Reply to "Comments on 'A Bias in the Midtropospheric Channel Warm Target Factor on the *NOAA-9* Microwave Sounding Unit'"

STEPHEN PO-CHEDLEY AND QIANG FU

Department of Atmospheric Sciences, University of Washington, Seattle, Washington

(Manuscript received 2 July 2012, in final form 26 November 2012)

ABSTRACT

The main finding by Po-Chedley and Fu was that the University of Alabama in Huntsville (UAH) microwave sounding unit (MSU) product has a bias in its *NOAA-9* midtropospheric channel (TMT) warm target factor, which leads to a cold bias in the TMT trend. This reply demonstrates that the central arguments by Christy and Spencer to challenge Po-Chedley and Fu do not stand. This reply establishes that 1) Christy and Spencer found a similar, but insignificant, bias in the UAH target factor because their radiosonde data lack adequate sampling and measurement errors were considered twice; 2) the UAH individual satellite TMT difference between *NOAA-9* and *NOAA-6* reveals a bias of 0.082 ± 0.011 in the UAH *NOAA-9* target factor; 3) comparing the periods before and after *NOAA-9* is not an adequate method to draw conclusions about *NOAA-9* because of the influence of other satellites; 4) using the Christy and Spencer trend sensitivity value, UAH TMT has a cold bias of 0.035 K decade^{-1} given a target factor bias of 0.082; 5) similar trends from UAH and Remote Sensing Systems (RSS) for the lower tropospheric temperature product (TLT) do not indicate that the UAH TMT and TLT *NOAA-9* target factor is unbiased; and 6) the *NOAA-9* warm target temperature signal in UAH TMT indicates a problem with the UAH empirical algorithm to derive the target factor.

1. Background

Po-Chedley and Fu (2012) worked toward reconciling a previously noted, long-standing difference between the University of Alabama in Huntsville (UAH) and the Remote Sensing Systems (RSS) Microwave Sounding Unit (MSU) midtropospheric temperature (TMT) datasets. This difference is also evident between the UAH and the National Oceanic and Atmospheric Administration (NOAA) MSU TMT dataset. The difference is related to the warm target calibration of the MSU measurements (Mears et al. 2003; Karl et al. 2006). UAH, RSS, and NOAA utilize a correction factor, referred to as a warm target factor, that is multiplied by the warm target temperature of the satellite to remove the residual signal of the warm target temperatures in the MSU measurements. For each satellite, the correction has the form $T_{\mathrm{MSU},C} = T_{\mathrm{MSU}} - \alpha \times T_{\mathrm{WT}} + C$, where T_{MSU} and $T_{\mathrm{MSU},C}$ are the measured Earth brightness temperatures before and after correction, respectively; α is the target factor; C is a constant offset; and T_{WT} is the warm target temperature of the satellite (Christy et al. 2000; Mears et al. 2003). Each team solves for this target factor differently, but in order to achieve the same goal: to remove warm target temperature contamination in the final MSU products (Christy et al. 2000; Mears et al. 2003; Zou et al. 2009).

Figure 1 shows the differences between the RSS and UAH TMT and lower tropospheric temperature (TLT) datasets over the *NOAA-9* satellite time period versus the warm target temperature on board *NOAA-9*. We see that the differences in both TMT and TLT are significantly related to the warm target temperature of the *NOAA-9* satellite, indicating that there are still large warm target temperature signals in one or both of the UAH and RSS MSU products. The differences between the UAH and the NOAA TMT products are also significantly related to the *NOAA-9* warm target temperature (the slope is −0.053 ± 0.010 and the r^2 value is 0.81). The difference between the RSS and NOAA TMT products versus the *NOAA-9* warm target temperature has a slope of −0.010 ± 0.007 with an r^2 value of 0.25, which is also statistically significant. NOAA does not yet produce a TLT dataset.

Corresponding author address: Stephen Po-Chedley, Department of Atmospheric Sciences, Box 351640, University of Washington, Seattle, WA 98195.
E-mail: pochedls@uw.edu

DOI: 10.1175/JTECH-D-12-00131.1

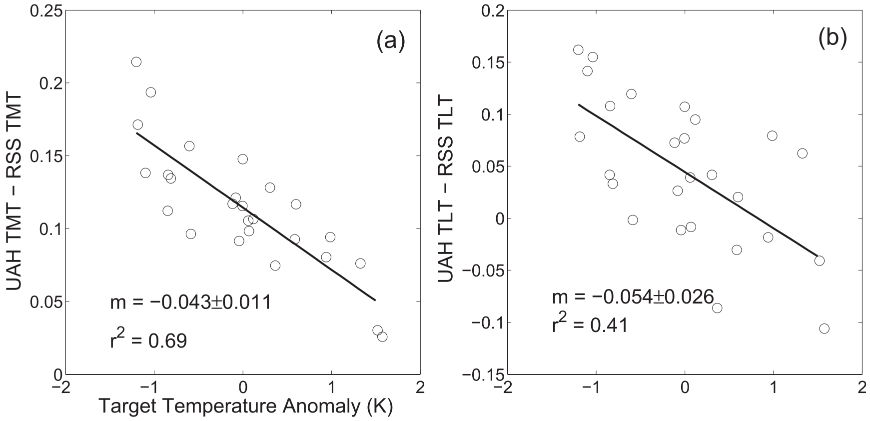

FIG. 1. Scatterplots of the differences between UAH and RSS for (a) TMT and (b) TLT vs the warm target temperature of *NOAA-9* for the 26-month *NOAA-9* time period (January 1985–February 1987).

There are large differences in the magnitudes of the target factors from each group for the *NOAA-9* satellite (Po-Chedley and Fu 2012). The UAH *NOAA-9* target factor is more than 2 and 3 times larger than the target factors used by RSS and NOAA, respectively. We recognize that target factors may not be exactly the same because of different algorithms used in the satellite merging process, but there should be no detectable warm target signal in the final MSU product. Because the *NOAA-9* warm target temperature explains most of the discrepancies between the datasets during the *NOAA-9* era (Fig. 1), it is not possible that all target factors are equally valid (Po-Chedley and Fu 2012). Since the warm target temperature for *NOAA-9* drifts over time, a target factor that is too large or too small would leave a spurious signal related to the warm target temperature drift in the final MSU TMT and TLT time series. The difference in the magnitude of the target factor has been well documented as an important discrepancy between the UAH and RSS datasets, contributing to about half of the trend difference between the groups (Mears et al. 2003; Karl et al. 2006). Po-Chedley and Fu (2012) sought to reconcile this specific, yet important, difference and not other differences between the three groups.

2. Radiosonde comparisons

In Po-Chedley and Fu (2012), we attempted to detect artificial residuals related to the warm target calibration in MSU TMT products from each group using five global, homogenized, peer-reviewed radiosonde datasets as references. In particular, we examined whether there is a significant relationship between the difference of collocated MSU and radiosonde TMT measurements and the *NOAA-9* warm target temperature. Note that this difference is actually the difference between MSU errors and radiosonde errors, and that the latter is unrelated to the satellite warm target temperature (Po-Chedley and Fu 2012). Thus, a significant relationship would indicate a detectable warm target temperature signal in the MSU datasets. We found that we could only detect a significant relationship using the UAH dataset with a mean slope of -0.051 ± 0.031. This value represents the magnitude of the bias in the target factor for UAH TMT (the target factor bias and the slope have the same magnitude but opposite signs) (Po-Chedley and Fu 2012). Christy and Spencer (2013) repeated our calculation using U.S. VIZ radiosondes (see their Fig. 1, top). They obtained a statistically insignificant slope of -0.042 ± 0.047. They further asserted that this calculation assumes no errors for the individual points. By adding an error bar as the "measurement error" in the VIZ radiosondes at each point, they produced a relationship of -0.042 ± 0.073. Below we demonstrate that their claim cannot be substantiated because they used a limited number of radiosonde stations and their consideration of measurement errors is incorrect.

Figure 2 shows the effect of the number of radiosonde stations on the bias detection threshold by randomly subsampling the Radiosonde Innovation Composite Homogenization (RICH) global radiosonde dataset (Haimberger et al. 2008). We obtain similar results from other radiosonde datasets utilized in Po-Chedley and Fu (2012). It shows that the uncertainty declines dramatically as we incorporate more radiosonde locations. There is a large uncertainty when few radiosonde stations are used, owing to the large error noise from individual radiosonde stations. For this reason, it is important to use a large number of radiosonde sites. The Christy and Spencer (2013) value is insignificant, owing to

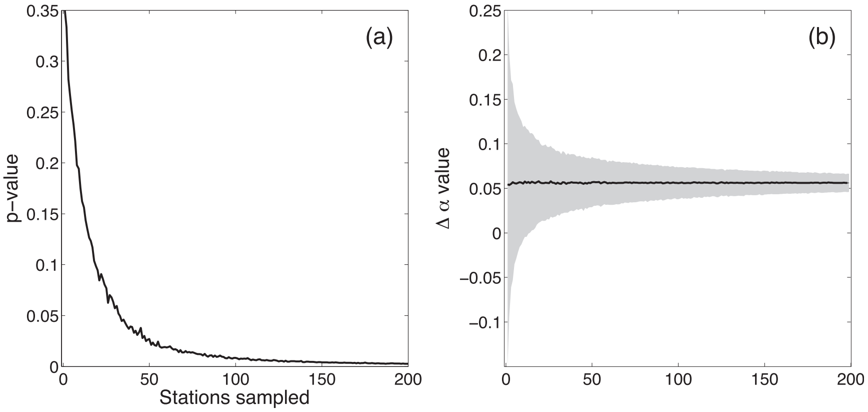

FIG. 2. Effects of sample size on statistics in Po-Chedley and Fu (2012). We computed the (a) *p* value and (b) target factor bias, $\Delta\alpha$, for the regression of UAH-RICH radiosondes vs the *NOAA-9* warm target temperature for different numbers of radiosonde stations (collocated with UAH data over the *NOAA-9* time period). For this calculation we randomly subsample a certain number of stations and create an average, collocated UAH minus radiosonde difference time series, which we then regress against the *NOAA-9* warm target temperature. We redo this calculation 1000 times for each number of stations sampled and then present the mean *p* value and $\Delta\alpha$ value; *p* values less than 0.05 indicate significant biases in the UAH target factor with 95% confidence. The shaded region around the $\Delta\alpha$ value is the 95% confidence interval from the subsampling statistics only. The results become significant when about 35 stations are included in the global average; below this number, the signal-to-noise ratio is too low.

poor radiosonde sampling; Christy and Spencer (2013) utilized 31 radiosonde stations, while Po-Chedley and Fu (2012) used between 45 and 451 stations. While 31 stations are not enough to significantly quantify this bias, it is encouraging that Christy and Spencer (2013) find a similar target factor bias of 0.042 using a different subset of radiosondes [Po-Chedley and Fu (2012) measured a bias of 0.051 ± 0.031].

As discussed in Po-Chedley and Fu (2012), the difference of collocated MSU and radiosonde TMT measurements is actually the difference of measurement errors from the satellite MSU and radiosondes. By regressing this difference against the satellite warm target temperature, the effect of the target factor bias is separated from other errors. Its statistical uncertainty is thus determined by other unresolved errors in satellite measurements and errors in radiosonde measurements, and the latter dominates. Note that it is the radiosonde uncertainty that prevents us from detecting any significant target factor bias in the RSS and NOAA datasets using the radiosonde data, although the TMT difference between the RSS and NOAA datasets is still significantly correlated with the *NOAA-9* warm target temperature (Po-Chedley and Fu 2012). The UAH target factor bias is large enough that we can detect a calibration bias. By adding an error bar as the measurement error at each individual point, Christy and Spencer (2013) considered the measurement errors twice, which is incorrect. Note that the radiosonde measurement error that Christy and Spencer (2013) reference is simply derived from the differences between collocated UAH MSU and radiosonde TMT measurements (Christy et al. 2011), which is actually the measurement error difference between satellite MSU and radiosonde measurements. Regardless, this uncertainty is already included in our estimation.

Furthermore, when we ignore the data for February and March of 1985 (influenced by *NOAA-7*) as done in Christy and Spencer (2013), we still measure a significant bias in the UAH *NOAA-9* target factor. Christy and Spencer (2013) also showed that if they only used the TMT measurements during overlaps of *NOAA-6* with *NOAA-9* and *NOAA-10* with *NOAA-9* (14 months), then they found no relationship between the UAH error and the warm target temperature (their Fig. 1, bottom). This is an expected outcome of their calibration procedure. Our further comment on this finding is that regardless of the details of the methods used to derive the warm target factor, the final MSU product should not have a residual signal related to the warm target temperatures. Again, from Fig. 1, there is a residual related to the warm target temperatures and it is the UAH dataset that has a detectable bias (Po-Chedley and Fu 2012).

Christy and Spencer (2013) state that Po-Chedley and Fu (2012) calculated a target factor bias for RSS of 0.023. Po-Chedley and Fu (2012) did not calculate a target factor bias for RSS (there is no significant relationship between RSS TMT and the warm target temperature using radiosondes as a reference; the r^2 value was 0.03). Christy and Spencer (2013) also state that Po-Chedley and Fu (2012) utilized RSS as a reference and then claim that the target factor bias for RSS (which we did not calculate) represents a drift in the radiosondes. Po-Chedley and Fu (2012) did not use RSS as a reference. Recall that there is a residual bias in RSS or NOAA, but any bias is too small to detect via radiosondes (Po-Chedley and Fu 2012). Furthermore, we do not expect that the target factors should be exactly the same because RSS, UAH, and NOAA perform other corrections that may alter the magnitude of the target factor (as noted by Christy and Spencer 2013). The derivation of the target factor of 0.071 in Christy and Spencer (2013) is a result of their unrealistic assumptions.

Christy and Spencer (2013) also compare the differences in the TMT temperature before and after the *NOAA-9* time period for a number of datasets, claiming that radiosondes have a spurious shift relative to RSS and UAH and that *NOAA-9* differences between MSU groups have little impact on the long-term time series. It is important to note that Christy and Spencer (2013) did not collocate radiosonde and MSU measurements in this comparison. Spatial sampling alone can account for very large differences between datasets (Mears et al. 2011), so the comparisons between radiosonde and MSU datasets in Christy and Spencer (2013) are actually comparisons of very different metrics. Christy and Spencer (2013) suggest that the bias we detect is caused by radiosonde warming relative to RSS and UAH. This is unlikely because Po-Chedley and Fu (2012) found a bias in the UAH target factor relative to five global, homogenized radiosonde datasets but did not find a bias in the RSS or NOAA target factor. If this were simply an issue of radiosonde quality, then we would expect to measure a bias in each of the three MSU datasets. It is also important to note that the slope of the UAH minus RSS (NOAA) TMT versus the *NOAA-9* warm target temperature, which is independent of radiosondes, is −0.043 (−0.053). This is consistent with a UAH target factor bias of 0.051 as derived from radiosondes.

Christy and Spencer (2013) argue that there are no significant differences between RSS and UAH before and after *NOAA-9*. Unfortunately, the Christy and Spencer (2013) comparison is confounded by the influence of satellite problems in other time periods. For example, UAH TMT spuriously cools relative to RSS and NOAA between 1983 and 1985. It is unclear which dataset has the artificial warming or cooling, but it leads to spurious agreement between UAH and RSS (NOAA) during the time intervals utilized in Christy and Spencer (2013). In general, we object to the Christy and Spencer (2013) method of comparing the periods before and after *NOAA-9* because it introduces the influence of other satellites, which makes it difficult or impossible to draw conclusions about *NOAA-9*. This is also a less direct method than that of Po-Chedley and Fu (2012), who use the *NOAA-9* time period to make conclusions about *NOAA-9*. It is clear that the *NOAA-9* target factor is responsible for long-term trend differences, based not only on previous studies (e.g., Mears et al. 2003; Karl et al. 2006) and Po-Chedley and Fu (2012), but also on Christy and Spencer (2013), who find that their TMT trend increases when the target factor value is reduced. The fact remains that there must be a bias in one or more MSU TMT products (Fig. 1) and when we attempt to detect the bias, UAH is an outlier relative to two complementary MSU datasets, five radiosonde datasets and, as we will demonstrate, its own co-orbiting satellite measurements.

One important point made in Christy and Spencer (2013) is that the bias measured in Po-Chedley and Fu (2012) may be influenced by other co-orbiting satellites during the *NOAA-9* time period. Here, we check the UAH *NOAA-9* TMT time series for a residual bias using the UAH warm-target-corrected global mean TMT values for the *NOAA-6* and *NOAA-9* satellites. The warm target factor of *NOAA-6* is near zero for all three MSU teams and thus *NOAA-6* has little warm target temperature contamination. We find that the warm target temperature of *NOAA-9* significantly explains the differences between the UAH warm-target-corrected *NOAA-9* and *NOAA-6* TMT measurements. In Fig. 3a, we show UAH *NOAA-9* minus UAH *NOAA-6* TMT versus the warm target temperature for *NOAA-9*. We find that the UAH *NOAA-9* target factor has a bias of 0.082 ± 0.011, which is larger than the target factor bias measured in Po-Chedley and Fu (2012). One reason for this difference, as Christy and Spencer (2013) point out, is that the influence of satellites other than *NOAA-9* may diminish the signal measured in Po-Chedley and Fu (2012). In Fig. 3b, we show the *NOAA-9* minus *NOAA-6* differences over time and the fit to these data using the *NOAA-9* warm target temperature as a predictor. Figure 3 clearly illustrates that the warm target bias has not been removed from the UAH *NOAA-9* TMT time series. Furthermore, since the *NOAA-9* constant offset is calculated relative to *NOAA-6* in late 1985 and 1986, *NOAA-9* will start off too warm and spuriously cool because of this bias. *NOAA-9* is incorporated into the TMT time series in late 1984 and overlaps with *NOAA-7* during this time (when *NOAA-9* was artificially warm), so we would expect large positive residuals for *NOAA-9*

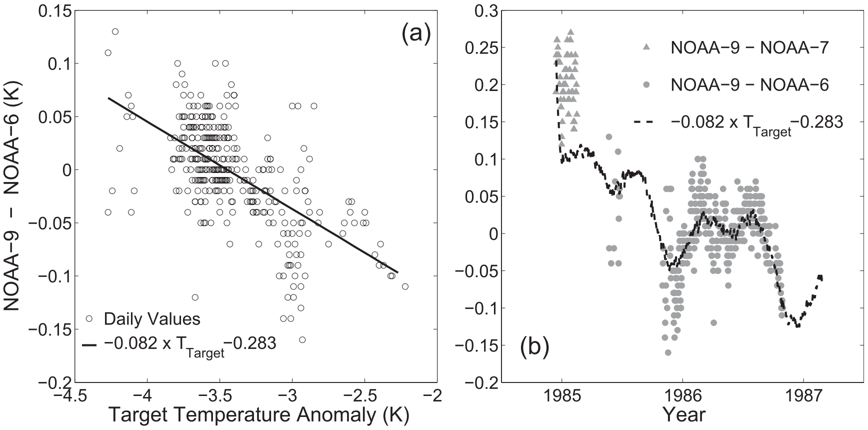

FIG. 3. (a) Scatterplots of the difference between daily global mean values for UAH *NOAA-9* and UAH *NOAA-6* (circles) vs the *NOAA-9* warm target temperature anomaly and a linear fit to the data. The individual satellite time series include the UAH corrections for the warm target bias. The slope value is -0.082 ± 0.011 with an r^2 value of 0.38, which represents the magnitude of the bias in the UAH *NOAA-9* warm target factor. (b) Daily differences of *NOAA-9* minus *NOAA-6* (gray circles) and *NOAA-9* minus *NOAA-7* (gray triangles) over time, and the linear fit to the *NOAA-9*/*NOAA-6* data using the *NOAA-9* warm target temperature as a predictor (dashed line).

minus *NOAA-7*, since both had constant offsets calculated relative to *NOAA-6*. We indeed find that there are large residuals between *NOAA-9* and *NOAA-7* (the average is 0.205). We show the residuals for *NOAA-9* minus *NOAA-7* in Fig. 3b, even though *NOAA-7* was not used in determining the bias in the UAH *NOAA-9* target factor. The large residual between *NOAA-9* and *NOAA-7* is further evidence that *NOAA-9* has a calibration problem related to the warm target factor.

Christy and Spencer (2013) point out that a major difference between RSS and UAH is the degree of temporal smoothing used to determine satellite target factors. UAH smoothes MSU daily data over relatively long periods (61–121 days), while RSS uses 5-day averages (pentads) when computing target factors (Christy et al. 2000; Mears et al. 2003). Note that our result using UAH *NOAA-9* and UAH *NOAA-6* daily data (Fig. 3) is very similar to that derived using 5-day average data. Christy and Spencer (2013) explain that without sufficient temporal smoothing, intersatellite difference trends remain. But it is not necessarily true that these trends are caused by the warm target calibration for *NOAA-9*. Mears et al. (2003) utilized the UAH *NOAA-9* target factor and found that the UAH coefficient reduced the intersatellite trend between *NOAA-6* and *NOAA-9*, but that it significantly increased intersatellite trends for other satellites, especially satellite overlaps ignored by UAH. Mears et al. (2003) also found that processing decisions other than temporal smoothing are important in determining the *NOAA-9* target factor. When RSS utilized the UAH diurnal drift correction and merging procedure, but used pentad data, they found a target factor of 0.075—nearly as large as the actual UAH value (Mears et al. 2003). In general, smoothing, diurnal drift corrections, and the selection of satellite overlaps all seem to influence the *NOAA-9* target factor. Most importantly, UAH is the only MSU dataset containing detectable residual warm target signals compared to independent radiosonde datasets.

3. Impact of target factor bias on TMT trend

We made a simple estimate of the impact this bias would have on the trend, warning that ‘‘while our estimate of the UAH TMT trend sensitivity to the warm target factor is similar to estimates by the UAH and RSS teams, our study indicates that the UAH team will need to incorporate an optimal *NOAA-9* target factor into their merging procedure for an accurate trend estimate’’ (Po-Chedley and Fu 2012, 650–651). When the UAH team does incorporate the target factor that we suggest into their algorithm, they find that their TMT trend increases by 0.022 K decade^{-1} (Christy and Spencer 2013). Christy and Spencer (2013) report a lower trend sensitivity value, because the drift of *NOAA-9* due to the target factor bias only introduces a cold bias between the *NOAA-6*/*NOAA-9* overlap and the *NOAA-9*/*NOAA-10* overlap (*NOAA-9* connects *NOAA-6* to *NOAA-10*). In Po-Chedley and Fu (2012), we had assumed that the drift caused a cold bias throughout the entire *NOAA-9* time series.

The Christy and Spencer (2013) estimate of the trend sensitivity is still significant (it would increase the UAH TMT 1979–2009 trend by about 50%) but, importantly, it may not be appropriate to simply fix the *NOAA-9* target factor to estimate the impact of this bias on the trend. The *NOAA-9* target factor influences other satellite target factors and the constant offsets between satellites. It is important to optimize all of the target factors and constant offsets. The UAH *NOAA-9* target factor may retain a residual bias because of differences in the treatment of the diurnal cycle drift bias, smoothing, or because UAH uses fewer satellites to constrain the *NOAA-9* target factor compared to RSS and NOAA. It is important to isolate the cause of this bias.

Finally, given the fact that the final MSU TMT product during the *NOAA-9* period is a combination of measurements from *NOAA-9* with other co-orbiting satellites, the central estimate of the warm target factor bias for UAH TMT as estimated from Po-Chedley and Fu (2012) may be too low. Since the UAH TMT trend varies linearly with the *NOAA-9* target factor (J. Christy 2012, personal communication), we can estimate the impact of the *NOAA-9* target factor bias on the UAH TMT trend. Using a warm target factor bias of 0.082 (from the *NOAA-9* and *NOAA-6* comparisons in this note) and the Christy and Spencer (2013) value for the trend sensitivity, the UAH trend would increase by 0.035 K decade^{-1}.

4. The lower tropospheric temperature time series

Christy and Spencer (2013) present the agreement between UAH and RSS for global TLT trends as evidence that there is no UAH target factor bias. This is not true; it is possible that the UAH trend could exceed that of RSS when this bias is accounted for with trend differences resulting for different reasons. In other words, the current trend agreement may be due to compensating biases in one or both datasets. Po-Chedley and Fu (2012) never claimed that RSS should be used as a reference. The *NOAA-9* target factor bias in UAH TMT would affect the UAH TLT product because UAH uses the TMT target factor for TLT. Figure 1b clearly shows that the differences in the TLT measurements between RSS and UAH over the *NOAA-9* time period are explained by the warm target temperature of *NOAA-9*. We could not detect a bias in the warm target factor for TLT using radiosondes because the noise in the TLT product is amplified by a factor of 2–3 compared to TMT (Hurrell and Trenberth 1998; Christy et al. 2000; Mears and Wentz 2009).

5. Summary and discussion

The main finding in Po-Chedley and Fu (2012) was that UAH has a bias in its *NOAA-9* warm target factor. To reiterate some of the key points that indicate that UAH has a bias in the *NOAA-9* warm target factor: 1) We show that the *NOAA-9* warm target temperatures and thus target factor differences explain the differences between the MSU teams during the *NOAA-9* time period (Fig. 1), which has important implications for the TMT trend (Mears et al. 2003; Karl et al. 2006); 2) this indicates that one or more teams has a bias in its warm target factor; 3) Po-Chedley and Fu (2012) found that UAH has a bias in its target factor using five peer-reviewed, homogenized radiosonde datasets; 4) Christy and Spencer (2013) found a similar, though insignificant, bias in the UAH target factor, but we show in this work that their radiosonde data lack adequate sampling to detect this bias and that their uncertainty is overestimated; 5) we show from individual UAH satellite records that a large, significant bias exists in its *NOAA-9* target factor; and 6) the large residuals between UAH *NOAA-9* and UAH *NOAA-7* are further evidence of a UAH *NOAA-9* target factor bias. The results 1, 2, 5, and 6 are independent of the radiosonde data.

As suggested in Po-Chedley and Fu (2012), UAH will need to determine the source of this bias and correct it for an accurate trend estimate in TMT. Since their TLT product utilizes the TMT target factor, a bias should also exist in their global TLT trend. UAH will need to remove the target factor bias for more reliable UAH TMT and TLT trend estimates. Using the UAH trend sensitivity (Christy and Spencer 2013) with a bias of 0.051 and 0.082 in the UAH *NOAA-9* warm target factor, the trend in the UAH TMT product increases by 0.022 and 0.035 K decade^{-1}, respectively, accounting for a majority of the global TMT trend differences between UAH and RSS for 1979–2009.

Christy and Spencer (2013) describe other documented reasons for differences between the RSS and UAH datasets. This information pertains mainly to differences in the 1990s and the diurnal cycle drift bias corrections. This information is not relevant to Po-Chedley and Fu (2012), though we agree that other differences between MSU datasets, particularly in the tropics, need to be resolved (e.g., Fu and Johanson 2005; Karl et al. 2006; Santer et al. 2008; Christy et al. 2010). The scope of ‘‘A bias in the midtropospheric channel warm target factor on the *NOAA-9* Microwave Sounding Unit’’ (Po-Chedley and Fu 2012) pertained to the *NOAA-9* warm target bias, though different biases that apply to other satellites during different time periods are still important.

The UAH group has been a pioneering force in temperature measurements from the MSU. In fact, it was the UAH team that developed the warm target calibration (Christy et al. 1998; Christy et al. 2000) that is employed by RSS and NOAA. Po-Chedley and Fu (2012) demonstrate that the UAH warm target correction for the *NOAA-9* satellite is too large, which artificially reduces the UAH TMT trend. The cause of this bias should be explored further to understand, in more detail, the effect of the diurnal cycle drift correction, the effect of smoothing, and the selection of satellites used in determining the *NOAA-9* target factor. Regardless of the cause of the bias, it leaves *NOAA-9* warm target temperature signals in the UAH MSU products and leads to a long-term cooling bias in the UAH dataset.

Acknowledgments. We thank Dr. John Christy (UAH), Dr. Carl Mears (RSS), and Dr. Cheng-Zhi Zou (NOAA) for their useful comments on our work, for providing us additional data related to the MSU, and their continued willingness to make clarifications about MSU data. We also thank Pu Lin for her helpful suggestions on this manuscript. This work was supported by the National Science Foundation Graduate Research Fellowship (Grant DGE-0718124) and Grant NESDIS-NESDISPO-2009-2001589 (SDS-09-15).

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.

——, ——, and E. S. Lobl, 1998: Analysis of the merging procedure for the MSU daily temperature time series. *J. Climate,* **11,** 2016–2041.

——, ——, and W. D. Braswell, 2000: MSU tropospheric temperatures: Dataset construction and radiosonde comparisons. *J. Atmos. Oceanic Technol.,* **17,** 1153–1170.

——, and Coauthors, 2010: What do observational datasets say about modeled tropospheric temperature trends since 1979? *Remote Sens.,* **2,** 2148–2169, doi:10.3390/rs2092148.

——, R. W. Spencer, and W. B. Norris, 2011: The role of remote sensing in monitoring global bulk tropospheric temperatures. *Int. J. Remote Sens.,* **32,** 671–685, doi:10.1080/01431161.2010.517803.

Fu, Q., and C. M. Johanson, 2005: Satellite-derived vertical dependence of tropical tropospheric temperature trends. *Geophys. Res. Lett.,* **32,** L10703, doi:10.1029/2004GL022266.

Haimberger, L., C. Tavolato, and S. Sperka, 2008: Toward elimination of the warm bias in historic radiosonde temperature records—Some new results from a comprehensive intercomparison of upper-air data. *J. Climate,* **21,** 4587–4606.

Hurrell, J. W., and K. E. Trenberth, 1998: Difficulties in obtaining reliable temperature trends: Reconciling the surface and satellite Microwave Sounding Unit records. *J. Climate,* **11,** 945–967.

Karl, T. R., S. J. Hassol, C. D. Miller, and W. L. Murray, Eds., 2006: Temperature trends in the lower atmosphere: Steps for understanding and reconciling differences. Synthesis and Assessment Product 1.1, Climate Change Science Program and the Subcommittee on Global Change Research, 164 pp. [Available online at http://www.climatescience.gov/Library/sap/sap1-1/finalreport/sap1-1-final-all.pdf.]

Mears, C. A., and F. J. Wentz, 2009: Construction of the RSS V3.2 lower-tropospheric temperature dataset from the MSU and AMSU microwave sounders. *J. Atmos. Oceanic Technol.,* **26,** 1493–1509.

——, M. C. Schabel, and F. J. Wentz, 2003: A reanalysis of the MSU channel 2 tropospheric temperature record. *J. Climate,* **16,** 3650–3664.

——, F. J. Wentz, P. Thorne, and D. Bernie, 2011: Assessing uncertainty in estimates of atmospheric temperature changes from MSU and AMSU using Monte-Carlo estimation technique. *J. Geophys. Res.,* **116,** D08112, doi:10.1029/2010JD014954.

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

Santer, B. D., and Coauthors, 2008: Consistency of modelled and observed temperature trends in the tropical troposphere. *Int. J. Climatol.,* **28,** 1703–1722, doi:10.1002/joc.1756.

Zou, C.-Z., 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.