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

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1. Project Summary

The purpose of this project is:

- 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; Figure 1).
- To improve the climate-scale SST analyses produced at NOAA for climate research and monitoring as well as applications to societal benefits. These datasets are the foundation products for generating NOAA's climate monitoring reports that are produced monthly or as needed (Figure 2; http://lwf.ncdc.noaa.gov/sotc/global/).

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 following Climate Observation Division's Program Deliverables: 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 SST analyses/data are available via
http://www.ncdc.noaa.gov/oa/climate/research/sst/oi-daily-information.php
http://www.ncdc.noaa.gov/ersst

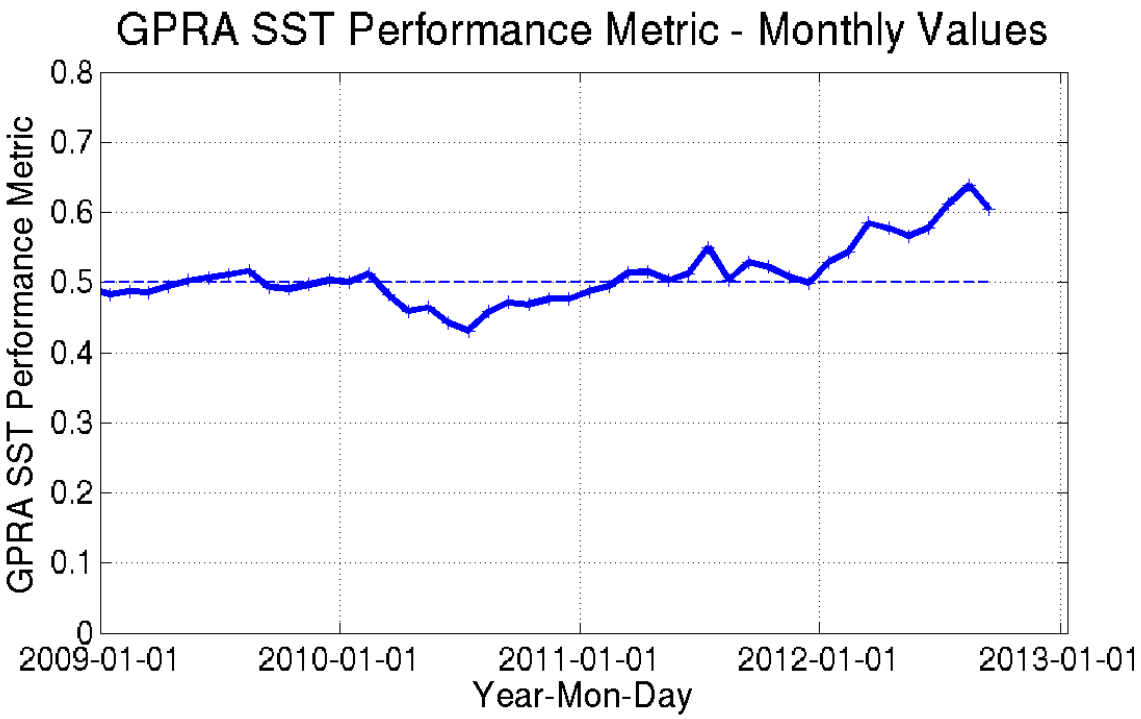

Figure 1: The GPRA Performance Measure versus time. The dashed line is the target.

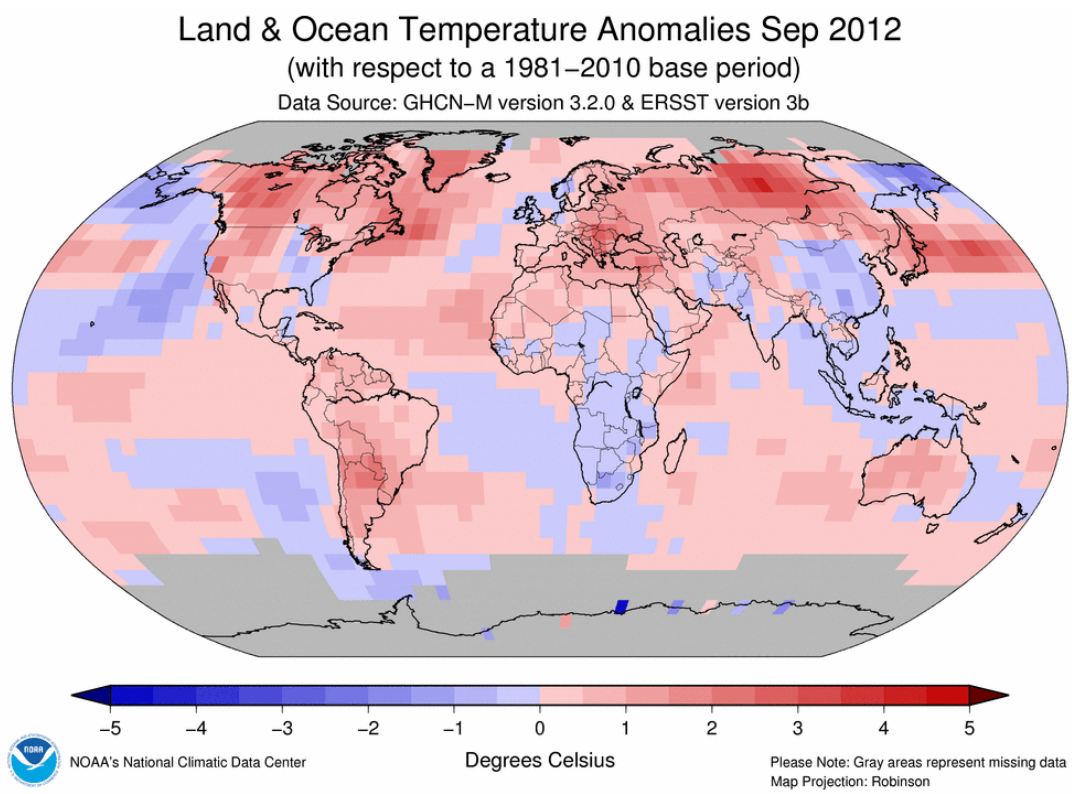

Figure 2: The SST observations and products are the foundation products for generating NOAA's climate monitoring reports that are produced monthly or as needed, as shown in this figure as an example (http://lwf.ncdc.noaa.gov/sotc/global/).

2. Scientific and Observing System Accomplishments

Accomplishment Highlights: 1) In FY2012, we delivered on-time quarterly reports on the SST GPRA Performance Measure and the Buoy-Need Map. Importantly it showed the metric's importance to capture the homogeneity (of lack of) of the global drifter distribution. 2) We have nearly completed an evaluation of the higher resolution (~ 1/23°) SST analyses, and a manuscript for J. Climate is near completion. 3) We have completed an evaluation of the utility of the WindSat microwave SST in the OISST analysis, and a manuscript has been submitted to J. Climate. 3) We have conducted evaluations of producing a nighttime-only OISST analysis; sparser data distribution is an issue and need to be farther investigated. 4) We have revised ship SST bias correction and extend the (re)analysis from 1880-1941 in ERSST.v3b to 1880-2005 in ERSST.v4, and we have revised SST Anomaly calculation method, upgraded the EOT functions, replaced ICOADS Release 2.4 by ICOADS Release 2.5, and updated the sea ice concentration.

Our data and products 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 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.

The OISSTs are updated daily. The ERSSTs are updated monthly. Our data management is done 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 quarterly basis, we have produced the seasonal maps showing where drifting buoy are adequate and where additional drifting buoys need to be deployed, together with the SST GPRA performance metric. These have been sent to AOML and CPO/OCO and reported upward to NOAA, as well as quarterly report to the Department of Commerce as one of NOAA's Balanced Scorecard. In 2012, the GPRA measure was slightly below the target (errors are slightly above 0.5°C; Fig. 1). This has been attributed to the increased number of 10°x10° boxes in which data are inadequate, in particularly in the Southern Ocean regions (e.g. Fig. 3). The primary reason for the increase is the residual effect of the previously identified drifter problems (unexpected short life spans for some batches of drifters). While correction procedures have been in place and more drifters have been deployed since April 2012 by the Global Drifter Program, deployments are lacking in the Southern Ocean during the southern hemisphere winter season. Combining with the times required for the deployed drifters to disperse to other areas from the deployment points, this resulted in more data gaps particularly in the Southern Ocean regions. Compared to

CY12 Q2 (Apr - Jun), the attached Buoy-Need-Map for the CY12 Q3 (Jul - Sep) has fourteen (14) more 10°x10° RED boxes (less than one buoy within each box). However, the combined RED+YELLOW box number has **decreased** by 19 for Q3 over Q2, showing overall coverage improvement for Q3 over Q2. With the planned enhanced deployment for the Southern Ocean region as the warmer southern hemisphere seasons come, combined with the farther spread of last season's deployed drifters, it is hoped that the SST GPRA will improve.

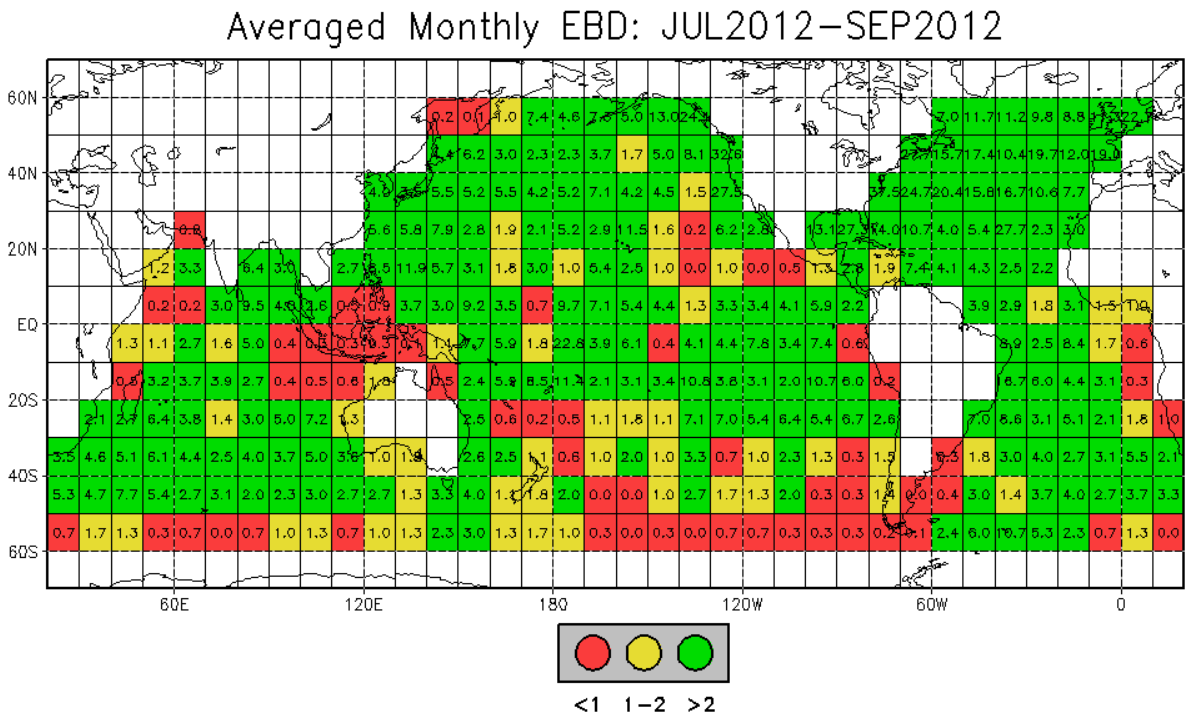

Figure 3: The Buoy Need Map showing where observations are adequate (green) and where additional buoys are needed (red).

- ***High Resolution OI Blended SST Analysis:*** During the last year the work on the objective determination of small-scale feature resolution in SST analyses has been completed. The purpose of this effort is to objectively determine the resolution capability and accuracy of SST analysis products. Ocean model SST fields are used in this study as "true" SST data and subsampled based on actual infrared and microwave satellite data coverage. The subsampled data are used to simulate sampling errors due to missing data. In a separate case, additional noise is added to the model data to also simulate random errors. Two different SST analyses are considered: a 2-stage optimum interpolation (OI) analysis (Figure 3) and the high-resolution Operational SST and Sea Ice Analysis (OSTIA). Comparisons of the 2-stage OI and OSTIA show important differences. The OI tends to show reproduce small-scale features more accurately than OSTIA when the high-resolution data coverage is good. However, the OI also tends to produce more small-scale noise than OSTIA when the high-resolution data coverage is poor. The paper recommends that an improved analysis be developed with variable resolution and with noise variance that is more constant in space and time.

A draft paper (attached) is in the final stage of editing. The paper is entitled "Objective Determination Of Feature Resolution in Two Sea Surface Temperature Analyses" by R. W. Reynolds, D. B. Chelton, J. Roberts-Jones, M. J. Martin, D. Menemenlis, and C. J. Merchant. Reynolds spent a month this summer at Oregon State University working with Professor Dudley Chelton on earlier drafts. During the last year the preliminary results from the paper have been presented at four meetings.

1) The NASA, SST Science Team Meeting, Miami, FL, 2-4 November, 2011, by Chelton
2) The Statistical and Applied Mathematical Sciences Institute (SAMSI) Observations Workshop, Asheville, NC, January 17-19, 2012 by Reynolds
3) The Ocean Science Meeting, Salt Lake, UT, 20-24 February 2012, by Reynolds
4) The Group for High-Resolution Sea Surface Temperature (GHRSST) Science Team meeting, Tokyo, Japan, 4-8 June 2012, by Chelton

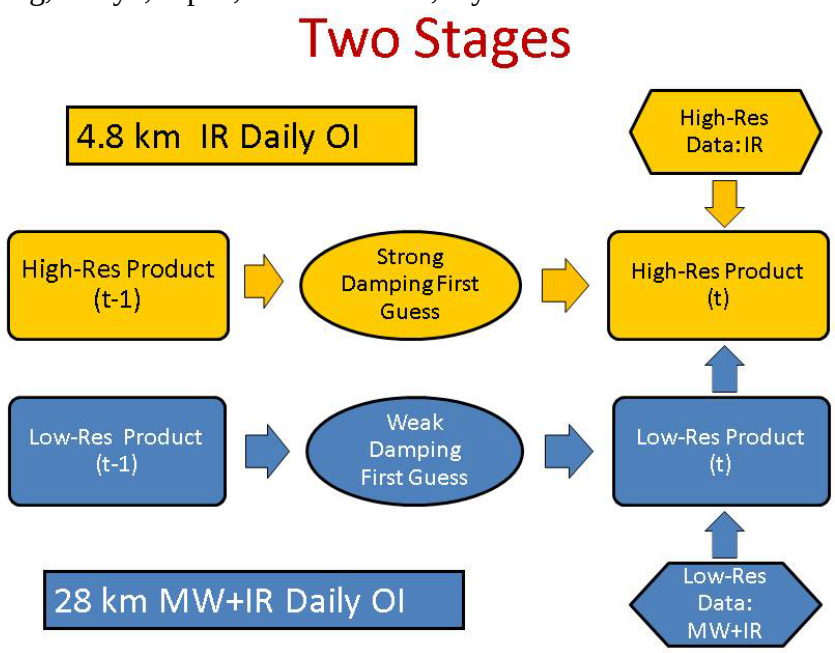

Figure 3: Schematic of the low-resolution (in blue) and the high-resolution (in yellow) 2-Stage OI Processing.

- ***Nighttime-only OISST:*** The current operational OISSTs combine nighttime and daytime observations. The latter may contain diurnal warming, thus increasing variability in the SST analysis. To minimize this effect, a nighttime only version of the OISST has been in development, using nighttime-only in-situ and AVHRR data. The caveat is that the amount of input data available to the analysis is significantly reduced. Additional evaluations showed that this reduces the stability of the OISST product. Therefore, strategies to mitigate this need to be considered. For example, daytime in situ data in well mixed waters (winds >7 m/s) could be included. The nighttime SST time series will be provided to satellite SST algorithm developers to see if they are useful as a reference field and/or a first-guess field. It could also provide as a daily baseline ocean temperature for diurnal flux computations (Carol Anne Clayson, WHOI, personal comm.).
- ***Microwave + Infrared (MI) daily OISST:*** The focus in 2012 was to determine options for continuing the infrared+microwave daily OISST (after the original AVHRR+AMSR). WindSat was determined to be a viable replacement for AMSR after 2011. As described

in an article submitted to J. Climate, WindSat spatial coverage was found to be slightly inferior to AMSR due to the different viewing geometry, but much superior to AVHRR in terms of the all-weather capability. WindSat_only and AMSR_only OISST time series (2004-2010) were generated and found to be consistent with each other. If the bias adjustment step was skipped in generating the OISSTs, seasonally and latitudinal varying differences were detected between the two analyses. This is caused by the difference in the AMSR and WindSat overpass times (1:30 and 6:00 GMT for night). Hence, at a single location, each satellite measures SST at different point of the diurnal cycle. The bias adjustment is able to minimize this difference. One limitation is that WindSat is a non-civilian satellite and the supply of data is less regular than desirable for operational production. Therefore, at least initially, production at 15-day latency is planned.

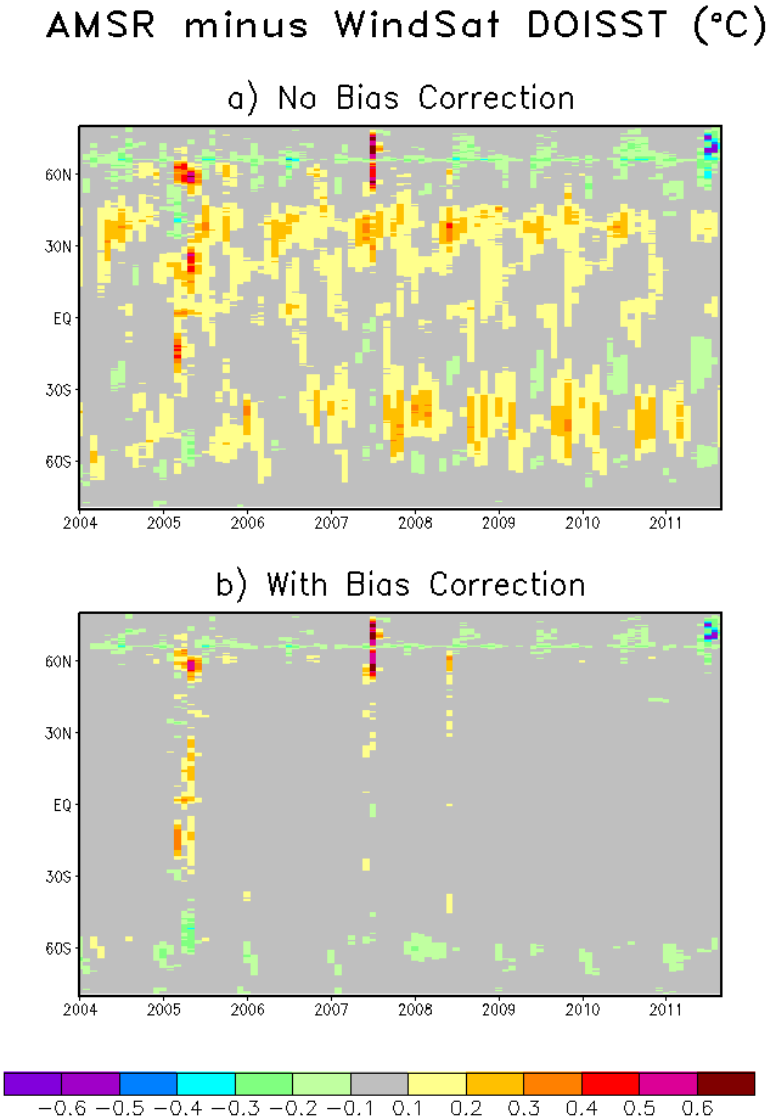

Figure 4: Hovmöller plot of the average monthly difference (AMSR minus WSAT) between SST analyses a) using gridded satellite observations "as is", and b) bias-corrected before interpolation.

- ERSST: The SST Anomalies (SSTAs) in ERSST.v4 have been developed and compared with previous ERSST.v3b and HadSST3 (Figure 5). Consistencies are shown in the

overall variations of SSTAs in different latitudinal bands, particularly after 1970 when observations are dense enough to well support the SSTA analysis and SST bias correction with different methods. The largest differences are found between 30°S and 30°N from 1910 to 1935 and from 1950 to 1970 (Fig. 5c). Those SSTA differences between ERSST and HadSST3 mostly result from the difference in their bias correction that is under further investigation.

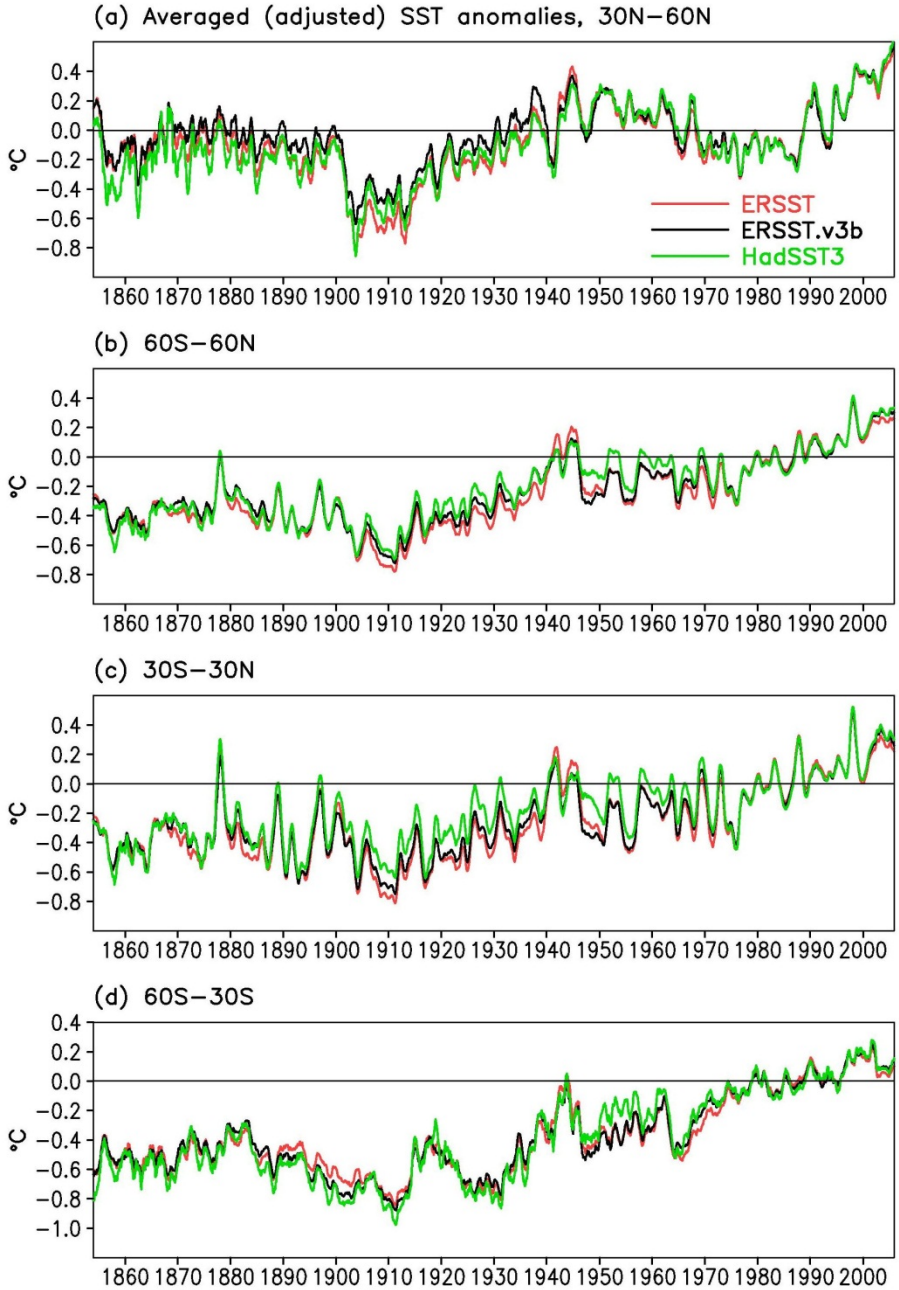

Figure 5: Collocated monthly SSTAs of ERSST, ERSST.v3b, and HadSST3 in (a) 30°N-60°N, (b) 60°S-60°N, (c) 30°S-30°N, and (d) 60°S-30°S. A 12-month running mean has been applied.

2.1. Outreach and Education

Dr. Richard W. Reynolds serves on the WCRP's 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. Dr. Reynolds is a well-respected and published scientist as noted at: http://in-cites.com/papers/RichardReynolds.html. The SST analyses, often referred as the "Reynolds SSTs" or "Optimum Interpolation (OI) SSTs", 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. Dr. Huai-Min Zhang has taken the lead publishing papers on the requirements for buoy SST data to ensure that satellite data can bias corrected. He produces seasonal summaries which impact buoy deployments. Dr. Zhang serves on the WCRP SEAFLUX and SURFA (Surface Flux Analysis) Working Groups. Dr. Viva Banzon worked on the ERSST and night-time only OI SST projects, and made numerous presentations at national and international meetings. She is also a member of the GHRSST Science Team.

Results from this project 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 citied publications in geosciences internationally (more than 3000 citations). Non-inclusive registered users are roughly 350 for the OISSTs, and about 140 for the ERSST.

3. Publications and Reports

3.1. Publications by Principal Investigators

- **Published**

Martin, M., P. Dash, A. Ignatov, **V. Banzon**, H. Beggs, B. Brasnett, J.-F. Cayula, J. Cummings, C. Donlon, C. Gentemann, R. Grumbine, S. Ishizaki, E. Maturi, **R. W. Reynolds**, J. Roberts-Jones, Group for High Resolution Sea Surface temperature (GHRSST) analysis fields inter-comparisons. Part 1: A GHRSST multi-product ensemble (GMPE), *Deep Sea Research Part II: Topical Studies in Oceanography*, 2012, ISSN 0967-0645, 10.1016/j.dsr2.2012.04.013

Dash, P., A. Ignatov, M. Martin, C. Donlon, B. Brasnett, **R. W. Reynolds, V. Banzon**, H. Beggs, J.-F. Cayula, Y. Chao, R. Grumbine, E. Maturi, A. Harris, J. Mittaz, J. Sapper, T. M. Chin, J. Vazquez-Cuervo, E. M. Armstrong, C. Gentemann, J. Cummings, J.-F. Piollé, E. Autret, J. Roberts-Jones, S. Ishizaki, J. L. Høyer, D. Poulter, Group for High Resolution Sea Surface Temperature (GHRSST) analysis fields inter-comparisons-Part 2: Near real time web-based level 4 SST Quality Monitor (L4-SQUAM), *Deep Sea Research Part II: Topical Studies in Oceanography*, 2012, ISSN 0967-0645, 10.1016/j.dsr2.2012.04.002

Xue, Y., Z.-Z. Hu, A. Kumar, **V. Banzon**, T.M. Smith, N.A. Rayner (2012) Sea Surface Temperatures in 2011. In: J. Blunden and D.S. Arndt (Eds). State of the Ocean Chapter. In: State of the Climate in 2011, *Bull. Amer. Meteor. Soc.*, **93**, S1–S282. doi: http://dx.doi.org/10.1175/2012BAMSStateoftheClimate.1.

Vose, R.S., D. Arndt, V. **F. Banzon**, D. R. Easterling, B. Gleason, **B. Huang**, E. Kearns, J. H. Lawrimore, M. Menne, T. C.Peterson, **R. W. Reynolds**, T. M. Smith, C. N. Williams Jr., D. Wuertz. 2012. "NOAA's Merged Land-Ocean Surface Temperature Analysis". Bulletin of the American Meteorological Society. doi: http://dx.doi.org/10.1175/BAMS-D-11-00241.1

- **In revision**

Banzon, V. F. and R.W. Reynolds, 2012: Use of WindSat to extend a microwave-based daily optimum interpolation sea surface temperature time series. (to be submitted to *J. Climate*)

Reynolds, R.W., D. B. Chelton, J. Roberts-Jones, M. J. Martin, D. Menemenlis, and C. J. Merchant, 2012: Objective Determination Of Feature Resolution in Two Sea Surface Temperature Analyses. (to be submitted to *J. Climate*)

3.2. Other Relevant Publications

The publications for SST products discussed above have been reference 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 1000 times. The two in-situ based ERSST papers (Smith et al 1996 and 2004) were cited about 733 times.

References:

Reynolds, R.W., T.M. Smith, 1994: Improved Global Sea Surface Temperature Analyses Using Optimum Interpolation. *J. Climate*, **7** (no. 6), DOI: 10.1175/1520-0442(1994)007.

Reynolds, R.W., N.A. Rayner, T.M. Smith, D.C. Stokes, and W. Wang, 2002: An Improved In Situ and Satellite SST Analysis for Climate. *J. Climate*, **15** (no. 13), 1609-1625.

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, DOI: 10.1175/2007JCLI1824.1

Smith, T.M., R. W. Reynolds, R.E. Livezey, and D.C. Stokes, 1996: Reconstruction of Historical Sea Surface Temperatures Using Empirical Orthogonal Functions. *J. Climate*, **9** (no. 6), 1403-1420.

Smith, T.M., R. W. Reynolds, 2004: Improved Extended Reconstruction of SST (1854–1997). *J. Climate*, **17** (no. 12), DOI: 10.1175/1520-0442(2004)017.

Smith, T. M., and R. W. Reynolds, 2002: Bias Corrections for Historical Sea Surface Temperatures Based on Marine Air Temperatures. *J. Climate*, **15**, 73-87.

Zhang, H.-M., R.W. Reynolds, R. Lumpkin, R. Molinari, K. Arzayus, M. Johnson, 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. Meteorol. Soc.*, **90** (No. 1), 31-38, DOI: 10.1175/2008BAMS2577.1