OceanScope

A Proposed Partnership between the Maritime Industries and the Ocean Observing Community to Monitor the Global Ocean Water Column

Report of SCOR/IAPSO Working Group 133

The OceanScope Vision

"In partnership with the maritime industries we will develop an integrated approach to observation of the global ocean on a regular and long-term basis as an essential component of, and contribution to, the Global Ocean Observing System (GOOS). This activity, 'OceanScope' will equip commercial ships with fully automated unattended instrumentation to accurately measure and report upon the currents and the physical, chemical and biological characteristics of the water column throughout the world ocean. The freely distributed data generated will be a fundamental resource for understanding the climatic state and health of our planet."

FOREWORD

The ocean is vastly under-observed, particularly below the ocean surface, where satellites cannot measure the ocean's properties. Observations below the surface depend on getting platforms (ships, moored buoys, floats, gliders, etc.) to locations far beyond the coasts, which can be expensive. Ships offer the best opportunities for applications that require significant power, frequent sampling, and/or real-time transmission of data to shore. Commercial vessels are particularly attractive as sampling platforms because they traverse the same routes on a regular basis. The industry has cooperated with the scientific community for more than 50 years to collect information on plankton community composition and distributions, meteorological measurements that are vital for weather forecasts, and basic measurements of water column properties that are used in global climate models.

The Scientific Committee on Oceanic Research (SCOR) and the International Association for the Physical Sciences of the Oceans (IAPSO) approved the OceanScope working group (WG 133) in 2008 to build on existing cooperation between the scientific community and the commercial shipping industry, and to suggest a new framework for future activities. SCOR and IAPSO hope this report will provide a useful stimulus for enhanced observations of the ocean from commercial ships, which will complement observations from other sources and will make important contributions to the Global Ocean Observing System.

SCOR and IAPSO look forward to implementation of the OceanScope concept. The proof-of-concept phase in the North Atlantic Ocean will be particularly important, as will new agreements to treat measurements of water column properties in a way analogous to unrestricted measurements of atmospheric conditions in coastal areas; both types of measurements are important to forecast weather, reduce loss of life at sea, protect coastal property, and protect coastal environments. We offer this plan as a vision for what is possible and thank the WG 133 members for the significant efforts required to produce this plan.

Lawrence Mysak
IAPSO President (2007-2011)

Mary Feeley
SCOR Secretary

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PREFACE

The concept underlying OceanScope has its origins in the 1853 Brussels Conference where several seafaring nations agreed to standardize and coordinate their reporting of marine weather and sea conditions. The ensuing organized collection and treatment of the observations led to new charts of prevailing winds that immediately benefited commercial vessel operations. Significantly, it is also thanks to these early efforts that oceanographers got a head start on preparing charts of currents, waves, and sea surface temperature throughout the world and how these vary with time of year. These have been of fundamental importance in documenting global climate change over the last century and a half. In the 20^{th} century interest in probing the water column from merchant vessels grew and through many individual efforts programs have been implemented to profile temperature, measure surface physical, biological and chemical properties and, in a very few cases, also measure currents.

Over the last several decades oceanographers of all disciplines have noted significant changes taking place in the marine environment: steady increases in upper ocean temperature, major shifts in plankton distributions, increases in dissolved CO_2 and acidity and possible circulation changes. These and other ocean issues were the subject of major reviews at the OceanObs'09 conference in Venice, Italy on 21-25 September, 2009 (see http://www.oceanobs09.net/). There was general agreement that the ocean, especially the water column, continues to be severely under-sampled. Calls for new and better sensors and measurement strategies, along with closer coordination among the many different ongoing ocean-observing programs, were strong recurring themes.

In parallel with OceanObs'09, a proposal was submitted to SCOR to establish a Working Group to develop a framework for an operational partnership between the ocean observing communities and the global maritime industries. SCOR approved the formation of Working Group #133, hereafter called "OceanScope" (see Appendix G), to develop an implementation plan to monitor the global ocean water column on a long-term continuing basis. The Working Group, co-sponsored by the International Association for the Physical Sciences of the Oceans (IAPSO), first met in Montreal, Canada in July 2009. The membership is a unique combination of the observational oceanography community, the maritime industries (commercial vessel owners and operators as well as the marine industries that they depend upon) and the oceanographic instrumentation community. This broad spectrum of expertise was assembled to address how to improve our ability to monitor the marine environment from commercial vessels in regular traffic. The members unanimously concurred that the OceanScope approach is not only eminently feasible and cost-effective (as proven through a variety of programs over the past fifty years), but also that it would greatly improve our ability to monitor the state and evolution of the global ocean. The members also noted that OceanScope needs to stimulate and facilitate the development of new sensors and new technologies to fully realize its ambitions. The Working Group met in London in April 2010 and smaller subgroups met later in the United States and the United Kingdom to finalize this report. The resulting document has evolved over more than a two-year period. An initial report on OceanScope was presented at OceanObs'09 and we note that this document is consistent with and supportive of the final recommendations from that meeting as reported in A Framework for Ocean Observing (Consultative Draft v.7, 15 May 2011). During and prior to the report development process, members presented a series of talks in different venues discussing the OceanScope concepts (see Appendix H). The appendices were developed first and served the group as the foundation for the core of the report (Chapters 1, 2 and 3).

It is hoped that this report will serve to accelerate international efforts to develop the capabilities and infrastructure required to implement long-term observation of the global ocean water column just as international space agencies have enabled studies of the global atmosphere and ocean surface. The establishment of the Working Group, the consensus process of developing this report, and the presentations made by Working Group members, have already facilitated an active dialogue with interested industry partners.

The Working Group is most grateful to SCOR and IAPSO for the encouragement and financial support provided to us. Dr. Edward Urban, Executive Director of SCOR, provided valuable guidance throughout all phases of our work and for this we are extremely grateful. Tom Rossby (TR) also thanks the International Meteorological Institute at the University of Stockholm for their gracious hospitality where much of the initial drafting of this document took place. Peter Ortner (PO) also thanks the Royal Caribbean Cruise Lines Ltd and their Ocean Fund. The document that follows was assembled and edited by PO and TR with regular input from the full Working Group.

EXECUTIVE SUMMARY

The ocean plays an absolutely central role in the Earth's climate and ecosystems. Despite its widely acknowledged importance, the interior of the ocean continues to be seriously under-sampled due to its global scale, the lack of resources commensurate to the task, and the technical challenges presented by the marine environment. While satellites routinely scan the state of the sea surface (when cloud cover permits), high resolution in situ data are essential to extend the scientific utility of present and planned satellite missions. For example, what is proposed herein will ideally complement planned high-resolution altimetry. While the global Argo and Ship-of-Opportunity (SOOP) programs provide broad coverage of the hydrographic state of the ocean, and the international global drifter program has yielded invaluable insight into surface currents, we are still severely handicapped with respect to measuring both the vertical structure of currents and the biogeochemical properties of the water column. Indeed, knowledge about ocean circulation as a whole is derived from various data-fitting techniques and not directly measured. Powerful as these measurements and techniques are, there is much they are unable to capture, including the most energetic part of the velocity spectrum, the structure of eddies and fronts, the deep velocity field and many circulation features in shallow seas and coastal areas. The ability to measure currents globally from vessels underway would be a transformational development enabling us to track what the ocean is doing in real time - to view the ocean engine in action and markedly improve our predictive capabilities by enabling truly rigorous validation and verification of the interior dynamics of ocean circulation models.

Commercial ships have a presence on the high seas second to none and offer society a feasible and cost-effective opportunity to contribute to solving this observational deficiency. Building upon the success of the present Global Ocean Observing System (GOOS) and pilot research projects aboard selected commercial vessels, OceanScope proposes a formal partnership with the maritime industries (commercial vessel owners and operators as well as the marine industries they depend upon) to enable systematic and sustained observation of the structure and dynamics of the ocean water column so that physical, chemical, and biological processes can be studied simultaneously across all the inter-connected ocean basins.

The programmatic approach of OceanScope is novel. It proposes to develop and implement techniques including acoustic and optical remote sensing, expendable probes and towed systems to monitor the entire oceanic water column, and to do so not only with respect to ocean physics, but also ocean chemistry and biology - all optimized for use on merchant marine vessels in regular traffic. The partnership between the ocean observing community and the maritime industries would be implemented through or associated with an international non-governmental organization working closely with the industry through institutions already in place (e.g. the International Chamber of Shipping and the World Ocean Council). This coordinated approach will enable the implementation of standardized methodologies and technologies that will be essential for operational reliability and data continuity and to provide the economies of scale essential to reduce installation, maintenance, and operational costs. Standardization will also enhance the commercial viability of developing and marketing new and improved observational technologies and facilitate the preparation of vessels "ready-built" to join the OceanScope fleet. OceanScope has the potential to capture the attention of industrial partners that have significant resources devoted to bringing the best ideas into the marketplace.

OceanScope would be a major addition to the international GOOS, building upon and complementing programs such as Argo, Ship of Opportunity Program (SOOP), the Integrated Carbon Observation System (ICOS) and the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) that operates the Continuous Plankton Recorder (CPR) program. With respect to initial instrumentation, technology development and operational assistance and coordination, we would look to the SOOP and ICOS communities in regard to expendable probes and inorganic carbon measurement technology, and to SAHFOS in regard to the CPR to the extent that a ship operator is willing to provide support since the CPR (unlike other proposed technologies) is not fully automated. OceanScope would offer all those programs not only additional vessel platforms, but more significantly, the critical synoptic environmental data needed to understand the causes of the patterns observed and access to continually improving technologies. With respect to the Argo program and SOOP, the physical data streams themselves are inherently complementary. That is, drifters and profilers are, by design, freely drifting and comparatively widely distributed. However numerous, drifters and profilers alone are inadequate to directly sample either dynamic frontal regimes or oceanic eddy activity. While Argo floats (and drifters) continue to evolve as new sensors are added, choices will be limited by available space and power. Both impose fundamental sampling constraints. Sampling from commercial vessels on selected repeat routes can directly address both of these inherent limitations (technical and spatio-temporal).

OceanScope data will have four distinct but related applications: (1) forecast/nowcast models, (2) processes and dynamics, (3) climatology, and (4) the state of the ocean. The first application addresses societal needs for real-time information on ocean currents (e.g., to improve ocean forecasting services); the second one the need to understand physical, biological and chemical variability; the third one long-term and global-scale change of the coupled ocean-atmosphere system; and the fourth, regulatory and management issues relating to ocean health. OceanScope would be implemented in phases. Phase One (lasting about five years) would extend and integrate today's activities into a fleet of 20 instrumented vessels operating in the North Atlantic Ocean. During this phase, OceanScope oversight, organizational and administrative structures would be formalized and staffed and, equally significantly, data management, quality control and dissemination procedures would be implemented. Legal and jurisdictional issues will also be addressed prior to and during this phase. A North Atlantic Test Bed phase will not only focus attention upon a system of major importance to global climate dynamics (e.g. the meridional overturning circulation), but also leverage existing scientific collaborations with the maritime industry. A set of core measurements would be made on all ships with additional instruments upon a selected few vessels/routes. While vessels would at first rely upon existing technology (or small improvements thereof), fundamental to OceanScope thinking will be targeted development of new marine vessel-optimized and standardized instrumentation, which as it becomes ready would be installed across the fleet of OceanScope vessels. Building upon the success of the North Atlantic Test Bed, OceanScope would then gradually expand throughout the world ocean eventually consisting of a fleet of approximately 100 vessels incorporating these next-generation technologies.

What OceanScope proposes is nothing less than the creation of an Earth-spanning framework - a facility or capability analogous to the European Organization for Nuclear Research (CERN) particle accelerator facility or the Hubble Space Telescope - freely providing data to the entire climate research, oceanographic research and operational oceanographic communities. To realize its full potential, it is essential that the ocean observing community speak with one voice with respect to the scientific benefits of such a facility as this partnership goes forward. The data that would be made available will revolutionize our ability to visualize the global ocean and track its evolution as the coupled physical, chemical, and biological whole that it truly is.

CHAPTER 1

THE NEED FOR OCEANSCOPE

Summary

This chapter develops the case for OceanScope, a partnership between the global ocean observing community and the maritime industries for the systematic and sustained study of the world ocean. A driving force is society's need to have a much better understanding of the ocean's role in global change than is currently possible. We propose a way forward: OceanScope, a facility or capability analogous to a CERN or a Hubble Space Telescope, freely providing data to the entire oceanographic and climate research and operational communities. The data that would be made available will revolutionize our ability to visualize the interconnected whole of the global ocean.

Introduction

Our knowledge of the ocean, from the surface to the bottom, its currents and its physical, chemical and biological properties, is limited by our observational ability. The vastness of the ocean makes it difficult to sufficiently understand many important ocean processes. The techniques available today are simply not equal to the task. Satellites cannot look deep into the ocean, and research vessel observations are too few and far between to fill the gaps. The extensive arrays of drifters and profiling floats (the Argo program) do an excellent job of providing global coverage of the upper 2000m with respect to temperature and salinity, information of great value in real-time data assimilation and ocean forecasting. But drifters and profilers are, by design, freely drifting and comparatively widely distributed. However numerous, they are inadequate to directly sample either the frontal regimes or oceanic eddies that constitute the most dynamically significant circulation features. While Argo floats (and drifters) continue to evolve as new sensors are added, choices will be constrained by available space and power and this fundamental sampling limitation will remain. Sampling from commercial vessels on selected repeat routes directly addresses both of these inherent limitations.

OceanScope proposes to develop a close partnership with vessel operators around the world to obtain high-resolution coverage of the ocean's physical, chemical and biological properties. Without such information it may be very difficult—if not impossible—to rigorously determine the ocean's role in and response to global changes in wind, heating and precipitation. Consider the increase in atmospheric CO_2, a significant portion of which is taken up by the ocean. CO_2 absorbed by the ocean is increasing its acidity which can affect a wide range of calcifying marine organisms, including primary producers. Large-scale changes have been reported in pelagic ecosystems, but without knowledge of their extent, rate of change and the degree to which these local changes are interconnected or reflect global trends we cannot fully know the risks posed to the future health of the ocean (see Doney et al., 2009).

The Scientific Challenge

The density of seawater is about 1000 times that of air. This means that the weight of the overlying atmosphere is equivalent to 10 meters of water. The heat capacity of the overlying atmospheric column of air is equivalent to the heat contained in only about 2.4 m of seawater. Whereas the atmosphere mainly transports heat, the ocean both transports and stores heat. Thus, the advection of heat plays a central role in the global heat balance such that a slight change in circulation may have a major impact on future heat exchange with the atmosphere as demonstrated by the El Niño–La Niña cycle.

Precisely the same point can be made about the ocean's capacity to both store and redistribute fresh water and gases. The amount of heat, fresh water, and CO_2 stored and released during annual cycles depends upon location, the severity of winter, and the ocean currents that move heat, fresh water, and CO_2 away from the place they enter the ocean. In the subtropics, mixed layers of water are permanently moved deeper into the water column in spring, with the properties of the water set by the atmospheric conditions at the time they were formed (e.g., Stommel, 1979). These waters are not exposed to the atmosphere the following winter. Instead, years to decades later, after coursing their way through the interior of the ocean, they return to the surface, bringing with them a memory of the properties they had when they disappeared from the surface.

The return of waters with distant origins occurs in many places all over the globe, but our ability to identify, track, and predict how these water masses (with their specific properties and conservative constituents) make their way through the ocean, and their eventual impact (both upon the ocean and the atmosphere), is severely limited. Knowledge of how water masses and their properties are moved around the global ocean is of fundamental importance to allow correct representation of these processes in general circulation models used for climate and climate impact predictions. It is relevant to note here that our assessment of change in the ocean comes from changes in the inventory of heat, salt and other properties, rarely if ever from direct measurements of the circulation itself (IPCC, 2007).

The large volume and scale of the ocean, and the fact that small changes can have large consequences, presents an inherent measurement problem. Short-term variability is so huge that it is difficult to identify longer-term trends accurately. Only through repeated surveys over long time periods can such variation be identified and rigorously quantified. Oceanographers have struggled with this measurement problem for years. At a few sites—such as Stations S (Bermuda) and P (NE Pacific)—the long time series of hydrographic observations have both the duration (>50 years) and frequency (biweekly or better) so that fast time scales can be filtered out and interannual variations and long-term trends can be identified (www.whoi.edu/virtual/OceanSites). These records provide a high-resolution window to the past while providing a robust context for future observation and patterns of change. New systems, particularly the global Argo array and decadal hydrographic surveys, have added both spatial coverage and repeat sampling to substantially reduce (or identify) high-frequency variability. Nonetheless the former is severely limited in parameter space and the latter by its geographical resolution and decadal repeat rate (Gruber et al., 2010).

The spectrum of variability in the ocean is so broad that a large number of degrees of freedom are required to determine trends or variability at the low end of the spectrum. This requires sufficient measurement to average out short-term variability so that long-term trends can be discerned. This problem is well recognized in the oceanographic literature and contributes to large uncertainty in some estimates. The risk for aliasing applies in space just as well as in time, the reason being the small scale of eddy activity mentioned earlier. The richness of eddy activity went essentially unnoticed in the sparse data sets used to map the ocean from discrete hydrographic stations widely separated in both space and time (Robinson, 1983). Similarly, the gradient of planetary vorticity (i.e., the effect of Earth's rotation) and/or variations in depth can set up local or regional gyres that may be hard to detect at any given moment yet which exhibit well-defined mean flows when the energetic mesoscale fields are filtered out (Knutsen et al., 2005; Cunningham et al., 2010). That is to say, the fine structure in the mean field and underlying transport fields will only become apparent with sufficient data.

Systematic long-term observation of the global water column serves four distinct needs:

- forecast/nowcast applications
- process and dynamics
- climatology
- state of the ocean

The first need addresses societal requirements for real-time information on surface currents and weather; the second a mechanistic understanding of physical, biological and chemical variability; the third long-term and global-scale change; and the fourth, policy issues relating to ocean health. Because the Earth's rotation and the topography of ocean basins constrain ocean currents so strongly, there is good reason to suspect that the ocean possesses far more structured characteristics than is presently known. Since this applies to currents it very likely also applies to chemical and biological fluxes and distributions that are affected by currents. Only through repeated measurements at high horizontal resolution will we be able to discover, explore, and quantify these patterns. But this is not easy to achieve, due to a lack of regular access to the global ocean water column and the lack of appropriate cost-effective sensors. Where do we stand today and what can be done?

Ocean Physics

Knowledge of the distribution of heat and salt has been a cornerstone of modern oceanography. First, the fields of temperature and salt tell us that the properties of all water masses are set at the surface, the only active boundary of the ocean. These and other properties, especially oxygen, tell us where the various water masses are formed, and the pathways along which they spread out and fill the ocean. Second, the fields of heat, salt, and oxygen give us a context or framework for understanding the distributions of marine flora and fauna. Third, temperature and salinity are used to derive density and thus the corresponding geostrophic velocity field, which informs us about currents and transports. Indeed, much of what we know about the general circulation of the ocean has been learned this way. While repeat surveys of the hydrographic fields give us insight into oceanic variability, it became clear long ago that this approach is inadequate. A major improvement in monitoring ocean variability came with the expendable bathythermograph (XBT), a technology that in the 1970s led to several discoveries about eddy activity in the ocean. Those observations, together with both Eulerian and Lagrangian studies enabled oceanographers to describe the structure and energetics of mesoscale circulation features (Robinson, 1983). At the same time the XBT became, and still is, the tool of choice to study temperature, transport, and heat flux variability along several commercial shipping routes in the ocean (Roemmich et al., 2001; Goni et al., 2010). Technological advances in the 1990s led to the implementation of the global array of Argo floats, a major improvement in our ability to track the *state* of the ocean worldwide. This uniformly distributed set of more than 3000 floats provides global updates of the 0-2000 m temperature and salinity field at ten-day intervals. Hydrographic, XBT, and Argo profiles all have as their primary objective to determine the physical *state* of the ocean. Given this information, a variety of methods can be used to estimate the velocity field (Wunsch, 2010). This means our knowledge about ocean circulation as a whole is derived from various data-fitting techniques and circulation is not directly measured. Powerful as these measurements and techniques are, there is much that they are unable to capture, including the most energetic part of the velocity spectrum, the structure of eddies and fronts, the deep velocity field and many circulation features in shallow seas and coastal areas. The ability to measure currents globally from vessels underway would be a transformational development enabling us to track what the ocean is doing in real time, to view the ocean engine in action, and to improve our predictive capabilities significantly by enabling truly rigorous validation and verification of the interior dynamics of our circulation models.

Direct measurement of currents at low latitudes would be transformational because (a) the Coriolis force (i.e., the effect of Earth´s rotation) and hence the geostrophic balance is weaker there, with the consequence that oceanic variability is more complex, with more varieties of eddy/wave motion in both the horizontal and vertical; and (b) currents at low latitudes have a huge impact on the thermohaline structure of the ocean and hence the exchange of heat and gases with the atmosphere (El Niño/La Niña). At high latitudes where stratification is weak, winds directly impact the pressure field at all depths. Since we cannot directly measure this pressure field we are substantially handicapped in our knowledge of vertical current structure throughout the water column. Much effort has been devoted to resolving these conundrums, but these are very challenging issues. Directly measuring high- and low-latitude currents along dynamically significant routes would change this situation.

Even at mid-latitudes the need to measure currents directly is important because currents at depth are not weak. There is also emerging observational evidence and solid theoretical reasoning that the topography of the ocean bottom plays a fundamental role in shaping the deep circulation—the classic example being deep western boundary currents and flows along bottom slopes. Surprisingly, even the upper ocean can feel the shape of the ocean bottom; a conspicuous example being the way warm water crossing the Atlantic Ocean is forced to cross the mid-Atlantic ridge in the vicinity of deep fracture zones (Bower et al., 2002). For the upper ocean there is good reason to suspect that at mid-latitudes (as in the tropics) ocean variability is organized such that variations in the density field and concomitant currents are greater in the east-west than in the north-south direction, especially on longer time scales. In short, the ocean exhibits considerable fine structure, even in the mean field. By this we mean that even after removing the average eddy activity, there exists an underlying mean field that is far more structured and detailed than previously suspected. This increases the challenge to distinguish between local and basin-wide changes, and underscores the need to monitor the ocean along several transect lines, to avoid the assumption that mean conditions for a particular region or latitude apply to entire ocean basins (Cunningham et al., 2010).

The above shortcomings can be overcome thanks to the emergence of a current measurement technology that is particularly well-suited for use on vessels underway, namely the acoustic Doppler current profiler (ADCP). Using the ADCP it is possible to profile currents in the upper 1200 m of the ocean, and with appropriate investment profiling to greater depths should be possible in the future (Appendix B). Not only do ADCPs routinely measure currents to an accuracy of 0.01 ms^{-1}, but because their return signal depends upon the presence of biological backscatter material, an appropriately calibrated ADCP can give us information on backscatter density and its distribution in the vertical. Vessels equipped with ADCPs can report in real-time the oceanic velocity field on scales from 1 to 10^3 km (Rossby et al., 2010; Rousset and Beal, 2010). Figure 1.1 shows directly measured currents in the Gulf Stream and surrounding waters. The left panel shows the typical state of the Gulf Stream while the right panel shows it being torn apart by strong eddy activity to either side. Moored and shipboard ADCP data have already been used to verify and validate circulation modeling, most recently with respect to the *Deepwater Horizon*'s oil spill in the Gulf of Mexico, and this is likely to become a fertile area of oceanographic study as more vessels become equipped with deep-reaching ADCPs.

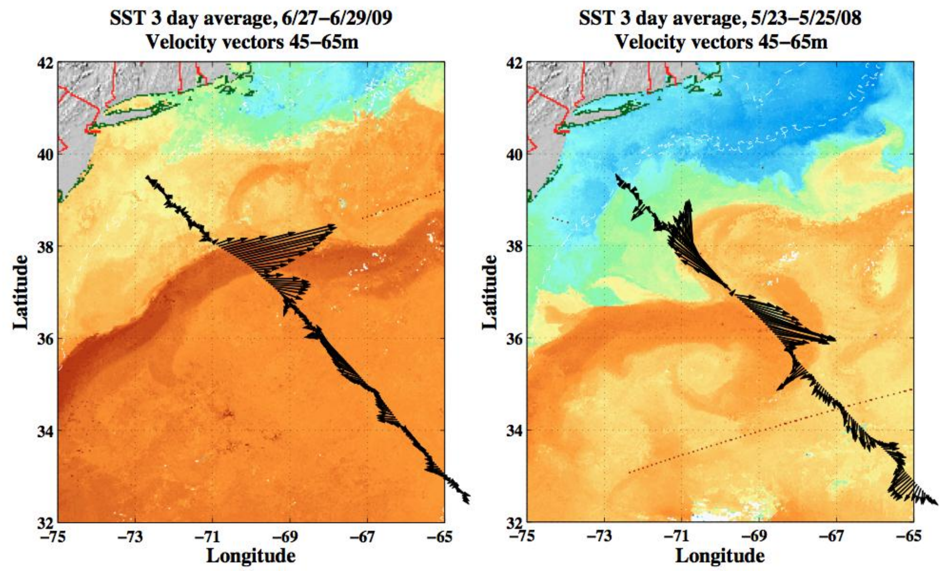

Figure 1.1: The two panels show sea surface temperature (http://fermi.jhuapl.edu/avhrr/gs) with superimposed ADCP velocity vectors from the CV *Oleander* that operates between Bermuda and New Jersey (http://po.msrc.sunysb.edu/Oleander/index.html). The left panel shows a typical Gulf Stream path whereas the right panel shows the Gulf Stream being torn apart by a warm core ring to its north and a cold core ring to its south (used with permission JHU/APL, copyright 2008 all rights reserved).

Ocean Chemistry

Research vessels have taken water samples in all corners of the global ocean. The Geochemical Sections (GEOSECS) surveys in the 1970s made huge strides in establishing global coverage, followed by the South Atlantic Ventilation Experiment (SAVE) and Transient Tracers in the Ocean (TTO) projects in the 1980s, the Joint Global Ocean Flux Study (JGOFS) and World Ocean Circulation Experiment (WOCE) in the 1990s, and the Climate Variability (CLIVAR) and GEOTRACES project at present. These projects have given us a clear picture of the bulk chemical structure of the ocean and how concentrations of the elements relate to the major circulation patterns. Transient tracers in the ocean such as Tritium (^{3}H), ^{14}C and halocarbons have provided time scales for spreading and mixing in the ocean (Jenkins and Smethie, 1996; Broecker et al., 2004; LeBel et al., 2008). The challenge is now to identify the processes controlling the variability of chemical tracers. This goal requires repeated long-term measurements to determine how these patterns evolve on time scales of days to decades. A second challenge is to understand the ocean's role in moderating climate change and whether or not the system feedbacks will be positive or negative. A third challenge is to understand biogeochemical cycles and the interactions among biology, chemistry, and circulation. These too can best be addressed by regularly repeated long-term global-scale measurements.

Chemical measurements from instrumented commercial vessels are another area in oceanography in which we already have a very strong proof of concept for OceanScope. Ships of opportunity are measuring surface water properties over a wide range of space and time scales, giving us a window into biogeochemical processes. One topic where this approach has significantly contributed is improving our understanding of the relationship between eutrophication and harmful algal blooms and their impact upon shelf sea ecosystems (Rantajärvi et al., 1998). This concept was taken forward in the EU Framework Project "FerryBox" (Petersen et al, 2007) between 2002 and 2005. The name Ferrybox has become virtually synonymous with using ships of opportunity for biogeochemical measurements of near-surface seawaters (Hydes et al., 2010).

The recognized need to understand and quantify the ocean's role in buffering greenhouse gases on the global scale has led to major initiatives to determine the rate of air-sea exchange of CO_2 (Gruber et al., 2010) from several instrumented commercial vessels. Essential communication and coordination has been provided by the International Ocean Carbon Coordination Project (IOCCP) (www.ioccp.org). An important lesson from this community is the advantage of a central data repository at CDIAC (Carbon Dioxide Information Analysis Center - www.cdiac.ornl.gov). The strength of coordinated observations has been shown in the North Atlantic Ocean (CarboOcean). Historically, observations had been too sparse to allow accurate tracking of changes in rates of CO_2 uptake over ocean basins, so little was known about how these vary. In CarboOcean, Schuster and Watson (2007) found substantial variability in the CO_2 uptake by the North Atlantic on time scales of a few years, which was suggested to be due to variations in circulation related to variations in the North Atlantic Oscillation (NAO). An important advance was achieved by the community (Watson et al., 2009) using measurements from a coordinated network of instrumented commercial ships and two time-series stations, to estimate the 2005 annual flux into the North Atlantic Ocean to a precision of about 10% (Figure 1.2).

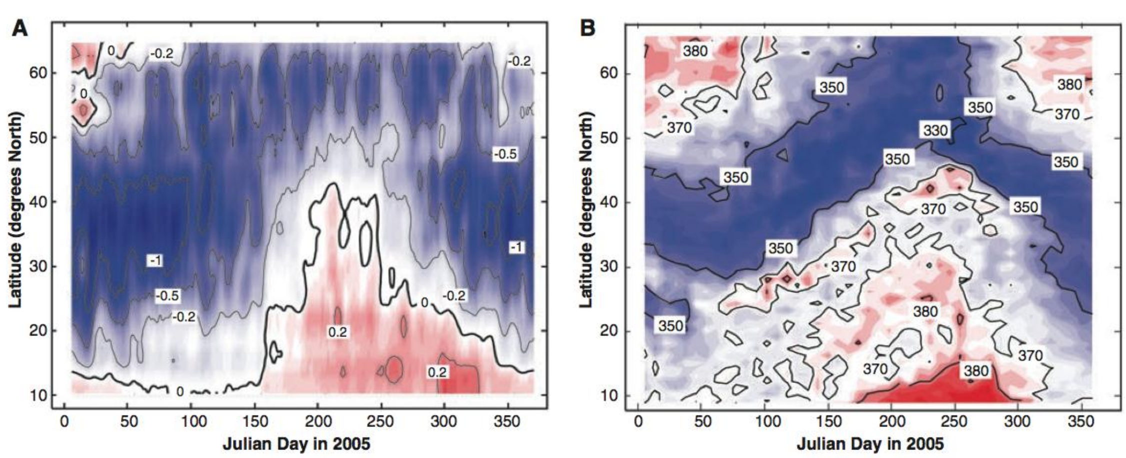

Figure 1.2: Contours of ocean-atmosphere flux of CO_2 [(A), in Tmol year^{-1} per degree of latitude], and surface ocean fugacity of CO_2 [(B), in μatm] in the North Atlantic in 2005, as a function of latitude and time (from Watson et al., 2009, reprinted with permission from AAAS).

This level of precision was achievable in 2005 because there were six ships instrumented with CO_2-monitoring systems. That result highlights the promise of using shipping routes to accurately monitor the ocean's uptake of CO_2. Plans to support such operations are the basis of the marine component of ICOS (ICOS - Integrated Carbon Observation System [for Europe] http://www. icos-infrastructure.ipsl.jussieu.fr/).

A key requirement for the future will be to continue these measurement programs, but at a much reduced operational cost (Feely et al., 2010; Monteiro et al., 2010). There is also considerable potential for improving and expanding the range of carbonate system parameters that can be measured (Byrne et al., 2010).

As many of the papers cited above note, a full understanding of air-sea exchange, that is, the sequestration and/or release of gases from the ocean interior, will require information on how the mixed- layer deepens during the cooling months and shoals during the warming months. What happens between weak and severe winters? Is the subduction of the mixed- layer waters (and their dissolved gases) permanent, or will they be re-exposed to the atmosphere in the following winter? There is a sense that the variability of CO_2 drawdown may be related to changes in the North Atlantic Oscillation (NAO) (Watson et al., 2009), and similarly for El Niño/La Niña events in the Pacific Ocean. These kinds of questions require not only chemical measurements, but also the synoptic study of subsurface velocity structure and its variability. Interannual variations in mixed-layer depth, and/or direction of subsurface flow could determine the degree to which subducted gases remain sequestered over long periods of time (Waniek, 2003). In the tropics, and much of the subtropics, where variations in mixed layer depth are modest, it may be quite important to determine diapycnal fluxes across the surface pycnocline.

To obtain chemical information from well below the surface requires the development of expendable probe technologies. This will be aided by the development of microchip-based sensors that could be optimized for use on next-generation expendable probes and Argo floats. New sensors could enable profiling O_2, CO_2, nitrates, and other properties to great depth (Appendix B). With such probes, sections of chemical properties at high horizontal and vertical resolution will become possible (Adornato et al., 2010; Claustre et al. 2010; Appendix B).

Ocean Biology

Primary productivity in the ocean is the basis for all marine life and it takes place at, or very near, the surface across the entire global ocean. Rates vary enormously depending upon the local ecology, sunlight, mixed-layer depth and the supply of nutrients. Generally, productivity is quite high along subpolar fronts and farther north and lowest in the center of subtropical gyres. For more than thirty years ocean color satellites have been mapping the global distribution of ocean color, from which primary productivity can be estimated. These systematic surveys have led to major advances in our knowledge of how primary productivity varies spatially and temporally as well as the reasons for these variations. The satellite records are long enough that variations from one year to another can be examined. The OceanObs'09 plenary paper by Yoder (2010) gives an informative overview of both the progress made and the issues involved in future applications.

The remote sensing of primary productivity from satellites is a testimony to what can be done if there is a will. Several satellites in orbit today (with others planned) measure upwelling light in several bands of the blue-green part of the visible spectrum (a few as well in the infrared portion of the spectrum). By looking at the relative power in different bands the concentration of chlorophyll in the surface waters can be estimated. The algorithms that have been derived for this purpose are complex and require ground-truth information for calibration, development and to check on the stability of the satellite sensors. Shipboard measurements of the same optical properties and independent measurements of the pigments provide such ground truth information. Equally significantly, phytoplankton pigments from the surface ocean alone are insufficient to measure, understand, and predict change in upper water column primary productivity; indeed, pigments alone are insufficient to measure biomass. Additional data (e.g., from flow cytometry, ship-based optics, oxygen, nutrients and pulsed-amplitude-modulation fluorometry) are necessary to make the satellite pigment data truly useful in both ecosystem and climate prediction contexts. Shipboard flow-through systems can measure such properties at the depth of the water intake. These *in-situ* data will be particularly helpful in regions where cloud cover makes satellite optical measurements difficult or impossible. "Tow-yow" systems could profile fluorescence at 50-80 m depth. While that depth penetration would be insufficient to reach the chlorophyll maximum in tropical waters, it would suffice to reach the productivity maximum. Finally, active optics mounted on deck can profile water clarity and ocean color continuously within the upper mixed-layer. Data from such active systems and from optical flow-through sensors can be reported in real time and distributed as reference or calibration information for remote sensing systems. The relatively near-surface vertical structure of these optical properties and their change with time and across oceanographic boundaries, is information of great value both in its own right and as a context for higher trophic level studies.

Phyto- and zooplankton surveys represent the most extensive and longest duration marine monitoring activities (aside from surface temperature). The Continuous Plankton Recorder (CPR) has been towed from commercial vessels of all kinds since the 1930s. This continuity is testimony to the viability of long-term collaborations between commercial vessel operators and the scientific community. Towed at about 10 m depth, the CPR collects and saves samples of plankton continuously along the vessel's route. It delivers a record of the presence and abundance of plankton species. Repeat CPR surveys have documented major shifts in plankton distributions in the North Atlantic Ocean. A striking change that took place in the late 1980s was the 1000 km northward shift of temperate plankton species and concomitant changes in overall species composition and abundance in the northeast Atlantic and North Sea. Broadly speaking, these changes follow a general warming of the surface waters over the northeast Atlantic (Burkill and Reid, 2010). Many questions are being raised about whether shifts in ocean circulation, and/or changes in fishing pressure in these same waters, also had an imprint on these distributions and, if so, what were the mechanisms involved.

Use of the CPR is expanding globally, with new surveys in the North Pacific and other regions (Reid et al., 2010). In order to make maximum use of these surveys, strong scientific arguments can be made for the simultaneous collection of variables such as temperature, currents, plant pigments, and biomass (a point made in many of the OceanObs'09 conference papers). Concurrent information on these other variables will lead to a much-improved understanding of the mechanisms that control the distribution and abundance of plankton in the ocean. Systems that simultaneously measure plankton and these other variables have been used in various research contexts over the past decade or more (see Appendix B) and some of these could be adapted to deployment on commercial vessels.

Optics and acoustics are particularly well suited to unattended automated use on commercial vessels and can chart the distribution of plant and animal biomass both in the vertical and the horizontal: optics for surface and near-surface waters and acoustics for the water column. They can map out the distribution of phytoplankton, zooplankton and nekton in considerable detail. These data—together with concurrent CPR and primary production data—will open up new perspectives on how primary production is passed up the food chain to higher trophic levels. What happens at the surface can shape or influence processes at depth (and vice versa). Examples include direct feeding (and subsequent excretion) by vertically migrating zooplankton and mesopelagic fish, and detrital fallout drawing down surface carbon and providing nutrition to benthic and deep-living species. The growing use of acoustics is leading to the development of increasingly accurate algorithms that can translate calibrated backscatter strength into the abundance of individual plankton size classes, an important step to permit comparison and merging of different data streams.

The high spatial resolution provided by acoustic techniques is revealing remarkable patterns in backscatter intensity, particularly in well-defined oceanic structures such as fronts, eddies, and lenses. Figure1.3 shows a vertical cross-section of current structure and acoustic backscatter in an anti-cyclonic eddy in the northwest Sargasso Sea.

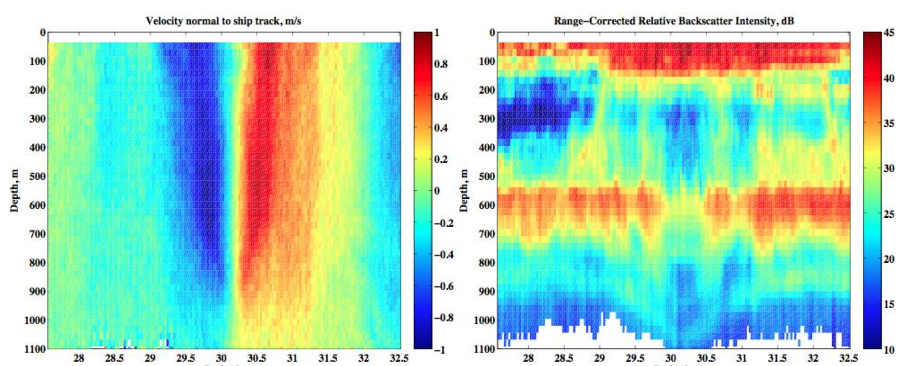

Figure 1.3 ADCP data from the *Explorer of the Seas* transiting an energetic anti-cyclonic eddy at 30°N, 70°W. Velocity normal to the ship track is shown in the left panel and backscatter signal strength is shown in the right panel. Note the interruption of deep scattering layer at 600 m and the deepening of a second scattering layer at 900m (Rossby et al., 2011). Used with permission of the American Geophysical Union.

As vessels continue to scan the ocean, the pool of information on these patterns will rapidly grow, and we will be able to explore how organisms adapt to these highly dynamic environments. Acoustic backscatter at several frequencies can also provide a very powerful tool for mapping (and distinguishing) zooplankton and nekton distributions, how these vary with time of day, season, and year, and how they may be influenced or shaped by the mesoscale velocity fields (e.g., Luo et al., 2000; Hitchcock et al., 2002). The data will be invaluable both for biophysical and population studies. The fact remains that, at present, insight into important aspects of these distributional questions is comparatively limited and yet it is essential to know and understand these distributions so that the role and response of underlying biogeochemical processes in the ocean to global change can be assessed and predicted.

The Observational Challenge

Technologies have improved our ability to probe the ocean: the modern research vessel with its powerful set of observational and analytical tools, the global deployment of the Argo profiling float fleet and surface drifters, and the increasing use of gliders, moored systems, and cabled observatories. Commercial vessels can add another dimension to this set of ocean observations because they transit the ocean basins both regularly and repeatedly, and traverse regions infrequently visited by research vessels. As such, they are particularly well suited to assess frontal regime and eddy dynamics and to provide cost-efficient platforms for making measurements not just at the surface but throughout the water column. The ocean observing community has worked successfully over decades through various ship-of-opportunity programs. Based upon recent technological advances, the experience of these programs and the success enjoyed by the few ongoing research projects being conducted aboard commercial vessels, we are now ready to take the next step forward.

In the following two chapters and the appendices, this document develops the case for a new approach we call OceanScope. The scale and organizational approach of OceanScope will open up entirely new opportunities. OceanScope is envisioned as a global activity in which vessels function like satellites orbiting Earth at sea level. As such they would scan the water column systematically over long periods of time. While the spatial extent and temporal density would never approach that of satellites, the horizontal resolution would greatly exceed that of satellites or autonomous samplers. OceanScope would operate like an 'Inner' Space Agency—analogous to current "Outer" Space Agencies—freely providing data to the research and operational communities, soliciting and encouraging new ideas and approaches and facilitating the development and operation of technologies that can enhance our ability to monitor the state and health of the global ocean water column. The next chapter discusses how maritime industries can provide the framework for this essential contribution to the Global Ocean Observing System. The third chapter suggests a sequenced program implementation starting with a regional North Atlantic Test Bed and leading within a decade to a global OceanScope.

CHAPTER 2

OCEANSCOPE AND COMMERCIAL SHIP OPERATIONS

Summary

Based upon the global traffic of merchant vessels, this chapter discusses how OceanScope, a partnership with the maritime industries, can provide a framework for an integrated interdisciplinary approach to monitoring the world ocean. Given this coverage and the autonomous observational technologies already available and coming on line, OceanScope can provide a substantial new capability to explore and accurately monitor the dynamics, chemistry, and biology of the global ocean water column. This will not happen overnight, but this new capability will represent a significant addition to how we explore the global ocean water column and a fundamental contribution to the Global Ocean Observing System.

Introduction

About 50,000 commercial vessels ply the waters of the global ocean, compared to a global total of ~300 (>55m in length) * ocean-going research vessels , a ratio > 100:1. More than half of the commercial fleet is made up of general cargo vessels and tankers. Bulk carriers and container vessels account for another 17 and 13%, respectively, and passenger ships (including ferries) total 13% (http://www.marisec.org/shippingfacts/worldtrade/number-of-ships.php). Commercial vessels are present in all areas of the world ocean, but at different densities. The Northern Hemisphere sees far more traffic than the Southern Hemisphere, but it is important to note there are some Southern Hemisphere routes (Figure 2.1). There is currently little to no commercial traffic poleward of 60° except for polar supply vessels and summer cruise traffic, an activity that is steadily increasing in both hemispheres, especially summer cruise traffic to Antarctica, and North West Passage shipping. Some operators are planning to build new vessels for these services. The formal partnership with vessel operators will facilitate access to the vessels that ply these climatically significant waters.

Commercial vessels sail at relatively high speeds. Container vessels commonly cruise at ~20 Kt, and even bulk carriers travel at speeds much greater than most research vessels. High speed does not pose an inherent problem thanks to accurate GPS navigation and the fact that most of these vessels have a deep draft (except in ballast voyages) and thus rather stable conditions of flow. Moreover, the continuous forward motion of a transiting vessel means that the commercial fleet can provide a quasi-synoptic view, which is an important aspect for many regions of the ocean where currents are rapid and variability has short time scales. The whole scene can be captured before it evolves. What especially distinguishes commercial traffic is that many routes are repeatedly traversed. Vessels on such routes, when instrumented, will produce a steadily

* According to the www.researchvessels.org Web site.

growing set of sequential measurements in both time and space at very high horizontal resolution that will provide accurate characterization of the regions along the vessel route. While measurements at any point (or within any small area) will be infrequent compared to those from moored instrumentation, each transect is essentially independent, thus very effectively contributing degrees of freedom and statistical rigor. These data are unobtainable from any other platforms.

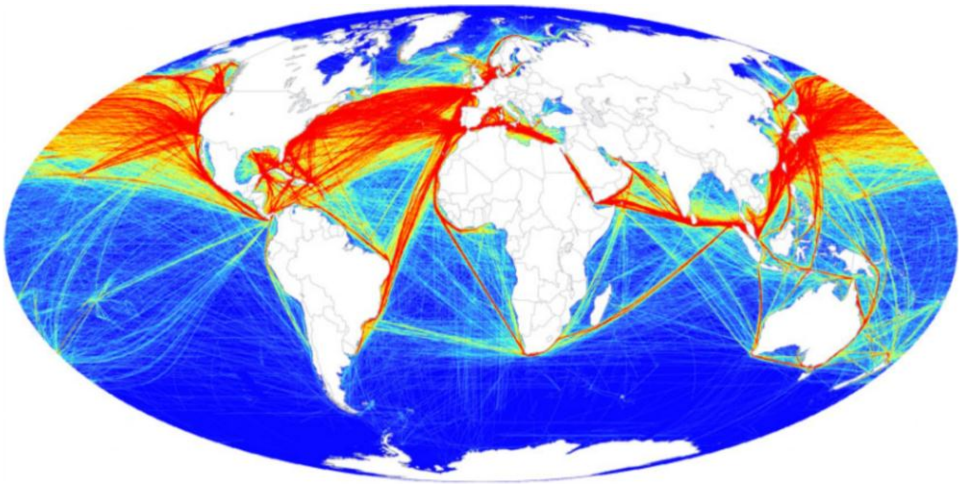

Figure 2.1: Reported shipping for year 2005; est ~11% of global total. (From Halpern et al., 2008. Reprinted with permission from AAAS.)

Commercial vessels in regular service offer another major advantage for ocean observation, namely continuous measurement in the horizontal. This is significant because the most energetic scales in the ocean are small compared to their counterparts in the atmosphere (a few tens of km versus 500 km or more). This will be a major addition to the existing oceanographic observational toolkit.

Another inherent strength of measuring from vessels is that much of the data can be reported in real time. Indeed, this has been routine for XBT data for decades. More recently this has been done with some Ferrybox and thermosalinograph data. There is no reason it could not apply to a subset of all OceanScope optical and acoustic data as well. Within a period of a few weeks to a month one could have a global update on water chemistry and biology, upper and deep ocean currents, subsurface particulate matter, and other parameters.

For a network of instrumented commercial vessels to reach maximum effectiveness, existing measurement technologies will have to be adapted for use on such vessels. The main criteria will be operational reliability, ease of use, and transparency to ship operators. Standardization will also be essential to ensure consistency of performance and to achieve economies of scale. Some instruments, such as the continuous plankton recorder, Ferrybox and the ADCP, meet or are close to meeting these requirements, but further improvements can be anticipated. A fundamental advantage of vessel-based measurements in contrast to autonomous vehicles (drifters, floats, gliders or moorings) is the availability of space and power. Other technologies—such as towed undulating systems, shipboard optical remote sensing, and next-generation expendable probes—are still in their infancy, but OceanScope could provide the motivation necessary to accelerate technological progress. The applicability and availability of relatively mature and evolving measurement technologies applicable for commercial vessel use are discussed in detail in Appendix B.

A surmountable stumbling block in working on commercial vessels with respect to scientific instrumentation (in particular hull-mounted ADCPs) has been the fact that a ship can be assigned to a different route on short notice (less than one month). The degree to which this is the case depends upon the class of vessel and the business model of the corporate partner. To date this has been a limited problem since most ships so equipped have either been locally owned or dedicated to specific areas of service. The problem will become more acute with a global network of transoceanic vessels. This problem can be resolved but requires addressing two inter-related tasks: an appropriate organizational framework and agreement upon a standard installation.

The first task will be to develop an organizational framework that brings together commercial ship operators and the ocean observing community. An appropriate ocean science advisory body would work with an operations office to identify routes or sections of climate or marine environmental interest or concern, and that office would then work with industry partners to identify primary and alternative vessels suitable to be enlisted as instrumented platforms. Wherever possible, priority will be given to vessels that tend to operate on the same or a limited set of routes.

The second task will be to establish an agreed-upon standard interface between vessels and instruments that eases both the initial installation and possible transfer of instrumentation—including hull-mounted equipment—when and where necessary. Common sense and experience tell us that solutions are possible. The first step is to agree on certain standards (dimensions and location of equipment, power and communication cabling, air sources, water inlets and outlets). The next step would be to run cables and to build in dedicated instrument spaces (including sea-chests and cofferdams) during construction. Incorporating these preparations into vessels during construction is comparatively inexpensive and potential industry partners have already discussed their willingness to incorporate these in "new builds" as they are brought on line. Standardization and scalability are extremely powerful concepts in another sense; they can motivate and develop demand for technologies that do not exist today or that would otherwise not be commercially viable. This technology impact should not be underestimated; as merchant marine vessels become part of the global observational community, people will start to think about new possibilities and thereby new commercial ventures.

With respect to technology there are two distinct but inter-related components: the vessel and the instrumentation. For the vessel, it will be essential to rigorously identify both the advantages offered and constraints imposed by different vessel types in terms of shipboard and hull-mounted instrumentation. These include questions of location of equipment, wire runs, internal networking, power availability, space, and environmental exposure. Adequate consideration of these issues will greatly facilitate future operations; they need to be addressed early on. These are discussed in Appendix A and are included in the Early Issues (see Figure 3-2) of the proposed OceanScope implementation timeline. One of the most fundamental questions will be where and how to deploy hull-mounted instrumentation on different vessels to ensure a bubble-free view of the underlying water column. This needs to be addressed early on through a proper engineering study.

With respect to instrumentation the key requirement is that it be truly designed and optimized for the operational environment of a commercial vessel and that it can be moved from one vessel to another, if necessary. This implies: i) long-term reliability (including protracted service intervals); ii) standardization to both control costs and ensure uniformity of performance; and iii) minimal impact upon vessel operations (including maximal possible autonomy). Instrument reliability is always an important goal, but instruments intended for OceanScope service must be designed and built for long-term operation with minimal attention. Designing in this reliability in advance will greatly reduce long-term operational cost. Instrumentation issues are reviewed in greater detail in Appendix B. As the ocean observing community increasingly recognizes the capability of a fleet of OceanScope-instrumented vessels, it will begin to think of ways to enhance their measurement portfolio. Obvious immediate needs include profiling currents to greater depth, additional electronic sensors of water properties, and the ability to measure gas and nutrient fluxes in/out of the mixed layer. The status of some of these topics is also discussed in Appendix B.

Putting it together: The global opportunity

OceanScope is founded upon a close partnership between the maritime industries, instrument developers, and the ocean observing community. While inspired by and anchored in past activities, it will nonetheless represent a novel approach to the art and science of ocean observation. To be successful, OceanScope must be thought of from inception as an evolving long-term ocean observing capability, not a research project with a particular focus and defined duration. To realize the full potential of the platform of commercial ships, it is essential that the ocean observing community speak with a single voice as this partnership goes forward. OceanScope will be to oceanographers like the Hubble Telescope to astronomers or CERN to particle physicists, in providing a community facility that will be the basis for innumerable individual analysis programs and research projects.

Repeated regular measurements are absolutely fundamental; this is the central advantage of partnering with commercial operators. It is the foundation upon which the many dimensions of

OceanScope will be integrated: oceanic coverage provided by a fleet of instrumented vessels, high resolution in both the horizontal and vertical, temporal coverage through sustained repeat transects, and inter-disciplinary understanding through concurrent measurements of physical, chemical, and biological observables. These aspects expand the concept of oceanography from commercial ships to an entirely new level. Bringing this integrated measurement skill to a select number of oceanic routes will enable the ocean observing community to address a wide class of ocean state and flux questions.

It will be assumed that all OceanScope-participating vessels will be equipped with ADCPs. The reasons are twofold. The first is that this direct measurement of currents is accurate, cost-effective, and greatly improves upon geostrophic methods, and because this acoustic method reaches to depths we have never been able to monitor on a regular basis. The second reason is that knowing velocity permits a direct determination of the flux of concurrently measured properties, such as heat, fresh water, carbon dioxide, and oxygen. The need to know fluxes accurately at low and equatorial latitudes is acute because measuring currents at low latitudes by other means (altimetry, floats, and sparse arrays) cannot resolve the spatially complex equatorial system. It is a near certainty that there is much yet to be discovered and explored. OceanScope vessels can play an enormous role in monitoring choke points, passages, and transoceanic sections.

Choke points, places where water masses are forced to pass through relatively narrow constrictions that separate ocean basins, have particular appeal. At such places one can measure properties and their fluxes to great accuracy. Examples of choke points include the Drake Passage between the Pacific and Atlantic Oceans, the Agulhas Current that links the southern Indian and Atlantic Oceans, and the Indonesian Throughflow between the western tropical Pacific Ocean and the eastern Indian Ocean (You et al., 2010). With respect to Drake Passage, supply vessels that serve stations on the Antarctic Peninsula are already monitoring currents with ADCPs (Lenn et al., 2007). The Agulhas Current presents a different challenge, but Cape Town serves as a base for traffic to stations in eastern Antarctica. Traffic to/from Durban and Cape Town into the Indian Ocean offers the possibility of monitoring the Agulhas Current.

There is particular interest in the Atlantic Meridional Overturning Circulation (AMOC), which is driven by both the Nordic Seas overflow and the production of intermediate water in the Labrador Seas. While several programs monitoring regional warm water flow are in place, only one is designed to resolve all the components of north- and south-flowing waters. Recent studies have shown the meridional circulation to be complex, with zonal recirculation patterns of limited latitudinal extent. Thus there is interest in expanding the number of sections spanning ocean basins. Candidate sections could include Canada to Europe, Iceland/Greenland to Europe and North America, sub-tropical sections (U.S. east coast to Europe), near-equator sections (Brazil to Africa), and South Atlantic sections (South Africa to Argentina). Similar arguments can be made for trans-Indian and trans-Pacific sections. For all these sections our knowledge of absolute transport and its variability is so limited that it isn't clear that we can assign uncertainties with confidence. We have even less knowledge of how the ocean bottom shapes and guides these flows.

Western and eastern boundary currents—with their large fluxes, and their sharp physical, chemical, and biological gradients—play a major role in climate regulation, biological productivity, and carbon cycling. Repeat measurement at high-resolution along selected routes can greatly augment and complement existing global ocean observing efforts. For example, western boundary currents transport quantities of mass and heat to high latitudes. Knowledge of how these fluxes vary over time is an important question for understanding and predicting climate change. Vessels that cross western boundary currents frequently can determine absolute transport and its variability at seasonal and longer time scales to great accuracy (e.g., Tokyo-Ogasawara Line Experiment (TOLEX) across the Kuroshio Current, and the Gulf Stream (*Oleander* and *Explorer of the Seas*)). Eastern boundary currents contribute to the global heat balance through their equatorial transport of cold water. These are also areas of upwelling and substantial primary productivity.

High-latitude and arctic waters are of rapidly growing interest. As ice coverage recedes, commercial traffic is expected to increase, taking advantage of the much shorter transit times between the Atlantic and Pacific oceans through the Arctic Ocean. While fluxes in and out of the Arctic are being measured well (the Arctic and sub-Arctic Ocean Fluxes program, ASOF; Dickson et al., 2008), there is much to be learned about currents and circulation both into and *within* the Nordic and Arctic seas.

In summary, given the coverage provided by commercial traffic and the autonomous observational technologies now available or coming on line, OceanScope offers the research and operational oceanographic communities a substantial new capability to explore and accurately monitor the dynamics, chemistry, and biology of the global ocean. This will not happen overnight, but this additional capability will represent a significant addition to how we explore the global ocean water column.

CHAPTER 3

THE IMPLEMENTATION OF OCEANSCOPE

Summary

The transition to a global OceanScope program would take place in a series of expanding steps with respect to geographical coverage, parameters observed, and technologies utilized. The first ocean basin to be monitored would be the North Atlantic, in large part because of the ocean-observing initiatives already underway to which OceanScope could immediately contribute. A five-year ramp-up is envisioned, leading to full operation of the North Atlantic Test Bed during the fourth year and full readiness for initiation of a global program by the end of Year Five. At that point OceanScope will be fully operational with respect to four inter-related components: (1) an operations function, (2) a data and communications function, (3) a technology function, and (4) a planning function. OceanScope would be limited to existing technology at first, but incorporate new sensors and technologies as these become available. This initial five-year phase incorporating a North Atlantic Test Bed will serve to fully test, evaluate, and refine the OceanScope concept.

Introduction

This chapter describes a plan for implementing OceanScope. It discusses organization, priorities, technologies, and a schedule for its realization. But before doing so it is important to restate the overall purpose of OceanScope: to provide a global framework for sustained ocean observation of the water column from commercial vessels, so that physical, chemical, and biological processes can be studied simultaneously across all ocean basins. We study the atmosphere as a whole, and satellites monitor the global surface, land and sea alike. A corresponding capability to monitor the global ocean water column has been sorely lacking, as noted by numerous papers given at the OceanObs'09 conference (Hall et al., 2011; www.oceanobs09.net). The OceanScope concept is propelled by the idea that an organized partnership between the ocean observing community and the maritime industries can open up new capabilities. OceanScope would equip vessels in regular traffic with instruments that can regularly and repeatedly scan the water column while underway and do so continuously over the coming decades. Data would be freely disseminated in real time or as rapidly as technology permits. OceanScope would solicit recommendations for areas of the global ocean that should be regularly monitored, as well as proposals for sensors, instruments, and technologies that can expand the observational capabilities of ships in transit. It would collaborate closely with existing institutions and activities where appropriate (e.g., SOOP, ICOS), contribute to the Global Ocean Observing System, and complement the observational efforts already underway.

To implement the above activities, OceanScope will be organized in a fundamentally different way from existing ocean observing activities using commercial vessels. Rather than being project-based, OceanScope's management structure will be centralized to ensure effective coordination among all parties. This approach is important for at least two reasons. First, it will be mutually advantageous for everyone and essential for vessel owners and operators to have one point of contact for all observations being made by the commercial fleet. Second, operating as a centralized entity, OceanScope will be better able to foster the development and deployment of technologies optimized for autonomous use on commercial vessels. Anyone who has proposed an instrument idea to a technology company well knows that the initial response is invariably "great idea, but is there a market for this?" Chapter 2 and Appendix B highlight the tremendous possibilities that exist for improved observation ("the low-hanging fruit"), but this fruit can be harvested only if there is sufficient demand for the product. A third reason for a centralized approach follows from the first two: the necessity for standardization across the fleet. This would apply to both the technologies employed, and to the operations, including the servicing and installation of shipboard equipment by certified and trained technicians under contract to OceanScope. OceanScope has the potential to capture the attention of industrial partners that have significant resources devoted to bringing the best ideas into the marketplace.

Part 1: <u>OceanScope Organization</u>

It is proposed that OceanScope be an internationally funded non-governmental organization (NGO)—either as an independent entity or by association with an established NGO. It could be modeled after existing multi-agency global programs such as the Integrated Ocean Drilling Program (see http://www.iodp.org/). It must be given a long-term mandate in order to be meaningful and effective, which will require that it be a freestanding body with its own charter (see Appendix F for a draft charter document) and Memoranda of Understanding between OceanScope and sponsoring agencies and foundations. Such documents can ensure the required stable environment for development and operations. Deciding where OceanScope headquarters should be located is not crucial at this time, but one possibility that has been discussed is adjacent to the International Chamber of Shipping (ICS) in London. ICS represents the global commercial maritime community and has been collaborating closely with the OceanScope Working Group. The OceanScope organization would initially consist of an Executive Director, overseeing four inter-related functions that would operate out a single office: planning, technology, data management-dissemination, and operations; all are essential for OceanScope success. If and when these functions require a separate person and/or office will depend on the scale and pace of OceanScope development. The Executive Director will be an *ex-officio* member of the Governing Board, which will provide oversight to OceanScope operations. The Governing Board will consist of representatives of the maritime industries, the ocean observing community, and the sponsoring agencies.

The Executive Director

OceanScope will require a staff of both outstanding professional caliber and a thorough understanding of the OceanScope concept. S/he will be responsible for generating appropriate proposals and work plans to the international sponsors of OceanScope and, in consultation with the Governing Board, setting priorities for OceanScope activities. Because OceanScope will depend upon a firm and lasting partnership with the maritime industries, we suggest that this person either come from or have extensive experience working with industry. At the same time, the director must be intimately familiar with the ocean observing community and its present and future needs.

Planning

The fundamental planning function will be to develop a detailed schedule for implementation, and to solicit feedback and recommendations regarding ongoing and future OceanScope activities. Examples include translating observational needs into choice of routes, measurement densities, and instrumentation methodologies. This may also include responding to and/or contributing to new science initiatives under development elsewhere and organizing workshops to discuss and develop new initiatives. The guiding philosophy for this function would be the promotion of an integrated global oceanographic observational capability, which may support, but be distinguishable from, research projects and programs. This function will primarily be the responsibility of the Executive Director.

Technology

The fundamental technology function includes the selection and acquisition of all OceanScope technology. Resources must be found to work with developers to deliver technologies optimized for use in the commercial marine environment. This means an emphasis upon performance reliability for the simple reason that access to vessels for service and repair will be limited. The technology and operations functions in OceanScope must be closely coordinated to ensure timely input with respect to “new builds” and vessels about to enter dry dock. The technology and planning functions must be similarly coordinated with respect to the development and incorporation into OceanScope of new and improved technologies and methodologies.

Operations

The fundamental operational function encompasses all vessel-related operations and provides a single point of contact between the ocean observing community and vessel operators. Operations and planning functions will cooperate with representatives of the commercial operators to locate suitable vessels, including, for example, identifying ships operating in the Southern Hemisphere. Based on the successful experience of research programs employing this approach, Operations will set up long-term operating contracts with oceanographic or other local institutions to provide support while vessels are in port. Typical activities would include delivery of expendables such as probes and chemicals, and instrument replacement/repair as needed. Using local capabilities to the extent possible will reduce costs. OceanScope will require a pool of standard instrumentation both for initial installation on vessels and for immediate replacement in the event of failure. Operations will have to remain cognizant of industry vessel procurement plans so that they can be readied for subsequent OceanScope service during construction. While it may seem a tall order, and it is, vessel preparation should be seen as an integral part of the OceanScope partnership (see Appendix A). The immediacy and scope of operational support required suggests that this office will need to be staffed early in the implementation of OceanScope.

Data

The Data function will work closely with and take full advantage of present operational data centers and other facilities that collect and archive data. There are well-developed centers for some of the data streams envisioned (e.g. TSG data or carbon data). In other cases, including the ADCP data so central to the OceanScope concept, these have yet to be developed, funded, and agreed upon. OceanScope may also need to foster the development of value-added products that integrate and display interdisciplinary data in near-real time. These may include integration with completely independent oceanographic data from Argo, surface drifters, and satellites.

Urgent technology issues regarding ships and instrumentation

OceanScope expects to initiate operations with instruments essentially available off-the- shelf. Their successful use in automated and semi-automated applications is a major motivator for the OceanScope concept. These include XBT, flow-through seawater systems, and ADCP systems. However, some of these systems still need to be optimized for long-term unattended operation on commercial vessels. Another early priority will be for OceanScope to work with ship designers and builders to develop standardized procedures, and technologies for installing instrumentation in locations that facilitate installation and yield optimal performance (see Appendix A).

"Future" technologies

Technologies essential to take full advantage of the opportunities that OceanScope can provide include deep-reaching expendable probes that can profile oxygen, CO_2, nutrients, deeper-reaching ADCPs and geomagnetic techniques for measuring vertically averaged mass transport, and improved methods for scanning biomass at depth (see Appendix B for further details). An early priority will be to hold workshops to select among these, identify promising additional technologies (those closest to commercial development), and determine how to facilitate their development (perhaps through a collaborative proposal process with appropriate national and international governmental agencies).

Other OceanScope Activities

When fully implemented, the OceanScope headquarters would also include support for scientific/technical rotators or post-doctoral fellows who will not only work with OceanScope operations and help to coordinate data dissemination to the ocean observing community, but also solicit feedback from the community regarding evolving user needs and expectations.

Part 2: <u>An OceanScope Regional Test Bed</u>

We propose that OceanScope focus initially upon the North Atlantic basin. The primary reason is that the North Atlantic is already exhibiting substantial variations in circulation patterns, gradual heating, reduced CO_2 uptake, and reorganization in plankton distributions. A second advantage is the suite of ongoing activities underway and institutional infrastructures already established to which OceanScope can contribute. Common regional and national interests in the future of the North Atlantic also suggest that it will be relatively easy to obtain permission to conduct operations within relevant EEZs. What follows is intended as a conceptual outline upon which a detailed proposal might be subsequently based. It relies solely upon presently available tools and technologies. The frequency of sampling that would result is sufficient with respect to the oceanographic features discussed below and characteristic of what OceanScope could achieve in other oceanic basins.

A North Atlantic OceanScope Test Bed

In a general sense, the North Atlantic Ocean comprises two major subsystems, the subpolar and subtropical gyres, separately roughly by the 40°N latitude. Physically, biologically, and chemically these subsystems exhibit very different characteristics. Broadly speaking, waters south of 40°N leave the surface for a decadal or longer journey around the ocean. They return to the surface somewhere north of 40°N. To the south the atmosphere sets the properties of the ocean; to the north the ocean substantially influences the atmosphere, a delayed transfer of information from low to high latitudes. In the south the ocean is highly stratified; in the north the ocean loses heat to the atmosphere through convection that can reach to substantial depths. This mixing (or lack thereof) from the surface down has a major influence on the exchange of gases, heat, and other properties. The subpolar gyre undergoes major reorganizations in response (we think) to the state of the North Atlantic Oscillation (NAO). The subtropical gyre very likely also undergoes substantial adjustments as the westerlies crossing the Atlantic vary in intensity and latitude, but much remains to be explored about their imprint on the ocean. Indeed, our knowledge of the circulation of sub-thermocline waters is limited.

The proposed network (which incorporates present commercial vessel routes on some of which oceanographic data are already being collected) would provide coverage of both subgyres (Figure 3.1). Sections 1-6 focus on the subpolar gyre and its exchanges with the Nordic (1) and Labrador seas (3). Section 3 cuts across the subpolar gyre near where—according to some studies—the largest shifts in circulation occur. Section 6 corresponds to the frequently occupied 42°N section. Section 5 provides a valuable north-south transect through the eastern part of the subpolar gyre, where it is thought major shifts in the path of the North Atlantic Current/Subpolar Front take place. This section could also monitor the subtropical/subpolar transition of flows south versus north, biomass patterns both at the surface and at depth, and correlations between currents, biomass, and chemical patterns.

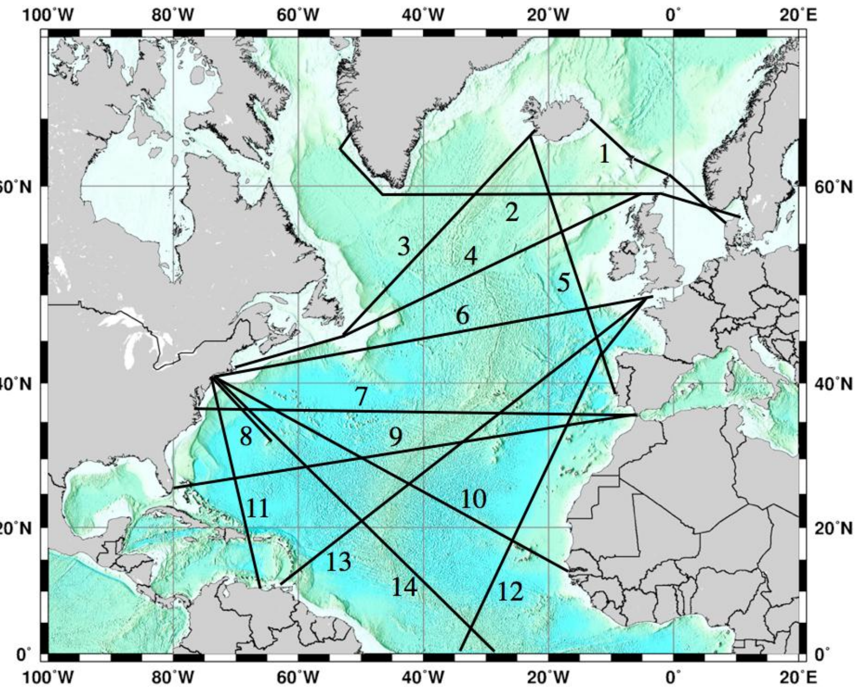

Figure 3.1: Potential OceanScope routes spanning the North Atlantic Ocean. Routes 1-6 span the subpolar gyre and routes 7-14 the subtropics and tropics.

The subtropical sections (7-12) provide a mixture of roughly zonal (7-10) and meridional (10-12) coverage. Section 13 from the English Channel to the Caribbean Sea provides a valuable orthogonal (NE to SW) cut across the subtropical gyre. Sections 12 and 14 extend coverage to the equator and beyond. Section 12 would also provide valuable extension of section 5 farther south along the eastern margin of the North Atlantic.

These routes are not traversed at equal frequency. Section 8 has weekly service; section 2 is repeated every three weeks. Typically, the longer the route, the less frequently it is revisited. This argues for instrumenting more than one vessel on the longer routes so that sampling densities are similar. We suggest here that two ships be employed on routes 6, 9, 10, 12, 13, and 14. That yields a proposed total of 20 vessels.

Wherever possible, OceanScope would build upon and integrate with the observations ongoing or planned by other programs and projects. As noted earlier, some of these lines are already being occupied and oceanographic measurements have been made on others for considerable periods of time. For example, CPR activities have been underway in the North Atlantic since the 1930s, XBT operations have been underway for decades, and ADCP operations were started in 1992 on section 8 and in 1999 on section 2.

A budget estimating the cost of installing core (and optional) instrumentation, operating the vessels and administering OceanScope is provided in Appendix I.

Part 3: <u>OceanScope Implementation Timeline</u>

The timeline envisioned for OceanScope Implementation is depicted in Figure 3.2.

Early issues: Establish *pro tem* advisory board and continue process of developing partnership with industry. Agree upon OceanScope charter and structure including a Governing Board. Develop funding sources. Address EEZ access issues. Establish vessel and instrument technology working groups.

Year 1: Full funding available. Management positions filled. Vessel and route selection processes initiated. Initiate funding for priority equipment and technology development. Develop data management and dissemination procedures and policies.

Year 2: Equip initial vessels on selected Test Bed routes. Set up contracts with local groups for in-port operational support (e.g., data transfer, supplies, rapid response repairs).

Year 3: Continue equipping the Test Bed vessels and begin operations. Work with established data management entities to ensure sustained data distribution and archival.

Year 4: Complete equipping the Test Bed vessels. Full operations underway. Review operations and change procedures if required.

Year 5: Full operation continues. Convene independent review panel for North Atlantic Test Bed program. Prepare recommendations and priorities to guide global OceanScope expansion.

Year 6-10: OceanScope goes Global

Figure 3.2: Proposed Timeline for OceanScope Implementation.

Early Issues:

OceanScope has already stimulated a dialogue with potential industry partners, which has been facilitated by including individuals from industry associations in the Working Group. Most recently OceanScope participated in a World Ocean Council (WOC) meeting (Paris, December 2011). A major outcome of this meeting was the agreement to establish an industry-science working group to explore alternative ways that commercial vessels could be used to improve the ocean observation enterprise. At the same time, Working Group members intend to continue to work with the International Chamber of Shipping in addressing the legal issue of EEZ access. During this period (prior to identifying funding for implementation), we propose to establish a *pro tem* Advisory Panel to guide the process forward. This includes establishing subgroups to address technology issues that need to be resolved to finalize the initial implementation plan, reaching final agreement on an OceanScope Charter and organizational structure (including a Governing Board) and exploring private funding options for the North Atlantic Test Bed. Eventually, a standing Advisory Panel will be established.

Year 1:

Once funding is available, the first actions will be to begin to staff OceanScope with qualified individuals and initiate vessel and route selection with respect to the North Atlantic Test Bed. Other tasks that need to be addressed include initiating funding for priority equipment and technology development based on the recommendations of the technology subgroup, and developing data management and dissemination procedures and policies well before any data are actually collected. As noted earlier, this will involve explicit collaboration with present efforts in the ocean observation, satellite and weather communities to avoid re-inventing the wheel.

Year 2:

At this point we will be ready to begin to install instrumentation on vessels. This will likely involve a combination of retrofitting on existing vessels (which will require a dry dock period) as well as taking advantage of planned new builds should they be intended for North Atlantic service. To ensure effective operations OceanScope will contract with appropriate local groups to support in-port operations (e.g., data transfer, supplies, rapid response repair). OceanScope will have to establish training and certification procedures for these contractors.

Year 3:

OceanScope will continue equipping Test Bed vessels and extend operations. This implies a rapidly increasing data stream; therefore, OceanScope will continue to work closely with established data management entities to ensure sustained data distribution and archival. Special attention will have to be given to data sets that have not yet been fully standardized at the international level and OceanScope may have to collaborate with other groups to establish mechanisms for handling some of these data.

Year 4:

All North Atlantic Test Bed vessels will be equipped and be operational by the end of this year. Toward the end of the year, operations will be reviewed by the standing Advisory Board and recommendations made to OceanScope management and the Governing Board.

Year 5:

The North Atlantic Test Bed will be in full operation. The Advisory Board will convene an independent review panel to evaluate Test Bed success and incorporate community recommendations for further improvement. The review panel will then prepare recommendations and priorities that the Advisory Board can use to guide global OceanScope expansion and the transition of OceanScope from private philanthropic funding to governmental support.

Year 6-10:

The implementation of the North Atlantic Test Bed does not in any way suggest that one must necessarily wait until its conclusion before any expansion of OceanScope activities into other basins. Drake Passage coverage is already underway, and it would be desirable to explore ways of further strengthening it. Similarly, it would not be difficult to envision an Equatorial Pacific program, involving routes fanning out from Panama, and the west coasts of North and South America, of enormous interest to ENSO-related processes. Other opportunities exist with inter-Pacific island routes. In implementing OceanScope globally, all routes do not need to span an entire ocean basin. Eastern gyres and boundary currents can be monitored with routes between Chile, Peru, Panama and the U.S./Canada and the energetic western part of the Pacific Ocean. The Pacific's rich north-south gyre structure can readily be monitored thanks to the dense network of north-south traffic between China/Korea/Japan, Indonesia and Australia.

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Appendix A: Vessel Types and Their Potential as OceanScope Platforms

Summary

The characteristics of ocean-going vessels vary enormously; this appendix discusses these with respect to their advantages (and disadvantages) as OceanScope platforms. The principal topics include vessel classes with respect to routing, speed, and duration of service on specific routes and hull types, particularly with respect to the downdraft of bubbles that interfere with or block acoustic remote sensing. It also discusses approaches that could be taken to minimize or avoid the impact of bubbles to hull-mounted instrumentation.

Introduction

The international merchant marine fleet comprises a wide range of vessel types. These include container ships designed for rapid just-in-time service, roll-on roll off (Ro-Ro) passenger ferries to transport Ro-Ro cargo and passengers on longer and shorter distances on domestic and international routes, cruise liners optimized for passenger comfort and convenience, car carriers intended for car transport on longer and shorter routes, tankers delivering oil and oil products, and a variety of bulk carriers for grain, ore, coal and other products. Given OceanScope's proposed global purview and range of scientific requirements, it would be desirable to be able to operate on any and all of these vessel types and in all geographic areas of interest. It is therefore essential to have a good grasp of the characteristics, strengths, and weaknesses of each vessel type to know how they can be best instrumented. This appendix is divided into two parts. We first give an overview of OceanScope needs for effective operation on any vessel. We then review the principal vessel types and their potential as instrument platforms including recommended or necessary steps needed to bring them into effective OceanScope service.

OceanScope requirements

Three issues are addressed here: (1) use of the hull for remote sensing (i.e., optical and acoustic) instrumentation and for acoustic telemetry; (2) access to the deck areas needed to deploy and retrieve towed systems and expendable probes or mount optical instrumentation; and (3) access to seawater intakes for surface water analyses.

1. Vessel characteristics for acoustic remote sensing and telemetry

Two critical areas with respect to hull-mounted instrumentation are the bow, which defines the properties of flow around and under the vessel, and the skeg, which can be comparatively bubble-free, depending upon hull configuration.

The bow—Experience has increasingly shown that the shape of the bow, specifically that of the bulbous bow, plays a decisive role in the use and location of hull-mounted instrumentation. It can induce significant drawdown of air that envelopes the hull in a thin blanket of bubbles that interferes with acoustic remote sensing.

Bulbous bows are present on virtually all commercial vessels except on very high displacement volume bulk carriers and tankers, where a blunt cylindrical bow has become more popular in recent years (see Figure A.1).

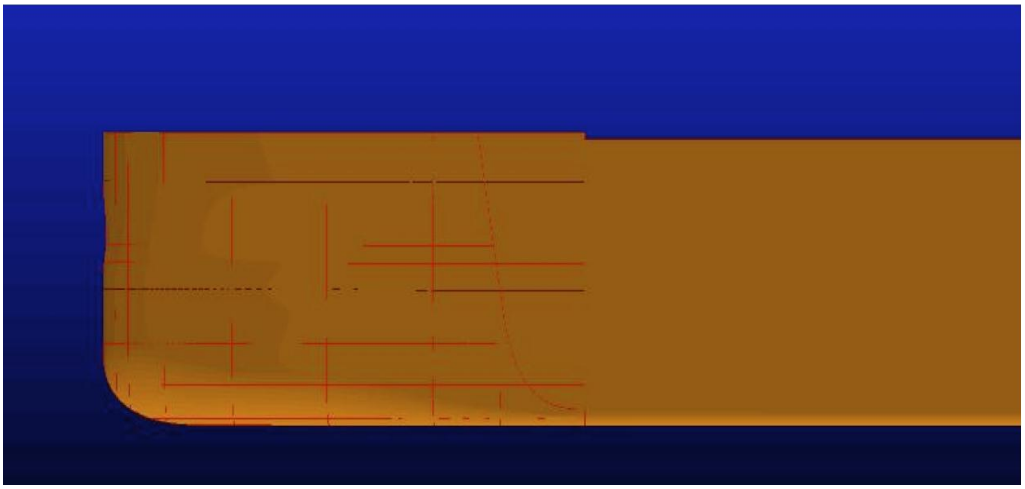

Figure A.1: Schematic side view of a bulk carrier with its vertical blunt bow. Figure courtesy Deltamarin, Turku, Finland.

The purpose of all bulbous bows regardless of shape is to reduce the effect of the bow wave system by setting up a leading bow wave that is out of phase with the normal bow wave, thereby canceling its drag on the vessel (see Figure A.2). The bow's shape and size are ship-specific and designed to minimize fuel consumption at a vessel's normal cruising speed. The savings can be enormous and easily exceed 10% of total fuel consumption. Generally speaking, the larger and faster the vessel the greater the savings and the more pronounced are the bulbous bow structures.

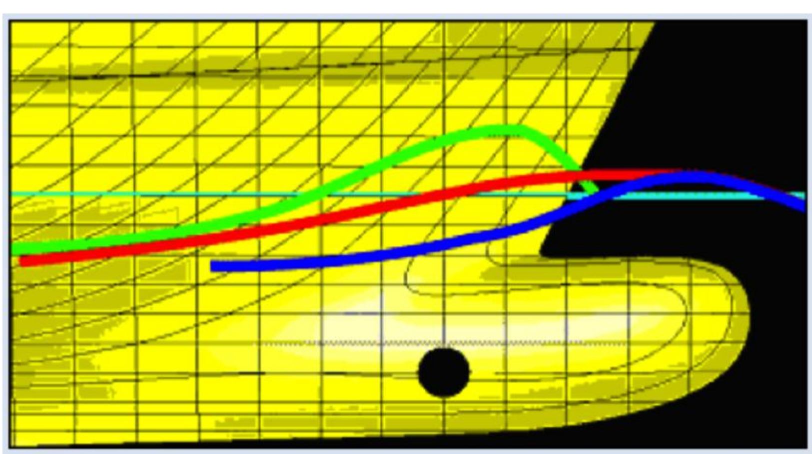

Figure A.2: The green line represents schematically the natural bow wave of the hull without the protruding bulb. The blue line represents the wave created by the protruding bulb. The red line is the sum of these two. Notice that the height of the bow wave is substantially reduced, which in turn, reduces the form drag associated with the bow wave. Figure courtesy Jet-Tern Marine.

Bulbous bows can be sorted into three groups: Δ (delta), O (cylinder), and ∇ (nabla) (Kracht, 1978). Figure A.3 shows examples of the first and third type. Cylindrical forms consist of essentially a straight tube extending forward.

Figure A.3: A delta (left) and a nabla (sometimes known as inverted tear drop) bulbous bow (right). Both ships are equipped with ADCPs. The *Oleander* (left) operates between New Jersey and Bermuda, the *Norröna* out of the Faroes to Denmark and Iceland. Photos courtesy T. Rossby.

From OceanScope's perspective, the nabla design can be problematic in that its top surface glides just below or pierces the surface with considerable frothing as a result. These waters are then subducted along the bulb and chine (the fold between the bulbous bow and the hull) leading to the injection of a so-called bubble blanket underneath the vessel, which can reduce skin friction along the hull. Although the shape of nabla-type bow is primarily governed by the desire to reduce form drag, this reduction of skin drag can also improve fuel economy. The nabla-type of bulbous bow works extremely well at design draft, but may create a very deep wave at ballasted draft (light load) when the bulbous bow pierces the surface and thus also induces the draw-down of large quantities of air below the hull. The relative importance of the two factors in conserving fuel is not well understood and is certainly vessel- and sea state-specific. Regardless of cause the presence of such a bubble blanket seriously impacts hull-mounted acoustic transducer efficiency (and above some sea-state will make reliable acoustic measurements impossible). Nonetheless, this problem can be avoided if transducers are located far forward below and immediately behind the bow, just in front of the bubble blanket, and perhaps also in the skeg far aft; the two most promising locations for OceanScope remote sensing and acoustic telemetry systems. Regardless of location any OceanScope instrumentation would have to be installed such that the ship's draft is not increased. Figure A.4 demonstrates schematically a possible OceanScope approach.

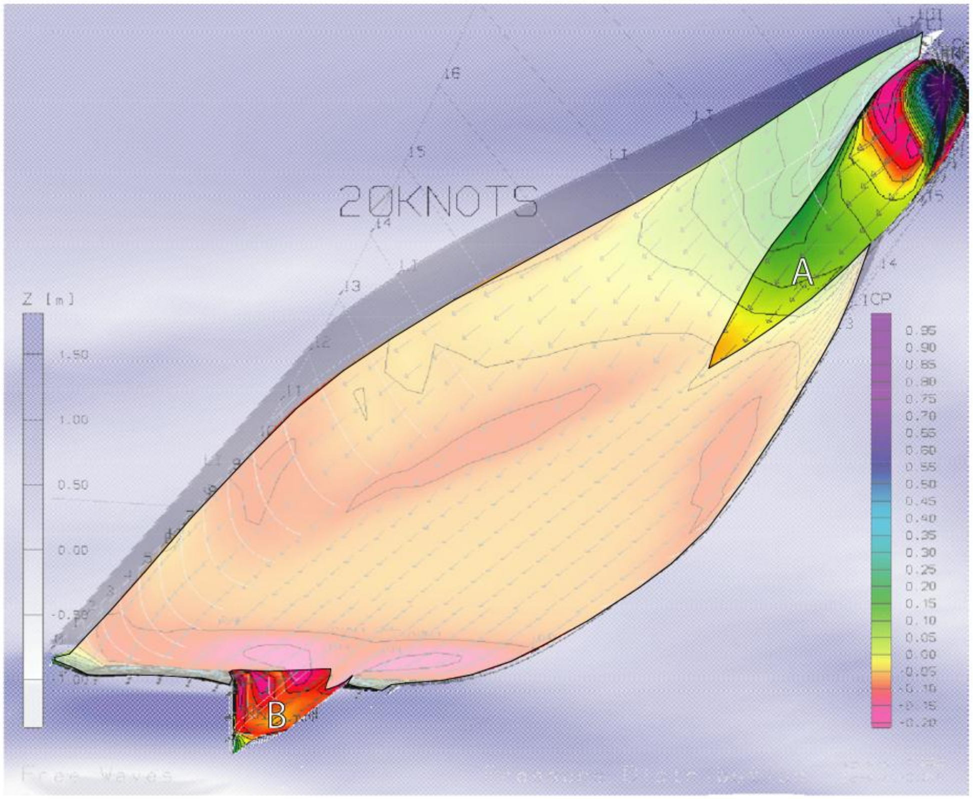

Figure A.4: A fish-eye view (distorted proportions) of an ocean-going ferry. The translucent color of the hull sketches the aft-spreading bubble blanket. Only the region around the forward part of the bulbous bow (A) and aft skeg (B) remain bubble-free. Remote sensing transducers could be located in either area or in a pod that extends out to the side of the skeg (not shown). Figure courtesy Flensburger Schiffbau-Gesellschaft mbH & Co. KG.

Figure A.4 is only a sketch and proper flow calculations need to be done to identify what parts of specific hulls can be kept bubble-free under most operating conditions. This applies particularly to the nabla-type shape for the reasons discussed above. The delta shape also sets up a pressure wave but does not subduct water; it acts more like a plow and deflects water to the side. This shape used to be more common in slow-moving vessels whose draft varies widely under different loading conditions, for example, very deep when fully loaded or fully ballasted (such as bulk carriers and tankers) and for this reason it is appealing for OceanScope purposes. Unfortunately, this type of bulbous bow is no longer as popular as it was in the 1980s and early 1990s. It has gone out of favor, primarily due to experience with other bow types, reflecting the improved understanding of the actual flow conditions around the bow area thanks to more recent Computational Fluid Dynamic (CFD) studies. *Further research is needed to identify and, if possible, parameterize the bubble-free domains for all hull forms in common use today.*

Figures A.5 and A.6 present a CFD calculation of flow lines around a typical modern Handysize (37,000 deadweight ton) bulk carrier, having a blunt or bulb-free vertical bow.

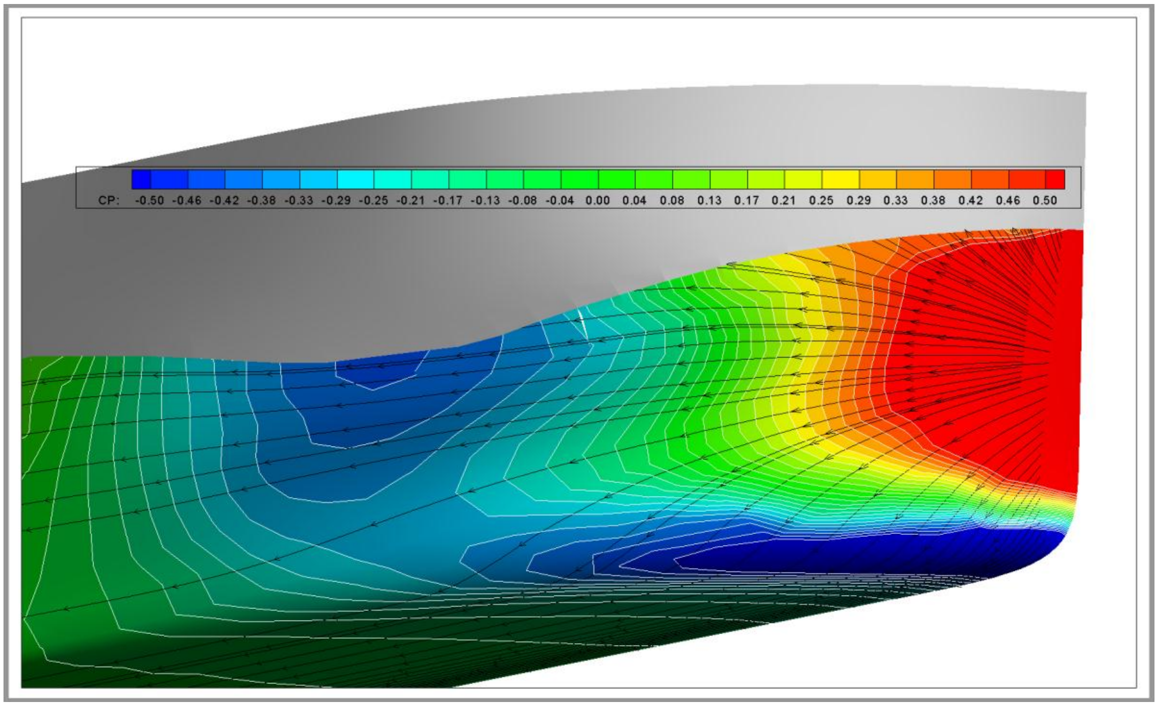

Figure A.5: CFD study of flow around the bow of a bulk carrier. One sees how the bow waves wets the side of the vessel and the relatively horizontal pattern to the streamlines. The color indicates pressure (red = high static pressure, blue = high dynamic pressure). Figure courtesy of Deltamarin, Turku, Finland.

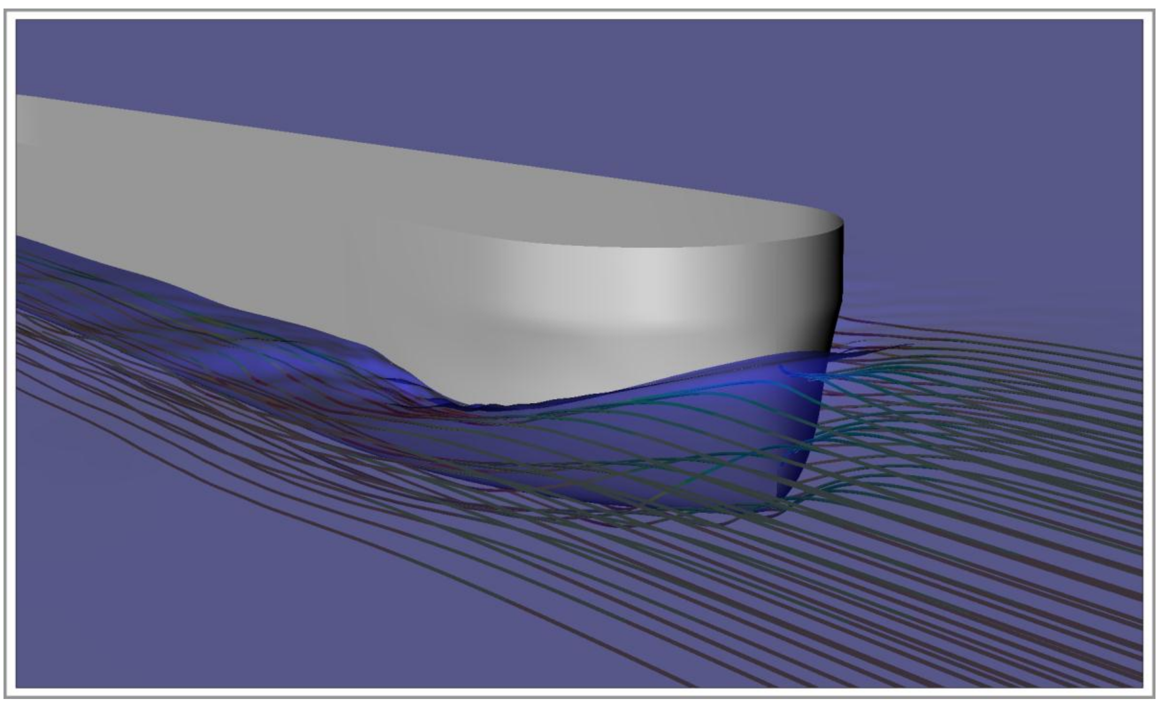

Figure A.6: Perspective view of bow wave around a blunt bow bulk carrier. Figure courtesy Deltamarin, Turku, Finland.

The skeg—The skeg area offers a potentially very important advantage for remote sensing instrumentation because, as shown in Figure A.4, it protrudes into clear water, much like a dome or a pod on research vessels. Thus, an ideal location for instrumentation would be in the bottom side of the skeg, a bit forward of the propeller(s). The bubbles will follow the shoaling hull, leaving the bottom side of the skeg in clear water. (Some device to induce removal of any remaining bubbles from the centerline may also be needed.) While proximity to the propeller(s) and presence of cavitation noise in rough seas would seem to make this area a poor choice for acoustic systems, even if it were free of bow wave-induced bubbles, this may not be true at the higher frequencies of ADCPs (38 kHz) and potential acoustic telemetry systems. Quite a bit is known about the acoustic environment of vessels in the 20 kHz range, where most noise comes from cavitation at the propeller tips. Experience to date has shown that higher frequency ADCPs (150kHz) are insensitive to ship-radiated noise. The same arguments would apply to potential future acoustic telemetry systems.

If research confirms the skeg area is sufficiently quiet at 20-30 kHz and higher frequencies, then there is a possibility that all OceanScope acoustics could be located there. In research contexts where augmenting the ship's draft is not an issue, acoustic transducers have been installed on protrusions that extend below the bubble zone and this has proven to be a highly effective approach and permits uninterrupted data collection even in quite high sea states. Such domes could be a solution for commercial vessels in specific cases where the draft is not critical in the operation regime of the vessel, but this is the exception, not the rule, in the commercial fleets. We suggest two alternative approaches. The first is that the equipment could be flush-mounted in the bottom side of the skeg. Because the skeg is so narrow, it would likely be necessary to install and service the equipment via an opening to the side of the skeg. Assuming this is possible, it has the clear advantage of zero hydrodynamic presence. (However, such a system could only be serviced at dry dock.) An alternative approach would be to attach a pod with its instrumentation to the side of the skeg just above the keel line. The pod would be hydrodynamically consistent with the shoaling flow to keep drag to an absolute minimum and located where the flow past it is not felt by the propeller. A final advantage to working in the skeg area is that it greatly simplifies the routing of cables (especially when retrofitting vessels for OceanScope service). These issues need to be addressed by the proposed technology subgroup and are likely to require issuing a contract for a detailed engineering analysis. This is an early funding priority.

Some instrumentation—such as beam-formed hydrophones for acoustic telemetry and optical systems—can be towed using a depressor to keep it below the ship's wake, a depth of roughly 1.5 times the draft of the vessel (Culver and Trujillo, 2007). This is not difficult to do and devices have been constructed that facilitate deployment and recovery of towed systems (such as the CPR, next section).

2. The stern as a staging area for towed instrumentation

The success of the towed Continuous Plankton Recorder (CPR) has been extraordinary. This strictly mechanical device has been in use since the early 1930s. About one meter in length, the CPR is towed on a 10 mm diameter wire connected to the CPR nose via a shock absorber. The CPR has been operated successfully at speeds of up to 25 knots, and can be handled in wind force 8 conditions from larger merchant ships. In recent years other towed technologies, including undulating vehicles, have come into widespread use, some on merchant marine vessels. They offer the potential to monitor and perhaps profile water not in direct contact with the atmosphere, that is, below the mixed layer.

Both the CPR and undulating vehicle systems require space in the stern area for a dedicated davit and winch for their deployment and recovery. Since the CPR has already been used for many years on a wide variety of vessels (all six types listed below), it appears that stern space has generally proven adequate. However, none of the towed instrument systems has yet been fully automated. Research and development is required to minimize any effect on commercial ship operations (changes in speed or heading and utilization of crew assistance) to use any of these systems in OceanScope.

Another stern-based activity has been the deployment of expendable bathythermograph (XBT) probes. These have been in widespread use since the 1960s to obtain temperature profiles in the top 500 to 1000 m of the water column, depending on the specific probe type. A mature technology, its success is leading to growing interest in expanding its capability, both to greater depths and a wider range of sensors. Thus, expendable conductivity-temperature-depth devices (XCTDs) and expendable current profilers (XCPs) have been developed and used in research applications. To facilitate their use several research groups have developed automated launchers. One can anticipate an expanding suite of expendable probes in the future as well as a fully automatic launcher for future and present probes (see Appendix B for further discussion).

Future developments will require access to deck spaces where probes can be stored and released on command (the launcher “magazine”). At present, however, it appears that these space-needs do not exceed those of the towed technologies mentioned above. However, it should be noted that in some of the modern cruise ships and ferries and other types of ships as well, a ducktail has been incorporated to reduce the transom wave system. This means that the stern slopes down and back, sometimes several meters, making it more challenging to lower any equipment into water from the aft deck.

Optical sensors of other types (see Appendix B) do not necessarily have to be located astern—they can look ahead or to the side—but do require limited deck space at or near the rail as well as power and communications cableways. Analysis of these data is likely to require knowledge of and correction for ship movement. This is available from the high resolution GPS units required for ADCP data collection.

3. Seawater intake for surface water monitoring

All vessels have seawater intakes for engine cooling. The water goes through a sea-chest or tank to remove bubbles before it is circulated through the machinery. It is assumed here that this technology is rather uniform across vessel types. It is essential to connect to the inlet prior to the tank and to remove bubbles as required with thermosalinographs (TSGs), FerryBoxes, and most optical sensors. In both cases, adequate space for instrumentation and communications is needed which, pending more precise information, is not expected to exceed more than full-height wall, perhaps 2 m in length with 1 m of space in front free and clear for instrumentation. Considerable attention needs to be given to the risk for biofouling, which can corrupt measurements of dissolved nutrients and biologically active gases (O_2 and CO_2). This could point to the need for OceanScope-dedicated intakes with stainless steel piping and/or use of Teflon™ to ensure biologically or chemically inert plumbing. It also suggests that where possible a separate seawater intake located in the bow would be preferable to connection to the ship's sea-chest.

All instrumentation will require access to power and communication links to their respective control boxes and central processing/communication units. There is, however, a considerable amount of cabling between the engine room and the navigation bridge and a route for a few additional cables should be easily found, especially in new vessel construction. In all cases this is seen as principally a cabling issue, although some space for data logging and communication in or near the bridge or radio room would also be required.

High-seas and coastal vessel types

There are six principal vessel types in widespread use of interest to OceanScope: bulk ore carriers or bulkers, tankers, container ships, RoRos, ocean-going ferries, and cruise liners. Other vessels of lesser interest to OceanScope include multipurpose, heavylift, and offshore support vessels since their work is more contract-specific or demand-based and their routes are therefore less predictable and sustained only for shorter durations.

Bulk carriers

Bulk ore carriers are deep draft, slow speed, and come in a wide range of sizes. They are mainly double-hulled and typically outfitted with blunt bulbous or cylindrical bows. Some, ore bulkers in particular, operate between specific ports for long periods of time, which is helpful in assuring data continuity on specific routes, but there are exceptions to this where some bulkers operate in the charter market, that is, with changing cargos and destinations. Unloading a bulker takes far longer than all other types of cargo, and thus they spend much more time in port—upward of five days for the largest vessels. Time in port can facilitate data transmission and dissemination; however, the same in-port times, and slow transits, imply a hiatus in data collection. The draft of large bulkers can also be a limiting factor, with some approaching 20m; however, most bulkers have a draft from 10 to 15m fully loaded and 5 to 7 m in ballast condition. Moreover, as discussed earlier bulkers typically spend half of their transit time in ballast and changing draft can complicate data collection.

Tankers

These ships have much in common with bulkers with respect to modest speed and deep draft, hull form and (especially crude oil tankers) in operating about half the time in ballast. Moreover, the routing of large tankers tends to be dictated by market conditions, which may also limit their utility for sustained monitoring. Tankers can be divided into three main categories: Large or Very Large Crude Tankers, Product Tankers and Chemical Tankers. The first group has typically very deep draft, exceeding 20 m, whereas product and chemical tankers have typically a loaded draft from 8 to 12 m.

Container Ships

These vessels operate at increasingly high speeds, anywhere from 16 to 25 Kt for the very largest vessels, and have a moderately deep draft of about 15 m. They typically operate under strict schedule requirements for "just-in-time" delivery. Since speed is an economic requirement, these ships often have very pronounced nabla-type bulbous bows, increasing the likelihood of bubble drawdown. Much ship-of-opportunity work (XBT, CPR, TSG, ADCP) is being done on container vessels, but for some OceanScope purposes, principally acoustics, they present challenges as discussed above. Container vessels can be subdivided into two major groups: Large Ocean Going and Feeders. Feeders are smaller in size and operate in distributing the cargos from main hubs to smaller ports, typically coast-wise or even inland rivers and smaller sea areas, such as the Baltic Sea. Large ocean-going vessels operate typically between different continents on scheduled service. Modern container vessel ports minimize in-port times with efficient and simultaneous loading and unloading, which means less interruption of data collection.

RoRo ships

RoRo stands for roll on–roll off, that is, wheeled cargo. Those used for new car delivery are also known as pure car carriers or PCCs or PCTCs (pure car and truck carriers). They have a very distinctive profile, with high sides to protect their cargo from salt water. Cars are driven on and off through stern and side ramps. RoRos operate at intermediate speeds, not as fast as containers for the same size, but faster than bulkers. Their bows are vertical and narrow, with modest delta-type bulbous bows. As a class they operate between specific ports and thus lend themselves to the repeat sampling requirements of OceanScope. Typically, their routes and in-port times are shorter than for tankers, containers, or bulk carriers, but longer than the ocean-going ferries discussed below. Car carriers are also subdivided in the same manner as container vessels; Large Ocean Going and Feeders. Pure RoRo vessels are mainly used in smaller sea areas between dedicated ports, such as Baltic Sea, North Sea, Mediterranean Sea, and similar sea areas.

Ocean-going ferries

These vessels have operated for many years to nearby islands, ports, and populations. They operate on very strict schedules and as a class have the most stable operating schedules of all vessel types. As with pure RoRos, ferries are particularly appropriate for coastal and regional observation programs. Because of their high operating speed and tight schedules, they tend to have shallow draft with quite pronounced nabla-type bulbous bows (see right panel in Figure A.3) as do the cruise liners discussed in the next section.

Cruise liners

These vessels come in a wide variety of sizes. As a class the fleet of cruise liners has grown rapidly in response to their increasing popularity for vacation travel. Some operate on fairly stable routes, but in other cases their routing is changed to increase revenues (cruise lines that operate stable routes often rotate vessels among their routes to attract repeat customers). There may also be seasonal variation in routes. The large modern cruisers are highly efficient, often spending less than one day in any port. They have shallow draft and cruise at quite high speeds, such that the location of OceanScope instrumentation is a challenge with respect to bubble interference as discussed above. Some cruise lines venture into very high latitudes and others focus upon small-island developing states, both of which offer OceanScope the potential of obtaining data where other regular large vessel commercial traffic is minimal. High-latitude routes are of special interest given the scarcity of data and the rapid changes taking place there (Chapter 2). The size of cruise ships today vary from relatively small 80 m vessels operating to Antarctica up to 360 m operating in the Caribbean and worldwide.

From a strictly acoustic remote-sensing perspective tankers and bulkers have considerable appeal in that almost certainly they have the lowest density of bubbles along the hull, especially in loaded conditions. For all other hulls it seems possible to avoid bubbles by locating instrumentation ahead of the down-drafted bubble blanket, but this will need to be confirmed both through numerical analysis and direct measurement. The skeg area shows promise for instrumentation given sufficient upwelling along the shoaling hull such that the skeg cuts like a pod into clean water underneath the hull. This expectation also needs to be rigorously evaluated. On the other hand, options for deployment of other instrumentation from the stern area (and given staffing levels the availability of crew assistance should it be necessary) may be greatest aboard ferries or cruise liners. The global distribution of ship vessel types will, of course, reflect market conditions and needs.

Appendix B: Instrumentation

Summary

Several ocean observing technologies are already in use on commercial vessels. These are organized here by technology type: towed, flow-through, expendable, and remote sensing instrumentation. We survey the technologies of each group in use today and review improvements that would facilitate their systematic use (and likely decrease costs) on OceanScope vessels. We then discuss possible sensors and technologies that could significantly improve the vertical reach of OceanScope-instrumented vessels into deeper waters. This is perhaps where a partnership with commercial operators can make its most lasting impact—creating the framework and motivation to expand our coverage of the water column.

Background

A major impediment to systematic ocean observation from merchant marine vessels has been the lack of instrumentation that can be deployed for sustained unattended operation. Important exceptions exist and the systems in use and the state of development of other such instruments make the OceanScope concept both attractive and feasible. This appendix explores several avenues to substantially improve the observational potential of commercial vessels in regular traffic.

The Approach

The approach taken here will be to classify sensors and systems by method of use rather than by discipline since a given technology or deployment method can serve multiple observational needs. For example, expendable probes could measure physical, biological, or chemical properties. The technologies addressed herein include towed vehicles, flow-through systems, expendable probes, acoustic remote sensing and topside optical remote sensing of sea surface properties. Each section includes present and future aspects, existing or near-existing skills, and what could be realized in the relatively near future with comparatively modest additional investment and community attention. An additional deployment option, the limpet approach, is also addressed in a future context alone (although there have been preliminary feasibility tests).

Towed Vehicles

Present—The fundamental model of towed vehicles is without question the Continuous Plankton Recorder (CPR), which has been in use since the 1930s. These devices can be towed at speeds up to 25 knots, sampling the near-surface plankton environment at a depth of about 10 m (www.sahfos.org). Plankton are filtered by a continuously moving band of 270 µm mesh silk gauze. Water enters through a small aperture at the front of the device and passes through a rectangular cross section, across which passes the silk band that filters the plankton. The silk slowly moves across the filtering area, at a rate that is proportional to the speed of the towing ship so that 5 m of silk is equivalent to about 500 nautical miles (NM) of tow. When unrolled, the band of silk is like a film of the changing plankton along the route of the towing ship. Deployment of CPR machines has proved to be an efficient and cost-effective way of monitoring plankton variability at regular intervals over large areas of oceanic and coastal water. CPRs have been deployed and recovered at the end of transit lines by the crews of commercial vessels with minimal impact upon their own operations. The CPR is a purely mechanical device but is increasingly equipped with a small self-contained temperature recorder, a device that could easily evolve to include conductivity, oxygen, and fluorometry.

Aquashuttles (Chelsea Marine Systems) and related near-surface profilers have been equipped with a variety of sensors and have been towed at speeds up to 25 Kt in various research contexts and aboard commercial and military vessels. While this class of instrumentation may require further development for routine use on commercial vessels, their strength lies in their ability to cycle to a fixed depth at regular intervals (the so-called tow-yow), providing profiles to depths of 50-100 m. For example, profiling into the seasonal pycnocline confers enormous possibilities to learn more about diapycnal fluxes of gases and nutrients.

Future— Demand is expected to grow for improved towed vehicle systems to map in the horizontal the layering, concentration, and correlation of planktonic distributions with corresponding density, light, and nutrient chemistry profiles. Sensors are rapidly becoming available for such parameters, and decreasing in size and power requirements. Many sensors have been used on autonomous vehicles, a more challenging application. Improved deployment and handling systems will be required to deploy the next-generation towed vehicles from commercial vessels. Moreover, it is highly unlikely that more than one such vehicle could be deployed at the same time.

The towed transport meter (TTM) is a modern version of the Geomagnetic-Electrokinetograph (GEK) (von Arx, 1950). It measures the depth-averaged or barotropic velocity from ships underway. By combining TTM observations with the ship’s velocity and leeway drift (both obtained from GPS), the depth-averaged ocean velocity normal to the vessel’s track can be determined. A next generation TTM that measures both normal and along-track components is expected to give vertically averaged currents at an accuracy approaching 1-2 cm s^{-1}. However, the method depends upon the Earth’s magnetic field, and significant contamination by magneto-telluric currents from fluctuations of the Earth’s magnetic field will occur on occasion, particularly in the auroral zone (above 60^{o} latitude). Improvements and modifications to the technology would be needed before TTMs could be put to use on OceanScope vessels. Nonetheless, given the extreme lack of information about the spatial structure of deep ocean currents this technology needs to be given serious consideration. Towing this instrument is not much different than vessels of the past towing logs to keep track of distance traveled.

Flow-through systems

Present—Shipboard flow-through sampling systems are well established in the research arena, and the technology continues to evolve rapidly. An operational version of these systems, the Ferrybox, is in widespread use on many European ferry routes. It obtains its water from the cooling water intake of a vessel, although in some cases separate hull penetrations have been employed. In either case these systems have become increasingly compact and rugged, making them easy to install or relocate to other vessels as required. Such systems record temperature and salinity (conductivity) and many also measure oxygen, particle density, plant pigments, and nutrients. These systems have reached a high level of reliability and can operate for months without attention. Assuming stable sensors the time-limiting factor appears to be the size of the chemical reservoirs for the nutrient analyzers. A fully autonomous remotely controllable flow-through system is now being tested aboard a commercial cruise-liner. Continuous reporting of sea surface water properties from across the world ocean will provide valuable ground truth information to the satellite remote sensing communities. Experience suggests that these systems should, if possible, have a dedicated intake located up near the bow ahead of any subducted bubble envelope.

A parallel development has been the measurement of the partial pressure of CO_2 (pCO_2). The existing instrumentation is very accurate and precise (± 1 μatm), and includes a series of fail-safe mechanisms and self-diagnostics that facilitate unattended operation (Figure B.1). These systems are the "gold standard" due to their high-quality measurements, but the infrastructure requirements are significant. The instruments and parts—such as compressed gas calibration standards—require significant space on the ship. They require an air-water equilibrator with gaseous headspace for measurement of CO_2 concentrations with infrared analyzers. The equilibrators require a gravity drain and an appreciable water flow of approximately 4 liters per min. The equilibrator must be near the seawater inlet to minimize respiration of microorganisms in the intake line. Some units require auxiliary cooling units to keep the analyzer temperature below 50˚C in the hot engine rooms. Thus they do not (yet) qualify for long-term unattended service and are more complicated to install below the ship's waterline.

Future—Several alternative pCO_2 instrument designs are coming on the market; sealed units with gas permeable membranes that pass CO_2 either into a closed loop infrared analyzer or through a pH-sensitive dye from which the pCO_2 is determined (Figure B.2). Accuracy and long-term stability have been issues with these units, in part, because of limited ability to perform routine standardizations, and therefore these sensors have not been widely deployed. And, despite their smaller size compared to the established instrumentation, these sensors still do not allow easy installation and maintenance when moved from one vessel to another. Several recent collaborations between scientists and the commercial sector have begun involving miniaturized sensors. However, ensuring that the accuracy and precision of measurements is not compromised will present a challenge to the miniaturization progress. Addressing these issues will require not only technological innovation but also establishing an integrated system for data quality control. Currently available instruments and sensors to measure surface pCO_2, as well as other marine inorganic carbon parameters, are listed on the Sensors page of the IOCCP Web site (http://www.ioccp.org/Sensors.html).

Figure B.1: Autonomous underway pCO_2 system installed on a research ship. The system is built by General Oceanics (http://www.generaloceanics.com/) based on specifications resulting from community workshops organized by the International Ocean Carbon Coordination Project (IOCCP). Photo courtesy of Kevin Sullivan, UM/CIMAS.

Figure B.2: Example of an inline pCO_2 system produced by Pro-Oceanus. This system is installed in a sealed seachest. Photo courtesy of Brian Ward, Univ. of Galway.

Elucidation of related biological processes (chlorophyll, primary production and oxygen) is an important challenge. Photosynthesis in the surface mixed layer has a large effect on pCO_2 levels, but is difficult to measure consistently. Research instruments are available to indirectly measure photosynthesis, or more accurately, photosynthetic efficiency, through Pulse Amplitude Modulation (PAM) and other fluorescence-based approaches. These techniques could be adapted to flow-through systems to test the same water in which the pCO_2 is being measured. For all these optical fluorescence-based instruments, calibration of the signal remains a major issue and an inherent limitation. Fortunately, there have been various successful mechanical and chemical approaches to address biofouling, which previously limited extended deployments of optical sensors. Photosynthesis is also understood by measuring change in oxygen over time. Recent development of accurate, stable, and precise oxygen sensors has enabled independent assessments of biological productivity and air-sea gas exchange. Bubble entrainment is an issue for sensors that rely upon a flow-through system water supply. As noted before, there is considerable evidence that bubble ingestion is best minimized by located the seawater intake in the bottom of the hull in/near the bulbous bow. In-line bubble traps will always be required.

Constraining the inorganic carbon system: For a quantitative assessment of the impact of biology and mixing on sea surface pCO_2, and for shedding light on the causes of ocean acidification, measurement of additional inorganic carbon parameters is absolutely essential. In particular, either total alkalinity (T_{Alk}) or total dissolved inorganic carbon (DIC) need to be measured.[1] No automated instrument exists for the measurement of T_{Alk} or DIC; all instruments giving the required accuracy and precision ($\pm$ 1 μmol kg^{-1}) are manual and are therefore used only in laboratories and onboard research vessels. Several efforts are now underway to develop automated instruments and sensors to determine T_{Alk} and DIC that would be located on moorings; these should be readily amenable for shipboard application. Continued development of highly accurate and precise carbon sensors, especially those that can measure more than one parameter, is imperative, to fully utilize merchant marine vessels as comprehensive autonomous observatories of the upper ocean carbon cycle.

Expendable Probes

Present—Expendable probes (XBTs) have been in widespread use for more than 40 years to profile upper ocean temperatures to as deep as 1000 m at up to 30 Kt ship speed. Many thousands of probes are dropped each year. Originally developed for naval applications, XBTs quickly became the instrument of choice for repeat and regular surveys of upper ocean heat content, an activity that will continue into the foreseeable future. Efforts are well underway to

[1] Measurements of pH would be less helpful (although there have been significant developments in autonomous pH instruments) in that pH provides essentially the same information as pCO_2 with respect to understanding inorganic carbon system dynamics. Moreover, to study ocean acidification, pH would have to be measurable to 0.001 units. This is well beyond the precision of available sensors.

automate probe deployment and the subsequent data transmission to reduce the need for dedicated operators onboard. Expendable probes that measure conductivity, sound velocity, and currents are also available. However, the copper wire link to the vessel limits the depth to which an XBT can profile, and it will on occasion get wrapped into any system being towed—hence it would be desirable if there were a means for wireless transfer of data, whether acoustic through the ocean or by radio after the probe resurfaces.

Future—The power of expendable probes lies in their ability to give us real-time information on any properties that can be converted into an electric signal for telemetry back to the vessel. Certainly, some sensor technologies will require considerable investment, but this cost must be viewed in the context of the very efficient access to the global ocean provided by OceanScope-equipped vessels. Knowing that these technologies would be widely deployed could justify development costs that a single project would not contemplate. Some of the more common variables, such as temperature, conductivity, pressure, oxygen, and perhaps pH might someday be combined into a single unit by putting their sensors together on a single chip. Whatever the combination, mass-producing integrated sensors on silicon wafers could lead to highly effective and cost-effective ways to profile the water column.

Acoustic telemetry: For the reasons mentioned earlier (greater range, no wire entanglement, simple storage and release) acoustic telemetry from expendable probes should be seriously considered. The telemetry unit in the probe can be quite simple. Key to effective transfer will be to have a directive hydrophone located in the stern area, perhaps on the bottom side of the skeg or in a pod extending out to the side (see Appendix A for further details). Having removed the copper wire constraint, probes of various kinds can be held ready for deployment much like soft drinks are stored in a vending machine. A command would release the desired probe, which would begin its telemetry after it is immersed. This activity would be entirely transparent and independent of other OceanScope activities onboard. Expendable probes require only one-way communication, which greatly reduces the cost and complexity. The telemetry part of expendable probes might be manufactured in large numbers. Other companies that specialize in sensor technology would buy the telemetry subunits and merge their specialized nosecone to complete the probe. Such approaches would open up the expendable probe market to a variety of new players with their specific skills while maintaining standardized telemetry to keep unit costs down. OceanScope, by virtue of its proposed size and organization, could underwrite the exploration and development of these possibilities.

Radio telemetry: Future expectations for expendable probes might require greater data transfer rates than acoustic telemetry will permit. Examples of these might include probes to map for example thermal dissipation in the ocean; camera-equipped probes to inventory fauna in the water column, including backscatterers (next section); and probes that must sink more slowly to give sensors time to equilibrate, putting the probe out of acoustic range from the vessel. This class of probes would drop ballast and return to the surface, whereupon they would telemeter their data via Iridium Next satellites. Iridium data transmitters are no larger than a matchbox, and these soon will be further shrunk into a couple of chips, bringing the cost of telemetry down further yet.

Acoustic measurement of currents and biomass

Present—An Acoustic Doppler Current Profiler (ADCP) is a type of remote sensing sonar used to profile currents. It produces a short burst of sound at a known frequency and projects it into the water column in narrow oblique beams. Particles in the water column reflect the sound back, but with a frequency shift proportional to the relative velocity between the particles and the ADCP—the familiar Doppler effect or shift. The Doppler shift of the reflected sound is measured and converted to the velocity of the particles (and hence the water) along the beams. As the signal propagates through the water column, reflections are received from particles farther and farther away, such that a profile of along-beam velocities is created by "range-gating" the returned signal into bins along each beam. The ADCP then combines the measurements from bins at equivalent ranges from all four beams, each pointing in a different direction, to create a profile of the three-dimensional currents within range of the ADCP. The ADCP can measure currents with a 1-2 cm s^{-1} accuracy from near the surface to depths exceeding one kilometer, depending upon acoustic operating frequency and the backscatter properties of the water column.

Since the ADCP measures relative motion between the particles and the vessel, one needs to know the velocity of the ADCP itself and the direction in which it is pointing. Conveniently, GPS provides both, the first in terms of movement of the vessel through space, and the latter by means of a GPS-based vessel orientation system. Hence, the accuracy of reported currents depends not only upon the ADCP, but also upon the performance of GPS-heading system, which for this reason should always be viewed as an integral part of the system. ADCPs are now used on research vessels around the world and have been successfully installed and operated by researchers on commercial freighters, ferries, and cruisers. Since the 38 kHz units have been shown to reach to 1200-1400 m depths and hence across the main thermocline everywhere, they should be included in all OceanScope installations.

The strength of the backscattered signal used by the ADCP to estimate currents is a measure of the biomass present. It is a very indirect measure because it depends upon the concentration of the backscattering organisms present, their size distribution, and their acoustic properties. Nonetheless, along-track profiles of backscatter strength give valuable information about the spatial variability of biomass and, with repeat sampling, about its temporal variability. More advanced acoustic systems profile backscatter at multiple frequencies. But these are costly research systems that generate copious amounts of data. Their utility on OceanScope vessels would need further study. On the other hand, two different frequencies, if sufficiently separate, have been shown to provide considerably more biological information and ADCP units at 38 and

150 kHz have already been successfully integrated into one automated system using the same GPS-heading system aboard a cruise liner. A strong case can be made for routinely operating both low- and high-frequency ADCPs. The 150 kHz unit does a far better job of resolving the near-surface velocity field, and as mentioned, the combination of the 38 and 150 kHz units can give complementary information on the make-up of the backscattering particles.

Future—The impressive range, accuracy, and resolving power (both vertical and horizontal) of the existing ADCP technology not withstanding, this technology still does not reach into the *deep* ocean. This shortcoming is arguably one of OceanScope's highest priorities to rectify given our near total lack of knowledge about the spatial structure, strength, and variability of deep ocean currents and how these link together to shape global deep ocean circulation. We need to increase the reach of the ADCP to, if possible, 2 km depth range. An OceanScope implementation would provide a market to justify such an initiative. Such instruments should be designed specifically for merchant marine application. If they could be given a slim profile, perhaps they can be attached externally rather than mounted into the hull (see limpet approach below). Such instruments would enable profiling biomass to greater depths. As remarked earlier, one could imagine using digital camera-equipped expendable probes to identify the backscatterers in particularly intense and persistent layers.

Remote sensing of sea surface properties

The presence of OceanScope-instrumented vessels throughout the high seas would make them useful to the remote sensing communities for ground-truthing the sea surface. As mentioned earlier, the flow-through systems will provide continual reports of mixed-layer temperature and salinity, but these do not measure ocean surface skin temperature, what satellites see. This can be addressed with infrared interferometric spectro-radiometers, which are used to make very accurate measurements of the sea-surface temperature, surface emissivity, and the temperature profile through the skin layer. Such instruments have been used aboard research vessels and are mentioned here because two generations of one such system has been successfully deployed in fully autonomous mode aboard a cruise liner. The data have proved very significant in validating and ground-truthing data retrievals from satellite sensors.

Another parameter of great interest is ocean color, and it can also readily be monitored with an above-surface ocean color sensor. These sensors measure the spectral radiance from the ocean and the sky. Spectral resolution ranges from 3 nm to 20 nanometers across the visible and near infrared. A typical mounting configuration would be at the rail on the top deck, with the radiance sensors looking 45° above and below the horizon. This puts the footprint of the sensor out beyond the wake of the vessel. The footprint also needs to be outside of the shadow of the vessel, so it may be useful to mount one on each side of the vessel. No access to seawater is required. Figure B.3 shows a commercial ocean color sensor mounted on the railing of a research vessel.

That said similar information can be obtained from appropriate sensors connected to a flow through system albeit at the intake depth rather than the very surface of the ocean.

Figure B.3: Photo of commercial ocean color radiometers (photo courtesy of Satlantic HyperSAS).

Active Optical Systems

While passive optical systems can provide valuable data for ground-truthing ocean color satellite systems, they are limited to daytime operation. These problems can be overcome by the use of active optics, or LIDAR (light detection and ranging). LIDAR data directly provide chlorophyll *a* fluorescence, beam attenuation coefficient, and volume backscatter coefficient. These data can also determine the depth of shallow scattering layers in surface waters, which are often related to surface mixed-layer depths.

A LIDAR system could be mounted on a railing, in a sea chest, as a limpet, or in a towed body, but issues about safety around the laser beam argue for a water-based system, either in the hull looking straight down or from a towed body, to prevent any and all exposure of humans to the laser beam. A clear window would be required. There is no commercial LIDAR currently available for this application, but enough experience has been gained with the operation of experimental LIDARs on research vessels to demonstrate that the concept is feasible. Significant engineering would be required to develop a system that could operate unattended for long periods of time. It is unlikely that such a system would penetrate more than 20-30 m in most oceanic waters but that is considerably deeper than any seawater intake.

The Limpet Approach

The difficulty of installing instruments in the hull of commercial vessels has without question been a major reason why they have not been sought out more often for ocean observation. Installation of acoustic remote sensing instrumentation has invariably required significant, albeit not difficult, construction work, specifically the installation of sea chest and cofferdam to accommodate the equipment. When the OceanScope proposal was written, it was assumed that any and all hull-mounted acoustic instrumentation would sit in sea chests welded in place when the vessel is in dry dock. Sea chests for acoustic Doppler current profilers (ADCP) have been installed on many if not most research vessels around the world as well as in a modest number of commercial vessels. It is routine technology and we anticipate that it will continue to be used. However, doing so requires installing the sea chest at vessel construction time or during dry dock for vessels already in service. Both approaches are awkward.

A new concept for installing hull-mounted instrumentation has recently emerged, the "limpet approach." It is attractive for several reasons. Instead of installing instrumentation in sea chests, the idea is to bolt or magnetically attach the entire instrument externally to the hull using magnets. The feasibility of this approach has been demonstrated. The advantages are (1) no need to await dry dock, (2) the instrument can be designed to act as its own fairing and sweep waters to the side, (3) it would afford greater flexibility in terms of precise location, (4) it would make it easier to move systems from one vessel to another; and,(5) servicing the units would not require extended periods in port. Hull ports would still be needed for power and signal, but these are small penetrations and standardized procedures exist for comparatively rapid installation by divers.

If we take an ADCP as the most demanding of potential instrumentation that might qualify for a limpet installation, in terms of space and power requirements, it defines the challenges that must be overcome. The first is the size of the transducer. The current version of RD Instruments' 75 kHz Ocean Surveyor uses a flat phased-array transducer about 40 cm in diameter, while the combined height of the transducer and electronics together is about 30 cm. The recommended 38 kHz Ocean Surveyor has twice the diameter of the 75 kHz instrument, nearly 1 m. The electronics could be re-arranged to reduce the vertical profile, although it is not yet clear to what degree. In any case, this suggests that the maximum size of a limpet could be kept to less than about 0.2 m height x 1-2 m in length depending upon trade-offs between drag, interior volume, and whether the limpet had to contend with significant bubble sweepdown (see below regarding location).

In order for the limpet concept to work efficiently it must be fairly easy to install and retrieve while posing minimal demand to the hull. Powerful rare earth magnets offer a possible solution.

Cup magnets about 7.6 cm in diameter are commonly available with a holding power of 91 kg. A series of eight of these magnets were used on the MV *Norröna* recently to hold a video camera to the bottom of the hull to study the bubble clouds (http://po.msrc.sunysb.edu/Norrona). A lever and cam arrangement was used to unstick the magnets, and the entire unit was easily handled by a single diver. This technology was used for five week-long deployments under the ship, which typically traveled at 20 Kt. To facilitate deployment by divers, a limpet instrument should be slightly buoyant. A series of 30 to 40 magnets with a hold force of 6800 to 9100 kg on screw jacks should hold the limpet against the hull very effectively. The magnetic force falls away very quickly so that by pulling the magnets 1 cm from the hull, the limpet can easily be maneuvered. If the diver is equipped with an air-powered wrench the screw jacks could be quickly adjusted. Initial calculations also suggest that there is little or no significant interference with the transducers in modern phased-array ADCP systems, which do not have an internal flux-gate compass. Discussions with shipping industry personnel have made it abundantly clear that limpets cannot increase the ship's draft or fuel consumption or economic considerations will preclude their use on many vessels—hence the need for a very slim profile to externally mounted equipment. The advantages and limitations of the limpet technology with respect to ship's drag (fuel consumption), how that can be minimized, and what the trade-offs there might be between limpet shape, drag, and its ability to minimize the effects of bubble sweep down all need to be more thoroughly investigated.

Facilitating Technology Development

It is worth noting that most oceanographic instruments in use today have their origins from within the applied university research community. Many of the successful oceanographic instrumentation companies started out as small businesses based on a single very good idea from a very capable researcher. However, there are undoubtedly many more ideas with good potential for broader adoption that lie languishing without further development for a variety of reasons. Universities are well aware of this and most now have technology transfer offices to facilitate the translation of such ideas into products for the marketplace. While these offices are generally very helpful, they tend to operate in isolation from each other, perhaps because the legal frameworks vary from one institution to another or because they view each other more as competitors than collaborators.

The above notwithstanding, marine science and ocean monitoring are rapidly evolving as new and larger projects such as the ocean observatory initiatives and Argo are being implemented internationally. OceanScope implementation has the potential to capture the attention of industrial partners that have significant resources devoted to bringing the best ideas into the marketplace. The challenge is to make it profitable for them to do so. Many countries recognize the potential and power of public-private partnerships to stimulate high-priority research and development. We see examples of this in alternative energy and space-based remote sensing. Given the societally critical nature of the scientific issues that can only be addressed with the improved global ocean data OceanScope envisions, similar public-private stimuli for research and development of global ocean technology should be the next priority recognized by the international community.

OceanScope has a founding premise of three-way communication among science, government, and industry as already indicated with respect to the specification of OceanScope-ready vessels (see Appendix A). To help motivate and facilitate this approach, OceanScope needs to foster communication among researchers, instrument developers, and marine industry representatives to facilitate the development of new measurement concepts. We cannot know what fresh minds might dream up to meet new needs once they are inspired by the possibilities opened up by a global network of vessels scanning the ocean water column. A specific mechanism to bring scientists with pressing observational needs together with the technology and merchant marine communities is outlined in the proposed management structure of OceanScope (Appendix E).

Appendix C: Communications and Data Management

Summary

Scalable and effective dissemination of information implies that OceanScope must have an integrated approach to communications and data handling. We discuss some of the options for data transfer from ship to shore and beyond that to designated archival and distribution centers. This is an area of rapid technological development and this review is not intended to be comprehensive. It is essential to build upon existing data management capabilities to the fullest extent possible. Integral to the OceanScope concept is that data will be made freely available to the global community as close to real-time as possible, that is, consistent with what communications and quality control technologies will permit.

Introduction

OceanScope will have a range of communications and data archival requirements depending upon the type of data being collected, the volume of data to be transferred, and the urgency of the information. Current practice with respect to oceanographic observations on commercial and research vessels is to transmit sub-sampled XBT and limited surface seawater property data in near real-time, while all acoustic (ADCP) data are saved until the vessel reaches port, due to the large volumes of data involved. The growing need for timely information for operational use on the one hand, and the need to maintain tight quality control and minimal downtime on the other, argues strongly for enhanced real-time transfer capability from ship to shore for quality control and use. This need, in turn, argues for effective procedures to monitor incoming data quality in real-time and to flag instruments or equipment that may require attention at the next port of call. This appendix explores some of the possible options for expeditious transfer and distribution of data in both real-time and at next port of call. It also proposes possible data handling procedures. The topics are treated rather briefly since both the hardware technology for telemetry on the high seas and the software technology for data handling and management are rapidly evolving. The material here can be read as a forerunner of possible approaches.

Telecommunications

OceanScope, in its full implementation, will produce a large volume of data, so considerable attention needs to be given to both cost of transfer to shore and how the data are subsequently managed. These functions must be automated and integrated since the classical oceanographic research vessel paradigm of collecting and submitting individual data sets *a posteriori* is not appropriate to the operational setting of OceanScope. Automation is necessary because, unlike research vessels, there will be no scientists onboard, and integration is desirable because only a unified data management enterprise can provide the necessary real-time quality control, efficiency of operation, and economies of scale. However, this is not meant to imply a monolithic structure or a single communications channel because it is likely that different data streams may be handled by different expert centers and then subsequently integrated or cross-referenced for wider dissemination.

The following table summarizes possible modes of data transfer from vessels. It is organized according to latitudinal coverage (ordinate) and bandwidth cost per MB (abscissa). Costs were estimated in 2010 and are very approximate. They will almost certainly decrease in the future.

Table C.1. Summary of communications systems

Area	High Seas Operation					In-port Operation	
Coverage 90°N Equator -90°S	| | | | Iridium | | | |	| | | Iridium NEXT (start 2015) | |	| | SSKU | ++ ++ ++	| | KU | ++ ++ ++	| | INMAR- SAT FBB | |	Wi-Fi/ SSRM	HSDPA (3G/4G)
Equipment Cost & Install	$5,000	$5,000	$30,000	$90,000	$15,000	$5,000	$5,000
Bandwidth (Kbps)	2.4-9.6	1,000	64-2048	64-2048	32-256	>300	>3,000
$/mo	$49 +fee /MB	not set	$1,700 or $2.99/ MB	$7,000	$10/ MB	free	$50 est. *

* 4G is new; specifics vary with service provider. ++ = spotty coverage, mostly near coasts.

The characteristics of these systems differ enormously. Iridium is the only system that provides global coverage; however, it has the lowest bandwidth, by far. However, this will change dramatically starting in 2015 when the Iridium Next constellation with its hundred-fold increase in bandwidth is launched. Geosynchronous satellites provide other modes of communication. The SSKU (spread-spectrum-KU) bands have directed antennae providing coverage primarily in the Northern Hemisphere. However, this is apparently changing rapidly as new satellites provide increasingly global coverage, with localized beams in the Southern Hemisphere. INMARSAT provides global coverage up to about ±70° latitude, and its newest satellites also provide limited area coverage in the form of wide and narrow spot beams.

Maritime communication technology is evolving rapidly. New systems coming on-line focus on the KU-band, where the present pricing policies are a fixed fee per month rather than per usage.

KU-band is growing rapidly as shipping companies use satellite communications for a wider spectrum of activities. Some modern receivers can even switch seamlessly to INMARSAT or Iridium to maintain service if the KU band is unavailable. In such a rapidly evolving situation and given that our marine industry partners are following these issues closely, one might argue for OceanScope to link wherever possible into existing shipboard systems. OceanScope demand on such systems can be kept within specified limits. An OceanScope installation can tailor its real-time telemetry according to the available bandwidth or shift its use to times when the vessel is not using the bandwidth for other purposes. Large-volume data flows can be sub-sampled to meet quality control and real-time data needs, saving the rest until the vessel reaches port.

Having stated this, it seems likely that communications will be vessel or vessel-type specific. For example, systems available on cruise liners have permitted full duplex VPN (virtual private network) connection to automated shipboard systems. Whichever approach is employed, such arrangements will inevitably add another level of complexity to the relationship between OceanScope and vessel operators. In many cases, OceanScope will need to be capable of providing for its own communications needs. This would also facilitate adoption of system-wide uniform communication standards and protocols. Viewed this way it would seem that Iridium and the future Iridium Next will be the best approach. It offers global coverage, is simple, portable, inexpensive to install, and is completely independent of the vessel.

In-port communications can be provided by Wi-Fi/SSRM (spread-spectrum radio modem) or HSDPA (3G/4G) service. Since the former are not generally available, the hardware required would have to be installed for OceanScope use. The cost is comparatively small, roughly $5,000 per ship. Both Wi-Fi and SSRM have been used effectively in different projects aboard different vessels (*Oleander*, *Norröna*, *Explorer of the Seas*), so enough experience exists to conclude that these are both reliable solutions. These shore-side links generally provide excellent bandwidth at low or no cost (assuming free shore-side Internet access), apart from the above-mentioned installation of the hardware. These hook-ups could also be made available for general vessel use once OceanScope needs in port have been met, although on larger modern ships wireless telephone connections serve this function in port. HSDPA (aka 3G/4G) has become the mobile phone industry standard, although it will likely be five years or more before 4G becomes widely available. The 4G bandwidth is impressive and over time its operating cost will likely decrease. However, there are some warning signs of inadequate spectrum availability to meet future customer demand as 4G becomes fully implemented. From OceanScope's perspective the bigger issue concerns the lack of (1) a common operator-independent technology standard, and (2) global maritime 3G/4G access like the use of country code 870 for all INMARSAT calls. This means separate services would be established for each country since international roaming charges would not be economically feasible.

Decision-making about OceanScope communications will need input from industry experts due to the complexity of technology options and the rapidity with which these and licensing policies are evolving. At this stage, and given the complexity of the topic, the simplest recommendation would appear to be to rely on Iridium for small-volume data transfers at sea, and 3G/4G HSDPA in port, with the system automatically identifying which network to connect to. For vessels in repeat traffic between the same or a limited set of ports Wi-Fi/SSRM is particularly attractive since the start-up costs are modest and the running costs essentially free. However, as a general rule OceanScope should strive for a system-wide approach and avoid site-, ship- or people-specific solutions.

Data Management and the GTS

Data management is an enormous and challenging topic, and one that has been explored and developed to a considerable extent in various related contexts. Oceanographic data centers exist for archiving a wide variety of oceanographic data, starting with the World Data Centers for physical and chemical oceanographic data. In recent years, there has been movement towards distributed data centers specializing in certain classes of data, be they Argo, surface drifter, XBT, hydrographic, thermosalinograph (TSG)/FerryBox, pCO_2, ADCP (moored and underway), current meter, and chemical data. It would seem sensible that, where possible, OceanScope data streams be tied into the most appropriate existing data center. Whatever the arrangement, a fundamental requirement will be efficient operation and real-time availability of data.

A fundamental difference exists between OceanScope, where data flow will be essentially continuous from a fleet of vessels, and the present typical oceanographic research mode, the “cruise concept” with a chief scientist serving as the responsible contact for data collected on a specific research cruise. Instead, OceanScope itself would be the responsible entity. The OceanScope data set would be identified as such rather than tied to a specific vessel. OceanScope needs to operate as an integrated global ocean observatory rather than as a collection of instrumented vessels. Individually, the vessels will scan their specific routes at very high horizontal resolution; collectively they will provide an integrated approach to the observation of the global water column. Since there will be a very large volume of data with the underlying requirement that the data streams be viewable and accessible in a coordinated manner, OceanScope will be obliged to take a unified and integrated approach to data transmission, management, and dissemination.

To implement this approach will require a “…coordinated global system of telecommunications facilities and arrangements for the rapid collection, exchange and distribution of observations and processed information…” These words are taken from the definition of the Global Telecommunication System (GTS) for the exchange of weather data. They fit the objectives of OceanScope so precisely that the very same philosophy should be adopted in the design of OceanScope’s data collection and distribution system. The good news is that the requirements of satellite data processing and the global adoption of the Internet have led to the development of numerous procedures for management, analysis, archiving, and dissemination of large volumes of data. There is much experience available from which to draw, not only within the remote sensing and meteorology communities, but also the operational GOOS community (e.g., the SOOP and Argo programs). Lessons can also be learned from management-complex systems such as power-grid and traffic flow monitoring.

Forwarding data from ships in near real-time (or at the first port of call for large-volume data sets) confers many advantages. These include serving near real-time needs, fast response to quality-control issues, and simpler management by eliminating alternative sources of the "same" data.

1. *Real-time needs* include transfer of physical oceanographic data that can be of use in operational forecasting. These include TSG/FerryBox, XBT, and a subset of the ADCP data. Shipboard ADCP processing can produce data files of average velocities at standard depths every 10 minutes, for example (to maintain good horizontal resolution) just as methods have been developed to reduce the size of the XBT and Argo profiles transmitted to shore-side data centers. Methods for doing this with ADCP data are already in use in the research community and efforts are underway to adapt these to OceanScope requirements.
2. *Fast response* to quality control issues speaks for itself. While it will be absolutely imperative for instrumentation to be certified for OceanScope use, meaning built to standards of utmost reliability, equipment failures will occur and shipboard sensors will drift or malfunction. It will not be acceptable to learn about problems weeks or months after they occur. OceanScope would be able to swap out or repair suspect sensors and instrument packages at the very next port of call. Doing so means not only that data need to be regularly sent from the shipboard systems to shore, but also implies shore-side automated data processing/quality control and notification. Methods for doing this are already in use (e.g., the Ferrybox and *Explorer of the Sea* activities) and should become the norm for all OceanScope activities.
3. *Simplified data management* means that data collected onboard a vessel should have a specified transmission path from the ship to the respective data management and distribution centers. Again, the objective is to eliminate the chance of duplicate (or worse "near duplicate") data sets residing in multiple data archives. Subsets of large-volume data sets will need to be clearly marked and identified as such to be eventually associated with the complete OceanScope data set.

Many organizations have dealt with these issues and OceanScope intends to avail itself of their expertise in developing its own data management practices. As noted above, this will be one of the very first tasks undertaken by OceanScope management staff. There is no question that OceanScope will need to think through its data requirements with care so that the assembly, pre-processing, and transfer of data can be done as expeditiously and as cost-effectively as possible.

Appendix D: Legal Issues

Summary

OceanScope vessels will ideally collect data as they traverse the open ocean, exclusive economic zones (EEZ), and coastal waters. In this appendix we discuss some of the legal issues that will have to be resolved in advance based upon ongoing discussions in international forums and the experience of international (and national) programs that have faced these issues with respect to the collection of scientific data. Vessel operators (and their insurers) will need assurance that the collection and dissemination of OceanScope data does not put them at any additional legal risk.

Introduction

The implementation of OceanScope raises legal issues that will have to be resolved. Some issues involve the ownership of the instrumentation and liability for damage by or to them; other issues involve arrangements between vessel owners/operators and OceanScope concerning the placement, operation, and access to the instrumentation. All such issues are governed by *national* (private) law and will have to be covered by contracts or memoranda of agreement to be concluded between OceanScope and the owner/operators of the vessels involved. In related projects already underway, these issues have been addressed by arrangements between individual investigators/institutions and individual ship owners or operators. This *ad hoc* approach is not appropriate to the eventual scale of OceanScope and we will need a more comprehensive systematic institutional framework. An interim approach might involve the approach taken by the Voluntary Observing Ship (VOS) community: a circular provided to and accepted by the industry through the IMO by the World Meteorological Organization (WMO) (see IMO MSC/Circs. 1017 and 1293. This option will not be developed fully herein, but we are pursuing discussions and this may in the end provide an interim solution enabling relatively rapid implementation of the OceanScope North Atlantic Test Bed. Having such a circular may help not only in this context (the relationship between the scientific community and maritime industry), but also in the more challenging international law context discussed below.

The EEZ and International Law

The operators of OceanScope vessels will need assurances that their operations are in full compliance with international law and that they are not putting their vessels at risk. This means that legal arrangements will have to be in place before OceanScope implementation on any scale. OceanScope observations, like all observations from the coast to the open ocean, are governed by the UN Convention on the Law of the Sea (UNCLOS) of 1982. UNCLOS entered into force in 1994 and now has 162 States parties. Although some major States are still not a party to UNCLOS (including the United States), the provisions of the convention relevant for OceanScope activities are by this time considered to reflect general customary international law, which means that they are binding on all States, whether they are signatories or not to the Convention.

UNCLOS allows unhindered observation of the ocean in High Seas areas, which will be the major operating area for OceanScope-equipped vessels. The situation is more complicated in that in their regular transits OceanScope vessels will pass through waters under the authority of coastal States (the 200 nautical mile EEZs and 12 nautical miles territorial waters). In these areas, OceanScope will want to retain its ability to conduct routine observations of water column parameters and to distribute such observations in real time to benefit society, as is now allowed for the routine meteorological observations being collected from VOS vessels. It may be necessary to develop a specific legal framework for oceanographic observations in territorial waters and EEZs for OceanScope and all similar programs that routinely and autonomously sample water column properties, to differentiate them from "Marine Scientific Research" (MSR), which is regulated by UNCLOS through individual notification of and approval by the country into whose waters research vessels will enter under a well-established process.

OceanScope activities are analogous to routine meteorological (VOS) observations, which are excluded from the MSR regulation under a widely accepted specific exception to UNCLOS. One reason for that acceptance is that all VOS data are made freely available to all national and international meteorological agencies, organizations, and scientific communities and the value of the VOS data is widely recognized. This would also be the case with OceanScope observations and that would be reflected in a newIMO Circular. The concept of "operational oceanography" has been introduced to cover observational methods that provide for general availability of the collected data in real time for practical purposes (like the World Weather Watch), with the implication that such activity could be conducted freely within EEZs without prior coastal State consent. However, the term "operational oceanography" has yet to achieve universal legal acceptance. OceanScope's goal will be to be granted such an exemption. Without question, the water column parameters to be sampled will need to be specified and in a sense limited (that is, an open-ended list will never be acceptable). OceanScope observations almost certainly will include physical, chemical, and biological properties of surface (and with probes deeper) waters, ocean currents, ocean temperature structure, and the optical and acoustic properties of the water column, but should include neither observations of the ocean bottom depth nor the physical characteristics of the ocean bottom. It is possible that acceptance of such a legal regime might be facilitated by introducing an entirely new and more acceptable term, such as "Autonomous Ocean Data Collection" or "Routine Ocean Observations".

If OceanScope cannot achieve a general exemption akin to that of the VOS fleet, the next best approach would be similar to that developed for the Argo project for drifting profiling floats. That project is working within a specific framework using somewhat complicated notification procedures, which have generally proved sufficient. Specifically, a semi-automated system provides coastal states notification (one month lead time) that a float will enter their EEZ. If they do not respond by asking that the data flow be terminated, they are deemed to have consented.

If a similar approach were used in OceanScope, it would be operationally easier than for Argo, since OceanScope instruments would be on ships whose routes are known well in advance and repeatedly traversed, making prior notification considerably less daunting than with freely drifting autonomous instrumentation (like Argo floats). On the other hand, the Argo program is the subject of an International Oceanographic Commission (IOC) resolution providing operational guidelines that was developed by the Advisory Body of Experts on the Law of the Sea of the IOC. It is also a major component of the international JCOMM (an IOC and WMO entity) global observing system with major elements funded through IOC. Thus, the Argo notification system has been approved at the intergovernmental level.

The proposed phased implementation of OceanScope, beginning with a regional Test Bed in the North Atlantic, will provide a test of the OceanScope approach. It will involve a comparatively limited number of coastal States who have raised no prior objections in the related Argo context. It should be possible to work with or through present diplomatic channels to develop a template/standard agreement or understanding to be executed through OceanScope with each of these coastal States. A practical arrangement would likely encompass the following: a registry of participating vessels (with the details of the standardized equipment they carry), notification to all coastal States involved on a regular basis of all relevant OceanScope transits and, without question, explicit full and open access for all States to all OceanScope data that have been collected. A fourth, and considerably less desirable option that could be made available if needed, would be to switch off OceanScope instruments when the commercial vessel enters waters of a State that specifically refuses data collection during transit.

Recommendation: As soon as possible, OceanScope needs to begin to work through the ICS with the IMO to prepare a document describing "Routine Ocean Observations from participating vessels in transit." This Memorandum would be provided to the industry through an IMO Circular providing some form of tacit acceptance, barring objections from specific coastal States. At the same time, it would be prudent to craft standard agreements addressing specific state concerns and to develop practical protocols based upon the Argo model, which has been explicitly referenced within the 2010 UN Revised Guide on Marine Scientific Research (United Nations Publication, Sales No. E.10.V.12).

Appendix E: Organization

Summary

To operate a large number of vessels equipped to scan the world ocean regularly, repeatedly, and over long periods of time will require careful planning and management. The relative merits of an inter-governmental or non-governmental organization (or a mixed model) are discussed with respect to their applicability to OceanScope and its unique public/private/science/industry partnership. We conclude that the non-governmental approach offers greater flexibility for collaboration with the maritime industries.

Introduction

It seems clear that OceanScope will require a well-defined international structure to define, coordinate, and execute its various activities. This appendix offers an initial discussion and proposal for how OceanScope should be organized. This will doubtless be subject to modification and refinement based upon the international response to this draft Implementation plan and the resources available. Given the breadth of OceanScope's proposed activities, the organization needs to exercise a supervisory role over all its constituent activities. Specifically, these include procurement of instrumentation optimized for commercial vessel use; selection and prioritization of oceanic routes from among those transited by commercial vessels; vessel identification and operational support; collection, distribution and archiving of data (see Appendix C); procurement and coordination of support services such as instrumentation maintenance and repair; coordination of legal issues relating to the implementation of OceanScope (see Appendix D); and facilitation of the development of new and improved technologies with which to scan and profile the ocean from vessels underway (see Appendix B).

How to organize OceanScope

To efficiently implement OceanScope will require an intimate and ongoing partnership among the scientific community, the maritime industries, and the instrumentation research and development industry. There are many reasons for this. First, the maritime industry representatives with whom we have already been working have clearly expressed their preference for working with a single entity that speaks with one voice. Second, this integrated approach will carry weight with individual vessel operators/owners by providing clear evidence that their own community has endorsed the OceanScope concept. Third, only a centralized organization can effectively ensure the operational uniformity of approach and cohesiveness required to sustain long-term operations. Last, but not at all least, the increased scale of such an OceanScope partnership is essential to stimulate the development of new vessel-based observational strategies and technologies that individual institutions and developers would otherwise be reluctant or unable to consider.

If implemented properly, OceanScope will make possible a broad, multi-disciplinary approach to monitor the ocean's interior, much as the advent of satellites opened up new ways of remotely sensing our planetary surface. The analogy with satellites is deliberate: the commercial fleets are platforms "orbiting" the global ocean at sea level: appropriately instrumented vessels in regular traffic will provide a well-defined and (with time) an increasingly effective window into the water column of our entire planet. Figure E.1 illustrates the envisioned relationship between the OceanScope organization, the maritime industry, the ocean observing community, and the instrumentation industry. The three participating components (the Maritime Industries, the Global Ocean Observing Community and the Instrumentation Industry) play complementary roles and represent the foundational pillars for the realization of OceanScope.

The Maritime Industries will identify (and provide) vessels and routes, identify "new builds" and notify OceanScope as to dry dock scheduling and work with OceanScope to formalize an acceptable legal regime. The Instrumentation Industry will conceive and develop new instrumentation concepts optimized for the commercial vessel environment based upon OceanScope recommendations and priorities. The Ocean Observing Community (both research and operational) will be the primary user of OceanScope data. As such it will provide the essential overall intellectual and scientific leadership and will provide continuing guidance as to evolving scientific information needs. It will use OceanScope data to refine scientific understanding of the ocean system and to improve the operational products of national and international agencies. As illustrated in Figure E.1, OceanScope is the nexus between these groups—an integrating administrative entity, operator of the community facility and data provider.

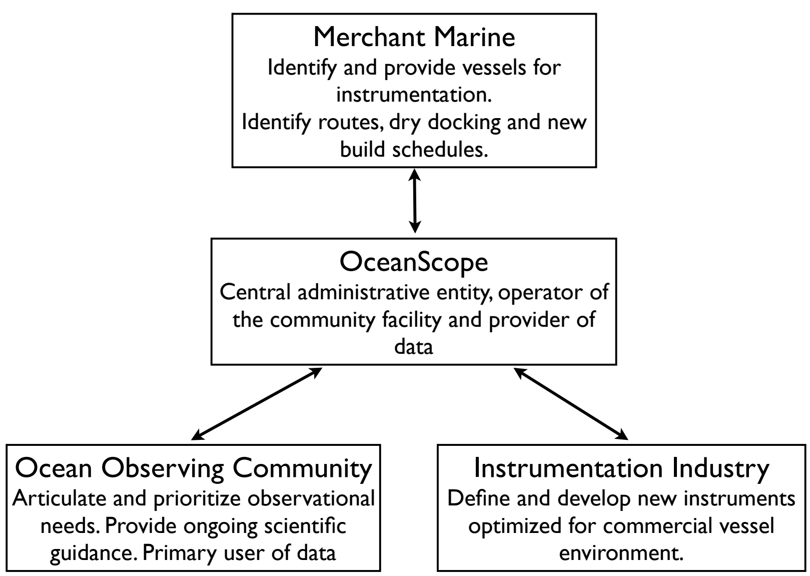

Figure E.1: Schematic diagram illustrating the links between OceanScope and the maritime industry, the ocean observing community, and instrumentation industries.

Types of Organizations

For any international entity, a basic question is whether it should be organized as a non-governmental organization (NGO) or intergovernmental organization (IGO). Regardless of the type of organization it is assumed that majority of OceanScope funding would come from participating nations. However, efforts will be made, particularly in OceanScope's initial phases to secure private philanthropic funding from individuals or foundations concerned with the global environment.

A **non-governmental organization** (**NGO**) is a legally constituted organization, created by natural or legal persons rather than by governments and their representatives, and is governed by the laws of the country in which it is incorporated. Even where an NGO is funded totally by governments, such an organization can nonetheless maintain its non-governmental status. , "Non-governmental organization", while a term in general use, does not have a precise legal definition. In many jurisdictions, such organizations are defined as "civil society organizations" or referred to by other names. The International Council for Science (ICSU) is one example of an NGO. An inherent advantage of an NGO is that such status typically facilitates securing supplementary or constitutive non-governmental funding for the organization. Private sources are accustomed to supporting NGO activities.

An **intergovernmental organization** (**IGO)** is an organization composed primarily of sovereign states (referred to as *member states*), and/or of other intergovernmental organizations. In such organizations the member states have direct representation and participation.

It is possible that implementing the OceanScope paradigm will require that some tasks can be better performed by an IGO, whereas other tasks might be better performed by an NGO. Complementary collaborating OceanScope organizations can be readily envisioned. In any case, the question arises as to whether an already existing organization(s) can be adapted or expanded in scope, or if a new organization(s) needs to be established. The central and comparatively unique question that must be kept in mind is what structure or mechanism will best sustain a long-term partnership between the diverse scientific, maritime, and instrument-development communities, none of which are governmental entities. That partnership is the core of OceanScope and we believe it suggests the need for at least one new organizational entity.

As discussed in Appendix D, a central issue that will need to be resolved is how best to ensure the permission of coastal States for OceanScope activities within their EEZs and territorial seas. Resolving this has organizational implications. If the task were approached on a bilateral basis between the coastal States and OceanScope, government support and involvement will be required (for example, the flag State(s) of the vessel(s), or a State which is willing to act on behalf of OceanScope for this purpose). This could quickly become unmanageable. Another option (discussed in Appendix D) is to seek general international agreement (akin to meteorological VOS ships) that OceanScope observations are allowable within coastal state's jurisdictional waters by working through or with an IGO. In that case, the agreement would apply only to coastal States that are members of that IGO so the broader the membership of the involved IGO, the better.

Global IGOs relevant to OceanScope are the World Meteorological Organization (WMO), the International Maritime Organization (IMO) and the Intergovernmental Oceanographic Commission (IOC). By analogy with the Argo float program, IOC might be envisaged as the IGO responsible for facilitating the implementation of OceanScope and this task would include the adoption of an arrangement ensuring access of all OceanScope vessels to all waters of IOC member States. The concern would be that this approach might be incapable of providing the flexibility and nimbleness required to work effectively with the industry partners who might be more comfortable having operational ties with an NGO, perhaps one associated with or sponsored by an IGO like IOC (and of course by the IMO). In any case, the concept of OceanScope calls for a central organizational structure with a clear mandate not only to initiate the implementation of OceanScope, but also to stimulate new thinking and new methodologies for monitoring the global ocean. A well-defined top-down management structure seems best suited to its needs.

Recommendation: OceanScope should be an internationally funded NGO with its own charter (see Appendix F for a suggested charter document), even if it is associated with a pre-existing NGO. It will be helpful if OceanScope is endorsed by one or more pre-existing IGOs (see prior discussion of an IMO circular in Appendix D). Memoranda of Agreement between OceanScope and supporting countries should be sought to ensure the stable funding environment required for long-term operations. Deciding where the OceanScope Secretariat might be located is not crucial at this time, but locating it close to the International Chamber of Shipping in London would offer obvious advantages. The OceanScope organization would comprise a Governing Board, an Advisory Panel and the Secretariat itself that will provide central day-to-day management of core functions: planning, technology, operations and data. At the outset, these functions might not each require a separate office/responsible individual; however, implementation of OceanScope will eventually require several offices determined by their functions and overall leadership, that is, an Executive Director. As in most organizations the Executive Director would report to and be an *ex officio* member of the Governing Board.

Appendix F: A Draft OceanScope Charter

The OceanScope paradigm pivots around a close partnership between the ocean observing communities, and the maritime and instrument development industries. This is the underlying logical assumption in all that follows.

Therefore:
Given the recognized need for a comprehensive and coordinated mechanism to implement the systematic observation and monitoring of the global ocean water column, from the surface to the bottom,

Given the presence of the global commercial fleet in almost all open oceans and seas that can serve as the underlying framework an ocean observing system,

Given the need for providing the market incentives required to develop new measurement technologies that will enable vessels to reach deeper into the water column from vessels underway,

Given the need for an efficient, cost-effective, and responsive organizational framework within which to encourage, develop, organize, and pursue these activities,

Given the need for an organization that can immediately begin to work with responsible authorities to resolve issues arising from the current international legal framework governing oceanographic activities (both interim and long-term solutions),

We propose the establishment of an international organization to be known as OceanScope. Its charge will be to fundamentally enhance our ability to monitor the global ocean water column on a sustained basis. It will obtain funding to provide (a) the operational support, (b) the observational and technological incentive, and (c) the long-range planning required to meet the stated objectives of the OceanScope mission.

OceanScope will be supervised by a Governing Board that will include representatives the merchant marine industries, the ocean-observing community, the marine technology industry and sponsors. It will have an Executive Director and Secretariat (the offices required to carry out its activities), and a standing Advisory Panel.

The OceanScope Governing Board will meet regularly to review progress in implementation and establish priorities for the Executive Director, Secretariat and Advisory Panel. The Board shall review the OceanScope charter every five years and update/amend it as required.

OceanScope shall have no other agenda than to strive to deliver the best possible information about the global water column in as close to real time as possible.

OceanScope shall, as appropriate, establish field offices or representatives at/near major shipping centers to provide operational support.

OceanScope shall ensure that the data flow from participating vessels takes place in a timely manner, and be subject to immediate and effective quality control measures.

OceanScope will pursue the resources to promote the development of new measurement strategies and will issue or coordinate calls for proposals in pursuit thereof.

OceanScope will maintain close ties with the user community and all other stakeholders with a vested interest in the timely availability of global water column data.

Appendix G: Membership of SCOR WG #133 – OceanScope

Participants at First Working Group Meeting, Montreal July 17-19, 2009

Full Members (11):

Joe Cox, CEO, Chamber of Shipping of America, representing Peter Hinchliffe, ICS

David Hydes, Scientist, National Oceanographic Centre, Southampton, UK

Markku Kanerva, Director, Deltamarin, Turku, Finland

Kuh Kim, Professor, Seoul National University, Seoul, Korea

Peter Ortner, Research Professor, University of Miami, USA

Chris Reid, Senior Fellow, SAHFOS, Plymouth, UK

Tom Rossby, Professor, University of Rhode Island, USA

Ute Schuster, Senior Research Associate, University of East Anglia, UK

Fred Soons, Professor, Utrecht University, The Netherlands

Javier Valladares, Navy officer (ret.) and Science advisor, Argentina

Yasuo Yoshimura, Professor, Hokkaido University, Japan

Associate Members (12):

Jim Churnside, Scientist, ESRL/NOAA, Boulder, CO, USA

Rich Findley, Director UM Marine Technology Group, Fort Pierce, FL, USA

Charlie Flagg, Professor, Stony Brook University, Stony Brook, NY, USA

Arnold Furlong, Director, ODIM Brook Ocean, Dartmouth, NS, Canada

Don Scott, Engineer, Sippican, Marion, MA, USA (representing James Hannon)

Robert Luke, VOS program manager, NOAA, Stennis Space Center, MS, USA

Jerry Mullison, Engineer, RDInstruments, San Diego, CA, USA

Glenn Pezzoli, Manager, SOP Program, SIO, La Jolla, USA

Steve Piotrowicz, U.S. Argo Program Manager, NOAA, Washington DC, USA

Corinna Schrum, Professor, University of Bergen, Norway

Peter Sigray, Professor, University of Stockholm, Sweden

Denise Smythe-Wright, Scientist, National Oceanographic Centre, Southampton, UK

Observing Participant:

Lawrence Mysak, McGill University, Montreal, Canada

Participants at Second Working Group Meeting, ICS, London April 12-14, 2010

Full Members (10):

Peter Hinchliffe, International Chamber of Shipping, London

David Hydes, Scientist, National Oceanographic Centre, Southampton, UK

Markku Kanerva, Director, Deltamarin, Turku, Finland

Kuh Kim, Professor, Seoul National University, Seoul, Korea

Peter Ortner, Research Professor, University of Miami, USA

Chris Reid, Senior Fellow, SAHFOS, Plymouth, UK

Tom Rossby, Professor, University of Rhode Island, USA

Ute Schuster, Senior Research Associate, University of East Anglia, UK

Fred Soons, Professor, Utrecht University, The Netherlands

Yasuo Yoshimura, Professor, Hokkaido University, Japan

Associate Members (10)

Richard Burt, Sales & Marketing Director, Chelsea Technologies Group

Rich Findley, Director, Marine operations, Fort Pierce, FL, USA

Charlie Flagg, Professor, Stony Brook University, Stony Brook, NY, USA

Boris Kelly-Gerreyn, Scientist, National Oceanographic Centre, Southampton, UK

Bev MacKenzie, Technical Liaison Manager, IMarEST

Jerry Mullison, Engineer, RDInstruments, San Diego, CA, USA

Steve Piotrowicz, U.S. Argo Program Manager, NOAA, Washington DC, USA

Wolfgang Schlegel, Lockheed-Martin Sippican, Marion, MA, USA

Corinna Schrum, Professor, University of Bergen, Norway

Denise Smythe-Wright, Scientist, National Oceanographic Centre, Southampton, UK

Appendix H: Principal OceanScope "Presentations" to Date (chronological order)

Summary

Provided below is a list of the formal presentations given by the Working Group members in a variety of contexts to begin the process of obtaining feedback from the diverse industry and scientific communities.

Before SCOR/IAPSO WG Established:
T. Rossby: 'Sustained ocean observations from merchant marine vessels'.
Title of presentations at:
JCOMM/SOT-4 meeting at WMO Headquarters, Geneva, Switzerland, April 2007
SCOR executive committee meeting, Bergen, Norway, August 2007
Town hall meeting. Ocean Sciences Conference, Orlando, FL, March 2008

On behalf of WG:
T. Rossby, Kuh Kim and Peter Ortner (presenter). OceanObs '09. OceanScope: sustained ocean observations from merchant marine vessels. Venice, October 2009

T. Rossby, OceanScope – a SCOR/IAPSO sponsored initiative. A discussion given at CIMAS, AOML, Miami, January 29, 2010

T. Rossby, OceanScope: A Science – Industry Partnership for the Systematic Study of the global ocean water column: A Discussion at ECMWF, Reading, UK, April 15, 2010

Richard Burt: 'Oceanographic sensors and technology'. IOC-50th anniversary plenary session, UNESCO, Paris, May 2010

Boris Kelly-Gerreyn: 'Oceanography all day every day and everywhere: Marine research and the role of the shipping industry'. Talk given at American Bureau of Shipping UK National Committee Meeting, London, May 2010

Phillip C. Reid: 'OceanScope – a New Paradigm for Observing the Water column and Surface of the Global Ocean'. Sustainable Ocean Summit, Belfast, June 2010

T. Rossby: OceanScope: 'A Science - Industry Partnership for the Systematic Study of the Global Ocean Water Column'. Seminar on Green Internet and Sensors, Chalmers University, organized by Science and Innovation Network, British Embassy, Stockholm. Göteborg, June 2010.

P. Hinchliffe: Presentation to Shipbuilders. Tokyo, October, 2010

David Hydes: 'SCOR- OceanScope and ships of opportunity'. Talk given to Marine Observation and Data Expert Group (MODEG). Brussels. November, 2010

T. Rossby: 'OceanScope'. Talk given at WOC meeting, Paris, Dec. 12-13, 2011.

D. Hydes: 'International Carbon Coordination Project'. Talk given at WOC meeting, Paris, Dec. 12-13, 2011

P. Ortner: 'Royal Caribbean Cruise Lines: Next Generation Ships of Opportunity Program'. Talk given at WOC meeting, Paris, Dec. 12-13, 2011.

M. Edwards: 'Continuous Plankton Recorder'. Talk given at WOC meeting, Paris, Dec. 12-13, 2011 - Given by P. Ortner.

Appendix I: Glossary and Acronyms

ADCP: acoustic Doppler current profiler

Argo: float that surfaces periodically to report position and water properties

ASOF: Arctic and Subarctic Ocean fluxes

CDIAC: Carbon Dioxide Information Analysis Center

CFD: computational fluid dynamics

CLIVAR: Climate Variability project

Coriolis force: Force proportional to speed at right angle to the direction of motion

CPR: Continuous Plankton Recorder

EEZ: Exclusive Economic Zone

EGCM: Eddy-resolving general circulation model

Eulerian: Observing variables at fixed points as a function of time

FerryBox: Instrument that records surface water properties as a function of time

GEK: Geoelectrokinetograph; it measures currents using Earth's magnetic field

GEOSECS: Geochemical Sections project

Geostrophic flow: a balance between the pressure field and the Coriolis force

GTS: Global telecommunications system sponsored by WMO

HSDPA: High-speed data packet access

IAPSO: International Association for the Physical Sciences of the Oceans

ICOS: Integrated Carbon Observing System

ICS: International Chamber of Shipping, London, UK

IGO: Inter- or international governmental organization

IMO: International Maritime Organization

IOCCP: International Ocean Carbon Coordination Project (IOC, SCOR)

IOC: Intergovernmental Oceanographic Commission

Iridium Next: Next generation Iridium satellite cell-phone system

Lagrangian: following fluid parcels and their properties as a function of time

LIDAR: Light detection and ranging

MAERI: Marine Atmospheric Emitted Radiance Interferometer

MSR: Marine scientific research

NAO: North Atlantic Oscillation

NGO: Non-governmental organization

Oleander: Vessel that operates between NJ and Bermuda

PCC: Pure car carrier

PCTC: Pure car and truck carrier

Ro-Ro: roll on roll off cargo vessels

SAVE: South Atlantic Ventilation Experiment

SCOR: Scientific Committee on Oceanic Research

SOOP: Ship Of Opportunity Program

SSRM: spread-spectrum radio modem

TOLEX: Tokyo-Ogasawara Line Experiment

TSG: Thermosalinograph; see FerryBox

TTM: Towed transport meter; see GEK

TTO: Transient Tracers in the Ocean project

UNCLOS: UN Convention on the Law of the Sea

VOS: Volunteer observing ship

Wi-Fi: wireless local area network based on the IEEE 802.11 standards

WMO: World Meteorological Organization

WOC: World Ocean Council

WOCE: World Ocean Circulation Experiment

XBT: Expendable bathythermograph

XCP: Expendable current profiler

XCTD: Expendable conductivity, temperature and depth profiler

Appendix J: OceanScope Implementation Budget

Summary

Provided below is a rough estimate of the funding required for the first five years of OceanScope, including its organizational infrastructure and implementation of a North Atlantic Test Bed.

Introduction

The following cost estimates can be used as a starting point. Organization and North Atlantic Test Bed Implementation are considered separately. The first includes administration and related expenses. We are not including herein any costs associated with Early Issue activities (see Figure 3.2) and have assumed the Working Group will be interested in continuing to participate on a volunteer basis. However, progress would definitely be accelerated (and Year 1 reached much sooner) if funds can be found to cover costs such as technical working subgroup and *pro tem* Advisory Panel meeting logistics as well as recommended early engineering studies. It has also been suggested to us that we will need professional assistance with respect to private philanthropic fund-raising to implement the Test Bed and that too will require start up financial assistance. None of these preliminary expenses are included in the following budget estimate.

1. OceanScope Organization

The OceanScope organization would eventually include an Executive Director (part of whose duties include the planning function), three officers (operations, data, and technology), permanent, and temporary staff. A rough estimate of salary costs would be four high-level professionals (averaging US$100,000 each), two postdoctoral fellows ($60,000 each), four office and data management staff ($60,000 each) = $760,000. For simplicity we double these salaries to cover fringe benefits and overhead for a total of about $1.5 million per annum. Computers, supplies, office rental and travel will cost perhaps another $0.2 million per annum. Except for possible expansion of operations if additional field offices are required, we do not anticipate organization costs to be significantly higher for a 100-ship global operation, and as earlier noted, not all of these positions need to be filled immediately.

Approximate cost of equipping a Test Bed fleet of 20 vessels

Table J.1 summarizes a fully equipped OceanScope vessel. It lists instrument type, location, unit purchase cost, costs to prepare vessel (signal and power wiring, plumbing, sea-chest for hull-mounted equipment), and whether the vessel needs to be dry-docked. All these costs represent relatively conservative estimates. The reader is referred to Appendix A for a detailed discussion about vessel modifications, and Appendix B regarding present and future instrumentation opportunities.

Table J.1: OceanScope instrumentation including vessel preparation costs

Instrument	Instrument site	Unit cost ($)	Vessel costs ($)	Dry-dock
CORE INSTRUMENTATION				
Core Flow-Thru System (t,sal,O_2,fluor)	Engine room	50,000	5,000	No
ADCP, 38 kHz	Hull	150,000	40,000	Yes
ADCP, 150 kHz	Hull	50,000	(shared with 38)	Yes
Autonomous XBT system	Stern area	40,000	5,000	No
GPS-heading for ADCP	Top side	20,000	5,000	No
Data logging/System Integration/Data Transmission	Bridge	10,000	5,000	No
OPTIONAL INSTRUMENTATION DESIRABLE ON SELECTED ROUTES				
"Continuous Plankton Recorder (CPR)"	Stern area	10,000	10,000	no
CO_2 seawater system	Engine Room	100,000	5,000	no
CO_2 atmospheric	Bow	100,000	20,000	no
Nutrient Sensor	Engine Room	100,000	5,000	no
AutoSampler	Engine Room	25,000	5,000	no
Sample Processor	Engine Room	100,000	5,000	no
Automated Atm Gas Sampler	Bow	50,000	5,000	no

The total cost per ship is about $380,000 for the Core fully-automated instrumentation suite. The Optional Instrumentation on selected routes would add up to an additional $540,000 per ship. Rounding the Core up to $400,000/ship, the cost for 20 vessels would be $8.0 million. Most of the above equipment should last 10 years or so, such that a prorated annual cost would be about $800,000. Three ships with Optional Instrumentation would add another $1.62 million. Nutrient sensors, autosamplers, and sample processors can be deployed where sufficient shore-side technical support can be made available. CPR can be deployed where arrangements can be made for handling at sea by shipboard personnel since it cannot at this time be fully automated. These funds would all be expended within the first five years to implement the North Atlantic Test Bed.

2. Test bed operation

The following discussion gives an initial estimate of operating costs. It attempts to include the major costs, but it is not a detailed budget. Certain assumptions were made. Specifically, with respect to operations, it is assumed that:

1. SAHFOS will continue to take the lead with respect to CPR sample analysis and instrumentation preparation. It is a highly developed and experienced organization that is well positioned to provide advice for and participate in future CPR activities around the world.

2. The FerryBox consortium, which has been coordinating all FerryBox activities in Europe shelf areas, could provide the foundation for activities such as the Nutrient Sampler, Autosampler, and Sample Processor.

3. The few groups already experienced with operating ADCPs on commercial platforms would contribute their experience with regard to the installation of OceanScope ADCPs as well as the processing and distribution of ADCP data.

4. XBT operations on commercial vessels are being handled efficiently by a number of institutions that coordinate their activities through JCOMM-SOT as part of SOOP. We expect they will be willing to assist with OceanScope XBT and future-generation probe operations because that data will be collected in conjunction with a considerably expanded suite of relevant oceanographic data. They would therefore incorporate OceanScope XBT data into their own data quality control and archiving systems.

5. ICOS, which functions as the foundation for the global carbon measurement network, would provide their expertise with respect to carbon dioxide and other atmospheric gas measurement systems and associated data management issues.

Nonetheless, with respect to OceanScope vessel operators all of the above activities will be carefully coordinated through the single point of contact provided by OceanScope operations. This is a central tenet of the OceanScope operational paradigm.

With the above understanding Table J.2 gives an overview of likely operational and supply costs per vessel-year. As with installation (Table J.1), they are broken down into Core and Optional costs.

Table J.2: OceanScope operating and supply costs per vessel-year

Instrument	Months of personnel time if cost basis	Annual staffing costs (US$)	Supply costs ($)
CORE INSTRUMENTATION			
Core Flow-Thru System	1	15,000	4,000
ADCP, 38 kHz	2	30,000	2,000
ADCP, 150 kHz	2	30,000	2,000
XBT system	1	15,000	60,000
GPS/Data Logger	1	15,000	10,000
OPTIONAL INSTRUMENTATION			
CO including SW-ATM-and other Atmospheric Gases	NA	100,000	included
Continuous Plankton Recorder (CPR)	NA	300,000	4,000
Nutrient Sensor	0.5	4,000	1,000
AutoSampler	??	??	??

Assumptions in preparing Table J.2:
1 person-month = $15,000 (including fringe and overhead).
CPR: Operated 10% of the time and alternate segments only
Core Flow-Thru: 1 person-month per year for service and processing of data.
ADCP: 2 person-months per instrument per year.
Carbon and Other Gas Costs taken from ICOS2010 annual per ship estimate
XBT: 1 person-month to service and process data from one ship. The table assumes an XBT every three hours (~60 NM distance). Assuming the ship is at sea 240 days/year, and 8 XBTs/day = 1920 XBTs = $60,000 at $30/XBT.

The total annual core operating and supply costs per ship for the Core Instrumentation are $183,000. For 20 vessels this would total $3.66 million. Assuming that during the Test Bed phase three ships are fully instrumented (including all Optional Instrumentation) that adds another $1.2 million, excluding the Auto-sampler, which would be deployed on a few selected occasions primarily for intercalibration purposes and assuming the ICOS instrumentation. The total operational total for the full Test Bed fleet would be about $4.9 million per year. This cost is based upon the present experience of Working Group participants already responsible for the installation, operation and maintenance costs for individual system components (ADCP, flow through/FerryBox systems, CO_2, CPR, XBT etc.) in other contexts. No potential savings due to economies of scale or synergies in maintenance and operational cycles have been included.

In accordance with our Implementation Timeline (see Figure 3.2), each vessel in the fleet of 20 vessels would operate only two of the first years on average (2x20 = 40 vessel-years). Therefore, the total capital equipment and operational cost for the first five years would be $19.4 million. If as suggested in Chapter 3, and again following the timeline, we gradually fill positions to staff the Secretariat (50%, 75%, 75%, 100% and 100%) that adds another $7.5M for a total cost over the first five years of about $27 million. Expansion into global operations after Year Five can be estimated roughly from the above tables. Vessels for additional routes will proportionally add to the capital equipment and annual operational costs, but core organizational costs would change only marginally since our timeline indicates that the central function would be fully staffed by the end of Year Five.