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

Dr. C.L. Gentemann
Unaffiliated
Phone: (707) 363-9215 E-mail: cgentemann@gmail.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

Navy Partners
Charlie Barron, Naval Research Laboratory, Stennis Space Center, MS.
charlie.barron@nrlssc.navy.mil.
Cummings, James. Oceanographer, Naval Research Laboratory, Monterey, CA.
james.cummings@nrlmry.navy.mil.
Doug May, Naval Oceanographic Office, Stennis Space Center, MS.
doug.may@navy.mil
Bruce McKenzie, Naval Oceanographic Office, Stennis Space Center, MS.
bruce.mckenzie@navy.mil

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

FY1 – FY4

Task 1.2: *Process and distribute L2P NPP VIIRS (May), METOP-B GAC (May and McKenzie) in GDS 2.0.* NAVOCEANO began operationally disseminating NPP VIIRS SSTs in GDS 2.0 format in May 2013. NAVOCEANO has provided NPP VIIRS SST product improvement updates annually. NAVOCEANO began operationally disseminating METOP-B SSTs in GDS 2.0 format in April 2013. Delivery of all NAVOCEANO legacy AVHRR L2P SST products in both GDS 1.0 and GDS 2.0 format continued until November 2014 at the request of multiple users. Since November 2014 only GDS 2.0 format files have been delivered. *Obtain and utilize Sentinel-3 SLSTR L2P data provided by GHRSST (May and McKenzie).* Sentinel-3 launch delayed until December 2015. Focus of effort shifted to Task 1.6.1.1 until after Sentinel-3 is launched and L2P data is made available by the GHRSST provider..

Task 1.6.1.1 *Investigate assimilation of sea ice concentration into NAVO K10 L4 analysis product (May and McKenzie)*. Determined that the Daily Ice Analysis Products from U.S. National Ice Center (NIC), being available for both the Arctic and Antarctic, were the most appropriate data sets to add sea ice information to the K10 L4 analysis product. Software was written to download and assimilate ice data into the K10. Plan to implement into operations during the first quarter of 2016.

Task 1.6.1.1 *Implement new and existing FNMOC/NCODA SSTs in GDS 2.0 (Cummings).* Due to limited funding, this task has been combined with the very similar Task 1.6.2.

Task 1.6.2 *Include new NAVOCEANO/MISST data sets (METOP-B GAC; NPP VIIRS; GCOM-W AMSR2) in NCODA analysis (Cummings)*. All NAVOCEANO satellite SST retrieval data types have

been defined in NCODA. This integration includes processing the data through the ocean data quality control system and the 3DVAR analysis. Existing NCODA SST quality control procedures include checks against climatology, cross validation with co-located observations, and comparisons with global and regional analysis fields. New quality control procedures based on simulations of the top-of-atmosphere SST radiances have been added to the system. These simulations use the Community Radiative Transfer Model (CRTM) and the Navy Generalized Environmental Model (NAVGEM) global atmospheric forecast system. SST retrievals from METOP-B (GAC and LAC) went operational in June, 2013, while SST retrievals from NPP VIRRS went operational in January, 2013. Note that SST retrievals from GCOM-W (AMSR2) are not available in operations yet, and that NAVOCEANO has decided to not produce SST retrievals from COMS-1. Rather, NAVOCEANO has decided to focus their efforts on generating SST retrievals from Himarwari-8.

Task 1.6.2 *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. Reported on impact in global, Mediterranean, Western Pacific, Gulf of Mexico, and South African region.

Task 1.6.4.1 *Participate in GHRSST L4 analysis intercomparison project using formal analysis error estimates (Cummings).* The FNMOC 10-km resolution global SST analysis and analysis error fields continue to be made available on the US GODAE data server. However, the fields are not being used in the GHRSST L4 intercomparison project. It is unclear if the GHRSST L4 intercomparison project is still active.

Task 3.1 *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 3.4 *Evaluate diurnal SST forecasts from NAVOCEANO assimilative ocean models (NCODA/NCOM, NCODA/HYCOM) relative to other MISST diurnal products (Barron).* Analysis of diurnal variations around South Africa demonstrated effectiveness of model in identifying combination of persistently low wind speed and high insolation that led due large diurnal warming events represented by NCOM and HYCOM models assimilating VIIRS and/or AVHRR observations. Patterns, amplitudes, and distribution of diurnal variations predicted by the ocean models were consistent with corroborating observations and predictions from other MISST and GHRSST researchers. The diurnal SST forecasts have proved an important aspect of Navy coupled ocean/atmosphere/acoustic modeling and products.

Task 3.5 *Disseminate NOGAPS diurnal SST model output for validation (Cummings*). This task has been dropped since the Navy emphasis is now on development of a fully coupled global ocean-atmosphere prediction system (Earth System Prediction Capability), not an atmospheric system coupled to a diurnal warming SST model. However, a limited time period of NOGAPS diurnal SST model output is available from the NOGAPS ensemble prediction system running at T119 spectral resolution.

Task 3.5 *Evaluate use of radiative transfer model to estimate satellite-corrected heat flux from NAVGEM and COAMPS (Barron)* Use of the Rapid Radiative Transfer Model in the RRTM-G formulation in the NRL ocean surface flux (NFLUX) system showed that incorporation of satellite-based estimates of the ocean and atmospheric state led to reduced errors in estimated longwave and shortwave radiant fluxes relative to operations global (NAVGEM) and regional (COAMPS) atmospheric model forecasts. NAVGEM is being evaluated as a tool for reducing flux bias in ocean and coupled air/ocean forecast systems.

Task 3.5 *Physical SST retrievals (Cummings)*. Physical SST retrievals are routinely produced at FNMOC using NAVGEM and cloud cleared radiances obtained from all of the satellites processed by NAVOCEANO (GOES-13 and GOES-15; METOP-A and METOP-B; NOAA-18 and NOAA-19; NPP-VIIRS). The physical SST retrieval methodology has been implemented as an observation operator in the NCODA 3DVAR. The operator uses an incremental approach. It takes as input prior estimates of SST from an ocean forecast model and profiles of atmospheric state variables known to affect satellite SST radiances. Currently these variables include specific humidity and air temperature, which are routinely available from NAVGEM. The inclusion of aerosol optical depth profiles from the Navy Aerosol Analysis Prediction System (NAAPS) is being evaluated. Observed radiances are simulated using CRTM. Differences between observed and simulated radiances force a SST inverse model that outputs the change in SST that takes into account the variable temperature and water vapor content of the atmosphere at the time and location of the satellite radiance measurement. These SST corrections are treated as innovations in the variational minimization, and assimilated simultaneously with other observations of ocean temperature, salinity, and velocity. This direct assimilation of satellite SST radiances is a true example of coupled data assimilation. An observation in one fluid (atmospheric radiances) creates an innovation in a different fluid (ocean surface temperature). The radiance assimilation operator is ideally suited for coupled ocean/atmosphere forecasting systems where the atmosphere and ocean states have evolved consistently over time. The operator is being evaluated in the National Earth System Prediction Capability (ESPC) program. The physical SST system is documented in Cummings and Peak (2014).

Task 3.6 *Develop and implement observation impact and diagnostic tools in CeNCOOS coupled model system. (Cummings).Add new MISST data sets and error estimates to coupled model system. Evaluate atmospheric model sensitivities to MISST data (Cummings)*. This task will be completed using additional funding obtained from ONR in 2015 to support evaluation of the accuracy, utility, and impact of sea surface temperature observations on reducing forecast model error of the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS) running in full air-ocean coupled mode. SST radiances will be directly assimilated by NCODA and data impacts will be estimated using the NCODA and COAMPS

moist adjoint models. These adjoint-based data impact procedures characterize the forecast impact of every observation assimilated, and allow observation impacts to be partitioned by data type, geographic region, and vertical level. The COAMPS coupled model runs are being done in support of CalWater2, a multi-agency field campaign conducted during January-March 2015 over the northern California coast. The CalWater2 field campaign examined water supply variability and high-impact extreme precipitation events that can lead to flooding. Observations of the upstream Atmospheric River (AR) evolution over the ocean and downstream rain, snow, temperature, and soil moisture were obtained to improve forcing for hydrological prediction and subsequent freshwater discharge into the ocean. Navy and NOAA conducted a series of coordinated deployments of AXBTs and dropsondes during CalWater2. The combination of these measurements provide co-located atmospheric and ocean temperature profiles that can be used to study air-sea flux exchange and its influence on the evolution and prediction of AR events in COAMPS. There were several AR events in the area during the field program. Fig. 1 shows the CalWater 2 AXBT locations during Jan-Feb 2015, while Fig. 2 shows an example of the 48-hour COAMPS moist adjoint sensitivity to SST during an AR event that occurred on 7 Feb 2015.

The NCODA adjoint-based data impact system is described in Cummings and Smedstad (2014). It is used routinely to assess impacts of all data assimilated on reducing HYCOM 48-hour forecast error. In addition to data impacts, the adjoint-based system can be used to identify problems with data quality. A data quality issue was found for the NAVOCEANO SST retrievals from GOES-13. The geographic distribution of non-beneficial GOES-13 retrievals show a distinct pattern that indicates assimilation of GOES retrievals near the edge of the disk are more likely to increase HYCOM forecast error than assimilation of retrievals in the center of the disk (Fig. 3). These differences are likely due to increased noise in the data from the use of infrared radiance measurements at high zenith angles (55-70°) in the NAVOCEANO retrieval algorithm for GOES-13. The high zenith angles mean a longer atmospheric path length and increase in total column water vapor and other atmospheric constituents that are inadequately modeled or corrected in the split window SST retrieval algorithm used by NAVOCEANO.

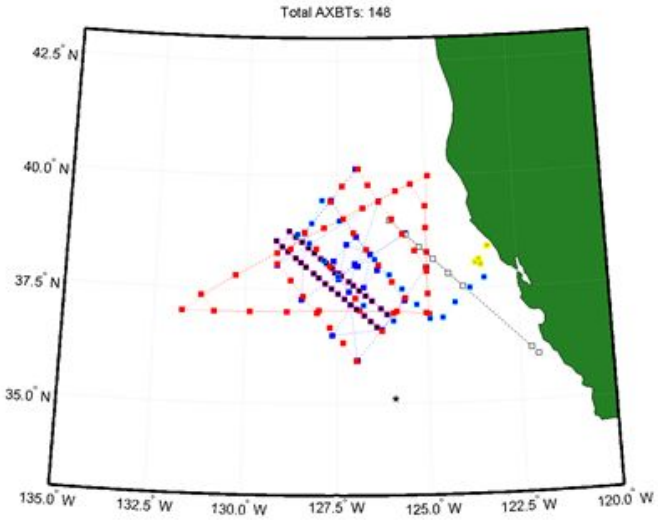

Figure 1. A schematic of AXBT locations deployed during the seven CalWater P-3 flights during Jan-Feb 2015. The color codes and symbols represent the different flights.

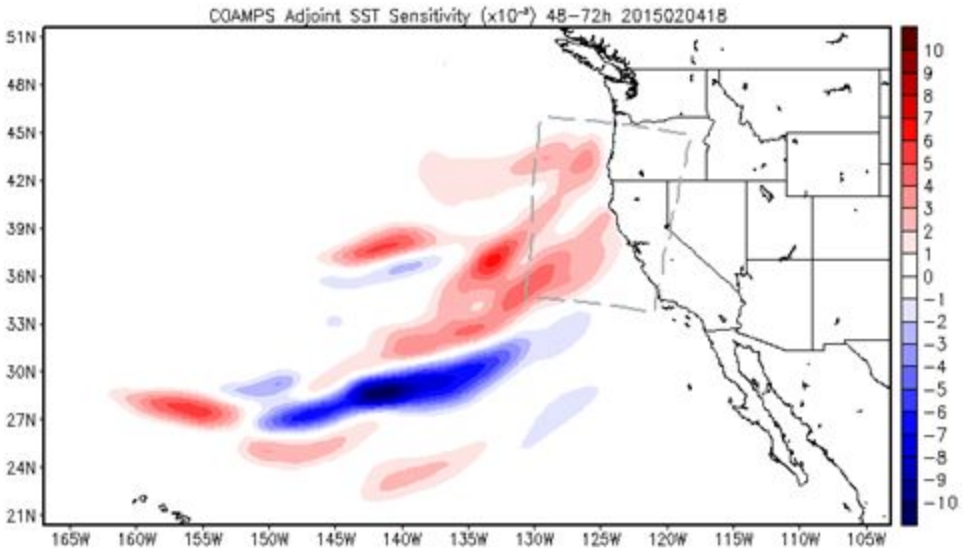

Figure 2. An example of COAMPS moist adjoint 48-72 h SST sensitivity during an AR event that occurred on 7 Feb 2015.

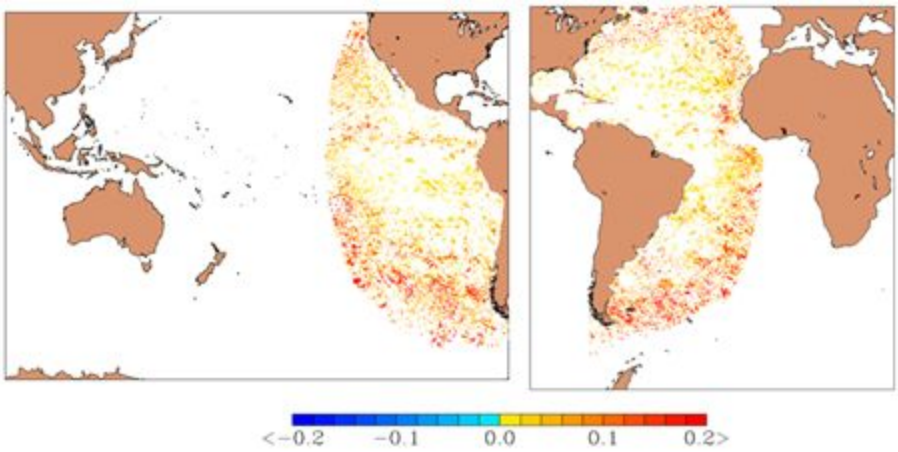

Figure 3. Geographic distribution of non-beneficial impacts from assimilation of GOES-13 satellite SST retrievals (°C). Beneficial impacts of GOES-13 data are not displayed. Results are averaged over daily analyses within HYCOM grid locations for the month of November 2012.

Results

NAVO is now providing VIIRS to operational NWP centers, worldwide through the GHRSST GDAC. Building these relationships has led to an increase in Navy access to international data sources.

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.

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.

Future Work

FY5 6/1/2015-5/31/2016: Task 1.2 Process and distribute JPSS-1 VIIRs in GDS 2.0 (May). **Task 1.3** Implement lake SST algorithms. Implement regional L3 product improvements into operational areas of interest (May/McKenzie). **Task 3.6** Evaluate use of radiative transfer model in expanded 4DVAR assimilation to estimate satellite-corrected heat flux from NAVGEM and COAMPS. Report impact of new MISST sensors (MSG-4, AMSR-2) to NCODA as funded by 6.4 Space METOC (Barron).

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 group 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.

References:

Cummings, J. and J. Peak (2014). Validation Test Report for the Variational Assimilation of Sea Surface Temperature Radiances. NRL Technical Memorandum NRL/MR/7320--14-9520, 26 pp.

Cummings, J. and O.M. Smedstad (2014). Ocean data impacts in global HYCOM. J. Atm. Ocn. Tech. 31:1771-1791, doi:10.1175/JTECH-D-14-00011.1.