Preface

Building on a decade of progress in satellite and in situ observing of the global ocean and developing useful scientific and policy information from growing data sets, the OceanObs'09 conference was held in Venice, Italy, 21-25 September 2009, ten years after OceanObs'99 in Saint-Raphaël, France. The conference was sponsored and/or endorsed by many marine observing agencies and programs. More than 600 participants from 36 nations came together to build a common vision for the provision of routine and sustained global information on the marine environment sufficient to meet society's needs.

The conference was convened to bring together the communities undertaking these activities to share their experiences, interact with each other, and identify opportunities to work together in the coming decade. These communities coordinate their work through a wide range of national efforts, often coordinated via international and intergovernmental programs and technical commissions; the conference also sought to encourage improved links between these various organizations. Finally the conference sought to demonstrate the utility of a more fully integrated observing system that can address societal needs across the sweep of climate, marine carbon and ocean acidification, marine biogeochemistry, fisheries and ecosystem management issues and to make the case for expanded national investments in integrated ocean observing and marine information delivery.

OceanObs'09 was based on contributed community input. The organizers solicited Community White Papers describing aspirations for the coming decade from all interested communities of international collaboration and large-scale sustained ocean observing efforts. Other community efforts of smaller scope were accepted as Additional Contributions. The organizers developed the agenda to highlight observing system progress, research, information and services development, technology development, and to identify issues and opportunities for the coming decade. Each agenda item was represented by a single presentation and accompanying Plenary Paper that was asked to draw upon all relevant contributions. The conference process is described in the Conference Summary.

The Community White Papers and Plenary Papers underwent a peer-review process and an open comment period on the web, and were subsequently revised before being accepted. The few single-author Plenary Papers in this Proceedings volume represent the opinion of their authors and are not the result of a community process.

The conference provided many opportunities for interaction. The Conference Statement, the first document in this volume, was developed and agreed during the conference. The Conference Summary, which follows it, expands on the Conference Statement and highlights some of the opportunities and challenges raised by the wealth of input to the conference.

At the conference there was a very high level of excitement about both the progress that has been made and the opportunities to do much more in the decade ahead. It was clear that we stand on the threshold of a decade of great possibility for marine and climate research, forecasting and management. It remains for the nations of the world and the national, international and intergovernmental organizations that sponsor marine observation activities to respond these opportunities.

We would like to recognize the contribution of all the agencies, programs, institutions and organizations that supported the conference, in particular [detailed list to be added]. And we thank all of the participants who worked so hard to develop community agreements and plans to support the conference, as well as the rest of the Organizing Committee, the Programme Committee, the reviewers, plenary speakers, keynote speakers, session chairs, rapporteurs, forum organizers and poster presenters for making the conference a success.

- Julie Hall (NIWA), D.E. Harrison (NOAA), and Detlef Stammer (KlimaCampus Hamburg)
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http://www.oceanobs09.net

between the Preface and the Conference Summary, the volume will hold:

[Table of Contents]

[Conference Statement]

CONFERENCE SUMMARY

Ocean information for society: sustaining the benefits, realizing the potential

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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 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 influences mankind in profound ways. The oceans hold 97% of all water on Earth, and half of the surface of our planet are made up of the high seas, under the legal jurisdiction of no one nation, but under the common stewardship of all. The oceans have absorbed about half of human emissions of greenhouse gases and prevented 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: by the human role in climate change and therefore in ocean temperature, stratification, biogeochemistry and acidification; but also through pollution, nutrient loading, harvesting of marine resources, and habitat destruction. 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.

Accurate regional climate forecasts and projections are fundamental for decisions in agriculture, human health, energy and water management, coastal management, transport, and tourism and other sectors. These forecasts require a constant flow of ocean observations, as ocean dynamics play a key role in regulating and modulating climate and the hydrological cycle on timescales of weeks to decades. 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, and economic theory is 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 oceans 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. The willingness of the ocean observing community to share data freely and openly and to work to best practices to ensure consistent data sets is growing as the benefits have been identified and proven, and this willingness is spreading from the physical variables to 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. 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.

2. The OceanObs'09 conference process

Ten years after the OceanObs'99 conference (San Rafaël, 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* were solicited as group contributions with one identified corresponding author. Nearly 100 accepted proposal authors were asked generate papers that were forward-looking, stating new opportunities for a particular element of the sustained observing system, a CEOS satellite virtual constellation, 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 and were available in draft form for review and comment. and form the core of Volume 2.
- Volunteer *Additional Contributions* were solicited to broaden the 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 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 Symposium, and introduce 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 applications. Day three examined how ocean services can be expanded, anticipating benefits and identifying which observing, 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, identify big remaining research questions and challenges, provide particular examples of the benefits of ocean information, outlining the scientific and technological underpinnings of generating services for society, or envision 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 Volume 1 of these proceedings.

The conference provided for 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 information system would have to include many elements: observations both satellite and in situ platforms, but also 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 observations 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

The scientific and societal issues that are the drivers of the requirements for the sustained ocean observing system must be met with the use of individual observing platforms and sensors. The observing system therefore 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. Both satellite and in situ platforms are key to observing the oceans, and are complementary.

3.1.1 Ships

Ships do and will continue to play a multitude of functions in an integrated observing system as platforms carrying many high-quality instruments. They are also required to deploy, recover or service most of the other platforms listed below and are often the only means of access to remote areas not easily reached by other observing system platforms. Ships are also important in recovering existing instruments for recalibration or testing of new technology.

Research ships: Research vessels (RV) are equipped with high-quality instruments and carry expert teams required to run those instruments. Variables measured from RVs include all parameters for which sensors exist, including all physical variables of the water, in the air and on or below the sea floor; and all biological or biogeochemical variables. Some variables are also measured after water samples or samples from the sea floor or sediment have been collected. RVs have the advantage of providing measurements of the full water column, and provide data with high quality standards. Through their unique equipment and capabilities RVs will continue in the foreseeable future to be required for the specific function of repeated measurements of hydrography and biogeochemical variables along fixed lines (repeat hydrography). However, there is a need to routinely add a wider set of biogeochemical variables such as DIC, total alkalinity, pCO2 and pH and biological variables for example calcifying organisms. The sampling strategy for the GO-SHIP repeat hydrography program should be reviewed on a regular basis, with input from multiple disciplines including the modeling community.

Instruments on RVs are in general not run in an autonomous way but deployed for specific purposes. However, the role of RVs is gradually changing with more robotic systems are being deployed to investigate the sea floor, biological and biogeochemical variables. It is also anticipated that in the future, RVs will be used as platform for autonomous near-surface underway observations with great potential for direct data links so that observations can be tracked and utilised in real time.

Commercial ships: Commercial ships serve as platforms obtaining routine observations near the surface in the ocean and the atmosphere along selected commercial shipping routes. These voluntary observing ships (VOS) are presently being used to measure a small number of physical parameters (surface temperature and salinity, temperature XBT profiles, and meterological observations), although the resulting data quality can be reduced relative to what can be obtained from RVs. VOS programs also exist for ocean carbon variables, and in limited areas for biological variables for example the Continuous Plankton Recorder observations. There is large potential for observing many physical and biogeochemical observations, including improved meteorological variables as well as biological variables such as acoustic sensors for the identification and quantification of mid trophic level mesozooplankton species. Because commercial ships are often a cost-effective way of providing sustained observation, the network of VOS ships in coastal regions should be increased to improve the spatial coverage of pCO2The problem on VOS ships of continuously changing ship routing is hindering an increased use of the commercial shipping fleet as part of the global observing system. Measurements have to be autonomous, and the maintenance and calibration of sensors on VOS is not as simple as it is on RVs and improving sensors and systems (higher quality, long-term stability, improved data transmission) is key for an enhanced use of VOS in the future.

3.1.2 Moored Buoys

Moorings provide high temporal-resolution observations at key sites, capturing important events in a specific region. They are platforms that can carry a multitude of sensors and can provide a long-lasting energy supply as well as fast data transmission, within the limits of the capabilities of the mooring. Expanding the spatial coverage of mooring sites, and expand the suit of sensors deployed could greatly expand the importance of mooring data. In particular, there is a need to develop this type of platform coastal areas and at sites deeper than 1000m. Technology development is required to extend the power supply of moorings, to improve data transmission, and to improve the durability and cost-effectiveness of the platform. In terms of an expanded parameter suite, new carbon (DIC and total alkalinity) and pH sensors should be added to moorings to help constrain ocean carbon changes, and acoustic sensors added for biological variables. Several mooring platform types will be required in a future integrated observing system:

Long-term (OceanSITES-type) timeseries: This will be an extension of the existing global network of moorings, which provides critical information for climate variability and change and for evaluation of model outputs. This component should continue to full implementation, with emphasis on continuity of existing time series and the most comprehensive feasible suite of sensors to expand the number of variables observed. Observations of photosynthetically active radiation, bio-optical variables and ocean color can be made, along with the use of acoustic sensors for various applications, such as surface precipitation and biological measurements. Pilot project deployment of new sensors will help develop this observing platform to its full potential.

Tropical arrays: a global tropics-spanning network of moorings is deployed in key areas for understanding and forecasting tropical air-sea interaction and seasonal-to-interannual variability, and should be fully implemented. Representative moorings should continue to provide measurements and need to have enhanced sensor suites as resources permit, to increase understanding of the global carbon cycle, hydrological cycle and primary productivity, linking to the timeseries moorings described above.

Observatories: Observatories are a relatively new concept of providing infrastructure on the sea floor, including power and communication to individual applications. Several permanent underwater networks have been established recently and have begun to prove their value.

3.1.3 Lagrangian Buoys

The existing Lagrangian buoy networks (the surface drifter array and the subsurface Argo profiling float array) have been a demonstrated success, building out from limited geographical-range research measurements to sustained global observing platforms since OceanObs'99. In both cases the existing arrays need to be maintained at their initial target densities and for their original design goals, but more sensors could be added. For example, prototype sensors for oxygen, rainfall, and bio-optical variables have all been tested. The addition of carbon and pH sensors would provide shorter time and space scale measurements, but the technology needs development.

Drifting buoys: The global surface drifter array is critical to maintaining the climate record of sea surface temperature and surface pressure, and must be maintained. Drifters with sensors for pCO2, sea surface salinity and other variables have been used in pilot programs and will figure more and more in the coming decade. 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 must be maintained. Rainfall, oxygen and bio-optical variables sensors are ready for pilot project use and are encouraged, but when added will carry data system, float lifetime and array maintenance costs. 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. Technology exists in prototypes to sample the full water column, and has potential to contribute to a deep system.

Also, potential exists for two-way communication to change sampling behavior. A strategy for sustained sampling under seasonal sea ice needs to be developed.

Gliders: Glider development has progressed rapidly and pilot projects are in place in several regions. Rapid development of systems and best practices for use are expected to continue. It is also expected that they will contribute particularly in observing frontal regions, but also more widely in the evolving deep ocean observing system. Gliders have the capacity to conduct cross-shelf depth profiles of a range of measurements such as salinity, temperature, oxygen, chlorophyll a, dissolved organic matter, turbidity, and phytoplankton composition. The same holds under sea ice including permanent sea ice. This list of measurements will grow as more sensors are developed for long-term autonomous deployment.

3.1.4 Satellites

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

In the future it can be expected that hyper-spectral technology will gain increased importance to resolve more processes and phenomena than can be observed with current technology. This will increase the number of biogeochemical and ecosystems variables that can be inferred. Further improvements will also come from increased space-time resolution of individual satellite missions and sensors, as well as increased space-time sampling emerging from constellations of satellites being organized by the international community through CEOS. We expect that an increased use of SAR and ALT technology will lead to improved information about sea ice (motion, concentration, thickness, age). New gravity missions are required for monitoring mass changes (e.g., ice sheets) within the Earth system, measurements fundamental for projections of sea level. For climate applications, long-term stability is required for individual variables, requiring elaborate intercallibration procedures between satellite missions and between old and new technology.

Improved satellite measurements of solar insulation, cloud cover, turbidity, and ocean color have the potential to improve the assessment of potential variation in fish stock recruitment, by providing seasonal and interannual variability in phytoplankton populations which form the base of the oceanic food web. There is a clear need to maintain and enhance ocean color measurement network with geostationary sensors, sensors with increased spectral resolution, and increased spatial resolution which would assist with improved ocean color products in coastal waters.

A clear weakness of satellite data is due to sea water being opaque to electromagnetic radiation, allowing satellites to observe only the surface ocean. To extract ocean information from satellite measurements in an optimal way requires a merger with in situ information (also required for calibration purposes) through analysis and dynamically consistent synthesis activities. A close link between the satellite community and the modeling/assimilation community needs to continue for an optimal use of satellite and in situ data. Another issue is the migrating of research missions into operational missions across agency boundaries. The community needs to work out a long-term strategies to serve ocean satellite observations with the stability that is required for research and operations alike.

3.1.5 Ocean Acoustics

Ocean acoustics opens new opportunities for monitoring properties of the ocean currently not observed with existing observing components. In this context, we can distinguish between proven technology and new emerging opportunities:

(1) **Proven technology** of active acoustics; includes the monitoring of temperature changes as integrals over long distances. Ocean acoustic tomography can be done along single path or in a tomographic setting to resolve entire basins. Other applications include the tracking of floats, e.g. under ice. Sonar systems also have shown enormous potential in the past and will be used in increased applications in the future, particularly for exploring the sea floor.

(2) **New acoustic technology** will reside especially in the passive applications. Here the monitoring of rain near the surface, the monitoring noise in the ocean, or fish and larger marine organism logging will be among the important new applications and opportunities. Technology for acoustic assessment of mid trophic level organisms (mesozooplankton and micronektonic prey) is now possible using multifrequency acoustics providing data for identification and quantification at a global scale.

Tracking: Ocean bottom acoustic sensors play a critical role in tracking the movements of taggable marine organisms such as sharks, tuna, turtles, seals and whales which are being used to carry in situ sensors measuring pressure, salinity, water and body temperature, light, and position. Using these animal platforms allows sensors to collect data of direct relevance to understanding animal behavior and their relationships with other elements of their ecosystem. It also allows data to be collected in areas often difficult to access such as under ice shelves. The miniaturization of sensors to measure ocean variables like chlorophyll a, pH, pCO2, O2, and animal variables like acceleration, feeding, and heart rate in the future will increase the utility of these data, but there is an ongoing need for manufacturing technologies to improve and for prices to drop.

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. They will be key in developing an integrated system across disciplinary boundaries, a system that will have more 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 these sensors and increasing battery capacity of existing platforms are both needed to improve the observing system. Developments are also needed in miniaturization, cost reduction, and sensor stability, and will be essential for increasing the quality of the integrated observing system, for expanding 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 platforms such as floats, and the use of animals for carrying a wider array of sensors are all dependant on the our ability to reduce the power demand of sensors and /or increase the battery capacity without increasing the weight or size of battery packs. The development of renewable energy sources hold great long-term promise and may include methane hydrate fuel cells, microbial fuel cells, sea surface voltaic cells and motion-to-electricity technology. For sensors deployed on animals the use of water movement or pressure changes may be future sources of energy. There is also a need to reduce the power requirements for data transmission as will an increase in bandwidth for data transmission for example the increase in bandwidth will assist in retrieving data from sensors carried by animals who often spend a very limited time on the surface, as well as increasing the effectiveness of man-made observing platforms.

The miniaturization of all in situ sensors is an ongoing technical challenge, and one which 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 the recent adoption of “Laboratory on a chip” technology from the health care industry and the use of microfabrication techniques such as photolighography, laser micomaching and embossing in, in situ nutrient analyzers. A careful tradeoff in sensor accuracy must be evaluated as low accuracy measurements will reduce the possible applications of data.

The further development of current biogeochemical sensors and the development of new sensors is critical to the ongoing development of an integrated ocean observing system. Reliable sensors for autonomous platforms is an important research and development focus for pCO_2 and other carbon sensors including DIC and total alkalinity. These sensors along certified reference material would enable the ocean carbonate system to be 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 a low lifecycle cost, high reliability, allow real time data transmission, have low maintenance requirements and be compatible with other sensors. The major challenges are biofouling and long term reliability.

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 the size, and further development is needed to deploy these on autonomous platforms.

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, as well as to routinely include new biogeochemical and ecosystem variables..

The interoperability of sensors and instrumentation on platforms is a concept that is being developed, and holds promise in facilitating 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.

Finally, 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.

3.3 The data system

An effective data management system is vital to nearly every element of the ocean observing system. It serves essential functions 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 planners, educators and may 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 in software and hardware to support these goals over the past decade. The Argo program’s data management system has demonstrated how effective it is to have data management be an integral part of any new observing technology. The OceanSites Program is following a similar path. The JCOMM Data Management Program Area has made great strides bringing order to the deployment of platforms. 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. There is general agreement that the wide-spread use of standards will be a key element in achieving further progress.

But other considerations must also be addressed. In some cases national policies limit the sharing of data; the funding of data systems must rise to levels that can address the needed developments; and an international community of data management professionals must be fostered and given sufficient control over the data interchange standards to shape effective data management solutions. Perhaps the most critical need for progress in the coming decade is increased national support. The user communities have agreed on the importance of sharing data; national policies are urged to respect this agreement and support the widest possible sharing of ocean observations. Program managers are urged to recognize that data management needs to be incorporated into programs from their conception and not hurriedly addressed long after observing work is established. Data managers need support to have sustained interations with their national and international counterparts. Mechanisms to foster continuing engagement between the data management community and the science community are essential. The JCOMM Data Management Program Area and IODE are urged to interact closely with each other and with the observing and user communities.

The development of the ocean data system also faces a fundamental dilemma. The pace of change in information technology is rapid.. The changes advocated in the preceding paragraph will be comparatively much slower. If the data integration plans that we formulate are too ambitious, we are likely to see them rendered obsolete by technology advances long before they are implemented. Yet we can only achieve coordinated action if we share a vision.

Within the software development world this type of dilemma is commonplace and has given rise to a collection of ‘agile’ management strategies. These approaches maximize the rate of progress by focusing on incremental tasks that can be achieved with some confidence on modest time scales. The approach is characterized by adages such as “Don’t let perfect be the enemy of good” and “Don’t solve problems; copy successes.” The adoption of the well-proven tools mentioned above – netCDF, CF and OPeNDAP – would exemplify the agile philosophy applied to ocean data management. These technologies can provide a quantum improvement in several aspects of ocean data management at a level of effort that is realistic. Yet adopting these technologies is by no means a panacea as a number of significant challenges will remain unsolved – notably the management of metadata. The JCOMM exists to provide international uptake of agreed community standards, but observing communities must undertake the development and agreement before these can be adopted intergovernmentally. And national support for the needed metadata system infrastructure will also be required.

Data transport issues remain. Inexpensive bandwidth for rapid satellite transmission of all desired observations is needed, and is key to participation in the existing GTS data transport system and future data transmission systems. Cellphone 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 would be very valuable as would improved biotagging capability.

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. In this context, models include statistical relations between observables and parameters of interest, a process that is usually referred to as analysis. The other end of the spectrum of providing information includes the assimilation of data into complex dynamical ocean circulation models, coupled climate systems or coupled biogeochemical-ecosystem models, thus providing information about the state of the ocean or the ocean as part of the climate system by merging observations with the physical, chemical and biological dynamics embedded in these models. Today, the resulting information includes full descriptions and predictions through numerical simulations of the ocean or of the coupled ocean-atmosphere-sea ice climate system on seasonal to decadal time scales. In the future, forecasts by coupled climate-carbon models to predict the evolution of atmospheric CO_2 and changing role of oceans in the carbon cycle will gain importance as will the role ocean data play in initializing seasonal to decadal predictions.

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.

Model-based generation of information and services (assimilation and modeling) is feasible now, and needs to be sustained and improved as part of an integrated observing system of the ocean, translating both scientific knowledge and ocean observations into useful information.

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. It also forms the basis of the observations for marine meteorology and weather forecasts, and for ocean forecast systems oriented towards real-time services.

Sustained observations have the potential to serve a wider range of services, including fisheries management, 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 the more integrated system that includes biogeochemical and biological elements to the greatest extent feasible. 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 is a core question for the post-Conference Working Group set up by the sponsors of the conference.

The post-OceanObs'09 Working Group was tasked with recommending a framework for moving global sustained ocean observations forward in the next decade; integrating feasible new biogeochemical, ecosystem, and physical observations while sustaining present observations; considering how best to take advantage of existing structures, and was formed by the international sponsors of the conference.

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.