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5A Remote sensing of reef environments

# Enhanced Satellite-Remote Sensing for Coral Reef Management: Next Decade

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**Abstract.** For the past decade remote sensing products provided by NOAA's Coral Reef Watch (CRW) have used satellite-derived sea surface temperature (SST) measurements to inform coral reef managers, scientists, and the public about thermal stress events throughout the tropics. These products, tailored primarily for managers, have become well-accepted as they provide a cost-effective means of conducting near-real-time monitoring of changes in SSTs that impact coral reef ecosystems over broad spatial scales. While satellite-based measurements of SSTs on and around coral reef ecosystems can describe part of what is occurring in reef environments, incorporating additional remotely-sensed environmental variables will provide a more complete assessment of changing environmental conditions and corals' responses. Non-SST-based satellite product development areas include ocean color to track land-based sources of pollution; synthetic aperture radar to detect oil spills and possibly coral spawning events; insolation to measure coral photosystem health; ocean surface vector winds to model biological connectivity via wind currents; and satellite altimetry to measure and track long-term trends in sea-level rise and short-term storm surge and wave damage. These product development areas hold great promise for improving the effectiveness of coral reef management in the United States' coastal marine jurisdictions and internationally. This presentation introduces a newly produced report describing NOAA's recent and forthcoming remote sensing products and correlates their applicability to U.S. jurisdictional coral reef management priorities and NOAA Coral Reef Conservation Program (Coral Program) Goals & Objectives. Targeting development of these high-priority remote sensing products will significantly contribute to addressing the Coral Program's identified three top threats to coral reef ecosystems.

**Key words:** Remote Sensing, Satellite, Management tools, Coral reef.

## Introduction

Utilizing satellite sensors to remotely collect data on environmental variables, satellite remote sensing, has become an important component of a comprehensive ecosystem-based approach to coral reef research, monitoring, and management. Coral reefs are broadly distributed around the globe, making it financially and logistically infeasible for coral reef managers and scientists to continuously monitor various environmental parameters onsite with sufficient spatial and temporal coverage. For the past decade, remote sensing products provided by NOAA's Coral Reef Watch (CRW) have used satellite-derived sea surface temperature (SST) measurements to inform coral reef managers, scientists, and the public about thermal stress that impacts coral reef ecosystems over broad spatial scales throughout the tropics (Strong et al. 2011). CRW uses satellite-derived SST measurements to develop products such as HotSpots, Degree Heating Weeks, Bleaching Alert Areas, and Satellite Virtual Stations. These products are disseminated via its web site and automated Satellite Bleaching Alert e-mails to coral reef managers, informing them about the environmental conditions in and around coral reef ecosystems. Existing experimental products include a Doldrum wind condition monitoring product, an Ocean Acidification Product Suite, a Light Stress Damage product and others.

Additional satellite remote sensing products based on non-SST environmental variables are also being developed at NOAA. These hold great promise for improving the quality and effectiveness of information for coral reef management in the United States' coastal marine jurisdictions and internationally. Funding the development and operationalization of new, non-SST-based satellite remote sensing products that complement CRW's current and planned SST products is necessary to provide environmental data needed by resource managers and scientists. These environmental data will enhance our understanding of coral reef ecosystems and environments as a whole to

make efficient, effective and comprehensive ecosystem-based management decisions to maintain the health and enhance the resilience of coral reef ecosystems. For this reason, a report (Lucas and Strong 2012) has recently been prepared to inform the NOAA Coral Reef Conservation Program (Coral Program) of satellite remote sensing product areas that are ready for development and will satisfy existing, high-priority needs of coral reef managers. For example, the knowledge of how wind and currents transport larvae and land-based sources of pollution (LBSP) can be used to guide decisions regarding where to site future marine protected areas. The new products planned in this technical report will improve the ability of NOAA's Coral Program and NOAA's National Environmental Satellite, Data and Information Service (NESDIS) to meet their complementary missions and to better address the expressed jurisdiction-level coral reef management priorities of the seven U.S. jurisdictions.

**Material and Methods**

This study examines six diverse bodies of information (listed to the right) to identify new areas in which satellite remote sensing can effectively contribute to U.S. jurisdiction-level, NOAA's Coral Program's National, and International Goals & Objectives for coral reef management (More complete summaries for the six informational bodies reviewed/consulted for the domestic and international analyses can be found in the full report by Lucas and Strong (2012). Guidance was sought from within the Coral Program to ensure jurisdiction-level priority observing system needs were sufficiently represented within the report and from NOAA remote sensing scientists to capture the potential of new satellite remote sensing tools to meet these needs.

The study's primary focus investigates the applicability of seven selected NOAA satellite remote sensing product development areas (Table 1) for addressing the Coral Program's National Goals & Objectives and the U.S. jurisdiction-level priority goals and objectives (American Samoa, CNMI, Florida, Guam, Hawaii, Puerto Rico, and USVI). A secondary focus investigates the applicability of the satellite remote sensing product development areas for addressing the Coral Program's International Strategy Goals & Objectives. The international analysis differed from the national/jurisdiction-level crosswalk analysis in that there were no documents identifying high-priority goals and objectives from the four Coral Program priority geographic regions (wider Caribbean, Micronesia, Samoa and the Southwest Pacific, and the Coral Triangle) comparable to the documents from the seven U.S. coral reef jurisdictions. (For these results see Lucas and Strong 2012).

1. *NOAA Coral Reef Conservation Program Goals & Objectives 2010-2015* (NOAA 2009a).
2. The seven jurisdiction-level Coral Reef Management Priorities documents:
   - 2.1. *American Samoa's Coral Reef Management Priorities* (American Samoa, 2010).
   - 2.2. *Commonwealth of the Northern Mariana Islands' Coral Reef Management Priorities* (CNMI, 2010)
   - 2.3. *Florida's Coral Reef Management Priorities: 2010-2015* (Florida, 2010).
   - 2.4. *Guam's Coral Reef Management Priorities* (Guam, 2010).
   - 2.5. *Priorities for Coral Reef Management in the Hawaiian Archipelago: 2010-2020* (Hawaii, 2010)
   - 2.6. *Puerto Rico's Coral Reef Management Priorities* (Puerto Rico, 2010).
   - 2.7. *United States Virgin Islands' Coral Reef Management Priorities* (USVI, 2010).
3. *NOAA Coral Reef Conservation Program International Strategy 2010-2015* (NOAA 2009b).
4. *NOAA Coral Reef Ecosystem Integrated Observing System (CREIOS) Workshops Report.* (Morgan and Waddell 2009).
5. *Satellite Monitoring of Reef Vulnerability in a Changing Climate* (Nim and Skirving 2010)
6. NOAA satellite remote sensing capabilities relevant to marine ecosystems. (Results from structured interviews with NOAA remote sensing scientists are detailed in the full NOAA Technical Report: Lucas and Strong, 2012).

Three levels of analysis were utilized to identify significant correlation[1] between national, jurisdiction-level and international goals and objectives for coral reef management and the selected satellite remote sensing product development areas (Table 1).

To investigate which of three Coral Program's identified threat categories (Climate Change Impacts, Fishing Impacts, and Land-based Sources Pollution Impacts) are most effectively addressed by the seven selected remote sensing product development areas, the number of times an individual remote sensing

[1] "Correlation" is defined within this study as: "*having a mutual relationship or connection.*"

product development area addressed a particular jurisdictional priority goal and objective irrespective of jurisdictional affiliation was tallied for each of the three Coral Program's threat categories within the national/jurisdiction-level crosswalk analysis (Table 2; Columns).

| Product Development Areas | Brief Description of Potential Uses |
|---|---|
| Ocean Color | Measure turbidity and total suspended solids, track LBSP movement, measure chlorophyll α concentration, identify harmful algal blooms, assist oil spill identification |
| Synthetic Aperture Radar (SAR) | Detect wind speed and direction to assist with issues of larval transport and LBSP connectivity mapping and to detect oil and chemical spill, vessel activities for enforcement and possibly large-scale spawning events |
| Ocean Surface Vector Winds (OSVW) | Detect prevailing ocean surface wind currents that influence biological connectivity, LBSP transport, and localized upwelling events |
| Sea-Surface Temperature (SST) Improvements | Improve bleaching event prediction via SST product improvements to proactively trigger response plans. Assist the identification of areas resilient to bleaching |
| Insolation | Measure solar radiation energy to model coral photosystem health and assess potential light stress for corals |
| Ocean Acidification (OA) | Monitor regional changes in ocean acidification over decadal timescales to aid prioritization of reef management efforts |
| Satellite Altimetry | Detect and measure intermediate to long-term local, regional and global sea-level rise and monitor significant wave height for providing storm surge advisories for local coral managers |

Table 1. Remote sensing product development areas and description of potential uses.

This permitted the examination as to which remote sensing product development areas held the highest overall interest across the seven jurisdictions. The count of individual jurisdictional priority goals and objectives that can be addressed by an individual remote sensing product development area was tallied across the three Coral Program's threat areas irrespective of jurisdictional affiliation within the jurisdiction-level correlation analysis (Table 2; Rows).

**Results and Discussion**

Our national/jurisdiction-level crosswalk analysis (Table 2; bottom row) revealed that remote sensing development areas that could address jurisdictional objectives pertaining to Climate Change Impacts (79 occurrences) held the highest tally; twice as many as the next highest threat category – LBSP Impacts (39 occurrences). Products that could address Fishing Impacts correlated with 29 jurisdictional objectives.

The jurisdiction-level correlation analysis (Table 2; far right column) revealed that the Ocean Color product development area held the highest overall interest with 28 occurrences compared to the other product development areas for the seven jurisdictions. SST Improvements and Insolation displayed the second and third highest overall interest with 26 and 25 occurrences, respectively. Synthetic Aperture Radar (19 occurrences), Ocean Surface Vector Winds (19 occurrences), Ocean Acidification (21 occurrences) and Satellite Altimetry (9 occurrences) rounded out the results.

Although the international correlation analysis lacked specific regional priority goals and objectives to which the Coral Program International Strategy Goals & Objectives (NOAA, 2009b) and the selected satellite remote sensing product development areas could be correlated, the majority of the remote sensing product development areas addressed the eligible Coral Program International Strategy Goals & Objectives (NOAA, 2009b) goals and objectives evenly, indicating that any of the product areas developed would have international applications.

The goal of the technical report by Lucas and Strong (2012), summarized here, has been the formulation of recommendations pertaining to which NOAA satellite remote sensing data products should have the highest priority for the development of coral reef specific management applications. Two findings were revealed from the national/jurisdiction-level crosswalk analysis. First, US reef managers persistently place high value on the existing remote sensing products for climate change and there is a strong need for continued development and support of SST Improvements, Insolation and Ocean Acidification. This is indicated by the products' high correlation tallies shown in Column 1 of Table 2. Secondly, the Ocean Color product development area received the highest number of cumulative correlations with the Coral Program Goals & Object-

| Product Development Area | No. of Climate Change Impacts to be Addressed by Product | No. of Fishing Impacts to be Addressed by Product | No. of LBSP Impacts to be Addressed by Product | Total |
|---|---|---|---|---|
| Ocean Color | 1 | 4 | 23 | **28** |
| Synthetic Aperture Radar (SAR) | 7 | 5 | 7 | **19** |
| Ocean Surface Vector Winds (OSVW) | 7 | 5 | 7 | **19** |
| Sea Surface Temperature (SST) Improvements | 20 | 5 | 1 | **26** |
| Insolation | 20 | 5 | 0 | **25** |
| Ocean Acidification (OA) | 15 | 5 | 1 | **21** |
| Satellite Altimetry | 9 | 0 | 0 | **9** |
| **Total** | **79** | **29** | **39** | *Intentionally Blank* |

Table 2. Number of U.S. jurisdiction-level priority goals and objectives potentially addressable by individual remote sensing product development area, grouped by the Coral Program threat category.

ives irrespective of jurisdictional affiliation shown in the last column of Table 2 and has the greatest applicability to addressing LBSP impacts.

The jurisdiction-level correlation analysis also revealed that all seven U.S. coral reef jurisdictions have priority goals and objectives in the area of LBSP impacts (see Lucas and Strong 2012). This indicates a broad appeal across the jurisdictions for developing Ocean Color products.

As a result of these analyses, the following set of recommendations has been made to NOAA's Coral Program:

1. *Continue to fund SST, Insolation and Ocean Acidification product development and improvement.*
2. *Begin the development of Ocean Color remote sensing products for coral reef specific applications (proposed 2013 start date).*
3. *Phase in the development of SAR and OSVW product development areas for coral reef management applications, synergistically with the development of Ocean Color products.*
4. *Revisit and reevaluate this product development priority list every 2-3 years or as new efforts begin or new satellite technologies emerge.*

The development of these remote sensing products for coral reef specific use would address existing issues coral reef managers currently face in the field as well as address NOAA's Coral Program National and International Goals & Objectives for coral reef management. Simultaneously, collaborations in coral

reef management between NOAA remote sensing scientists and NOAA/Coral Program would be strengthened, and new products would be made available through NOAA/CRW. Once products are selected and funded for development for coral reef specific applications, limited sites should be chosen strategically, first with user input as pilot sites and, upon validation, the products could be expanded for broader geographic use in the U.S. and internationally. Similar to the NOAA/CRW's satellite SST-based product suite, any coral reef specific satellite remote sensing product generated would be released through user-friendly, web-based platforms allowing managers with different levels of technical expertise to access and utilize the products efficiently and productively. Use of these products could then be promoted and enhanced through personal, remote, and online training programs.

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