A Comparative Analysis of Data Derived from Orbiting MSU/AMSU Instruments

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ABSTRACT

Spencer and Christy of the University of Alabama in Huntsville (UAH) recently introduced a new method to process MSU/AMSU satellite brightness temperature data with their version 6 (v6) data. A comparison of UAH v6 north polar lower stratospheric (TLS) data with that from Remote Sensing Systems (RSS) is presented, indicating a possible bias between 1986 and 1988. Comparing UAH and NOAA Center for Satellite Applications and Research (NOAA) TLS data produces a similar result. An additional analysis utilizing midtropospheric (TMT) data also found a similar bias. Comparing the NOAA TMT data for the May 2016 release against UAH and RSS TMT evidenced another excursion, dated at the middle of 2005, that was corrected in later releases. These comparisons reinforce the concerns expressed by other analysts regarding the merging procedure for UAH v6, repeating similar concerns regarding the earlier UAH v5 products. Any biases in the UAH, RSS, or STAR products would impact the trends calculated for these products and could explain the differences between these trends. Biases in the UAH series would also impact the UAH TLTv6 lower-troposphere product, which is a linear combination of the UAH TMT, tropopause temperature (TTP), and TLS series.

1. Introduction

Spencer and Christy at the University of Alabama in Huntsville (UAH) proposed the use of brightness temperature measurements from satelliteborne Microwave Sounding Units (MSU), which have been flown on several satellites since 1978, for use in assessing climate change (Spencer and Christy 1990). Their original scheme involved averaging data from channel 2 of the MSU instruments into time series beginning in 1979. They later described a modified approach again using data from MSU channel 2, adding a correction for "limb darkening" in the off-nadir scan positions to remove the influence of higher altitudes found in MSU channel 2 (Spencer and Christy 1992a). The temperature, lower troposphere (TLT), combined data from MSU channel 2 scan positions 3, 4, 8, and 9 and a correction derived from differencing those positions and outer scan positions, 1, 2, 10, and 11 (Spencer and Christy 1992b). As the MSU instruments were replaced with the Advanced Microwave Sounding Unit (AMSU) instruments, UAH extended its time series by combining AMSU channel 5 data with the MSU channel 2 data (Christy et al. 2003). UAH also produced a time series for the middle troposphere (TMT) using MSU channel 2 and the lower stratosphere (TLS) using MSU channel 4, both also later merged with AMSU data. Several researchers found flaws in the UAH TLT product, resulting in revisions over the years. Other research teams have produced alternative products from the MSU/AMSU data, including Remote Sensing Systems (RSS) (Mears and Wentz 2009a,b), Qiang Fu (University of Washington) (Johanson and Fu 2006), and Cheng-Zhi Zou at the NOAA Center for Satellite Applications and Research (NOAA) (Zou et al. 2006, 2009; Zou and Wang 2011). As differences between the UAH results, other data series, and climate model experiments were reported (Seidel et al. 2004), a major effort was undertaken to reconcile these questions (Karl et al. 2006).

The UAH TMT is a combination of MSU channel 2 and AMSU channel 5, the new UAH tropopause temperature (TTP) is a combination of MSU channel 3 and AMSU channel 7, and the TLS is a combination of MSU channel 4 and AMSU channel 9. UAH released a new version, version 6 (v6), of their MSU/AMSU products with an Internet blog post (Spencer et al. 2015). This new version represents a fundamentally different processing methodology to calculate the TMT, TTP, and TLS data series, and the new TLT v6 product is a linear combination of the data from these three channels. At present, the UAH v6 results

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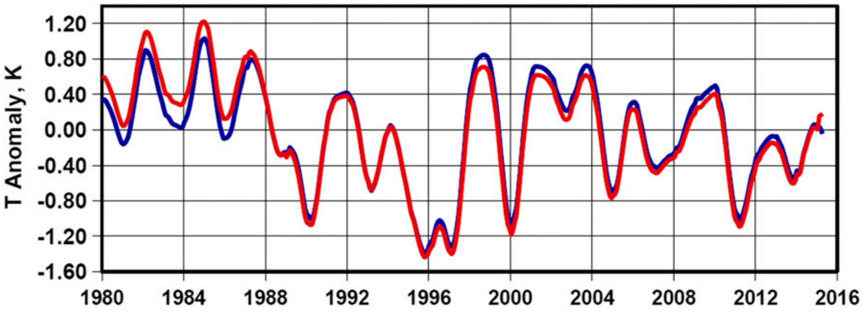

FIG. 1. UAH v6b5 and RSS v3.3 TLS NoPol lower-stratospheric series after applying an H25 filter. Red is UAH and blue is RSS.

are preliminary and a fifth revision has now been released as v6beta5 (v6b5) (Spencer 2016). The release of the UAH version 6 products before publication is unusual, and Spencer recently stated that a manuscript has been submitted for a peer-reviewed publication. While some may feel it scientifically inappropriate to utilize UAH v6b5 data before publication, these data have already been presented in testimony during congressional hearings before both the U.S. House and Senate and have also appeared on websites and in public print articles.

UAH produces monthly updates to both the v5.6 and v6 products, from December 1978 through the most recent month (UAH 2016a,b). RSS produces TLS, TMT, TTP, and TLT series, as well as its version of T24 from Fu and Johanson (2004), Fu et al. (2004), and Johanson and Fu (2006), called TTT by RSS, and these data are available from the RSS website (RSS 2016a,b). The NOAA group produces a TMT, TUT, and TLS data series that is available on their website (NOAA/STAR 2016a,b). These data are typically available as regional monthly anomaly time series, as well as gridded monthly anomaly and/or brightness temperature data.

2. Method

Swanson (2003) presented a comparison of the annual cycle in data from radiosondes located around Antarctica with south polar UAH TLT data. Because of this previous interest, a comparison between the newly released UAH TLS v6 and the RSS TLS v3.3 was undertaken. Initially, the north polar (60°–90°N) lower-stratospheric data were selected, since the new UAH TLT v6 incorporates a small fraction of the MSU channel 4 (MSU4) series. The respective TLS anomaly time series through April 2016 were downloaded and then processed by applying Hamming filters to the combined land and ocean TLS datasets, with the goal of understanding the apparent differences in trends and annual cycle. These data were processed to extract a yearly signal by bandpass filtering through the application of a 7-month filter (H7) and a 25-month filter (H25) to each series. The H25 series was subtracted from the corresponding H7 series, with the resulting series exhibiting a bandpass of about 12 months. The UAH and RSS 25-month filtered TLS north polar (NoPol) time series are shown in Fig. 1. Next, the RSS bandpassed series was subtracted from the UAH bandpassed series, with the result clearly exhibiting an annual cycle, shown in Fig. 2a. The presence of a yearly cycle was also found in a recent paper analyzing stratospheric temperatures (Seidel et al. 2016). The two H25 filtered series were cross plotted, shown in Fig. 3a. Last, the H25 series were detrended and differenced; the result is plotted in Fig. 4a.

Gridded 2.5° × 2.5° monthly TLS brightness temperature data from NOAA were reduced to a comparable time series, beginning by calculating zonal average series from the longitudinal values, and then converting these data to zonal anomalies using a base period of 1981–2010. These zonal anomalies were further reduced to a north polar series by extracting data from 60° through 85°N latitude, which were summed using cosine weighting, producing a single value for each month in the final time series, to enable comparison with the TLS data from UAH and RSS. The processing algorithms were tested by reproducing the NOAA NH and SH TLS series; the resulting series exhibited differences of no more than 0.001 K. The computed NOAA north polar series was further processed as described above for the UAH and RSS TLS series, applying 7-month and 25-month Hamming filters, and computing a bandpassed series and a detrended H25 series. These data are shown in graphs comparing UAH against NOAA results in Figs. 2b, 3b, and 4b and in graphs comparing RSS against NOAA results in Figs. 2c, 3c, and 4c. In addition, an identical analysis using TMT data from UAH v6.5, RSS v4.0, and NOAA v3.0 was also undertaken, with the results shown in Figs. 5 and 6.

3. Discussion

The annual cycles seen in Fig. 2 are likely related to the different averaging periods selected by each team to calculate their anomaly time series. UAH v6b5 team

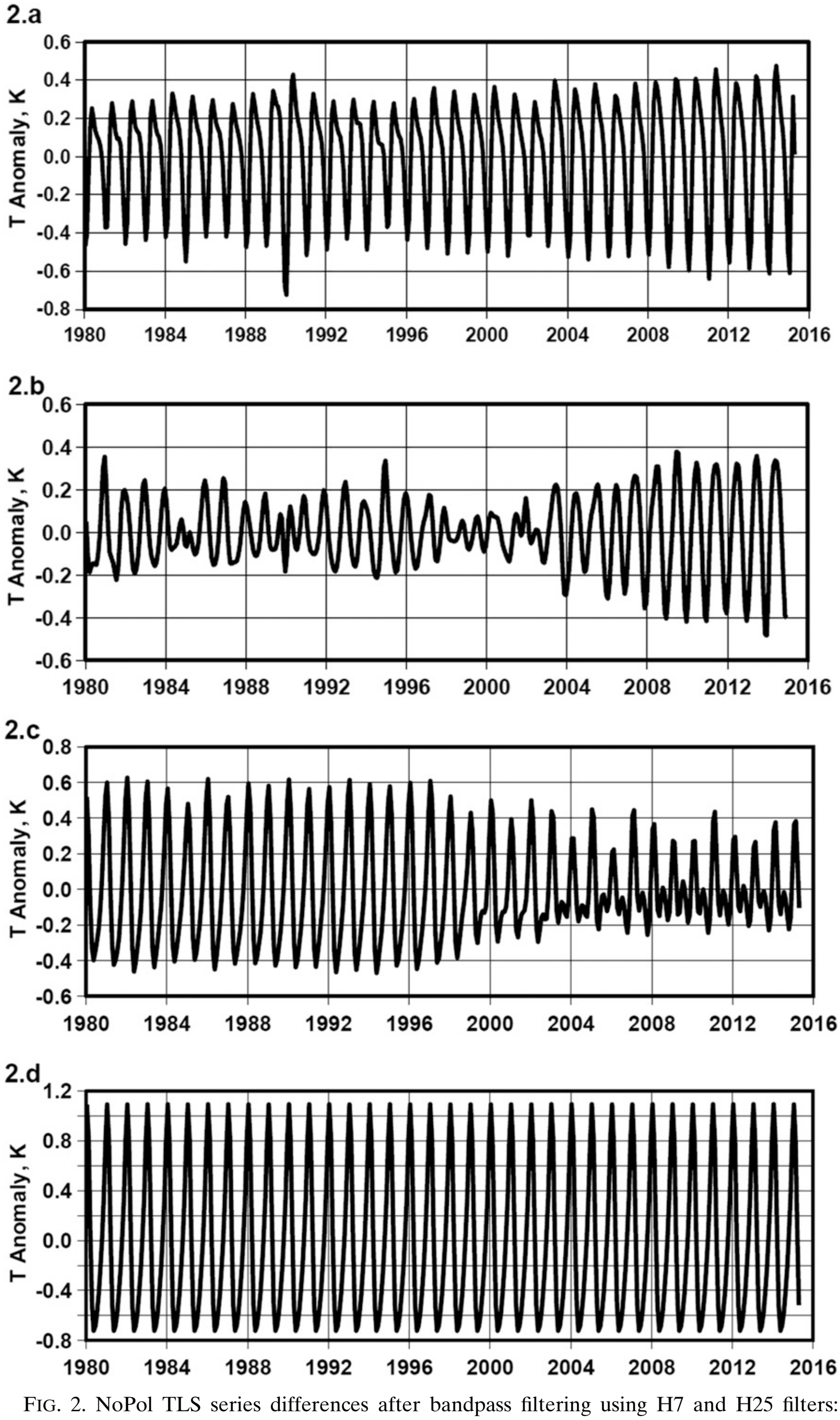

FIG. 2. NoPol TLS series differences after bandpass filtering using H7 and H25 filters: (a) UAH v6b5 minus RSS v3.3, (b) UAH v6b5 minus NOAA v3.0, (c) RSS v3.3 minus NOAA v3.0, and (d) NOAA with bandpass of 1981–97 minus NOAA bandpass of 1998–2015.

calculates their annual average over a base period of 1981–2010, while the RSS TLS v3.3 base period is 1979–98. The longer averaging period selected by UAH compared with RSS v3.3 may be masking subtle changes in the annual cycle, but it will not impact the trends calculated for the complete anomaly series. In this paper, the NOAA series was produced with a base period of 1981–2010; thus, the seasonal differences between

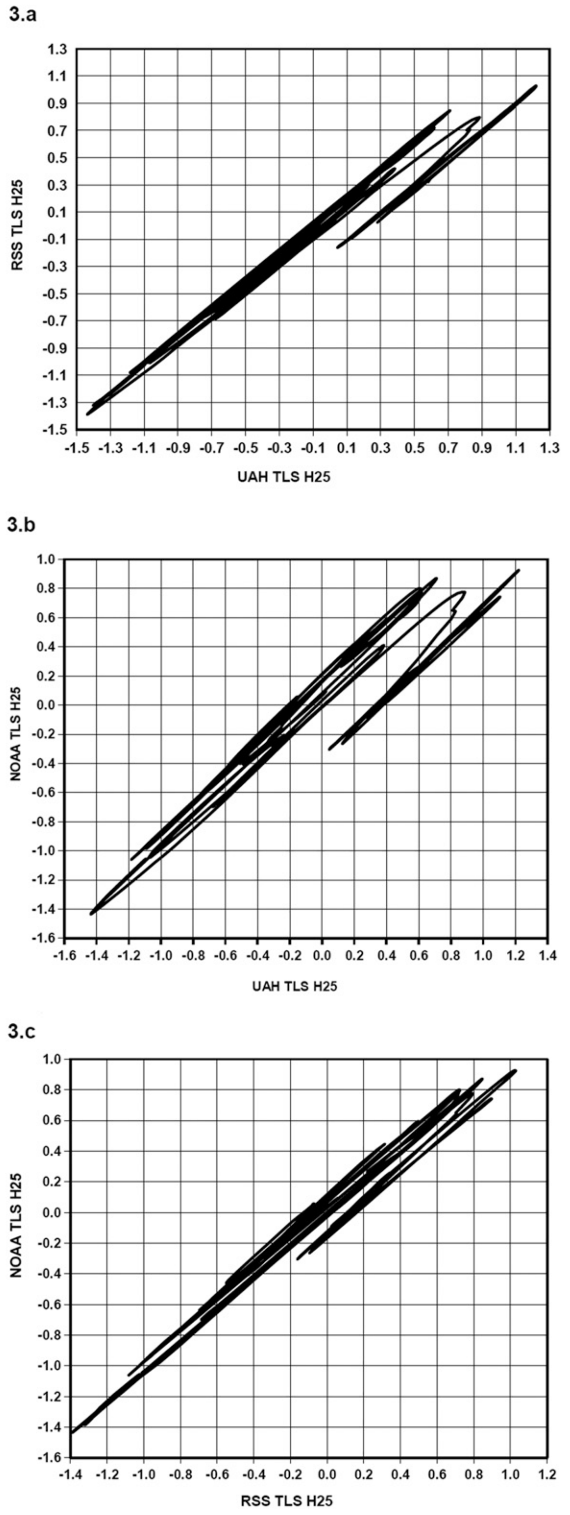

FIG. 3. Cross plots of TLS NoPol series after applying an H25 filter: (a) UAH v6b5 vs RSS v3.3 TLS, (b) UAH v6b5 vs NOAA v3.0, and (c) RSS v3.3 vs NOAA v3.0.

UAH and NOAA shown in Fig. 2b are not from base period differences. A test of the effects of different base periods was undertaken using the NOAA v3.0 data, first calculating a polar time series using an early base period of 1981–1997 and then calculating another time series with a late base period of 1998–2015. The resulting difference between the two H7-minus-H25 filtered series is shown in Fig. 2d, which demonstrates clearly the impact of using different base periods, as the amplitude of the annual cycle from the test is greater than any of the other panels in Fig. 2. Also, in this test the two series exhibited essentially identical trends, proving that the base period does not affect the long-term trend.

Comparing the UAH and RSS H7 series indicates that the annual cycle in the RSS TLS tends to be warmer than the UAH TLS during December–February, but UAH is warmer for the other months of the year (not shown). A similar result was found in the bandpassed series from the NOAA base period test in which the early base period exhibited warmer months for November–February, while the late base period exhibited cooler months for April–September, and the months of March and October being near neutral. The new UAH version 6 grid registration procedure, which apparently extends farther poleward than previous versions, may also influence the difference in yearly cycles, especially for the higher latitudes analyzed herein. Further investigation of the annual cycle is beyond the scope of this study.

Another issue is evident in plots of the UAH and RSS TLS H25 time series. The scatterplot shown in Fig. 3a exhibits an abrupt shift between the two series, appearing in the upper-right quadrant of the graph, between 1986 and 1988. This shift could arise from a step change or bias in either series, which could indicate a problem resulting from merging the data streams from several different satellites around those dates. This shift appears again in the comparison between UAH and NOAA, shown in Fig. 3b; however, this shift does not appear in the comparison between RSS and NOAA, shown in Fig. 3c. This shift was visible in Fig. 3 of Seidel et al. (2016), which compared the TLS global averages from UAH v5.6, RSS v3.3, and NOAA v3.0.

The timing for the TLS shift is about the same as that previously associated with the merging of *NOAA-9* data caused by diurnal drift and the "warm target factor." Differences between UAH and RSS products have been exhaustively considered in several studies comparing the earlier UAH v5.6 and RSS v3 TMT and TLT products, as recently detailed in Po-Chedley and Fu (2012a,b) and in Christy and Spencer (2013). A graphic illustration of the UAH "backbone" merging process is shown in Fig. 2 of Christy and Spencer (2013), a paper presented in reply to Po-Chedley and Fu (2012a). These

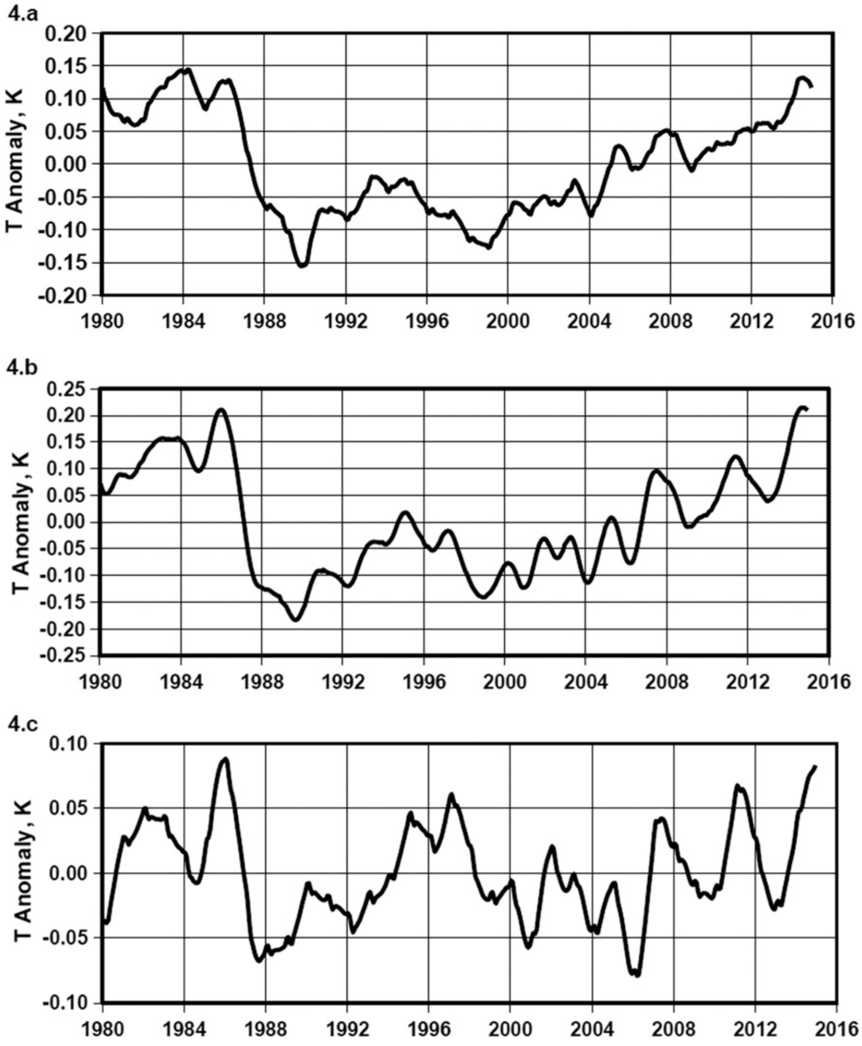

FIG. 4. Difference between TLS series after applying an H25 filter and detrending: (a) UAH v6b5 minus RSS v3.3, (b) UAH v6b5 minus NOAA v3.0, and (c) RSS v3.3 minus NOAA v3.0.

exchanges resulted in a further rebuttal by Po-Chedley and Fu (2013) in which the differences between the UAH TMT and the data from RSS and NOAA are linked to the warm target factor used by UAH for the *NOAA-9* satellite, leading to relative cooling in the UAH TMT between 1985 and 1987. Yet another study of the merging process for the TMT by Po-Chedley et al. (2015) found that the UAH TMT exhibited a distortion between 1985 and 1987, which they again link to the UAH merging of *NOAA-9*, a finding that mirrors the timing for the TLS "shift" found herein. Wang and Zou (2014) compared AMSU-only results for NOAA, UAH, and RSS. Since each MSU instrument utilizes a single warm target to calibrate the three channels, one would expect that this warm target factor would also impact the TLS series. This could provide an explanation for the shift evident in Figs. 3 and 4, and it may indicate a repeat of the UAH v5.6 warm target factor issue in the new UAH v6b5 time series.

The TMT comparison graphs in Figs. 5a and 5b also show evidence of a shift in the lower-left quadrant where one would expect to find any shift early in the series, as all three series exhibit a warming trend. The magnitude of the shift is not as great as that found in the TLS results, Figs. 3a and 3b. For the UAH TMT, Figs. 6a and 6b also show a warming excursion relative to RSS and NOAA between 1982 and 1985, while the comparison between RSS and NOAA in Fig. 6c exhibits greater agreement during that period.

An additional issue appeared in the TMT graphs comparing NOAA with UAH and RSS, where Figs. 5b and 5c exhibit a "loop" in the H25 cross plots. In detrended H25 difference plots for UAH minus NOAA and RSS minus NOAA, this loop appeared as a negative "spike" centered at June 2005. During the review of this study, it was

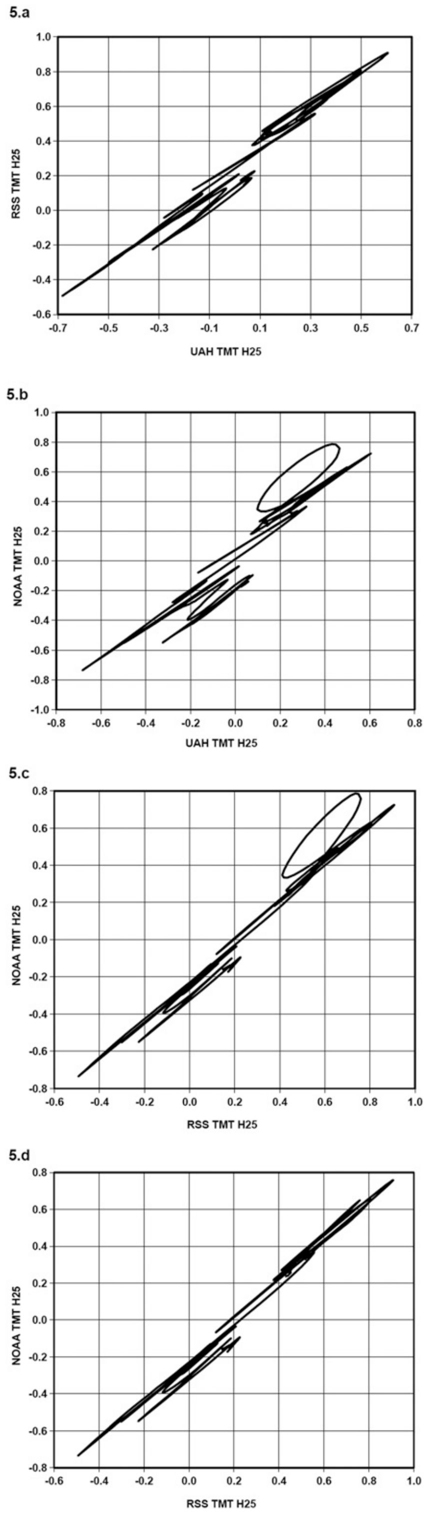

FIG. 5. Cross plots of TMT NoPol series after applying an H25 filter: (a) UAH v6b5 vs RSS v4.0, (b) UAH v6b5 vs NOAA v3.0, (c) RSS v4.0 vs NOAA v3.0, and (d) RSS v4.0 vs NOAA v3.0 using July 2016 NOAA data.

revealed that the loop and spike seen in NOAA TMT v3.0 data through April 2016 (released in May) had been identified as a processing error that was corrected in later releases. The NOAA TMT released in July 2016 was used to construct the graphs shown in Figs. 6b and 6c, which show no evidence of a spike. The loop and corresponding spike were the result of an offset of about +0.3 K in the NOAA time series for 12 months during 2005. The graphs in Figs. 5b and 5c used the May data release and are presented as an example of the effects of an offset. The loop excursion no longer appears in graphs employing the NOAA July release, as shown in Fig. 5d.

Other research efforts have documented excursions as found in the TLS and TMT series as described above. Seidel et al. (2016) noted an excursion in the UAH TLS v5.6 beginning about 2005, shown in their Fig. 5, but they found none in the new UAH TLS v6b5. Po-Chedley et al. (2015) notes a break point at 1985–87 when comparing UAH and UW TMT v5.6 tropical data, and another break point at about 2004 (their Figs. 8 and 9). Po-Chedley et al. ascribe the latter break point to diurnal drift differences between *NOAA-15*, *NOAA-17*, and *Aqua* near 2004. Mears and Wentz (2016) describe in considerable detail the method used to calculate their latest RSS TMT v4.0, incidentally confirming the results of Po-Chedley et al. (2015).

Determining the correct adjustments and merging procedure for these data is at the heart of the continuing controversy regarding the use of the MSU/AMSU satellite data for assessing climate change. The shift noted in comparisons of H25 filtered TLS data (Fig. 3) appears to repeat previously raised concerns regarding the UAH v5 series merging of *NOAA-9* data due to the warm target factor, suggesting that these concerns may also apply to the new UAH v6 series. The AMSU package utilizes two separate instruments, which may present an additional complication, as AMSU channel 5 employs a different warm target than that used for AMSU channels 7 and 9. Through June 2016, the TMT north polar trends differ considerably: UAH reports 0.17 K decade^{-1}, RSS reports 0.21 K decade^{-1}, and the NOAA trend calculated herein is 0.28 K decade^{-1}. The presence of any emergent biases that may be ascribed to the UAH products would also impact the new UAH v6 TLT, since this series is a linear combination of its TMT, TTP, and a small fraction of the TLS series. Further investigation of these merging issues must be left for more detailed analysis by other researchers.

4. Conclusions

This paper presents an alternate analysis of MSU/AMSU TLS and TMT brightness temperature anomaly

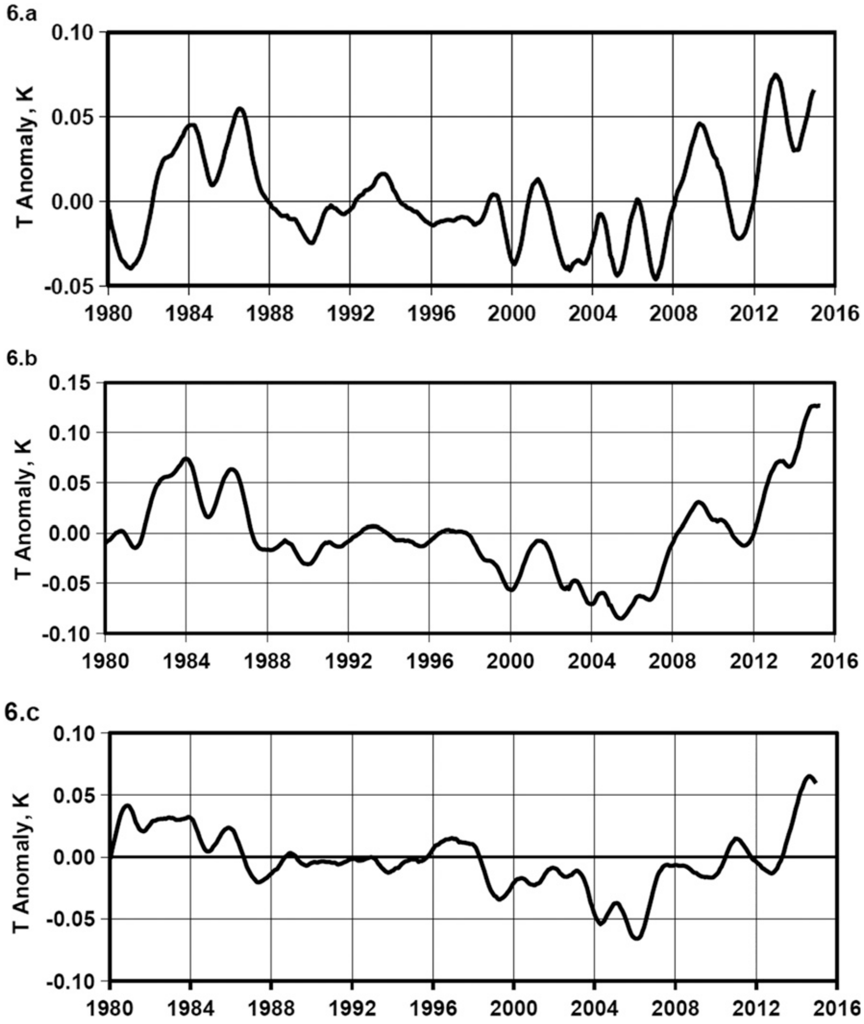

FIG. 6. Difference between TMT NoPol series after applying an H25 filter and detrending: (a) UAH v6b5 minus RSS 4.0, (b) UAH v6b5 minus NOAA v3.0, and (c) RSS v4.0 minus NOAA v3.0.

data products, from UAH, RSS, and NOAA. Removing short-period variations from these data, including any remnants of the annual cycle through the application of improved filtering, allows for clearer visualization of differences between these datasets. While the techniques presented can illuminate differences between these time series, a comparative analysis cannot determine the cause of such differences. Since these series are derived from the same set of measurements taken from orbit, these differences are the result of each group's analytical assumptions and merging decisions, which are then translated into the computer programming steps employed to process these data. These data have gained considerable prominence in public discussion of Earth's changing climate; thus, it is imperative that any remaining questions regarding differences between these series be resolved.

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REFERENCES

Christy, J. R., and R. W. Spencer, 2013: Comments on "A bias in the midtropospheric channel warm target factor on the *NOAA-9* Microwave Sounding Unit." *J. Atmos. Oceanic Technol.*, **30**, 1006–1013, doi:10.1175/JTECH-D-12-00107.1.

——, ——, W. B. Norris, and W. D. Braswell, 2003: Error estimates of version 5.0 of MSU–AMSU bulk atmospheric temperatures. *J. Atmos. Oceanic Technol.*, **20**, 613–629, doi:10.1175/1520-0426(2003)20<613:EEOVOM>2.0.CO;2.

Fu, Q., and C. M. Johanson, 2004: Stratospheric influences on MSU-derived tropospheric temperature trends: A direct error analysis. *J. Climate*, **17**, 4636–4640, doi:10.1175/JCLI-3267.1.

——, ——, S. G. Warren, and D. J. Seidel, 2004: Contribution of stratospheric cooling to satellite-inferred tropospheric temperature trends. *Nature*, **429**, 55–58, doi:10.1038/nature02524.

Johanson, C. M., and Q. Fu, 2006: Robustness of tropospheric temperature trends from MSU channels 2 and 4. *J. Climate*, **19**, 4234–4242, doi:10.1175/JCLI3866.1.

Karl, T. R., S. J. Hassol, C. D. Miller, and W. L. Murray, Eds., 2006: Temperature trends in the lower troposphere: Steps for understanding and reconciling differences. Synthesis and Assessment Product 1.1, U.S. Climate Change Science Program and Subcommittee on Global Change Research, 164 pp. [Available online at http://www.globalchange.gov/browse/reports/sap-11-temperature-trends-lower-atmosphere-steps-understanding-reconciling.]

Mears, C. A., and F. J. Wentz, 2009a: Construction of the Remote Sensing Systems V3.2 atmospheric temperature records from the MSU and AMSU Microwave Sounders. *J. Atmos. Oceanic Technol.*, **26**, 1040–1056, doi:10.1175/2008JTECHA1176.1.

——, and ——, 2009b: Construction of the RSS V3.2 lower-tropospheric temperature dataset from the MSU and AMSU Microwave Sounders. *J. Atmos. Oceanic Technol.*, **26**, 1493–1509, doi:10.1175/2009JTECHA1237.1.

——, and ——, 2016: Sensitivity of satellite-derived tropospheric temperature trends to the diurnal cycle adjustment. *J. Climate*, **29**, 3629–3646, doi:10.1175/JCLI-D-15-0744.1.

NOAA/STAR, 2016a: Merged_MSU4_AMSUA9_Monthly data, v3.0. NOAA/STAR, accessed 4 May 2016. [Available online at ftp://ftp.star.nesdis.noaa.gov/pub/smcd/emb/mscat/data/MSU_AMSU_v3.0/Monthly_Atmospheric_Layer_Mean_Temperature/.]

——, 2016b: Merged_MSU2_AMSUA5_Monthly data, v3.0. NOAA/STAR, accessed 4 May 2016. [Available online at ftp://ftp.star.nesdis.noaa.gov/pub/smcd/emb/mscat/data/MSU_AMSU_v3.0/Monthly_Atmospheric_Layer_Mean_Temperature/.]

Po-Chedley, S., and Q. Fu, 2012a: A bias in the midtropospheric channel warm target factor on the *NOAA-9* Microwave Sounding Unit. *J. Atmos. Oceanic Technol.*, **29**, 646–652, doi:10.1175/JTECH-D-11-00147.1.

——, and ——, 2012b: Discrepancies in tropical upper tropospheric warming between atmospheric circulation models and satellites. *Environ. Res. Lett.*, **7**, 044018, doi:10.1088/1748-9326/7/4/044018.

——, and ——, 2013: Reply to "Comments on 'A bias in the midtropospheric channel warm target factor on the *NOAA-9* Microwave Sounding Unit.'" *J. Atmos. Oceanic Technol.*, **30**, 1014–1020, doi:10.1175/JTECH-D-12-00131.1.

——, T. J. Thorsen, and Q. Fu, 2015: Removing diurnal cycle contamination in satellite-derived tropospheric temperatures: Understanding tropical tropospheric trend discrepancies. *J. Climate*, **28**, 2274–2290, doi:10.1175/JCLI-D-13-00767.1.

RSS, 2016a: RSS_TS_channel_TLS_Northern Polar_Land_And_Sea_v03_3. Remote Sensing Systems, accessed 7 May 2016. [Available online at http://www.remss.com/measurements/upper-air-temperature.]

——, 2016b: RSS_TS_channel_TMT_Northern Polar_Land_And_Sea_v04_0. Remote Sensing Systems, accessed 7 May 2016. [Available online at http://www.remss.com/measurements/upper-air-temperature.]

Seidel, D. J., and Coauthors, 2004: Uncertainty in signals of large-scale climate variations in radiosonde and satellite upper-air temperature datasets. *J. Climate*, **17**, 2225–2240, doi:10.1175/1520-0442(2004)017<2225:UISOLC>2.0.CO;2.

——, and Coauthors, 2016: Stratospheric temperature changes during the satellite era. *J. Geophys. Res. Atmos.*, **121**, 664–681, doi:10.1002/2015JD024039.

Spencer, R. W., 2016: UAH V6 global temperature update for January, 2016: +0.54 deg C. [Available online at http://www.drroyspencer.com/2016/02/uah-v6-global-temperature-update-for-january-2016-0-54-deg-c/.]

——, and J. R. Christy, 1990: Precise monitoring of global temperature trends from satellites. *Science*, **247**, 1558, doi:10.1126/science.247.4950.1558.

——, and ——, 1992a: Precision and radiosonde validation of satellite gridpoint temperature anomalies. Part I: MSU channel 2. *J. Climate*, **5**, 847–857, doi:10.1175/1520-0442(1992)005<0847:PARVOS>2.0.CO;2.

——, and ——, 1992b: Precision and radiosonde validation of satellite gridpoint temperature anomalies. Part II: A tropospheric retrieval and trends during 1979–90. *J. Climate*, **5**, 858–866, doi:10.1175/1520-0442(1992)005<0858:PARVOS>2.0.CO;2.

——, ——, and W. D. Braswell, 2015: Version 6.0 of the UAH temperature dataset released: New LT trend = +0.11 C/decade. In press. [Available online at http://www.drroyspencer.com/wp-content/uploads/Version-61.pdf.]

Swanson, R. E., 2003: Evidence of possible sea-ice influence on Microwave Sounding Unit tropospheric temperature trends in polar regions. *Geophys. Res. Lett.*, **30**, 2040, doi:10.1029/2003GL017938.

UAH, 2016a: Uahncdc_ls_6.0beta5. University of Alabama in Huntsville, accessed 7 May 2016. [Available online at http://vortex.nsstc.uah.edu/data/msu/v6.0beta/.]

——, 2016b: Uahncdc_mt_6.0beta5. University of Alabama in Huntsville, accessed 7 May 2016. [Available online at http://vortex.nsstc.uah.edu/data/msu/v6.0beta/.]

Wang, W., and C.-Z. Zou, 2014: AMSU-A-only atmospheric temperature data records from the lower troposphere to the top of the stratosphere. *J. Atmos. Oceanic Technol.*, **31**, 808–825, doi:10.1175/JTECH-D-13-00134.1.

Zou, C.-Z., and W. Wang, 2011: Intersatellite calibration of AMSU-A observations for weather and climate applications. *J. Geophys. Res.*, **116**, D23113, doi:10.1029/2011JD016205.

——, M. D. Goldberg, Z. Cheng, N. C. Grody, J. T. Sullivan, C. Cao, and D. Tarpley, 2006: Recalibration of microwave sounding unit for climate studies using simultaneous nadir overpasses. *J. Geophys. Res.*, **111**, D19114, doi:10.1029/2005JD006798.

——, M. Gao, and M. D. Goldberg, 2009: Error structure and atmospheric temperature trends in observations from the Microwave Sounding Unit. *J. Climate*, **22**, 1661–1681, doi:10.1175/2008JCLI2233.1.