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

Dr. C.L. Gentemann
Remote Sensing Systems, 444 Tenth St., Suite 200; Santa Rosa, CA 95401
Phone: (707) 545-2904x14 Fax: (707) 545-2906 E-mail: Gentemann@remss.com

Co-I: Dr. Kenneth Casey
NOAA/NODC, 1315 East-West Highway, Silver Spring MD 20910
Phone: (301) 713-3272x133 Fax: (301) 713-3300 E-mail: Kenneth.casey@noaa.gov

Co-I: Dr. Peter Cornillon
U. of Rhode Island, Graduate School of Oceanography, South Ferry Road Narragansett, RI 02882
Phone: (401) 874-6283 Fax: (401) 874-6728 E-mail: pcornillon@gso.uri.edu

Contract Number: NA11NOS0120167
http://www.misst.org

LONG-TERM GOALS

Sea Surface Temperature (SST) is vital to coastal and marine spatial planning, global weather prediction, climate change studies, search and rescue, and ecosystem based management. SST is derived from measurements taken by numerous satellites carrying infrared and microwave radiometers, and measured from moored buoys, drifting buoys, and ships. This project focuses on completing research to improve the quality of the satellite SSTs from existing and new sensors, produce multi-sensor blended gap-free SSTs from US and international datasets, and successfully broaden the use of these products within specifically targeting coastal applications and the Integrated Ocean Observing System (IOOS).

OBJECTIVES

The objectives of this project are to (1) improve and continue generation of satellite SST data and SST analyses in the IOOS DMAC and CF compliant Group for High Resolution Sea Surface Temperature (GHRSST) Data Specification GDS format; (2) distribute and archive these data; and (3) use this improved SST data in applications, many specifically targeted for the Integrated Ocean Observing System (IOOS).

APPROACH AND WORK PLAN

In the full proposal, each task has been assigned to one or more partners. This partnership consists of 28 scientists from industry, academia, and government with wide ranging experience spanning the initial calibration of satellite sensors, development of SST algorithms, assessment of SST uncertainties, production of NRT satellite data, research into data fusion methodologies and the production of blended data sets, research into diurnal warming and the cool skin effect which both affect satellite SST measurements, and applications that utilize SSTs.

WORK COMPLETED

FY3 6/1/2013-5/31/2014

Task 1.2 *Process and distribute L2P AVHRR HRPT SSTs for the eastern North Atlantic 1993-present (Cornillon),* We have acquired all of AVHRR HRPT data for the western North Atlantic (Wallops Island receiving station) from 2000 through 2010. We have extended the archive of L1a data acquire from CLASS through March 2013 while we await the final version of the processing algorithm from the University of Miami. Data through 2010 have been processed through the Pathfinder retrieval algorithm yielding L2 SST fields. These fields have been analyzed and a problem with the daytime quality flag has been detected. The problem will be fixed and the data rerun through the retrieval algorithm. On completion of the reprocessing, the data will again be validated, then sent to NODC for the addition of GHRSST-recommended fields and reformatting to GDS 2.0. As noted above we still await the final processing algorithms from U. Miami. In the meantime, in addition to acquiring the Wallops Island data stream from CLASS for 2011-2013, we have also acquired all available L1 data from IMARPE in Peru covering waters of the western South Pacific from 1998-2008. Some of these data are on old tapes. We have located a reader that is capable of reading them and will begin conversion to disk soon. The rest of the data are on disk. We are also acquiring an extensive archive of L1 data from the Karlsruhe Institute of Technology, 3+TB at present and counting. Finally, we are (hopefully) in the final stages of debugging the ingest program for 1981-2000 HRPT data for the western North Atlantic and the eastern and western North Pacific in our archive. A significant fraction of these data are not available in CLASS. *GPM GMI (Gentemann) in GDS 2.0.* Waiting and preparing for GPM launch. *Obtain and utilize Sentinel-3 SLSTR L2P data provided by GHRSST (May and McKenzie).* NAVOCEANO is in the final stage of making NPP VIIRS SST operational. L2P datasets in GDS 2.0 will be produced soon after NPP VIIRS SST is operational. METOP-B data has yet to arrive at NAVOCEANO due to the delay in launch.

Task 1.3 *Provide recommendations for integrated MISST lake temperature products (Crosman).* We have acquired in situ buoy temperature data for a number of lakes (e.g., Salton Sea, Laurentian Great Lakes, Great Salt Lake) and continue working with the GHRSST Inland Waters Working Group coordinating a SST validation and metadata archive for lakes worldwide. We have identified a growing list of current lake temperature products (NAVOCEANO and others) to evaluate and have gathered subsets of these products over various lakes in preparation for upcoming validation between these products and in situ buoy data. We continue to document known issues in lake temperature products (e.g. retrieval, cloud mask, land mask errors) as they are discovered.

Task 1.4.1 *Calculate 6-hourly diurnal warming estimates from POSH, CG04, and other models using NWP output in NRT (Gentemann, Castro).* Publication of manuscript describing comparisons of diurnal heating from Near-Surface Argo floats and SEVIRI satellite data. Castro et al., (2014). RSE, 140, 789-799, doi: 10.1016/j.rse.2013.08.042, *Apply diurnal cycle correction to G1SST (Chao). Implemented facility (Castro in collaboration with Gary Wick, from NOAA) for computation and evaluation of diurnal warming estimates from multiple numerical models forced with real time numerical weather predication forecast data from the NOAA NCEP Global Forecast System model. Real time function to be turned by early 2014 and run at NOAA.*

Task 1.5 *Revision of VIIRS SST SSES; publication on shallow-water diurnal heating and SST signatures (Minnett, Evans).* Marine-Atmosphere Emitted Radiance Interferometers (M-AERI's) have been mounted on cruises of the NOAA Ship *Ronald H Brown* and the R/V *Knorr* for research cruises

in the Atlantic Ocean, and Infrared Sea surface temperature Autonomous Radiometers (ISAR's) have been installed on commercial vessels in the Pacific Ocean to assess the accuracies of the VIIRS skin SST retrievals. The VIIRS SST uncertainties are small (e.g. for 78 matchups for the *Knorr* cruise, the mean error is 0.024K, with a standard deviation of 0.201K). A paper has been submitted to the reviewed literature: Zhu, X., P. J. Minnett, J. Hendee, C. Manfrino and R. Berkelmans. Diurnal Warming in Shallow Coastal Seas. *Continental Shelf Research. Investigate accuracy of satellite retrievals relative to profiling float data and impact of tightening satellite-buoy matchup time and distance constraints on accuracy statistics (May and McKenzie). Determine SSES for GPM GMI (Gentemann).* Waiting for launch. *Evaluate NPP products (Banzon).* Evaluation put on hold until stable algorithm available. NCDC has focused instead on transferring the OISST code to a virtual machine in preparation for a more expanded reprocessing capability. The evaluation of VIIRS will be done afterwards. *Analyze SSES formulations for GOES, SEVIRI and MTSAT (Castro). Analyze buoy (drifting + moored) SSTs for identification of regional biases and SSES specification (Emery). Develop new calibration for GOES and AVHRR HRPT (Mittaz & Harris).* Reported on new GOES calibration at EUMESAT 2013 and finalizing AVHRR/3 calibration for dissemination

Task 1.6.1.1 *Process and distribute MWIR SST in GDS 2.0 (Gentemann).* Expect to release GDS2.0 in Jan 2014. Currently working on final testing of code.

Task 1.6.2 *Continue production of MUR using the HRPT and VIIRS data (Chin).* Six tera-bytes of HRPT data have been transferred from P.Cornillon to the JPL Team (Chin, Vazquez) and are in process of being incorporated into MUR. The new NAVO VIIRS L2P data set was ingested into MUR as the sole 1-km resolution input data set during the October 2013 Federal government shutdown and shown to be an effective replacement of the MODIS L2P whose delivery had been disrupted. (MUR was later reprocessed with the MODIS data sets when their delivery resumed.) *Include new NAVOCEANO/MISST data streams (Sentinel-3 SLSTR) into NCODA analysis (Barron).* With the launch of Sentinel-3 pushed back from 2013 until 2014 or later, work on new SST data streams has included NPP (VIIRS), GCOM-W1 (AMSR-2), MSG (SEVIRI), and COMS-1 and MTSAT imagers. Experiments are underway to evaluate the impact of these data streams in global and regional assimilative ocean model analyses and forecasts.

Task 1.6.4.1 *Participate in GHRSST L4 analysis intercomparison project using formal analysis error estimates (Cummings).* Intercomparison of GHRSST L4 SST analyses can best be performed by calculating formal analysis errors and checking to see if an analysis lies outside the error bounds of another analysis. This comparison can be done grid point by grid point with maps produced to illustrate areas of statistically significant differences. These areas can then be examined for cause: differences in data assimilated, differences in covariance models, etc. The FNMOC SST analysis produced by NRL is a contribution to GHRSST and GMPE and has the capability of computing formal analysis error. These error fields are routinely computed for both SST and sea ice and are made available on the US GODAE server (http://www.usgodae.org/ftp/outgoing/fnmoc/models/ghrsst/latest_data/). However, there has been no guidance from the chair of the GHRSST IC-TAG working group on a way forward here using analysis error fields in L4 intercomparison within GHRSST.

Task 2.2 *Continue archiving and providing IOOS-based access to and discovery of all MISST products. Update virtual aggregations for all gridded MISST products. Maintain and update LAS access to gridded MISST products.* The LTSRF now accepts GDS2 data and OPeNDAP/TDS services are provided. All GHRSST/MISST data provided to the LTSRF are archived and made available daily.

Virtual aggregations have been created for all L3 and L4 data and are in the NODC Live Access Server (http://data.nodc.noaa.gov/las). A rich inventory (RI) has now being computed for the GDS2-compliant Pathfinder Version 5.2 data and is also available on the LAS. The RI contains total valid observation number, observation number over a 3-sigma edit, mean, standard deviation, minimum, maximum, and median for SST, 10 m wind speed, sea ice fraction, and aerosol dynamic indicator globally and for these geographic subsets: 540 x 540 pixel tiles, low latitudes, Southern and Northern mid-latitudes, Arctic, Antarctic, and Nino34 (note: the rich inventory is a "red" item and not funded by MISST, but we are continuing to make progress on it with NODC-provided resources). The MUR team (Chin, Vazquez) has assisted JPL scientists (Gierach, Holt) to compare MUR and bouy SST values over the Great Lakes (good agreement overall).

Task 2.3 *Conduct satellite applications class for marine managers and researchers featuring GHRSST products. (Foley).* Several additional MISST L3 and L4 products have been placed for fully interoperable access on the ERDDAP server at NOAA/SWFSC/ERD (http://coastwatch.pfel.noaa.gov/erddap). We continue to establish partnerships with fisheries and protected species researchers to ensure that they are aware of these data sets, and can readily access and use them. These have resulted in the inclusion of MISST products in peer-reviewed publications, providing a pathway to establish MISST products in resource management. MISST products have been put forward at a series of National and International Training Workshops. *Attend IOOS RA annual meeting to present MISST SST datasets (Gentemann).* We have participated and presented at several IOOS telecons.

Task 3.1 *Utilize proposed higher resolution MISST L4 data products to increase predictability of annual coral bleaching at American Samoa and to explain historical record of episodic bleaching at Florida and Caribbean reef sites (Hendee, Gramer).*

Task 3.4 *Determine gradients and fronts for 1993-present AVHRR HRPT SST fields for the eastern N. Atlantic (Cornillon). Incorporate new NAVOCEANO/MISST data streams (Sentinal-3 SLSTR) into NAVOCEANO assimilative ocean models to be evaluated in IOOS regional SST forecasts. Include evaluations of diurnal signals (Barron), Evaluations were reported examining different GHRSST and NAVOCEANO data streams in the Gulf of Mexico (IOOS-region) and the Mediterranean Sea focusing on the interaction of the new data streams with alternate data assimilation approaches under conditions of diurnal warming. 3DVAR with and without First Guess at Appropriate time showed different levels of effectiveness depending on the amplitude and timing of diurnal variations relative to the nowcast analysis time and forecast length.*

Task 3.6 *Compare 6-hourly skin-SST analyses with other MISST L4 analyses that include diurnal warming component (Cummings).*

Tasks 3.7 and 3.8 *Implement ocean observing sensitivity system in coupled model support of CeNCOOS (Cummings).* Work is moving forward on implementing the coupled COAMPS model for support of CeNCOOS. With the ocean forecast model in place in the coupled system the adjoint of the 3DVAR ocean data assimilation system can be executed to compute data impacts of ocean observations assimilated on reducing coupled model forecast error. In addition, a diurnal warming SST model (Zeng and Beljaars, 2005) has been integrated with the COAMPS atmospheric model. Here, we will perform experiments in the CeNCOOS region with direct assimilation of satellite SST radiances using the coupled model state as the prior information (both ocean and atmosphere) in the forward modeling.

RESULTS

We continue to establish partnerships with fisheries and protected species researchers to ensure that they are aware of these data sets, and can readily access and use them. These have resulted in the inclusion of MISST products in peer-reviewed publications, providing a pathway to establish MISST products in resource management. MISST products have been put forward at a series of National and International Training Workshops.

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 (Delete this section if there are none)

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.

Science Education and Communication (Delete this section if there are none)

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. 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. MISST SST fields will be used for targeted applications including IOOS regional partners, coral reef research and monitoring, fisheries planning, commercial fisheries.

RELATED PROJECTS

The need for a uniform approach to SST measurements and estimation of measurement errors resulted in the formation of the international Group for High Resolution SST (GHRSST), with partners in Japan, Europe, Australia, and the United States. This groups acts to coordinate international collaboration, research, and SST data sharing. A full description of GHRSST can be found at http://www.ghrsst.org.

NASA's Physical Oceanography Data Active Archive Center (PO.DAAC) is the GHRSST global data assembly center (http://ghrsst.jpl.nasa.gov). After 30 days, all of the data are sent to the GHRSST Long Term Stewardship and Reanalysis Facility (LTSRF) at NOAA's National Oceanographic Data Center (NODC, http://ghrsst.nodc.noaa.gov) for long term preservation and to support climate-oriented applications. This global, collaborative system supports the research necessary to estimate and reduce uncertainty in SST retrievals and improve the multi-sensor blending methodology, which in turn results in enhanced societal benefits.

MISST SST fields will be used for targeted applications including IOOS regional partners, coral reef research and monitoring, fisheries planning, commercial fisheries, Navy fleet operations, naval and civilian NWP, operational oceanography including coastal applications, and climate monitoring and forecasting. More information on IOOS is available at www.ioos.gov.