

# Remote Sensing of Coral Reefs

## Overview of Integrated Collaborations, Projects and Products

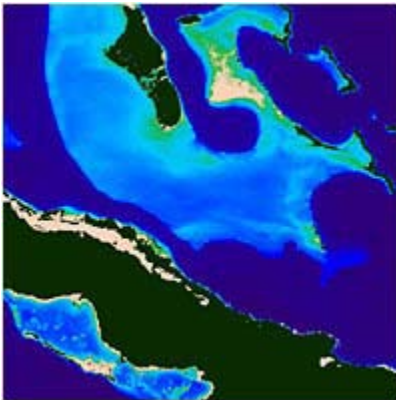
<http://eol.jsc.nasa.gov/Reefs/>

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Natural resource managers around the world desperately need maps of coral reefs and adjacent land areas. The current level of knowledge about such simple measures as the total area and locations of coral reefs in the world is not sufficient as a baseline for monitoring change. Regional studies attempting to identify the risk factors for decline of coral reefs are also faced with inadequate maps of reefs and adjacent land uses. At the same time, local managers clamor for detailed reef habitat maps for monitoring smaller scale changes in reef communities. These managers are making daily decisions that impact the health of coral reefs and the economies of the communities that depend on them.

In a NASA-sponsored partnership between remote sensing scientists, international agencies and NGOs, new efforts are being made to (1) develop baseline global reef maps that can be a foundation for future more detailed investigations, (2) assemble the key baseline remote sensing data that is needed for researchers to study coral reef environments, and (3) partner with international organizations to use remote sensing data for applied science problems and improve the management of coral reefs.

## Global Shallow Bathymetry from SeaWiFS

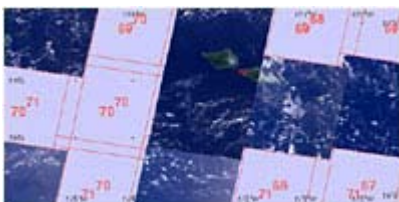


Characterizing water depth in tropical oceans is an important first step for improving the identification and characterization of coral reefs. NOAA scientists have developed a revised bathymetry algorithm, originally applied to 4-meter IKONOS imagery ([Stumpf et al. 2003b](#)), that could be applied to that can be applied to data from a variety of sensors. This algorithm was used to produce a global composite 1-km bathymetry map from SeaWiFS data ([Robinson et al. 2000](#), [Stumpf et al. 1999, 2003a](#)). The value of each pixel in the full-resolution SeaWiFS depth classification image is derived from depths computed from different SeaWiFS overflights so that cloud pixels can be removed and best depth estimates developed that eliminate transient effects of sediment, chlorophyll, etc. We have

used the median measurement (after cloud pixels have been removed) to represent each 0.01 by 0.01 degree location on the map.

The Global SeaWiFS Bathymetry Map was includes all five years of data from the SeaWiFS mission through November 2002. It is available for access online at <http://seawifs.gsfc.nasa.gov/cgi/reefs.pl>.

## Assembly of Landsat 7 Data for Coral Reef Mapping



The first challenge for global coral reef mapping with Landsat 7 is in getting global data that is not obscured by cloud cover. Global data acquisition for coral reef mapping was initiated through the Landsat 7 Long Term Acquisition Plan ([Gasch et al. 2000](#)). Once the instrument began acquiring data over coral reefs, it took several years to get the needed acquisitions because of tropical cloud cover, and to find ways to purchase or trade for the nearly 1000 scenes necessary to complete the

global coverage. The data assembly was led by scientists in the Institute for Marine Remote Sensing (<http://www.imars.usf.edu/MC/index.html>) at the University of South Florida. A number of groups within NASA provided Landsat scenes, and collaborators in mapping projects around the world shared their data in order to assemble the most complete possible archive of Landsat 7 data. The archive and online data interface has been developed by the SeaWiFS Project at Goddard Spaceflight Center.

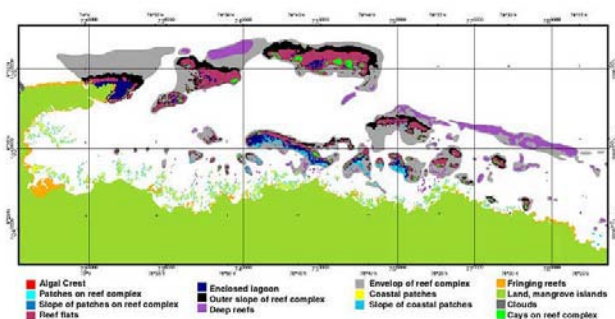
At present, two different online products allow access to the data:

1. An index ([http://imars.marine.usf.edu/corals/maps/reef\\_count.html](http://imars.marine.usf.edu/corals/maps/reef_count.html)) with browse images of all the Landsat 7 data assembled by region
2. A [Landsat Coral Reef Data Archive](#) displays data that is tiled, zoomable, and downloadable via FTP

Approximately 120 Landsat 7 scenes remain to be acquired, and it is anticipated that an announcement of the completion of the archive (with at least one good scene per target path-row) will be possible very shortly.

The collection of this set of global data was a necessity of the Millennium Coral Reef Mapping project, and satisfies a need identified by members of the [U.S. Coral Reef Taskforce](#). By assembling these data in a single freely accessible location, the use of Landsat data in a variety of local, regional, and global mapping projects will become possible.

## The "Millennium Coral Reef Mapping Project" Geomorphological Reef Map



By using a consistent dataset of high-resolution (30 meter) multispectral Landsat 7 images acquired between 1999 and 2003, Institute for Marine Remote Sensing at the University of South Florida is developing the first global uniform map of shallow coral reef ecosystems. The program aims to highlight similarities and differences between reef structures at a scale never before considered by traditional work based on field studies. The project has included

an unprecedented standardization of geomorphological structures for reefs around the world. It will provide a reliable, spatially constrained data set for biogeochemical budgets, biodiversity assessment, reef structure comparisons and will also provide new high-quality information for reef managers about reef location, distribution and extent. The maps are constructed scene-by-scene, with mosaics produced for selected locations.

Extensive details on the mapping philosophy, global classification scheme, and other aspects of the project are available online at the Millennium Coral Reef Mapping (<http://imars.marine.usf.edu/corals/index.html>) website. The portion of the project supported by NASA was completed in 2007, however the lead investigator, Serge Andrefouet, expects to continue working with the data and validating maps under support for other organizations for many years to come. Scientists interested in unvalidated maps and working in these regions should contact him for potential collaboration opportunities.

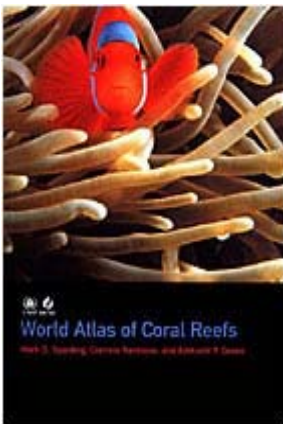
The part of the data produced under NASA support (including validated maps for some regions, and unvalidated maps for other regions) is available for download on NASA web servers at the following location: <http://oceancolor.gsfc.nasa.gov/cgi/landsat.pl>. Click on "Access to validated and unvalidated reef classification products". There is also information there on how to cite the information if it is used, and whom to notify about major uses at <http://oceancolor.gsfc.nasa.gov/LANDSAT/HTML/README.html>.

## Science Applications and Data Distribution with International Partners



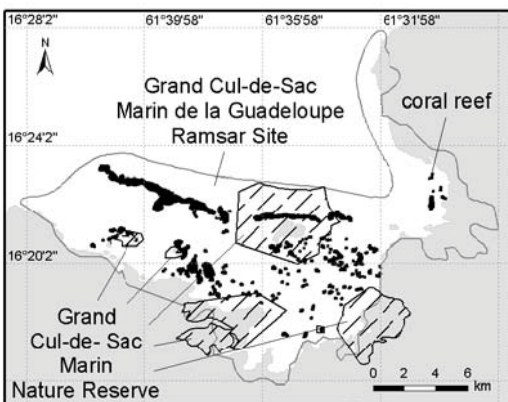
linkages for data distribution through the partners.

*UNEP World Conservation Monitoring Centre*



The UNEP-WCMC (<http://www.unep-wcmc.org/index.html>) serves as a major provider of information for developing conservation policies around the world. They serve as the primary reef map producers for the International Coral Reef Action Network (ICRAN) (<http://www.icran.org/>). They produced and maintain the current existing global coral reef map from a compilation of cartographic sources, and published the World Atlas of Coral Reefs (Spalding et al. 2001) (<http://www.unep-wcmc.org/marine/coralatlas/>). Although the atlas is a landmark product and provides the best current estimate of the global area of emergent reef crest, it is limited by the variety of cartographic sources that were used. Only 30% of the reefs in the atlas had source data at a 1:250,000 scale or better. Sources also differed in their definitions of the reef areas that were mapped. Spatial and positional accuracy in a cartographic compilation product is also a difficult challenge.

Through partnerships with NASA, the global SeaWiFS bathymetry map was used to identify and correct errors in the WCMC reef map. For example, in this map of Kiritimati, Kiribati, the light blue pixels represent shallow depths and the black areas represent land. The existing WCMC map (red lines) has positional inaccuracies with the reef mapped on top of the land. The shallow bathymetry allows correction of the position of the reef (yellow line on the south side of the island).



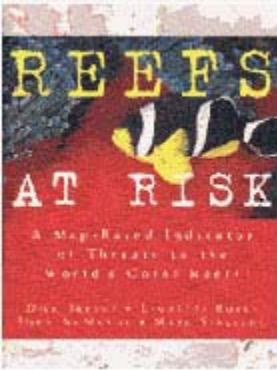
Combining the SeaWiFS bathymetry product with the WCMC map has increased map accuracy for use in evaluating the global distribution of marine protected areas (Green et al. in review). The SeaWiFS bathymetry allowed identification of the level of protection of tropical shallow marine habitats around the world. Important considerations in evaluating whether shallow marine and coral reef environments are protected are the degree to which designated marine protected areas overlap (as shown in this map of Grand Cul-de-Sac Marin Reserve, Guadeloupe), and whether protected habitats are representative of the marine biodiversity of different regions.

WCMC personnel were trained by and have participated in the Millennium Coral Reef Mapping project at the University of South Florida. After the Millennium Maps are complete, a reduced "reef-no reef" global map product with uniform global accuracy will be derived as a substantial update to the *World*

## *Atlas of Coral Reefs.*

An important area in global coral reef conservation is evaluating changes in related marine ecosystems such as mangroves and seagrasses. WCMC is also collaborating with Johnson Space Center and Florida International University in evaluating methods for updating the *World Mangrove Atlas* ([Spalding et al. 1997](#)) using Landsat 7 and MODIS data.

## *World Resources Institute*



Reefs at Risk (<http://wri.igc.org/reefsatrisk/>) is a series of projects at the World Resources Institute that develop indicators to evaluate the human pressures on coral reefs. The projects, which entail extensive collaboration with partners across each region, evaluate threats to coral reefs from coastal development, marine pollution, pollution and sedimentation from inland sources, and overexploitation of resources. A global analysis was released in 1998 ([Bryant et al. 1998](#)) and was important for raising global awareness of the extent of threats to reefs around the world. A more detailed analysis of Reefs at Risk in Southeast Asia was released in 2002 ([Burke et al. 2002](#)). A more detailed regional analysis for the Caribbean is currently in progress and expected to be released in 2004.

The main objectives for collaboration between NASA and WRI was to help improve the accuracy of input data used in the threat models in the Caribbean regional study. The Reefs at Risk methodology relies on GIS-based modeling with existing map datasets. In previous studies, the threat of pollution and sedimentation were evaluated using the 1-km IGBP DISCover/USGS Global Land Cover dataset ([Belward et al. 1999](#)) and WCMC coral reef maps as base information. These coarse datasets were not suitable for modeling the risks to many small islands in the Caribbean such as the Lesser Antilles. Such analyses need to be made at a finer spatial resolution.

Since Millennium Coral Reef Maps for the Caribbean are being completed simultaneously to the Reefs at Risk Caribbean analysis, Millennium Maps are being delivered directly to WRI to allow updated coral reef data to be used in the Reefs at Risk Caribbean analyses.

Through NASA support, Florida International University has been collaborating with WRI in evaluating different sources of higher resolution land cover data by comparing three global land cover maps ([IGBP DISCover/USGS Global Land Cover](#), Boston University's MODIS/Terra Land Cover (<http://geography.bu.edu/landcover/index.html>), and EarthSat's Geocover-LC ([http://www.geocover.com/gc\\_lc/index.html](http://www.geocover.com/gc_lc/index.html))) with a custom classification using Landsat 7 data. WRI partners have been providing expert local review of the maps, and the effect of the different source data on the land pollution and sedimentation risk models is currently being determined. This will allow WRI to better understand their data needs as they complete subsequent regional Reefs at Risk Analyses.

## *ReefBase*



ReefBase ([www.reefbase.org](http://www.reefbase.org)) is the premier online information system on coral reefs. It includes a database of information on the location, status, legislation and management of coral reefs around the world, archives of coral bleaching observations, and data collected by the Global Coral Reef Monitoring Network (<http://www.gcrmn.org/>). It serves as the primary data archive and distribution center for the International Coral Reef Action Network (ICRAN) (<http://www.icran.org/>).

As part of their collaboration with NASA, ReefBase developed a new online interactive map server that allows users to interactively assemble and view key reef mapping datasets, including the coral reef and mangrove maps from UNEP-WCMC, Reefs at Risk data,

ReefCheck maps, NOAA AVHRR Coral Reef Hotspot data, NASA remote sensing imagery of reefs, and the SeaWiFS shallow bathymetry product.

The Millennium Coral Reef Map products were developed so that they could be easily incorporated into ReefBase when they are complete. Test datasets have already been successfully included in the interactive map server. Plans are also being implemented to allow users to include viewing a reduced-resolution Landsat-7 layer as an option, and to link to the Landsat Coral Reef Data Archive so that users can seamlessly find the underlying data needed for management applications.

## Other Data Sources and Related Scientific Projects

In addition to the major collaborations outlined above, NASA support has led to a number of spin-off projects that have improved local and regional studies around the world.

### *Astronaut Photography as Supplemental Data*

Astronaut photography of coral reef areas has been an important source of supplemental data in coral reef mapping. [Astronaut photographs](#) were key illustrations throughout the World Atlas of Coral Reefs (Spalding et al. 2001) (<http://www.unep-wcmc.org/marine/coralatlas/>), and a major early source of remote sensing information in ReefBase (Robinson et al. 2000).



The availability of a significant number of digital photographs (3-band data) of coral reefs taken from the International Space Station with spatial resolution ranging from 5-10 m has been of particular interest to coral reef researchers. NOAA has successfully applied its new bathymetry algorithm to digital astronaut photography with excellent results (Stumpf et al. 2003). Additional collaborations have evaluated and refined the use of astronaut photography in cloud detection (Andréfouët and Robinson 2003) and evaluated the influence of the spatial scale of the imagery on determining landscape parameters of atolls (Andréfouët et al. 2003). Applied scientists have also taken advantage of the high spatial resolution of digital astronaut photography for use in planning dive surveys and other management activities (e.g., Quod et al. 2002).

### *Regional Collaborations*

The University of South Florida has participated in regional projects that have included data exchange and technology development. Synthesis and sharing of data in these projects has been critical to developing the global geomorphology classifications, and to assembling the necessary Landsat 7 data. They also have significantly enhanced NASA's objectives in increasing capacity for use of remote sensing data in coral reef mapping. Highlights of these regional projects include studies of the status of reefs in Panama (with the Smithsonian Tropical Research Institute, [Andréfouët and Guzman 2004]), status of reefs in Cuba (with the University of Miami/Rosenstiel School of Marine and Atmospheric Science and Int. Oceanologia Cuba), status of reefs in French Polynesia (with U. Polynesie Francaise), geodetic accuracy of Landsat 7 on Great Barrier Reef (with the Great Barrier Reef Marine Park Authority), study of climate forcing in the Maldives and Marshall atolls (with Dalhousie University, Canada and National Institute of Environmental Sciences, Japan).

Future NASA-sponsored activities in Interdisciplinary Science will include calibration of a sediment transport model in the New Caledonia lagoon (with Institut de Recherche pour le Développement, New Caledonia, [Ouillon et al. 2004]), calibration of circulation and larval transport models in Mesoamerican Reef System (with Dalhousie University, Canada), and enhancement of a coral bleaching risk model for

the Great Barrier Reef (with Australian Institute for Marine Science and NOAA).

### *NOAA Coral Reef Mapping Activities*

NOAA has taken the primary responsibility for mapping activities in U.S.-Flag waters under the U.S. Coral Reef Task Force's Mapping Implementation Plan. NOAA National Ocean Service's work in developing bathymetry algorithms (described previously) has provided new opportunities for automation of coral reef mapping on regional and global scales. NOAA's most recent coral reef mapping activities have focused on producing benthic habitat maps of the Northwest Hawaiian Islands for the Office of National Marine Sanctuaries. Extensive methods development has focused on using IKONOS and Landsat data to make habitat maps that are consistent with previous habitat mapping efforts by the NOAA NOS Biogeography Program. These efforts have involved aerial photography in the Florida Keys and Caribbean, and a combination of aerial photography and hyperspectral imagery in the main Hawaiian Islands. Satellite data are also being used to determine water quality patterns and identify broad trends in the condition of habitats in coral reef areas. NOAA and NASA scientists continue to collaborate in methods development and product refinement to meet common objectives.

### *Reefs at Risk*

The World Resources Institute has used Millennium Coral Reef Maps in regional assessments (such as Reefs at Risk in the Caribbean, 2004 <http://www.wri.org/publication/reefs-risk-caribbean>) and as part of Reefs at Risk Revisited (<http://www.wri.org/project/reefs-at-risk/reefs-at-risk-revisited>), an update of their influential 1998 assessment of risks to the world's coral reefs expected to be released in 2011.

## **Conclusion**

Through a set of NASA-sponsored partnerships, and the efforts of numerous project partners, the quantity and detail of globally available information on coral reefs is being greatly expanded. The new accessibility of low cloud remote sensing data selected for reef mapping will also provide significant new opportunities for research and management applications. Perhaps most importantly, the integration of efforts of NASA scientists and university researchers with international non-government organizations facilitates the immediate incorporation of data and map products into analyses that will change the management of coral reefs. The availability of datasets for interactive mapping via the ReefBase interface, and for downloading of raw data provides an unprecedented opportunity for the global coral reef community to benefit from NASA data and technologies and to improve the management of reefs worldwide. At the upcoming meeting of the 2004 International Coral Reef Symposium a special Mini-symposium on "Producing, Distributing, and Analyzing Global Coral Reef Maps - the State of the Art" will examine all these major efforts for global coral reef mapping, the technologies and methods that will make these maps and underlying data available to the coral reef research and management communities, and the potential for global syntheses.

## **Sponsorship**

Using Landsat 7 Data in a GIS-based Revision of ReefBase (A Global Database on Coral Reefs and Their Resources): Distributing Information on Land Cover and Shallow Reefs to Resource Managers. *NASA Office of Earth Sciences, Earth Science Enterprise, Carbon Applications*. To the Earth Observations Laboratory, Johnson Space Center, University of South Florida, and Florida International University (J. A. Robinson, S. Andréfouët, G. Feldman, J. Gebelein, J. K. Oliver, M. Noordeloos, E. Green, and M. K. Spalding). 2001-2004.

A Millennium Global Scale Coral Reef Ecosystem Assessment using High Resolution Remote Sensing Data. *NASA Office of Earth Sciences, Earth Science Enterprise, Interdisciplinary Science*. To the University of South Florida (S. Andréfouët and F. Muller-Karger). 2001-2004.

Environmental Assessments of Coral Reef Ecosystems: Interdisciplinary Research Using EOS

Platforms and Numerical Models. *NASA Office of Earth Sciences, Earth Science Enterprise, Oceanography Program*. To the University of South Florida (S. Andréfouët and F. Muller-Karger). 2004-2007.

NASA Support of the U.S. Coral Reef Taskforce *NASA Office of Earth Sciences, Earth Science Enterprise*. To the SeaWiFS Project, Goddard Spaceflight Center (G. Feldman).

## Partners

Julie A. Robinson, Alan Spraggins, Earth Observations Laboratory, Johnson Space Center

Serge Andréfouët, Frank Muller-Karger, Chuanmin Hu, Christine Kranenburg, Damaris Torres, Brock Murch, Millennium Global Coral Reef Mapping Project, Institute for Marine Remote Sensing, University of South Florida

Gene Feldman, Norman Kuring, and Bryan Franz, SeaWiFS Project, Goddard Space Flight Center

Richard P. Stumpf, Steve Rohmann, and Kris Holderied, NOAA National Ocean Service

Jennifer Gebelein, Department of International Relations, Florida International University

Marco Noordeloos and Jamie Oliver, ReefBase, World Fish Center

Edmund P. Green, Corinna Ravilious, and Michelle Taylor, UNEP-World Conservation Monitoring Centre

Lauretta Burke and Jon Maidens, Reefs at Risk Project, World Resources Institute

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## **Press Releases**

[NASA Astronaut Photos Contribute to New Coral Reef Atlas](http://eol.jsc.nasa.gov/newsletter/CoralReefs/). (Johnson Space Center, 10/22/2001), Images at <http://eol.jsc.nasa.gov/newsletter/CoralReefs/>

[Landsat 7 Shows Global Trove of Coral Images/Movies](http://eol.jsc.nasa.gov/newsletter/CoralReefs/) (Goddard Space Flight Center, 10/25/2000)