MSU/AMSU atmospheric temperature products.
Changes from RSS Version 2.1 to RSS Version 3.0

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I. Introduction and Brief Summary.

In changing from Version 2.1 to Version 3.0 of our MSU/AMSU atmospheric temperature products, we made a number of changes to our merging methodology which are described informally this document. A longer manuscript the describes the V3.0 methods in more detail is in preparation.

The most important changes:

- *AMSU data is now included in the TLT product.* This allows us to extend the TLT product to the present.
- *Intersatellite offsets now vary as a function of latitude.* This leads to changes in the long-term trends when plotted as a function of latitude. These changes are fairly small for TLT, TMT, and TLS, but quite large for TTS (MSU3/AMSU7). The intersatellite offsets for MSU3 are strong functions of latitude, with the later satellites (NOAA-14 and NOAA-12) showing substantially different offsets when compared to the earlier satellites (NOAA-10 and NOAA-11). This coherence between the later satellites results in a large change in the long-term trends as a function of latitude. This difference is large enough that earlier versions of TTS should be considered to be wrong.
- *All processing is done using monthly averages.*
- *Data from NOAA-16 is no longer used.* The data from this instrument appears to be drifting relative to data from the earlier satellites. The cause of this drift has not yet been determined. The drift is as large as several tenths of a degree K per decade, as large or larger than the expected climate signal.
- The format of the NetCDF files is altered so that there is only 1 time dimension.

An unresolved issue:

- *There also appears to be a drift between NOAA-14 (MSU) and NOAA-15(AMSU) for MSU2/AMSU5.* The cause of this drift has not yet been determined. Global maps of the trend difference during the NOAA-14/NOAA-15 overlap period (1999-2005) show that the problem is greatest over wet tropical land regions, suggesting that the problem may be related to the diurnal cycle in precipitation or surface emission. Due to its smaller footprint size, AMSU may be more sensitive to the presence of precipitation than MSU. We are currently working to resolve this issue. Since we do not know whether the NOAA-14 or the NOAA-15 is closer to the truth, the data that we report includes the combined results of both satellites, and the difference between the two satellites is used to help estimate the uncertainty in the results.

II. Summary of changes to the results between V2.1 and V3.0.

A. Global Time Series and Trends.

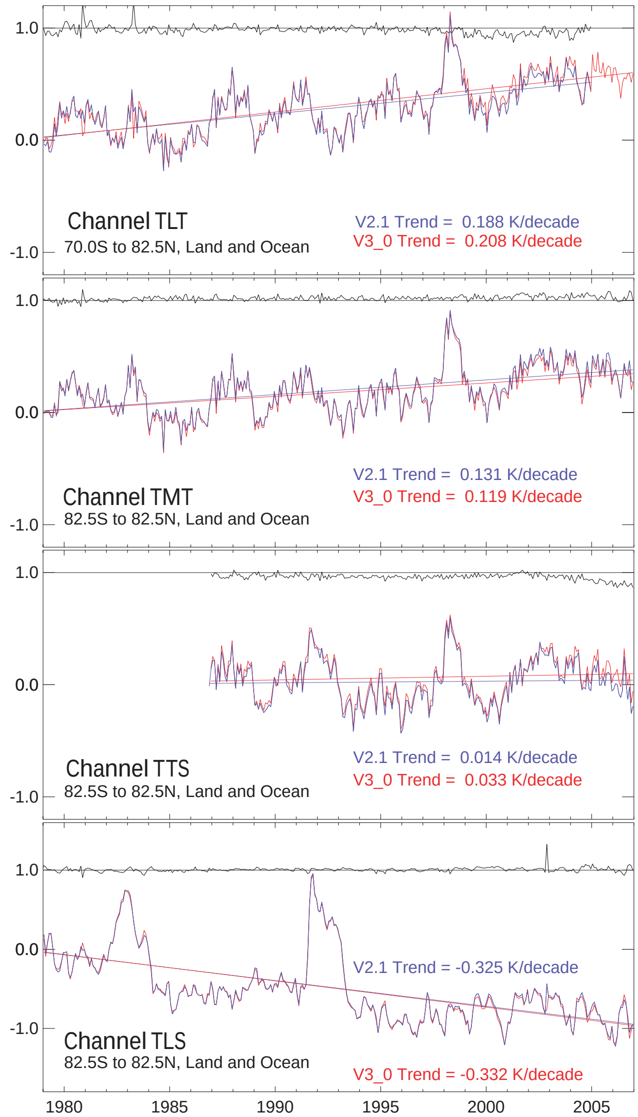

Fig. 1. Global time series for the V2.1 and V3.0 versions of each data product. The V2.1 data is plotted in blue, and the V3.0 data is plotted in red. Trends and trend lines are calculated over the period during which both version have valid data.

In Fig. 1, we plot the globally averaged time series for V2.1 and V3.0 for each channel. In general, the global time series are not significantly affected by the versions change. For TMT, TTS, and TLS, the largest changes occur after 2001, the time period during which data from NOAA-16 satellite was include in the earlier version (V2.1). These changes are especially large for TTS. For TLT, the largest difference occur after 1998, AMSU data from NOAA-15 starts in mid 1998. AMSU data was not included in the earlier version of the data (V2.1). Small differences on short time scales, such as the "spikes" in the difference in the early part of the TLT data are due to changes in sampling that occurred when we switched to processing using monthly averages, and to the removal of several dozen orbits from NOAA-06 which had corrupted data (these orbits were included in previous versions, and led to small errors in those versions). The relatively small changes shown here are expected because both merging methodologies minimize the globally averaged differences between different satellites.

B. Tropical Time Series and Trends

When we restrict our averaging region to the deep tropics (20S to 20N), the differences between the versions become more pronounced, particularly for the TLT and TTS products. In Fig. 2, we plot tropical time series and trends lines for both versions of the four temperature products.

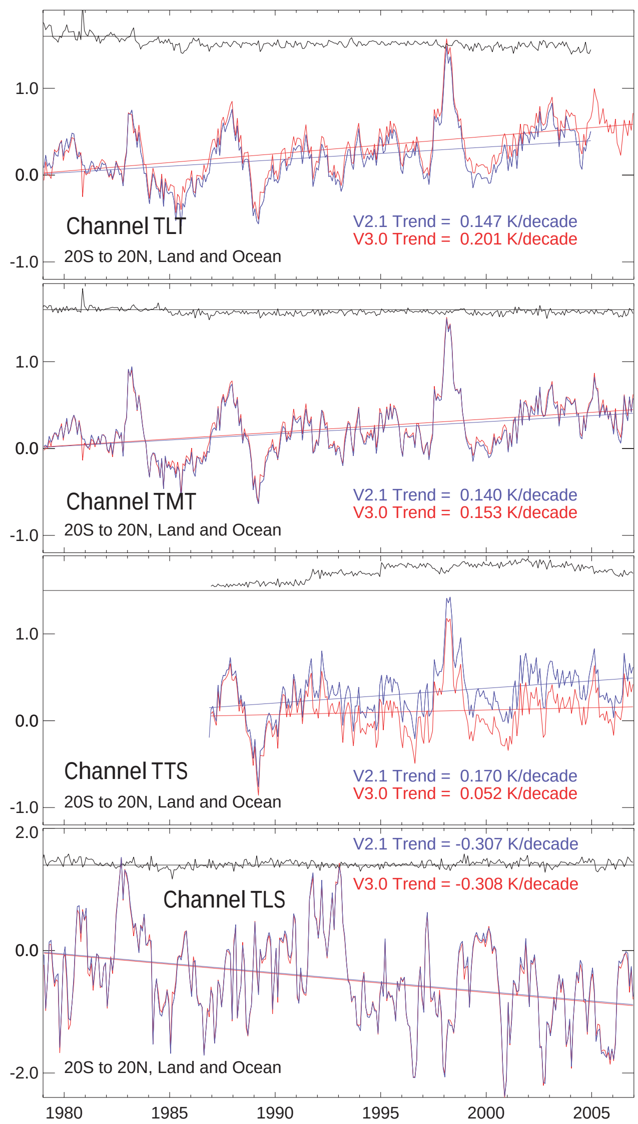

Fig. 2. Tropical (20S to 20N) time series for the V2.1 and V3.0 versions of each data product. The V2.1 data is plotted in blue, and the V3.0 data is plotted in red. Trends and trend lines are calculated over the period during which both version have valid data. Note the expanded vertical scales relative to Fig. 1.

The TLT product shows a substantially increased trend in the tropics, with most of the changes occurring in the first 10 years of the dataset. The early satellites (TIROS-N - NOAA-09) offsets that have a larger latitude dependence than the later satellites, which accounts for the larger changes in this time period. For TTS, the very large dependence of offset on latitude for the later satellites leads to a dramatic reduction in TTS trend in the tropics.

C. Trends as a Function of Latitude.

To further investigate the effects of the new method as a function of latitude, in Fig. 3 we plot trends as a function of latitude for each temperature product. For most products, the change at any given latitude is less than 0.1 K/decade. The TTS product changes by a larger amount, with changes as large as 0.2 K/decade.

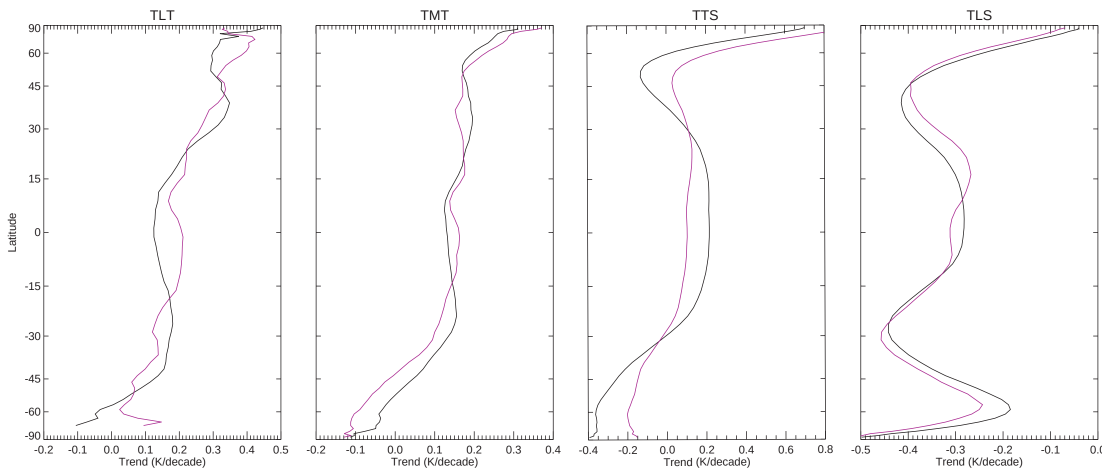

Fig. 3. Linear trends as a function of latitude for each temperature product. The black curves are for the earlier (V2.1) versions, and the purple curves are for the new (V3.0) versions.

D. Trend Maps.

On the following 4 pages (Figs. 4-7), we plot maps of trends for each version of the temperature products, and their difference. In general, the largest changes are between different latitude bands. Smaller differences as a function of longitude are due to changes in sampling that occurred when all processing was changed to using monthly averages.

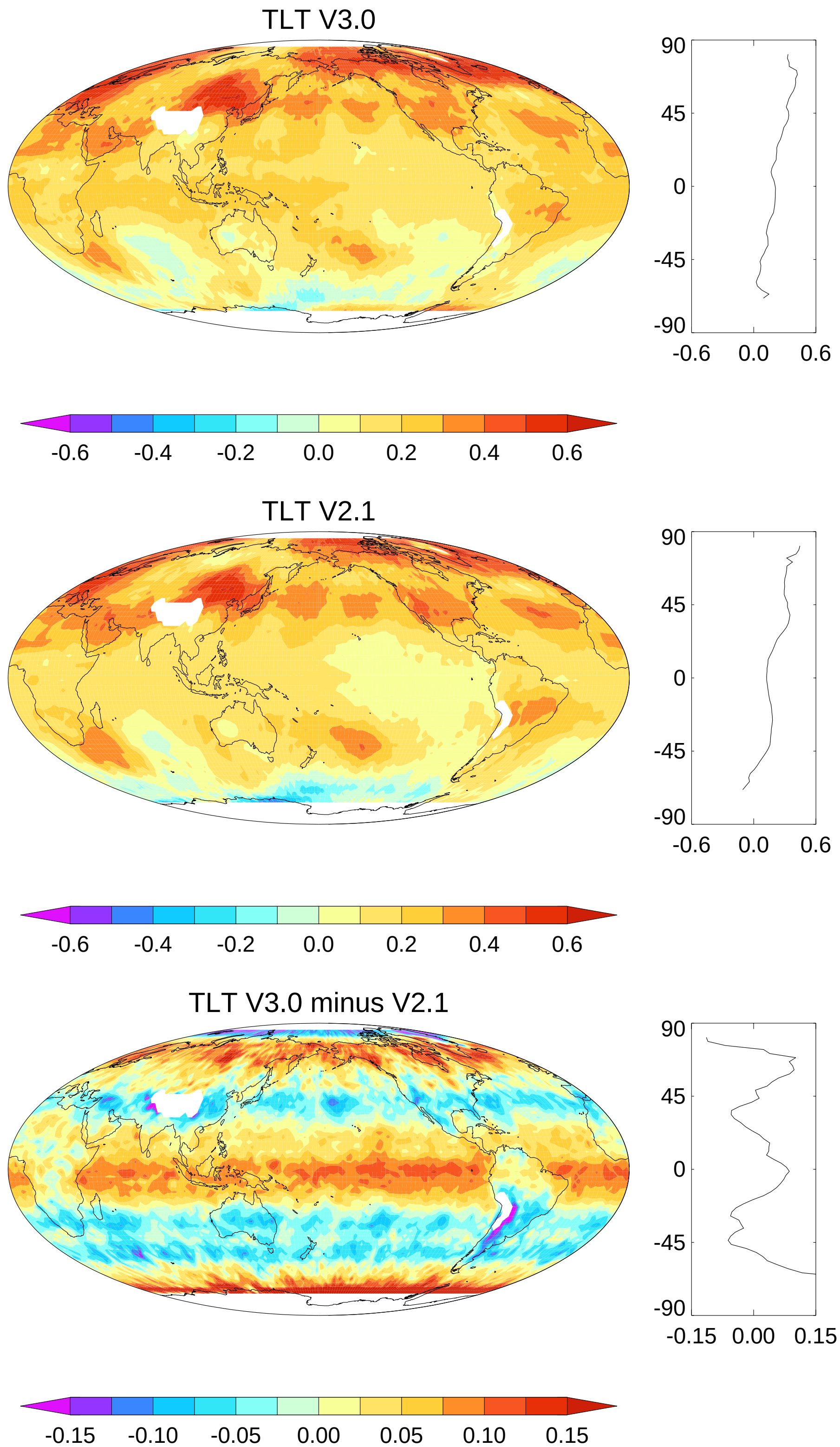

Fig. 4. Maps of TLT trends for the two versions, and a map of the trend differences.

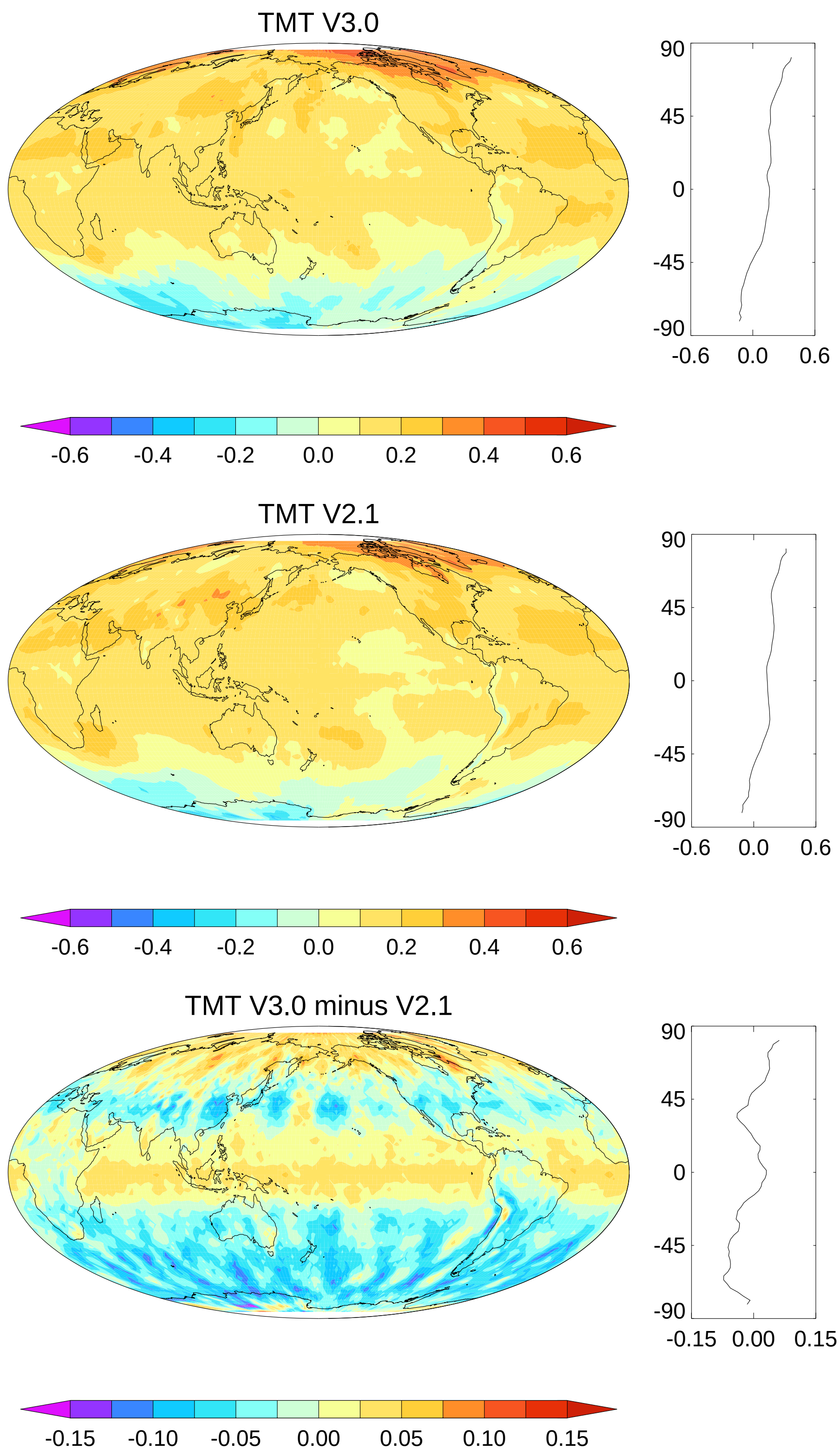

Fig. 5. Maps of TMT trends for the two versions, and a map of the trend differences.

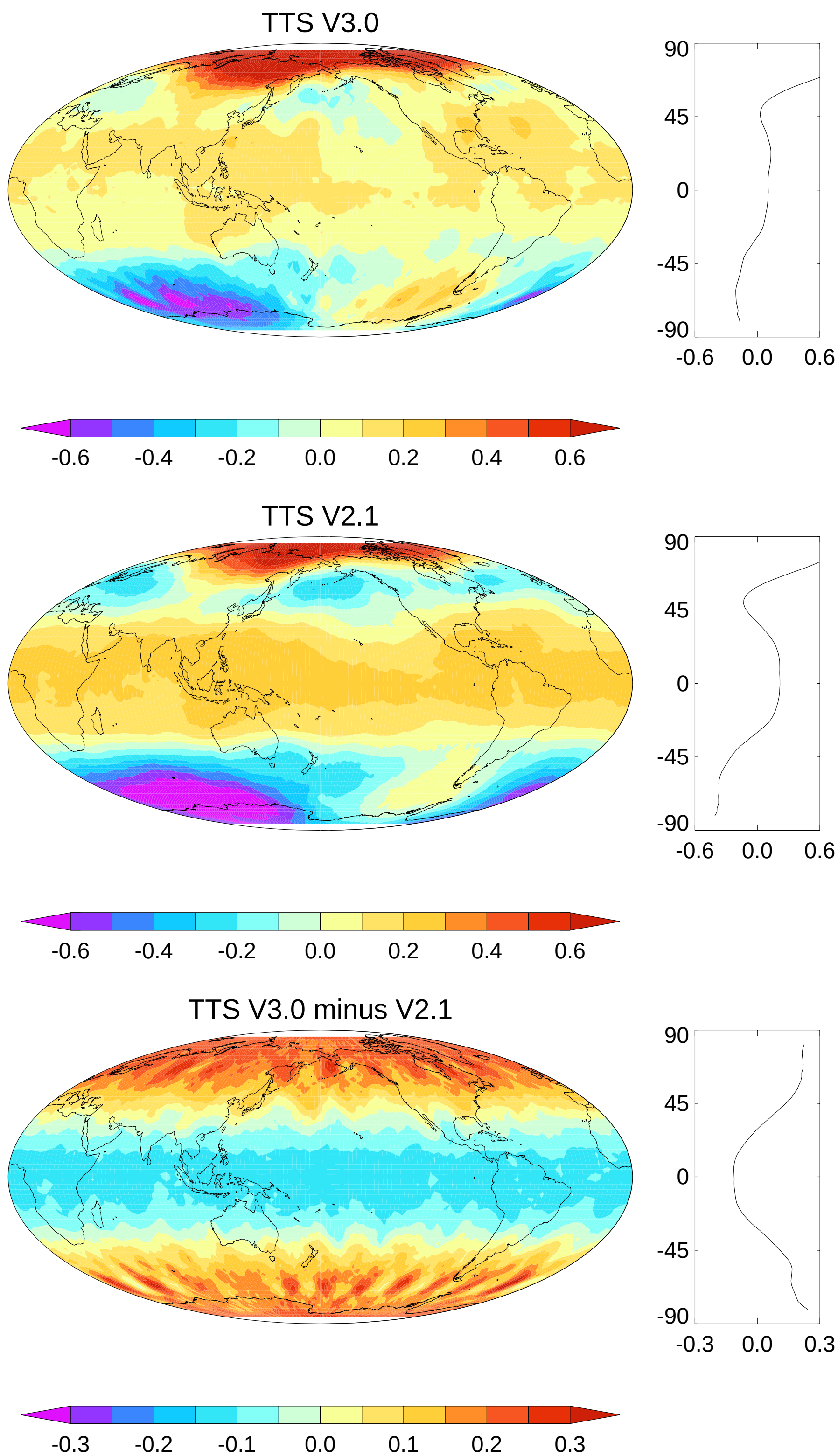

Fig. 6. Maps of TTS trends for the two versions, and a map of the trend differences.

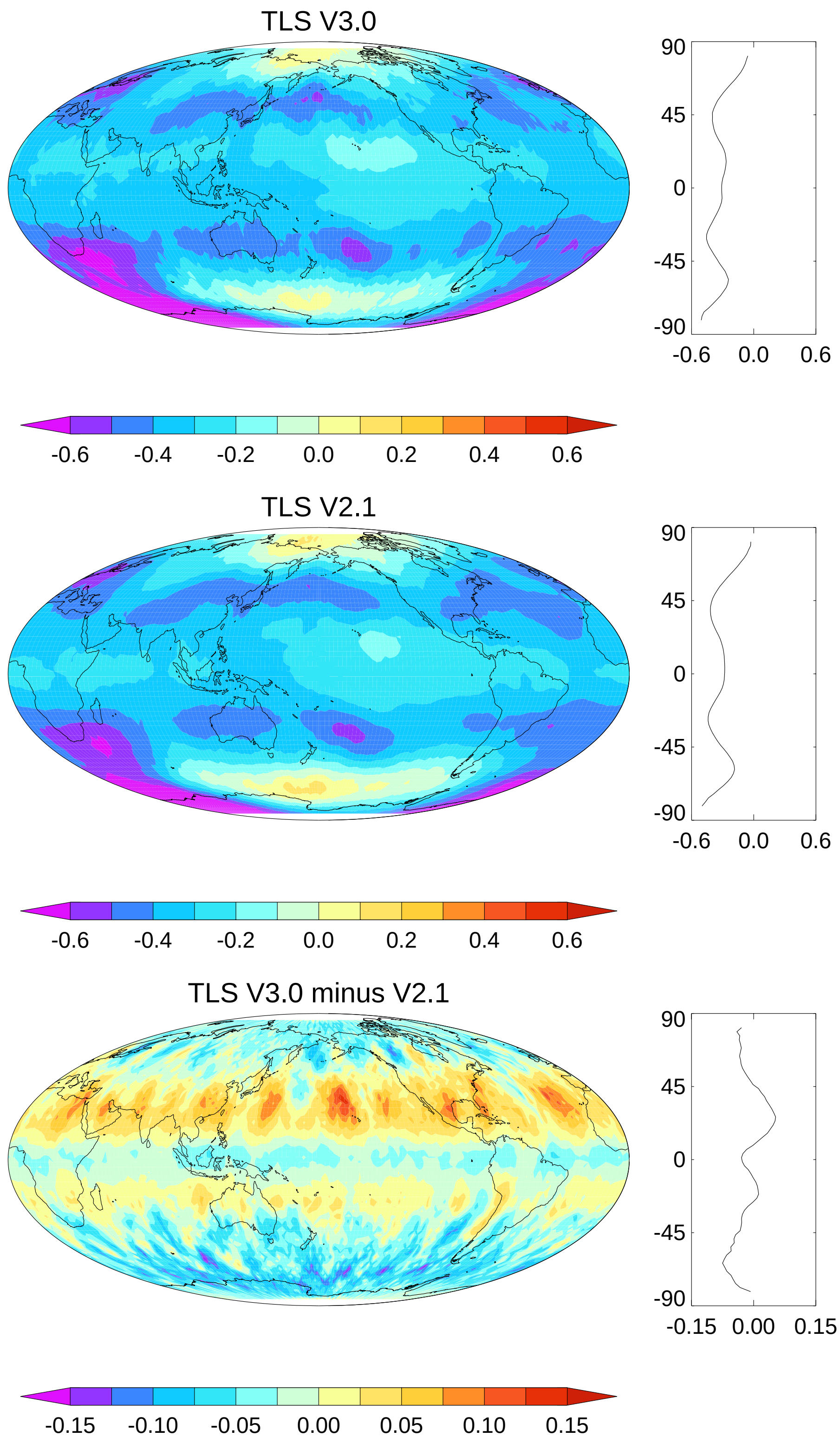

Fig. 7. Maps of TLS trends for the two versions, and a map of the trend differences.

III. Drifts in NOAA-16.

As noted above, there are significant differences in interannual trends between NOAA-15 relative to NOAA-16. In this section we characterize these differences, and provide evidence that supports our conclusion that drifts NOAA-16 are responsible for most of these differences. Since an important part of our evidence is based on the inconsistency of the NOAA-16 data between channels and view angles, we also present data from channels that are not used in our data products, which include AMSU4, AMSU6, and AMSU8. We focus on data over the tropical oceans (30S to 30N) because a number of calibration issues are simpler in this region. First, the average annual cycle is relatively small in the tropics, reducing the tendency for differences in sampling during a month to add error to the monthly average. Second, the diurnal cycle for those channels (AMSU4 and AMSU5) that sense a significant amount of signal emitted by the surface is much reduced for ocean scene. We formed monthly time series of brightness temperature for each instrument, channel, and field of view for the time period (2001-2006) when both instruments were operating simultaneously. The time series we investigated for evidence of both overall drifts of one instrument relative to the other, and also for evidence of "target factor" type calibration issues, which result when a calibration error proportional to the temperature of the calibration target is present. Over this time period, all channels investigate, except for channel 4 (and to a lesser extent) channel 9, showed large trends differences between NOAA-15 and NOAA-16 data.

The challenge present by these apparent drifts is that we have no absolute temperature references in the upper air that would make it possible to unambiguously decide which instrument is producing data that is closer to the truth. We have concluded that radiosonde datasets are not suitable for this task, due to the possibility of large errors, particularly at high altitude, and measurements based on GPS measurements are not sufficiently mature at this point. We instead turn to the internal consistency of the data from each instrument. The measurements should be consistent both between nearby channels, and between nadir and limb measurements[1]. In Figure 8, we plot bar graph of the trends over this time period for nadir (an average of the central 12 fields of view), and the limb (an average of the outer 8 fields of view) for each satellite. By evaluating the data both as presented in this plot, and in a number of other ways, including difference time series between instruments for each channel and field of view, and trends as a function of field of view for each instrument, we have come to the following conclusions.

- First, channel 6 appears to be drifting in both satellites. Its large negative trend is inconsistent with channels 5 and 7 for NOAA-15 (and with MSU 2 and MSU 3 data from NOAA-14, not shown). In both satellites, the near-limb trends are less negative than the near-nadir trends -- the opposite is likely to be true since the limb views sample more of the stratosphere, which cools rapidly over this period.
- If channel 6 is excluded, the rest of the channels from NOAA-15 form a consistent set of observations, with trend that increase slightly as we leave the surface, and then decrease as more stratospheric (cooling signal) is included. Note that for channels 7 though 9, the limb views show a more negative trend

[1] Due to their longer slant path through the atmosphere, the vertical weighting function for limb views is typically centered a kilometer or two higher in the atmosphere than the corresponding nadir views.

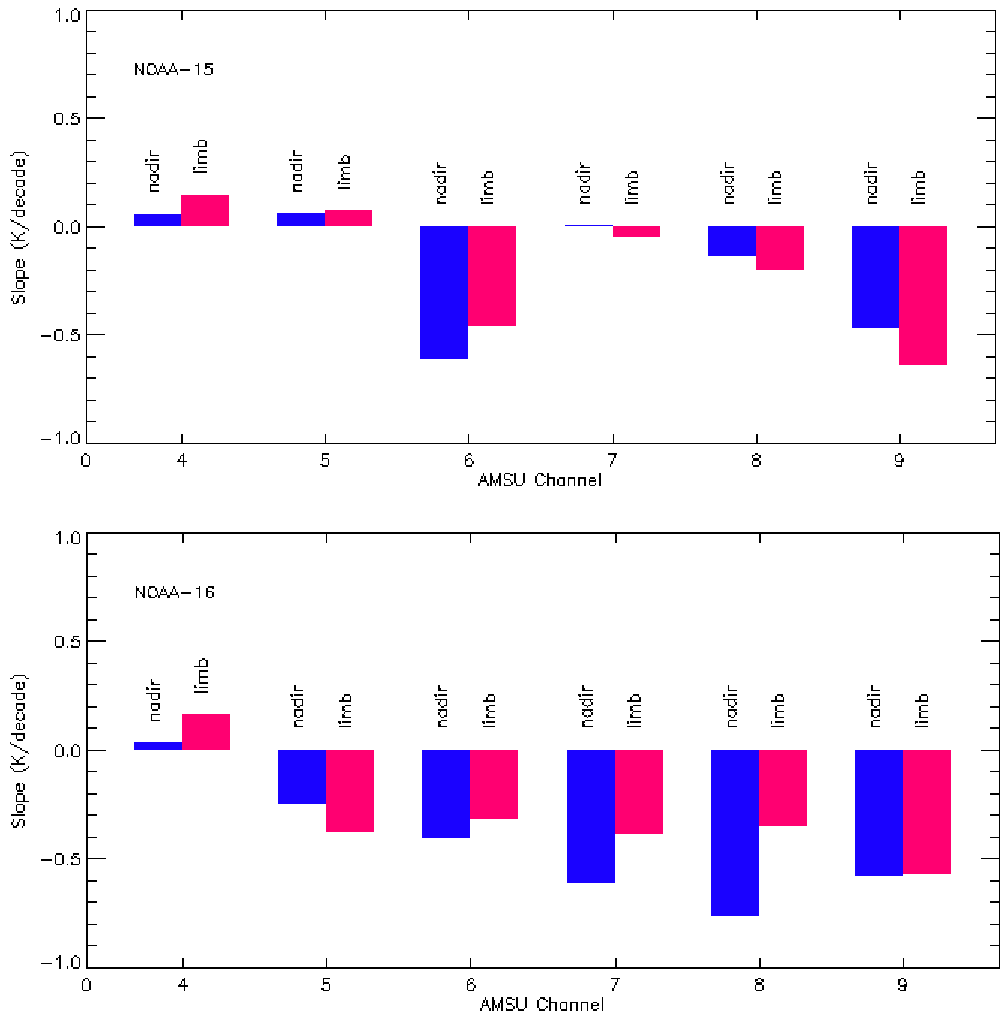

Fig. 8. Tropical (30S to 30N) oceanic temperature trends over the time period 2001-2006 for the NOAA-15 and NOAA-16 AMSU instruments. Trend are computed separately for the near-nadir and near-limb trends. The more consistent data from NOAA-15 (except for Channel 6) leads us to conclude that NOAA-16 is more likely to be suffering from calibration drifts than NOAA-15.

than the nadir view as expected. The behavior of the limb/nadir views is more complicated for channels 4 and 5. The analysis of these channels is complicated by the competing effects of changes in trend with height in the troposphere (the trends are expected to increase with height), and increased contribution from the stratosphere, as well a changing surface emissivity with angle and polarization.

- Data from NOAA-16 is not internally consistent, even if we ignore channel 6. Data from the limb views is typically less negative (by a huge amount) than the nadir views for channels 6 through 9, contrary to expectations. It would be impossible to construct a vertical trend structure consistent with NOAA-16 measurements that did not show unreasonably large changes in trend with small changes in altitude. Data from channel 5 inconsistent with NOAA-15 and MSU2 data from NOAA-14. Data from channel 4 may be OK.

Based on these arguments we have decided to remove NOAA-16 data from our dataset. We are continuing to study this problem, and it is possible that these drifts will be remove in the future if we develop sufficient understanding of their source. We are currently beginning to process data from the AMSU instrument on the NASA AQUA satellite, as well as data from the conically scanning sounder SSMIS to further evaluate this problem.

IV. Further Processing Differences.

Some further processing details are presented in outline form below.

Target Factors

V2.1

A. Determined for all satellites simultaneously
B. Pentad ocean only averages

V3.0

A. Determined for MSU and AMSU satellites separately
B. Monthly global ocean-only averages
C. Target factor for NOAA-15 channels 5 and 7 set to zero

Offsets

V2.1

A. Independent of Latitude
B. Determined from Land and Ocean Pentad Data

V3.0

A. Dependent on Latitude (2.5 degree bands)
B. Determined from Land and Ocean Monthly Data

Scene Temperature Factors

V2.1

A. Not Used
B. Determined using zonal monthly averages *after* target factors and offsets are applied.

NOAA-16

V2.1

A. Included

V3.0

A. Substantial Drift in NOAA-16 discovered -- NOAA-16 excluded until reason for drift is determined.
B. Trends in NOAA-16 not consistent from channel to channel, and from limb to nadir.

Merge Processing

V2.1

A. Grid point processing done using daily averages
B. Merged Daily Time series then averaged to monthly time series

V3.0

A. All processing done using monthly averages.
B. MSU and AMSU merged separately, and then combined
C. Location and Time of Year dependence offsets applied to match AMSU to MSU.

TLT Specific Issues

V2.1

A. AMSU data not included -- dataset stopped after December 2005

V3.0

A. AMSU data from NOAA-15 included
B. FOV weights determined by empirically matching brightness temperatures to MSU data.
C. Target factor set to zero for NOAA-15.

TLT FOV weights used:

A. The weights are

FOV 9 through 22	0.00000
FOV 8 and 23	0.14076
FOV 7 and 24	0.56850
FOV 6 and 25	0.91274
FOV 5 and 26	1.11883
FOV 4 and 27	1.00845
FOV 3 and 28	0.45880
FOV 2 and 29	-0.68506
FOV 1 and 30	-2.52133

only the outer 8 views on each side are used in the analysis. Moving inward to include more views resulted in views with very small negative weighting at the nadir end of the included view sets -- it doesn't seems like a good idea to include a lot of views with small absolute weights.

V. The Unresolved Issue: AMSU/MSU Drift -- Channel 5

In this section, we present some more details about the apparent drift between MSU2 (on NOAA-14) and AMSU5 (on NOAA-15). Unlike the drift between the AMSU instruments, the MSU/AMSU tropospheric drift is mostly confined to small geographic regions. In Fig. 9, we show a color-coded map of trend differences (1999-2004) between MSU2 and AMSU5. There are clearly regions where the trend differences are concentrated. In the mid latitude, a pattern of positive and negative trend differences is apparent. This is probably due to different sampling in the monthly averages aliasing the seasonal cycle into the data. This type of error is reduced when zonal averaging is performed, e.g. the small average trend difference over the southern mid latitudes shown in the plot to the right. In the northern latitudes, the effects of the seasonal cycle is complicated by the presence of large land areas. A more serious problem is evident in the deep tropics, where there is little trend difference over the oceans, and a large trend difference over the land regions, particularly regions with tropical rain forest. The trend differences in the deep tropics do not average toward zero when averaged over longitude. The origin of these trend differences is unresolved at this time. Possible causes include errors in the modeled diurnal cycle used to adjust for drifts in measurement time -- these could arise either from the surface contribution (AMSU5 is more surface sensitive than MSU2), or from a diurnal cycle in precipitation (AMSU5 has significantly smaller footprints than MSU2, which increases its sensitivity to precipitation.).

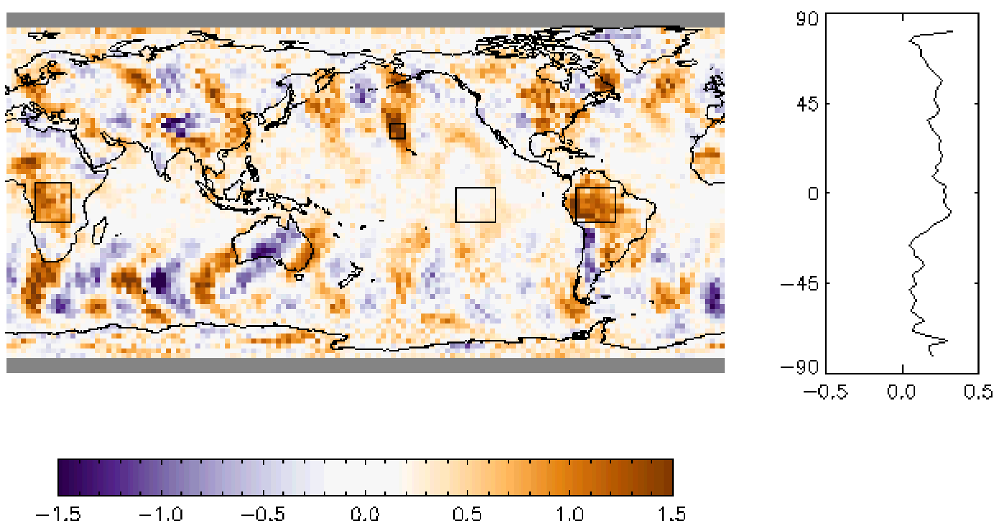

Fig. 9. Map of the trend difference between MSU and AMSU5 (NOAA-14 minus NOAA-15) for the time period 1999-2004.

Since we do not yet know whether MSU2 on NOAA-14 or AMSU5 on NOAA-15 is closer to the true temperatures, we choose to include data from both satellites in the V3.0 products during the period of overlapping data from mid-1998 through 2004[2]. To test the effects of these drifts on the long-term means, we also produced 2 other versions of the data, "no early AMSU", where AMSU data is not used until January 2004, and "no late MSU", where MSU data is not used after December 2000. We present the effects of these choices on the long term means in Table 1.

[2] NOAA-14 continued to operate after 2004 -- however there are increasingly large regions of missing data for some months starting in mid 2005. This missing data adds noise to the merging procedure, thus we choose not to use data after December 2004.

Table 1.
MSU/ASMU Trends, 1979-2006, K/decade

	V3.0	no early AMSU	no late MSU
Global (70S to 82.5N) TLT Trend	0.205	0.214	0.202
Tropical (20S to 20N) TLT Trend	0.196	0.197	0.190
Global (70S to 82.5N) TMT Trend	0.119	0.133	0.105
Tropical (20S to 20N) TMT Trend	0.153	0.169	0.135

Table 1 suggests that the effect of the MSU/AMSU drift is relatively small, a few hundredths of a K per decade, on large spatial scales so far. However, these differences are obviously concentrated in the last few years of the data record, where they cause differences in the anomaly time series on the order of a few tenths of a degree K. If, for example, the cause of the drift is some recurring problem in the AMSU instruments, the effects of the drift could accumulate as we add to the dataset. We are working to further our understanding of this drift. As in the case for the NOAA-15/NOAA-16 drift, the analysis of data from more satellites may shed light on the problem.