

Remote-sensing imperatives of the Global Ocean Observing System (GOOS)

Colin Summerhayes¹, Ehrlich Desa² and G. Narayana Swamy²

¹GOOS Project Office, Intergovernmental Oceanographic Commission of UNESCO
1, rue Miollis, 75732 Paris Cedex 15, France

²National Institute of Oceanography, Dona Paula 403004, Goa, India
E-mail: narayana@csnio.ren.nic.in

Abstract

This paper discusses the implications of the recent progress in the implementation of Global Ocean Observing System (GOOS), to the satellite remote-sensing community. The imperatives are to increase the scales of observation and thus to extend the range of observable phenomena, with reduction in cost and effort.

Since GOOS aims at being a systematic, routine and long-term observational arrangement, continuity in satellite missions is essential. Further, the occasional redundancies of satellite data could be treated as valuable data streams in their own right, e.g. for cross-calibration of sensors on different platforms. This is an important aspect the remote-sensing community needs to address.

Remote sensing has been highly successful in observing the climatic component of the ocean. It is yet to reach this level of observational strength for the other GOOS components of Living Marine resources (LMR) and Health of the Ocean (HOTO), especially in coastal waters. Appropriate proxy parameters are to be devised for those oceanic variables not measured remotely as of date. *In situ* validation of these parameters through dedicated cruises, SOOP (Ships of Opportunity), drifters, *Argo* (the global array of profiling floats) and autonomous moored arrays is crucial.

The tasks are thus to advance the function of remote-sensing algorithms to encompass those variables which are presently monitored by *in situ* systems, leaving these systems to act more as sea-truth validators than as *in situ* data suppliers.

Successful implementation of GOOS therefore depends largely on critical scientific feedback on powerful satellite sensor technology, fine-tuning remote-sensing algorithms, and further data assimilation into real-time operational models.

1. Introduction

The terrestrial, atmospheric and oceanic processes are interlinked in some way or the other. Ocean is the ultimate sink for the materials of terrestrial origin, and is also the key to several atmospheric modulations. Ocean conceals a lot of information and reveals a little on interception. There is a flow of information from one part of the ocean to another (Woods, 1999). It is the interception of oceanic information flow that ocean monitoring is all about. Apart from understanding the inherent processes of the sea, ocean monitoring lays much stress on the oceanic aspects common with the atmospheric and terrestrial processes.

Information flows through the ocean by means of waves of different kinds (wind waves, Kelvin waves, tidal waves, etc.) or by currents and turbulence transporting water with particular properties (Woods, 1996). The ocean is much more difficult to predict than the other two natural systems, partly because its weather systems are very much smaller than those in the atmo-

sphere, and partly because the customer wants products which depend not only on physics but also on chemistry, biology and sedimentology.

In practical terms, oceanographic information translate themselves as the following (IOC, 1998):

- National agencies and regulatory authorities, both individually and regionally need to know the scale and effects of contaminant discharge into the coastal areas. Sequestration of chemicals by particles, the production of authigenic compounds and subsequent sedimentation means that what is discharged from the shores or into rivers does not simply pass through the coastal zone into the deep ocean. It is possible, using physical and geochemical models, augmented by measurements, to determine local trapping and storage and the net efflux across the continental shelf from estuaries and the nearshore environment. Such predictive systems need to be able to deal with point and distributed sources and

with gradual and episodic changes in forcing functions.

- To improve local flood defences, and to manage ports and harbours effectively, coastal zone and port managers need to know how water levels are varying in their area. Water levels may vary because of tides, changes in sea level caused by climate change, surges caused by storms, or changes in wave height, all of which may be independent but also may be combined. All can be monitored, modelled, and forecast.
- The growth in ocean trade, the increasing automation of ships, and the development of super-giant bulk and oil carriers demands much improved planning of ocean routes to take advantage of knowledge of the changing positions and strengths of ocean currents and the eddies and storm tracks with which they are associated, as well as the likely occurrence of unusually high waves. This demand greatly improved now-casts of ocean conditions and numerical weather forecasts.
- Those concerned with the harvest and conservation of living marine resources need operationally useful information on changes in the state of those resources and the ecosystems in which they exist, for example to be able to assess present stocks and predict their future states, and their vulnerability to forcing by changes in climate, fishing pressure, pollution, or the incidence of harmful algal blooms.
- The oil-industry is exploring and beginning to exploit reserves below 1000 metres water depth – on both the continental shelf and slope. New engineering techniques are having to be developed to cope with often vigorous and rapidly changing regimes. For design purposes, detailed oceanographic and meteorological data are required to assess operability and extreme loads on floating production systems. For day-to-day operations such data are required for vessel selection, the use of Remotely Operated Vehicles, riser deployment and ship loading.
- The availability of skilful seasonal predictions can have a profound effect on the efficiency of agriculture and management of food stocks. Such predictions invariably depend upon complex interactions between the atmosphere and oceans. Measurement and modelling of both components and exchanges between them are essential if reliable predictions are to be made.
- Climate also affects the demand for energy; so major energy suppliers need accurate forecasts of how

long and cold winter conditions are likely to be year-to-year for a decade or more ahead. Farmers can use similar information to assess changes in the length of the growing season.

- Climatic factors have a major influence on the emergence and re-emergence of infectious diseases, particularly those that are transmitted by insect vectors. A direct link has been established between malaria in tropical regions and El Nino events.

2. Global Ocean Observing System (GOOS)

Because monitoring has this double function: to provide information for knowledge (that is *science*) and information for policy (that is *management*), Intergovernmental Oceanographic Commission (IOC), together with the other sister organisations of the United Nations and with the other UNESCO's intergovernmental programmes are called to play a fundamental role in making this new paradigm (monitoring for science and management) a reality (Bernal, 2000). Operational oceanography is being developed at the global scale under the aegis of GOOS, which is sponsored by the Intergovernmental Oceanographic Commission (IOC), World Meteorological Organisation (WMO), United Nations Environment Programme (UNEP) and the International Council of Science. GOOS has emerged as a clear focus of IOC activities over the past decade. The concept of GOOS as a user-driven project is supported by governments and implemented according to a set of principles to which all participants adhere (IOC, 1998). GOOS is a new way of acquiring and using oceanographic information to produce deliverables of practical use in the national, regional and global scales. GOOS will differ from most present observing systems (i) in having modelling and forecasting as part of its mandate, as well as the collection of data; (ii) in being holistic, integrated and interdisciplinary, rather than narrow and sectoral; and (iii) in being designed to deliver useful products for both decision makers and the scientific community. GOOS has been identified and encouraged in other intergovernmental fora, such as UN Conference on Environment and Development (UNCED) and UN Commission on Sustainable Development (UNCSD). GOOS is a response to the demands of UNCED's Agenda 21.

The Global Ocean Observing System is conceived as (IOC, 1998):

- a sustained, co-ordinated international system for gathering data about the oceans and the seas of the Earth,
- a system for processing such data, with other relevant data from other domains, to enable the

generation of beneficial, analytical and prognostic environmental information services, and

- the research and development on which such services depend for their improvement.

Foundations of GOOS are on the technological base in the form of:

- Space-based techniques and instruments for making complementary *in situ* measurements with the accuracy and stability required for GOOS purposes;
- Systems for tracking and/or relaying data from low-power, low-cost platforms operating in the hostile marine environment;
- Very high performance processors and high capacity data storage systems capable of running numerical models of the resolution and capacity to adequately represent the essential physics, chemistry and biology of the oceans;
- Information management and presentation methods and systems.

The primary objectives of GOOS are:

- to specify the marine observational data needed to meet the needs of the world community of users of the oceanic environment;
- to develop and implement an international co-ordinated strategy for the gathering, acquisition, and exchange of these data;
- to facilitate the development of products and services based on the data, and widen their application in the use and protection of the marine environment;
- to facilitate the means by which less-developed nations can increase their capacity to acquire and use marine data according to the GOOS framework;
- to co-ordinate the ongoing operations of the GOOS and ensure its integration within wider global observational and environmental management strategies.

Most operational oceanography is carried out locally to solve local problems - for instance to provide information for oil platform operators in a specific area, or to model water levels in a particular port and its approaches, or to model an oil slick. However, in all of those cases local conditions are subject to regional controls set in a global ocean-atmosphere-ice system within which there are teleconnections between areas thousands of miles apart. GOOS is designed to assess and analyse the information flow, so as to provide the boundary conditions required to improve the accuracy

of local forecasts and other services. By providing the local user with an accurate regional framework, GOOS will help to improve predictability. In many respects, GOOS is like a spatially distributed large facility. GOOS will complement, but not replace, the collection of data and application of models for specific local applications.

Implementation will be incremental, and full implementation, following tests of the system through pilot projects, is expected to be achieved in the period 2010-2020. As part of the design and implementation exercise, Observing System Simulation Experiments (OSSEs) will be needed to discover what appears to be the most economical mix of observations capable of constraining models so that they yield desired products with appropriate accuracies.

At the detailed design level, it is anticipated that we will see an open ocean GOOS devoted mainly to weather climate forecasting and related issues, and a coastal GOOS that has a much higher density of observations and addresses a wider variety of issues including pollution and living marine resources. The details of the design will vary from one area to another, depending on local concerns.

3. Recent developments

The GOOS development has been planned to build on existing capabilities and networks, to develop in regional areas where specific priorities can be identified and resolved, to investigate technologies and methodologies to improve the effectiveness and efficiency of ocean measurement and monitoring systems and to build capacity and capabilities in developing countries in order for them to recognise potential benefits and contribute to their attainment (Zillman, Field & Jarmache, 2000). It is designed to provide descriptions of the present state of the sea and its contents, and forecasts of these for as far ahead as possible, for a wide range of users, and to underpin forecasts of changes in climate. It is not solely operational, but includes work to convert research understanding into operational tools.

Some of the recent developments in GOOS are the following (IOC, 1999 a):

3.1 The GOOS Initial Observing System (GOOS-IOS)

There is now a GOOS Initial Observing System (GOOS-IOS) uniting the main global observing subsystems supported by the IOC, WMO and (in the case of coral reefs) the IUCN, and including measurements

from ships, buoys, coastal stations and satellites. In addition to these international elements, many nations are contributing substantial parts of their national observing systems to GOOS. The GOOS-IOS is the nucleus on which GOOS will grow in the future. GOOS-IOS was expanded by the inclusion of the Continuous Plankton Recorder Survey, the ICES International Bottom Trawl Survey, and selected time series stations ('S' and BRAVO). Although the implementation of GOOS through the GOOS-IOS has begun by exploiting existing systems, rather than following a specified design, it is expected that the existing systems will be adapted to meet the design requirements, and that new components will be added as appropriate.

3.2 GOOS Pilot Projects

Pilot projects are being developed to take forward aspects of the GOOS design. The main GOOS pilot project is GODAE, the Global Ocean Data Assimilation Experiment. GODAE will demonstrate the power of integrating satellite and *in situ* data, the power of assimilating data into numerical models, and the value of a global system capable of working in real-time. GODAE is needed not only for open ocean analyses and forecasts, but also to establish boundary forcing for regional models to improve forecasting in coastal systems at the local level.

To feed the requirements of GODAE, a global net of upper ocean temperature and salinity data is needed for integration with the global net of surface ocean data provided by remote sensing from satellites. To provide global coverage of upper ocean temperature and salinity, the GOOS/GODAE community is planning the Argo Pilot Project, which will seed the ocean with 3000 profiling floats that will rise from (say) 2000 m to the surface every 14 days, each one collecting 100 CTD profiles over a 4-year period. At maximum capacity Argo should provide 300,000 profiles that together give full global coverage of the ocean interior for the first time. Added to satellite data from the ocean surface these profiles will underpin models of ocean behaviour and of climate.

Another major GOOS pilot project is PIRATA (Pilot Research Moored Array in the Tropical Atlantic), which extends the TAO array to monitor ocean and atmospheric variables and upper ocean thermal structure at key locations in the tropical Atlantic region. PIRATA data, in real-time will improve understanding of ocean-atmosphere processes, so leading to improved climate prediction for Africa and South America. It is intended that once past the research phase, PIRATA should become a permanent operational programme by the beginning of 2001.

3.3 Integrated Global Observing Strategy (IGOS)

It is easy to see that the range of observations needed to understand and monitor Earth processes, and to assess human impacts, cannot be satisfied by any single programme, agency or country. International cooperation is essential to provide these observations; effective monitoring of our planet on the global scale requires cooperation on that scale. Recognising this requirement, in 1998 GOOS became part of an Integrated Global Observing Strategy (IGOS) involving the major space-based and *in situ* systems for global observations of the Earth. IGOS provides an integrated framework enabling better observations to be derived in a more cost-effective and more timely fashion by building on the strategies of existing international global observing programmes.

The IGOS Partners comprise the offices of the three global observing systems - the Global Ocean Observing System (GOOS), the Global Climate Observing System (GCOS), and the Global Terrestrial Observing System (GTOS), along with their sponsoring agencies (WMO, UNEP, UNESCO, FAO, ICSU and the IOC), plus the space agencies represented by the Committee on Earth Observation Satellites (CEOS), along with the World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP), and the International Group of Funding Agencies for Global Change Research (IGFA). Other organizations are expected to join in due course.

IGOS is developing through the promotion of a set of themes, the first of which is the Oceans Theme (IGOS-P, 2000), which will emphasise to Governments the requirements for a comprehensive GOOS.

3.4 GOOS Regional and National Programmes

GOOS is also being planned and implemented at the regional level. Several newly created GOOS regional bodies are expected to increase their capabilities and implement operational activities during the next 5-10 years, thus helping the further development of GOOS. In many respects these regional programmes, with their focus largely on coastal seas, are already implementing aspects of Coastal GOOS, as well as elements of the GOOS-IOS, like GLOSS and the GCRMN. GOOS regional policies are being worked out.

Already Euro-GOOS and NEAR (North East Asia Region)-GOOS are at advanced stages of development. The EuroGOOS planning continues for the development of pre-operational research projects to develop the skills and capabilities to implement GOOS. And significant operational developments are taking place in the six EuroGOOS sub-regions: the Mediterranean,

the Arctic, the Baltic, the northwest shelf, the Black Sea and the wider Atlantic. NEAR-GOOS is increasing its constituents and contributors and will soon move towards ocean forecasting.

The needs of Small Island Developing States (SIDS) and developing countries are addressed in four main GOOS regional projects: PacificGOOS, covering S.W. Pacific island states; IOCARIBE-GOOS for Caribbean states; MedGOOS for Mediterranean states; and WIOMAP (Western Indian Ocean Marine Applications Project). The Indian Ocean is moving towards GOOS slowly. With a dedicated Indian remote-sensing satellite (IRS P4 – OceanSat) in the orbit for oceanic observations, hundreds of drifting buoys spread over the northern Indian Ocean and the first mooring of the proposed equatorial array in place for hydrographic measurements, the stage has been set for basin-scale monitoring services. In particular, the Indian waters are well served by shallow-water and deep-sea moorings and a network of water-level monitoring systems. There is specific recommendation to deploy a permanent geostationary satellite over the Indian Ocean to improve weather and climate forecasting (IOC, 1999 b).

MedGOOS provides a link between EuroGOOS and GOOS-AFRICA, some Mediterranean countries belonging to both EuroGOOS and MedGOOS, and some African countries belonging to both MedGOOS and GOOS-AFRICA.

At the national level, many coastal countries are planning or collecting their own coastal seas observations following GOOS Principles. All IOC Member States are encouraged to form National GOOS Coordinating Committees involving all stakeholders. By July 1999, as many as 22 countries have committed substantial parts of their present observing systems to GOOS. We anticipate that national agencies will adapt their observing systems and data exchange practices to meet the emerging GOOS requirements, so as to make GOOS work as intended.

Recent developments within the IOC have consolidated many of the observational elements within GOOS. IGOSS (Integrated Global Ocean Services System) and GLOSS (Global Sea-Level Observing System), and the former WMO Commission for Marine Meteorology have been brought into the Joint IOC-WMO Technical Commission on Oceanography and Marine Meteorology (JCOMM), that will serve as the main technical committee for GOOS. JCOMM will also encompass the IOC Ships-of-Opportunity Programme (SOOP) and the WMO Voluntary Observing Ships Programme (VOS), the Data Buoy Cooperation Panel (DBCP) and others. GOOS has a Steering Committee

(GSC), supported by various expert panels, to develop realistic plans with holistic issue-driven approach.

Several major oceanographic institutions have formed a Partnership for Observation of the Global Oceans (POGO), designed to aid in the development and implementation of GOOS.

4. Remote sensing implications

An operational global ocean observing system remains to be implemented, and satellites are an indispensable component of such a system, which will materialise based on the successful transitioning from research to operational programmes (IOC, 2000, a). Elements of the GOOS exist today in the form of partially coordinated, local and temporary data capture and processing initiatives, often implemented as part of a research and development programme to investigate particular problems, to detect biological or chemical anomalies or to test a new technology. The contemporary and past projects of the World Climate Research Programme (WCRP) (TOGA, WOCE, CLIVAR) and the International Geosphere-Biosphere Programme (IGBP) (LOICZ, JGOFS, GLOBEC) have generated strong science base for ocean monitoring initiatives. Many national projects have made major contributions outside these programmes too. Some physical data, mainly relevant to the upper levels of the ocean, are gathered and processed on an operational basis, e.g. the temperature and salinity data captured by the SOOP of the Integrated Global Ocean Service System (IGOSS) and the meteorological observations made by the Voluntary Observing Ships (VOS) of WMO Members. Physical, chemical and biological data are collected to aid national coastal zone or fisheries management and to assess the state of the marine environment. Some monitoring is undertaken commercially, particularly to aid offshore operations in the oil and gas industries.

At the same time as the benefits of developing GOOS are becoming more apparent, the costs of making observations are dropping. Satellites are becoming cheaper, and measurements of upper ocean properties are beginning to be made by profiling floats and autonomous underwater vehicles more cheaply than can be achieved from expensive research vessels (Woods, 1999). This places remote sensing in a more comfortable position, also in the sense that there are more opportunities and less arduous procedures for sea-truth validations. However GOOS has to accommodate the fact that space-based observations derive from instruments and missions that have long lead time, and are designed currently without the sort of close coordination with *in situ* observation programmes that the IGOSS is attempting to achieve.

The implications of global ocean monitoring to remote sensing are thus many:

- assured availability of satellite missions
- wide-ranging capability for the monitoring systems
- long-term sustainability of the outputs
- reduction in cost-factor
- global coverage
- local applicability

5. Remote sensing imperatives

In order to ensure sure success to a truly functional and useful global ocean observation programme, the remote-sensing community has to address the following:

5.1 Continuity of satellite missions

Since GOOS aims at being a systematic, routine and long-term observational arrangement, continuity in satellite missions is essential. The spectacular performance of the TOPEX/POSEIDON altimeter vastly improved global wind fields provided by the NSCATT scatterometer, and the increased lifetimes and reliability of profiling floats forced a revisit of the original design for an observing system for ocean climate. The message for the space agencies is the need for continuity of key observations (e.g. sea-surface height; surface winds; ocean colour; sea-ice).

One key aspect of an operational oceanographic system is altimetry. Space agencies have spelt out plans for the high accuracy radar altimeter missions needed to continuously observe the global ocean and to understand short- to long-term changes to ocean circulation (IOC, 2000, a). Whilst the future looks secure for the next five years with Jason-1, a firm decision is needed in the very short term to secure continuity through Jason-2 measurements in the GODAE timeframe. To this end CNES, NASA, NOAA and EUMETSAT are discussing a cooperative approach for transitioning to a fully operational satellite service starting with Jason-2.

The value of ocean-colour data lies in the long-term monitoring of the marine environment which will provide a better understanding of the role of the oceans in the global carbon cycle. The principal deliverable from the ocean-colour missions is the concentration of chlorophyll pigments in the surface layer of the oceans (IOCCG, 2000). Beyond their importance for fisheries management, ocean-colour data are significant as a tool for coastal zone management in general. After the first experimental CZCS observations of NASA between 1978 to 1986, orderly development of ocean-colour science was hindered by the lack of an operational satellite producing ocean-colour data till the pic-

ture began to improve in 1996 when India launched MOS. The powerful combination of Japanese OCTS and the French POLDER launched in 1996, failed in 1997. Since 1997, SeaWiFS has been in routine operation. Over and above these sensors, a number of others are planned for the very near future. Recent experience has emphasised that a certain controlled redundancy is essential if we are to enjoy an unbroken stream of ocean-colour data into the indefinite future.

5.2 Redundancy factor

In order to capture the large-scale process mechanisms, synoptic observations are employed in both atmospheric and ocean sciences. For episodal events, time-specific or location-specific observations are carried out. However, this approach is subject to the maxim "limit of sampling is the extent of distribution". Optimum sampling is therefore a dream. An inadequate monitoring system is, in all likelihood, bound to give inadequate information about the system observed. Under-sampling leads to aliasing, and over-sampling results in redundancy cost.

Many satellite missions are discontinued and newer ones are added. Economic considerations limit the number of satellites in orbit. Special attention is being given not to duplicate functions of other missions. While this may be prudent from the redundancy point of view, we miss a vital aspect of the value of redundancy. Occasional redundancies of satellite data could be treated as valuable data streams in their own right, e.g., for cross-calibration of sensors on different platforms.

5.3 Replacement of *in situ* observations

Satellites have a dual function – communication of data from the *in situ* systems in the sea, and actual remote sensing of the sea. Many a time the former role overshadows the latter. A revision in the role of satellites, more as data facilitators than as data communicators, is needed. A crucial task is to advance the function of remote-sensing algorithms to encompass those variables which are presently monitored by *in situ* systems, leaving these systems to act more as sea-truth validators than as *in situ* data suppliers. For this, remote sensing *per se* has to penetrate beyond mostly physical surficial parameters.

5.4 New algorithms

The fundamental long-term goal of applied research underpinning operational information services is to increase the range of phenomena that can be addressed to make predictions with greater accuracy and/or further into the future than at present (IOC, 1998). The science base finds out proxy parameters to represent

the processes, and the prerequisites for monitoring them. Predictability of a process or a system depends on the judicious combination of the observed parameters.

Remote sensing has been highly successful in observing the climatic component of the ocean. It is yet to reach this level of observational strength for the other GOOS components of Living Marine resources (LMR) and Health of the Ocean (HOTO), especially in coastal waters. Appropriate proxy parameters are to be devised for those oceanic variables not measured remotely as of date.

5.5 Satellite sensor technology

Techniques (algorithms) alone for deriving useful information from measurements cannot extend the power of remote sensing beyond certain limits. Measurement technology itself needs to be revisited.

Ocean salinity, more than temperature, controls the dynamics of the deep ocean circulation and long-term climate. Sea surface salinity (SSS) determines the depth to which cold surface water may sink to form intermediate water masses in the deep ocean. Worldwide, there is a lack of systematic ocean salinity measurements, except for occasional oceanographic cruises and automatic salinity measurements on vessels that support the voluntary observing system. Thus global remote sensing of SSS to a useful level of accuracy (better than 1 PSU) would be very significant achievement. Developing microwave remote-sensing techniques for global observation of sea surface salinity from space is a NASA priority being pursued together with the observation of soil moisture. As a part of its Earth Explorer programme, the European Space Agency is also currently conducting design studies for a Soil Moisture and Ocean Salinity measuring mission (SMOS) using a 2-dimensional interferometric synthetic aperture radiometer system.

The Gravity Recovery and Climate Experiment (GRACE), an Earth System Science Pathfinder mission, currently being implemented in partnership between United States and Germany, should be able to detect the minute changes in the earth's gravity field associated with transient variations in fluid masses at the surface of the earth. Oceanographers would then be poised to exploit the extreme accuracy of present and future space-based gravity measurements for remote sensing, for the time-dependent distribution of ocean water masses (equivalent to a global measurement of ocean bottom pressure). This would be the first remote-sensing application for earth based on the detection of a signal other than electromagnetic radiation (IOC, 2000, b).

5.6 Data assimilation

It has been recognised that the accuracy of routine forecasts depends on three factors: understanding of each phenomenon and its intrinsic limits to predictability, the availability of data, and the power of computers used to integrate the mathematical models (Woods, 1996). Remote sensing is crucial to the first two directly. The third factor should ready itself to assimilate the steady stream of data provided by satellites to drive real time forecast systems. The delay in time enjoyed by the remote-sensing community earlier for data reduction, quality control, data assimilation and information generation will no more be available. Challenges imbedded in driving iterative forecast models with remote data streams are great.

5.7 Spatial coverage

Variation (with space) and variability (with time) are the hallmarks of the ocean. Oceanographers often label ocean properties and processes on temporal and spatial scales varying over eight orders of magnitude. Most of the physical processes are dynamic, chemical and biological properties semi-dynamic, and geological and geophysical characteristics nearly static. The temporal and spatial scales required to monitor and document the respective parameters vary from one set to another.

Improving predictability demands routine, systematic, long-term measurements of relevant ocean properties on a global basis, or at the very least on a basin-wide scale. Sea surface temperature, salinity, and winds, variations in sea level, plankton and nutrient distributions, upper ocean heat content and the transport of heat and water horizontally and vertically around the world are required in common for a wide range of applications. Specific regional and local problems will require additional local observations.

The natural space and time scales of variability set design criteria for observing systems. Remote sensing has to be sensitive to these varying needs of the down-stream oceanographic applications.

5.8 Capacity building

It may also be seen that only a fraction of actual satellite data have been put to actual use. This is an important aspect the remote-sensing community needs to address. In this context, we note that another aspect of GOOS is the need to build the capacity of developing countries to participate in, contribute to, and benefit from GOOS, especially in the area of remote sensing. Many developing countries would find remotely sensed data from satellites extremely useful for the purposes

of management of their coastal seas and EEZs. However, many of these countries find it very difficult to access these data at high resolution and in real time. Indeed, even if they could access the data they lack the personnel trained to use them for practical purposes. Thus a potentially huge valuable resource is wasted by the collectors, and unavailable to the needy.

This question was addressed by the African nations assembled at the Pan-African Conference on Sustainable Integrated Coastal Management (PACSICOM), held in Maputo, Mozambique in 1998 (IOC, 1999b). The report of the meeting identifies the following pressing need: "To encourage formation of a network of specialists trained in the use of remotely-sensed data from space satellites, and to ensure the increased access to regional satellite receiving stations in Africa, so as to ensure that coastal managers have ready access to the rapidly increasing wealth of spatial data on the coastal environment." This need applies to all of the developing world, not just to Africa. Here then is a challenge for the space agencies and the countries that own them. It would not seem difficult to do the little that is required to build the capacity of the developing world to quickly access and make use of satellite data so as to become involved with and benefit from GOOS. A rather small investment could make a huge difference.

6. Conclusions

Future technological advances may reduce the significance of environmental variations for specific activities; however, past experience suggests such advances often expand the range of conditions within which operations can take place, but the pressure to minimise costs and operate at the new limits remains (IOC, 1998).

It is in this context remote sensing assumes unprecedented significance.

Successful implementation of GOOS depends largely on critical scientific feedback on powerful satellite sensor technology, fine-tuning of remote-sensing algorithms, and further data assimilation into real-time operational models.

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