

## OceanObs'09 Conference Summary

### OCEAN INFORMATION FOR SOCIETY: SUSTAINING THE BENEFITS, REALIZING THE POTENTIAL

**Albert S. Fischer**<sup>(1)</sup>, **Julie Hall**<sup>(2)</sup>, **D.E. Harrison**<sup>(3)</sup>, **Detlef Stammer**<sup>(4)</sup>, **Jérôme Benveniste**<sup>(5)</sup>

<sup>(1)</sup> *OceanObs'09 Organizing Committee, Intergovernmental Oceanographic Commission of UNESCO, 1 rue Miollis, 75015 Paris, France, E-mail: a.fischer@unesco.org*

<sup>(2)</sup> *OceanObs'09 co-chair, National Institute of Water & Atmospheric Research (NIWA), Private Bag 14901, Kilbirnie Wellington, 6241, New Zealand, E-mail: j.hall@niwa.co.nz*

<sup>(3)</sup> *OceanObs'09 co-chair, NOAA/PMEL, 7600 Sand Point Way, Seattle WA 98115, USA, E-mail: d.e.harrison@noaa.gov*

<sup>(4)</sup> *OceanObs'09 co-chair, Institut für Meereskunde, KlimaCampus, University of Hamburg, Bundesstr. 53, 20146 Hamburg, Germany, E-mail: detlef.stammer@zmaw.de*

<sup>(5)</sup> *OceanObs'09 Organizing Committee, European Space Agency/ESRIN, Via Galileo Galilei, Frascati (Rome), I-00044, Italy, E-mail: Jerome.Benveniste@esa.int*

The OceanObs'09 conference (21-25 September 2009, Venice, Italy) celebrated a decade of progress in implementing an initial ocean observing system focused on ocean physics and carbon, identified the scientific and societal benefits it has enabled, and looked forward to the coming decade. The conference called for full implementation and sustaining of the planned physical and carbon observing system, and highlighted a wealth of opportunities to extend the system to include comprehensive integrated observations, data sharing, analysis and forecasting of the biogeochemical state of the ocean and the status of marine biodiversity and ecosystems.

The executive summary of the conference (Section 1) outlines the key accomplishments of the conference in highlighting societal needs for a sustained ocean observing system, identifying opportunities and challenges. Section 2 describes the process of community input that culminated in the conference and the papers in these proceedings. Section 3 provides our view of key opportunities and challenges for components of the ocean observing system identified by the conference participants through the Plenary Papers and Community White Papers.

#### 1. EXECUTIVE SUMMARY

##### 1.1. Ocean information for society

The global oceans influence mankind in profound ways. They hold 97% of all water on Earth, and half of the surface of our planet is made up of the high seas, under the legal jurisdiction of no one nation, but under the common stewardship of all. The oceans absorb about a quarter of ongoing human emissions of greenhouse gases, preventing stronger warming of the atmosphere, but as a consequence are acidifying, with growing but still uncertain impacts on marine ecosystems.

The health of ocean ecosystems and their ability to sustain ecosystem services and societal benefits are threatened by human activity: through pollution, nutrient loading, harvesting of marine resources, habitat destruction, increasing CO<sub>2</sub> concentration and ocean acidification, and by global changes in ocean temperature, stratification, and biogeochemistry. Management of these threats to the oceans is critical to sustaining benefits to society for both present and future generations, and requires better understanding, models, assessments, and therefore observation of the natural state and of how these threats are changing the ocean.

Coastal populations exposed to ocean-related natural hazards such as tsunamis and storm surges, as well as longer-timescale sea level rise, are projected to grow rapidly. Early warning systems, as well as accurate regional projections that underpin adaptation and mitigation strategies, depend on real-time sharing of ocean observations. Global forecasts of marine hazards built on observations also support the more than 90% of internationally-traded goods that are transported by sea.

Ocean dynamics play a key role in regulating and modulating the hydrological cycle and climate on timescales of weeks to decades, and good ocean observations, analyses, and forecast systems provide key information for decisions in agriculture, human health, energy and water management, coastal management, transport, tourism and other sectors. Moreover, oceans provide a number of key ecosystem services to the human population of the planet: they produce the majority of oxygen through ocean primary productivity, hold the major part of the planet's wealth of biodiversity, and provide a source of food and economic gain from fish and other marine resources.

The economic benefits of ocean observations are large and growing, but difficult to estimate precisely. The benefits are interconnected and reach into many sectors

of society, making them difficult to track. Economic theory is also only beginning to grapple with the valuation of ecosystem services that are not traded but are critical to life on earth. Ultimately, given the finite resources of the planet, there is infinite value in maintaining the ocean's benefits to society - and we can view a sustained ocean observing system as a public good activity helping shape sound decisions for our collective futures.

**Observing the ocean is critical to understand, assess, forecast future threats, and to manage and reduce human vulnerability and risk linked to the oceans.**

### 1.2. A wealth of opportunity

The OceanObs'09 conference identified an incredible wealth of opportunities and enthusiasm in the ocean observations community to extend the benefits of the ocean observing system in new domains and for new uses. Important scientific progress was presented in every area and important new questions to be addressed were identified. The critical importance of comprehensive, integrated long-term observations was identified repeatedly. Only with long, high quality records can the extremes as well as modes of natural variability be identified and long-term trends estimated.

Technologies for ocean observations are advancing at a rapid rate, enabling new observations and an ability to integrate measurements of more ocean variables on a single platform. New information technology has revolutionized what is possible for data system improvements, yet community acceptance and adoption remains incomplete. There is growing willingness of the ocean observing community to share data freely and openly and to work to best practices to ensure consistent data sets as the benefits have been identified and proven, and this willingness is spreading from observing networks focused on the physical variables to those tackling biogeochemical and biological variables.

Some new elements of a sustained ocean observing system are **ready for immediate implementation** and could create new global observing networks based on technology proven in pilot projects, and on common standards to find and access data. Their implementation will quickly enable new science and new information support tools for a range of decisions. Other elements are **emerging**, and will require additional development in technology or methodology to enable them to contribute to the future sustained ocean observing system.

The conference was a unique opportunity to increase communication between scientific disciplines, and exposed a strong collective desire to work together on an ocean observing system integrated across disciplinary barriers. This will bring great scientific and societal benefit, and be the foundation for the

development of many new uses of ocean observations, for research and for applied use.

### 1.3. The way forward

A global ocean information system for society will need to be based in core principles called for in the Conference Statement: rapid and free access to relevant data, integration between satellite and in situ observations, the application of internationally-agreed standards for the collection, analysis, archiving, and distributing of data. The current system has made great strides, but adherence to these principals does not always take place, as observations are funded to meet local concerns and to local standards. A small additional investment in meeting international standards in sustained ocean observations would multiply the value of data locked away in individual systems, allowing it to meet many users' needs, even those yet to be identified. As new systems move from research observations to becoming part of a sustained system, adherence to these principles will allow the largest possible community to benefit.

**The major challenges to success in the coming decade can be simplified to the need for long-term funding and improved international and national organizational structures to build and sustain a true interdisciplinary, coherent, systematic, sustained ocean observing system.**

Research funding agencies are often unwilling to sustain observations in the long term, as they do not see this as part of their mission of innovation. The scientific research community is the primary consumer of sustained ocean observations, and a key intermediary in developing information from observations that are useful to society. In terms of publishable scientific results, sustained observations can be perceived to have diminishing returns. The observing progress of the past decade needs new national investment simply to continue and complete what was started, much less to become more effective and more comprehensive. Communities that have functioned primarily within research frameworks have realized the importance of observing to agreed practices and with interoperable data systems and with rapid data sharing. Yet significant progress is required in international coordination for the full range of ocean data.

Resources for international planning, implementation coordination, and the development and promotion of standards and best practices are low, particularly in comparison with the level of investment in observations. In the face of national priorities, it is often difficult to identify resources to support the involvement of national programs and experts in international efforts. There is also a growing need to ensure that global-scale sustained ocean observations are a true global

partnership, with strong local benefits for all nations. Education and capacity building in marine science and in ocean observations need additional investment.

The conference called for actions on the parts of nations and governments that will sustain the benefits and realize the full potential of ocean observations (see the OceanObs'09 Conference Statement). It agreed that the initial ocean observing system proposed following OceanObs'99 is still needed and full deployment should be sought by 2015. It called for commitments for implementation and international coordination of systematic global biogeochemical and biological observations. It also called for increased efforts in capacity building and education and urged the ocean observing community to adhere to the core principles outlined above. Moreover, the conference called for a post-conference Working Group to meet and to recommend a framework to take a more comprehensive system forward in the coming decade, integrating new physical, biogeochemical, and biological observations while sustaining present observations. This framework will help to set rational requirements for the system based on key societal issues, and review the system to ensure it remains fit for purpose as technology evolves and as societal needs and questions evolve. At press time a consultative draft of the *Framework for Ocean Observing* was available on the [www.oceanobs09.net](http://www.oceanobs09.net) web site.

## 2. THE OCEANOBS'09 CONFERENCE PROCESS

Ten years after the OceanObs'99 conference (San Raphaël, France, 18-22 October 1999) played a major role in consolidating the plans for a comprehensive ocean observing system able to deliver systematic global information about the physical environment of the oceans, the organizers of the OceanObs'09 conference developed a conference process with the goal of ensuring the sustainability and further development of the present system and of realizing the full extent of the benefits across all stakeholders and for all participating nations. The conference organizers also wanted to define a clear path to plan for extending the present system to include comprehensive observation, analysis and forecasting of the biogeochemical state of the ocean and the status of marine ecosystems.

OceanObs'09 was planned around and firmly based on community contributions and community consensus provided in three levels as input to the conference. The first two solicited were:

- *Community White Papers*, solicited as group contributions with one identified corresponding author. Nearly 100 accepted proposal authors were asked to generate papers that were forward-looking, stating new opportunities for a particular (in situ or satellite) element of the

sustained observing system, or the requirements for a user need. The Community White Papers refresh existing plans in the light of new information and technology, or describe contributions to the sustained global ocean observing system from new communities with a plan for a globally-deployed network or infrastructure or service. These papers were available in draft form for review and comment, and they form the core of Volume 2.

- *Volunteer Additional Contributions* were solicited to broaden exchange in the community, and were presented at the meeting in poster form. Short-form papers from these contributions are in the Annex of these proceedings.

The Community White Papers were peer-reviewed prior to the conference and made available for community comment using a blog commenting system on the [www.oceanobs09.net](http://www.oceanobs09.net) web site. These were revised after the feedback from the review process and the conference itself.

The Programme Committee devised an agenda built on five daily themes. The first day celebrated the decade of progress in the ocean observing system since the OceanObs'99 conference, and introduced high-level perspectives and visions for the observing system and delivery of information for the coming decade, from both the provider and user perspective. The second day was devoted to describing the advances in scientific understanding of the ocean reached through the increase in ocean observations during the last decade, and looked forward to the need for sustaining and expanding our knowledge for future science applications. Day three examined how ocean services can be expanded, anticipating benefits and identifying which observing, data management, modeling, and synthesis systems are required to reach those goals. The fourth day examined the frontiers in observing technology and infrastructure, and the final day concentrated on the frameworks to develop and deliver information to science and to society from the ocean observing system in the coming decade, based on sustaining the existing system, expanding and enhancing the system with new observations and capabilities, and developing useful information.

The agenda was made up of invited Plenary talks, drawing from community input. These had one lead author as speaker, accompanied by other contributing authors. Plenary Papers, depending on their theme, summarized progress in the last decade, identified big remaining research questions and challenges, provided particular examples of the benefits of ocean information, outlined the scientific and technological underpinnings of generating services for society, or envisioned upcoming observing technology and

projects; all were asked to identify current and needed assets in the observing system that will allow progress. Presentations on the last day were asked to describe the plan for the coming decade for a sustained, interdisciplinary observing system, and to showcase examples of significant benefits, confronting in particular the frameworks in place and needed to make progress.

A peer review of the Plenary Papers took place after the conference. Single-author papers in the volume are the opinion of those authors, rather than reflecting community views. The Plenary papers form the core of this Volume 1 of the proceedings.

The conference provided many opportunities for community discussion, through question and discussion sessions, poster sessions, roundtable discussions, and side meeting opportunities. Four Community Fora were led by international research organizations to debate common plans and strategies.

The unique structure of the conference allowed the development of a community conversation about the future of the sustained ocean observing system, and revealed significant prospects and interest in building on current successes and expanding the prospects for ocean observations in new disciplines, with an enhanced set of societal benefits.

### **3. TOWARD A GLOBAL INTEGRATED OCEAN INFORMATION SYSTEM**

The presentations at the conference emphasized that a future global integrated ocean observation and information system would have to include many elements: observations from both satellite and in situ platforms, a data infrastructure based on common standards, and analysis and modeling systems with widely discoverable data and outputs. The system will benefit greatly from coordination across platforms, across disciplines, and from requirements to observations and through to the final outputs: information useful for science and for society. Innovation in sensor technology and platforms will increase capability, and should be encouraged to expand the capabilities of the system. The conference also made it clear that strong communities have built around existing and emerging observing platforms, and that nurturing but also coordinating the work of these communities will be a fundamental building block moving forward.

This section is our view of the opportunities and challenges that were presented at the conference. It is organized around observing system platforms, key required technological developments, the data system, the development of information and services, and structural developments that will help realize the full potential of the sustained ocean observing system in the

coming decade. It clearly cannot be exhaustive, as this weighty volume implies. However we hope it will help the ocean observing community to focus their efforts while identifying their role in the improvement of the future ocean observing system.

#### **3.1. Platforms**

Scientific and societal issues are drivers of the requirements for the sustained ocean observing system, and these requirements are met with observations taken with individual observing platforms and sensors. The observing system naturally groups around communities that focus on a particular platform, which is how we chose to organize some of the key opportunities and challenges identified by the conference. Satellite and in situ platforms are both key to observing the oceans, measuring them in complementary ways.

##### **3.1.1 Ships**

Ships as platforms are able to carry many high-quality sensors, including ones with large volume and power requirements. Ships are also needed to deploy, recover or service most of the other in situ platforms below, and are often the only means of accessing remote areas not easily reached by other observing platforms. They are also important in recovering other platforms for recalibration and during the testing of new observing technologies.

**Research ships:** Research vessels (RV) are equipped with high-quality sensors and carry the expert teams required to run them. Variables measured from RVs include all parameters for which sensors exist, including physical, biogeochemical, and biological measurements of the ocean, the atmosphere, and on or below the sea floor. Some data is generated after water samples or samples from the sea floor or sediments have been collected and brought back to shore. RVs can measure variables in the full water column, and provide data with high quality standards overseen by the scientists on board or in laboratories on shore.

Because of their unique equipment and capabilities, RVs will in the foreseeable future continue to be required for repeated measurements of hydrography and biogeochemical variables along fixed lines (repeat hydrography). Routinely adding a wider set of biogeochemical variables will be beneficial. The GO-SHIP repeat hydrography program serves many users, and many disciplines including the modeling community would benefit if they could review the sampling strategy on a regular basis.

Widespread deployment on RVs of more autonomous systems with real-time data transmission should be encouraged, allowing data to be managed and used in real time by a wider range of users.

The number and countries operating open-ocean-capable RVs is changing, and continued investment in their development and operation is needed.

**Commercial ships:** Commercial ships allow routine near-surface atmospheric and oceanic observations along commercial shipping routes. They presently measure a small number of physical parameters (surface temperature and salinity, temperature XBT profiles, and marine meteorological variables), although the resulting data quality is often lower compared to observations from RVs. Commercial ships are also used to measure underway ocean carbon variables, and in limited areas biological variables such as through the use of Continuous Plankton Recorders.

There is great potential to observe many more physical, biogeochemical, and biological variables from commercial ships, for example with acoustic sensors for the identification and quantification of zooplankton species. Commercial ships are often a cost-effective way of providing sustained observations, and an increase in the number participating in ocean observations would increase the density and global coverage of data, for example for pCO<sub>2</sub> measurements in coastal regions.

One challenge is increasingly variable ship routing, which reduces the regularity of observations on a particular route or in a geographical region. Instruments on commercial ships have to be autonomous and acceptable for installation to the ship master and owner. The maintenance and calibration of sensors on commercial ships also poses a challenge, and improving sensors and systems (higher quality, long-term stability, improved data transmission), as well as improving communication with the shipping industry, will both be key for an enhanced use of commercial ships in the future.

### **3.1.2 Moored Buoys**

Moorings provide high temporal resolution observations at key sites, capturing important events in a specific region. Compared to drifting platforms, they can generally carry a larger number of sensors with higher power requirements.

Expanding the spatial coverage of mooring sites, and expanding the suite of sensors deployed could greatly expand the impact of mooring data. Technology development is required to increase the power supply of moorings, to improve data transmission, and to improve the durability and cost-effectiveness of the platform.

Several mooring platform types will be part of a future integrated observing system:

**Long-term timeseries:** The existing global network of timeseries moorings provides key data on climate variability and change and for evaluation of model

outputs at fixed points and as end-point arrays for transport measurements. This network needs additional investment for full implementation, and we suggest emphasis on continuity of existing time series and the most comprehensive feasible suite of sensors to expand the number of variables observed. Potential exists to add new carbon (DIC and total alkalinity) and pH sensors to moorings to help constrain ocean carbon changes, bio-optical and acoustic sensors for biological variables, and acoustics for precipitation. Pilot project deployment of new sensors will help develop this observing platform to its full potential.

**Tropical arrays:** the global tropical network of moorings for understanding and forecasting air-sea interaction and seasonal-to-interannual variability should be maintained in the Pacific and Atlantic, and fully implemented in the Indian Ocean. Key moorings should have enhanced sensor suites as resources permit, to increase understanding of the global carbon cycle, hydrological cycle and primary productivity, linking to the network of timeseries moorings described above.

**Observatories:** New developments in cabled ocean observatories providing sustained infrastructure above, on, and below the seafloor, including power and communication, have begun to prove their value, expanding the capabilities of these fixed autonomous platforms. Their development should be encouraged and assessed for inclusion in a sustained ocean observing system.

### **3.1.3 Lagrangian Buoys and gliders**

The surface drifter network and the subsurface Argo profiling float network were identified by many at the conference as a demonstrated success of the previous decade, developing from limited-geographical-range research measurements to true global observing networks since OceanObs'99. In both cases these networks need constant investment and effort to be maintained at their target densities in the future. There is good potential to increase the number of variables measured from these networks.

**Drifting buoys:** The global surface drifter array is critical in maintaining the climate record of sea surface temperature and surface pressure, provides real-time data for forecast systems, and should be maintained. Drifters with sensors for pCO<sub>2</sub>, sea surface salinity and other variables have been tested in pilot programs. The future use of drifters in an overall strategy for measuring global surface currents needs to be evaluated.

**Profiling Floats:** The Argo array is transforming our knowledge of the upper ocean density field and its variability, and its data streams are being used in many scientific and forecasting applications. The network should be maintained.

There was great interest at the conference in increasing the number of variables measured from profiling floats. A strategy for the next generation of observation via profiling floats should be developed, and aim to meet a wider variety of scientific and societal goals, but this strategy will carry a higher cost. Oxygen, bio-optical variable, and acoustic rainfall sensors are ready for pilot project use, but when added will carry data system, float lifetime and array maintenance costs. Further sensor development will bring the potential to measure an even larger number of variables. Pilot projects underway for floats that can sample the full water column, change sampling behavior with two-way communication, and sample under seasonal sea ice (with an acoustic infrastructure for tracking and communication) will also help to expand the capabilities of this observing platform.

**Gliders:** Glider development has progressed rapidly and pilot projects are in place in several regions. Development of the platform and development of best practices for use should be encouraged. They are already being used to conduct cross-shelf and frontal region profiles of a range of variables such as salinity, temperature, oxygen, chlorophyll a, dissolved organic matter, turbidity, and phytoplankton composition. There is potential for their role in deep ocean observations and in taking observations under sea ice. Building a global community and strategy around glider observations will increase their future contribution to sustained ocean observations.

### **3.1.4 Satellites**

The success of satellites as platforms for continuous ocean observation has been demonstrated over the last decade, and satellites are now a central part of the ocean observing system. Satellites observe the surface ocean globally with high space-time sampling, irrespective of political boundaries, and provide observations year-round, often independent of weather systems and seasons. Continuous measurements of key variables need to be maintained at current levels of coverage and expanded in the future.

Potential exists to increase the number of biogeochemical and ecosystems variables that can be inferred with hyper-spectral technology. Improved information about sea ice (motion, concentration, thickness, age) could come from an increased use of Synthetic Aperture Radar (SAR) and altimetric technology. Further improvements will also come from increased space-time resolution of individual satellite missions and sensors, and increased space-time sampling emerging from constellations of satellites being organized by the international community through the Committee on Earth Observation Satellites (CEOS). New gravity missions are required for monitoring mass changes including those of the ice sheets, fundamental

for projections of sea level. For climate applications, long-term stability is required for individual variables, requiring elaborate inter-calibration procedures between satellite missions and as sensor technology changes.

Improved satellite measurements of solar insolation, cloud cover, turbidity, and ocean color have the potential to improve the assessment of variation in fish stock recruitment, by providing estimates of seasonal and interannual variability in phytoplankton populations which form the base of the oceanic food web. Ocean color measurement could be expanded with geostationary sensors, sensors with increased spectral resolution, and increased spatial resolution, which would improve ocean color products in coastal waters.

Satellites can only observe the surface ocean, and merging this data with in situ observations through analysis and synthesis activities greatly expands its value. Continued and improved links between the satellite observing and the modeling/assimilation communities are needed.

Migrating of research missions into operational missions across agency boundaries remains an ongoing challenge.

### **3.1.5 Ocean Acoustics**

Acoustic measurements of the ocean have been a part of research observations, but are not currently used in a globally-deployed sustained manner (apart from applications of acoustics as sensors for velocity and the tracking of floats under the ice). In contrast to satellite and electromagnetic remote sensing, the ocean is largely transparent to sound enabling this form of in situ remote sensing. Potential exists for these measurements to be a part of an integrated ocean observing system.

**Proven technology** using active acoustics can be used for ocean tomography monitoring of temperature changes as integrals over long distances, as well as providing acoustic infrastructure for the tracking and communication of other autonomous platforms.

**New acoustic technology** using passive acoustic listening has the potential to monitoring surface precipitation, waves, sea ice dynamics, and anthropogenic noise in the ocean and its impact on marine ecosystems. New active multi-frequency acoustic sensors also have potential for the global sustained observation of mid-trophic level organisms such as mesozooplankton.

### **3.1.6 Tracking and animal tagging**

Tracking the movements of tagged marine organisms such as sharks, tuna, turtles, seals and whales is providing new insight into animal behavior and ocean ecosystems. In some cases, in situ sensors can also measure pressure, salinity, water and body temperature,

light, and position, yielding further information about interactions with the physical environment. As a by-product, it can generate useful physical data in hard-to-access areas such as under ice shelves.

### 3.2. Sensor and technology development

Sensors are at the core of expanding the capabilities of the ocean observing system, as they bring the ability to make stable sustained measurements of new variables to existing ocean observing platforms. Improving them will be key in developing an integrated system across disciplinary boundaries, a system that will have more users, advocates and increased success.

Many sensors for physical parameters of the ocean have been developed and deployed on most of the existing platforms. Reducing the power consumption of sensors and increasing battery capacity of platforms will improve the observing system. Developments in miniaturization, cost reduction, and sensor stability will be essential for increasing the quality of the integrated observing system, for extending the lifetime of its platforms, and for making ocean data more cost efficient.

An increase in payloads of floats and gliders, the effective lifetime of autonomous platforms such as floats, and the ability of animal tags to measure more variables are all dependant on a reduction of the power demand of sensors and/or an increase in platform battery energy density. The development of renewable energy sources holds great long-term promise and may include methane hydrate fuel cells, microbial fuel cells, sea surface voltaic cells, ocean thermal and motion-to-electricity technology. For sensors deployed on animals the use of water movement or pressure changes may be future sources of energy. Reducing power requirements and increasing bandwidth of data transmission will assist in retrieving data from sensors carried by animals who often spend a very limited time on the surface, and increase the effectiveness of man-made observing platforms.

The miniaturization of all in situ sensors is an ongoing technical challenge, and one that will allow the migration of sensors from research ships and moorings to autonomous platforms. This is an area where adoption of technologies from other areas of science will be important, such as “Laboratory on a chip” technology adopted from the health care industry and the use of microfabrication techniques such as photolithography, laser micromachining and embossing. A careful tradeoff in sensor accuracy must be evaluated, as low accuracy measurements will reduce the possible applications of data.

For biogeochemical variables, the development of sensor technology is important, particularly for reliable sensors for autonomous platforms. Improved pCO<sub>2</sub> and

other carbon sensors including DIC and total alkalinity, along with certified reference material would enable the ocean carbonate system to be better-constrained. For oxygen measurements drift problems, long response times, and longer term calibration issues need to be overcome. The development of in situ nutrient sensors will provide new and important insights into global biogeochemical cycles. Nutrients analyzers need to be self-calibrating, capable of multiple analyses, resistant to biofouling, have low lifecycle cost, high reliability, and low maintenance requirements, and allow real time data transmission. Biofouling and long term reliability remain major challenges.

To enable a fully integrated ocean observing system to be implemented the development of biological sensors is critical. There are a wide range of biological sensors that are currently being developed and trialed. These include chlorophyll a and POC (particulate organic carbon), which would provide critical bio-optical measurements for the validation of ocean color remote sensing. For plankton, developments in optical imaging are promising, but optimal designs need to address issue of logic in the system or compression of images for remote processing. For assessment of larger zooplankton and small fish, acoustic sampling using multifrequency acoustics is currently restricted to use on ships due to the high power requirements and size. Genetic barcoding for sampling is a promising approach for observations of marine biodiversity.

The development of integrated Ferry-box systems will allow the further instrumentation of commercial volunteer observing ships. Current designs need to be optimized for reliability and robustness, and developed to include new biogeochemical and ecosystem variables.

The interoperability of sensors and instrumentation on platforms is a concept that is being developed, and will facilitate new measurements. For example the Open Geospatial Consortium has developed standards for connecting sensors to global information structures and Sensor Web Enablement standards now define standards for interfaces and protocols for accessing all types of sensors over the web.

Economies of scale suggest a need for communities to come together and work with industry to define and consolidate markets. This approach has proved to be effective within the Ocean Tracking Network where researchers came together to order collectively, which facilitated working with suppliers in development of technology and supply of biologging sensors.

The deepest part of the oceans are not routinely measured by the platforms detailed above, apart from repeat hydrography and some timeseries sites. There is a need for technology development focused on improving

reliable and cost-effective access of observing platforms and the capabilities of sensors for the deep ocean.

### **3.3. The data system**

An effective data management system is vital for an effective ocean observing system. It is needed in the program-level management of in situ platforms and sensors; in the timely and reliable delivery of observations to data assimilation and data assembly centers; in linking observations to the metadata that describes them; in the feedback loops that ensure quality control of observations; in the creation and delivery of products; and in the long term, secure management of the climate data record. It has a highly visible role in meeting the needs of scientists, environmental managers, and educators and many other classes of users, who need to access data and information. For these end users the data system must make it easy to locate data and products, to utilize them effectively in the software tools of their choice, and to correctly interpret this data through ready access to metadata.

The preceding description represents a vision, rather than a reality today, though significant progress has been made toward these goals over the past decade. For example, the Argo data management system has demonstrated how effective it is to have data management be an integral part of any new observing technology. OceanSITES is following a similar path. Some de facto best practices for data formats and data access are emerging from these activities and merit consideration for more general adoption. In particular, NetCDF/CF and OPeNDAP have come to serve many groups well and deserve formal recognition. The widespread use of standards will be a key element in achieving further progress.

Other considerations must also be addressed: in some cases national policies limit the sharing of data, the funding of data systems is often lacking, and an international community of data management professionals should be fostered. User communities have agreed on the importance of sharing data, and national policies need to support the widest possible sharing of ocean observations. Data management needs to be incorporated into programs from their conception and not addressed long after observing work is established. Mechanisms to foster continuing engagement between the data management community and the science community are essential. The Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) Data Management Program Area and the IOC International Oceanographic Data and Information Exchange (IODE) need to continue to interact closely with each other and reach out to the observing and user communities.

A tension between the rapid change of information technology and the comparatively slow process of building consensus on data sharing and standards is best faced with 'agile' management strategies, which seek progress on incremental tasks on modest timescales. Clear international consensus on metadata standards needs to be built, along with national infrastructure for metadata systems.

Data transport issues remain a challenge. Inexpensive bandwidth for rapid satellite transmission of all desired observations is needed, and is key to participation in the existing real-time GTS data transport system and future data transmission systems. Mobile phone transmission of near-shore observations is often feasible, but community standards need to be developed and documented. Acoustic transmission from sensor to a relay device has potential to allow measurements in previously inaccessible areas.

Data set assembly merits much greater financial support than has been available. All programs that have had funding to support specialist data assembly activities have benefitted greatly from these efforts. Ideally those involved in data assembly also work closely with development and implementation of appropriate system-specific metadata standards.

Because long records have great information-development value, data archeology also merits additional funding for all variables. A great deal of value will be realized if the many observations, however imperfect, now resident in specialist data archives can be 'rescued' and brought into more comprehensive data sets.

It is also critical that the data system support access to and interpretation of ocean information products. Much remains to be done in both the design and implementation of this component of the data system in the coming decade. User-driven technologies are available; their development should be supported and their use fostered.

A particular challenge that requires close interaction between the science and data management communities is the preparation of reference data sets with useful assigned uncertainties. There are not agreed procedures for this type of work at present, yet the availability of reference data sets including climatologies (with means and co-variances) is critical for the development of ocean information to serve societal and scientific needs.

## **3.4. Information and services**

### **3.4.1 Analysis and models**

Delivering information and services is part of an integrated ocean observing and information system. Building on existing ocean observations, models help to generalize information and make projections and

forecasts. These models include statistical relations between observables and parameters of interest, or analysis. More complex systems include the assimilation of data into dynamical ocean circulation models, coupled climate systems or coupled biogeochemical-ecosystem models. These provide information about the state of the ocean by merging observations with the physical, chemical and biological dynamics embedded in these models. At present these systems focus on the physical ocean as a part of the climate system. In the future, forecasts by coupled climate-carbon models to predict the evolution of atmospheric CO<sub>2</sub> and changing role of oceans in the carbon cycle, as well as ocean initialization of seasonal to decadal predictions will grow in importance. Coupled ecosystem models will evaluate the impact of human threats on ecosystem services, and serve in scenarios of ecosystem-based management of fisheries. Ocean services will be based on both ocean observations and ocean models.

Improved effort and investment is needed in model-based generation of information and services, translating both scientific knowledge and ocean observations into useful information. The utility of this information coming from models will need to be assessed also for its implications for the design of the observing system.

#### **3.4.2 Interfacing with providers of societally-relevant services**

Ultimately the ocean observing system is funded for public good, and needs to respond to societal needs. The current system of sustained ocean observations is focused largely on providing information for climate monitoring, projections, and research, while also providing information for ocean and weather forecasting, and ocean hazard warning systems.

Sustained observations have the potential to serve a much wider range of services, including ecosystem-based management, assessments of the marine environment, emergency response, and regionally-set priorities. As the sustained ocean observing system expands, maintaining strong interaction and dialogue with the developers of these services will help drive towards a system and ocean observations that are fit for purpose.

### **3.5. Observing system design**

A major activity ahead is to expand the adaptive design process that has been used for the initial climate observing system into a more integrated system that includes biogeochemical and biological variables, and serves further scientific and societal requirements to the greatest extent feasible. Particular attention may need to be paid to undersampled regions: the deep ocean, high latitudes, boundary currents, and marginal seas.

Recognizing that our knowledge is often quite imperfect, it should be expected that any plan will need to be revisited routinely, in order to incorporate new technology, new knowledge gained from the observations collected and the information developed from the forecasts made and services developed. We suggest that a 5- to 10-year revisit cycle is appropriate, based on the experience of the past decade. How best to carry out the many different activities that will be needed was a core question for the post-Conference Working Group set up by the international sponsors of the conference.

The post-OceanObs'09 working group has recommended a Framework for Ocean Observing for moving global sustained ocean observations forward in the next decade; integrating feasible new biogeochemical, ecosystem, and physical observations while sustaining present observations; and considering how best to take advantage of existing structures. At press time this report was in consultative draft form, and is available on the [www.oceanobs09.net](http://www.oceanobs09.net) web site. Proposed Framework processes to identify requirements, coordinate observing networks, data management streams, and the generation of ocean information would be organized around "essential ocean variables (EOVs)". The output of the system would be assessed for its fitness-for-purpose, feeding back into revised requirements. Implementation of new initiatives would be carried out according to their assessed readiness levels, encouraging innovation and formal efforts to improve readiness and build capacity. The Framework would take advantage of existing structures, promote a collaborative system with voluntary participation, and seek to support self-funding and self-managing elements that together will provide more than the sum of their individual efforts.

Making this Framework work in the real world, fostering interactions between all the international, regional, national, and individual players involved in taking or using ocean observations, will be a continuing but rewarding challenge in reaching the objectives of OceanObs'09: ocean information for society that sustains its benefits, and realizes its full potential.