The Volunteer Observing Ship and Future Ocean Monitoring

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Abstract

Widespread and sustained in situ ocean measurements are essential to an improved understanding of the state of the ocean and its role in global change. Merchant marine vessels can play a major role in ocean monitoring, yet apart from routine weather observations and upper-ocean temperature measurements, they constitute a vastly underutilized resource due to lack of suitable instrumentation. Examples of ways in which vessels can assist include profiling techniques of physical properties, chemical sampling via automated water samplers, optical techniques to measure various biological parameters, and ground truth measurements for remote sensing from orbiting and geostationary satellites. Further, ships can act as relays between subsurface instrumentation and satellite communication services.

To take advantage of the opportunities that the maritime industry can provide, two steps must be taken. The first is to initiate an instrumentation development program with emphasis on techniques optimized for highly automated use onboard ships at 15–20-kt speeds. The second is to forge partnerships or links between academic and government laboratories and the maritime industry for the institution and maintenance of such monitoring programs. No doubt significant resources will be required, but in the long run the improved ability to monitor the state of ocean in situ will make the effort more than worthwhile.

1. Introduction

Widespread, frequent, accurate, and timely in situ observations of ocean properties such as temperature, salinity, oxygen, nutrients, dissolved gases, and currents will be an important part of monitoring oceanic changes. Such datasets are required for the development and verification of oceanic and coupled ocean–atmosphere circulation models and for climate change models. They are also needed for monitoring the health of the ocean and for predicting future trends in the development of the marine and coastal environment in view of the strain imposed by the use of marine and land resources.

With new and more sophisticated satellite observing systems optimized for ocean monitoring, the quality and precision of global datasets for determining sea state, surface winds, surface temperature, surface geostrophic currents, and ice coverage is improving dramatically. The availability of such remote sensing data, however, does not reduce, but rather increases, the need for long-term in situ observations with high quality and sufficient regional coverage. Progress in satellite data quality and coverage has highlighted the difficulty of establishing, let alone maintaining, corresponding in situ measurement programs on sufficiently long timescales.

International programs like TOGA (Tropical Oceans Global Atmosphere) and WOCE (World Ocean Circulation Experiment) combine the use of in situ and satellite observations and related modeling studies, but they are research programs that are limited in time and are to a large extent based on individual research efforts by academic laboratories, where financing is usually sought for only a few years at a time. Further, the notion of "monitoring" is often regarded as incompatible with the spirit of basic research.

Research vessels are necessary platforms for most in situ observational programs. In order to justify their high operating costs they must be shared by a large number of investigators and therefore be multipurpose and capable of operating over widely diverse areas. Programs must be mission oriented. While government laboratories are better organized to establish and maintain long-term measurement programs, their vessels are usually available only for selected and limited monitoring activities. All this is, of course, well known, but a corollary is that we have not given sufficient thought to the use of commercial vessels for ocean research and monitoring. The following discussion is aimed at identifying possible new approaches to the use of ships of opportunity for oceanic observations.

Merchant marine vessels have for decades provided routine meteorological observations for the weather services. An example of regional coverage is shown in Fig. 1. Such observations typically include the oceanic parameters of sea surface temperature (SST) and sea state, and also the standard set of surface meteorological observations: barometric pres-

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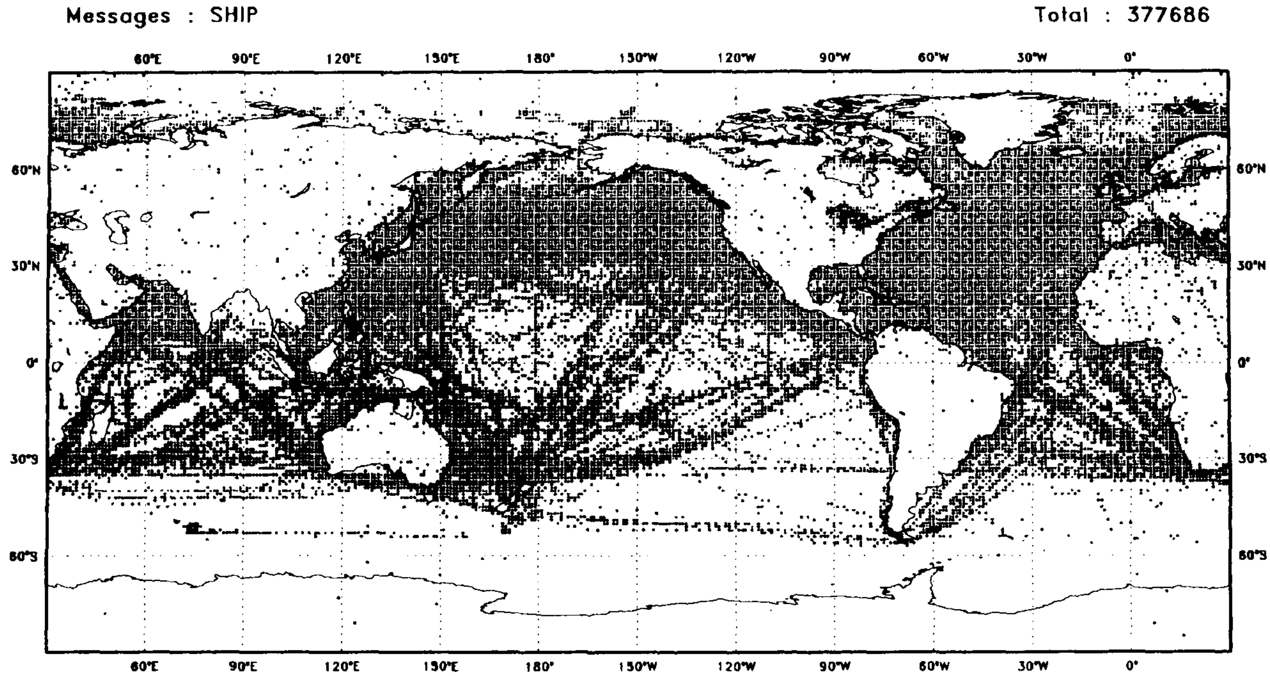

FIG. 1. Regional coverage of meteorological observations from merchant vessels, July 1993–September 1993 (IOC/WMO 1993).

sure, wind, dry and wet temperatures, and cloud coverage. In recent years, containers with semiautomatic equipment for launching radiosonde balloons and transmitting subsequent satellite data have been used on commercial vessels (Fig. 2). Such a meteorological station is shown in the cover figure. Thus, the maritime industry is familiar with the requirement of routine observations for weather forecasting. In addition, commercial vessels have been made available for a number of years, particularly in TOGA and WOCE, to obtain subsurface temperature measurements by means of expendable bathythermographs (XBT), and these programs have been quite successful. Figure 3 presents an example of the regional coverage of such observations. The temporal span is only three months, yet the spatial coverage is quite extensive.

We want to argue, however, that the volunteer observing ship (VOS) can be transformed into a much more powerful tool for sustained, high-quality ocean observations, both for research purposes and for the needs of a future global ocean observing system (GOOS). Two steps are necessary. The first is to institute a program of instrumentation development. The second is to establish partnerships with the maritime industry for the institution and maintenance of such observational programs.

The following discussion will deal with three topics. The first concerns the relation of satellite and in situ observations and the cost effectiveness of VOS observations in this context. The second explores the development program needed to obtain instrumentation that can be used on vessels traveling at 15–20-kt speeds. The third covers the possible institution of the related observations, first in the near term, and then on a more permanent basis consistent with gathered experience and identified needs.

2. Remote sensing and in situ observations

Despite its brief life span in 1978, SEASAT, the first satellite dedicated to the study of the ocean, was a tremendous success. It clearly demonstrated the feasibility of global observations of SST, surface winds, surface roughness, and sea level. This success, however, would not have been possible without the availability of simultaneous ground truth data, such as those supplied by ship and buoy observations of the Joint Air–Sea Interaction Study (JASIN) (see Seasat special issue of the *Journal of Geophysical Research,* Vol. 87 (C5), 1982). As another example of the importance of simultaneous direct measurements, Evans and Gordon (1994) argued that the data from the coastal zone color scanner (CGCS) on the *Nimbus-7* polar-orbiting satellite would have been of much higher quality had there been a regular program of sea truth observations.

The reliability and precision of satellite altimeters for ocean circulation studies has improved greatly in recent years with Geosat (1985–89) and the currently operative satellites *ERS-1* (since 1991) and Topex/Poseidon (since 1992). These altimeter measurements have benefited greatly from calibration and verification from a variety of sea level (island tide gauge) and hydrographic data [see Geosat special issue of the *Journal of Geophysical Research,* Vol. 95(C3), 1990].

Information about ocean properties below the surface can to a certain degree be obtained from surface data alone if the data are ingested into an appropriate empirical framework for interpretation or into a dynamical model. This is especially true of near-surface current velocities, including wind-generated as well as geostrophic flow, deduced from scatterometers and altimeters. The geostrophic current field at greater depth, however, can only be determined with a knowledge of the subsurface temperature/salinity and thus the density field. A determination of heat and freshwater fluxes also requires in situ data from the water column below the surface. Visible radiation satellite measurements have to be supplemented by subsurface observations of plankton distributions to obtain valid distribution patterns of organic matter in the ocean. Calibration problems become greater at higher latitudes because of increased cloud cover, significant seasonal variability, and the increasingly three-dimensional fields of motion; they become greater at lower latitudes because of difficulties with wet atmosphere corrections and because of the smaller slopes of surface geostrophic currents. There are, of course, other data of interest that still cannot be obtained at all by remote sensing at this time, such as dissolved gas concentrations and nutrient levels.

A growing demand can be expected for routine yet high-quality observations for the combination with satellite datasets and with a wide regional coverage not only from the sea surface but also the waters beneath. The obvious platforms for such in situ observations are vessels of the merchant marine, because of their worldwide distribution and continuous operation. Along the major shipping lanes of the North Atlantic and Pacific, there are container ships in constant traffic (Fig. 4). Even in the remote South Atlantic and Pacific, there is regular traffic, albeit less frequent. Another type of VOS not sufficiently used is passenger ferries in adjacent seas. A recent survey of ferry boat lanes in the Baltic Sea is shown in Fig. 5.

3. Instrumentation

Currently, the XBT is the almost exclusively used profiling instrument on VOS. The maximum depth attainable from ships at 20-kt speeds is somewhat greater than 1000 m. In the VOS operations of TOGA and WOCE, some vessels are also equipped with thermosalinographs, instruments that record continuously sea surface temperature and salinity at the cooling water intake, that is, a few meters below the surface. Equipment thus exists for temperature measurements down to 1000 m and for surface salinity measurements. There exists a need for instrumentation that will allow routine profiling of upper-ocean salinity and oxygen content and possibly of chemical properties that are currently obtained from the laboratory analysis of water samples. It has to be anticipated that the concentrations of the majority of chemicals and other constituents of seawater currently cannot be obtained remotely on a profiling instrument. As a consequence, water sampling devices are required that can be used from vessels under way. In the following we will review some possible routes in the development of VOS instrumentation.

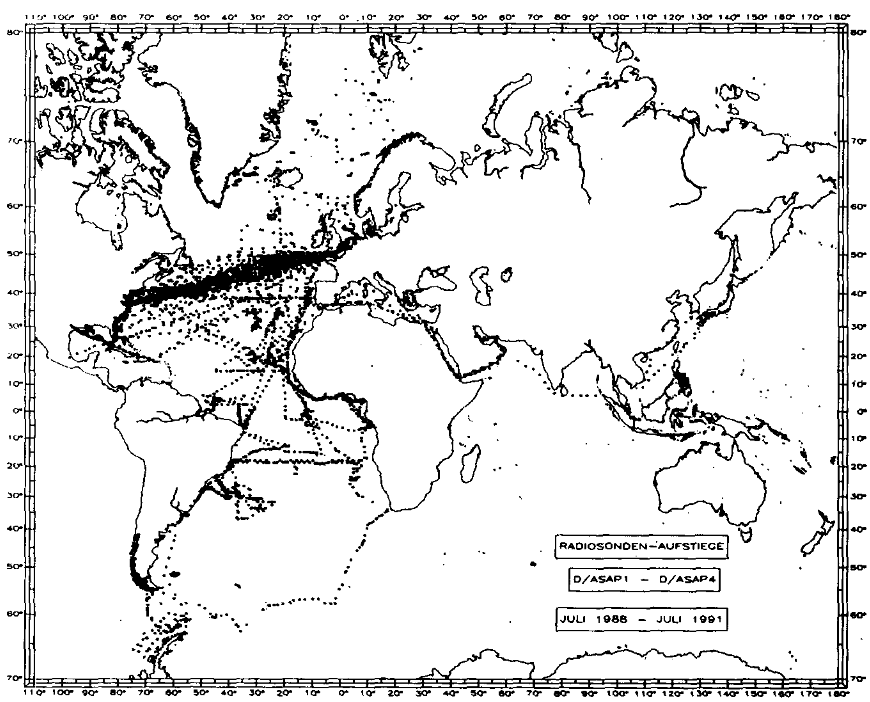

FIG. 2. Summary of radiosonde observations collected from merchant and research vessels under way, July 1988–July 1991 (with permission of Seewetteramt, Hamburg, Germany).

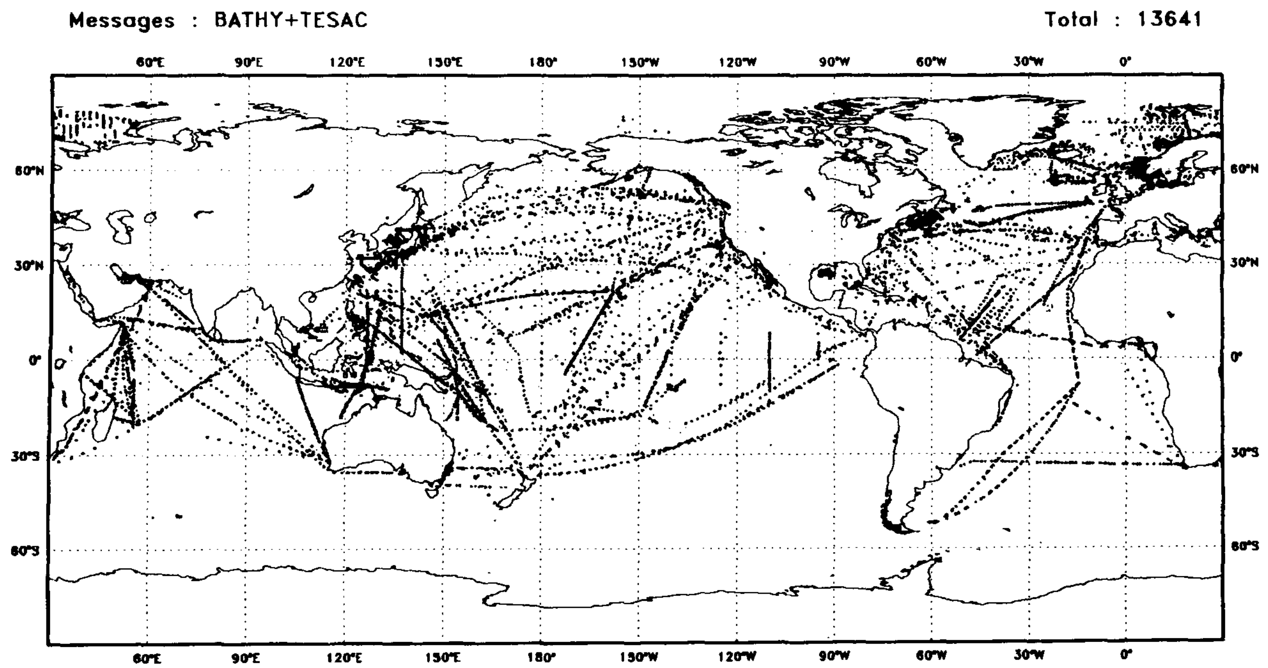

FIG. 3. Regional coverage of XBT and TESAC (temperature and salinity at the surface) messages from volunteer observing ships, July 1993–September 1993 (IOC/WMO 1993).

a. Expendable profilers

Standard XBTs are convenient to use and will continue to be available. Further, expendable conductivity–temperature–depth (XCTD) probes for the measurement of temperature and electrical conductivity and thus salinity have been developed and are currently under evaluation. It is unlikely, however, that these two techniques alone will meet the future demand. One problem is the cost of XCTDs. There is also a mismatch in sampling: the seasonal variability of the ocean typically is, except at high latitudes, limited to the top of the ocean, 100–200 m whereas the XCTD profiles to 1500 m.

b. Shipboard profilers

The mechanical bathythermograph was widely used by the U.S. Navy during World War II and by the research community until the mid-1960s, when the XBT came into widespread use. It appears timely to reconsider the use of wire-tethered free-fall profilers. Among their advantages are repeated use, possibility of sensor recalibration, and possession of multiple sensor equipment. A reliable conductivity measurement is of particular importance. A good regional coverage in upper-ocean salinity data could be the basis for an accurate determination of freshwater fluxes between ocean and atmosphere.

With enough wire on the winch, one could profile to about 200 m from vessels at 20 kt. We will make a rough guess on the requirements for a moment. The T-7 XBT has a drag coefficient of 0.2. Weighing 0.74 kg, it sinks at 6 m s^{-1} at 12 kt. To make it sink twice as fast so that it does not have to spool and drag as much wire would require four times the weight, or 3 kg. The drag of the line is significant and will limit the maximum depth of operation. But even 3 kg is not very much; the mechanical bathythermograph weighed about 5 kg and had a drag coefficient close to one. Thus, by hydrodynamically shaping the probe and by using modern microelectronics and sensors, solid-state memory, and induction for recharging an internal battery, the profiler can be kept small and optimal in shape. By using high-strength fibers, the wire can be

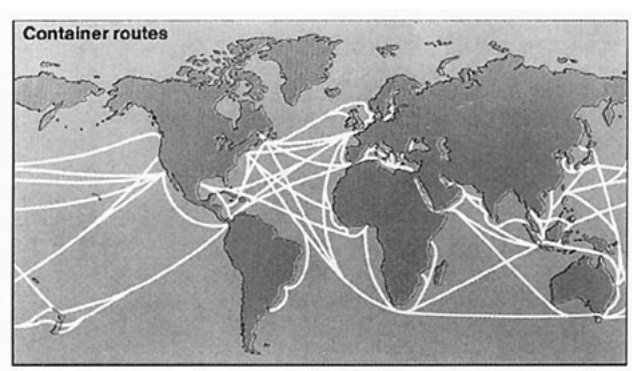

FIG. 4. Global coverage of container routes (Couper 1983).

kept thin to achieve low drag. Wireless data transfer can be done immediately afterward. At a fall rate of 10 m s^{-1}, the probe needs to gather data for only 20 s to a depth of 200 m. Profilers could carry sensors for temperature and conductivity, but there is no reason why similar probe techniques cannot be developed for oxygen, chlorophyll-a, light absorption, or upward irradiance. In order to operate such equipment under VOS conditions, it would have to be designed for automatic or quasi-automatic operation, including the profiling and sensor recalibration procedures. A system for profiling to 500-m depth from ships under way is currently under development at the Bedford Institute of Oceanography (A. Clarke and W. Emery 1993, personal communication).

c. Water samplers

Similar probe design and fall rate considerations apply to "subsurface bucket" techniques as well. By shaping the bucket to have a small drag coefficient, it should be possible to obtain water samples from depths comparable to that of the profiler. In fact, it might be convenient for it to have similar characteristics, even though they would be used separately. A pressure-actuated trigger would close the bucket at the desired depth. In order to keep the bucket small, the volume of water collected would not be large: a few deciliters. An attached or built-in thermometer could record the temperature. Possible closure mechanisms include go-flo valves, tygon tubing with clamps, spring-loaded stoppers, and others. "Multiple bucket" profilers are also conceivable: Spilhaus and Miller (1948) developed a variation of the mechanical bathythermograph (BT) that could take up to 12 samples during a single cast.

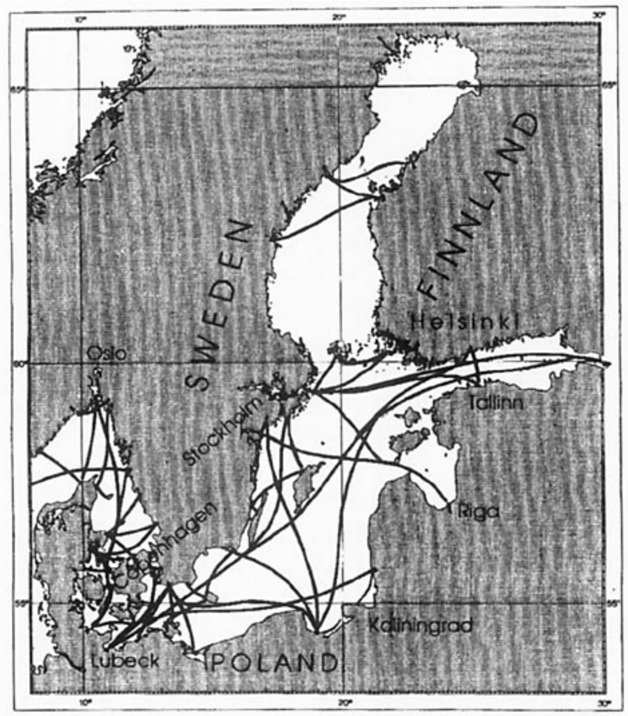

FIG. 5. Ferry boat routes in the Baltic Sea, summer 1993. Compiled with the assistance of Capt. Wagner, R/V *Alkor,* and Reedereigemeinschaft Forschungsschiffahrt, Bremen, Germany.

d. Flow-through techniques

Near-surface flow-through methods are in some use, primarily for the earlier-mentioned thermosalinographs, but also for chlorophyll-a. The equipment is usually located in the engine room at the cooling water intake. If access to the intake were more widely available, there would probably be interest in including nutrients, dissolved gases, and perhaps even some biological components such as bacteria and plankton. Recent progress on the development of autonomous autoanalyzers suggests that these could be adapted for engine room operation.

e. Towed techniques

Before the days of electronic navigation, ships routinely towed a log that indicated the distance traveled. Today there exist geomagnetic methods for estimating the vertically averaged water motion that could be used on VOS-towed instruments (Dunlap et al. 1990). Also, towed thermosalinographs molded in the form of small V-fin depressors might permit continuous sampling at modest depths. Towed equipment could also include plankton recorders, downward and upward irradiance sensors, and acoustic packages for biomass monitoring. It should be noted that Hardy plankton recorders have been towed routinely by VOS's for many years. These observations have contributed significantly to studies of zooplankton distributions and their temporal variability (e.g., Jossi and Goulet 1993). The development of nets that can be spooled out to reduce the relative speed to the water is also conceivable. The net opening would collapse to minimize drag when it is winched back.

f. Hull-mounted techniques

Acoustic Doppler current profilers (ADCPs) are widely used on research vessels, but not yet on commercial vessels. There is one exception: an ADCP is in continuous operation on a freighter that operates between New Jersey and Bermuda (Gottlieb et al. 1994). While shipboard ADCPs can now operate in a completely automatic or "turnkey" mode, the quality of the data acquired is dependent upon regular and skilled support by shore-based personnel. Other acoustic monitoring—for example, of biomass content—may be possible. An interesting idea is to equip the

VOS with hull-mounted penetrators so that instrument packages can be easily mounted and exchanged externally (E. Firing 1993, personal communication).

g. Instrument release

ARGOS[1]-tracked surface drifters have been extensively deployed in the Atlantic (Krauss 1986) and in the Pacific (Niiler 1991) and can be released from vessels under way by unskilled personnel. Appropriate design and handling techniques would allow release of deep-sea floats (Rossby et al. 1986) or complete instrument moorings that unfold and deploy themselves after being released without the vessel stopping (D. Pillsbury 1994, personal communication).

h. Telemetry relay station

With towed or hull-mounted hydrophones and a satellite link on board, a VOS can act as a relay station in the communication between moored underwater units and a shore analysis center (e.g., Catipovic et al. 1989). This application would be valuable for datasets that are needed in near-real time for the assimilation in operational ocean forecasting models. If moorings can be deployed from vessels under way and data telemetered upon command (automatically) as a vessel passes overhead, it would not be necessary to devote expensive ship time to retrieve the mooring. Instead, the instrumentation could be designed and powered for long-term performance rather than for recoverability.

Modern techniques in electronics and mechanics allow instrumentation to be packaged very densely and efficiently. Robotic techniques can be used to achieve highly automated operation to minimize the burden to the officers at sea. The major exception will be the sampling and preservation of water. In those cases where a technician on board is required, it is tempting to speculate that on selected vessels a laboratory container could be carried by the ship, permitting chemical and biological sample preparation and preliminary analysis.

4. Implementation of extended VOS program

It is almost certain that a new framework for working with the merchant marine will be needed for the implementation of such a program. Academic institutions are not well suited for implementing the routine long-term operations, but they can contribute to the identification of requirements and priorities, to the development of techniques and methodology, and to the prototype testing at sea. In the long run, however, government agencies such as the National Oceanic and Atmospheric Administration in the United States, the Bundesamt für Seeschiffahrt und Hydrographie in Germany, or Institute Francais de Recherche pour l'Exploitation de la Mer in France would almost certainly be better able to provide the necessary stability and continuity in such programs. It can be expected that intergovernmental mechanisms, primarily through IOC/UNESCO (Intergovernmental Oceanographic Commission/United Nations Educational, Scientific, and Cultural Organization) will be used for the international coordination and data exchange.

The implementation would be facilitated by convincing the merchant marine that an extended VOS program will improve the conditions for ship routing and for environmental impact prediction in the event of ship hazards. Experience with existing XBT programs teaches us that such programs can be operated most effectively if the shipping company is located at a short distance to the lead institution and repeated direct contacts with the company's personnel can be ensured.

Looking further into the future, we imagine an observational system consisting of numerous VOS vessels with standard quasi-automatic equipment operated by the ships' officers, and of selected VOS vessels on certain routes of particular interest carrying dedicated instrumentation and a laboratory container to collect and process samples. Such a system with wide regional coverage needs to be supplemented by a few permanent stations where similar repeated observations are being made routinely on fixed positions in the open ocean. Such stations already exist at Bermuda and at the Hawaii ocean time series station. Another, called ESTOC, will be operational off the Canary Islands by the end of 1995.

The central point of this article is simply that VOS offers an extraordinary access to the monitoring of the ocean that cannot be achieved otherwise. The most important issue is to get an early start with the instrumentation development and testing on research vessels as well as pilot VOS's. While significant resources will be required to develop the instrumentation and to maintain a VOS system, we believe the question is not whether we can afford it, but whether we can afford to ignore it.

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[1]Data location and platform location system

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