NOAA Climate and Global Change Program
Annual Progress Report for
July 2008 through March 15, 2009

Continued Monitoring of Atmospheric Temperature Using Data from Microwave Sounding Instruments

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Introduction.

The work for this award is focused on the following areas.

1. Continued production of Climate Data Records (CDRs) from available microwave sounders.
2. Investigation and removal of any calibration problems that develop in the dataset.
3. Development of CDRs from new instruments that are suitable for merging with the earlier data.
4. Validation of CDRs using adjusted radiosonde and radio occultation measurements.
5. Software engineering to improve the reliability, transparency, and efficiency of our data processing system. The end result would be a processing system suitable for converting to operational status.

We have made progress in many of these areas. Work in each area is discussed in the sections below.

1. Continued production of CDRs from the available microwave sounders.

We update the combined data from the Microwave Sounding Units (MSUs) and the first Advanced Microwave Sounding Unit (AMSU) each month. The data are made available to the research community via our website (www.remss.com/msu). This year, the data will be included in several chapters of the State of the Climate Report, published in the Bulletin of the American Meteorological Society (BAMS).

2. Investigation and removal of any calibration problems that develop in the dataset

We continue to monitor data from the AMSU satellite on NOAA-15 for new calibration problems. So far, none have revealed themselves in studies based on NOAA-15 data alone. However, the comparisons of the NOAA-15 data with newly computed results from the AMSU on the AQUA platform reveal a trend difference between the results from these two satellites that needs to be investigated. See the next section for more details.

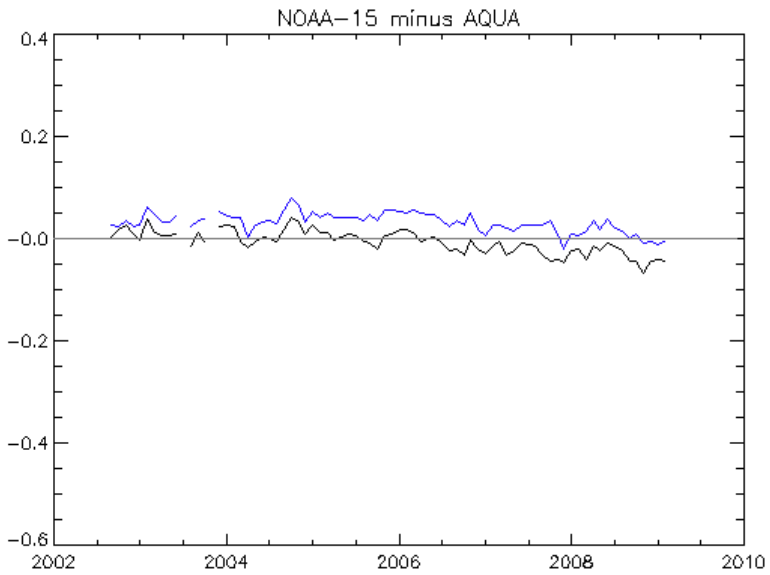

Fig. 1. Globally averaged (50S to 50N) difference between NOAA-15 and AQUA for AMSU channel 5 measurements. The black line is land and ocean measurements, and the blue line is ocean only measurements.

3. Development of CDRs that include data from new instruments.

We are currently performing the calibration studies necessary to include data from more recently launched AMSU instruments into our merged temperature datasets. We

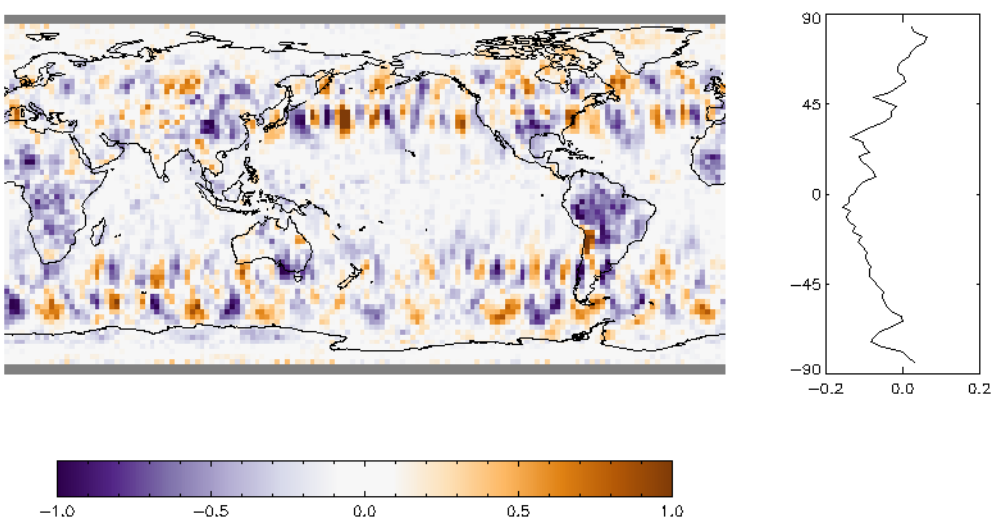

Fig. 2. Map of the trend difference (NOAA-15 – AQUA) over the 2003-2008 period. The largest differences appear to be over tropical land areas. The difference "noise" poleward of ~35 degrees is due to sampling noise.

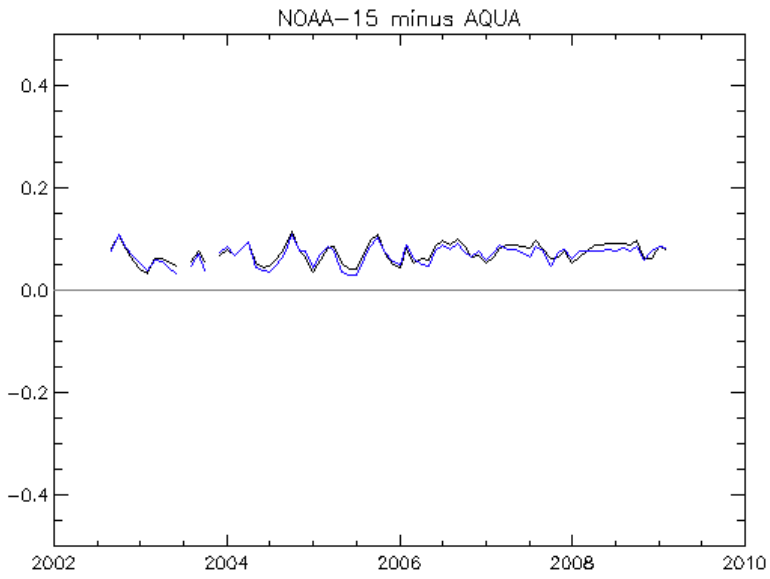

Fig 3. Globally averaged (50S to 50N) difference between NOAA-15 and AQUA for AMSU channel 9 measurements. The black line is land and ocean measurements, and the blue line is ocean only measurements.

are beginning this process with AMSU channel 5 using data from the NOAA-18, MetOP-A, and AQUA satellites. We plan to pay special attention to data from the AMSU instrument on the NASA AQUA spacecraft. This satellite is in a controlled orbit with little or no change in local observation time. Thus data from this satellite in not subject to drifts caused by changes in diurnal sampling and can be used to help check the diurnal adjustments made for the other satellites.

Data from each of these satellites has been processed to Level 2C, which is monthly gridded averaged with a number of adjustments applied. The steps performed in this processing include:

A. Assembly of L1A data from NOAA's CLASS system into complete orbits.
B. Conversion of raw instrument counts to unadjusted brightness temperatures.
C. Calculation of adjustments that account for changes in earth incidence angle. These are due to both the non-spherical nature of the earth, and short and long-term changes in orbital height.
D. Calculation of adjustments that account for changes in local measurement time due to drifts in local equator crossing time.
E. Calculations of adjustments that refer off-nadir measurements to nadir.
F. Calculation of residual cross track adjustments. These are presumably due to antenna spill-over sampling earth, space, and other parts of the satellite.
G. Calculation of monthly gridded averages for each channel.

For AMSU on AQUA data, the processing steps are slightly different, since the AQUA data are only available from NASA in a form where the conversion to brightness temperature has already been performed, so step B is eliminated, and the brightness

temperature data "granules" for NASA are assembled into complete orbits. From step C onward, processing is performed using identical code.

We have investigated merging of data from these newer satellites with data from the AMSU instrument on NOAA-15. (We do not use data from the AMSU on NOAA-16 due to an unexplained drift in the measurements from this instrument (Mears and Wentz, 2009)). In Fig. 1 we show the globally averaged difference between NOAA-15 and AQUA for AMSU channel 5. This plot reveals a small but significant trend difference, with the NOAA-15 drifting down relative to AQUA by about 0.07K over the 2003-2008 period. A map of the trend differences between these satellites (Fig. 2) suggests that most of this trend occurs over tropical land areas, though the ocean-only difference plotted in Fig. 1 still shows some trend. The large trend differences over land suggest that the differences may partly result from inaccuracies in the diurnal cycle adjustments because the diurnal cycle is typically much larger over land (Mears et al., 2002).

For AMSU channel 9, there is no evidence of a trend difference between NOAA-15 and AQUA. In Fig. 3, we plot difference time series analogous to that in Fig. 1 for AMSU channel 9.

4. Validation of CDRs using adjusted radiosonde datasets.

We have completed a comparison of our current versions of the merged satellite temperature datasets with results from the 4 most recent versions of radiosonde datasets that have been adjusted to reduce the effects of measurement inhomogeneities. These are the HadAT (U.K. Met Office)(Thorne et al., 2005), IUK (Yale Univ.) (Sherwood et al., 2008), RAOBCORE and RICH (both from Univ. of Vienna)(Haimberger, 2007; Haimberger et al., 2008). In all cases, we found that in order to make an accurate

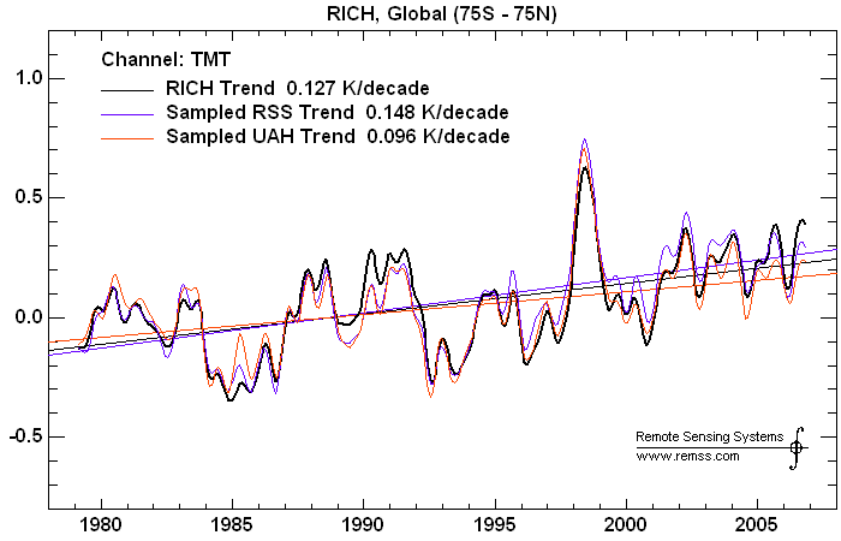

Fig. 4. Time series of globally averaged TMT (middle tropospheric) temperature anomalies for the RSS and UAH satellite data, and the RICH adjusted radiosonde dataset. The satellite data were sampled at the locations of the radiosonde stations used in the RICH dataset.

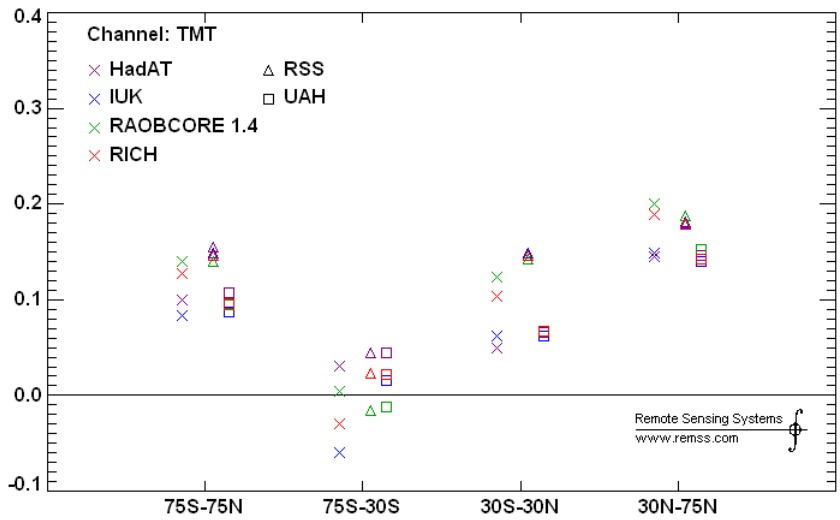

Fig. 5. Summary plot of TMT trends (1979-2007) for our radiosonde/satellite intercomparison study. The colored x's show the radiosonde trends, and the colored square show the satellite trends after sampling the satellite data at the radiosonde locations (thus, there is a satellite point corresponding to each radiosonde dataset).

comparison, the spatial sampling in each radiosonde network needed to be considered. We also included MSU/AMSU results from Univ. of Alabama, Huntsville (UAH) (Christy et al., 2003) in our comparison. For the tropospheric channels (Temperature Lower Troposphere or TLT, and Temperature Middle Troposphere or TMT) the results are encouraging. As an example, in Fig. 4 we plot globally averaged time series of TMT anomalies for the 1979-2007 period for the RSS and UAH satellite data, and for the RICH adjusted radiosonde data. On short time scales, the 3 different datasets are in excellent agreement. On longer time scales, there is a spread in linear trend of about 0.05 K/decade, with the radiosonde data between the two satellite datasets. We performed similar analyses for other radiosonde datasets, and for global, tropical (30S to 30N), southern extratropical (75S to 30S), and northern extratropical (30N to 75N) averages.

In Figure 5, we show a plot that summarizes the trend results. In general, the radiosonde results and the satellite results are in good agreement, with differences typically less than 0.05 K/decade. The largest discrepancies occur in the Southern extratropics, where radiosonde coverage is limited, which may reduce the accuracy of the radiosonde adjustment methods.

Higher in the atmosphere, the intercomparisons are less encouraging. In Fig. 6, we show a plot similar to Fig. 4, except for the lower stratosphere (TLS). Note that there is considerably less agreement between the various datasets, and in particular the radiosonde datasets. The trend differences are now typically greater than 0.1 K/decade. For the radiosonde data, these differences are likely to be related to the increased difficulty in making accurate temperature measurements in the stratosphere due to larger

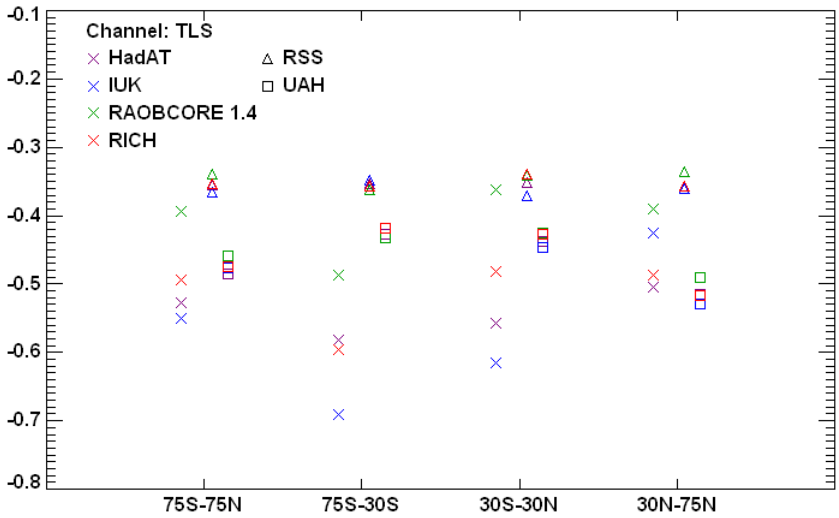

Fig. 6. Summary plot of TLS trends (1979-2007) for our radiosonde/satellite intercomparison study. As in Fig. 2, the colored x's show the radiosonde trends, and the colored square show the satellite trends after sampling the satellite data at the radiosonde locations. Note the expanded vertical scale relative to Fig. 2.

radiation corrections. For the satellites, the problem may be due to the differences in the methods used to perform the diurnal correction by the RSS and UAH groups.

The time series plots for each channel, radiosonde dataset, and geographic subset can be viewed by our validation tool (http://www.remss.com/msu/msu_data_validation.html.)

5. Software engineering to improve the reliability, transparency, and efficiency of our data processing system.

Part of our effort is focused on improving the transparency and reliability of our data processing system. We are developing a number of automatically updated web-based tools to make it easier to ensure that the processing system is operating normally. At the same time, we deployed an automatic system for routinely downloading AMSU on AQUA data, so it made sense to try out our new tools on the AQUA processing stream. In Fig. 7, we show a screen shot of the web-based AMSU/AQUA monitoring system. The page displays the results of the last file download (the NASA ftp site is polled every 30 minutes for new data), the latest assembly into complete orbits or "orbitification", and the latest calculation of the incidence angle and diurnal corrections. The operator can easily see that the last download occurred only a few hours ago, and that the data has been orbitified up to roughly 18 hours before the date of the screen shot. At the time of the screen shot, the adjustment task had been put temporarily on hold so that some improvements could be integrated into the system. It easy to see that this part of the processing is 19 orbits behind, and has not been successfully run for over 2 days.

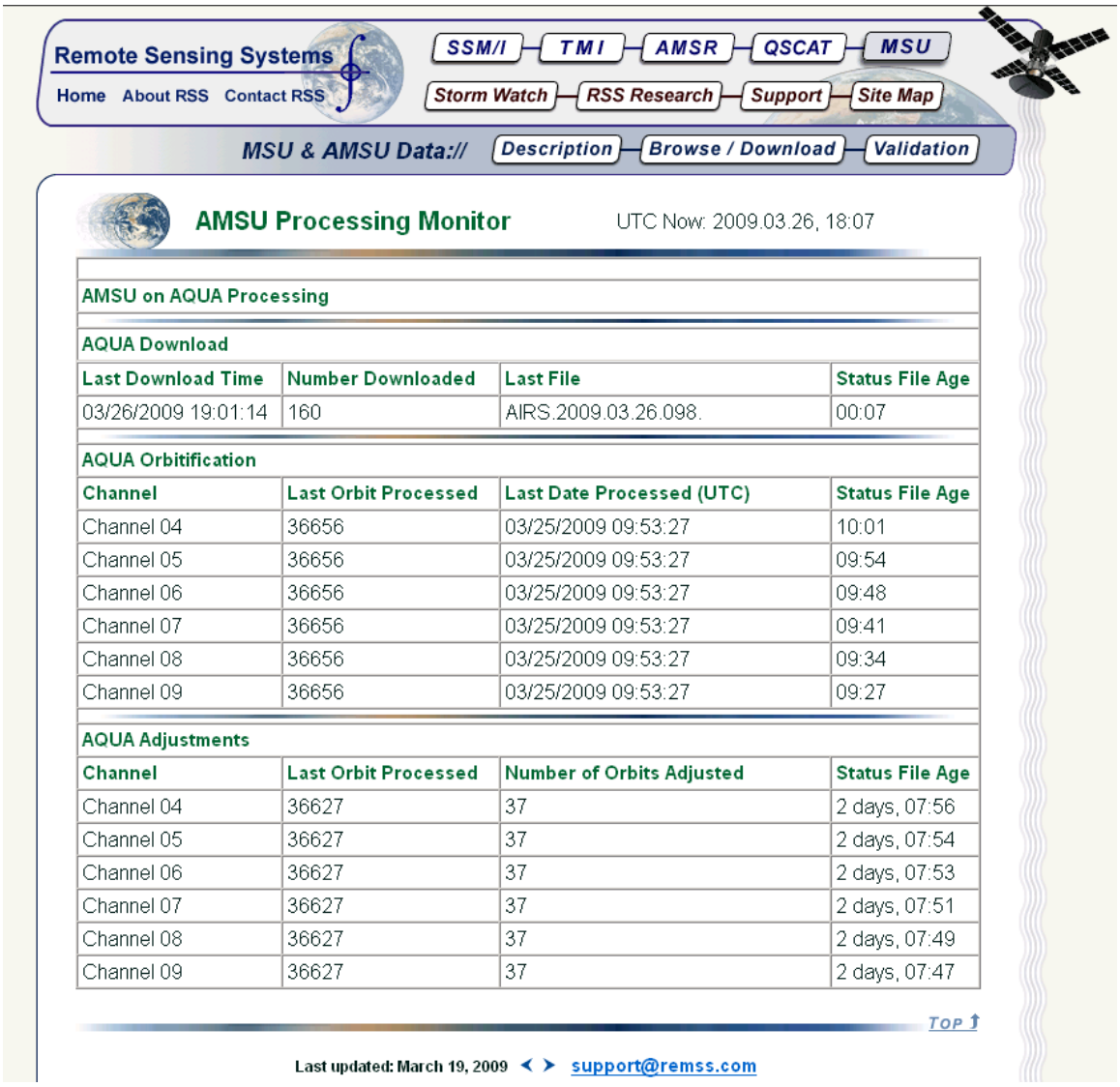

Fig. 7. Screenshot of the AMSU/AQUA process monitoring web page. All orbit-level processing steps are currently monitored, including the download of data from the NASA ftp site, assembly of the data granules into complete orbits, and the adding of incidence angle and diurnal sampling adjustments to the assembled orbits.

6. Planned Work for 3/2009 – 3/2010.

During the next year, we plan work in each of the focus areas for this proposal. An outline of our planned work is presented below.

- Continued production of Climate Data Records (CDRs)
- Investigation of potential problems with the current diurnal correction methods

    - Intercomparison of model-based diurnal cycles derived from different models
    - Use of simultaneous nadir overpass calibration to attempt a satellite-based diurnal cycle validation
- Investigate reasons for RSS/UAH differences for TLS.
- Complete the merging of NOAA-18, MetOP-A, and AQUA data into the merged dataset for all channels
- Begin validation of results vs. radio occultation data
- Continue to improve automatic monitoring system.
    - Automated Quality Control displays
    - Extend monitoring to all current AMSU's

Reference List

Christy, J. R., R. W. Spencer, W. B. Norris, W. D. Braswell, and D. E. Parker, 2003: Error Estimates of Version 5.0 of MSU-AMSU Bulk Atmospheric Temperatures. *Journal of Atmospheric and Oceanic Technology*, **20**, 613-629.

Haimberger, L., 2007: Homogenization of Radiosonde Temperature Time Series Using Innovation Statistics. *Journal of Climate*, **20**, 1377-1403.

Haimberger, L., C. Tavolato, and S. Sperka, 2008: Towards the Elimination of Warm Bias in Historic Radiosonde Records -- Some New Results From a Comprehensive Intercomparioson of Upper Air Data. *Journal of Climate*, **21**, 4587-4606.

Mears, C. A., M. C. Schabel, F. J. Wentz, B. D. Santer, and B. Govindasamy, 2002: Correcting the MSU middle tropospheric temperature for diurnal drifts. *Proceedings of the International Geophysics and Remote Sensing Symposium*, vol. 3, Toronto, Canada, 1839-1841.

Mears, C. A. and F. J. Wentz, 2009: Construction of the Remote Sensing Systems V3.2 Atmospheric Temperature Records From the MSU and AMSU Microwave Sounders. *Journal of Atmospheric and Oceanic Technology*, **published online**, DOI: 10.1175/2008JTECHA1176.1.

Sherwood, S. C., C. L. Meyer, R. J. Allen, and H. A. Titcher, 10-1-2008: Robust Tropospheric Warming Revealed by Iteratively Homogenized Radiosonde Data. *Journal of Climate*, **21**, 5336-5352, DOI: 10.1175/2008JCLI2320.1.

Thorne, P. W., D. E. Parker, S. F. B. Tett, P. D. Jones, M. McCarthy, H. Coleman, and P. Brohan, 2005: Revisiting Radiosonde Upper-Air Temperatures From 1958 to 2002. *Journal of Geophysical Research*, **110**, D18105, doi:10.1029/2004JD005753.