In Situ and Satellite Sea Surface Temperature (SST) Analyses

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1. Abstract

This project improves sea surface temperature (SST) analyses produced at NOAA's National Climatic Data Center. The analyses include a high resolution daily optimum interpolation analysis, which was designed to use multiple infrared and microwave satellite data sets as well as in situ (ship and buoy) data. In this analysis the most important role of the in situ data is to correct large-scale satellite biases. Simulations with different buoy densities show the need for at least two buoys on a 10° spatial grid to ensure that satellite biases do not exceed 0.5°C. A lower resolution historic Extended Reconstruction SST analysis is also available using only in situ data and begins in 1854. A merged surface temperature version beginning in 1880 uses both SST and land surface temperature data.

2. Project Summary

The purpose of this project is to focus on improvements to the climate-scale sea surface temperature (SST) analyses produced at NOAA's National Climatic Data Center. Most of the recent effort has been the development of a new daily optimum interpolation (OI) analysis, which was designed to use multiple satellite data sets as well as in situ (ship and buoy) data. The analyses are produced daily on a 1/4° spatial grid. There are two products. One product uses infrared satellite data from the Advanced Very High Resolution Radiometer (AVHRR). The second product uses AVHRR and microwave satellite data from the Advanced Microwave Scanning Radiometer (AMSR) on the NASA Earth Observing System. The AVHRR-only product now begins in September 1981 and the AMSR+AVHRR product begins in June 2002 when the microwave satellite data became available. Both products include a large-scale adjustment of satellite biases with respect to the in situ data. Two products are needed because there is an increase in signal variance when microwave satellite data became available due to its near all-weather coverage. Information on the analyses is available at:

http://www.ncdc.noaa.gov/oa/climate/research/sst/oi-daily.php; the data can be downloaded from this site.

Additional work has been carried out to improve the historic Extended Reconstruction SST (ERSST) analysis which begins in 1854. This analysis uses in situ data and is computed monthly on a 2° spatial grid. The reconstructions are produced from a low frequency (or decadal-scale component) and from a residual high-frequency component. The high frequency analysis was performed by fitting the observed high frequency anomalies to a set of large-scale spatial-covariance modes. A merged surface temperature product uses both SSTs and land surface temperatures and is produced monthly on a 5° grid beginning in 1880. Both the SST-only and merged products are important in monitoring long-term changes in climate and are available at: http://www.ncdc.noaa.gov/oa/climate/research/sst/ersstv3.php and http://www.ncdc.noaa.gov/oa/climate/research/anomalies/index.html#means, respectively.

One of the important goals of the Sustained Ocean Observing System for Climate is to improve the SST accuracy over the global ocean. Because of the dense spatial coverage of satellite data, in situ data tends to be overwhelmed by satellite data. Thus, the most important role of the in situ data in the analysis is to correct large-scale satellite biases. Simulations with different buoy densities showed the need for at least two buoys on a 10° spatial grid. This coverage ensures that satellite biases do not exceed 0.5°C. Using this criterion, regions were identified where additional buoys are needed, and a metric was designed to measure the adequacy of the present observing system. Improved bias correction methods now being developed which may reduce the needed sampling.

Richard W. Reynolds serves on the Ocean Observation Panel of Climate (OOPC) and the Group for High Resolution Surface Temperature (GHRSST) Science Team. Members of both groups consist of well-known national and international scientists. All work presented here follows the Global Climate Observing System (GCOS) Ten Climate Monitoring Principles. Reynolds is a well respected and published scientist as noted at:
http://www.in-cites.com/papers/RichardReynolds.html. The SST analyses are widely used for many purposes including hurricane and other weather forecasting, fisheries (through better location of isotherms and the fish that follow them) and for climate prediction and analysis.

3. Scientific Accomplishments

Four of the scientific accomplishments are linked to the deliverables from last year's work plan, which are:

1. Daily OI version 2 analyses made operational at both NCDC and NCEP.

All codes have been transferred from NCDC to NCEP. The codes and script to run them have been tested for the analysis steps at NCEP. However, the codes to do the preliminary data processing need to be modified at NCEP and this modification has not yet been completed. The NCDC Fortran analysis codes have been carefully documented. This includes information of the purpose of the each code with documentation on each subroutine as well as defining major variables and all input/output files. Documentation of the preliminary data processing and final

output codes and the scripts still needs to be completed. The actual transfer to operations will be partially funded under a separate Climate Change and Data Detection companion SST proposal.

2. Paper prepared on the impact of TMI and AATSR on Daily optimum interpolation (OI) analysis version 2 analyses. These instruments are the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) (which samples between 38°S and 38°N) and the global Advanced Along Track Scanning Radiometer (AATSR) series of instruments.

This paper is complete and in press as: Reynolds, R.W., C. L. Gentemann and G. K. Corlett, 2009: Evaluation of AATSR and TMI Satellite SST Data. *J. Climate*, (in press). The results of this study show that adding AATSR to two AVHRR instruments made little difference in the final product because the coverage of the AVHRR instruments was already adequate. Furthermore, the impact of TMI on the analysis is small because there is already microwave coverage using the AMSR instrument. Furthermore, the major impact of microwave satellite is primarily in cloudy regions poleward of the tropical coverage provided by TMI.

3. Paper prepared on differences among daily SST analyses.

This paper has been written and submitted to the Journal of Climate as: Reynolds, R. W., and D. B. Chelton, 2009: Comparisons of daily sea surface temperature analyses for 2007-08. *J. Climate*, (in review). A poster of the results was presented at the Ocean Observations '09 meeting in Venice, Italy in September 2009. The study shows that spatial resolution does not correlate with grid resolution of the analyses. Furthermore, one analysis tended to be noisy because the spatial resolution often went beyond what could be provided by the data. Resolution requirements are complicated because the coverage from a microwave instruments is better than infrared in cloudy areas, while the infrared resolution in cloud-free regions is better than microwave. This complication suggests that a two stage analysis processing with low and high resolution may be successful.

4. Seasonal maps showing where drifting buoy are adequate and where drifting buoys need to be deployed. Maps are produced within three days following the end of the season and sent to AOML and OCO.

These products are produced operationally and distributed to both AMOL and OCO on time. In addition a summary paper was published and featured as cover page story (illustrated in Figure 1): Zhang H. M., R. W. Reynolds, R. Lumpkin, R. Molinari, K. Arzayus, M. Johnson, and T. M. Smith, 2009: An Integrated Global Ocean Observing System for Sea Surface Temperature Using Satellites and In situ Data: Research-to-Operations. *Bull. Amer. Meteor. Soc.*, **90**, 1–38.

In addition to these 4 items, an additional project was completed. In this effort a final Pathfinder data set was processed for the AVHRR instrument on NOAA-7. This processing extended the Pathfinder AVHRR dataset (Kilpatrick, 2001) from January 1985 to late August 1981. The original processing was delayed because of limited buoy data in this period. The buoy data are needed to tune the Pathfinder retrieval algorithm. In this effort, Reynolds provided bias corrected ship which was used to processes the Pathfinder data. The daily OI was then extended to 1 September 1981 extended using the new NOAA-7 pathfinder data. A draft paper describing this

work is being prepared: Kilpatrick, K.A. , R. H. Evans, R. W. Reynolds, G.P. Podesta, 2009: Impact of In Situ Buoy Distribution on Coefficient Estimation for the Pathfinder SST Algorithm: A Case Study of NOAA-7 and NOAA-14 AVHRRs using Buoy and Ship Matchups.

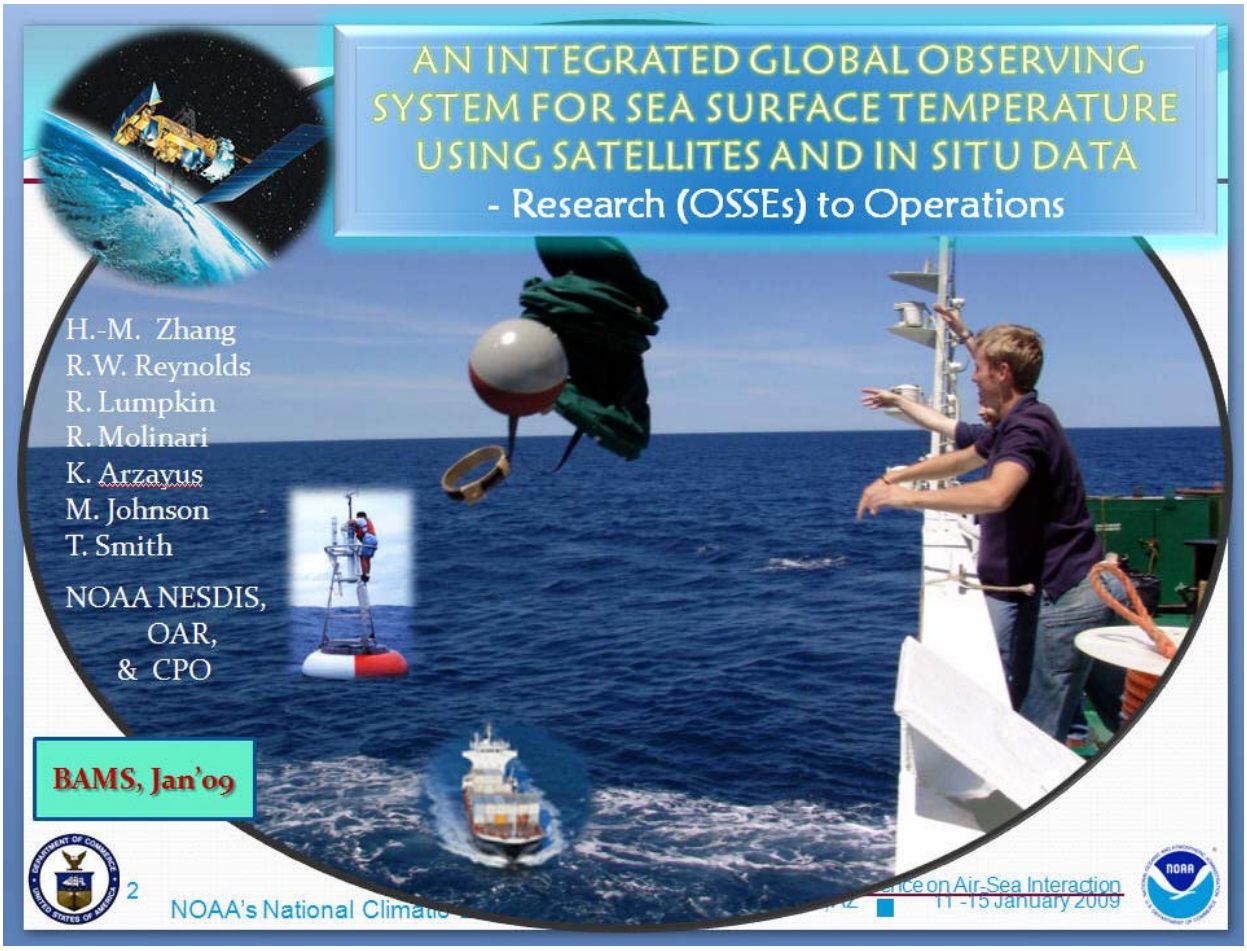

Figure 1: Through one-NOAA approach, the Research-to-Operation transition was implemented for a global ocean climate observing system. The system was designed for optimum use of the system components from satellites, ships and buoys. A Government Performance Results Act (GPRA) performance measure was also formulated, tracted, and reported to Congress and the White House through NOAA's Planning, Programming, Budgeting and Execution System (PPBES). The transition process was featured as a covery story in the Januray issue of the *Bull. Amer. Meteor. Soc.*

4. Education and Outreach

The daily optimum interpolation analysis web site asked users to register. To date we have 124 people registered including 91 who are not from the US. In addition users can also access the data via the GHRSST data server at the Jet Propulsion Laboratory: http://podaac.jpl.nasa.gov. We are happy to work with any users who need more information and help getting any SST datasets.

5. Publications and Reports

5.1. Publications by Principal Investigators

Donlon, C. and others, 2009: The GODAE high-resolution sea surface temperature pilot project. *Oceanography*, **22**, 34-45.

Goddard, L., D. G. DeWitt, and R. W. Reynolds, 2009: Practical Implications of Uncertainty in Observed SSTs. *Geophys. Res. Lett.*, **36,** L09710, doi: 10.1029/2009GL037703.

Peterson, T. C., and others, 2009: State of the Climate in 2008. *Bull. Amer. Meteor. Soc.*, **90**: S1-S196.

Reynolds, R. W., and D. B. Chelton, 2009: Comparisons of daily sea surface temperature analyses for 2007-08. *J. Climate*, (in review).

Reynolds, R.W., C. L. Gentemann and G. K. Corlett, 2009: Evaluation of AATSR and TMI Satellite SST Data. *J. Climate*, (in press).

Zhang H. M., R. W. Reynolds, R. Lumpkin, R. Molinari, K. Arzayus, M. Johnson, and T. M. Smith, 2009: An Integrated Global Ocean Observing System for Sea Surface Temperature Using Satellites and In situ Data: Research-to-Operations. *Bull. Amer. Meteor. Soc.*, **90**, 1–38.

5.2. Other Relevant Publications

The publications for SST products discussed above have been reference extensively. For example the paper describing the daily OI is: Reynolds, R. W., T. M. Smith, C. Liu, D. B. Chelton, K. S. Casey, and M. G. Schlax, 2007: Daily high-resolution blended analyses for sea surface temperature. *J. Climate,* **20**, 5473-5496. To date this paper has been cited in 31 journal articles. Furthermore, the most recent paper on ERSST and the merged land surface temperatures is: Smith, T.M., R. W. Reynolds, T. C. Peterson, and J. Lawrimore, 2008: Improvements to NOAA's historical merged land-ocean surface temperature analysis (1880-2006). *J. Climate,* **21**, 2283-2296. To date this paper has been cited in 29 journal articles.

The Pathfinder AVHRR reference is:

Kilpatrick, K. A., G. P. Podesta, and R. Evans, 2001: Overview of the NOAA/NASA advanced very high resolution radiometer Pathfinder algorithm for sea surface temperature and associated matchup database. *J. Geophys. Res.*, **106**, 9179-9198.