In Situ and Satellite Sea Surface Temperature (SST) Observations and Analyses

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1. Project Summary

The purposes of this project are:

- **To monitor and report the performance of the global ocean SST observing system in terms of a Government Performance and Results Act (GPRA) Performance Measure, for an optimum integration of the in-situ and satellite observation systems for climate scale Sea Surface Temperature (SST; Figures 1 and 2).**

This project supports the NOAA's Next Generation Strategy Plan (NGSP) goal of "Climate Adaptation & Mitigation" through sufficient climate observation and analysis. This project directly serves the Climate Observations Division's Program Deliverables in: 1) To identify climate variability through surface marine observations including SST and sea surface winds; and 2) To identify changes in forcing functions through the air-sea exchange processes.

Based on these and other observations, NCDC produces SST analyses/datasets and climate monitoring products (Figure 3) that are available via the websites below:
http://www.ncdc.noaa.gov/oa/climate/research/sst/oi-daily-information.php
http://www.ncdc.noaa.gov/ersst
http://www.ncdc.noaa.gov/climate-monitoring/

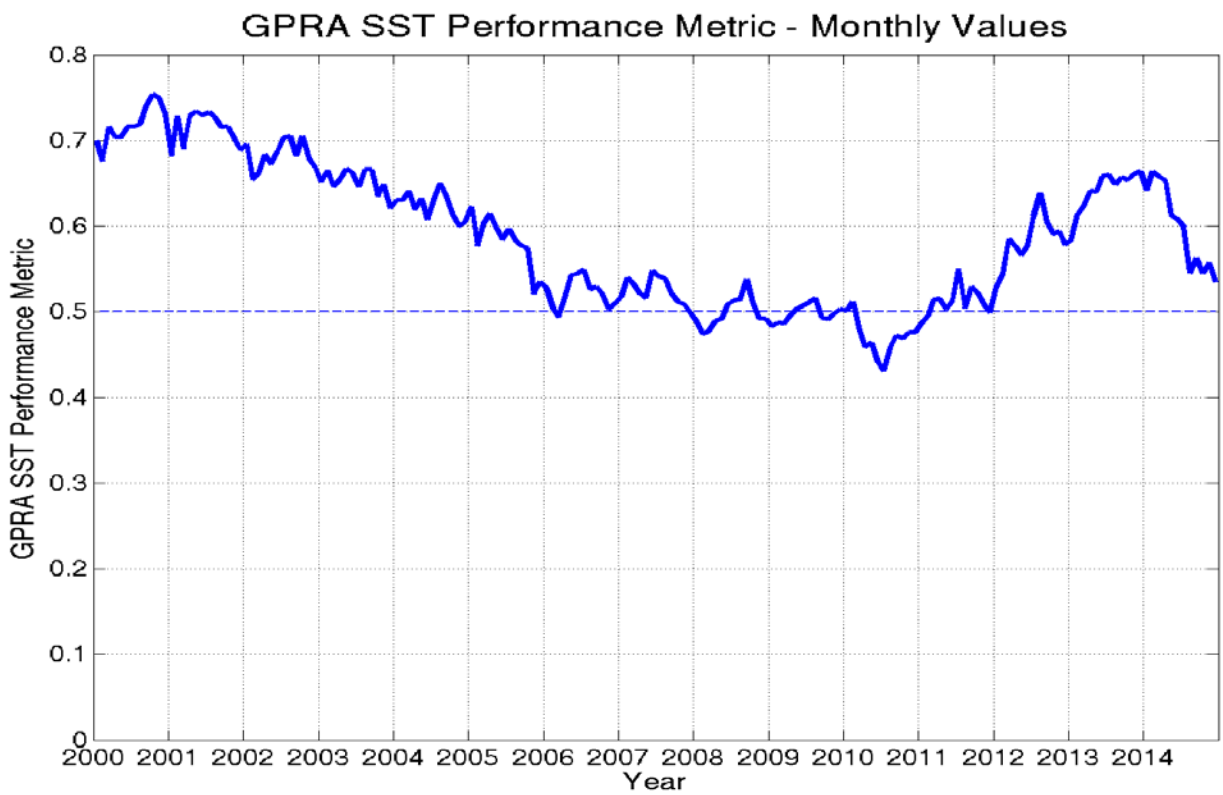


Fig. 1 The GPRA Performance Measure versus time. The dashed line is the target.

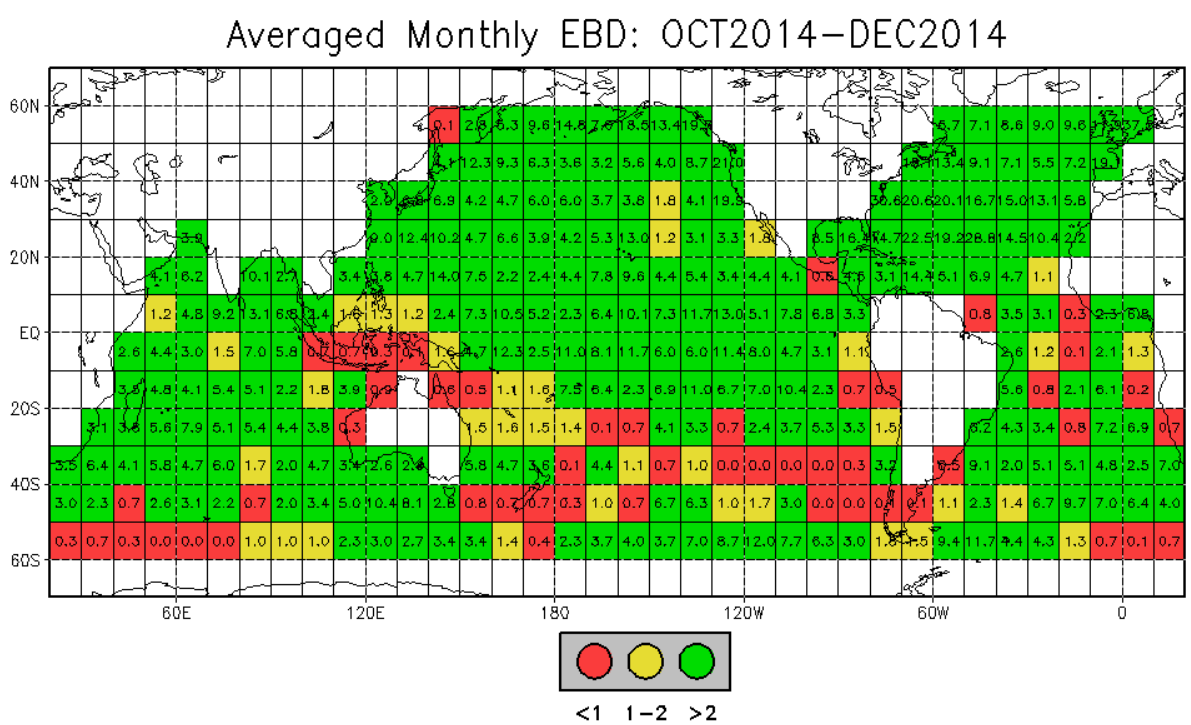


Fig. 2: The quarterly "Buoy-Need Map". Green boxes are satisfactory; Red boxes need highest priority for additional in-situ observations.

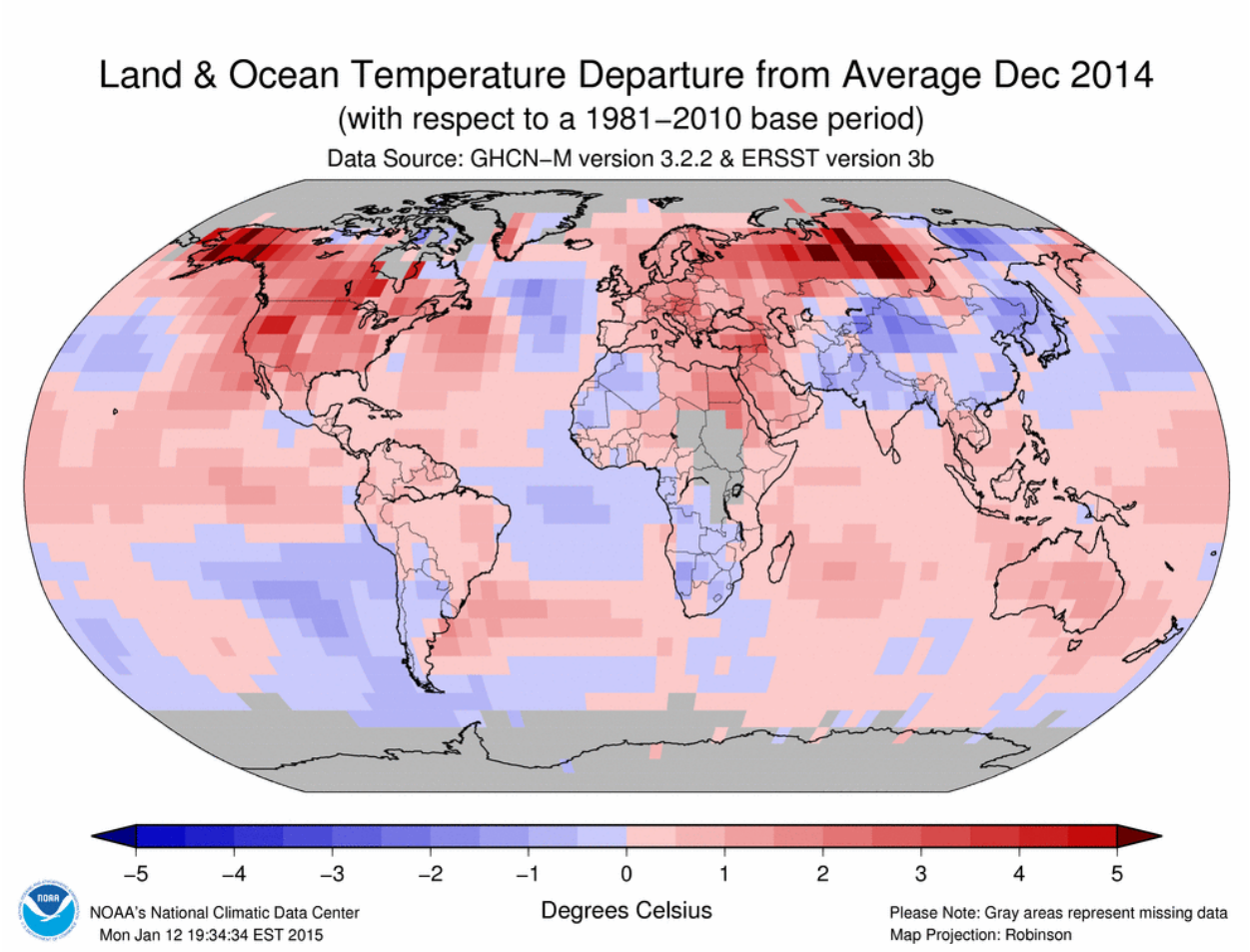


Figure 3: The SST observations and products are the foundation products for generating NOAA's climate monitoring reports that are produced monthly or as needed.

<u>Project Principles:</u> *Modern day Global Ocean Observing System (GOOS) consists of multiple platforms and instruments [both on-ground (in-situ) and remote sensing (e.g. satellites)]*. Each of these observations contributes to the understanding and assessment of climate change signals complementarily. On the other hand, individual instrument observations have limitations in coverage (in both time and space) and limitations on accuracy (e.g. Zhang et al 2004). To maximize benefits and integrally use all the available observations, it is necessary to blend them together to produce higher resolution and higher accuracy products, as well as for information extraction in the big-data era (Zhang et al 2006; Reynolds et al 2007).

Data blending results in reductions in uncertainties on the blended products. There are typically three types of errors in observations and blended products: 1) random error; 2) sampling error; and 3) bias error. The bias error is the systematic difference between one instrument (or a set of instruments, e.g., in-situ observations) and another (e.g., remote sensing/satellite observations). The combined error for all terms should be reduced to a required accuracy for meaningful climate change diagnostics. In the satellite era, satellite observations provide dense data coverage, thus in-situ data play a minor role in the reduction of random and sampling errors and in increasing resolutions in blended products. However, in-situ observations provide the "ground-truth", thus play an essential role in correcting the systematic biases of indirect

measurements (e.g., remote sensing/satellite observations that are calibrated to in-situ observations, e.g. Zhang et al 2009).

An objectively determined Performance Measure is formulated for the integrated SST observing system. One of the important goals of the Sustained Ocean Observing System for Climate is to improve the SST accuracy over the global ocean for climate change monitoring and assessment. Because of the denser 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 to reduce a satellite bias of 2°C to not exceeding 0.5°C (minimum requirement; citations in Zhang et al 2009). 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 as a GPRA performance measure. The work presented here follows the Global Climate Observing System (GCOS) Ten Climate Monitoring Principles.

NOAA has combined the in-situ and satellite SST observations into gridded SST products. The NOAA's Optimum Interpolation (OI) SST analysis products (Reynolds et al 1994, 2002, 2007) are among the most utilized SST products (more than 3000 citations). They are widely used for many purposes including hurricane and other weather and ocean forecasting, fisheries (through better location of isotherms and the fish that follow them) and for climate prediction and analysis. In addition, NCDC also produces century scale climate dataset [Smith and Reynolds (2004), Huang et al (2013 and 2014), Liu et al 2014].

The re-scoped OAR/CPO fund is used for monitoring and reporting the performance of the global ocean SST observing system in terms of a Government Performance and Results Act (GPRA) Performance Measure, for an optimum integration of the in-situ and satellite observation systems for climate scale SST. High level blended SST products are continuously improved under NCDC's activities.
[NOTE: The Project Summary is slightly modified to clarify the new CPO funded scopes as discussed at a conference call on April 17, 2014.]

2. Scientific and Observing System Accomplishments

Accomplishment Highlights: In FY2014, we delivered quarterly reports on the SST GPRA Performance Measure (PM) and the Buoy Need Maps. It showed the metric's importance of capturing the homogeneity (or lack of) of the global drifter distribution. ***In particular, 2014 featured a dramatic improvement in the SST GPRA PM (Figure 1***), reversing the degradation of the past two years and on path to meet the GPRA PM target. The SST GPRA PM started degrading in 2012 and persisted in 2013, due to the unexpected early death of the surface drifting buoys associated battery failures and other technical issues, as well as the failures of the tropical moored TAO buoys associated with lack of maintenance. The above issues had been addressed diligently and aggressively by CPO/CMOD and AOML, resulting in the dramatic performance improvement starting in the Spring of 2014.

NCDC's data and products based on the above foundation observational data are available from web-based servers:
http://www.ncdc.noaa.gov/oa/climate/research/sst/oi-daily-information.php
http://www.ncdc.noaa.gov/ersst
http://lwf.ncdc.noaa.gov/sotc/global/

These data and products support CPO/COD/OCO's missions: 1) To identify climate variability through surface marine observations including SST and sea surface winds; and 2) To identify changes in forcing functions through the air-sea exchange processes.

The OISSTs are updated daily. The ERSSTs are updated monthly. Our data management is performed according to NOAA/NCDC archive requirements. Our data and products are not linked to the National Environmental Policy Act (NEPA) and other NOAA Environmental Statutes (e.g. Marine Mammal Protection Act (MMPA), Endangered Species Act (ESA), Essential Fish Habitat (EFH), and the National Marine Sanctuaries Act (NMSA).

Specific Deliverables:

- ***Operational Monitoring of the SST GPRA Performance Metric and Buoy Need Maps:*** On a quarterly basis, we have produced the seasonal maps showing where drifting buoys are adequate and where additional drifting buoys need to be deployed, together with the SST GPRA performance metric. These have been sent to NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) and CPO/CMOD, and reported upward to NOAA, along with quarterly reports to the Department of Commerce as one of NOAA's Balanced Scorecard. In the second half of 2014, the SST GPRA PM has been dramatically improved (Figure 1), reversing the degradation of the past two years and on a path to meet the GPRA PM target (0.5°C). The SST GPRA PM started degrading in 2012 and persisted in 2013, due to the unexpected early death of the surface drifting buoys associated battery failures and other technical issues, as well as the failures of the tropical moored TAO buoys associated with lack of fund for maintenance. The above issues had been addressed diligently and aggressively by CPO/CMOD and AOML, resulting in the dramatic performance improvement starting in the Spring of 2014, Fig. 4.

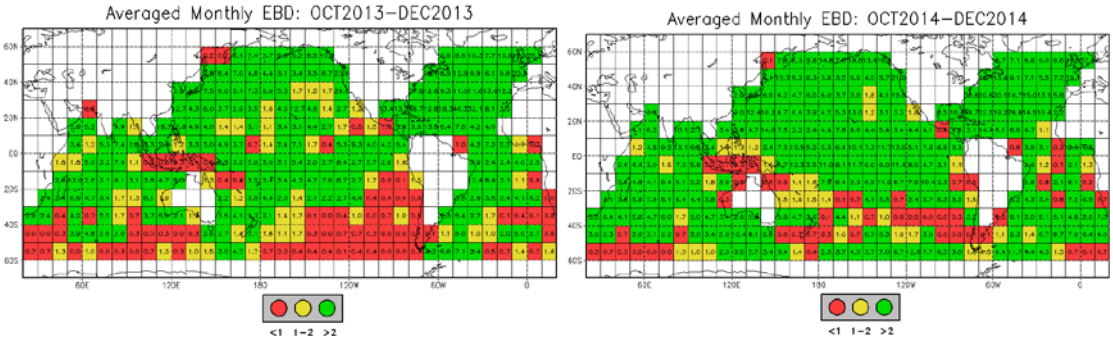


Figure 4: Improvement of data coverage in October – December 2014 over the same period of 2013. The Buoy Need Map showing where observations are adequate (green) and where additional buoys are needed (red).

3. Outreach and Education

In 2014, Dr. Huai-Min Zhang mentored two Postdoctoral scholars at the Cooperative Institute for Climate and Satellites. NCDC's SST products based on the ocean observing system have been selected to be included in the "Climate Data Guide", published online by the National Center for Atmospheric Research (NCAR). See: https://climatedataguide.ucar.edu/.

Dr. Huai-Min Zhang took the lead publishing papers on the requirements for buoy SST data to ensure that satellite data can be bias corrected. He produces seasonal summaries which impact buoy deployments. Dr. Zhang serves on the WCRP SEAFLUX and SURFA (Surface Flux Analysis) Working Groups.

Results based on these observations have been reported in national and international meetings, including AMS, AGU, the GHRSST Science Team, NASA SST Science Team, among others. The OISST papers have been among the most cited publications in geosciences internationally (with more than 3,000 citations). There are approximately 350 non-inclusive registered users for the OISSTs, and about 140 for the ERSST.

4. Publications and Reports

4.1. Publications by Principal Investigators

- **Published**

Huang, B., M. L'Heureux, J. Lawrimore, C. Liu, **H.-M. Zhang**, V. Banzon, Z.-Z. Hu, and A. Kumar, 2013: Why did large differences arise in the sea-surface temperature datasets across the tropical Pacific during 2012? *J. Atmos. Oceanic Tech*., doi:10.1175/JTECH-D-13-00034.

Peng, G., **H.-M. Zhang**, H. P. Frank, J.-R. Bidlot, M. Higaki, S. Stevens, and W. R. Hankins, 2013: Evaluation of remotely-sensed and model surface wind forecast and reanalysis products with OceanSITES buoy measurements. *Weather and Forecasting*, doi: 0.1175/WAF-D-12-00086.1.

- **In press/Submitted/Conference Presentations**

Huang, B., W. Wang, C. Liu, V. Banzon, **H.-M. Zhang**, and J. Lawrimore, 2015: Bias Adjustment of AVHRR SST and Its Impacts on Two SST Analyses. *J. Atmos. Oceanic Tech*., (**in press**, doi: doi:10.1175/JTECH-D-14-00121.1).

Huang, B., V. Banzon, E. Freeman, J. Lawrimore, W. Liu, T. Peterson, T. Smith, P. Thorne, S. Woodruff, and **H. Zhang**, 2015: Extended Reconstructed Sea Surface Temperature version 4 (ERSST.v4), Part I. Upgrades and Intercomparisons. *J. Climate*. (**in press,** doi: 10.1175/JCLI-D-14-00006.1)

Liu, W., B. Huang, P. Thorne, V. Banzon, **H. Zhang**, E. Freeman, J. Lawrimore, T. Peterson, T. Smith, and S. Woodruff, 2015: Extended Reconstructed Sea Surface Temperature version 4 (ERSST.v4): Part II. Parametric and Structural Uncertainty Estimations. *J. Climate*., (**in press,** doi:10.1175/JCLI-D-14-00007.1)

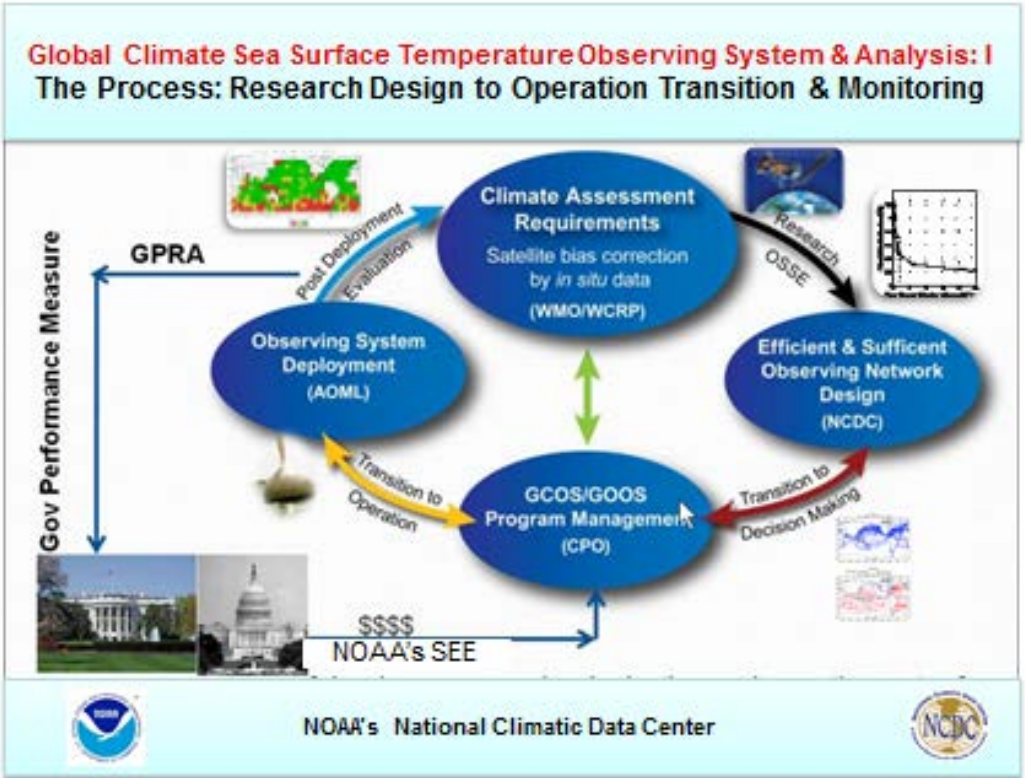
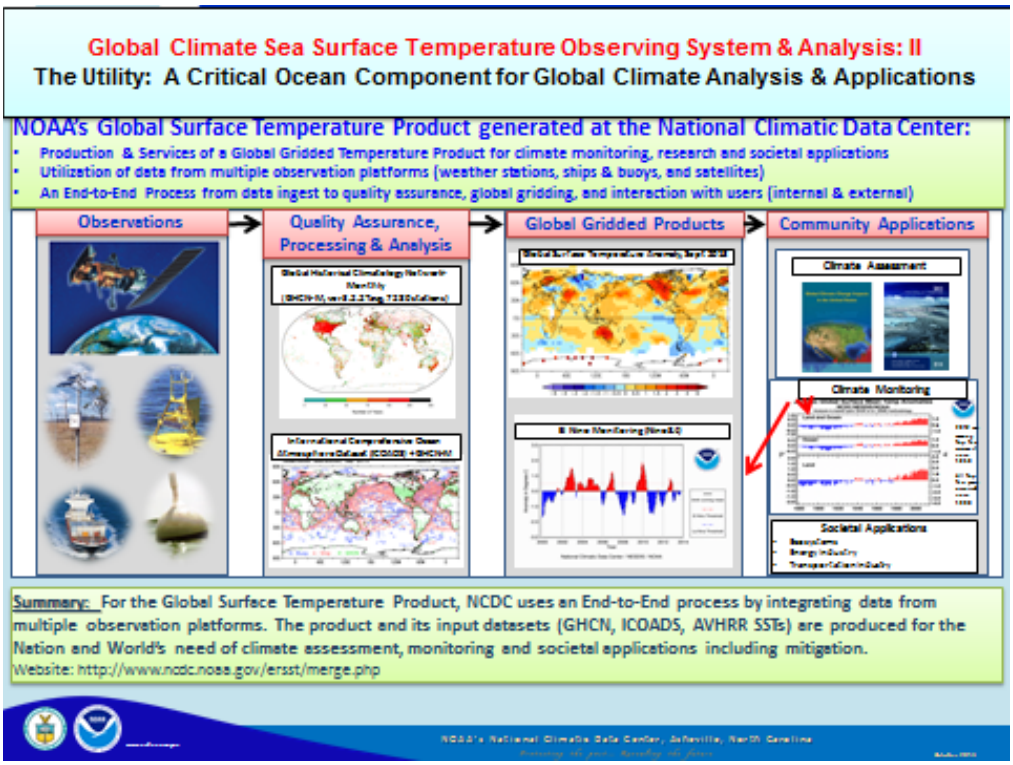
Karl1, T.K., B. Huang, J. H. Lawrimore, J. R. McMahon, M. J. Menne, T. C. Peterson, R. S. Vose, and **H.-M. Zhang**, 2015: The Recent Global Surface Warming Hiatus: Fact or Artifact? *Science*, (**submitted**)

Nickl, E., **H.-M. Zhang**, and D. Wuertz, 2014: Data gap impact analysis on Global Surface Temperature trends using GFDL CM3-CMIP5. *SAMSI/IMAGe Summer Program: the International Surface Temperature Initiative.* National Center for Atmospheric Research, Boulder, CO., July 8 – 12, 2014.

Stegall, S., **H.-M. Zhang**, and L. Shi, 2014: An Assessment on Integrating Satellite and in-Situ Data to Generate Globally Gridded Surface Temperature Products. *AGU Fall Meeting*, Paper # GC51D-0438, San Francisco, CA, December 15 – 19, 2014.

Zhang, H.-M., D. Wuertz, E. Nickl, V. Banzon, B. Gleason, B. Huang, J.H. Lawrimore, M. Menne1, P. Thorne, and C. Williams, 2014: Data Gap Impacts on Global Surface Temperature Trends From Various Datasets. *SAMSI/IMAGe Summer Program: the International Surface Temperature Initiative.* National Center for Atmospheric Research, Boulder, CO., July 8 – 12, 2014.

4.2. Other Relevant Publications

The publications for SST products discussed above have been referenced extensively. For example, a web search on the "Microsoft Academic Search" (http://65.54.113.26/Search?query=richard%20w%20reynolds) showed that the original OISST paper (Reynolds and Smith 1994) was cited nearly 1300 times! The second OISST paper (Reynolds et al 2002) was cited nearly 1,000 times. The two in-situ based ERSST papers (Smith et al 1996 and 2004) were cited about 733 times.

5. Appendix: Poster Slides: