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CITATION

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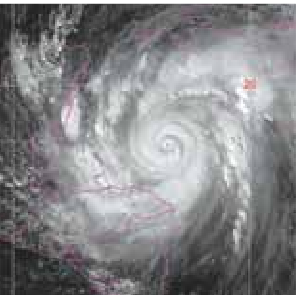
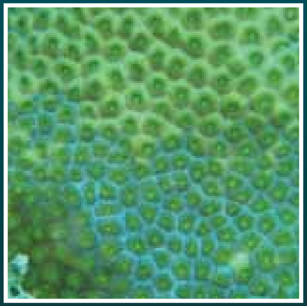
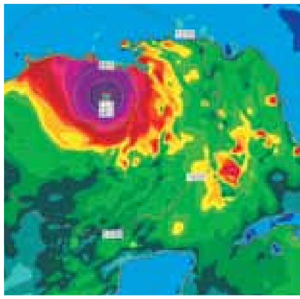
MISST

THE MULTI-SENSOR IMPROVED SEA SURFACE TEMPERATURE PROJECT







ABSTRACT. Sea surface temperature (SST) measurements are vital to global weather prediction, climate change studies, fisheries management, and a wide range of other applications. Measurements are taken by several satellites carrying infrared and microwave radiometers, moored buoys, drifting buoys, and ships. Collecting all these measurements together and producing global maps of SST has been a difficult endeavor due in part to different data formats, data location and accessibility, and lack of measurement error estimates. The need for a uniform approach to SST measurements and estimation of measurement errors resulted in the formation of the international Global Ocean Data Assimilation Experiment (GODAE) High Resolution SST Pilot Project (GHRSST-PP). Projects were developed in Japan, Europe, and Australia. Simultaneously, in the United States, the Multi-sensor Improved SST (MISST) project was initiated. Five years later, the MISST project has produced satellite SST data from nine satellites in an identical format with ancillary information and estimates of measurement error. Use of these data in global SST analyses has been improved through research into modeling of the ocean surface skin layer and upper ocean diurnal heating. These data and research results have been used by several groups within MISST to produce high-resolution global maps of SSTs, which have been shown to improve tropical cyclone prediction. Additionally, the new SSTs are now used operationally for marine weather warnings and forecasts.

INTRODUCTION

Sea surface temperatures (SSTs) are used for forecasting weather and in climate research, and they are key to understanding both the atmosphere and the ocean. One of the first studies of SST was done in 1770 by the US Postmaster General, Benjamin Franklin, and a whaling ship captain, William Folger. Curious as to why mail ships took longer to sail from Europe to America than in the opposite direction, Benjamin Franklin sponsored Folger to map a rumored ocean current using sea surface temperature. Almost 100 years later, when a bucket lowered over the side of a ship was still the standard tool for measuring SST, the first idea for a satellite was published in a series of *Atlantic Monthly* short stories (Hale, 1869). Now, there are over 25 currently active US satellites focused on Earth observation (Union of Concerned Scientists, 2009). The Gulf Stream's location and structure can be mapped on a daily basis using infrared (IR) and microwave (MW) satellite SST measurements (Figure 1). The serene vision of Franklin's rumored "ocean river" is now known to be a turbulent, ever-changing stream adorned by loops, rings, and eddies.

SEA SURFACE TEMPERATURE

SST is now recognized as one of the most important variables related to the global ocean-atmosphere system. It is a key indicator of climate change, is widely applied to studies of upper ocean processes and air-sea heat exchange, and is used as a boundary condition for numerical weather prediction (NWP). Changes in SST can dramatically impact weather, fisheries, and climate. For example, large changes in ocean temperatures during El Niño/La Niña events can have dramatic impacts on fisheries by forcing fish into regions where they are not commonly found, and these events can alter rainfall patterns that may lead to floods or droughts over land, with associated changes in agricultural crop yields. Coral bleaching due to warm ocean temperatures can result in reduced fish habitat and fish species diversity (see Box 1). Measurements of SST changes are important for accurate weather forecasting of both daily weather and severe events, such as hurricanes (see Box 2).

As satellite measurements of SST and other oceanographic variables have become more common, scientists have started thinking about forecasting ocean currents and temperatures. Ocean forecasting has many applications, including marine safety (e.g., using current and wind forecasts to find missing vessels), fisheries monitoring (e.g., using current and temperature information to determine dispersal of lobster larvae), and tracking marine pollution (e.g., to best position response measures for oil spills).

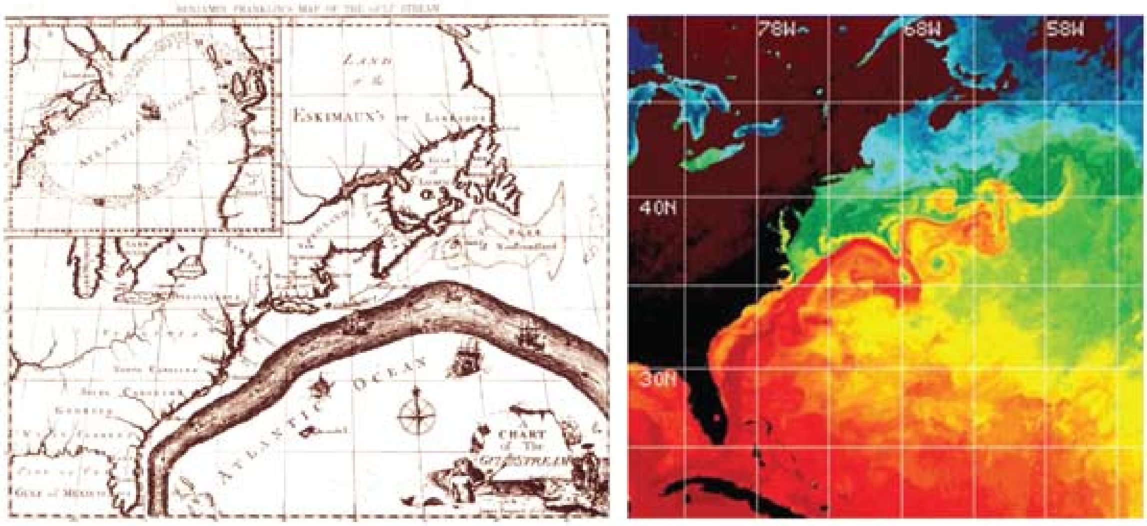


Figure 1. The Gulf Stream by Benjamin Franklin (at left) and satellite sea surface temperatures (SSTs, at right). Shown as a bright red band, the Gulf Stream is about 27°C (~ 80°F) in this SST image of the western North Atlantic during the first week of June 1984. This image is based on data from NOAA-7 Advanced Very High Resolution Radiometer (AVHRR) infrared observations. Warmer hues denote warmer temperatures. *Left image credit: NOAA Central Library. Right image credit: O. Brown, R. Evans, and M. Carle, University of Miami Rosenstiel School of Marine and Atmospheric Science, Miami, Florida*

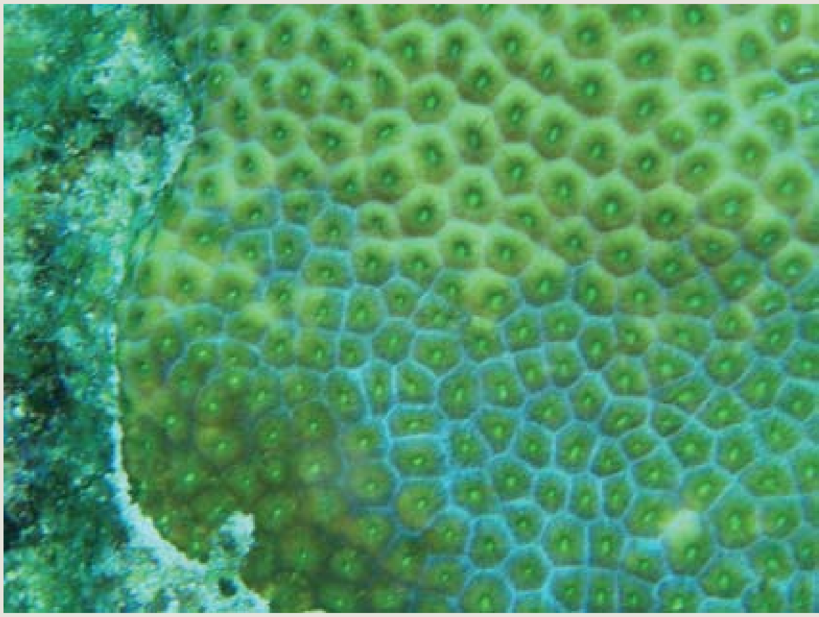
BOX 1: CORAL REEFS

Coral reefs, together with the myriad species of marine life associated with them, form one of the most diverse and fragile ecosystems on the planet, second only to tropical rainforests for sheer biodiversity (Connell, 1978). Reefs provide a critical habitat for tropical coastal marine life, and as such, they represent a major source of nutrition to coastal populations around the world (Kenchington and Hudson, 1988). They are also a vital source of income both to developed and less-developed communities—income directly related to diving and other reef-related tourism in one key reef area of the United States alone has been valued at over US$1 billion per year (Causey, 1998). Reef-building corals form the linchpin of coral reef communities: under conditions of constant erosion, the long-term viability of the coral community depends on the health of these hard coral species, and on the health of the symbiotic zooxanthellae that facilitate their rapid growth.

Zooxanthellae are photosynthetic organisms that reside in the tissue of coral polyps. However, under the influence of extreme sea temperature, alone or in combination with other environmental stressors such as high salinity, irradiance, or low water circulation (Manzello et al., 2007), hard corals can expel these colorful symbionts from their tissues, resulting in the "paling" or "bleaching" of corals. Bleaching hinders the ability of corals to replace erosion with new growth, and in extreme cases can contribute to mass coral mortality. Such events are anticipated to become more common as ocean temperatures increase under the influence of climate change.

Through hydrodynamic processes, major reef systems around the world are strongly linked both to crucial inshore habitats such as sea grass beds and mangrove estuaries, and to major ocean current systems in the deep ocean offshore. To effectively monitor environmental conditions related to bleaching and coral health, it is therefore necessary to take a regional view of the physical environment: innovative, high-resolution satellite data for SST, ocean color, and other inherent water properties of shallow coastal waters play an indispensable role in understanding and monitoring coral reef ecosystems.

Coral reefs harbor a profusion of coastal marine life, including many economically important fish and invertebrate species of the tropics. *Photo from La Parguera Natural Reserve, Puerto Rico, courtesy of Derek Manzello*



This close-up image shows hard coral polyps, some of which have begun to "pale" (i.e., expel their colorful, photosynthetic symbionts). *Photo courtesy of Derek Manzello*

FORECASTING OCEAN “WEATHER”

In 1997, the Global Ocean Data Assimilation Experiment (GODAE) was initiated to provide a coordinated international approach to establishing global operational oceanography and to provide better ocean observations and ocean forecasts to users. When the GODAE project started, most operational SSTs were determined from a single satellite’s measurements to generate a weekly average 100-km map of SSTs. With the deployment of improved satellite IR sensors and new MW sensors, notable advances in SST measurement were made possible. Not only did the additional satellites provide more frequent coverage, but the IR and MW retrievals proved to be highly complementary. Clouds prevent SST measurement by IR sensors, yet they have little impact on MW retrievals. However, the IR SSTs are very valuable because they measure at a high spatial resolution (~ 1 km at nadir) in comparison to the low-spatial-resolution MW SSTs (~ 25 km). These complementary factors created interest in the development of merged IR and MW SST products to leverage the positive characteristics of each sensor type.

GODAE project scientists realized that ocean models needed better SST inputs than the weekly 100-km maps historically used, and that, with the new satellites, better SST measurements were possible. This realization led Neville Smith, Chair of the International GODAE steering team, to call together ~ 28 representatives, including satellite SST algorithm scientists, SST researchers, and governmental operational providers and users of SST. This first meeting was held in 2001 at the European Commission’s Joint Research Council near Lake Maggiore, Italy. The discussion centered around how to take advantage of all the different satellite SSTs available to provide a higher spatial and temporal resolution SST using satellite and in situ data. At the meeting, it was decided to start an international pilot project to promote research required to better produce and use SST information, including how to test and provide observations, how to integrate and assimilate these data at operational agencies, and how to use the data in downstream applications. The GODAE High Resolution SST (GHRSST) pilot project was born.

To put the magnitude of this undertaking in context, it is worth looking back at the state of SST production just before the project started. The community of users (mostly scientists) thought SST was “done”—research and operational agencies had been creating IR SST products for over a decade, and they were routinely used. But problems existed, including incompatible formats, restrictive data access policies, and out-of-date algorithms with uncertain error characteristics. The available products were difficult to use, harder to access, and were often years behind the latest research. The success of the joint National Aeronautics and Space Administration/National Oceanic and Atmospheric Administration (NASA/NOAA) Pathfinder SST effort was a roadmap for future work: it provided the Advanced Very High Resolution Radar (AVHRR) SSTs in a single data format with metadata, subsetting and viewing tools, and a matchup database.

The next series of GHRSST meetings developed ideas for framing a “new” SST project that would define research topics, design data formats, and develop a structure for data distribution to ensure “new” SST data integration at operational centers. Projects were funded in Japan, Europe, Australia, and the United States.

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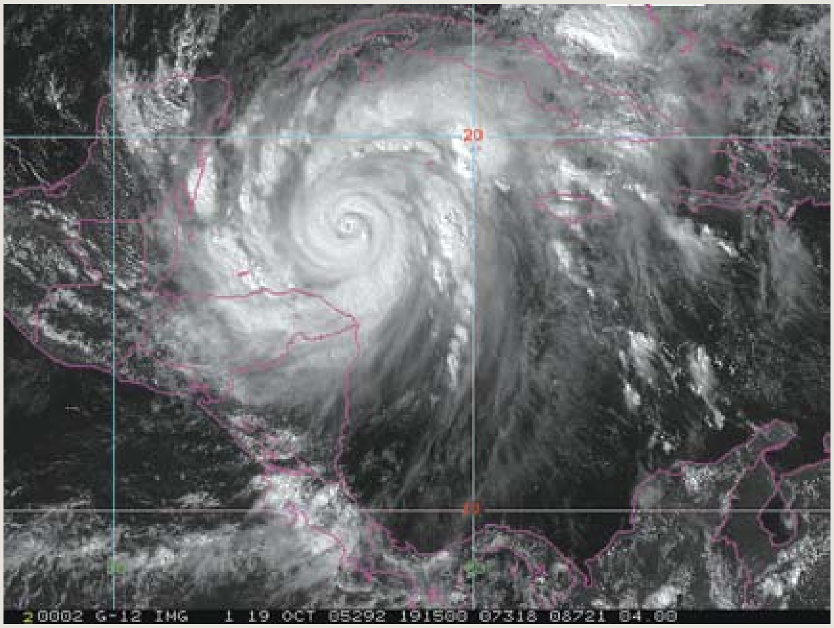
BOX 2: THE MOST INTENSE ATLANTIC HURRICANE

Hurricanes draw their strength from the vast ocean. The warm summer and fall tropical and subtropical SSTs provide heat (energy) to developing hurricanes. The transfer rate of this energy to the atmosphere is controlled by the difference between the ocean temperature and the air just above the surface. Theoretical studies show that maximum intensity of hurricanes is strongly controlled by SSTs. One measure of hurricane intensity is the minimum sea level pressure at the storm center. Hurricane Wilma in October 2005 had the lowest pressure ever measured in the Atlantic Basin. The figure in this box shows a satellite image of Hurricane Wilma and nearby SSTs close to the time of its maximum intensity. SSTs below Wilma were more than 1°C warmer than is typical for that location in October, and 3°C warmer than the minimum temperature required to sustain a hurricane, which helps to explain the extreme intensification of that storm.

Hurricane Wilma on October 20, 2005. The SSTs surrounding Wilma are hovering near 85°F, about 3° higher than the temperature required to fuel a hurricane. This image shows SSTs from October 15–20. Above 82°F, storms can strengthen (shown in areas of yellow, orange, or red). Wilma had the lowest surface pressure (882 hPa) ever measured in an Atlantic storm just before the time of this image. *Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio*



Geostationary satellite image of Hurricane Wilma at 18 UTC on October 19, 2005, showing the extent of the storm.

IMPROVED SEA SURFACE TEMPERATURES

In the United States, as a contribution to the GHRSST project, the National Oceanographic Partnership Program (NOPP) funded the Multi-Sensor Improved SST (MISST) project. NOPP is a unique organization that coordinates partnerships among federal agencies, academia, and industry. The NOPP MISST team is a partnership of over 25 scientists from academia (University of Colorado, University of Miami, University of Maryland, Woods Hole Oceanographic Institution, and University of Edinburgh), industry (Remote Sensing Systems), and federal agencies (NOAA, NASA, Naval Research Laboratory [NRL], and Naval Oceanographic Office [NAVOCEANO]). The team includes satellite SST algorithm developers, validation scientists, modelers, developers of operational SST analyses at government agencies, and scientists from data centers. Additionally, the project teamed with members of other, complementary NOPP projects, such as the "NOPP partnership for skin sea surface temperature" and the "US GODAE: Global Ocean Prediction with the Hybrid Coordinate Ocean Model (HYCOM)." This partnering provided a seamless transition of results between the research efforts.

The MISST project set out to reach several goals: (1) produce an improved SST product using multiple sensors; (2) demonstrate the impact of improved multi-sensor SST on operational ocean models, numerical weather predictions, and tropical cyclone forecasting; and (3) minimize duplication of efforts, harmonize research and development activities, and maximize data access through close collaboration with the international GHRSST project. To produce an improved global SST product, we had to start by improving how the satellite SST measurements were used. This pursuit required more knowledge about the accuracy of SST retrievals and a better understanding of real geophysical differences between measurements.

ACCURACY OF SST MEASUREMENTS

Accurate error estimates are necessary for optimally blending different measurements. For example, if one measurement is more accurate than another nearby measurement, the more accurate measurement should be more trusted. It is easier to do this if each measurement has an accurate error estimate. The primary factors contributing to IR retrieval error include undetected clouds and variations in atmospheric water vapor distribution and aerosol content. Errors associated with sensor calibration are also important and vary significantly between sensors. For MW SSTs, measurement error is based on the environmental scene and on other factors such as proximity to land, sea ice, and sun glitter. Errors for both IR and MW SSTs are determined by collocating satellite SSTs with in situ measurements from buoys, ship radiometers, and other independent SST measurements. An example of a valuable source of in situ SST validation data is given in Box 3. The coordination of research efforts through the NOPP project resulted in significant advances in error assessment. The challenge to estimate errors for every SST measurement requires a new approach to the problem and collaboration among different scientists. One of the new methods developed was the "hypercube," a method to estimate errors for each measurement based on known sources of error (Evans and Kilpatrick, 2008). The hypercube is a multidimensional array of errors generated from comparisons of independent SSTs with satellite SSTs. The array dimensions correspond to known error sources such as satellite zenith angle or wind speed. Errors for each SST measurement are determined by examining the environment and retrieval characteristics modeled by the hypercube.

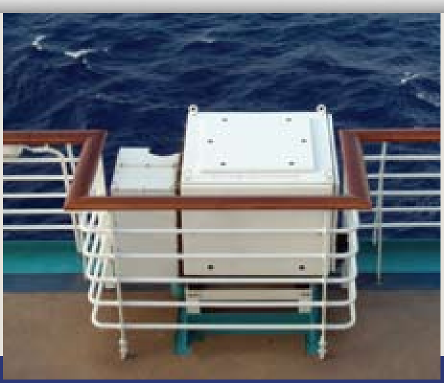
UPPER OCEAN MODELS

The upper ocean is a complex environment. Just above the sea surface, the atmosphere is usually a degree or two cooler than the ocean. This temperature difference means that heat will flow from the ocean to the atmosphere and cool a very thin layer of the ocean's surface. This layer is called the "cool skin" because it is just a bit cooler than the ocean waters below. IR and MW SSTs measure at slightly different depths because the emission depths for MW radiation are deeper than for IR radiation. Therefore, to blend MW and IR SSTs, a model is needed to estimate how the very top of the ocean, the cool-skin layer, affects the IR and MW measurements.

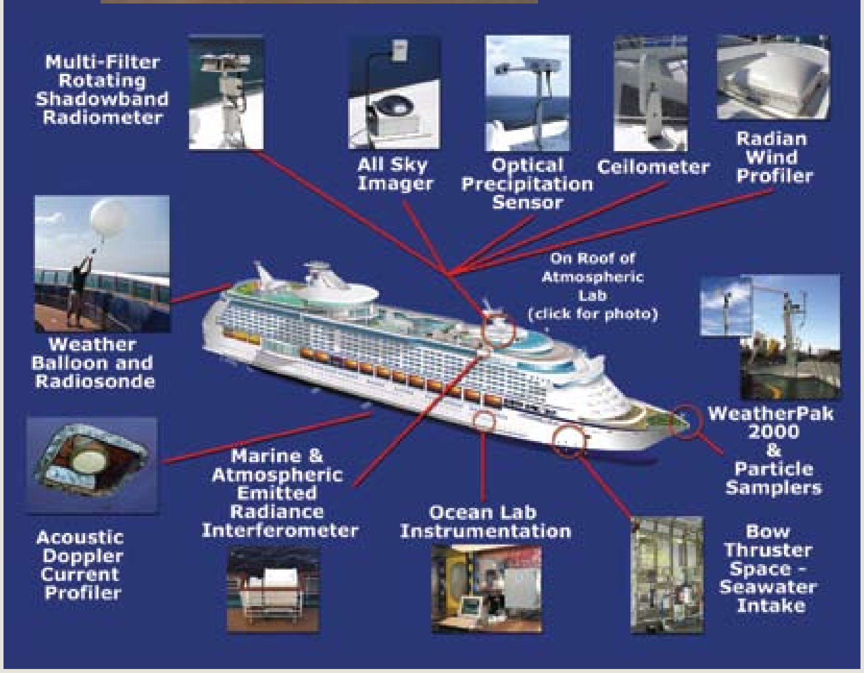
Both IR and MW SST measurements are affected by daytime solar heating of the ocean. If there is vigorous mixing in the ocean (usually due to high wind speeds), the sun's heat is mixed down below the surface. If the ocean is calm, the heat can become trapped in the upper few meters of the ocean and the surface can warm by 3–6°C. This

BOX 3: SHIP-BASED RADIOMETER

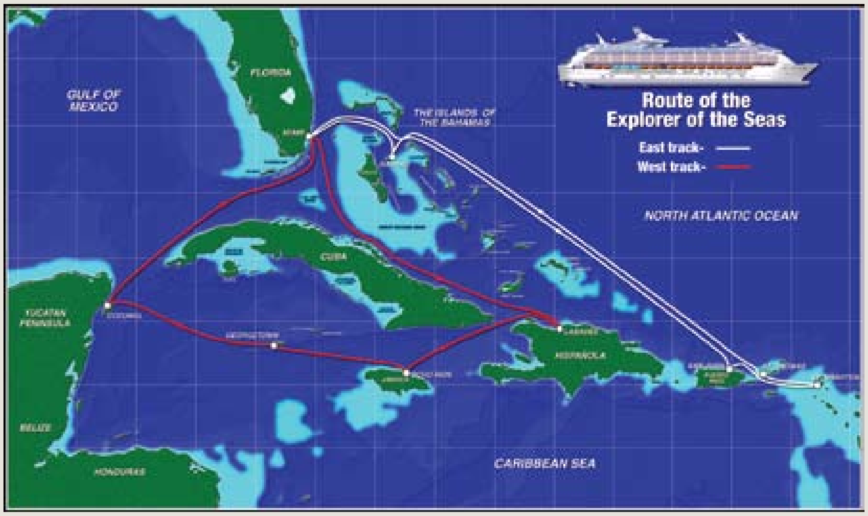
One of the continuing issues with using satellite data for scientific applications is determining the retrieval accuracy. After all, the instruments cannot be brought back to the laboratory for post-deployment calibration. In the case of SSTs, the best approach is to compare the satellite retrievals with independent measurements, ideally of the same type and of superior accuracy, such as from well-calibrated shipboard radiometers. In an unusual collaboration between the University of Miami and Royal Caribbean Cruise Lines, the ship *Explorer of the Seas* has been equipped with standard and advanced instrumentation to measure oceanographic and meteorological variables (Williams et al., 2002). Included in these instruments is a Marine-Atmospheric Emitted Radiance Interferometer (M-AERI), which is a well-calibrated infrared interferometric spectroradiometer that yields accurate measurements of skin temperatures (Minnett et al., 2001). Other deployments of the M-AERIs are on research vessels for cruises to specific areas, but the eight-year time series from *Explorer of the Seas* has become a very valuable resource not only for the validation of satellite-derived SSTs, but also for studying the physics of the upper ocean, such as the ocean response to diurnal heating (Gentemann and Minnett, 2008). Some of the deployments of the M-AERI and other infrared radiometers, such as CIRIMS (Calibrated Infrared In Situ Measurement System; Jessup and Branch, 2008) and ISAR (Infrared Sea Surface Temperature Autonomous Radiometer; Donlon et al., 2008), on research vessels and commercial ships (notably *Jingu Maru* of NYK Lines) have been funded by the NOPP Partnership for Skin Sea Surface Temperature.



The Marine-Atmospheric Emitted Radiance Interferometer (M-AERI), which accurately measures the ocean's skin temperature. *Credit: Hunter Augustus, University of Miami, Rosenstiel School of Marine and Atmospheric Science*



Instrumentation, including the M-AERI, on the *Explorer of the Seas. Credit: Hunter Augustus, University of Miami, Rosenstiel School of Marine and Atmospheric Science*



The routes followed by *Explorer of the Seas. Credit: Hunter Augustus, University of Miami, Rosenstiel School of Marine and Atmospheric Science* daytime warming can make it difficult to combine day- and nighttime retrievals, or those from day to day. To determine the amount of warming in daytime measurements, the MISST project needed a diurnal model.

The collaborations within the MISST team and with members of the international GHRSST science team have lead to great advances in cool-skin and diurnal warming modeling, with 12 peer-reviewed papers from the MISST project alone (Castro et al., 2003; Gentemann et al., 2003; Minnett, 2003; Ward et al., 2004; Wick et al., 2005; Ward, 2006; Ward and Donelan, 2006; Gentemann and Minnett, 2008; Gentemann et al., 2008; Merchant et al., 2008; Gentemann and Minnett, in press; Kettle et al., 2008). The modeling and measurement error results now needed to be moved from research to operations. This transition was accomplished through a new data format that included these results along with the SST measurements.

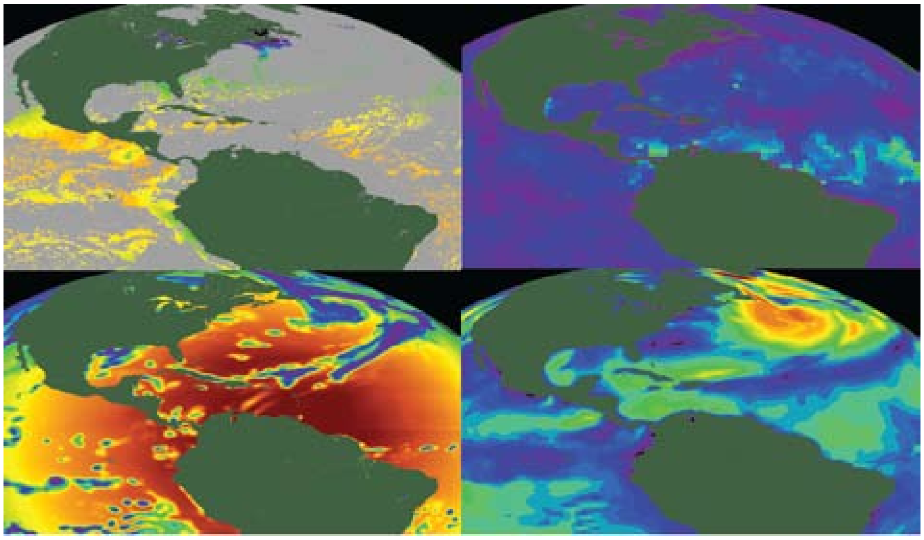


Figure 2. Example fields taken from GOES-E Northern Hemisphere sector L2P file for 15:15 UTC on March 28, 2007. Clockwise from top left: SST, aerosol optical depth, wind speed, and solar surface irradiance. Note the 1° resolution of the aerosol optical depth field, and the fact that the insolation is the average from 1500–1800 UTC. *Credit: Andrew Harris, University of Maryland*

A SINGLE FORMAT FOR ALL SST DATA

A data set is of little use if it cannot be easily accessed. To tackle this issue, the GHRSST project addressed data distribution and access by designing a single data format that would be used for all SSTs. This new format was called GHRSST Level-2 Pre-processed, or L2P data. This data format was carefully designed to accommodate new developments in SST research, such as error estimation, cool-skin modeling, diurnal-warming modeling, and ancillary fields useful for analysis and research such as aerosol, wind speed, and insolation values. Figure 2 shows an example of this data structure, with some of the ancillary data fields. The files are in netCDF format, follow the Climate Forecast (CF) convention, and include granule metadata. This universal format makes it very easy to add new SST data sets to analyses or research projects. The format was agreed on by the international GHRSST science team, carefully balancing the different requirements of numerous operational agencies. Now, almost all current satellites are distributing SST data in GHRSST L2P format.

Development and agreement on a data format was a very contentious process that required overcoming inertia. Each scientist had a particular way of doing things (and didn't want to change), and each operational agency had its own way of doing things (and also didn't want to change). Resources and time had already been invested into handling known products. Arriving at an agreement that would require all parties to change their methodology was not easy, but the GHRSST team and the NOPP partnership put everyone in the same room, with the same goal, and a data framework was developed. On the US side, this progress was only possible because of the organizational structure of the MISST project. "Research to operations" has long been a NOPP goal, but a difficult one to reach. The scientists who develop SST measurement algorithms, validation scientists, diurnal-warming and cool-skin modelers, the scientists who develop and run operational SST analyses, and people from data distribution centers were all represented on the MISST project. This combination of participants ensured that everyone involved in producing an SST product had a voice when decisions were being made. This organizational structure also ensured that research results did not languish in academic journals but were directly implemented into the project.

CREATING NEW GLOBAL SST ANALYSES

Many users require globally complete maps of SST, which are created by interpolating the satellite SST and in situ SST data to a regular grid. By making different satellite SST products easy to read and ensuring through partnerships that operational users were prepared to use the new data, scientists producing operational global SST analyses began using the GHRSST L2P data. At NOAA, the National Climate Data Center (NCDC) began producing a daily 25-km analysis incorporating IR and MW SSTs and the Center for Satellite Applications and Research (STAR) developed a 0.1° resolution daily global SST analysis using two IR SST data sets. NAVOCEANO personnel modified their operational SST analysis to assimilate data from three IR and one MW satellites and modified the analysis procedure to weigh each data set according to the error estimates calculated for each measurement. At Remote Sensing Systems, the daily SST analysis was modified to include IR and MW SSTs, including SST error estimates, and a correction for diurnal warming. These new data sets were used to evaluate how additional satellite SSTs impact weather and ocean forecasts.

DATA DISTRIBUTION

All data, from MISST and international partners, are now available at the NASA JPL Physical Oceanography Distributed Active Archive Center (PO.DAAC) Global Data Assembly Center (GDAC, http://ghrsst.jpl.nasa.gov/). GDAC provides user support, documentation, and data searching capabilities. After 30 days, data are automatically archived at the NOAA National Oceanographic Data Center (NODC) GHRSST Long Term Stewardship and Reanalysis Facility (LTSRF, http://ghrsst.nodc.noaa.gov). The data are searchable via the NODC Ocean Archive System as well. GDAC, in collaboration with LTRSF, manages and distributes the largest public collection of satellite SST measurements and mapped SST analyses in existence. They are the key link between data providers and data users, both within the United States and internationally.

IMPACT STUDIES

Members of the NOPP partnership performed impact studies to evaluate whether the new high temporal and spatial resolution SSTs helped or hindered weather and ocean forecasting. Researchers at NOAA's National Center for Environmental Prediction (NCEP) Ocean Prediction Center (OPC) set up a daily data flow for the new NCDC daily 25-km SST and established a process to easily create an acceptable file format for display on the operational workstations of the National Centers Advanced Weather Interactive Processing System (N-AWIPS). Operational production of the NCDC SSTs for OPC forecasters began January 10, 2008. These new SST data are used to issue operational marine weather warnings and forecasts of winds and waves for high seas (Box 4).

At NRL Stennis, an analysis of SST alternatives to the operational Modular Ocean Data Assimilation System (MODAS2D) SST product was completed. Results showed that SST analyses that include MW SSTs have the advantage that the microwave measurements are not obscured by clouds. Evaluations of global analyses have demonstrated that SST sensitivity is relevant for many aspects of Navy oceanography, including front and eddy resolution, persistent high-latitude cloud coverage, uncertainty of the ice edge, nearshore coverage, impact of clouds and precipitation events in the intertropical convergence zone (ITCZ) and western Pacific warm pool, and diurnal variations. Results of the MISST work have been reported in four peer-reviewed journal articles (Barron and Kara, 2006; Kara and Barron, 2007; Kara et al., 2008, 2009), with a fifth submitted and additional articles planned.

Both NOAA and the US Navy have explored the effect of high-resolution SSTs on Hurricane forecasts. At NOAA, the impact of high-resolution SSTs on the Statistical Hurricane Intensity Prediction Scheme (SHIPS) is being evaluated. The SHIPS model is run operationally at the National Hurricane Center for all tropical cyclones in the Atlantic and East Pacific basins. At NRL, a coupled model forecasts both storm intensity and location. The new high-resolution SSTs show a reduction in forecast error for both intensity and track prediction (see Box 5).

NEW DIRECTIONS

The MISST NOPP partnership required collaboration with other NOPP projects, members of an international science team and other scientists, industry, and government. All partnered data providers are now producing SST data in the GHRSST L2P format and all partnered operational SST analysis systems are taking advantage of the new data and producing higher temporal and spatial resolution SST products. These new SST analyses are working

BOX 4: NOAA OCEAN FORECASTING

The NOAA Ocean Prediction Center (OPC) issues operational marine weather warnings and forecasts of winds and waves for high seas areas in the North Pacific and North Atlantic oceans and offshore regions adjacent to the United States. High-resolution SST analyses are an important tool for forecasters to determine the location and strength of features associated with the Gulf Stream and Kuroshio currents, to estimate vessel freezing spray accretion rates, and to help determine numerical-model, wind-speed biases. Frequent heavy cloud cover associated with large winter storms over extra-tropical seas obscures SST measurements by IR sensors and results in a significant loss of information. Techniques that employ a combination of IR and MW SST observations have demonstrated a capability to provide much improved SST coverage.

In January 2008, OPC introduced the new NOAA National Climate Data Center (NCDC) MW and IR SST analysis into marine forecast operational National Centers All-Weather Integrated Processing System (N-AWIPS) workstations (desJardins et al., 1991). The addition of the MWIR SST complements the use of the geostationary IR SST composites and the current SST analysis available to OPC forecasters in N-AWIPS. With the addition of the NCDC SST, OPC forecasters are now able to continue to view and track ocean features such as the Gulf Stream North Wall and large eddies through persistent cloudy conditions.

Aside from the direct use of SST fields by forecasters, OPC uses SST to estimate a variety of analysis and forecast parameters such as correcting the wind speed bias of Numerical Weather Prediction models and estimating potential areas of moderate to heavy freezing spray. The current SST analysis has typically been used to calculate these parameters; however, the NCDC SST is also well suited for use in these applications. Short-term plans are to use both SST analyses in parallel.

OPC traditionally has been an operational weather forecast center, with wind warning and forecast responsibility for large ocean areas. However, in response to a growing need to produce and distribute oceanographic analyses and forecasts, OPC has an increasing oceanographic focus. The NCDC MW and IR SSTs help to fill that need.

To help make forecast decisions, NOAA Ocean Prediction Center forecasters have a variety of SST analysis products available in the operational N-AWIPS workstations, including the NOAA National Climate Data Center multi-instrument Optimally Interpolated Sea Surface Temperature.

BOX 5: HURRICANE KATRINA

The effect of SST on tropical cyclone (TC) track and intensity forecasts was evaluated for Hurricane Katrina in the Gulf of Mexico during 2005 using the US Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS, trademarked by the Naval Research Laboratory). The COAMPS simulations were initialized at 0000 UTC 24 August 2005 when Katrina was a tropical depression, and update cycles were performed every six hours until 1200 UTC 27 August, at which time two 72-hour forecasts were issued. This 72-hour time period corresponds to the time the storm made landfall. Two separate runs of COAMPS are cycled with the different SST maps as the lower boundary. Both SST maps were calculated using NCODA (NRL Coupled Ocean Data Assimilation System; Cummings, 2005). In the control run, only IR SSTs from two satellites and in situ SST measurements were assimilated. In the experimental run, an additional MW satellite SST was added to the assimilation.

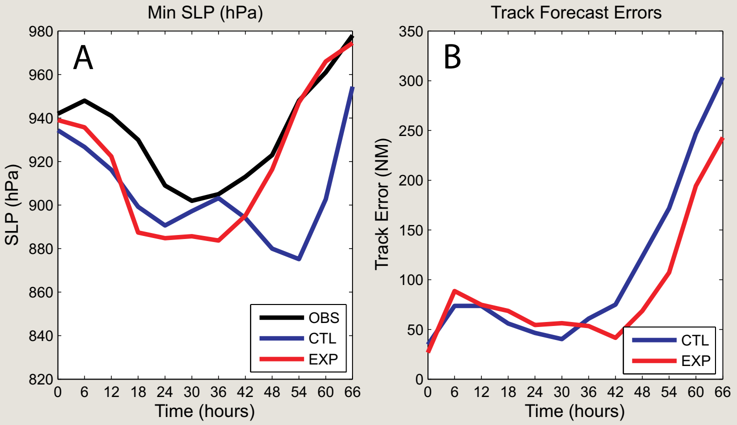


Figure B5-1. Time series of Hurricane Katrina. (A) sea level pressure (SLP). (B) Track forecast errors every six hours (12 UCT on August 27 to 0600 UTC on August 30, 2005). Colors indicate the best track data (black), the predicted IR-only SST analysis run (blue), and the predicted IR+MW SST run (red). The IR+MW SST run predicts a storm intensity (as indicated by the SLP) closer to the data than the IR-only SST run for 48–66 hour predictions. The predicted track error for the IR+MW SST run is also less than the IR-only SST run for 36–66 hour predictions. The improved location for the IR+MW SST run provided improved enthalpy fluxes and a better prediction of storm intensity.

Figure B5-1(A) shows the sea level pressure (SLP) of Katrina from the two experiments during the first 66 hours of the forecast compared with the best track data (Katrina dissipated toward the last six hours of the 72-hour simulation). The inclusion of the MW data in NCODA SST analyses clearly improves COAMPS' skill in simulating the observed intensity, including the phase change, over that of the IR-only SST analysis. The IR-only run continues to deepen the storm after 48 hours when the observed storm weakened rapidly, although the storms in the two experiments share similar intensity at the initial time. As the model forecasts continue, the track errors also increase, with track errors in the IR-only SST run 75 NM larger than the errors in the MW SST run (Figure B5-1[B]). This difference in track forecast errors between the two experiments translates into a slower northward motion of the storm in the IR-only SST case. The hurricane core region in the IR-only SST run at 48 h is still over the warm ocean, which continues to provide large amounts of heat and moisture fluxes to the storm (Figure B5-2[A]). On the contrary, the MW SST run has the storm much closer to the coastline at this time, with the northern half of the storm circulation over land and a much reduced (< 100 W m^{-2}) enthalpy flux into the system (Figure B5-2[B]). Our results suggest that the accuracy and distribution of SSTs play an important role in better hurricane track forecasts, which in turn lead to improved hurricane intensity forecasts. These improvements result from a cumulative impact of update cycles of enhanced SST data assimilation that include MW measurements of SST.

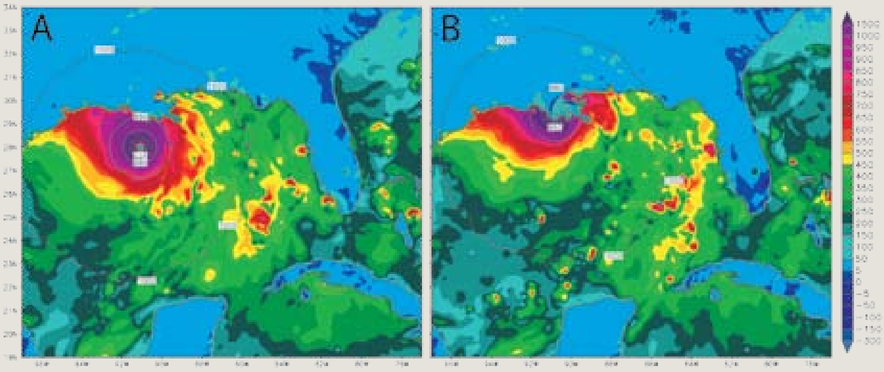


Figure B5-2. Enthalpy flux (shaded, W m^{-2}) and sea level pressure (contoured at 20 hPa intervals) in the 6-km resolution domain after 48 hours of simulation, valid at 1200 UTC on August 29, 2005. (A) The IR-only SST run. (B) The IR+MW SST run. The two runs show the difference in storm location and enthalpy flux due to the use of IR-only or IR+MW SSTs.

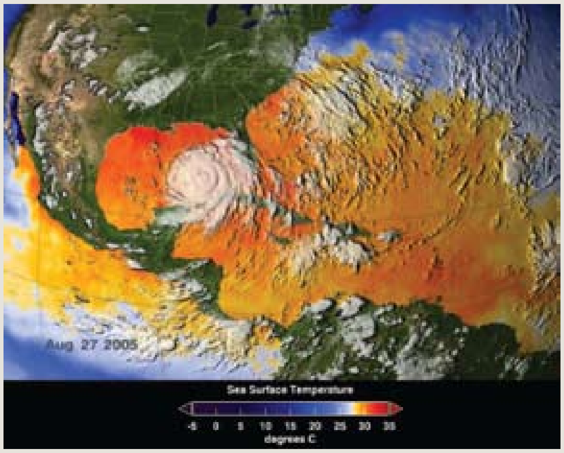


Figure B5-3. Hurricane Katrina approaches Louisiana. This image depicts a three-day average of SSTs for the Caribbean Sea and the Atlantic Ocean, from August 25–27, 2005. A hurricane needs SSTs at 82°F or warmer to strengthen. Regions with SSTs above 82°F are shown in yellow, orange, or red. *Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio* their way into operational use and are found to improve forecasts through the impact studies. In addition, we have had a strong alliance with the international GHRSST science team, working together for data exchanges and on research collaborations.

The future work of MISST focuses on continuing and broadening our accomplishments by reaching out to new operational and scientific partners. The success of the new SST L2P data leads us to focus on a full retrospective analysis of SST data sets, and research on the modeling of diurnal warming also continues to be an exciting and dynamic focus area. Although the current impact studies were performed for large-scale weather and ocean prediction, future work will move toward our coastal resources, teaming with coastal operational oceanographers.

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