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

Lead PI : Chelle L. Gentemann
438 First St, Suite 200; Santa Rosa, CA 95401
Phone: (707) 545-2904x14 FAX: (707) 545-2906 E-mail: gentemann@remss.com

CO-PI: Gary A. Wick
NOAA/ETL R/ET6, 325 Broadway, Boulder, CO 80305
Phone: (303) 497-6322 FAX: (303) 497-6181 E-mail: gary.a.wick@noaa.gov

CO-PI: James Cummings
Oceanography Division, Code 7320, Naval Research Laboratory, Monterey, CA 93943
Phone: (831) 656-5021 FAX: (831) 656-4769 E-mail: cummings@nrlmry.navy.mil

CO-PI: Eileen Maturi
NOAA/NESDIS/STAR/SOCD, Room 601 WWB, 5200 Auth Road, Camp Springs, MD 20746
Phone: (301) 763-8102x172 FAX: (301) 763-8572 E-mail: Eileen.Maturi@noaa.gov

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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 (NWP), 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. Merging multiple SST sensors into a single analysis will result in enhanced operational reliability, data availability, and analysis accuracy.

This project has two distinct goals: (1) producing an improved sea surface temperature (SST) product through the combination of observations from complementary IR and 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 GODAE by working within the GODAE High-Resolution SST Pilot Project (GHRSST-PP), initiated by the international GODAE steering team, to coordinate the production of a new generation high-resolution SST. By contributing to the GHRSST-PP this team will minimize duplication of efforts, harmonize research and development activities, and maximize data access.

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. 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. 3) Production and dissemination of Level 2 Processed (L2P) sensor-specific SST products. 4) Production of improved multi-sensor high-resolution SST analyses. 5) Targeted impact assessment of the new SST analyses.

APPROACH

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 GHRSST-PP Data processing Specifications (GDS), which is 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 GHRSST-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, NOAA (NESDIS, NCDC, NODC, ESRL), US Navy (NRL, NAVOCEANO), NASA (JPL PODAAC), U. Maryland, U. Edinburgh, U. Miami, Florida State U., U. Colorado, Old Dominion U., and the International GHRSST-PP Project Office.

WORK COMPLETED

(1) Produced GHRSST-PP compliant L2P formatted data for AVHRR, GOES-E, GOES-W, MODIS-Terra, MODIS-Aqua, TMI, and AMSR-E SSTs (2) continued the NRT *in situ* satellite database, (3) determined and updated SSES for AVHRR, GOES-E, GOES-W, MODIS-Terra, and MODIS-Aqua, TMI, and AMSR-E, (4) updated diurnal and skin layer modules, (5) continued development on blended SSTs, and (6) performed impact studies.

RESULTS

(1) Produced GHRSST-PP compliant L2P formatted data for AVHRR, GOES-E, GOES-W, MODIS-Terra,MODIS-Aqua SSTs, TMI, and AMSR-E . GHRSST compliant L2P SSTs are being produced by the NOAA Office of Satellite Data Processing and Distribution (OSDPD) operational environment for GOES-E and GOES-W. NASA's Ocean Biology Processing Group (OBPG) produces L2P SSTs for MODIS TERRA and AQUA. RSS produces TMI and AMSR-E L2P SSTs in GHRSST compliant L2P data format. NAVOCEANO produces AVHRR L2P SSTs. MODIS, TMI, and AMSR-E L2P data are available for both NRT and archive (from launch). All MISST datasets are provided to the NASA JPL Global Data Assembly Center for NRT distribution and archived at the NOAA NODC GHRSST Long Term Stewardship and Reanalysis Facility (LTSRF, http://ghrsst.nodc.noaa.gov).

(2) Continued the NRT in situ satellite database. Database updated continually with AVHRR by NAVOCEANO, with TMI and AMSR-E by RSS, and with GOES-E, GOES-W, MT-SAT, and MSG by NOAA. The database is updated monthly for MODIS TERRA and AQUA by U. Miami.

(3) Determined and updated SSES for GOES-E, GOES-W, MT-SAT, MSG, MODIS-Terra, and MODIS-Aqua. GOES SSES are determined using clear-sky transmittance calculated from radiative transfer modeling and NCEP air-sea temperature differences. A complete set of SSES, the MODIS uncertainty hypercubes for mean and standard deviation, have been generated for TERRA and AQUA using all available *in situ*-satellite matchup points from launch through mid-2007. Error characteristics for AVHRR are continually updated by NAVOCEANO. NOAA and the University of Colorado have extended the derivation of alternative environmentally-based SSES for AVHRR to include the sensor on the NOAA-18 satellite. The study specifically evaluated the retrieval bias as a function of SST to fulfill a request from the Navy to understand the sources of the SST bias at cold temperatures in the NAVO retrieval algorithm. SSES for TMI and AMSR-E are continually updated. Static error tables for TMI and AMSR-E were updated after the September 2006 TMI and AMSR-E reprocessing.

(4) Updated diurnal and skin layer modules. An improved physics-based diurnal warming model, the Profiles of Ocean Heating (POSH) model, has been developed specifically for application within this project. Validation of a detailed second moment turbulence closure model for diurnal warming was extended with new skin layer observations and characteristic temperature profiles were generated from idealized forcing for incorporation in the simplified diurnal warming model.

(5) Continued development on blended SSTs. The MISST project has several blended SST analyses. The research analysis is developed at RSS while operational analyses are being developed within NOAA and US Navy. This project is focused on the transition of research to operations. Development of blended SSTs requires new data streams. NAVOCEANO has improved on its methodology to add

retrieval error information to the US Navy operational data stream. Quantitative estimates of reliability are added to each MCSST sample utilized at NAVOCEANO. NOAA has extended coverage of SST retrieval from geostationary satellites to include MT-SAT and Meteosat-9. Both sensors have some calibration issues which will be addressed in the final SST product. NOAA is operationally producing a new daily blended POES/GOES analysis. RSS is producing a blended daily 9 km global SST analysis using MODIS, TMI, and AMSR-E data (Fig. 1). This analysis includes corrections for diurnal warming.

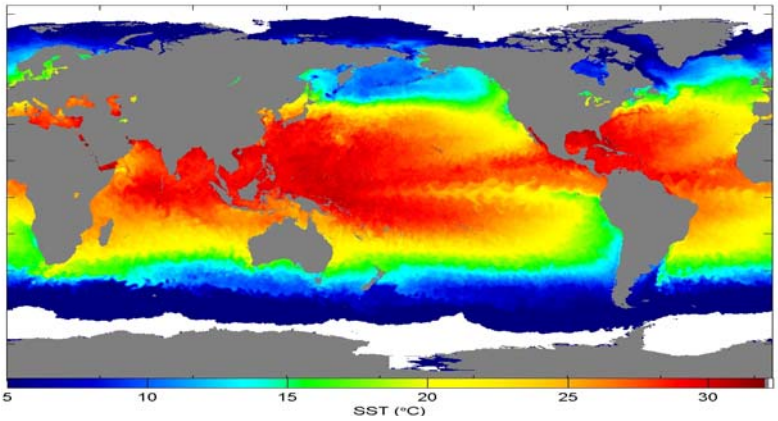

Fig. 1. Global 9km MODIS, TMI, and AMSR-E blended SST on 1 September 2007.

(6) Performed impact studies. The effect of sea surface temperature (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®). The inclusion of microwave SST data in the NRL Coupled Ocean Data Assimilation System (NCODA) SST analyses clearly improves COAMPS skill in simulating the observed storm intensity and track (location), over that of the IR-only SST analysis (Fig. 2). 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.

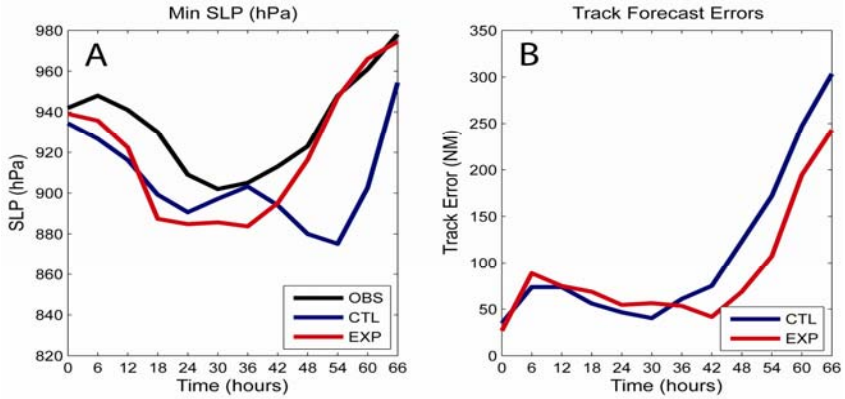

Fig. 2. Time series of Hurricane Katrina every 6 hours (12 UCT 27 August to 0600 UTC 30 August 2005, from the best track data (black), the IR-only SST analysis run (blue) and the IR+MW SST run (red). A) The sea level pressure. (SLP) B) The track forecast errors.

NRL globally evaluated the existing operational MODAS AVHRR-only SST and RSS MW SST. Overall performance of global SSTs from individual sensors and blended products showed error levels similar to the observational uncertainty. Transition to a blended SST would not be expected to have a

large impact globally; however, in regions with persistent cloud cover the RSS MW SST gave superior correlations. Demonstration of positive improvement in some regions with no significant overall negative impact has led to a plan to transition a blended NCODA SST into Navy operational ocean products in 2008.

The NOAA Ocean Prediction Center (OPC) issues operational marine weather warnings and forecasts of winds and waves for high seas area in North Pacific and North Atlantic oceans and offshore regions adjacent to the U.S. The OPC introduced the L4p analysis Optimum Interpolation Sea Surface Temperature (OISST) Product developed by Reynolds, et al., 2007 into marine forecast operational National Centers All-Weather Integrated Processing System (N-AWIPS) workstations in January 2008. The addition of the OISST complements the use of the GOES SST composites and the NCEP Real Time Global SST analyses presently available to OPC forecasters in N-AWIPS. With the addition of the OISST, 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.

NOAA evaluated the impact of blended MW SSTs on the Statistical Hurricane Intensity Prediction System (SHIPS). Results from the SHIPS evaluation shows that the MW SST product reduced the intensity forecast error by about 2% for the Atlantic forecasts, with small positive to neutral impact for the eastern Pacific sample. These results indicate that there is the potential to improve operational hurricane intensity forecasts by improving the SST analysis through the inclusion of MW data.

IMPACT/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.

Science Education and Communication: The NASA Earth Observatory (EO) provides an online magazine includes feature articles, daily news and images, breaking news Earth Sciences events (www.earthobservatory.nasa.gov). MISST SSTs provide visuals for a variety of media updates, alerts (the most common of which are hurricane-related), and a number of museum projects. These data are quite useful for periodic requests from NASA/GSFC Public Affairs Office, staff scientists wanting to talk about events with reporters, etc. The MISST SSTs has also been appearing in flagship NASA productions, (eg: Hurricane Watch (www.nasa.gov/mission_pages/hurricanes/main/index.html), of which one of the most intriguing visualizations uses MISST SSTs, GOES clouds, and recorded storm tracks to show the 2005 hurricane season: (http://learners.gsfc.nasa.gov/mediaviewer/27storms/).

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, in FYO8 the NRL will begin transition of the Navy Coupled Ocean Data Assimilation (NCODA) global SST into the operational data stream at NAVOCEANO for use in operational models. MISST contributed to the development of the NCODA SST, which blends IR and MW SSTs with *in situ* observations. The NCODA SST will replace the existing MODAS SST which utilizes only IR AVHRR observations from polar orbiters. To accomplish the goal of determining the impact of the SST improvements in 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, to support forecast of wind and waves, the MISST SST merged products have been integrated into NOAA's Ocean Prediction Center (OPC) for operational marine forecasts. Through involvement with the international GHRSST-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"
CIRA/CSU Joint Hurricane Testbed project (http://www.nhc.noaa.gov/jht/05-07_proj.shtml)
NRL Ocean Data Assimilation (ODA) project funded under PMW 180
NRL Improved Synthetic Ocean Profiles (ISOP) project funded under ONR

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