Lessons Learned From Operating Global Ocean Observing Networks

Robert L. Molinari
Atlantic Oceanographic and Meteorological Laboratory,
National Oceanic and Atmospheric Administration, Miami, Florida

ABSTRACT

The Global Ocean Observing System Center (GOOSC) at the National Oceanic and Atmospheric Administration's (NOAA) Atlantic Oceanographic and Meteorological Laboratory operates two global observing networks, a drifting buoy array, and a Voluntary Observing Ship network. The arrays provide in real time surface atmospheric and subsurface oceanographic data needed by NOAA weather and climate forecasters. The data are used in delayed mode to verify model simulations of the ocean and atmosphere, to provide in situ calibration/validation data for remote sensing observations, and to increase understanding of the dynamics of the ocean and atmosphere. The operational and research lessons learned in the operation of the GOOSC are reviewed. Operationally, it was learned that, because of costs, international participation is required to maintain global networks; data management methodology is a critical component of operations; and integrated observing systems using multiple platforms provide more accurate products. Scientifically, it was learned, for example, that accurate characterizations of the salinity field must be available in model simulations. As more data become available it is found that scales of important phenomena such as equatorial upwelling are smaller, and high-frequency signals can impact on the mean structure of the upper ocean. These findings must be considered when designing effective sampling strategies.

1. Introduction

The National Oceanic and Atmospheric Administration (NOAA) maintains a Global Ocean Observing System Center (GOOSC) at the Atlantic Oceanographic and Meteorological Laboratory. The GOOSC operates two global networks that provide real-time data needed to satisfy critical NOAA missions. A Voluntary Observing Ship (VOS) network (Fig. 1) collects both surface marine meteorological data that are used in weather forecasting and subsurface oceanographic data (Fig. 2) that are used in climate forecasting (Ji and Leetmaa 1997). A global surface drifting buoy (drifter) array (Fig. 3) provides surface marine meteorological and subsurface oceanographic data that are also used in both weather and climate (Reynolds and Smith 1994) forecasting activities. In addition to serving the prediction community, the data obtained by these networks are important components of many research programs.

During the operation of these networks, we have learned many valuable lessons about the requirements for a successful data-collecting activity. Herein, we summarize these lessons to assist other operators. We also encourage suggestions on how to improve our operations (contact molinari@aoml.noaa.gov). The lessons learned are followed by statements on future requirements for improving the present networks.

2. Lessons learned

The lessons learned are summarized in terms of the conditions needed to ensure a successful operation. These are the following.

1) Multiple platform networks. There is seldom a "perfect" sensor that provides all the information

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Corresponding author address: Dr. Robert L. Molinari, Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, 4301 Rickenbacker Causeway, Miami, FL 33149.
E-mail: molinari@aoml.noaa.gov
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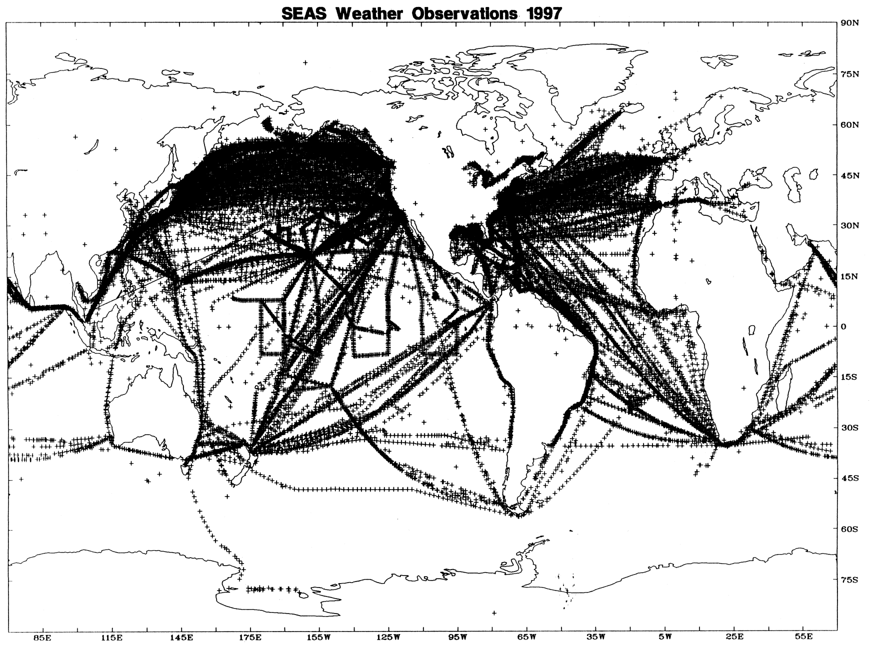

FIG. 1. Surface meteorological data observations (each + represents a data point) provided by a network of Voluntary Observing Ships operated by NOAA during 1997 and transmitted in real time by the Shipboard Environmental Data Acquisition System (SEAS).

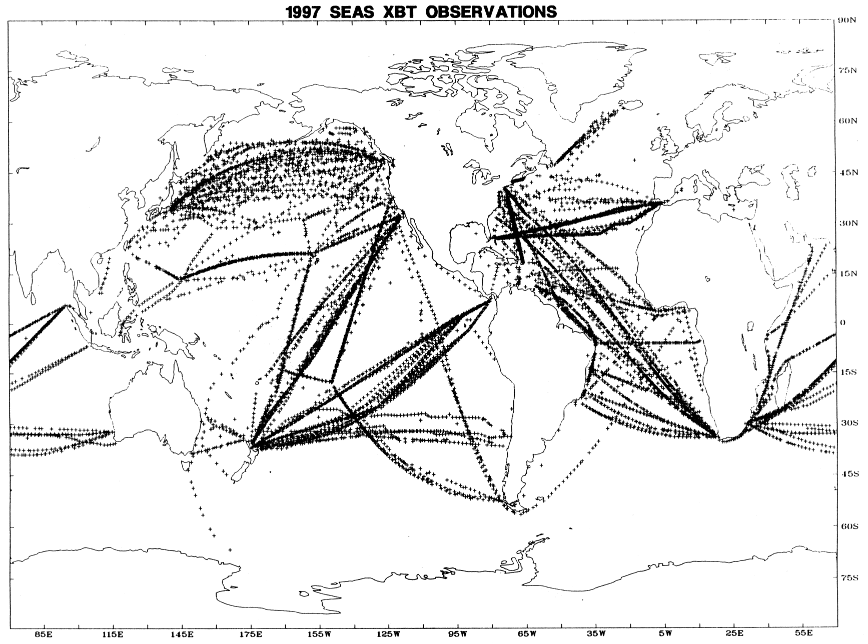

FIG. 2. Subsurface temperature profiles obtained using XBT probes deployed from a VOS network operated by NOAA during 1997 and transmitted in real time by SEAS.

needed for a particular use. For example, satellites provide global coverage of sea surface temperature (SST) to meet forecast requirements. However, the resulting data can be severely degraded by other environmental impacts (e.g., volcanoes; Reynolds and Smith 1994). An in situ network of data is thus needed to calibrate and validate the remote observations. The global drifter and VOS networks (Figs. 1 and 3) provide the needed in situ data. There is a similar requirement for subsurface temperature and salinity data to interpret sea surface height measurements from satellite altimeters. The "optimal" observing system for SST or sea surface height, for example, would be designed to maximize the strengths and minimize the weaknesses of the remote and in situ arrays. To date, however, there have been few quantitative studies directed at network design.

2) Multiple-purpose platforms. The satellite-tracked drifting buoys composing the array shown in Fig. 3 have the ability to house many sensors. The basic drifter provides SST and surface current (through its trajectory) information. It was recognized in early atmospheric experiments such as the First Global Atmospheric Research Program (GARP) Global Experiment (FGGE) that, when properly instrumented, the drifters can provide surface meteorological data in remote areas and/or areas subject to severe conditions, for weather forecasting applications. Thus, many of the drifters in the Southern Hemisphere are outfitted with a sea level pressure sensor (Fig. 3). Similar drifters that also measure surface winds have been deployed in "hurricane alley" of the North Atlantic (Fig. 4). A VOS can also be outfitted with thermosalinograph systems to provide sea surface salinity and temperature data; improved meteoro-

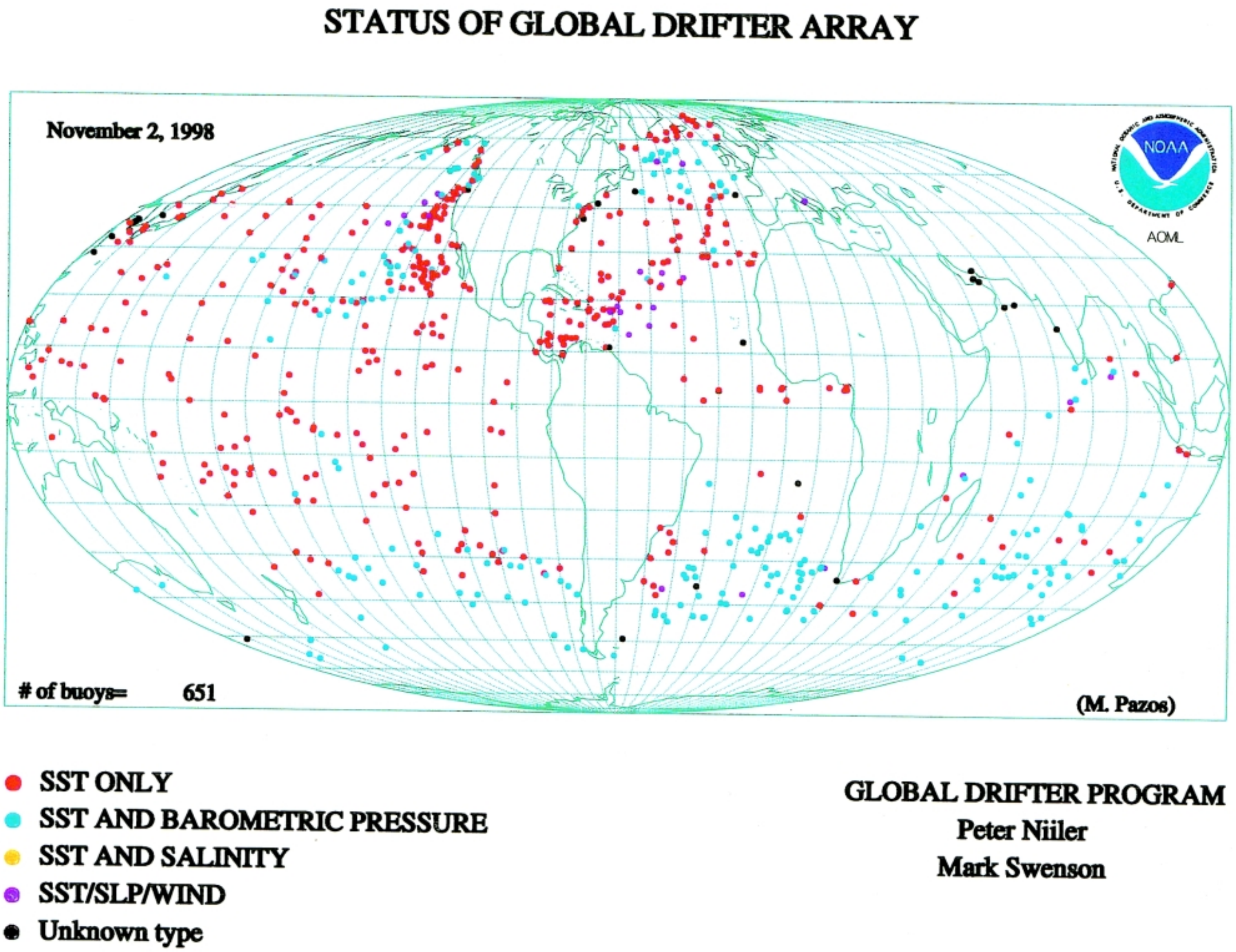

FIG. 3. Status of a global drifter array on 2 Nov 1998 (each dot represents a transmitting buoy). Types of observations obtained from the drifters are also indicated (SST, sea surface temperature; SLP, sea level pressure). No SST and salinity drifters (yellow dots) were active on this day.

logical instrumentation to obtain additional atmospheric observations (e.g., radiation, flux, wind profiles, etc.); and gas exchange systems to monitor carbon dioxide fluxes. Multiple-use data collection platforms greatly facilitate operations by standardizing deployments and data transmission systems. They also improve the quality of data by providing concurrently the multiple variables needed to interpret certain measurements (e.g., the surface atmospheric observations needed to analyze gas flux data).

3) Multiple deployment options. To maintain a truly global array of sensors requires different deployment strategies. In particular, the ability to deploy instruments in remote areas is needed. Thus, to maintain the global drifter array shown in Fig. 3, VOS, research ships, and aircraft are used (Fig. 5). Obviously, this requires instrumentation sufficiently sturdy to withstand air deployments.

4) Multiple national and international partners. Because of the costs inherent in collecting oceanographic data, few, if any, of the existing global networks are maintained by one country, much less one agency within a country. Thus, the global drifter array (Fig. 3), for example, is operated by a consortium of 16 countries. To effectively manage the resources provided by each national group, a coordinating mechanism is needed. The surface drifter community is coordinated by the Data Buoy Cooperation Panel and the VOS expendable bathythermographs (XBT) community by the Ship of Opportunity Program Implementation Panel. Both panels operate under the auspices of the International Oceanographic Commission and the World Meteorological Organization. Each group convenes meetings to discuss resource sharing and advances in technology and to evaluate the networks.

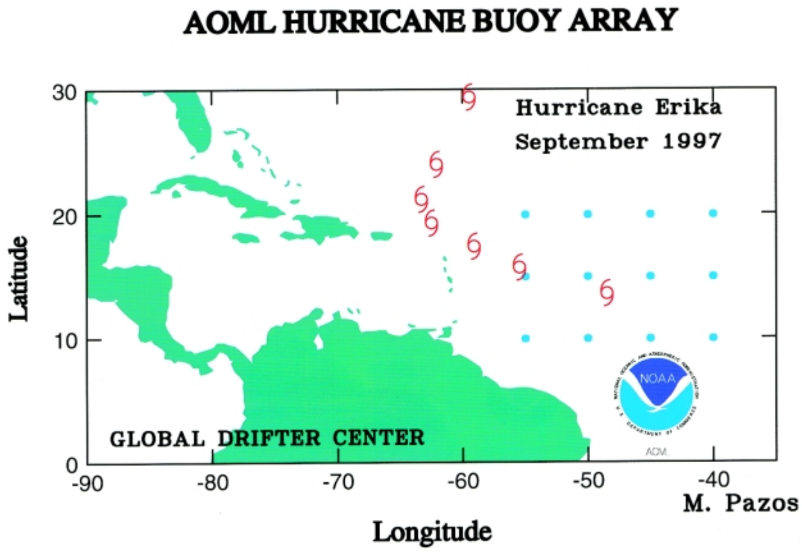

FIG. 4. Status of a portion of the drifter array in the Atlantic Ocean during the passage of Hurricane Erika. Drifters provide surface wind and sea level pressure observations.

5) Multiple nodes for data tracking. It is critical to ensure that the data collected actually gets to the user in a timely fashion (e.g., hours for the weather forecaster, days for the climate forecaster). Thus, we have established data "pipelines" that characterize the flow of information from sensor to user. The drifting buoy data pipeline is shown schematically in Fig. 6. Taps are placed at various locations in the pipeline and data counts are made at each node. Causes for differences in counts are determined and remedies are then applied.
6) Multiple levels of quality control. Weather and climate forecasters require data in a timely fashion as discussed above. This constraint limits the time available for quality control for these data. However, for the climate record, timeliness is not as strict a constraint and more detailed quality control is possible. The more detailed quality control also permits inclusion of the metadata needed by future users of the data to evaluate the strengths and weaknesses of a particular observation. For example, before insertion of subsurface temperature data on the Global Telecommunications System (GTS; the source of real-time data to operational agencies), a comparison of observed temperature structure to a long-term climatology is made and outliers are eliminated. For the long-term record, we have the advantage of inspecting the observations within the context of other data collected close by in time and space. Vertical sections of temperature can be generated, for example, from a particular VOS transect to identify additional outliers. Quality flags and metadata can then be added to a particular record prior to submission to a data repository.
7) Multiple uses for the data. The data and data networks become more valuable if used for more than only forecast purposes. In particular, scientific research can improve prediction models, develop design strategies, and increase understanding of ocean dynamics. For example, comparing drifter data to model results, Acero-Schertzer et al. (1997) show that simulations of Pacific surface currents are improved if accurate representations of salinity structure are included in the model. Furthermore, Poulain (1993), using tropical Pacific drifter data, shows that when more data are available, finer spatial resolution of equatorial upwelling dynamics is possible. This information on important spatial scales, in turn, can feed back to the design of an equatorial drifter array. Finally, Hansen and Paul (1987) employed a surface drifter dataset to show that tropical instability waves play an important role in the maintenance and decay of the Pacific equatorial cold water tongue, again, information that can be used in designing an equatorial array.

3. Future requirements

Future requirements are based on a combination of the lessons learned, above, and findings of national and international planning groups. For instance, the need for the "end-to-end" information management system described below is documented by the Ocean Observing System Development Panel (OOSDP 1995). The need for a governance protocol is based on experiences "operationalizing" the ENSO Observing System (National Research Council 1994).

1) Establishment of an end-to-end information management system. To fully realize the value from existing global observing networks, an end-to-end information management system must be estab-

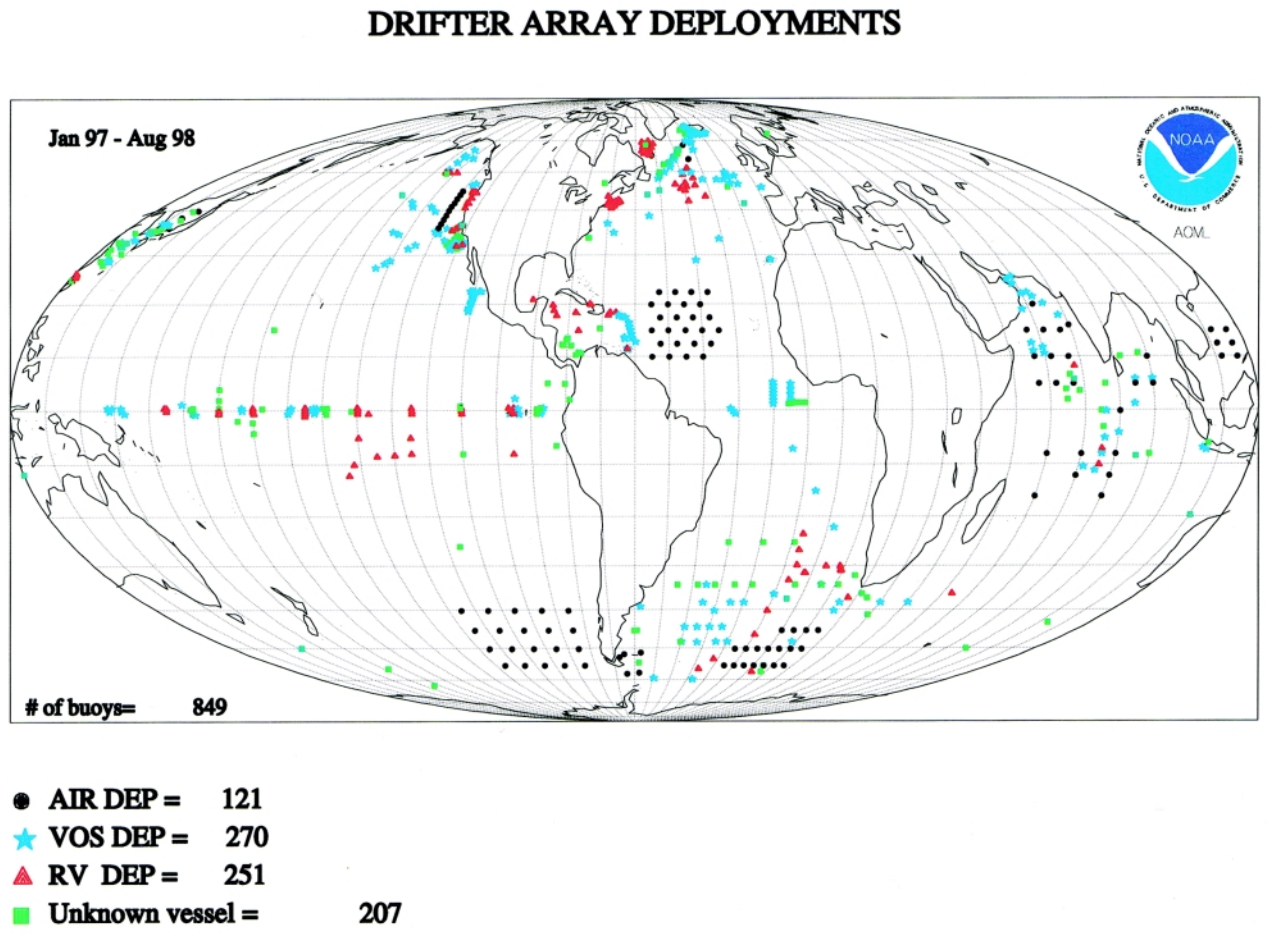

FIG. 5. Form of launch vehicles to deploy the global drifter array (AIR DEP, deployed by military aircraft; VOS DEP, deployed by VOS; and RV DEP, deployed by research vessel).

lished. An end-to-end system takes data from sensor to user (Fig. 7), in NOAA's case the weather and climate forecasters, and includes the data tracking and quality control functions described above. Many pieces of such a system are in place, but additional efficiencies can be realized. For example, presently both forecasters and network operators perform quality controls on the data, the former to remove questionable data prior to assimilation and the latter to identify problems in data collection. However, frequently information is not exchanged between the two groups in a timely fashion, as needed to repair faulty sensors. If the operators could review the forecast "discard" files (i.e., data that are not ingested by the model for initialization) as they are generated, timely resolution of problems would be realized. Furthermore, the need for the operators to perform the actual quality control would be eliminated. Similarly, both forecasters and network operators track information through data pipelines (Fig. 6). By centralizing the tracking tasks at one location, duplication would be eliminated.

2) Increased interactions between the research and operational community. In oceanography, the majority of the global observing systems have begun in the research community. This community frequently defines the important signals to observe and the spatial and temporal resolution needed to characterize these signals. This interaction must continue and increase with particular emphasis on the use of the data to verify forecast models and, conversely, the use of the operational models to perform design studies to develop cost-efficient observing networks. With respect to the latter, the design studies must stress the development of networks that mix and match the strengths of remote and in situ observing techniques. The expertise to conduct these studies resides in both academia and government agencies and only through continued

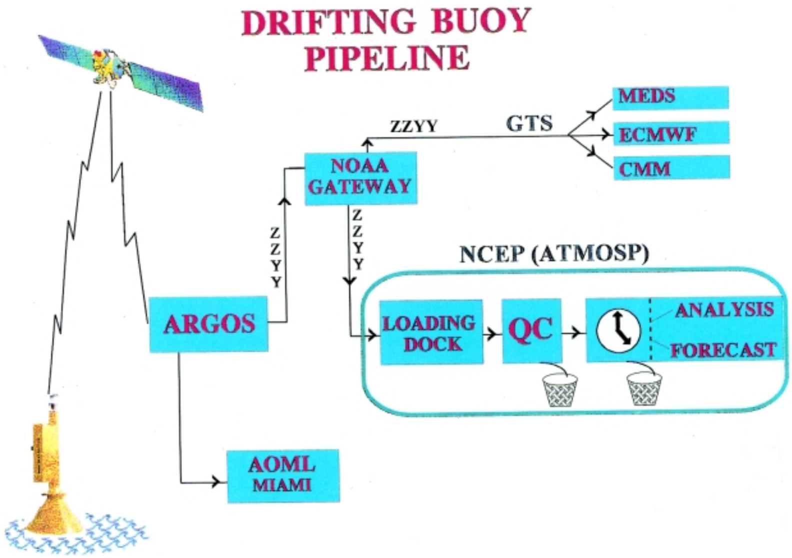

FIG. 6. Path (pipeline) of atmospheric (ATMOSP) data from a drifting buoy to the forecasters at the National Centers for Environmental Prediction (NCEP). The data, identified by the header ZZYY, are transmitted from the buoy to Service Argos for dissemination to AOML and the NOAA telecommunications gateway. The gateway transmits the data via the GTS to NCEP and other users, including the Marine Environmental Data Service (MEDS) of Canada, the European Centre for Medium-Range Weather Forecasts, and the Commission for Marine Meteorology (CMM) of the World Meteorological Organization. The baskets at NCEP represent discard files of data that fail quality control (QC) and analysis tests. Data are reviewed at AOML but are forwarded to final data repositories by other routes (not shown).

interactions can this expertise be effectively applied to achieving improved forecast models and observing networks.

3) Establishment of governance protocols. Governance herein applies to the procedures for transitioning research and development activities to operational activities. Ideally, the transition is characterized by retention of the research funds and new funds becoming available for operations. To date, this process has been achieved on a rather ad hoc basis (e.g., the transition of the ENSO observing system including tropical Pacific moorings, drifters, and XBTs from research to operational status; National Research Council 1994). Formal procedures should be developed and implemented whereby the appropriate government agency can review the results from a research network (e.g., the proposed global profiling float array; Argo Science Team 1998) and determine the appropriateness for transition, based on user requirements, to operational status. For example, a review panel of research scientists and operational forecasters could be established to perform the evaluation. An important task for the panel would be to integrate new instrumentation into existing observing networks, such that "climate" signals are not introduced into the measurement record because of differences in observing techniques.

4) Obtain long-term funding commitments. Perhaps the most obvious of the future requirements, obtaining long-term funding commitments for sustained ocean observations remains one of the most difficult objectives to achieve. However, as basic research and operational investigators realize the importance of sustained observations for satisfying the requirements of both communities, stron-

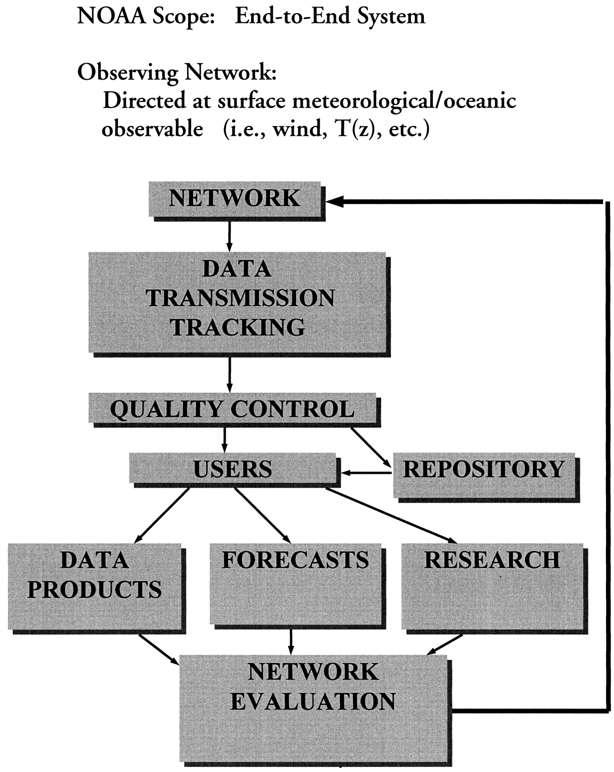

FIG. 7. A schematic diagram of an end-to-end observing network demonstrating desired interactions between data collection and evaluation functions.

ger arguments become possible. For example, planning for "CLIVAR: A Study of Climate Variability and Predictability" recognizes the need for sustained observations to improve understanding of the dynamics of the coupled air–sea climate system (World Climate Research Program 1995). This increased understanding is a necessary step toward achieving improved forecast skill. Speaking with a single voice, the two communities can increase the potential for obtaining the support needed for a sustained ocean observing system.

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