

## **Multi-sensor Improved Sea Surface Temperature (MISST) for GODAE**

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<http://www.usgodae.org>

### **LONG-TERM GOALS**

The Multi-sensor Improved Sea Surface Temperatures (MISST) for the Global Ocean Data Assimilation Experiment (GODAE) project intends to produce an improved, high-resolution, global, near-real-time (NRT), sea surface temperature analysis through the combination of satellite observations from complementary infrared (IR) and microwave (MW) sensors and to then demonstrate the impact of these improved sea surface temperatures (SSTs) on operational ocean models, numerical weather prediction, and tropical cyclone intensity forecasting.

SST is one of the most important variables related to the global ocean-atmosphere system. It is a key indicator for climate change and is widely applied to studies of upper ocean processes, to air-sea heat exchange, and as a boundary condition for numerical weather prediction. The importance of SST to accurate weather forecasting of both severe events and daily weather has been increasingly recognized over the past several years. Despite the importance and wide usage of operational SST analyses, significant weaknesses remain in the existing operational products.

The improved sensors on the Terra, Aqua, and EnviSAT-1 satellites, in conjunction with previously existing sensors on several other US Navy, NASA, and NOAA satellites, provide the opportunity for notable advances in SST measurement. In addition to more frequent coverage for increased temporal resolution, these sensors permit the combination of highly complementary IR and MW retrievals. While clouds, aerosols, and atmospheric water vapor affect IR retrievals, these phenomena have little impact on MW retrievals. Characteristically, IR SST provides high spatial resolution (~1 km at nadir) but poorer coverage with the presence of clouds. Although having a reduced resolution (~25 km grid), MW SST provide >90% coverage of the global ocean each day. These factors have motivated interest in the development of merged IR and MW SST products to leverage the positive characteristics of each

sensor type. Merging multiple SST sensors into a single analysis will result in enhanced reliability, availability, and accuracy.

This project has two distinct goals: (1) producing an improved sea surface temperature (SST) product through the combination of observations from complementary infrared (IR) and microwave (MW) sensors, and (2) demonstrating the impact of improved multi-sensor SST products on operational ocean models, numerical weather prediction, and tropical cyclone intensity forecasting. Close collaboration and the international coordinated exchange of SST products with error statistics with operational agencies will optimize utility of these new data streams by US and international operational agencies. Innovative techniques to blend these complementary data will be applied in operational frameworks at NOAA and Navy. This project will make a direct US contribution to the Global Ocean Data Assimilation Experiment (GODAE) by working within the GODAE High-Resolution SST Pilot Project (GHRSSST-PP), initiated by the international GODAE steering team, to coordinate the production of a new generation high-resolution SST. By contributing to the GHRSSST-PP this team will minimize duplication of efforts, harmonize research and development activities, and maximize data access.

Consolidation of the numerous SST data products into optimal, easily accessible, new generation products shared by the US and international community, will be particularly valuable as it will maximize the synergy benefits of previously unavailable combined IR and MW SST products. This effort will ensure that US scientists and operational activities remain at the forefront of the international ocean and weather forecasting activities and are provided with state-of-the-art SST data products and analyses.

## **OBJECTIVES**

To produce multi-sensor improved SSTs and successfully assess the impact of these products, five clear project objectives have been identified:

- 1) Computation of sensor-specific observational error characteristics is required for optimal application and data fusion techniques.
- 2) Parameterization of IR and MW retrieval differences, with consideration of diurnal warming of the ocean surface and cool-skin effects at the air-sea interface is required for multi-sensor blending and production of both skin and bulk analyses.
- 3) Production and dissemination of sensor-specific SST products with associated retrieval bias error, standard deviation (STD), and diurnal warming estimates to the application user community.
- 4) Production and dissemination of improved multi-sensor high-resolution skin and bulk SST analyses to demonstrate and optimize utility in operational applications.
- 5) Targeted impact assessment of the SST analyses on hurricane intensity forecasting, numerical data assimilation by ocean models (both national and within GODAE), numerical weather prediction, and operational ocean forecast models.

## **APPROACH AND WORK PLAN**

Production of a multi-sensor, improved SST product requires detailed, consistent processing of all input data and characterization of retrieval errors and differences in addition to development of fusion techniques. Much of the methodology to be applied is selected for consistency with the GHRSSST-PP Data processing Specifications (GDS), which is being designed to produce SST data products that satisfy the requirements of existing operational ocean forecast and prediction systems.

This project will also provide an assessment of the operational impact of improvements by the enhanced sampling and error characterization of the IR and MW sensors in the areas of NWP and ocean modeling. Targeted applications include Navy fleet operations, naval and civilian NWP, operational oceanography, and climate monitoring and forecasting. Each of these areas is of national importance and has corresponding national programs. For each of these applications, it is anticipated that this project will provide significant enhancements to the quality and availability of data. Through affiliation with the GHRSSST-PP, the products will also be directly utilized by the international GODAE modeling communities. This product sharing will be achieved through the partnerships and close connections between the data provider and user communities.

The MISST project has a broad partnership of scientists from academia, government, and private industry, including **Remote Sensing Systems** (C. Gentemann), **NOAA** (G. Wick, J. Cione, K. Casey, E. Bayler, M. DeMaria, R. Reynolds), **NRL** (J. Cummings, C. Barron, N. Baker, J. Goerss), **NAVOCEANO** (D. May), **NASA JPL PODAAC** (J. Vasquez), **U. Maryland** (A. Harris), **U. Edinburgh** (C. Merchant), **U. Miami** (P. Minnett, B. Evans, E. Chassignet), **U. Colorado** (B. Emery, S. Castro), **WHOI** (B. Ward), and the **International GHRSSST-PP Project Office** (C. Donlon). The project has identified specific tasks: data provision (C. Gentemann, B. Evans, D. May, E. Bayler), determining sensor errors (G. Wick, C. Gentemann, A. Harris, P. Minnett, B. Evans, S. Castro, B. Emery, D. May), modeling diurnal warming and skin layer effects (G. Wick, C. Gentemann, S. Castro, B. Emery, B. Ward), production and distribution of data analyses (J. Cummings, E. Bayler, J. Vasquez), and performing impact studies (E. Bayler, J. Cione, J. Goerss, N. Baker, E. Chassignet, C. Barron).

Additionally, this NOPP project is closely partnered with two other NOPP projects: “U.S. GODAE: Global Ocean Prediction with the HYbrid Coordinate Ocean Model (HYCOM)” and “POSITIV: Prototype Operational System – ISAR – Temperature Instrumentation for the VOS fleet”. The HYCOM Consortium will evaluate the impact of the improved SSTs on its ocean forecast system and the POSITIV ocean temperatures will be utilized in NRT for error characterization of satellite SST retrievals.

During the first year of the project (June 2004 – June 2005) we plan to (1) purchase and install a data production facility, download datasets, and provide interfacing software, (2) write software to calculate time of observation for MODIS data, (3) establish and populate diagnostic datasets and a collocated *in situ* satellite database, (4) begin development of error characteristics for AVHRR, TMI, and AMSR-E SSTs, (5) begin production GHRSSST-PP compatible datasets for AVHRR, TMI, AMSR-E SSTs, and (6) begin development of models to determine diurnal warming and skin layer effects.

## **WORK COMPLETED**

(1) The data production facility specifications are being determined and purchase is planned for June 2005. (2) MODIS time of observation has been calculated for the first 2 years of the instrument, from orbital track information provided by U. Miami and an instrument data simulator provided by RSS. (3) Collocated satellite *in situ* database has been established and populated for AVHRR, MODIS, AMSR-E, and TMI. They are available in NRT from NAVOCEANO, U. Miami, and RSS. The diagnostic datasets are not completed as the GHRSSST project is refining the file format. (4) Initial error characteristics reports have been completed for AVHRR, TMI, and AMSR-E. (5) GHRSSST-PP compatible datasets are being produced for AMSR-E and are expected to be publicly released

1/31/2005. (6) Initial models for diurnal warming and skin layer effects have been delivered and sensitivity studies initiated.

## RESULTS

Significant progress has been made towards a better understanding of the errors in MW and IR SST retrievals and methods to estimate these errors in NRT. Better estimates of sensor errors are necessary for multi-sensor data fusion because the accuracy of the commonly used statistical method depends on the accuracy of our understanding and modeling of biases between sensors.

A report on AVHRR error statistics has been completed, using moored and drifting buoy reference observations. The reported statistics are presented for one year of NOAA-17 operation where the results are stratified a number of different error sources. Additionally, the effect of aerosols on IR SSTs is being investigated. Initial studies have been carried out to model the effects of various types of aerosol on top-of-atmosphere brightness temperatures in the three AVHRR thermal-IR window channels (3.7, 11 and 12  $\mu\text{m}$ ). For each type of aerosol, a correction is possible with two parameters: clear-sky transmittance and the air-sea temperature difference.

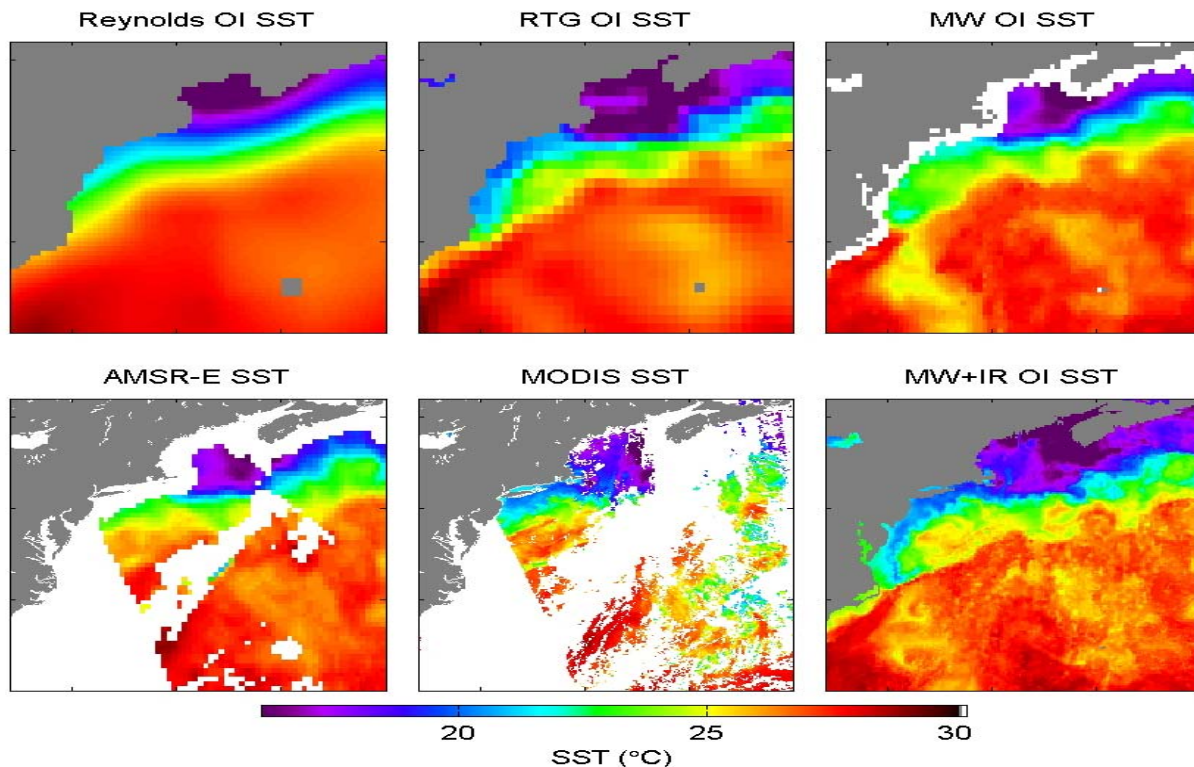
TMI and AMSR-E error statistics were computed using both *in situ* data and the Reynolds optimum interpolated analysis. The errors are stratified by SST and wind speed. A NRT analysis of *in situ* collocation to satellite data was completed. The initial reports are currently being used to produce the GHRSSST formatted AMSR-E SSTs.

NAVOCEANO has developed a methodology to add information on retrieval error to the US NAVY operational data stream. This method adds quantitative estimates of reliability to every MCSST sample operationally generated at NAVOCEANO. The current scheme appears to be robust and low-maintenance, both attributes being major requirements in an operational environment. Future work may include expanding the assignment of reliability estimates to samples that are currently discarded. This would allow end-users to select the data according to their actual needs.

NRL has developed an analysis metrics document; a quality control test for diurnal warming that incorporates model wind speed and solar radiation fields. These data are available on the GODAE server in NRT. Additionally, a NRT global, 9-12 km SST analysis has been running at FNMOC since November 2004. This analysis currently uses *in situ* and AVHRR SSTs but the infrastructure for AMSR-E SSTs has been established and they will be incorporated once available. A formal evaluation of SST observation errors provided by NAVO has been initiated.

An initial model of diurnal warming was provided to the MISST team members. The development of the model focused on determining a simple model that could be easily applied to NRT satellite data. It was determined that a quadratic dependence on modeled top-of-atmosphere daily-averaged insolation, exponential dependence on wind speed, and a time dependence described by a five-term Fourier series best described the diurnal warming. The model was tested with AMSR-E SST and was determined to diminish the magnitude of the mean difference and standard deviation. Further extensions to the diurnal model are being explored through sensitivity studies. The sensitivity of estimated diurnal warming at the ocean skin and 1-m depth to the assumed wind speed and insolation has been evaluated using the warm layer/cool skin theoretical model. While it may be impractical to run a full diurnal thermocline model operationally given the limited satellite-derived inputs, the model is useful in helping decompose, from simpler parameterizations, the various contributions of uncertainty to

estimates of diurnal warming. The more complex diurnal model was used to help determine what inputs might provide the best results and how the warming uncertainties would vary as a result of these choices.



**Figure 1.** This figure shows Gulf Stream SSTs on September 21, 2003. The top row of images show currently available interpolated SST analyses. The top, left image shows the Reynolds OI SST, a weekly 100km SST, is the most widely used SST for weather and climate. The top, center image shows the Real-Time-Global (RTG) SST, a daily 50 km SST. The top, right image shows the MW OI SST, a daily 25km SST. In the bottom row, the left image shows data from a single orbit of AMSR-E SSTs (25km resolution), the center image shows 4 km MODIS SSTs, and the right image shows a 10 km optimal interpolation of the AMSR-E and MODIS data for a three-day window centered on September 21, 2003.

Figure 1 shows an example of data merging in the Gulf Stream region. AMSR-E (bottom, left image) and MODIS (bottom, center image) data clearly show some of the MW and IR data characteristics discussed previously. The optimally-interpolated IR and MW data shown in the bottom image is clearly better than either individual product, and a significant improvement on any of the available interpolated products shown in the top row of images. Better error statistics, diurnal modeling, and data provision in NRT, all on-going areas of research within this project, are focused towards operationally producing this kind of 10 km daily analysis in NRT.

## IMPACT AND APPLICATIONS

### National Security

SST is routinely used both directly in Naval fleet operations and as an input to weather forecast models used to support Naval operations. The improved SST products and better understanding of the associated errors resulting from this project will provide a more accurate description of environmental conditions enabling better planning of operations. A key aspect of this project is directly evaluating the impact of the improved SSTs on Naval applications. SSTs are also a key parameter for identifying

the location and strengths of thermal fronts and eddies, information crucial to assessing the acoustic environment for submarine and antisubmarine operations, as well as for Homeland Security considerations of coastal currents and eddies for public health and safety in the advent of deliberate dumping and dispersion of hazardous material.

### **Economic Development**

SST data is a significant consideration for planning and conducting commercial fishing operations, as well as fisheries management and monitoring efforts. Likewise, SST data is relevant to marine protected species monitoring and de-conflicting protection efforts from commercial fishing.

### **Quality of Life**

The potential for producing more accurate SST products has important application to areas including environmental monitoring and weather forecasting. More accurate knowledge of the SST can lead to improved understanding of coral health, better forecasting of routine and severe weather events, improved recreational fishing, and increased ability to monitor climate change. Improved understanding in these areas will lead to a more informed public and better decision-making. The specific focus on tropical cyclone intensity forecasting will potentially impact warning and evacuation decisions.

## **TRANSITIONS**

### **National Security**

Through direct project partnership with US Navy efforts, the improved SST products and methodologies will be directly integrated into Naval SST products and numerical weather forecasting procedures both in use and under evaluation. As one example, improved error characterization will be incorporated in the NCODA model. To accomplish the goal of determining the impact of the SST improvements on Naval applications, transitioning results to the Naval partners is a central focus of this project.

### **Economic Development**

Satellite IR SST data are already in use by the National Marine Fisheries Service. Improved coverage in persistently cloudy regions will facilitate protected species and fisheries management efforts. The merged IR-MW SST product will be provided when available via the NOAA CoastWatch program.

### **Quality of Life**

Key impact assessments are planned in the areas of numerical weather prediction and tropical cyclone intensity forecasting through the activities of project partners. New SST retrievals and improved error estimates are to be integrated into existing forecast models to determine their impact. Additionally, the merged products will be provided to NOAA's National Weather Service (NWS) National Centers for Environmental Prediction (NCEP)'s Ocean Prediction Center to support ocean forecasting of winds and waves, as well as thermal conditions. Through involvement with the international GHRSSST-PP, the resulting products will be further available for incorporation by a diverse, interested user group.

## **RELATED PROJECTS**

“U.S. GODAE: Global Ocean Prediction with the HYbrid Coordinate Ocean Model (HYCOM)”:

<http://hycom.rsmas.miami.edu/>

“POSITIV: Prototype Operational System – ISAR – Temperature Instrumentation for the VOS fleet”