SHIP-BASED REPEAT HYDROGRAPHY: A STRATEGY FOR A SUSTAINED GLOBAL PROGRAM

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ABSTRACT

Ship-based hydrography is the only method for obtaining high-quality measurements with high spatial and vertical resolution of a suite of physical, chemical, and biological parameters over the full ocean water column, and in areas of the ocean inaccessible to other platforms. Global hydrographic surveys have been carried out approximately every decade since the 1970s through research programs such as GEOSECS (Geochemical Ocean Sections Study), TTO/SAVE Transient Tracers in the Ocean (/South Atlantic Ventilation Experiment), WOCE/JGOFS (World Ocean Circulation Experiment/Joint Global Ocean Flux Study), and CLIVAR (Climate Variability and Predictability). It is time to consider how future surveys can build on these foundations to create a coordinated network of sustained ship-based hydrographic sections that will become an integral component of the ocean observing system. This white paper provides scientific justification and guidelines for the development of a regular and coordinated global survey.

1. INTRODUCTION

Despite numerous technological advances over the last several decades, ship-based hydrography remains the only method for obtaining high-quality, high-spatial and vertical resolution measurements of a suite of physical, chemical, and biological parameters over the full water column.

Ship-based hydrography is essential for documenting ocean changes throughout the water column, especially for the deep ocean below 2 km (52% of global ocean volume not sampled by profiling floats). Hydrographic measurements are needed to:

- reduce uncertainties in global freshwater, heat, and sea-level budgets,
- determine the distributions and controls of natural and anthropogenic carbon (both organic and inorganic),
- determine ocean ventilation and circulation pathways and rates using chemical tracers,
- determine the variability and controls in water mass properties and ventilation,
- determine the significance of a wide range of biogeochemically and ecologically important properties in the ocean interior, and
- augment the historical database of full water column observations necessary for the study of long timescale changes.

These results will be critical for evaluating ocean models and providing data constraints for state estimation, assimilation and inverse models. In addition, ship-based hydrographic measurements provide a standard for validating new autonomous sensors and a reference/calibration dataset for other observing system elements (in particular Argo profiling floats, expendable bathythermographs (XBTs) and gliders). Hydrography cruises also provide cost-effective access to remote ocean areas for the deployment of these instruments.

The first attempt at a global hydrographic survey took place during the International Geophysical Year (1957-1958), but only in the Atlantic was a systematic high-quality survey conducted [1]. The Geochemical Ocean Sections Study (GEOSECS) did provide hydrographic surveys in all three major ocean basins (Atlantic 1972-73, Pacific 1973-74, and Indian 1977-78), but focused on the chemistry and did not provide high-resolution land-to-land transects. It was not until the decade of the 1990s that the World Ocean Circulation Experiment (WOCE) conducted an extensive survey of hydrographic properties and circulation in the global ocean in an effort to develop a global picture of ocean transport that was as synoptic as possible. In collaboration with the WOCE global survey, the Joint Global Ocean Flux Study (JGOFS) ensured that carbon measurements were made on a majority of the cruises. The WOCE/JGOFS effort led to numerous scientific advances in understanding the physical and biogeochemical state of the global ocean, including:

- computation of a globally consistent picture of meridional heat, freshwater, oxygen and nutrient transport [2, 3 and 4] with associated estimates of divergence and air-sea exchange, and a comprehensive analysis of the errors involved [5],
- quantification of the temporal variations of oxygen from biology, ventilation, and circulation [6] and [7],
- characterization from the spatial patterns of alkalinity of the production and dissolution of calcium carbonate [8] and the impact of anthropogenic CO_2 on ocean acidification [9 and 10],
- determination of the global-scale inventory of anthropogenic CO_2 in the ocean [11] which is providing unprecedented constraints on the global re-distribution of anthropogenic CO_2 [12],
- development of constraints on ocean centennial and decadal time-scale ventilation from natural and bomb-radiocarbon [13] and documentation of ventilation pathways returning deep-water to the upper ocean using ^{3}He [14],
- estimation of oceanic denitrification and nitrogen fixation rates [15], [16] and [17],
- construction of the first large-scale data set of full-depth diapycnal diffusivities covering all major ocean basins [18],
- development and application of inverse methods that estimate the exchange fluxes of natural and anthropogenic carbon between the atmosphere and the ocean [19] and [20],
- development of assimilating basin and global-scale models bringing insight to our understanding of 3-dimensional time-varying ocean circulation and its impact on property budgets and their variability [21, 22, 23, 24 and 25],
- determination of regional and global-scale oceanic inventories [26] and [27] and distribution of CFCs (chlorofluorocarbons), which has provided a means to determine water-mass formation rates and the oceanic uptake of anthropogenic CO_2 [28 and 29], and
- the first accurate estimates of dissolved organic carbon (DOC) in the ocean and its transport [30] and [31].

While WOCE and JGOFS were successful in answering many first-order questions about large-scale ocean circulation and carbon inventories, their results also raised many new questions concerning ocean variability, controls on carbon and tracer inventories and distributions and long-term secular trends associated with climate change, oceanic CO_2 uptake and ocean acidification. These programs confirmed that the ocean exhibits significant interannual variability on top of the expected smooth decadal trend as part of patterns of global change, complicating efforts to detect and attribute human influences on the ocean. WOCE and JGOFS, along with many other studies conducted over the last two decades, suggests that the effect of climate forcing on the ocean may be substantial, but is poorly understood, and that the next generation of hydrographic surveys would need to be designed to examine the drivers and impacts of this variability, in concert with modelling and assimilation activities.

An international conference entitled "The Ocean Observing System for Climate" (or OceanObs'99) set the initial scientific and implementation framework for post-WOCE hydrography [32]. Recognizing the need to focus research on climate variability as well as on the documentation of trends from anthropogenic forcing, it was decided to incorporate a program of repeat hydrography in the 15-year international Climate Variability and Predictability Study (CLIVAR). This first global repeat survey of a select subset of WOCE hydrographic sections is scheduled to be completed in 2012 and the field program is presently 75% completed.

Preliminary results show significant changes in water mass distributions and biogeochemical properties over the last decade, influenced by both secular changes (e.g. anthropogenic CO_2 invasion) and natural climate mode variability such as the North Atlantic Oscillation, the Pacific Decadal Oscillation and the Southern Annular Mode. Some recent research highlights on interannual variability include:

- documentation of substantial changes in the oceanic inorganic carbon content, driven by both the uptake of anthropogenic CO_2 and natural variability
- evidence of large-scale changes in oceanic oxygen concentrations
- near global-scale warming of abyssal waters of Antarctic origin, and freshening of these waters in deep basins adjacent to Antarctica
- freshening of the Atlantic waters
- equatorward penetration of CFCs from high-latitude sources filling the deep and abyssal basins on time scales of decades, allowing estimates of water mass formation rates, and
- evidence of reduction in downstream primary productivity brought on by strong convection and mode water formation.

These results illustrate the importance of repeated global surveys for interpreting and attributing changes to physical and dynamical mechanisms operating on a variety of time scales. As this CLIVAR hydrography program comes to an end, it is clear that the global repeat survey approach is very effective at quantifying variability and trends of a large suite of physical and biogeochemical parameters. Integration of ship-based repeat hydrography with other observing system elements, such as the Argo profiling float program, Ship of Opportunity Program, Volunteer Observing Ship Program, time-series stations and satellite remote sensing that provide complementary scales of information, is required for the accurate monitoring of ocean change and variability. A comprehensive ocean observing system, in conjunction with synthesis and numerical models, is vital to understand the drivers of global climate change and variability

It is time to consider how future global ship-based hydrography can build on the foundations established by the global surveys of GEOSECS, WOCE, JGOFS, and CLIVAR. The IOCCP (International Ocean Carbon Coordination Program) and CLIVAR, in collaboration with the Integrated Marine Biogeochemistry and Ecosystem Research Project (IMBER) and the Surface Ocean-Lower Atmosphere Study (SOLAS), developed the Global Ocean Ship-based Hydrographic Investigations Panel (GO-SHIP) to bring together interests from physical hydrography, carbon, biogeochemistry, Argo, OceanSITES (OCEAN Sustained Interdisciplinary Time series Environment observation System), and other users and collectors of survey data. The Panel is tasked to develop guidelines and a general strategy for the development of a globally coordinated network of sustained ship-based hydrographic sections that will become an integral component of the ocean observing system.

While it is essential to maintain a repeat hydrography program firmly linked to national, regional and global research programs, some elements of coordination and implementation could benefit from a more proactive oversight structure, including the development of

- a sustained international coordination body and scientific steering committee for integrated/interdisciplinary repeat hydrography that is independent of any specific time-limited research program (for example, following the model of Argo or OceanSITES)
- a single, international information and communications forum to facilitate field program planning, agreements on standards and methods, and data sharing/synthesis activities, and
- coordinated international data management and data synthesis activities.

2. SCIENTIFIC OBJECTIVES AND RATIONALE

- The principal scientific objectives for a sustained repeat ship-based hydrography program have two closely linked components: (1) understanding and documenting the large-scale ocean water property distributions, their changes, and drivers of those changes, and (2) addressing questions of a future ocean that will increase in dissolved inorganic carbon (DIC), become more acidic and more stratified, and experience changes in circulation and ventilation processes due to global warming, altered water cycle and sea-ice. An observation program must be designed in light of these expected changes (and potential surprises) and the way in which they will interact with natural ocean variability.

The full version of the community white paper (www.go-ship.org) provides information about recent findings, emerging issues, and implications for sampling for the following topics:

1. Understanding the controls and distribution of natural and anthropogenic carbon and biogeochemistry in the ocean interior

Inorganic carbon and anthropogenic carbon

- Dissolved organic carbon and export flux
- Ocean acidification
- Oxygen
- Pigments and bio-optical measurements
- Trace elements and isotopes

2. Understanding ocean changes below 2 kilometers and their contributions to global heat budget and sea-level budgets

3. Understanding the variability in water masses, ventilation, and pathways
4. Quantifying transports
5. Evaluating ocean models
6. Providing a platform for testing new shipboard sensors and providing an opportunity to deploy and evaluate other platforms
7. Underway measurements

- Climate quality surface meteorology and air-sea fluxes of heat, freshwater, momentum
- Underway oceanographic and meteorological sampling
- Carbon dioxide

3. STRATEGY

3.1. Temporal and Spatial Sampling

In developing an integrated and interdisciplinary framework for ship-based repeat hydrography, it is important to consider the time scales of variability of the phenomena under investigation. For example, repeat occupations at decadal intervals are mostly appropriate for the characterization of the uptake of transient tracers, such as bomb radiocarbon, as these inventories are expected to change smoothly with time. For the detection of changes in the anthropogenic carbon inventories, one is challenged by two opposing constraints. On the one hand, the limits for the detection of changes in anthropogenic CO_2 are 8-10 years for most regions [33], so that a decadal repeat frequency seems adequate. On the other hand, changes in the natural carbon cycle occur on shorter temporal intervals, requiring higher frequency sampling. Since both (natural and anthropogenic) signals are present in the measured dissolved inorganic carbon fields, one would therefore infer a need for higher frequency sampling. However, the availability of ancillary observations, such as sea-surface height, may substantially relax this requirement, so that an approximate decadal repeat frequency could be sufficient for determining the changes in the oceanic inventory of anthropogenic CO_2. A more detailed assessment requires a dedicated sampling study. For other goals, a decadal survey is clearly less appropriate. For example, the quantification of transport changes requires higher frequency sampling since it is known to have substantial interannual variability. While the Argo program will resolve some of these issues for physical variables in the upper 2 km, it does not currently sample deeper than 2 km or in areas with ice cover. Another factor is the need for approximate synopticity on basin scales and the constraint that cruises are carried out on a rolling basis, based either on funding cycles, ship schedules, or a deliberate strategy of trying to carry out several cruises each year in order to capture special events that might occur. A high-frequency survey in addition to the decadal survey would be effective to reduce the biases in some regions, such as the western boundaries, where the basin-scale dynamic response signals are strong and high-latitude areas where property concentrations/inventories are affected by short-term climate variations through water mass formation.

Taking into account these considerations, two types of surveys are presently required to meet scientific objectives: (1) decadal surveys and (2) a sub-set of the decadal survey lines sampled at high frequency (repeats every 2-3 years), ideally, repeats of lines sampled in the past decade. To capture the change within a quarter or shorter period of the decadal time scale, the decadal repeat survey requires full basin synopticity over a < 3 year period (beginning in 2012). Both surveys should be initiated no later than 2012 to ensure continuity following the termination of the current CLIVAR survey.

This level of synopticity may become less necessary as assimilation techniques develop, but is currently necessary to distinguish between spatial and temporal variability. The Argo program provides a crucial complement to hydrographic section data, a synergy that has not yet been fully exploited. With the logistical difficulties of obtaining large-scale synoptic snapshots of basin dynamics and properties, it is imperative to develop methods of normalizing section data to a common year, and in some cases, over 10-year scales, without introducing significant biases. These techniques do not yet exist, and use of high-frequency Argo data and data assimilation methods will be increasingly important to develop the required methods.

The survey to begin in 2012 will take into consideration the sampling schedule carried out during the CLIVAR program in order to ensure decadal repeat frequency for each basin as much as possible. For example, the Atlantic was sampled most densely between 2003-2005, the Pacific between 2005-2007, and the Indian in 2007-2009, implying that the first post-CLIVAR survey should start with the Atlantic from 2012-2014, the Pacific from 2015-2017, and the Indian from 2017-2019.

Spatial sampling should follow past surveys, with major efforts carried out in the Atlantic, Pacific, and Indian oceans, with the Southern Ocean integrated as part of the other basins. The Arctic is of increasing importance and should be emphasized, either as a separate effort or a coordinated effort from Atlantic and Pacific basin efforts.

Ideally, sections should extend from coast to coast, or coast to ice, follow standard WOCE lines with small modifications as necessary for territorial waters, ice coverage, etc., and maintain the standard WOCE sampling strategy.

Horizontal resolution:

- Physical measurements: nominal 30 nautical mile spacing with higher resolution in regions of steep topography and boundary currents.
- Carbon measurements: carbon and tracers at 60 nautical miles or better.

Vertical resolution: full water column.

It is also recognized that several open-ocean hydrographic programs exist that do not meet the sampling resolution criteria outlined by the GO-SHIP Panel or are one-time hydrographic surveys with no commitment for repeats. As with the WOCE program, which was composed of both repeat sections and one-time surveys, the GO-SHIP Panel recommends that all hydrographic sections meeting minimum criteria (see below) be included as part of the global hydrographic program. Broad participation in the hydrography program will facilitate standardization of methods, data management and sharing, and integration of all appropriate ocean interior data in data synthesis activities.

3.2. Core Variables

For the decadal survey, the core program lines should measure:

- temperature, salinity, and pressure
- oxygen, phosphate, silicate, and separate measurements of NO_2 and NO_3 if possible; otherwise, $NO_2 + NO_3$ (with clear reporting of what was measured)
- at least two (2) carbon parameters (e.g.: DIC, Alkalinity, pCO_2, pH), where DIC and Alkalinity are the preferred pair, but spectrophotometric pH is a useful 3rd parameter because of high measurement precision and growing interest in ocean acidification.
- carbon isotopes (^{13}C, ^{14}C), chlorofluorocarbon tracers (CFC-11 and/or 12) and SF_6; tritium and helium-3 should also be measured on key sections, including meridional sections P10, P16, P18, I06S, I08, I10, A16, A22, A20, and zonal sections I05, P06, P04, and A24).
- shipboard and lowered ADCP (Acoustic Doppler Current Profiler

Salinity and oxygen should also be measured on every bottle. Also recommended are organic carbon parameters (POC (Particulate Organic carbon, DOC (Dissolved organic carbon)) and underway surface measurements (including pCO_2, pigments, and related biological parameters at the surface). By 2012, microstructure measurements from profilers may also be considered for routine application during the next decade of hydrography. A certain subset of trace elements and isotopes should be included in future high-frequency repeat sections, particularly for parameters to deduce atmospheric mineral dust deposition to the surface ocean in key areas.

For bio-optical measurements, GO-SHIP endorses the recommendations of the International Ocean-Colour Coordination Group, including the following parameters:

Instruments to be added to a profiling CTD (Conductivity-Temperature-Depth):

- Fluorometer to measure chlorophyll fluorescence
- Transmissometers and/or light-scattering sensors and nephelometers to measure particle beam attenuation coefficient
- PAR (Photosynthetically Active Radiation) sensor (where possible)

Water samples collected for the following measurements:

- Chlorophyll-*a* (Turner Fluorometer)
- HPLC (High-Performance Liquid Chromatography) pigments
- Phytoplankton absorption
- CDOM (Colored Dissolved Organic Matter) (desirable measurement)
- Flow cytometry

Many of the above samples can be stored in liquid nitrogen for later analysis back in the laboratory.

On deck measurements:

- Continuous recording of incoming photosynthetically-active radiation (PAR), using a PAR sensor with a data logger (automatic).
- Measurements of spectral reflectance using a hyperspectral hand-held radiometer.

Several ancillary observations should be made whenever possible. The repeat hydrographic ships should make surface meteorological observations, following the guiding principles of the WOCE hydrographic program described in the handbook by

Bradley and Fairall [34]. The observations should include wind speed and direction (relative to the ship and corrected to absolute), air temperature and humidity, sea surface temperature, rainfall, barometric pressure, incoming shortwave radiation, and incoming longwave radiation. Several bio-optical measurements are also highly desirable, including profiling underwater spectral-radiometer measurements and photosynthesis-irradiance experiments.

It is also suggested that each cruise should collect between 20 and 100 seawater samples (150ml plastic bottles) for the direct measurement of density in the laboratory, in order that the effect of the spatial variation in the composition of seawater can be estimated. The 150ml bottles would be sent to a laboratory where their density (at the laboratory temperature and pressure) would be measured with a vibrating tube densimeter along with the sample's Practical Salinity. The same laboratory procedure would be applied to some ampoules of standard seawater as a check on the laboratory procedure and as a check of the stability of the standard seawater ampoules.

For the high-frequency/other sustained repeat lines, T, S, O_2, and nutrients should be measured as the minimum core variables, as well as any other variables useful for understanding subdecadal-scale variability. The target vertical spacing for these lines can be selected according to the water masses under investigation. However, during the decadal survey period in each ocean basin, the high-frequency lines should be carried out using the same specifications as the decadal survey in order to construct a uniform data set over the whole basin.

For one-time or non-core survey lines, sections should be open-ocean, adhere to the data sharing policy (below), and follow the criteria for high frequency lines.

3.3. Sustained Repeat Lines

Figure 1 below outlines the repeat sections felt to be most critical for the decadal survey (solid lines) and the high-frequency repeat lines (dashed lines). Many of the lines, both decadal and high-frequency, represent sections that already have on-going national commitments for implementation. Several of the lines represent sections that are important for science goals, although may not be possible owing to problems with territorial waters or ship resources. The lines shown here are the minimum thought required for a global periodic survey. Additional lines would help to meet many other program goals.

The program design calls for zonal sections at mid-latitudes in all the major ocean basins, locations where the ocean transports of heat and carbon are near their maximum. Zonal lines in the sub-polar regions and the tropics are designed to capture maximum freshwater transport by the ocean. The meridional lines, at least one through each set of ocean basins, are ideal for inventory studies of ocean properties such as heat and CO_2. Sections also cross the Antarctic Circumpolar Current at various chokepoints around the globe to facilitate studies of inter-ocean transports, including both limbs of the meridional overturning circulation. In addition, sections around Antarctica and in the northern North Atlantic Ocean allow monitoring of outflows of bottom and deep water just downstream of their formation regions, as well as upwelling of warm deep waters that may be critical to understanding changes in the cryosphere. Finally, some Arctic sampling is essential, as recent changes there are dramatic.

3.4. Quality Assurance Practices

To detect statistically significant decadal changes in any property field requires high- quality data. Not only are high precision and accuracy necessary, but also knowledge of the uncertainty in the reported numbers. As part of the GO-SHIP effort to reach the highest possible data quality, the 1994 WOCE hydrographic program manual is being revised and should be published in early-2010. These references will provide details of best practice for each of the variables to ensure comparability of measurement programs. Similarly, the use of certified reference materials (CRMs) is very helpful in improving data quality and should be used as frequently as necessary to reach the highest possible data quality. For alkalinity and DIC the use of CRMs is now a common practice that has increased the quality of measurements significantly. Much effort is being put into the development of CRMs for nutrients [35]. Efforts to provide CRMs for other parameters, such as oxygen and pH are underway. Using these materials on all repeat hydrography cruises will solve a key problem by enabling the relative accuracy of the measurements to be maintained between cruises.

4. DATA MANAGEMENT, DATA SHARING, AND PRODUCT DEVELOPMENT

The general strategy proposed for data management is to better support and coordinate the existing data assembly and archive centers, to develop new tools and centers to manage the increasing variety of properties observed on hydrographic lines, to coordinate data management activities with those of the operational programs such as Argo and OceanSITES, and to improve technology and data policies to release data in a more timely manner.

It is also proposed to develop a single international information center for repeat ship-based hydrography that will serve as a central communication and coordination forum and include a portal or directory to the data assembly centers.

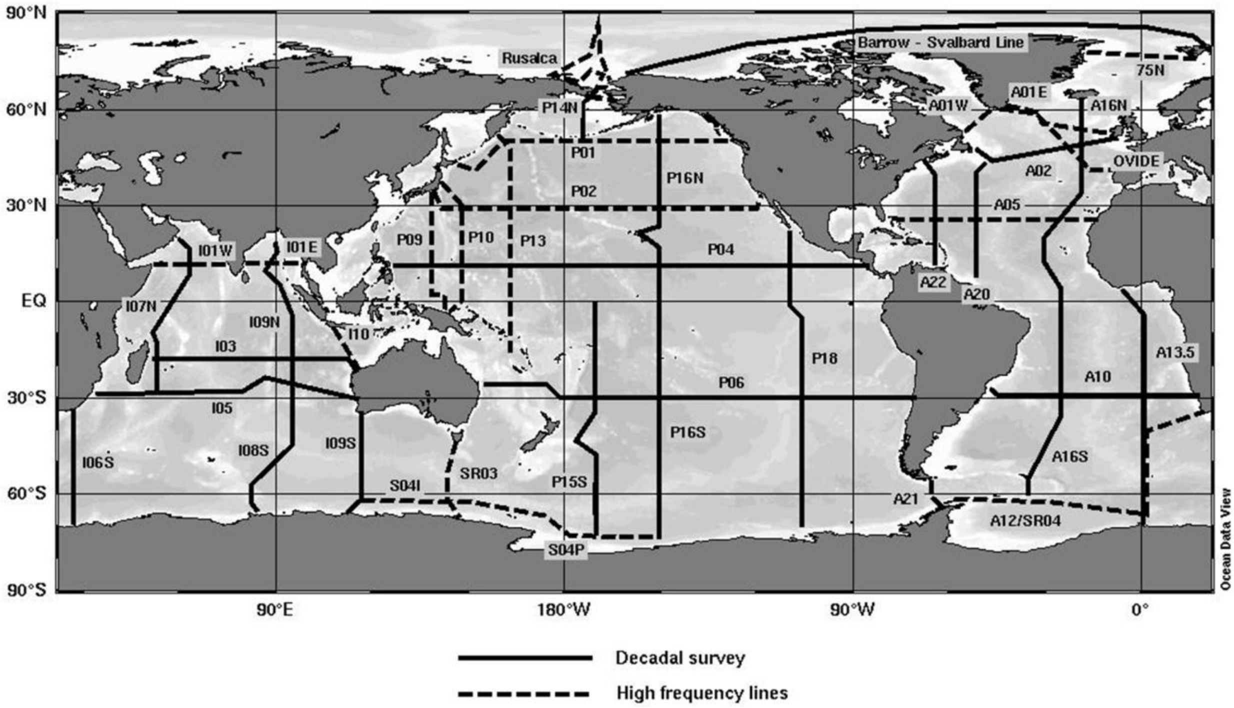

Figure 1. Decadal (solid lines) and high-frequency (dashed lines) repeat sections.

4.1. Data Sharing and Release Policy

While it is important to protect individual scientific interests and investment of effort by investigators, evolving towards a more operational system will be essential for justifying a sustained program with national funding support, and closer coordination with the operational programs may require some changes to data-release practices. For example, in the next-generation hydrographic program, it may be possible to implement real-time or near real-time CTD data release using Argo technology. Near real-time data, release of underway carbon and other semi-automated biogeochemistry measurements, may also be possible through closer coordination with the Global Ocean Surface Underway Data Project (GOSUD) and the Shipboard Automated Meteorological and Oceanographic System (SAMOS) programs, which have developed a data management system for real-time surface temperature and salinity data from research ships.

At present, the GO-SHIP panel recommends the following data-release guidelines:

- Preliminary dataset released within 6 weeks (e.g., all data measured on the ship)
- 6 months for final physical data
- 1 year for final data of all other variables (except for isotopes or tracers with shoreside analysis where 1 year is difficult).

The relatively rapid release of data is motivated by their usefulness for climate studies, which are of increasing societal importance. Some countries are already following these guidelines. However, to facilitate rapid release of data by all participants, a system should be developed to appropriately recognize the efforts of data contributors. While having data contributors participate in synthesis activities for co-authorship could resolve some issues of ownership, ultimately the international research community needs to evolve to the point that data are released as soon as possible without waiting for a 2-3 year synthesis activity. Establishing community-wide practices to standardize how to appropriately acknowledge data contributors may help some participants to accelerate their current data-release practices. One solution that should be adopted immediately is to publish the Final Cruise Reports in the journal *Earth System Science Data* (ESSD) with all participating PIs as authors.

4.2. Data Assembly and Archive Centers

Several data centers currently provide data management services for particular types of hydrography data. However, to meet the needs of a sustained global program, data assembly centers will need dedicated staff time and new funding, and will need to be increasingly integrated with the data management systems for other sustained programs such as Argo and OceanSITES. The challenges of such integration, both operationally and financially, should not be underestimated, but without this level of support for the data centers, a globally coordinated hydrography program with regular deliverables will not be possible.

4.3. Data Products and Joint Synthesis Activities

Development of international synthesis activities must address new realities of working within the framework of a sustained observation program that has no "sunset clause", but which will have a requirement to produce scientific products on a time scale that is much shorter than the traditional 10-year approach carried out by global research programs in the past. The repeat hydrography program will need to continually justify its value through publications and data products, and while analyses of individual and small groups of investigators will play a valuable role in this regard, development of a mechanism for data syntheses should also help to address these needs.

Data syntheses activities should be driven by the science. Data syntheses are only successful when there is a clear science issue to be resolved through standardizing and merging of basin- and global-scale datasets. Ship-based repeat hydrography data will increasingly be synthesized with data from other platforms and models to address specific scientific issues, which requires a bottom-up science approach rather than a top-down data management approach. It should be noted that synthesis activities will require additional funding to support data quality control, compilation, and PI meetings. It will also require the development of standing synthesis groups that meet regularly, both in basin groups and across basins. To ensure that these groups are implemented on a regular and rolling basis, it will be important for them to be managed through a sustained global coordination effort or program rather than a time-limited research program.

Data syntheses have typically been carried out starting with a basin approach since this is a convenient scale to define many scientific issues. Basin groups developed in WOCE/JGOFS and CLIVAR already exists for most areas. Building on this approach, GO-SHIP recommends four (4) groups:

- Atlantic (including the Arctic)
- Pacific
- Indian
- Southern Ocean

Based on recent synthesis activities that were conducive to both science and contributing to the development of a continuously growing global synthesis (e.g., the Carbon in the Atlantic Project, the Global Ocean Data Analysis Project, the North Pacific Synthesis Project), GO-SHIP proposes a 3-step approach for basin syntheses that brings together interdisciplinary science, the data synthesis activity, interpretation, and product development:

1. For each basin, develop a science workshop to bring together observations, models, and ideas around a particular science issue that sets the framework for the data synthesis activity. These issues will evolve over time with the science and with the state of the observing system, and may include topics such as the value of adding new biogeochemical sensors to profiling floats, looking at what we know about decadal variability, comparisons between observations and models, or using models to evaluate interpolation methods and to bridge the considerable spatial and temporal gaps between repeat lines. This would involve (and may be led by) existing global or regional research programs, where appropriate.
2. From these basin-scale workshops, develop a list of the collaborative projects to be carried out to address the science issues, and establish a working group that will carry out the necessary data synthesis activities. Technical coordination groups such as the IOCCP, the Ocean Observations Panel for Climate (OOPC), the North Pacific Marine Science Organization (PICES) Carbon and Climate Group (Pacific), and research program-based groups such as CarboOcean (Atlantic), and the CLIVAR Basin Panels could provide support for these activities.
3. Hold smaller follow-up workshops to present results and outline product development, including scientific journal articles (e.g., papers contributing to a special issue of a journal) as well as publication and release of the data synthesis and merging these data with the global dataset.
4. This 3-step procedure for each basin should take no more than 2-3 years from first workshop to final product delivery to be able to show continued progress and justification of the continued program. A process like this would provide flexibility for science issues to evolve over time and foster integration among a wide range of communities (physics, biogeochemistry, observationalists, modelers, etc.). Moreover, it would also provide a more sustained and continual framework for producing coordinated basin- and

global- scale data products on a regular basis. It should be noted, however, that new resources would need to be found to support the working groups and workshops, as well as data handling.

4.4. Development of an International Coordination and Communication Forum

Having up-to-date and comprehensive information is crucial to plan, implement, and coordinate global hydrography. At present, there are several Web sites providing information about particular aspects of ship-based repeat hydrography. What is lacking is a common international information and communications forum to facilitate field program planning, agreements on standards and methods, and data sharing/synthesis activities.

GO-SHIP recommends the development of a single Web site that will serve as a central communication and coordination forum for both physical and carbon/biogeochemistry aspects of ship-based repeat hydrography. Along with the site, an email list should be developed to improve communication among the various groups. A Web site will be developed jointly by CLIVAR and the IOCCP for community review and launch in late 2009. Elements of the site will include:

- Cruise plans (maps, tables, contact information)
- Data directory
- Hydrography Manual
- Reference Documents (data policies, national / global research program strategies, etc.)
- Summary of synthesis activities and research programs
- Calendar
- News / Bulletin Board

The sponsors of GO-SHIP are committed to working with the international community to develop a sustained coordination activity and to seek endorsement from appropriate international and intergovernmental organizations for repeat hydrography to become a recognized part of the global observing system.

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