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OCEANOGRAPHIC TIMESERIES OBSERVATORIES

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ABSTRACT -The establishment of oceanographic observatories at selected sites around the world's oceans is recommended. These observatories would collect time series of surface meteorology, air-sea exchanges of heat, freshwater, and momentum, and provide full depth sampling of ocean temperature, salinity, velocity, and biogeochemical variables. Such measurements also allow direct or geostrophic transport estimates at key sites or along selected sections. New mooring and instrumentation technology makes it possible to maintain such observatories at a fraction of the cost of the previous ocean weather stations. The ocean observatories will provide a critical component of the Global Ocean Observing System (GOOS) needed to develop a description and understanding of the ocean's role in climate. Time series from the observatories will provide the means to develop accurate fields of the air-sea fluxes, observe water mass formation and transformation, quantify the transports of the major ocean current systems, and assess the variability of the vertical structure of the ocean and the role of eddy processes in the transport of heat and other properties.

1 - INTRODUCTION

To unravel the ocean's role in global climate change, oceanographers desperately need long-term observations of ocean water properties, circulation intensity and patterns, and of the exchange of heat, freshwater, and momentum between the ocean and the atmosphere. Such records are notably scarce today. One treasured source of such data is the network of ocean weather stations (OWS) established after World War II (Figure 1). This array was augmented in 1954 by an oceanography-only station offshore from Bermuda, euphemistically termed Station S in honor of Henry Stommel who initiated the idea, or the Panuliris Station after the first ship to service the site (Michaels and Knap, 1996). Unfortunately, in 1981 the international OWS program ended. At present only OWS M, off Norway, is routinely occupied.

The demonstrated value of the Bravo and Papa time series has led to efforts to continue at least annual sampling at these sites. Research vessels, for example, have occupied one or more central-Labrador-Sea stations in 16 of the subsequent 23 years after 1973, though obviously without superannual-frequency resolution. Regular ship-supported sampling at Station S does continue. In addition, a small number of new long-term measurement programs have been recently initiated, e.g., Bermuda Atlantic Time Series (BATS) program co-located with Bermuda Testbed Mooring (BTM) program; Hawaii Ocean Time-series (HOT) program; European Station for Timeseries in the Ocean Canary Islands

(ESTOC). Some sites are also being maintained at present with annual mooring technology (Bravo, Bermuda, ESTOC).

The OWS time series played a critical role in early efforts to build an understanding of the variability of the ocean and its response to atmospheric forcing. At present, just as we seek to develop an understanding of the ocean's role in climate variability, we find we lack the continuing long time series stations critically needed to support such work. Thus, we recommend that new long time series stations, which we call Ocean Observatories be established.

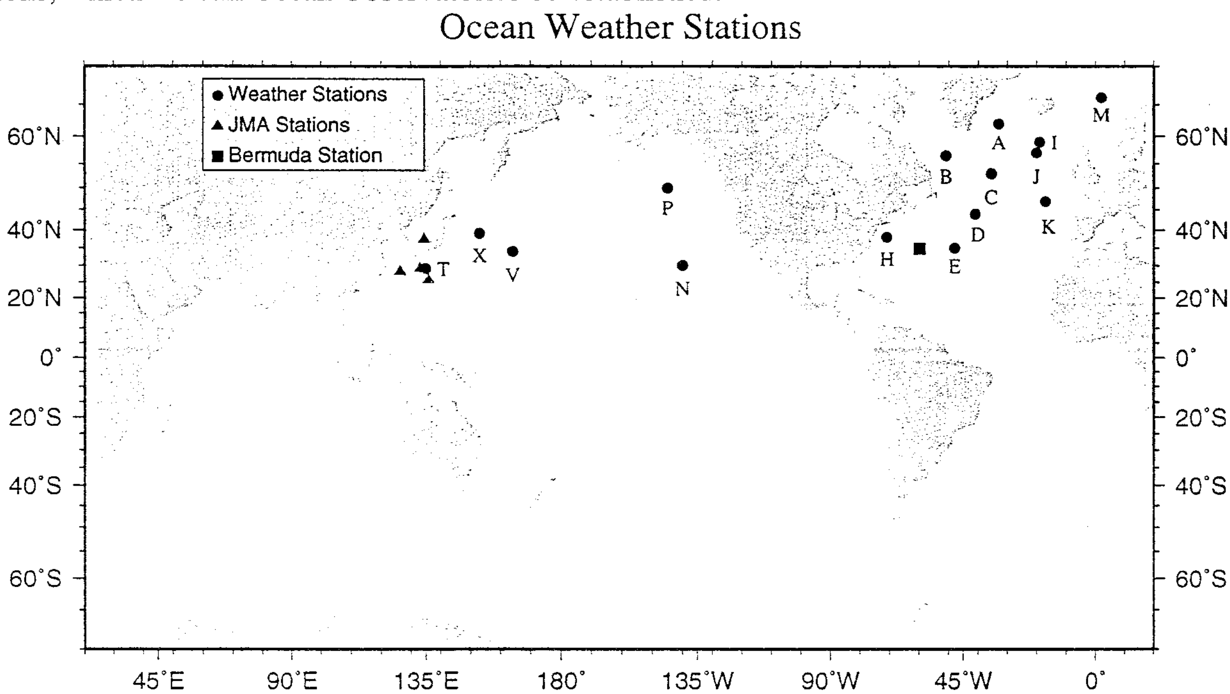

Fig. 1 - The historical Ocean Weather Stations (OWS) network

2 – BENEFITS OF EULERIAN TIMESERIES

Fixed-point Eulerian Ocean Observatories would represent one component of an ocean-atmosphere measurement network whose products will enhance our abilities to understand, model and predict global climate change. The Ocean Observatories concept complements other planned elements of the ocean observing system, such as that for a widely dispersed system of profiling quasi-Lagrangian floats (ARGO). Eulerian timeseries will, in particular, have the following benefits:

- Fixed point observing systems can provide information at high vertical and temporal resolution from the atmospheric boundary layer, down through the ocean mixed layer, to the abyss, on time scales of minutes to years. This type of information is not available from other types of observational systems. It is an ideal complement to systems which give spatial information.

- A large suite of sensors/types of measurements can be employed at fixed observatories, thus providing many linked variables at one place.

- In regions characterized by significant current, a ground-fixed measurement system can insure that continuous observations from a site are available. Observation of ocean features having small spatial scales may be more effectively carried out with coherent arrays of fixed instruments or integrating techniques between fixed instruments than e.g. by randomly seeded Lagrangian devices.

- Only at a fixed point station can autonomous/continuous measurements be combined over long times with in-situ sampling programs and high-accuracy analysis work requiring laboratory procedures, such as chemical, optical, and biological research. Thus, fixed-point stations provide a unique opportunity for multidisciplinary and interdisciplinary work, combining physical, chemical and biological observations.

- Fixed point observations made with periodically recovered and redeployed automatic measurement instruments may be corrected for sensor drift using post-recovery laboratory calibration data and occasional ship-based in situ measurements during site visits. Small climate change signals may thus be first detectable by ocean observatories.

- Fixed point observations can provide important reference/calibration information for freely drifting instruments (where the above calibration and in situ referencing is generally not possible) and for remote sensing data (wind stress and surface chlorophyll, salinity and other properties). In turn, the timeseries measurements can help relate observed changes in those surface properties to the underlying water column.

- Moored observatories are ideal for developing and testing new instrumentation (testbed concept), particularly when located within easy reach of coasts or islands. Some tested instruments may eventually be interfaced to drifters, floats, gliders, and AUVs .

3 – SCIENTIFIC OBJECTIVES

The measurement programs at the new Ocean Observatories would collect observations to begin a new set of long time series similar to those from the OWS. The objectives of establishing ocean observatories are to:

a) Investigate and monitor water mass formation or transformation
Ocean observatories would be established in key sites of water mass formation and/or transformation by air-sea interaction. Their observations aid in determining the depth of convection at a reference site, while simultaneous float data could be compared to give indications of its spatial variability and tomographic observations might provide the horizontal extent/average. From the meteorological data obtained by these stations, accurate air-sea fluxes will be estimated, which is one of the forcing functions for the water mass transformation. Another controlling factor, the initial (fall) stratification (buoyancy content) can be determined with surface-mooring techniques (see below). The change with time of ocean heat and fresh water content can be determined, and compared with the surface fluxes, this allows estimates of the horizontal advection/mixing. Altogether, such observation would provide insight into the mechanisms and variability of water mass transformation, and at the same time monitor changes at the origins of deep water masses and of elements of the thermohaline circulation. Links can thus be investigated with changes in these water masses or in the thermohaline circulation in other places of the ocean.

b) Establish air-sea flux reference sites

Well-instrumented surface moorings are recommended at a subset of locations in order to provide high quality, accurate reference data to be used to check, verify, and calibrate surface meteorological fields from models, remote sensing, and other in-situ measurements. Further, work in progress to upgrade the quality of the surface meteorology and air-sea fluxes on a global basis from the Volunteer Observing Ship (VOS) fleet is based on a strategy that will rely on the fixed reference sites. The reference sites will serve both as primary standards for quality control of the VOS data and as the basis for validating regional choices of flux formulae. The present drifting buoys provide a good example of how in-situ observations are used to calibrate satellite data; in their case, they provide the means to calibrate the AVHRR fields of SST. In addition to SST, the reference site surface moorings will provide surface winds, surface shortwave and longwave radiation, and rainfall for use in validating and calibrating remotely sensed values of these variables. (See also separate paper on surface fluxes and reference sites).

c) Measure the transport and variability of major current systems

At key sites, direct measurement of ocean currents is envisioned. The transport variability of important current systems is presently hardly known. Long term Eulerian measurements of e.g. surface and deep western boundary currents and of the dense overflows of Nordic Sea waters through the Denmark Straits and Faroe Bank Channel will help quantify changes in important elements of the climate system. Throughflow/outflow measurements will document the exchange (and its variability) between ocean basins or oceans and marginal seas, providing integral information on the basin average processes. Different approaches will be compared for such transport measurements, like boundary arrays of current meter moorings, dynamic height moorings on opposite sides of major ocean currents, acoustic transmissions or hydraulic reservoir height measurements. These data will prove valuable in estimating ocean heat and property fluxes and constraining models developed to extrapolate downward the remotely sensed fluctuations in sea level from altimetric satellites. Moreover, by instrumenting sites on opposite sides of ocean basins variations in the ocean's net meridional overturning circulation could be investigated.

d) Investigate the variability of the ocean's interior

Moored velocity and water property measurements will be made of specific ocean regions and their associated eddy to long-term variability. Variability occurs on all time and space scales. Both the multi-annual and the eddy time scale pose a problem for current climate models. Such models cannot yet be run routinely in the "eddy resolving" mode, and eddy processes need to be parameterized. Field experiments will need to be designed and performed to achieve this goal. Some of the supportive field work will be focused limited duration process experiments, but other elements will need to be sustained measurements programs, for example to document variability in eddy statistics. Efforts are also under way to assimilate statistical quantitites into model. Fixed point, or Eulerian, measurements will be crucial for this. For the multi-annual timescale, very few observations of variability exist. The longest available record is of order one decade and there exist very few locations where currents have been observed for longer than 2 years over the water column. New technology is expected to permit durations of 5 years or longer and allow frequent transmission of data back to the lab. With this new capability we would propose to maintain moorings in a number of locations around the world to obtain a global picture of long term internal variability and its depth structure for comparison with that being obtained by the altimetric satellites.

e) Enable multidisciplinary and interdisciplinary research
The combination of physical, chemical and biological observations is a powerful argument for ocean observatories. A central theme for this work involves developing understanding of how synoptic-scale and annual-to-interannual variations in atmospheric forcing and ocean circulation, stratification, and water mass properties impact the ecosystem and biogeochemical properties and fluxes (e.g., nutrients, carbon dioxide, oxygen, and trace metals). Fixed-point timeseries observations can also serve as a reference and provide background information for multidisciplinary process studies and spatially distributed measurements.

4 – EXAMPLES FROM EXISTING TIMESERIES

The potential value of ocean observatories can be demonstrated by looking at results derived from the Ocean Weather Station records and from the few existing timeseries stations.

Surface meteorology and air-sea fluxes
While marine meteorological observations have long been obtained from merchant ships, the OWS time series are unique and valuable. Merchant ship reports are of lesser quality, do not provide time series at fixed points, and are biased by the avoidance by the ships when possible of severe weather. The 3-hourly OWS reports have provided the only means to produce time series of the exchange of heat at the surface in the open ocean that resolve the diurnal period. They have also provided the consistent, long-running time series needed to examine seasonal to interannual variability of the surface fluxes (e.g., the analysis of 11 years of data from OWS N in the eastern North Pacific by Ronca and Battisti, 1997).

Mixed-layer studies
The oceanographic data from these stations, having high temporal resolution relative to the seasonal cycle and the oceanic mesoscale, have also been used extensively. For example, much of the pioneering research on the ocean's surface mixed layer was based on data collected at Station Papa in the Gulf of Alaska (e.g. Denman and Miyake, 1973; Davis et al., 1981a,b). The upper ocean thermal data from the North Atlantic weather ships were used by Gill and Turner (1976) to intercompare a variety of seasonal thermocline models. More recently, Denman et al (1992) and Freeland et al (1998) document significant freshening of the surface waters at Station Papa on inter-annual time scale. They speculate on the possible associations between the related increase in vertical stability and an observed decrease in surface nutrient concentrations.

Deep convection and long-term salinity changes
Upper-ocean salinity observations were collected at a subset of these weather ship stations. The suite of these stations in the subpolar and polar North Atlantic provided the means to allow recognition of the existence and decadal propagation of the Great Salinity Anomaly (Dickson, et al., 1988) and its descendants (Belkin, et al., 1998). More generally, description of the seasonal cycle of upper ocean salinity and its climatic change signal anomalies, has been thus far largely reliant on the weather ship data sets (Taylor and Stephens, 1980; Reverdin et al., 1997). Decadal-time scale variability of deep convection and water mass formation have been described using the observations from Stations Bravo

(Lazier, 1980) and Mike (Osterhus et al., 1996) in the Labrador and Norwegian Seas respectively, and from Station S in the North Atlantic western subtropical gyre (Talley and Raymer, 1982; Talley, 1996). The interrelationships of these data form the core of Dickson et al's (1996) evidence for coordinated variation of deep convection in the North Atlantic possibly associated with the North Atlantic Oscillation.

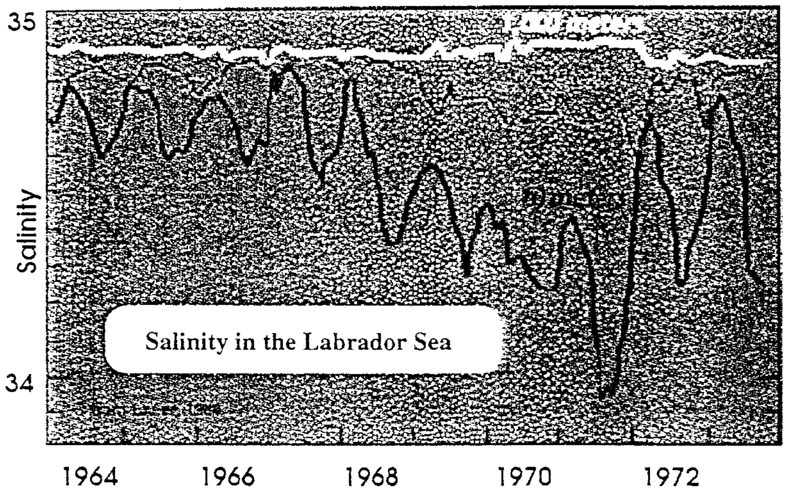

Fig.2 – Salinity evolution (10, 200, 1000m) showing convection variability at OWS Bravo (after Lazier, 1980)

Deep branch of the thermohaline circulation

Weather ship hydrography has also illuminated the cold limb of the meridional overturning circulation. Understanding this overturning system is a climate problem, for it is this circulation that dominates the poleward transport of heat by the ocean and the resulting heating of the mid-latitude and sub-polar and polar atmosphere it achieves. The stations Bravo and S data have been used together to deduce a time lag of about 6 years between the evolving deep convection produced water mass of the western subpolar gyre and signals at the base of the thermocline in the subtropics (Curry, et al., 1998), defining the time scale for the communication pathway. An attempt to track the time lag signals farther south (Molinari, et al., submitted) using deep western boundary current data near Abaco in the Bahamas suggests a 10-year lag, but the lack of high temporal resolution much limits the lag estimate from what could be done with weather ship - like sampling.

Deep interannual to decadal-scale water mass changes

At longer time scale, Joyce and Robbins (1996) discovered a 30-year warming trend in the deep water (1500-2500 m) offshore from Bermuda that, based on historical hydrographic stations near this site, may extend back in time to at least 1922. Curry et al. (1998) show that warming in this water at station S reversed in 1988, and with the subpolar source time series from Bravo showing cooling since 1980, and the documented time delay, these time series allows a prediction that station S will continue to cool at depth until at least 2005. Occasional basin scale hydrographic sections and surveys have shown the basin scale redistributions of heat and salt which accompany the station S record. The station S record, and the weather ship hydrography allows the interannual time scales involved to be identified and the general time evolution context to be sorted out, answering the question of whether sections widely separated in time can be differenced to produce meaningful images of long term oceanic warming/cooling and freshening/salinification.