COASTAL theme REPORT

IGOS
Integrated Global Observing Strategy

For the Monitoring of our Environment from Space and from Earth

2006

An international partnership for cooperation in Earth observations

A COASTAL THEME
FOR THE IGOS PARTNERSHIP

Report of the Coastal Theme Team

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About the cover image : True-color image showing phytoplankton and sediments near the Mississippi River delta in the Gulf of Mexico acquired 15 January 2002 by the MODIS sensor aboard NASA's Terra satellite

Credit Jacques Descloitres, MODIS Land Rapid Response Team, NASA/GSFC ;
Source : http://visibleearth.nasa.gov/view_rec.php?id=2404

The Integrated Global Observing Strategy[1] (IGOS) Partnership represents a teaming of international organizations that are concerned with global environmental change issues. It links research, long-term monitoring and operational programmes, bringing together the producers of global observations and the users that require them in order to identify products needed, gaps in observations, and mechanisms necessary to respond to needs in the science and policy communities. A principal objective is to integrate satellite and *in situ* observation systems.

The IGOS Partners are comprised of the Global Observing Systems, the international organizations which sponsor the Global Observing Systems, the Committee on Earth Observation Satellites (CEOS), the International Group of Funding Agencies for Global Change Research (IGFA), and international global change science and research programmes.

The IGOS Partners recognise that a comprehensive global Earth observing system is best achieved through a step-wise process focused on practical results. The IGOS Themes allow for the definition and development of a global strategy for the observation of selected environmental issues that are of common interest to the IGOS Partners and to user groups. The currently approved IGOS Themes include the Oceans, the Global Carbon Cycle, Geohazards, the Water Cycle, Atmospheric Chemistry, and a Coral Reef Sub-Theme.

Recognising the need to coordinate and facilitate diverse coastal observing efforts by the Global Ocean Observing System (GOOS) and Global Terrestrial Observing System (GTOS) of the United Nations among other international programmes, the IGOS Partnership approved the development of a Coastal Theme in June 2003. A Coastal Theme Team was established to determine requirements for observations needed to assess interactions among coastal marine and terrestrial systems across the land-sea interface. This team included representatives of GOOS, GTOS, CEOS, and IGBP among others (see list in Coastal Theme Team Members Section). Coastal Theme meetings were held in Washington D.C. (January 2003, May 2005), Hamilton, New Zealand (November 2003), Paris, France (February 2004) and Miami, Florida (August 2004), with this report formally presented to the IGOS Partners in November 2004 in Beijing, China.

This effort builds on and complements design and implementation plans of the coastal modules of GOOS and GTOS[2]. Both plans identify phenomena of interest, such as land-use, land-cover, coastal flooding and erosion, habitat loss, water quality, and harmful algal blooms. In so doing, it was recognised that terrestrial and marine phenomena, or changes in them, are often related and that interactions among them must be addressed explicitly. The special interest of coral reefs was also recognised, in part because of their importance to the economies of tropical and subtropical nations and in part because of their significance as sentinel habitats for global and regional environmental change. Thus, the IGOS Sub-Theme on Coral Reefs[3] has been incorporated into the Coastal Theme.

Finally, over thirty nations agreed to a declaration at the first Earth Observation Summit[4] in July 2003 affirming the need to support:

- Improved coordination of strategies and systems for observations of the Earth and identification of measures to minimize data gaps, with a view to moving toward a comprehensive, coordinated, and sustained Earth observation system of systems;
- A coordinated capacity-building effort to involve and assist developing countries in improving and sustaining their contributions to Earth observing systems, including access to and effective utilization of observations, data and products, and related technologies;
- The full and open exchange of observations recorded from *in situ*, aircraft, and satellite networks with minimum time delay and minimum cost, recognising relevant international instruments and national policies and legislation; and
- Preparation of a 10-year Implementation Plan, building on existing systems and initiatives.

The IGOS Coastal Theme is supportive of this effort by addressing coastal observing needs that are responsive to the nine societal benefit areas (disaster, health, energy, climate, water, weather, ecosystem, agriculture, and biodiversity) of the planned Global Earth Observing System of Systems (GEOSS), for which a 10-year implementation plan was adopted at the third Earth Observation Summit in Brussels, in February 2005, where the intergovernmental Group on Earth Observations (GEO) was likewise formally established.

Further information on IGOS can be obtained from: http://www.igospartners.org
The Coastal Theme Report is available at: http://www.igospartners.org/Coastal.htm
Inquiries on the IGOS Coastal Theme can be sent to: Paul.M.DiGiacomo@jpl.nasa.gov

1. http://www.igospartners.org
2. http://ioc.unesco.org/goos/coop.htm; http://www.fao.org/gtos/C-GTOS.html
3. http://www.igospartners.org/Coral-Reef.htm
4. http://www.earthobservationsummit.gov/declaration.html

Global, regional, and local trends in natural processes and human demands on coastal ecosystems jeopardize the ability of these ecosystems to support commerce, living resources, recreation, and habitation. Concerns have led to numerous international agreements that require sustained and routine observations of both coastal terrestrial and marine systems. Meeting the terms and conditions of these conventions and action plans requires a strategy for the establishment of an integrated global system of observations for the atmosphere, oceans, and terrestrial systems under the auspices of the Integrated Global Observing Strategy (IGOS). The IGOS Partnership approved the development of a Coastal Theme in June 2003, and a Coastal Theme Team was established to determine requirements for observations needed to assess interactions among coastal marine and terrestrial systems across the land-sea interface. This effort builds on and complements design and implementation plans of the coastal modules of GOOS and GTOS. In so doing, it was recognised that the occurrence of, or changes in, terrestrial and marine phenomena are often related and that interactions among them must be addressed explicitly. It was also recognised that coral reefs are of special related interest, and thus, the IGOS Coral Reef Sub-Theme has been incorporated into the Coastal Theme.

Building on the coastal modules of GOOS and GTOS, the IGOS Coastal Theme focuses on the observing requirements across the land-sea boundary and the information products that can and should be generated for users. Marine effects on land of particular interest include coastal flooding and erosion, sea level change, and salt intrusions up rivers and into ground water. Similarly, land influences marine ecosystems through surface runoff and attendant loadings of dissolved and particulate matter, pollutants et al., as well as ground water discharge of fresh water, impacting biogeochemical and hydrological cycles, and ecosystem health and productivity. The following priority issues have been identified for the IGOS Coastal Theme:

- **Coastal Populations** at risk, including coastal hazards and coastal development and urbanization;
- **Coastal Ecosystems**, including the hydrological and biogeochemical cycles, and ecosystem health and productivity.

Implementation of the Coastal Theme is critically important to the development of robust and effective policies and management plans to ensure that coastal regions are managed in a sustainable manner with respect to such interfacial phenomena.

Thus, the goal of the Coastal Theme is to develop a strategy for integrated observations across the land-sea interface that will provide data and information needed to make informed decisions on issues related to change and variability as required for use, study, or management of coastal systems or components thereof. The objectives are to:

1. Specify requirements for *in situ* and remote observations (as an integrated package) needed to provide data and information at rates and in forms needed by decision-makers in both private and public sectors (e.g., variables to be measured, appropriate time-space scales of observations, platforms/sensors to be used) (Chapters 2 & 3);
2. Evaluate current and projected observation capabilities in terms of the extent to which they meet these requirements, identifying gaps, redundancies, and activities that need to be strengthened (Chapter 3);
3. Establish a framework to integrate observations (*in situ* and remote), particularly across boundaries, as time-space scales of variability differ significantly between the terrestrial side and the marine side of the coastal zone (Chapters 4 & 5);
4. In the process of addressing 1-3, stimulate coordination and collaboration among institutions/bodies/organizations (including different science disciplines, research and operational groups, scientists and managers, public and private sectors, and political bodies including governments, and agencies/ministries) (Chapter 5).

The user groups are varied but can be summarized as follows:

- **Regional and global environmental assessments, agencies, accords, and conventions**, needing data and information regarding the coastal regions.
- **Advisory and regulatory agencies**, the primary users of data and information for management of the coastal regions throughout the world.
- **National governments** with wide ranging responsibilities for legislation and for implementing international conventions and agreements. Small island States have particular interest in this Coastal Theme, as small islands are entirely coastal in nature and the problems of the coastal zone are particularly important to their vital national interests.
- **Research communities** that both provide derived data and information products for the advisory and regulatory agencies, commercial end users, and the public that use the coastal region, as well as utilize the data to develop a greater scientific understanding.
- **Commercial organizations** that require information for their safe and effective operations and benefit from informed decisions toward sustainability.

There are three critical coastal observing needs: 1) Concurrent long-term time series observations of both terrestrial (including fresh water) and marine (including estuarine) ecosystems; 2) Spatially coordinated, high-resolution observations of both terrestrial and marine environments; and 3) Analyses of the temporal and spatial coherence of changes across the land-sea interface. Through distillation and synthesis of the observation needs, a core group of cross-cutting coastal observing requirements emerges to provide useful products to these users on the priority issues. These observations can be grouped into three basic categories:

- **Geophysical**: e.g., ocean winds, waves, sea surface height, currents, salinity, temperature, discharge, precipitation, ice cover;
- **Biological and Biogeochemical**: e.g., pigments, nutrients, particulate and dissolved matter, aerosols, slicks and spills, optical properties, biomass, and productivity;
- **Mapping (Physical, Ecological, and Socio-Economic)**: e.g., topography, bathymetry, shoreline position & use, high/low tide lines, habitat types and condition, land cover/use, coastal population assessments/demographics.

A combination of remotely sensed (satellite, airborne, and ground-based platforms) and *in situ* observations is required. Satellite observations provide valuable synoptic coverage, but extensive *in situ* measurements are a necessity since some measurements cannot presently be made remotely (e.g., nutrients, pollutants and pathogens, measures at depth). Further, *in situ* assets provide accurate measurements crucial for the calibration and validation of remotely sensed products. However, significant gaps emerge upon comparing the existing and planned capabilities with the Coastal Theme observing requirements; specific challenges related to these are discussed herein. These coastal observing challenges can be organized into three types that are not mutually exclusive. "Knowledge" challenges require research and development (R&D) to address observation and data gaps. "Resolution and Coverage" challenges address the need for improved spatial, temporal, and spectral resolution and/or coverage in existing measurements. "Continuity" challenges focus on maintaining existing observation capabilities, particularly those for which continuation is uncertain. Priority areas for space agencies and other partners to address vis-à-vis these challenges are identified herein.

While data integration remains a major goal of the IGOS Partnership Process, there are significant challenges to meeting this goal in coastal regions. Activities that promote cross-boundary/discipline integration, such as those that merge land and sea data, those that fuse *in situ* and remotely sensed data, and approaches that link socioeconomic with coastal environmental data, are crucial for establishing a coastal global observing strategy which is not only scientifically robust but also policy relevant for stakeholders in the coastal domain. Integration challenges will be addressed through a variety of mechanisms. Models validated by rigorous tests and supported by observations are a valuable tool for synthesizing the spectrum of coastal observations. Data assimilation represents a crucial approach for integrating data from different sources and times with predictions into a common framework; an integrated COastal Data Assimilation System (CODAS) is proposed that would bring together the land and sea domains across the coastal interface.

There is also a compelling need for robust user-driven decision support tools that are web-based and bring together multi-sensor satellite and *in situ* data streams and coupled models across the coastal interface (e.g., CODAS) with easy to manipulate information query and download capabilities and user-defined scenarios. Leveraging existing GIS-based tools, an Integrated Coastal Decision Support System (ICoDSS) would provide coastal users with high resolution, cross-boundary, and easily accessible retrospective and appropriately timed data and information, as well as robust short-term and long-term predictions, to support improved coastal understanding and management.

Focused, coherent funding mechanisms are needed to underpin initiatives, especially as the coastal community seeks to move beyond applied science in the developed countries into global observing to support improved understanding and decision-making in all countries. As such there is a special need to target the coastal issues and problems of developing countries and coastal regions that have not yet benefited from the rapid development of observing technologies, both *in situ* and space-based. This can be addressed through education and training, knowledge and technology transfer and capacity building in appropriate institutions and industries. Coastal freshwater resources management, coastal hazard vulnerability assessments, prediction and mitigation strategies, coral reef management (addressed in the Coral Reef Sub-Theme), and estuarine and delta pollution and management are but a few of the benefits of the Theme of special importance to developing countries. Both the coastal modules of GTOS and GOOS have proposed initial projects to promote capacity building. These efforts provide specific opportunities for the Coastal Theme.

The implementation of the Coastal Theme will be jointly led by GOOS and GTOS, through their respective scientific steering committees. The coastal modules/components of both GOOS and GTOS have identified existing networks and structures among data and service providers as well as among end users from local to global scales that will be leveraged. The GOOS Regional Alliances and GTOS regional programmes are likely implementing bodies on a regional scale. Pilot projects are critical to the implementation of the coastal modules of both GOOS and GTOS, and those that will accelerate implementation of the Coastal Theme have been identified and will be targeted. Contributions from global change research projects including LOICZ and IMBER will also aid in implementation.

There is a recognised need to establish a mechanism for intergovernmental coordination and technical support for integrated coastal observing comparable to the IOC/WMO Joint Commission on Oceanography and Marine Meteorology (JCOMM). Whether this entails creation of a new joint commission for coastal observations or the identification of an existing body for this purpose is presently under consideration. In terms of a potential new body, discussions are underway regarding the potential formulation of a Joint-Panel for Integrated Coastal Observations (J-PICO), with resolution expected in the foreseeable future. In the interim, the Coastal Theme will be implemented with personnel and programmatic leadership and support from its lead IGOS Partners. To ensure a user- and issue-driven participatory process, workshops and developmental efforts will ideally be undertaken under the auspices of a Coastal Theme Community of Practice, which has recently been approved and will be developed as part of the emerging GEO process.

The anticipated benefits of the IGOS Coastal Theme are:

- Identify gaps in observations and reduce unnecessary duplication
- Strengthen the linkage between *in situ* and space-based observations, integrated with watershed-ocean models, for coastal research and management applications
- Stimulate building of long-term, accurate coastal data sets
- Assist in the design and implementation of the coastal components of GOOS and GTOS
- Establish priorities for research & development projects to improve the operational elements of observing systems and other programmes
- Support user needs through improved products and services
- Cross-cutting links with other IGOS Themes and the emerging GEO effort

Chapter 1 examines the land-sea interface, describes ecological challenges to assessing and anticipating changes in the coastal zone, and addresses the detection and prediction of change across the land-sea interface. It identifies social and economic factors that require consideration, details the overall goals and objectives of the Coastal Theme, and identifies the linkage with research programmes that will support its implementation.

Chapter 2 provides an overview of key coastal issues, focusing on coastal populations at risk and coastal ecosystems at risk, as well as specific users and products in this context. It also addresses existing coastal observing system elements, including the coastal modules of the Global Ocean Observing System (GOOS) and Global Terrestrial Observing System (GTOS), as well as the IGOS Coral Reef Sub-Theme.

Chapter 3 provides an overview of the primary observation needs for coastal interface issues, a summary of the cross-cutting observing requirements, an assessment of existing and planned observing capabilities and attendant gaps, and finally current challenges in making coastal observations.

Chapter 4 discusses systemic challenges to data integration, including communication issues, data access and management issues, and unique challenges of coastal regions. It describes some of the general strategies necessary to overcome these challenges, and also provides specific approaches for integrating observations in the coastal domain.

Chapter 5 describes the institutional arrangements for implementation of the Coastal Theme as well as initial prototype efforts and pilot projects. It addresses linkages with other IGOS Themes as well as the emerging GEO process, articulates the need for capacity building, presents an action plan and schedule, and finally proposes a plan for leadership, assessment and feedback.

The coastal zone (Figure 1.1) encompasses a broad diversity of terrestrial and marine habitats from rivers, coastal forests, wetlands, cities, and farms to coral reefs, sea grass beds, soft bottom or rocky benthic substrates, and the open waters of estuaries and coastal marine environments. It is an area where inputs from land, sea, air, and people converge, an area of remarkably high productivity, an area where ecosystem goods and services are concentrated, and an area that has been a center of human activity for millennia (Costanza et al., 1997; Cohen and Small, 1998; IOC 2003). Thus, changes in the physical and ecological states of coastal terrestrial and marine systems have disproportional effects on the safety and well being of human populations (IWCO, 1998; Watson et al., 1998; GESAMP, 2001; Field et al., 2002). Coastal ecosystems and human populations are especially vulnerable to the negative impacts of these changes (Jackson et al., 2001; Nicholls and Small, 2002).

As evidenced by troubling trends in the occurrence (magnitude or frequency) of a broad spectrum of phenomena from climate change and sea level change to habitat loss and declines in living resources, coastal systems are experiencing unprecedented alteration. They are becoming more susceptible to natural hazards, more costly to live in, and less able to support living resources. The social and economic costs of uninformed decisions are increasing accordingly.

Figure 1.1. The Coastal Zone: Where inputs from land, sea, air and people converge

Heavily developed coast of Cancun, Mexico mostly for international tourism. Image credit: © Wolcott Henry 2001.
Image source: www.marinephotobank.org.

Trends such as these are related to both natural processes and increasing human demands on coastal ecosystems to support commerce, living resources, recreation, and living space and to receive, process, and dilute the effluents of human society. These realities have led to numerous international agreements that require sustained and routine observations of coastal terrestrial and marine systems (Table 1.1).

Meeting the terms and conditions of these conventions and action plans requires the establishment of an integrated global system of systems for the atmosphere, oceans, and terrestrial systems, e.g., GEOSS, as well as a strategy for acquiring and coordinating the necessary observations, e.g., IGOS.

Populations at Risk: Coastal populations are impacted by a variety of natural hazards including erosion, saltwater intrusions, subsidence, tsunamis and floods due to both storm surges and swollen rivers. Exposure to such natural hazards is expected to increase due both to increases in population density in low lying coastal areas and the effects of global climate change (e.g., sea level change and possible increases in the frequency of extreme weather such as tropical cyclones). Recent estimates of the global distribution of people show the following (Nicholls and Small, 2002):

- Based on a recent census (1990), the number of people inhabiting the near-coastal zone (defined here as the land area within 100 km of the shoreline or 100 m above mean sea level, which ever come first) is about $1.2x10^9$ or about 23% of the 1990 global population.
- The average population density of the near-coastal zone is about 112 people km^2, or about 2.5 times higher than the global average (44 people km^2).
- About 40% of the near-coastal population inhabits 4% of the near-coastal land area at local population densities of about 1000 people km^2. The most densely populated near-coastal areas are in Europe and south, southeast, and east Asia. Thus, despite the concentration of people near coasts, the majority of land area within the near-coastal zone is relatively sparsely populated.
- While eleven of the world's fifteen largest cities (> 10,000 people km^2) are located in the near-coastal zone, only about 10% of the near-coastal populations live in these cities. Most of the exposed population is in small cities and in rural settings such as densely populated deltaic areas (1000 people km^2). However, urbanization is expected to continue at rapid rates, and these patterns are likely to change.

Coastal populations are growing and urbanizing, trends that serve to increase the economic and social impacts of natural hazards. It must also be emphasized that while it is conceptually straightforward to quantify populations exposed directly to natural hazards, it is more complex to evaluate indirect exposure, including wider socio-economic impacts. For example, storm surges directly affect life and livelihoods within a short distance of the shoreline while indirect impacts may be much broader if infrastructure and services such as waste-water treatment facilities, ports, agriculture, and power plants are incapacitated.

Informed management for sustained use of these goods and services requires the capacity to assess routinely and

Table 1.1. Conventions Requiring Data and Information on Coastal Marine and Terrestrial Systems: Requires the establishment of an integrated global system of observations.

CONVENTIONS AND ACTION PLANS
Ramsar Convention on Wetlands
UN Conference on the Human Environment
The UN Convention on the Law of the Sea
The International Convention for the Safety of Life at Sea (SOLAS)
The UN Framework Convention on Climate Change (UNFCCC)
The UN Convention on Biological Diversity
Agenda 21, the Programme of Action for Sustainable Development
The Implementation Plan of the World Summit on Sustainable Development
The Convention on the Prevention of Marine Pollution by Dumping of Wastes & Other Matter
Barbados Action Plan
Global Programme of Action for the Protection of the Marine Environment from Land Based Activities
FAO Code of Conduct for Responsible Fisheries
Agreement for the implementation of the provision of the UNCLOS relating to the conservation of straddling fish stocks and highly migratory fish stocks
Regional conventions like Oslo and Paris Conventions (OSPAR) and the Convention on the protection of the marine Environment of the Baltic Sea area (HELCOM)
UNEP agreements like the Convention on International Trade in Endangered Species of wild flora and fauna (CITES), Convention for the Conservation of Migratory Species

rapidly the state of coastal marine and terrestrial systems and provide timely predictions of likely future conditions. Both depend on coordinated, sustained, repeated, routine and high quality observations of coastal marine and terrestrial systems across the land-sea interface. To this end, the IGOS Coastal Theme focuses on land-sea interactions as they influence dominant trajectories of change in the coastal marine and terrestrial systems (Table 1.2).

Implementation of the Coastal Theme is critically important to the development of robust and effective policies and management plans to ensure that coastal regions are managed in a sustainable manner.

A single definition of "coastal zone" or "coastal region" that provides meaningful landward and seaward boundary conditions is not possible. For example, if the phenomenon of interest is the direct risk of coastal storm surge flooding, a reasonable definition of the landward boundary might be a few km inland from the coastline. For many human impacts associated with habitat alteration, a better definition may be 100 km inland from the coastline or 100 m above mean sea level, whichever comes first (Nicholls and Small, 2002). Alternatively, if the phenomenon of interest is coastal eutrophication from land-based sources of nitrogen and phosphorus, the landward boundary might be defined in terms of coastal drainage basins. The Land-Ocean Interactions in the Coastal Zone (LOICZ) coastal typology uses 200 m above and 200 m below mean sea level for landward and seaward boundaries, respectively (Pernetta & Milliman 1995). A recent analysis of "Human Links to Coastal Disasters" (http://www.heinzctr.org/NEW_WEB/PDF/Full_report_human_links.pdf) defines the "coast" as a "strip of land of indefinite width that extends from the shoreline inland to the first major change in terrain features". Likewise, the seaward boundary could be defined by the depth limit of seagrasses for the purposes of habitat management, the EEZ (Exclusive Economic Zone) for legal purposes, the migratory ranges of tuna or salmon for fisheries management, the seaward extent of detectable concentrations of land-based sources of contaminants for environmental protection, etc. The one constant in all definitions is that the coastal zone always includes the shoreline, the interface between land and sea.

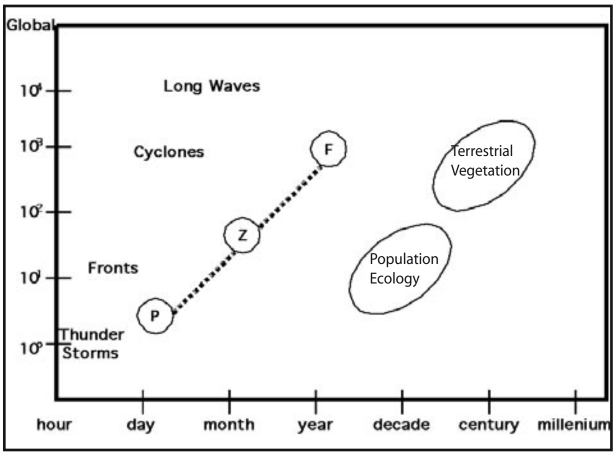
1.1 ECOLOGICAL CHALLENGES TO ASSESSING AND ANTICIPATING CHANGES IN THE COASTAL ZONE

The coastal zone from drainage basin to coastal ocean is a mosaic of complex, interacting ecosystems from forests, lakes, farmlands, and cities to rivers, estuaries, and the open waters of the coastal ocean. Furthermore, the scales of variability that characterize terrestrial ecosystems are quite different from those that characterize coastal marine and estuarine ecosystems. Clearly, these differences must be considered in the design of observing systems intended to detect and pre-

Table 1.2. Cross-boundary Issues of major Interest to IGOS Coastal Theme: Informed management requires the capacity to assess and predict.

DIRECTION OF PROPAGATION	CROSS-BOUNDARY ISSUES
OCEAN-TO-LAND	Coastal flooding & erosion
	Sea level change
	Salt intrusions up rivers and into ground water
LAND-TO-OCEAN	Surface runoff and material loadings; Ground water discharge of fresh water
	Biogeochemical cycles
	Ecosystem health & productivity

Figure 1.2. Comparison of time-space scales: Physical atmospheric processes (thunderstorms to long waves), physical mixing processes in the oceans (dashed line), and marine and terrestrial ecosystems.



Marine ecosystems are represented by population dynamics of phytoplankton (P), zooplankton (Z), and fish (F). Terrestrial ecosystems are represented by population ecology and biologically structured habitats (e.g. forests and grasslands).

dict the effects of interactions across the land-sea interface on coastal marine and terrestrial systems.

Characterizing Scales of Variability and Mechanisms of Change in Terrestrial and Marine Environments: On ecological time scales (< 100 years), there is a strong dichotomy between the time-space scales of physical atmospheric and terrestrial ecological processes (expressed in terms of population dynamics and changes in plant distributions), with the former being much shorter than the latter (Figure 1.2). In contrast, the time-space scales of physical and ecological processes in the marine environment (expressed in terms of pelagic trophic dynamics) are virtually identical (Figure 1.2; Steele, 1985; Steele, 1991; Levin, 1992). These relationships suggest that there are very different time scales for processes governing the rates of change in the physical environments of marine and terrestrial systems. Physical and ecological processes are closely coupled in the pelagic environment of marine and estuarine ecosystems relative to terrestrial environments where biological processes play a much greater role in structuring ecosystems (forests, grasslands, marshes, etc.). In terms of time-space scales of variability, biologically structured habitats in the marine environment (e.g., coral and oyster reefs, sea grass and kelp beds) resemble biologically structured habitats on land.

Improving the capacity to detect changes on local to global scales and to predict how larger scale changes are expressed within and propagated among coastal ecosystems are major goals of this strategy. Typically, the mechanisms or causes of change operate at different scales than those of the observed pattern (Steele, 1985; Steele, 1991; Levin, 1992). The Coastal Theme is primarily concerned with mechanisms of change that propagate across the land-sea interface. Therefore, detecting and predicting the effects of these requires the consideration of cross-boundary issues (Table 1.2) in the broader context of external forcings in general. Large scale forcings that impact socio-economic systems, coastal ecosystems, and natural resources include the following:

- Marine basin scale oscillations such as the El Niño-Southern Oscillation, the North Pacific Decadal Oscillation, and the North Atlantic Oscillation (e.g., Barber and Chavez, 1986; Dayton and Tegner, 1984; Francis and Hare, 1998; Pearce and Frid, 1999; Wilkinson et al., 1999; Kudela and Chavez, 2000; Arcos et al., 2001; Beaugrand et al., 2002);
- Global climate change including sea level change and changes in the hydrological cycle (e.g., Barry et al., 1995; Najjar et al., 1999);
- Changes in inputs of water, sediments, nutrients and contaminants (pollutants and pathogens) from coastal drainage basins due to human activities (e.g., Limburg and Schmidt, 1990; Smith et al., 2003; Vitousek et al., 1997; Jickells, 1998; Howarth et al., 1991; Howarth et al., 2000);
- Extraction of living marine resources (e.g., Pauly et al., 1998; Jackson et al., 2001); and,
- Introductions of human pathogens and non-native species related to the globalization of commerce (e.g., shipping ballast water discharge, seafood shipments) and the translocation of species from one region to another (e.g., Carlton, 1996 and references therein).

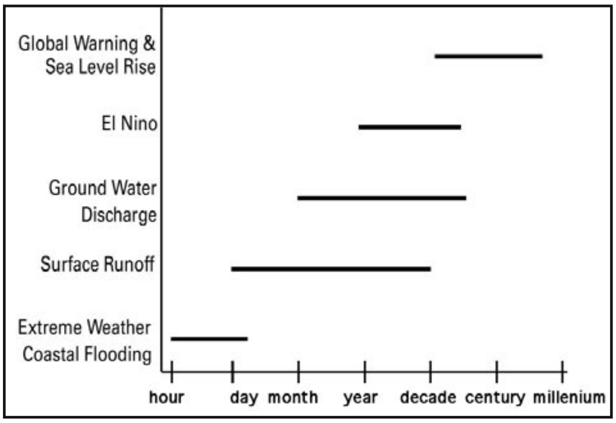
The importance of quantifying these forcings through the design of the coastal modules of GOOS and GTOS underscores the need for an integrated approach on their part that also coordinates their development in conjunction with the Global Climate Observing System (GCOS) and other relevant efforts.

1.2 DETECTING AND PREDICTING CHANGE ACROSS THE LAND-SEA INTERFACE

Current efforts to manage human uses and mitigate both anthropogenic and natural impacts typically focus on specific human activities (urbanization, agriculture practices, sewage discharge, fishing mortality, physical alteration of habitats), specific habitats and places (coastal forests, grasslands, lakes, mangroves, marshes, coral reefs, sea grass beds, estuaries, flood plains, etc.), or individual species (management of natural resources, identification of endangered species). In most circumstances, due consideration is not given to the propagation of variability and change across multiple scales or boundaries between terrestrial and marine ecosystems (Gardner et al., 2001).

Although the time-space scales of ecosystem dynamics are much shorter for pelagic marine than for terrestrial ecosystems, the time scales that characterize cross-boundary forcings encompass both terrestrial and marine ecosystem dynamics (Figure 1.3). This has important implications for the design of an observing system to provide the data needed to link changes in coastal terrestrial ecosystems to changes in coastal marine ecosystems. Given the range of time-space scales that must be captured, both remote (satellite, aircraft, land-based) and *in situ* sensing will be needed. Spatial dimensions of pattern are best captured using remote sensing, especially in those environments that exhibit high frequency temporal variability (atmosphere and ocean). Remote sensing is also useful for capturing temporal changes in systems and processes characterized by relatively low frequency variability (climate change, sea level change, patterns of land-cover and land-use practices, etc.). With a few important exceptions, temporal variations in surface runoff, groundwater discharge, tides, and subsurface pelagic and benthic habitats are currently best captured through *in situ* observations. Important exceptions include coral reefs and sea grass beds in clear, shallow waters.

Figure 1.3. Time Scales of Major, Cross-boundary External Forcings in the Coastal Zone: Given the range of time-space scales that must be captured, both remote (satellite, aircraft, ground-based) and *in situ* sensing will be needed.



1.3 SOCIAL AND ECONOMIC FACTORS

There is a clear need for a more holistic view of system dynamics that links ecological and socio-economic systems across the land-sea interface. The Driver-Pressure-State-Impact-Response (DPSIR) model (e.g., Bowen and Riley, 2003) provides a framework for achieving this by relating large-scale human drivers of change (e.g., increases in population density and land use patterns in coastal drainage basins) to pressures (e.g., extraction of living resources, nutrient loading and contaminant loading of coastal marine ecosystems), changes in state (mass mortalities, harmful algal blooms, eutrophication) of coastal ecosystems, their consequences or impacts (loss of commercial fishing value, public health costs), and management responses to them (e.g., fishery management, management of land-use activities, sewage treatment). Simultaneous, integrated and sustained observations of both socio-economic and environmental variables are needed to effectively link each of these phases.

The DPSIR approach provides a useful framework to guide the coordinated development of the coastal modules of GOOS and GTOS (e.g., Bowen and Riley, 2003). Both systems clearly have common needs for socio-economic and environmental information and the development of the DPSIR approach provides a means to establish priorities to implement observing systems that transcend the land-sea interface.

As summarized above, issues that must be addressed in the coastal zone transcend national borders, ministries, and scientific disciplines. However, new scientific understanding in itself rarely initiates government actions, in part because of the boundaries that isolate these communities (Malone et al., 1993). Scientists and government officials speak different languages, function in response to different reward systems, and work on different time scales.

The DPSIR framework helps to allow sustained and routine provision of quality environmental data and information and the availability of sound scientific advice to enable responsive government decisions and to enhance the effectiveness of management actions. The Coastal Theme in turn will help bridge cultural gaps (between nations, ministries and scientific disciplines), reinforce management actions to control or mitigate the effects of human activities, and build public and political support for sustained and integrated observations across the land-sea interface (e.g, National Research Council, 2000). Breaking the "ice" of cultural inertia to begin developing the IGOS vision will be especially challenging in the coastal zone.

1.4 GOALS AND OBJECTIVES

The goal is to develop a strategy for integrated observations across the land-sea interface that will provide data and information needed to make informed decisions on issues related to the propagation of change and variability across the land-sea interface as they involve the use, management, or study of coastal systems or components thereof.

Objectives are as follows:

1. Specify requirements for *in situ* and remote observations (as an integrated package) needed to provide data and information at rates and in forms needed by decision-makers in both private and public sectors (e.g., variables to be measured, appropriate time-space scales of observations, platforms/sensors to be used); (Chapters 2 & 3)
2. Evaluate current and projected observation capabilities in terms of the extent to which they meet these require-

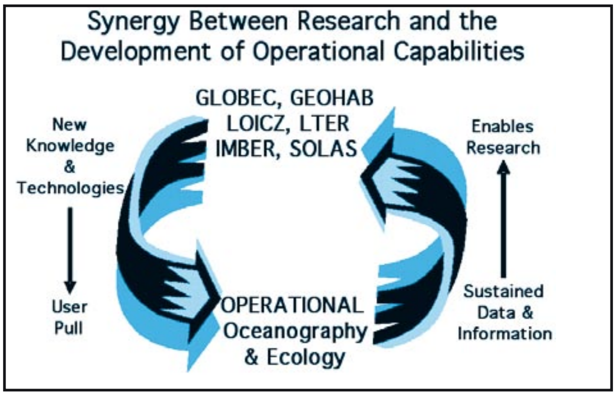
ments, identifying gaps, redundancies, and activities that need to be strengthened; (Chapters 3)
3. Establish a framework to integrate observations (*in situ* and remote), particularly across boundaries, as time-space scales of variability differ significantly between the terrestrial side and the marine side of the coastal zone; (Chapters 4 & 5)
4. In the process of addressing 1-3, stimulate coordination and collaboration among institutions/bodies/organizations (including different science disciplines, research and operational groups, scientists and managers, public and private sectors, and political bodies including governments, and agencies/ministries) (Chapter 5).

1.5 RESEARCH AND IMPLEMENTATION OF THE COASTAL THEME

There is a key interrelationship between the Coastal Theme and several international research programmes as the latter will help to develop this theme and the necessary observing capabilities (Figure 1.4). Research programmes important to developing the Coastal Theme include the following:

- **International Long-Term Ecological Research (I-LTER)** – advance our understanding of long-term ecological variability and change, contribute to the scientific foundations for ecosystem management, and promote international collaborations;
- **Land-Ocean Interactions in the Coastal Zone (LOICZ)** – effects of anthropogenic forcings and natural variability on life-sustaining functions and structure of the global coast;
- **Global Ocean Ecosystem Dynamics (GLOBEC)** – advance our understanding of the structure and functioning of the global ocean ecosystem, its major subsystems, and its response to physical forcing to forecast responses of marine ecosystems to global change;
- **Global Ecology of Harmful Algal Blooms (GEOHAB)** – foster international research collaborations on HABs to determine the oceanographic processes that influence their population dynamics and thereby develop the capability to predict when and where blooms are likely to occur;
- **Surface Ocean, Lower Atmosphere Study (SOLAS)** – to achieve quantitative understanding of the key biogeochemical-physical interactions and feedbacks between the ocean and atmosphere, and how this coupled system affects and is affected by climate and environmental change;
- **Integrated Marine Biogeochemistry and Ecosystem Research (IMBER)** – advance our understanding of the effects of global change on the biogeochemistry and ecosystems of the marine environment with an emphasis on the coastal ocean; and
- **Man and the Biosphere (MAB)** – foster interdisciplinary research involving natural and social sciences and its applications to sustainable resource management

Figure 1.4. Research Programme Synergies: The development of operational capabilities for rapid detection and timely predictions of environmental state changes across the land-sea interface critically depends on environmental research programmes such as LOICZ, GLOBEC and IMBER.



An overview of the information needs of the range of coastal users who fall within the scope and goals of the framework outlined in Chapter 1 is provided below. The key issues identified by the coastal modules of GOOS and GTOS are presented in terms of coastal populations and ecosystems at risk (Section 2.1). The primary users and products are discussed (Section 2.2). Finally, intersections of the Coastal Theme with these and other existing programmes are outlined (Section 2.3).

2.1 KEY ISSUES

In the development of the coastal modules of GOOS and GTOS, the programmes identified phenomena of interest that are key to end-users and hence to the development of the respective observation systems. For the coastal module of GOOS these phenomena include (among others):

- Fluctuations in sea level and coastal flooding events,
- Changes in sea state; surface and sub-surface currents; shoreline and shallow water bathymetry,
- Seafood contamination and increasing abundance of pathogens,
- Habitat modification and loss and changes in biodiversity,
- Eutrophication and harmful algal events,
- Changes in water clarity, and quality, and
- Chemical contamination of the environment and its biological effects.

For Coastal GTOS they are:

- Human dimensions, land use, land cover, and critical habitat alterations,
- Sediment loss and delivery,
- Water cycle/water quality, and
- Effects of sea level change, storms, and flooding.

The IGOS Coastal Theme builds on the coastal modules of GOOS and GTOS and focuses on the observing requirements across the land-sea boundary and the information products that can be generated for users. The following priority issues have been identified for the IGOS Coastal Theme and are described below:

- **Coastal Populations at risk**, including coastal hazards and coastal development and urbanization
- **Coastal Ecosystems at risk**, including the hydrological and biogeochemical cycles, and ecosystem health and productivity

Coastal Populations at Risk

The people concentrated in coastal areas are subject to the combined impacts of climate variability and human mismanagement. High population densities place humans and their property at considerable risk from direct or indirect ocean impacts. Coastal planners and developers, engineers, disaster managers, local governments, public health officials, managers of protected areas, and fisheries and tourism operators need products such as risk maps, forecasts of extreme conditions, planning guidelines, health alerts, and other practical information products to mitigate these risks such as those below.

Figure 2.1. Coastal Hazards: High population densities place humans and their property at considerable risk from direct or indirect ocean impacts, including hurricanes and tsunami.

ASTER satellite images of New Orleans, LA, U.S.A., before (top) and after (bottom) Hurricane Katrina. *Image credit: NASA/JPL. Image source: http://www.nasa.gov/vision/earth/lookingatearth/h2005_katrina-aster-091405.html*

Coastal Hazards: The dynamic land-sea interface in the coastal zone subjects human beings to a number of coastal hazards, the likelihood and frequency/intensity of which are expected to increase due to climate change coupled with global, regional and local scale human perturbations to the environment. In particular, coastal flooding is a common short-term concern for coastal inhabitants globally (Figure 2.1). Storms, earthquakes, and other episodic events often lead to extreme wind, wave, and tidal conditions that can result in flood tides and high waves at the coast. These conditions often combine with heavy rain and increased runoff to endanger people and their property. At longer time scales, the potential for sea level rise associated with subsidence and/or climate change is likewise a significant concern for the millions who reside at low elevations near the coast and in small island States. Coastal erosion and deposition processes that affect shoreline morphology and sediment distribution interact with these phenomena to accelerate or reduce their effects.

Coastal Development and Urbanization: The activities of coastal populations represent the greatest immediate pressures on coastal ecosystems. Urbanization (Figure 2.2), with its concentrated population density, intense economic activity, and high consumption of goods and services, inevitably alters the coastal environment. The degradation of coastal ecosystems also feeds back to impact the resident human population, with severity increasing with population density. The mechanisms for these alterations are numerous, but degradation of coastal water quality through terrestrial, atmospheric or oceanic loadings is a major concern. The coast is also the focus of many kinds of development. Identifying the development potential of coastal areas as well as the proper siting and design of such developments, also require a good knowledge of the resources, dynamics, and limits of the coastal zone.

The impacts of human populations in coastal regions place coastal ecosystems at considerable risk. Managing and reducing impacts, and maintaining or restoring natural systems, requires information products like habitat maps, long-term records of population dynamics and sustainable yield, water quality reports, and early warning systems for fisheries, protected area managers, tourism operators and health officials. The following two dimensions of this problem, as outlined in the next section, are a particular priority.

Figure 2.2. Coastal Development and Urbanization: Cities grow along coastlines and transportation networks.

Image of Earth's city lights
Image credit: DMSP-OLS data courtesy Marc Imhoff, NASA GSFC and Christopher Elvidge, NOAA-NGDC. Image by Craig Mayhew and Robert Simmon, NASA GSFC. Image source: http://visibleearth.nasa.gov

Coastal Ecosystems at Risk

Hydrological and Biogeochemical Cycles: Many coastal zone impacts result from changes in land use and land cover in and beyond coastal watersheds. The coastal zone is downstream of significant material deliveries from land, including the major nutrients (nitrogen and phosphorus), carbon, sediments, and waste resulting from human activity. Because water dissolves and transports these materials, the hydrological cycle (Figure 2.3) that determines the flow of surface runoff and seepage of groundwater is tightly coupled with their cycling and biogeochemical transformation in freshwater, estuarine, and near-shore ecosystems. In terms of representative impacts of loadings, excess nutrients lead to eutrophication, where plants grow faster than herbivores can eat them and consume dissolved oxygen when they decay, to the detriment of many coastal organisms. Wetlands trap sediments in the root systems of aquatic plants, including tropical mangroves and seagrasses or temperate salt marsh macrophytes. When the sediment load exceeds their binding capacity, or wetland areas have been reduced for agriculture, aquaculture, tourism or residential development, the excess sediment buries important marine macrophytes, including seaweeds, and likewise negatively impacts sessile organisms like corals and shellfish.

Figure 2.3. Hydrologic Cycle: Many impacts result from changes in land use and land cover in and beyond coastal watersheds.

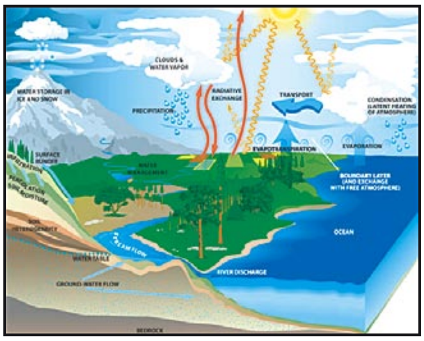


Image credit: NASA/GSFC. Image source: http://gwec.gsfc.nasa.gov/

Ecosystem Health and Productivity: Assessing and understanding ecosystem health and productivity and variability associated with both natural forcing and anthropogenic impacts is a primary need and concern (Figure 2.4). On a global scale some of the most serious coastal zone problems include habitat alteration and biodiversity loss, especially in the tropics/subtropics, coastal eutrophication in subtropical/temperate latitudes producing both hypoxia/anoxia and increases in harmful algal blooms (HABs), and melting sea ice, glaciers, and permafrost in polar regions. All of these reflect and induce deficiencies in ecosystem health.

Contaminants also impact coastal ecosystems and organisms. With excessive loadings, organisms ingest and accumulate these materials, often with negative impacts. Chronic pollutants accumulate in organisms, especially top predators, reaching levels that can be detrimental to the health of the ultimate predator, humans.

2.2 USERS AND PRODUCTS

Two specific goals of the Coastal Theme are to ensure the availability of data and information required to detect rapidly any changes in the status or health of coastal zone ecosystems, and to predict the interacting effects of human activities, climate change, and natural variability, with a focus on land-based sources of change. Toward these goals there are three critical coastal observing needs:

1. Concurrent long-term time series observations of both terrestrial (including fresh water) and marine (including estuarine) ecosystems;
2. Spatially coordinated high-resolution observations of both terrestrial and marine environments; and
3. Analyses of the temporal and spatial coherence of changes across the land-sea interface.

The coastal observing needs identified above make it possible to identify some of the representative information products that can be generated from observational data, and many of the specific national and local user groups that will benefit from this information, as summarized in Table 2.1. International agencies, accords and conventions would in general be users of information associated with all issues.

Figure 2.4. Ecosystem Health & Productivity: Phytoplankton bloom off West Africa coast.

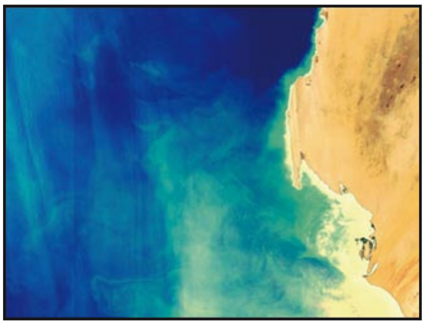


Image credit: © European Space Agency. Image source: http://visibleearth.nasa.gov

The users described below will have the leading role in converting observational data into final information products.

The user groups can be summarized as follows:

- **Regional and global environmental assessments** needing data and information regarding the coastal regions.
- **Advisory and regulatory agencies**, the primary users of data and information for management of the coastal regions throughout the world.
- **National governments** with wide ranging responsibilities for legislation and for implementing international conventions and agreements. Small island States have a particular interest in this Coastal Theme, as small islands are entirely coastal in nature and the problems of the coastal zone are particularly important to their vital national interests.
- **Research community** that both provide derived data and information products for the advisory and regulatory agencies, commercial end users and the public that use the coastal region as well as utilize these data to develop a greater scientific understanding.
- **Commercial organizations** that require information for their safe and effective operations and benefit from informed decisions toward sustainability.

2.3 EXISTING COMPONENTS

As indicated, considerable work has already been done to define elements of a coastal observing system within the coastal modules/components of GOOS and GTOS and the Coral Reef Sub-Theme already approved by the IGOS Partnership. Avoiding duplications and focusing on synergies, this work has been extended and integrated as part of the Coastal Theme activity. The corresponding reports and plans from these respective efforts should be examined in their own right and viewed as complementing, supporting, and benefiting from the recommendations made here.

The IGOS Coral Reef Sub-Theme report (http://www.igospartners.org/Coral-Reef.htm) made specific recommendations for the observations required for coral reef mapping and monitoring, given the urgent need to improve understanding of these threatened ecosystems. It also emphasized some challenges common to all coastal observations: increased resolution of observations; better integration of remote sensing with *in situ* observations across multiple scales; improved observations in deeper coastal waters; more instrumented monitoring stations for better time series and real-time reporting of data; and correlation of ecosystem changes with oceanographic, terrestrial, atmospheric, and climatic parameters integrated across the land-sea interface.

Both the coastal modules/components of GOOS and GTOS (http://ioc.unesco.org/goos/coop.htm; http://www.fao.org/gtos/C-GTOS.html) will use the observational data and tools/capabilities identified by the IGOS Coastal Theme to develop information-based products and services for a wide range of end users in coastal regions. Further, the Coastal Theme will help support the implementation of the coastal components of both GOOS and GTOS .

Given these existing plans and processes, the IGOS Coastal Theme has emphasized their integration across the land-sea boundary, and has recommended observing requirements for the coastal area that encompass all these programmes.

Table 2.1. Coastal Theme Issues, Representative Products and Potential Users: An integrated coastal observing strategy is required

CROSS-BOUNDARY ISSUES	REPRESENTATIVE PRODUCTS	USER GROUPS
COASTAL HAZARDS **Flooding** **Erosion** **Sea level change**	· Assessments & Risk maps: Episodic events Long term trends · Early warnings of where & extent (temporal and spatial) · Risk-based planning: Building codes Transportation	· Coastal Zone Management · Coastal Engineering · Emergency Response Teams · Disaster Planning & Mitigation · Land-Use Planners · Insurance/Re-insurance industries · Non-governmental organizations · Weather forecasters
COASTAL DEVELOPMENT AND URBANIZATION	· Public health risks and hazards forecasts: Sewage contamination maps Beach closures Harmful algal bloom alert · Water quality classification maps · Air quality classification maps · Siting of energy production facilities · Port development & shipping · Spill contingency plans · Urban planning & zoning · Risk maps of shoreline contamination	· Air-Water Quality Regulators · Sewage Authorities & Sanitary Engineers · Dischargers and Emitters · Port Authorities · Recreational users · Tourist Industries · Public health officials · Energy Industries · NGOs · Coastal Zone Management · Coastal Engineering · Emergency Response Teams · Disaster Planning & Mitigation · Land-Use Planners & Regulators · Insurance/Re-insurance industries · Resource managers
HYDROLOGICAL & BIOGEOCHEMICAL CYCLES	· Land-Sea fresh water flux · Maps of ice volume · Sediment budgets · Nutrient budgets · Eutrophication index · Carbon inventory and flux maps	· Coastal Zone Management · Commerce · Agro-Industries · Living Resource Managers · Sewage Authorities & Sanitary Engineers · Land-Use planners · Water Resource Managers · Energy Industries · Coastal Engineers · Climate forecasters
ECOSYSTEM HEALTH & PRODUCTIVITY	· Habitat maps: Terrestrial, marine, polar · Biomass and productivity assessments · Maps of biodiversity across the land- sea interface · Aquaculture siting and permitting · Harmful algal bloom risk maps · Coral reef bleaching hot spots · Land-sea maps of coastal protected areas · Maps of bottom water hypoxia	· Fisheries managers · Fishers · Forest managers · Protected area managers · Coastal Zone Management · Aquaculture industry · Tourist industry · Recreational users · Recreational vendors

An overview of the broad suite of observations needed to address the priority needs of the coastal users outlined in the previous chapter is provided below (Section 3.1). A prioritized list of cross-cutting observing requirements (Section 3.2) has been distilled from these and assessed relative to existing and planned observing capabilities (Section 3.3). These are used to identify gaps and their associated observing challenges discussed in detail (Section 3.4). The highest priorities are summarized in Table 3.1

3.1 PRIMARY OBSERVATION NEEDS FOR COASTAL INTERFACE ISSUES

The four cross-boundary issues (Table 3.2) and representative products that have been identified as observation priorities for the Coastal Theme are linked in Table 3.3 to key fields necessary to generate them, as well as with some of the *in situ* and remote assets from which these fields can be acquired. The context and scope of the required observations for these four issues is discussed below.

Coastal Hazards: The potential for coastal flooding and sea-level rise and related issues such as coastal erosion and deposition needs to be continually monitored and assessed to identify, and if possible reduce, the potential risk from these coastal hazards to humans and their property. Toward this goal a broad suite of trans-boundary observations are required to provide accurate vulnerability assessments. These include oceanographic (e.g., sea level, tides, currents, waves/swell, sediment flux, sea-surface temperature) and atmospheric (e.g., atmospheric pressure, wind speed/direction) parameters, as well as mapping of bathymetry, topography, coastline morphology, and land use/land cover.

Table 3.1. Recommended Space Agency Observing Priorities for Coastal Areas: Satisfying the needs of coastal users

PROVIDE	Geostationary, hyperspectral visible spectral radiance (i.e., ocean colour) data for coastal waters
	Higher resolution/improved coverage for ocean vector winds & sea surface height
	High spatial and spectral resolution capacity to assess changes in coral reef & other terrestrial and aquatic habitats (e.g., estuaries)
	Ocean surface current observations and river discharge in coastal regions
	InSAR measurements for coastal subsidence and erosion
IMPROVE	Calibration/validation of measurements in coastal regions
	Data management infrastructure (near-real-time delivery; climate data records)
SUPPORT	Development of an integrated COastal Data Assimilation System
	Adaptive, coordinated remote and *in situ* sampling

Table 3.2. Cross-boundary Issues: The observation priorities for the Coastal Theme

USER PRIORITY ISSUES
Coastal Populations
1. Coastal Hazards
2. Coastal Development & Urbanization
Coastal Ecosystems
3. Hydrological & Biogeochemical Cycles
4. Ecosystem Health & Productivity (includes coral reefs)

Coastal Development and Urbanization: To address the potential for human health risks associated with increasing coastal urbanization, a broad suite of observations are required, falling within three principal categories: (1) Socio-economic and ecological human population assessments derived from census data as well as satellite sources (e.g., night-time lights); (2) Watershed land use and cover change (e.g., impervious surfaces, deforestation) and shoreline/ocean use and cover; and (3) Contaminant sources and loadings and their transport via wind or currents throughout the air-sea-land domains. Linking observations from these three categories allows for assessments of contamination across boundaries and enables risk predictions for local human populations as well as marine life. On a constructive note, these linked observations will also support well-planned and executed coastal development.

Hydrological and Biogeochemical Cycles: Cross-boundary coastal observing systems are needed to provide timely delivery of data to help assess and monitor fundamental hydrological processes and material deliveries from the watershed to the coast. Critical data include river runoff, suspended sediment load, and salinity in estuaries and in adjacent coastal seas, dissolved inorganic and organic nutrient concentrations in estuarine and coastal waters, and particulate and dissolved organic and inorganic carbon, among others. Climatic (e.g., ENSO) and physical factors (e.g., eddies) that directly influence freshwater flow or mixing processes in (to) the sea have to be observed with sufficient temporal and spatial resolutions to account for changes in material loads and the attendant biological responses.

Ecosystem Health and Productivity: Synoptic and high spatial resolution maps, on seasonal and interannual time scales, of the distribution, spatial extent and condition of key habitat types such as coral reefs (discussed in further detail in the IGOS Coral Reef Sub-Theme), sea grass and kelp beds, and mangrove forests and tidal marshes are required in support of improved decision-making. Estima-

Table 3.3. Coastal Theme Issues, Products, Fields and Sources: Addressing user needs

CROSS-BOUNDARY ISSUES	REPRESENTATIVE PRODUCTS (NOT COMPREHENSIVE)	IMPORTANT FIELDS[1] (PARTIAL LISTING)	EXISTING SOURCES[1] (PARTIAL LISTING)
COASTAL HAZARDS	· Assessments & Risk maps: Episodic events Long term trends · Early warnings of where & extent (temporal and spatial) · Risk-based planning: Building codes Transportation	· Sea level/SSH · Surface waves · Currents · Wind · Bathymetry · Shoreline · Topography · Land use/cover	· Tide gauges, altimeters · Buoys, SAR, altimeters · ADCP, HF radar, drifters · Field sensors, SCAT, SAR · Lidar, VIS imagery, Sonar · Lidar, VIS imagery, surveys · Radar, Lidar, VIS imagery · VIS/IR sat imagery, radar, lidar
COASTAL DEVELOPMENT & URBANIZATION	· Public health risks and hazards forecasts: Sewage contamination maps Beach closures Harmful algal bloom alert · Water quality classification maps · Air quality classification maps · Siting of energy production facilities · Port development & shipping · Spill contingency plans · Urban planning & zoning · Risk maps of shoreline contamination	· Demographics · Night-time lights · Land use/cover · Shoreline/ocean use and cover · DEM · Discharge · Precipitation · Salinity · Currents · Wind · Surface roughness · Particulate/dissolved matter; pigments · Pollutants/pathogens · Aerosols	· Census data · VIS/IR sat imagery · VIS/IR sat imagery, surveys, radar, lidar · VIS/IR sat imagery, surveys, radar, lidar · Radar · Gauges · Gauges, Doppler radar · Field/airborne sensors · ADCP, HF radar, drifters · Field sensors; SCAT, SAR · SAR · Bio-optical field sensors; ocean colour sat imagery · Field/lab assays · Field counters; VIS/IR sat imagery; Lidar
HYDROLOGICAL & BIOGEOCHEMICAL CYCLES	· Land-Sea fresh water flux · Sediment budgets · Nutrient budgets · Eutrophication index · Carbon inventory and flux maps · Maps of ice volume & ice extent	· Particulate /dissolved matter; pigments, OPs · Nutrients · Precipitation · Discharge · Salinity · Ice cover & ice thickness · Air-sea CO_2 flux	· Bio-optical field sensors; ocean colour sat imagery · In situ/lab (auto)analyzers · Gauges, Doppler radar · Gauges · Field/airborne sensors · Active/passive MW sensors · Moored pCO_2 sensors
ECOSYSTEM HEALTH & PRODUCTIVITY	· Habitat maps: Terrestrial, marine, polar · Biomass and productivity assessments · Maps of biodiversity across the land-sea interface · Aquaculture siting and permitting · Harmful algal bloom risk maps · Coral reef bleaching hot spots · Land-sea maps of coastal protected areas · Maps of bottom water hypoxia	· Air/Sea Temperature · Particulate /dissolved matter; pigments, OPs · species/assemblage · Land use/cover · Ocean/coast use/cover · Currents · Nutrients · Oxygen · Salinity	· Field Sensors; IR sat imagery · Bio-optical field sensors; ocean colour sat imagery · Surveys; VIS/IR sat imagery · VIS/IR sat imagery, surveys, radar, lidar · VIS/IR sat imagery, surveys, radar, lidar · ADCP, HF radar, drifters · In situ/lab (auto)analyzers · Field sensors · Field/airborne sensors · Active/passive MW sensors

[1] Abbreviations: ADCP: Acoustic Doppler Current Profiler; DEM: Digital Elevation Model; HF: High Frequency; MW: microwave; OPs: Optical Properties; SAR: Synthetic Aperture Radar; Sat: Satellite; SCAT: Scatterometry; SSH: Sea Surface Height; VIS/IR: Visible/Infrared

tion of three-dimensional structure, biomass and/or productivity of each of these components is also necessary. Using high spatial resolution remote sensing and *in situ* observations and techniques, we can assess the ecological value and productivity of coastal land cover and the exchange of materials (e.g., sediments, nutrients) between the land and the sea. Empirical models with ecological measurements can extend these remote sensing measurements to ecosystem productivity. Accurate DEM and soil maps can be used to model flow to the rivers and the coast; coupled with near-real-time meteorological and stream flow/discharge data. Information is also required on the spatial and temporal extent of hypoxic or anoxic water masses, as well as phytoplankton productivity, biomass and species composition, highly resolved in space and time, particularly to quantify the coastal carbon cycle and detect/monitor harmful algal blooms. Accurate and timely information (volume and ice extent et al.) is also required to assess rapidly changing coastal polar and other high latitude ecosystems.

3.2 SYNTHESIS OF KEY OBSERVING REQUIREMENTS

Through distillation and synthesis of the above critical coastal observing needs, a core group of cross-cutting coastal observing requirements emerge. For our purposes, these required observations can be grouped into three basic categories:

- **Geophysical**: e.g., ocean winds, waves, sea surface height, currents, salinity, temperature, discharge, precipitation, ice cover;
- **Biological and Biogeochemical**: e.g., pigments, nutrients, particulate and dissolved matter, aerosols, slicks and spills, optical properties, biomass and productivity;
- **Mapping (Physical, Ecological, and Socio-Economic):** e.g., topography, bathymetry, shoreline position and use, high/low tide lines, habitat types and condition, land cover/use, coastal population assessments/demographics.

Specific observing requirements for the parameters that fall within each of these three basic observing categories are presented in Table 3.4.

3.3 EXISTING/PLANNED CAPABILITIES AND GAPS

As highlighted left (Table 3.3) and detailed below, a broad suite of observing assets are available to address, at least partially, the observing requirements in these categories. A combination of remotely sensed (satellite, airborne, and ground-based platforms) and *in situ* observations is required. Satellite observations (Table 3.5) provide valuable synoptic coverage, but extensive *in situ* measurements continue to be a necessity since many variables cannot presently be measured remotely (e.g., nutrients, pollutants and pathogens, values at depth). Further, *in situ* assets provide accurate measurements crucial for the calibration and validation of remotely sensed products. Although the most basic observing requirements are within our capabilities, significant gaps emerge when comparing the existing and planned capabilities with the Coastal Theme observing requirements. Specific challenges related to these will be discussed in Section 3.4.

Geophysical Observations: The geophysical observing requirements of the Coastal Theme are only partially addressed by existing and planned satellite capabilities (Table 3.5a). Since these assets are primarily focused on the global domain, the observed fields do not have sufficient temporal and/or spatial resolution in coastal regions (particularly salinity, wind, sea surface height, waves, and precipitation). Satellite-derived SST is a mature and robust measurement, but likewise still requires improved resolution (in both space and time) to address coastal needs. For observations that use visible and IR bands, cloud cover reduces actual viewing opportunities; this effect is exacerbated for large pixel sizes. Other limitations in satellite capabilities include a general restriction to surface observations in most cases, requiring complementary ocean *in situ* measurements of the interior of the ocean. An additional limitation is the present inability to adequately measure remotely several required parameters (e.g., discharge, currents). Continuity of measurements is also a concern as there is no guarantee that key measurements (e.g., sea surface height or ocean vector winds) will be sustained without breaks in the record. In terms of other observing capabilities for geophysical observations, ground-based remote sensing provides local measurements of precipitation (Doppler weather radar) and surface currents (high frequency (HF) radar arrays), but coverage needs to be significantly expanded. Stream/tide gauges and other geo-physical sensors on a variety of fixed (e.g., moorings, piers, ground stations) and mobile (e.g., drifters, autonomous underwater vehicles, profilers) *in situ* platforms collect data on sea level, river discharge, wind, and currents operationally as well as part of research programmes, but are also limited in their scope in time or space.

Biological and Biogeochemical Observations: As is the case with the geophysical observing requirements, the biological and biogeochemical requirements are only partially satisfied by existing and planned capabilities. There are numerous multi-spectral satellite sensors (e.g., MODIS, MERIS) that can provide optically-derived products such as chlorophyll-a and dissolved & suspended matter concentrations or aerosol properties (Table 3.5b), but again these are primarily focused on the global domain which leads to limitations in their spatial and/or temporal resolution. Temporal resolution in particular is the biggest concern in this category as existing Low Earth Orbit (LEO) platforms can provide only one ocean colour observation per day. This daily acquisition is subject to tidal aliasing and data dropout due to cloud cover, both of which are a significant concern in most coastal regions. Temporal coverage is likewise a significant problem in high-resolution synthetic aperture radar (SAR) observations which are well-suited to monitor slicks and spills. Coastal waters are also optically complex, and existing multi-spectral satellite sensors have inadequate spectral resolution to fully resolve and discriminate optical constituents. In this context, airborne hyperspectral instruments are available but provide limited coverage. Improved instrument calibration and validation remains a general need. Robust atmospheric corrections are also a crucial need. Ground-based remote sensing is available on a limited basis to provide information on aerosol fields (e.g., lidar, sun photometers), but station coverage needs to be expanded, and better coincident information from space is required. As in the case of the geophysical variables, fixed (e.g., moorings, ground stations) and mobile (e.g., ships, gliders) *in situ* observing assets acquire data pertaining to biogeochemical (e.g., nutrients, particulate and dissolved matter, pCO_2) and ecological parameters (e.g., pollutants, pathogens), but spatial coverage and delays in processing and analysis remain a significant problem.

Physical, Ecological, and Socio-Economic Mapping: Existing and planned observing capabilities (Table 3.5[c]) do a marginally better job at addressing identified requirements in this category than in the two previous categories (at least for the land observations), but significant gaps still likewise exist. There are numerous high-resolution optical satellite sensors to support maps of terrestrial habitat types, to assess changes in land use/land cover (e.g. grasslands, forests, impervious surface cover), and to identify and assess hazards (e.g., impact of coastal flooding "before" and "after" imagery pairs). Likewise, some existing remote sensing observing assets can be employed for physical mapping (e.g., bathymetry, topography, shoreline position), although in many instances they need to be either better utilized (e.g., improved access to existing data and value-added products), expanded in use/deployment to cover other coastal locations, particularly in developing nations (e.g., airborne colour, interferometric radar and lidar), or improved in accuracy. Overall, these existing capabilities are generally inadequate either in deployment/scope or their ability to resolve the coastal domain at the necessary scales. In this context, the priority should be to guarantee continuity of existing capabilities, to ensure data access and expanded use of current tools, and also to develop new and improved (especially in resolution and coverage) capabilities. For example, the need for improved estimates of human population in coastal regions and more efficient and effective methods to estimate socio-economic variables are specific gaps. There is also a need for improved spatial and spectral observations of coral reefs as identified in the Coral Reef Sub-Theme Report, as well as for terrestrial vegetation cover, three-dimensional structure and condition.

3.4 CHALLENGES IN MAKING COASTAL OBSERVATIONS

Description of Challenges

Comparison of the Coastal Theme observing requirements (Section 3.2) with existing and planned observational capabilities (Section 3.3) reveals significant gaps between what is required to support coastal user needs and what is available. Deficiencies exist not only in the observations themselves, but also in harmonizing, managing, modeling, and communicating data and information to users. This section primarily focuses on the deficiencies in the observations themselves, presenting them in the form of "challenges" for making observations and for producing data sets that satisfy the identified user requirements. Chapter 4 focuses on challenges to the integration of these observations and data sets towards providing products and information for users.

These coastal observing challenges can be organized into three types, not necessarily mutually exclusive of one another:

- "**Knowledge**" challenges require research and development (R&D) to address observation and data gaps. Solutions to "knowledge" challenges involve R&D support to improve current observing capabilities (e.g., platforms, sensors, and algorithms), fuse different types of observations to extract better information, and develop entirely new observing capabilities, as well as to improve the transfer of technology and capacity to operational use.

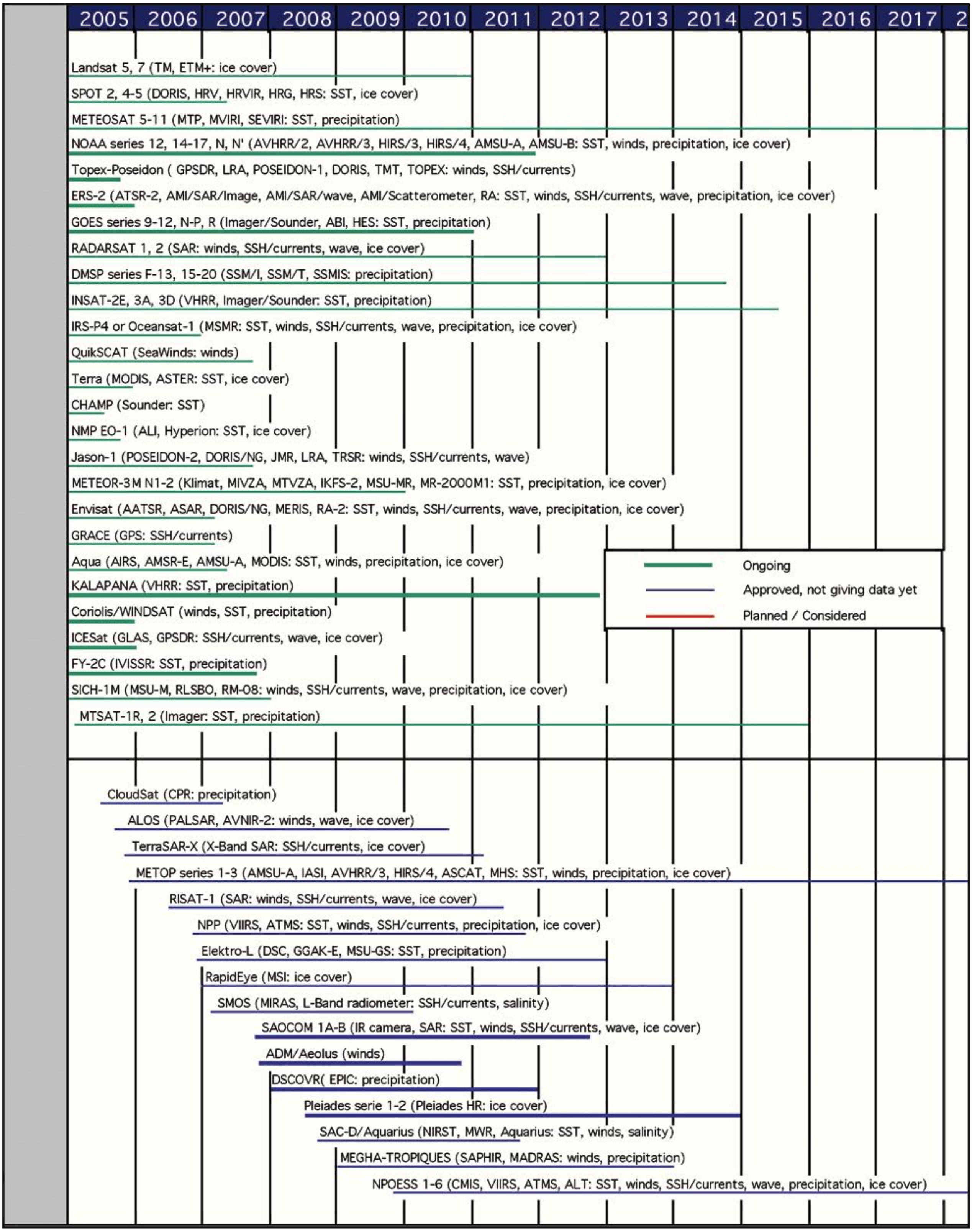
- **"Resolution/Coverage"** challenges address the need for improved spatial, temporal, and spectral resolution and/or coverage of existing measurements. The dynamic nature of the coastal zone lends itself to processes and phenomena that exhibit significant variability in both space and time, and typically are episodic and/or small-scale in their manifestation. In this context, coastal observations, obtained both remotely and *in situ*, need to be configured to resolve the finer temporal and spatial scales relevant to the core priorities of this theme. Remote sensing systems have both technical and knowledge challenges and limitations and require significant infrastructure investment. Solutions to these challenges for *in situ* observations generally involve an investment to increase the density of the observation network.

- **"Continuity"** challenges focus on maintaining existing observation capabilities, particularly those whose continuation is uncertain. Solutions to "continuity" challenges include sustained commitment, support, and capacity for operational activities as well as faster transition of pre-operational sensors to operational use. Operational agencies will need to work with and facilitate hand-offs from R&D agencies for measurements of interest on a continuing basis. The continuity challenge applies to both *in situ* and remotely-sensed observations. Beyond

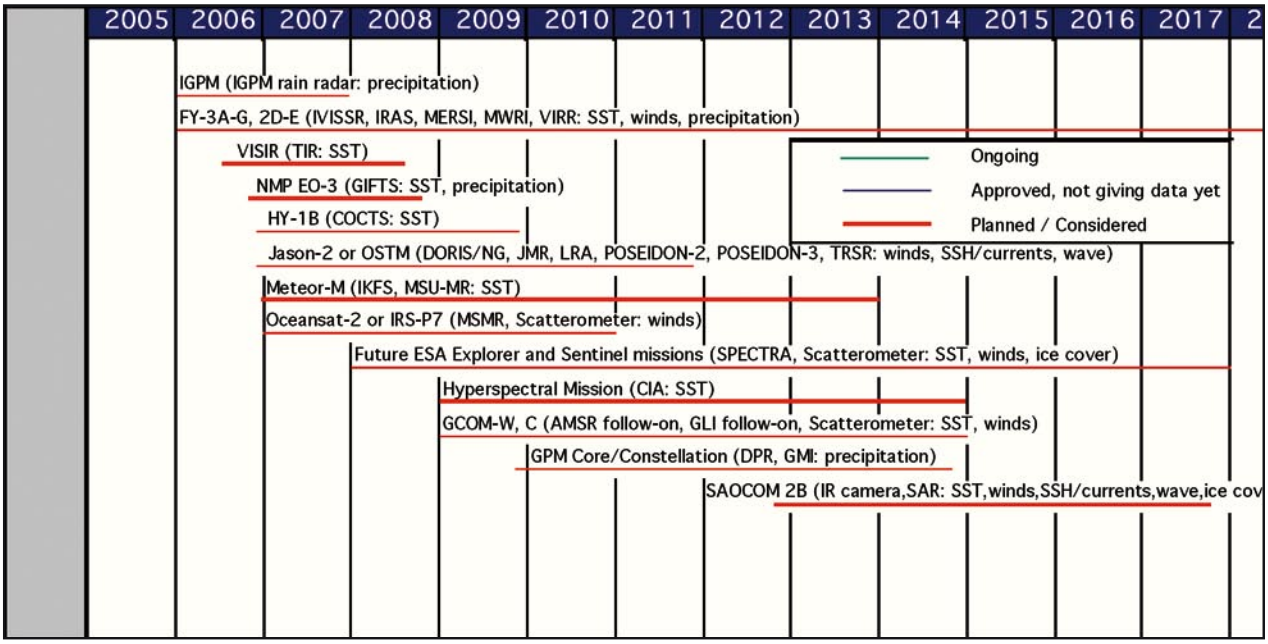
Table 3.4. Coastal Theme Observing Requirements: Specific observing requirements for the parameters that fall within each of the three basic observing categories. Note that many of these are not intended to be globally resolved at the identified scales; often these will be limited to regional coverage (e.g., high priority areas).

	PARAMETER	HOR. RES	HR MIN	OBS. CYCLE	OC MIN	AVAIL	AVAIL MIN	ACCURACY	ACC. MIN
GEOPHYSICAL OBSERVATIONS	Sea surface temperature	100 m	1 km	3 h	6 h	1 h	3 h	0.2° C	0.5° C
	Wind speed and direction	300 m	5 km	1 h	6 h	1 h	3 h	1 m/s 10°	2 m/s 20°
	Sea surface height	1 km	15 km	1 d	10 d	1 h	3 h	4 cm	6 cm
	Surface wave height & direction	1 km	10 km	3 h	1 d	1 h	3 h	0.2 m 5°	0.2 m 10°
	Salinity	1 km	25 km	1 d	7 d	1 h	3 h	0.1 psu	0.3 psu
	Currents	300 m	5 km	1 h	24 h	1 h	3 h	3 cm/s	10 cm/s
	Streamflow/river discharge	10 m	100 m	1 h	3 d	1 h	3 h	10%	30%
	Precipitation	1 km	15 km	1 h	8 h	1 h	3 h	0.5 mm/h	2 mm/h
	Ice cover	50 m	100 m	6 h	24 h	1 h	3 h	100 m	200 m
BIOLOGICAL/BIOGEOCHEMICAL OBSERVATIONS	Phytoplankton pigments (e.g., chl-a)	100 m	500 m	1 h	2 h	1 h	3 h	20%	30%
	Total suspended matter	100 m	500 m	1 h	2 h	1 h	3 h	30%	40%
	Coloured dissolved organic matter	100 m	500 m	1 h	2 h	1 h	3 h	30%	40%
	Optical properties (includes PAR)	100 m	500 m	1 h	2 h	1 h	3 h	10%	20%
	Chlorophyll fluorescence	100 m	500 m	1 h	2 h	1 h	3 h	30%	40%
	Aerosol properties (includes AOT)	100 m	500 m	1 h	2 h	1 h	3 h	10%	20%
	Nutrients	10 km	100 km	1 d	1 mo	1 d	7 d	10%	30%
	O_2 and pCO_2	10 km	100 km	1 d	1 mo	1 d	7 d	10%	30%
	Slicks/films (sea surface roughness)	25 m	50 m	3 h	2 d	1 h	3 h	50 m	100 m
MAPPING (PHYS./ECOL./SOCIO.)	Bathymetry	30 m	50 m	2 d	24 d	4 h	1 d	0.1m (depth)	1 m (depth)
	Land Topography	30 m	50 m	3 mo	1 yr	--	--	5 cm (height)	10 cm (height)
	Shoreline position	1 m	5 m	15 d	3 mo	1 d	7 d	1 m	5 m
	Habitat maps (e.g., mangroves)	5 m	20 m	15 d	3 mo	1 d	7 d	--	--
	Reef maps	1 m	5 m	15 d	3 mo	1 d	7 d	2 m	10 m
	Land cover/use	15 m	1 km	1 yr	10 yr	--	--	--	--
	Night-time lights	1 km	5 km	1 yr	5 yr	--	--	--	--

Table 3.5.a. Satellite Assets for Coastal Geophysical Observations: Since these assets are primarily focused on the global domain, they generally do not provide sufficient temporal and/or spatial resolution in coastal regions. (Extracted from CEOS Handbook, 2005).



(*continued*) **Table 3.5.a**. Satellite Assets for Coastal Geophysical Observations: Since these assets are primarily focused on the global domain, they generally do not provide sufficient temporal and/or spatial resolution in coastal regions.



supporting near-real-time applications that utilize these observations, continuity is crucial to develop the climate data records needed to assess climate variability and change.

Table 3.6 lists key Coastal Theme challenges of these three types according to whether they represent distinct challenges in the Geophysical, Biological and Biogeochemical, or Mapping observation categories, or otherwise represent cross-cutting challenges that pertain to all three observing categories.

Challenges Across Observing Categories

- Improved spatial and temporal resolution from satellite sensors is required to satisfy the coastal observational requirements addressed above for numerous parameters. Opportunities for increased spatial resolution include wide-swath altimetry for ocean surface topography (Fu, 2003), SAR processing of scatterometer measurements for ocean vector winds (Spencer, 2004), and lightweight large-aperture mirrors for optical measurements. Improved temporal coverage could be provided by pursuing alternatives to LEO orbits, including Medium Earth Orbits (MEO) for vector winds (Spencer, 2004) and Geostationary Earth Orbits (GEO) for visible spectral radiance (i.e., ocean colour) (IOCCG, 1999). Multiple platforms, e.g., micro-satellite constellations, could also provide significantly improved temporal coverage for SAR (Holt and Hilland, 2000) and other sensors. There exists a critical, yet under-served, need for calibration of instruments as well as the routine validation of remotely-sensed data. Both *in situ* and remote sensing instruments require calibration prior to deployment and a continuing programme for periodic calibration during their use. In situ measurements also play a crucial role in the calibration and validation of remotely sensed observations, and obtaining sufficient and representative *in situ* measurements to adequately assess and improve the accuracy of the remotely-sensed observations represents a significant challenge. For terrestrial observations, calibration and validation could be implemented within a network of sentinel sites as envisioned by the coastal module of GTOS. For marine observations, calibration and validation could be accomplished in conjunction with the coastal component of GOOS.
- While maintaining existing operational satellite observing capabilities (e.g. IR sea-surface temperatures), there is a need to facilitate the transition of existing and proposed research and pre-operational observing capabilities into a fully operational mode. Prime candidates include altimetry, synthetic aperture radar, visible spectral radiance, active and passive wind sensors, and microwave SST observations.
- Improved methods need to be developed to fill gaps and remove "contamination" from aerosols or clouds for optical measurements and that due to precipitation for microwave measurements. Land contamination is a particular challenge for most sea-viewing satellite measurements. The data loss in pixels adjacent to land must be minimized and discriminating mixed land-sea pixels across the tidally variable land-water boundary should be a priority.

Table 3.5.b. Satellite Assets for Coastal Biological and Biogeochemical Observations: Since these assets are primarily focused on the global domain, they generally do not provide sufficient temporal, spatial and/or spectral resolution in coastal regions. (Extracted from CEOS Handbook, 2005).

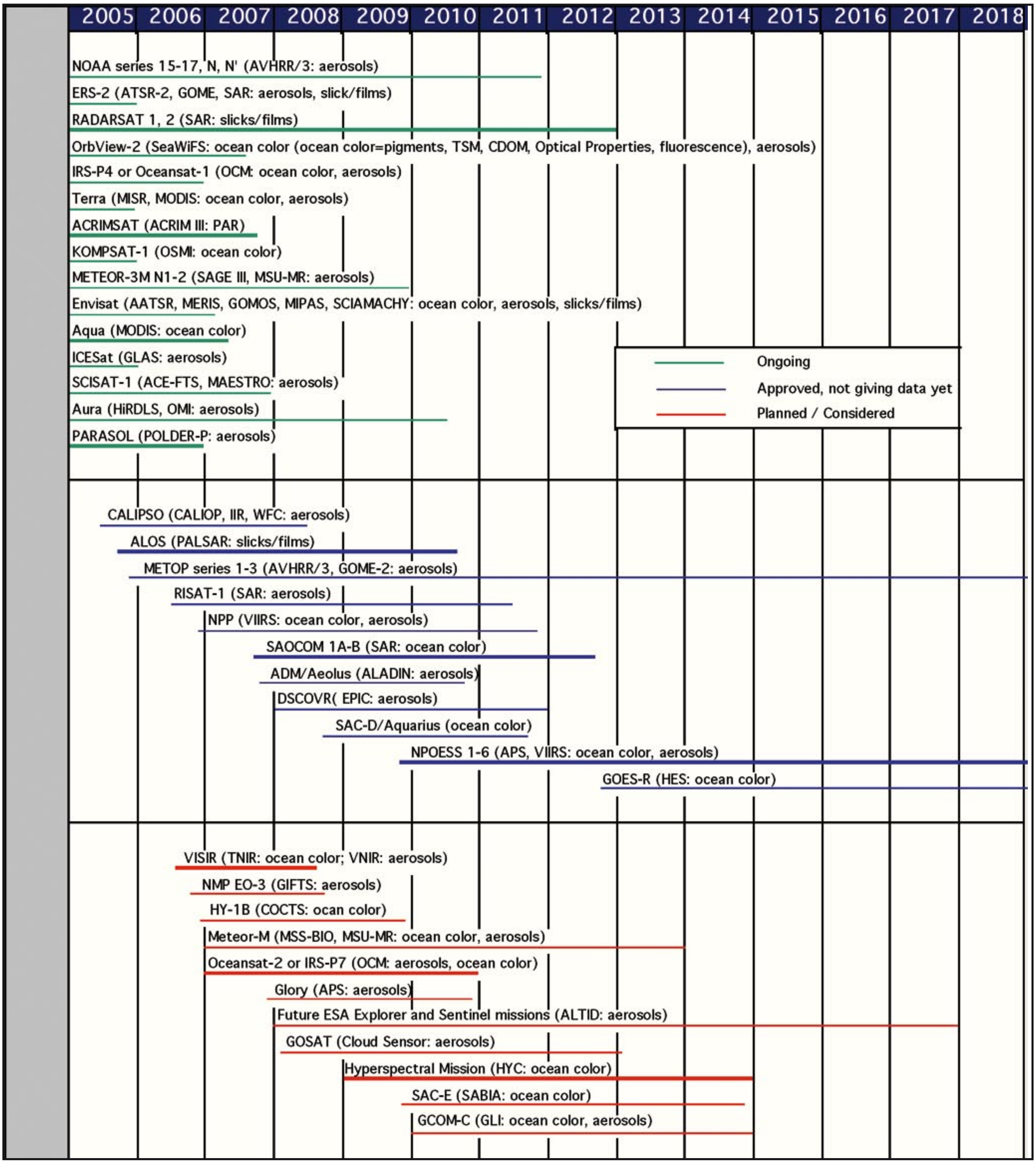
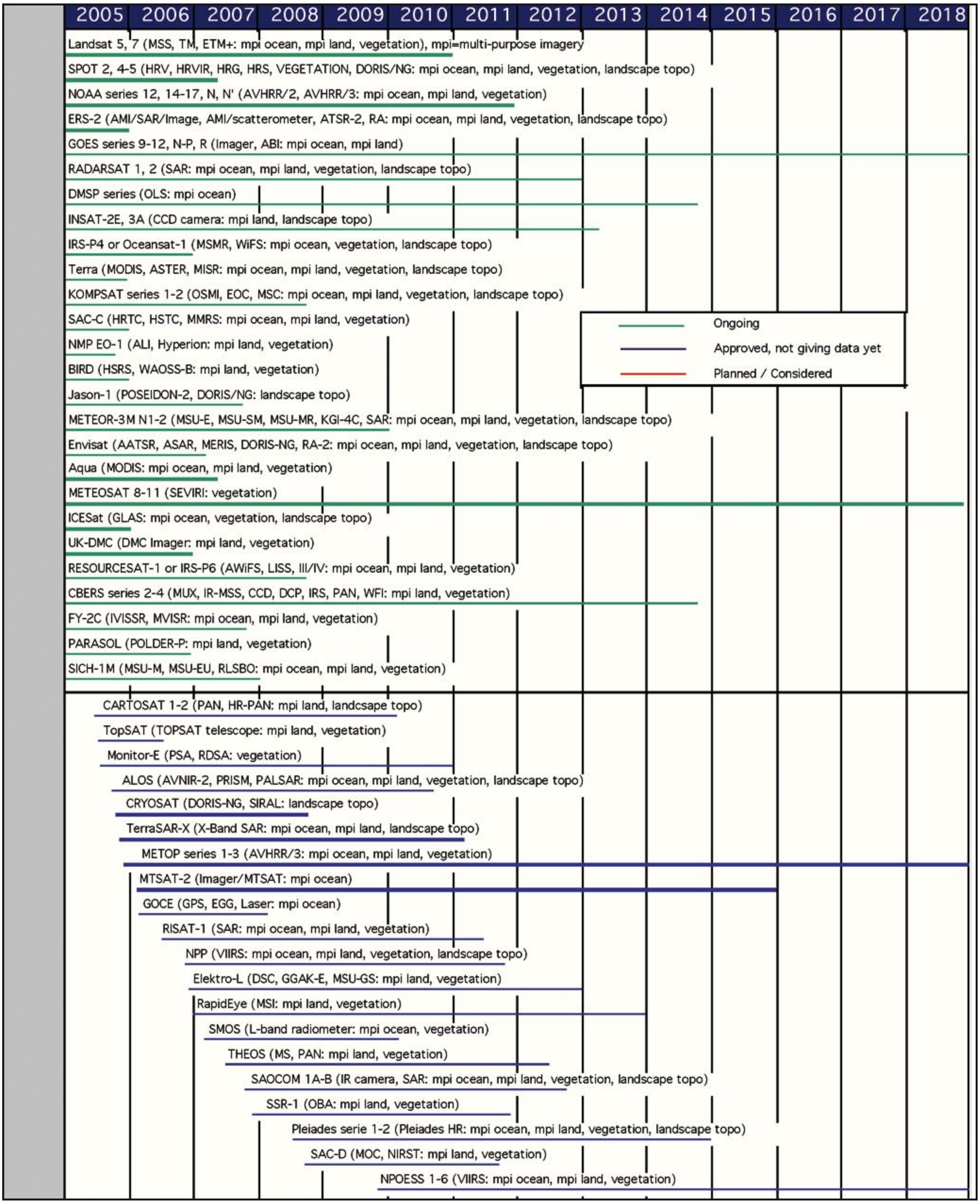


Table 3.5.c. Satellite Assets for Coastal Physical, Ecological and Socio-Economic Mapping: New and improved capabilities as well as continuity of some existing measurements is required for coastal observations. (Extracted from CEOS Handbook, 2005).



(*continued*) **Table 3.5.c**. Satellite Assets for Coastal Physical, Ecological and Socio-Economic Mapping: New and improved capabilities as well as continuity of some existing measurements is required for coastal observations. (Extracted from CEOS Handbook, 2005).

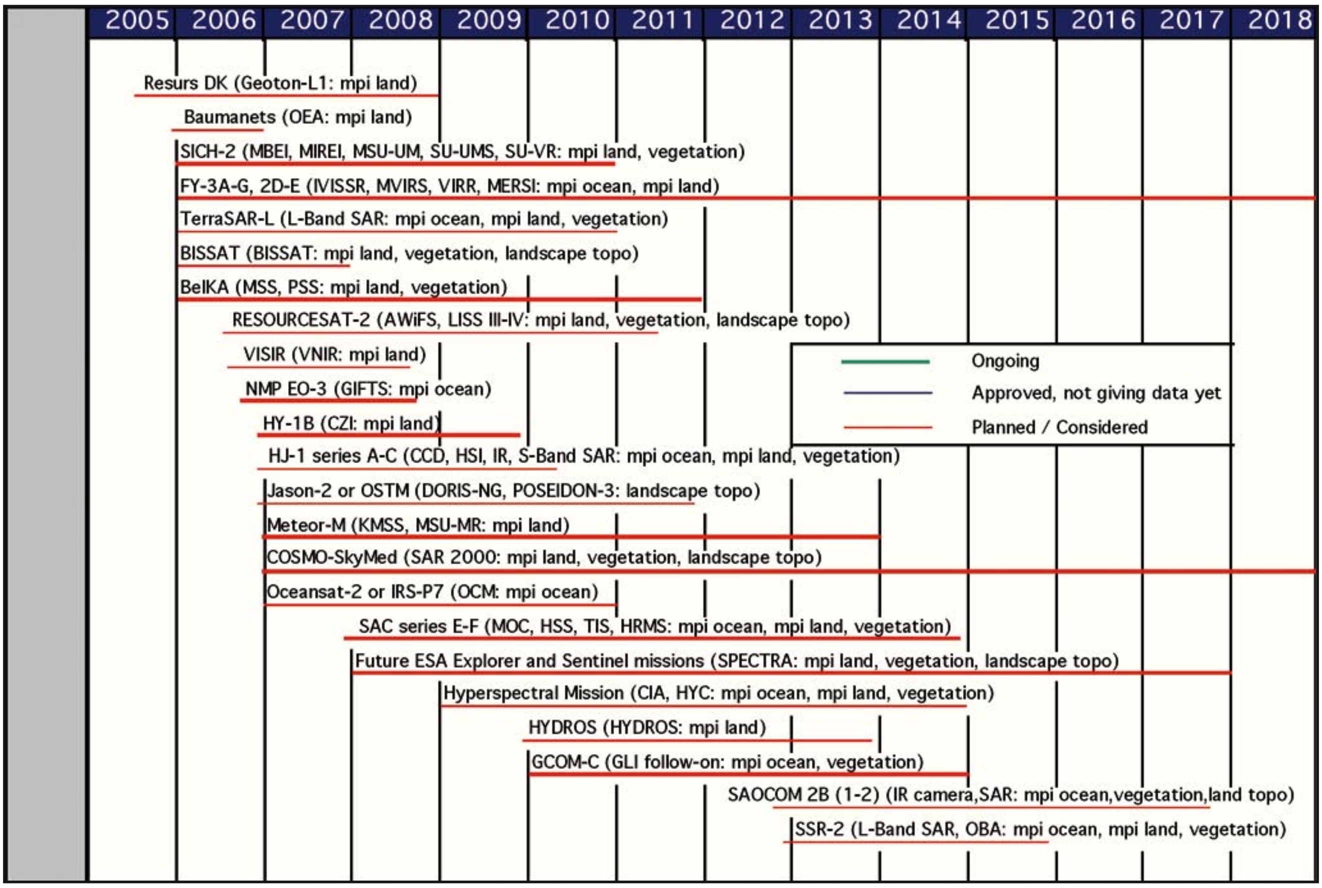


Figure 3.1. Adaptive coastal sampling: Coordinated, synergistic use of multiple remote and *in situ* assets

Image credit: David Fierstein, © 2001 MBARI.

- Adaptive sampling capabilities need to be developed whereby coordination between *in situ* and remote observing assets enables a timely response to episodic coastal events (Figure 3.1). This could involve tasking mobile *in situ* assets (e.g., gliders) to head toward a certain location based on discontinuities observed in satellite data streams, or conversely using field assets to identify interesting areas for dedicated, sustained surface observations by a geostationary satellite imager. A robust systems engineering approach will be necessary to realize these synergies.
- As indicated earlier, *in situ* assets generally provide spatially sparse measurements (except for dense local networks). Increasing the coverage of these *in situ* measurements is a significant challenge, as is devising a strategy to secure the necessary funding for the installation of additional sensors on both fixed and mobile platforms (e.g., rain/stream/tide gauges; instrumented moorings, profilers, gliders). Funding is typically provided at the national or sub-national levels, with limited global or regional coordination for such deployments. This funding challenge also exists for the implementation, utilization and maintenance of non-satellite remote sensing assets (i.e., ground-based and airborne).
- A continuity challenge for *in situ* observations is maintenance and replacement of instruments subject to the harsh environmental conditions of the coastal zone. Aside from the need for sustained funding, this challenge requires technical and logistical support, particularly the trained manpower capacity to perform these tasks. As experimental observa-

tions are transitioned from a research to operational mode, there likewise needs to be a corresponding development of trained personnel to conduct and maintain quality observations.

- The capacity to make standardized, inter-comparable and cost-effective field measurements in the coastal zone is a challenge that requires the development of rapid, accurate, automated, and inexpensive observation techniques, as well as the development of common sampling and quality assurance/quality control (QA/QC) protocols. There is also a need to build capacity for labor-intensive measurements, such as habitat surveys and water quality sampling.
- *In situ* sensors and platforms require technical improvements in power supply, data transmission, and mitigation of bio-fouling. Novel approaches are re-

Table 3.6. Summary of Coastal Theme Observing Challenges: Considerable effort and investment is required to satisfy user requirements.

OBSERVATION	KNOWLEDGE CHALLENGES[1]	RESOLUTION/COVERAGE CHALLENGES[1]	CONTINUITY CHALLENGES[1]
CROSS-CUTTING	· Satellite Cal/Val · Standardize & QA/QC *in situ* observations · Adaptive sampling · Power/telemetry/biofouling issues	· Require improved temporal & spatial resolution from satellite sensors (also see knowledge) · Expand coverage of *in situ* measurements	· Need to facilitate transition from research to operational satellites · Need to maintain and replace *in situ* assets
GEOPHYSICAL	· Improve SSH & wind measurements from space · Measuring coastal surface currents and river discharge from space · Measuring salinity remotely · Assimilate HF radar data and derive user products · Develop SAR algorithms & assess other SAR products · Measuring sea ice thickness remotely	· Extracting higher resolution information from satellite wind sensors · Add additional Doppler weather radar & HF radar sites · Densify stream & tide gauge networks	· Maintain existing stream & tide gauge networks · Maintain microwave RS capabilities for ice · Facilitate shore-based HF radar transition: research to operational mode · Make GHRSST-PP operational (see page 32)
BIOLOGICAL & BIOGEOCHEMICAL	· Use radar and/or lidar to obtain vegetation structure, regrowth, biomass · Improve bio-optical algorithms & atmospheric corrections · Merged chlorophyll & other VSR products · VSR/SAR data relationships with ecology · Functional type discrimination · Improve aerosol characterization	· Geostationary, hyperspectral, visible spectral radiance observations (VSR; i.e., ocean colour) · Expand coverage of nutrient measurements · Rapid & accurate pollutant assays	· Maintain high-quality global multi-spectral VSR observations for context and climate data records
MAPPING	· Require high spatial res. hyperspectral imagery for corals and vegetation assessments · Require InSAR for coastal subsidence/erosion · Need a common habitat classification system · Spatially explicit socio-economic variables	· Improve availability and use of high-resolution optical and lidar data for physical mapping · Access to highest resolution (spatial and vertical) DEMs	· Maintain DMSP-OLS (or related capabilities) for human population assessments · Maintain high-res. multispectral optical imagers for habitat maps

[1] Abbreviations and notes: Cal/Val: Calibration/Validation; HF: high frequency; OLS: Operational Linescan System; QA/QC: quality assurance/quality control; res: resolution; RS: remote sensing; SAR: Synthetic Aperture Radar; SSH: sea-surface height; SST: sea-surface temperature; VSR: visible spectral radiance (~ocean colour)

quired, including installation of nearshore cable systems to address power and communication needs.

Challenges Within Observing Categories

Geophysical:

- Robust methodologies are needed to blend SST measurements from a variety of satellite platforms, i.e., LEO and GEO, and different measurement techniques, i.e., infrared and microwave, to minimize the effect of clouds and coastal aerosols among other concerns. Initial efforts are underway, e.g., the Global Ocean Data Assimilation Experiment (GODAE) high-resolution sea surface temperature pilot project (GHRSST-PP; Figure 3.2), that need to be expanded and made operational.
- For ocean surface winds, improved spatial and temporal resolution is required for coastal regions. A key challenge is the extraction of higher-resolution information from existing satellite scatterometry and future operational passive polarimetry, particularly in close proximity to land. There is a need to implement the next generation scatterometer (using simple real aperture SAR processing) to enable measurements of wind vector velocities on the order of 1-5 km. Additionally, accurate algorithms for extreme conditions are required. • Airborne and satellite observations of sea-surface salinity represent an emerging observing capability that requires continued development, particularly to resolve important coastal zone phenomena such as river and stormwater runoff.
- Sea-surface height measurements in the coastal zone require improved spatial and temporal resolution and coverage, perhaps leveraging technologies such as wide-swath (resolution of 1-15 km), delayed-Doppler, or GPS (Global Positioning System) altimetry. Improved models are also needed to accurately remove tidal signals.
- Sea-surface roughness observations employing SAR data require continued development, validation, and implementation of algorithms for wind speed and direction and wave height and direction. Other SAR challenges for coastal regions include understanding the differences and advantages to be gained through the use of different kinds of SAR measurements, e.g., C-band vs. L-band, multi-polarimetric, and interferometric.
- Airborne and satellite remote sensing of ocean surface currents is an important capability to develop and foster, potentially from SAR Along-track Interferometry (ATI) and/or SAR Doppler measurements. High-resolution currents from space or aircraft would address multiple coastal zone needs. Resolving the innermost near-shore region (i.e., < 1 km) is particularly challenging and important.
- For ground-based remote sensing, such as Doppler weather radar (precipitation) and HF radar (ocean surface current vectors), primary challenges are to increase the density of observing systems by both adding observation sites as well as improving the technology to increase the resolution of each observation bin. However, users and providers might ultimately be better served by implementing space-based systems (e.g., see above for surface currents).
- Delivery of surface current fields and derived products via HF radar needs to be transitioned from research to operations.
- There is a need to assimilate HF radar surface current observations into coastal nowcasting and forecasting models, and to derive user-driven products and information from HF radar fields, e.g., particle trajectory maps for pollution applications, near-shore rip current forecasts.
- Stream flow networks are declining on a worldwide basis, including regions where stream flow is comparatively well observed. It is strongly recommended that global stream flow networks for measuring river discharge be maintained and expanded. Current stations require dedicated support; discontinued gauges require restoration; and new gauges, especially downstream near the coast, need installation. Likewise, there is a need to characterize river discharge into coastal receiving waters from space.
- The global tide gauge network needs to be expanded, particularly in the southern hemisphere, and properly maintained to ensure continued access to one of the most important coastal observations of global change. Relevant time scales for observations span decades (sea-level change) to minutes (storm surge). The tide gauge networks represent the sole mechanism for obtaining such data.
- There is a strong need to maintain microwave remote sensing capabilities to assess sea ice cover, particularly toward assessing long term trends. Measurements of sea ice thickness are also required.

Figure 3.2. Improved data products: Operational blended SST product.

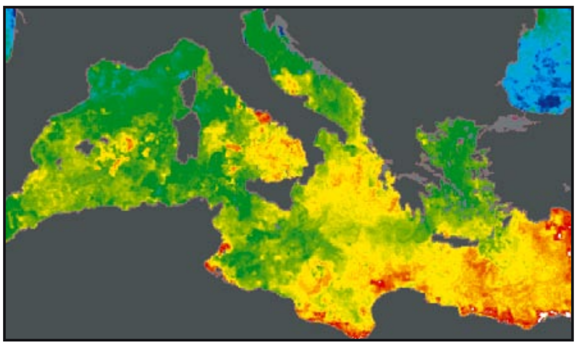


Image credit: Medspiration Project/GHRSST-PP. Source: Ed Armstrong, NASA/JPL Physical Oceanography Distributed Active Archive Center (PO.DAAC).

Biology and Biogeochemistry:

- There is a compelling need to expand visible spectral radiance (VSR; i.e., ocean colour) observations from a LEO to GEO vantage point to better resolve dynamic coastal processes and phenomena, as well as to mitigate cloud cover and tidal aliasing.
- Satellite VSR (i.e., ocean colour) challenges also include the necessary development and utilization of hyperspectral approaches (spectral bands ≤ 5 nm wide and a broad spectral range) to more accurately quantify optically complex coastal waters. This requires a sensor(s) with coverage into the UV (e.g., 350-400 nm) and a high signal-to-noise ratio. The new technology must be accompanied by development of new and improved algorithms to retrieve relevant bio-optical properties and parameters on both a global and regional basis, improved characterization of aerosols for atmospheric corrections, and adequate calibration and validation. Furthermore, a robust strategy for dealing with the potentially large data volumes needs to be developed and implemented.
- In terms of existing satellite VSR (i.e., ocean colour) observations (e.g., MODIS, MERIS, OCM), there is a need to merge or blend multi-sensor data streams and create merged chlorophyll and other VSR-derived products (as with SST data above) that address data dropout due to clouds or other factors. This will require robust inter-sensory calibration. For non-concurrent sensors, vicarious calibration is needed to enable long time-series of relevant variables spanning different sensors.
- A challenge for both VSR (i.e., ocean colour) and SAR data is to conduct basic research aiming to understand and quantify the relationships between parameters being quantified (e.g., suspended particulate matter, coloured dissolved organic matter, surfactants) and relevant coastal ecosystem indicators (e.g., pollutant or pathogen distribution and abundance), towards development of new information products for decision makers. In this context, the application of SAR requires further studies on using multiple frequencies, e.g., L- and X-bands, to discriminate slicks of different origins.
- Improved aerosol characterization for coastal zones is required, via satellite or ground based remote sensing (e.g., lidar), to enable improved atmospheric corrections for coincident VSR (i.e., ocean colour) measurements as well as for improved assessments of air quality.
- The ability to discriminate (*in situ* and/or from space) functional types of phytoplankton as well as other organisms in near-real-time is an important need, particularly towards identifying incipient harmful algal blooms and to reveal shifts in ecosystem dynamics and nutrient cycling (e.g., changes in the pools of nitrogen fixers or calcareous phytoplankton). New genetic-based markers show promise for several ecologically critical organisms as do algorithms and classification schemes for resolving (directly or indirectly) functional types.
- There is a clear need for more synoptic measurements of coastal biogeochemical and ecological parameters, including nutrients, O_2 and green house gases including pCO_2 and pN_2O, pollutants and pathogens. This entails continued development, refinement and deployment of accurate and affordable *in situ* nutrient and gas sensors. Likewise the development of rapid and inexpensive *in situ* assays for pollutants, pathogens and natural toxins (e.g., domoic acid) should be a priority.
- It is necessary to identify better surrogates for labor-intensive measures of biomass and production to aid the evaluation of habitat and ecosystem conditions. Primary production algorithms from satellite sensors, especially when regionally validated, can be of great use for planktonic, terrestrial, or macrophyte (e.g. seagrass) communities. Further, over land, radar interferometry, or low frequency radar measurements, and lidar can improve estimation of biomass, regrowth, and productivity significantly (e.g., mangroves).

Mapping:

- The continuity of high resolution (nominally 5-15 m) multi-spectral optical imagers (e.g., ASTER, AVNIR-2, ETM+, LISS-IV), is required to produce key habitat maps, to assess changes in land use/land cover (e.g., impervious surface cover), and to identify and assess hazards (Figure 3.3).
- Of particular interest and importance is ensuring access to highest resolution global Digital Elevation Models (DEMs) for determining elevation with land-sea continuity. Presently, SRTM DEMs are only available globally at

Figure 3.3. Landsat 7 ETM+ false colour image: Ganges River Delta, mostly covered by swamp forest (Sunderbans) where the Bengal tiger is found. The delta is inhabited by about 120 million Bangladeshi who are extremely vulnerable to coastal flooding.

Image credit: USGS EROS Data Center Satellite Systems Branch. Source: http://visibleearth.nasa.gov/

90 m spatial resolution (C-band). SRTM X-band 30 m data is available, but is distributed with coverage gaps.

- InSAR (Interferometric Synthetic Aperture Radar) is required for geographically comprehensive change maps of coastal subsidence, erosion and wetland water levels.
- DMSP-OLS (Operational Linescan System) (or similar) capabilities must be continued to provide indirect estimates of human population via night-lights (Figure 2.2). This is particularly important for their contribution in building extended time series needed to predict the growth of urban and peri-urban areas relative to the coast, for example.
- Better characterizations of bathymetry, shoreline position and topography are needed in coastal regions. Improved availability and use of high-resolution satellite observations as well as airborne VSR and lidar data are needed for such physical mapping. Radiometric accuracy of 12 bits or better is required for bathymetry and other applications (see below).
- Fine spatial resolution (≤ 5 m) imagery with high spectral resolution (~ 5 nm bandwidth) is needed to accurately map and monitor coral reefs at appropriate resolutions and to assess coral reef community changes.
- Hyperspectral imagery with high spatial resolution (~ 30m) and a high signal-to- noise ratio (SNR) is also needed to provide accurate vegetation cover assessments or resolve functional type mixtures without heavy local supervision.
- The need exists for a common classification system (e.g., habitats, ecosystems, land cover, population dynamics) for both terrestrial and human systems. This has been highlighted in the Coral Reef Sub-Theme, but also applies in a broader sense here. Different observing entities (e.g., international or national agencies, the research and remote sensing communities) often have classification schemes that suit their needs but are not shared with other groups. Early efforts require developing common or at least coordinated classifications.
- More efficient and effective methods for estimating socio-economic variables are critical for linking the human dimension with physical and ecological phenomena in the coastal zone.
- Mapping vegetation three-dimensional structure with radar interferometry and lidar is useful to assess its health and ecological value .

While effective data integration remains a major goal of the IGOS Partnership, significant challenges exist (Table 4.1). This section discusses some of the systemic challenges to data integration (Section 4.1) as well as some general strategies necessary to overcome these challenges (Section 4.2). Finally, specific approaches towards effective integration are discussed, with recommendations for activities to support users (Section 4.3).

Table 4.1. Integration Challenges and Strategies: Breaking down barriers across the land-sea interface.

INTEGRATION CHALLENGES	INTEGRATION STRATEGIES (see text for details)
Communication: • Biases in disciplines & applications	• Interdisciplinary training programmes & workshops • Prioritizing interdisciplinary observation products
Data Access & Management • What data is available? • Data sharing across national boundaries • Separation of land & ocean data and models; separation of remote and *in situ* data	• Coordinated cataloguing, archiving & distribution of current and historical coastal datasets & metadata; potentially leveraging the GTOS-TEMS database • Improve data management infrastructure to store, (re)process and disseminate expanding data streams, incl. (near) real-time & climate data records • Modeling & data assimilation => COastal Data Assimilation System (CODAS)
Unique Challenges • Mapping the coast • Scale dependent attributes • People at the coastal interface – linking natural with social sciences	• Tidal monitoring, hydrodynamic models + Vertical datum transformation tool • Long term time series and data continuity • Humans & ecosystems => Coastal GIS => Integrated Coastal Decision Support System (ICoDSS)

4.1 SYSTEMIC CHALLENGES TO DATA INTEGRATION

Significant obstacles exist that have hindered data integration for the holistic study of the coastal domain. These include communication issues among the disparate elements of the coastal community, data access and management issues, and finally unique challenges characteristic of coastal regions.

Communication Issues

Biases Among Disciplines and Applications: Discipline-based biases remain a fundamental barrier to data integration. Traditionally, land and ocean sciences have viewed the coast as a source of noisy data where analysis is difficult and the search for causality becomes intractable. To exacerbate the problem, the intense human use of the coast leaves many overwhelmed by the complexity of human-environment interactions. As a result, fewer researchers venture into the study of coastal processes for which models, analytical tools, and instrumentation tend to lag in development compared to the land and open ocean environments. However, growing environmental pressures on the coastal zone necessitate a community of scientists who are willing to cross the discipline divide and focus on the land-sea-air and the human-environment interactions which play out in the coastal domain. On a national level as well, agencies in charge of the collection of coastally-focused data sets often have different mandates and goals that hinder communication between their scientists, users and decision-makers.

Data Access and Management Issues

What is Actually Available? The first challenge in data access is to determine what, in fact, is actually available. Data sources for the coastal domain frequently include multiple communities of organizations, agencies, and scientists who may have little history of interacting. This lack of communication is evident both between and within satellite and *in situ* observing communities. For example, although an individual space agency may collect and analyze data from both terrestrial and marine systems, the intra-agency organization may effectively separate personnel working in these different areas. Further, there is often an artificial separation of remote versus *in situ* derived data sets. There are common as well as unique challenges associated with all types of data, but ultimately they all contribute to the overall pool of coastal data.

Bias Among Disciplines: Reflecting the discipline divide identified above, traditional data management approaches, by preference and design have chosen to segregate into either dry and/or freshwater areas in the case of land, or offshore marine waters in the case of ocean databases. As such, the interface areas, which have both land and water components and whose features represent the dynamic interactions between land and ocean, remain poorly represented or characterized. The distinct agency mandates for coastal observations have been developed from single-customer and single-discipline views. Consequently, the expectation of data sharing and integration across organizations is considered unrealistic and such activities represent a cumbersome burden.

Data Sharing Across National Jurisdictions: Data sharing across jurisdictional limits, especially national boundaries, is a challenge for international organizations dealing with global databases (Maurer, 2003). Concerns regarding national security and regional political alliances directly affect the willingness of nations to make coastal environmental data accessible to national and international groups, even for valid/noble global causes. Under a national umbrella, coastal states have begun to form interagency groups to implement coastal initiatives, ranging from mapping to assessments under more holistic mandates than traditional organizational charters or goals would otherwise allow. At the regional and global scales, similar mechanisms and institutions are evolving, but an effective education and capacity building programme at national scales will have to be developed concurrently before global initiatives can receive broad base support. It is the clear intent of the IGOS Coastal Theme to provide the platform for GTOS and GOOS to work together with regional bodies and national agencies and help facilitate and deliver coastal information products critical to decision makers and to the broader public.

Using Historical Non-digital Data: In principle, long-term data sets from both an ecological and geological perspective are required to determine trajectories of change. Retrospective analyses of records embedded in biotic life histories, through fossil and sedimentary elemental signatures, for example, are used to describe historical scenarios. Another methodology for historical scenarios is to utilize data sets of the pre-digital information age. These include topographic and bathymetric maps as well as scientific expedition data covering taxonomy, biogeography, species abundance, and fisheries data, among many others. Because of the labor-intensive mechanisms (including access, encoding, and data analysis) necessary to integrate these paper records with current digital information, the practice of incorporating these records in contemporary studies is declining. A recent example involves a study on the convergence of tuna, marlin, whales, and other pelagics to the west of Baja California (Etnoyer et al., 2004). Longhurst (2004) pointed out that the investigators failed to examine important historical records of species distribution in this productive region. In particular, he singled out the records of the distribution and abundance of the red crab obtained by monitoring programmes, such as the California Cooperative Oceanic Fisheries Investigations (CalCOFI), and by the Eastern Tropical Pacific expeditions. These data clearly indicated the role of the red crab as the main prey item and how its distribution reflected the physical process of upwelling, in turn driving predator aggregations.

Unique Challenges of Coastal Regions

Difficulty in Mapping the Coast: The coastal zone is a dynamic region where humans and the environment interact as a function of a multitude of natural (land, sea, air) and anthropogenic drivers (trade, globalization, development). Understanding of these interactions requires a multidisciplinary framework supported by accurate geospatial information in maps and charts. One of the major challenges in coastal mapping involves the use of a common set of vertical reference layers for both the land (topographic) and ocean (bathymetric) sides of the coastal zone (National Academy of Sciences, 2004). Bathymetric definitions are affected by the tidal cycle, which cannot be generalized across different locations. Consequently, an integration of land-based and ocean-based reference levels requires highly resolved tidal data and models.

Scale-dependent Attributes of Coastal System Processes and Components: As discussed in the previous chapter, the coastal domain presents many challenges to our ability to identify the spatial and temporal dimensions of coastal processes, such as circulation and biogeochemical transformations, system metabolism, and biotic regime shifts in response to natural variability and anthropogenic pressures, among many others. From short-term site-specific studies to analyses to discern global patterns of long-term change, scientists are faced with mismatches between available data sets and the necessary space and time coverage to understand the inherent properties of coastal phenomena. Depending on the breadth and depth of studies across time and space, the features one can resolve will subsume unknown properties at smaller scales and likewise will be embedded in potentially as yet undescribed phenomena at larger scales.

Highly resolved yet long-term time series acquired from both satellite and *in situ* observing assets are required to unravel this complexity. Long-term ecological research sites can provide insights into recent variability. Remote sensing data continuously acquired over an extended period of time, e.g., > 10 years, can provide both the necessary geographical coverage and temporal resolution (interannual to decadal) to resolve long term as well as emerging coastal trends. Gaps in coverage are still a concern as monitoring programmes can be terminated for lack of funding or sensors can fail or have a break in their continuity. Retrospective data analyses can be performed for those variables that have geologically recorded signatures or proxies. In addition, sites along gradients of anthropogenic disturbance may enable the use of space as a proxy for time to construct pre-disturbance scenarios. All of these approaches need to be coupled with models.

4.2 GENERAL STRATEGIES NECESSARY TO OVERCOME THE CHALLENGES

The urgency of addressing coastal environmental issues has served as an impetus for data integration at various levels. In this context, several strategic elements are required to overcome the above challenges to integrating current and future knowledge of the coastal domain. These can be grouped into the categories of community efforts (i.e., improved communication, capacity building, education), data management and distribution (to enable optimal dissemination and utilization of past, present, and future observations), and model development and data assimilation (for prediction, improved understanding, and to integrate diverse or incomplete data types).

Community Efforts

The importance of improved communication between coastal scientists and decision makers cannot be overly stressed. Many of the impediments to progress described above have been caused by a mismatch between the information currency used by the differing communities. The lack of integration has a negative effect on the wider recognition of the impact of coastal issues. This in turn decreases opportunities to meet the needs of the coastal community. In a practical sense, it reduces the effectiveness of attempts to seek sponsorship and funding for large-scale projects critical to the mitigation of coastal concerns. To this end, users and scientists in both the public and private sectors must communicate in order to understand both what is required and what is possible, so that appropriate information products can be developed. Attempts to bridge the gap between, for example, circulation modelers and water quality managers or geologists and city engineers, can only come through concerted efforts to bring the communities together through coordinated interdisciplinary workshops and conferences, training courses for young scientists and junior management, and active efforts of education within, for example, coastal management, fisheries, coastal resource, and natural science programmes.

Another, equally important, arena of community building is that which transcends national boundaries. There must be focused efforts to build capacity in all countries if operational monitoring is to take on a global nature. This involves training and education investments, technology transfer, and focused efforts to increase the capabilities of the appropriate institutions and industries. Barriers exist between different communities in both developing countries and developed nations. Thus, thought must be invested to ensure proper and fair dissemination of information and management practices within and between nations.

The goal of bridging different communities and nations requires focused and coherent funding mechanisms. The Coastal Theme aims for the coastal community to transition beyond a situation of disjoint science in developed countries and applied science in undeveloped countries towards global observations in support of greater scientific understanding and operational monitoring and assessments in all countries.

Data Management and Dissemination

Critical to the success of all IGOS Themes is an effective strategy for data management and dissemination. Toward this end the IGOS Partners need to work in concert to facilitate coordinated archiving and distribution of existing and historical data sets for coastal applications, as well as coherent plans, processes, and infrastructure for the impending deluge of remote sensing data and expanded *in situ* data. Given the anticipated data volumes, archive responsibilities will need to be distributed. It will be a challenge to ensure that this distributed structure be largely transparent to the user for proper integration and exploitation of the data. Compounding the data management challenge will be the need to address near-real-time data flows together with climate-quality data records. The near-real-time data flows represent the greatest challenge with respect to dissemination, principally due to the volume of data.

A central element of data management is the issue of access. In addition to technical challenges, there is need for enhanced political willingness to share archived data and provide ready access between agencies and countries. Technical challenges include developing the capability for remote and automated data mining, standardized formats, and durable media. With the global push to address climate questions and the subsequent need for longer data records, investments are required to make older digital and non-digital records available in a digital format.

The need for climate-quality data records implies the capability to reprocess archived data for its improved accuracy and consistency. Archive responsibilities include the need for common processing protocols. This is relatively simple for single sensor data records, but multi-sensor records have the challenge of accurately combining the data to achieve the best representation (e.g., merging *in situ* "bulk" sea-surface temperatures with remotely-sensed infrared "skin" sea-surface temperatures and with remotely-sensed microwave sea-surface temperatures). A common framework is required for each parameter to assess data quality and to integrate with data from multiple sources.

Careful development of meta-data for each data stream and data record is crucial for maintaining the value of the data and for ensuring its long-term usability. Meta-data is key to enable proper exploitation of data for applications and products (e.g., climate data records). In this context, a meta-data base catalogue of existing coastal observations, potentially leveraging the GTOS-TEMS (Terrestrial Ecosystem Monitoring Sites) database, is necessary. Enhancement of TEMS is an implementation goal of the coastal module of GTOS, and should likewise be linked to the implementation of the Coastal Theme.

Quality assurance, including instrument characterization, calibration, and data validation, presents a significant infrastructure challenge for data management. Too frequently, these crucial components are short-changed to the detriment of climate-quality data records. This is particularly important for satellite remote sensing as there is no second opportunity after launch; complete pre-launch instrument characterization and calibration, along with a strategy for on-orbit calibration, are absolute requirements. Subsequent to launch, calibration and validation (e.g., to correct for changes in sensor performance) are ongoing activities which require continuity of resources as part of a committed investment by the source agencies.

Data dissemination includes both the data streams directed towards select users and sites and making data and products available for universal access at the general user's discretion, such as via web-based sites. Dissemination challenges include access, continuity, latency, and formats. The IGOS Partners should work towards ensuring unimpeded access in real-time to *in situ* and satellite data sets, particularly by contributing to the development of improved data telemetry and communication networks. In near-real-time applications, users rely on the relevant data streams; this implies a dissemination requirement for the corresponding data providers to ensure continuity. Continuity challenges include reserve replacement sensors, robust communications links, and data backups for filling voids produced by communications outages. Near-real-time users also have latency concerns, imposing requirements on the frequency of data collection and dissemination. Latency issues include the frequency of observation, processing time requirements, and communications bandwidth limitations. Latency tolerances are application-specific and can be quite small, as in the case of data assimilation for synoptic modeling efforts. Disseminating data implies providing data in a selected format; consequently, disseminating agencies need to ensure that the selected formats adequately address user needs, are user friendly, and represent the data without the loss of content. An important effort to emphasize is the dissemination of data in Geographic Information System (GIS) compatible formats and web-based applications, directly facilitating the conversion of data into information of value to decision makers. Expanded efforts are encouraged for the dissemination of web-based information products by data providers (see below).

Modeling and Data Assimilation

Models validated by rigorous tests and supported by observations are invaluable to synthesize the spectrum of coastal observations. The types of models needed to integrate relevant data from the coastal domain, and generally to address the Coastal Theme, include simple conceptual relationships (e.g. between discharge, wind, currents and freshwater plume distributions), high-resolution numerical simulations of coastal circulation, detailed models of sediment chemistry, biogeochemistry or ecosystems, and sophisticated frameworks that link environmental change to the socio-economic response system. Models allow us to interpret observations, test hypotheses, make predictions of future changes, and very importantly, integrate disparate elements of a coupled system. No model is perfect and each must undergo validation and scrutiny. Ultimately, a model is only as good as the knowledge that informs its formulation and even then, poor input or forcing data and sub-grid-scale simplifications, required to allay computational limitations, introduce additional uncertainties.

For added complexity, it is an immense challenge to couple processes relating to the human dimension to observations and simulations of a geospatially explicit natural environment. Flows of trade and interactions among human institutions through legal instruments and political mechanisms are not amenable to comparatively straightforward geospatial mapping. To date, visualization of integrated human environment data is best accomplished using GIS tools to group spatial and non-spatial elements into information layers. The integration of data across layers generally employs model algorithms while visualization of results can assume various formats, not exclusively with spatially explicit variables. By far, GIS tools offer the best means to integrate spatially explicit *in situ* with remotely-sensed biogeophysical data, and to juxtapose them onto socioeconomic data layers. However, further effort is required to develop effective 4-dimensional GIS models that handle time and vertical extent (altitude and depth), as well as can directly ingest a broader range of data sets.

To fully incorporate the needs of policy-makers, frameworks such as the Driver-Pressure-State-Impact-Response framework (DPSIR) discussed in Chapter 1 are also necessary. DPSIR was developed to explicitly juxtapose environmental changes, whether driven by socio-economic pressures or natural variability, with the required socio-economic measures to mitigate adverse impacts of change.

Model Philosophy & Recommendations: The physical environment of the coastal zone will be modeled to support endeavors such as coastal ocean and weather forecasting, coastal engineering, and flooding risk assessments. Through energetic research efforts, coastal circulation models are evolving rapidly and being applied to a broad range of coastal environments. Models of beach dynamics and sediment transport are increasingly being developed and utilized. Models of the planktonic ecosystem (and accompanying biogeochemistry) are an object of much research, and have been successfully coupled to circulation models. Terrestrial, wetland and aquatic freshwater systems have been modeled successfully for biogeochemical processes and for successional changes in plant communities. These remain more as research efforts at present than operational models. Much work is still required to include communities at depth in aquatic systems, higher trophic levels and larger organisms with broader geographic domains. Likewise these models need to be better designed to address socio-economic issues such as public health, sustainable development, and non-point source pollution. A cross-cutting challenge for physical and biological modeling, and the primary focus of the IGOS Coastal Theme, is the coupling between models of land, of shallow water or beaches, and of the offshore/deeper water column and the formulation of the fluxes between these sub-domains.

Figure 4.1. Three Level Nested Monterey Bay ROMS Model: SST Shaded Relieved with SSH.

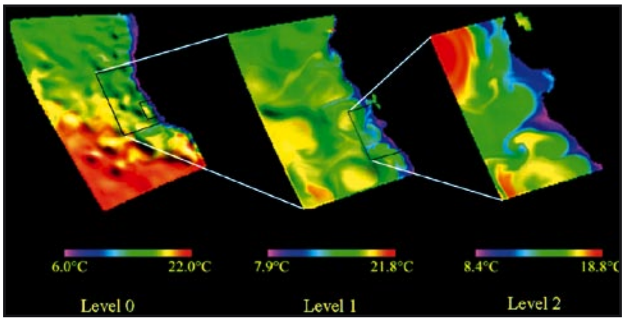


Image credit: Dr. Yi Chao, Jet Propulsion Laboratory

Because of computational limitations and the generally high resolution required to examine coastal processes, there will be a continued focus on local and regional efforts. These require boundary conditions and forcing fields that are consistent with the broader context. Nesting (Figure 4.1) therefore plays a crucial role both within regional models (to move to smaller scales) and external to them (as forcing and boundary/initial conditions). Such nesting schemes provide integration and continuity with larger-scale or global ocean and atmospheric observations and models as well as allowing more detailed examinations of small scale processes. There is no unified model, and, likewise, no single family of observations, that enables us to address fully the coastal domain. Given the diversity of scales, a suite or a hierarchy of coupled models (nested in turn) will be needed to properly capture the variability inherent to some observations, each with suitable resolution.

Although models represent our best strategy to integrate data, generate and test hypotheses, and make predictions, there are numerous challenges to coastal modeling. These include the different spatio-temporal scales of products relevant to different submodels (for example coastal flooding and the impact of bacterial blooms for development of anoxic conditions), incorporating the widely different response time and memory of various components, characterizing the error in instantaneous measurements and in their time-integrated products, and quantifying the impact of error propagation between submodels.

Data assimilation is a family of techniques to improve estimates of geophysical quantities by combining models and observations. Data assimilation can integrate data from different sources and times into a common model-driven framework. The model estimates spatio-temporal fields for regions and variables where minimal data are available. As discussed in the next section, data assimilation is particularly valuable in bringing disparate observations to bear on a common problem in order to achieve the best analysis that is consistent with all the available information and for the model formulation. This is an approach that should be readily embraced during implementation of the Coastal Theme.

4.3 SPECIFIC APPROACHES FOR INTEGRATING OBSERVATIONS FOR THE COASTAL DOMAIN

Here we present some specific approaches towards effective integration of coastal observations, focusing on the land-sea interface as well as linking *in situ* with remote observations, and natural science with social science data. Specific recommendations are presented for activities that leverage and build on existing tools and capabilities to support user needs (see summary in Table 4.2).

Table 4.2. Specific Approaches to Data Integration (see text for specific details): Bringing together disparate data sets

***IN SITU* WITH REMOTELY SENSED DATA**	• Expanded use of data assimilation techniques to accurately characterize the 4-dimensional variability of the coastal environment • Need to develop integrated CODAS (COastal Data Assimilation System)
LAND & SEA DATA	• Link and improve global land and ocean data assimilation efforts through an integrated high resolution CODAS using catchment-coastal basins as hydrologically linked geospatial units • Improve shoreline mapping = Tidal monitoring + Hydrodynamic models + Vertical Datum Transformation tool (VDatum)
SOCIAL & COASTAL ENVIRONMENTAL DATA	• Support GIS-based simulation modeling, e.g., Dynamic & Interactive Vulnerability Assessment (DIVA) tool • Leverage conceptual models, e.g., Driver-Pressure-State-Impact-Response (DPSIR) model • Develop an Integrated Coastal Decision Support System: ICoDSS • Initiate pilot projects to develop capabilities: e.g., impacts of urbanization or inundation on coastal ecosystems & populations.

Integrating In Situ and Remote; Land-Sea Data

Knowledge challenges for integration of *in situ* & remote and land & sea data include: (1) bridging different disciplines and/or approaches; (2) accommodating the vast amounts of disparate satellite observations; (3) accounting for uneven distribution of *in situ* measurements within and between regions; (4) evaluating measurement bias or uncertainty (from instruments, algorithms, or sampling) associated with the disparate data sources and types; and (5) the difficulty of linking land and sea data specifically at the interface.

There are a number of approaches, particularly data assimilation techniques that can foster improved understanding and management of coastal regions by integrating atmospheric, terrestrial, and oceanic data acquired from *in situ* and remote assets into a common analysis framework.

There are numerous examples of successful incorporation of remotely sensed and *in situ* data in geophysical studies without explicit data assimilation schemes. Models of sediment delivery on continental shelves and biological studies of nutrient uptake and primary production and their response to environmental forcing such as El Niño have highlighted the value afforded by scaling up *in situ* values through the synoptic views afforded by satellite sensors (e.g., Kudela and Chavez, 2000; Smith et al., 2003).

Through explicit data assimilation methods, models can integrate a wide range of routine observations from *in situ* or remote sensing platforms, allow the use of imperfect or proxy measurements, help fill gaps in time or incomplete coverage, and provide a quantification of errors. Through inverse models, observations can be converted into the desired quantities, such as sources and sinks or key driving parameters that may not be directly measurable or are unobservable at a particular scale. In addition, through coupling and nesting, models can encompass the necessarily wide range of spatial and temporal scales to quantify sources, sinks, and fluxes. Thus, they provide an efficient means to optimize the design of cost-effective observational strategies. Studies will be encouraged that develop an integrated approach encompassing both modeling and observations to address coastal questions and issues (see below).

The Global Ocean Data Assimilation Experiment (GODAE, 2001) presently uses data assimilation to provide near-real-time estimates of the three-dimensional physical state of the ocean. Recently there has also been considerable discussion of extending this pilot project and developing a Coastal Ocean Data Assimilation Experiment (CODAE) that provides significantly higher resolving capabilities to better address coastal ocean physical variability. Biogeochemistry and coupling with the terrestrial system remain key challenges. Assimilation of biogeochemical data is still in development. Regarding coupling with land, the primary interface with terrestrial modeling is through the hydrological cycle. The land component of the hydrological cycle might be obtained from existing or planned efforts, e.g., Land Data Assimilation Systems (http://ldas.gsfc.nasa.gov/), or the IGBP Global Land Project (GLP). Outputs from these efforts can potentially be utilized to initialize coupled land-coast models.

In this context, existing and planned land efforts should be nominally linked with GODAE and the envisioned CODAE using watershed and associated coastal basins as geospatial units to verify, for example, the material fates and transformations obtained from efforts discussed above. Along these lines we propose the development of an integrated **COastal Data Assimilation System (CODAS)** that would bring together the land and sea domains across the coastal in-terface. Scientifically, CODAS would help characterize the variability of the coastal environment, identify sources and sinks of loadings, aid in confirming the mechanisms causing sources and sinks, and, ultimately, increase the credibility of prediction of the coastal system. An initial demonstration could be the impact of coastal urbanization (e.g., changes in land cover/land use and impacts on runoff/loadings) in the context of climate variability (e.g., ENSO events). Ultimately, CODAS would function operationally to provide data and information products (short-term forecasts of coastal states for immediate use in fisheries, hazard management, coastal infrastructure planning, navigation, etc.) in real-time to support crucial management decisions for a multi-use domain. Steps towards formulation and implementation of a CODAS will be described in the next chapter.

Regarding the specific challenge of linking land and sea data exactly at the interface, the merger of topographic and bathymetric data produced from traditional surveys into coastal digital elevation models is now possible with the development of a vertical datum transformation tool (VDatum) developed by the joint NOAA-USGS Bathymetric/Topographic Shoreline Demonstration Project (Millbert and Hess, 2001). The tool has been applied to a number of demonstration sites with the goal of extending the VDatum transformation database (http://nauticalcharts.noaa.gov/csdl/vdatum.htm) to cover US coastal areas (Figure 4.2). Application of the VDatum to produce accurate shoreline and coastal mapping in other countries requires prior efforts at tidal monitoring and development of hydrodynamic models for representative coastal areas. The protocol itself provides a common geospatial framework to merge existing topographic and bathymetric surveys which many developing countries primarily depend upon for their coastal mapping needs.

Figure 4.2. Example of mapping using VDatum tool: A 1-arc-second seamless topographic/bathymetric digital elevation model for Tampa Bay, Florida.

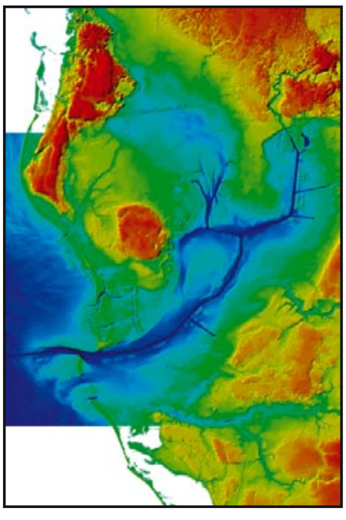


Image credit: NOAA-NOS/USGS. Source: http://nauticalcharts.noaa.gov/BathyTopo/welcome.html

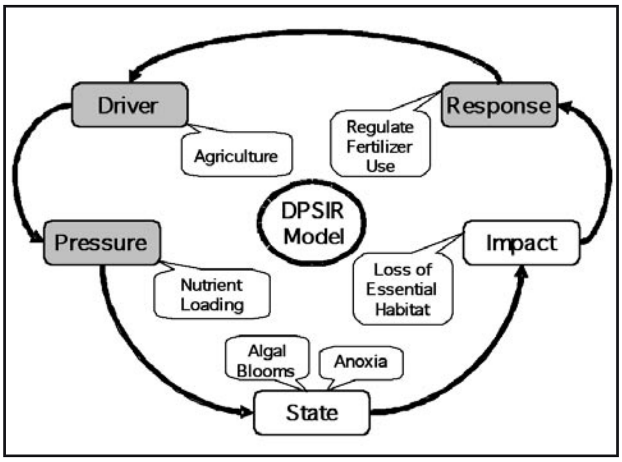
Apart from mapping, work focused on understanding processes such as material delivery from land to sea at the global scale exemplify interesting approaches in data fusion (Syvitsky et al. 2002). The quality of sediment delivery models improves when they are linked and informed by global environmental data sets. The model results are better able to reflect the heterogeneity in time and space as influenced by climate, land, and sea processes.

Merging Social and Coastal Environmental Data

Advances in modeling and sensor/platform technology are enabling rapid progress in efforts to integrate *in situ* data for land and sea with satellite data, and making them available to users. Indeed, this is an ideal time for observing systems to realize these levels of data integration, particularly in combination with socio-economic data and information.

A GIS-based tool, the Dynamic and Interactive Vulnerability Assessment (DIVA), developed as part of a larger EU project, has proven useful for decision-makers (http://www.dinas-coast.net/). A simulation model ingests information from the natural and social sciences contained in an external GIS database, and a graphical user interface (GUI) allows users to select data, prescribe scenarios, run model simulations, and to analyze results (Hinkel and Klein, 2003). Flooding resulting from sea-level change and storm surges, the value of different wetland types as a function of GDP, population density and wetland area, direct and indirect erosion in tidal basins, and socioeconomic impacts of geodynamic changes are some of the variables that can be addressed with DIVA based on user-prescribed scenarios. The flexible design allows for ongoing evolution as more data and increased understanding becomes available. DIVA and other similar GIS-based tools need to be further developed and become more widely utilized.

Figure 4.3. Example Schematic of the Driver-Pressure-State-Impact-Response Model: Impacts of agricultural practices.



Note: Drivers describe large-scale patterns of human activity, e.g., agricultural practices and the use of fertilizers in a drainage basin. The resulting pressure is increased nitrogen and phosphorus loading which change the state of coastal marine ecosystems by causing algal blooms which lead to oxygen depletion (anoxia) in bottom water. Algal blooms result in the loss of sea grass beds and benthic habitats reducing the carrying capacity of the marine ecosystem for living resources and associated declines in fish landings or consumer demand (impact). Government institutions respond by regulating the use of fertilizers by agriculture (driver) to control nutrient loadings (pressure), etc. In this example, all of the arrows are one way. However, feedbacks (2-way arrows) often occur among compartments. For example, the driver (agriculture community) may fight the passage of laws to regulate fertilizer use (response) resulting in a different outcome. Grey compartments indicate human activities that have social and economic consequences. White compartments indicate environmental conditions.

On a less specific level, a conceptual framework that links policy in response to changing environment states and oriented towards desired environmental targets can be used to array data prior to developing database and modeling architecture. In this context the (Socio-economic) Driver – (Environmental) Pressure - (Environmental) State – Impact - (Policy) Response framework (DPSIR) discussed earlier can provide significant insight (Turner et al 1998). Both quantitative and qualitative models can be used to elucidate each component of the DPSIR framework. An example of DPSIR application is provided in Figure 4.3.

Building on the models and tools described here and in the previous section, the next step is to couple these elements and develop an **Integrated Coastal Decision Support System (ICoDSS).** The envisioned ICoDSS would provide coastal users with high resolution, cross-boundary, and easily accessible retrospective and appropriately timed (~near-real-time or better) data and information, as well as robust short-term and long-term predictions, to support improved coastal understanding and management. The envisioned ICoDSS would be web-based and bring together multi-sensor satellite and *in situ* data streams and coupled models across the coastal interface (e.g., CODAS) with easy to manipulate information query and download capabilities and user-defined scenarios. Precursors of such a system currently exist as large-scale assessment tools. As discussed earlier, DIVA is a modeling tool primarily designed to assess coastal vulnerability to sea-level change at national to global scales (McFadden et al., 2003). With its innovative data flow architecture, it has the potential to assimilate data in various formats from a variety of sources and disciplines, and may be reconfigured to assess other environmental stressors. Although it cannot currently be used as a local planning tool given a relatively coarse resolution, it provides a valuable blueprint for ICoDSS, which aims to support local-scale decision processes as well as large-scale assessments.

Looking Ahead...

Data integration requires the collective will of traditionally disjoint institutions and mandates. It will not occur without directed changes to break down barriers that prevent data and information exchange between organizations and between countries. It will demand innovative design of and committed compliance to data standards, formats and etiquettes of data exchange and networking. Beyond improved scientific understanding, policy has to both support and desire the data integration, which lies at the core of an integrated global observing system for the coast.

Prototype development efforts and pilot projects that work toward these goals will be described in the next chapter. Focusing on the interfacial issues identified earlier (e.g., coastal hazards; coastal urbanization and development), these activities will leverage and build on the models, tools and capabilities previously described towards eventual development of a CODAS, and more broadly, an ICoDSS, in support of diverse coastal user information and decision-making needs

This chapter describes the institutional arrangements for implementation of the Coastal Theme, as well as development of workshops, prototype efforts and pilot projects toward addressing the priority needs identified in earlier chapters. It addresses linkages with the emerging GEO process as well as other IGOS Themes, articulates the need for capacity building, presents an action plan and schedule, and finally proposes a plan for leadership, assessment and feedback.

5.1 INSTITUTIONAL ARRANGEMENTS FOR IMPLEMENTATION

Internationally, the implementation of the Coastal Theme will be jointly led by GOOS and GTOS (Figure 5.1), through their respective scientific steering committees. Letters of support and commitment to facilitate theme implementation are appended at the end. In particular, the Strategic Implementation Plan for the Coastal Module of the Global Ocean Observing System (IOC, 2005), recently approved by the Intergovernmental (IOC-WMO-UNEP) Committee for GOOS, highlights the Coastal Theme and the need to implement its recommendations. Similarly, the Coastal GTOS Strategic Design and Phase I Implementation Plan was recently published (http://www.fao.org/gtos/gtospub/pub36.html) and likewise discusses the need to promote development of the IGOS Coastal Theme and facilitate its recommendations. In turn, the Coastal Theme will complement and support present and future activities of the coastal modules/components of GOOS and GTOS as well as promote and strengthen their mutual integration.

In terms of supporting infrastructure, the coastal modules/components of both GOOS and GTOS have identified existing networks and structures among data and service providers as well as among end users from local to global scales. The GOOS Regional Alliances and GTOS regional programmes are prospective implementing bodies on a regional scale. Pilot projects are critical to the implementation of the coastal components of both GOOS and GTOS. Priority projects that will accelerate implementation of the Coastal Theme have been identified by the respective coastal panels as follows:

Coastal module of GTOS: Current priority and pilot projects of C-GTOS will provide foundation for many of the intended products of the Coastal Theme. One such project, the World Deltas Network, focuses on deltaic ecosystems, their dynamics and functionality (http://cires.colorado.edu/science/pro/wdn/). A second project, SeaNet, builds on efforts to organize networks on coastal lagoons in countries of southern Europe (e.g., Lagunet in Italy; http://www.dsa.unipr.it/lagunet/). SeaNet will organize a network for lagoons and estuaries bordering the Mediterranean Sea to assess impacts of human activities on the delivery of materials to the Sea. Monitoring of coastal sites within international cultural and conservation networks is also being fostered by C-GTOS. Specifically, plans to enhance the capacity to monitor for the Convention on Biological Diversity within coastal sites of Ramsar Wetland, World Heritage, and Biosphere Reserves are underway. These efforts all cross the land-sea interface. The GTOS web-based tool, TEMS, links to these and other networks, and its parent sponsor, FAO, has other programmes that will complement the Coastal Theme activities.

Coastal component of GOOS: A high priority pilot project for the coastal component of GOOS is the South American Antares Project (http://home.antares.ws/) to establish a coastal network for comparative ecosystem analysis and the creation of a common database that will be used to validate and improve algorithms for retrieving oceanographic information by remote sensing including Visible Spectral Radiance (VSR, i.e., ocean colour), Sea Surface Temperature (SST), and ocean vector winds.

Contributions from other partners will aid in implementation. Global change research projects such as LOICZ and IMBER will provide additional implementation support through coastal process studies, regional and global assessments and attendant tool and capability development towards improved scientific understanding and subsequent knowledge transfer for societal benefits.

As part of the Coastal Theme implementation process, there is a recognised need to establish a mechanism for intergovernmental coordination and technical support for integrated coastal observing comparable to the IOC/WMO Joint Commission on Oceanography and Marine Meteorology (JCOMM). Whether this entails creation of a new joint commission for coastal observations or the identification of an existing body for this purpose is presently under consideration. In terms of a potential new body, discussions are underway regarding the potential formulation of a Joint-Panel for Integrated Coastal Observations (J-PICO), with resolution expected in the foreseeable future.

In the interim, the Coastal Theme will be implemented with personnel and programmatic leadership and support

Figure 5.1. Institutional Arrangements: Implementation of the Coastal Theme will complement existing GOOS and GTOS coastal activities while facilitating their integration.

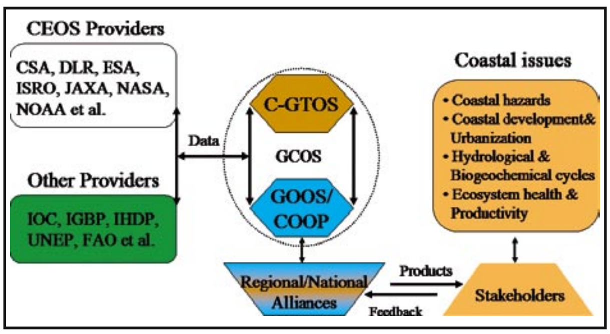


Table 5.1. Initial Coastal Theme Implementation Team: Broad representation from the coastal community.

LEAD	Robert Christian	C-GTOS
	Tom Malone	GOOS
CEOS REPS	Eric Bayler	NOAA/CEOS
	Paul DiGiacomo	JPL-NASA /CEOS
	Hiroshi Kawamura	JAXA/CEOS
	Peter Regner	ESA/CEOS
USER REPS	Arthur Dahl	UNEP
	Julie Hall	IGBP/IMBER
	Liana Talaue McManus	IGBP-IHDP/LOICZ
	John Parslow	Australia CSIRO
RESOURCE SUPPORT	GOOS, GTOS, IGBP, NASA, NOAA, ESA, JAXA	

from its lead IGOS Partners, i.e., CEOS (including NASA, NOAA, ESA, JAXA) and IGBP-IHDP LOICZ in addition to GOOS and GTOS. Membership of the initial Coastal Theme Implementation Team is detailed in Table 5.1. Aside from providing support for this team, resources have been pledged by several of these IGOS Partners to conduct workshops in the foreseeable future towards developing the needs and capabilities identified earlier (see Section 5.2). To ensure a user- and issue-driven participatory process, these workshops and developmental efforts will ideally be undertaken under the auspices of a Coastal Theme Community of Practice (CoP), to be developed as part of the GEO process (see Section 5.3).

5.2 COASTAL THEME WORKSHOPS AND DEVELOPMENT OF PROTOYPE EFFORTS AND PILOT PROJECTS

The Coastal Theme will coordinate and implement several international community workshops to link data providers with data users and develop necessary tools and capacity. Three initial overarching workshops are envisioned to spur development of related pilot projects by the broad coastal user community.

The first workshop will be on: **Coastal development and urbanization: Human health and ecosystem impacts**.

Increases in coastal urban population, as well as pesticide and fertilizer use for agriculture, in coastal catchments and floodplains have led to rapid and accelerating increases in loads of sediments, nutrients and pollutants and pathogens into coastal waters. These pose serious risks for human and ecosystem health, directly through exposure to pollutants and pathogens, as well as indirectly e.g., harmful algal blooms. In addition, material fluxes have significant impacts on key coastal habitats, ecosystem function, biodiversity and associated ecosystem services and renewable resources. These local pressures will likely be compounded by global change impacts in coastal systems. As such, this workshop will provide an end-to-end forum for data providers and users to interact on these issues and identify necessary observing and decision-making approaches. Plenary sessions and focused workshops will be used to:

- **Facilitate** linkage of space-based observations, *in situ* measurements and models with studies focusing on the impacts of coastal development and urbanization on human and ecosystem health, particularly water quality;
- **Promote** development of land-sea data assimilation schemes, building towards an integrated CODAS prototype with operational nowcasting & forecasting (short & long term) capabilities to support users;
- **Support** development of standardized user interface tools (e.g, GIS) and integrated decision support systems for coastal management (e.g., ICoDSS) that can be used for both short-term decisions (e.g., beach closures, HAB alerts), as well as long-term planning.

From this workshop, it is anticipated that several "coastal development and urbanization" pilot projects will be articulated for subsequent development efforts, focusing on both developed and developing urban coastal regions. These efforts will be pursued by a broad suite of IGOS and other global, regional and local partners, ideally under the umbrella of a GEO Community of Practice (see Section 5.3).

These "coastal development and urbanization" pilot projects will also be linked and developed in conjunction with two other planned Coastal Theme workshops and their subsequent development efforts, one on: **Developing a multi-hazard alert and forecasting system for coastal regions**; the other focusing on: **Catchment state and coral reef environmental health**.

The "coastal hazards" workshop will provide a framework for specifying observing system requirements for observations and models based on the data and information needs of specific users (flood plain managers, emergency response organizations, coastal zone managers, resource managers, environmental protection ministries, etc.). Coastal flooding caused by tropical storms, tsunamis and extratropical storms is an ever-present threat to low-lying, coastal regions globally. The recent tsunami and hurricane disasters, predictions of acceleration in the rate of rise of global sea level and possible climate change scenarios have led to increased public concern about more severe flooding over the coming century. As such, the general purpose of pilot projects initiated under the coastal hazards workshop framework are to build a multi-hazard alert and forecasting system that will provide data and information needed to address the following broad goals:

- **Provide** the data and information needed for more effective warnings of the time-space extent of coastal flooding caused by natural hazards (short-term forecasts and disaster response);
- **Provide** the data and information needed to more effectively mitigate and manage impacts of coastal inundation on coastal communities (socio-economic impacts), coastal marine and estuarine ecosystems, and living marine resources (run-up and runoff impacts, post-event impact assessments); and
- **Build** capacity to address these goals globally.

Finally, the "catchment state/coral reef" workshop will examine the relationship between catchment state and neighboring coral reef environmental health. Alterations to environmental health are expected to provide a feedback to human activities in which ecotourism and integrated coastal area management would be instrumental in policy development targeting coral reef protection. A progression of links might be:

Catchment State > Water Quality > Reef Health > Economics > Catchment state, with each link being a product focus.

An example of where this could be specifically implemented is the Great Barrier Reef, twinned with sites in the Philippines or elsewhere, to provide an interesting scenario comparing developed vs. developing coastal states.

Prospectuses for these three Coastal Theme workshops will be circulated and used to solicit interest and participation from the broad coastal user community, as well as obtain additional support from interested sponsors and partners.

5.3 LINKAGES WITH GEOSS

As detailed in Table 5.2, there are strong linkages between the Coastal Theme priority user issues discussed in Chapters 2 and 3 and the GEO Societal Benefit Areas (SBAs). In fact, the Coastal Theme is responsive to all nine of the GEO SBAs. Further, the Coastal Theme activities proposed here address a significant number of the 2, 6, and 10 year work plan targets identified in the GEO 10-Year Implementation Plan (available at: http://earthobservations.org/). As such, efforts are presently underway to pursue development of a Coastal Theme GEO Community of Practice (CoP), a proposal for which was approved in the GEO II meeting (December 2005), to ensure that the Coastal Theme implementation activities and attendant partners will specifically address the user needs articulated in the GEO implementation plan. The workshops identified above are expected to be a significant step toward addressing these important user needs.

Table 5.2. Coastal Theme Linkages to GEO Societal Benefit Areas: Significant support opportunities exist.

IGOS COASTAL THEME		GEO
Priority User Issues		Societal Benefit Areas
Coastal Human Populations	1. Coastal Hazards	Disasters, Climate
	2. Coastal Development & Urbanization	Human Health, Water, Climate, Agriculture, Energy
Coastal Ecosystems	3. Hydrological & Biogeochemical Cycles	Water, Weather, Climate
	4. Ecosystem Health & Productivity	Ecosystems, Biodiversity

5.4 LINKAGES WITH OTHER THEMES

The Coastal Theme links well with all existing and developing IGOS Themes. In particular, it is benefiting from coordinated development and implementation with the Ocean Theme, which provides context and boundary conditions and facilitates nesting across multiple spatial scales. This linkage is primarily provided through GOOS. Other linkages with IGOS Themes are with the Water Cycle Theme (e.g., coastal hydrology and water quality), the Global Carbon Theme (e.g., coastal sources/sinks of carbon), the Geohazards Theme (e.g., coastal hazards such as tsunami impacts), and likewise with the anticipated Land and Cryosphere Themes. Joint Theme workshops (e.g., with the Water Cycle Theme on water quality) and other coordinated implementation opportunities will be identified and developed.

5.5 CAPACITY BUILDING

There is a special need to target the coastal-focused issues and problems of developing countries and regions that have not yet benefited from the rapid development of observing technologies, both *in situ* and space-based, as well as information management and decision support systems. Coastal freshwater resource management, coastal erosion (e.g., in West Africa), coastal vulnerability and disaster prevention (e.g., tsunami risk assessments and mitigation efforts), coral reef management (already addressed in the Coral Reef Sub-Theme), estuarine and delta pollution, are but a few of the issues of significance to developing countries that the Coastal Theme implementation will help address. The coastal modules/components of both GOOS and GTOS have proposed and ongoing initial projects to promote capacity building. Much of the effort in capacity building for C-GTOS is associated with land cover observations, classification and products, as discussed previously. These efforts provide specific opportunities for the Coastal Theme.

National capacity building should include in-country infrastructure to collect, store, process, analyze, use, and disseminate coastal observation data and information for use by national policy makers. This can take the form of simple interactive coastal information systems with GIS tools integrating data layers from project based *in situ* measurements and historical data, working towards the more comprehensive Integrated Coastal Decision Support System (ICoDSS). In key localities of coastal states, the need is for continuity of core measurements. All countries must enhance their capacity to utilize and integrate remotely-sensed data with *in situ* measurements through the development of modeling, computational and analytical skills among scientists at in-country institutions.

While the focus of capacity building is at the country level for coastal developing states, new capacities in coordination and policy making on coastal issues are also needed regionally and globally. This can provide context and connectivity for national efforts. For example land cover classification should be appropriate locally, but information should also be amenable to merging with regional and global datasets that allow for large-scale assessment efforts. Existing initiatives for capacity building for both space and Earth-bound observation systems can be used as models for delivering training and training products at appropriate scales.

5.6 ACTION PLAN AND SCHEDULE

2005

- Coastal Theme Report submission for publication by IOC
- Incorporation of relevant components of the theme recommendations into the strategic design and implementation efforts of the coastal modules of GOOS and GTOS;
- Establishment of initial Coastal Theme implementation team and first implementation team meeting;
- Wide distribution of the theme report and its recommendations among coastal stakeholders;
- Under the auspices of the GEO User Interface Working Group, develop a proposal for a Coastal Theme Community of Practice and work toward its implementation;
- Conduct joint workshop with the IGBP-IHDP LOICZ project on integrating socio-economic variables in mapping and modeling the material deliveries from catchment to coast during the LOICZ-II Open Science Meeting;
- Cross-link the Coastal Theme with relevant elements of other IGOS Themes, including the Water Cycle, Ocean, Global Carbon, Geohazards and Land Themes, as well as GEO Societal Benefit Areas.

2006-2007

- Publication of Coastal Theme Report by IOC;
- Continue to develop Coastal Theme Community of Practice under auspices of GEO;
- Establishment of a joint coastal observing oversight mechanism between GOOS and GTOS to link the efforts of their respective coastal components and draw on the experience and expertise of other IGOS Partners (e.g., CEOS, IGBP) to provide leadership for theme implementation;
- Facilitate CODAS and ICoDSS protoype development efforts through international community workshops that bring together data providers with the user community to develop priority pilot projects, coordinated under the auspices of GEO;
- Support development of sensors/platforms with the CEOS members that respond to the higher spatial, temporal and spectral resolution needs for coastal observing;
- Support the maintenance and reinforcement of *in situ* monitoring networks including tide and stream gauges and coastal mooring arrays;
- Support development of integrated land-coast-sea models for the major integrating processes in coastal areas and the pressures that threaten their productivity of goods and services and sustainability;
- Support development of improved global and regional satellite algorithms;
- Support building of a nested but integrated approach to data management and information product delivery that links global data centres and providers, regional programmes across the land-sea interface;
- Support development of capacity-building efforts to extend coastal observing to developing country areas, through efforts by the coastal GTOS and GOOS;
- Assemble examples of best practice in integrated coastal observations from those countries and coasts that are farthest ahead in this field, to show what can already be done with existing data and imagery, as a basis for wider replication;
- Identify the appropriate geographic units for operational coastal observing based on ecosystem processes and biological exchanges, coastal sediment transport, coupling to large marine ecosystems, socio-economic and political groupings, and other integrating factors;
- Promote research, development, and operational efforts that integrate terrestrial and coastal aquatic phenomena, especially germane pilot and proof of concept projects identified by the coastal modules/components of GOOS and GTOS;
- Stimulate research on poorly resolved coastal processes, phenomena and user issues.

2008-2010

The next three years should see the following steps in implementation:

- Implement a three year CODAS and ICoDSS phase to demonstrate the feasibility of assimilation, integration and dissemination of high resolution, multi-sensor/platform, satellite and *in situ* coastal observations and derived information products on a large scale;
- Strengthen the socio-economic component in coastal observing to demonstrate cost-effectiveness and to provide the basis for wider public education and stakeholder involvement in coastal protection and management;
- Continue development of capacity-building efforts to extend coastal observing to developing country areas,

through integration of efforts by the coastal modules/ components of GOOS and GTOS;

- Revision of the Coastal Theme Report after 5 years to incorporate the experience acquired and to refine the necessary observing requirements (e.g., Table 3.4).

2011-2014

- Assess the functionality and benefits from CODAS and ICoDSS as the basis for designing operational coastal observing programmes and support systems in different coastal regions, in response to user demand;
- Assess research activities and proposal of new research on priority issues blocking effective information for decision-making;
- Increasingly implement operational coastal observing programmes on a regional basis;
- Assess adequacy of measurements and recommendations for priority revisions and needs for continuity of measurements in the coastal zone;
- Continue development of capacity-building efforts to extend coastal observing to developing country areas, through integration of efforts by the coastal modules/ components of GOOS and GTOS;
- Second revision of the Coastal Theme Report after 10 years.

5.7 LEADERSHIP, ASSESSMENT, AND FEEDBACK

As the Coastal Theme addresses boundary issues relevant to GOOS, GTOS and other programmes and observing systems, leadership in implementing the Coastal Theme should be shared by implementing bodies identified by each. Each should develop mechanisms to link their efforts in the coastal zone using the Coastal Theme Report as a guide and drawing on the experience of the IGOS Coastal Theme Team. They will need to decide which system will take the lead on which aspects of coastal observation, and how the results will be integrated. The GOOS and GTOS regional alliances and programmes will be particularly useful in developing governmental support and institutional arrangements for coastal observing.

The regional programmes will provide the mechanism for assessment of progress in implementing the theme, reporting to both the GOOS and GTOS Steering Committees. These scientific steering committees will then contribute both personnel and information to an integrated Coastal Theme working group or panel and the broader IGOS and GEOSS efforts. Indicators of success will include prototype development of an integrated data assimilation system (CODAS) and the increasing production and distribution of integrated coastal information products through an Integrated Coastal Decision Support System (ICoDSS). A formal review and update of the Coastal Theme Report should be made every 5 years.

Other institutions and programmes that will have a role in implementation include the various UNEP and UNESCO programmes, as well as the germane Conventions, which can provide a legal framework for intergovernmental collaboration in the coastal zone. The Coral Reef Sub-Theme Report identifies a number of institutions responsible for coral reefs that are collaborating in implementing that component of the Coastal Theme. Other partnerships around large marine ecosystems, or other coastal ecosystems such as mangroves and seagrasses, will also need to be involved.

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ADCP – Acoustic Doppler Current Profiler
ASTER – Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATI – Along-track Interferometry
AVNIR – Advanced Visible and Near-Infrared Radiometer
BRGM – Bureau de Recherches Geologiques et Minieres
CalCOFI – California Cooperative Oceanic Fisheries Investigations
Cal/Val – Calibration/Validation
CEOS – Committee on Earth Observation Satellites
C-GTOS – Coastal-GTOS
CITES –Convention on International Trade in Endangered Species of Wild Fauna and Flora
CODAE – Coastal Ocean Data Assimilation Experiment
CODAS – COastal Data Assimilation System
CoP – Community of Practice
CSA – Canadian Space Agency
DEM – Digital Elevation Model
DIVA – Dynamic and Interactive Vulnerability Assessment
DLR – Deutschen Zentrum für Luft und Raumfahrt (German Space Agency)
DMSP – Defense Meteorological Satellite Program
DPSIR – Driver-Pressure-State-Impact-Response
EEZ – Exclusive Economic Zone
ENSO - El Niño/Southern Oscillation
ESA – European Space Agency
ETM – Enhanced Thematic Mapper
EU – European Union
FAO – Food and Agriculture Organization
GAW – Global Atmospheric Watch
GCOS – Global Climate Observing System
GDP – Gross Domestic Product
GEO – Geostationary Earth Orbits
GEO – Group on Earth Observations
GEOHAB – Global Ecology of Harmful Algal Blooms
GEOSS – Global Earth Observation System of Systems
GHRSST-PP – GODAE High-Resolution Sea Surface Temperature Pilot Project
GIS – Geographic Information System
GLOBEC – Global Ocean Ecosystem Dynamics
GODAE – Global Ocean Data Assimilation Experiment
GOOS – Global Ocean Observing System
GPS – Global Positioning System
GTOS – Global Terrestrial Observing System
HAB – harmful algal blooms
HF – High Frequency
ICoDSS – Integrated Coastal Decision Support System
ICSU – International Council for Science
IGBP – International Geosphere-Biosphere Programme
IGFA – International Group of Funding Agencies
IGOS – Integrated Global Observing Strategy
IHDP - International Human Dimensions Programme
I-LTER – International Long-Term Ecological Research
IMBER – Integrated Marine Biogeo-chemistry and Ecosystem Research
InSAR – Interferometric Synthetic Aperture Radar
IOC – Intergovernmental Oceanographic Commission
IOCCG – International Ocean Colour Coordinating Group
IR – Infra-red
ISRO – Indian Space Research Organisation
JAXA – Japan Aerospace Exploration Agency
JCOMM – Joint Technical Commission for Oceanography and Marine Meteorology
J-PICO – Joint-Panel for Integrated Coastal Observations
LEO – Low Earth Orbit
LISS – Linear Imaging Self-Scanner
LOICZ – Land-Ocean Interactions in the Coastal Zone
MEO – Medium Earth Orbit
MERIS – Medium Resolution Imaging Spectrometer
MODIS – Moderate resolution Imaging Spectrometer
MPI – Multi-Purpose Imagery
MW – Microwave
NASA – National Aeronautics and Space Administration
NGO – Non Governmental Organization
NIWA – National Institute of Water and Atmospheric Research
NOAA – National Oceanic and Atmospheric Administration
OCM – Ocean Colour Monitor
OLS – Operational Linescan System
OPs – Optical Properties
QA/QC – Quality Assurance/Quality Control
R&D – Research and Development
ROMS – Regional Ocean Modeling System
RS – remote sensing
SAR – Synthetic Aperture Radar
SBAs – Social Benefit Areas
SCAT – Scatterometry
SOLAS – Surface Ocean, Lower Atmosphere Study
SSH – Sea Surface Height
SST – Sea Surface Temperature
TEMS – Terrestrial Ecosystem Monitoring Sites
UN – United Nations
UNEP – United Nations Environment Programme
UNESCO – United Nations Educational, Scientific and Cultural Organization
UNFCCC – The UN Framework Convention on Climate Change
USGS – United States Geological Survey
UV – ultraviolet
VIS/IR – Visible/Infrared
VSR – Visible Spectral Radiance (i.e., ocean colour)
WCRP – World Climate Research Programme
WMO – World Meteorological Organization

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2nd November, 2004

Dr. Paul M. DiGiacomo
Scientist, Oceanography Group, Jet Propulsion Laboratory
California Institute of Technology, MS 300-323
4800 Oak Grove Drive
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Dear Liana and Paul,

Please, consider the Coastal Module of the Global Terrestrial Observing System (C-GTOS) as a full partner in the Coastal Theme of the Integrated Global Observing Strategy (IGOS). Organizers of C-GTOS and coastal programme of GOOS have worked together over recent years to help make their respective systems compatible and cooperative. Formal liaisons between organizing panels have been maintained and areas of interface identified. Integration of the programmes has been a goal, but each programme has had to evolve somewhat independently to address detailed issues within coastal marine waters and coastal land, wetlands and fresh waters. The IGOS Coastal Theme provides an essential mechanism for that integration.

Members of the expert panel for the development of "C-GTOS Strategic Design and Phase 1 Implementation Plan," including the two of you and me, have played an important role in also developing the Coastal Theme. The trans-interface issues delineated in the Theme's proposal are critical elements to the integration of the relevant observing systems. The Theme's proposal has included elements that C-GTOS intends to provide and elements required by C-GTOS. C-GTOS is committed to develop products for coastal human populations, land use and land cover, digital elevation maps, river discharge and associated transport of materials, and socio-economic conditions of coastal populations. These are all important elements of the Coastal Theme and its goals of assessing the impacts of humans on the sea and the sea on humans. Furthermore, CODAE provides a venue to achieve the beginnings of the integrative process, and C-GTOS will work toward establishing the project

In summary, please, consider that you have the full endorsement of C-GTOS for the IGOS Coastal Theme. We will work toward the success of the observing strategy with the resources available to C-GTOS.

Yours sincerely,

Robert R. Christian
Chair, CGTOS expert panel

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Dear Paul and Liana:

Implementation of the IGOS Coastal Theme will, for the first time, provide the sustained data and information required to understand and mitigate the effects of global climate change, extreme weather and human activities on ecosystems across the land-sea interface from coastal drainage basin to the coastal ocean. In this regard, implementing the Coastal Theme is critical to successful implementation of the coastal module of GOOS. Major goals of GOOS include reducing risks of coastal populations of exposure to natural hazards, sea level rise, and human pathogens and sustaining and restoring healthy coastal marine ecosystems and the resources they support. Rapid detection and timely predictions of changes in land-use and land-cover patterns and associated inputs of fresh water sediments, nutrients and contaminants are critical to achieving these goals.

Implementing the Coastal Theme will also promote interdisciplinary approaches ecosystem-based management of resources, environmental protection, coastal engineering and integrated coastal area management. In the process this will enable more effective data and information exchange among countries, disciplines, and public and private sectors.

Thus, it is with great enthusiasm that we endorse the coastal theme and commit to facilitating its implementation through the Coastal Ocean Observations Panel, the GOOS Steering Committee, and the Intergovernmental (IOC-WMO-UNEP) Committee for GOOS (I-GOOS).

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Your Ref.:

8 November, 2004

Dear Dr Talaue McManus and Dr DiGiacomo,

The Environment and Natural Resources Service of the FAO Sustainable Development Department strongly endorses the coastal theme of IGOS. The proposed theme is a unique opportunity to improve both the acquisition and quantification of data necessary to understand and better manage global and regional change in coastal areas.

For the first time, the implementation of this IGOS theme will provide the sustained collection of coastal information necessary to address environmental and socio-economic change in an often problematic area for earth observation systems and environmental management programmes. This difficulty is largely due to the heterogeneity of issues and habitats in coastal land and ocean areas; spanning both trans-sectoral impacts and trans-boundary issues.

FAO assists countries in sustainable development of their coastal resources, and the implementing of the IGOS coastal theme will be critical to these activities. In particular, important activities include: monitoring and prevention of environmental degradation, institutional capacity building, and the integrated planning and management of agriculture, forestry and fisheries sectors that are within, or influence, coastal areas.

In addition, FAO hosts the GTOS secretariat and, through the support of the NOAA GCOS programme office, has provided strong institutional and financial assistance to

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- 2 -

development of the GTOS coastal programme, and to integrate it with the coastal activities of GOOS and GCOS. The IGOS Coastal Theme will constitute an important framework for fruitful broad international cooperation, providing a necessary tool to harmonise G3OS (GOOS/GCOS/GTOS) activities, contribute to planned international programmes (e.g. GEO), and facilitate the availability of needed earth observations for conventions and international agreements with coastal mandates (e.g. WSSD and CBD).

We would like to take this opportunity to express our strong support for the development of the IGOS Coastal Theme and commit to its facilitation.

Yours sincerely,

Jeffrey B. Tschirley
Chief
Environment and Natural Resources Service (SDRN)

ACKNOWLEDGEMENTS

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The IGOS Partners

CEOS
Committee on Earth Observation Satellites
http://www.ceos.org

FAO
Food and Agriculture Organization of the United Nations
http://www.fao.org

GCOS
Global Climate Observing System
http://www.wmo.ch/web/gcos/gcoshome.html

GOOS
Global Ocean Observing System
http://ioc.unesco.org/goos/

GOOS/GAW
Global Observing System/Global Atmosphere Watch of WMO
http://www.wmo.ch

GOOS/GAW
Global Terrestrial Observing System
http://www.fao.org/gtos/

ICSU
International Council for Science
http://www.icsu.org

IGBP
International Geosphere-Biosphere Programme
http://www.igbp.kva.se/

IGFA
International Group of Funding Agencies For Global Change Research
http://www.igfagcr.org

IOC
Intergovernmental Oceanographic Commission
http://ioc.unesco.org

UNEP
United Nations Environment Programme
http://www.unep.org

UNESCO
United Nations Educational, Scientific and Cultural Organization
http://www.unesco.org

WCRP
World Climate Research Programme
http://www.wmo.ch/web/wcrp/wcrp-home.html

WMO
World Meteorological Organization
http:/www.wmo.ch

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