NEW ENGLAND CENTER
UNIVERSITY OF NEW HAMPSHIRE
REMOTE SENSING WORKSHOP REPORT
DURHAM, NEW HAMPSHIRE
OCTOBER 3-5, 2006

WORKSHOP ON REGIONAL NEEDS FOR COASTAL REMOTE SENSING

WORKSHOP REPORT

The National Office for
Integrated and Sustained Ocean Observations
Ocean.US Publication No. 16

Workshop on Regional Needs for Coastal Remote Sensing

Workshop Report

October 3-5, 2006
New England Center
University of New Hampshire
Durham, New Hampshire, USA

Steering Committee

Janet Campbell, Chair, University of New Hampshire
Mary Culver, NOAA/CSC
Paul DiGiacomo, NOAA/NESDIS
Dave Foley, University of Hawaii/JIMAR
Roger Gauthier, Great Lakes Observing System
Eric Lindstrom, NASA
Jon Malay, Lockheed Martin
Tom Malone, Ocean.US
Stan Wilson, NOAA/NESDIS
Workshop Coordinator: Josie Quintrell

Sponsored by:

National Aeronautics and Space Administration
National Federation of Regional Associations for Coastal Ocean Observing
National Oceanic and Atmospheric Administration
Ocean.US

Hosted by:

The Coastal Ocean Observing Center at the University of New Hampshire

University of New Hampshire

Table of Contents

Executive Summary

Challenges in observing the coastal zone have recently been documented in extensive detail (e.g., IGOS Coastal Theme, 2006; Christian et al., 2006, NRC, 2007). Most of the existing satellite assets are primarily globally-oriented and do not provide the spatial, temporal and/or spectral resolution and coverage for observing coastal regions (IGOS Coastal Theme, 2006). Other capabilities of interest to the coastal community such as detecting river discharge have not yet been developed and satellite data is not thoroughly integrated with other elements of coastal observing systems (Christian et al., 2006). More attention and resources are required, particularly to develop new and improved satellite-derived (or integrated satellite and *in situ*) products that users can readily incorporate into their decision-support systems or other applications. This will depend on the timely transitioning of research capabilities (e.g., NASA sensors) into user-driven operations (e.g., NOAA, regional programs). On top of all this, the continuity of many existing satellite capabilities is uncertain at best (GCOS, 2006).

This workshop examined the short and long term needs of the IOOS Regional Associations for satellite data and information for a variety of coastal users. Representatives from all 11 RAs met with representatives from NOAA, NASA and Ocean.US at the New England Center in October 2006. This report summarizes the findings of the workshop.

A combination of short term actions and long term planning is required. Remote sensing capabilities vary across regions. A first step is to enhance the regional remote sensing capabilities to address the needs of coastal users. Simultaneously, future satellite missions should increase the temporal, spatial and spectral resolution of the coastal zone.

Six broad recommendations emerged from the workshop:

1) ***Enhance regional capacity to address user needs for remote sensing products.***

2) ***Simplify access to data and products.***

3) ***Expand the role of airborne sensors to fulfill user needs.***

4) ***Develop compelling education and outreach material that demonstrates the power of remote sensing.***

5) ***Ensure continuity and enhance utility of existing and planned satellite observing capabilities and data streams.***

6) ***Develop and implement new and improved space-based observing capabilities that better resolve and sample the coastal zone.***

Implementation of these recommendations require coordination and collaboration among NASA, NOAA, Ocean.US and the IOOS Regional Associations.

Workshop Goals and Organization

Workshop Purpose and Goals

The purpose of this workshop was to identify and document the satellite remote sensing needs of the users in the 11 Regional Associations (RAs). The RAs are responsible for the development and coordination of the regional component of the Integrated Ocean Observing System (IOOS) on behalf of the users of the coastal marine waters, Great Lakes, trust lands, and territories of the United States. This workshop identified both the near-term and long-term needs of the RAs for satellite information to meet the needs of their users. The workshop was held at the University of New Hampshire (UNH) on 3-5 October 2006, with goals that included:

1. Documenting established requirements for coastal remote sensing on a regional basis;
2. Suggesting new and improved user-driven products;
3. Providing ideas for next-generation remote sensing capabilities.

Workshop Organization

Representatives from each of the 11 RAs gathered at the UNH for two and a half days to identify user needs and to put forth recommendations for how NOAA, NASA and the RAs could make short and long term improvements and investments to address remote sensing needs. In this context, representatives of NASA, NOAA and Ocean.US attended the meeting to listen and engage in the discussions. Prior to the workshop, each RA surveyed users in their region; this information was collected and collated by the workshop organizers and discussed at the workshop. Each RA also made a presentation at the workshop on regional needs, providing further context and insights for the group discussions.

Specifically, workshop attendees addressed the following questions for their region:

- Who are the current users of satellite remote sensing data and data products in your regions? How are they accessing the information and for what purposes are they using the data?

- How might coastal satellite products be used to fulfill IOOS societal goals? What type of products would be useful? What data fields are required? How many currently exist?

- What are the challenges for providing satellite data and data products to meet user needs? There can be several types of challenges:

    - ***Knowledge*** -- requirements for research and development for new technology, to integrate data sets and to transfer research to operational use.

    - ***Resolution/Coverage*** -- need for improved spatial, temporal and spectral resolution and coverage.

    - ***Continuity*** -- need to maintain existing capabilities and transition research and developmental (R&D) sensors and programs to operational and application use.

    - ***Integration*** -- need for advances in information technology to integrate, distribute, and archive satellite data, to integrate with *in situ* data, and for model assimilation.

- What solutions can be acted upon immediately? Which require longer timeframes?

- What are the major short-term actions to close the gaps between user needs and existing capabilities

Following the presentation of this information, workshop attendees were divided into two working groups and asked to 1) identify user needs and requirements for coastal satellite data and products; 2) determine how those needs compare with existing capabilities, and 3) recommend short-term and long-term actions to bridge the gaps.

Background

The coastal zone is a productive, dynamic and interfacial region where inputs from land, sea, air and people converge (IGOS Coastal Theme, 2006). Global, regional and local trends in natural processes and human demands on coastal ecosystems jeopardize their ability to support commerce, living resources, recreation and habitation. Timely, accurate and sustained observations across the land-sea interface from *in situ* and remote (satellite, airborne and ground-based) platforms, coupled within a modeling framework, are needed to detect and predict change (e.g., Malone and Hemsley, 2007). Satellites provide synoptic, frequent observations for many important coastal ecosystem parameters, mitigating weaknesses of *in situ* observing networks, e.g., coarse sampling, and complementing their strengths, e.g., broad and diverse parameter suite, measurements at depth (Christian et al., 2006).

Challenges in observing the coastal zone have recently been documented in extensive detail (e.g., IGOS Coastal Theme, 2006; Christian et al., 2006, NRC, 2007). With regard to space-based observations, continuity of many existing satellite capabilities is uncertain at best (GCOS, 2006). Furthermore, existing satellite assets are primarily globally-oriented and do not provide adequate spatial, temporal and/or spectral resolution and coverage for observing coastal regions (IGOS Coastal Theme, 2006). Other necessary capabilities have not yet been developed (e.g., river discharge). Finally, satellite data has not yet been thoroughly integrated with other elements of coastal observing systems (Christian et al., 2006). More attention and resources are required to develop new and improved satellite-derived (or integrated satellite and *in situ*) products that users can readily incorporate into their decision-support systems or other applications. Other challenges have been identified, including the need for timely transitioning of research capabilities (e.g., NASA sensors) into user-driven operations (e.g., NOAA). This workshop and report addresses these and many other important issues.

User Needs and Requirements

The IGOS Coastal Theme Report (IGOS, 2006) documents in detail coastal user groups and their associated information needs and observing requirements (primarily satellite-based). It provides an excellent overview from a global, overarching perspective. Here we focus on specific IOOS regional user needs, requirements, and applications as a logical follow-on to the IGOS report.

Users within IOOS regions presently utilize a variety of satellite data and products. All 11 regions reported using data from thermal (predominantly sea-surface temperature from AVHRR and GOES) and ocean color sensors (MODIS and SeaWiFS). In terms of ocean color-derived products, chlorophyll-a concentration for phytoplankton biomass represents the primary usage, but assessments of colored dissolved organic matter (CDOM) and total suspended matter (TSM) as well as primary productivity are also of significant interest to coastal users (including researchers, managers, and decision-makers) in support of a variety of near-real time and retrospective applications. Ocean vector winds (from QuikSCAT), sea surface height (presently from Jason), storms and clouds (from GOES), and land cover/use (from Landsat and other high-resolution sensors) follow sea-surface temperature (SST) and ocean color (chlorophyll-a) as products most used by regions. Other sensors/products are utilized to a limited extent within some regions. For example, synthetic aperture radar (SAR) data are used for coastal winds and pollution hazard studies in the Gulf of Mexico, Alaska, and southern California, as well as ice observations in Alaska, but general lack of access to these data prevents widespread usage (also generally infrequent temporal revisits for most areas, except Alaska).

Regional providers of remote sensing data and derived products utilize a variety of satellite platforms/sensors, the majority of which are federal assets operated or supported by NASA and NOAA. Some international data streams are accessed (e.g., OCM, MERIS, Radarsat), but to a very limited extent. Data and imagery may be processed and delivered by more than one source within a region, and the source may be a government agency, academic institution, or private industry distributor. For any given sensor, the products that are available from different sources may vary, e.g., due to the amount of (re)processing needed for product quality for a specified purpose, differences in the algorithm applied to generate a specific regionally-tuned product, geographic coverage, and data format.

Types of Users:

Current regional users range from sophisticated users (i.e., "super" users, typically from federal agencies and research institutions) that have the expertise and technical capacity to routinely access, process, and analyze multi-sensor satellite data from agency data streams, to intermittent lay users that require highly processed, derived, value-added products that can be easily viewed and incorporated into existing software or databases with minimal if any additional work. Specific categories of users include:

Researchers: By far the predominant group of users in all regions are researchers who utilize satellite data for a variety of purposes, including for analyses of ocean geophysical and biogeochemical processes and phenomena using synoptic satellite-derived fields, for model development, data assimilation and coastal forecasts, and to assist with strategic sampling and field work (habitat characterization, animal tagging experiments, feature tracking, etc). Amongst researchers there are various degrees of proficiency in using satellite data. Some merely have a cursory knowledge and only use the data occasionally; others fall into the "super" user category and are experts who use the data daily, often developing new algorithms, products, and capabilities for others to utilize and leverage.

Managers and Decision-makers: Management agencies have a broad range of experience and expertise utilizing satellite data, products and imagery, but for the most part this is still an emerging information source for them. Managers of living marine resources use satellite-derived information in support of a variety of applications, e.g., to study phenomena such as sea lion diving behavior, to understand larval recruitment and settlement, to characterize marine habitats for stock assessment purposes, to predict whale movement and behavior, to identify mesoscale conditions associated with mortality events, to monitor submerged aquatic vegetation (e.g., kelp forest canopies), and to track phytoplankton blooms, including harmful algal bloom (HAB) events. Some coastal managers and decision-makers use satellite data to track storms, as well as assess fate and transport of pollutant and pathogen-laden terrestrial runoff or oil/sewage spills and discharge. Higher-resolution MODIS data (250-500 m bands) are becoming an increasingly valuable and utilized resource for mapping and monitoring water quality parameters of interest in large estuaries. This category of users represents a tremendous opportunity for growth in terms of infusing satellite data and derived products into decision-support systems; training, education, improved regional products and other support are necessary to facilitate usage by these users.

Commercial and public users: A variety of commercial enterprises use oceanographic satellite data. Several private companies specialize in providing interpreted, value-added satellite products to other commercial or private users. Many in the fishing industry use multi-sensor satellite imagery to track ocean fronts, eddies and other features for locating fish or for navigation purposes. Both commercial and recreational mariners use satellite data for ocean and weather conditions, and the reinsurance industry is starting to use the data for determining risk. Expanding this sector and broadening the market for service oriented, value-added satellite data products would create a strong user pull beyond that which already exists.

Educators: Educators typically make use of processed and interpreted satellite data products and imagery in both formal and informal settings. The compelling images available from satellites provide powerful visualization tools for understanding ocean and coastal dynamics. There is a need for enhanced training and support for teachers to assist them in incorporating satellite imagery and analysis tools into their curricula.

Table 1 summarizes the major users identified by the regions, their purpose or need, and the general types of information, products or data required to fulfill those needs that are or can potentially be provided by satellite remote sensing. The user categories that were most often mentioned by the regions include: fisheries and aquaculture management agencies (noted by all regions as one of their top three users), state public health agencies, emergency responders, recreational users, and the shipping industry (primarily in the nearshore areas around ports and harbors). Researchers are listed last but comprise the largest group of users as noted above. Additional information on this subject can be found in Tables 2.1 and 3.3 of the IGOS Coastal Theme Report (IGOS, 2006).

Table 1: Types of Users of Satellite Remote Sensing Data

	Users	Purpose	Information
Managers			
Federal	Coast Guard	Search and rescue; Homeland security	Real-time currents, winds, waves for search and rescue models; vessel tracking
	Navy security	Homeland security	Real-time conditions; vessel tracking; tracking of aerosols; Ice maps
	NOAA-ports, navigation	Navigation safety	Surveying, bathymetry, water levels
	NOAA- NMFS	Fish response to environmental conditions; ecosystem-based management; hypoxia events	Feature (e.g., frontal) detection and identification; habitat assessments; seasonal and interannual ocean variability; primary productivity
State	Public health managers		
	Water quality	Pollution detection; fate and transport of pollutants and pathogens; monitoring	Water quality indicators/assessments (e.g., chlorophyll, turbidity/total suspended matter, color dissolved organic matter; other proxies for pollutants/pathogens); Pollution detection (slicks, oil, debris); plume tracking (river discharge); land cover/use change
	Shellfish sanitation	Consumer protection	Water quality indicators/assessments (as above); Early warning for HAB events
	Beaches	Safe swimming	Water quality status (particularly proxies for pathogens); Fate and transport of pathogens/pollutants for accurate, timely beach closure decisions
	Emergency response managers		
	Spills	Protection of resources; emergency preparation and response	Benthic habitats (present state, change, and impact analysis). Early warning of storm events; assimilation of data into trajectory models; real-time ocean conditions and marine weather for response
	"Natural" event response (storms, flooding, sea level rise)	Prediction of impacts; emergency planning and response	Benthic habitats; inundation models and maps; forecast of effects of sea level on habitat, coastal development; land cover/use change
	Tourism officials	Beach closures; storm events	Water quality standards; early warning of storm or pollution events
	Environmental managers	Habitat protection; pollution detection	Benthic habitats; coastal circulation patterns; pollution detection; impacts of sea level rise; indices and thresholds for management and mitigation response (water quality, hypoxia, upwelling)
	Coastal managers	Dredging, disposal and monitoring of dredge material; siting energy facilities (wind, liquefied natural gas, oil); hazard mitigation, cumulative impacts of coastal development	Benthic habitats; ocean patterns and circulation; ocean conditions and marine weather; inundation maps, shoreline topography; land cover/use change
	Fisheries managers	Fish response to environmental conditions; aquaculture siting	Benthic habitats; seasonal and interannual ocean variability; front identification; bathymetry and nearshore topography; primary productivity; ecosystem models

Local	Emergency managers	Planning and response for spill events, storm events	Bathymetry and nearshore topography; land cover/use change detection; habitat assessments; ocean conditions; marine weather; Event predictions; inundation maps
	Water utilities	Monitoring	Water quality indices; plume detection; coastal circulation
	Municipal treatment plants	Monitoring outfalls	Water quality indicators/assessments (e.g., chlorophyll, turbidity/total suspended matter, color dissolved organic matter; other proxies for pollutants/pathogens); Pollution detection (slicks, oil, debris); plume tracking
Industry	Reinsurance industry	Predictions of storm impacts; coastal development impacts	Ocean forecast; vessel tracking
	Legal, forensic, marine salvage	Recovery services	Historic ocean conditions
	Commodities trading		Ocean conditions, patterns, variability
	Local weather services	Local forecasts	Ocean conditions, marine weather
	New and media	Public education; reporting on current events	Ocean conditions, marine weather
	Energy industries – oil, gas, wind	Exploration, operations and emergency response	Patterns, ocean currents, ocean conditions, marine weather; ocean circulation
	Commercial fishing	Fish location, ocean conditions	Feature (e.g., frontal) detection; seasonal forecasts
	Power utilities	Emergency mitigation and response, power load estimates	Localized forecast of extreme events; sea breezes for power load estimates
	Shipping	Safe navigation, route planning	Ocean conditions, storm events; ice maps (concentration; thickness, movement)
	Aquaculture	Sighting and monitoring	Ocean conditions (exposure to waves); primary productivity; phytoplankton composition, oxygen concentration, upwelling events, sea ice coverage, water quality indicators/assessments (as above)
	Aviation services	Safe flight conditions	Ocean conditions and marine weather; vertical profiles of dust/ash in atmosphere
	Environmental consultants	Facility siting and permitting; environmental impact statements	Ocean conditions, patterns, habitats
Recreational Users	Cruise ships industry	Safe navigation and trip planning	Real-time ocean conditions (waves, wind, currents, temperature)
	Charter fishing boats	Safe navigation and fish location	Feature (e.g., frontal) detection; real-time ocean conditions (waves, wind, currents, temperature, visibility)
	Surfers	Surf conditions; safety	Wave height and period
	Sailors and motor boaters	Safe navigations; racing	Real-time ocean conditions (waves, wind, currents, temperatures)
	Recreational divers	Diving conditions; water quality	Water clarity, temperature, ocean conditions
Education	K-12, university, informal	Curriculum units, data, public displays	Packaged product to meet teaching standards, easily accessible data
Researchers	Satellite research, physical, biological and chemical oceanographers	Research data, preparation for field work, modeling	Geophysical, biological and biogeochemical satellite data for research and models; near real-time data for planning field experiments

* Ocean conditions = present/real-time accurate and absolute values for wave direction, wave height, currents, temperature, wind, salinity, biological water quality
* Marine weather = wind, pressure, dew point, water vapor, precipitation, temperature

Types of Products

Most satellite data/products are used by researchers and modelers for a variety of purposes. Routine use of satellite data and derived information products are still in the early stages for coastal managers and decision-makers. There is still often a gap between what data providers routinely produce and exactly what these particular users need. Generally speaking, most coastal end-users do not want basic data (e.g., normalized water leaving radiances or inherent optical properties from satellite ocean color sensors). Instead, they want derived, distilled and/or integrated products and fields (e.g., total suspended matter, phytoplankton biomass or productivity) and information (e.g., near-real time representations or predictions on fate and transport of runoff/spills or harmful algal bloom notifications). In some cases, proxies need to be developed and/or utilized to represent properties that cannot be measured remotely. For example, CDOM could serve as a tracer for salinity to assess terrestrial runoff or discharge until space-based (salinity) sensors with appropriate spatial resolution can be developed.

Further, for satellite data to be useful to the more general population, products should be delivered in a format that is easily interpreted, does not require specialized software to view or large capacity to download, and are accessible in a timely manner. Managers have a variety of staffing, financial and time constraints that often make access and interpretation of large satellite data sets difficult if not impossible. Remote sensing data incorporated into products and decision support systems provides interpreted information that would be of use to managers. These products may be used for near real-time assessments or for longer-term decisions. Indices are one example of using remote sensing to alert managers to changes in conditions that are detected by satellite sensors. Indices and threshold standards provide managers with a set of guiding parameters that have been vetted through scientific and public policy processes.

An analysis of the types of information that is requested by the user groups listed in Table 1 indicates that there are 5 major types of products that could be developed using existing or future satellite assets (alone or in concert with other remote and *in situ* data sets) to meet multiple needs. Representative examples are as follows:

1. **Near-real-time data and nowcasts for navigation, fisheries, aquaculture, water quality, scientific investigations, and other uses**
    - Ocean Conditions – including sea-surface temperature, vector winds, phytoplankton biomass and productivity, total suspended matter, waves, sea surface height, currents, fronts, et al.
    - Marine weather (wind, pressure, dew point, water vapor, precipitation, temperature) Feature tracking (blooms, plumes, vessels, shoreline)
2. **Early warning capacity for HABs, flooding, erosion, ice extent/coverage, et al.**
    - Data assimilation for models of movement, intensity, and effects for both short-term and seasonal forecasts
3. **Long-term trends and change detection for habitats (ocean, terrestrial and benthic), water quality, fisheries, land cover and land use, sea level rise, carbon and water cycles, and other climate change issues**
    - Trends in environmental conditions over time – requires climate-quality data records
    - Analysis of the impact of changing conditions
    - Cumulative effects of coastal development
4. **Indices, thresholds and proxies for management purposes**
    - Integrated data for status of conditions (acceptable/marginal/unacceptable)
        - o Water quality - HABs, assessments/ impacts of nutrient loading, pollutants/ pathogens, suspended particulate matter
        - o Dust/ash/aerosols in the atmosphere
        - o Pollution detection
5. **Education and visualization products for informal and formal audiences**
    - Curriculum units that are packaged w/ curriculum to meet teaching standards
    - Remote-sensing based maps of local area, including, for example, inundation and habitat maps

To create these derived products and meet the information needs of most users, a combination of remotely sensed data, *in situ* data, and models will be necessary. Remotely sensed data, particularly satellite data, provide synoptic information that is difficult to obtain from other sources. For the most part, satellites can only provide information for ocean surface waters and must be used in

combination with *in situ* data (from fixed or mobile platforms) to provide details about subsurface conditions. High resolution *in situ* measurements will be provided as part of the regional component of the Integrated Ocean Observing System. The regional components will be tailored to acquire process and provide access for the specific products and coastal issues of each region, spanning the needs of researchers, managers and decision-makers, commercial users, educators, and the general public. The physical, biogeochemical and ecosystem models that are expected to be developed under the auspices of IOOS will provide a predictive capacity of interest to many users within a region. Many of these models would benefit by having the ability to assimilate remote sensing data in near-real-time.

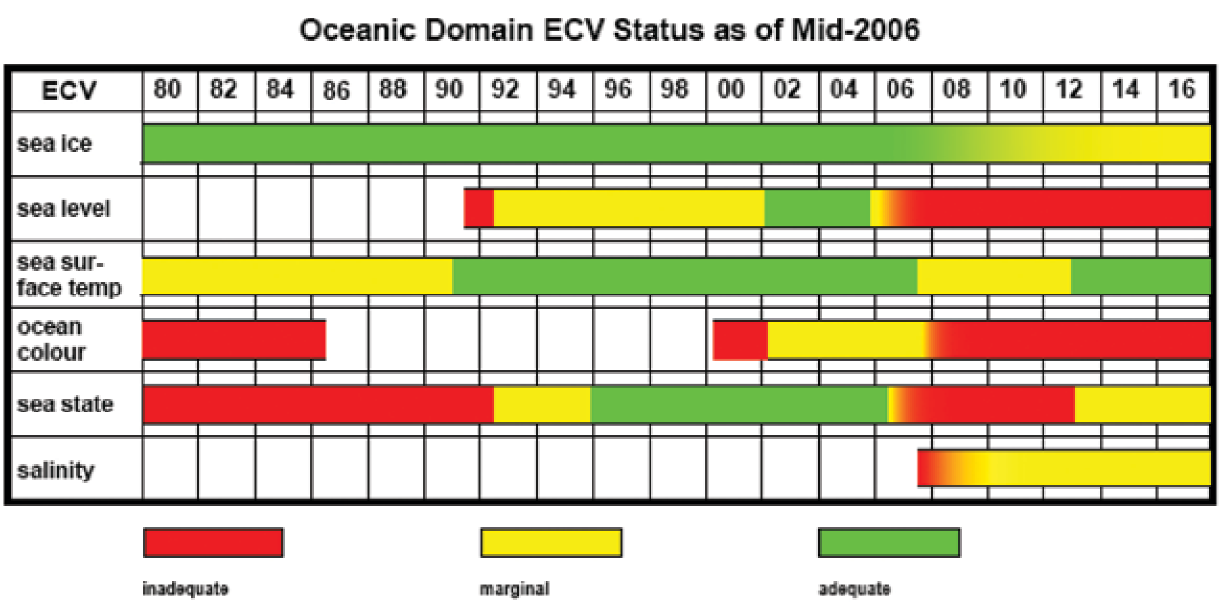
Challenges and Opportunities

Based on the findings from this workshop, as well as other recent assessments (Christian et al., 2006; IGOS Coastal Theme Report, 2006; GCOS, 2006; IGOS Ocean Theme Report, 2001, in revision), a comparison of existing capabilities and user needs reveals major gaps and challenges in satellite and other observations for the coastal zone. These challenges are broken into four categories: Continuity, Resolution & Coverage, Knowledge, and Data Management and Integration. These are addressed in greater detail for coastal regions in the IGOS Coastal Theme Report (2006).

Continuity

While researchers can develop algorithms to provide new and improved satellite-derived products and regional data providers can assist in providing access and facilitating use of these products, all are dependent on the space agencies to develop, launch, operate and maintain the satellites and sensors. A collective challenge for these agencies is to ensure continuity of satellite data streams and associated products in support of user needs. The transition from R&D to operational, shifts in agency program priorities and budget profiles, and delays or gaps in planned missions threaten the continuity of ocean and coastal data from satellites (see Table 2).

Table 2: Ocean Essential Climate Variable (ECV) Status, generated by the CEOS/GCOS Task Team in association with the GCOS-107 Assessment.



In some cases, foreign satellites may provide data and imagery that can be used to augment or replace U.S. capabilities (e.g., MERIS has 300-m spatial resolution suitable for coastal applications), but access to these data are often limited or restricted, with no guarantee of sustained accessibility or suitability (e.g., coverage), and in many cases there are significant hurdles that would need to be overcome in terms of their acquisition, evaluation, and subsequent use by U.S. regional users. For these and other reasons, there is a serious risk of losing access to satellite data that will affect the U.S. capability to understand and monitor ocean, atmosphere and land conditions. This is detailed further below in terms of anticipated U.S. capabilities.

In terms of biological, biogeochemical and ecological observations, ocean color continuity is facing a significant near-term risk given that continuation of the U.S. SeaWiFS commercial data buy is uncertain and the sensor has been in orbit for over 10 years as of this report. NASA's MODIS on both Terra and Aqua are already into extended mission operations, with only Aqua ocean color data currently being utilized due to issues with the Terra data. Furthermore, the first VIIRS sensor (NPP) will not be in space until 2009 (or perhaps 2010), with significant unresolved concerns as of this writing regarding the ability of VIIRS to meet ocean color requirements for operational users as well as for scientific research, especially for climate-related applications. On a related note, calibration and validation (cal/val) plans for VIIRS remain unclear. The future of the MOBY ocean color vicarious calibration site has transitioned to NOAA following ~10 years of support by NASA's R&D program. However, MOBY is currently not funded as part of VIIRS operations.

Regarding geophysical observations, thermal-IR SST measurements now provided by both AVHRR and MODIS will continue to be acquired from AVHRR and then VIIRS, and also from GOES platforms from geostationary orbit. There is also a need to sustain microwave SST measurements (continuing observations from TRMM/AMSR-E), transferring this into an operational capability with suitable coverage and resolution, helping mitigate data dropout due to cloud cover (albeit with limitations close to the coast). In terms of other near-term risks, continuity of U.S. ocean vector wind measurements is uncertain given that NASA's QuikSCAT mission is already well into extended operations, and also due to the termination of the CMIS sensor on the NPOESS (C1) platform, which was to provide an operational source of passive microwave wind measurements which would have been inferior to those provided by QuikSCAT (alternative, less capable options are being explored for NPOESS (C2), none of which will satisfy stated coastal user requirements). The upcoming launch of the Ocean Surface Topography Mission (Jason-2) will continue the Topex/Jason satellite altimetry series, but continuity for precision sea-surface height measurements beyond that is uncertain, particularly given that NPOESS no longer includes plans for an altimeter.

Continued and enhanced coverage for precipitation represents a significant need for a variety of coastal zone related applications. The upcoming Global Precipitation Measurement (GPM) mission and constellation, an expanded follow-on of the Tropical Rainfall Measuring Mission (TRMM) that will consist of a NASA/JAXA core spacecraft and international constellation satellites, is anticipated to provide improved spatial resolution, more frequent sampling, and extend precipitation measurements to higher latitudes.

In terms of sea-ice observations, there is a need to sustain ice concentration measurements from passive microwave (e.g., DMSP SSM/I and AMSR-E), ice extent/type from VIS/IR imagery (e.g., AVHRR, MODIS, DMSP-OLS), and scatterometer data (e.g., QuikSCAT) for research efforts and also in support of operational ice services (IGOS Cryosphere Theme Report, 2007). However, these data do not adequately resolve finer-scale details, particularly at the ice edge and near the coast as discussed further below. Continuity and sustained access to SAR data for U.S. users for sea ice monitoring, as well as for pollution hazard assessments and other applications, are in question as the U.S. does not have a SAR mission, and current access to foreign data is extremely limited with continuity not guaranteed.

Resolution and Coverage

Coastal zones are complex, dynamic regions, marked by extreme environmental heterogeneity and variability of geophysical and biological properties in time and space. Existing satellite assets are primarily globally-oriented and generally do not provide adequate spatial, temporal and/or spectral resolution and coverage for observing coastal regions. Coastal user needs for both research and management require that data be acquired at increased spatial, temporal, and spectral resolution. Small-scale changes can have major implications in the nearshore zone (e.g., river plumes moving alongshore and offshore; phytoplankton blooms in bays and estuaries that result in hypoxic events). Improved understanding, management and decision-making would result from synoptic satellite data that adequately resolve coastal processes and phenomena in time and space.

High temporal resolution SST and cloud observations are already available from the NOAA GOES series; the need and challenge are for higher spatial resolution observations. These might be provided by a higher resolution imager on a geostationary platform, or by improving the resolution of microwave sensors which can potentially overcome data losses due to cloud cover (subject to land "contamination" issues/limitations). In terms of other geophysical parameters, a significant challenge exists in terms of providing higher resolution/improved coverage for sea surface height measurements, such as from a wide-swath altimeter, to resolve mesoscale and other under-sampled oceanic features, particularly in coastal regions. A related challenge exists for ocean vector wind measurements to provide improved spatial, as well as temporal resolution observations to better support weather analysis and forecast requirements (including extreme, episodic events) as well as other applications (e.g., coastal upwelling and productivity, navigation, marine hazards and spill response, search and rescue). Improved ocean wind vector accuracy is needed for rainy conditions, at higher wind speeds, and in coastal regions. For sea-surface roughness measurements, SAR sensors (e.g., Radarsat) provide excellent spatial resolution. Temporal revisits and data access are typically poor, however, making it difficult to adequately observe and characterize coastal features and phenomena of interest (except at high-latitudes). Regarding sea ice observations, passive microwave and scatterometer-based products (~10-25 km) are too coarse to obtain fine-scale details of the sea-ice cover (IGOS Cryosphere Theme Report, 2007), particularly in the nearshore ice zone where scales of a kilometer or less are critical. AMSR-E has provided some improvement, but this still remains a significant challenge (IGOS Cryosphere Theme Report, 2007), particularly since higher-resolution optical measurements are frequently hampered by cloud cover. Additionally, enhanced spatial and temporal coverage is still needed from SAR sensors to better monitor variability in the ice cover (IGOS Cryosphere Theme Report, 2007).

With regard to ocean color, sub-diurnal temporal revisits on the order of 3 hours or ideally more frequently (hourly, or better) for observing dynamic regions and rapidly evolving and/or ephemeral ocean events would enable coastal processes and phenomena to be better characterized and monitored. This would help to resolve the effects of tidal cycles as well as mitigate losses due to cloud cover. Improved spectral resolution (>> 20 bands with narrow bandwidth and high signal-to-noise ratio) and coverage (broad spectral coverage across the UV, visible and near/shortwave IR) would enable improved atmospheric corrections as well as better discrimination of optical constituents for development of new and improved derived products that can be used to more effectively characterize coastal ecosystem dynamics (e.g., HABs, river runoff and sediment transport, primary productivity). Spatial resolution on the order of 100-300 m (versus ~1 km presently) is necessary for broad, synoptic observations of the U.S. EEZ, whereas an order of magnitude increase in resolution, i.e., ~10-30 m, is required to effectively study and monitor ecosystems and habitats at the land-sea interface, particularly small bays, estuaries, mangroves, kelp and sea grass beds. Existing high resolution sensors (e.g., Landsat) do not provide the necessary bands or radiometric sensitivity for coastal/ocean applications. The above gaps could be addressed by a geostationary hyperspectral radiometer working in concert with a high resolution ocean imager (an "ocean" Landsat) in low Earth orbit, providing a nesting of observations from global (~VIIRS) to regional to local scales.

This workshop/report is focused exclusively on satellite observations. For some uses, airborne sensors may be more appropriate than satellite sensors. Many state and local coastal managers presently rely on airborne sensors for the high resolution measurements they need for shoreline mapping, habitat mapping, inundation maps and other uses.   They often cobble together funding to collect the data over several years. At this point, airborne sensors are expensive and there is limited capability for routine monitoring of coastal ocean parameters. Hiring a private contractor to acquire and process data routinely is often prohibitively expensive. Alternately, agencies could utilize their own sensor(s)/aircrafts. Uniform calibrated standards would enhance the use of existing and developing technology for research or operational monitoring.

Knowledge Gaps

From the IGOS Ocean Theme Report (2001, presently under revision), "Knowledge" challenges or gaps require research and development (R&D) activities and greater data collection and analysis to address unmet observation needs and information gaps. Solutions to knowledge challenges involve R&D support to improve current observing capabilities (e.g., platforms, sensors, and algorithms), to fuse different types of observations to extract new/better information, and to develop entirely new observing capabilities, as well as to improve the transfer of technology and capacity to operational use. Results and benefits would include:

- Greater understanding of coastal processes and phenomena
- Development of new technology (e.g., sensors, platforms), data streams and products
- Improved data integration techniques and ability to mine data and translate data into information
- More effective coastal management and decision-making

As Table 3 indicates, many of the gaps for regional users call for an improved understanding of the links between the parameters that satellites can measure and geophysical, biogeochemical, and ecological processes and phenomena of interest in coastal regions. In this context, more extensive coastal R&D activities and greater transitioning from research to operations is necessary to address these needs. Technology development to measure new parameters from space is needed, including salinity at appropriate resolutions for coastal regions, synoptic surface currents, and river discharge, as well as to improve upon existing measurement capabilities for ocean/land color, ocean vector winds, sea surface height, et al. as addressed above. There is still a significant need for improved sea ice observations, especially in the nearshore ice zone, and also for model development. Sea ice thickness in particular represents a "holy grail" of sorts for the sea ice community (IGOS Cryosphere Theme Report, 2007), with suitable measurements needed from airborne and/or satellite platforms, particularly the anticipated launch of Cryosat-2 in the 2009 timeframe. Improved atmospheric corrections and cal/val approaches are needed for ocean color, as are development of new and improved regionally-tuned algorithms and also proxies developed for properties that cannot be directly measured from space. Finally, merged or blended data products for all parameters are needed to address issues such as cloud cover and other data dropouts, providing users with accurate, integrated products, with original source data still made available if requested.

In terms of an integrated observing system approach, per the IGOS Coastal Theme Report (2006), adaptive sampling capabilities need to be developed and refined whereby coordination between *in situ* and remote (satellite and/or airborne) observing assets enables a timely response to episodic coastal events. This could involve tasking mobile *in situ* assets (e.g., gliders) to target a certain location based on discontinuities observed in satellite data streams, or conversely using *in situ* sensors to identify interesting areas for dedicated, sustained observations by a geostationary imager. This will support improved understanding of coastal processes and phenomena, leading to more effective management and decision-making.

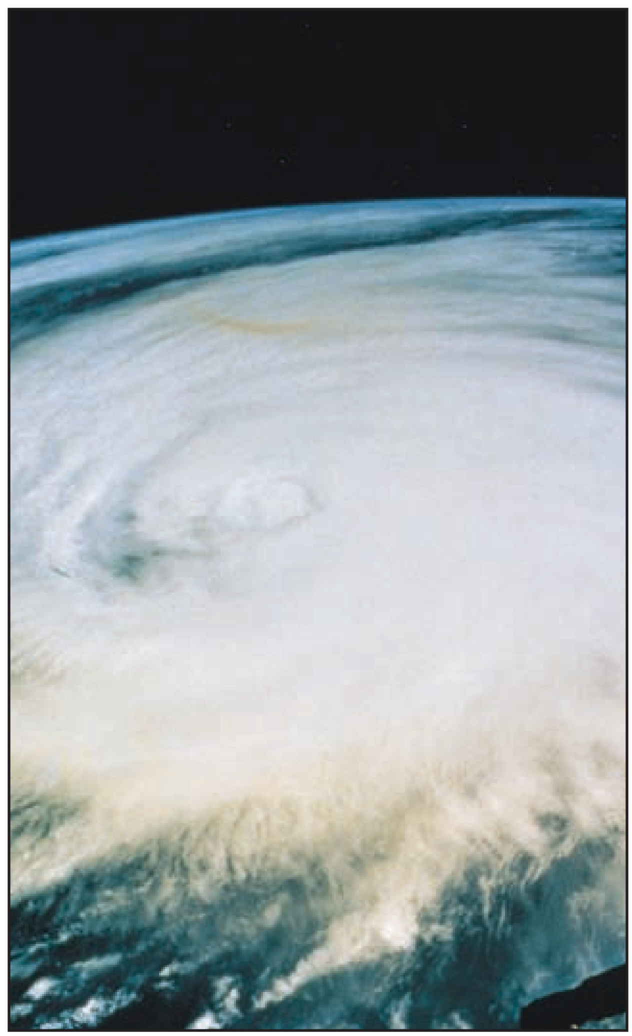


Table 3: Examples of Knowledge Gaps for Identified Uses of Satellite Data

Users	Purpose	Knowledge Gaps
Fisheries Managers	Fisheries and aquaculture management: Ecosystem-based management; stock assessments	• Satellite use in identifying habitats and understanding fish behavior • Improved seasonal and shorter-time frame fisheries forecasts • Regional algorithms for turbidity (e.g., TSM, light availability) and interpretation of imagery • Ecology and physiology of HAB species • Satellite use in understanding ecosystem processes and links between physics and biology, including trophic levels • Relationship between ocean color and phytoplankton composition • Differentiation between human impacts (e.g. overfishing) and natural variability of habitat change
Public Health Managers	Pollution detection and prevention; human safety; monitoring	• Effect of land use on water quality • Relationship between satellite measurements and water quality parameters (including nutrients) • Differentiation between human impacts and natural variability in water quality • Incorporation of contaminant transport into improved, high-res circulation models • Improved, localized atmospheric correction of satellite imagery
Emergency Response Managers	Mitigation of impacts from inundation events	• Precise, accurate estimates of the spatial and temporal variability of sea level rise • Comprehensive land use and resource mapping for a region • Accurate delineation of shoreline • Accurate and comprehensive topographic and bathymetric data • Local and regional forecast models for inundation
Search and Rescue Personnel	Rescue and recovery operations	• Ship identification from satellite • High resolution nowcasts and forecasts for circulation and sea state
Coast Guard, Navy, State and local emergency responders	Homeland Security	• Ship identification from satellite • Detection/assessment of biological hazards or disturbances in imagery
Commercial shipping, fishing, cruise industry	Shipping and navigation	• Ship identification from satellite • Rapid delivery of real-time sea state characterization to ships • Technology and algorithms to routinely and accurately determine ice thickness and type, position, concentration, and movement • High resolution, precise, and accurate detection of coastal currents
Oil and Gas Industry	Safe exploration and delivery of oil and gas to consumers	• Acoustic effects on marine mammals • Spatial and temporal variability in benthic habitats • Slick detection, transport, potential for dispersal • Technology and algorithms to routinely determine ice thickness and type, position, concentration, movement • Forecasts for storm events and impacts on oil and gas infrastructure • Detection of internal waves and understanding of the impacts
Educators	Compelling educational material	• Visualization techniques for displaying complex data • Effective techniques for information dissemination • Satellite oceanography and ocean observation curricula that satisfy state standards • Translation of scientific knowledge into education (learning about learning)

Data Management and Integration

Common frameworks and their uniform implementation are needed for data management. Data (re)processing, distribution and access, in real-time and on an archived basis, continue to represent a significant challenge. Quality assurance, including instrument characterization, calibration and validation, presents a significant infrastructure challenge, particularly toward development of climate quality data records (IGOS, 2006; NRC, 2004). Novel approaches are needed for coastal data delivery, manipulation (e.g., ocean GIS), and visualization (e.g., Google Earth and other alternatives).

Accessing large satellite data sets and sorting through information to locate a specific product pertaining to a certain location is confusing and frustrating to many coastal end-users. Unless a user knows exactly what they are looking for and has the appropriate software and storage capacity, satellite data are often effectively inaccessible. The cost of data, hardware and software, and having staff with the technological skill to process and interpret the data are all barriers to the use of remote sensing data. Most managers prefer data in a GIS-compatible format, in order to overlay the imagery with other data sources and use it in their decision making processes. GIS or similar software approaches that allow for the geographical display of data is common in most state and local agencies. Many remote sensing data formats (e.g. hierarchical data format (HDF), net CDF) are not easily or readily translated into a GIS format. GIS companies and freeware sources are aware of the problem and working on solutions to facilitate the incorporation of imagery.

The IGOS Coastal Theme Report (IGOS, 2006) identified various needs and challenges for data integration. In particular, there is a need to bring together multi-sensor satellite data for various parameters, creating uniform/merged products that enable accurate comparisons across missions and over time. There is a need to more efficiently and effectively bring together satellite data and *in situ* data, in conjunction with models, with expanded use of data assimilation (for nowcasts, forecasts, etc). There is a need to break down disciplinary barriers to integration, bringing together geophysical with biological/ecological data, aquatic with terrestrial data, environmental with socio-economic data. Common frameworks and approaches are needed in this regard.

Recommendations

The primary recommendations to emerge from the plenary and breakout session of this workshop are presented here and in the next section. Here we divide recommendations into those calling for immediate, intermediate, and longer term actions. In the following section, recommendations specifically directed to NASA, NOAA, and the RAs are summarized.

Immediate Actions:

I. Enhance regional capacity to address user needs for remote sensing products

The capabilities of the Regional Associations with regard to satellite remote sensing vary. Some regions have capabilities centered at one or two institutions, which through their interest and goodwill make data and to a lesser extent derived products and information available. Other regions have more dispersed capabilities. Some Regional Associations have the knowledge and expertise to process and deliver standard products, but require additional capacity to pursue development and validation of new and improved products, to fine tune distribution mechanisms or increase band width for effective delivery, and/or to deliver data in GIS or other user-desired formats.

To enhance the regions' capacity for addressing user needs and for facilitating effective working relationships with federal and other partners, the following actions should be taken immediately:

1) Convene discussions with Regional Associations on roles and responsibilities. NOAA and NASA representatives should meet locally with representatives from each RA (i.e., those who best understand regional user needs) and the principal local remote sensing experts in each region (e.g., academic institutions, corresponding CoastWatch regional node, private sector entities) to discuss the appropriate roles and responsibilities for each player. These relationships will vary among the regions depending on the interest, capabilities and established infrastructure and relationships. These should be small, informal meetings that facilitate communication amongst these principals.

2) Convene regional technical workshops on user needs. RAs, in conjunction with their corresponding CoastWatch regional node, should convene regional technical workshops to discuss in detail user needs and methods for addressing those needs, articulating and refining user requirements, desired data sets and products, delivery mechanisms, and other technical approaches, solutions, etc. It is suggested these workshops be convened on the scale of the CoastWatch regions, some of which may include more than one Regional Association.

3) Establish an IOOS Remote Sensing Technical Committee. Ocean.US should organize a Remote Sensing Technical Committee to continue the development of a remote sensing capability for IOOS. The charge should include 1) synthesize lessons learned; 2) identify common capabilities, needs and gaps; 3) validate requirements and 4) work with NASA and NOAA to translate requirements into missions. The Committee should include two representatives from each region and federal representatives from NASA, NOAA, USGS, NAVY, and Ocean.US.

4) Fund pilot projects to demonstrate applications of remote sensing data. NOAA and NASA should jointly fund projects that demonstrate the advantages of integrating remote sensing imagery with other ocean observations to address coastal user needs. These competitively awarded projects must consider the transferability of the project to other regions and mechanisms for continuation beyond the pilot stage as criteria in planning. Lessons learned and common capabilities needed at the regional level should be distilled and synthesized. Some possible demonstration projects that would highlight application and integration of remote sensing data for improved coastal management or other purposes include:
    a. Assessments of HAB dynamics, impacts and forecasting;
    b. Coastal inundation risks;
    c. Habitat assessments;
    d. Assessment of water quality in urban ocean environments

Intermediate Actions

II. Simplify access to data and products

Improved accessibility to data and products is critical to the use of remote sensing data by coastal users. NASA and NOAA should work with Ocean. US to identify potential funding (such as NASA information technology development or other grants) to fund the development of:

- Improved search capability to look across agencies and other data providers for products and imagery;
- Web-based and other tools developed with OGC standards to apply algorithms, change formats, and project imagery;
- Customized products for local users that utilize regional algorithms and provide products and imagery according to preferences for type, geography, map projection, format, etc.;
- Sophisticated software designed for the casual user with user-friendly interfaces to allow for easy manipulation of data;
- User-friendly software for data integration (multiple remote sensing data sets, remote sensing with *in situ* data – including biology and fish distribution data sets).
- Data integration projects (e.g., GHRSST and GlobColour) that use multi-sensor satellite and *in situ* data for creating high-resolution, accurate, and more complete coastal data sets that help provide measurement continuity across multiple missions and over time;

III. Expand the role of airborne sensors to fulfill user needs.

Space-borne sensors are not appropriate for all uses. In coastal areas terrestrial signals can affect ocean satellite measurements and the seascape changes on rapid spatial and temporal scales. For some coastal needs, the technology to acquire the data is not adaptable to a satellite platform. Currently, the need for high resolution data for bathymetry, shoreline topography and nearshore habitats is primarily being filled by airborne sensors. Aircraft can provide higher spatial resolution data, can be timed to correct for tidal stages or sample at sub-tidal frequencies, and can carry sensors that have not yet been adapted for satellites. These sensors can provide the data required by coastal managers and are reasonably affordable. The development of high resolution imagery using aircraft-based sensors also can lead towards future space borne instrumentation.

The next workshop in this series should focus on high resolution airborne sensors, and should involve the private sector that currently provides such services.

IV. Develop compelling education and outreach material that demonstrates the power of remote sensing.

Ocean.US should work with NOAA, NASA, the OOS Education Caucus, NFRA, the Alliance for Earth Observations and others to ensure the following are developed:

- Compelling visualizations demonstrating the utility and power of remote sensing suitable for public audiences;
- Case studies using stories in which the general public is interested, such as natural hazards, coastal development/urbanization, public and individual health. These could be tied to the pilot projects mentioned above;
- Climatologies that demonstrate the value of long-term measurements and are at a scale beyond the individual research's efforts;
- Develop "State of the Ocean Report" that uses remote sensing, including climatologies, to show how current conditions compare to past trends and what can be expected next year, etc.;
- Technical training sessions with a focus on problem-driven curricula where users bring a project to focus their learning;
- K-12 curriculum modules that highlight remote sensing, in collaboration with existing educational networks such as Sea Grant and COSEE.

V. Ensure continuity and enhance utility of existing and planned satellite observing capabilities and data streams

A crucial recommendation is to avoid the loss and interruption of time series and other products that have proven valuable to users. A significant investment has been made by data providers and data users to access and apply remote sensing data from satellites that are currently operating. These investments range from establishing receiving stations, processing data and developing products to integrating remote sensing data into decision support systems. Maintaining access to data streams that sustain these investments is important to an efficient product development system. In some cases ensuring a continuous data stream will require additional satellites; in other cases, it may mean investment in and improvement to an existing capability. As an added benefit, additional investment in existing and/or planned sensors may improve the utility and quality of these data streams.

- Facilitate and sustain greater access to and utilization of existing and planned international moderate and high-resolution coastal satellite data and imagery, e.g., ocean color (MERIS, OCM/2), SAR (Radarsat/2, ASAR) and other imagery (e.g., SPOT). Note in particular that cost-effective access to Radarsat-1 data potentially to end soon.

Ocean Color:

- Continue SeaWiFS contract to purchase full-resolution (1 km) data for this widely utilized sensor that has a decade long time-series;
- Utilize foreign ocean color satellites (e.g. MERIS, OCM/2) to supplement U.S. capabilities and potentially bridge gaps in data availability should SeaWiFS and/or MODIS fail;
- Enhance utilization of MODIS data by supporting development and widespread utilization of coastal products derived from the high-resolution (250/500 m) bands;
- Develop merged/blended ocean color products to provide improved coverage;
- Ensure continuity of vicarious calibration capabilities, particularly into the VIIRS/ operational ocean color era.

Altimetry:

- Bring altimeter tracks closer to the coast to increase coverage in the coastal zone;
- Facilitate user access to along-track altimeter data for higher-resolution applications.

Sea Surface Temperature

- Maintain and expand the GODAE High Resolution SST Pilot Project (GHRSST-PP);
- Maintain data access and archive for all functional AVHRR sensors on NOAA satellites.

Winds

- Provide and facilitate user access to higher resolution QuikSCAT products for improved resolution in coastal regions;
- Develop merged/blended wind products to provide improved coverage.

Long term recommendations

- At a minimum ensure continuity of existing capabilities for measuring ocean color, thermal and microwave sea-surface temperature, precision sea-surface height, and ocean vector winds;
- Invest in Synthetic Aperture Radar (SAR), an invaluable all-weather tool for coastal research and applications (e.g., sea ice monitoring, pollution hazard assessments, high resolution local wind fields), to ensure access to data. The U.S. does not currently have its own SAR mission, or immediate plans for one, access to foreign data is limited with continuity not guaranteed, and presently there is a significant risk of loss of access to key foreign data sets.
- Continue efforts to efficiently and effectively transition priority R&D capabilities into operations, avoiding significant degradation of these capabilities in the process as most users (scientists, managers or decision-makers) still require high quality data streams that have undergone robust calibration and validation.

VI. Develop and implement new and improved space-based observing capabilities that better resolve and sample the coastal zone

This workshop reviewed the IGOS Coastal Theme Report (IGOS, 2006) and endorsed its recommendations as to the observing requirements (e.g., spatial, temporal, spectral) for primary geophysical, biogeochemical and ecological parameters of interest in coastal regions. In most cases these requirements are not met by existing or approved satellite missions, thus limiting our ability to adequately understand and monitor complex, dynamic coastal ecosystems (particularly at the land-sea interface) and address the information needs of the managers and other users who live, work and play in the coastal environment. Overall, new and improved space-based observing capabilities are needed to provide greater temporal, spatial and spectral resolution/coverage for diverse parameters in coastal regions.

Specific needs as identified at the workshop include:

Ocean color:

- Spatial resolution of ~100-300 m is necessary for broad, frequent synoptic observations of the U.S. EEZ; an order of magnitude increase in resolution, i.e., ~10-30 m, is required to effectively study and monitor aquatic ecosystems and habitats at the land-sea interface, particularly small bays, estuaries, mangroves, kelp and sea grass beds.
- As a minimum standard, new ocean color sensors should be MERIS-class multispectral, including fluorescence bands as well as UV and SWIR bands (the latter for improved atmospheric corrections); hyperspectral imaging capabilities are optimal;
- Synoptic sub-diurnal temporal revisits on the order of 3 hours or ideally more frequently (hourly, or better) for observing dynamic coastal regions and rapidly evolving and/or ephemeral ocean events, helping to effectively resolve coastal processes and phenomena influenced by tides and other factors as well as mitigate data losses due to cloud cover.

Altimetry:

- High spatial resolution (1 km desired) and better coverage near the coast are needed for sea surface height measurements, such as from a wide-swath altimeter, to resolve mesoscale and other under-sampled coastal and oceanic features as well as provide important information regarding sea level change.

Ocean winds:

- Spatial resolution (~1-5 km) & coverage of ocean vector winds in coastal regions are required to support weather analysis and forecast requirements (including extreme, episodic events) as well as other applications (e.g., coastal upwelling and productivity, navigation, marine hazards and spill response, and search and rescue).
- Improved ocean wind vector accuracy under rainy conditions and at higher wind speeds.
- Multiple platforms to satisfy the desired revisit time (6 hours or better).

Sea Surface Temperature:

- Spatial resolution of 100 – 300 m, to better support coastal research and applications requiring SST data.

Other measurements

- A constellation of SAR sensors is necessary to provide improved temporal resolution.
- New space-based measurements tailored for coastal regions, including sea-surface salinity (at a higher resolution than will be provided by either Aquarius or SMOS), as well as river discharge.

Agency-specific recommendations

The following section breaks down the above recommendations into actions for specific partners:

For NASA

Immediate actions:

- Pursue technology development and implementation to ensure that there are high data volume telecommunication capabilities for transmitting data to the RAs;
- Support research and development of remote-sensing based climatologies;
- Ensure archiving capabilities satisfy the requirements/needs of the RAs;
- Provide representation to regional meetings organized by the RAs to address the needs of users for satellite data and data product;
- Support improved communication and coordination of information and existing activities/projects within and between agencies and RAs vis-à-vis remote sensing by participating on the IOOS RS Technical Committee discussed above;
- Work with NOAA and other partners to facilitate the transition of successful R&D technologies for use in operations and other applications.

Longer-term actions:

- Develop and launch in the earliest possible timeframe the next generation R&D ocean missions that will provide greater understanding of processes and phenomena in coastal regions through new and improved (e.g., increased spatial, temporal, spectral resolution) observations, including:
  - The “SWOT” mission concept identified in the NRC Decadal Survey (NRC, 2007) for improved measurements of sea level, circulation, river discharge, and bathymetry in coastal regions;
  - The Geostationary Hyperspectral Imaging Radiometer concept identified in the (draft) advance plan of NASA’s Ocean Biology and Biogeochemistry Research Program, or the related “GEOCAPE” mission concept in the NRC Decadal Survey (NRC, 2007);
  - The Multi-Spectral High Spatial Resolution Imager concept identified in the (draft) advance plan of NASA’s Ocean Biology and Biogeochemistry Research Program, or the related “HyspIRI ” mission concept in the NRC Decadal Survey (NRC, 2007), assuming the latter has suitable specifications for aquatic applications;
- Develop and utilize sub-orbital platforms and instruments for coastal investigations, including as identified in the (draft) advance plan of NASA’s Ocean Biology and Biogeochemistry Research Program;
- Pursue technology development and research investigations into microwave and LIDAR remote sensing approaches to provide novel and improved coastal observing capabilities;
- Pursue development of advanced information technologies to increase the accessibility and utility of coastal remote sensing data as well as enable new observation measurements and information products.

For NOAA

Immediate actions:

- Competitively fund alone or in partnership with NASA a series of regional pilot projects that demonstrate the integration and utility of remote sensing products, with an emphasis on transferability and sustainability beyond the pilot stage. Such pilot projects must involve the RAs and generate products to serve end users in the region;
- Facilitate (regional) leveraging and integration of the CoastWatch Program as part of IOOS;
- Ensure continuity of vicarious calibration capabilities for ocean color heading into the VIIRS operational ocean color era;
- Support development of high-resolution climatologies/climate quality data records for multiple parameters (e.g., SST, ocean color) for coastal management and applications;
- Fund planning and coordination at the regional level to develop a plan for data distribution, access, and product development;
- Ensure that there are high data volume telecommunication capabilities to get the data out to the RAs;

- Ensure archiving capabilities satisfy the requirements/needs of the RAs;
- Identify and implement low-cost aircraft solutions to complement satellite measurements for coastal applications;
- Support improved communication and coordination of information and existing activities/projects within and between agencies and RAs vis-à-vis remote sensing.

Longer-term actions:

- Transition measurement of ocean vector winds from research to operations by supporting development and launch in the earliest possible time frame of the next generation scatterometer mission (i.e., the XOVWM mission concept in the NRC Decadal survey), which would provide high-resolution ocean vector winds in support of a number of coastal applications with great socio-economic significance;
- Ensure continuity of precision altimetry, working with NASA and other partners to continue the Jason series, eventually transitioning to swath altimetry;
- Work with NASA and other partners to facilitate the transition of successful R&D technologies (hardware, software et al.) for use in operations, particularly the geostationary ocean color and high spatial resolution coastal imaging capabilities identified above.

For the RAs

- Host regional meetings bringing together data providers as a first step towards coordinating and enhancing remote sensing capabilities within each region, followed by regional user-driven technical workshops across regions to better meet the needs of users. Necessary efforts include coordinating and integrating data, products and services provided by regional data providers, delivering information products to users (particularly through pilot projects and demonstration efforts), and building regional capacity to acquire and utilize remote sensing data and products;
- Identify and coordinate existing data reception, archiving, and distribution assets within the region, and the mechanisms for accessing and archiving the data etc. Coordination and integration within regions are essential, and between regions are strongly recommended whenever possible;
- Communicate needs, outcomes of demonstration projects, successful (and unsuccessful) product to other RAs and federal agencies in order to build a networked system;
- Identify promising pilot projects and demonstration efforts as above;
- Provide regional perspective on needs for and challenges of handling the growing volume of data, anticipated to dramatically increase in the coming years, particularly as new sensors come online.

For Ocean.US

- Better incorporate remote sensing into IOOS development and implementation plans, leveraging agency and community expertise.
- Organize a Remote Sensing Technical Committee to continue the work begun by this workshop and further integrate remote sensing into IOOS.
- Work with education and outreach experts to communicate the contribution of long-term remote sensing measurements to the IOOS.

Acknowledgements

NASA, NOAA and Ocean.US are thanked for their support and sponsorship of this workshop. The contents of this report are solely those of the participants and the workshop steering committee and do not constitute a statement of policy, decision, or position on behalf of NASA, NOAA or the U.S. Government.

References

Christian, R.R, P.M. DiGiacomo, T.C. Malone, and L. Talaue-McManus. Opportunities and Challenges of Establishing Coastal Observing Systems. Estuaries and Coasts, 29:871-875. 2006.

Global Climate Observing System (GCOS). Systematic Observation Requirements for Satellite-Based Products for Climate: Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in support of the UNFCCC" GCOS - 107 (WMO/TD No. 1338). September 2006.

IGOS: A Coastal Theme for the IGOS Partnership – For Monitoring of our Environment from Space and from Earth. Paris. UNESCO. 60pp. (IOC document No. 1220). 2006

IGOS: A Cryosphere Theme Report for the IGOS Partnership - For the Monitoring of our Environment from Space and from Earth. Geneva: World Meteorological Organization. WMO/TD-No. 1405. 100 pp. 2007

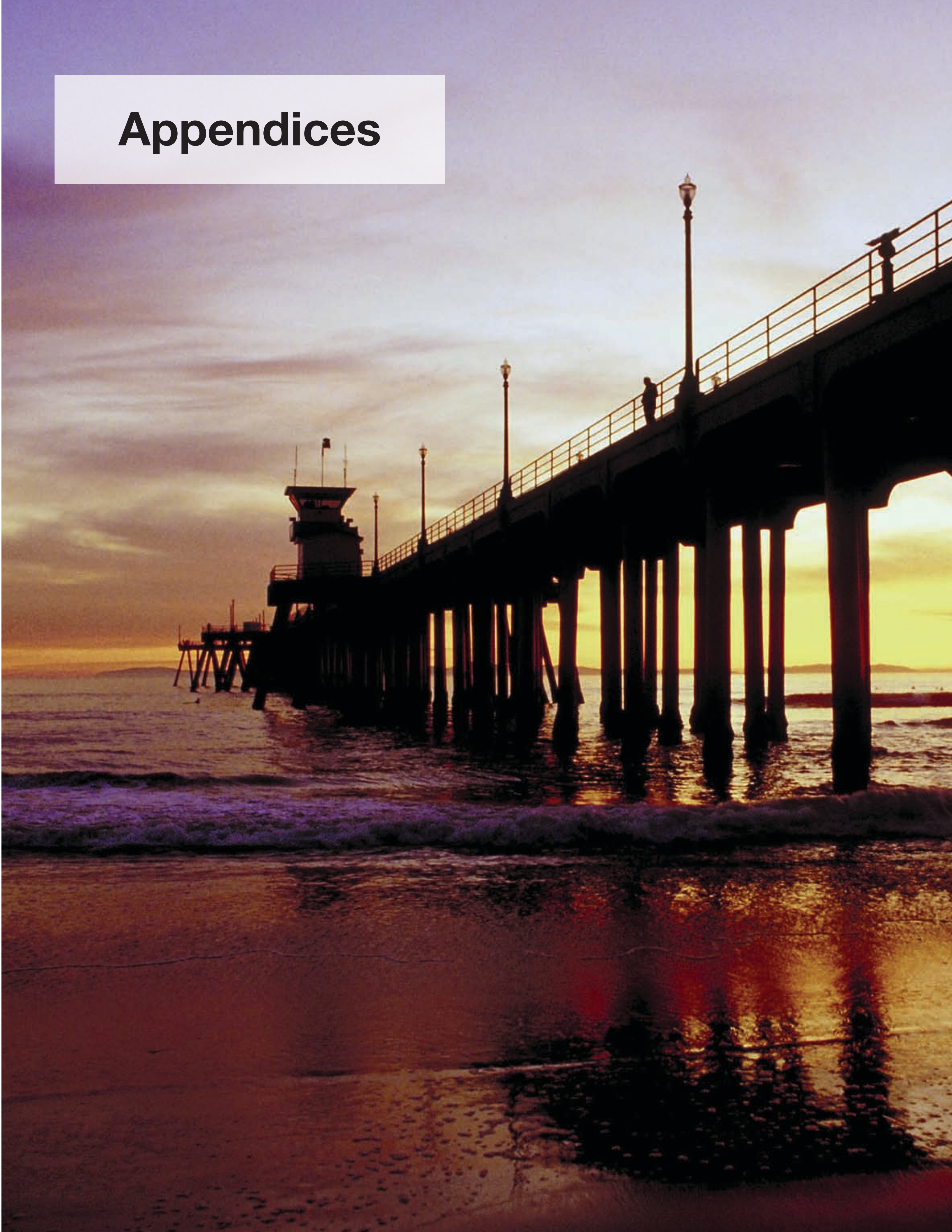
IGOS: An Ocean Theme for the IGOS Partnership: The Final Report of the Ocean Theme Team. NASA. 2001

Malone, T. and M. Hemsley. Developing the IOOS for improved management and mitigation of coastal inundation. Marine Technology Society Journal, 40(4):45-55. 2007.

National Research Council (NRC), Report by Committee on Climate Data Records from NOAA Operational Satellites: David Robinson (chair), Janet Campbell, Ruth Defries, Bill Emery, Milton Halem, James Hurrell, Arlene Laing, Roberta Balstad Miller, Range Myneni, Richard Somerville, Paul Try, Thomas Vander Haar, Seldon Drubot, and Rob Greenway. Climate Data Records from Environmental Satellites: Interim Report, National Academies Press, 2004.

National Research Council (NEC), Report by Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future. Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. National Academies Press. 2007

Appendices



Appendix A: Workshop Agenda

Workshop on Regional Needs for Coastal Remote Sensing

Tuesday, October 3 – Thursday, October 5, 2006
New England Center, University of New Hampshire
Durham, NH

Workshop Purpose: Identify and document space-based remote sensing requirements of the RAs and identify commonalities. This will be the first in a series of biennial workshops on the topic. This workshop will focus on satellite remote sensing needs.

Agenda

Tuesday, October 3

5:00 PM Reception and Cash Bar: Champlain Foyer
6:00 PM Dinner: Penobscot Room
7:00 PM Key Note Speaker: Michael Crowley, SeaSpace Corp.
"Remote sensing as an integral part of a coastal observing system: Experiences at LEO-15 and beyond…"

Wednesday, October 4

7:30 AM Breakfast: Great Bay Foyer
8:15 AM Plenary Session: Great Bay Room
Purpose of workshop/introductions:
Janet Campbell, Workshop Chair
8:30 AM Outlook for Ocean Remote Sensing
Eric Lindstrom, NASA
8:45 AM An Overview of Coastal Remote Sensing Challenges and the IGOS Coastal Theme Report
Paul DiGiacomo, NOAA NESDIS
9:15 AM Status of the Decadal Survey conducted by NRC's Space Studies Board
Berrien Moore, UNH/EOS Director
9:45 AM Coffee Break
10:00 AM Regional Needs
Short summaries of regional needs
10 minutes for each of the 11 regions (5 slides each)
12:00 PM Discussion and Charge to the Working Groups
Eric Lindstrom and Stan Wilson
12:15 PM Lunch: New England Center Dining Room
1:00 PM Break-out Session #1: User needs and requirements for coastal satellite data and products
Mansfield Room: Andy Thomas, Leader
Mary Culver, Reporter
Kennebec Room: Ted Strub, Leader
Janet Campbell, Reporter

1. *Who are the current users of satellite remote sensing data and data products in your regions? How are they accessing the information and for what purposes are they using the data?*

2. *How might coastal satellite products be used to fulfill IOOS societal goals? What type of products would be useful? What data fields are required? How many currently exist? (see chart #1 Societal Goals)*

2:45 PM Break

3:00 PM Break-out Session #2: Needs *versus* Current

1. What are the challenges for providing satellite data and data sets to meet user needs? These can be several types of challenges:

a. Knowledge -- requirements for research and development for new technology, to integrate data sets and to transfer research to operational use.

b. Resolution/Coverage – the need for improved spatial, temporal and spectral resolution.

c. Integration -- need for IT to integrate, distribute, archive satellite data and to integrate with in situ data, and for model assimilation.

d. Continuity -- maintaining existing capabilities and the transition of sensors and programs to operational use.

e. Other --

2. What solutions can be acted upon immediately? Which require longer timeframe?

4:30 PM Plenary Session: Great Bay Room
Recap of Group Discussion

5:00 PM Adjourn for the day

Thursday, October 5

7:30 AM Breakfast: Great Bay Foyer

8:15 AM Plenary Session: Great Bay Room
Working Group Reports – WG Chairs
Assessing Progress -- Views from NOAA and NASA
Eric Lindstrom and Stan Wilson

9:30 AM Break-out Session #3: Filling the Gaps: Identifying short-term and long-term priorities.
Mansfield and Kennebec Rooms.

1. What are the major short-term actions to close the gaps between user needs and existing capabilities? Identify the top 5-7 priorities common to all RAs and explain how they will be used by regional users.

2. What are the major long-term actions?

12:00 PM Lunch

1:00 PM Plenary Session: Great Bay Room
Working group reports and discussion -- WG Chairs

2:00 PM Working Session: Development of recommendations
Janet Campbell

3:30 PM Conclusions—Wrap up and next steps

4:00 PM Adjourn

Appendix B: Participants

Ed Armstrong
California Institute of Technology
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109-8099
edward.m.armstrong@nasa.gov

Sam Batzli, Asst. Scientist
Environmental Remote Sensing Center
Rm 1215, 1225 W Dayton St
University of Wisconsin - Madison
Madison, WI
sabatzli@wisc.edu

Jennifer Bosch
Rutgers University
71 Dudley Road
New Brunswick, NJ 08901-8521
bosch@marine.rutgers.edu

Subrahmanyam Bulusu
Dept of Geology
University of South Carolina
701 Summer St EWS 617
Columbia, SC 29208
sbulusu@geol.sc.edu

Janet Campbell
Director, Coastal Ocean Observing Center
University of New Hampshire
30 College Road
Durham, NH 03824-3525
janet.campbell@unh.edu

Yi Chao
M/S 300-323
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
Yi.Chao@jpl.nasa.gov
(818) 393.6099

David Collins
President, SeaSpace Inc.
12120 Kear Place
Poway, CA 92064
dcollins@seaspace.com

Mike Crowley
SeaSpace, Inc.
12120 Kear Place
Poway, CA 92064
mcrowley@seaspace.com

Mary Culver
NOAA-Coastal Services Center
2234 South Hobson Ave
Charleston, SC 29405
mary.culver@noaa.gov

Paul DiGiacomo
NOAA-NESDIS
NOAA Science Center Room 601
5200 Auth Road
Camp Springs, MD 20746 USA
paul.digiacomo@noaa.gov

Dave Foley
Southwest Fisheries Science Center
1352 Lighthouse Ave
Pacific Grove, CA 93950
Dave.Foley@noaa.gov

Roger Gauthier
Great Lakes Commission
1135 Industrial Highway
Ann Arbor, MI 48034
gauthier@glc.org

Linda Hayden
Elizabeth City State University
Box 672 1704 Weeksville Rd
Elizabeth City, NC 27909
haydenl@mindspring.com

Tom Heinrichs
University of Alaska Fairbanks
PO Box 757320
Fairbanks, Alaska 99775
tom.heinrichs@alaska.edu

George Leshkevich
Great Lakes Environmental Research Lab
2205 Commonwealth Blvd
Ann Arbor, MI
george.leshkevich@noaa.gov

Eric Lindstrom
Physical Oceanography Program Scientist
NASA Headquarters
300 E St SW
Washington, DC 20546
eric.j.lindstrom@nasa.gov

Jon Malay
Director, Civil Space Programs
Washington Operations, Space Systems & Operations
1550 Crystal Drive, Suite 300
Arlington, VA 22202
jon.malay@lmco.com

Tom Malone
Ocean.US
1100 Wayne Ave
Silver Spring, MD 20910
T.Malone@ocean.us

Molly McCammon
Chair, NFRA
1007 West 3rd Str,
Anchorage, AK 99501
mccammon@aoos.org

Berrien Moore
Director, Inst. for the Study of Earth, Oceans, and Space
University of New Hampshire
Durham, NH 03824-3525
bmoore@unh.edu

Ru Morrison
University of New Hampshire
30 College Road
Durham, NH 03824-3525
ru.morrison@unh.edu

Frank Muller-Karger
University of South Florida
140 7th Ave. South
St Petersburg, FL 33701
carib@marine.usf.edu

Nikolay Nezlin
Southern California Coastal Water Research Project
3535 Harbor Blvd., Suite 110
Costa Mesa, CA 92626
nikolayn@sccwrp.org

John Oram
San Francisco Estuary Institute
7770 Pardee Ln
Oakland, CA 94621
joram@sfei.org

Mark Otero
University of California San Diego
9500 Gilman Ave
San Diego, CA 92093
motero@mpl.ucsd.edu

Jim Potemra
University of Hawaii
2325 Correa Dr,
Honolulu, HI 96822
jimp@hawaii.edu

Rachel Potter
University of Alaska Fairbanks
245 O’Neill Bldg
Fairbanks, AK 99775-7220
rpotter@ims.uaf.edu

Kota Prasad, Staff Scientist
SeaSpace, Inc.
12120 Kear Place
Poway, CA 92064
kota@seaspace.com

Josie Quintrell
Director, NFRA
205 Oakledge Rd.
Harpswell, ME 04079
jquintrell@suscom-maine.net

Mitchell Roffer, President
Roffer's Ocean Fishing Forecasting Service, Inc.
60 Westover Drive
West Melbourne, Florida 32904
roffers@bellsouth.net

Steve Steinberg, Asso. Professor
ENRS Dept
Humboldt University
Arcata CA 95521
gis@humboldt.edu

P. Ted Strub
Oregon State University
104 Ocean Admin. Building
Corvallis, OR 97331-5503
tstub@coas.oregonstate.edu

Richard Stumpf
NOAA – Nat'l Ocean Service
1305 East West Hwy Rm. 9115
Silver Spring, MD 20910
Richard.Stumpf@noaa.gov

Andrew Thomas
5706 Aubert Hall
University of Maine
Orono, ME 04468
thomas@maine.edu

Roy Watlington
University of the Virgin Islands
No. 2 John Brewers Bay
St Thomas VI 00802
rwatlin@uvi.edu

Doug Whiteley
NOAA NIOT
doug.whiteley@noaa.gov

Cara Wilson
NOAA-NMFS
Environmental Research Division
Southwest Fisheries Science Center
1352 Lighthouse Avenue
Pacific Grove, CA 93950-2097
Cara.Wilson@noaa.gov

Stan Wilson
NOAA-NESDIS
1335 East-West Highway SSMCI
8th Floor
Silver Spring, MD 20910
stan.wilson@noaa.gov

Dana Woodruff
Battelle Marine Sciences Laboratory
Pacific Northwest National Laboratories
1529 West Sequim Bay Rd.
Sequim, WA 98382
Dana.woodruff@pnl.gov

Dorsey Worthy
US EPA National Exposure Research Lab E243-05
Research Triangle Park, NC 27711
Worthy.dorsey@epa.gov

Victor Zlotnicki
M/S 300-323
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
Victor.Zlotnicki@jpl.nasa.gov

Appendix C: Questionaire Responses

SECOORA

For quick looks for the S Atlantic Bight region (SE US) we use SST imagery (infrared) from Johns Hopkins APL and from the SEACOOS data portal (supplied by the USF IMaRS). The regional node for NOAA Coastwatch had been useful for SST, but that stopped operating and has not apparently been revived. The SEACOOS site also provides MODIS SST from USF IMaRS. For browsing MODIS ocean color (chlorophyll, ERGB), I also use the SEACOOS web portal (again supplied by USF IMaRS). For analyses, we download AVHRR SST products from the NASA Physical Oceanography DAAC via the POET portal. The higher resolution MODIS Ocean Color and SST (1 km and 250 m at nadir, selected scenes for the latter) and SeaWiFS ocean color (1 km) data files are downloaded from the NASA Goddard DAAC via the Ocean Color portal. Processing for the higher resolution products uses the NASA SEADAS program on-site and process files are archived locally. Infrared and ocean color imagery from the NOAA, GOES, Aqua and Terra satellites are easily available and useful for both the Gulf of Mexico and US east coast from a variety of sources including University of South Florida_IMaRS, Rutgers Univeristy, The John Hopkins University,NOAA, NASA, and ROFFS™. We would like to see more ocean color data at 1.1 km resolution for the Caribbean Sea region. We would also like 250-500 meter multispectral imagery (IR-Ocean color) hourly for all areas. Also altimetry data are available from NOAA and University of Colorado For an occasional quick look, Quik-Scat winds are also viewed via the SEACOOS web portal. Lidar and radar for surface topography is available for our region.

A broader suite of 1 km and higher ocean color products and SST produced in near-real time and archived would be useful. In particular K490 and CDOM-related products, hopefully in the future with regionally and seasonally "tuned" algorithms.

USF IMaRS presently supplies the SEACOOS portal for mapped images. For the MODIS ocean color and SST and SeaWiFS ocean color products, getting good quality higher resolution products generally requires download from NASA DAAC and processing. This requires significant local computing resources (higher end workstations), a good deal of disk space for archiving processed imagery, and local experience with the download procedures and processing software (NASA SEADAS). The in-house processing requirement imposes limitations on the general availability of the higher resolution products. For near-real time applications (e.g., use for targeted ship sampling), we have relied on the web portals (SEACOOS for SST and limited ocean color products, Johns Hopkins for SST) and satellite downloads on the ship. Getting lat/lon grids and zoomed views requires a fair amount of satellite connect time (costly). Mechanisms to allow set preferences (image area, bathymetry and lat/lon grid overlays) to be delivered can help reduce connection times. The SEACOOS portal can be slow due to the Mapserver application needing to access the database to generate new images (e.g., various overlay products) and might not be appropriate for a highly accessed source of imagery. Another need area for future applications is to broaden the suite of products that are readily available for near real-time browsing (e.g., CDOM-related products) that have regional applications for tracing water masses, assessing water clarity, etc. University of South Florida_IMaRS, NOAA via FTP and ROFFS™ inhouse LAN. The limitations of NOAA are that not all of the available satellites are provided, e.g. NOAA_12 and NOAA_14. Also the European, Indian and Japanese satellite data are not available. The data from NASA are in difficult to use formats and require expensive systems to process to usable imagery

1 Applications of SST and ocean color products for our purposes include defining water mass distributions and seasonal and event-related shifts in water mass distributions. Products used include SST (primarily winter-spring, summer SST gradients are typically less), CDOM-related for tracking low salinity water masses, turbidity-related products for high particle water masses and detecting sediment resuspension events; ERGB for distinguishing different optical water types, particularly in summer when SST gradients are low (e.g., detecting the Gulf Stream front).

2 Another application is bloom detection using the chlorophyll product, for our purposes particularly along the Gulf Stream front in winter-spring. Harmful algal blooms on the shelf are not the issue in the SAB that they are on the West Florida Shelf, but satellite products have demonstrated export of WFS blooms and impacts in NC waters. Inshore HABs can occur, but spatial resolution and the optically complex waters are issues for use of satellite products inshore

3 Regular use of satellite products by coastal managers/decision-makers seems to me to still be in an early stage, but there are a number of likely application areas in fisheries management (e.g., input for primary producer biomass to NPZ components of ecosystem models; bloom detection and possible relation to near-shore and shelf hypoxia events; detection of low salinity water masses and possible stratified conditions, again with possible significance for evaluating when and where hypoxia events may occur).

4 We use satellite data as our primary data source for our commercial enterprise with the fishing industry, as well as, with academic and government researchers. The satellite data are critical because they provide synoptic real-time and near real-time views of the ocean surface circulation. The data are being used by some coastal managers and fisheries decision makers.

SECOORA

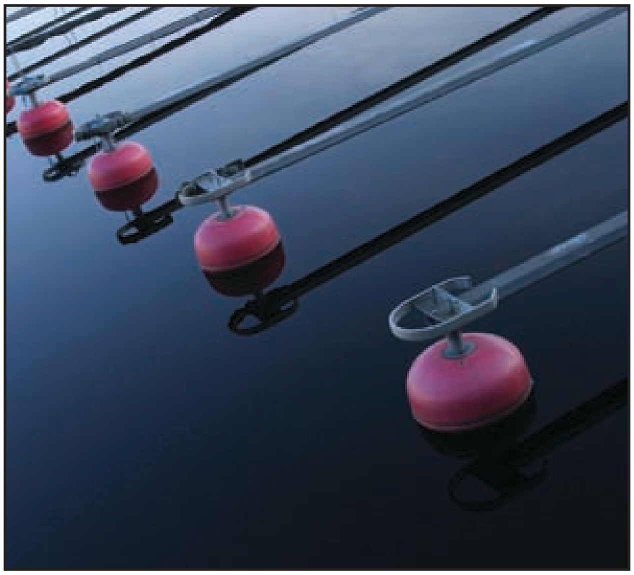
Regionally tuned and validated algorithms for ocean color are needed. Coastal and inner shelf waters are typically optically complex and the standard blue-water algorithms (e.g., chlorophyll) must be interpreted with caution. A regional program for calibration and validation of ocean color products would help develop more robust regional ocean color products. Ancillary measurements (winds, wave breaking) can also contribute to assessing the quality of the satellite product retrievals. The "optimal interpolation" approach for generating "cloud-free" imagery has promise, but again requires solid verification of the quality of the products for both SST and ocean color. Various merged products combining (in situ observations, HF radar surface currents) and satellite imagery could help relate variability in satellite features to coastal ocean circulation, cross-shelf transport. There is a need for regionalized calibrations of the satellite data both, IR and ocean color.

Multiple data sources, varying requirements for processing or accessing the data are issues for broader use/application. Similarly, file formats and the application software required to read these is an barrier to broader and routine use of the imagery. For many applications, broader availability of higher resolution processed imagery via web sources could expand use of the imagery by managers, educators, etc. There are some more user-friendly portals being developed (e.g., NASA GIOVANNI), but the resolution of imagery required for many shelf and coastal applications remains an issue (i.e., the initial focus is more on larger scale ocean applications). Access to the data in a useful format. The limitations of NOAA are that not all of the available satellites are provided, e.g. NOAA_12 and NOAA_14. Also the European, Indian and Japanese satellite data are not available. The data from NASA are in difficult to use formats and require expensive systems to process to usable imagery. Data should be made available in useful formats.

Regionally tuned remote sensing algorithms; Improved spatial and spectral resolution in optically complex waters associated with atmospheric corrections and contamination from adjacent land pixels. High resolution, geostationary SST/ocean color satellites. Improved temporal limitations from polar-orbiting satellites. Getting "beyond chlorophyll". Detection of, and possible correction for bottom reflectance are issues for clear water conditions in shallower waters. Detection and quantifying Trichodesmium biomass from ocean color would be a significant biogeochemical application. Improved delivery of near real-time imagery and mechanisms for efficient delivery for targeted surveys (ships, gliders) would be useful. SAR products could be further explored and mechanisms established to make these products more readily available. Appropriate portals, both real-time and archived, will facilitate educational use, based on needs of various grade levels. 250-500 meter multispectral imagery (IR-Ocean color) hourly for all areas that could be used in riverine, intercoastal, coastal and open ocean areas.

The transfer of ocean color data delivery from NASA to NOAA is a concern for many. Many of the ocean color products remain in the research realm, as opposed to being operational products. As I understand this, it appears that the NOAA strategy for delivery of NPOESS products will be through contracted algorithm development, with delivery of final products as opposed to the radiometric data at levels appropriate for rigorous validation of products and satellite sensor performance, and further algorithm development (particularly for getting beyond chlorophyll as the primary ocean color product). The need for developing time series of climate quality data records for the coastal ocean as well as open ocean needs to be emphasized. The delivery of research as well as "operational" quality products will need to be continued if the full value of the satellite systems is to be realized.

Bob Evans & Otis Brown – U. Miami; Frank Müller-Karger & Chuanmin Hu – U. South Florida; Ed Kearns – National Park Service; John Morrison – U. North Carolina Wilmington; Dan Kamykowski – North Carolina State University; Subrahmanyam Bulusu – University of South Carolina, Columbia



Appendix D: List of Acronyms

AMSR-E	Advanced Microwave Scanning Radiometer for EOS (Earth Observing System)
ASAR	Advanced Synthetic Aperture Radar
AVHRR	Advanced Very High Resolution Radiometer
CDOM	Color Dissoloved Organic Material
DMSP-OLS	Defense Meteorological Satellite Program - Operational Linescan System
EEZ	Exclusive Economic Zone
ESA	European Space Agency
GCOS	Global Climate Observing System
GEOS	Geostationary Satellite Server
GHRSST	Global High-Resolution Sea Surface Temperature
GIS	Geographic Information System
GlobColour	European Node for Global Ocean Colour
GODAE	Global Ocean Data Assimilation Experiment
GPM	Global Precipitation Measurement
HAB	Harmful Algal Bloom
IGOS	Integrated Global Observing Strategy
IOOS	Integrated Ocean Observing System
JAXA	Japan Aerospace Exploration Agency
MERIS	Medium Resolution Imaging Spectrometer Instrument
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautic and Space Administraion
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
OCM/z	India's Ocean Colour Monitor
OGC	Open Geospatial Consortium
QuikSCAT	Quick Scatterometer
SeaWiFS	Sea-viewing Wide Field-of-View Sensor
SPOT	Systeme Pour l'Observation de la Terre
SST	Sea Surface Temperature
SWOT	Surface Water Ocean Topography
TRMM	Tropical Rainfall Measuring Mission
TSM	Total Suspended Matter
VIIRS	Visible Infrared Imager/Radiometer Suite