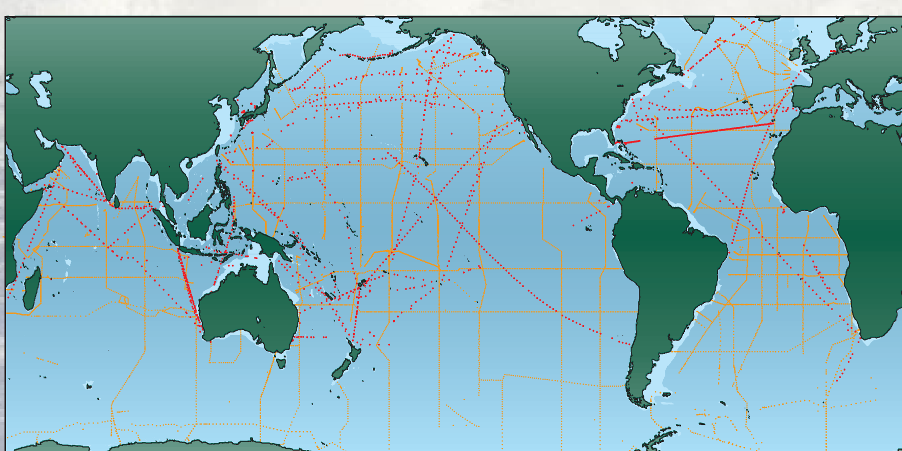
The Arctic Oscillation (AO), closely related to the North Atlantic Oscillation (NAO), is a shifting pattern of winds that affects temperatures and rainfall over Europe and Eastern North America. It appears to vary with sea surface temperatures in the North Atlantic. The Pacific Decadal Oscillation (PDO) is another climate pattern in which sea surface temperature anomalies are associated with substantial anomalies in U.S. weather. Its pattern resembles that of El Niño/ La Niña, but its timescale is much longer.

To forecast the sea surface temperature patterns related to these phenomena, we must be able to observe and understand conditions at and beneath the surface of the global ocean. TOPEX/Poseidon, a collaboration between the National Aeronautics and Space Administration (NASA) and the Centre National d'Etudes Spatiales (CNES, the French Space Agency), uses satellite altimetry to measure global sea level every ten days, with high accuracy. The NASA/



The shifting winds of the Arctic Oscillation influence weather throughout the North Atlantic. During the oscillation's 'high index,' stronger westerly winds circle the Arctic. Cool winds move across Eastern Canada, and milder conditions prevail in the U.S. More intense storm tracks across the North Atlantic pick up warmth and moisture, to take mild temperatures and rain to Northern Europe. When the oscillation shifts to its "low index," weaker westerlies circulate around the Arctic. More frequent cold air "outbreaks" spill across Eastern North America and Western Europe. Farther south, weak storm systems carry rain across the Mediterranean region. Source: Dave Thompson, John M. Wallace, and Kay Dewar. University of Washington.

Fritz Heide, WHOI

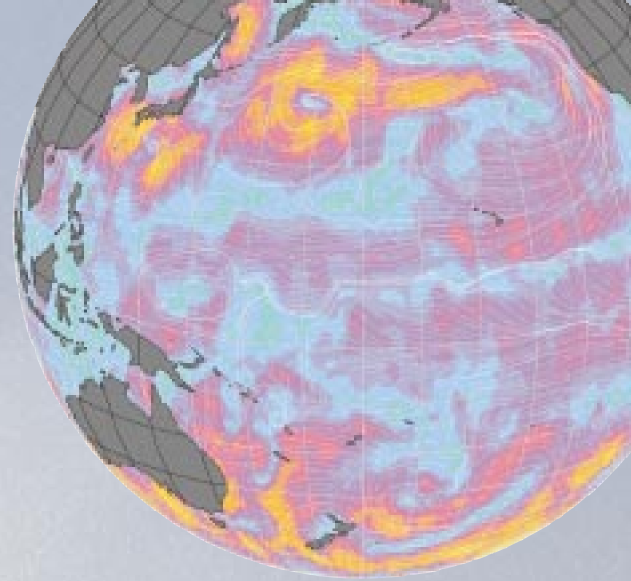


Two examples of global subsurface ocean observations. Red dots show the distribution of expendable bathythermographs (XBTs) deployed in a typical month from volunteer observing ships; these collect real-time, upper-ocean temperature profiles. Orange dots show all cruise tracks occupied by the World Ocean Circulation Experiment (WOCE) between 1990 and 1998; about 20,000 hydrographic stations collected comprehensive information between the surface and the sea floor. WOCE is now moving into the analysis phase, during which time the data are being made available.

Jay Shriver, Naval Research Lab and WOCE Project Office

NASA/JPL

NASA's QuikSCAT satellite (left) scheduled for imminent launch, will observe surface vector winds over the global ocean. Illustration at right shows surface wind speed (yellow strongest and green weakest) and direction (white streamlines) collected by NASA's NSCAT scatterometer, which flew aboard the Japanese ADEOS-1 satellite in 1996/97.

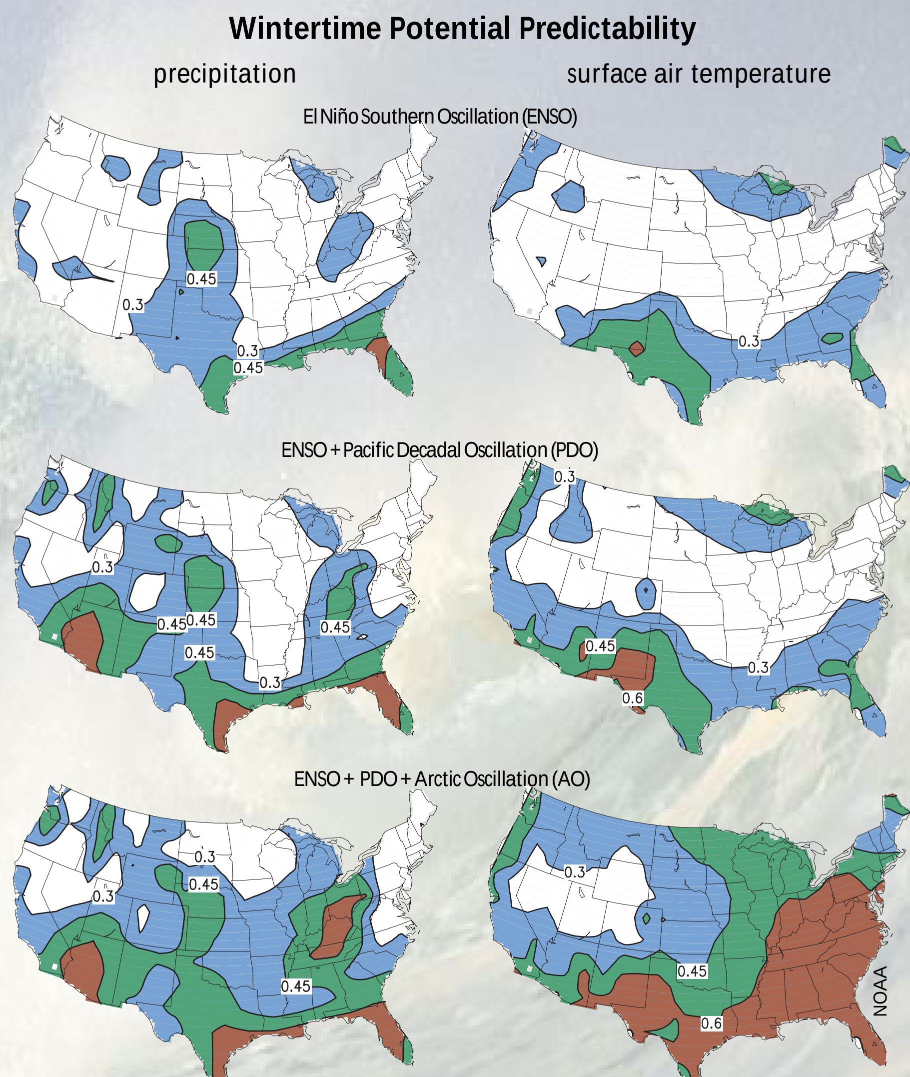


CNES Jason-1 mission will be launched in 2000 to continue these observations. In addition, the operational NOAA Polar-Orbiting Environmental Satellites are measuring global sea surface temperature on a continuing basis.

NASA's QuikSCAT satellite and the Japanese ADvanced Earth Observing Satellite (ADEOS-2), scheduled for launches in 1999 and 2000, will each carry a NASA Sea Winds scatterometer to measure surface vector winds over the global ocean.

Observations from the ocean surface are needed to correct and complement satellite data for maximum utility. More importantly, satellites can't collect data from beneath the surface. Peaks and valleys in the height of the sea surface are caused by wind-driven currents, heating and cooling, or changes in salinity (via evaporation and precipitation). For example, the rise of more than a foot in the surface of the Eastern Pacific during the 1997 El Niño was caused by strong subsurface warming and freshening.

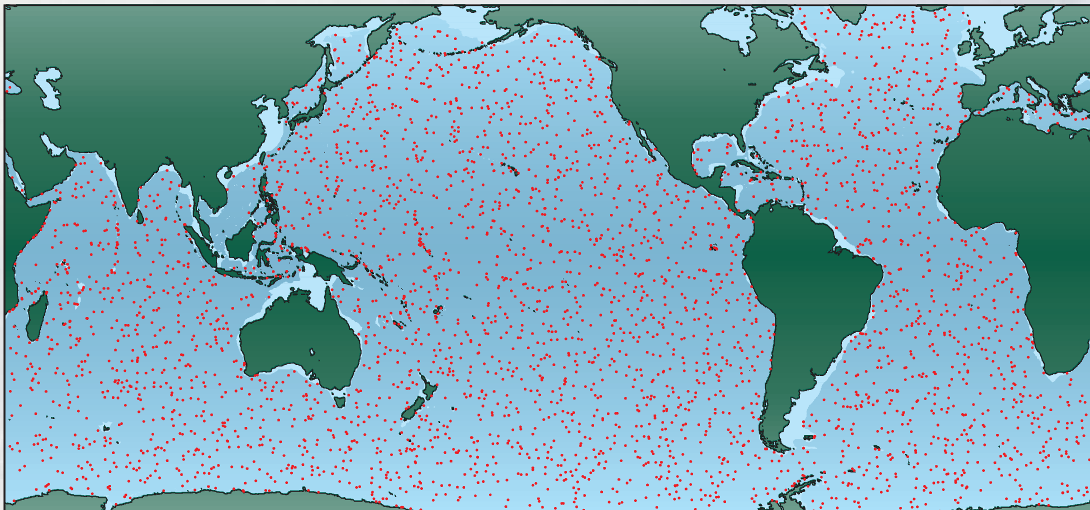
At present, our knowledge of the subsurface structure of the AO, PDO, and NAO is very limited. While we have the ENSO Observing System for the Tropical Pacific, we lack a consistent, long-term observing system to collect temperature and salinity profiles in the global ocean. Until we have this, we won't be able to incorporate the effects of oscillations such as the AO, PDO, and NAO into our climate forecasts.



The greater our understanding of ENSO and the decadal oscillations, the better we will be able to forecast climate variability. For a 35-year period, wintertime climate variability has been correlated with each of the three phenomena in question. The maps indicate the potential predictability associated with the indicated phenomena. Top panels show potential predictability associated with ENSO alone; middle panels show that associated with ENSO and PDO; bottom panels show potential predictability associated with ENSO, PDO, and AO. Brown areas have the highest potential predictability; white areas have little or no predictability. For more information, see http://www.cpc.ncep.noaa.gov.

Argo is the next step in global ocean observations

It will complement our existing satellite capability



Jay Shriver, Naval Research Laboratory

A typical global distribution of Argo floats. The floats were initially distributed at a uniform spacing in a computer model of the ocean. The floats moved with the model's currents for three years. The result shows that the floats maintain a reasonably uniform distribution.

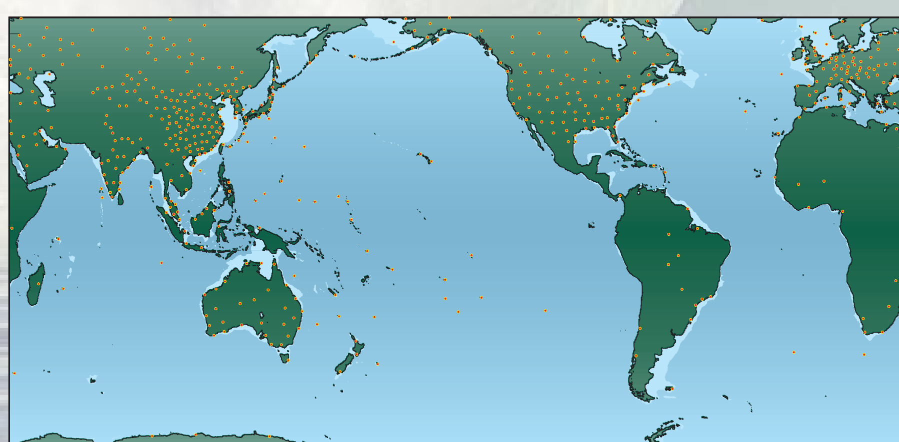
Argo is the result of over two decades of development and utilization of float technology sponsored by the National Science Foundation and the Office Of Naval Research. It represents a critical complement to NASA's $1 billion investment in space-based ocean observatories. Argo will be a global network of 3,000 profiling floats, spaced about 300 kilometers (186 miles) apart. When deployed at the surface, each float will sink to a typical depth of 2,000 meters (slightly more than a mile). After drifting with the ocean current at that depth for ten days, it will rise to the surface, measuring the temperature and salinity of the layers through which it rises. On the surface, the float will radio its data and position to an orbiting satellite before returning to depth and continuing another cycle. A technique based on differential buoyancy ensures that the floats sink to the required depth and rise to the surface on schedule, and continue to do so throughout their design lifetime of four to five years.

Satellites will relay the data they receive from Argo floats to land-based receiving stations. From there, the data will go to a number of scientific teams around the world, who will carry out initial quality control. They will then make the data available for operational forecast centers and scientists in near real time, via the Global Telecommunications System. All data will be openly available, without proprietary restrictions.

The observations will be used, together with other available data, to make 'weather maps' of the ocean, to initialize climate forecast models for the ocean-atmosphere system, and to improve our understanding of the ocean itself.

The Argo network will gather data

NOAA



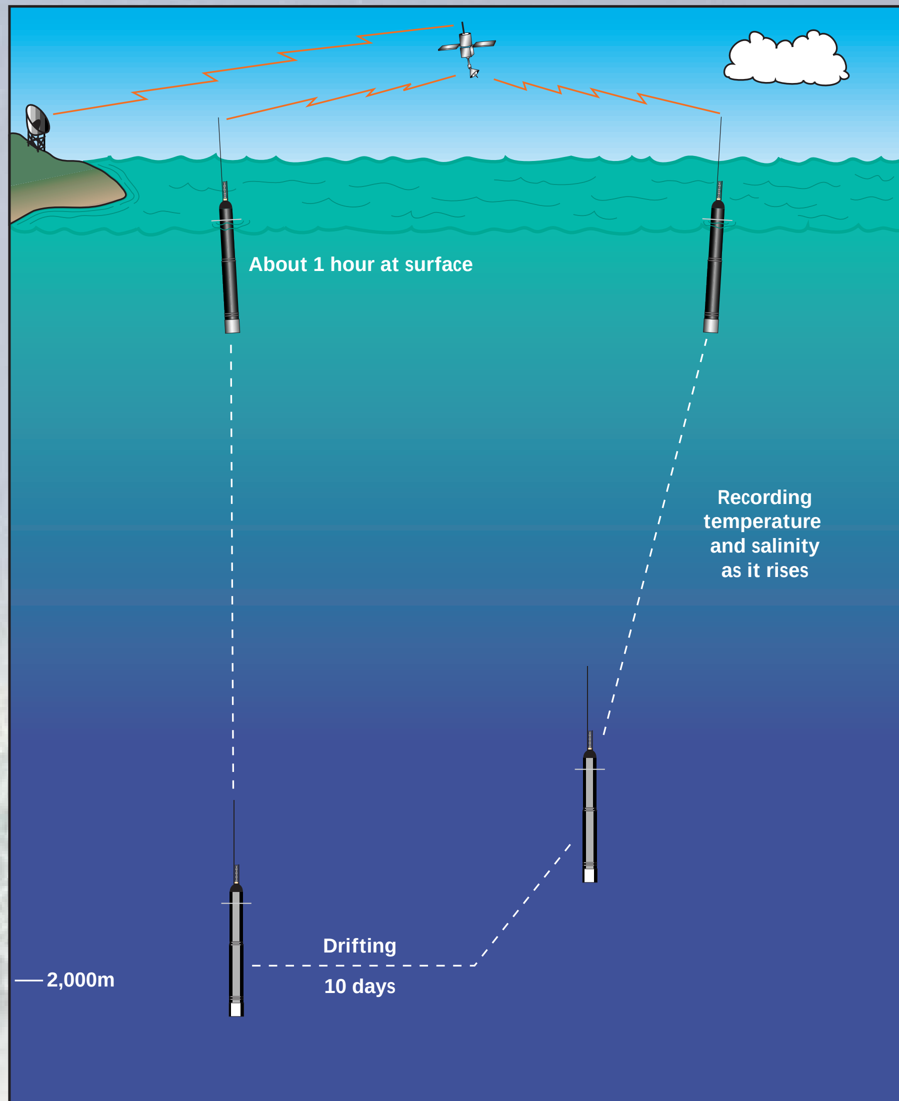
Jay Shriver, Naval Research Laboratory

Profiling the atmosphere. A typical network of surface observing stations from which radiosonde balloons (left) collect atmospheric temperature and humidity profiles every 12 hours. An Argo float is the oceanic equivalent of a radiosonde.

with high efficiency. Between 1990 and 1998, the World Ocean Circulation Experiment (WOCE) program completed a global ocean survey, collecting as many temperature and salinity profiles (20,000) as were taken over the previous 100 years. Argo will provide 3,000 profiles down to 2,000 meters depth every ten days.

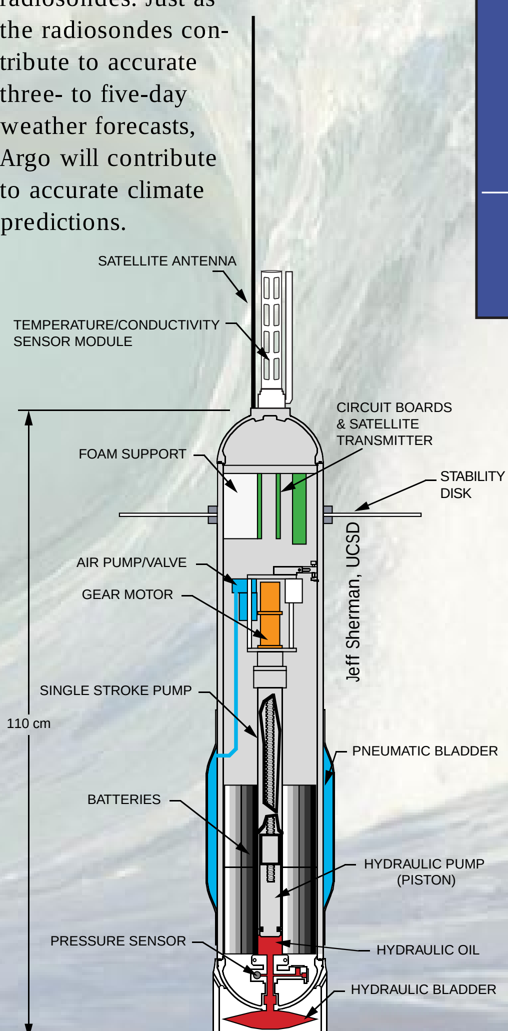
Argo floats will be deployed from a variety of ships and aircraft (see next page). Hundreds of commercial vessels that ply trading routes across the globe can deploy floats, just as they now make meteorological observations and drop instruments that give a single ocean profile. The remotest regions of the ocean can be seeded by air. The great advantage of the floats is that, after deployment, they will continue to operate unattended.

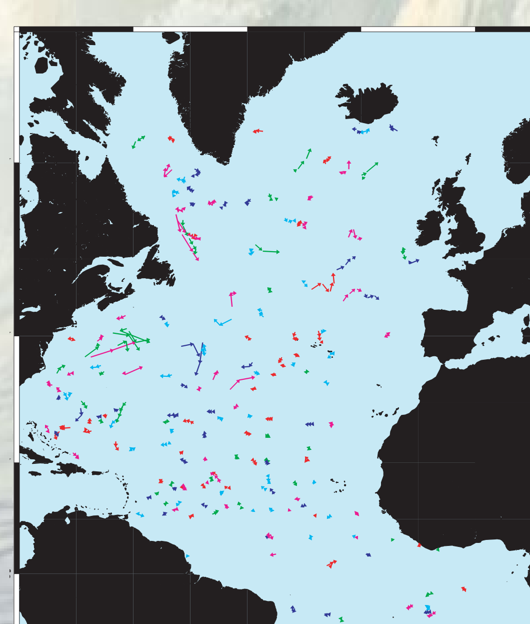
Once fully implemented, Argo will constitute an oceanic equivalent of the worldwide network of balloon-borne radiosondes. Just as the radiosondes contribute to accurate three- to five-day weather forecasts, Argo will contribute to accurate climate predictions.



Jack Cook, WHOI

The Argo float cycle, with communications and positioning by satellite.




WHOI

Positions in December 1998 of 190 profiling floats gathering data in the North Atlantic Ocean.

Argo is one element of a comprehensive international system for observing the global ocean

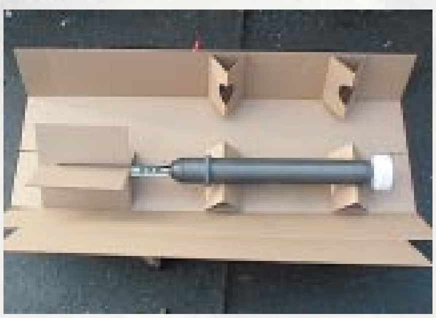
The need for better monitoring of the ocean for a wide range of purposes has become clear over the past decade. The same information that will contribute to short-term climate forecasts will serve a variety of other purposes. Examples include the Climate Variability and Predictability Program (CLIVAR), the Global Ocean Data Assimilation Experiment (GODAE), the Global Ocean Observing System (GOOS), and the Global Climate Observing System (GCOS).

Argo will provide essential broadscale, basin-wide ocean data sets for CLIVAR. This program's scientific objectives include describing and understanding the physical processes responsible for climate variability and predictability, through the collection and analysis of observations and the development and application of models of the coupled climate system. CLIVAR also aims to extend the range and accuracy of seasonal to interannual climate prediction.

Argo will serve as a critical source of observations for GODAE. The goal of this program is to demonstrate the practicality and feasibility of routine, real-time global ocean data assimilation and prediction. GODAE will emphasize integration of the remote and direct data streams, and the use of models and data assimilation to draw maximum benefit from the observations.

Argo will also be a major component of GOOS, an international effort led by the Intergovernmental Oceanographic Commission of UNESCO, the World Meteorological Organization, and the United Nations Environmental Program, with scientific guidance from the International Council of Scientific Unions. Endorsed at the Earth Summit

Webb Research



Steve Riser, University of Washington

Dave Gray, WHOI

Argo floats can simply be deployed over the rail of small vessels (right). For deployment from ships, they can be lowered in biodegradable cardboard boxes (left), bound with string secured with a soluble link. When the link dissolves, it frees the string, opening the box and releasing the float. Present plans for deployment in remote areas include the use of aircraft such as the C-130 (top).

in 1992, GOOS is an international initiative to create a global system for gathering, archiving, and distributing ocean data and derived products with worldwide utility. Its objectives include improving the management of living resources and coastal areas, ensuring safe marine navigation, and assessing the health of the ocean—as well as laying the basis for improved understanding and forecasting of climate. GOOS shares its climate objective with GCOS, a long-term observing system designed to meet climate information requirements.

For Further Reading

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Summary of results from float deployments
http://wfdac.whoi.edu
http://flux.ocean.washington.edu

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http://www.pub.whitehouse.gov/uri-res/I2R?pdi://oma.eop.gov.us/1998/6/16/2.text.1

Some forecast centers to use real-time Argo data
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http://www fnoc.navy.mil
http://www.coaps.fsu.edu
http://www.ecmwf.int
http://iri.ldeo.columbia.edu

In-situ observations of the Tropical Pacific
http://www.pmel.noaa.gov/toga-tao/

Satellite altimetry and scatterometry
http://www.jpl.nasa.gov

Climate Variability and Predictability Program
http://www.dkrz.de/clivar/hp.html

Global Ocean Data Assimilation Experiment
http://www.bom.gov.au/bmrc/mrlr/nrs/oopc/godae/homepage.html

Global Climate Observing System
http://www.wmo.ch/web/gcos/gcoshome.html

Global Ocean Observing System
http://ioc.unesco.org/goos/

Acknowledgements

This brochure was produced by the Woods Hole Oceanographic Institution, with financial contributions from the University of Miami, Scripps Institution of Oceanography (University of California, San Diego), and the University of Washington. Editor: Stan Wilson, NOAA; Designer: Jim Canavan, WHOI Graphic Services; and Writer: Peter Gwynne.

George Tupper, WHOI

A specially modified profiling float, with propellers to measure vertical currents while it drifts at depth, is lowered into the Labrador Sea in January 1997.

The time is right for Argo.

Float technology has been demonstrated.
Spaceborne remote sensing has been proven and will be in place.
Communications are available to collect resulting observations in real time.
Data assimilation techniques are under development to incorporate the float and satellite data into computer models.
The latest generation of super computers have the capability to run the models and generate forecasts to meet a variety of societal needs.

Argo is ready to start. Its benefits will be immense.

For additional information about the Argo Program

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