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Using limited time period trends as a means to determine attribution of discrepancies in microwave sounding unit–derived tropospheric temperature time series

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[1] Limited time period running trends are created from various microwave sounding unit (MSU) difference time series between the University of Alabama in Huntsville and Remote Sensing System (RSS) group's lower troposphere (LT) and mid troposphere to lower stratosphere channels. This is accomplished in an effort to determine the causes of the greatest discrepancies between the two data sets. Results indicate the greatest discrepancies were over time periods where NOAA 11 through NOAA 15 adjustments were applied to the raw LT data over land. Discrepancies in the LT channel are shown to be dominated by differences in diurnal correction methods due to orbital drift; however, discrepancies from target parameter differences are also present. Comparison of MSU data with the reduced Radiosonde Atmospheric Temperature Products for Assessing Climate radiosonde data set indicates that RSS's method (use of climate model) of determining diurnal effects is likely overestimating the correction in the LT channel. Diurnal correction signatures still exist in the RSS LT time series and are likely affecting the long-term trend with a warm bias. Our findings enhance the importance of understanding temporal changes in the atmospheric temperature trend profile and their implications on current climate studies.

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1. Introduction

[2] Accurate assessment of satellite-derived temperature trends in the atmosphere is paramount to our understanding of climate change. The microwave sounding unit (MSU)-derived temperature trends are used in various climate studies for model verification, to infer trends in other atmospheric parameters [*Soden et al.*, 2005], and to derive trends in atmospheric layers not directly obtained from MSU [e.g., *Fu and Johanson*, 2005; *Fu et al.*, 2004]. In addition, the resultant MSU global and tropical trends are at the center of determining whether amplification (greater warming in the troposphere than at the surface) of temperatures in the atmosphere exists as prescribed by climate models and the current understanding of the physics [*Christy et al.*, 2007; *Karl et al.*, 2006; *Santer et al.*, 2005]. The MSU data suffer from a number of calibration issues and time-varying biases that must continue to be addressed as they are used for climate change studies [*Mears and Wentz*, 2005]. Although the MSU was not originally meant for climate studies [*Christy et al.*, 2003], it is extensively used, and a thorough examination of these data is necessary to ensure the required long-term stability for climate change studies.

[3] Currently, there are multiple temperature databases derived from satellite-based MSU radiance measurements by three separate groups: the University of Alabama in Huntsville (UAH), Remote Sensing System (RSS), and the University of Maryland (UMd). RSS and UAH produce temperature products for three layers: the lower troposphere (LT), roughly surface to 300 hPa; the mid troposphere to lower stratosphere (MT), roughly surface to 75 hPa; and the lower stratosphere (LS), roughly 150 to 15 hPa [*Christy and Norris*, 2006]. UMd produces a temperature product for MT only.

[4] Each group's database produces different temperature trend results for their respective channels (MT and LT). Differences in the satellite estimates of trends by each group are caused by the use of each group's different processes in merging data from the individual satellites used in the time series and differences in the diurnal adjustments that are used to account for orbital drift of the satellite [*Mears et al.*, 2006].

[5] Recent studies have documented biases between the UAH and RSS data sets [*Christy and Norris*, 2006; *Christy et al.*, 2007; *Mears et al.*, 2006; *Mears and Wentz*, 2005] and find that the likely primary cause of differences between

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Table 1. Radiosonde Stations Used in This Study

Station	Time, UT	Latitude, deg	Top Level With Continuous Data, hPa
Amundsen-Scott	0000	−90.0	10
McMurdo	0000	−77.9	30
Syowa	0000	−69.0	20
Macquarie Island	1200	−54.5	50
Marion Island	0000	−46.8	20
Gough Island	0000/1200	−40.3	20
Martin de Vivies	1200	−37.8	30
Adelaide	1200	−34.9	30
Capetown	0000	−33.9	20
Durban	0000	−29.9	20
Norfolk Island	0000	−29.0	20
Rio de Janeiro	1200	−22.8	20
Townsville	0000	−19.2	20
Darwin	0000	−12.4	20
Manaus	1200	−3.1	20
Nairobi	0000	−1.3	20
Bangkok	0000	13.7	30
San Juan	0000/1200	18.4	10
Hilo	0000/1200	19.7	10
Jeddah	1200	21.6	20
Minamitorishima	1200	24.3	20
Brownsville	0000/1200	25.9	10
Santa Cruz	1200	28.4	20
Kagoshima	1200	31.6	20
Bet Dagan	0000	32.0	50
Miramar	0000/1200	32.8	10
North Front	0000/1200	36.2	10
Dodge City	0000/1200	37.7	10
Kashi	0000	39.4	20
Wakkanai	0000/1200	45.4	20
Rostov	0000	47.2	30
Great Falls	0000	47.4	10
Torbay	0000	47.6	20
Munchen	0000/1200	48.2	20
Moosonee	0000/1200	51.2	20
Petropavlovsk	1200	53.0	20
Omsk	0000/1200	54.9	20
Annette Island	0000	55.0	10
Saint Paul Island	0000	57.1	10
Kirensk	0000/1200	57.7	30
Lerwick	0000/1200	60.1	20
Keflavik	0000/1200	64.0	20
Baker Lake	0000/1200	64.3	20
Pechora	0000	65.1	30
Turuhansk	0000/1200	65.8	20
Verkhoyansk	0000	67.6	30
Alert	1200	82.5	10

the two groups in the LT and MT channels is the onboard calibration target parameters calculated by each group because of the different overlap periods of the satellites used to create the time series. Methods to determine diurnal correction are found as a secondary issue. The U.S. Climate Change Science Program (CCSP) [*Karl et al.*, 2006] addressed discrepancies in satellite trends and methods for creating temperature anomaly time series. Their recommendation is to diagnose the relative merits of different merging methods for satellite data over limited time periods (LTPs) where the largest discrepancies between satellites and radiosonde data are found [*Mears et al.*, 2006].

[6] A linear fit to compare long-term trends may not be the best technique to compare the databases in order to diagnose differences in merging methods. Comparing the data over shorter periods, or LTPs, affords the opportunity to determine how merging methods affect data for the actual time period over which they are used, helping to more accurately determine the merits. In addition, any similar discrepancies among the processes found at more than one LTP could be resolved by using a single process over those time periods. These similar discrepancies may not be seen using one long-term linear trend.

[7] The objective of this study, as recommend by the CCSP, is to find and attribute the largest discrepancies between MSU data sets using trends analyzed over LTPs. Our LTP method determines 5- and 10-year running trends on various difference time series created from each group's MSU database and is described further in section 3. In order to attribute results found in the analysis using LPT we summarize merging methods used in creating each group's time series in the first part of section 4 and follow with results and attribution. Radiosonde comparison is explained in section 5, followed by summary and conclusions in section 6.

2. Data

[8] Here we consider results based on two different groups' globally and tropically averaged MSU MT and LT channel data. One database is produced by RSS and sponsored by the NOAA Climate and Global Change Program. Data are version 3.0 and are available at www.remss.com and are described by *Mears et al.* [2003] and *Mears and Wentz* [2005]. The other from UAH is available at http://vortex.nsstc.uah.edu/ and is described by *Christy and Spencer* [2005] and *Christy et al.* [2003]. The LT data from UAH are from the updated version (5.2). Published results from the University of Maryland's recently developed MT data, described by *Vinnikov et al.* [2006], are not used in this work as they do not produce an LT database to use for our analysis.

[9] Radiosonde data are used as an independent database to compare each group's MSU data. The radiosonde data used here are based on the temporally homogenized data set described by *Free et al.* [2005] available at http://www.ncdc.noaa.gov/oa/cab/ratpac/index.php. The Radiosonde Atmospheric Temperature Products for Assessing Climate-B (RATPAC-B) database is used to have monthly anomalies and individual radiosonde sites. *Randel and Wu* [2006] found jumps and discontinuities in individual station records that are used in the RATPAC-B data, causing a tendency for spurious cooling in stratospheric and tropospheric data. For this reason, we use only those radiosonde sites and times that were found to be "good" by this group, minimizing a long-term cooling bias in the results of the comparison portion of this study. A list of the specific sites used in this study is provided in Table 1. The RATPAC-B data include the following levels: surface, 850, 700, 500, 300, 250, 200, 150, 100, 70, 50, and 30 hPa.

[10] To compare the radiosonde and MSU satellite data, we vertically integrate the radiosonde temperatures using the MT and LT static weighting functions following procedures of *Spencer and Christy* [1992] and *Christy et al.* [2006]. The radiosonde data were weighted equal to the cosine of their latitude to ensure proper comparison with MSU data, and then all radiosonde data at both 1200 UT and 0000 UT were globally or tropically (20°N–20°S) averaged. The MSU brightness temperature depends on surface skin temperature. Owing to the current debate on the accuracy of surface data [*Parker*, 2004; *Pielke et al.*, 2007; *Pielke and Matsui*, 2005] we used the radiosonde

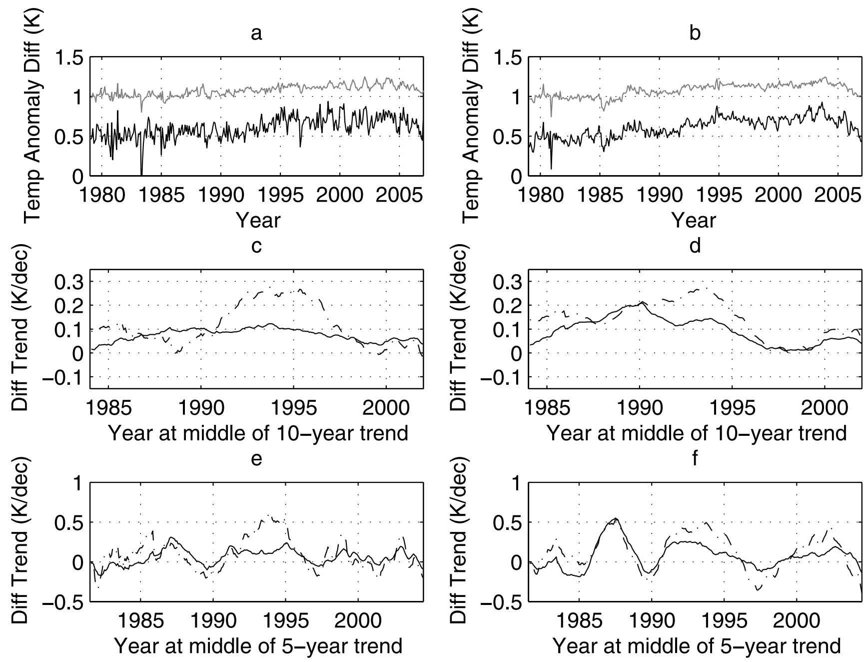

Figure 1. RSS (MT)−UAH (MT) (shaded curve offset by 1.0) and RSS (LT)−UAH (LT) (solid curve offset by 0.5) temperature difference anomaly time series for (a) global data over land and (b) tropical data over land. Ten-year LTP trends of difference time series for (c) global LT (dashed curve) and MT (solid curve) data and (d) tropical LT (dashed curve) MT (solid curve) data. Five-year LTP trends of the difference time series for (e) global LT (dashed curve) and MT (solid curve) data and (f) tropical LT (dashed curve) and MT (solid curve) data.

1000-hPa temperature as the best estimate of skin temperature, understanding that they are not quite the same. For comparison purposes we used only the MSU anomalies over land, as the distribution of the radiosonde locations were more closely land based.

3. Methods

[11] We define the LTP method as running 5- and 10-year least squares fit trends of various difference time series created from RSS and UAH MSU data. A linear fit to the entire long-term trends of RSS and UAH data may not be the best technique to diagnose differences in merging methods. Comparing the data over a shorter time period, or LTP, affords the opportunity to determine how corrections for time-dependent effects, such as orbital changes, affect the data for the actual time period over which they are applied. In addition, any similar discrepancies among the merging methods found over more than one limited time period may resolve problems from using a single process over those time periods. These similar discrepancies may not even be seen using one long-term linear trend.

[12] Using difference time series removes any variability that may be common to both data sets and isolates those differences that are due to differing data set production methods or temperature measurement methods [*Wigley*, 2006]. Thus any LTP trend anomaly indicates those time periods where differences in data set production methods are isolated.

[13] Difference time series were created from the UAH and RSS MT and LT channels in two different ways. First, UAH data were subtracted from RSS data for each channel (RSS (LT)−UAH (LT) and RSS (MT)−UAH (MT)). Analyzing LTP on this type of difference series leads to locating discrepancies found between the two groups in the same channel. Figure 1 shows an example of the effect of LTP on this type of difference series. Figures 1a and 1b show the difference time series RSS−UAH for MT and LT channels for global and tropical anomalies, respectively, over land. The 10-year LTP for these difference series are shown in Figures 1c and 1d, respectively. For global data (Figure 1c) the 10-year LTP trends in the MT channel are fairly constant, while in the LT channel they are quite variable. The reason for the variability is seen in the difference time series (Figure 1a) as a slow increase in the LT difference anomalies from 1989 to mid-1994 and a general slow decrease from mid-1994 to 2003. This feature is in the LTP trend curve where the maximum 10-year trend is from 1989 to 1999 (shown as centered on 1994 in Figure 1c) and the relative minimum 10-year trend is from 1994 to 2004 (centered on 1999 in Figure 1c).

[14] It is important to show that the LTP trends are capturing what can appear to be an obvious feature in the MSU difference time series. Some of the difference time series created do not have such an obvious signature, yet discrepancies are apparent when LTP trends are accomplished. This increases the confidence that the LTP method is robust in capturing the differences present between each group's data sets, a point which becomes more vital when radiosonde data comparisons are made (see section 5).

[15] Difference trends were also created by subtracting the MT channel from the LT channel for each group (RSS

(LT) – RSS (MT) and UAH (LT) – UAH (MT)). LTP trends completed on this type of difference series result in locating differences in the trend tendency between the channels (LT and MT) within each group. It is possible to see variations in this type of difference series due to the different temporal variability of each channel's trend; however, as each group is using the same raw data, any departure in the LTP trends between the two groups would indicate a time period where processing methods differ not something physically happening in the atmosphere. Additionally, any discrepancies found in this type of difference series indicate time periods where different correction methods between the MT and LT channels were used, as opposed to a constant correction between the LT and the MT channel (within each group); this is discussed further in section 4.

[16] In summary, we calculated LTP trends on time series created from RSS – UAH for both MT and LT channels and LT – MT for both RSS and UAH. This was done for global and tropical data for land and ocean.

4. Results and Attribution

[17] In order to assign attribution to results found in the LPT analysis we briefly discuss methods used in creating each group's time series and then discuss results and attribution to those methods.

4.1. Review in Correction/Merging Methods

[18] Important contributions to the uncertainty in satellite estimates of trends for MSU data sets result from corrections for orbital drifts resulting in different diurnal sampling times and different methods of merging data from the different satellites [*Mears et al.*, 2006]. To correct for diurnal drift in the each of the satellites, both groups first average together the ascending and descending orbits [*Mears et al.*, 2006]. This removes the first harmonic of the diurnal cycle. Each group then uses a different method for removing the second- and higher-order harmonics of the diurnal cycle (hereinafter termed diurnal correction).

[19] For the MT channel the UAH group calculates mean differences, arising from different measuring time, by subtracting the temperature measurements on one side of the satellite track from the other [*Christy et al.*, 2000; *Mears et al.*, 2006]. As these two measurements are for different local times, this, in addition to different adjustments used for land and ocean, leads to an averaged diurnal adjustment for each zonal band. For the LT channel the UAH group uses a regression-derived diurnal correction based on 1 year of data from co-orbiting advanced MSU (AMSU) satellites that measure a total of six nominal local satellite overpass times. Three assumed diurnal functions are fitted by regression to the grid point, monthly averaged brightness temperatures for AMSU channels 3 through 10. The three functions include a 24-hour trace of the solar flux, the time integrated solar flux, and a linear term representing infrared cooling. The three functions were chosen a priori for their ability to represent the dominant components of the diurnal cycle in the surface-troposphere system temperature (R. Spencer and J. Christy, personal communication, 2007). The RSS group uses, for both MT and LT channels, an hourly output from a climate model which allows adjustments at the same resolution as the data [*Mears et al.*, 2006].

[20] After the diurnal corrections are applied, the data from different satellites in orbit at any given time are merged together to create one time series for each channel. To accomplish this, each group must remove calibration drifts that are correlated to the temperature of the onboard hot calibration target and correct for offsets found by comparing co-orbiting satellites [*Christy et al.*, 2000; *Mears et al.*, 2006, 2003]. Each group removes the calibration target temperature effect using a model that includes a constant offset for each satellite and an additional empirical "target factor" multiplied by the calibration target temperature. The diurnal correction for each channel has already been added to the raw data before the regression procedure is accomplished to create the target factor and offset; therefore any errors present in the diurnal correction will influence the merging coefficients [*Mears and Wentz*, 2005]. RSS uses all available data from overlapping satellites in the regression procedure, and UAH uses only satellite overlaps with durations longer than 2 years. UAH removed three periods of data that showed insignificant variance when overlapping with co-orbiting satellites [*Christy et al.*, 2000]: TIROS-N in its overlap with NOAA 6 (July–December 1979), NOAA 10 in its overlap with NOAA 11 (October 1988 to August 1991), and NOAA 12 with its overlap with NOAA 11 (September 1991 to March 1995).

4.2. Results and Attribution

[21] Analyzing several combinations of difference time series helped us narrow our focus for further analysis on those combinations that have the greatest discrepancies. Figure 1 shows 10-year LTP trends from the RSS (MT)–UAH (MT) and RSS (LT)–UAH (LT) temperature anomaly difference series for global (Figure 1c) and tropical (Figure 1d) data over land. As mentioned in section 3, the trends for the MT channel are relatively constant, with noted variability in the LT channel trends for the global data set. The tropical data show the trends in the LT channel to be consistent with the MT channel until trends centered on 1990, when they depart and the LT trends become variable as seen in the global case. Departures in the LTP trends are due to differences in construction methods and not physical changes in the atmosphere; therefore we are able to state that the correction method by one or both of the group's LT channels is indicated by the variability in trends. Figure 2 compares 10-year LTP global trends for the RSS (LT)–UAH (LT) temperature anomaly difference series over ocean and land. Here there are relatively small changes in trends over the ocean as opposed to the high variability in trends over land. This indicates the greatest discrepancies between RSS and UAH are not only in the LT channel but are over land as well.

[22] One of the greatest discrepancies is a departure seen in the 5-year LTP trends centered on July 1987 in the tropics (Figure 1f). This departure is caused by the difference in the target parameters used for NOAA 9 (which was only in service for 2 years), which were poorly determined because of the short overlap of NOAA 9 with other satellites [*Mears and Wentz*, 2005]. The departures in trends are seen to be similar in both the MT and LT channels in the tropics and relatively small in the global trends. Because of this we

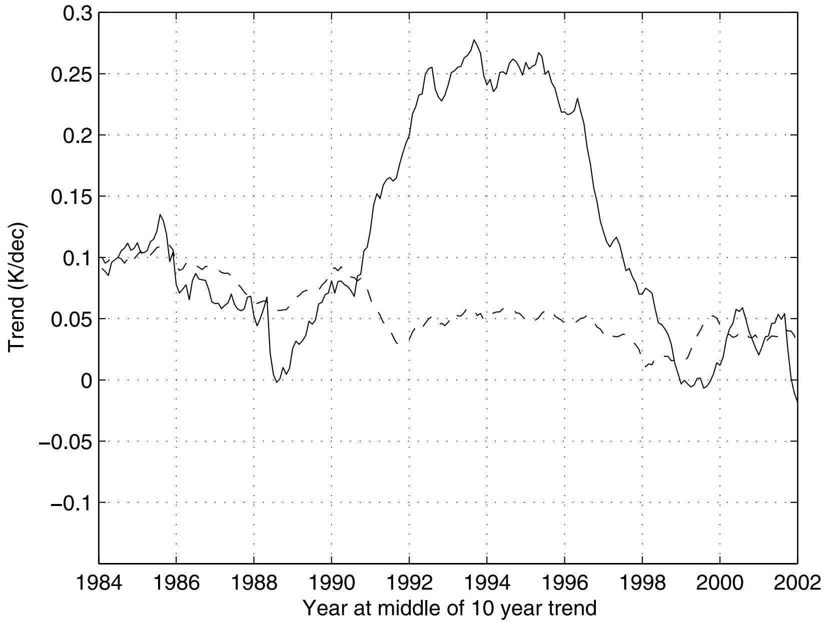

Figure 2. Ten-year LTP global trends for the RSS (LT)−UAH (LT) difference series over ocean (dashed curve) and land (solid curve).

were unable to determine any other information, and we continue to analyze discrepancies found in trends not affected by NOAA 9 corrections. This includes 10-year trends centered on 1993 and after and 5-year trends centered on mid-1989 and after.

[23] The greatest discrepancies in the 10-year LTP trends are those in the LT channel centered on 1993 through those centered on 1995 in both global and tropical data (Figures 1c and 1d). The largest discrepancies for 5-year LTP trends are those in the LT channel centered on 1993 in both global and tropical data, and also in the tropics we see a significant departure in LT trends, again centered on 1997, 2002, and mid-2004 (Figure 1f). The best example in a difference series is the tropical difference series shown in Figure 1b. Here we see RSS (MT)−UAH (MT) compared to RSS (LT)−UAH (LT) over land, and the signatures that cause the rapid LT trend departures in Figure 1d are seen in the larger increase in difference anomalies from 1989 to 1995. This is over the time period where the corrections for NOAA 11 are accomplished. Signatures causing trend variability are also seen in the moderate decrease in difference anomalies from 1995 to 1999 when corrections for NOAA 12 are accomplished. After 2000, there is another larger increase in LT difference anomalies when NOAA 14 merging parameters are introduced into the time series, and there is a sharp decline in anomalies from 2004 through 2006 when NOAA 15 parameters are applied. The increases and decreases in the LT difference time series correspond to the maxima and minima in the LTP trends which correspond to what appears to be signatures in the shape of the diurnal corrections of NOAA 11 through NOAA 15. The shape of the diurnal correction and the target temperature drift are the same [*Christy et al.*, 2000; *Mears et al.*, 2003], however, indicating the discrepancies can arise from either the actual diurnal correction or the derived target factors.

[24] The target factors are constants that describe the behavior of the radiometer and are determined using the MT channel data with the diurnal correction already applied [*Christy et al.*, 2000; *Mears and Wentz*, 2005]. These coefficients can be applied to other linear combinations of the MT channel, including the LT channel. Both groups accomplish this in the creation of their final series with slight variations between MT and LT target factors in UAH data. Because the target parameters are nearly constant between channels (indicating they are the same over land and ocean), if they were the primary cause of the discrepancies found, one would expect the same variation in LTP trends created from channel differences over ocean as seen over land. Discrepancies are significantly different for the LTP trends over land than over ocean (see Figure 2), which is not consistent with discrepancies being caused by target factors but is more in line with diurnal corrections. Diurnal corrections should be larger over land and in the LT channel than over ocean and in the MT channel. An additional test to eliminate target factors as the primary cause of discrepancies is comparing difference series created by subtracting channels in each group (RSS (LT)−RSS (MT) and UAH (LT)−UAH (MT)). Discrepancies created by the target factors and offsets are minimized in this type of difference series as they are nearly constant in both channels; therefore the discrepancies seen, between groups, are predominantly caused by diurnal corrections. Figure 3 shows the difference series RSS (LT)−RSS (MT) and compares to UAH (LT)-UAH (MT) for 10-year LTP over land for global (Figure 3a) and tropical (Figure 3b) data. Departures between the two groups' databases are seen, and because this difference series shows primarily diurnal correction discrepancies, we are able to conclude that the departures are dominated primarily by the diurnal correction discrepancies. This is expected, as the greatest discrepancies are found over land in the LT channel, both of which have the greatest diurnal

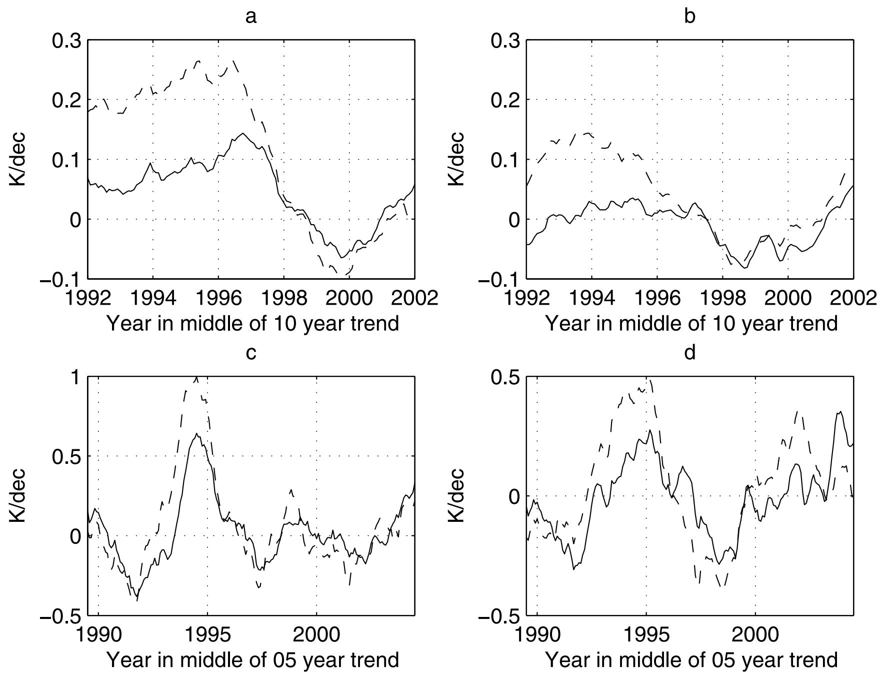

Figure 3. Ten-year LTP trends on UAH (LT)−UAH (MT) (solid curve) and RSS (LT)−RSS (MT) (dashed curve) for (a) global and (b) tropics. (c) and (d) Same as Figures 3a and 3b for 5-year LTP trends.

cycle and thus greatest corrections required. It is important to note here that this does not indicate which group's process may be causing the departure in trends. Signatures in this type of difference series can be caused by the UAH method underestimating the diurnal correction or the RSS method overestimating the diurnal correction or a combination of both. This will be discussed further when the MSU and radiosonde data are compared in section 5.

[25] At first our findings may appear to be in complete opposition to the CCSP key findings that for the tropospheric satellite data (MT and LT) the primary cause of trend discrepancies is from differences in merging methods [*Mears et al.*, 2006]. However, with an expanded definition our findings may be considered consistent with the CCSP findings in the MT channel. Differences in derived target parameters have been explained as resulting from the two groups' data choices for the regression procedure [*Mears and Wentz*, 2005]. UAH uses only satellite overlaps with durations longer than 2 years, while RSS uses all available data from overlapping satellites. Our findings, however, may be consistent with the CCSP findings in the MT channel if the total discrepancies created by the final target factors are further defined by two separate causes: (1) discrepancies resulting strictly from the method in which overlaps were selected and (2) discrepancies resulting from differences in the diurnal correction. *Mears and Wentz* [2005] find that MT channel data over ocean are best for determining target parameters due in part to a greater diurnal cycle over land than over ocean. As the total diurnal-shaped correction includes both the diurnal correction and the target parameters, any overestimated (underestimated) diurnal correction, including initial discrepancies, would have to be compensated for by a smaller (greater) target parameter (bias plus target temperature factor). Thus the mere fact that the final target factors are different can be explained by an initial discrepancy in diurnal corrections and not necessarily the selection of the overlap of satellites alone. In reality, it is likely a combination of both, but the correction dominating the discrepancy appears to be different for each channel.

[26] Our findings show that the diurnal correction dominates the discrepancies in the LT channel; however, it is in addition to differences in target bias parameters, as *Christy et al.* [2007] determined, that steps between the databases exist during some of the LT time periods. Determining which parameter dominates MT channel discrepancies is more difficult, mainly because of the target parameter's dependence on the initial diurnal correction. The total discrepancies in the difference time series are combinations of differences in diurnal corrections and differences in target parameters. The differences in target parameters result from differences in choice of overlap and differences in diurnal correction. This indicates that an initial discrepancy from the diurnal correction will not only be present in the final data series but will be in addition to the discrepancy created by its contribution to the target parameter correction. As the diurnal correction method is overestimating or underestimating the diurnal correction in the LT channel, it follows that the same process is invoking a discrepancy in diurnal correction in the MT channel. The difficulty lies in the fact that the target parameter determination is dependent on the diurnal correction applied. However, any signatures found in LTP trends in the MT channel are not large enough to extract any concrete information. An initial overestimation or underestimation of the diurnal correction in the MT channel may be small enough to either be masked or dominated by the target factors.

[27] As stated previously, the LT diurnal correction discrepancies can either be explained by an overcorrection in the database by the RSS group or an undercorrection by the

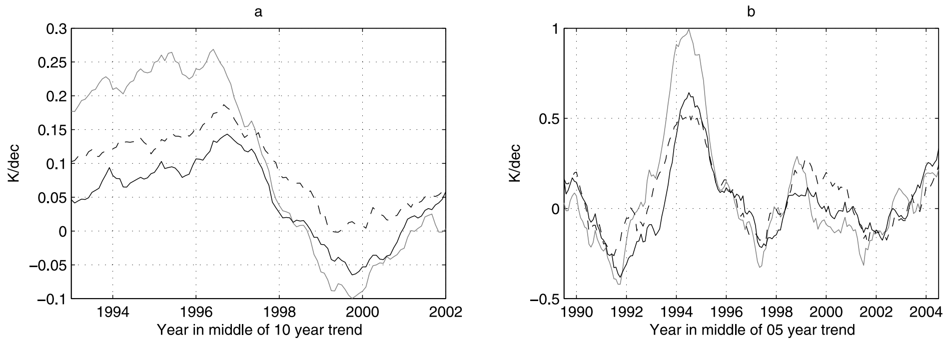

Figure 4. (a) Ten-year LTP trends on UAH (LT)–UAH (MT) (solid curve), RSS (LT)–RSS (MT) (shaded curve) and sonde (LT)–sonde (MT) (dashed curve). (b) Same as Figure 4a for 5-year LTP trends.

UAH group (seen by order of subtraction in difference series) or a combination of both.

5. Radiosonde-MSU Comparison

[28] To compare the UAH and RSS data sets to radiosonde data, we use the anomaly difference series created by subtracting channels of each group (RSS (LT)–RSS (MT) and (UAH (LT)–UAH (MT)). This type of difference series was used for two reasons. First, using the two channels created by the same instrument (MSU or radiosonde) helps eliminate any structural inconsistencies. Second, this difference series compares predominantly diurnal inconsistencies between the groups as discussed in section 4.2. We also create the same type of difference series from simulated channels using LT and MT static weighting functions [*Spencer and Christy*, 1992] on an independently derived radiosonde data set. Here we use RATPAC-B data based on the temporally homogenized data set described by *Free et al.* [2005]. *Randel and Wu* [2006] found jumps and discontinuities in individual station records that are used in the RATPAC-B data, causing a tendency for spurious cooling in stratospheric and tropospheric data. For this reason we used only those radiosonde sites and times that were found to be "good" by this study, minimizing a long-term cooling bias in the results of the comparison.

[29] The three difference series (MT–LT for UAH, RSS, and sonde data) are shown in Figure 4a for 10-year LTP trends (global and land) and Figure 4b for 5-year LTP trends (global and land). The LTP trend series created from the radiosonde data follows the UAH better for both 10-year and 5-year LTP trends. The strong departure in trends of the RSS data versus UAH and sonde data are consistent with the time periods the diurnal correction dominates the LT channel. Although we used "good" radiosonde data [*Randel and Wu*, 2006] in order to minimize negative biases in the radiosonde data, biases may still exist in the data during some time periods. Sonde data follow the UAH data most closely for 10-year trends; therefore coincidence of agreement between data sets where a long-term negative bias through time still exists is unlikely. There may be biases induced, however, from each group's different method of categorizing MSU land anomalies or the radiosonde processing choices used (e.g., estimated skin temperature or coastal and island stations versus land).

[30] Ten-year LTP difference time series shown in Figure 4a were differenced ((Sonde (LT)–Sonde (MT))-(UAH (LT)–UAH (MT)) and ((RSS (LT)–RSS (MT)-Sonde (LT)–Sonde (MT))) accounting for autocorrelation correction using the methods of *Santer et al.* [2005], and they are shown in Figure 5. Here the differenced series with the 95% confidence interval are shown. Figure 5 shows that ten 10-year trends centered on mid-1994 through the 10-year trends centered on mid-1995 indicate the RSS–sonde trends are significantly different from zero where the sonde–UAH trends are not. In addition, for 10-year trends centered on late 1999 through the 10-year trend centered on early 2000, the RSS–sonde trends are significantly different from zero where sonde–UAH trends are marginally not. Another key feature in the RSS–sonde series is the rapid departure in trend magnitude from trends centered on 1995 through trends centered on late 1999 where the sonde–UAH magnitude in trends is nearly constant. These features are consistent with the diurnal correction signatures discussed in section 4.2. These findings suggest that the RSS method for creating the diurnal correction (use of a climate model) is likely the primary cause for discrepancies between RSS and UAH databases in the LT channel.

[31] It is important to note that results of the radiosonde/MSU comparisons are for the radiosonde data set described and the processing choices used to created simulated satellite data in this work. Sampling errors caused by the reduced RATPAC data set, reduced MSU sampling, or processing methods of the radiosonde data are possible. *Randel and Wu* [2006] focused additionally on removing stratospheric cooling biases, and the reduced RATPAC data set may cause, yet to be investigated, errors in the LT channel. We believe, however, sampling errors described above would be seen throughout the LTP trends, and discrepancies found in radiosonde/MSU comparisons would likely not be consistent with the discrepancies found in the MSU/MSU comparisons.

[32] Causes of errors are likely due to the inability of the climate model, used by RSS to evaluate diurnal effects, to accurately represent the diurnal cycle or include diurnal variability for surface temperature [*Dai and Trenberth*, 2004; *Mears et al.*, 2006]. However, if the diurnal temperature range has decreased over time [*Braganza et al.*, 2004; *LaDochy et al.*, 2007], then a mean diurnal amplitude created from a 5-year time period (1979–1984) will be greater than any diurnal amplitude created after that time

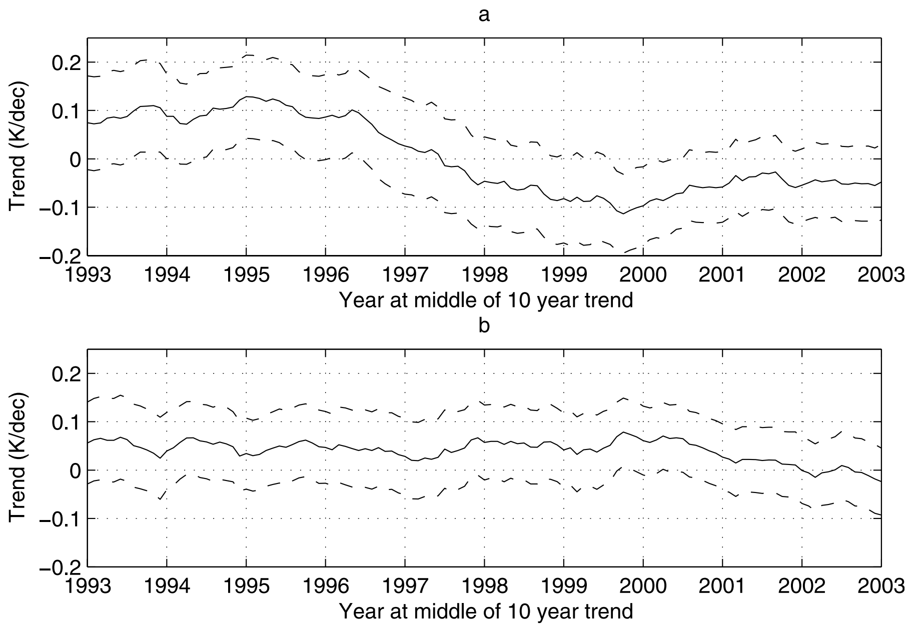

Figure 5. Differences from series types created in Figure 4. Ten-year LTP trends for (a) RSS−sonde (global and land) and (b) sonde−UAH. Dashed curves around each are the 95% confidence interval.

period. Using a correction based on this earlier time period would overestimate the diurnal correction needed in a later time period. This is what is done by the RSS method and may also be a plausible explanation for errors.

[33] We cannot dismiss that the UAH results may still have errors in the method since their diurnal correction is sensitive to satellite attitude errors and uses latitudinal averages [*Mears et al.*, 2006; *Mears and Wentz*, 2005]. At this time we are unable to see significant signatures using the LTP analysis when each database is compared to this particular radiosonde data set.

6. Summary and Conclusions

[34] The use of LTP trends on various difference time series created from UAH and RSS MT and LT channels has been shown to indicate that the greatest discrepancies between these two databases are over the time periods when correction methods for NOAA 11 through NOAA 15 are accomplished. Greatest discrepancies are shown to be in the LT channel and most prominent over land. These discrepancies were additionally found to be predominantly caused by differences in diurnal corrections. This was done by minimizing the target factors and offsets by differencing the LT and MT channel in each group.

[35] We compared the MSU data to the radiosonde data and found that the RSS − sonde is significantly different from zero, while sonde − UAH is not during time periods that are consistent with overcorrected diurnal corrections dominating the LT channel. We used "good" radiosonde data [*Randel and Wu*, 2006] in order to minimize negative trend biases in stratospheric and upper tropospheric radiosonde data. Corrected diurnal signatures were shown to still exist in the RSS LT time series. The longer 10-year LTP trends were additionally shown to have a positive bias; thus the present corrected diurnal signatures are likely affecting the long-term trend with a warm bias. The RSS method is likely overestimating the diurnal correction in the LT channel, and it follows that the same process is invoking a discrepancy in the diurnal correction in the MT channel. An initial overestimation of the diurnal correction may be small enough to either be masked or dominated by the target factors in the MT channel, but further research is necessary to isolate which correction method is dominant, if any.

[36] Causes of these diurnal errors are likely due to the inability of the climate model, used by RSS, to accurately represent the diurnal cycle or include diurnal variability for surface temperature. However, if the diurnal temperature range has decreased over time, then using a correction from an earlier time period would overestimate the diurnal correction needed during a later time period. This is what is done by the RSS method and may also be a plausible explanation for errors. In any case, these findings enhance the importance of understanding temporal changes in the atmospheric temperature trend profile. This understanding would further lead to insight into temporal changes in vertically integrated diurnal cycles. The implications for multiple climate studies using these data series include the current quest to understand model versus observation differences in atmospheric amplification.

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