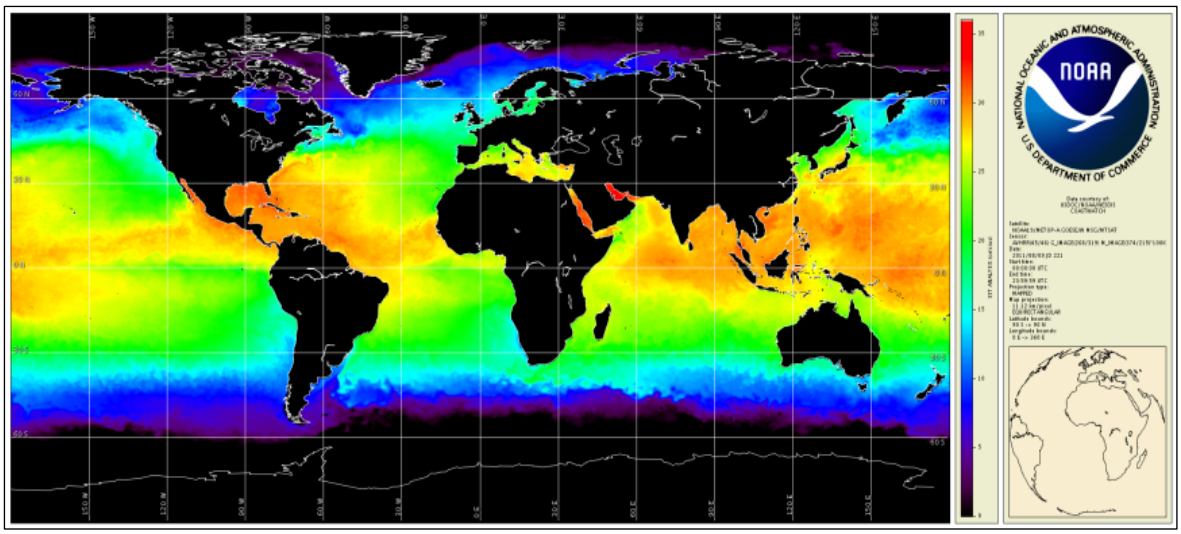
NOAA Technical Report NESDIS 142

Product Development Plan for the Next Generation of Satellite Remote Sensing Products for NOAA Coral Reef Ecosystem Management Activities



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NOAA TECHNICAL REPORTS

National Environmental Satellite, Data, and Information Service

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A limited number of copies of earlier reports are available by contacting Juanita Coller, NOAA/NESDIS/STAR, E/RA, 5830 University Research Court, 2nd Floor, Room 2608, College Park, Maryland 20740, (301) 683-3491. A partial listing of more recent reports appears below:

NESDIS 110 An Algorithm for Correction of Navigation Errors in AMSU-A Data. Seiichiro Kigawa and Michael P. Weinreb, December 2002.

NESDIS 111 An Algorithm for Correction of Lunar Contamination in AMSU-A Data. Seiichiro Kigawa and Tsan Mo, December 2002.

NESDIS 112 Sampling Errors of the Global Mean Sea Level Derived from Topex/Poseidon Altimetry. Chang-Kou Tai and Carl Wagner, December 2002.

NESDIS 113 Proceedings of the International GODAR Review Meeting: Abstracts. Sponsors: Intergovernmental Oceanographic Commission, U.S. National Oceanic and Atmospheric Administration, and the European Community, May 2003.

NESDIS 114 Satellite Rainfall Estimation Over South America: Evaluation of Two Major Events. Daniel A. Vila, Roderick A. Scofield, Robert J. Kuligowski, and J. Clay Davenport, May 2003.

NESDIS 115 Imager and Sounder Radiance and Product Validations for the GOES-12 Science Test. Donald W. Hillger, Timothy J. Schmit, and Jamie M. Daniels, September 2003.

NESDIS 116 Microwave Humidity Sounder Calibration Algorithm. Tsan Mo and Kenneth Jarva, October 2004.

NESDIS 117 Building Profile Plankton Databases for Climate and Ecosystem Research. Sydney Levitus, Satoshi Sato, Catherine Maillard, Nick Mikhailov, Pat Cadwell, Harry Dooley, June 2005.

NESDIS 118 Simultaneous Nadir Overpasses for NOAA-6 to NOAA-17 Satellites from 1980 and 2003 for the Intersatellite Calibration of Radiometers. Changyong Cao, Pubu Ciren, August 2005.

NESDIS 119 Calibration and Validation of NOAA 18 Instruments. Fuzhong Weng and Tsan Mo, December 2005.

NESDIS 120 The NOAA/NESDIS/ORA Windsat Calibration/Validation Collocation Database. Laurence Connor, February 2006.

NESDIS 121 Calibration of the Advanced Microwave Sounding Unit-A Radiometer for METOP-A. Tsan Mo, August 2006.

*Cover image: Global image of operational 11-km Geo-Polar blended SST - August 9, 2011.

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Executive Summary

Satellites provide consistent and routine monitoring in near-real-time at sites and spatial scales that are not possible through *in situ* or site-based monitoring alone – and at no added cost to local managers. Considering the broad spatial scale of coral reef ecosystems under U.S. jurisdiction, coral reef managers need products with the even broader spatial coverage afforded by satellite-based sensors. While satellite-based measurements of sea surface temperatures (SST) 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.

This report is designed to assist the NOAA Coral Reef Conservation Program (Coral Program) to identify satellite remote sensing opportunities and plan for the application of these technologies to coral reef management. The report highlights product development areas using NOAA satellite remote sensing and analyzes their applicability to the Coral Program National and International Goals & Objectives for coral reef management and the U.S. jurisdictional coral reef management priorities. The report highlights remote sensing product development areas that best correlate with needs identified in these documents and that can best inform coral reef resource management in the next few years. The report concludes with a set of recommendations for product development areas the Coral Program should pursue. Appendices further describe each of these remote sensing product development areas using information gained from structured interviews with NOAA remote sensing scientists. Targeting development of these high-priority remote sensing products will significantly contribute to addressing the Coral Program's three top threats to coral reef ecosystems: the impacts of Climate Change, Fishing, and Land-based Sources of Pollution (LBSP).

We found that US reef managers still 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, GOES Insolation, and Ocean Acidification. It is crucial that NOAA continue funding of these products to assure their continuity. The top new non-SST product suggested for development is the application of Ocean Color to coral reef environments. Ocean Color displayed both the broadest appeal and the highest overall interest within the priority goals & objectives of the US coral reef jurisdictions. It most directly addresses LBSP threats and all seven jurisdictions identified a high-priority interest in LBSP issues to which Ocean Color remote sensing can contribute. The report identified Ocean Color as the "lowest-hanging fruit" for new funding and product development. Further algorithm development and enhancement is needed to fine-tune sensor measurements for use over coral reefs. The level of effort required for these tasks is relatively low at 1-3 FTEs/year, for an estimated timeframe of ≤ 5 years.

Synthetic Aperture Radar (SAR) and Ocean Surface Vector Winds (OSVW) were the second and third ranked new satellite remote sensing product development areas for coral reef application. SAR products can be utilized synergistically with both Ocean Color and OSVW products. Due to the variety of data collected via SAR sensors, future products for coral reef application could address objectives in all three Coral Program threat categories. While SAR data are currently costly to obtain, free operational SAR data from a satellite constellation managed by Canada and Europe will be available to NOAA within two years. SAR products for coral reef applications have an estimated product development timeframe of 2-5+ years. Those products derived from

existing operational products (e.g., SAR Wind) would require less time to develop while pilot projects for new variables (i.e., significant wave height) would take longer. The estimated level of effort for further algorithm development is 1-2 FTEs/year.

OSVW provides global coverage of wind speed and direction but cannot be used within approximately 25 km of the coast. In contrast, SAR provides higher resolution local and regional scale wind speed data right up to the coastline, but for limited regions. In this way the OSVW and SAR could be utilized synergistically to provide global wind data with minimal gaps. Future coral reef specific applications of OSVW could contribute towards understanding pollution transport, larval connectivity, and climate change resilience via wind generated cooling. OSVW data have not been available from US satellites since 2009; however data from an Indian satellite are expected to become available in 2012. Development of algorithms for OSVW derived products would require approximately 1-2 FTEs/year for a period of 2-5+ years.

1. Introduction

This technical report is an output of work undertaken by the 2011 NOAA John A. Knauss/Sea Grant Fellow hosted by NOAA Coral Reef Watch (CRW), under the mentorship of Dr. Alan E. Strong. The Fellow, Ethan Y. Lucas, was co-tasked by NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) Center for Satellite Applications and Research (STAR) and NOAA's Coral Reef Conservation Program (Coral Program) to create a product development plan for new satellite remote sensing product development areas that addresses the remote sensing needs of both jurisdiction-level coral reef managers and Coral Program National and International Goals & Objectives for coral reef management. The technical report concludes with recommendations as to which NOAA satellite remote sensing product development areas should be prioritized for the development of operational products and how soon such products could become available.

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 coverage. For the past decade, remote sensing products provided by 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. CRW scientists use satellite-derived SST measurements in computer programs and algorithms to develop products such as HotSpot Charts, Degree Heating Weeks Charts, and Bleaching Indices. These products are disseminated via Bleaching Alert e-mails to coral reef managers, informing them about the environmental conditions in and around the coral reef ecosystems that have been detected by NOAA satellites. Experimental product suites include a Doldrum wind condition monitoring product, an Ocean Acidification Product Suite, a Light Stress Damage product and others. Additional satellite remote sensing product development areas based on non-SST environmental variables are also being developed at NOAA. These hold great promise for improving the quality and effectiveness of coral reef management in the United States' coastal marine jurisdictions.

As both the frequency and severity of thermal stress events that can cause mass coral bleaching, disease, coral mortality, and reef ecosystem deterioration are predicted to increase through the end of the century (Donner et al. 2009; Hoegh-Guldberg et al. 2007; Simpson et al. 2009), the ability to provide coral reef managers with a variety of timely and accurate information related to coral reef health will continue to become more valuable. Satellite remote sensing is the only practical tool to continuously monitor coral reef stress (e.g., anomalously high or low water temperatures; ocean acidification; suspended particulates from land-based sources of pollution) that affect coral reef ecosystem health across large areas. By collecting data on environmental variables at global and regional scales in near-real-time, satellite remote sensing products enable coral reef managers to more timely and efficiently identify, prioritize, and initiate management efforts on stressed reefs. Historical satellite data are critical to track and analyze past changes in large-scale disturbances over time, such as increase in frequency and severity of thermal stress that caused mass coral reef bleaching events during the past decades (Eakin et al. 2010) to understand past variability and reef response as a backdrop to our changing climate.

Presently Coral Program's application of satellite remote sensing for coral reef management relies primarily on CRW's SST-based coral bleaching thermal stress monitoring products that swiftly identify and notify coral reef regions that are at risk of mass bleaching. CRW also archives satellite SST data and uses historical satellite SST data for retrospective analyses to aid reef management, scientific research, and monitoring climate change. Based on input from managers, it is crucial that NOAA continue funding of these products that require ongoing revision to account for changes in satellite sensors and data delivered by other parts of NESDIS. However, thermal stress is only one of many ever-increasing, lethal stresses that coral reef ecosystems are facing in the current changing climate. Various environmental stresses impact the health of coral reef ecosystem in many comprehensive and interactive manners. 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 sufficient environmental data for 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 example, the knowledge of how wind and currents transport larvae and LBSPs can be used to guide decisions regarding where to site future marine protected area. The new products planned in this technical report will improve the ability of Coral Program and NESDIS to meet their complimentary missions and to better address the expressed jurisdiction-level coral reef management priorities of the seven U.S. jurisdictions (American Samoa 2010; CNMI 2010; Florida 2010; Guam 2010; Hawaii 2010; Puerto Rico 2010; USVI 2010).

Coral Program Mission: "…*support effective management and sound science to preserve, sustain and restore valuable coral reef ecosystems for future generations"*

NESDIS Mission: *"…dedicated to providing timely access to global environmental data from satellites and other sources to promote, protect, and enhance the Nation's economy, security, environment, and quality of life"*

2. Materials and Methods

This technical report reviews six diverse bodies of information to identify new areas in which satellite remote sensing can effectively contribute to U.S. jurisdiction-level, Coral Program National, and Coral Program International Goals & Objectives for coral reef management. 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 satellite remote sensing tools to meet these needs.

The report's primary focus investigates the applicability of seven selected NOAA satellite remote sensing product development areas for addressing U.S. jurisdiction-level priority goals and objectives and Coral Program National Goals & Objectives. A secondary focus investigates the applicability of the satellite remote sensing product development areas for addressing the Coral Program's International Strategy Goals & Objectives. Three levels of analysis were utilized to identify significant correlations between national, jurisdiction-level and international goals and objectives for coral reef management and the selected satellite remote sensing product development areas.

2.1 Summary of the Documents' Roles

The six bodies of information examined for correlation[1] analysis applicability are listed here while content summaries for the six informational bodies reviewed/consulted for the domestic and international analyses by this report are provided below.

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 & Waddell 2009).

5. *Satellite Monitoring of Reef Vulnerability in a Changing Climate* (Nim & Skirving 2010) (findings from the 2010 Queensland, Australia workshop, aka the "Lamington Report").

6. NOAA satellite remote sensing capabilities relevant to marine ecosystems (results from structured interviews with NOAA remote sensing scientists, detailed in Appendices A-G).

2.1.1 *NOAA Coral Reef Conservation Program Goals & Objectives 2010-2015*

NOAA's national coral reef management goals & objectives are clearly laid out in the Coral Program document, *NOAA Coral Reef Conservation Program Goals & Objectives 2010-2015*. This document outlines the Coral Program's domestic strategy for tackling the top three recognized global threats to coral reef ecosystems: Climate Change, Fishing, and Land-based Sources of Pollution. Each of the three threats is coupled with a set of goals & objectives to describe how the Coral Program will "*address strategic coral reef management needs in a targeted, cost-effective and efficient manner*", making the most of limited resources, while having the largest impact on reversing general declines in coral reef health (Coral Reef Conservation Program 2009a). Coral Program National Goals & Objectives are correlated[2] to

[1] "Correlation" is defined within the Technical Report as: "*having a mutual relationship or connection*."

jurisdiction-level management priorities within each of the seven jurisdiction-level NOAA Coral Reef Management Priorities documents and was therefore pertinent to include the Goals & Objectives in this analysis and report.

2.1.2 *Seven Jurisdiction-level NOAA Coral Reef Management Priorities Documents*

While the *NOAA Coral Reef Conservation Program Goals & Objectives 2010-2015* addresses the focal threats of climate change, fishing, and land-based sources of pollution, the Coral Program recognizes that jurisdiction-level management priorities may differ from national goals and objectives. To address this matter, each of the seven major management jurisdictions (American Samoa, Guam, CNMI, Hawaii, Florida, Puerto Rico and USVI) was tasked with creating a management priority document using a collaborative process in which management entities, organizations involved in coral reef conservation, and local stakeholders developed place-based, local coral reef management priorities. Within each of the seven Coral Reef Management Priorities documents, a set of priority goals with coupled objectives were presented outlining how the jurisdiction's unique priority goals and objectives correlate to Coral Program National Goals & Objectives. The Coral Program plans to utilize these documents to direct investment in activities within each jurisdiction. It also looks to target future investments in coral reef management based on areas in which proposed jurisdiction-level actions address national goals and objectives. The results of a dedicated Coral Program priority-setting process, the seven jurisdiction-level Coral Reef Management Priorities documents were a primary focus of the analysis that led to this report.

2.1.3 *NOAA Coral Reef Conservation Program International Strategy 2010-2015*

NOAA's international coral reef management goals and objectives were identified within *NOAA Coral Reef Conservation Program International Strategy 2010-2015.* The document outlines the Coral Program's strategy to "*strengthen and expand the Program's international coral reef conservation efforts… to effectively reduce international threats to coral reefs"* (Coral Reef Conservation Program 2009b). The International Strategy contains four priority goals with coupled objectives. The document notes that international efforts will concentrate in four priority geographic regions: the wider Caribbean, Micronesia, Samoa and the Southwest Pacific, and the Coral Triangle. Resulting from a dedicated Coral Program priority-setting process, the Coral Program International Goals & Objectives were the focus of the international correlation analysis.

2.1.4 *NOAA Coral Reef Ecosystem Integrated Observing System (CREIOS) Workshops Report*

The Coral Program conducted two regional workshops, one in Hawai'i (November 2008) and one in Puerto Rico (May 2009), to address national mapping and monitoring activities under the Coral Reef Ecosystem Integrated Observing System (CREIOS). Through the two workshops, NOAA scientists with technical expertise in mapping and monitoring coral reef ecosystems met with other local scientists and resource managers from all U.S. coral reef jurisdictions, in addition to representatives from Federal agencies and Fishery Management Councils. The

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[2] An explanation of the correlation between a jurisdiction's Coral Reef Management Priorities and *Coral Reef Conservation Program Goals & Objectives 2010-2015* can be found in each of the Coral Reef Management Priorities documents, available for download from NOAA's Coral Reef Information System – CoRIS (http://coris.noaa.gov/).

facilitated workshops elicited top monitoring and mapping needs from managers and highlighted important issues of concern. However, this document played a limited role in the Coral Program priority setting process. Therefore, while consulted for informational purposes, the CREIOS Workshops Report was not a primary focus within the analysis that led to this report.

2.1.5 *Satellite Monitoring of Reef Vulnerability in a Changing Climate*

NOAA Coral Reef Watch and The University of Queensland conducted a workshop in Queensland, Australia (February 2010) to investigate additional ways that satellites could be used for the benefit of management by monitoring coral reef vulnerability in a changing climate. Remote sensing scientists, coral reef researchers, and resource managers from around the world discussed "state of the art" uses of satellite remote sensing for coral reef monitoring with a focus on the climate change impacts on coral reefs. Nim & Skirving (2010) provides substantive information on the current understanding of coral reef experts on applications of environmental satellite remote sensing to aid in research and management of coral reefs. Presentations and discussions held during the workshop discussed future directions in satellite remote sensing that should be considered to benefit the coral reef management community. However, this document was not included in the Coral Program priority setting process. While consulted for informational purposes, it too was not a primary focus in the analysis that led to this report. The author suggests that the Coral Program consider the Technical Report as a valuable complimentary document to this report.

2.1.6 *NOAA Satellite Remote Sensing Product Development Areas*

To identify recent and forthcoming NOAA satellite remote sensing capabilities, structured interviews were conducted with seven NOAA (primarily NESDIS/STAR) remote sensing scientists regarding satellite remote sensing product development areas capable of detecting and monitoring environmental variables of interest to coral reef managers. Interviews were conducted in Camp Springs and Silver Spring, Maryland between June and October 2011. Interviews focused on specific information regarding how satellite remote sensing technologies can aid the Coral Program's monitoring and management of coral reef ecosystems. Relevant information was extracted to assist in creating uniformly styled product "one-pagers." The one-pagers are used to supplement and contextualize the results from the three correlation analyses: the national/jurisdiction-level crosswalk analysis; the jurisdiction-level correlation analysis; and the international correlation analysis. One-pagers are included as Appendices A-G of this report. Specific remote sensing product development areas investigated are included in Table 1.

Table 1. NOAA remote sensing product development areas, description of potential uses, and scientist interviewed.

NOAA Product Development Area	Brief Description of Potential Uses	Scientist Interviewed
Ocean Color	Measure turbidity & total suspended solids, track LBSP movement, measure chlorophyll α concentration, HAB identification, assist oil spill identification	Menghua Wang, NOAA/NESDIS/STAR/SOCD/MECB, Marine Ecosystems & Climate Branch
Synthetic Aperture Radar (SAR)	Detect wind speed & direction to assist with issues of larval transport and LBSP connectivity mapping. Oil and chemical spill detection. Vessel detection for enforcement. Possible detection of large-scale spawning events	William G. Pichel, NOAA/NESDIS/STAR/SOCD/MECB, Marine Ecosystems & Climate Branch
Ocean Surface Vector Winds (OSVW)	Detect prevailing ocean surface wind currents that influence biological connectivity, LBSP transport, and localized upwelling events	Paul Chang, NOAA/NESDIS/STAR/SOCD/OSB, Ocean Sensors Branch
Sea-Surface Temperature (SST) Improvements[+]	Predict bleaching events via SST product improvements to proactively trigger response plans. Assist the identification of areas resilient to bleaching	Eileen Maturi, NOAA/NESDIS/STAR/SOCD/MECB, Marine Ecosystems & Climate Branch
GOES Insolation[+]	Measure solar radiation energy to model coral photosystem health and assess potential for coral polyp mortality	Istvan Laszlo, NOAA/NESDIS/STAR/SMCD/EMB, Environmental Monitoring Branch and University of Maryland at College Park
Ocean Acidification (OA)[+#]	Monitor regional changes in ocean acidification over decadal timescales to aid prioritization of reef management efforts	Dwight Gledhill, NOAA/OAR, Ocean Acidification Program
Satellite Altimetry	Detect and measure intermediate to long-term local, regional and global sea-level rise. Significant wave height measurements & potential storm surge advisories for local coral managers	Laury Miller, NOAA/NESDIS/STAR/SOCD, Laboratory for Satellite Altimetry

[+] *= NOAA/Coral Program supported product development area.* [#] *= NOAA/OAR supported product development area.*

2.2 National/Jurisdiction-level Crosswalk Analysis Methodology

The methodology for the national/jurisdiction-level crosswalk analysis consisted of correlating the seven jurisdiction-level Coral Reef Management Priorities documents; *Coral Reef Conservation Program Goals & Objectives 2010-1015*; and the *NOAA Satellite Remote Sensing Product Development Areas* to identify areas in which satellite remote sensing products could contribute to both jurisdiction-level coral reef management priorities and Coral Program National Goals & Objectives for coral reef management. Each of the jurisdiction-level Coral Reef Management Priorities documents contain selected priority goals and objectives that have been correlated to *NOAA Coral Reef Conservation Program Goals & Objectives 2010-2015*. The

seven jurisdiction-level documents were first filtered to identify jurisdiction-level priority goals & objectives that the selected NOAA satellite remote sensing product development areas could address. Please note that the filter was restricted to priority goals & objectives only. While the jurisdictions had typically correlated one jurisdiction-level priority objective to one Coral Program National Objective within the documents, our in-depth review led to the inclusion of additional Coral Program National Goal & Objective correlations that we found to be appropriate. Once the jurisdiction-level priority goals objectives had been correlated to the Coral Program National Goals & Objectives, they were then correlated to the appropriate satellite remote sensing product development area(s), grouped by Coral Program threat category (e.g., Climate Change, Fishing, and LBSP) and tallied. Individual satellite remote sensing product development areas were found to correlate with multiple Coral Program Goals & Objectives, across multiple Coral Program threat categories; therefore the number of times an individual product development area addressed a particular Coral Program Goal & Objective was also tallied across the three Coral Program threat categories. Outcomes from this two-part analysis are included below in the Results.

2.3 Jurisdiction-level Correlation Analysis Methodology

The methodology for the jurisdiction-level analysis consisted of correlating the *Seven Jurisdiction-level Coral Reef Management Priorities Documents*; *Coral Reef Conservation Program Goals & Objectives 2010-1015*; and *NOAA Satellite Remote Sensing Product Development Areas* to provide information regarding which remote sensing product development areas have the broadest appeal across the seven jurisdictions. The same filter methodology and subsequent inclusion of additional appropriate correlations as was performed in the national/jurisdiction-level crosswalk analysis was also applied to the jurisdiction-level correlation analysis. Correlations were grouped by Coral Program threat category and jurisdictional affiliation and then tallied. The outcome of this analysis is included in the Results.

2.4 International Correlation Analysis Methodology

The international analysis methodology differed from the national/jurisdiction-level crosswalk analysis methodology in that there were no unique goals and objectives from the four priority geographic regions of the wider Caribbean, Micronesia, Samoa and the Southwest Pacific, and the Coral Triangle to correlate with Coral Program International Strategy Goals & Objectives. Therefore the *NOAA Coral Reef Conservation Program International Strategy 2010-2015* and *NOAA Satellite Remote Sensing Capabilities* were correlated to identify which NOAA satellite remote sensing product development areas had the highest total number of correlations to eligible Coral Program International Strategy Goals & Objectives. The outcome of this analysis is included in the Results.

3. Results

3.1 National/Jurisdiction-level Crosswalk Analysis Results

To investigate which Coral Program threat categories were perceived to be most effectively addressable by remote sensing, we tallied the number of times each individual remote sensing product development area addressed a particular jurisdictional priority goal & objective, grouped by Coral Program threat categories (Table 2, column totals). This analysis revealed that managers who prepared the jurisdictional priorities identified remote sensing products as best

addressing Climate Change Impacts (79 occurrences); a 2:1 ratio when compared to the next highest threat category. Products that could address LBSP Impacts received the second highest tally with 39 occurrences. Products that could address Fishing Impacts were third with 29 tallies.

Table 2. Number of jurisdiction-level priority goals and objectives addressable by each NOAA remote sensing product development area, grouped by Coral Program threat category.

NOAA Product Development Area	**Climate Change Impacts - Goal 1**	**Climate Change Impacts - Goal 2**	**Climate Change Impacts - Goal 3**	**Fishing Impacts - Goal 2**	**LBSP Impacts - Goal 1**	**LBSP Impacts - Goal 2**	**LBSP Impacts - Goal 3**	**Total**
Ocean Color		2.2		2.1(3); 2.3	1.1(2); 1.3(6); 1.4(5); 1.5(4)	2.1(2)	3.5(4)	**28**
Synthetic Aperture Radar (SAR)		2.1; 2.2; 2.4(4); 2.5		2.1(4); 2.3	1.1; 1.3; 1.4(3); 1.5	2.1		***20**
Ocean Surface Vector Winds (OSVW)		2.1; 2.2; 2.4(4); 2.5		2.1(4); 2.3	1.1; 1.3; 1.4(3); 1.5	2.1		**19**
Sea Surface Temperature (SST) Improvements+	1.3(2); 1.5	2.1(4); 2.2(3); 2.4(4); 2.5(5)	3.2	2.1(4); 2.3			3.5	**26**
GOES Insolation+	1.3(2); 1.5	2.1(4); 2.2(3); 2.4(4); 2.5(5)	3.2	2.1(4); 2.3				**25**
Ocean Acidification (OA)#	1.5	2.1(3); 2.2(2); 2.4(4); 2.5(4)	3.2	2.1(4); 2.3			3.5	**21**
Satellite Altimetry	1.5	2.1(3); 2.2; 2.4; 2.5(3)						**9**
Total	**79**			**29**	**39**			*Intentionally Blank*

If a listed Coral Program Objective is followed by a number in parentheses [ex. 2.4 (4)], the number indicates that Objective 2.4 appeared four times for the specific jurisdiction.

***While Hawai'i Goal 1; Objective 1.3 held no correlation to the three national-level threats, SAR did match well with the Hawai'i Goal, therefore raising the total SAR tally from 19 to 20.*

+ = NOAA/Coral Program supported product development area. # = NOAA/OAR supported product development area.

The row totals in Table 2 show the remote sensing product development areas that held the highest overall applicability across the seven jurisdictions. This analysis revealed that the Ocean Color product development area (28 occurrences) can address the most jurisdictional needs compared to the other product development areas. SST improvements and GOES Insolation displayed the second and third highest overall applicability with 26 and 25 occurrences

respectively. SAR (20 occurrences), OSVW (19 occurrences), ocean acidification (21 occurrences) and satellite altimetry (9 occurrences) rounded out the results.

3.2 Jurisdiction-level Correlation Analysis Results

This analysis revealed areas of agreement among the jurisdictions. Correlation is clearly revealed when *NOAA Coral Reef Conservation Program Goals & Objectives* that address specific jurisdiction-level Coral Reef Management Priorities are displayed according to jurisdiction in table format. Most prominently, 100% of the seven examined U.S. jurisdictions were found to have priority goals and objectives that correlate to Coral Program's LBSP Impacts Goal-1 (Table 3). Five of the seven jurisdictions were found to have priority goals and objectives that correlate to Climate Change Impacts Goal-2. Four of the seven jurisdictions were found to have priority goals and objectives that correlate to Fishing Impacts Goal-2 and LBSP Impacts Goal-3; whereas Climate Change Impacts Goals-1 & 3 and LBSP Impacts Goal-2 were each found to have three or fewer jurisdictions with priority goals and objectives that correlate. Results suggest that a remote sensing product suite for utilization by the Coral Program that can address LBSP Impacts in coral reef environments would hold the broadest appeal across the seven jurisdictions.

Table 3. Alignment of jurisdictions with priority goals and objectives that correlate to Coral Program Goals & Objectives, grouped by Coral Program threat category.

Jurisdiction	**Climate Change Impacts - Goal 1**	**Climate Change Impacts - Goal 2**	**Climate Change Impacts - Goal 3**	**Fishing Impacts - Goal 2**	**LBSP Impacts - Goal 1**	**LBSP Impacts - Goal 2**	**LBSP Impacts - Goal 3**
American Samoa	1.5	2.1, 2.4, 2.5		2.1	1.1, 1.4(2), 1.5	2.1	
CNMI	1.3	2.1, 2.2, 2.5			1.3(3)		
Guam	1.3				1.3 & 1.4		3.5
Hawaii		2.1, 2.2, 2.4, 2.5(2)	3.2	2.1, 2.3	1.3		
Florida		2.4		2.1	1.3, 1.4, 1.5(2)		3.5
Puerto Rico					1.4, 1.5		3.5
USVI		2.1, 2.2, 2.4, 2.5		2.1	1.1	2.1	3.5
Total number of Jurisdictions	**3**	**5**	**1**	**4**	**7**	**2**	**4**

If a listed Coral Program Objective is followed by a number in parentheses [ex. 1.4 (2)], the number two indicates that Objective 1.4 was correlated two times to the specific jurisdiction.

3.3 International Correlation Analysis Results

The international correlation analysis lacked specific regional priority goals and objectives to which Coral Program International Strategy Goals & Objectives and the selected satellite remote sensing product development areas could be correlated. Satellite remote sensing product development areas were found to correlate well with Coral Program International Strategy Goal 1 - Objective 1.5; Goal 2- Objectives 2.1 & 2.2; and Goal 4 - Objective 4.1 (Table 4). However, all remote sensing development areas ranked about the same in the analysis.

Table 4. Number of Coral Program International Strategy Objectives to be addressed by NOAA remote sensing product development area, grouped by Coral Program International Strategy Goal.

NOAA Product Development Area	**International Strategy-Goal 1**	**International Strategy-Goal 2**	**International Strategy-Goal 3**	**International Strategy-Goal 4**	**Total**
Ocean Color	1.5	2.2		4.1	**3**
Synthetic Aperture Radar (SAR)	1.5	2.2		4.1	**3**
Ocean Surface Vector Winds (OSVW)	1.5	2.2		4.1	**3**
Sea-Surface Temperature (SST) Improvements[+]	1.5	2.1 & 2.2			**3**
GOES Insolation[+]	1.5	2.1 & 2.2			**3**
Ocean Acidification (OA)[+#]	1.5	2.1 & 2.2		4.1	**4**
Satellite Altimetry	1.5	2.2			**2**

[+] *= NOAA/ Coral Program supported product development area.* [#] *= NOAA/OAR supported product development area.*

4. Discussion

To generate a set of well-balanced recommendations that take into account both the results from the various correlation analyses as well as the supplementary information contained in the product development one-pagers (Appendices A-G), the findings from the analyses are first discussed below. Second, each product development area is individually discussed to more accurately contextualize the conclusions. Estimates for product development time and cost are best-guess estimates derived from information received during the structured interviews conducted with NOAA remote sensing scientists. A summary table regarding the current status of the remote sensing product development areas is provided at the end of this section (Table 5).

The national correlation analysis revealed two separate findings. First, when the seven jurisdictions are considered together as a whole, remote sensing product development areas that address Climate Change Impacts Goals & Objectives (e.g., primarily SST improvements, GOES Insolation and OA) have the highest number of correlations to jurisdiction-level priority goals and objectives from the three Coral Program threat categories (Table 2) by a 2:1 ratio. This result indicates that managers who prepared the jurisdictional priorities perceive remote sensing products that address Climate Change Impacts to be highly valuable. Second, when jurisdiction-level priority goals and objectives are tallied irrespective of their Coral Program threat category, Ocean Color arose as the analysis' most numerically dominant product development area (Table 2). This may have to do with the fact the jurisdiction-level priority goal and objective setting process tended to focus on identifying local rather than global needs and LBSP Impacts typically occur at the local scale. The second through fourth ranked areas were SST improvements, GOES Insolation and OA respectively, indicating the perception of a strong management need for the Coral Program to continue to develop and support delivery of these products.

Complementing the results from the national correlation analysis, the results from the jurisdiction-level correlation analysis highlight that all seven jurisdictions (100%) have priority goals and objectives correlated to LBSP Impacts Goal 1 (Table 3). This was the only area of complete agreement among all seven jurisdictions within the analysis and indicates that remote sensing products have a broad appeal because of their ability to address local challenges of LBSPs across the jurisdictions. Remote sensing of LBSPs can be achieved primarily through the Ocean Color, SAR and OSVW product development areas (Table 3). Lastly, the results from the international correlation analysis revealed that in the absence of unique goals and objectives from the four priority geographic regions, all remote sensing product development areas are similarly able to address the eligible Coral Program International Strategy Goals & Objectives (Table 4). This result indicates that whatever product development area(s) is/are selected for funding domestically will also address the majority of eligible Coral Program International Strategy Goals & Objectives.

Ocean Color (Appendix A) was the product development area addressing the most priority needs across the seven jurisdictions (Table 3). Although the current ocean color product suite has yet to be optimized for use in optically shallow and typically clear waters over coral reefs (typically < 70m deep), it does work well over both optically deep and turbid waters. Future Ocean Color products for coral reef management would provide the most direct information related to addressing LBSP impacts by measuring turbidity and total suspended solids, tracking LBSP movement, in addition to other application which include long-term tracking of regional and global CO_2 uptake by phytoplankton in reef environments, harmful algal bloom (HAB) identification, and assisting with oil spill identification. Further algorithm development and enhancement is needed to fine-tune sensor measurements for use over coral reefs. The amount of effort required for these tasks would be relatively low at 1-3 FTEs/year for approximately 2-5 years. Products for coral reef application would be considered "low-hanging fruit" due to the broad appeal within the seven jurisdictions, relatively low investment cost, and estimated timeframe for product development.

SST improvements and GOES Insolation were found to be the second and third most numerically dominant correlated product development areas within the national analysis (Table 2). Their virtually equal scores are due to the fact that the temperature of the ocean's surface and the amount of light being received by coral polyps are separate but tightly coupled environmental variables. Both product development areas are best suited to address Climate Change impacts.

As noted by Guam, *"With regard to the CRW Program, in particular, their high quality products that have become integral to our coral bleaching response efforts ... We have also benefitted from the quality and utility of training opportunities provided by the CRW Program and its partners, and the positive, collaborative interactions with CRW Program staff over the last several years. We rely heavily upon several of the Coral Reef Watch Program's operational products, such as HotSpots, Degree Heating Weeks, Sea Surface Temperature (SST) and SST anomalies, and gains particular utility from the Virtual Station email notifications* (Guam comments on the NOAA National Coral Reef Monitoring Plan)". Improvements to the existing SST product suite (Appendix D) are ongoing and will enhance both the accuracy and spatial and temporal resolution of the current SST product. These improvements are critical to aid in prompt, effective management of coral reef ecosystems facing ever-growing challenges in an era of unprecedented climate change. With the launch of a new generation of NOAA satellites and conversion to new data products from NOAA/NESDIS, even the continuity of existing thermal stress products will require continued development. New high-resolution data are currently being tested and validated while improved products are estimated to become available within the next 4 years.

Although only one GOES Insolation product (Appendix E) currently exists for coral reef applications, light products could be used in a wide range of coral reef applications because light is a fundamentally important environmental variable for most marine organisms. CRW is currently developing an experimental product incorporating GOES Insolation, the Light Stress Damage (LSD) product, which will monitor coral photosystem health. While the GOES Insolation data are funded by NESDIS/STAR, the LSD product is presently being funded by the Coral Program and the Australian Research Council (ARC) through an $8.3M Linkage grant and is expected to become available within 5 years time. As noted above, temperature and light products are presently ongoing efforts that receive funding through the Coral Program and their high rankings indicate their value to managers and justify continued funding for further development and improvement.

Within the national analysis, the Ocean Acidification (OA) product development area (Appendix F) held the fourth highest correlation tally (Table 2) and was primarily aligned with addressing Climate Change impacts. Within the international analysis, OA was the only product development area identified in all four eligible Coral Program International Strategy objectives. The OA product suite is also a pre-existing development effort that has received past funding through NOAA/OAR and the Coral Program. The existing OA product suite measures changes in ocean chemistry that have the potential to impact a broad range of marine species, including reef building organisms, by affecting coral growth rates, bioerosion, and larval survivability and recruitment rates. The OA product suite will require additional *in situ* data from waters outside the greater Caribbean region to expand the products' utility into new areas (e.g., the Pacific Ocean). NOAA is actively seeking funding to continue product development efforts for both data and algorithm improvement. Upon acquisition of new *in situ* data, the estimated level of effort for product expansion would be 1 FTE/year for approximately 2-5 years.

SAR (Appendix B) ranked fifth within the national analysis (Table 2) and was the second most numerically dominant *new* product development area (excluding SST improvements, GOES Insolation and OA). SAR is perhaps the most versatile remote sensing tool and already has operational uses at NESDIS/STAR (e.g., surface wind speed, surface oil detection, vessel tracking, and derelict fishing gear detection – GhostNet project). Due to the variety of data collected via SAR sensors, future products for coral reef application could address objectives in all three Coral Program threat categories. SAR data provide valuable information on the

identification and transportation of oil and chemical spills and larvae as well as future applications that include internal waves that can cause upwelling. Although the US does not currently have SAR instruments aboard domestic satellites and data acquisition from foreign and private sources is costly, this scenario will change within approximately two years when operational SAR satellite constellations from Canada and Europe will provide valuable SAR data to NOAA at no cost. However, because of the high data density and narrow sensor swaths, SAR products are best applied to local product development. SAR products for coral reef application have an estimated product development timeframe of 2-5+ years. Those products derived from existing operational products (i.e., SAR Wind) would have a shorter developmental timeframe while pilot projects for a new investigated variable (e.g., significant wave height) would take longer. The level of effort required for algorithm development would be about 1-2 FTEs/year.

Ocean Surface Vector Winds (OSVW) was the sixth ranked product development area or third ranked *new* product development area (Appendix C; Table 2). It virtually tied with SAR due to their similar abilities to address objectives in all three Coral Program threat categories. OSVWs are global near real-time indirect measurements of both wind speeds and direction. OSVW data differs from SAR wind data by providing global wind speed and direction data, but not available within 25 km from the coast, while SAR provides higher resolution local and regional scale wind speed data right up to the coastline. In this way the two tools could be utilized synergistically to provide global wind data with minimal gaps. Future coral reef-specific applications of OSVW will contribute towards understanding LBSP transportation, larval connectivity, and climate change resilience via wind generated cooling effects. Domestic OSVW data have not been available from NOAA research satellites since 2009; however data from an Indian satellite may become available in 2012. A current OSVW-based product for coral reef management application is the CRW Doldrums product. The Doldrums product tracks the number of days low wind speed conditions or "doldrum" conditions exist. These doldrum events amplify light penetration and warming, increasing the probability a particular area will experience coral bleaching conditions. Additional OSVW derived products still need to be developed and would require an estimated 1-2 FTEs/year for approximately 2-5+ years.

The final product development area, Satellite Altimetry (Appendix G), was ranked lowest amongst the seven product development areas (Table 2). Although found to correlate quite well to Coral Program Climate Change Impacts Goal 2, Satellite Altimetry was less frequently applicable to Fishing and LBSP impacts. Satellite Altimetry provides valuable data on decadal and longer timescales while jurisdiction-level priority goals & objectives tended to focus on more immediate needs. Still, Satellite Altimetry as a remote sensing product development area holds significant promise for coral reef management once products have been developed. Satellite Altimetry products could be employed to investigate environmental variables that influence coral reef health, such as local changes in sea level height, significant wave height, and tropical storm surge. A first step towards creating coastally optimized satellite altimetry products would be for coral experts to begin attending the annual Coastal Altimetry Workshop held in conjunction with the Ocean Surface Topography Science Team (OSTST) annual meeting. There, a NOAA/Coral Program representative could present coral-specific satellite altimetry needs to the research community, making in-roads towards a collaborative product development effort. Assuming there are improvements to the density and quality of altimetry data in the coastal zone, 1 FTE/year, for a period of 5+ years, would be required to develop the Satellite Altimetry product for coral reef management applications.

It is important to note that once a satellite product becomes operational, a reduced but continuous funding level is usually needed to cover the maintenance and production of operational data. Operational products can and will evolve as procedures and algorithms advance with technology. This evolution requires continual support. Occasionally, additional funding may be required to overcome satellite losses, transitions, and/or significant technological advances that require reprocessing of past data sets or redevelopment of existing products. Changes from a retired satellite to a new satellite replacement (e.g. NOAA 17 transition to NOAA 19) usually require adjustments and validation to account for the subtle changes in the characteristics of the sensors and subsequent measurements. As improved algorithms are developed, retrospective analyses become important since an up-to-date time series is needed to effectively measure changes in climate or other environmental stresses.

Table 5. Summary table of NOAA product development area one-pagers.

NOAA Product Development Area	**Are proper instruments available on existing satellites?**	**Do products exist for coral reef environments?**	**Estimated product development timeframe**	**Existing gaps**	**Approximate level of effort required to address gaps**
Ocean Color	Yes	No (however products work over deep and turbid waters)	2-5 years	Data quality issues directly over coral reefs	1-3 FTE/year
Synthetic Aperture Radar (SAR)	No for U.S.; Yes for ESA and Canada	Yes (e.g., SAR wind & waves; surface oil; vessel tracking derelict fishing gear-GhostNet project)	2-5+ years	Data availability, coverage and purchasing costs	1-2 FTE/year
Ocean Surface Vector Winds (OSVW)	No for U.S. (until 2012); Yes for ESA and India	Yes (e.g., experimental Doldrum product)	2-5+ years	Coastal interference	1-2 FTE/year
Sea-Surface Temperature (SST) Improvements[+]	Yes	Yes (e.g., SST; HotSpot; DHW; Anomaly; Outlook; Virtual Stations)	0-4 years	Current testing and validation of new data retrieval methods; gaps being addressed currently	Work presently underway at STAR
GOES Insolation[+]	Yes	Yes (e.g., experimental Light Stress Damage product)	0-5 years	Product validation	Work presently underway at STAR and ReefSense (CRW-Australia)
Ocean Acidification (OA) [+#]	Yes	Yes (limited to the Caribbean); presently suspended due to data limitations	2-5 years	*In situ* observations needed for product expansion into Pacific (e.g., Hawai'i)	1 FTE/year with OAR oversight (assuming acquisition of new *in situ* data)
Satellite Altimetry	Yes	No (however sea-level rise and significant wave height products work well outside coastal zone)	5+ years	Resolution and spatial coverage; coastal interference	1 FTE/year (assuming improvements in both data density and quality in the coastal zone)

[+] *= NOAA/ Coral Program supported product development area.* [#] *= NOAA/OAR supported product development area.*

5. Conclusion

The goal of this report has been the formulation of recommendations pertaining to which NOAA satellite remote sensing product development areas should be prioritized for the development of applications for coral reef management and estimates of how soon coral reef specific products could be made available. Ranking the degree of correlation with jurisdictional needs provided insights into which satellite remote sensing product development areas should be given highest priority. Development of these remote sensing tools for coral reef use would address existing issues facing US coral reef managers as well as address Coral Program National and International Goals & Objectives for coral reef management. Simultaneously, the release and delivery of new remote sensing products by NOAA/CRW would strengthen STAR- Coral Program collaborations to tackle coral reef management needs. Taking into account the results from each of the correlation analyses and seven product development area one-pagers, the following set of recommendations are put forth to the Coral Program.

1. *Continue to fund SST, GOES Insolation & Ocean Acidification product development and improvement.* The high rankings of these three product development areas indicated their value to managers and demonstrated a strong need for continuous development and support of existing products for the coral reef management community. Changes in satellite sensor technology and SST data streams require ongoing QA/QC and redevelopment to assure continuity of these products identified as high-priority by the management community. Both SST and GOES Insolation are currently ongoing. SST receives funding from the Coral Program while GOES Insolation and the Light Stress Damage product receive funding from NESDIS/STAR, the Coral Program, and an ARC Linkage Grant. Ocean Acidification previously received funding support from the Coral Program and OAR.

2. *Begin the development of Ocean Color remote sensing products for coral reef specific applications (proposed 2013 start date).* Ocean Color is ripe for development of new coral specific applications and received the highest number of correlations out of all seven areas investigated. Ocean Color is the product development area that most directly addresses LBSP impacts and interest in LBSP spanned all seven jurisdictions. Ocean Color would be considered the "lowest-hanging fruit" option to address.

3. *Phase in the development of SAR & OSVW products for coral reef management; SAR (proposed 2015 start date) and OSVW (proposed 2017 start date).* SAR and OSVW were the second and third ranked new satellite remote sensing product development areas. Anticipated developments and improvements in the near-future will allow these product areas to become more applicable to coral reef management. Additionally, SAR can be utilized synergistically with both the Ocean Color and OSVW product development areas.

4. *Revisit this schedule every 2-3 years or as new efforts begin.* It will be important to consistently meet and revisit this suggested development schedule to track progress and maintain momentum and flow of information between both NESDIS/STAR and the Coral Program.

As noted within the international correlation analysis discussion, selection of any of the product development areas for funding would provide tools applicable to the Coral Program International Strategy Objectives. Once product development areas are selected for development into coral reef specific products, strategically selected sites could be chosen for use as "pilot sites" and upon validation, the products could be expanded for broader geographic use. Similar to the NOAA/CRW SST-based product suite, any new coral reef remote sensing products should be made available through user-friendly, web-based platforms. Intuitive design will allow managers with different levels of technical expertise to navigate the products efficiently and productively. Lastly, immediate action should be taken to capitalize on the momentum gained from the presentation and subsequent discussion of the study's findings with the Coral Program, STAR, and CRW. Presently, plans for quarterly discussions among STAR, Coral Program, and the CRW have been suggested to maintain this momentum. Steps to solidify these plans include:

1. Selecting a person to lead, document and track the follow-up coordination efforts;

2. Discuss with Coral Program as to what types of additional information or product capability demonstrations they are interested in; and

3. Creating an agenda and schedule a date for the first and subsequent meetings.

6. Acknowledgements

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7. Disclaimer

The technical report contents are solely the opinions of the authors and do not constitute a statement of policy, decision, or position on behalf of NOAA or the U.S. Government.

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9. List of Acronyms and Abbreviations

Ω arag	Aragonite Saturation State
$pCO_{2,sw}$	Surface Water CO_2 Partial Pressure
ABI	Advanced Baseline Imager
ABM	Australian Bureau of Meteorology
AOML	Atlantic Oceanographic and Meteorological Laboratory
ARC	Australian Research Council
ASCAT	Advanced Scatterometer
BIO	Bedford Institute of Oceanography
CO_2	Carbon Dioxide
CoRIS	Coral Reef Information System
CNES	Centre National d'Etudes Spatiales
CNMI	Commonwealth of Northern Mariana Islands
Coral Program	Coral Reef Conservation Program
CREIOS	Coral Reef Ecosystem Integrated Observing System
CRW	Coral Reef Watch
DHW	Degree Heating Week
DLR	German Aerospace Center
EEZ	Exclusive Economic Zone
EMB	Environmental Monitoring Branch
ESA	European Space Agency
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
fd	Full Disk
GDR	Geophysical Data Record
GOES	Geostationary Environmental Satellite
GSIP	GOES Surface and Insolation Product
HAB	Harmful Algal Bloom
HYCOM	Hybrid Coordinate Ocean Model
in situ	In place where it occurs
IOCCG	International Ocean Color Coordinating Group
IOOS	Integrated Ocean Observing System
ISRO	Indian Space Research Organization
JAXA	Japanese Aerospace Exploration Agency
JCSDA	Joint Center for Satellite Data Assimilation
K	Thousand
km	Kilometer
LBSP	Land-based Source of Pollution
LSA	Laboratory for Satellite Altimetry
LSD	Light Stress Damage
MECB	Marine Ecosystems and Climate Branch
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NESDIS	National Environmental Satellite, Data and Information Service
NGSP	NOAA Next Generation Strategic Plan
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration

NOS	National Ocean Service
NWS	National Weather Service
OA	Ocean Acidification
OAR	Office of Oceanic and Atmospheric Research
OCR	Ocean Color Radiometry
OSB	Ocean Sensors Branch
OSCAR	Ocean Surface Current Analysis-real time
OSPO	Office of Satellite and Product Operations
OSTST	Ocean Surface Topography Science Team
OSVW	Ocean Surface Vector Winds
PAR	Photosynthetically Active Radiation
QA/QC	Quality Assurance/Quality Control
SAR	Synthetic Aperture Radar
SMCD	Satellite Meteorology and Climate Division
SOCD	Satellite Oceanography and Climatology Division
SST	Sea Surface Temperature
STAR	Center for Satellite Applications and Research
USVI	United States Virgin Islands

Appendix A. Ocean Color One-pager

Lead staff: Menghua Wang, NESDIS/STAR/SOCD/MECB, Marine Ecosystems & Climate Branch

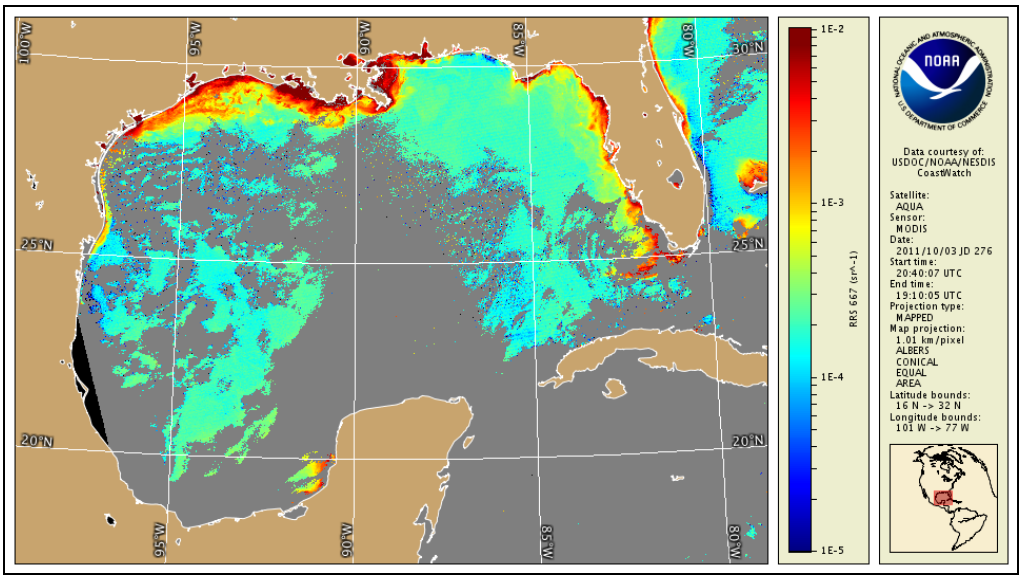


Figure 1: October 3, 2011 MODIS-Aqua image of remote sensing reflectance in the Gulf of Mexico.

What is the products development area: Ocean color radiometry (OCR) is the measure of water hue due to the presence of phytoplankton, sediments, and colored dissolved organic material via satellite sensor. Presently STAR has three operational ocean color products that provide data in near-real-time where skies are clear for waters offshore from coral reefs: chlorophyll, harmful algal blooms, and normalized water-leaving radiance. Clear, shallow water over reefs allows satellite sensors to detect the bottom, making it difficult to accurately measure suspended sediments and/or chlorophyll α in the water column. The removal of this bottom signal will allow sensors to measure spatially and temporally anomalous periods of suspended sediments and chlorophyll α over shallow coral reefs. High quality ocean color data products will be produced from national and international satellite sensors and then provided to the user community for research and management applications.

Near-term vision: To produce high quality satellite ocean color data products from national and international satellite sensors that would provide data to the user community that is routinely used and implemented in the coral reef monitoring system.

How can the products be used for corals: Ocean color is of interest to coral managers as a cost effective way to track land-based sources of pollution including nutrients and sediments, primary productivity, light reaching corals, and harmful algal blooms, among others. Regional perturbations can be identified and effects on the marine ecosystem quantified. Inter-annual variability of phytoplankton in marine ecosystems can be monitored to help explain fluctuations in larval species survival. Coastal water quality can be monitored to track land-based sources of pollution and pollutant transport. Harmful algal blooms can be monitored by tracking the lifecycle of a bloom to aid state agencies, tourism and aquaculture industries. Future marine protected areas can be more effectively delineated with the help of ocean color data to show spatially and temporally productive areas (high phytoplankton biomass) that can be targeted for protection. Educational materials from ocean color images enhance public awareness regarding coral reef conservation issues.

Customers: NOAA's Coral Reef Conservation Program (Coral Program), CoastWatch, National Ocean Service (NOS), National Marine Fisheries Service (NMFS), and Integrated Ocean Observing System (IOOS), federal, state and local coral reef managers, ocean and additional science communities.

Current products and planned advances:

- **Remote Sensing Reflectance *or* Normalized Water-leaving Radiance (MODIS-Aqua sensor):** Remote sensing reflectance (or normalized water-leaving radiance) spectra provide water column information that can be related to water optical, biological, and biogeochemical properties. An example of this is how remote sensing reflectance can be used as a proxy for the suspended sediments in surface waters. The product has a 1km resolution with 1-2 day repeat cycle.
    - **Status:** NESDIS/STAR operational product for deep water near coral reefs and coastal waters with low visibility

- **Chlorophyll Concentration (MERIS and MODIS-Aqua sensors):** Chlorophyll concentration provides an estimate of the phytoplankton biomass in the surface layer. Daily, bi-monthly mean and anomaly chlorophyll products are available. The product has a 1km resolution with a daily repeat cycle.
    - **Status:** NESDIS/STAR operational product for deep water near coral reefs and coastal waters with low visibility

- **Harmful Algal Bloom Bulletins (MODIS-Aqua and MERIS sensors):** Harmful algal bloom bulletins provide notification of bloom conditions to state and local coastal managers in the Gulf of Mexico. Bulletins include information on wind conditions, chlorophyll levels, and potential or actual bloom events. The product has a 1km resolution with 1-2 day repeat cycle.
    - **Status:** NESDIS/STAR operational product for deep water near coral reefs and coastal waters with low visibility

Planned Advances: To build ocean color data processing capability for coral reef environments into existing NOAA/STAR ocean color coastal products.

Existing gaps: A key component in solving the issue of bottom reflectance is to gather comprehensive measurements regarding the inherent optical properties of bottom reflectance in shallow coral reef waters to account for their effects within algorithms. Additionally, the presence of clouds prevents data retrieval.

Resources needed to address near-term vision: Funding is needed for data storage and work on algorithm development and refinement. Total estimated level of effort for product development would be 1-3 FTEs/year for approximately 2-5 years.

Key partners: *National Aeronautics and Space Administration* (*NASA*), Navy, European Space Agency (ESA), Japanese Aerospace Exploration Agency (JAXA), International Ocean Color Coordinating Group (IOCCG).

Coral Program Goals & Objectives addressed:

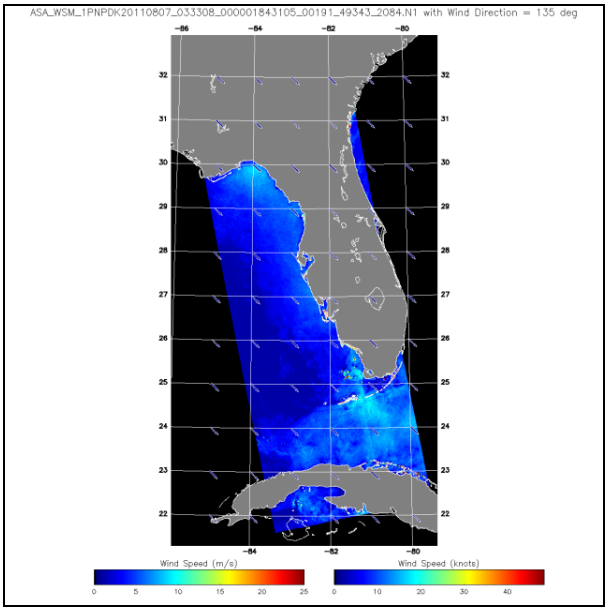
- Climate Impacts Goal 2; Objective 2.2
- Fishing Impacts Goal 2; Objectives 2.1 & 2.3
- Land-based Sources of Pollution Impacts Goal 1; Objectives 1.1, 1.3, 1.4 & 1.5
- Land-based Sources of Pollution Impacts Goal 2; Objective 2.1
- Land-based Sources of Pollution Impacts Goal 3; Objective 3.5

Objectives of Next Generation Strategic Plan (NGSP) Addresses:

- Climate Adaptation and Mitigation Goal: Improved Understanding Objective
- Oceans Goal: Improved Understanding Objective (ex. current conditions, forecasts)
- Resilient Coastal Communities Goal: Improved Coastal Water Quality Objective

Appendix B. Synthetic Aperture Radar (SAR) One-pager

Lead staff: William G. Pichel, NOAA/NESDIS/STAR/SOCD/MECB, Marine Ecosystems and Climate Branch



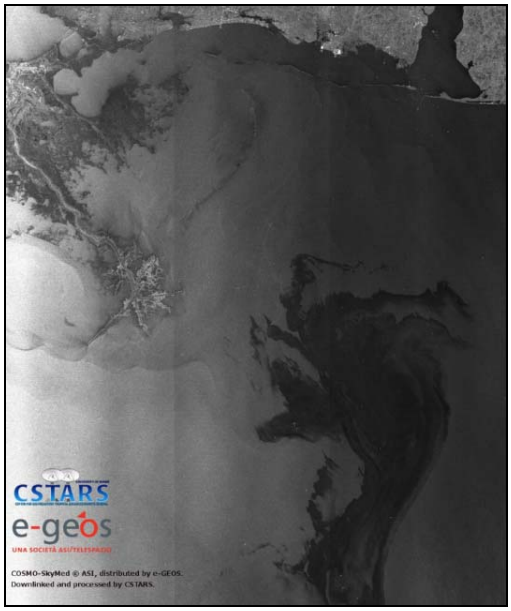


Figure 2 (left): August 7, 2011 SAR image displaying wind speed (m/s & knots) and direction off Florida and Cuba. Figure 3 (right): May 13, 2010 SAR image showing the main area of the Deepwater Horizon oil spill in the Gulf of Mexico (dark colored area – center lower-right), near the coast of Louisiana and Mississippi (May 13th).

What is the product development area: Synthetic Aperture Radar (SAR) is a satellite-based radar system that provides a high resolution view of ocean surface features including ocean roughness. SAR functions in all weather conditions including day and night, cloudy or clear skies, and is not hindered by coastal land interference. Presently NOAA/Center for Satellite Applications and Research (STAR) has one operational SAR product and two experimental SAR products projected to become operational in the near-future.

Near-term vision: Implement operational versions of the oil, wind, and vessel products using available research and commercial SAR data over the next few years.

How can the products be used for corals: SAR derived ocean roughness measurements can detect a diverse variety of sea surface phenomena that interact with coral reef environments, making them ideally suited for incorporation into management strategies. SAR wind imagery is useful for identifying local and regional scale coral reef areas exposed to persistent or anomalous low/high wind conditions that contribute to/alleviate bleaching events at much higher resolution compared to 25 km resolution for OSVW. Oil spills and surfactants suppress wave action and reduce surface roughness compared to surrounding waters resulting in anomalous dark regions on the image. This can be used to identify both oil spills and surfactants on the ocean's surface that may negatively impact coral reefs. Mass spawning events also can suppress wave action and large events may possibly be detected via SAR. SAR Vessel Detection imagery is important for coral reef management to track commercial fishing vessel intrusion into EEZ waters and coral reef environments. These features play an important role in coral reef health and influence management decisions. Measurements of significant wave height can be obtained and are necessary for hydrodynamic modeling of currents.

Customers: Federal, state and local coral reef managers, NOAA marine sanctuary and monument managers, National Marine Fisheries Service enforcement personnel and researchers, scientists, educators, and the public.

Current products and planned advances:

- **SAR Wind:** Wind speed is measured at pre-determined locations along a 300 km to 500 km swath with 500 m resolution. Wind directions are obtained from both scatterometer measurements and meteorological models and then integrated into SAR images. SAR Wind data has been available since 1999 in near-real-time with potentially a 1-3 day repeat cycle for a single satellite.
    - **Status:** NESDIS/STAR Experimental Product (Operational in May, 2012)

- **SAR Oil:** SAR detects both oil and surfactants at pre-determined locations along a 100 km to 400 km swath with 30 m to 150- m resolution. Data available since 2011 in near-real-time with a potential 1-3 day repeat cycle for a single satellite.
    - **Status:** NESDIS/STAR Operational Product

- **SAR Vessel Detection:** SAR can identify vessels and vessel wakes at pre-determined locations along a 100 km to 500 km swath with 30 m to150 m resolution. Data available since 2000 in near-real-time with a 1-3 day repeat cycle for a single satellite.
    - **Status:** NESDIS/STAR Experimental Product (Operational in 2013)

- **Planned Advances:** Surface and internal waves, upwelling zones, oil spill boundaries, shallow water bathymetry, current boundaries, and river plumes can be identified via SAR and will be transitioned from research to operations as soon as operational algorithms are developed, tested and validated.

Existing gaps: A substantial gap for SAR experimental and operational products is data availability and limited coverage. However, the operational SAR satellite constellations of Canada and Europe will mitigate present data gaps within two years. Thereafter, 1-2 FTEs/year would be necessary to begin work on pilot projects and further algorithm development (ex. significant wave height) over an estimated timeframe of 2-5+ years.

Resources needed: Access to near-real-time data from the ESA, Canadian Space Agency, and McDonald Dettwiler and Associates.

Key partners: *Commercial partners*: General Dynamics, Global Ocean Associates, I.M. Systems Group (IMSG) at NOAA/*National Environmental Satellite, Data, and Information Service (*NESDIS); *Academic Partners*: The Johns Hopkins University, University of California – Los Angeles, Florida State University, George Mason University; *International Partners*: Environment Canada, German Aerospace Center (DLR), Japan Aerospace Exploration Center (JAXA), Bedford Institute of Oceanography (BIO).

Coral Program Goals & Objectives addressed:

- Climate Impacts Goal 2; Objectives 2.1, 2.2, 2.4 & 2.5
- Fishing Impacts Goal 2; Objectives 2.1 & 2.3
- Land-based Sources of Pollution Impacts Goal 1; Objectives 1.1, 1.3, 1.4 & 1.5
- Land-based Sources of Pollution Impacts Goal 2; Objective 2.1

Objectives of NOAA Next Generation Strategic Plan (NGSP) Addresses:

- Climate Adaptation and Mitigation Goal: Improved Understanding Objective
- Oceans Goal: Improved Understanding Objective (ex. current conditions, forecasts)

Appendix C. Ocean Surface Vector Wind (Satellite Winds) One-pager

Lead staff: Paul Chang, NESDIS/STAR/SOCD/OSB, Ocean Sensors Branch

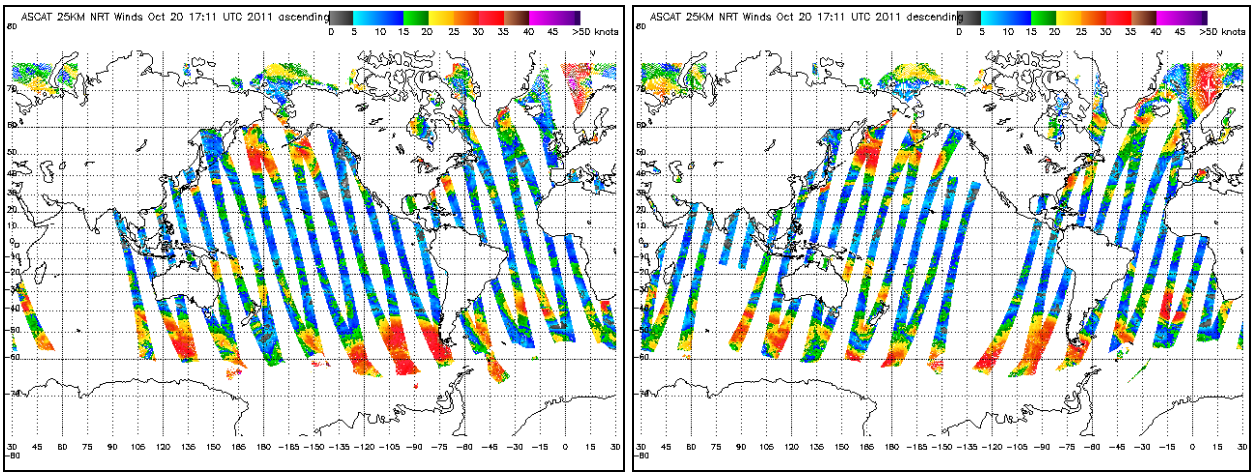


Figure 4: November 20th, 2011 Satellite Winds ASCAT ascending and descending 25 km resolution images displaying global wind speeds at the ocean surface.

What is the product development area: Satellite ocean surface vector winds (OSVW) are an indirect measurement of both wind speed and direction using a satellite-based sensor called a scatterometer. Sensors on non-US polar-orbiting satellites systematically provide both wind speed and direction measurements over the entire globe. Scatterometers utilize active microwave radar frequencies to make measurements of ocean surface roughness in day and night, under nearly all weather conditions, and in near-real-time. Winds along the ocean's surface influence the interaction between the atmosphere and the ocean by modifying air-sea exchanges of heat, moisture, gases, and particulates as well as influencing localized upwelling events. Not only do these interactions influence changes in global and regional climate that can trigger coral bleaching events, but they also affect local currents influencing both the transportation of both water-based sources of pollution and marine larvae.

Near-term vision: The development of OSVW-based products for use in coral reef management that can provide improved assistance with issues regarding bleaching events influenced by doldrum conditions and new assistance regarding issues of land based sources of pollution (LBSP) transportation and biological connectivity.

How the products are used for corals: OSVWs are needed to understand and predict both the short-term and longer-term wind-driven processes that influence coral reef ecosystems. Trend and anomaly detection in these satellite-derived wind measurements already assist with the understanding and prediction of climate change related impacts to corals such as bleaching events. The NOAA/Coral Reef Watch Doldrums product uses these data to identify regions of wind conditions of less than five knots, commonly known as doldrums, that can increase the temperature and light stress that contribute to coral bleaching. Winds promote mixing of the surface waters helping to cool the waters and deliver oxygen to corals and remove nutrients and waste products. Wind-generated waves also scatter light reducing incoming solar radiation to below harmful levels. During periods of sustained low winds, there is less mixing of shallow waters, higher temperatures and increased light penetration promoting environmental conditions adverse to corals, increasing the likelihood of bleaching.

Customers: NOAA/Coral Reef Conservation Program (Coral Program), federal, state and local coral reef managers, scientists, educators, and the general public.

Current products and planned advances:

- **Doldrums product:** The NOAA/Coral Reef Watch Doldrums product is derived from the NOAA *National Environmental Satellite, Data, and Information Service (*NESDIS) National Climatic Data Center Blended Sea Winds product which itself is a composite of up to six satellite observations obtained by both passive (radiometer) and active (scatterometer) means. The duration of a doldrum events (defined here as exhibiting a daily mean of less than 3 m/s; i.e. "doldrums") is tracked by accumulating the number of days over which this condition is met (doldrums days). As an experimental product with ~25 km spatial resolution and quasi-daily temporal resolution, continual development and refinement are needed to determine the best configuration for the algorithm and to test its utility against past bleaching events.
    - **Status:** NOAA Experimental Product

- **Planned Advances:** Improved quality OSVW data collected via satellite scatterometer can be utilized to create wind pattern climatologies for specific geographic areas in which coral reef ecosystems exist. In the future OSVW-based remote sensing products could be created to understand issues of transport and connectivity for land and marine-based sources of pollution and marine larvae.

Existing gaps: OSVW data is presently provided by two non-US satellites; the Advanced Scatterometer (ASCAT) operated by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) since 2006 and the OceanSat-2 Scatterometer operated by Indian Space Research Organization (ISRO) with data for NOAA use expected to become available in 2012. Satellite wind products from ASCAT are somewhat limited in their ability to measure wind accurately within ~70 km of the coast. An improved ASCAT product is running experimentally measuring wind accurately within ~25 km of the coast and will be operational by 2012. Additionally, although cloud does not limit retrievals of satellite derived winds, moderate to heavy rainfall may result in corrupted wind retrievals.

Resources needed to address near-term vision: Funding is needed to begin working on algorithm development and refinement. Total estimated level of effort needed to develop algorithms for OSVW products for coral reef applications is 1-2 FTEs/year over a period of 2-5+ years.

Key partners: Domestic agencies and foreign countries that will be launching future OSVW missions. NOAA presently has no plans to develop/launch its own scatterometer mission.

Coral Program Goals & Objectives addressed:

- Climate Impacts Goal 2; Objectives 2.1, 2.2, 2.4 & 2.5
- Fishing Impacts Goal 2; Objectives 2.1 & 2.3
- Land-based Sources of Pollution Impacts Goal 1; Objectives 1.1, 1.3, 1.4 & 1.5
- Land-based Sources of Pollution Impacts Goal 2; Objective 2.1

Objectives of NOAA Next Generation Strategic Plan (NGSP) Addresses:

- Climate Adaptation and Mitigation Goal: Improved Understanding Objective
- Oceans Goal: Improved Understanding Objective (ex. current conditions, forecasts)

Appendix D. Sea Surface Temperature (SST) Improvements One-pager

Lead staff: Eileen Maturi, NESDIS/STAR/SOCD/MECB, Marine Ecosystems and Climate Branch

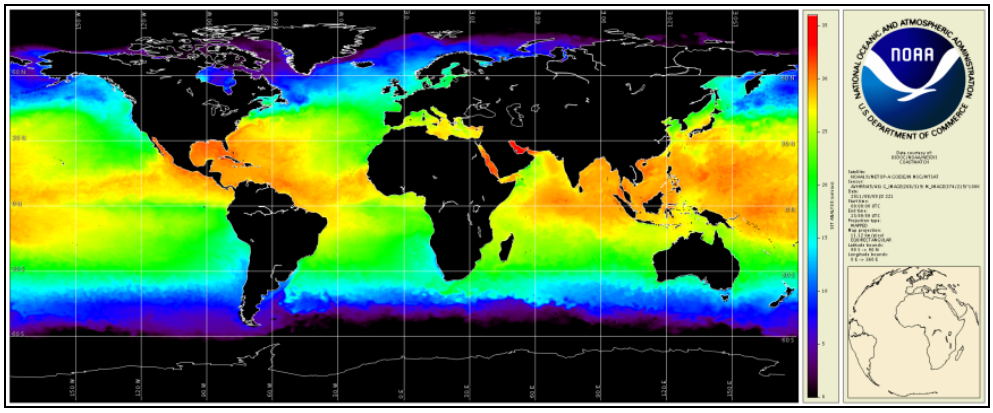


Figure 5: Global image of operational 11-km Geo-Polar blended SST - August 9, 2011.

What is the product development area: Improvements to Coral Reef Watch's (CRW) satellite sea surface temperature (SST)-based product suite will create higher-resolution, higher-quality versions of the coral bleaching monitoring tools that CRW has been providing to the U.S. and international coral reef communities for decision making and support for more than a decade. The major improvements found in the next-generation products are achieved through advances in two key integrated components: higher-resolution near-real-time analysis of satellite SST data and new climatologies derived from 4 km historical satellite SST data.

Near-term vision: To improve the ability of satellites to accurately retrieve SSTs from space through increases in both the frequency of data retrievals and spatial coverage.

How can the products be used for corals: Products at spatial resolutions of 11km and finer will provide near-real-time reef-scale monitoring for use by coral reef managers and other stakeholders to make fast, effective decisions during bleaching events. Planned improvements will enhance the data density, accuracy, and spatial and temporal resolution of these products and are critical to aid prompt, effective management of coral reef ecosystems. When bleaching conditions do occur, new advances can be used to enhance monitoring; guide timely and effective surveys at accurately targeted locations; trigger bleaching response plans and well-organized, fast, and effective management decisions, at less cost to managers.

Customers: NOAA/ Coral Program, federal, state and local coral reef managers, scientists, educators, and the public.

Current products and planned advances:

- **Next-generation near-real-time SST Analyses:**

    - **Blended Geostationary-Polar SST Analysis:** This SST analysis utilizes observations from infrared (IR) sensors onboard two classes of US and international environmental satellites to provide vastly increased data density, and applies new-generation SST retrieving and blending algorithms to significantly increase data quality at ~11 km resolution. This will provide a vast improvement over CRW's current operational products that are based on ~50 km SST analysis. A ~5 km spatial resolution version will become available soon after for potentially improved finer-scale regional applications.
        - **Status:** Day-night 11 km SST is a current NESDIS/STAR operational product. Nighttime-only and 5 km products are under development at NESDIS/STAR.

- **Physical Retrieval of Satellite SST:** A new algorithm for deriving SST from satellite sensor measurements is under development that utilizes local atmospheric conditions to account for atmospheric influence (absorption, scattering, etc.) on light as it travels from the sea surface to the altitudes of satellites. SST obtained in this manner is termed "physical" retrieval and should improve the quality of SST analysis for reef areas over the current "statistical" retrievals.
    - **Status:** Currently under development at NESDIS/STAR.

- **Blended Geo-Polar-Microwave SST Analysis:** Unlike IR sensors, microwave sensors can see through clouds, although the data are at a lower resolution. Combining data from satellite microwave sensors with IR sensors will further enhance the coverage of the next-generation SST products in cloud-persistent regions.
    - **Status:** Pending NESDIS/STAR's implementation.

- **Diurnal Correction for Day-Night Blended SST Analysis:** Utilization of both day and night satellite SST observations significantly increases data density. However, combined daytime solar heating at the sea surface and daily variability in cloud cover may cause significant, often unpredictable daily bias in SST analysis. An algorithm will be developed for diurnal correction to address such biases.
    - **Status:** Pending NESDIS/STAR's implementation.

- **Next-Generation Climatologies:** Accurate climatologies are essential for producing CRW's coral bleaching monitoring products as they set thresholds to track the onset, development, and intensity of bleaching-inductive thermal stress. CRW is developing high-quality, climatologies for the new SST near-real-time analyses based on the best available high-resolution historical satellite SST data.
    - **Status:** Ongoing development at CRW.

Existing gaps: NOAA/NESDIS is currently testing and validating its newest physical retrieval of SST data and the nighttime-only products. Additionally, work is needed to develop corrections for diurnal temperature variation in the GOES/POES Blended Product, and to possibly develop microwave to help during long periods of cloudiness. These gaps (except microwave) are presently being addressed at STAR with plans to complete this effort by 2014.

Resources needed to address near-term vision: Work is presently underway at STAR and improvements are estimated to be made within the next 4 years.

Key partners: NESDIS Office of Satellite and Product Operations (OSPO), National Weather Service (NWS), Joint Center for Satellite Data Assimilation (JCSDA).

Coral Program Goals & Objectives addressed:

- Climate Impacts Goal 1; Objectives 1.3 & 1.5
- Climate Impacts Goal 2; Objectives 2.1, 2.2, 2.4 & 2.5
- Climate Impacts Goal 3; Objective 3.2
- Fishing Impacts Goal 2; Objectives 2.1 & 2.3
- LBSP Impacts Goal 3; Objective 3.5

Objectives of NOAA Next Generation Strategic Plan (NGSP) Addresses:

- Climate Adaptation and Mitigation Goal: Improved Understanding Objective
- Oceans Goal: Improved Understanding Objective (ex. current conditions, forecasts)

Appendix E. Geostationary Operational Environmental Satellite (GOES) Insolation One-pager

Lead staff: Istvan Laszlo, NESDIS/STAR/SMCD/EMB, Environmental Monitoring Branch and University of Maryland at College Park

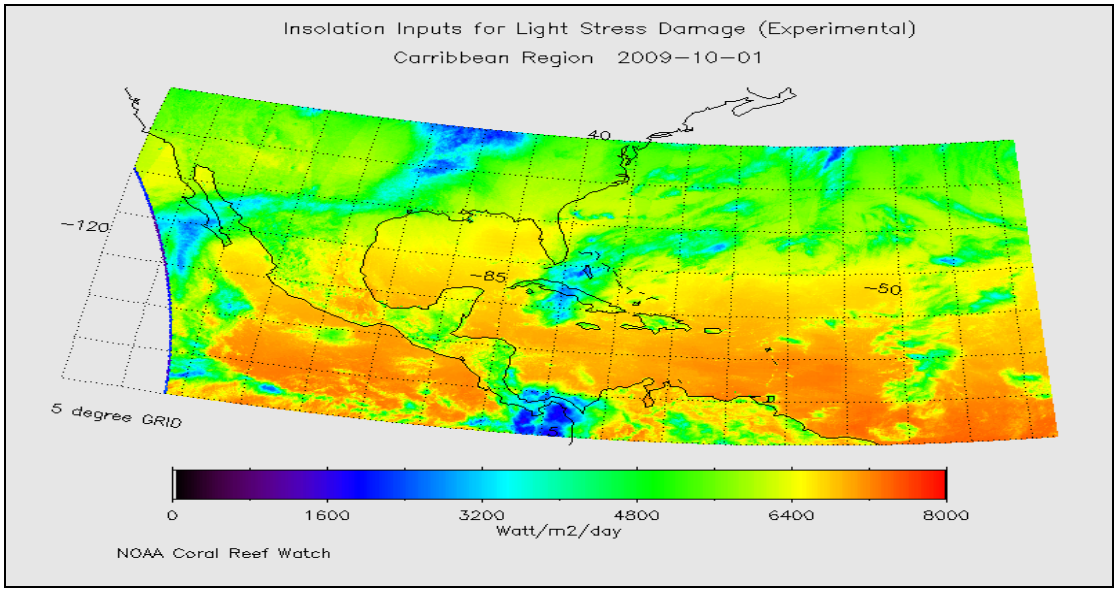


Figure 6: October 1st, 2009 image displaying insolation inputs (shortwave downward surface flux) in the Caribbean region for Light Stress Damage (experimental) in Watt/m²/day.

What is the product development area: Satellite-derived insolation measures the solar radiation energy received on the earth's surface (land or water). Insolation data are presently available from two GOES satellites. GOES satellites orbit high above the Earth, fixed directly over a spot on the Earth's equator. Using GOES we are able to get 10-50 "snapshots" per day, depending on the satellite and the location of the measurements. GOES insolation products can be used in a wide range of applications since light is a fundamentally important environmental variable for marine ecosystems.

Near-term vision: The near-term goal for GOES insolation coral reef related products is to further develop the experimental Light Stress Damage (LSD) algorithm's capabilities to provide near-real-time predictions not only of coral bleaching onset and severity, but also recovery and resultant mortality.

How can the product be used for corals: Of interest to coral reef managers are the quantities of solar radiation being received by the waters proximate to coral reefs such as photosynthetically active radiation (PAR). Light energy is one component of insolation and is the basis for photosynthetic activity occurring in a healthy coral's symbiotic algae-zooxanthellae. An example of the use of light is the new experimental LSD product, presently under development by NOAA/Coral Reef Watch (CRW). This product uses an understanding of coral physiology and the effects of light and temperature from satellite data on the coral photosystem to derive a prediction of photosystem health on a daily basis throughout the year. Among other things, this product should improve our ability to predict not only the onset and severity from coral bleaching, but also recovery. It is also likely to provide an improved prediction of mortality as a result of a coral bleaching event. This is all due to the improved predictive ability of thermal stress when combined with a measure of light stress derived from the GOES light products.

Customers: NOAA/Coral Reef Conservation Program (Coral Program), federal, state and local coral reef managers, scientists, educators, and the public.

Current products and planned advances:

- **Light Stress Damage (LSD) product:** The LSD product is the first remote sensing product to use both satellite-derived light and temperature data to predict coral stress that leads to bleaching. The methodology uniquely expresses both thermal stress and excess-light stress as an equivalent light stress value, allowing the light and temperature data to be combined in a single product of stress on the coral photosystem, called the Light Stress Damage (LSD) product. Insolation data is received from the GOES Surface and Insolation Product (GSIP)-full disk (fd) satellite platform. Data from two GOES satellites covering most of the western hemisphere are blended to produce a14 km resolution diurnal dataset every three hours for the GOES full disks (fd) and every hour for the GOES northern hemisphere sub-set.
    - **Status:** NESDIS/STAR experimental product for the Caribbean region

- **Planned advances:** PAR data in addition to a broader spectrum of radiation data (infrared and ultraviolet) will be collected using the Advanced Baseline Imager (ABI) sensor on the GOES-R series satellites which are under development and projected to be launched in 2015. Data will become available after satellite activation. STAR has requested funding to develop a future 4 km, hourly resolution daytime PAR dataset produced every hour with complete ocean coverage but conversion to operational status is conditional upon NESDIS and STAR funding availability.

Existing gaps: A present gap in GOES insolation measurements is the lack of an ability to properly validate the LSD product due to a mismatch between the geometry and scale of satellite instruments and ground-based sensors. This factor combined with a lack of onboard calibration for the current GOES imager instruments may lead to the degraded accuracy of the product.

Resources needed to achieve near-term vision: Work is presently underway at NOAA/STAR and Reef Sense (CRW-Australia) and products are estimated to become available within the next 5 years.

Key partners: University of Maryland, Cooperative Institute for Meteorological Satellite Studies at Madison, Wisconsin, NOAA/Coral Reef Watch program, NOAA/National Weather Service, Environmental Modeling Center, European Space Agency (ESA), National Space Development Agency of Japan (NASDA) and Australian Bureau of Meteorology (ABM).

Coral Program Goals & Objectives addressed:

- Climate Impacts Goal 1; Objectives 1.3 & 1.5
- Climate Impacts Goal 2; Objectives 2.1, 2.2, 2.4 & 2.5
- Climate Impacts Goal 3; Objective 3.2
- Fishing Impacts Goal 2; Objectives 2.1 & 2.3

Objectives of NGSP Addresses:

- Oceans Goal: Improved Understanding Objective (ex. current conditions, forecasts)
- Coastal Goal: Resilient Coastal Communities (Early Warning Systems)

Appendix F. Ocean Acidification One-pager

Lead staff: Dwight Gledhill, NOAA/OAR, Ocean Acidification Program

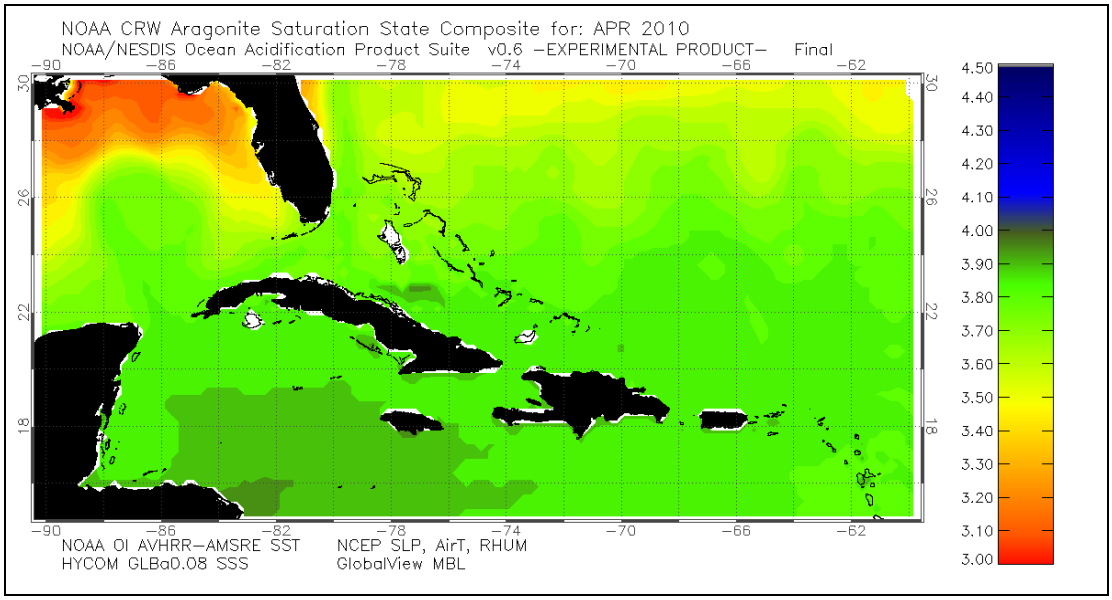


Figure 7: Carbonate mineral saturation state map for the Greater Caribbean Region- April, 2010.

What is the product development area: Ocean acidification is the process by which increases in atmospheric CO_2 have resulted in increased CO_2 concentration and reduced pH in the ocean. Although surface ocean acidification cannot be directly measured via remote sensing, the dynamics of surface ocean carbonate chemistry can be modeled using other environmental parameters including satellite-observed sea surface temperature, wind speed, and atmospheric chemistry, along with modeled salinity. Sea surface temperature and atmospheric CO_2 are remotely sensed by NOAA & NASA satellites and then assimilated with *in situ* measures of surface air pressure, air temperature, and ocean salinity values to model the affects ocean acidification on surface ocean chemistry. Satellite-observed salinity (available in 2012) may be included in the future.

Near-term vision: The near-term vision for the ocean acidification product suite is to provide ocean acidification products for all coral reef regions globally.

How can the products be used for corals: Changes in ocean chemistry may impact a broad range of marine species including reef building organisms through effects on coral growth rates, bioerosion and even larval survivability and recruitment. The product suite provides estimates of changing ocean chemistry on a broader spatial and temporal scale than shipboard observations alone can permit. Presently the experimental product suite is best suited for monitoring regional changes in ocean acidification over decadal timescales using monthly means of surface ocean carbonate chemistry. By measuring the change in ocean surface carbonate chemistry over time, assimilated ocean acidification data from the product suite can be used to inform long-term strategic management decisions and efforts. Tracking regional trends in ocean acidification are a necessary prerequisite to interpreting changes observed in local reef carbonate chemistry. The data is currently applied as part of a 'Data in the Classroom' educational outreach tool helping to educate students about the topic of ocean acidification.

Customers: The research community; education institutions; policy makers. Eventual adoption by NOAA/Coral Reef Conservation Program (Coral Program), federal, state and local coral reef managers.

Current products and planned advances:

- **Ocean Acidification Product Suite:** This experimental product suite provides a 25 km resolution monthly estimate of sea surface carbonate chemistry for the Greater Caribbean Region. The suite of ocean acidification products provide spatial and temporal data on the following ocean acidification related variables: Aragonite Saturation State (Ω arag); Surface Water CO_2 Partial Pressure ($pCO_{2,sw}$) (µatm); Total Alkalinity (µmol/kg); Total CO_2 (µmol/kg); Carbonate Ion (µmol/kg); Bicarbonate Ion (µmol/kg).
    - **Status:** NOAA/AOML Experimental OA Product Suite for Coral Reef Watch (CRW) is updated monthly using data since 1988 for the Caribbean region.

- **Planned advances:** While this is currently only available for the Caribbean region, NOAA would like to expand the coverage to include all global coral reef regions. This is conditional upon receiving *in situ* data from the areas into which the product would expand.

Existing gaps: Presently the product suite is limited geographically by the extent of *in situ* measurements in the Greater Caribbean Region and is itself dependent on multiple external datasets (e.g., atmospheric CO_2, HYCOM salinity) which themselves are non-operational. The assimilated datasets that compose the ocean acidification product suite are produced on different timescales and contribute to an inherent delay in the release of updates to the ocean acidification data product suite. The assimilated data set is vulnerable to interruption when one or more of its assimilated products go offline. Additionally, the algorithm used in the product suite does not explicitly account for biological perturbations such as algal blooms fueled by nutrient rich riverine inputs and vertical entrainment without assimilated ocean color data. Algal blooms draw down CO_2 levels from the water to fuel growth and reproduction while vertical water exchange can either enhance acidification through high CO_2 subsurface waters or counteract it in some instances where subsurface waters can exhibit elevated alkalinity concentrations (e.g. central Gulf of Mexico). Lastly, due to the complexity of coastal and riverine interactions and their influence on ocean water chemistry, near shore data is excluded from within ~25 km of the coast.

Resources needed to address near-term vision: The main limitation keeping the OA product suite from being extended to a global scale is the lack of *in situ* calibration data needed from each area of expansion. Once appropriate *in situ* data becomes available, 1 FTE/year would be required, with OAR oversight, to expand the product suite within an estimated 2-5 years.

Key partners: NOAA/ Coral Program; NOAA/Atlantic Oceanographic & Meteorological Laboratory (AOML); NOAA/CRW; *National Aeronautics and Space Administration* (NASA); Texas A&M; University of New Hampshire; Hybrid Coordinate Ocean Model (HYCOM).

Coral Program Goals & Objectives addressed:

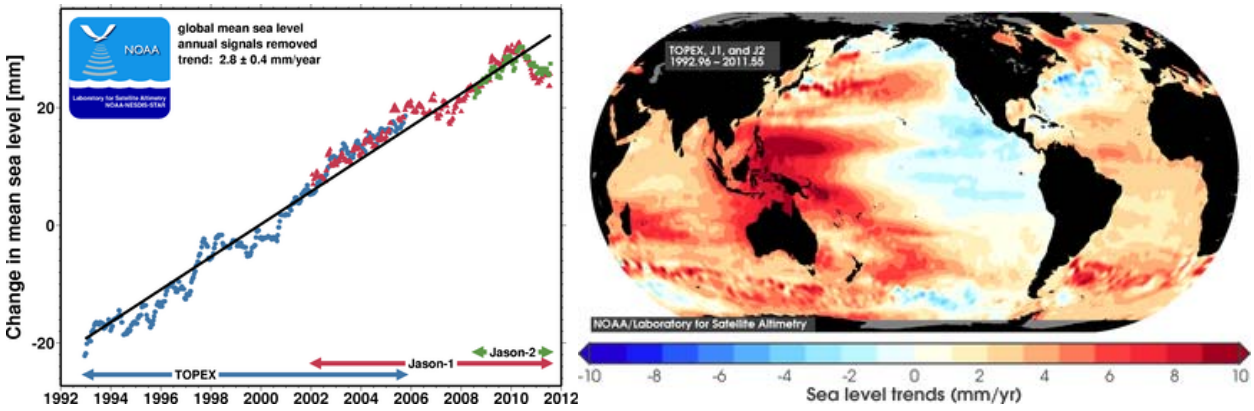
- Climate Change Impacts Goal 1; Objective 1.5
- Climate Change Impacts Goal 2; Objectives 2.1, 2.2, 2.4 & 2.5
- Climate Change Impacts Goal 3; Objective 3.5
- Fishing Impacts Goal 2; Objectives 2.1 & 2.3
- LBSP Impacts Goal 3; Objective 3.5

Objectives of NOAA Next Generation Strategic Plan (NGSP) Addresses:

- Climate Adaptation and Mitigation Goal: Improved Understanding Objective
- Oceans Goal: Improved Understanding Objective (ex. current conditions, forecasts)

Appendix G. Satellite Altimetry One-pager

Lead staff: Laury Miller, NOAA/NESDIS/STAR/SOCD/LSA, Laboratory for Satellite Altimetry



Figures 8&9: (Left) Change in global mean sea-level (mm) from 1992-2011; (Right) regional sea-level trends (±mm/yr) from 1992-2011.

What is the product development area: Satellite altimetry uses microwave radar to measure sea-surface height, a reflection of what is occurring over the entire water column, as well as significant wave height and wind speed. Data from three satellites (Jason-1, Jason-2, and Envisat) are merged to produce global sea surface height maps every 10 days. Satellite altimetry accurately measures cm-scale differences in sea-surface height that are validated against *in situ* measurements collected by tide gauges around the globe.

Near-term vision: To enhance both the resolution and spatial coverage of an individual altimeter sensor to produce coastally-optimized data sets from satellite altimetry measurements, more ideal for coral mangers.

How can the products be used for corals: Satellite altimetry measurements could be employed to investigate variables that influence coral reef health such as local changes in sea level caused by El Niños/La Niñas and long-term and intermediate-term climate variability. Short-term tropical storm events generate both positive and negative anomalies in sea-surface and significant wave height. These anomalies impact the health of both coral reef ecosystem and coastal communities. Similar to coral reef bleaching alerts, satellite altimetry data could be used to produce local sea-level rise/storm surge/significant wave height advisories to coral managers via hydrodynamic models. While global satellite altimetry data show a 3mm/yr global mean sea-level rise, regional sea-level variations are much larger and their measurements could play an important role in understanding coral resilience.

Customers: NOAA/Coral Reef Conservation Program (Coral Program), federal, state and local coral reef managers, NOAA/National Weather Service (NWS) scientists, educators, and the general public.

Current products and planned advances:

- **Short-term Timescales:** Significant wave height and storm surge anomalies can be measured accurately within a few centimeters by satellite altimetry. Operational Geophysical Data Records (OGDRs), a near real-time product, are issued 3 hours after acquisition with 15 km resolution sampling from 1992 to the present only for significant wave height currently.
    - **Status:** CNES Jason-1 Operational Product; NESDIS and EUMETSAT Jason-2 Operational Product

- **Intermediate Timescales:** Global and regional sea-level altimetry measurements are interpreted in timescales from 10 days up to several months to detect variations in sea-surface height. Interim Geophysical Data Records (IGDRs), a provisional research-grade product, are issued 1 to 2 days after acquisition with 15 km resolution sampling from 1992 to the present.
    - **Status:** CNES Jason-1 & -2 Operational Product; ESA Envisat Operational Product

- **Long-term Timescales:** Global and regional sea-level altimetry measurements are interpreted over inter-annual and inter-decadal timescales, revealing multi-decadal and even multi-century trends in sea-surface height when combined with historical tide gauge data. Geophysical Data Records (GDRs), the final science data product, are issued 1 to 2 months after acquisition with 15 km resolution sampling from 1992 to the present.
    - **Status:** CNES Jason-1 &-2 Operational Product; ESA Envisat Operational Product.

- **Planned Advances:** Future satellites aim to employ technology that will increase sampling resolution and spatial coverage to aid the creation of coastally-optimized data sets. These technologies will allow a single satellite (rather than three satellites) to produce a high resolution global image every 10 days. When used in combination with OSVW data in the ocean surface current analysis-real time (OSCAR) model, satellite altimeter data could assist in providing near real time ocean surface current information to useful for investigating larval drift and oil spill transport. Future coral specific satellite altimetry products utilizing significant wave height data from a synthetic aperture altimeter could be used to produce a mechanical damage product for coral reefs.

Existing gaps: Satellite radar altimeters are flown on polar orbiting satellites. Currently these instruments are capable of making only single measurement every 7 km along a track directly below the satellite, unlike other satellite sensors that can record swaths or entire fields of data at any given instant. Therefore the measurements from altimeters on three or more working satellites are needed for adequate global coverage. Water vapor and land interference presently inhibit satellite altimetry sensors from collecting useful data within 10 km of the coast.

Resources needed to address near-term vision: A first step towards creating coastally-optimized satellite altimetry products would be to attend the annual Coastal Altimetry Workshop held in conjunction with the Ocean Surface Topography Science Team (OSTST) annual meeting. A NOAA Coral Program representative could present coral specific satellite altimetry needs to the research community, making in-roads toward a collaborative product development effort. Thereafter, assuming the development and launch of new technology, 1 FTE/year would be needed to develop the satellite altimetry products over the period of 5+ years.

Key partners: National Weather Service (NWS), National Aeronautics & Space Administration (NASA), European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), Centre National d'Etudes Spatiales (CNES), and the European Space Agency (ESA).

Coral Program Goals & Objectives addressed:

- Climate Impacts Goal 1; Objective 1.5
- Climate Impacts Goal 2; Objectives 2.1, 2.2, 2.4 & 2.5

Objectives of NOAA Next Generation Strategic Plan (NGSP) Addresses:

- Climate Adaptation and Mitigation Goal: Improved Understanding Objective
- Weather Ready Nation: Reduced Loss and Disruption Objective
- Oceans Goal: Improved Understanding Objective (ex. current conditions, forecasts)
- Resilient Coastal Communities and Economies Goal: Comprehensive Planning Objective

Appendix H-1. Correlation of NOAA remote sensing product development areas to American Samoa Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management.

American Samoa Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 1: To maintain and, where necessary, improve the status of fish stocks through protection and sustainable use.		
Objective 1.2: To promote and facilitate the development of a network of no-take Marine Protected Areas (MPAs) to assist the territory in efforts to meet the 20% goal, in addition to continuing the development and incorporation of other MPAs, some of which may be designated for purposes other than improving the status of fish stocks (e.g. resource protection) into a wider network to ensure the long-term sustainability of the region's coral reef resources.	**Fishing Impacts Objective 2.1:** Identify, characterize and rank priority areas for protection within each jurisdiction, including (but not limited to): • Spawning sites, nursery habitats, or other areas critical to particular life-history stages • Biodiversity hotspots • Areas with greatest resilience or potential for restoring resilience • Areas facing the greatest threats ***Climate Impacts Objective 2.4:** Promote conservation of coral reef ecosystems through identification of areas that are potentially resilient to climate change and vulnerable areas where actions are likely to increase resilience. Encourage and promote management actions necessary to avoid or minimize impacts and spread the risk due to climate change and ocean acidification.	• **Ocean Color:** Detect areas of consistently high chlorophyll concentration to target for protection; Track LBSPs to detect effects on MPAs. • [+]**SAR:** Detect wind speed & direction to assist with issues of larval and LBSP connectivity; Possible detection of large-scale spawning events. • [+]**OSVW:** Detect prevailing ocean surface currents that influence biological connectivity, larval transport, and LBSP transport. • [#]**Sea Surface Temperature (SST) Improvements:** Bleaching events predicted by SST products can proactively trigger response plans. Assist identification of areas resilient to bleaching. • [#]**GOES Insolation:** Model coral photosystem health and assess potential coral polyp mortality as a part of an improved SST Product Suite. • [#]**Ocean Acidification (OA):** Monitoring regional changes in ocean acidification over decadal timescales.

** American Samoa has correlated American Samoa Priority Goal 1; Objective 1.2 to Coral Program Fishing Impacts Objectives 2.1-2.5. Fishing Impacts Objectives 2.2-2.5 have been removed from the analysis due to their lack of remote sensing correlation in this context. However, we feel that Coral Program Climate Impacts Objectives 2.4 is also an appropriate correlation for American Samoa Priority Goal 1; Objective 1.2. Therefore, Coral Program Fishing Impacts Objective 2.1 is correlated to Ocean Color, SAR, OSVW, SST Improvements, GOES Insolation and Ocean Acidification. Coral Program Climate Impacts Objective 2.4 is correlated to SAR, OSVW, SST Improvement, GOES Insolation, and Ocean Acidification.*

[+]*Winds may play a role in the cooling of SSTs and therefore increase reef resilience.*

[#]*Changes in temperature (SST) and pH (OA) can affect reef organisms during certain life stages as well as affect overall reef health and resiliency.*

Table 1. Correlation of NOAA remote sensing product development areas to American Samoa Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

American Samoa Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 2: Improve coastal watershed quality and enhance coral reef ecosystem function and health by reducing land-based sources of pollution.		
Objective 2.1: Improve our understanding of the links between land-based sources of pollution and coral reef health through focused scientific research and monitoring so that site-specific actions and practices can be developed and implemented.	**LBSP Impacts Objective 1.4:** Promote an integrated effort to fill strategic science gaps that directly inform management decisions related to planning and implementation activities in priority coral reef ecosystems and associated watersheds.	• **Ocean Color:** Track LBSPs to detect possible effects on corals. • **SAR:** Detect wind speed & direction to assist with issues of larval and LBSP connectivity; Possible detection of large-scale spawning events. • **OSVW:** Detect prevailing ocean surface currents that influence biological connectivity, larval transport, and LBSP transport.
Objective 2.3: Reduce nutrient and bacterial loading to surface and groundwater.	**LBSP Impacts Objective 1.1:** Identify and prioritize those coral reef ecosystems and associated watersheds, within each jurisdiction, that will benefit the most from implementing management conservation strategies to reduce land-based sources of pollution. **LBSP Impacts Objective 1.4:** Promote an integrated effort to fill strategic science gaps that directly inform management decisions related to planning and implementing activities in priority coral reef ecosystems and associated watersheds.	• **Ocean Color:** Track LBSPs to determine point sources of pollution.

Table 1. Correlation of NOAA remote sensing product development areas to American Samoa Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

American Samoa Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 2: Improve coastal watershed quality and enhance coral reef ecosystem function and health by reducing land-based sources of pollution.		
Objective 2.3: *Continued from above*	**LBSP Impacts Objective 1.5:** Determine the efficacy of management activities through coordinated baseline and performance monitoring to assess progress and adapt management actions as needed. ***LBSP Impacts Objective 2.1:** Identify and prioritize coral reef ecosystems from those prioritized under Objective 1.1 where in-water management activities are needed to promote reef recovery.	*Continued from above*

**American Samoa also correlated American Samoa Priority Goal 2; Objective 2.3 to Coral Program LBSP Impacts Objectives 1.2 & 1.3. They have been removed from the analysis due to their lack of remote sensing correlation in this context. However, we feel that LBSP Impacts Objective 2.1 is also an appropriate correlation for American Samoa Priority Goal 2; Objective 2.3.*

Table 1. Correlation of NOAA remote sensing product development areas to American Samoa Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

American Samoa Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 3: Plan for and mitigate the effects of global climate change – including changes in sea temperature, ocean acidification and sea level rise.		
Objective 3.1: Increase research and monitoring to identify, implement and support management strategies for reducing climate change and its impacts.	**Climate Impacts Objective 1.5:** In collaboration with reef managers, develop, test and apply the best available science to provide new and innovative tools to help managers prepare and respond to climate change and ocean acidification related impacts. **Climate Impacts Objective 2.1:** Characterize the physical and chemical changes in coral reef environments by enhancing question-based monitoring to fill gaps in our current observations. This both establishes a baseline to assess climate change impacts on coral reef ecosystems and reveals changes through time. ***Climate Impacts Objective 2.5:** Provide and communicate regular national comprehensive risk assessments regarding the threat of climate change and ocean acidification to coral reefs and dependent human communities Through relevant, existing reports such as local, national, and global reef status reports and IPCC assessments.	• **Sea Surface Temperature (SST) Improvements:** Bleaching events predicted by SST products can proactively trigger response plans. Assist identification of areas resilient to bleaching. • **GOES Insolation:** Model coral photosystem health and assess potential coral polyp mortality as a part of an improved SST Product Suite. • **Ocean Acidification:** Monitoring regional changes in ocean acidification over decadal timescales. • **Satellite Altimetry:** Local sea-level rise/storm surge/significant wave height advisories for coral managers.
Goal 4: None Applicable		

**American Samoa has correlated American Samoa Priority Goal 3; Objective 3.1 to Coral Program Climate Impacts Objectives 1.5, 2.1, 2.2 & 4.1. Climate Impacts Objectives 2.2 & 4.1 have been removed from the analysis due to a lack of remote sensing correlation in this context. We feel that Coral Program Climate Impacts Objective 2.5 is also an appropriate correlation for American Samoa Priority Goal 3; Objective 3.1 as it contributes to national and international climate change assessments.*

Table 2. Correlation of NOAA remote sensing product development areas to CNMI Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management.

CNMI Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 1: Improve the condition of CNMI's coral reef ecosystems by reducing the amount of sediment, nutrients and other land-based sources of pollution in CNMI's watersheds.		
Objective 1.1: Implement LaoLao CAP[3] as a model approach to site-based planning and management by 2013 (end of ARRA road improvement project in LaoLao Bay)	**LBSP Impacts Objective 1.3:** Implement watershed management plans and relevant LAS within priority coral reef ecosystems and associated watersheds to improve water quality and enhance coral reef ecosystem resilience. Where needed, develop (or update) watershed management plans that incorporate coral reef protection measures.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals.
Objective 1.2: Develop and begin implementing a CAP or comprehensive watershed management plan in Garapan (defined as American Memorial Park to Garapan Fishing Base) by 2015 to improve water quality and condition of adjacent coral reefs.	**LBSP Impacts Objective 1.3:** Implement watershed management plans and relevant LAS within priority coral reef ecosystems and associated watersheds to improve water quality and enhance coral reef ecosystem resilience. Where needed, develop (or update) watershed management plans that incorporate coral reef protection measures.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals.
Objective 1.3: Develop and begin to implement a CAP or comprehensive watershed management plan for a key watershed in Rota to improve water quality and condition of adjacent coral reefs.	**LBSP Impacts Objective 1.3:** Implement watershed management plans and relevant LAS within priority coral reef ecosystems and associated watersheds to improve water quality and enhance coral reef ecosystem resilience. Where needed, develop (or update) watershed management plans that incorporate coral reef protection measures.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals.
Goal 2: None Applicable		
Goal 3: None Applicable		

[3] CAPs are site-based plans that address watershed management and other issues and identify specific actions at the local level to reduce threats to resources.

Table 2. Correlation of NOAA remote sensing product development areas to CNMI Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

CNMI Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 4: Monitor the short and long-term impacts of global climate change as part of a longer-term adaptation strategy.		
Objective 4.1: Create and build capacity to implement a response plan by 2012 to quantify and characterize bleaching events, building on recommendations from NOAA climate-change workshop held in Guam, September 2009.	**Climate Impacts Objective 1.3:** Develop and implement climate-related crisis response plans in all U.S. coral reef jurisdictions to provide a framework for early warning, communication, monitoring, research and management response to protect coral reef ecosystems from acute events such as coral bleaching, infectious disease outbreaks, tropical storm impacts and major rainfall events. ***Climate Impacts Objective 2.1:** Characterize physical and chemical changes in coral reef environments by enhancing question-based monitoring to fill gaps in our current observations. This both establishes a baseline to assess climate change impacts on coral reef ecosystems and reveals changes through time. ***Climate Impacts Objective 2.2:** Characterize the responses of coral reef ecosystems and their related components to climate change and ocean acidification to separate impacts from climate change and ocean acidification from impacts of other environmental threats and to test the effectiveness of management actions. ***Climate Impacts Objective 2.5:** Provide and communicate regular national comprehensive risk assessments regarding the threat of climate change and ocean acidification to coral reefs and dependent human communities Through relevant, existing reports such as local, national, and global reef status reports and IPCC assessments.	• **Sea Surface Temperature (SST) Improvements:** Bleaching events predicted by SST products can proactively trigger response plans. Assist identification of areas resilient to bleaching. • **GOES Insolation:** Model coral photosystem health and assess potential coral polyp mortality as a part of an improved SST Product Suite.

**While CNMI has correlated CNMI Priority Goal 4; Objective 4.1 to Coral Program Climate Impacts Goal 1; Objective 1.3, we feel that Coral Program Climate Impacts Goal 2; Objectives 2.1, 2.2 & 2.5 are also appropriate correlations for CNMI Priority Goal 4; Objective 4.1.*

Table 3. Correlation of NOAA remote sensing product development areas to Guam Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management.

Guam Priority Goals and Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 1: Improve the condition of coral reef ecosystems by reducing the amount of sediment and pollution from development, fires, recreational users and agriculture in Guam's watersheds.		
Objective 1.1: Implement CAPs for priority watersheds by 2015 as a model approach to site-based planning and management. (The Piti CAP includes activities to manage land-based sources of pollution and recreational impacts to reefs, increase awareness of the impacts to reefs, increase awareness of the impacts to reefs and fill gaps in knowledge through management-related research.)	**LBSP Impacts Objective 1.3:** Implement watershed management plans and relevant LAS within priority coral reef ecosystems and associated watersheds to improve water quality and enhance coral reef ecosystem resilience. Where needed, develop (or update) watershed management plans that incorporate coral reef protection measures.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals. These can be shown on images created from ocean color products.
Objective 1.3: Educate target stakeholder groups about the sedimentation issues associated with specific watershed uses and activities.	**LBSP Impacts Objective 3.5:** Increase public and political awareness and understanding of the ecological and socioeconomic impacts of land-based sources of pollution on coral reef resources to promote better stewardship and informed decisions regarding activities in watersheds that may adversely impact coral reef ecosystems.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals. These can be shown on images created from ocean color products.
Goal 2: None Applicable		
Goal 3: None Applicable		
Goal 4: None Applicable		

Table 3. Correlation of NOAA remote sensing product development areas to Guam Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

Guam Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 5: Improve management of Guam's coral reef ecosystems to enhance resilience and recovery processes.		
Objective 5.1: Establish and prepare response teams to address bleaching events, disease and predator outbreaks and other acute events (e.g. ship groundings, chemical spills).	**Climate Impacts Objective 1.3:** Develop and implement climate-related crisis response plans in all U.S. coral reef jurisdictions to provide a framework for early warning, communication, monitoring, research and management response to protect coral reef ecosystems from acute events such as coral bleaching, infectious disease outbreaks, tropical storm impacts and major rainfall events. ***LBSP Impacts Objective 1.4:** Promote an integrated effort to fill strategic science gaps that directly inform management decisions related to planning and implementation activities in priority coral reef ecosystems and associated watersheds.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals. These can be shown on images created from ocean color products. • **SAR:** Detect wind speed & direction anticipate oil/chemical spill movement. Detect grounded ships on reefs. • **OSVW:** Detect prevailing ocean surface currents that influence oil/chemical transport. • **Sea Surface Temperature (SST) Improvements:** Bleaching events predicted by SST products can proactively trigger response plans. Assist identification of areas resilient to bleaching. • **GOES Insolation:** Model coral photosystem health and assess potential coral polyp mortality as a part of an improved SST Product Suite.

**While Guam has correlated Guam Priority Goal 5; Objective 5.1 to Coral Program Climate Impacts Objective 1.3, we feel that Coral Program LBSP Impacts Objective 1.4 is also an appropriate correlation for Guam Priority Goal 5; Objective 5.1. Therefore, Climate Impacts Objective 1.3 is correlated to SST Improvements and GOES Insolation. LBSP Impacts Objective 1.4 is correlated to Ocean Color, SAR, and OSVW.*

Table 4. Correlation of NOAA remote sensing product development areas to Hawai'i Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management.

Hawai'i Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 1: Coral reefs undamaged by pollution, invasive species, marine construction and marine debris.		
Objective 1: Reduce key anthropogenic threats to two priority nearshore coral reef sites by 2015 using ahupua'a-based management[4]. Two sites – Ka'anapali-Kahekili and Pelekane Bay – Puako-Anaeho'omalu Bay – were identified as 3-5 year priority areas for the program funding support. (Main Hawaiian Islands)	***LBSP Impacts Objective 1.3:** Implement watershed management plans and relevant Local Action Strategies (LAS) within priority coral reef ecosystems and associated watersheds to improve water quality and enhance coral reef ecosystem resilience. Where needed, develop (or update) watershed management plans that incorporate coral reef protection measures.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals. • #**SAR:** Detect wind speed & direction anticipate oil/chemical spill and LBSP movement. Detect grounded ships on reefs. • #**OSVW:** Detect prevailing ocean surface currents that influence oil/chemical and LBSP transport.
Objective 1.3: Derelict fishing gear will be removed from coral reef environments at or above the rate at which it is introduced, minimizing damage to coral reefs (Papahānaumokuākea Marine National Monument (PMNM)).	**None**	• **SAR**: Detection of derelict fishing gear (e.g. nets).

**Hawai'i also correlated Fishing Impacts Objective 2.4 to Hawai'i Priority Goal 1; Objective 1. However, this was removed from the analysis due to a lack of remote sensing correlation in this context.*
#SAR and OSVW speak to the transportation of LBSPs from source to reef ecosystems.

[4] Ahupua'a-based management is a traditional Hawai'ian land and sea tenure system in which local communities and resource systems were organized.

Table 4. Correlation of NOAA remote sensing product development areas to Hawai'i Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

Hawai'i Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 2: Productive and sustainable coral reef fisheries and habitat.		
Objective 2: Designate a sufficient area of marine waters under effective conservation by 2020 to ensure sustainable and resilient coral reef ecosystems. (Main Hawaiian Islands)	**Fishing Impacts Objective 2.1:** Identify, characterize and rank priority areas for protection within each jurisdiction, including (but not limited to): • Spawning sites, nursery habitats, or other areas critical to particular life-history stages • Biodiversity hotspots • Areas with greatest resilience or potential for restoring resilience • Areas facing the greatest threats **Fishing Impacts Objective 2.3:** Using outputs of Objective 2.1 and 2.2, appropriate models, and socioeconomic considerations, identify MPAs that require increased protections or improved management, and areas to be considered for siting of new MPAs that protect key coral reef ecosystem components and functions. ***Climate Impacts Objective 2.2:** Characterize the responses of coral reef ecosystems and their related components to climate change and ocean acidification to separate impacts from climate change and ocean acidification from impacts of other environmental threats and to test the effectiveness of management actions. ***Climate Impacts Objective 2.4:** Promote conservation of coral reef ecosystems through identification of areas that are potentially resilient to climate change and vulnerable areas where actions are likely to increase resilience. Encourage and promote management actions necessary to avoid or minimize impacts and spread the risk due to climate change and ocean acidification.	• **Ocean Color:** Detect areas of consistently high chlorophyll concentration to target for protection; Track LBSPs to detect effects on MPAs. • [+]**SAR:** Detect wind speed & direction to assist with issues of larval and LBSP connectivity; Possible detection of large-scale spawning events. • [+]**OSVW:** Detect prevailing ocean surface currents that influence biological connectivity, larval transport, and LBSP transport. • [#]**Sea Surface Temperature (SST) Improvements:** Bleaching events predicted by SST products can proactively trigger response plans. Assist identification of areas resilient to bleaching. • **GOES Insolation:** Model coral photosystem health and assess potential coral polyp mortality as a part of an improved SST Product Suite. • [#]**Ocean Acidification (OA):** Monitoring regional changes in ocean acidification over decadal timescales.

Table 4. Correlation of NOAA remote sensing product development areas to Hawai'i Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

Hawai'i Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 2: Productive and sustainable coral reef fisheries and habitat (*continued from above*).		
Objective 2: *Continued from above*	***Climate Impacts Objective 2.5:** Provide and communicate regular national comprehensive risk assessments regarding the threat of climate change and ocean acidification to coral reefs and dependent human communities Through relevant, existing reports such as local, national, and global reef status reports and IPCC assessments. ***Climate Impacts Objective 3.2:** Through process studies and modeling, develop integrated impact models of changes in coral reef ecosystems in response to the physical and chemical processes associated with climate change and ocean acidification, and the interactions of these processes with local stressors.	*Continued from above*

**While Hawai'i has correlated Hawai'i Priority Goal 2; Objective 2 to Coral Program Fishing Impacts Objectives 2.1-2.5, Fishing Objectives 2.2 & 2.4-2.5 have been removed from the analysis due to a lack of remote sensing correlation in this context. We feel that Coral Program Climate Change Impacts Objectives 2.1, 2.4, 2.5 & 3.2 are also appropriate correlations for Hawai'i Priority Goal 2; Objective 2. Therefore, Fishing Impacts Objectives 2.1 & 2.3 are correlated to Ocean Color, SAR, OSVW, SST Improvements, GOES Insolation, and Ocean Acidification. Climate Change Impacts Objectives 2.2, 2.5 & 3.2 are correlated to SST Improvements, GOES Insolation and Ocean Acidification. Climate Change Impacts Objective 2.4 is correlated to SAR, OSVW, SST Improvements, GOES Insolation, and Ocean Acidification.*

[#]Changes in temperature (SST) and pH (OA) can affect reef organisms during certain life stages as well as affect overall reef health and resiliency.

[+]Winds may play a role in the cooling of SSTs and therefore increase reef resilience.

Table 4. Correlation of NOAA remote sensing product development areas to Hawai'i Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

Hawai'i Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 3: Coral reef ecosystems resilient to climate change, invasive species and marine disease.		
Objective 3.1: Establish a baseline and tracing of information over 10 years by which the PMNM can be used as a sentinel site for assessing impacts of climate change and ocean acidification in the Main Hawaiian Islands.	**Climate Impacts Objective 2.1:** Characterize the physical and chemical changes in coral reef environments by enhancing question-based monitoring to fill gaps in our current observations. This both establishes a baseline to assess climate change impacts on coral reef ecosystems and reveals changes through time. ***Climate Impacts Objective 2.5:** Provide and communicate regular national comprehensive risk assessments regarding the threat of climate change and ocean acidification to coral reefs and dependent human communities Through relevant, existing reports such as local, national, and global reef status reports and IPCC assessments.	• **Sea Surface Temperature (SST) Improvements:** SST climatologies inform the prediction of bleaching events. Assist identification of areas resilient to bleaching. • **GOES Insolation:** Model coral photosystem health and assess potential coral polyp mortality as a part of an improved SST Product Suite. • **Ocean Acidification:** Monitoring regional changes in ocean acidification over decadal timescales. • **Satellite Altimetry:** Long-term and intermediate term sea-level rise variation measurement.
Goal 4: None Applicable		

**While Hawai'i has correlated Hawai'i Priority Goal 2; Objective 2 to Coral Program Climate Impacts Objective 2.1, we feel that Coral Program Climate Impacts Objective 2.5 is also an appropriate correlation for Hawai'i Priority Goal 2; Objective 2 as it contributes to national and international climate change assessments.*

Table 5. Correlation of NOAA remote sensing product development areas to Florida Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management.

Florida Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal A1: Manage the Florida Reef Tract and Ecosystem using an ecosystem-based approach, including zoning/marine spatial planning and other appropriate tools.		
Objective 2: Develop and implement a comprehensive zoning plan for the entire Florida Reef Tract and Ecosystem and implement through placed-based entities and management plans within three to five years.	**Fishing Impacts Objective 2.1:** Identify, characterize and rank priority areas for protection within each jurisdiction, including (but not limited to): • Spawning sites, nursery habitats, or other areas critical to particular life-history stages • Biodiversity hotspots • Areas with greatest resilience or potential for restoring resilience • Areas facing the greatest threats ***Climate Impacts Objective 2.4:** Promote conservation of coral reef ecosystems through identification of areas that are potentially resilient to climate change and vulnerable areas where actions are likely to increase resilience. Encourage and promote management actions necessary to avoid or minimize impacts and spread the risk due to climate change and ocean acidification.	• **Ocean Color:** Detect areas of consistently high chlorophyll concentration to target for protection; Track LBSPs to detect effects on MPAs; Track harmful algal blooms. • [+]**SAR:** Detect wind speed & direction to assist with issues of larval and LBSP connectivity; Possible detection of large-scale spawning events. • [+]**OSVW:** Detect prevailing ocean surface currents that influence biological connectivity, larval transport, and LBSP transport. • [#]**Sea Surface Temperature (SST) Improvements:** Bleaching events predicted by SST products can proactively trigger response plans. Assist identification of areas resilient to bleaching. • [#]**GOES Insolation:** Model coral photosystem health and assess potential coral polyp mortality as a part of an improved SST Product Suite. • [#]**Ocean Acidification (OA):** Monitoring regional changes in ocean acidification over decadal timescales.

**While Florida has correlated Florida Priority Goal A1; Objective 2 to Coral Program Fishing Impacts Objective 2.1, we feel that Coral Program Climate Impacts Objective 2.4 is also an appropriate correlation for Florida Priority Goal A1; Objective 2. Therefore, Fishing Impacts Objective 2.1 is correlated to Ocean Color, SAR, OSVW, SST Improvements, GOES Insolation, and Ocean Acidification. Climate Impacts Objective 2.4 is correlated to SAR, OSVW, SST Improvements, GOES Insolation, and Ocean Acidification.*

[#]Changes in temperature (SST) and pH (OA) can affect reef organisms during certain life stages as well as affect overall reef health and resiliency.

[+]Winds may play a role in the cooling of SSTs and therefore increase reef resilience.

Table 5. Correlation of NOAA remote sensing product development areas to Florida Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

Florida Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal C1: Reduce pollutant loading to south Florida coastal waters.		
Objective 1: Minimize the impacts of reduced water quality associated with controlled freshwater deliveries and coastal construction activities on coastal, estuarine and lagoonal habitats (i.e., seagrass, oyster, mangrove, hardbottom and coral reef communities). Irregularly timed, high volume releases of freshwater into the marine and estuarine coastal systems can carry excessive nutrient and pollutant loads and are detrimental to coastal habitats and biota.	**LBSP Impacts Objective 1.3:** Implement watershed management plans and relevant LAS within priority coral reef ecosystems and associated watersheds to improve water quality and enhance coral reef ecosystem resilience. Where needed, develop (or update) watershed management plans that incorporate coral reef protection measures.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals.
Objective 2: Assess the impacts of pollutants known to affect corals and coral reef systems (concentration, interactive/synergistic effects of pollutants and physicochemical characters), including freshwater, nutrients, sedimentation, turbidity, heavy metals, pesticides and herbicides on the Florida Reef Tract and Ecosystem to inform management actions, policy decisions and outreach.	**LBSP Impacts 1.4:** Promote and integrated effort to fill strategic science gaps that directly inform management decisions related to planning and implementing activities in priority coral reef ecosystems and associated watersheds.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals.
Objective 3: Design and implement a long-term, spatially robust water-quality monitoring program for the southeast Florida coastal waters in order to determine sources of pollution and prioritize reduction efforts, as well as indicate successes of current pollution reduction efforts.	***LBSP Impacts Objective 1.5:** Determine the efficacy of management activities through coordinated baseline and performance monitoring to assess progress and adapt management actions as necessary.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals.

**While Florida also correlated Florida Priority Goal C1; Objective 3 to LBSP Impacts Objective 1.3, this was removed from the analysis due to a lack of remote sensing correlation.*

Table 5. Correlation of NOAA remote sensing product development areas to Florida Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

Florida Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal C2: None Applicable		
Goal C3: Educate the public and elected officials on the need to maintain coral reef habitats and coastal water quality. This includes opportunities for economic development in tourism and recreation.		
Objective 1: Develop an education program for elected officials to impress the need for the activities defined in this document as well as the environmental and socioeconomic value of southeast Florida's coral reefs and associated habitats. Emphasis shall be placed on the watershed concept and need for environmentally suitable flood control measures.	**LBSP Impacts Objective 3.5:** Increase public and political awareness and understanding of the ecological and socioeconomic impacts of land-based pollution on coral reef resources to promote better stewardship and informed decisions regarding activities in watersheds that may adversely impact coral reef ecosystems.	• **Ocean Color:** Track LBSPs to determine point sources of pollution from flood events and effects on corals. These can be shown on images created from ocean color products.
Objective 2: Use monitoring data to assess effectiveness of abatement measurements that can be easily and effectively communicated through outreach and education.	**LBSP Impacts Objective 1.5:** Determine the efficacy of management activities through coordinated baseline and performance monitoring to assess progress and adapt management actions as needed.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals. These can be shown on images created from ocean color products.
Goal D1: None Applicable		
Goal D2: None Applicable		
Goal D3: None Applicable		

Table 6. Correlation of NOAA remote sensing product development areas to Puerto Rico Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management.

Puerto Rico Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal A1: None Applicable		
Goal A2: Control and reduce pollutant transportation to the marine environment		
Objective A2.4: Establish water quality monitoring stations in coral reef ecosystem areas and add water quality monitoring components to establish coral monitoring sites around Puerto Rico. Establish standards in terms of what to monitor for and how to ensure comparability of data across locations. Use data regarding areas where water quality is an issue to enhance agency decision- making related to issuance of permits.	**LBSP Objective 1.4:** Promote and integrated effort to fill strategic science gaps that directly inform management decisions related to planning and implementing activities in priority coral reef ecosystems and associated watersheds. **LBSP Impacts Objective 1.5:** Determine the efficacy of management activities through coordinated baseline and performance monitoring to assess progress and adapt management actions as needed.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals. These can be shown on images created from ocean color products. • **SAR:** Detect wind speed & direction to assist with issues of larval and LBSP connectivity; Possible detection of large-scale spawning events. • **OSVW:** Detect prevailing ocean surface currents that influence biological connectivity, larval transport, and LBSP transport.
Goal A3: Strengthen enforcement and engage stakeholders through education to reduce pollutant transport to the coral reef ecosystem.		
Objective A3.1: Reduce erosion from any earth movement activities (e.g., development, home expansion, agriculture) through a mix of education and enforcement.	***LBSP Objective 3.5:** Increase public and political awareness and understanding of the ecological and socioeconomic impacts of land-based pollution on coral reef resources to promote better stewardship and informed decisions regarding activities in watersheds that may adversely impact coral reef ecosystems.	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals. These can be shown on images created from ocean color products.
Goal B1: None Applicable		
Goal B2: None Applicable		
Goal B3: None Applicable		
Goal C1: None Applicable		
Goal C2: None Applicable		

**While Puerto Rico also correlated Puerto Rico Priority Goal A3; Objective 3.1 to LBSP Impacts Objective 3.4, this was removed from the analysis due to a lack of remote sensing correlation.*

Table 7. Correlation of NOAA remote sensing product development areas to USVI Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management.

USVI Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 1: Reduce impacts to coral reef ecosystems by reducing terrestrial sediment and pollutant inputs and improving water quality.		
Objective 1.1: Define and identify priority watersheds and develop management plans that reduce the effects of contaminants and poor water quality on reef resources.	**LBSP Impacts Objective 1.1:** Identify and prioritize those coral reef ecosystems and associated watersheds, within each jurisdiction, that will benefit the most from implementing management conservation strategies to reduce land-based sources of pollution. ***LBSP Impacts Objective 2.1:** Identify and prioritize coral reef ecosystems from those prioritized under Objective 1.1 where in-water management activities are needed to promote reef recovery.	• **Ocean Color:** Track LBSPs to determine point sources of pollution; Help assess whether watershed management plans are actually improving reef water quality. • **SAR:** Detect wind speed & direction to assist with issues of larval and LBSP connectivity; Possible detection of large-scale spawning events. • **OSVW:** Detect prevailing ocean surface currents that influence biological connectivity, larval transport, and LBSP transport.

**While USVI correlated USVI Priority Goal 1; Objective 1.1 to Coral Program LBSP Objectives 1.1 & 1.3, LBSP Objective 1.3 was removed from the analysis due to lack of remote sensing correlation in this context. We feel that LBSP Impacts Objective 2.1 is also an appropriate correlation for USVI Priority Goal 1; Objective 1.1.*

Table 7. Correlation of NOAA remote sensing product development areas to USVI Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

USVI Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 2: Comprehensive education and outreach program to create buy-in and build public support for an effective coral reef conservation program that targets resource users, general public and decision-makers.		
Objective 2.1: Convey the importance and economic value of the reef to key constituencies and measure their understanding of the effect of human impacts, such as overfishing, pollution, etc., on this value.	***LBSP Impacts Objective 3.5:** Increase public and political awareness and understanding of the ecological and socioeconomic impacts of land-based pollution on coral reef resources to promote better stewardship and informed decisions regarding activities in watersheds that may adversely impact coral reef ecosystems.	• **Ocean Color:** LBSP is a human impact to the reef. Point sources of pollution and its effects on corals can be shown on images created from ocean color products. • **Sea Surface Temperature (SST) Improvements:** Bleaching events triggered by SST, increases in which are a human impact, can be shown on images created from SST products. • **Ocean Acidification:** Ocean acidification (OA) is a human impact to the reef. Increases in OA over decadal timescales can be shown on images created from ocean color products.
Goal 3: None Applicable		

**While USVI has correlated USVI Priority Goal 2; Objective 2.1 to Coral Program Fishing Impacts Objective 4.4, Climate Impacts Objective 2.3 and LBSP Impacts Objective 3.5, both Coral Program Fishing Impacts Objective 4.4 and Climate Impacts Objective 2.3 have been removed from the analysis due to a lack of remote sensing correlation in this context.*

Table 7. Correlation of NOAA remote sensing product development areas to USVI Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

USVI Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 4: Reduce fishing impacts on critical stocks that most directly affect the health and resilience of the reef ecosystem.		
Objective 4.11: Understand ecological connectivity through dispersal of eggs and larvae to identify key sources and sinks, assess connectivity between existing and potential MPAs and between spawning aggregations and juvenile habitat to identify resilient areas for protection.	**Fishing Impacts Objective 2.1:** Identify, characterize and rank priority areas for protection within each jurisdiction, including (but not limited to): • Spawning sites, nursery habitats, or other areas critical to particular life-history stages • Biodiversity hotspots • Areas with greatest resilience or potential for restoring resilience • Areas facing the greatest threats	• **SAR:** Detect wind speed & direction to assist with issues of larval connectivity; Possible detection of large-scale spawning events. • **OSVW:** Detect prevailing ocean surface currents that influence biological connectivity and larval transport. • [#]**Sea Surface Temperature (SST) Improvements:** Bleaching events predicted by SST products can proactively trigger response plans. Assist the identification of areas resilient to bleaching. • [#]**GOES Insolation:** Model coral photosystem health and assess potential coral polyp mortality as a part of an improved SST Product Suite. • [#]**Ocean Acidification (OA):** Monitoring regional changes in ocean acidification over decadal timescales.

[#]Changes in temperature (SST) and pH (OA) can affect reef organisms during certain life stages as well as affect overall reef health and resiliency.

Table 7. Correlation of NOAA remote sensing product development areas to USVI Priority Goals & Objectives for coral reef management and Coral Program National Goals & Objectives for coral reef ecosystem management (*continued*).

USVI Priority Goals & Objectives	Coral Program National Goals & Objectives for Coral Reef Conservation	NOAA Remote Sensing Product Development Areas
Goal 5: Manage for resilience to climate change and related effects, including impact of elevated sea temperature; sea level rise; acidification and calcium carbonate dissolution; hurricane intensity/frequency and sedimentation to promote recovery of reefs from previous events.		
Objective 5.1: Support more research on and better understanding of the following issues. These are priorities for USVI given this management goal and objectives: • Coral diseases (understanding of the holobiont and dynamics of the health gradient in the holobiont, etiology). • Relationship between bleaching and disease. • Coral resistance to bleaching and disease. • Cumulative effects of multiple stressors. • Resilience following global, regional and local stressors. • Possible effects of climate change on coral reefs and associated ecosystems. • Physiological tolerances and predicted shifts in species distributions. • Currents; distribution patterns and sources of stressors; distribution and sources of seed. • Thresholds for stressors (i.e., sediment, pollutants, temps, etc.) above which health/resiliency of holobiont becomes compromised. • Short-and long-term effects of stressors on coral reef ecosystem (as a whole and ecosystem function).	**Climate Impacts Objective 2.1:** Characterize the physical and chemical changes in coral reef environments by enhancing question-based monitoring to fill gaps in our current observations. This both establishes a baseline to assess climate change impacts on coral reef ecosystems and reveals changes through time. **Climate Impacts Objective 2.2:** Characterize coral reef ecosystems responses and their related components to climate change and ocean acidification to separate impacts from these from impacts of other environmental threats, and to test management action effectiveness. ***Climate Impacts Objective 2.4:** Promote conservation of coral reef ecosystems through identification of areas that are potentially resilient to climate change and vulnerable areas where actions are likely to increase resilience. Encourage and promote management actions necessary to avoid or minimize impacts and spread the risk due to climate change and ocean acidification. ***Climate Impacts Objective 2.5:** Provide/communicate regular national comprehensive risk assessments regarding climate change and ocean acidification threats to coral reefs and dependent human communities through relevant, existing reports (e.g., local, national, and global reef status reports and IPCC assessments).	• **Ocean Color:** Track LBSPs to determine point sources of pollution and detect effects on corals. • **SAR:** Detect wind speed & direction to assist with issues of larval and LBSP connectivity; Possible detection of large-scale spawning events. • **OSVW:** Detect prevailing ocean surface currents that influence biological connectivity, larval transport, and LBSP transport. • **Sea Surface Temperature (SST) Improvements:** SST climateologies inform the prediction of bleaching events. Assist the identification of areas resilient to bleaching. • **GOES Insolation:** Model coral photosystem health and assess potential coral polyp mortality. • **Ocean Acidification:** Monitoring regional changes in ocean acidification over decadal timescales. • **Satellite Altimetry:** Long-term and intermediate term sea-level rise variation measurement. Short-term local sea-level rise/storm surge/significant wave height advisories for coral managers.

**While USVI has correlated USVI Priority Goal 2; Objective 2 to Coral Program Climate Impacts Objective 2.1, we feel that Coral Program Climate Impacts Objectives 2.1, 2.4 & 2.5 are also an appropriate correlation for USVI Priority Goal 2; Objective 2. Therefore, Climate Change Objectives 2.1, 2.4 & 2.5 are correlated to SAR, OSVW, SST Improvements, GOES Insolation, Ocean Acidification, and Satellite Altimetry. Climate Change Objective 2.2 is correlated to Ocean Color, SAR, OSVW, SST Improvements, GOES Insolation, Ocean Acidification, and Satellite Altimetry.*

Appendix H-2. Number of jurisdiction-level priority goals and objectives addressable by each NOAA remote sensing product development area, grouped by threat category.

Table A. Climate Change Impacts

NOAA Product Development Area	**Climate Change Impacts - Goal 1**	**Climate Change Impacts - Goal 2**	**Climate Change Impacts - Goal 3**	**Climate Change Impacts - Goal 4**	**Number of Correlations per Product Development Area**
Ocean Color		2.2			**1**
Synthetic Aperture Radar (SAR)		2.1; 2.2; 2.4(4); 2.5			**7**
Ocean Surface Vector Winds (OSVW)		2.1; 2.2; 2.4(4); 2.5			**7**
Sea Surface Temperature (SST) Improvements [+]	1.3(2); 1.5	2.1(4); 2.2(3); 2.4(4); 2.5(5)	3.2		**20**
GOES Insolation[+]	1.3(2); 1.5	2.1(4); 2.2(3); 2.4(4); 2.5(5)	3.2		**20**
Ocean Acidification (OA)[#]	1.5	2.1(3); 2.2(2); 2.4(4); 2.5(4)	3.2		**15**
Satellite Altimetry	1.5	2.1(3); 2.2; 2.4; 2.5(3)			**9**

**If a listed Coral Program Objective is followed by a number in parentheses [ex. 2.4 (4)], the number indicates that Objective 2.4 appeared four times for the specific jurisdiction.*

[+] = NOAA/Coral Program supported product development area. [#] = NOAA/OAR supported product development area.

Appendix H2. Number of jurisdiction-level priority goals and objectives addressable by each NOAA remote sensing product development area, grouped by threat category (*continued*).

Table B. Fishing Impacts

NOAA Product Development Area	**Fishing Impacts - Goal 1**	**Fishing Impacts - Goal 2**	**Fishing Impacts - Goal 3**	**Fishing Impacts - Goal 4**	**Number of Correlations per Product Development Area**
Ocean Color		2.1(3); 2.3			**4**
Synthetic Aperture Radar (SAR)		2.1(4); 2.3			**5**
Ocean Surface Vector Winds (OSVW)		2.1(4); 2.3			**5**
Sea Surface Temperature (SST) Improvements[+]		2.1(4); 2.3			**5**
GOES Insolation[+]		2.1(4); 2.3			**5**
Ocean Acidification (OA)[#]		2.1(4); 2.3			**5**
Satellite Altimetry					**0**

** If a listed Coral Program Objective is followed by a number in parentheses [ex. 2.1 (3)], the number indicates that Objective 2.1 appeared three times for the specific jurisdiction.*

[+] = NOAA/Coral Program supported product development area. [#] =NOAA/ OAR supported product development area.

Appendix H2. Number of jurisdiction-level priority goals and objectives addressable by each NOAA remote sensing product development area, grouped by threat category (*continued*).

Table C. Land-based Sources of Pollution (LBSP) Impacts

NOAA Product Development Area	**LBSP Impacts - Goal 1**	**LBSP Impacts - Goal 2**	**LBSP Impacts - Goal 3**	**Number of Correlations per Product Development Area**
Ocean Color	1.1(2); 1.3(6); 1.4(5); 1.5(4)	2.1(2)	3.5(4)	**23**
Synthetic Aperture Radar (SAR)	1.1; 1.3; 1.4(3); 1.5	2.1		**7**
Ocean Surface Vector Winds (OSVW)	1.1; 1.3; 1.4(3); 1.5	2.1		**7**
Sea Surface Temperature (SST) Improvements[+]			3.5	**1**
GOES Insolation[+]				**0**
Ocean Acidification (OA)[#]			3.5	**1**
Satellite Altimetry				**0**

** If a listed Coral Program Objective is followed by a number in parentheses [ex. 1.1 (2)], the number indicates that Objective 1.1 appeared two times for the specific jurisdiction.*

[+] = NOAA/Coral Program supported product development area. [#] = NOAA/OAR supported product development area.

Appendix H2. Number of jurisdiction-level priority goals and objectives addressable by each NOAA remote sensing product development area, grouped by threat category (*continued*).

Table D. All NOAA remote sensing product development areas and Coral Program threat categories combined.

NOAA Product Development Area	Climate Change Impacts - Goal 1	Climate Change Impacts -Goal 2	Climate Change Impacts -Goal 3	Fishing Impacts - Goal 2	LBSP Impacts - Goal 1	LBSP Impacts - Goal 2	LBSP Impacts - Goal 3	Total
Ocean Color		2.2		2.1(3); 2.3	1.1(2); 1.3(6); 1.4(5); 1.5(4)	2.1(2)	3.5(4)	**28**
Synthetic Aperture Radar (SAR)		2.1; 2.2; 2.4(4); 2.5		2.1(4); 2.3	1.1; 1.3; 1.4(3); 1.5	2.1		***20**
Ocean Surface Vector Winds (OSVW)		2.1; 2.2; 2.4(4); 2.5		2.1(4); 2.3	1.1; 1.3; 1.4(3); 1.5	2.1		**19**
Sea Surface Temperature (SST)[+]	1.3(2); 1.5	2.1(4); 2.2(3); 2.4(4); 2.5(5)	3.2	2.1(4); 2.3			3.5	**26**
GOES Insolation[+]	1.3(2); 1.5	2.1(4); 2.2(3); 2.4(4); 2.5(5)	3.2	2.1(4); 2.3				**25**
Ocean Acidification (OA)[#]	1.5	2.1(3); 2.2(2); 2.4(4); 2.5(4)	3.2	2.1(4); 2.3			3.5	**21**
Satellite Altimetry	1.5	2.1(3); 2.2; 2.4; 2.5(3)						**9**
Total	**8**	**68**	**3**	**29**	**29**	**4**	**6**	*Intentionally Blank*

If a listed Coral Program Objective is followed by a number in parentheses [ex. 2.1 (3)], the number indicates that Objective 2.1 appeared three times for the specific jurisdiction.

***While Hawai'i Goal 1; Objective 1.3 held no correlation to the three national-level threats, SAR did match well with the Hawai'i Goal, therefore raising the total SAR tally from 19 to 20.*

[+] = NOAA/Coral Program supported product development area. [#] = NOAA/OAR supported product development area.

Appendix H2. Number of jurisdiction-level priority goals and objectives addressable by each NOAA remote sensing product development area, grouped by threat category (*continued*).

Table E. All NOAA remote sensing product development areas and Coral Program threat categories combined (*numbers only*).

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

***While Hawai'i Goal 1; Objective 1.3 held no correlation to the three national-level threats, SAR did match well with the Hawai'i Goal, therefore raising the total SAR tally from 19 to 20.*

[+] = NOAA/ Coral Program supported product development area. [#] = NOAA/OAR supported product development area.

Appendix H2. Number of jurisdiction-level priority goals and objectives addressable by each NOAA remote sensing product development area, grouped by threat category (*continued*).

Table F. Summary table of the number of national goals & objectives and jurisdiction-level objectives addressed within the seven jurisdictions (*totals only*) per NOAA product development area.

NOAA Product Development Area	**Number of National Goals Addressed**	**Number of National Objectives Addressed**	**Number of Jurisdiction-level Objectives Addressed**	**Within Number of Jurisdictions**	**Jurisdictions Without Correlations to Product Development Area**
Ocean Color	5	9	28	7	None
Synthetic Aperture Radar (SAR)	4	11	*20	6	CNMI
Ocean Surface Vector Winds (OSVW)	4	11	19	6	CNMI
Sea-Surface Temperature (SST) Improvements[+]	5	10	26	6	Puerto Rico
GOES Insolation[+]	4	9	25	6	Puerto Rico
Ocean Acidification (OA)[+#]	5	9	21	4	CNMI, Guam, Puerto Rico
Satellite Altimetry	2	5	9	3	CNMI, Guam, Florida, Puerto Rico

***While Hawai'i Goal 1; Objective 1.3 held no correlation to the three national-level threats, SAR did match well with the Hawai'i Goal, therefore raising the total SAR tally from 19 to 20.*

[+] = NOAA/ Coral Program supported product development area. [#] = NOAA/OAR supported product development area.

Appendix H-3. Alignment of jurisdictions with priority goals & objectives that correlate to Coral Program Goals & Objectives, grouped by threat category.

Table A. Climate Change Impacts

Jurisdictions	**Climate Change Impacts - Goal 1**	**Climate Change Impacts - Goal 2**	**Climate Change Impacts - Goal 3**	**Climate Change Impacts - Goal 4**
American Samoa	x	x		
CNMI	x	x		
Guam	x			
Hawaii		x	x	
Florida		x		
Puerto Rico				
USVI		x		
Number of Jurisdictions	**3**	**5**	**1**	**0**
Jurisdictions	**Climate Change Impacts Objective(s)**	**Climate Change Impacts Objective(s)**	**Climate Change Impacts Objective(s)**	**Climate Change Impacts Objective(s)**
American Samoa	1.5	2.1, 2.4, 2.5		
CNMI	1.3	2.1, 2.2, 2.5		
Guam	1.3			
Hawaii		2.1, 2.2, 2.4, 2.5(2)	3.2	
Florida		2.4		
Puerto Rico				
USVI		2.1, 2.2, 2.4, 2.5		

Appendix H-3. Alignment of jurisdictions with priority goals & objectives that correlate to Coral Program Goals & Objectives, grouped by threat category (*continued*).

Table B. Fishing Impacts

Jurisdictions	**Fishing Impacts - Goal 1**	**Fishing Impacts - Goal 2**	**Fishing Impacts - Goal 3**	**Fishing Impacts - Goal 4**
American Samoa		x		
CNMI				
Guam				
Hawaii		x		
Florida		x		
Puerto Rico				
USVI		x		
Number of Jurisdictions	**0**	**4**	**0**	**0**
Jurisdictions	**Fishing Impacts Objective(s)**	**Fishing Impacts Objective(s)**	**Fishing Impacts Objective(s)**	**Fishing Impacts Objective(s)**
American Samoa		2.1		
CNMI				
Guam				
Hawaii		2.1, 2.3		
Florida		2.1		
Puerto Rico				
USVI		2.1		

Appendix H-3. Alignment of jurisdictions with priority goals & objectives that correlate to Coral Program Goals & Objectives, grouped by threat category (*continued*).

Table C. Land-based Sources of Pollution (LBSP) Impacts

Jurisdictions	**LBSP Impacts - Goal 1**	**LBSP Impacts - Goal 2**	**LBSP Impacts - Goal 3**
American Samoa	x	x	
CNMI	x		
Guam	x		x
Hawaii	x		
Florida	x		x
Puerto Rico	x		x
USVI	x	x	x
Number of Jurisdictions	**7**	**2**	**4**
Jurisdictions	**LBSP Impacts Objective(s)**	**LBSP Impacts Objective(s)**	**LBSP Impacts Objective(s)**
American Samoa	1.1, 1.4(2), 1.5	2.1	
CNMI	1.3(3)		
Guam	1.3, 1.4		3.5
Hawaii	1.3		
Florida	1.3, 1.4, 1.5(2)		3.5
Puerto Rico	1.4, 1.5		3.5
USVI	1.1	2.1	3.5

Appendix I-1. Correlation table of NOAA remote sensing product development areas to Coral Program International Strategy Goals & Objectives.

Coral Program International Strategy 2010-2015 Goals & Objectives	NOAA Remote Sensing Product Development Areas
Priority Goal 1; Objective 1.5: Use regionally appropriate biophysical and socioeconomic monitoring and evaluation protocols to: a. Establish baselines and detect changes over time in an adaptive management framework; and b. Identify priority sites for conservation and assess community support for designation of new MPAs and MPA networks	• **Ocean Color** (e.g. chlorophyll concentration, HAB identification, LBSP tracking) • **SAR** (e.g. wind speed & direction; oil & spawning detection; vessel detection) • **OSVW** (e.g. currents, larval transport, connectivity) • **Sea Surface Temperature (SST) Improvements** (e.g. predict bleaching events; assist identification of areas resilient to bleaching) • **GOES Insolation** (e.g. model coral photosystem health as part of improved SST product suite) • **Ocean Acidification** (e.g. monitor regional changes in ocean acidification over decadal timescales) • **Satellite Altimetry (e**.g. sea level rise; storm surge and significant wave height measurement)
***Priority Goal 2; Objective 2.1:** Collaborate with global partners to broaden the international delivery of coral bleaching prediction and warning tools and improve the science and technology for predicting climate impacts on global coral reef ecosystems. **Priority Goal 2; Objective 2.2:** Expand observing networks to identify and monitor priority coral reef areas that are especially resilient or vulnerable to climate change.	• **Ocean Color** (e.g. chlorophyll concentration, HAB identification, LBSP tracking) • **SAR** (e.g. wind speed & direction; oil & spawning detection; vessel detection) • **OSVW** (e.g. currents, larval transport, connectivity) • **Sea Surface Temperature (SST) Improvements** (e.g. predict bleaching events; assist identification of areas resilient to bleaching) • **GOES Insolation** (e.g. model coral photosystem health as part of improved SST product suite) • **Ocean Acidification** (e.g. monitor regional changes in ocean acidification over decadal timescales) • **Satellite Altimetry** (e.g. sea level rise; storm surge and significant wave height measurement)

** Priority Goal 2; Objective 2.1 is correlated to SST Improvements, GOES Insolation (as part of the LSD product) and Ocean Acidification. Priority Goal 2; Objective 2.2 is correlated to all seven product development areas.*

Appendix I-1. Correlation table of NOAA remote sensing product development areas to Coral Program International Strategy Goals & Objectives (*continued*).

Coral Program International Strategy 2010-2015 Goals & Objectives	NOAA Remote Sensing Product Development Areas
Priority Goal 4; Objective 4.1: Support national-level and regional initiatives to identify priority coral reef areas threatened by pollutants and assess pollutant sources to those areas.	• **Ocean Color** (e.g. chlorophyll concentration, HAB identification, LBSP tracking) • **SAR** (e.g. wind speed & direction; oil & spawning detection; vessel detection) • **OSVW** (e.g. currents, larval transport, connectivity) • **Ocean Acidification** (e.g. monitor regional changes in ocean acidification over decadal timescales)

Appendix I-2. Number of Coral Program International Strategy Goals & Objectives to be addressed by NOAA remote sensing product development area, grouped by threat category.

NOAA Product Development Area	**International Strategy-Goal 1**	**International Strategy-Goal 2**	**International Strategy-Goal 3***	**International Strategy-Goal 4**	**Number of Correlations**
Ocean Color	1.5	2.2		4.1	**3**
Synthetic Aperture Radar (SAR)	1.5	2.2		4.1	**3**
Ocean Surface Vector Winds (OSVW)	1.5	2.2		4.1	**3**
Sea-Surface Temperature (SST) Improvements+	1.5	2.1 & 2.2			**3**
GOES Insolation+	1.5	2.1 & 2.2			**3**
Ocean Acidification (OA)#	1.5	2.1 & 2.2		4.1	**4**
Satellite Altimetry	1.5	2.2			**2**

**Coral Program International Strategy Goal 3 is not compatible with ocean satellite remote sensing; therefore no correlations were able to be made for this goal.*

+*NOAA/Coral Program supported activity.* #*NOAA/OAR supported activity.*

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