OCEANOBS'09 CONFERENCE SUMMARY

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EXECUTIVE SUMMARY

[Synthetic summary of issues and recommendations to be written once the main body is final – will also be subject to open review at a later date before publication of the Conference Proceedings]

PREFACE

The Call for the OceanObs'09 Conference:

The OceanObs'09 conference was called for to provide an evaluation mechanism of progress on plans of the physical, geochemical and biological communities to observe the ocean in a sustained way. A decade after the OceanObs'99 conference (San Rafaël, France) 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 World Climate Research Programme (WCRP), the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS) asked their Ocean Observations Panel for Climate (OOPC) and the WCRP Climate Variability Programme (CLIVAR) Global Synthesis and Observations Panel (GSOP) to take responsibility for launching an OceanObs'09 process. With advantages to developing joint requirements and plans to address physical observing requirements together with those from the communities of biogeochemical, ecosystem and living marine resources aspects of the oceanic system, the leadership of the conference was expanded accordingly to include representatives from those communities, as reflected in three chairs and membership of the program committee from the International Geosphere-Biosphere Programme (IGBP), the Scientific Committee for Oceanographic Research (SCOR), GOOS and WCRP programs.

Background: sustained ocean observations

In 1993 three international organizations involved in the coordination of global climate observations and research: WCRP, GOOS and GCOS, agreed to co-sponsor the Ocean Observations Panel for Climate (OOPC). Since then the goals of the OOPC have been to (1) foster the development and agreement of an international plan for sustained global ocean observations in support of the goals of its co-sponsors, (2) suggest mechanisms for the evaluation and evolution of the agreed plan and (3) liaise between all entities involved in global ocean observations. At the same time the Climate Variability Program (CLIVAR) of the World Climate Research Program (WCRP) established the Upper-Ocean-Panel (UOP) to advise on scientific topics related to observing and modeling upper ocean variability. OOPC and the CLIVAR UOP jointly organized in 1999 the OceanObs'99 conference to bring together many groups interested in sustained observation and analysis of the physical oceanography of the world ocean, to review the status of progress and to present their aspirations for the coming decade[1]. The OceanObs'99 conference brought together the global physical climate observing community and stimulated the implementation of a first basic large-scale observing system in support of research and operations.

In 2002, the United Nations Framework Convention on Climate Change asked the GCOS program to review the adequacy of the by then existing global observing system for climate in the atmospheric, oceanic and terrestrial domains. The OOPC, with its many partners within the research and operational oceanography communities provided the oceanic contribution to this adequacy assessment (GCOS-82, 2003). The UNFCCC subsequently requested an implementation plan to address the requirements identified in the adequacy assessment and a GCOS Implementation Plan was developed (GCOS-92, 2004 and its satellite supplement, GCOS-107, 2006). Implementation was called for subsequently by the United Nations Framework Convention on Climate Change (UNFCCC) and the Global Earth Observing System of Systems program, GEO. The development of, and agreement on, the adequacy assessment and implementation plan has served as a powerful statement of priorities to the sponsors of international ocean climate observing, analysis and forecasting activities.

Over the same decade over which a first global physical observing component was developed, by two key initiatives have moved biogeochemical and biological observations forward. The development of the Design Plan and the Implementation Plan for Coastal GOOS under the direction of the Coastal Ocean Observations Panel (COOP) and the development of carbon observations under the direction of the International Ocean Carbon Coordination Project (IOCCP).

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[1] The conference proceedings, "Observing the Ocean in the 21st Century" presented papers on most of the conference presentations.

Plans for Coastal GOOS were formulated by COOP in response to the need for a global coastal observing network and to address a range of international conventions including Framework Convention on Climate Change, the Convention on Biodiversity, the Programme of Action for Sustainable Development (*Agenda 21*) at the UN Conference on Environment and Development (UNCED), Ramsar Convention, Convention on the Law of the Sea (including the Agreement on the Conservation and Management of Straddling & Highly Migratory Fish Stocks), Convention for the Conservation of Migratory Species, Reykjavik Declaration, Code of Conduct for Responsible Fisheries, Global Programme of Action for the Protection of the Marine Environment from Land Based Sources, and the Implementation Plan of the World Summit on Sustainable Development. In particular, *Agenda 21* called for the establishment of a global ocean observing system that will enable effective management of the marine environment and sustainable utilization of its natural resources. The Design Plan and the Implementation Plan, for Coastal GOOS are focused on observing system requirements for the provision of data and information needed to manage, mitigate and adapt to the impacts of climate change, natural hazards and human activities on human health risks, ecosystem health and living marine resources. We do not have this capability today.

IOCCP was started in 2000, sponsored by IOC and SCOR and is a communication and coordination service for the ocean carbon community. They have focused on the development of standardised methods, intercalibration exercises and the coordination of carbon observations at an international level.

Expanding the global sustained ocean observing system beyond its first physical and carbon pilot climate phase has been a goal of GCOS and GOOS from their inception and has recently been embraced by CLIVAR. A significant amount of work remains to be accomplished to provide the sustained observations needed to address the requirements of WCRP, GCOS and GOOS and to meet the sustained observing, analysis and prediction aspirations for biogeochemical, ecosystem and living marine resources.

<u>Vision for the next decade</u>

OceanObs'09 was charged with initiating the development of a mechanism that in the future will allow us to define and to implement an international global integrated observing system for the physical, geochemical and biological information and forecasts and predictions

The vision to which OceanObs'09 aspired is accordingly to:

- Develop a consensus for structure required for sustaining and evolving systematic and routine global ocean observations in the physical, geochemical and biological measurements over the next 10 years which are needed to create ocean data and information in support of societal benefits, including ocean weather, climate, ecosystems, carbon and chemistry, and to support oceanographic research and science.
- Develop infrastructure required to store and distribute data, to develop and distribute information.
- Ensure sustainability of the initial observing system and further develop it to include new measurements that are critically important for evaluating and to realize the full extent of the benefits across all stakeholders and for all participating nations.
- 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.
- Strengthen and enhance the international framework under GCOS, GOOS, WCRP, IGBP, ICES, PICES, CoML, SCOR, GEO and supporting regional and national frameworks for sustained world ocean observing

<u>The Conference Process</u>

To reach the vision of the OceanObs'09 conference, a process was put in place that goes beyond the OceanObs'09 conference itself by including a pre-conference development of a community consensus and a post-conference activity required to establish a structure capable of supporting sustained ocean observations within existing international frameworks.

The OceanObs'09 process leading to the conference and beyond is shown in Fig. 1. It included the involvement of the community at large to prepare for the conference by putting together Community White Papers (CWP) as well as additional contributions. CWP served as input from the community about specific aspect of the ocean observing system providing detailed requirements for a modification and extension of observing capabilities. In addition the community was able to submit additional contributions that are relevant but not of "global scale". CWP and AC served as input for Plenary Papers, which stimulated the community consensus building that took place during the conference. The meeting was structured in terms of plenary talks, roundtable discussions, high-level perspectives and community fora. In each of these

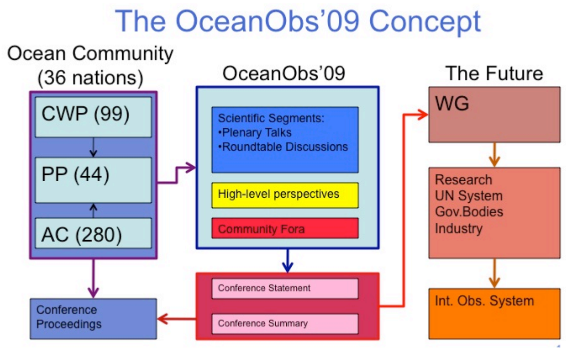

Figure 1. The OceanObs'09 concept

components the community discussed the needs for sustained and new observations covering physical, geochemical and biological aspects.

Together with the input to the conference, the discussions and consensus building during the conference lead to four conference products:

1. Conference Statement summarizing the community consensus of actions required in th epos-conference era.
2. Conference Summary: The conference summary accompanies the Conference Statement and is provided here. It summarizes the recommendations from each session of the conference.
3. Conference Proceedings: Plenary papers will be published together with Community White Papers, and additional contributions. Also included in the OceanObs'09 Conference Proceedings will be this conference summary and the conference statement. The conference proceedings will be printed in the form of a multi-volume book.
4. Working Group: at present there is no mechanism in place to define and coordinate the collection of sustained observations from the many international groups involved in research and observations of the biogeochemistry, ecosystems and living marine resources of our planet; or the integration of these measurements with the current observing system; nor is there a structure to coordinate sponsor evaluation and to endorse the development of joint plans. A limited-duration working group will be called for to recommend a structure for enhanced global sustained ocean observing system over the next decade, considering how to best take advantage of existing structures, while at the same time integrating new physical, biogeochemical, biological observations while sustaining present observations.

In the following we will summarize the outcome from each of the scientific sessions of the conference, as well as from community fora round table discussions and high-level perspectives, which together document the community view of the future of the observing system requirements.

1. DAY 1: CELEBRATING A DECADE OF PROGRESS AND PREPARING FOR THE FUTURE

The first day of the conference celebrated the last 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 side. The day had four sessions, which include the Celebration of a decade of progress; High level perspectives and the need for ocean observations and information; and the

Early successes in ocean observations.

We summarize in the following only the results from the Session on early successes.

Session 1D: Early Successes

During the last few decades, remarkable progresses have been made in many areas supported by ocean observations. During the conference highlights were provided, taken from the fields of seasonal forecasts, climate change assessments, tsunami warning systems, and monitoring climate system impacts on global ocean marine ecosystems. These are just a few of the stories that owe their success to the improved ocean observation coverage implemented during the last 20 years.

SI Forecasting: The WCRP/TOGA program provided the real-time ocean observations that helped the detection and prediction of El Nino; the extension of the TAO array to the Atlantic (PIRATA) and Indian (RAMA) oceans provides the data for initialization and validation of seasonal forecasts. Improvement of observational network is also needed to improve model and analysis technique.

IPCC: Ocean studies played a major role in the IPCC AR4 (2007). The fundamental basis for the studies were ocean observations, their analysis and synthesis, empirical studies, ocean and coupled climate system modeling of the climate record, detection and attribution studies, and the projection of climate into the future using models. Sea level is important for impacts and received a lot of attention, but left a number of issues unresolved, especially with respect to ice sheet contributions. Problems after 2003 were also evident in AR4 and related to the changing observing system and evolution of the Argo observations and their analysis.

Tsunami Warning Systems have evolved into regional end-to-end systems with global standards and guidelines. Real Time Tsunami Forecasts are now possible for distant and local tsunamis.

Satellite ocean color radiometry measurements are currently the only tool we have to measure climate system impacts on ocean marine ecosystems globally and with monthly to seasonal temporal resolution, and thus are critical to the goals of GCOS. These data are much more valuable when combined with in situ measurements that validate the satellite measurements and capture the vertical dimension. New sensing systems, as well as new programs to process archived data, will provide unprecedented coverage of global coastal and continental shelf waters at 300-m resolution and will initiate a new global view of changes that are occurring in coastal systems. These measurements will be crucial for supporting GEO societal benefit areas.

The Continuous Plankton Recorder (CPR) is the only routinely deployed sampling system that provides biological data on global scales in the oceans. CPRs are towed on voluntary ships of opportunity (SOOP). Since the 1930s this robust and well tried methodology has demonstrated that it is a powerful tool for detecting, understanding and predicting the impacts of global climate change on the biosphere as well as contributing to understanding of feedbacks from ocean ecosystems to climate change.

Recommendations:

The experts convened at the session stressed the importance of ocean data for advancing in the science areas they represented at the conference and identified the following key elements for an integrated ocean observing system that successfully serves a variety of end users for societal benefits:

1. Long-term sustained observations that satisfy the GCOS observing principles and which ensure continuity of record
2. Ongoing reanalysis and reprocessing of the data with advanced assimilation system
3. Robust monitoring system that is resilient to shortfalls or possible failures of parts of the observing system and also has the capacity to respond to new societal demand arising from significant natural events
4. Constant engagement with the user community, including for example those involved in: climate/environmental change, fisheries, and coastal populations, to meet their requirements
5. Free and open data availability in real-time or near real time
6. More integrated comprehensive environmental models with more diverse and useful products for a variety of applications.

2. DAY 2: SCIENTIFIC RESULTS AND POTENTIAL BASED ON GLOBAL OBSERVATIONS

The day was devoted to the success in describing and understanding the ocean reached through the increase in ocean observations in the last decade (since OO'99). The day examined how the large-scale ocean is being affected by climate and what its role is in climate variability, and other insights into physical, biogeochemical, and ocean ecosystem dynamics enabled by long term ocean observations. In particular all talks were forward looking addressing the need for sustaining and expanding (where necessary) our knowledge in large-scale properties of the ocean and by discussing the impact of this knowledge for future applications, e.g., the impact of large-scale changes in the physical fields on biological resources of the oceans and fisheries.

The day had three science sessions, one round table discussion and 2 community fora.

Session 2A: Large-scale ocean properties: science, observations, and impacts

The ocean stores vast amounts of heat and freshwater and therefore plays a key role in the climate system. Changes in ocean heat content modulate the heat flux to the atmosphere, the ocean vertical stratification and modulate the absorption and release of greenhouse gases. The oceans are a key source of predictability for our climate on many timescales. The session described progress in our understanding of the ocean heat, freshwater and sea level budgets, and what observational infrastructure is needed for the upcoming decade to improve this understanding.

During the session the importance of data quality, particularly for climate applications, was emphasized. The presentations highlighted the importance of satellite altimetry and Argo in providing essential information for ocean dynamics, and for the detection and attribution of changes. Though ice covered regions pose a serious challenge to surface and subsurface data collection, recent technological developments now allow under ice measurements over extended regions for the first time. There is evidence of deep ocean (below 2000m) warming and salinity changes which have significantly impact our understanding of the planetary energy budget and long term sea level changes, but current sampling is inadequate. Though evaporation and precipitation estimates over the global ocean have improved during the last decade, they are still too inaccurate for climate applications.

Long-term ocean salinity changes are a means of tracking low-frequency changes in the hydrological cycle, and indeed ocean salinity changes to date are congruent with an intensifying hydrological cycle. Tide gauge and altimetry data indicates a global sea level rise < 2 mm/yr mm/yr during the past 50 years and >3 mm/yr since the early 1990s. During the satellite altimetry period (after 1993) about 1/3 of this change is attributable to thermal/halosteric expansions described above, while the remaining is due to equal contributions of glacier and ice sheet melting. Although available ocean and land ice observations allow closing the sea level budget, there exists a discrepancy with the Earth's global energy budget in recent years- an issue which needs to be investigated.

Recommendations:

- Key for estimating long-term changes in the ocean is to sustain and expand the existing observations elements.
- Key gaps are the ice-covered regions and the deep oceans. The latter requires further technological developments and system design.
- Improved global heat, freshwater and sea level budgets will require continuity of satellite altimetry, gravity, temperature and salinity observations, as well as improved in-situ observation networks for validation.
- Rehabilitation of past ocean archives remains an urgent need, especially to underpin decadal prediction.
- Future data streams must satisfy the needs of both climate and short-term forecasting applications.

Session 2B: Large-scale ocean circulation and fluxes

Detection of long-term changes in ocean properties requires quantitative information on the transports by ocean currents and a mechanistic understanding of their response to atmospheric forcing. New research has demonstrated the importance of both the near-surface and deep ocean circulation to issues of direct interest to society, including climate change, decadal climate variability, regional sea-level rise, the carbon cycle and food security.

While satellite and surface drifter data sets have resulted in enormous progress in observing the surface circulation, similar sampling is impossible for the subsurface ocean. The development of an observing system for the interior ocean circulation that would allow a quantification of changes in ventilation rates, or in the basin-scale overturning circulations, remains a substantial challenge: it requires the combination of various measurements, including repeat hydrography, ARGO profiles, boundary current moorings and acoustic techniques, in conjunction with improved data assimilation techniques and realistic circulation models. Additional system design studies are needed as a vital step to identify an optimal design, and to assess what additional resources are needed.

The determination of air-sea fluxes remains a critical aspect in ocean climate studies. While there were notable improvements due to in-situ, NWP and satellite missions in surface flux parameterizations and in the quality of surface flux products, some fundamental biases still remain unresolved: global imbalances of 20 to 30 W/m2 in VOS climatologies, low accuracy of satellite retrievals of air temperature and humidity, and tropical biases in NWP shortwave radiation and precipitation.

Recommendations:

- Improvement of salinity products to the level of temperature products is essential for circulation and ventilation studies. For quantitative use with temperature and surface fluxes, improved surface salinity products are essential.
- Argo profiling has proven to be an excellent, tantalizing tool for studying ventilation. If augmented with oxygen and EM profiling, and if the sampling density were increased in active ventilation regions, the descriptions could become much more physically significant.
- Determination of basin-scale fluxes of heat and other properties (freshwater, carbon, ...) remains a challenge: end-point monitoring can measure volume transport, but to observe the transport of properties like heat, it is necessary to resolve the correlations between velocity and temperature. At latitudes other than 26°N, horizontal gyres contribute to meridional heat flux. This poses serious technical challenges, although PIES can in some cases be used with proxy techniques to resolve the temperature field in the ocean interior.
- Improvement of air-sea flux products through a combination of efforts: extension of ocean sites with accurate measurements of turbulence and gases to subpolar and high latitudes; improvement of retrievals of satellite temperature and precipitation, and improved sampling for vector winds; and improvement of reanalysis systems to minimize biases in all flux components.

Session 2C: Biogeochemistry and ecosystems

There are several questions that need to be answered about the ocean's ecosystems and biogeochemical cycles and it is necessary to recognize the wider spectrum of issues, which do not necessarily require common approaches to observations. The most striking development in ocean observations over the last decade is perhaps the emergence of biological, biogeochemical and ecosystem observations. Ocean acidification and de-oxygenation have posed serious threat to ocean ecosystems, and furthermore, there is limited or no information on changes in various chemical properties. Oxygen sensors on Argo floats would be a desirable way to observe de-oxygenation.

Striking examples of ecosystems under threat are coral and coastal ecosystems. Threats include sea-level rise, increase in temperature, and ocean acidification, in addition to direct human impact. An International Network of Coral Reef Ecosystem Observing Systems (I-CREOS) has recommended the use of visual surveys, moored instrument arrays, spatial hydrographic and water quality surveys, satellite remote sensing and hydrodynamic and ecosystem modeling as monitoring tools, as well as genetic pyrosequencing techniques. New interests include fluorescence and acoustic techniques. Understanding ecosystem function calls for observations of additional environmental variables, including temperature, nutrients, light, phytoplankton pigments, salinity and ocean carbonate chemistry. Observations are essential at a variety of time and space scales. Low-cost, automated, "smart" observing systems are needed, that would require low maintenance.

Several tools and approaches are available to observe properties of the marine ecosystem, ranging from remote sensing, microscopes, Continuous Plankton Recorder (CPR), video plankton recorder, drifting buoys and gliders, digital holographic systems, repeat hydrography and time-series stations. Gaps in observations include fluxes of material at higher trophic levels.

There are several issues on basic biology that cannot be addressed without more detailed understanding of biodiversity. Standardized sampling methods are essential and tracking and tagging have emerged as viable methods, which also collect simultaneous environmental data. Long-term time series of biodiversity and ecosystem measurements are very valuable and necessary. There is need to integrate more ecosystems and biogeochemical studies with physical oceanographic measurement. Data management and data integration merit due attention. Combining various elements of ecological, bio-geochemical and biological observations into an integrated system requires further consideration. The biggest challenge is how to engage the broader community of nations, particularly in the developing world.

Recommendations:

- Certain elements of biological, biogeochemical and biodiversity observations have come of age, and should become part of sustained an ocean observation system at the global scale, for addressing various societal issues of the day.
- Research and development, including sensor development, have to go hand in hand with operational implementation, to mutual benefit, and to ensure structured evolution of observing systems over time.
- Synthesis and integration, both at the scientific level and at the level of databases are essential, to ensure optimal use of observations.
- The system should be global in scope, include organisms ranging from microbes to fish and marine mammals; and effective implementation requires capacity building at various levels.
- Particular issues that demand implementation of a biological observation system include ocean acidification, de-oxygenation of vast areas of the ocean, threat to coral and other coastal habitats, warming, and loss of marine biodiversity at regional and local scales (which is happening at an accelerated rate).
- There are gaps in the biological observing capabilities that merit further attention, including measurement of various biological process rates.

Day 2 Roundtable Discussion: How are changes in large-scale circulation impacting geochemical and biological processes in the ocean?

The second day of the OceanObs'09 conference focused on scientific results and on the future potential based on global observations. The plenary talks summarized the current understanding of the distribution and variations in several physical, geochemical and biological properties in the global ocean. At the end of the day a roundtable discussion was held to get feedback from the audience on the linkages between physical, geochemical and biological processes and the needs for an integrated global observing system. The discussion included opening comments from the six panel members and a dialog between the panel members and the audience.

One important issue that emerged from the discussion was recognition that while there have been many biological and geochemical measurements over the past few decades many of these observations are not well synthesized into global datasets or available to the general public. This lack of global perspective makes it difficult to determine exactly where there might be regional gaps (e.g. Southern Ocean, Indian Ocean) or whether the instruments and measurement approaches needed to characterize the full range of biogeochemical parameters are ready for a global sustained observing program (i.e. technology development is still needed in some areas). There was a clear call for a more integrated vision of physical and biogeochemical observations. The global network of physical measurements can provide useful products (e.g. global mixed layer depths) for understanding biogeochemistry, but the biogeochemistry (e.g. oxygen measurements on ARGO floats) can also provide useful information for understanding ocean physics as well as providing a socially important context for the observed physical and geochemical changes (e.g. impact of ocean acidification on marine resources). Finally, there was a plea for including coastal observations as part of the global observing program. This is particularly important as the community moves toward a coordinated physical, geochemical and biological observing network.

Recommendations:

- Generate global synthesis products of as many geochemical and biological properties as possible to establish a baseline assessment for interpreting variability and global change effects.
- Assess which technologies are ready for large-scale deployment and provide the funding and infrastructure support to include these in the global observing network.
- Determine what regional or instrumental gaps exist for important parameters and work to fill those gaps.
- Develop a data management approach that can handle the range of parameters that will come from a more integrated physical, biological and geochemical observational program.

Session 2E: Ecosystem Community forum: How should we move forward with ecosystem observations in the next decade?

Ecosystem observations should support our capability to address policy issues and directives including ecosystem-based management, ecosystem health, state of the marine environment reporting, maintenance of sustained ecosystem services and food security. They should also measure the impacts of humans on marine ecosystems, including climate, ocean acidification, fishing, and changing nutrient supply. Priorities for observations will be established based on how the proposed observations are essential to meet policy directives, end-user requirements. Priorities will be constrained by the maturity of the technology, its cost-effectiveness and ease of implementation. A suite of techniques, including remote sensing, towed bodies profilers, drifters, tagged animals, acoustic methods and molecular tools already exist to measure biological variables globally. The in situ observing systems are essential to complement the near-surface satellite observations and to provide sea-truthing. Marine ecosystem are likely to remain severely under-sampled well into the future, so that complementary methods (models, statistical tools) need to be developed to allow extrapolation of sparse observations to the global scale. Ideally a biological observing system should resolve not only biodiversity (with adequate taxonomic resolution) standing stocks, but also physiological rates, phenology and aspects of community ecology.

The perspective for the biological observations must be global, but the building blocks for the global system will come from the local, national and regional elements as a global perspective is often needed to find solutions to local or regional problems. There are many on-going and historical local or regional observational programmes, including coastal time series measurements, whose value could be enhanced by bringing them together into a common network (e.g. ChloroGIN for ocean color, CPR Survey for in-situ measurements of ecosystems and SAFARI for fisheries) that encourages sharing of information and data. The biological data need to be integrated with biogeochemical and physical oceanographic measurements, to provide the environmental context, and to facilitate interpretation and extrapolation of local measurements to larger scales.

Recommendations

- A strategy for the biological components of an integrated ocean observation system needs to be developed. This should identify a clear set of priorities for the biological elements of a global ocean observation and information system and work towards structured implementation of biological elements of a global ocean observation system.

It should include:

- Standardisation of measurements, including simple, cost effective low technology elements
- Recommendations for core variables
- Integration of data management which supports the principle measure once use many times
- Strategies for biological in both the open and coastal oceans
- and considers;
- The end to end nature of ecosystems including micro organisms
- Simultaneous observations of complementary physical, chemical and biological measurements
- Networking of existing observation systems at the local, national and global levels
- The need for forecasting and prediction of ecosystem responses to future global change
- The role of developing countries and their capacity building requirements
- Previous documents regarding biological observations systems
- New observing technologies that are under development
- The involvement of end-users in the collection of data

Session 2E: Community Forum on Biogeochemistry

The discussion started with a short review of the critical observing elements required to develop an integrated observing strategy to address the linked biogeochemical challenges of “warming up, Rising high, Turning sour, Losing breath”: (1) Repeat Hydrography, (2) Surface Observations, (3) Argo Biogeochemistry, (4) Sensor Development, and (5) Model-data integration.

Thereafter, most of these elements were discussed in turn (although not in the same order).

1. Repeat Hydrography: Little discussion. Generally viewed as a very critical element.
2. Surface Observations: Discussion focused on relative role of basin-scale measurements via VOS/RV versus time-series sites. Also role of time-series sites to better link repeat hydrography and surface observations was highlighted.
3. Argo Biogeochemistry: Strongly supported as the next major development step. Significant discussion on sensors etc. Also discussion on other platforms, especially animal based.
4. Sensor Development: Clearly recognized, there is a great deal in the pipeline, but very slow progress especially for carbon related parameters. See Warnemünde workshop on sensors and ALPS workshop in La Jolla. Also suggested was the development of ultra-cheap (one-way) sensors that could be mounted on XBTs.
5. Model-data integration: limited discussion. Strong data limitation have precluded major development efforts. With the possible advent of Argo-BGC and other new technology/platforms, major development can be expected. Required are better data management systems. For BGC outside of repeat hydrography, there is little homogeneity and or standards (for QC, etc).

The discussion of prioritization could only be touched upon. The challenges laid out at the beginning were generally shared, but no attempt at prioritizing them was made. Substantial time was devoted to the discussion of the complementarity of the various observing elements, and what this means for the design of the overall observing system. For example, it has been shown that observations of sea-surface height and in-situ oxygen substantially aid in the interpretation of decadal time-scale changes in ocean interior carbon, relaxing the temporal and spatial scales at which inorganic carbon needs to be sampled in order to arrive at a decadal inventory change. The consensus was that ancillary observations can and should be used for interpolating data, but not for extrapolating them.

Regarding observing system design, it was recognized that the CWP for the surface ocean and interior ocean (hydrography) have spent considerable effort in justifying their sampling design, while no such effort has been made for biogeochemical observations on Argo. This needs to be remedied.

The last item discussed was the global versus regional perspective of ocean biogeochemical observations. On the one hand, it was recognized that observations need to be taken at the global scale for addressing some of the global needs. On the other hand, many impacts occur at the regional level, so that regional enhancement of the observing system are often required, especially in some vulnerable coastal regions.

<u>Recommendations</u>

3. DAY 3: DELIVERING SERVICES TO SOCIETY

The day was devoted to describing the progress made during the last decade in delivering services to society based on ocean observations and ocean information. The day examined how the respective activities and applications can be expanded, what the anticipated benefits will be and which observing, modeling and synthesis systems are required to reach those goals. The session will concentrate on the scientific and technological aspects of developing and delivering services, with Day 5 concentrating on the frameworks to promote the development and delivery of these services.

The day had three science sessions, one round table discussion and 2 community for a, all summarized in the following.

Session 3A: Information and assessment

New science questions demand new data: Continuous improvement of operational oceanography systems and the development of new capability is needed to address these new societal needs. The session on information and assessment was about providing the physical, biological and chemical near-realtime information about the state of the ocean and its application for marine core services.

Although there are still major challenges to face, global operational oceanography (e.g., as pursued by GODAE) is transitioning from a demonstration to a permanent and sustained capability. The evolving systems are also evolving to satisfy new requirements for coastal zone and ecosystem monitoring and forecasting, climate monitoring and is already benefiting from scientific advances in ocean modeling and data assimilation. The integrated view presented in San Raphael 10yrs ago was key to prove that operational oceanography was possible – now, the integration concept has to be expanded in order to include the biogeochemistry. Bio-Argo is already a reality and the next few years will show how this near-realtime data will be assimilated in the operational models.

In a warming world, it is vital that we can understand and resolve the biogeochemical / physical mechanisms driving surface carbon, air-sea flux variability and ocean acidification. There still is an urgent need to implement, for example an effective, long-term pCO2 observing network that will reduce uncertainty in regional and global CO2. This will only be achieved if there is international coordination of the carbon observations and the development of regular products for global and regional use.

With respect to the biological aspect, much effort has been put into nowcasting of Harmful Algal Blooms (HABs). A big problem is to determine the distribution of the HAB field which is patchy and hence there is a need for better resolution of observations. Data has to be integrated into models to advance and assess nowcasting and forecasting skills. Ultimatately, as far as HABS are concerned, it is a coastal management/public problem.

The panel explained several systems which are at various stages of development toward becoming Ocean Services for Society. Each example was reported to be in need of additional observation techniques and sustained data sources. Questions from the audience seemed to support this view and focused questions on which observation systems are needed, what sensors can be deployed and how to support the observation streams. To justify and expand the ocean observation systems we need justify the system by concentrating attention on the useful services and products which we can deliver. There are many successes, and they can be highlighted. "We need to promote solutions, not the problems we want to solve"

Recommendations:

- Strength links to the coastal zone and the transition from open ocean to the coastal zone.
- There is a need for assimilation of Biological/Chemical into forecast models: For example integration of biogeochemical variables into the operational framework of GODAE – bio-Argo / O2 in Argo is a way into the future.
- Develop forecast skills for coastal (HAB) management.
- Implement global network of Carbon (pCO2) observing network;
- Continue VOS pCO2 network, repeat hydrography programme; continue and add time series stations.

3B: Forecasting

The potential for predicting natural internal climate variability resides in the ocean initial conditions, especially on seasonal and longer time scales. Typically, observations of temperature, salinity and sea surface height are used to create the ocean initial conditions. Assimilation of these observations reduces the uncertainty in the estimation of the upper ocean thermal structure and improves the skill of forecasts. Independent observations, not directly assimilated, have provided invaluable validation data.

Current forecasting systems, however, are not making optimal use of the existing observations, in particular in regions where model error is large. In those regions, the imbalance between the initial state and the model climate can create undesirable initialization adjustments with a detrimental effect on the forecast skill. Improvements in numerical models, assimilation techniques and initialization strategies are needed to exploit the full potential of current and future observing systems. One of the success stories of OceanObs'09 is the development and emergence of a sophisticated range of "operational" ocean prediction systems. Many important applications will be able to make progress through an incremental improvement to the current observing system, but other specific applications will require innovative strategies to provide the highest quality services. The next few years should see further progress on predictions if improvements continue in the ocean observing system, in numerical models and in initialization strategies.

Recommendations:

I) Providers of observational data:

- Sustain the current observing systems and complete impending missions -- no redundancies are identified in the observing system. Encourage national contributions for emerging operational funding and support other nations continuing to pursue research funding.
- Continue to build the observing system. Specific recommendations include extending the coverage of altimetry through constellation or wide-swath technology and to completing implementation of the RAMA array in the Indian Ocean. Add moorings in the south equatorial Atlantic, where PIRATA sampling is very sparse. Support technologies that build capacity in adaptive higher resolution space-time sampling, such as gliders. Expand profiles to provide full water column observations, such as Argo-type measurements below 2000, particularly for regions that are critical to decadal variability. Seek to enhance capabilities to measure mixed layer and near surface properties, as well as sea-ice concentration and thickness. Further responding to many societal questions from short through to climate scales will require the integration of coastal and marginal sea data with global networks.
- Must continually assess the utility of existing and planned ocean observations for prediction systems at all time scales for optimizing resources and potential benefits of GOOS.
- Ensure availability and accessibility of all observational data (including meta-data) through a common portal for research and model development purposes.
- Enable and/or encourage capacity building activities for use and understanding of ocean observations for forecasting in developing countries, such as multi-disciplinary trainings coordinated across observationalists, modelers and forecasters. (perhaps this is a recommendation for WMO/IOC).

II) Modeling and data assimilation communities:

- Further develop models and assimilation methods to exploit existing observations.
- Foster closer interaction between the oceanic and atmospheric communities for the balanced initialization of coupled models and development of coupled ocean-atmosphere reanalysis. This includes, continued efforts on ocean re-analyses aimed at providing long, climate-quality records of the history of the ocean and efforts on observation retrieval, quality control, and the improvement of assimilation methods. Further, forcing fluxes from atmospheric re-analyses must be improved, ensuring that the products continue in near-real-time
- Work should continue on SST products and re-analyses. (long records, high spatial and temporal resolution. Diurnal cycle)
- The assimilation community should be ready for the timely use of imminent observing systems (gravity missions, surface salinity and RAMA).

Session 3C: Hazards, Impacts, and Management

The oceans are affected by a multitude of threats. The most recently identified is ocean acidification and this impinges on ecosystems in a variety of ways. We need to better understand interactions between biota and water chemistry and quantify synergistic effects from other environmental variables, in order to determine the capacity of organisms to adapt to ocean acidification. Monitoring the effect of upwelling on carbonate chemistry and biota with a focus on coastal regions needs to be extended.

Knowledge of ecosystem threats and processes are necessary to understand the consequences of human action. Although ecosystem-based management has progressed conceptually and operationally over the past 5-10 years, challenges remain to develop better integration of observations, models and multidisciplinary process studies.

Particularly for coastal zones, where observations to model coastal processes need to be finely resolved in space and time, data integration must include land and sea remote sensing and in situ measurement as well as human field observations. For the coastal zone it is especially important to link scientific understanding with social issues in order to inform management decision making.

The GOOS Regional Alliances provide an excellent mechanism to bring together organisations with common needs across institutional and national boundaries between coastal states to mutual benefit.

The public, and particularly policy makers, need to be made more aware of the economic benefits derived from a sustained integrated ocean observing system. Although difficult to perform, evaluations of the benefits of ocean observations are an essential tool for supporting the case for investment.

Recommendations

- A coordinated regional and global network of observations, process studies, manipulative experiments and modelling that ultimately will lead to the understanding of long-term adaptation to ocean acidification.
- Utilize the GOOS Regional Alliances Network & establish north-south and south-south partnerships to enhance national capacities.
- Develop a coastal observing system with high resolution in space and time, and long-term continuity of operational life of sensors.
- Stimulate data integration through communication and data inventory activities across institutions/ national boundaries among different disciplines.
- A socio- economic benefit study based on the recommendations of the EuroGOOS scoping report needs to be undertaken at a global level.
- Especially urgently needed are socio-economic studies to determine the benefits ocean observations bring to improved weather forecasting and climate projections and to understanding changes in the efficiency of the oceans as a carbon sink and consequences for biological systems (e.g. coral reefs). These should be used to support a clear and compelling message to decision makers about the importance of ocean observations.

Day 3 Roundtable: Imperatives for Ocean Observing in a Changing World

Today there are many imperatives for ocean observing beyond ocean science and climate research. Operational oceanography, ecosystem-based management, sea level change, ocean acidification, coastal zone management, and sustainable resource development place new information demands on the global observing system. This roundtable explored the broader demands on the ocean observing system needed to better respond to societal needs while continuing to support ocean science and climate research.

One of the key phrases and ideas that emerged from the panel and the following discussion was the need for the ocean observing system to be seen as a “solution” to societal needs rather than a “problem” in itself to be solved for academic purposes. Clear objectives and information requirements for observing should be articulated. Several subjects that warranted special attention and priority are regional predictions of sea level rise, better coastal zone management, monitoring of marine carbon system, ocean acidification and deoxygenation. Such priorities also motivate development of cost-effective, robust sensor technology, moorings, and coastal data management schemes.

Data sharing and availability is critical to developing the high quality information systems need for a broad range of applications supporting societal needs. Limited reporting and restrictions of basic ocean data from Exclusive Economic Zones remains unsolved international dilemma. Participants also emphasized the need for capacity-building. This was needed to encourage nations that have ocean observing activities to fully participate in the acquisition and exchange of data according to international standards, as well as to build the scientific capacity to use ocean data for national priorities.

More fully including ecosystems and socioeconomics in design of the ocean observing system was emphasized. Sustaining our successful observing systems and building on the success of OceanObs'99 is essential to building climate records. Continued excellence in marine research and technology will help deliver a thriving maritime activity.

3E: Community Forum: World Climate Research Program: Towards integrated ocean basin observations planning

At present the World Climate Research Program (WCRP) is going through the process of deciding how it will evolve in the future. The role of the oceans in climate is one of the fundamental pillars of WCRP. In the future is it likely that within WCRP more emphasis will be placed upon stressing the interactions between, the oceans and the atmosphere or the oceans and the cryosphere but also the oceans role in biogeochemical cycling and the marine ecosystem. While it is important that we continue to engage the end user community and factor in societal needs into our activities the research element of WCRP remains its core mission.

Within WCRP, the Climate Variability and Predictability project (CLIVAR) has overall responsibility for coordination of activities on the role of the oceans in climate, including ocean interactions, both globally and regionally, with the atmosphere. Under WCRP and CLIVAR the notion of three kinds of ocean observations have been developed:

1. Process observations that are relatively short in duration (say up to 1-2 years) and focused on a particular aspect of the ocean.
2. Enhanced observations are regionally focused and try to understand dynamics and interactions of a key ocean element. They last typically 2-6 years and involve a density of observations that could not be sustained for a much longer time scale but can provide valuable guidance for sustained ocean observations.
3. Sustained observations that provide the long term perspective and spatial context for climate research.

Four short presentations reviewed in an exemplary fashion WCRP/CLIVAR ocean observations in the Atlantic, Indian, Pacific and Southern Oceans. The presentations highlighted the different approaches and regional foci, however the overarching principles are the same. A number of examples were provided where interdisciplinary projects are already taking place jointly with CLIVAR activities, e.g. the climate-biogeochemistry interactions project with a focus on oxygen minimum zones of the tropical oceans.

Process observations in the Indian Ocean have concentrated on the Madden Julian Oscillation (MISMO, CIRENE, CINDY/DYNAMO) and the Indonesian Throughflow (INSTANT) however there are also a number of regional ocean observing systems focusing on ecosystem and coastal currents. The GAIA project in the tropical Pacific Ocean will examine western boundary currents and the inflow side of the Indonesian Throughflow (ITF) while in the Weddell Sea gyre the deployment of acoustic stations to track floats that can operate under the sea ice has recently been completed.

Enhanced observations in the North Atlantic include the RAPID/MOCHA array, monitoring the Meridional Overturning Circulation, with plans to extend the array via AMOC/SAMOC (an enhanced long-term monitoring array in the South Atlantic-Southern Ocean) and via the THOR project in the North Atlantic. In addition, the TACE project is focused on processes in the tropical eastern Atlantic. In the Pacific Ocean, to be complemented by an upcoming OKMC, NPOCE has been running for some 15-years with a focus on the interaction between western boundary currents (WBCs) and marginal seas and between WBCs and the ITF and the tropical Pacific warm pool. Further South SPICE is looking at the highly dynamic area of the South Pacific Convergence Zone and the bifurcation of the south equatorial current, and the changing East Australia Current. The Southern Ocean has several full ocean depth hydrography and expendable bathythermograph lines that are repeated on regular intervals (some on a yearly basis and some for more than a decade now) and the addition of ARGO float and marine mammal profilers has greatly increased the number of high latitude profile data.

Sustained Observations include the equatorial moored arrays (PIRATA in the Atlantic Ocean, RAMA in the Indian Ocean (47% complete and part of the larger IndOOS program), and TAO/TOGA in the Pacific Ocean) and the OceanSITES long-term, deepwater reference stations (global) measuring dozens of biogeochemical and physical variables and monitoring the full depth of the ocean from air-sea interactions down to 5,000 meters.

It was commented that many CLIVAR process studies have evolved into a sustained observing effort (one example is the Kuroshio Extension System Study

(KESS) which launched the KIO time series reference station).

Studies of the upwelling regions in the east of the Pacific basin appear to be lacking? This could be important as changes in the east of the basin may govern the zonal gradient of sea-surface temperature in the future.

Recommendations:

- A key theme of the discussion was the need sustain medium to long-term measurements and to strengthening the links between the physical and biogeochemical observations.
- Cruise planning information of up-coming expeditions should be provided to the ARGO and surface drifter project offices. There is a shortage of deployment opportunities in some less frequently visited areas of the ocean and information on upcoming research cruises would help in the forward planning to seed these areas.
- The importance of the repeat hydrography program should be made more visible in the outcomes of this meeting.
- Data collected under CLIVAR should be made publicly available as soon as is feasible through the relevant Data Assembly Centre and/or data portal. The need for standardization of all available data and meta-data is still an issue for the community.
- CLIVAR should continue to make efforts to subsample hydrographic data and make it available on the Global Telecommunications System with the caveat that for climate analysis rigorous validation and calibration of the data is required.
- CLIVAR should encourage the modeling community to take advantage of our investment in new observations and also to revisit data from past studies in the light of new insights and parameterizations and to consider establishing Climate Process Teams internationally
- WCRP/CLIVAR might benefit by working more closely with the Arctic Climate community to secure the legacy of the International Polar Year.
- In terms of the observing system key gaps remain in the southern Atlantic and the Southern Ocean. The development of a South Atlantic Meridional Overturning (SAMOC) array in the Southern Atlantic and a Southern Ocean Observing System (SOOS) should improve the observing coverage although the challenges of ice-covered regions remain.

3E: Community Forum: Biodiversity Forum

It was suggested that research on ocean biodiversity has unique problems and values, and should resist being driven by "climate imperialism". Participants were reminded that the biodiversity community needs to provide a list of special priorities and associated costs, presenting his own favorites with associated prices, including a quiet-running research vessel similar to the G.O. Sars that CoML has used effectively on the Mid-Atlantic Ridge and a flying sequencing laboratory that could provide timely "barcodes" for specimens around the world to accelerate many biodiversity projects. The proposed vessel, perhaps named Patricio Bernal, would be run by an international consortium like the International Ocean Drilling Program, under the IOC flag to document Southern Hemisphere biodiversity and resources.

Despite having been considered as a "biological desert", largely due to a lack of sampling, the vast mesopelagic volumes are among the habitats most in need of description in terms of biodiversity and biomass, and acoustic techniques seem to be best suited to this study Participants discussed the importance of a variety of acoustic techniques, but also noted that these measurements have their limits and that optical measurements are still required. It was noted that images and genetic techniques are essential aids to "naming the carbon", but do not replace traditional taxonomic approaches.

The importance of good data management was stressed, with dedicated databanks for specific types of data (akin to the data assembly centers used by some research projects), making sure the data are exchangeable, accessible, and interactive with physical and chemical data systems. A global effort to consolidate animal-collected oceanographic data is expected to be online by 2010. It was noted that the integration of OBIS as a program of IOC/IODE as being very positive. There is a need for a common strategy and a coordinated approach so that it was easier to get funds to do all those things, with more attention being given to consolidating biodiversity, biogeochemistry, and ecosystems in a single proposal, not as separated issues. There was a reminder that a decade ago the physical oceanographic community was able to come up with the design of an observing system after having met specifically and formally for this. It was proposed that a similar kind of meeting with key people was needed to add a marine biodiversity observing system.

There was also a discussion of how Marine Protected Areas (MPAs) could be made most effective for conserving biodiversity, ensuring food security and maintaining ecosystem services, recognizing that complex biological data are crucial for the ecosystem-based management, generally accepted as an essential contributor to all of these societal benefits. It was pointed out that climate trends clearly preclude saving every bit of biodiversity, such as coral reefs in areas with high warming and acidification, in the near term. This calls for very hard, unpopular triage decisions in relation to MPAs.

The importance of empowering local communities (think global, act local) so that the regions hardest hit could take part in the global process, was highlighted. The importance for developing countries' institutions to enroll in international programs was identified as was the "International brands" such as CoML are being an advantage when seeking national funding.

When asked what biological data are most important, the participants agreed that the 60+ year time-series from SAPHOS CPRs is a priority and need to be expanded to developing countries and augmented with rapid DNA technologies, as well as physical and chemical data for context.

Recommendations:

1. Member states should support the ongoing integration of the Ocean Biogeographic Information System into the IOC's IODE to build compatible biodiversity, chemical and physical data sources to meet UN requirements for the Convention on Biological Diversity, the Law of the Sea and the Regular Marine Assessment.
2. Maintaining the 60+ year data series on plankton species distributions provided by the SAHFOS Continuous Plankton Recorders on voluntary ships of opportunity is recognized as a top priority for understanding marine biodiversity in the context of climate change. Expanding this approach to developing countries could be very cost effective.
3. CoML has demonstrated the power and economy DNA barcoding technologies to provide near real-time data consistent with the observing community's needs. Progress is being made on automating these approaches for both for plankton and coastal biodiversity. CPRs with real-time species information are attainable in the next decade.
4. Maintaining and expanding animal tagging programs for both satellite and acoustic arrays is essential to sustain physical/chemical databases and to understand climate-linked changes affecting ecosystem based management. These approaches are more cost effective than traditional sampling.
5. Because it is not possible to monitor the whole ocean, a focus on some key areas identified by migrating animals is recommended as a next step. An 'ecoscope' approach using existing tools to at these sites to record activities from top to bottom, from bacteria to whales, would clarify the requirements for ecosystem based management in the future. This could be a logical extension of the OceanSITES program. An operational upward-looking sonar system linked to the MARS cable in California (http://www.acoustics.washington.edu/DEIMOS/), illustrates the power of such an approach in real-time.

4. DAY 4: DEVELOPING TECHNOLOGY AND INFRASTRUCTURE

The day examined the frontiers in observing technology and plans, and in the infrastructure of the observing system, that will allow for a decade of expansion in the capabilities of the ocean observing system.

The day had three science sessions.

Session 4A: In situ ocean observation

The past decade has seen rapid development of systematic and innovative in situ ocean observing systems using both mobile and fixed-point platforms. These include research Ships, Volunteer Observing Ships (VOS), drifters, gliders, animals with sensors, moorings, cables, landers, AUVs and ROVs. These advances are set to revolutionize our understanding and monitoring capabilities of the global ocean, particularly for complex biological and biogeochemical variables and processes. For the first time we are addressing the reality of simultaneous multidisciplinary, multi-scale ocean observations with real-time open data access through technology e.g. telemetry and marine cables enabling intelligent, interactive sampling.

It is now vital that we validate and integrate the existing systems and expand them to regions of the globe or water column which are inadequately observed at present. The global community has started to establish a minimal list of key variables (eg at the OceanSites locations for climate-relevant variables). This principle must now be applied to all platforms in an objective manner relevant to the capabilities of the platform. Priorities need to be made to address key questions such as ocean health, marine resources, security and climate change and this must be reflected in the minimal variable list.

To achieve this vision we first need to enhance the capability of existing sensors (reliability, durability, sensitivity etc). In concert there is a real need for longer-term funding of emerging technologies and infrastructure through research and development up to a high readiness level to ensure their application as part of the enhanced operational system.

Much of the current observing systems is dependent on research funding and there is an urgent requirement for funding bodies across the world to adopt a longer term vision so that the transition from research to an operational basis can be achieved smoothly and with the vision of a sustained system. Continued dependence on short term research funding will, without doubt, inhibit development of a coherent network.

We need to work towards a global vision and an international agreement on the need to collect and exchange in situ climate data from the global Ocean. Synthesis and standardisation at a global level of expertise, variables, protocols and interactive data management are key to meet the increasing societal requirement for ecosystem based management of ocean resources. Open access to high quality data is also essential to feed into ever advancing global models to enable hindcasting, nowcasting and forecasting of complex oceanic processes and to produce relevant products, services. Effective science communication and outreach of these products and results is also key to increase global knowledge about the global Ocean through education.

Recommendations:

- We advocate a multi-scale and multidisciplinary approach to in situ observation with a focus in the next decade towards the increased integration of mobile and fixed-point platforms.
- This integration must at all times ensure the data are managed so that they are readily available to the various user communities with standardised international metadata and data policies in place to enhance interoperability and dissemination.
- Key and critical variables are under development to address the issues of ocean health, marine resources, security and climate change and a minimal list is urgently required relevant to these themes and the various platform types.
- In concert with this is the need to increase the rate of development of new sensor technology and to enhance the capability of existing sensors (reliability, durability, sensitivity etc).
- The observing network must be expanded to cover critical gaps (regional and vertical) such as the high latitudes and the deep ocean.
- Conduct state-of-the-technology assessments and support third-party technology demonstration and verification to provide credible, comparable and objective performance information in situ instrumentation for the observing system (e.g., expanding the Alliance for Coastal Technologies).

Session 4B: Satellite

Operational Missions: This presentation reported on the progress made in transitioning towards sustainable and permanent operational satellite systems for key oceanographic variables that can be observed from space (sea surface temperature, surface topography, Ocean vector winds,). Rather than addressing all the individual successes and achievements the presentation took a life cycle management perspective on the transitioning progress and challenge to conclude that this progress was considerable over the last decade in the sense that key remote sensors have series of follow-ons. The presentation highlighted that 1) the programmatic decision making process in some cases is still undesirably long and complex 2) the operational agencies need a strong user pull which requires timely and easy access to data. 3) international and intercontinental cooperations as well research-operations partnerships are key success factors for developing and sustaining the remote sensing infrastructure.

Research Missions: This presentation showed that the space research community has made great progress and stressed that research agencies will continue to contribute to the sustainment of the existing ocean remote sensing infrastructure. Seven GCOS ocean ECV's, Sea ice, sea level, SST, ocean color, sea state, ocean vector winds, SSS, were used as a model for the satellite continuity over the past and for the future, noting that for the latter avoiding funding gaps remains a challenge. The presentation concluded that for future research and improved understanding of the climate record depends on the following: Sea-Ice – Rapid changes in Arctic sea ice draw attention to the urgent need for sea ice missions for understanding of sea ice thickness and dynamics (e.g. Cryosat-2, Icesat-2, DesDynI), Sea Level – Confirmation of future missions – for operations and research is urgently needed (e.g. Jason-series, Sentinel-series, SWOT), SST - Donlon et .at CWP has a comprehensive set of recommendations for the SST observing system. Urgent attention to continuity of satellite microwave data is needed, Ocean color - acceleration of research missions (e.g. ACE) is needed, Sea state - research is enabled by success in meeting the sea ice, sea level, and wind recommendations.

Data Integration and Products: The presentation focused on the wealth of information and understanding that can be achieved by data integration and promoted the usage of dynamic frameworks to do so. The presentation stressed that full potential of the available vast amount of data still untapped and smart data mining should rapidly emerge. In particular, with SAR data swell waves can be mapped in time, SAR Doppler anomaly analysis derives surface velocity including the wind forcing , usage of the Earth Simulator for transfer functions to derive 3d ocean dynamics from lower resolution observations and high resolution snapshots of other data.

Recommendations:

- Implementation of the plans for new and sustained satellite missions in the coming decade is critical to maintain the integrated ocean observing system.
- Operational and R&D agencies and institutes are working on one sustained observing system. A close cooperation is mandatory to address the climate monitoring and other science issues in need of sustained and continued measurement.
- Enhance mandate for climate in R&D agencies
- Enhance science support in operational agencies
- Enhance internal and cross cutting cooperation between the standard data product communities.

Session 4C: Information Synthesis and Delivery

Observation system design and development remains a scientific endeavor and a multi-generational challenge because of the need to continually infuse scientifically-sound knowledge and experience and because of changing technologies. To meet the expectations and needs of users, observation system design must define the purpose(s) of the system (e.g. estimate the current rate of sea level rise) as well as the quantitative need (e.g. sea level rise with regional specificity to some stated degree of uncertainty). There are several approaches to observational network design (testing/evaluation and assimilative tools/models to name a few examples), but experiences to date suggest that only a global sustained observing system will provide the critical observational information needed to respond quantitatively to questions asked of us today and in the future. Moreover, an international authoritative body with a long time-horizon should guide the development of the system.

Major advances have been made over the last decade in assimilation systems and in the observing system, leading to significant advances in our understanding and prediction of ocean variations at both mesoscale and climate scales. There are many examples of successful applications from ocean assimilation products. Use of these systems for assessing the observing system helps identify the strengths of each observation type, and indicates that none of the observations currently used in assimilation systems is redundant. Many challenges remain, particularly with regards to the assimilation systems that, even in the more recent era of unprecedented observations from satellite altimetry and Argo, provide different views of climate variations. Efforts need to continue to improve models and assimilation systems and to develop stronger connections between the assimilation and observational communities. Future developments will be increasingly towards consistent analyses across components of the Earth system using, e.g., coupled atmosphere-ocean models.

There are many challenges to data assembly and delivery, including increasing data volumes and diversity and increasing importance of realtime data access. Data assembly, quality review, documentation, and archiving are all essential activities for the benefit of the user, but each presents challenges that are often specific to each data stream. Data assembly systems for most data streams do exist and are good foundations, but are not sufficiently coordinated. Moreover, many technical challenges (e.g. data duplication, data versioning, data quality review, metadata collection and consistency) remain. Delivery of information is an essential component of the observing system. Techniques to deliver observations and information are evolving rapidly using new internet-based technologies, but integration will require new efforts and pilot studies that consider end users. In summary, development of an ocean data management system remains a challenge.

Recommendations:

- The existing GOOS must be maintained and extended to include full-depth Argo-type measurements, and enhance information about boundary currents, transports through key regions, and in marginal seas.
- Ocean state estimates should be maintained and viewed as an integral part of the ocean observing and information system.
- Convene a meeting of data system developers and managers to seek common solutions (including the use of standards) and develop common elements of the data management system.
- Require all projects, national and international, to have a plan for managing data and migrating them to long term archives.
- Encourage integration by establishing a few cross-community pilot projects and linking data systems with end-user tools
- Identify an international authoritative body with a long time-horizon to guide the development of the ocean observation system
- Identify mechanisms to improve communications between data providers and assimilation groups regarding data availability and quality issues identified during the assimilation process

5. DAY 5: THE WAY FORWARD

The last day of the OceanObs'09 conference concentrated on the programmatic structures required 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 from the system.

Besides the presentation of the conference statement, the day had two science sessions, a high-level perspectives session on sustaining ocean observations and high-level session on the view-points of international programs.

Session 5A: Delivering Societal benefits from the ocean observing system

This session addressed services to society and how we continue to make use of our own observing system. Not only do services directly benefit society, but they are also able to provide impetus for improved science in our marine environment. Ocean monitoring and forecasting core services provide common data for all users, and can provide the stimulus for downstream marine activities. Ocean monitoring and forecasting "core services" are designed to foster services for societal benefits, e.g.

search and rescue, storm surge and coastal cyclone forecasting, coastal monitoring, fishery management and seasonal forecasting.

Core services add value to observations by providing a consistent and continuous flow of model and data products. MyOcean is the European initiative for a sustained Services. Its strategy is to meet this challenge based on a network of operational providers delivering qualified services with strong links to users and an open and free data policy. These services depend on the existence of ocean observations and information from the ocean observing system. In the next decade, an open exchange of skills, data and information will be a key factor for innovation, societal benefits and sustainability of Services. Unlocking data in real-time for incorporation in information products is vital for the continued success of services. Standardised quality control and validation of products is key and should be, and is, a major part of the services.

Monthly global sea surface temperature (SST) over historical time scales (150 years) has become available in the last decade which has permitted us to use climate models with realistic ocean conditions through time to assess the climate impact of ocean variability. The example discussed is the influence of the oceans on drought. On inter-annual to decadal time scales it has been shown that ocean SST variability can also lead to drought variability.

Although SST information can sometimes provide early warning of drought this is not always the case. Long-term SST data sets have been used to determine the role of the oceans in triggering historical droughts. In many cases there was a detectable impact of the ocean conditions on these events. Hence there is the prospect for creating drought warning systems that are intimately tied to ocean observations. A key outstanding question is which of the recent precipitation trends are consistent with changes in green house gas concentrations in the atmosphere. Oceans are certainly key factors in the attribution of regional drought and trends. However, climate-quality ocean observations are critical for distinguishing natural from human-induced ocean conditions.

In terms of fisheries management the main objectives are to achieve the greatest overall benefit, including ecosystem services while obtaining maximum sustainable yield, and rebuilding stocks if they have been overfished. Currently, although researchers agree ocean observations may be used effectively in fisheries management, there are few fisheries managers use them in routine assessments. Fisheries, are presently managed using fisheries landing data, and do not take into account the combined effect of the environment and fishing on fish populations. Modelling fish populations is difficult as deterministic models fail to capture the unpredictable behaviour of fish and statistical models provide only short-term predictions.

Most fishing occurs in coastal regions and thus observations in these areas are required if stock management is to make use of ocean observations. Moreover, capacity building is required to enable coastal fishers to take advantage of information from the global ocean observation system. The next 10 years should see a large increase in the use of ocean observations for fisheries management through the enhancement of sensors, platforms, integrated observing systems, data delivery and use, and models. For this an enhanced collaboration among the observing and fisheries communities is essential. Climate effects on fisheries will be much more apparent in the coming years and ocean observing has contributed to detecting and understanding these, including ocean warming, deoxygenation, and acidification. Progress on the understanding of the effects of climate and fishing on fish stocks, should allow advances in numerical fisheries prediction for fisheries management.

Recommendations

- The ocean observing system data delivery systems design should ensure data is available in real-time to maximise societal benefit from ocean observations.
- Quality control and validation of ocean observing products should be standardised where possible, although not at the expense of their rapid delivery.
- The use of the ocean observing system for societal benefit is expected to expand in future years, and the ocean observing system design should consider the needs of these new areas of benefit to maximise societal benefit from ocean observations

Session 5B: Toward in integrated Observing System

This session concentrated on the frameworks needed 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

Satellite observing system

- Solid progress towards more coherent and internationally-coordinated, satellite infrastructure
- Significant challenges are:
    - o to optimise infrastructure and to link complementary observing system elements
    - o to encourage involvement of new participating Agencies in Virtual Constellation framework and unrestricted data sharing
    - o to promote and achieve widespread adoption of best practices

- o to achieve unrestricted and free product access
- o for data assimilation methods to adapt to new data products
- o to guarantee sustainability of the essential system elements

In situ observing system

The elements of the present in situ observing system were described as was the means to combine them to improve the system. There is a need for a wide range and improved sensors, as well as improved platforms. The importance of making the networks more versatile by adding new sensors to the current platforms was highlighted as was the need to close gaps and increase observations in regions which are currently under sampled. The combination of the different types of data must be done taking into account the specificities of biogeochemical and ecosystem data. It will be essential to make sure that data can be exchanged and efforts to develop standards and best practices specially for biogeochemical and ecosystem parameters must be taken.

Biogeochemistry and ecosystems observing system

1. Integration means a real synergy between physical and biological oceanographers.
2. The choice of the biogeochemical and ecosystem variables is the key implementation and the sustainability of the ocean observation system.
3. The sustainability of the system will depend on the availability of QC data and on the rigor of the data management system
4. A sustained observing system should include "super sites" which would be in key areas in the first step towards integration. The importance of international cooperation was emphasized.

Climate modeling and assimilation

Climate services are already providing reliable, well documented authoritative and easily used information. And to do so, they have to develop interactions with the users. In the future, the operational earth system monitoring assimilation and prediction systems will include all those systems. The importance of the decadal climate prediction on a wide range of services was highlighted: the ocean will be at the heart of this prediction.

- No medium or long term forecast of the physical climate system and of the Earth system is possible without incorporating the ocean.
- Observations are also essential to understand the relations between ocean biogeochemistry, ecosystems and living marine resources.
- Forecasting require initial conditions, whose quality will depend on the quality of observations and (coupled) data assimilation systems
- The ocean remains under-sampled in spite of progress made in the last years.
- A well-designed integrated ocean observing system is essential for climate prediction on decadal timescales and will support societal needs.
- Climate Services will make use of such observational data.

Data management vision: A more cohesive data managers' community must be developed, and the users' community must be involved and an incremental approach should be adopted. In this sense, the convergence to use of NetCDF-CF format was mentioned. This format can be read by tools usually employed within the community. The installation of THREDDS and OPenDAP servers should follow, so that aggregation becomes possible.

Recommendations

Overall the message from this session was that it is essential to consolidate the enormous advances of the past decade using integration as a basis to optimize the use and availability of resources, to expand the observational programs to integrate the biogeochemical and ecosystem communities and to begin to extend the benefits to society through climate services frameworks.

Session 5C: High-level perspectives: sustaining ocean observations

We are living in a world of rapid change so observations are necessary to map these changes. The commitment of institutions to long-term support of ocean observing systems is essential for sustaining them.

Amongst numerous agencies within a number of national and regional frameworks, the conference heard from the European Commission and the US National Science Foundation, who have supported ocean observations with significant investments.

The European Commission, through the Global Monitoring for Environment and Security (GMES) is taking actions in order to establish an operational capacity for monitoring the marine environment, by assuring routine monitoring of the ocean (using in situ and satellite observations), but also by encouraging the assimilation of these observation data into models, in order to provide, on an operational basis, the information needed. In the development of GMES, the Commission has been making substantial efforts to involve user representatives. For the future, it is necessary to strengthen this dialogue between users and service providers, in order to assure the usefulness and uptake of the information produced.

The US National Science Foundation has funded several initiatives designed for basic research, and has made a 25-year commitment for operational and maintenance of the Oceans Observatories Initiative (OOI). For these initiatives to be successful, partnerships are essential and are being developed inter-institutionally and internationally. Now it is necessary to engage science community in planning specific experiments that maximize and leverage the impact of in situ assets.

It is important to highlight that the investment made by institutions to support ocean observations have to go hand-in-hand with an implementation of a full and open data policy and the need of combining innovative ocean observing technology and real time ocean data to inspire the public. Scientists and educators need to work together to maximize broader impacts of science and to develop educational materials for formal and informal education at all levels.

Session 5D: Viewpoints from International Programmes

Session chair: José Achache, with representatives from 12 international programmes:

- GEO Group on Earth Observations, José Achache, Director, GEO Secretariat
- CEOS Committee on Earth Observation Satellites Stan Wilson, CEOS Chair Representative
- POGO Partnership for Observation of the Global Oceans Trevor Platt Executive Director
- SCOR Scientific Committee on Oceanic Research Ed Urban Executive Director
- GCOS Global Climate Observing System John Zillman Chair,
- GOOS Global Ocean Observing System Keith Alverson Director, GOOS Project Office
- JCOMM Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology Jean-Louis Fellous Co-President
- PICES North Pacific Marine Science Organization A. Bychkov Governing Council; Executive Secretary
- ICES International Council for the Exploration of the Sea Yann-Hervé de Roeck
- CoML Census of Marine Life Ron O'Dor
- IGBP International Geosphere-Biosphere Programme Guy Brasseur Former Chair
- WCRP World Climate Research Programme Tony Busalacchi Chair

Representatives of the twelve international programmes gave an overview of the relationship of their programs with the achievements and goals of the OceanObs'09.

All International Programs agreed to support the OceanObs'09 conference declaration and the working group effort to devise implementation plans.

It was highlighted that a major value of the OceanObs'09 is the bringing together of communities. Coordinating and sharing resources of the international programmes will similarly help build and sustain an ocean observing system.

The programmes support the inclusion of biological observation systems within all components of GOOS, embracing living marine resources and ecosystem health alongside its current capabilities.

A free and open data policy was cited as a prerequisite to participation in their own programs and is strongly recommended for future observing systems. Several systems cited their successful experiences with data portals to improve and implement access to datasets.

Several programmes supported the use of existing frameworks and governance structures, eschewing the need for developing another coordination program and framework. Several supported working within the GOOS and GEO framework.

Several programs called for more engagement by scientists and their own organizations in convincing national agencies to support ocean observation systems. Many of the programs emphasized the continuing development of products serving societal needs, pointing out the value of societally relevant products in building support and advocacy of systems.

Several programmes are today emphasizing biological observation systems, CoML, PICES, ICES, IGBP and reported that integration of these systems with the physical systems is currently possible and beneficial.

GOOS Programme Office and GEO Secretariat offered assistance to scientists from developing countries who require resources to participate in the OceanObs'09 working group.