Popular summary: Unexplained discontinuity in the U.S. radiosonde temperature data, Part II: Stratosphere

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Special flight data from the NWS's test facility at Sterling, Va. have been obtained. This data can be used to deduce the bias correction applied by Vaisala's post processing system. By analyzing the correction data, it can be shown that the inconsistencies with non-US Vaisala RS80 data as well as most of the large 0/12 UTC differences over the US can be accounted for by mulitiplying the reported elapsed time (i.e. time since launch) by the factor five-thirds which is incorrectly applied by the post processing software. After being presented with the findings in this paper, Vaisala further isolated the source of the inconsistencies to a software coding error in the radiation bias correction scheme. The error effects only the observations reported by US stations.

Unexplained Discontinuity in the U.S. Radiosonde Temperature Data, Part II: Stratosphere

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Abstract

In part I of this paper, the United States (US) radiosonde temperature data are shown to have significant and unexplained inhomogeneities in the mid-troposphere. This part discusses the differences between observations taken at 0 and 12 UTC especially in the stratosphere by the Vaisala RS80 radiosondes that are integrated within the National Weather Service's (NWS) Micro-ART system. The results show that there is a large maxima in the horizontal distribution of the monthly means of the 0/12 UTC differences over the central US that is absent over Canada and this maxima is as large as 5 °C at 10 hPa. The vertical profiles of the root-mean-square of the monthly means are much larger in the US than those elsewhere. The data clearly shows that the 0/12 UTC differences are largely artificial especially over the central US and originate in the post processing software at observing stations, thus confirming the findings in part I.

Special flight data from the NWS's test facility at Sterling, Va. have been obtained. This data can be used to deduce the bias correction applied by Vaisala's post processing system. By analyzing the correction data, it can be shown that the inconsistencies with

non-US Vaisala RS80 data as well as most of the large 0/12 UTC differences over the US can be accounted for by mulitiplying the reported elapsed time (i.e. time since launch) by the factor $\frac{5}{3}$ which is incorrectly applied by the post processing software. After being presented with the findings in this paper, Vaisala further isolated the source of the inconsistencies to a software coding error in the radiation bias correction scheme. The error effects only the software installed at US stations.

1 Introduction

The National Weather Services (NWS) in the United States (US) launches radiosondes to measure meteorological quantities including temperatures and heights. These radiosondes are released twice daily, nearly one hour before 0 and 12 UTC, and typically reach pressure levels of 20 hPa or higher. The observations are widely used not only in performing analysis and initializing forecast models but also in climate studies as noted in Eskridge *et al.* (2002).

Recently, large differences between observations taken at 0 and 12 UTC have been revealed during routine monitoring of observations at the Data Assimilation Office (DAO) at NASA's Goddard Space Flight Center (GSFC). The differences are the largest in the stratosphere and can reach several degrees Celsius. As a result, an investigation has been conducted to confirm the large differences and isolate their source(s). This paper, which is the second of two, discusses the methods used in the investigation and presents the findings. The first paper (Eskridge *et al.* 2002) is concerned primarily with the inhomogeneities of the US data from the VIZ and Vaisala RS80 radiosondes in the mid-troposphere.

2 Method

All radiosonde data used in this study were taken by Vaisala RS80 instruments, and, unless noted otherwise, were provided by the National Center for Environment Prediction (NCEP). A random sample of the observed values was compared with the Comprehensive Aerological Reference Data Set (CARDS, Eskridge *et al.* 1995) from the National Climatic Data Center (NCDC) which acquires its data directly from the US stations via floppy disk. The temperature differences were no more than 0.2 °C and height differences at or less than 5 m. These differences can be attributed to the imprecision of the Global Telecommunication System (GTS), a meteorological network through which NCEP receives its data. Radiosonde observations on the GTS are reported using the World Meteorological Organizations's (WMO) radiosonde code (World Meteorological

Organization, 1995). With the WMO code, temperature data is encoded to an accuracy of 0.2 °C, and height data above 500 hPa is reported to the nearest dekameter.

The 0/12 UTC differences are calculated using the following expression:

$$\delta = \begin{cases} O_{00} - 0.5(O_{-12} + O_{+12}) \\ \\ O_{00} - O_{-12} \quad \text{if } O_{12} \text{ is missing} \\ \\ O_{00} - O_{12} \quad \text{if } O_{-12} \text{ is missing} \end{cases} \tag{1}$$

where δ is the 0/12 UTC difference, O_{00} is the observation at 0 UTC and O_{-12} and O_{12} are the observations at 12 hours before and after 0 UTC. These observations are subject to the complex quality control (CQC) developed by NCEP (Collins, 2001a, b). In the DAO's implementation, the first guess for the CQC was generated by the Physical space/Finite-volume Data Assimilation System (fvDAS), recently developed at GSFC. The fvDAS is based on the finite volume general circulation model of Lin and Rood (1996) and the

Physical-Space Statistical Analysis System as described in Cohn *et al.* (1998).

Equation (1) is formulated to remove or greatly reduce, in a time-mean, the significant effects of slow and steady long-term changes such as those exhibited in Fig. 1. For the first case in (1) where both O_{-12} and O_{12} are available, the long-term change is represented by a time-dependent linear function that is set to O_{-12} and O_{12} at the corresponding synoptic times. To generate a value representing the long-term changes at 0 UTC, a centered differencing interpolation scheme is employed. The interpolated value is then subtracted from the observation O_{00} to determine δ.

[Figure 1 about here.]

For the second and third cases in (1), no explicit representation of the long-term effects is implemented. Rather, it is assumed that the observation O_{12} is as likely to be missing (i.e. the second case in (1)) as O_{-12} (i.e. the third case). In addition, the long-term change embedded in δ for the second case has approximately the same magnitude as that for the third case, except for the factor, -1. Given these two assumptions for all available observations O_{00} in the time-mean, the effect of long-term changes would largely cancel out.

The monthly mean of δ at each station is calculated using the equation,

$$\overline{\delta_i} = \frac{1}{n}\sum_{t=1}^{n}\delta_{ti} \qquad (2)$$

where n is the sample size $\geq$ 15, i is the ith station, t is the tth synoptic date (time is 00 UTC) and δ is 0/12 UTC difference from (1). Finally, the root mean square (RMS) of the monthly means of all stations with a common instrument type in each select region is calculated for each mandatory pressure level up to 10 hPa according to the equation:

$$\delta_{rms} = \frac{1}{m}\left(\sum_{i=1}^{m}\overline{\delta_i^2}\right)^{\frac{1}{2}} \qquad (3)$$

where m is the number of stations with valid monthly means, i is the ith station and δ_{rms} is the regional RMS.

The instrument types considered in this study are the Vaisala RS80-57H (WMO code 52) used in the United States and the Vaisala RS80 Cora (WMO codes 60-63) used elsewhere. The selected regions are the entire globe, North America (bounded by 10N, 80N, 50W and 180W), Europe (30N, 80N, 60E and 20W) and Australia (45S, 0S, 160E, 90E).

3 Results

Vaisala RS80 radiosonde data were processed by applying (1), (2) and (3). Fig. 2 shows the vertical profiles for the RMS of the mean 0/12 UTC temperature and height differences for select regions and months for 2001. The RMS for Vaisala RS80-57H radiosondes are much larger than those from non-US radiosondes over North America and elsewhere at levels as low as 100 hPa. The profiles for non-US radiosondes are clustered close together at all levels while that for the US becomes an out-lier in the stratosphere. The contrast between the profiles for US and non-US radiosondes increases with altitude so that at 10 hPa the values from US radiosondes are twice as large as those from non-US radiosondes. In December, the 0/12 UTC differences are smaller near the winter solstice when the northern hemisphere undergoes the longest nights during the year. In March (figure not shown), the profiles are close to those in September.

[Figure 2 about here.]

Vertical profile plots for the RMS similar to Fig. 2 have also been generated for the years 1999 and 2000 (not shown) and reveal that the same general features persist for the same levels and months of the year. Only a few significant deviations are apparent, but, even then, a closer scrutiny reveals that the deviations are actually much less significant. For example, the regional RMS value calculated from (3) for Australia at 20 hPa in September 1999 is nearly as high as that for the US. However, only a few stations at 20 hPa have valid monthly means that could be included in (3) to calculate the regional RMS. Thus, the statistical reliability of the regional RMS value at 20 hPa for Australia is suspect.

Fig. 3 shows the horizontal distribution of the monthly mean of the 0/12 UTC temperature differences, calculated from (2), over select regions at 30 hPa for September 2001. The magnitude of the mean differences are much larger over the US than over Canada. In addition, a systematic pattern is evident over the US with the largest means over the central US and lesser values elsewhere. However, the large maxima is absent over Canada where no discernible pattern exists. The contrast between the magnitudes and patterns over the US and those over Canada is sharp with the transition primarily at the border between the countries. Over Europe and Australia, the magnitudes of the mean differences are also much smaller with no discernible patterns.

[Figure 3 about here.]

Many other horizontal plots of the monthly means of the 0/12 UTC temperature differences have been generated and have consistently exhibited a sharp contrast between the patterns over the US and those over Canada at 150 hPa and higher. These plots have also shown other features as well. For example, Fig. 4 displays the horizontal distribution of the monthly means at select pressure levels over North America for the same period. A comparison between the panels shows that the maxima progresses eastward with descending levels. At 10 hPa, the largest values are over the western US centered near 110° W and are as large 5 °C. At 20 hPa, 50 hPa and 150 hPa, the maxima shifts to near 105° W, 100° W, and 95° W, respectively with the magnitude decreasing to about 1.2 °C at 150 hPa.

[Figure 4 about here.]

Another feature that can be seen in the horizontal plots is the seasonal dependence of the patterns of the monthly means. Fig. 5 shows the monthly means calculated using (2) at 20 hPa for select months in 2001. During March and September, the patterns, including the location of the maxima near 100° W, are very similar. In June, the location of the maximum shifts to the eastern half of the US near 80°-85° W, and the magnitudes of the mean differences decrease. The patterns in December are similar to that for June except that the differences are smaller during the month of maximum darkness. Plots similar to Figs. 3-5 have been generated for the years 1999 and 2000 but are not shown in this article. They show that the same general patterns and magnitudes persist for the same level and month of year.

[Figure 5 about here.]

For heights, the horizontal plots of the monthly mean 0/12 UTC differences from (2) reveal similar features that are seen in Figs. 2- 5. For example, Fig. 6 shows the monthly mean differences at the levels in Fig. 4 for September 2001. The patterns are qualitatively the same except that the location of the maxima is about 10°-15° east of those in Fig. 4. The maxima at each level ranges from about 25 m at 150 hPa to about 150 m at 10 hPa. Again, the magnitude of the mean differences from (2) are much larger over the US than over Canada where the maxima is absent and no discernible pattern exists. As in Figs. 3-5, the contrast between the magnitudes and patterns over the US and those over Canada is sharp.

[Figure 6 about here.]

Time series plots of 0 UTC and 12 UTC temperature and heights at select stations have been examined. An example of the time-series plots is given in Fig. 7 which presents the temperature and heights at 10 hPa for September 2001 for select stations at longitudes of 101°-103° W. At US stations, the 0 UTC temperatures are consistently 2 to 4 °C greater than those at 12 UTC so that the time-series plots for both synoptic times are roughly parallel to each other. At 30 hPa (figure not shown) the 0 UTC and 12 UTC temperature time-series are noisy but nonetheless the 0 UTC observations are predominately greater than the 12 UTC observations. The same is true for heights at both 10 hPa and 30 hPa except that the data is considerably less noisy. At 10 hPa, 0 UTC heights are typically 100 to 150 m higher than those at 12 UTC.

[Figure 7 about here.]

At the Canadian station, the time-series data at 10 hPa show that the differences between the 0 UTC and 12 UTC data are much smaller than those at US stations. Other US and Canadian stations have been examined whose time-series plots are not shown. The plots for these stations are consistent with the horizontal plots shown earlier and that the plots for the 0 UTC and 12 UTC data are generally parallel especially at levels higher than 50 hPa.

In summary, there are large systematic 0/12 UTC differences as defined by (1) for both temperature and heights over the continental United States with monthly means calculated using (2) as large as 5 °C and 150 m. The location and magnitude of the maximum values vary with pressure (or altitude) and time of the year. From the time-series plots the observed values at 0 UTC are consistently larger than those at 12 UTC. These differences are much larger than the values from stations using RS80 radiosondes outside of the United States. In addition, the systematic patterns over the United States are absent elsewhere.

4 Analysis

As noted earlier, the observation data from the US radiosondes obtained through NCDC and NCEP are nearly identical. Furthermore, the large systematic 0/12 UTC differences calculated by applying (1), (2) and (3) with US observations are largely absent when using data from other stations that launch Vaisala RS80 radiosondes. Thus, the source of the large 0/12 UTC differences is not from any subsequent NCEP post processing but must be unique to the on-site post-processing software at the US stations.

To isolate the source of the large systematic 0/12 UTC differences, special flight data have been obtained from US Vaisala RS80 radiosondes launched at the NWS's test flight facility in Sterling, Virginia. This data was generated to determine the radiation bias correction that is applied by the Vaisala post-processing software and is described in Fitzgibbon and Facundo (2003). The baseline data is from a nighttime test flight which was launched on July 26, 2002 at 2:31 UTC and was terminated 101 minutes later at 4:12 UTC at

10 hPa. Since this flight occurred during the middle of the night where the solar elevation angle is well below the threshold of -7°, no bias correction is expected as can be seen in Fig. 8. During the flight the demodulated audio signal from the radiosonde was recorded by the ground equipment onto a digital audio tape. The tape was replayed back into the post-processing software with different launch times to simulate conditions near sunrise and midday. The bias correction applied by the post-processing software can be determined by calculating the differences between the temperatures from the replayed tape and those from the baseline flight.

[Figure 8 about here.]

Fig. 9 shows the corrections for a simulated flight. In this figure, the observed corrections are compared with those predicted by Vaisala's correction table (1993 version) and its formulae for solar elevation angle and ventilation factor (Vaisala 1983). [At US and non-US observing stations, the post-processing software checks and, if necessary, modifies the ventilation factor to ensure that the value is within the range of 0.6 and 1.4 (K. Goss 2003, personal communication).] The predicted corrections are consistently lower than the observed by up to 0.5 °C especially at elapsed times (i.e. times since launch) beyond 30 minutes.

[Figure 9 about here.]

The launch time for the simulated flight in Fig. 9 is well after sunrise so that the solar elevation angle is always 10° or higher, where, as evident in Fig. 8, the tabular values is insensitive to changes in the solar elevation angle. Also, the total correction is the product of the tabular value and the ventilation factor (Vaisala 1983). Thus, any substantial discrepancies between the observed and predicted corrections must largely be due to the differences in the ventilation factor and not in the tabular values. Furthermore, the ventilation factor is the square root of the rise rate (Vaisala 1983) and, thus, the square root of the elapsed time change. If the elapsed time as reported by the post-processing software were adjusted by a constant factor, then the bias correction, sensitive only to the ventilation factor, would be adjusted approximately by the square root of this constant.

A close fit between the observed and predicted corrections can be achieved by setting the factor to a value near $\frac{5}{3}$ as evident in Fig. 9. In this figure and hereafter, the adjusted correction is defined as the predicted correction obtained by multiplying the reported elapsed time by $\frac{5}{3}$. The adjusted corrections agree to within 0.1 °C with most observed values and to within 0.2 °C throughout the flight except for isolated exceptions within the first 20 minutes. Furthermore, the curve for the adjusted corrections is never outside the area of high concentration of empirical points.

Fig. 10 displays the corrections for a flight launched about 80 minutes before sunrise when the tabular corrections are sensitive to the solar elevation angle. Based on the comparision between the observed and predicted corrections, the post-processing software begins correcting the data about 30 minutes too early. Once the corrections begin, the differences between the observed and predicted values increase to 1.8 °C higher and is much larger than that seen in Fig. 9. As in Fig. 9, the adjusted corrections agree to within 0.1 to 0.2 °C with isolated exceptions, and the curve for these corrections is never outside the area of high concentration of empirical points.

[Figure 10 about here.]

Plots for other simulated flights of Vaisala RS80 radiosondes similar to those in Figs. 9 and 10 have been generated for launch times between 6 and 12 UTC but are not shown. All of these plots show that the predicted values are consistently lower than the observed. They also show that the observed corrections begin earlier than that predicted by the correction tables and by the formulae for the solar elevation angle and the ventilation factor. Furthermore, the discrepancies between the observed and adjusted corrections are almost never more than 0.2 °C, and the curve for the adjusted corrections consistently lies within the area of hight concentration of empirical points.

If the time were misspecified by a factor of $\frac{5}{3}$, then the calculated elapsed time at 10 hPa would be in error by about one hour. At this level, the solar elevation angle would be miscalculated by more than 10°. To illustrate the effect, a sample calculation was performed for a fictitious station near the location of the largest 0/12 UTC differences at 10 hPa (see Figs. 4 and 6.). The launch and unadjusted elapsed times and the ventilation factor are based on select US soundings from the CARDS data set. The result of the sample calculation is given in Table 1. If the elapsed time were misspecified to be 158.3 min, then the solar angle would be mis-calculated by about 12°. If -7° is the threshold for darkness, then for the synoptic hour 0 UTC, the post-processing system would assume darkness when in fact the thermistor is receiving sunlight. For the synoptic hour 12 UTC, the reverse is true.

[Table 1 about here.]

The effect on the bias correction is seen in Table 2 where at the synoptic hour 0 UTC the bias correction should have been nearly 2 °C but would have been set to 0 °C if the elapsed time were mis-specified. For the synoptic hour 12 UTC, the opposite is true. Furthermore, the adjustment in the elapsed time would decrease the balloon rise rate and increase the the ventilation factor which would add another 0.5 °C to the total correction at 12 UTC. Thus, the sensor would measure a temperature too high and low by nearly 2.0 °C and 2.5 °C for 0 and 12 UTC, respectively. The mis-calculation at these two synoptic times would account for 4.0 to 4.5 °C which is typically observed for the mean 0/12 UTC differences in the central US. Any remaining differences can be attributed to the factors that cause the 0/12 UTC differences at non-US stations which have values of about 0.5 to 1.0 °C (see Fig. 2).

[Table 2 about here.]

The effect of adjusting the elapsed time by a factor of $\frac{5}{3}$ on all US Vaisala RS80 observations was determined by first uncorrecting the heights and temperatures. In the calculations, the elapsed time reported by the observing station was adjusted by $\frac{5}{3}$. In addition, Vaisala's correction table, and its formulae for solar elevation and ventilation factor were used (Vaisala, 1983). In addition, the CARDS dataset from NCDC were used to acquire the reported elapsed time and merge it with the data from NCEP. However, about 5 to 10 percent of the radionsonde sounding reports do not include the elapsed time. For these reports, an empirical equation for defining the rise rate at a given altitude was used to estimate the reported elapsed time. After uncorrecting the data using the adjustment factor, $\frac{5}{3}$, re-corrections were then performed using the reported elapsed time without the factor.

Fig. 11 shows the vertical profiles for the RMS of the mean 0/12 UTC differences calculated by applying (3) with the unmodified and re-corrected observations from US Vaisala RS80 radiosondes and unmodified observations from the Canadian RS80 radiosondes. The 0/12 UTC differences of the re-corrected observations become much smaller and much closer to the RMS values over Canada. For temperatures, vertical profiles for the observations over the US are nearly identical to those for the unmodified observations over Canada. The same is true for the profiles for heights for June, 2001 but, for September, the RMS values from the re-corrected data are smaller than those from the data over Canada.

[Figure 11 about here.]

Fig. 12 compares the patterns of the monthly means [from (2)] at 50 mb for the re-corrected and unmodified temperature and height observations from Vaisala RS80 radiosondes. The figure shows that the magnitudes of the re-corrected means over the US are significantly smaller than that of the unmodified means. Also, the patterns of the means over Canada and the United States have become indistinguishable. The sharp contrast at the border between the US and southern Canada that exists with the unmodified data has become unnoticeable with the re-corrected data. The same is true at the border between Alaska and Canada. For temperatures, the re-corrected means reveal a general slight gradient oriented from southwest to northeast over the entire North American continent. For heights, no systematic patterns for the re-corrected means is evident over the US and Canada with minor exceptions. The exceptions include slightly larger positive values near the east coast and eastern Canada and a few isolated negative values near the west coast. However, these exceptions occur in both the US and Canada so that no contrast exists at the border.

[Figure 12 about here.]

At 10 hPa , the impact of the re-corrections on temperature and height data is similar to the effect at 50 hPa as shown in Fig. 13. As in Fig. 12, the mean 0/12 UTC differences over the US are greatly reduced, the patterns over Canada and the US become indistinguishable, and the sharp contrast at the boundary between the US and Canada becomes unnoticeable. For temperature, a few means over the US remain fairly large but have comparable values to some isolated stations over Canada. For heights, the patterns for the re-corrected means are flat over both the US and Canada except that larger positive values and isolated small negative values exist near the east and west coast, respectively. Re-corrections for temperatures and heights have been performed at other levels for the months July and September, 2001. The results consistently show results similar to those seen in Figs. 12 and 13.

[Figure 13 about here.]

Time series plots of the 0 UTC and 12 UTC re-corrected temperature and heights have been compared with those for uncorrected observations, examples of which are given in Figs. 14 and 15. At most stations like Amarillo, Texas and Rapid City, South Dakota, the time series show that the lines connecting the re-corrected 0 and

12 UTC observations become very close and the differences become similar that for the station at The Pass UA, Manitoba, Canada in Fig. 7. At some stations like Greensboro, North Carolina, only a modest change in the time series is evident. However, the time-series remains consistent with the larger mean 0/12 UTC differences observed near the eastern Canada and the east coast of the US.

[Figure 14 about here.]

[Figure 15 about here.]

In summary, the large 0/12 UTC differences over the continental US are greatly reduced if the observations from the Vaisala RS80 observations are uncorrected assuming that the reported elapsed time is adjusted by a factor of $\frac{5}{3}$ and then re-corrected using the unadjusted elapsed time. Furthermore, any significant contrast in the patterns of the monthly means disappears especially at the border between the US and Canada. Thus, multiplying the elapsed time (i.e. time since launch) by the factor $\frac{5}{3}$ can account for much of the 0/12 UTC differences and nearly all of the inconsistencies between the US and non-US observations.

5 Summary and Conclusions

Vaisala RS80 radiosonde temperature and height observations taken during the years from 1999 to 2001 were obtained from NCEP and compared with the CARDS data from NCDC to rule out any modifications performed at NCEP. The data was then checked by DAO's implementation of NCEP's complex quality control. Then, the monthly means from (2) of the 0/12 UTC differences from (1) were calculated as well as the root-mean-square (RMS) of the monthly means from (3). The list of select regions includes the United States (US), Canada, Europe and Australia. Plots were then generated to show the horizontal distribution of the monthly means at each station over select regions, levels and months; the vertical profiles of the regional RMS for select months; and the time series of the observed values.

The results showed large systematic 0/12 UTC temperature and height differences over the continental US with monthly means as large as 5 °C and 150 m at 10 hPa. The location and magnitude of the maximum values vary with pressure level and time of the year. The time-series plots show that the observed values at 0 UTC are consistently larger than those at 12 UTC. These differences are much smaller at non-US stations using RS80 radiosondes where there is no systematic patterns that is seen over the United States. Thus, the data clearly shows that 0/12 UTC differences are largely artificial especially over the central US. Furthermore, the independent verification from the CARDs data set shows that the differences largely originate in the post processing software at the observing stations.

These findings are confirmed from special flight data that was generated to determine the radiation bias correction that is applied by the Vaisala post-processing software. These corrections are significantly different from those predicted by Vaisala's correction tables and by the formulae for the solar angle and ventilation factor. The values are especially large near sunrise where the discrepancy between the observed and predicted corrections can be as large as 1.5

to 2.0 °C and are about 0.5 °C during the middle of the day. If the elapsed time (i.e. time since launch) as reported by the post-processing software is adjusted by a factor of $\frac{5}{3}$, then the predicted and observed corrections become identical to within 0.1 to 0.2 °C of all but isolated observed values.

The time error factor of $\frac{5}{3}$ explains much of the large 0/12 UTC differences that is evident over observing stations that launch Vaisala RS80 radiosondes in the US. The radiosondes are typically released near dawn or dusk especially in the central US, and the radiation bias correction is sensitive at low solar elevation angle. The combined effect at 0 UTC and 12 UTC could account for nearly all of the 0/12 UTC differences. The effects of the adjusted time (i.e $\frac{5}{3}$ times the reported elapsed time) was determined by first uncorrecting the observations with the adjustment factor and re-correcting using the unadjusted elapsed time. The results show that 0/12 UTC differences are reduced to the magnitudes found over Canada. In addition, any noticeable contrast between the patterns over Canada and the US disappear especially at the border. Thus, adjusting the reported elapsed time by a factor of $\frac{5}{3}$ accounts the inconsistency of the Vaisala RS80 temperature and height observations.

The findings in this article were communicated to the staff at Vaisala (K. Goss 2003, personal communication). In response, the staff reported that there is a coding error in the post-processing software at US stations. The Vaisala software at non-US stations reports data at 2 s, 5 s or 10 s intervals while at US stations, the NWS requires that the software report at 6 s intervals. The radiation bias correction portion of the software at US stations improperly increments the elapsed time by 10 s at each reporting time instead of applying the correct increment of 6 s, which confirms the adjustment factor $\frac{5}{3}$. As discussed earlier in this paper, the adjustment factor affects both the ventilation factor, which accounts for the rise rate, and the solar elevation angle. This coding error affects only the software installed at US stations. Vaisala has said that it is ready to correct the error and is willing to work with the NWS to implement the correction.

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7 Time series of 10 hPa observations at 00 UTC (solid line) and 12 UTC (dashed line) during September 2001. The top, middle and bottom panels correspond to data from Amarillo, Texas, US (WMO No. 72363), Rapid City, South Dakota, US (WMO No. 72662) and The Pass UA, Manitoba, Canada (WMO No. 71867), respectively. Right and left panels correspond to temperatures (K) and heights (m), respectively. . 41

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10 Same as Fig. ?? except that the simulated flight was launched on July 25, 2003 at 8 UTC 44

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15 Same as Fig. ?? for height (m) observations. 49

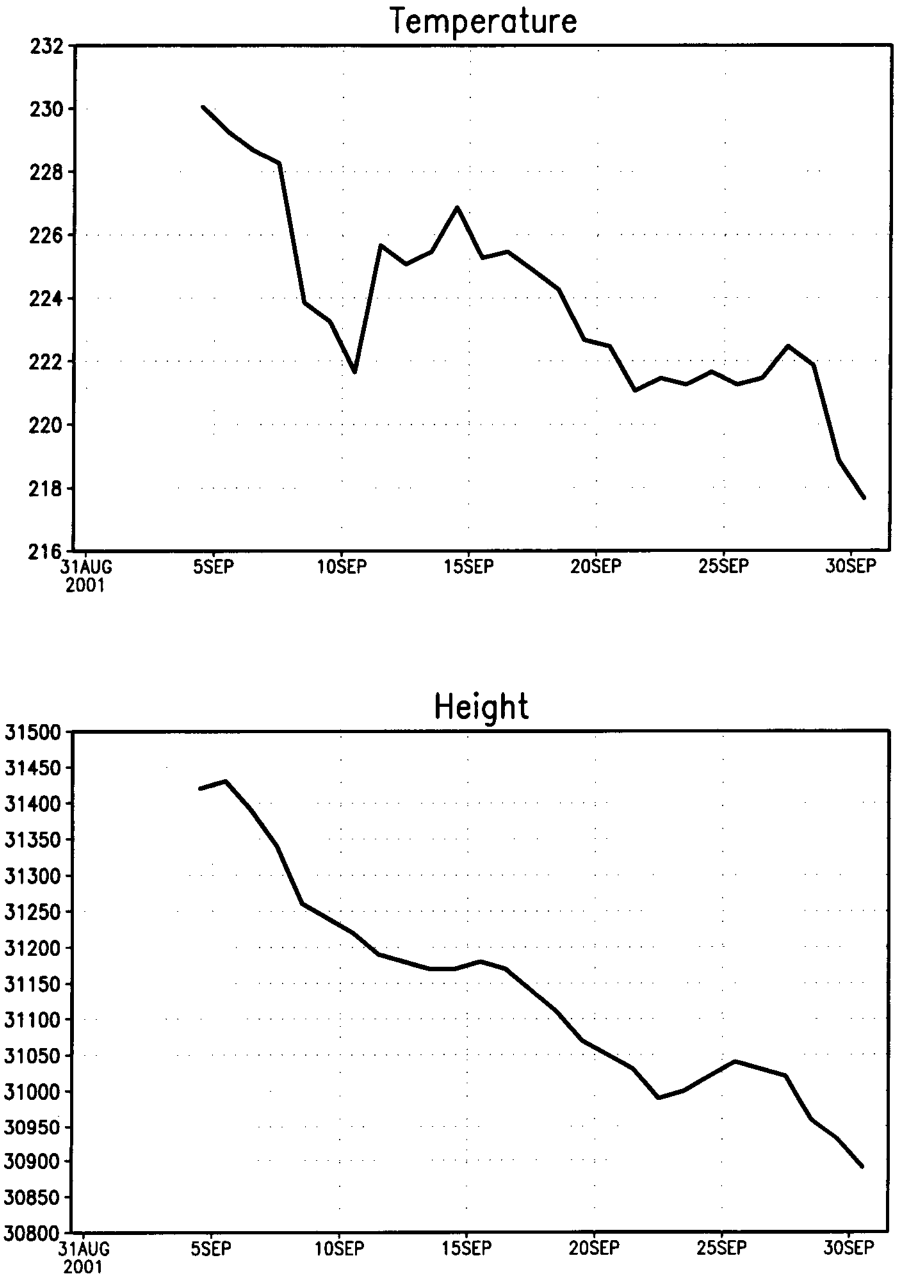

Figure 1: Time series of 10 hPa observations at 12 UTC during September 2001 from Norman Wells, Northwest Territories, Canada (WMO No. 71043). Top and bottom panels correspond to temperatures (K) and heights (m), respectively.

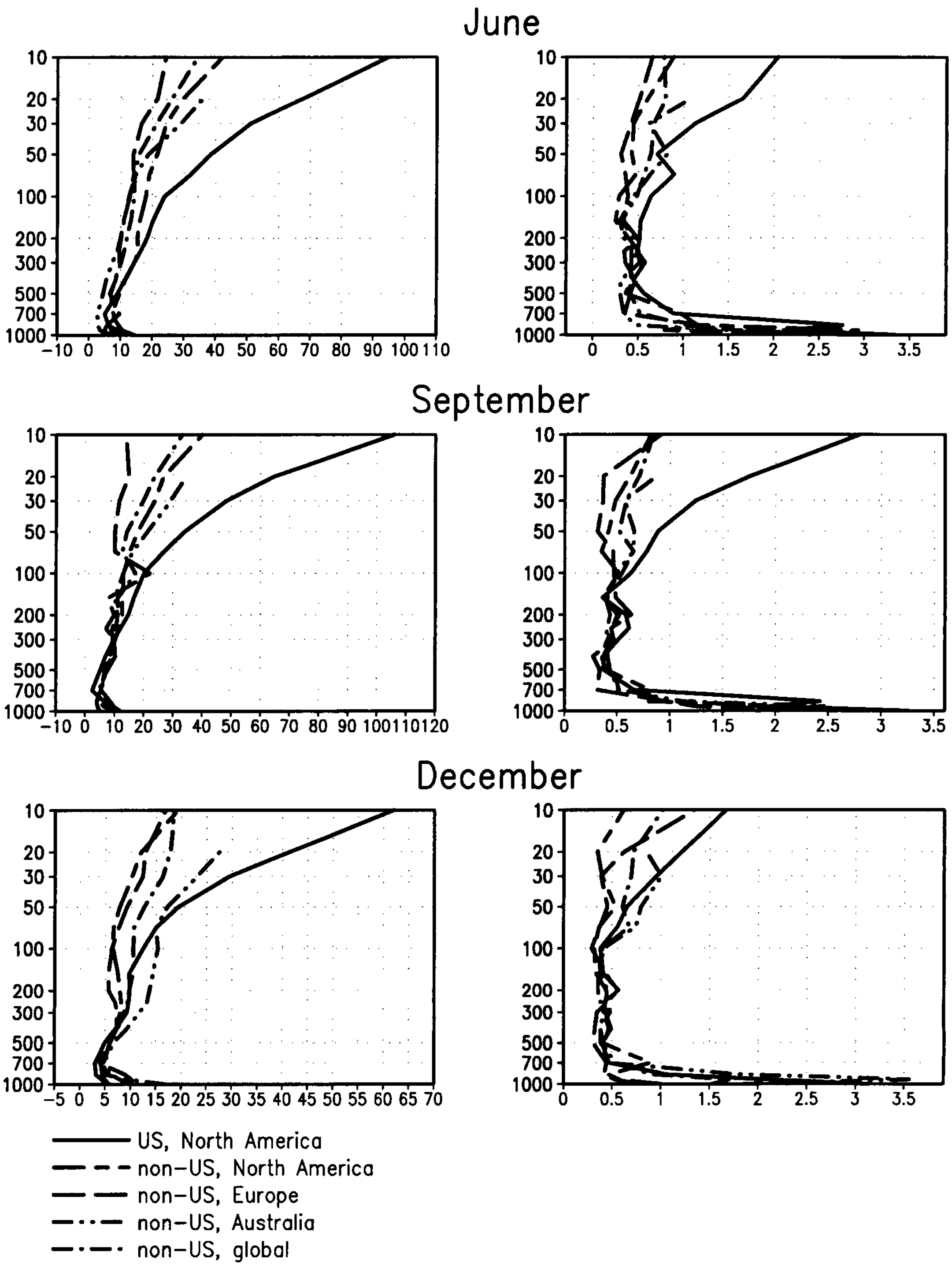

Figure 2: Regional root-mean-square of the mean 0/12 UTC differences at US and non-US stations calculated according to (3). Left and right panels correspond to heights (m) and temperatures (°C), respectively. Top, middle and bottom panels correspond to June, September and December, respectively.

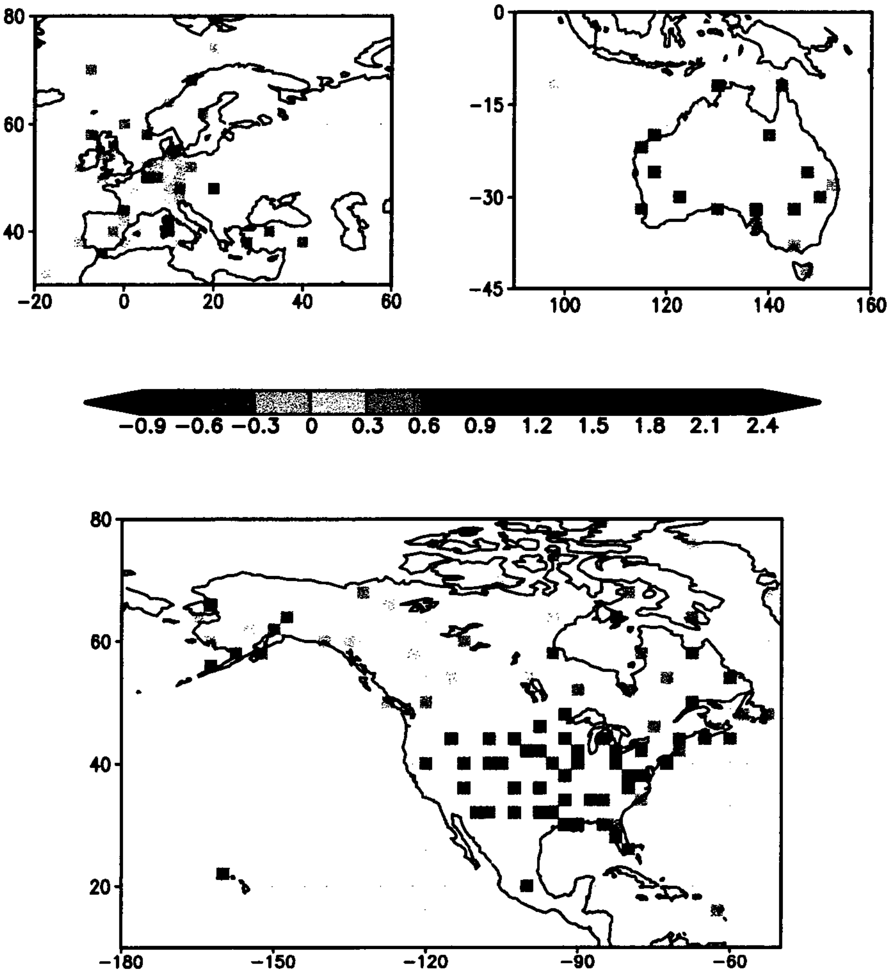

Figure 3: Monthly mean 00/12 UTC temperature (°C) differences at US and non-US stations in Europe, Australia and North America at 30 hPa for September 2001. The mean differences were calculated according to (2).

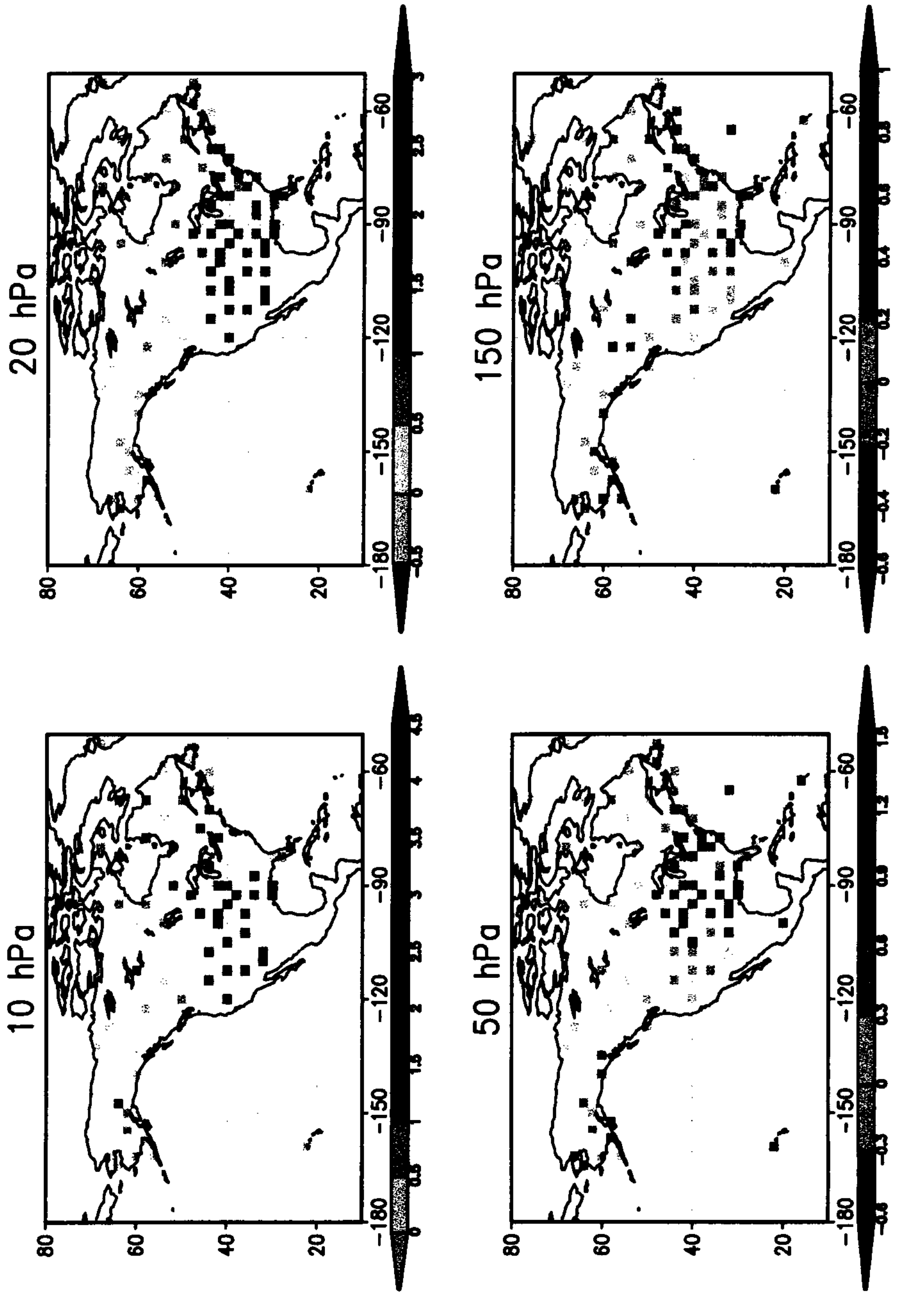

Figure 4: Same as Fig. 3 for the levels, 10 hPa, 20 hPa, 50 hPa and 150 hPa.

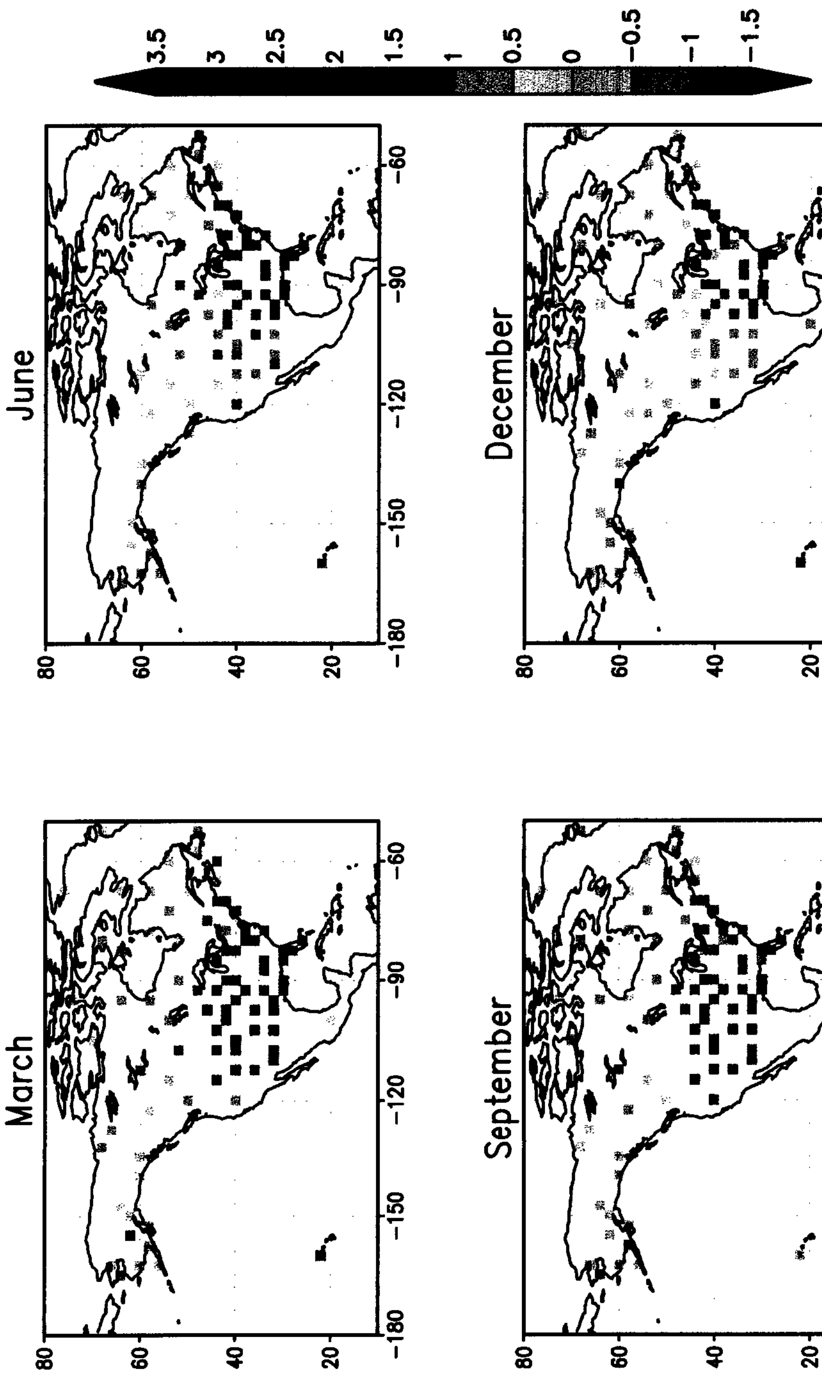

Figure 5: Same as Fig. 3 at 20 hPa for March, June, September and December, 2001.

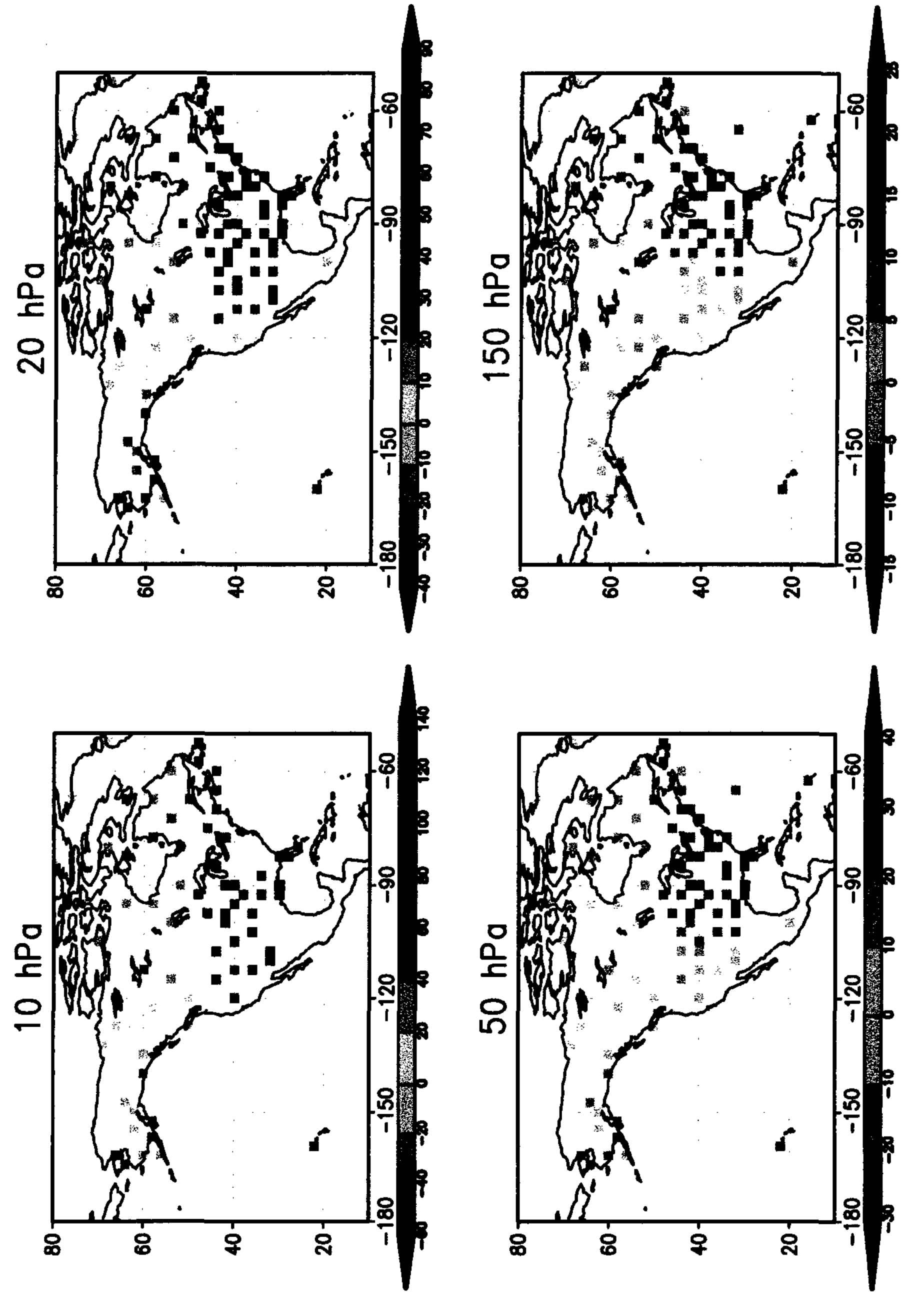

Figure 6: Same as Fig. 4 for heights (m).

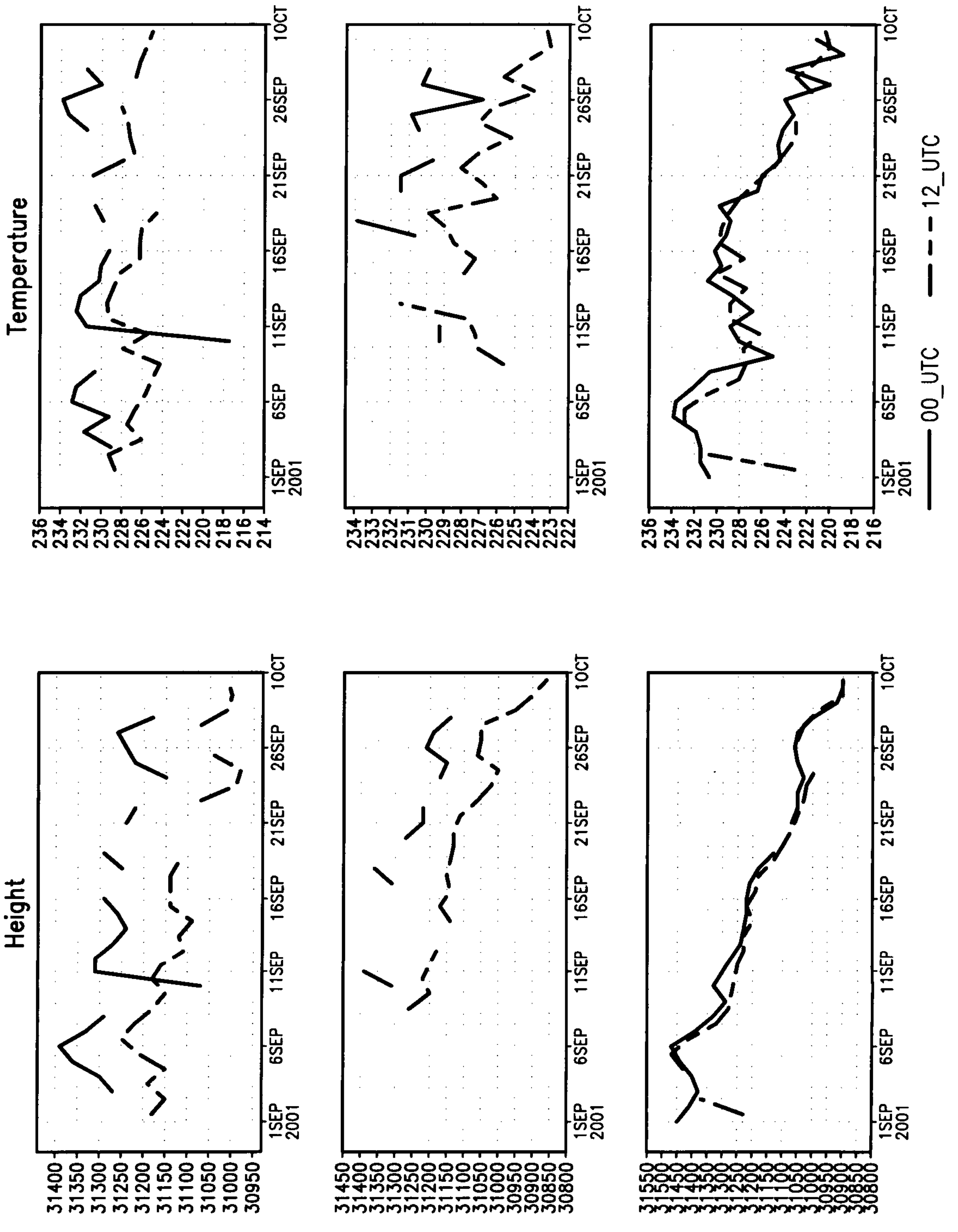

Figure 7: Time series of 10 hPa observations at 00 UTC (solid line) and 12 UTC (dashed line) during September 2001. The top, middle and bottom panels correspond to data from Amarillo, Texas, US (WMO No. 72363), Rapid City, South Dakota, US (WMO No. 72662) and The Pass UA, Manitoba, Canada (WMO No. 71867), respectively. Right and left panels correspond to temperatures (K) and heights (m), respectively.

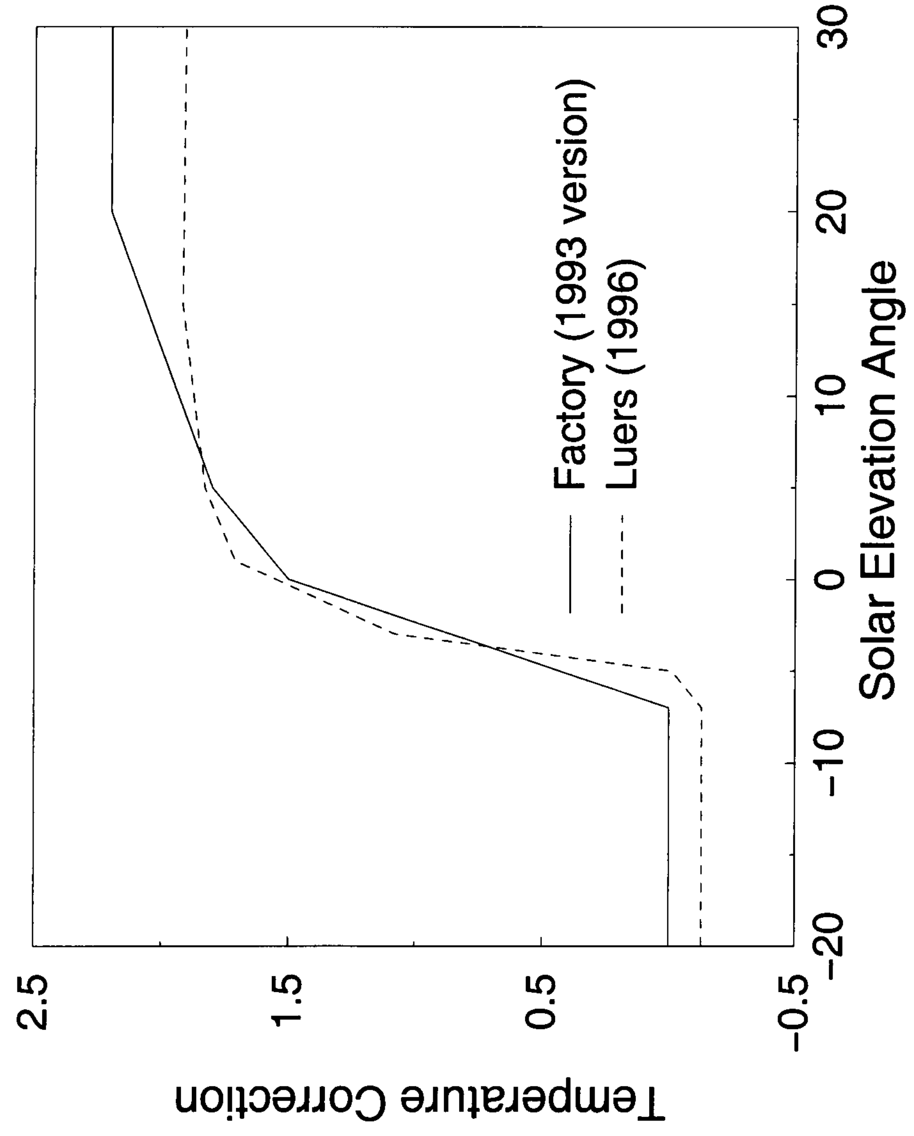

Figure 8: Temperature corrections (°C) versus solar elevation angle (°) at 10 hPa or about 30 km for Vaisala RS80 radiosondes. Included for comparison are the corrections from the heat transfer model of Luers (1996), validated in Luers and Eskridge (1995).

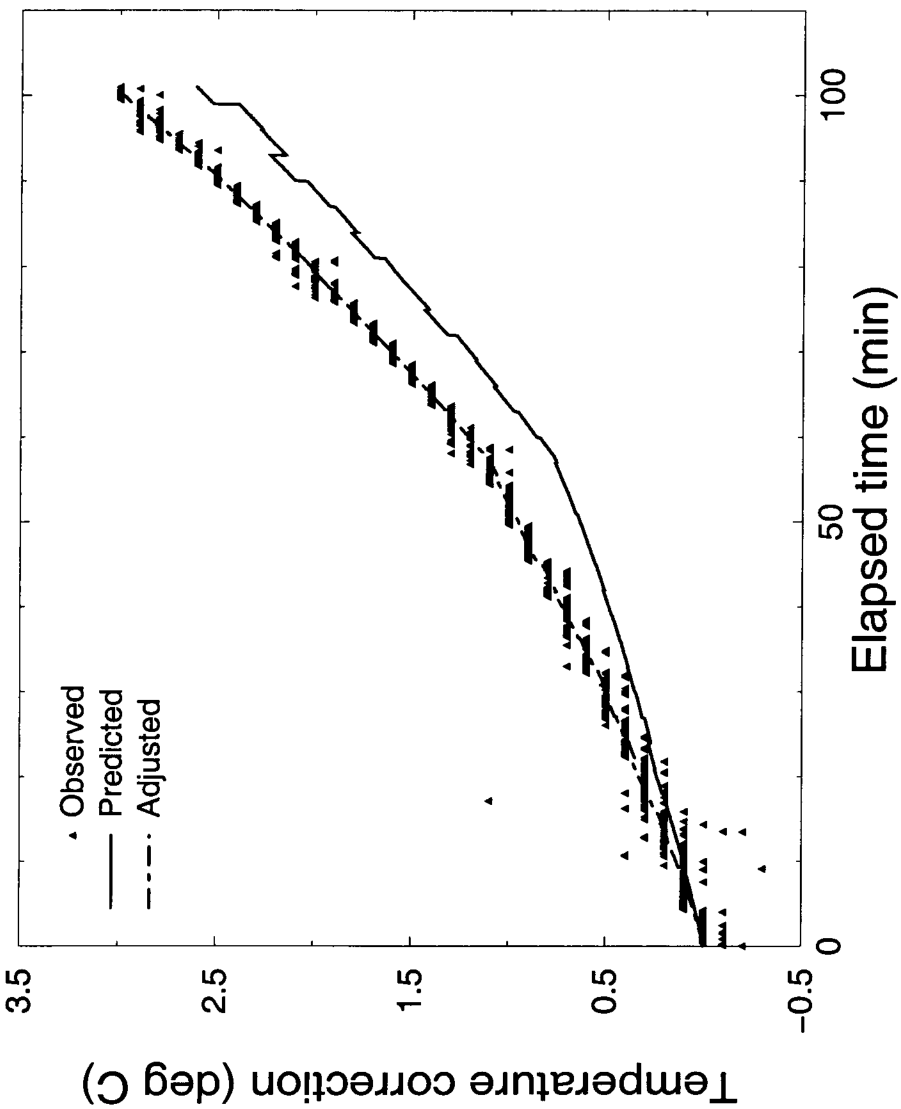

Figure 9: Temperature corrections (°C) versus the reported elapsed time (i.e. time since launch, min) for the simulated flight launched at Sterling, Virginia (39.0N,77.5W) on August 27, 2003 at 11 UTC. Observed corrections are calculated from temperatures reported to a precision of 0.1 °C. The adjusted correction is defined as the predicted correction obtained by multiplying the elapsed time by $\frac{5}{3}$

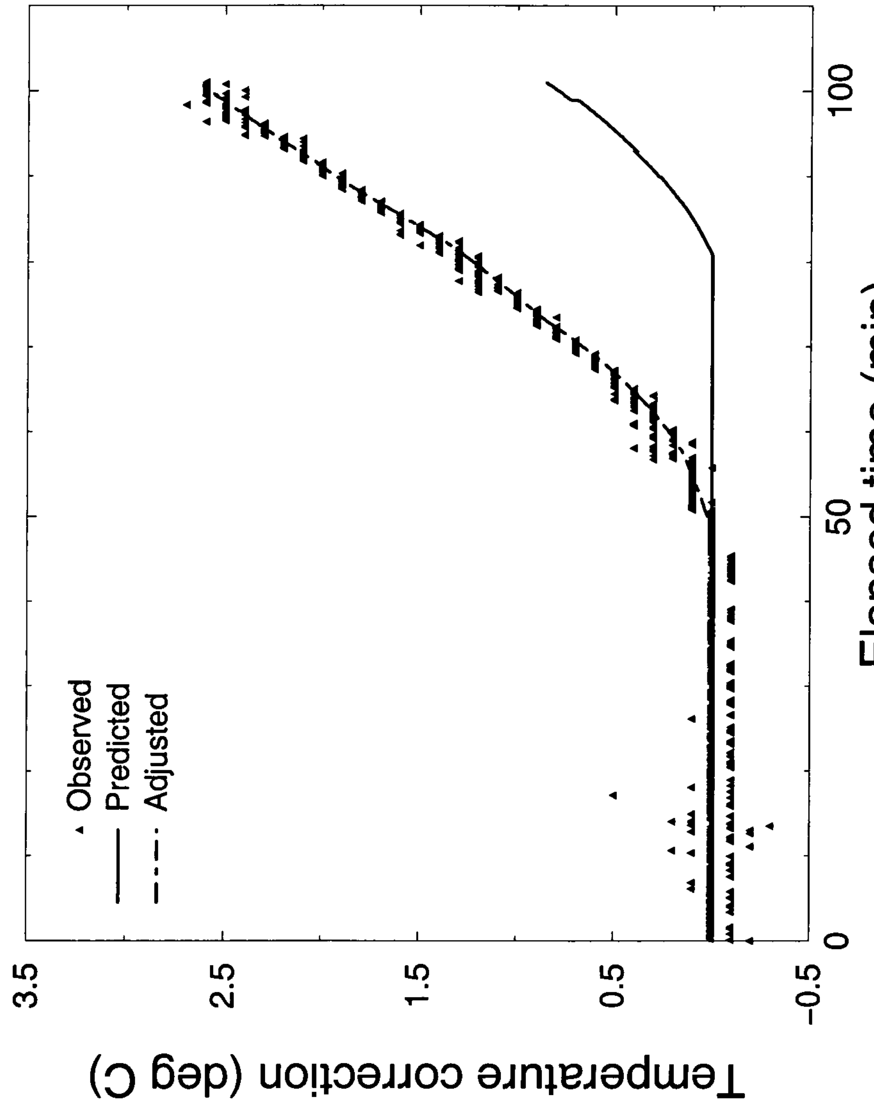

Figure 10: Same as Fig. 9 except that the simulated flight was launched on July 25, 2003 at 8 UTC

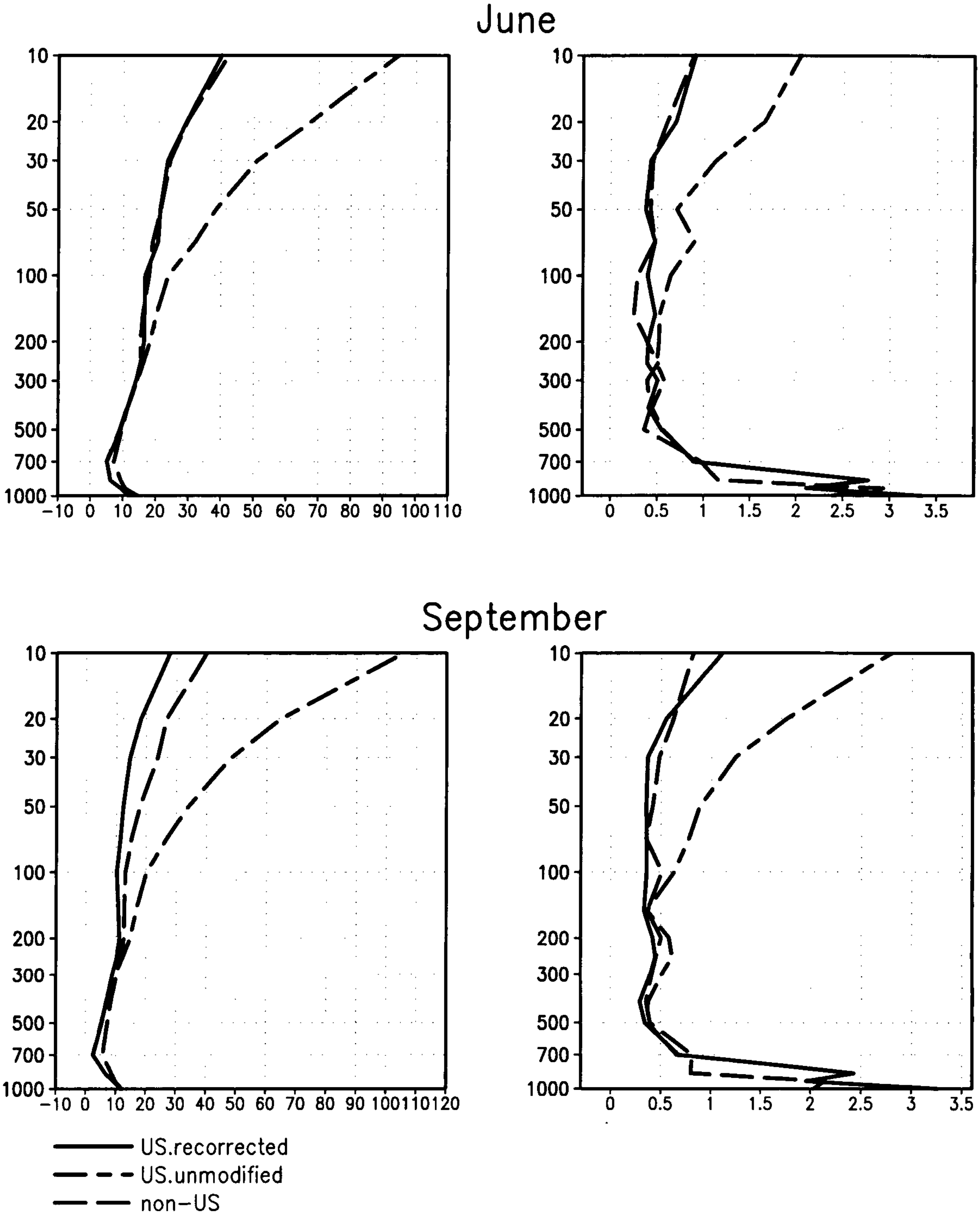

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Figure 12: Mean 00/12 UTC differences, both re-corrected (left panels) and unmodified (right panels), at 50 hPa for September 2001. The top and bottom panels corresponds to temperature (°C) and heights (m). The mean differences were calculated according to (2).

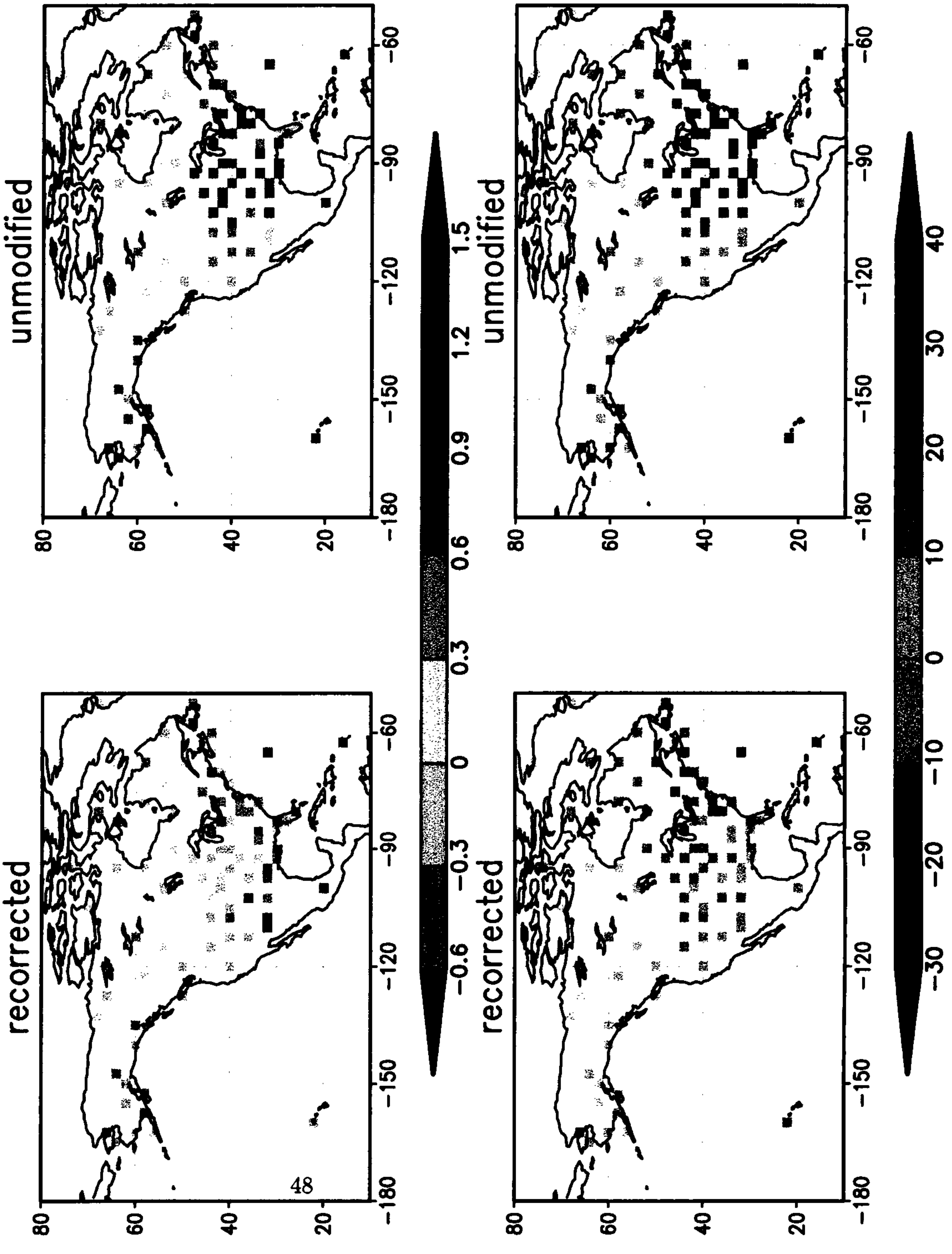


Figure 13: Same as Fig. 12 except at 10 hPa.

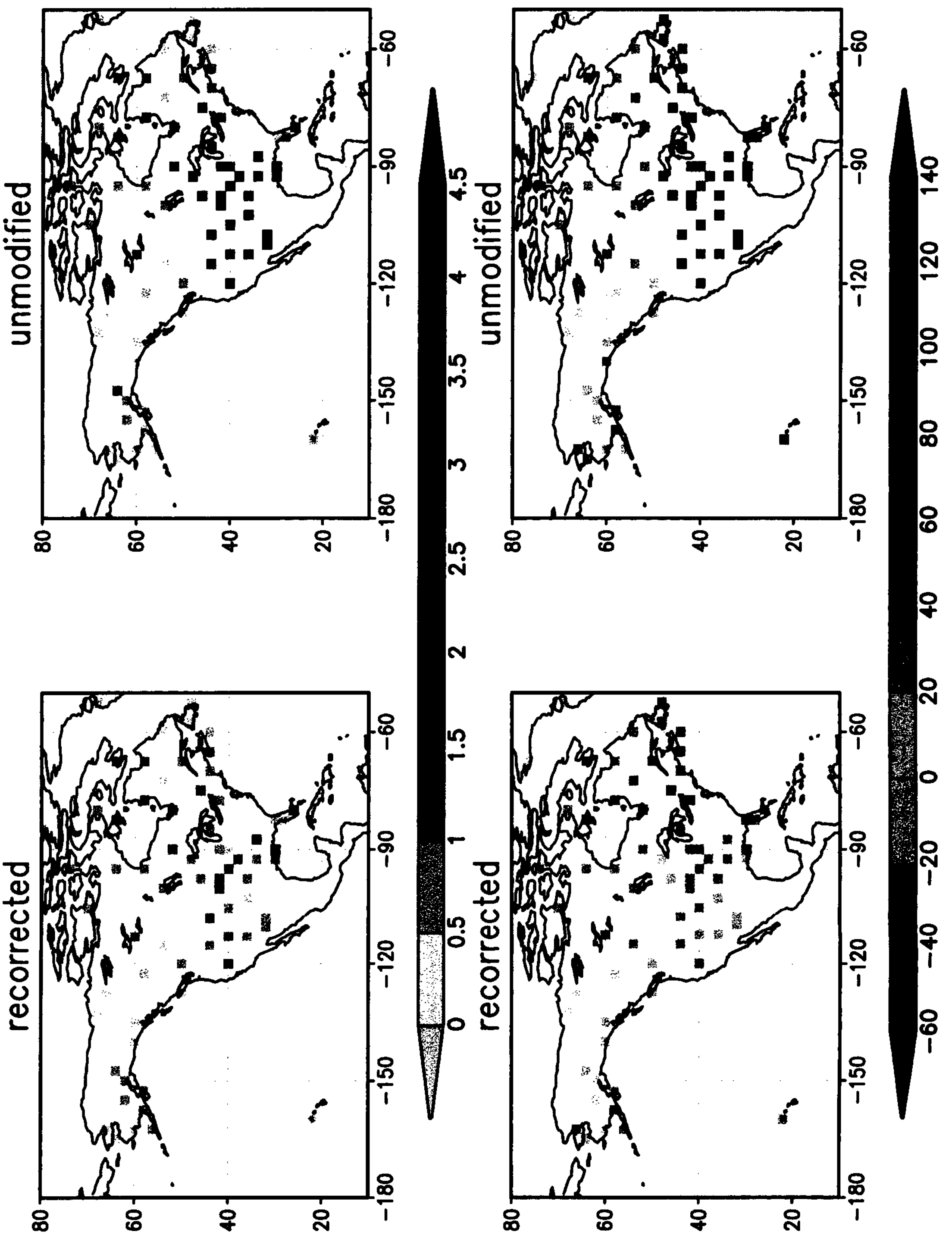
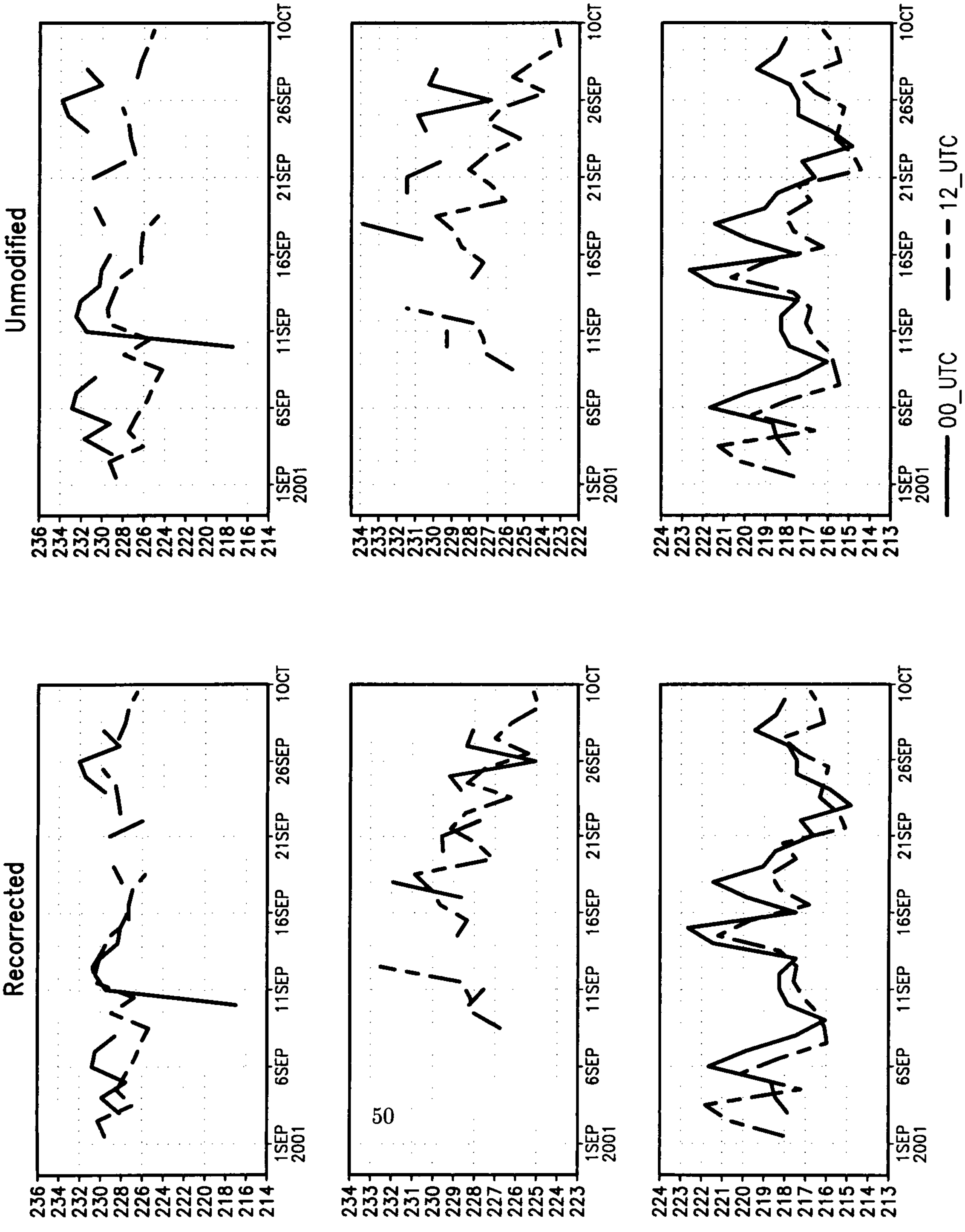


Figure 14: Time series of temperature (K) observations, re-corrected (left panels) and unmodified (right panels), at 00 UTC (solid line) and 12 UTC (dashed line) during September 2001. The top and middle panels correspond to data from Amarillo, Texas and Rapid City, South Dakota at 10 hPa, respectively. The bottom panel corresponds to Greensboro, North Carolina (WMO No. 72317) at 30 hPa.



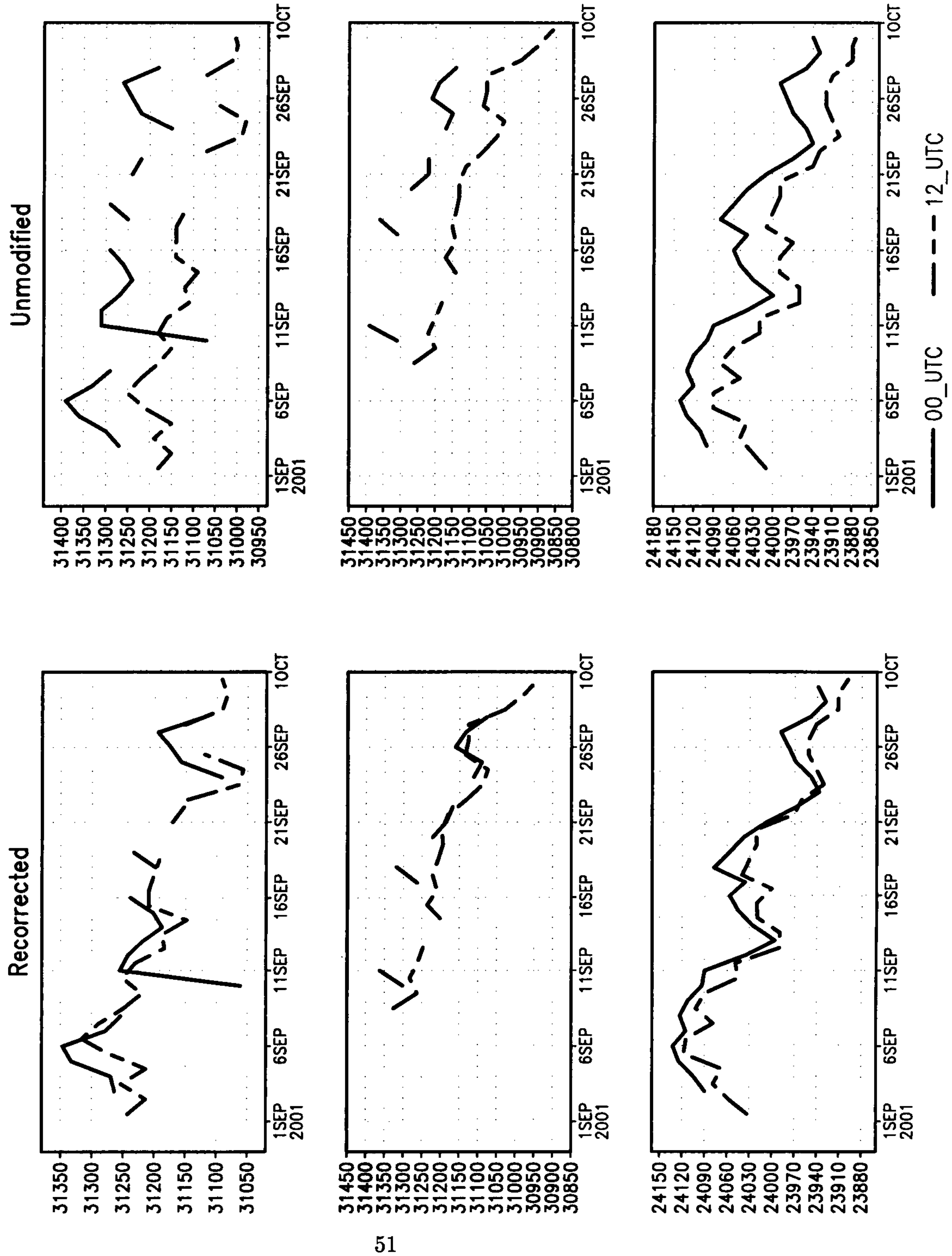


Figure 15: Same as Fig. 14 for height (m) observations.

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2 Temperature corrections (°C) at the fictitious station and with the parameters given in Table ??. The unadjusted ventilation factor is assumed to be 1.1. . . . 52

synoptic hour (UTC)	elapsed time set to ...	
	95 min	158.3 min
0	2.32	-9.80
12	-6.47	5.61

Table 1: Solar elevation angles (°C) at a fictitious station at 40N and 105W on September 31, 2001. The pressure level and the launch time are assumed to be 10 hPa and 58 minutes prior to the synoptic time.

synoptic hour (UTC)	elapsed time set to ...	
	95 min	158.3 min
0	1.80	0.0
12	0.12	2.55

Table 2: Temperature corrections (°C) at the fictitious station and with the parameters given in Table 1. The unadjusted ventilation factor is assumed to be 1.1.