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Workshop Proceedings

Optical Remote Sensing of Coastal Habitats

Moss Landing, California
9-11 January, 2006

Funded by NOAA's Coastal Services Center through the Alliance for Coastal Technologies (ACT)

An ACT Workshop Report

A Workshop of Developers, Deliverers, and Users of Technologies for Monitoring Coastal Environments:

Optical Remote Sensing of Coastal Habitats

Moss Landing, California
9-11 January, 2006

Hosted by Alliance for Coastal Technologies (ACT) , the Moss Landing Marine Laboratories (MLML), and the Monterey Bay Aquarium Research Institute (MBARI).

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Executive Summary

The Alliance for Coastal Technologies (ACT) Workshop on **Optical Remote Sensing of Coastal Habitats** was convened January 9-11, 2006 at Moss Landing Marine Laboratories in Moss Landing, California, sponsored by the ACT West Coast regional partnership comprised of the Moss Landing Marine Laboratories (MLML) and the Monterey Bay Aquarium Research Institute (MBARI). The "Optical Remote Sensing of Coastal Habitats" (ORS) Workshop completes ACT's Remote Sensing Technology series by building upon the success of ACT's West Coast Regional Partner Workshop "Acoustic Remote Sensing Technologies for Coastal Imaging and Resource Assessment" (ACT 04-07). Drs. Paul Bissett of the Florida Environmental Research Institute (FERI) and Scott McClean of Satlantic, Inc. were the ORS workshop co-chairs. Invited participants were selected to provide a uniform representation of the academic researchers, private sector product developers, and existing and potential data product users from the resource management community to enable development of broad consensus opinions on the role of ORS technologies in coastal resource assessment and management.

The workshop was organized to examine the current state of multi- and hyper-spectral imaging technologies with the intent to assess the current limits on their routine application for habitat classification and resource monitoring of coastal watersheds, nearshore shallow water environments, and adjacent optically deep waters. Breakout discussions focused on the capabilities, advantages ,and limitations of the different technologies (e.g., spectral & spatial resolution), as well as practical issues related to instrument and platform availability, reliability, hardware, software, and technical skill levels required to exploit the data products generated by these instruments. Specifically, the participants were charged to address the following: (1) Identify the types of ORS data products currently used for coastal resource assessment and how they can assist coastal managers in fulfilling their regulatory and management responsibilities; (2) Identify barriers and challenges to the application of ORS technologies in management and research activities; (3) Recommend a series of community actions to overcome identified barriers and challenges.

Plenary presentations by Drs. Curtiss O. Davis (Oregon State University) and Stephan Lataille (ITRES Research, Ltd.) provided background summaries on the varieties of ORS technologies available, deployment platform options, and tradeoffs for application of ORS data products with specific applications to the assessment of coastal zone water quality and habitat characterization. Dr. Jim Aiken (CASIX) described how multiscale ground-truth measurements were essential for developing robust assessment of modeled biogeochemical interpretations derived from optically based earth observation data sets. While continuing improvements in sensor spectral resolution, signal to noise and dynamic range coupled with sensor-integrated GPS, improved processing algorithms for georectification, and atmospheric correction have made ORS data products invaluable synoptic tools for oceanographic research, their adoption as management tools has lagged. Seth Blitch (Apalachicola National Estuarine Research Reserve) described the obvious needs for, yet substantial challenges hindering the adoption of advanced spectroscopic imaging data products to supplement the current dominance of digital ortho-quad imagery by the resource management community, especially when they impinge on regulatory issues. This concern was echoed in the breakout sessions where the need for development of ORS product focused outreach materials and application case studies was emphasized.

The rigorous discussions among the workshop participants led to their development of the following prioritized list of recommendations. The top ten recommendations highlighted the workshop participants' recognition of an existing disconnect between marine ORS research trends and potential resource management applications. The group strongly felt that development and dissemination of outreach tools focusing on ORS supplemented management applications is needed to enhance adoption of these tools for routine coastal zone resource assessment and management activities.

1. Encourage development and implementation of ORS tutorials, making use of case studies for management application of this technology and involve existing training programs (e.g., NERR Coastal Training). This would build on a recommendation for assembling a list of case studies highlighting application of ORS products for management uses.
2. Develop information tools on ORS collection process. Develop broad reaching educational tools (e.g., infomercial like DVD) to provide overviews of ORS applications in action. Potential target audiences: Resource Managers, regulators, and secondary education units
3. Provide cost benefit analysis for the entire ORS data collection and product distribution process using case studies (current approaches vs. implementation of new business models), and identify list of cost reduction strategies.
4. Establish catalog of field reference sites (target Marine Protected Areas (MPAs) and Coastal Ocean Observing System (COOS) sites with consistent support for in-water optical measurements) to aid in risk reduction activities associated with new data product validation and sensor design.
5. Promote development of national archives for standardized ORS data for coastal management. This could also promote development of centralized libraries of spectral signatures for targets of interest.
6. Develop ORS algorithm validation protocols to provide product accuracy determination to aid managers requiring defensible data products.
7. Develop ORS calibration and product validation protocols document to assure comparable results from various technologies (i.e., similar to SeaWiFS Ocean Optics protocols but optimized for coastal zone challenges). Encourage development of airborne remote sensing standard methods manual.
8. Develop linkages between ORS products (e.g., chlorophyll, CDOM, sediments) and parameters of regulatory interest.
9. Develop an ORS discussion forum on ACT web site to continue and enhance dialog among R&D, industry, and resource mangers, focusing on two-way communication to help define resource manager needs.
10. Provide readily accessible summary and glossary of current ORS technologies and links to example data products with user list.

Alliance for Coastal Technologies

The Alliance for Coastal Technologies is a NOAA-funded partnership of research institutions, resource managers, and private sector companies dedicated to fostering the development and adoption of effective and reliable sensors and platforms. ACT is committed to providing the information required to select the most appropriate tools for studying and monitoring coastal environments. Program priorities include transitioning emerging technologies to operational use rapidly and effectively; maintaining a dialogue among technology users, developers, and providers; identifying technology needs and novel technologies; documenting technology performance and potential; and providing the Integrated Ocean Observing System (IOOS) with information required for the deployment of reliable and cost-effective networks.

To accomplish these goals, ACT provides these services to the community:

- Third-party testbed for quantitatively evaluating the performance of new and existing coastal technologies in the laboratory and under diverse environmental conditions.

- Capacity building through technology-specific workshops that review the current state of instrumentation, build consensus on future directions, and enhance communications between users and developers.

- Information clearinghouse through a searchable online database of environmental technologies and community discussion boards.

The ACT workshops are designed to aid resource managers, coastal scientists, and private sector companies by identifying and discussing the current status, standardization, potential advancements, and obstacles in the development and use of new sensors and sensor platforms for monitoring, studying, and predicting the state of coastal waters. The workshop's goal is to help build consensus on the steps needed to develop and adopt useful tools, while facilitating critical communication among the various groups of technology developers, manufacturers, and users.

ACT Workshop Reports are summaries of the discussions that take place between participants during the workshops. The Reports also emphasize advantages and limitations of current technologies while making recommendations for both ACT and the broader community on the steps needed for technology advancement in the particular topic area. Workshop organizers draft the individual reports with input from workshop participants.

ACT is organized to ensure geographic and sector involvement:

- Headquarters is located at the UMCES Chesapeake Biological Laboratory, Solomons, MD.

- Board of Directors includes Partner Institutions, a Stakeholders Council, and NOAA/CSC representatives to establish ACT foci and program vision.

- There are currently eight ACT Partner Institutions around the country with coastal technology expertise that represent a broad range of environmental conditions for testing.

- The ACT Stakeholder Council is comprised of resource managers and industry representatives who ensure that ACT focuses on service-oriented activities.

ACT is committed to exploring the application of new technologies for monitoring coastal ecosystem and studying environmental stressors that are increasingly prevalent worldwide. For more information, please visit www.act-us.info.

Goals for the Workshop

The workshop was designed to:

- Summarize state of the art in Optical Remote Sensing (ORS) technologies.
- Identify how ORS products are used and how they can assist coastal managers in fulfilling their regulatory and management responsibilities.
- Identify barriers and challenges to the application of ORS technologies in management and research activities.
- Recommend a series of community actions to overcome these barriers and challenges.

Workshop Structure

The Alliance for Coastal Technologies (ACT) Workshop on **Optical Remote Sensing of Coastal Habitats** was convened January 9-11, 2006 at Moss Landing Marine Laboratories in Moss Landing, California. The workshop was sponsored by ACT West Coast headquartered at MLML, which maintains a collaborative partnership with MBARI. Invited participants were selected to include equal representation from three population segments concerned with water resource quality and included individuals from academic research institutes, private sector companies, and local, state, and federal resource managers.

An opening reception was held at the Embassy Suites Hotel in Seaside, CA for participants the first evening. Kenneth Coale (Director, Moss Landing Marine Laboratories) and G. Jason Smith (Technical Coordinator for ACT-Pacific Coast) provided an introduction to the workshop and programmatic overview of the national ACT program.

The following morning, during the opening plenary session, Co-Chairs, Dr. Paul Bissett and Scott McLean, provided an overview of the workshop goals. This introduction was followed by three plenary talks (Appendix B) to set the stage for subsequent breakout session discussions. Dr. Curtiss O. Davis (College of Oceanic and Atmospheric Sciences, Oregon State University) provided a summary of the evolution of optical remote sensing technologies and deployment platform options with emphasis on their application to "Ocean Color Remote Sensing of the Coastal Ocean." Dr. Stephan Lataille (ITRES Research Ltd.) provided examples of commercial applications and data fusion products obtainable from airborne ORS imaging in his presentation entitled "Optical Water Quality and Coastal Zone Information Products." Seth Blitch (Apalachicola National Estuarine Research Reserve) provided a real-world perspective on the challenges facing adoption of new remote sensing tools for application in ongoing management efforts in his talk "Coastal Resource Management and Remote Sensing: Challenges and Perceived Needs."

The remainder of the day was comprised of two breakout working group discussion and summary sessions. After the working sessions, a tour and dinner was hosted at MLML. Dr. Jim Aiken (Centre for Observation of Air-Sea Interactions & fluXes [CASIX], Plymouth Marine Laboratory) provided an informative and entertaining after dinner talk (with song!) describing the objectives of the CASIX program and how in-water ground-truth of ORS observations help address the importance of all the shades of greens to ocean ecosystem functions. The following morning was spent in open discussion of consensus recommendations derived from the working group discussions.

ORS Overview

The Promise and Practice of Using Spectrally Resolved Imagery for Assessment of the Coastal Zone

Few can deny an emotional response to imagery of the earth's surface. Indeed, the value of above ground observations as a survey tool providing unique perspectives on ecosystem structure and land use patterns has been exploited since the time that man achieved flight. The early incorporation of camera systems into flight systems to the development of the still active field of photogrammetry, from which modern remote sensing technologies continue to evolve. These earth observing technologies are based on common measurement principles by detecting a select ranges of electromagnetic waves passively reflected off (e.g., visible light) or emitted from (e.g., microwaves, thermal infrared) the earth's surface, and more recently, by monitoring reflection of transmitted signals (e.g., radar, Lidar) derived from active sources positioned at a defined geometry with respect to the sensor. This workshop focused on the acquisition and use of imagery derived from a narrow range of the electromagnetic spectrum impinging the earth, the visible to near infrared wavelengths, which for the purpose of discussion, was defined as Optical Remote Sensing (ORS) technologies.

The value of using earth imagery as a decision aid for gross assessment of military targets and terrestrial resources where visually identifiable ground reference points could be mapped or georeferenced to available survey data by expert interpreters has long been recognized. Yet non-military high altitude and satellite based observing platforms have only been available since the 1970s providing observations of abundant and dynamic mesoscale ocean features undetectable by existing point based oceanographic surveys. The growth of the commercial remote sensing industry and implementation of earth observation data sets for geospatial-based management schemes has been triggered in part by development and access to Global Positioning Systems (GPS) signals and Geographic Information Systems (GIS) applications, as well as enhancement in desktop computer performance and power.

Coastal zone and estuarine environments present a variety of challenges for interpretation of fixed point based and event time series survey transects due to high temporal dynamics associated with tidal and wind driven processes, as well as the fractal nature of shorelines and sub-tidal geomorphology. Clearly, regional monitoring efforts and development of ecosystem-based management strategies in these regions can benefit from the inclusion of synoptic data sets like those obtained from airborne and space-borne remote sensing technologies. Yet, public sector application of remotely sensed imagery for the assessment of aquatic environments, particularly coastal regions, has lagged behind the terrestrial systems, in part, because technological challenges inherent to obtaining robust passive reflectance imagery from water. A brief primer on the principles of aquatic optics is provided to help the reader understand that engineering solutions have been required to provide the essential data for development of quantitative assessment applications utilizing geospatially referenced imaging spectroscopy of coastal ecosystems.

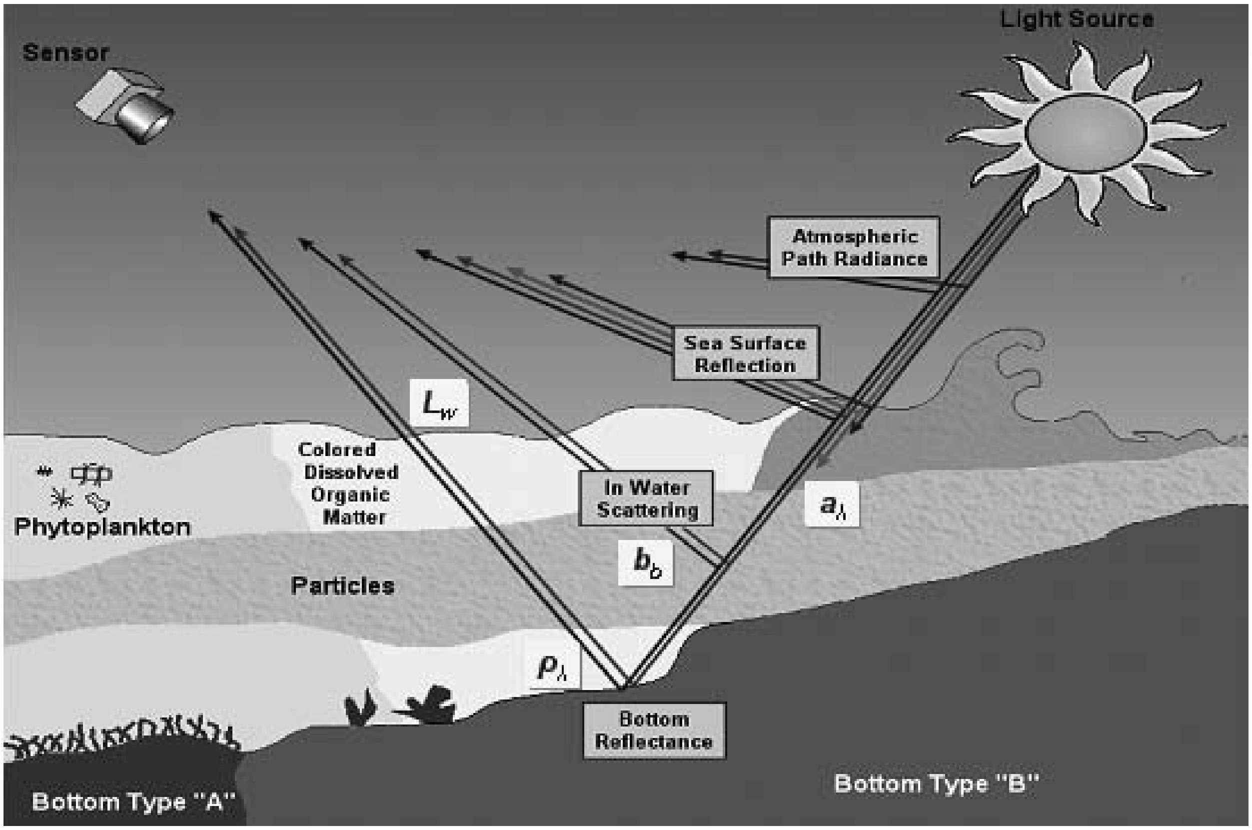

Figure 1. *Schematic of the complexities of the light field in coastal waters and the challenges for extracting quantitative information regarding biogeochemical composition of the water column and benthic habitats. Movement from multi- to hyperspectral data sets will permit quantification of the subsurface components with increasing resolution Reflection from neighboring coastal lands (not shown) will be significantly brighter than the darker water signal and place constraints on ORS system design for coastal zone applications. (Courtesy C.O. Davis, from Lee and Carder, 2002, Appl. Opt., 41(12), 2191 – 2201)*

Environmental Optics

Radiative transfer theory provides the analytical framework and numerical solutions for reconstructing the geometric paths and spectral losses (scatter and absorption) from the radiation source (e.g., sunlight or laser in the case of Lidar) to the target in the sensor field of view (FOV) and ultimately from the target to the detector surface. These processes are common to both aquatic and terrestrial imagery. However, in contrast to terrestrial targets, reflection from the water surface is of limited information value (e.g., surface roughness, wave patterns) and can overwhelm the water-leaving radiance signal derived from subsurface interactions (spectral attenuation, scatter, absorption, and bottom reflectance) that provides information on in-water constituents (Fig. 1). The variable transparency of aquatic targets (a visual index of water quality) presents unique analytical challenges and prompted the development of analytical tools (e.g., *Hydrolight*, Mobley 1994) to model the impacts of in-water constituents (phytoplankton abundance and species composition, sediment / particle load, dissolved organic matter, bottom features) and in optically shallow waters, bathymetry and bottom reflectance, on the in-water light field and water-leaving radiance, $L(\lambda)_w$ in the direction of the sensor under specified solar angles and meteorological conditions (henceforth L_w for typographic simplicity). Remote sensing reflectance, R_{rs}, represents a standardized metric of emission from the surface to normalize for sun angle and irradiance across image pixels (= nL_w/E_d, where E_d represents the downwelling plane irradiance and nL_w is L_w normalized to correspond to a solar zenith angle of 0, directly overhead). It is the spectral dependence of L_w (or R_{rs}) which provides information regarding the content and composition of in-water constituents and bottom reflectance. For the purposes of comparisons of geospatial, temporal, and even spectral patterns in L_w and derived products, radiometrically calibrated data from the optical sensors are required. Extensive and standardized field validation efforts are needed to enable development and validation of robust assessment information products for science and management applications from such well calibrated ORS based data products.

Regardless of the observational platform (i.e., aircraft or satellite), the initial target for ORS image analysis is to obtain robust measures of L_w from the total FOV radiance measured by the sensor, L_s, for each spectral channel. Hence ORS scene analysis entails sequential data processing for calibration and to remove the effects of the atmosphere and ocean surface adding to the expense of producing the ocean data products post collection. Scattering of radiation by the atmosphere (due to air molecules, aerosols, dust) contributes over 90% of the measured L_s depending on meteorological conditions. Additionally, these components lead to attenuation of L_w proportional to the atmospheric path length. Consequently, errors in correcting for the atmospheric contribution can cause much larger errors in the smaller L_w, particularly in blue wavelength bands. While robust atmospheric models have been developed and validated, the atmospheric correction of ORS scenes in the coastal zone presents unique challenges. The dynamic nature of the marine boundary layer combined with the mixtures of dark water targets (low L_w) and bright targets from clouds and the subtidal zone landward complicate correction processing. Hence, significant overestimates of L_w can occur if a single correction model is applied within scene. Inclusion of a near-IR bands (>750 -1100 nm) in multispectral and hyerspectral sensors, a region where L_w should be negligible, enables estimation of atmospheric aerosol content on a pixel by pixel basis and increased atmospheric correction accuracy in the visible wavelengths. For the highest accuracy L_w measures, programs dependent on long term high frequency ORS data sets should include support for in-scene deployment of instrumentation to make calibrated measurements of L_w (e.g., **MOBY**, physoce.mlml.calstate.edu/moby/) or for lower frequency collects, incorporate a field sampling program coincident with imaging overpasses (e.g., COAST, cioss.coas.oregonstate.edu/CIOSS/coast.html to provide surface truth data to help verify accuracy of not only the atmospheric correction but sensor calibrations as well.

As mentioned above, reflection from the water surface must also be corrected to retrieve L_w. Careful planning of local flight lines and collect timing for aircraft-based sampling to reduce specular reflections in scene and sun-synchronous orbits for satellite sensors can minimize but not entirely eliminate this problem. To eliminate this unwanted signal, residual correction for sea surface reflections must be an integral part of the atmospheric correction scheme used for ocean scenes. Additionally, ORS collections are generally avoided when possible in conditions with high wave activity and whitecaps that locally enhance surface reflectance and reduce the number of useful pixels for in-water analysis.

The contribution of bottom reflectance increases as scenes overlap nearshore and shoreline environments, especially in clear waters. Signal from the bottom can provide important information about bathymetry, bottom type, and vegetation. Data from the adjacent land areas can provide important information about beaches and wetlands. Land features can provide control points for geolocation of the scene. However, the mixture of bright and dark targets in these regions place demands on detector design for coastal zone applications, such that they need to have a large dynamic range while maintaining high signal to noise ratio for measurements over dark water targets, as well as adjoining terrestrial habitat reflectance signatures. It should be noted that nLw (derived from calibrated Lw along with precise navigational, viewing, and solar angle metadata) represents a consistent ORS metric enabling robust comparisons across spatial and temporal domains, as well as between sensor observations as long as there is sufficient waveband overlap.

The non-trivial computational processing required to generate image scenes comprised of georeferenced pixels of radiometrically calibrated L_w (Level 1A data product) should be conducted by the organizations responsible for the particular remote sensing platform operations. It is from these Level 1A data products that resource assessment information products can be derived, dependent on the level of sophistication of the user and quality of the in-scene ground truth data. At minimum, Level 2 image products should provide calibrated measures derived from pixel L_w's with image pixel coordinates mapped on to corresponding geospatial coordinates, such that these products are compatible with standard GIS data layers. Extraction of quantitative information on water quality parameters based on the physics of underwater optics requires robust measurements of at least two of a suite of inherent optical properties (IOPs) including the absorption coefficient, a_λ, beam attenuation coefficient, c_λ, and the volume scattering function, β_λ, from which the scattering coefficient, b_λ can be derived (also note that $c_\lambda = a_\lambda + b_\lambda$ and that $b_\lambda = b_f + b_b$, forward and backscatter respectively). As the definition of IOPs exclude multiple photon interactions, each whole water measure represents a summation of the corresponding IOP for each in-water component (e.g., $a_\lambda = a_{\lambda w} + a_{\lambda ch} + a_{\lambda ys} + a_{\lambda p}$, for absorption by water, phytoplankton, DOM, and suspended particles respectively). If the specific absorption coefficient for each component is known, the concentration of that component can similarly be derived. Radiative transfer equations (RTE) model the directionality of the underwater light field for given sea states, sky conditions, and solar angles and provide the analytical linkage between IOP measures and the apparent optical properties of the water column like the measured R_{rs} (Fig 2). In general, spectrally resolved reflectance will be proportional to b_b / a, so regional development of the spectral libraries of IOPs (and bottom reflectance where necessary) characterizing critical management targets (harmful or nuisance algal species, benthic habitats, vegetation, and sediments) is essential for developing robust assessments of their temporal and geospatial distributions.

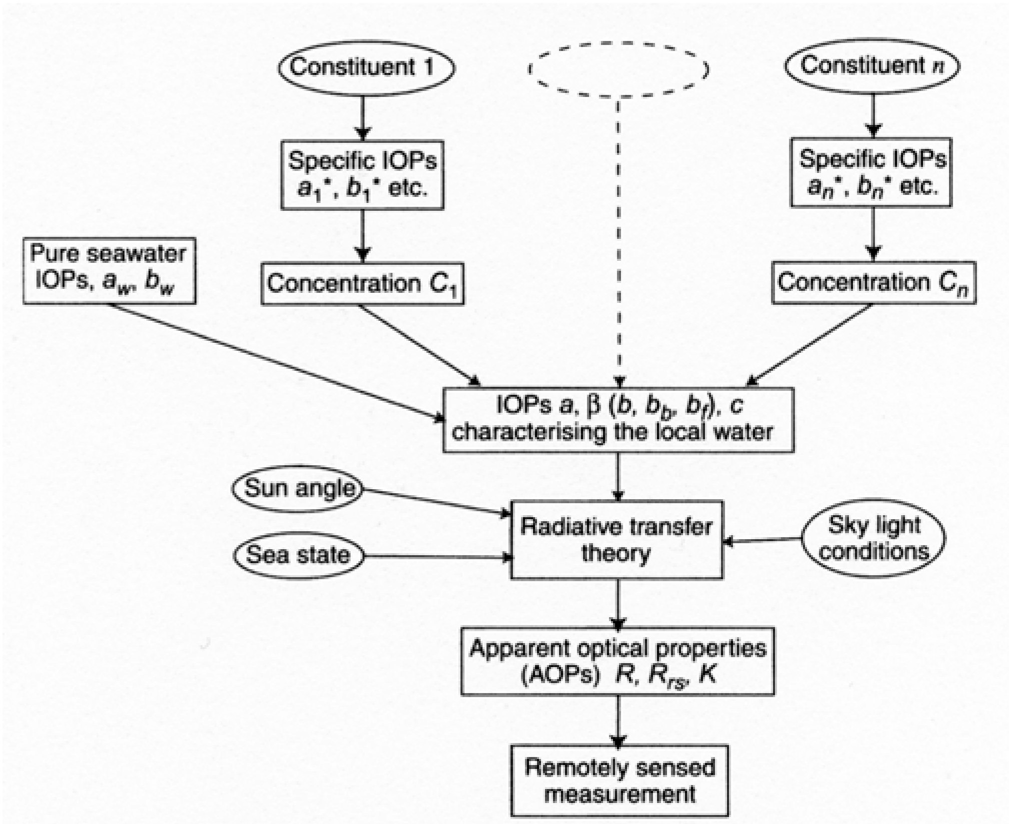

Figure 2. Causality flow for water column optical interactions demonstrates how ORS measurements are indicative of the sum total of interactions due to the inherent optical properties of water borne and bottom constituents. The challenge for development of ecosystem assessment applications in the coastal zone is developing robust inversion algorithms to derive constituent concentrations from spectrally resolved reflectance measures (from Robinson, 2004).

As should be obvious from this brief discussion, radiative transfer theory is well described and R_{rs} can be modeled for a range of water types, bathymetries, and meteorological conditions. However, the development of efficient numerical solutions for inversion of:

$R_{rs}(\lambda) = f[\ a(\lambda), b_b(\lambda), \rho(\lambda), H\ ]$,

(where $\rho(\lambda)$ is bottom reflectance and H, bottom depth) to provide quantitative measures of water quality parameters or other subsurface features is non-trivial and represents an active research focus of the marine ORS community. The accuracy and robustness of these data products clearly will depend on the degrees of freedom or spectral richness of both the image and ground validation data sets. Based on discussions throughout the workshop, increased interactions between the ORS research and coastal zone management sectors could help define critical analytical targets and ground/sea validation requirements for application development.

For qualitative assessments of ecosystem structure, unsupervised classification schemes can be applied to the spectrally resolved R_{rs} enabling identification of spectrally similar spatial domains (e.g., riparian and benthic communities, coastal geology, plume identification) that can be targeted for manual ground validation efforts. Hyperspectral data sets are amenable to many spectral analysis techniques, for example 4th-derivative analysis that enables identification of discrete components masked within the raw spectrum. This information could be used for characterization and track of discrete water masses. These qualitative approaches also can help guide the development of empirical algorithms derived from regression analysis of L_w spectral band ratios against scene-concurrent quantitative measures biogeochemical or resource component along with measures of associated statistical error. Development of empirical models, supported early on by rigorous sea-truth programs, has helped foster public acceptance of the importance of earth observation data sets from dedicated ocean color satellites (e.g., SeaWiFS, MODIS) providing accessible global, as well as regional assessments of key parameters in near surface waters such as chlorophyll *a* biomass, water clarity/optical depth, and surface temperature (see for example: oceancolor.gsfc.nasa.gov). However, it should be noted that empirical algorithms continue to evolve based on performance flaws revealed by ongoing regional validation efforts, particularly in coastal waters and that global empirical algorithms are rarely as accurate as regionally tuned products. These observations point to the critical need to support concurrent surface and in-water assessments as an integral part of any regional ORS collection program (e.g., www.cicore.org).

ORS Technology Trends

Ever since earth imagery revealed complex distributional patterns of apparent color, the subsequent recognition that reflectance signals from the land or through the water surface also represent a composite feature built from unique spectral features characterizing the components of the imaged ecosystem has driven the continued enhancement of ORS technologies. Many components or at least functional groupings have been demonstrated by laboratory-based and, more recently, field compatible spectrophotometric analysis to exhibit unique but subtle differences in spectral shapes that become apparent through analysis of high spectral resolution, ideally continuous, UV-VIS-IR spectra. Hence, there has been ample motivation to develop ORS systems with high spectral resolution. Increased spatial resolution is also a design target, especially for systems targeting coastal zone applications as critical in-water processes and coastal habitat features exhibit significant changes over meter scales (Fig. 3). An additional advantage of increased spatial resolution or decreased ground sample distance (GSD) per pixel is that it leads to better correspondence between remotely sensed signal and point-based ground samples. However, increased spectral and spatial resolution are competing design targets in terms of optimal SNR for imaging dark water targets as narrow spectral channels require longer integration times and the smaller GSD leads to less radiance per pixel and higher scan rates to cover an equivalent image swath. However, advent of area detector arrays of high dynamic range and high SNR and their coupling to diffraction grating in the optical scanning system have provided dramatic improvements over the single FOV and optical filtered band detectors deployed on the first generation of ocean color satellites (i.e., CZCS). While the linear and 2D detector arrays currently deployed on satellites (MODIS and MERIS respectively) are capable of detecting continuous (hyperspectral) spectra from the FOV, current ground telemetry data rates are incapable of transmitting the full spectral information, and it must be down-sampled to targeted wavebands. Ongoing development of lossless data compression algorithms will provide solutions to this issue. For a given optical system, GSD will be dependent on platform altitude and viewing angle, the aforementioned tradeoffs between spectral and spatial resolution restrict current satellite ocean color sensors to nadir GSDs >100m, which may not be sufficient for robust coastal assessments desired for management applications. A variety of aircraft have provided suitable platforms for a variety of hyperspectral imaging sensors (AVIRIS, CASI, PHILLS) being developed and operated by both government and commercial organizations that can provide high spectral ($\leq$10nm) and spatial resolution (<10m) data products for targeted coastal scenes (Fig. 4). While the magnitude of the hyperspectral image data cubes is again incompatible with real time telemetry, the imaging systems are designed for on-board storage and post-flight offloading for potentially rapid turnaround of Level 1A data products. The capacity to down-sample hyperspectral data to match that of existing multispectral satellite sensors provides an invaluable enhancement to algorithm development and validation and enhances the design cycle for new generations of ORS imaging systems. Hybrid ORS packages, combining hyperspectral imagers with LIDAR or high resolution oblique view digital camera, are being developed that enable production of co-registered spectral, bathymetric, elevation, and DOQ products for each scene deployment. Such systems offer the potential of encouraging cost sharing planning to support more frequent regional overflights.

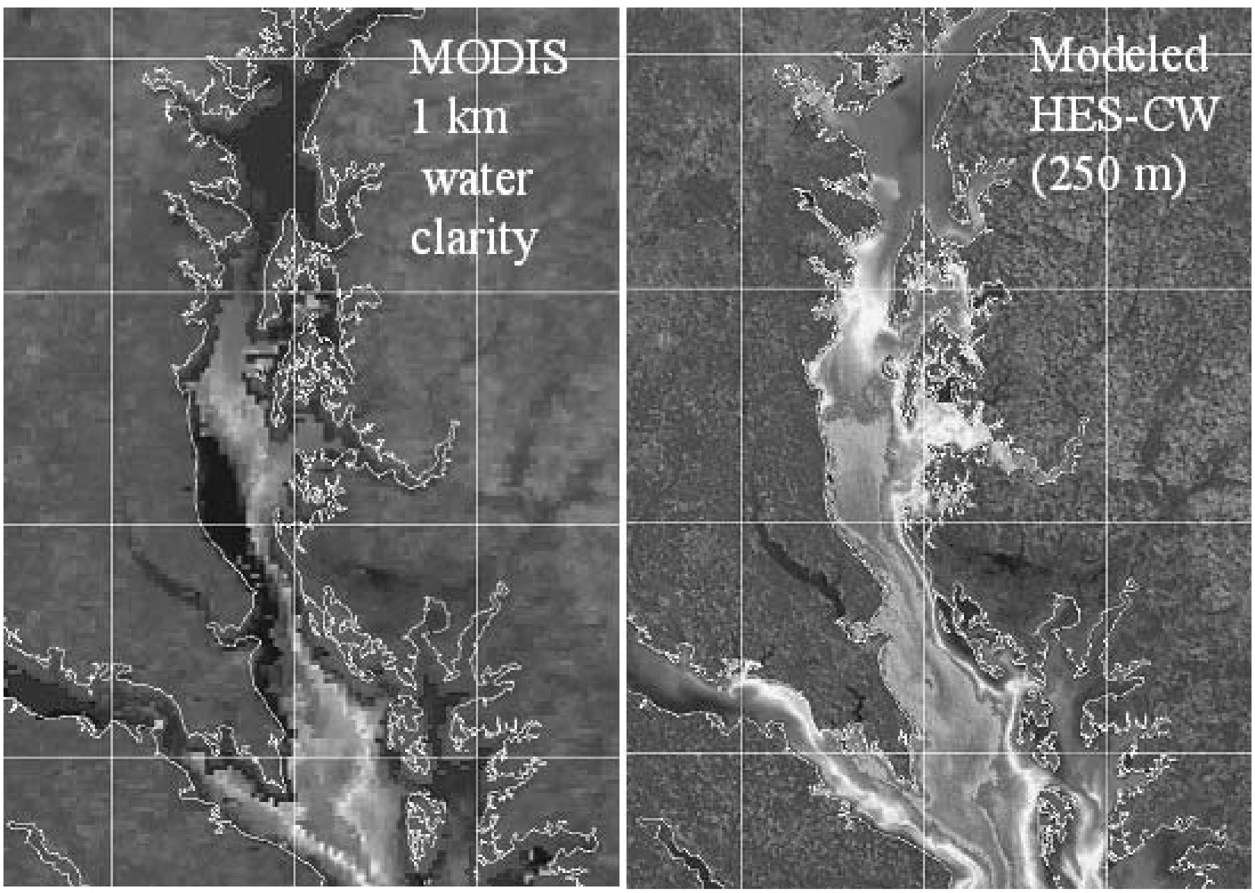

Figure 3. Example of how increase spatial resolution of ORS sensors and data products is essential for resolving complexities of ecosystem features associated with coastal and estuarine geomorphology. Here, a satellite-derived ORS measure of water clarity, the attenuation coefficient at 490 nm (K490) derived from 1 km GSD of a MODIS image of Chesapeake Bay has been resampled by algorithms that combine that data with a 250 m land channel to demonstrate products

at the higher spatial resolution required for Coastal Waters (Courtesy C.O.Davis and B. Arnone, NRL).

Development of ORS-based process studies in the coastal zone, where tidal and runoff effects often dominate, is limited by the current revisit times of polar orbiting satellites (1-3 days). While aircraft-based platforms can resample at higher frequency, it would be associated with loss of spatial coverage and increased deployment costs, as well as by the limited regional availability of these systems. Proposed deployment of hyperspectral sensors on geo-stationary platforms like the GOES satellites offers promise for solution to these sampling issues. Fixed observational platforms enable longer scene integration times, as well as scene resampling over hourly time scales.

Platform	Sensor	Swath	PixelSize	Data	Web Address
Aircraft	AVIRIS	2.6-11 km	5-20 m	HS	http:://aviris.jpl.nasa.gov
Aircraft	CASI	0.5-1.5 km	1-3 m	MS/HS	http://www.itres.com/
Aircraft	PHILLS	1-8 km	1-8 m	HS	http://rsd-www.nrl.navy.mil/7230
Aircraft	HyMap	2 km	4 m	HS	http:://www.aigllc.com/
Satellites					
Nimbus-7	*CZCS*	*~1700 km*	*850 m*	*MS*	*1978-1986*
NOAA	AVHRR	~2000 km	1000 m	MS	http://perigee.ncdc.noaa.gov/docs/intro.htm
Landsat 7	ETM+	185 km	30 m	MS	http://landsat7.usgs.gov/
Landsat 7	Pan	185 km	15 m	Pan	http://landsat7.usgs.gov/
Ikonos	MS	5 km	4 m	MS	http://www.spaceimaging.com/
Ikonos	Pan	5 km	1 m	Pan	http://www.spaceimaging.com/
OrbView 2	SeaWiFS	~2000 km	1000 m	MS	http://seawifs.gsfc.nasa.gov/SEAWIFS.html
Terra	MODIS	~2000 km	1000 m	MS	http://modis.gsfc.nasa.gov/MODIS/
Terra	Aster	60 km	15m	VNIR	http://asterweb.jpl.nasa.gov
Terra	Aster	60 km	30 m	SWIR	http://asterweb.jpl.nasa.gov
Aqua	MODIS	~2000 km	1000 m	MS	http://modis.gsfc.nasa.gov/MODIS/
ENVISAT-1	MERIS	1150 km	300 m	MS	http://envisat.esa.int/
Landsat 7	Pan	185 km	15 m	Pan	http://landsat7.usgs.gov/
OrbView 3	MS	8 km	4 m	MS	http://www.orbimage.com
OrbView 3	Pan	8 km	1 m	Pan	http://www.orbimage.com
Quickbird	MS	16.5 km	2.44 m	MS	http://www.digitalglobe.com
Quickbird	Pan	16.5 km	0.6 m	Pan	http://www.digitalglobe.com
SPOT 1-2-4	MS	60 km	20 m	MS	http://www.spot.com
SPOT 1-2-4	Pan	60 km	10 m	Pan	http://www.spot.com
NPOESS	*COIS*	*40 km*	*40 m*	*HS*	*http://rsd-www.nrl.navy.mil/7230*
GOES-R	*HES-CW*	*4000 km*	*300 m*	*VNIR*	*http://www.osd.noaa.gov/goes_R/index.htm*

Figure 4. Listing of ORS sensor suites whose data products are applicable to coastal remote sensing applications. Pan: panchromatic (grayscale imagers); MS: multispectral; HS: hyperspectral; VNIR: visible-near infrared detection range. Satellite sensor systems in italics are non-operational (CZCS) or have been canceled (HES-CW) or delayed indefinitely (NPOESS-COIS). (Courtesy C.O. Davis).

A layered approach to development of operational ORS monitoring of coastal zone environments should be envisioned. In such a system, identification of regional baseline trends and product validation, key components of resource management efforts, can be developed from long-term satellite observations and regionally targeted high resolution collects from aircraft. Satellite observations can be used to detect change events and targeted quick-response deployment of aircraft sensors for high resolution analysis. However, development of such observation systems is currently limited by funding support for regional placement of aircraft based ORS systems and for enhancement of satellite observation systems. It is apparent that a range of technology is in place and analytical tools continue to improve to support development of robust geospatial applications for coastal zone management (Fig 5). What is still needed in the ongoing development cycles are collaborative efforts and frank exchanges identifying the data product requirements (e.g., target parameters, spatial resolution, statistical confidence) for these efforts. This workshop was convened to help assess the current use and needs for ORS-based data products in coastal research, resource assessment, and regional policy decisions. It was intended as a forum to explore ideas to facilitate the use of available ORS products and encourage development of management focused information products from ORS data sets.

Applications / Issues	*Spatial Resolution x Extent*	*Temporal Resolution*	*Examples of suitable platforms / sensors*
River plumes, outfalls	**(20 m – 1 km) x (1 km – 100 km)**	**hours – weeks**	**MERIS, MODIS, SeaWiFS,**
Tidal plumes, jets, frontal dynamics	**(20 m – 1 km) x (1 km – 10 km)**	**hours**	**Airborne**
Harmful algal blooms, aquaculture, coastal water quality	**(100 m – 1 km) x (1 km – 100 km)**	**days – weeks**	**MERIS, SeaWiFS, MODIS,**
Bathymetry and shallow benthic habitat: ***distribution, status***	**(1 m – 30 m) x (1 km – 100 km)**	**weeks to months**	**Airborne platforms, Landsat TM, Ikonos**
Maritime operations: ***navigation, visibility***	**(20 m – 1 km) x (20 km – 100 km)**	**hours to days**	**MERIS,**
Oil spills.	**(10 m – 300 m) x (1 km – 30 km)**	**hours – days**	**Airborne, MERIS**
Operational fisheries oceanography	**(1 km) x (1000 km)**	**days**	**SeaWiFS, MODIS, MERIS**
Tidal marshes	**(1-30 m) x (1-30 km)**	**weeks to months**	**IKONOS, Landsat TM**
Coastal geomorphology	**(1-30 m) x (1-20 km)**	**weeks to months**	**Ikonos, Landsat TM,**
Integrated regional management	**(20 m – 300 m) x (20 km – 300 km)**	**days**	**MERIS**

Figure 5. Examples of coastal zone management targets, including their spatial and temporal scales, whose assessment can be enhanced through application development based on existing or emerging ORS sensor data products (Courtesy C.O. Davis).

Summary of Breakout Group Discussions

First Breakout Session

This breakout session sought to develop sector-specific viewpoints on the following aspects of optical remote sensing applications:

1. What are the key management issues in coastal habitats monitoring and regulation?
2. What types of ORS technologies are currently in use? What data products do they produce?
3. What data products are used in the coastal zone for habitat monitoring?
4. What new data products would be most desirable, and specifically, how would it help management and regulatory activities?

Management Sector Viewpoint

Group Chair: John Janssen; Rapporteur: George Leshkevich

Representatives of this sector expressed a general appreciation for the utility of ORS-based data products but recognized that this was tempered by the demands of their positions as resource managers. Generally, they felt their use of ORS data products beyond aerial photography was heavily constrained by lack of consistent and sufficient funding that would be required to maintain expert staff to interpret and manipulate these products, especially multi- and hyper-spectral data sets. To make use of any ORS product, it must complement their need to follow defined management schemes that include i.) definition of a target level for each management issue, ii.) establishment and maintenance of a monitoring program to track target changes, and iii.) if management targets are not met, then barrier(s) should be identified within current management practices that are preventing these achievements.

Within this management framework, they felt the following management foci are amenable to analysis with ORS products, particularly with respect to establishing base maps and subsequent change analysis for emergent, intertidal, and submerged habitats:

Physical Habitat: including shallow water bathymetry, sediment characterization and dynamics, hazards and event response (oil spills, hurricanes, floods), benthic substrate classification and digital elevation mapping of emergent habitats;

Biological Resources: including wetlands, submerged aquatic vegetation and reef communities, species distributions, invasive species dynamics, harmful algal blooms, and mapping of environmentally sensitive habitat areas;

Water Quality/Quantity: plume tracking and point source identification (both water and atmospheric plumes), system primary productivity and eutrophication as proxies for point-based nutrient monitoring programs, and dissolve organic matter dynamics via CDOM and salinity mapping as proxies; and

Coastal and Watershed Land-Use: identify patterns and changes in habitat use and impacts on the other three management foci.

At present, these issues are being addressed with a limited number of ORS-based products with the pattern of use reflecting an economically constrained lag in adoption of emergent technologies. In the group's view, ORS product use could be ranked as follows: i.) Traditional film-based aerial phototography (including color IR), ii.) digital aerial photography (both as ortho-rectified products), iii.) LIDAR for digital elevation maps and nearshore bathymetry, iv.) multispectral, and more recently, hyperspectral imagery, v.) thermal imagery and vi.) satellite imagery including IKONOS, Quickbird, SeaWiFS, MODIS, LandSat, AVHRR, AVIRIS, and GOES scenes. In almost all cases, this group indicated that processed imagery products were required as support for expert in-house staff and resources to develop required products was low. Regardless of image type, the group indicated that the primary use of imagery would be as additional layers in GIS maps of their management unit, which would permit generation of quantitative measures of management targets and their dynamics. Additionally, the power of imagery as outreach materials was also recognized as a value added benefit.

The management group felt that developing a dialogue on how ORS products can complement traditional monitoring investments was critical to support infrastructure investments required to obtain and manipulate ORS products as part of their management workflows. (I.e., how does the greater spatial coverage of ORS products map onto or complement the high temporal coverage of in situ or point based monitoring data?) As managers are charged to act within a regulatory framework, they felt that the issue of 'trustworthiness' in terms of accuracy, precision of spatial resolution, georectification, and spectral signatures needs to be clearly defined and accessible within each data product. In conjunction with these concerns, data accessibility was viewed as critical with appropriate use of metadata standards seen as a critical first step.

Research Sector Viewpoint

Group Chair: Raphe Kudela; Rapporteur: Chuck Trees

This set of charge questions helped to reveal a disconnect between the research and management sectors on the potential uses of ORS-based data products.

While there is an increasing use of aerial and satellite imagery as additional data layers in GIS-based descriptions of management units, the layers are generally presented as qualitative representation of resource distributions and monitoring sites. In contrast, the research sector felt their efforts to date were focused on developing solutions to critical issues in ocean optics, such as robust measurement of inherent optical properties for target water masses, development of algorithms to enable inverse modeling of in-water constituents based on these spectrally resolved measurements, and accurate estimation of near surface water-leaving radiances required for accurate atmospheric correction of aerial or satellite-based reflectance imagery. As a consequence of this essentially engineering focus, the group felt they had little direct knowledge of the types of ORS data products, aside from aerial maps, that would be useful to coastal managers.

The group's discussion therefore focused more on identifying achievable requirements to develop 'defensible' ORS data products for use in management applications. They felt that ORS sensor technologies and image processing algorithms have evolved sufficiently for both terrestrial and marine environments and that geospatial spectroscopic habitat classification is possible. However, they felt that knowledge of the types of spectroscopic data products needed for management is limited. They acknowledged that the ocean optics community has historically focused on open, optically clear (Case 1) waters, and only within the last two decades has attention been directed towards solving the more challenging optical problems encountered in more turbid coastal/estuarine (Case 2 and 3) waters or in regions where bottom reflectance is a significant component of the remote sensing reflectance signature. They suggested that identifying regional overlaps (i.e., estuarine, coastal, or oceanic) of ORS research expertise with corresponding management units would be critical in helping to identify the spatial (meters vs kilometer resolution) and temporal scales (diel, seasonal, yearly, or haphazard scene revisits) required in management targeted products. Adequate ground truth coverage in the region of interest was viewed as critical to the development of defensible products in that it would enable development of accurately geo-rectified, atmospherically corrected, and radiometrically calibrated ORS products within the region to change detection when used in regional assessments.

Based on the group's experience, they emphasized that regional validation efforts are required for accurate calibration and implementation of algorithms to extract local water quality (chlorophyll, turbidity, CDOM) and resource (benthic, intertidal, emergent vegetation coverage, and composition) distribution products. They acknowledge that this would entail significant infrastructure investments (equipment, calibration and maintenance, user training on deployment and data processing) beyond standard water quality monitoring stations; costs that would have to be borne either by local or regional management units, or in the case of aircraft based surveys, incorporated in the collect costs. The choice of ground truth support models would depend on the need for rapid event response (locally maintained and mobilized) versus routine baseline resource assessments. The group discussed the availability and abundance of archival data of varying spectral quality and resolution, and they determined that if this data were accessible, it could be used as a starting point for identifying and developing requirements for management targeted ORS products.

They also suggested that there is a need for the development of a nationally funded archive, which would buy ORS data sets (help defray collect and initial processing costs) for management access. This type of archival resource was viewed as critical to providing training for interpretation of ORS products and their limits. Additionally, access to archival datasets would enable algorithm testing and direct evaluation of improvements of new product types compared to the original base product. Availability of such national resources would facilitate the needed feedback loop between the research and management sectors to help identify the appropriate ORS platforms (satellite vs. aircraft), sensors (grayscale, RGB, multispectral, hyperspectral, IR) and ground truth requirements (in-water IOP measurements, above-water reflectance measures, spectral libraries for target management features) for operational implementation of ORS products in coastal management.

Industry Sector Viewpoint

Group Chair: Jan Svejkovsky; Rapporteur: Gerry Kinn

This group consisted of both ORS instrumentation developers and vendors, as well as representatives of remote sensing survey contract firms, and provided a unique perspective on the charge issues. They felt an important target for ORS applications would be to address issues related to environmental health safety (e.g., HABs, beach and watershed water quality, coastal use patterns and dynamics, hazard response) and its economics. Environmental health safety was viewed as a field whose issues could engage the public and help support efforts for increased funding. This group felt that for most issues public sector funds, particularly at the local and even state levels, were limited and would need federal supplementation.

In terms of ORS technologies being used by coastal and terrestrial resource managers, the group identified oblique imagery (including video, film, and digital photography) as an inexpensive, widely accessible product type that provides needed visual communication tools to both the public sector and for court deliberations. Digital Orthophoto Quadrangles (DOQ) rectified imagery has become an increasingly important data product format as image costs tend to be relatively affordable, images are widely available, they have defined standards (e.g., **http://online.wr.usgs.gov/ngpo/doq/**), and they can be directly used as a base layer in GIS applications. While DOQ use for mapping terrestrial or land-dominated scenes is widespread, their utility in water-dominated imagery may be less apparent due to lack of visual reference points. Nonetheless, web-based, public accessible applications for viewing and obtaining DOQ images of predominantly terrestrial scenes (e.g., *Google Earth*, earth.google.com, and *TerraServer*, terraserver.microsoft.com) have gone a long way to increase public awareness and use of earth imagery at least over land. In terms of imagery types in use, the group ranked black and white or panchromatic, RGB, and color infrared as commonly used image formats, with digital image files replacing older images based on digitally scanned film. Satellite-based multispectral imagery (4 to 15 broad spectral band channels) and aircraft-based LIDAR imagery were viewed as becoming increasingly important as coastal imagining tools, and hyperspectral sensor systems (>40 contiguous narrower spectral bands (<5 to 10 nm half width) over the visible to near infrared range) were seen as an emerging, rapidly maturing technological approach that could provide high spectral degrees of freedom for extraction of novel scene features. The group held that current patterns of ORS technology utilization is limited by public sector regulations and the traditional survey community, similar to the situation encountered following the advent of accessible GPS technology. While accessible GPS was the enabling technology for growth of GIS applications, it had the concurrent effect of driving legislation to restrict use of survey data to that produced by certified surveyors and restricted certification of ORS based products until DOQ standards were established.

Geospatially rectified oblique photos and DOQs were viewed as mainstream ORS products; their adoption largely driven by the market explosion in GPS/GIS applications across all management levels. Their inherent compatibility with GIS enables them to be used as base layers supporting interpreted data layers, such as those derived from automated or machine-produced scene classifications based on raw image features such as spectral signatures. It is likely that this capacity to overlay derived products on visually recognizable base imagery will enhance understanding and adoption of more derived and sophisticated ORS data products by the management community and public at large. They viewed that several classes of products initially derived as solutions to science issues (maps of seagrass, kelp canopy distributions (e.g., www.cicore.org), chlorophyll distributions, and early detection of HAB events (NOAA HAB Forcasting System **www.csc.noaa.gov/crs/habf/index.html**), riparian communities, nearshore bathymetry, oil spills, sediment plumes) are directly applicable to ecosystem-based management schemes.

In terms of current and future barriers to creation and adoption of ORS products for management applications, the group felt that low and uncertain sources of funding for acquisition and product development were the strongest impediments. While the National Research Council has held several workshops on the commercialization of satellite-based earth observation products (NRC, 2001, 2002, 2003), equivalent efforts have not been made for aircraft based ORS. However, it is these latter platforms that not only provide test sight for sensor innovations, but due to their ground proximity, they enable higher native ground point resolution for both multi- and hyerspectral sensors. While commercial high resolution ORS have been successful, costs are still high under current models, and new solutions are needed. Based on the groups combined knowledge, it was clear that business models based on speculative remote sensing (collect the raw data and low level derived products and customers will come) has not been viable. In general, although the market is projected to grow, commercial remote sensing is a difficult business to maintain profitability. Variation in ORS dataset quality was also viewed as an impediment. This data quality issue relates to i) the use of uncalibrated or non inter-calibrated sensor systems and ii) regional variation in target properties and associated processing algorithms, both of which impair scene and derived product comparisons for change detection within region and baseline comparisons across regions. It was recognized that an ORS analog of the catalytic effect of GPS on GIS is needed (GPS has had a positive impact on ORS imagery moving it from a visual to quantitative data product). Perhaps this will occur in the realm of innovations in real-time image processing algorithms to improve turnaround time for calibrated ORS product generation and delivery. The group was hopeful that tools like Google Earth will create additional demand for ORS products in both the public and private sector that could be leveraged for improved economies of ORS collects.

Second Breakout Session

Cross-sector groupings of the participants were formed to:

1. Identify barriers and challenges to the application of ORS technologies in management and research activities.
2. Recommend a series of community actions to overcome these obstacles.

Group Chairs: Gary Borstad, Scott Pegau, Bob Arnone
Rapporteurs: Dennis Bedford, John Ryan, Steve Lonhart

The workshop participants were in general agreement that all varieties of ORS data products (RGB photos, DOQs, LIDAR, multi- and hyperspectral data layers) are invaluable tools for coastal ocean research and resource assessments. The operational utilization of ORS products in any monitoring program are constrained by the fact that:

i) ORS acquisition costs [platform deployment (satellites vs aircraft), sensor calibration (spectral and spatial), concurrent acquisition of ground and in-water control data, data processing (georectification, atmospheric correction, product generation) and distribution] are too expensive for widespread use,
ii) ORS is not necessarily applicable in a time-series mode (satellites offer higher revisit rates and coverage than aircraft for similar weather conditions), which is a key design criteria for management programs,

iii) at present there are simply not enough experts available to interpret the rich synoptic data layers, and
iv) in general, the base technologies and processing algorithms are still in an evolutionary phase and not uniformly ready for operational deployment

Critically, even given these limitations, the group felt that ORS technologies offer the only uniformly applicable toolset to meet the operational mandates of OOS.

Suggested solutions to these current limitations on adoption ORS products for coastal monitoring and management were varied but centered around developing mechanisms to increase the awareness of what ORS can contribute and the associated economics for their implementation. The ORS and management communities must work to help develop a national mandate for sustained operational use of ORS products. This could be aided by developing a cost benefit analysis between traditional photography or other monitoring tools and higher information content ORS data layers. This analysis should include metrics of ORS product reliability relative to existing monitoring methods. Even under current business models, higher level ORS products were viewed as being competitive, especially as the spatial and time scales of required observations increase. Federally sponsored baseline surveys would provide accessible cost-effective time series data sets that regional groups could then leverage into collaborations to fund higher resolution surveys targeting regional needs and complementing regional assets. There was a call to continue time series ORS data collects where they exist. Demonstrations of the use of long-term ORS data sets (likely satellite earth observations like LandSAT, SeaWiFS, MODIS) for change detection highlighting coastal ocean processes and the land-sea interface should be pursued. Such efforts should also include identified protocols for mapping of ORS data layers onto traditional monitoring techniques (this includes reemphasizing the critical need for concurrent collection of appropriate ground truth data points). Clearly identified and established numeric criteria for regional management goals could be used to derive and evaluate suitable ORS datum, enabling robust and wide spatial scale assessment of system-wide criteria achievements. Targeting emerging Marine Protected Areas (MPAs) and reserves as test beds for demonstration / modification of existing and development of novel ORS management-oriented products was also viewed as being beneficial.

The participants outlined a series of community level actions needed to enhance the application of ORS-based information products. In the short term, foster communication between the ORS research and resource management communities in order to clearly define the latter's monitoring and assessment needs and the former's current ORS capacities. It was felt that the current workshop helped initiate this required dialog. In the intermediate term (1-5 years), i) a focus on tractable demonstrations of applications of ORS products to real world problems, such as changes in coastal land use and natural disaster impacts and recovery or even optimal citing of in situ sensor networks within a management unit, ii) implement training of regional personnel and development of accessible application software, and iii) enhance regional data accessibility.

In the long term (5+ years), the group felt it was important to i) promote an integrated view of coastal environments (watersheds, estuaries, shoreline, and adjacent ocean waters), including the use and synthesis of multiscale observations and assimilation of these data types into ecosystem-based management programs, ii) incorporate long term views of monitoring needs and associated management criteria into future ORS technology development efforts, and iii) define the best approach to facilitate movement of data and derived products between the research and management user communities.

Workshop Recommendations

The enthusiastic and rigorous discussions among the workshop participants led to their development of the following prioritized list of recommendations that highlighted the groups' recognition that a clear need for development and dissemination of outreach tools focusing on ORS management applications is needed to enhance adoption of these tools for routine coastal zone management activities.

1. Encourage development and implementation of ORS tutorials, making use of case studies for management application of this technology and involve existing training programs (e.g., NOAA Coastal Service Center Training, www.csc.noaa.gov/training/). This would build on a recommendation for assembling a list of case studies highlighting application of ORS products for management uses.

2. Develop information tools on ORS collection process. Develop broad reaching educational tools (e.g., infomercial like DVD) to provide overviews of ORS applications in action. NOAAs Coastal Service Center maintains a website dedicated to information on remote sensing applications (acoustic and optical) for coastal resource managers (www.csc.noaa.gov/crs/). Potential target audiences: Resource Managers, regulators, and secondary education units.

3. Provide cost benefit analysis for the entire ORS data collection and product distribution process using case studies (current approaches vs. implementation of new business models) and identify cost reduction strategies.

4. Establish a catalog of field reference sites (target MPAs and COOS sites with consistent support for in-water optical measurements) to aid in risk reduction activities associated with new data product validation and sensor design.

5. Promote development of national archives for standardized ORS data for coastal management. This could also promote development of centralized libraries of spectral signatures for targets of interest. Training workshops and internships would provide a means to establish and employ standardized protocols for developing regional validation/calibration databases.

6. Develop ORS algorithm validation protocols to provide product accuracy determination to aid managers requiring defensible data products.

7. Develop ORS calibration and product validation protocol document to assure comparable results from various technologies (i.e., similar to SeaWiFS Ocean Optics protocols but optimized for Case 2 waters and other coastal zone challenges). Encourage development of an airborne remote sensing standard methods manual.

8. Develop linkages between ORS products (e.g., chlorophyll, CDOM, sediments) and parameters of regulatory interest.

9. Develop ORS discussion forum on ACT web site to continue and enhance dialog among R&D, industry, and resource managers. Focus on two-way communication to help define resource manager needs.

10. Provide a readily accessible summary and glossary of current ORS technologies and links to example data products with user list.

Charges for ACT and Initial Follow-on Activities

Participants discussed how ACT could best support future efforts towards continued development and refinement of existing optical remote sensing technologies. While the participants voiced an overwhelming consensus that improved outreach on application of ORS data products as aids to management, decisions are needed. ACT was viewed as a resource that could help support some of these efforts as workshop follow-on activities, particularly with respect to recommendations 9 and 10. Additionally, because ACT recognizes the importance of remote sensing data products as tools for enhancing coastal zone management, regional ACT staff have supported several efforts directed at enhancing infrastructure critical to continued development of remote sensing capabilities. These activities have included support for national efforts to promote the use of aircraft as observational platforms for a variety of marine science applications, which has been championed by UNOLS SCOAR (Scientific Committee for Oceanographic Aircraft Research, unols.org/committees/scoar/). ACT also provided facilities support in aid of the Coastal Ocean Applications and Science Team's (COAST, cioss.coas.oregonstate.edu/CIOSS/coast.html) Monterey Bay Experiment conducted in September 2006 as part of the risk reduction activities and product development for coastal ocean products for NOAA.

Concluding Remarks

It is clear from the workshop discussions, presentations, and cursory surveys of the literature that optical remote sensing data products have become integral tools for broadscale characterization of habitats and aspects of ecosystem dynamics in aquatic, as well as terrestrial environments. Technological challenges to optical remote sensing of surface waters (low and spectrally complex reflectance signals, lack of visual georeference points to mixtures of bright and dark targets in nearshore and estuarine habitats) have been addressed by ongoing engineering improvements in sensor design, providing systems with high spectral resolution and near real-time geolocation required to derive synoptic views of water quality properties and production in both optically deep oceanic and optically shallow coastal environments. While the community sees the utility of ORS data products as unique and essential components of operational observing systems and geospatial data sets as essential for robust coastal management decisions, routine incorporation of these data sets has been hindered by the large data volumes indicative of their potential information content. Cross sector collaborations, including industry-management partnerships and internships, are envisioned as the route to promote confidence in the reliability of geospatial imagery and guide development of quick look GIS-compatible ORS data layers for regional management applications. Challenges also remain in terms of matching timescales of ORS sampling revisits (be they aircraft or spacecraft based) with the dynamic nature of coastal environments. One aspect of the solution lies in congealing user community support for regional staging of ORS assets that would enable event-based observations and baseline system characterization that may be required for use of ORS products in management decision making. A recent NOAA sponsored survey "Survey Analysis of Remote Sensing: Aerial and Spaceborne" (www.licensing.NOAA.gov) indicates that, while the future is bright for the optical remote sensing industry, the challenge to market expansion is the capacity to provide high quality data (i.e., geospatially and radiometrically accurate) products at affordable pricing to the users.

As ORS sensor technologies evolve, providing richer geospatial data cubes (geospatial spectroscopy), community involvement is essential to help identify mechanisms to improve the economics of not only the data collection operations but critically essential information product development to incorporate into *defensible* management decisions. While geospatial information applications have become integral decision-support tools at all levels of government, the fact that the suite of recommendations generated from this workshop closely match recommendations derived from an earlier National Research Council moderated workshop series focused on requirements to enhance technology transfer of satellite remote sensing data into information products (NRC 2001, 2002, 2003), indicates that the enabling first step in the transfer process, increased cross sector communication and outreach activities, have not yet come to fruition. It is our hope that the ACT remote sensing workshops have helped open and strengthen this needed avenue of communication.

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Information on Existing Management Applications of ORS Data Products

NOAA Coastal Services Center, 2006. Coastal Remote Sensing. NOAA/CSC/20221-PUB. *A NOAA CSC produced guide providing a range of examples of incorporation of remote sensing data sets (acoustic and optical) into information products for a range of coastal resource management targets. Visit* **www.csc.noaa.gov/crs** for more information

Training Resources and Free Software for ORS Image Analysis

Canada Centre for Remote Sensing: **ccrs.nrcan.gc.ca/index_e.php** . *Provides extensive online glossary of remote sensing terms.*

NOAA COASTWATCH: coastwatch.noaa.gov Program processes near real-time oceanographic satellite data and makes it available to Federal, State, & local marine scientists, coastal resource managers, and the general public

NOAA CSC Remote Sensing Training: **www.csc.noaa.gov/training/** *Offers introductory remote sensing training class at CSC. Also source for training modules for implementation of required metadata standards for all geospatial products.*

UNESCO-Bilko Virtual Faculty for Remote Sensing: **www.noc.soton.ac.uk/bilko/** *Provides a complete publicly accessible environment for learning and teaching remote sensing image analysis including targeted modules for ocean color and coastal management applications. Bilko software is free with registration.*

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Optical Remote Sensing of Coastal Habitats Workshop Participants Gathered on Martin's View at MLML

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Appendix B. Plenary Session Talks

Speaker	Topic
Stephan Lataille (ITRES Research Ltd.)	**Optical Water Quality And Coastal Zone Information Products**
Curt Davis (Oregon State University)	**Ocean Color Remote Sensing of the Coastal Ocean**
Seth Blitch (Apalachicola National Estuarine Research Reserve)	**Coastal Resource Management & Remote Sensing: Challenges and Perceived Needs**
Jim Aiken (Plymouth Marine Laboratory)	**CASIX (Centre for Observation of Air-Sea Interactions and Fluxes): An Earth Observation and Modeling Program**

Copies of the PowerPoint™ presentation files are available upon request from jsmith@mlml.calstate.edu .

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