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Witness Statement

THE BENEFITS AND PROBLEMS FACING THE DEVELOPMENT OF

AN INTEGRATED OCEAN OBSERVING SYSTEM

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Good afternoon Mr. Chairmen and members of the Subcommittees. Thank you for the opportunity to testify. I am Robert Weller, a sea-going research oceanographer at the Woods Hole Oceanographic Institution and also the Director of the Cooperative Institute for Climate and Ocean Research at the Woods Hole at Oceanographic Institution. In my testimony, I will focus on the open or blue water ocean, as you will hear other testimony on the coastal ocean.

There has been growing need for us to understand climate variability both to assess its impact on society and to guide policy decisions. This need provides a good starting point for a discussion of ocean observing systems. To understand climate variability and change in the earth system, which includes the atmosphere, the land, and the ocean, we need to make the observations necessary to track the energy balance among the components and the energy storage in each component. Critical to climate science are observations that explain the heating of the earth by shortwave radiation from the sun, the balance of that energy accumulation by longwave and reflected shortwave radiation returning to space, the impact of clouds, aerosols, and gases on the passage of longwave and shortwave through the atmosphere, and the partitioning of where energy accumulates. Equally important, observations are needed to track the redistribution of freshwater and the energy associated with changes in phase of water. For this reason, it is essential to field, maintain, and sustain the land stations, sounding balloons, aircraft, and satellites needed to collect these observations. Because of their importance to weather prediction, these atmospheric and terrestrial networks already exist and should be sustained and improved.

However, for the ocean, there is no comparable heritage of sustained observations and no operational global ocean observing system, either for understanding the ocean's role in climate or for support of fisheries, marine transportation, defense or other purposes.

An integrated global ocean observing system is needed. Consider the need from the point of view of climate. The ocean, which covers 70% of the earth, can store 1100 times more heat than the atmosphere due to the larger heat capacity and density of water. The upper 2.5 m of the ocean, when warmed 1°C, thus stores an amount of heat that would raise the entire column of air above it 1°C as well. As a consequence, an anomalously warm region of the ocean has the potential of releasing considerable energy to the atmosphere above. That heat release can alter the weather on short time scales and, if it persists, can alter climate.

The ocean has unique attributes, but these problems have been considered and a well thought out plan for the integrated ocean observing system exists. Because they dictate how to construct an integrated ocean observing system (one that is comprehensive and complete), these attributes are reviewed briefly here. Unlike the land, the ocean is not opaque to shortwave radiation and is mobile. Sunlight heats the upper ocean, and the strong solar insolation in the tropics leads to warm ocean temperatures there. There is thus often a warm surface layer that extends down to 50 to 100m. This layer is in direct contact with the atmosphere and isolates the bulk of the ocean from direct contact with the atmosphere. Surface currents, such as the Gulf Stream, carry warm water from the tropics poleward. In locations of heavy rain this surface layer is also made more buoyant by the additional freshwater. In the western equatorial Pacific, rain and solar heating combine to make a warm pool of surface water. During El Niño that warm water is found instead in the eastern tropical Pacific, and the anomalous location of such warm water is associated with the major climate and weather impacts of ENSO. In locations outside the tropics, however, our lack of observations of air-sea exchanges and ocean pathways leaves us unable to be definitive about the mechanisms by which the oceans and atmosphere influence each other, though patterns of variability, such as the Pacific Decadal Oscillation (PDO) and the North Atlantic Oscillation (NAO) are evident.

The circulation in the ocean is not limited to the surface layer. When surface water becomes denser when cooled by the heat loss to the atmosphere and when salt is left behind during evaporation, it can sink into the interior of the ocean. Convergent, wind-driven flow in the surface layer can also force water into the interior. Horizontal flow in the ocean's interior, like that in the atmosphere, is due to horizontal pressure gradients resulting from spatial differences in the density of seawater. The action of the surface winds, heat and freshwater fluxes and subsequent flows in the interior of the oceans yield a fully three-dimensional flow. Particularly dense water is formed in the northern North Atlantic and along the coast of Antarctica. A much-simplified schematic of the ocean's circulation shows these water masses sinking and flowing at depth through the global ocean, rising again to the surface where they are warmed by contact with the atmosphere in the tropics and subtropics the deep ocean over the globe. Note that a warmer globe could lead to melting of the polar ice caps and that the resulting freshness of the surface water at high latitudes could reduce the formation of dense water in the North Atlantic and in the Southern Ocean, thus altering the present large-scale three-dimensional flow of the world's oceans.

Changes in air-sea exchanges and in surface currents alter the pattern of sources and sinks for heat, freshwater, and other constituents at the base of the atmosphere and thus impact climate. The three-dimensional circulation in the ocean fully engages the very large reservoirs of the interior of ocean, over a wide range of time scales reaching to longer than decadal, in the climate system. An ocean observing system must thus observe the air-sea exchanges, the ocean pathways for transport, which lie along the boundaries of the basins as well as at the surface and in the interior, where heat, freshwater, and other properties are stored, and how the pattern of storage is evolving.

This is a challenge. Changes in interior temperature and salinity will result in changes in the density-driven flow, which, in turn, may further redistribute these properties. Thus, attribution of change in temperature at a site must consider not only the possibility that additional heat is accumulating or being lost but also that changes in the three-dimensional flow has brought water of a different temperature and salinity to the site.

Measuring the air-sea exchange of heat, freshwater, momentum, CO_2, and other constituents important to climate and weather is a central goal of an ocean observing system. Numerical models and existing climatologies have large errors in the air-sea fluxes they provide, and these errors are an impediment to gauging the ocean's role in climate; and the accuracy of weather predictions at sea is limited by the lack of data from the oceans. The installation of a number (5 to 10 per ocean basin) of surface buoys is recommended to provide, at key locations, accurate time series of the surface meteorology and air-sea exchanges. These buoys would be equipped to measure surface wind, relative humidity, air temperature, sea surface temperature, barometric pressure, incoming shortwave radiation, incoming longwave radiation, and rain. Sampling as fast as once per minute, these buoys are essential as the first step in an effort to obtain the air-sea fluxes over the basins needed to quantify the ocean's role as a source and sink in the climate system, to serve as the variable and energetic forcing on the bottom of 70% of the atmosphere (and thus a major role in weather), and to be used to understand ocean response to change in surface forcing. The choice of the locations for these sites is guided by the need to observe air-sea exchange in characteristic meteorological provinces over the ocean, such as in equatorial convection, under the stratocumulus clouds found west of California and of Peru and Chile, and in the trade wind belts, and to observe air-sea exchanges in regions of strong coupling between the ocean and atmosphere.

The buoys will serve as references sites or anchors in the work of making the maps of air-sea exchanges that are needed. The spatial distribution of the air-sea exchanges around the reference sites would be obtained, in the locations that merchant ships are available, by equipping those Volunteer Observing Ships (VOS) with similar instrumentation. The observations from the surface reference sites and VOS would be used to calibrate and drive improvements to atmospheric models and satellite remote sensing that would provide additional information about the surface meteorology and air-sea fluxes and allow production of global maps of air sea exchanges.

Observing the pathways for transport on the surface and in the interior of the ocean and the evolution of the property distribution within the ocean is also a central goal and requires broad spatial coverage of the fields, high spatial and temporal resolution to resolve pathways, and moorings. Broad coverage of the basins is to be accomplished by on an ongoing basis by a combination of the VOS, free-drifting instruments, and satellites. The VOS will drop expendable temperature probes (XBTS or expendable bathythermographs). The VOS can drop XBTS frequently enough to obtain the close spatial sampling needed to resolve the transport in boundary currents and the transport associated with ocean eddies. New, free-drifting ARGO floats that change their buoyancy and obtain vertical profiles every 10 days will be deployed globally with 100 km spacing to observe temperature and salinity in the upper 1500 to 2000 m. Together with satellite observations of sea surface height and surface wind, the ARGO floats will allow the broad scale evolution of the upper 1500 m of the ocean to be tracked. Surface drifters will be deployed for calibrating remotely-sensed sea surface temperatures, and land-based tide gauges are needed to calibrate satellite altimetry.

Moorings, both with surface meteorological buoys and with no surface buoy, will be used in key locations to quantify flow along pathways between the surface and the interior and between the warm tropics and the cooler extratropical regions. At sites where surface waters are cooled and sink and where convergent flow forces surface water into the interior, the air-sea fluxes will be quantified and the progression of water from the surface into the ocean interior will be observed. At sites where strong, narrow currents carry large volumes of water, arrays of moorings will measure the volume, heat, and salinity of these currents.

The time series collected by moorings or by frequent visitation by a ship will provide a key record of change from the surface of the ocean down to the bottom. At present, very few such observing sites exist in the ocean; and our record of change in the oceanic interior is sparse. In conjunction with plans to occupy a number of surface flux reference sites, the integrated ocean observing network would have time series sites at key locations to quantify transports and observe change.

The progression of water from the surface into the interior and to the ocean bottom is slow, estimated to take up to 100 years in some locations. Along the way, mixing processes modify the water mass, so tracking the slow overturning of the global ocean requires additional observations. Releases into the atmosphere of chemicals, such as of tritium, chlorofluorocarbons (CFCs), and CO_2, that enter into the ocean provide tracers that can be used to track the passage of chemicals through the ocean. Careful sampling, by lowering instruments from ships and obtaining water samples at depths through the water column, should be made along select north-south and east-west sections across the ocean basins. These sections would be occupied only every 5 to 10 years, and are essential to describing the slow overturning circulation of the ocean as well as change in the temperature and salinity of the deep ocean, at depths below where the ARGO profiling floats will sample. We now have few records of oceanic variability at depth. The repeat sections will build that record; and, at the same time, they will validate numerical models of the deep ocean circulation that may be used in coupled ocean-atmosphere models to investigate climate change and ocean variability.

While the focus of much of this discussion has been on physical observations, such as temperature and salinity, the required ocean observing network should make biological, chemical, and geological observations concurrently with physical observations. In the ocean, variability is often linked. For example, greater phytoplankton concentration in the upper ocean increases the absorption of sunlight and thus the heating of the water near the surface. Some platforms, such as moorings and ships, are now well equipped to carry out such multidisciplinary sampling. In addition to knowing how and where heat and freshwater are transported, the ocean observing system will provide the basis for understanding transport of nutrients, pollutants and harmful species (toxic algae, for example) and the observations needed to better predict surface waves and marine weather that impact transportation, recreation, and safety.

In contrast to the land and atmosphere, the ocean is sparsely observed. It is, however, a major part of the climate system, particularly so because of its large reservoirs and ability to move properties active in climate dynamics, such as heat, around over a wide range of time scales. An integrated ocean observing system for climate can be developed; such a system has been outlined above.

The ocean is where some of us work and many of us play. It is close to many of our homes and provides food and energy. An integrated ocean observing system will not only address climate issues; it will also provide benefits that address other societal needs, particularly if the data is available in near-real time. Knowledge of sea level change and of ocean currents, surface waves, temperatures, salinities, plant and animal populations, distribution and storage of greenhouse gases is important to weather prediction, the development of sound environmental policies and management strategies, to safety, to security, and to economic well being.

We do not have an integrated ocean observing system. Very few sustained ocean observations are now made. The plans and methods for an integrated observing system for the ocean have been developed. One region, the tropical Pacific Ocean, has been instrumented; and the return on the investment has been clear due to our increased ability to forecast El Niño and provide advanced warning of its impact on weather. In partnership with other nations, the United States should commit to completing a global ocean observing system.

The major problem facing the development of an integrated ocean observing has the lack to date of a national commitment to do so. This has resulted in the lack of key resources. These missing resources include: funding, technology, and infrastructure.

In most cases, observational priorities are agreed upon, the technology has been developed to collect the required observations, and the plan for implementing the system has been drafted. However, sustained funding has not been available. A few elements are in place, including the ENSO observing system in the tropical Pacific Ocean and the initial deployments of the Argo floats. There is no apparent source of support for the balance of a sustained, integrated ocean observing system.

In some cases, enabling technology is needed. A pressing need is increased capacity for passing data collected at sea from ships, buoys, and floats back to land. Technical advances have improved our ability to bring data to the sea surface from the ocean's interior. However, there is limited satellite capacity then available for relaying that ocean data back to the centers on land that would prepare the predictions, maps, and other products we need. This lack will limit the amount of ocean data we can acquire in near-real time. It will also prevent us from developing of an ocean observing system that resembles our present atmospheric and terrestrial systems in their ability to provide immediate coverage. Development of longer-lived and more capable observing instruments is needed to maximize the effectiveness and value of the ocean observing system.

Finally, the lack of a national commitment to sustained ocean observations has left us with have no infrastructure to support and guide such an development and maintenance of an ocean observing system. No agency has taken the lead. No person within the government is identified as a point of contact for other nations to interact with while agreeing on international commitments of support and responsibility for sectors of the ocean and contributions to the different observing elements. Progress to date has been made using the research infrastructure (funds, people, ships, labs). An integrated ocean observing system will require an investment in instrumentation and hardware, support for ships to deploy and service the system, people to quality control and process the data, communications systems to pass the data along, and the means to use the data to prepare products of use to society. This requires a commitment within the government.

In closing, thank you for allowing me to submit this testimony. The climate example was developed at length to demonstrate the readiness of the plans and methods to implement an integrated ocean observing system. Such an open ocean system links to the coastal observing systems, where it provides for them the knowledge that links those coastal regions to the open ocean and where the coastal observing systems provide key knowledge of coastal sinks and sources of carbon, freshwater, pollutants, marine life, and other quantities. The open ocean system described above is also linked to a system of operational satellites for oceanography, whose measurements would include sea surface temperature and winds, sea level from altimetry, and ocean color. I would be glad to answer questions and provide further explanation.

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