TOWARDS AN INTEGRATED GLOBAL OBSERVING SYSTEM: IN-SITU OBSERVATIONS

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ABSTRACT

The research and operational community represented at the OceanObs'09 conference has stated clearly that the future global ocean observing system must focus on applications that society cares about. This necessitates expanding the current system to include biogeochemical and ecosystem observations. There was also an unambiguous message that various gaps in the system need to be closed – in terms of technology, sampling, and geographical coverage. Closer integration is needed to exploit synergies between platforms and communities, and to provide seamless data access across all components. Capacity building and training the next generation of ocean observers is another area requiring work and funding. This paper argues that an efficient way forward is to (1) maintain the existing system, (2) close gaps, especially geographic ones, and (3) enhance Argo, OceanSITES (OCEAN Sustained Interdisciplinary Time series Environment Observation System) and VOS (Volunteer Observing Ship) to serve and be jointly operated with the biogeochemistry and ecosystem communities.

1. OBJECTIVE

The goal of the OceanObs'09 Conference and of the follow-up process is to build a community consensus for the path forward in building a *global integrated ocean observing system* that is ready to meet the scientific and societal needs and challenges of the future. Many critical aspects and components of such a system are presented in individual plenary papers from the conference. The objective of the present text is, by building on the other papers, to review the existing and emerging components, identify gaps, analyze integration needs and challenges, and propose required steps which might most effectively lead to the required future ocean observing system.

The important words describing the desired system are "global" and "integrated", and these terms will provide the thread and glue of the subsequent considerations and analyses. At the conference the general interpretation of "global" was the need for a permanent presence in all ocean regimes/provinces and the ability to provide access to them via platforms or vehicles. This presence is required for obtaining the information to understand and predict the ocean's role in the global climate and ecosystem, to conduct experiments, to detect changes, and to build a record that allows us to go back 50 years from now to look for events, processes, changes that we could not anticipate at present. We cannot afford to restrict ocean observations entirely to locations or regions that are deemed important according to our current knowledge, and thus risk missing and understanding/predicting new or unexpected interactions or responses in the system. The prudent approach for science, society, and policy makers would be a balanced observing system with a broad distributed global background coverage plus intense and focused observing capability in hot-spots or representative regions (according to current knowledge, which has to be allowed to evolve).

The "integration" aspect of the global in-situ observing system is more multi-faceted and ambiguous. The word itself means to *combine pieces or elements to form a whole*. Many of the possible and desirable elements of the future observing system are presented in individual plenary paper from the conference. There is no unique way to integrate these into a whole. For clarity of language, the terms "element" or "component" of the observing system will be used to refer to observing infrastructure components like floats, fixed time series, ship-based observations, or gliders. The term "ingredient" will be used to refer to other aspects of the observing system which may need to be inserted or integrated, such as observed variables, data management efforts, or the organizational aspects of programs. The approach pursued here is to first remind the reader of important and guiding consensus statements from the conference, then summarize existing and emerging components of the global ocean observing system and observational capabilities. This will naturally lead to a discussion of gaps, in terms of geography, technology, or sampling, and to the need for enhanced integration of components and ingredients. Concrete steps are then put forward with considerations of practicality and efficiency, exploiting synergies with existing programs where possible and by joining forces across disciplines.

2. CONSENSUS STATEMENTS GUIDING THE INTEGRATION

Probably the single most repeated statement in many conference presentations is the need to focus on applications that society cares about. Many examples for those are addressed throughout the contributions, including:

- sea level and storms
- climate change tracking and prediction (IPCC (Intergovernmental Panel on Climate Change) model initialization, testing, validation)
- changes in carbon uptake (including the biological pump), fate of anthropogenic carbon
- acidification (ecosystem damage, coral reefs, biological carbon sink impact)
- management of Living Marine Resources
- attribution of climate impacts
- health of ecosystems, Harmful Algal Blooms, hypoxia
- marine induced changes in the high-latitude cryosphere
- pollution and pollutant transports

The quintessential conclusion from these applications is that they span the three major disciplines, and thus it is inevitable that the future observing system *must* comprise physics, biogeochemistry, and ecosystems.

Another consensus statement to guide integration is the need for more global coverage and the inclusion of more key variables. In particular gaps in the global sampling locations/depths and undersampling in space and time are frequently drawn attention to. Even a basic quantity like global heat content has an unexplained imbalance due to undersampling, and this is far worse for surface fluxes, CO_2 fluxes and inventories, and other quantities. The already sampled variables require better spatio-temporal coverage, and the inclusion of new variables will require new sensors/techniques, as well as an adequate array of platforms to carry them.

The community also appears to agree on the need for long time series with high temporal resolution (or in the case of repeat hydrography, more frequent sampling). These observations are essential for detecting events, for documenting and quantifying changes in circulation, fluxes, and multi-disciplinary processes, for observing regime shifts, *changes* in biogeochemistry conditions, and more. It is recognized that collecting sustained time series is "not sexy" but nonetheless critical, and that funding for such efforts needs to be protected since repeated routine observations over long times are difficult to justify within short-term research funding programs.

An integration need, which has been articulated widely by the biogeochemical and ecosystem communities, is the collection of co-located observations of many variables, in order to provide a context for the interpretation and understanding of specific processes. This requires sampling many linked variables in physics, climate, geochemistry, ecology.

While integration of the many aspects and elements into an observing system will make it vastly more powerful, compelling, and effective, nothing would be gained without equal efforts to make the data and the *information* publicly available and to share them freely. It is probably fair to say that at the conference the majority of the community and all of the agencies endorsed this statement. The main reason is that the data can yield benefits only when they are *used*. In order to facilitate this usage, data and information exchange also needs to be enhanced (or enabled in the first place) among different research communities and countries, or among diverse types of databases.

Finally, many plenary presentations have emphasized also the human resource dimension in building, integrating, and sustaining a global ocean observing system. It will be crucial to train a new generation of ocean observationalists, and to include countries around the world via capacity building, for making the ambitious OceanObs'09 vision a reality.

Guided by the various above consensus statements the required steps for combining the elements and ingredients into an integrated system will be analyzed in the following sections.

3. PRESENT OBSERVING SYSTEM ELEMENTS

Sustained global ocean observations are currently being carried out in a variety programs, using a range of platforms, sensors, methods, and serving different scientific or climate-related monitoring needs. The scale of effort which goes into this is by itself an impressive achievement of the ocean observing community. Yet, as has been made clear throughout the conference, the existing system is substantially incomplete and poorly designed to address many of the new and growing scientific and societal needs. This section summarizes the existing backbone elements and emerging capabilities, upon which the future integrated ocean observing system must build. Detailed information about each component (and many others) is found in the community white papers (CWPs) which are part of this volume.

3.1 Established components of the global ocean in-situ observing system

3.1.1 Repeat hydrography

Repeated water sample measurements from research vessels along specific sections across ocean basins are still, at least for the biogeochemical and ecosystem communities, the "gold standard" observations due to careful analyses that can be carried out on water samples for a wide range of variables. It is also currently the global sampling of the bottom half of the ocean volume, important for climate on longer time-scales. This activity is usually called "repeat hydrography", and GO-SHIP (Global Ocean Shipbased Hydrographic Investigations Panel) [1, go-ship.org] is the recently formed program for this activity, sponsored by CLIVAR, SOLAS, IMBER and IOCCP (Climate Variability and Predictability, Surface Ocean-Lower Atmosphere Study, Integrated Marine Biogeochemistry and Ecosystem Research and International Ocean Carbon Coordination Program). As long as autonomous, stable, and lightweight sensors are not available for many of the important variables or full depth sampling, the only way for detecting changes in detailed aspects of chemical processes or ecosystem community structure is to collect and analyze samples from research vessels. For many studies and other (more autonomous or remote) techniques, ship-based hydrography still provides the "ground truth" and reference standard, and therefore is important to sustain. In a basic example of integration, Argo makes use of repeat hydrography data for checking and adjusting float salinity measurements as needed. See [1] for more details on repeat hydrography. Figure 1 shows the currently planned global network. Crucially in addition, this program supplies the only broadscale-sustained measurements of ocean heat, freshwater and circulation changes in the bottom half of the global ocean.

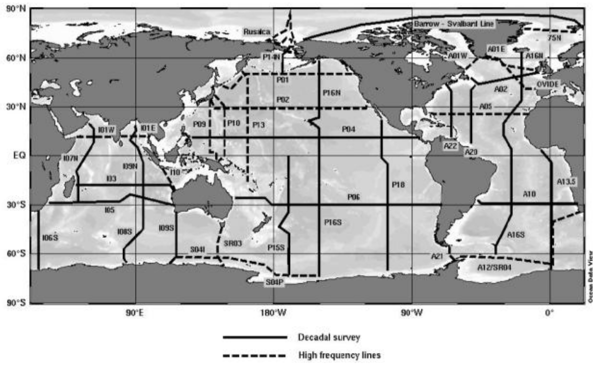

Figure 1: Repeat hydrography sections from the GO-SHIP project

3.1.2 Argo

The *global* sustained network of profiling floats measuring temperature/salinity profiles to 2000m depth every 10 days has become the most successful and widely used in-situ ocean observing program. It is our only tool for regularly sampling the upper half of the subsurface ocean on a global scale, covering virtually all of the ice-free region with a nominal 3°x3° resolution (see Fig.2 for a float coverage snapshot). A large Argo community exists around the world, with many national contributions, and with an efficient and effective approach to logistics, hardware, and data management. Important to the success of the program is ease-of-access and quality of the data, which are freely available to any researcher or student or agency in the world. Argo data represent a vital subsurface data set for ocean state estimation and assimilation/forecasting, and its sampling is designed as a natural complement to remote sensing data, in particular satellite altimetry [2, 3]. Without doubt, Argo will need to remain the backbone for routine broad-scale global sampling of the upper half of the subsurface ocean, and hopefully the full ocean depth in future. See [4] for more details on the program and technology.

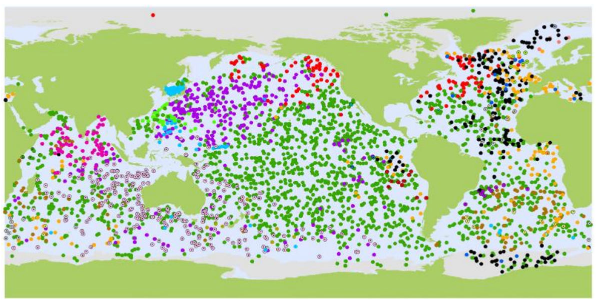

Figure 2: Snapshot of the global float coverage of the Argo *(Global array of free-drifting profiling floats) project*

3.1.3 OceanSITES

The fixed-point (or Eulerian) time series program OceanSITES is focussed on providing sustained multi-disciplinary observations with high temporal resolution and throughout the water column, at selected locations throughout the global ocean. Most of the present sites are equipped with subsurface or surface moorings, and some are occupied with frequent research ship visits. The goal is to provide “ocean reference” information at either representative or critical locations, and to establish oceanic equivalents of the atmospheric “Keeling curve” for different variables and regions (or ocean provinces). This will enable the observation of processes as they happen, detect events, and follow regime shifts or slow climate-induced changes without the danger of aliasing. Moorings can host more complicated, heavy, and power-hungry autonomous instrumentation, while frequent time series occupations by ships are able to take repeated in-situ samples, both of which enable the observation of a wide range of variables. OceanSITES currently consists of close to 100 extremely varied sites (Fig.3), plus the tropical moored arrays TAO/TRITON, PIRATA, and RAMA (Tropical Atmosphere Ocean/Triangle Trans-Ocean Buoy Network, Prediction and Research Moored Array in the Atlantic and Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction), and is part of the Global Ocean Observing System. It provides infrastructure (platforms) and logistics (service cruises) in many parts of the world ocean which could become a basis or resource for other programs and needs. Some of the data are available in real-time, and a global data system is under construction. See [5] for more details. Transitioning OceanSITES to a truly global (and not Northern Hemisphere dominated) network remains a challenge.

3.l.4 VOS

Underway observations from commercial ships along fixed routes have become a cost-effective way to analyze surface water properties from the vessel’s water intake(s), or to deploy XBT (expendable bathythermograph) probes (as well as surface drifters and Argo floats), to tow simple sampling systems, or to collect current profiles via hull-mounted ADCPs (Acoustic Doppler Current Profilers). The vessels are often called “volunteer observing ships” (VOS), and the main programs are SOOP/GOSUD (Ship-of-Opportunity Programme/Global Ocean Shipboard Underway Data) [6 and 7], and CPR (Continuous Plankton Recorder) for the continuous plankton recorder program [8]. The traditional quantities analyzed from continuously pumped surface water are temperature and salinity (thermosalinograph, TSG), however more complicated automated chemical analysis systems can now be installed in a similar way, most notably for pCO_2 [9]. The resulting global sampling network is impressive, as shown in the maps (Fig.4). Since a lot of effort has gone into setting this network up and maintaining/operating it, it may lend itself to enhancements for other surface ocean measurements. A public access global data management system also exists for many of the VOS observations.

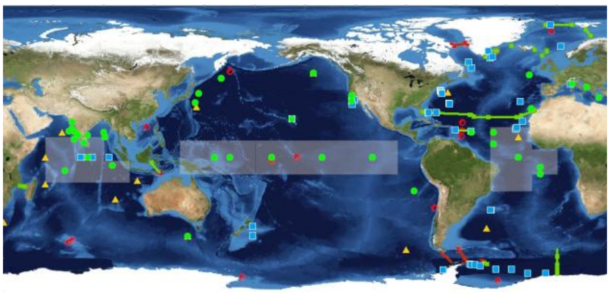

Figure 3: Operating sustained time series sites represented in the OceanSITES project

3.2 Emerging elements ready to become routine

3.2.1 Gliders

Underwater gliders are autonomous buoyancy-driven vehicles that translate through the water on inclined down/up trajectories, allowing horizontal speeds of typically 25 cm/s in standard applications and vertical coverage of the upper 1000 m [10]. They have endurances of several months and can carry a modest payload of usually 2-4 sensors, thus lending themselves to autonomous sampling along sections across oceanic sub-basins or boundary currents. At present they are still

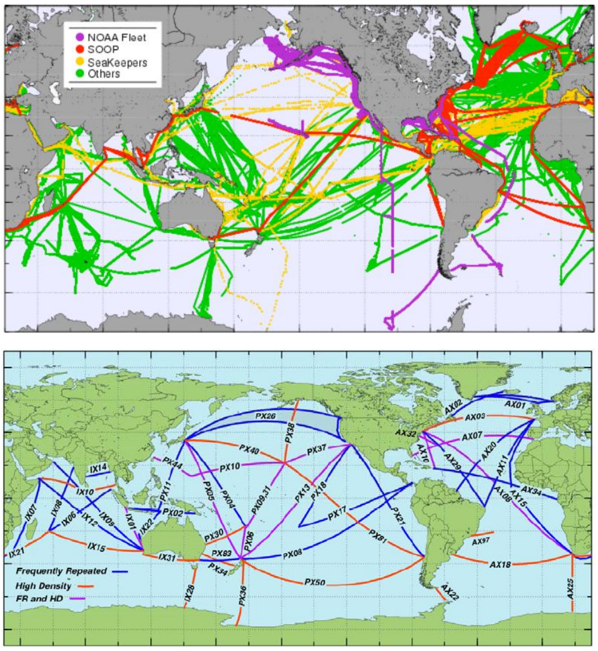

Figure 4: (Top) Global thermosalinograph network. (Bottom) Global XBT network.

being used largely in a research mode, but sustained operations are starting to be established, e.g. in the California Current where four years of regular transects along two sections exist now. A firmer and more formal role in the global ocean observing system is expected and desirable.

3.2.2 Floats with enhanced sensors

While the core Argo mission is to collect T/S profiles and deep flow data, there are increasing numbers of floats that carry additional sensors, the most widespread being for dissolved oxygen. However, floats have been deployed equipped with bio-optical or nutrient sensors, and research/prototype missions may carry others. Each sensor adds substantial cost and eats into the power budget and thus endurance of a float. Therefore, a careful consideration of tradeoffs is necessary and new resources need to be obtained in order to not jeopardize the core Argo mission. If sensor stability and QC (Quality Control) issues can be solved, and the required additional resources found, a subset of the 3300 floats to carry additional sensors may be a feasible next step (see [11] for more details). An outstanding issue for these data streams remains the lack of an international convention for the free and open exchange of biogeochemical data from countries EEZs (Exclusive Economic Zones).

3.2.3 Ice-tethered platforms

Observational platforms which operate under the ice, especially under permanent ice cover in the Arctic Ocean, have improved drastically in their capabilities. In most cases at present, this is carried out with sensors deployed from the ice (IBO's, ice-based observatories). These vary a lot in design, sensors, depth coverage, and telemetry capability. The most ambitious of these systems have a profiling capability, providing water column structure with fine vertical resolution, while drifting across the Arctic Ocean [12].

3.2.4 Biologging

Over the past 10 years, an increasing number of marine mammals and large pelagic fish have been tagged with probes measuring pressure, temperature, and sometimes conductivity (hence salinity), in the polar and subpolar oceans. Often they provide low-cost access and sampling in regions that are difficult or impossible to reach with existing routine technology. A lot has been learned about the behaviour of suitable animals so that the type of sampling that will be attained can be anticipated. Current limitations are the size/weight and power consumption of sensors and telemetry systems. While not currently a formal part of the global ocean observing system, biologging currently does help to close some gaps in hard-to-observe high-latitude regions of the global ocean. See [13] for more information.

3.2.5 Chemical sensors

In recent years, a number of new autonomous sensors have become available, and efforts are under way to assess their long-term behaviour, and to increase their endurance, stability, and accuracy. A number of them appear to be robust and stable enough for use in unattended and autonomous long-term deployments in the near future. For example, a variety of nutrient sensors are being used, which use either wet chemical reagents or optical spectrophotometric approaches, and remaining issues regarding reliability or sensitivity are being addressed [14]. pCO_2 and pH sensors for subsurface applications (moorings, floats, etc) are being developed and tested, but currently still suffer from some limitations like high power consumption, long time constants, or limited pressure ratings [15 and 9].

3.2.6 Biological sensing

Several techniques for routinely observing different trophic levels in the ocean ecosystems have made impressive advances, many of them spearheaded by the Census of Marine Life (CoML). Concentrations of phytoplankton and particulate organic matter (POC) can be estimated now with low power and increasingly stable optical techniques (given sufficient "ground truthing" to calibrate the variable conversion factors). Abundances and migrations of zooplankton, fish, and predators have been routinely observed recently with acoustics and tracking methods [16 and 17]. Up/downward-looking and horizontally-scanning active sonars can be deployed on moorings, while tagging animals with acoustic transmitters (e.g. OTN, Ocean

Tracking Network) or satellite beacons (e.g. TOPP, Tracking of Pacific Predators) allows to follow their movements.

4. GAPS AND TECHNOLOGICAL NEEDS

The previous section outlined that many of the building blocks of a future integrated global ocean observing exist. Without any doubt, the present (mainly physical) components that are operating are quite successful in themselves. Nonetheless, as detailed in many plenary presentations and CWP at the conference, much remains to be done in order to make the system more complete, especially because of the recognized and agreed need to include more biogeochemistry and ecosystem components, but also due to gaps in spatial and temporal coverage. These consensus gaps are addressed in the following subsections, and should be a priority for activities in building the future observing system. Other needs for completing a truly integrated system include more planning and synergy across the disciplines or integration of data sets across the components. These and other integration aspects will be covered in the subsequent Sect. 5.

4.1 More and Better Sensors

Regardless of the platforms or the geographic distribution of the in-situ observing system, there is an acute need for the implementation and deployment of additional sensors, in order to meet the scientific and societal challenges ahead. Much of the present sustained ocean observing system provides only physical observations, while it is clear now that the future system must cover a wide range of biogeochemical and ecosystem observations as well. Two plenary papers [16 and 17] deal with this topic in great detail.

There is a need for more (lower cost) and better sensors that are capable of the long-term and autonomous measurements which have to become part of an integrated in-situ system. Examples from the Community White Papers are improved wave sensors [18], more sensitive nutrient sensors [14], sensors for measuring additional components of the carbon system like alkalinity [15], autonomous optical plankton imaging sensors [19], and improved technology and analysis techniques for acoustic zooplankton/fish sonars [20]. Given the vast arrays of drifting floats, probably enhanced by gliders in the future, passive acoustic receivers for (tagged) fish, predators, and mammals would also be of value if they were broad-band, low-power, and compact enough in size to fit into floats or gliders. The same receivers could be used for acoustic tomography providing a network of widely distributed receivers. Chip-based DNA sensors are also under development and may represent a quantum leap forward in routine ecosystem studies, but reusable chips (as would be needed for autonomous system) are still on the drawing board. For virtually all of the non-physical sensors, developments for improved endurance, stability, accuracy, fouling protection, and size/power consumption are required before their broadscale use in the integrated in-situ system.

4.2 Improved Platforms

Future in-situ observing systems need to take advantage of new technological developments for deploying/ carrying the sensors and relaying the data to shore. This will increase coverage, efficiency, and impact of the observations, and help to close some of the geographic and sampling gaps stated below. For example, different types of novel profiling floats are now under development that are smaller, cheaper or have the ability to sample the deep ocean [21]. All would greatly increase the value of Argo and enable enhancements as discussed above (such as adding oxygen sensors).

Underwater gliders show great potential for becoming an element of the global observing system [10], but would benefit enormously from increased speed, endurance and range. Adding more sensors, as in the “bio-gliders” idea [17], will eat into the power budget and reduce the glider endurance/range further from the present typical 3-4 months. Another development is outfitting gliders with an acoustic navigation capability which would allow them operate under ice [12] or dive under strong current systems, while adding acoustic modems can turn gliders into data shuttles between subsurface instruments and shore [22]. Some of these and other developments are already under way. For instance, full depth gliders, which could augment global deep ocean sampling, are currently being field-tested.

Advanced mooring technology will also improve the range of applications (and thus benefits) of sensors deployed in time series mode. Platforms are now being designed which can survive being moored at the surface in high-latitude wave conditions, and others allow vertical profiling with sizeable sensor packages through different parts of the water column [23]. While these are ambitious and highly capable mooring systems, there will also be an increased need for simple and low-cost moored and bottom-mounted platforms. One conference contribution [24] outlines an innovative robust, simple and easy-to-deploy surface mooring design for the deep ocean. Multi-year deployments of moorings would be desirable to bring down their cost. And moored profilers that can bring a sensor package to the surface for sensor service without recovering the entire mooring would make moorings more efficient and attractive. Multi-year moorings can also be used to carry highly efficient low-frequency sound sources to “insonify” large parts of ocean basins, for tomography or navigation. Bottom-mounted sensors such as ADCPs, pressure sensors, inverted echosounders would benefit from acoustic modem enhancements, allowing the above-mentioned glider data shuttles to retrieve and telemeter data to shore in near real-time.

4.3 Geographic Gaps

Much discussion at the Conference was centered around identifying and closing spatial gaps in the current in-situ observing system. A variety of CWP's and plenary presentations are drawing attention to needed geographic additions. At a basin level, the Arctic Ocean [25, 12 and 26], the Southern Ocean [27], and the Indian Ocean [28] all require completion of their sampling coverage for existing networks, in order to build a truly global ocean observing system. The needed technologies are at hand, but coordination, agency funding, and implementers are now needed to make it happen. The ice-covered oceans remain a gap of increasing importance given the possible role of marine warming in driving ice loss.

On a more regional level, sustained <u>coastal</u> observing systems have not become a part of the global system. In many countries there are however national coastal observing systems, and GOOS (Global Ocean Observing System) Regional Alliances (GRAs) exist which make up the coastal modules of GOOS [29] and whose goal is to build a global coastal network of observations, data management and modelling. Implementation of the coastal module on the global scale still waits to be initiated. Major challenges include sustained implementation of GRAs in the developing world; capacity building in developing countries that leaves a legacy of self-determination and self-sufficiency; and more effective collaboration and coordination among GRAs, Large Marine Ecosystem programs, and regional seas conventions.

A widely recognized and stated phenomenological gap in the present in-situ observing system is the routine and sustained sampling of boundary currents [5] and of inter-basin exchanges [30]. These regions are agreed to be priority items both for the climate system and for climate impacts on ecosystems. Pilot projects are running in several boundary currents and throughflows. Technologies and methods exist to occupy important locations around the globe, but the mix of technologies needs to be explored and tuned to each site. Options for implementation and closing these gaps have been proposed in the various conference papers, and this needs to be a goal in parallel with the actual integration steps into a more unified and powerful global in-situ system.

4.4 Sampling Gaps

As pointed out in various places during the conference, the present observing system has several shortcomings in the way it samples the ocean. For example, the abyssal ocean is not reached by most of the existing observing infrastructure [31], the exception being ship hydrography and moored time series. Developments are underway to extend the depth capability of profiling floats and gliders. These efforts, coupled with making better use of existing moored systems (OceanSITES and tsunami networks), should enable the extension of broadscale observations of the ocean below 2000m.

Also improved horizontal and temporal resolution is needed to unravel the physical, biogeochemical, and ecosystem processes in the ocean. There is an increased recognition that small scales related to eddies, fronts, filaments, and sub-mesoscale features in general play an important role in ecosystem fluxes. Presently only gliders and satellites can resolve these structures. This suggests an increased role of gliders in the global observing system, not only near the coasts. At the same time, many processes and events occur on timescales too short for much of the broad-scale observing assets (mixing by storms, algal blooms, upwelling, air-sea gas exchange, vertical movements of pray and predators, etc). In order to address these, more use needs to be made of time series technologies, both in the global and coastal oceans.

5. INTEGRATION

As discussed in the introduction, integration means to combine many pieces to form a whole. For the global ocean observing system, in most cases this means to depart from the separate and uncoordinated observing efforts and management/data handling/funding approaches, and instead to merge the activities and exploit synergies and complementarities. The integration needs to happen across disciplines and variables, regions, vertically (surface to deep) and horizontally (coast to open ocean), across time and space scales, platforms, programs, across data systems, and with remote sensing and with users. Most of this long list can be grouped into the following integration needs.

5.1 Combining variables, platforms, programs at one place

One reason for integration across the elements, disciplines, platforms, and programs, is to provide complete supporting or background information for specific studies or societal needs in specific places. For example, often the physical and chemical measurements needed to link ecosystem variability to environmental and climate variability do not exist [11]. Truly integrating observations (as the basis for addressing the societal challenges) need more collaborative efforts among investigators, programs and disciplines, and increased sharing of platforms, of funding, and of expertise. This is currently hampered not only by traditional mindsets of researchers (focussing on justifying, funding, publishing their specific projects/objectives) but also of funding agencies which still have difficulty jointly supporting efforts or projects from several disciplines, or even multi-agency or multi-nation funding. The largest mutual benefit results if platforms and logistics are shared, development efforts and measurements are coordinated, and observations are placed into a mutual context with other information or programs.

As an example a novel multiple platform and disciplinary effort is under way in the southern California Current. Ongoing observations with quarterly ship surveys (for mainly fisheries applications, CalCOFI (California Cooperative Oceanic Fisheries Investigations)), are being augmented with moored observatories, intensive shipboard process studies (CCE-LTER (California Current Ecosystem-Long Term Ecological Research)), and with regular glider transects across the inshore part of the boundary current. The mooring closes the temporal gap in the sampling and allows continuous deployment of a large variety of state-of-the-art sensors, some of which (acoustic zooplankton/fish sonars) are designed to be identical to the ones used on the ship surveys for obtaining ground-truthing from the net hauls. The mooring (Fig.5) is a highly collaborative effort (seven principle investigators at SIO (Scripps Institution of Oceanography), NOAA SWFSC (National Oceanic and Atmospheric Administration/Southwest Fisheries Science Center), NOAA PMEL (National Oceanic and Atmospheric Administration/ Pacific Marine Environmental Laboratory) merging funding from several sources (institutional, NOAA climate, NOAA fisheries, Navy)). Everybody contributes and everybody gains from it. This is a promising model for future elements of a truly integrated in-situ observing system.

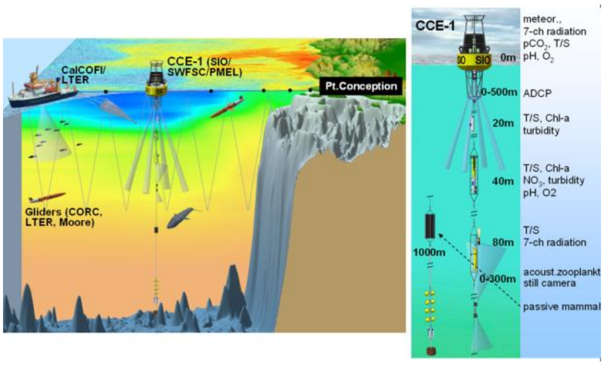

Figure 5: Example of highly multi-disciplinary mooring, with multi-PI and multi-institution contributions, multi-agency funding, embedded in an observing setting with survey and process cruises and glider transects.

5.2 Synergies among platforms

As the components of the existing observing system become more and more mature, and as increased needs and challenges arise, leveraging and synergies among the technologies, platforms, and logistics should be pursued for maximum impact and payoff of the investment. Synergies lie either in complementary types of sampling (horizontal and temporal resolution, broad-scale coverage, vertical reach), or in the different types of variables/observations enabled (larger suite of sensors on moorings than on moving platforms, complete sampling enabled by vessels), in cross-calibration or ground-truthing (recovered and post-calibrated sensors vs expendable systems and remote sensing), and in shared ship time. These synergies can be best exploited if the platforms are deployed in overlapping locations.

Some recommendations resulting from this are that

- temporal sampling by moorings should be enhanced by glider observation of the surrounding environment
- glider sections or moorings should augment (temporally and spatially) repeat hydrography tracks or fisheries surveys
- subsurface platforms should be used to enhance VOS surface sampling from commercial ships (physical, carbon, or plankton observations)
- autonomous acoustic backscatter sensors (for zooplankton/fish) should be calibrated with net tows from research or survey vessels
- tagged fish or mammals can be tracked with receivers on moorings, floats, gliders deployed for other purposes
- gliders can have a dual function for retrieving data from subsurface moorings or bottom-mounted instruments
- cruises servicing moorings or tagging animals should be used for deploying/recovering gliders, floats, drifters, and for taking water samples for chemical and biological analyses.

5.3 Combining efforts across communities

At present, each component of the present observing system (Argo, SOT (Joint Technical Commission for Oceanography and Marine Meteorology- Ship Observations Team), OceanSITES, Global Drifter Program, repeat hydrography, tsunami networks, coastal systems, wave observations) and each community (CLIVAR, carbon, IMBER, SOLAS, CoML) is working hard to develop and maintain its own observing system. While those efforts have paid off and are essential to get started, and there are already some synergies among these programs, the integration into a multidisciplinary system that serves the future societal needs now requires increased efforts to join forces across the communities.

Since the existing global components are mainly climate/physical systems, but have much of the programmatic and logistic (and data) structure in place, it would be beneficial and efficient if these (especially Argo, VOS, OceanSITES, repeat hydrography) strive to work more closely with the biogeochemical and ecosystem communities, to

- plan/design the future network together
- share the advocacy and funding burden
- share the implementation and the platforms
- merge disciplinary expertise
- build a joint data system
- collaborate on analyses.

New cross-community interactions will also be required by systems which reach from the coastal zone to the open ocean. An example for this is the ocean acidification network [32], which will require linking up with both coastal and open-ocean programs like OceanSITES. The same is true for tracking animals from the near-shore into the basin interior.

Other under-utilized infrastructure components are the tsunami warning systems and the tropical moored arrays, which are now installed in all the ocean basins. Both the platforms and the service cruises for these have the potential for carrying out additional ocean observing programs, and this opportunity should be pursued more intensively.

5.4 Scientific Data Merging

Combining the data from very diverse in-situ systems is still a significant challenge. Usually this is done via state estimation (using adjoint or Kalman filter data assimilation). For broadly distributed data (like Argo) of a simple quantity like T or S, the techniques are well established and successful. Problems arise when the sampling scales or accuracies are not well matched, or more indirect or bulk observations are collected.

For example, it is unclear how to optimally use time series from a small number of isolated points with high temporal resolution and accuracy in an eddy-resolving model. Expecting or forcing the model to reproduce every detail of the data would lead to huge (and unrealistic) local adjustments of the model. Assigning a large error corresponding to the eddy "noise" throws away the high accuracy of the data set. Forcing only the larger scales with the low-frequency part of the data loses just the high temporal resolution of such data. Maybe it is preferable (and possible) to only assimilate the temporal statistics of the time series (they can be temporally and vertically varying). Or possibly the best usage of such data sets would be to withhold them in state estimates or forecasts and use them for validation, skill assessments, performance metrics. This is a topic of ongoing research.

Somewhat related, the estimation of a specific quantity or process may require very high accuracy observations (e.g. calculating or constraining mass transports from T/S or density measurements). However the data error assigned to such inputs in usual cost functions is too large (to account for instrument and eddy noise) for really constraining the process. It is not clear at present, whether in such cases the mass transports should first be calculated directly from the density data and *then* be used as a constraint in the state estimate.

Finding ways to combine and incorporate biogeochemical and ecosystem observations (together with physical data) is another challenge. Many such observations are indirect and represent complicated (often poorly known) responses or properties of an organism (or a compound within an organism). Examples are chlorophyll fluorescence, acoustic backscatter, total biomass or displacement volume. In many cases even by themselves such observations are difficult to "invert" to yield the quantities really sought (chlorophyll concentration, abundance of species and size classes, etc). It will become increasingly important to find new ways to make use of such derived/indirect data jointly with other observations. With luck, it may turn out that the combination with additional information (via state estimates or other novel means) will make it easier to "invert" the indirect observations for the sought quantities.

5.5 Merging Data and Data Systems

An integrated observing system will require improved combination of data from in-situ systems and from remote sensing (possibly also with, or via, numerical models). Remote and in-situ observations depend on each other, and can multiply their stand-alone value by synthesizing their information. For example, remote sensing requires supplementing with in-situ data for knowledge of the internal structure/distribution of remotely sensed properties, for ground-truthing, and for obtaining critical parameters which cannot be observed from space (but which may be needed for an interpretation/application of the remotely sensed data).

In many cases, the data sets are too vast or specialized to make them useful to the other community in original form. The satellite community is generating an "avalanche" of data from an increasing number of platforms, while in situ data sets can be local and specific. A practical way forward may be to extract information and products needed by the others. Examples:

- provide in-situ information needed by the satellite community to use, interpret, and understand satellite data (like vertical structure of chlorophyll, of surface/subsurface currents, nutrients)
- provide multiple-platform and validated remote sensing products needed by the in-situ community

(like spatial statistics, maps, temporal variability on large scales)

- provide in-situ products useful to the modelling community (fluxes, time series for validation, statistics, integral constraints)
- provide model information useful for in-situ data interpretation.

The interoperability efforts outlined in [33] may lead a way to make this possible.

Integration of the observing system elements and programs also means to combine their data systems ultimately. This does not necessitate single joint databases or even common data formats, since modern technologies exist like distributed systems and Live Access Servers with data dictionaries and data discovery techniques that enable data access across diverse sources. Many programs have their own data system established (Argo, SOT, OceanSITES, CPR, CoML, OBIS), and a future challenge then is to provide seamless and cross-linked access to all of them. Technologies exist for this, and the programs to make that reality are under development [33].

No standards (i.e. formats, QC procedures, best practices) exist currently for many biogeochemical and ecosystem parameters (in profile or time series form). OceanSITES has started to try filling that gap and is working to define format and QC/QA procedures.

A possibly controversial recommendation, representing a subset of the community (originally the OceanSITES project, but now growing), is that real-time biogeochemical/ecosystem data (from autonomous systems) be shared in real-time, even without good automated quality control procedures in place (but with very clearly stated warnings to the user). The benefits of making even uncertain data widely available and *used* may outweigh the dangers of uncritical usage or misuse. Also, a large user community may find problems or draw attention to issues (from comparative analyses for example) which the data owner may not have time or expertise to detect.

6. NEXT STEPS

6.1 Enhancing the existing systems

One clear and unanimous outcome from the OceanObs'09 conference is that the future sustained global ocean observing system must expand to include significant biogeochemical and ecosystem components. This goal could be achieved by building additional and separate projects similar to Argo, OceanSITES, VOS, or the surface drifter program. A result then would be that the new systems compete for funding and visibility with the established ones and with each other. Instead, it is most likely easier and more powerful/compelling to aim for a *small* number of expanded, highly capable/versatile programs that address *many* societal needs in an integrated fashion, rather than many specialized programs.

Also in terms of programmatic effort, there is a high cost (elapsed time, people time, funding, effort) to set up new projects. It may be more efficient to add to existing projects, to their infrastructure, logistics, and data systems, rather than building separate ones. These considerations lead to the recommendation to look for natural synergies among the existing projects and the needed future enhancements outlined above, together with the various communities involved. Some potential synergies are given in the following, drawn from plenary presentations at the conference.

6.1.1 VOS Synergies

The VOS project, using commercial vessels to observe global surface distributions, currently collects mainly XBT and thermosalinograph data. Independently, separate projects exist that obtain more biogeochemical/ecosystem underway observations (VOS-Carbon, CPR). Once intake water on such vessels is diverted to an analysis system like a thermosalinograph, the shipping line already cooperates, and logistics are in place to collect/deliver the data, it may be relatively easy to add analysis systems for carbon parameters, trace metals and other chemicals, or pollutants. Also an effort could be made to try merging XBT and CPR sampling on some lines, and adding sonar to detect nekton. These may be low-hanging fruits that can vastly enhance the power and societal value of a global VOS project. Furthermore, the design of a VOS Science Module with standardized dimensions, interfaces and scientific payload modules is desirable and would facilitate synergistic VOS use.

6.1.2 Argo Synergies

The Argo project uses subsurface floats to observe global subsurface distributions of T and S. It has been demonstrated technologically that such floats can carry other sensors for biogeochemical and ecosystem applications (oxygen and various optical sensors, laser optical plankton counters, etc), and additional sensors are probably close to implementation for floats (such as pH). It would be reasonably straightforward to enhance the Argo network with several such sensors. The price would be the reduced endurance and higher cost, higher complexity and more failure modes, but this is probably more economical and efficient than building separate float programs, especially when taking into account also the deployment logistics.

Argo-like floats can also operate under the ice now, with ice-detection algorithms and acoustic (RAFOS-like) positioning. This is already being done in some parts of the Southern Ocean, but more widespread deployments, in the remainder of the Southern Ocean and the Arctic Ocean would be desirable. The needed type of acoustic hydrophones and receivers is simple and low power, and does not need to be powered up frequently for achieving a tracking equivalent to normal Argo positioning. The main price and effort would be for the sound sources, but once installed, can operate for many years.

A more advanced and demanding synergy offered by Argo-type floats would be to equip them with broadband acoustic receivers. These could be used for acoustic tomography [34] and animal tracking applications. The technology, especially to make it low-cost, miniaturized, and low power still needs development, but if it were available, the large number of floats would require only a modest number of sound sources. In the polar oceans, these could be the same that provide under-the-ice positioning.

Development of deep-profiling Argo floats also offers the potential to actually assess the entire global energy imbalance through truly global (including the lower half of the ocean volume) temperature measurements.

6.1.3 OceanSITES synergies

The OceanSITES project uses fixed-point measurements, mostly moored, to provide air-sea to bottom time series of many variables with high temporal resolution at selected locations around the globe. The sensors are regularly recovered, which allows post-calibration and even recovery of in-situ samples. At present, the sites are very dissimilar and frequently collect data for a single research project theme or discipline. With modest additional effort/funding a subset of core or backbone global sites could be upgraded to collect a wide range of truly identical observations serving the interests and needs of a variety of disciplines at once. A strawman for existing sites that would easily lend themselves to this enhancement is shown in Fig.6.

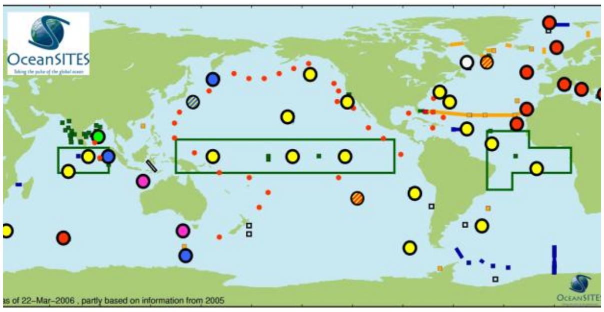

Figure 6: Subset of locations (large filled circles) which lend themselves to become a backbone system of equivalent multi-community time series sites.

The ability to carry many sensors, nearly regardless of size and power requirement (as long as autonomous) makes these installations ideal for incorporating the needs and the autonomous sensors from many research programs and disciplines. Sharing the sites in such a way would give an unprecedented capability and presence for many societal applications, while sharing the cost, logistics, and disciplinary expertise via collaborations would make their operation efficient and affordable.

The obvious candidate sensors, some of which are already being used on moorings, are biogeochemical and ecosystem instruments, like O_2, pH, pCO_2, radiation or nutrient sensors, and others. These are exactly the types of time series that many communities require to unravel processes and changes in biogeochemical systems.

The Census of Marine Life (CoML) project and many fisheries research or monitoring programs can join efforts with OceanSITES to deploy upward/downward looking fish/zooplankton sonar systems. These can be complemented by imaging techniques, like LOPC's (Laser Optical Plankton Counter) [19]. The acoustic volume sampling combined with optical species identification gives a powerful tool for studying the variability and events/processes in ecosystems.

The OceanSITES infrastructure also offers synergy opportunities for the various observing needs that require deep/abyssal measurements [31]. The existing moorings can easily be equipped to measure deep T/S changes with better accuracy than other autonomous systems, can contribute to global deep carbon inventory monitoring, and also supplement the circulation, boundary current, and basin-exchange observation effort.

In general, the OceanSITES system can provide surface and subsurface reference information for many programs and disciplines. In that sense, it is fitting that these time series are sometimes referred to as "ocean reference sites", somewhat like subsurface equivalents of the atmospheric Keeling curve. The suggested rationale is to choose "hotspots" for certain processes or disciplines or locations representative of ocean provinces, to establish a long-term multi-community presence in the global ocean.

6.1.4 Hydrography synergies

Enhanced shipboard monitoring is required to provide the broad range of observations needed to develop end-to-end ecosystem models and the integrated ecosystem assessments that underlie ecosystem-based management [35]. In general, existing programs fail to monitor the requisite range of variables: fishery surveys typically neglect key biogeochemical parameters and ocean time series, such as HOT (Hawaii Ocean Time-series) or BATS (Bermuda Atlantic Time-series Station), neglect the zooplankton and mid-to-higher trophic levels. Assembling teams to cover the range of disciplines from physics to fish is a challenge, and there are logistical roadblocks that must be overcome. For instance, most repeat hydrography program cruises are already using all available laboratory space and science berths, with a waiting list for ancillary measurements. For the foreseeable future, only shipboard sampling effectively provides data on the abundance and distribution of key species, which underpins ecological assessments and models. However, no single platform samples the range of oceanographic, biogeochemical and ecological variables across the spatial and temporal scales required to assess natural and anthropogenic change in marine ecosystems. Shipboard programs such as CalCOFI [36] therefore need to be integrated with satellite, mooring, glider, and other observations to develop integrated regional observation networks, which in turn need to be integrated internationally, across ocean basins, and globally.

6.2 Closing the gaps

It is to be expected that the technological development in the field of sensors and platforms will happen rapidly, and that therefore many of the gaps from Sects. 4.1 and 4.2 will shrink over the coming years. Similarly, the sampling gaps (Sect. 4.4) will be addressed with more widespread use of gliders, and with the integration and coordination efforts discussed elsewhere in this paper.

The main activity therefore must be to address the *geographic* gaps (Sect. 4.3). Some of that challenge can be met with the enhancements of the existing systems discussed in Sect. 6.1 (e.g. more VOS lines or moorings in the Indian and Southern Ocean), but the establishment of truly *global* boundary current, inter-basin through-flow, and coastal observing systems needs dedicated effort and funding now. This must be a parallel priority, together with exploiting the synergies from Sect. 6.1.

6.3 Capacity building and human resources

The global ocean observing system envisioned here would be impossible to build and operate without the involvement of local expertise and agencies around the global ocean basins. Elements of the coastal modules, operation of glider sections across boundary currents, and regional time series sites (mooring or ship occupied) all require training of scientists and staff in remote locations. This must become an element of building the next ocean observing system. In most cases, regional centers of expertise could be established in countries with more resources, and from there the outreach to nearby countries could be coordinated. Generally, the capacity building will need to come with funding to operate the infrastructure, and an international mechanism would need to be set up for this.

Another obstacle for the implementation of a more encompassing, complete, and powerful ocean observing system is the pure magnitude of the human resources needed. Many new jobs will need to be created, and a new generation of ocean observationalists and observers needs to be trained in order to sustain such an undertaking. This is true both for the countries building the present observing systems, and the more regional countries needed to operate locally.

One impediment to building and sustaining a global in-situ ocean observing system is the present academic review and reward structure. In the current system, there is not much merit associated with generating community data, and credit is given only for well-cited research publications. In order to make it attractive to build and sustain the needed observing system, appropriate recognition and credit must be associated with collecting and providing data for the global community and to the benefit of society. The new Earth System Science Data, an international, interdisciplinary journal for the publication of articles on original research data (sets), is a good example towards giving credit data providers and furthering the reuse of high (reference) quality data of benefit to Earth System Sciences.

7. CONCLUSIONS, CHALLENGES, AND RECOMMENDATIONS

The OceanObs'09 conference approximately marks the beginning of the 3rd decade of systematic global ocean observations. The first decade was dominated by WOCE (1990 – 2002) with primary objectives of observing the mean state of the ocean and collecting a set of high-quality global ocean climate baseline observations. It was followed by approximately a decade in which CLIVAR (2000 – present) was the main organizer for sustained global ocean observations, with a focus on the *variability* of ocean climate processes. The beginning of that last decade coincided with OceanObs'99 through which several of the current observing system elements got support or even initiated. These first two decades were driven nearly exclusively by research needs and by the (physical and chemical) ocean climate community.

The international community is at a new branch point now. The coming era of global ocean observation is clearly under the sign of societal applications, rather than pure research needs, and thus must embrace and address the many biogeochemical and ecosystem issues at hand. Probably 10 years from now OceanObs'09 will be seen as the start of the decade of truly multidisciplinary sustained global ocean observations.

The sections above attempt to summarize steps that are required to build a future system that is truly integrated in various respects. As a starting point, the majority of conference presentations and discussions suggest to

1. *maintain the existing system*
2. *close gaps in the spatial and temporal coverage of present observations focussing on geographic gaps – including the high latitudes, the global deep ocean, and boundary currents/throughflows, and using cost-effective technologies (such as gliders) as appropriate.*

As argued above, for the next steps it is likely most efficient, compelling, and cost-effective to <u>at least</u>

3. *enhance Argo, OceanSITES, and VOS to serve and be jointly operated with the biogeochemistry and ecosystem communities.*

The largest challenge however is the integration effort across elements, programs, and communities, and the coordination and merging of efforts, data, logistics, and resources across very diverse groups. This must be the longer-term goal. The integration components described in Sect. 5 require a coming-together of minds and interests. The active participants in each program need to see the mutual benefit of sharing and pooling platforms, sensors, ships, and data. Funding agencies can encourage such activities, and set an example by pooling their own resources and co-funding or sharing ocean observing system components.

Clearly, the overall plan outlined here is an ambitious endeavour. But since it would be jointly funded and implemented by the three communities and corresponding sections within (or across) agencies, such a system should also obtain several time the resources compared to the current observing system. In addition, the urgent societal needs/application may channel more resources into such a system. By following the integrations steps outlined in the above sections, and building an in-situ ocean observing that is ready to address all the scientific and societal needs in a single integrated way, an immensely powerful and compelling capability can be argued for. It would be able to address not only the present-day challenges, but also be ready for the unknown unknowns of the future.

REFERENCES

1. Hood, M. & Co-Authors (2010). "Ship-Based Repeat Hydrography: A Strategy for a Sustained Global Program." in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.44.

2. Drinkwater, M. & Co-Authors (2010). "Status and Outlook for the Space Component of an Integrated Ocean Observing System" in these proceedings (Vol. 1), doi:10.5270/OceanObs09.pp.17.

3. Cipollini, P. & Co-Authors (2010). "The Role of Altimetry in Coastal Observing Systems" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.16.

4. Freeland, H. & Co-Authors (2010)."Argo - A Decade of Progress" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.32.

5. Send, U. & Co-Authors (2010). "OceanSITES" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.79.

6. Goni, G. & Co-Authors (2010). "The Ship of Opportunity Program" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.35.

7. Smith, S. & Co-Authors (2010). "The Data Management System for the Shipboard Automated Meteorological and Oceanographic System (SAMOS) Initiative" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.83,

8. Burkill, P. and Reid, P., (2010). "Plankton Biodiversity of the North Atlantic: Changing Patterns Revealed by the Continuous Plankton Recorder Survey" in these proceedings (Vol. 1), doi:10.5270/OceanObs09.pp.09.

9. Gruber, N. & Co-Authors (2010). "Towards an Integrated Observing System for Ocean Carbon and Biogeochemistry at a Time of Change" in these proceedings (Vol. 1), doi:10.5270/OceanObs09.pp.18.

10. Testor, P. & Co-Authors (2010). "Gliders as a Component of Future Observing Systems" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.89.

11. Gruber, N. & Co-Authors (2010). "Adding Oxygen to Argo: Developing a Global in-situ Observatory for Ocean Deoxygenation and Biogeochemistry" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.39.

12 Lee, C. & Co-Authors (2010). "Autonomous Platforms in the Arctic Observing Network" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.54.

13. Boehme, L. & Co-Authors (2010). "Biologging in the Global Ocean Observing System" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.06.

14. Adornato, L. & Co-Authors (2010). "In Situ Nutrient Sensors for Ocean Observing Systems" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.01.

15. Byrne, R. & Co-Authors (2010). "Sensors and Systems for In Situ Observations of Marine Carbon Dioxide System Variables" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.13.

16. O'Dor, R. & Co-Authors (2010). "Bringing Life to Ocean Observation" in these proceedings (Vol. 1), doi:10.5270/OceanObs09.pp.29.

17. Claustre, H. & Co-Authors (2010). "Bio-Optical Profiling Floats as New Observational Tools for Biogeochemical and Ecosystem Studies: Potential Synergies with Ocean Color Remote Sensing." in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.17.

18. Swail, V. & Co-Authors (2010). "Wave Measurements, Needs and Developments for the Next Decade" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.87.

19. Sieracki, M. & Co-Authors (2010). "Optical Plankton Imaging and Analysis Systems for Ocean Observation" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.81.

20. Handegard, N. & Co-Authors (2010). "Toward a Global Ocean Ecosystem Mid-Trophic Automatic Acoustic Sampler (MAAS)" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.40.

21. Roemmich, D. & Co-Authors (2010). "Integrating the Ocean Observing System: Mobile Platforms" in these proceedings (Vol. 1), doi:10.5270/OceanObs09.pp.33.

22. Send, U. & Co-Authors (2010). "A Global Boundary Current Circulation Observing Network" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.78.

23. Brasseur, L., Tamburri, M. and Pluedemann, A., (2010). "Sensor Needs and Readiness Levels for Ocean Observing: An Example from the Ocean Observatories Initiative (OOI)" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.10.

24. Meinig, C. & Co-Authors (2010). "Low-cost, Robust and Easy-to-Deploy Surface Moorings for Tsunami and Climate Observations" in these proceedings (Annex).

25. Calder, J. & Co-Authors (2010). "An Integrated International Approach to Arctic Ocean Observations for Society (A Legacy of the International Polar Year)" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.14.

26. Sagen, H. & Co-Authors (2010). "Acoustic technologies for observing the interior of the Arctic Ocean" in these proceedings (Annex).

27. Rintoul, S. & Co-Authors (2010). "Southern Ocean Observing System (SOOS): Rationale and Strategy for Sustained Observations of the Southern Ocean" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.74.

28. Masumoto, Y. & Co-Authors (2010). "Observing Systems in the Indian Ocean" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.60.

29. Malone, T. & Co-Authors (2010). "Building a Global System of Systems for the Coastal Ocean: A Strategic Action Plan for Implementing the Coastal Module of GOOS" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.59.

30. Gordon, A. & Co-Authors (2010). "Interocean Exchange of Thermocline Water: Indonesian Throughflow; "Tassie" Leakage; Agulhas Leakage" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.37.

31. Garzoli, S. & Co-Authors (2010). "Progressing Towards Global Sustained Deep Ocean Observations" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.34.

32. Feely, R. & Co-Authors (2010). "An International Observational Network for Ocean Acidification" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.29.

33. Hankin, S. & Co-Authors (2010). "Data Management for the Ocean Sciences - Perspectives for the Next Decade" in these proceedings (Vol. 1), doi:10.5270/OceanObs09.pp.21.

34. Dushaw, B. & Co-Authors (2010). "A Global Ocean Acoustic Observing Network" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.25.

35. Koslow, J., Brander, K., Fogarty, M. and Schwing, F., (2010). "Integration of Ocean Observations into an Ecosystem Approach to Resource Management" in these proceedings (Vol. 1), doi:10.5270/OceanObs09.pp.26.

36. Koslow, J., Goericke, R., McClatchie, S., Vetter, R. and Rogers-Bennett, L., (2010). "The California Cooperative Oceanic Fisheries Investigations (CalCOFI): The Continuing Evolution and Contributions of a 60-Year Ocean Observation Program" in these proceedings (Vol. 2), doi:10.5270/OceanObs09.cwp.49.