Dynamics of Earth and Ocean Systems (DEOS)

John A. Orcutt, Director
Cecil and Ida Green Institute of Geophysics and Planetary Physics
Scripps Institution of Oceanography
La Jolla, CA 92093

Robert S. Detrick, Chair
Department of Geology and Geophysics
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

For more than a century oceanography has advanced rapidly through the mechanism of oceanographic expeditions aboard ships. This tradition extends back at least to Darwin's sailing on HMS Beagle in an extraordinary voyage of discovery, which took him around the world during the years 1831-1836. Subsequent expeditions such as that aboard HMS Challenger in 1872-1876 advanced this use of ships for understanding the oceans. In the U.S., the advent of the Office of Naval Research (ONR) in 1946 and the formation of the National Science Foundation (NSF) in 1950 led to a rapid expansion in the availability of oceanographic vessels for conducting research at sea. Today 28 ships comprise the academic fleet under the coordination of UNOLS. Conservatively, this represents an investment of more than $500,000,000 in the pursuit of basic research in the oceans. The total US investment in the infrastructure for expeditionary oceanography easily exceeds $1B. This investment has led to major discoveries about the ocean and, as a scientific community, we can look forward to many more decades of scientific advances. There are tasks, however, for which the expeditionary approach is not well-suited and which require major investments of a different kind.

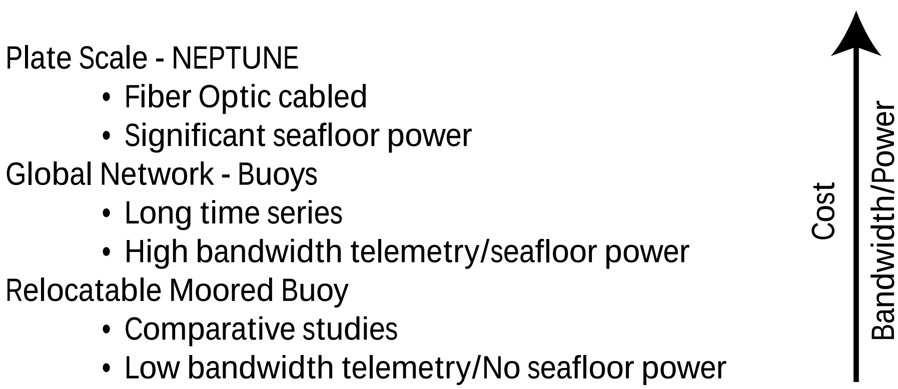

Figure 1: Technological solutions within DEOS.

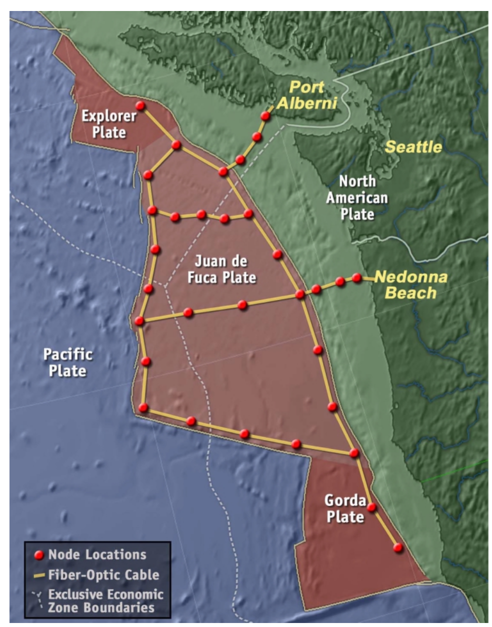

Figure 2: The NEPTUNE installation

Expeditions to sea concentrate on a particular point or portion of the oceans for a limited period of time. Expeditions, because of this brevity in both space and time are poorly suited for observing change. A permanent

Measurements	
Air-Sea Interaction & Meteorology	**Geomagnetism**
Oceanography	**Still Photographs**
Hydroacoustics	**Video**
Acoustic Thermometry	**AUV data**
Seismology	**Chemistry**
Seafloor Geodesy	**Biology**

Table 1: Potential time-series observations at fixed locations.

presence in the oceans is essential for gathering data to address a major class of scientific problems. Such observatories, while common on the continents, are rare in the oceans. These observatories, with the ability to provide power to the water column and the seafloor, and telemeter data to scientists ashore in real-time, are important for the observation of transients. There are also cases in which the signals of oceanographic phenomena are sufficiently small that long time series are needed to raise the signal-to-noise ratio to a level that is scientifically useful. For example, tomographic studies of the interior of the Earth require thousands of earthquakes recorded with good signal-to-noise ratio to define small variations in velocity. In coming years, requirements for the collection of long time series in the oceans will require investments which are comparable to those we have already made in oceanographic ships. It must be appreciated, however, that the advent of time series collection in the oceans on a large scale will only increase the need for ships at sea. New kinds of ships, which are well-suited for maintenance of the observatories, will be needed; ships thatare well-suited for operating large remotely operated vehicles (ROV) and with the handling gear and space for large moorings.

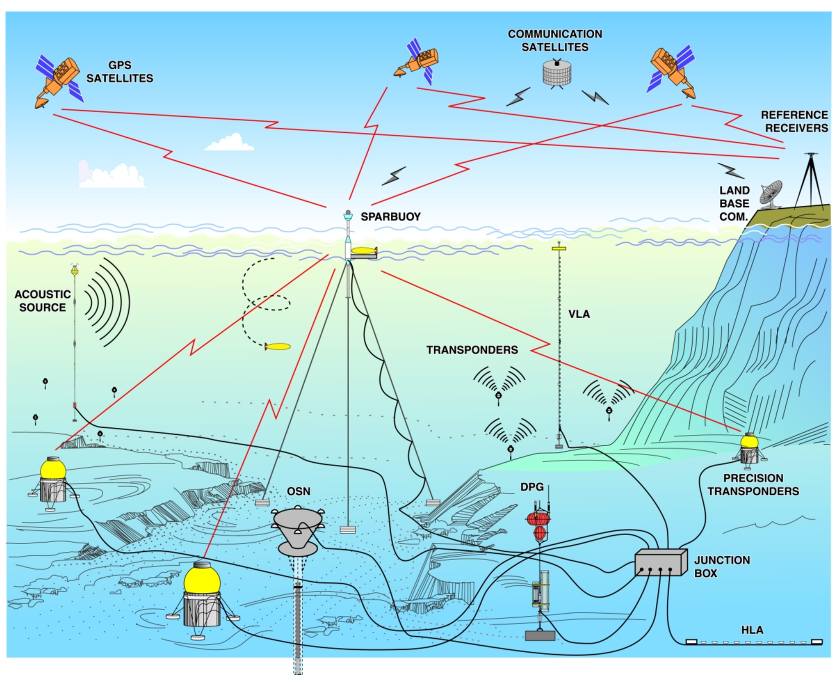

Figure 3: A mid-ocean global observatory with a variety of sensors for geophysical and oceanographic applications.

Recently, the NSF has initiated a Major Research Equipment (MRE) program to fund a program in ocean observatories, and the program has been approved by the National Science

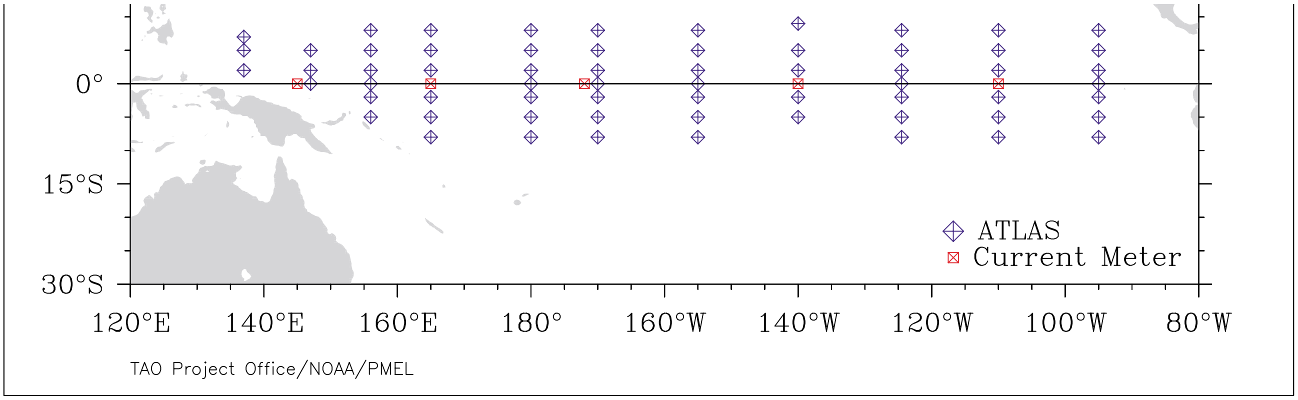

Figure 4: The TAO array installed in the equatorial Pacific for monitoring the development of El Niño.

Board. The Consortium for Ocean Research and Education (CORE) has established, with NSF funding, an Ocean Observatories Standing Committee (OOSC) to undertake planning for the implementation of a program for ocean observations with a funding profile in excess of $100M over a five year period. In the last several years DEOS concentrated on two aspects of time series data collection: tectonic plate scale and global observatories. The new Standing Committee adds coastal observatories to this mix to integrate global planning under a single community organization. However, this paper will concentrate on the aspects of time series collection which affect the plate-scale and global observatories - the work done by DEOS.

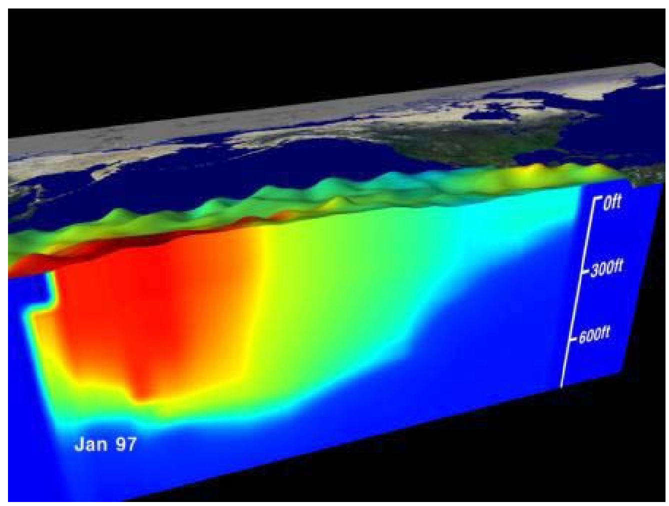

Figure 5: Shallow water temperature from TAO and surface height from Topex/Poseidon.

Within DEOS planning, there are three approaches to technical systems for the collection of data as shown in Figure 1. At the top of the bandwidth/power pyramid are cabled systems such as that proposed by NEPTUNE (Figure 2) with virtually unlimited power (> 500 kW) and bandwidth (>10 Gbps). At the bottom of the pyramid are relocatable moorings with low bandwidth telemetry (5 MB/day) and no power to the seafloor. The middle ground is represented by moorings capable of delivering 500W to the seafloor and continuously telemetering data at 64-128 kbps (Figure 3). While it might be anticipated that intermediate systems with capabilities lying between the two buoy types can be realized by simply metering the funds available, engineering studies have shown that this is not the case. These three classes of observatories represent the specific approaches available for exploring the oceans in time.

The collection of time series data in the oceans, while rare, is not unheard of. During the 40's and into the early 70's Ocean Weather Stations (OWS) were deployed to provide ocean observations of weather conditions for aircraft routing in the northern Atlantic and Pacific Oceans. Satellite observations eventually eliminated the need for these manned ships although at least two of these

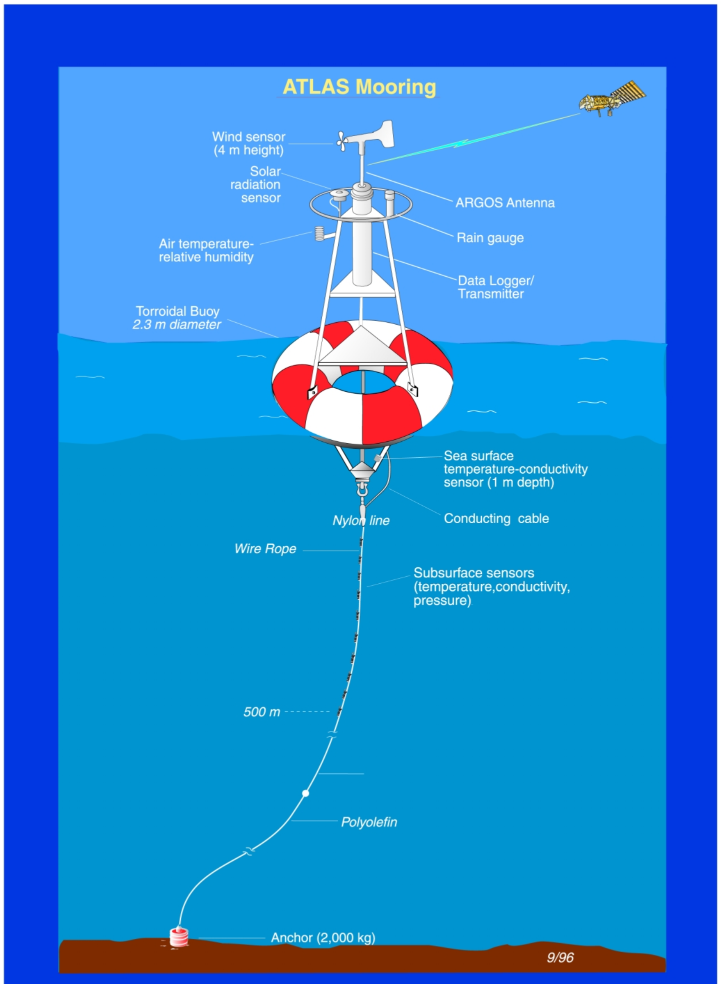

Figure 6: An Atlas buoy as used in the TAO array.

stations (S in the Atlantic and P in the Pacific) continue to be occupied by unattended moorings for collecting scientific data. The best modern example is the TAO array of moorings (Figure 4) in the equatorial Pacific. This array was begun with sponsorship, as a scientific program, by the NSF. However, the moorings are now maintained by the National Oceanographic and Atmospheric Administration (NOAA). The moorings recently proved their worth in detecting the formation of an El Niño event (Figure 5). The buoys (Figure 6) are simple structures with very limited satellite data telemetry and power derived largely from batteries.

Large portions of the ocean basins are distant from the nearest land – continents or islands. For example, Figure 7 shows all existing broadband seismographic observatories in operation with 2000 km radius circles drawn around them. Large portions of the oceans lie outside this network and understanding of the interior of the Earth, the nature of faulting, and the ability to monitor explosions suffer as a result. The Incorporated Research Institutions for Seismology (IRIS) began nearly 15 years ago with a goal of covering Earth’s surface with a uniform density of seismic observatories - the circled stations show that the goal will not be realized until many (20 - 25) sites are occupied on the seafloor.

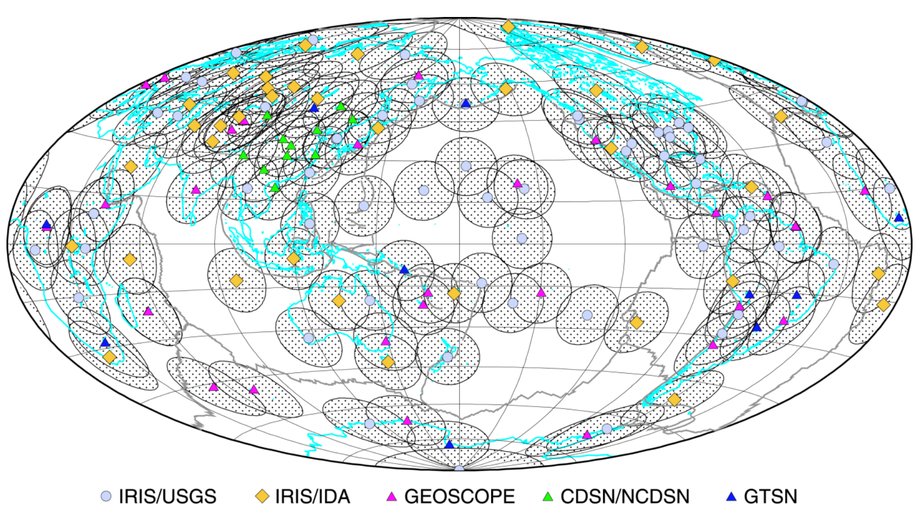

Figure 7: All existing broadband global stations in operation with 2000 km circles around each.

There are a broad set of oceanographic measurements which can and must be made from fixed platforms (Eulerian vis-a-vis

Lagrangian) and many are shown in Table 1. Observations in physical oceanography are particularly dependent upon such platforms.

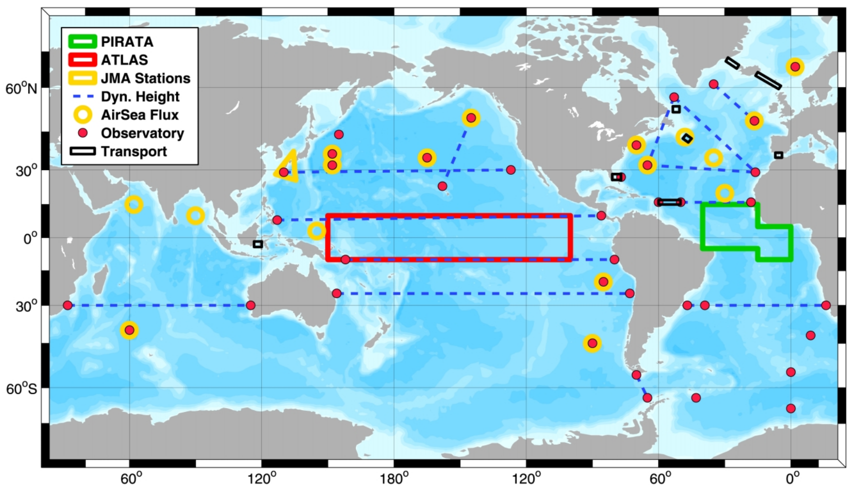

Figure 8: Global locations for proposed Global Eulerian Observatories (GEO) timeseries stations.

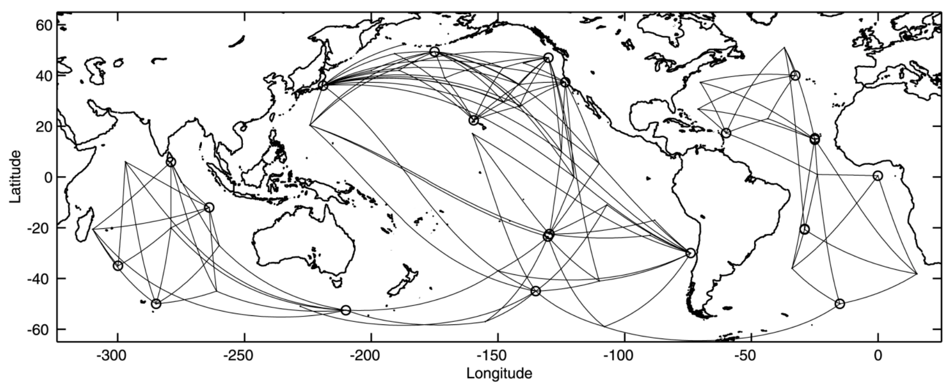

Figure 9: A potential configuration of acoustic thermometry stations integrating both DEOS and GEO moorings.

The Global Ocean Observations System (GOOS) and CLIVAR have formed a timeseries group for promoting observations at fixed sites. This timeseries group has cross-representation with the NSF ocean observatories steering committee. The timeseries group is promoting a series of Global Eulerian Observatories (GEO), many of which are co-located with DEOS sites (Figure 8). Another oceanographic application for DEOS is acoustic thermometry which uses low-power acoustic sources to measure travel times and, hence, average temperature profiles on an ocean basin scale. A hypothetical network of thermometry stations is shown in Figure 9 making use of both DEOS and GEO sites. While the data available from oceanographic observations from ships and satellites has grown exponentially over the past decade, the speed at which ships travel today has not changed significantly since the HMS Beagle! Acoustics, with waves that travel at 1500 m/s, must be used to observe and integrate ocean observations in coming years in many fields.

One of the greatest challenges in oceanography is the observation of geophysical and oceanographic phenomena in the Southern Ocean. This ocean is critical to life on Earth, and observations of its climate are needed to understand Earth’s deep interior. A suitable challenge for DEOS is to ensure that we are able, through improvements in mooring design, seamanship, and ship capabilities, to establish the first mooring in this inhospitable part of the world in a decade’s time.