ERA report series


# 8 Radiosonde temperature bias correction in ERA-Interim

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# 1 Introduction

There is increasing evidence that the global radiosonde temperature dataset must be homogenized for reanalysis purposes (Sherwood *et al.*2005; Haimberger *et al.*2008). In ERA-40, radiosonde temperatures have been adjusted using a solar elevation dependent adjustment technique from 1980 onwards, as described in Andrae *et al.*(2004). This scheme, with only few exception, did only adjust the daily/seasonal variation of the biases but not the annual means, mainly because it was considered too risky to rely on background forecasts fields as a reference for changing annual means. Consequently the scheme had little impact on trends from the adjusted radiosonde records.

Therefore, a radiosonde bias correction scheme has been prepared for use in the ERA-Interim reanalysis (Simmons *et al.*2007) that tries to adjust both annual mean and daily/seasonally varying biases. To achieve this goal, two rather different adjustment approaches have been combined. The two approaches have little in common except that they both use archived background departure statistics from ERA-40 and ECWMF operations as basis for calculating the adjustments.

The adjustments of the annual means are provided by tables from RAOBCORE (RAdiosonde OBservation COrrection using REanalyses). The version of the tables used is termed NOBGC in Haimberger (2007) and v1.3 in Haimberger *et al.*(2008). It could be demonstrated that the adjustments lead to an internally much more consistent radiosonde temperature dataset. RAOBCORE detects abrupt shifts in background departure time series of *individual* stations at 00GMT and 12GMT. If the shifts can be attributed to the observations, a temporally constant adjustment is calculated from the means of the background departures before/after a detected break. The diurnal variation of the biases is only partially taken into account through the separate analysis of 00GMT/12GMT time series. However, the annual cycle of the radiation error is not removed, although it can be fairly substantial, especially in polar regions and near 90E/90W. Fig. 2 shows the 12GMT-00GMT temperature difference at radiosonde station Sankt Petersburg (26063). The reason for the seasonal variation is the seasonal variation of the solar elevation at 12GMT which varies between about 40 degrees at the summer solstice to practically zero in December. The strong annual cycle almost disappeared at this site with the introduction of a new temperature sensor in 1999.

The remaining annual cycle of the bias, as well as biases at times between 00GMT and 12GMT can be estimated by the solar elevation dependent adjustment method developed originally for ERA-40 (Andrae *et al.*2004). The scheme assumes that the bg forecasts have a more realistic daily and annual cycle of temperature than most radiosondes. This is only partly true, especially before the first TOVS satellites became operational in 1979. Therefore adjustment tables from this method are available only from 1980 onward. Even in the 1980s and 1990s, there are some regions where the annual cycle of the background forecasts is questionable, particularly at very high latitudes. This has to be considered when interpreting background departures and adjustments in these regions.

In contrast to RAOBCORE, it works with station groups, not individual stations, and the adjustment tables are calculated for each year. Using station groups allows to get better statistics than for individual stations, but requires careful choice of stations. The time interval of one year has been chosen to represent all possible solar elevations in a certain region. Half a year would have possible as well, but this has not been tried since for some groups the samples are relatively small even with one year as interval. When the radiosonde type has changed at some time of the year, it has not been tried to calculate adjustment tables valid for parts of a year. Despite these limitations, the scheme generally reduces spurious annual cycles of the radiosonde temperature biases in a satisfying manner.

The following sections explain details of the combination and show various diagnostics for the unadjusted and various versions of adjusted datasets. Results gained with the solar elevation dependent bias correction only (SE), the RAOBCORE bias correction only (RA) and the combined bias correction (RASE) are compared. It is concluded that the RASE correction generally performs as expected, i.e. it reduces both the annual mean as well as the seasonally dependent radiation error.

## 2 Combination of adjustments

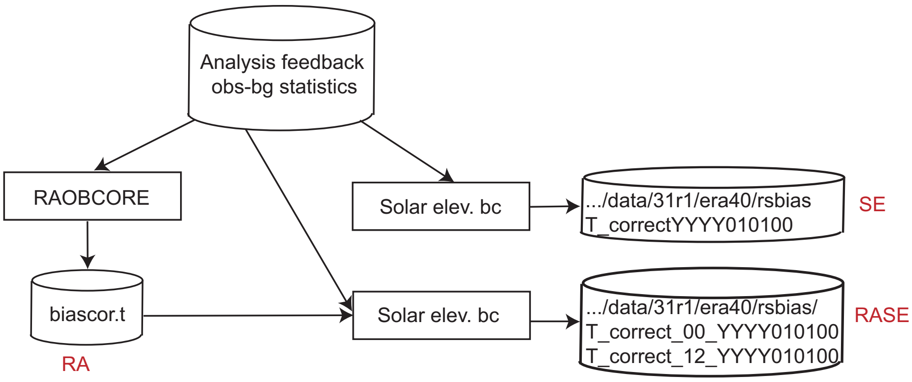


*Figure 1: Bias corrections available within the IFS. RAOBCORE calculates adjustments which are constant in time between breakpoints (RASE). Solar elevation dependent adjustments have been calculated from the raw obs-bg departure statistics (SE) and from obs-bg departures where the obs have been adjusted already with RAOBCORE (RASE).*

As is outlined in Fig. 1 there are three options for temperature bias correction within the IFS interim reanalysis system. All bias corrections are based on evaluation of statistics of temperature departures between radiosonde observations (obs) and background forecasts (bg) from ERA-40 (up to 2000) and from the operational ECMWF analysis system from 2001 onwards. The methodologies for calculating the bias corrections are, however, quite different. The correction labeled *SE* is an update of the bias correction system used in ERA-40. The main improvement compared to ERA-40 is that the one year lag in the bias corrections noted in Andrae *et al.*(2004) has been removed. The adjustments depend on the solar elevation angle and thus time of day and season. The adjustments are calculated for composites of ”similar” stations, typically of the same country and region. Adjustment factors are calculated for each year. The adjustments are zero when averaged over a year and over the composite. Thus they

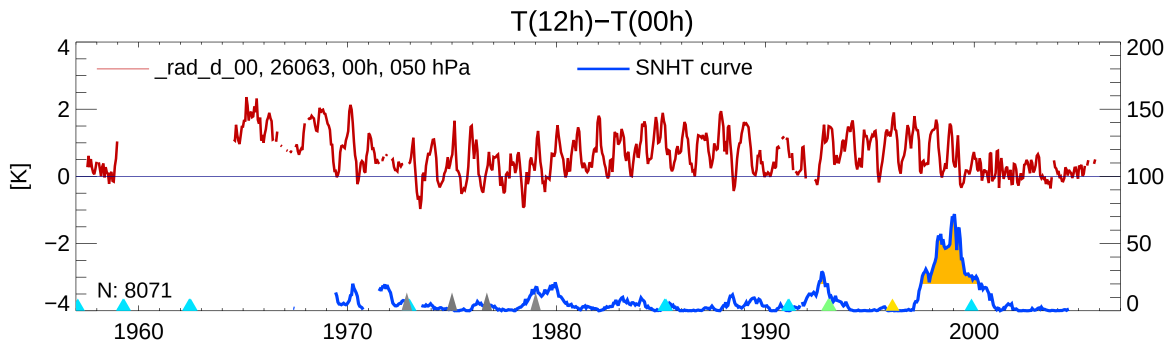


*Figure 2: Unadjusted 12GMT-00GMT T-difference (red) for radiosonde station 26063 (Sankt Petersburg). Blue is SNHT test statistic. Maxima above 25 indicate breaks in the time series. See Haimberger (2007) for details*

do not change composite mean temperature trends. An exception are Alaska and China where also the composite annual mean is allowed to change. The reason is that only the diurnal as well as the seasonal cycle of the bg are considered more realistic than that of radiosonde observations, but not its annual mean.

The RAOBCORE correction (labeled *RA*) is described in Haimberger (2007). The adjustments are calculated for 00GMT and 12GMT time series. 06GMT and 18GMT ascents are not adjusted or are adjusted by interpolation between 00h and 12h adjustments. There is no seasonal dependence of the adjustments. The adjustment factors change at detected breakpoints in the observation time series. The RAOBCORE adjustments have the potential to change temperature trends and also the climatology of the time series may change due to the adjustments.

The combined correction (labeled *RASE*) consists of the RAOBCORE correction and of solar elevation dependent adjustments that have been calculated from departure statistics between the *RAOBCORE-adjusted* observations and the bg. Since the daily cycle is partially taken into account in RAOBCORE due to the separate adjustment of 00GMT and 12GMT ascents, the solar elevation dependent adjustments are typically much smaller than in SE. They have been calculated for 00GMT and 12GMT ascents separately as well and are *neutral when averaged over a station group and over a year*. The station groups have been changed slightly compared to Andrae et al. (2004) especially over the US such that station groups do not cross 90W. This has been necessary to avoid over/undercorrection at station groups spanning a large longitude range.

Tables for the combined adjustments have been calculated from 1988 onwards. Since the solar elevation dependent adjustments are calculated for 00GMT and 12GMT separately, there are two tables per year. Their place can be found in Appendix A. For assimilation experiments with newer cycles, they need to be copied into the corresponding directories, e.g. 35r3 instead of 31r1.

# 3 Results

## 3.1 Adjustment results for selected time series

In general the performance of the combined adjustment system is satisfying. An example is Sankt Petersburg (station 26063). This station had a moderate day-night difference bias with a pronounced seasonal cycle before 1999 (see Fig. 2). After 1999, Vaisala RS80 temperature sensors have been used at this Russian stations, which had considerably less radiation errors. Fig. 3 shows the adjustment amounts suggested by RAOBCORE. The changes in the annual mean are detected and adjusted. However, the large seasonal variations of the bias at this station located at 60N remain. The variations are strongly damped by the solar elevation dependent adjustment procedure applied on top of RAOBCORE. The effect of the combined adjustment is shown in Fig. 4.

A comparison between the RAOBCORE-adjusted time series (Fig. 5) and the RASE-adjusted time series (Fig. 6) shows that RASE performs best between 1988 and 2000 in this case since it substantially reduces both the inhomogeneities and the seasonal variation of the error. In the 2000s, however, the day-night differences of the adjusted time series are larger than those of the unadjusted time series. The reason is that in the station group where station 26063 belongs to, a few Sondes with Vaisala RS80 temperature sensors are mixed with several MARS sondes. It is likely that the sondes with Vaisala RS80 sensor are overcorrected since the MARS sondes have larger daytime biases and thus the average daytime adjustment is large 4. This example shows that the station groups need to be carefully designed to avoid

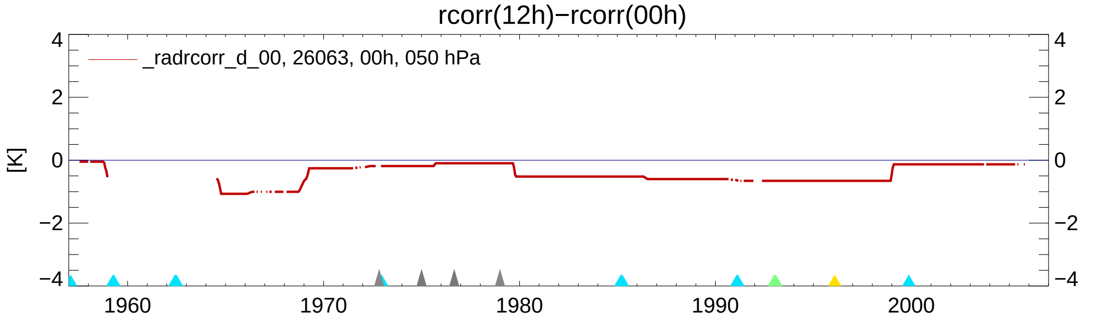


*Figure 3: Effect of RAOBCORE adjustment on 12GMT-00GMT difference at Sankt Petersburg*

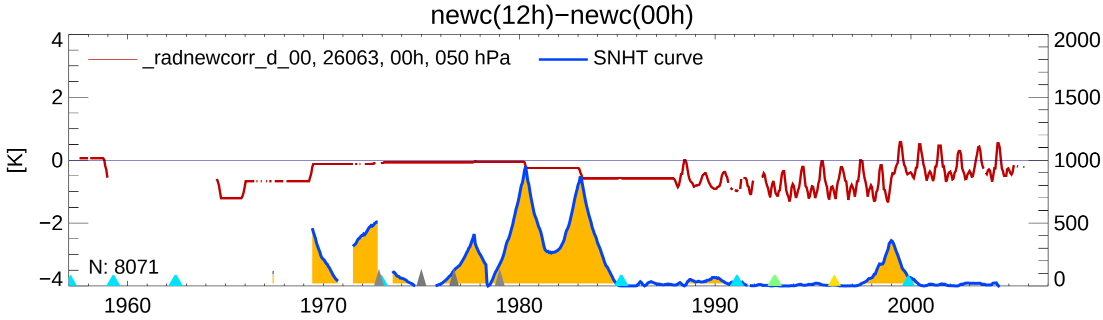


*Figure 4: Effect of both RAOBCORE and solar elevation dependent adjustment (=RASE) on 12GMT-00GMT difference at Sankt Petersburg. Solar elevation dependent adjustment was available for period 1988-2000*

averaging over different sonde types.

The second example is the station composite for Alaska. First the obs-bg differences for daytime (00GMT) ascents are examined (Fig. 7). The time series exhibits substantial breaks in 1989 and 1995 and also a very large seasonal variation of the obs-bg differences. The RAOBCORE adjustment reduces the inhomogeneities in the mean but not the annual cycle (Fig. 8). The combined adjustment (Fig. 9) substantially reduces the seasonal variation of the obs-bg difference.

Since the bg may be erroneous itself, the time series for 12GMT-00GMT differences over Alaska are shown as well. The 12GMT-00GMT composite difference time series in Fig. 10 again shows nicely the variations of the radiation error. The VIZ sondes in use all over Alaska had a strong radiation error with a seasonal amplitude of about 1 K. After 1989 several stations switched to rather biased Space Data

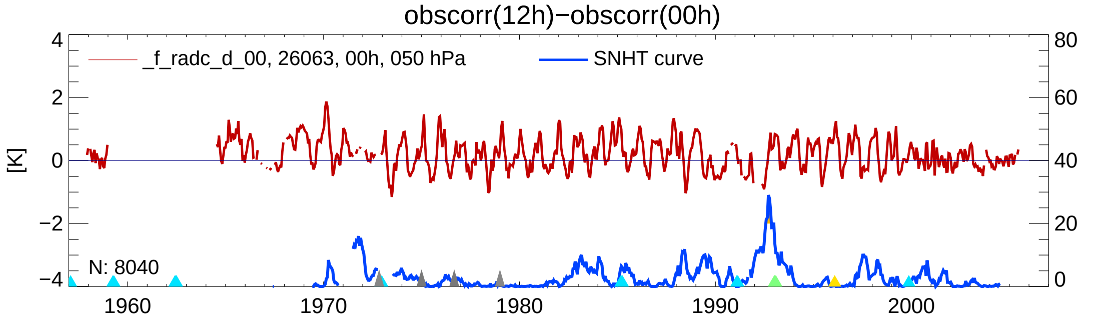


*Figure 5: 12GMT-00GMT difference at Sankt Petersburg after application of RAOBCORE adjustment*

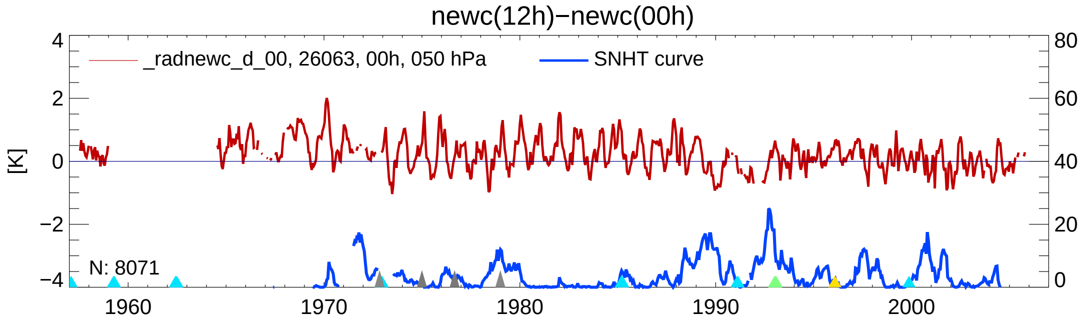


*Figure 6: 12GMT-00GMT difference at St. Petersburg after RASE adjustment. The seasonal variation of the 12GMT-00GMT difference is clearly reduced between 1988 and 2000.*

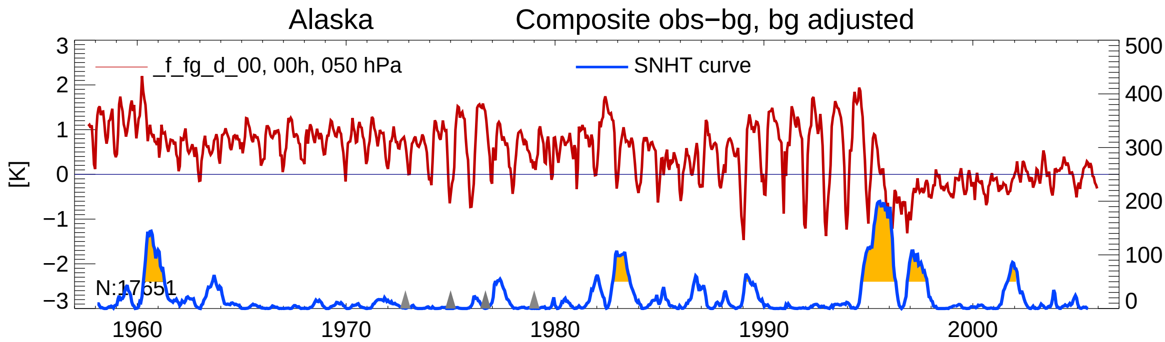


*Figure 7: Obs-bg for Alaskan composite in 50 hPa at 00GMT. Change from VIZ to Space Data in 1989, change from Space Data to Vaisala in 1995 at many but not all Alaskan stations.*

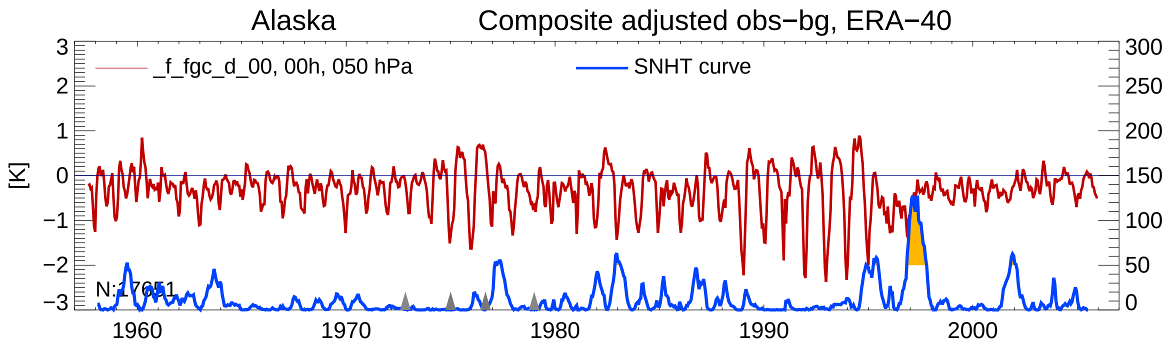


*Figure 8: Bg-obs adjusted with RAOBCORE for Alaskan composite in 50 hPa at 00GMT*

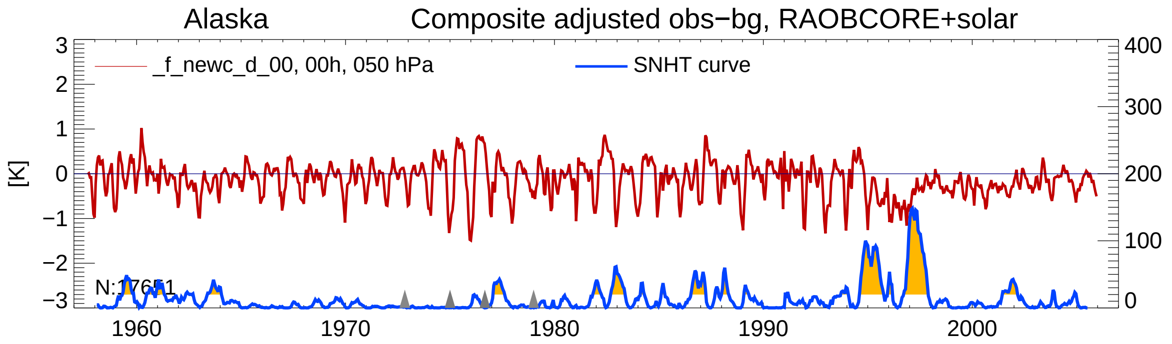


*Figure 9: Bg-obs adjusted with combined RASE method for Alaskan composite in 50 hPa at 00GMT. Note reduced annual cycle between 1989,1995*

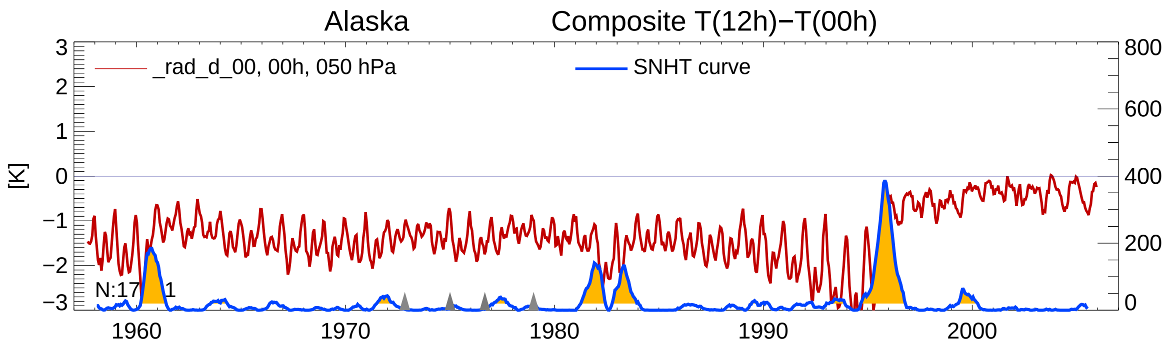


*Figure 10: 12GMT-00GMT T-difference of composite of unadjusted radiosondes over Alaska.*

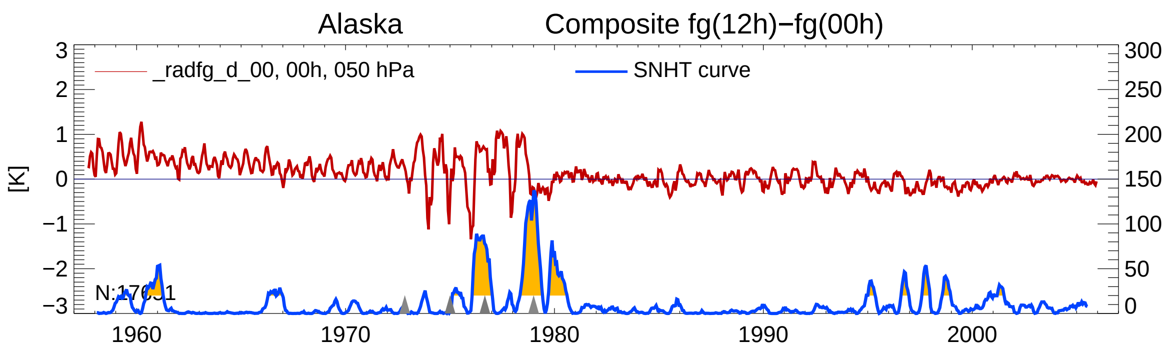


*Figure 11: Composite mean 12GMT-00GMT* bg *temperature difference over Alaska. This is shown for reference to understand adjustment values applied to Alaska. Note large spurious cycle of 12GMT-00GMT bg difference during VTPR period and bias of 12GMT-00GMT bg difference in the pre-satellite era compared to satellite era (1979-)*

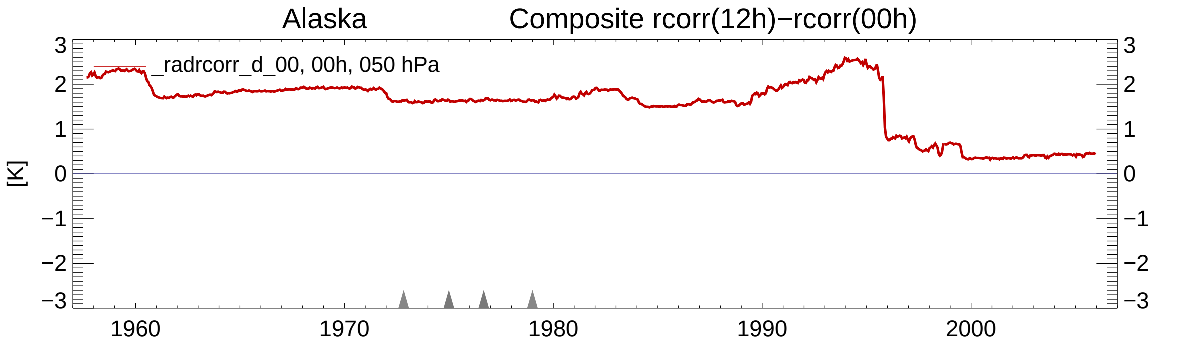


*Figure 12: 12GMT-00GMT composite mean effect of RAOBCORE adjustments on 12GMT-00GMT temperature difference over Alaska*

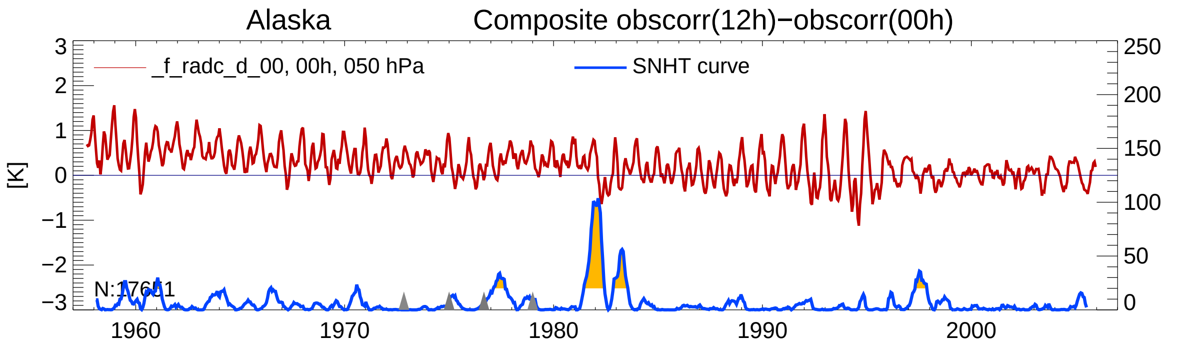


*Figure 13: 12GMT-00GMT difference after application of RAOBCORE adjustment. There is no annual mean overcorrection from 1989-1994, but a strong annual cycle compared to Fig. 16.*

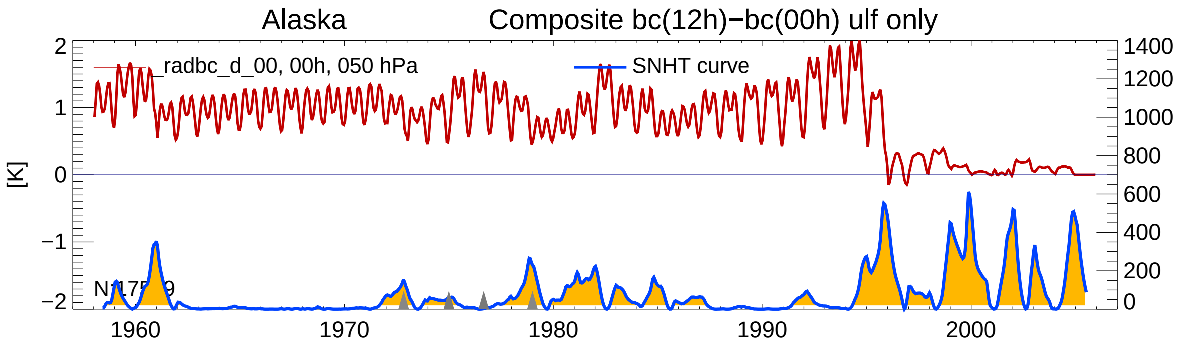


*Figure 14: Adjustment of 12GMT-00GMT difference suggested by pure solar elevation dependent (SE) adjustment.*

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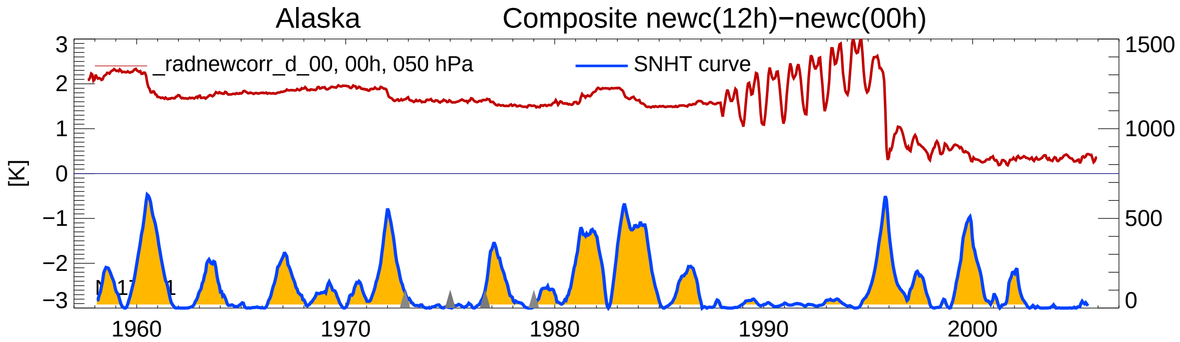


*Figure 15: 12GMT-00GMT composite mean effect of RAOBCORE plus solar elevation dependent adjustments on 12GMT-00GMT temperature difference over Alaska*

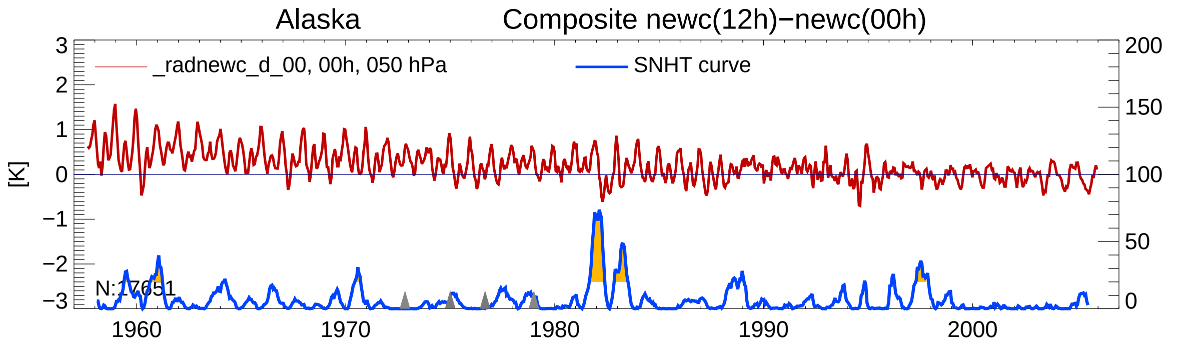


*Figure 16: 12GMT-00GMT difference for Alaskan composite after application of both RAOBCORE plus solar elevation dependent adjustment (RASE), which is recommended for ERA-Interim.*

radiosondes which were replaced by Vaisala RS80 radiosondes in 1995. Some stations kept the VIZ sondes. After 1995 the 12GMT-00GMT difference was quite small.

Fig. 11 shows the 12GMT-00GMT difference of the *background*, which is considered trustworthy in RASE. One can see that it is indeed quite small and stable back to 1979, the beginning of the TOVS era. Before 1979 there are significant problems with the bg mainly because of suboptimal handling of VTPR radiances. In view of these problems, the solar elevation dependent adjustment cannot be recommended at all for the VTPR period and also for the early years the seasonal cycle of the 12GMT-00GMT differences of the bg is quite different from that in the TOVS era (1979-). The positive bias in the early years is probably the result of the large negative 12GMT-00GMT differences from radiosonde measurements which lead to biases of opposite sign of the forecast temperatures 12 hours later, simply because there is no independent information to correct for that.

Fig. 12 shows that RAOBCORE changes the composite mean 12GMT-00GMT differences from these differently equipped radiosonde stations quite substantially. The change appears more gradual than at Sp. Petersburg since the radiosonde changes have not taken place at the same time over Alaska. The strong seasonal variability remains, however, as can be seen from the RAOBCORE-adjusted timeseries 13. The pure solar elevation dependent adjustment shown in Fig. 14 is too weak. It removes only part of the mean error.

The effect of the combined adjustment is shown in Figs. 15 and 16. The remaining radiation seasonally varying bias is again reduced compared to the RAOBCORE-adjusted time series.

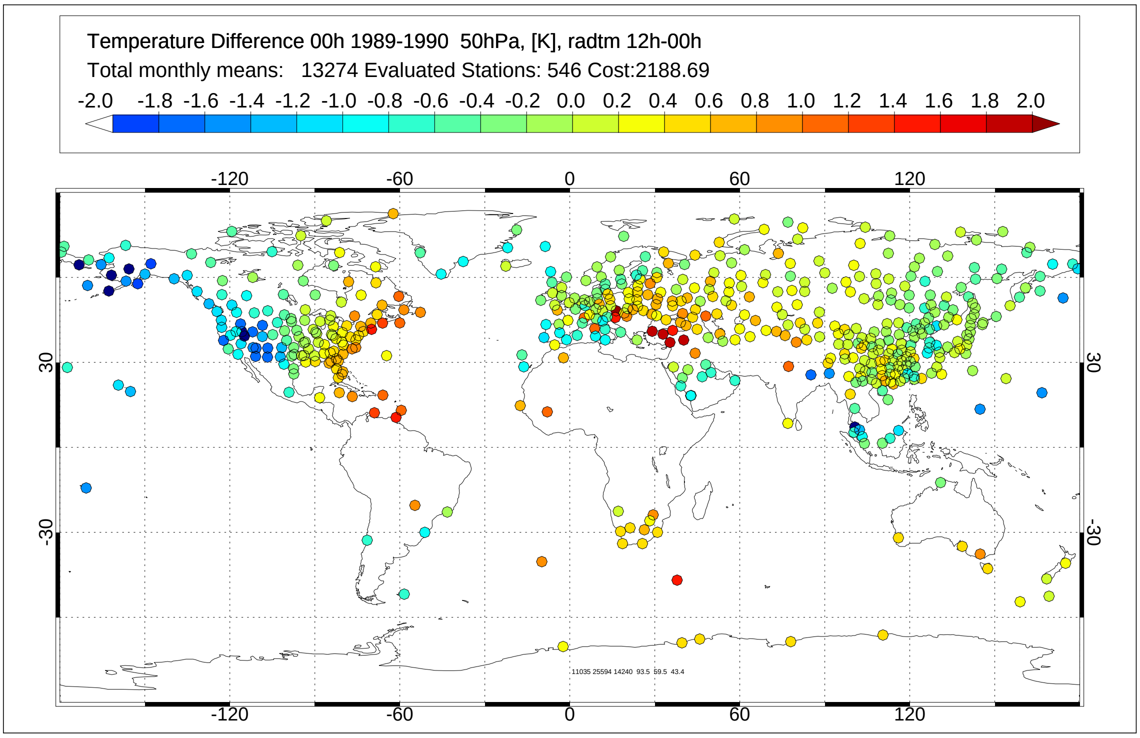


*Figure 17: Map of unadjusted 12GMT-00GMT temperature differences at 50 hPa averaged over 1989-90*

### 3.2 Spatial consistency of bias-corrected radiosonde temperatures

Fig. 17 shows the unadjusted 12GMT-00GMT differences averaged over 1989-1990. There are substantial radiation errors over Alaska, the US, Russia and some other areas. As has been discussed in Haimberger (2007) the spatial heterogeneities and unrealistically large values of the differences are substantially removed by RAOBCORE (Fig. 18). The solar elevation dependent adjustment (SE) removes only part of the heterogeneities (Fig. 19).

The combined RASE adjustment performs shown in Fig. 20 as good as the pure RAOBCORE adjustment in terms of spatial annually averaged homogeneity (Fig. 18). In terms of temperature trends the improvement in spatial consistency for the period 1989-2004 is evident from Fig. 21. A large number of detailed plots for individual stations as well as of global maps can be found at http://www.univie.ac.at/theoret-met/RAOBCORE.

## 4 Impact on departure statistics and analyses in ERA-Interim 1989

To assess the performance of the bias correction on the resulting reanalysis products, an assimilation experiment (1166) has been performed over the whole year 1989 and the analysis fields and departure statistics have been compared with the reference experiment 1151, which is part of the official experiment number 1 ERA-Interim record.

Fig. 22 shows that using the bias correction has a systematic effect on the analysis. Fig. 23, taken from the routine obstat output, reveals smaller biases and rms differences if the RASE bias correction is used, especially in the tropics.

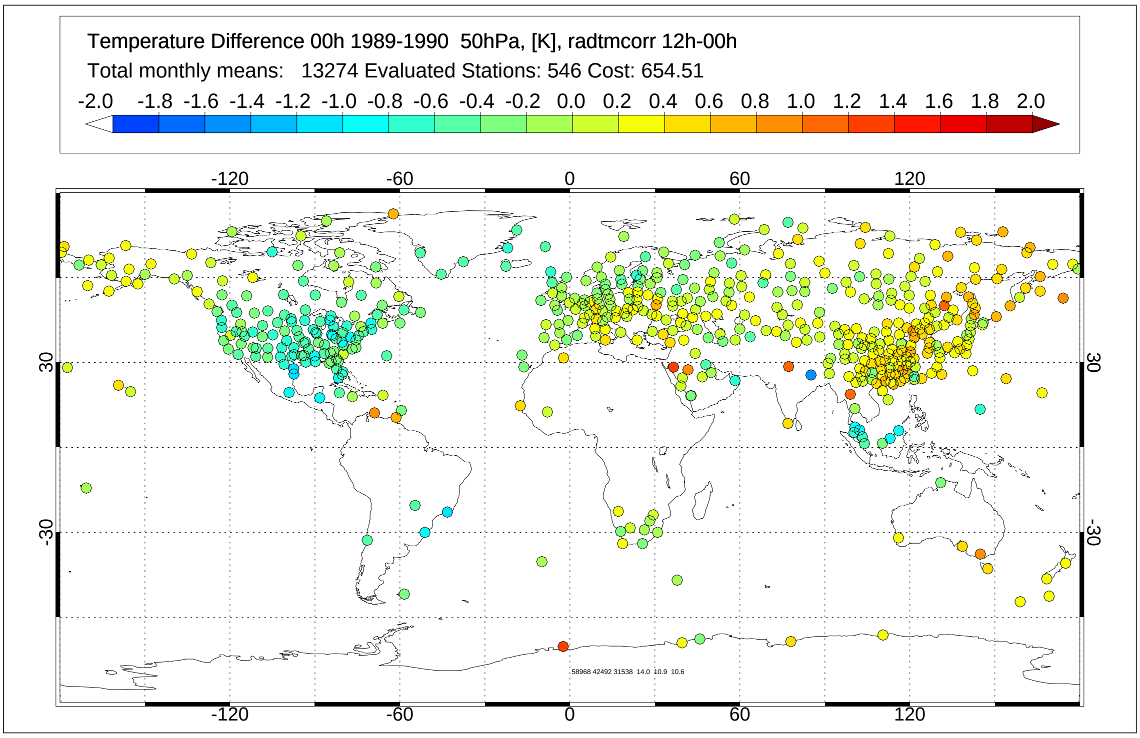


*Figure 18: Map of RAOBCORE-adjusted 12GMT-00GMT temperatore differences at 50 hPa averaged over 1989-90. Note improved spatial consistency of trends, especially over the U.S., China and the Western Pacific.*

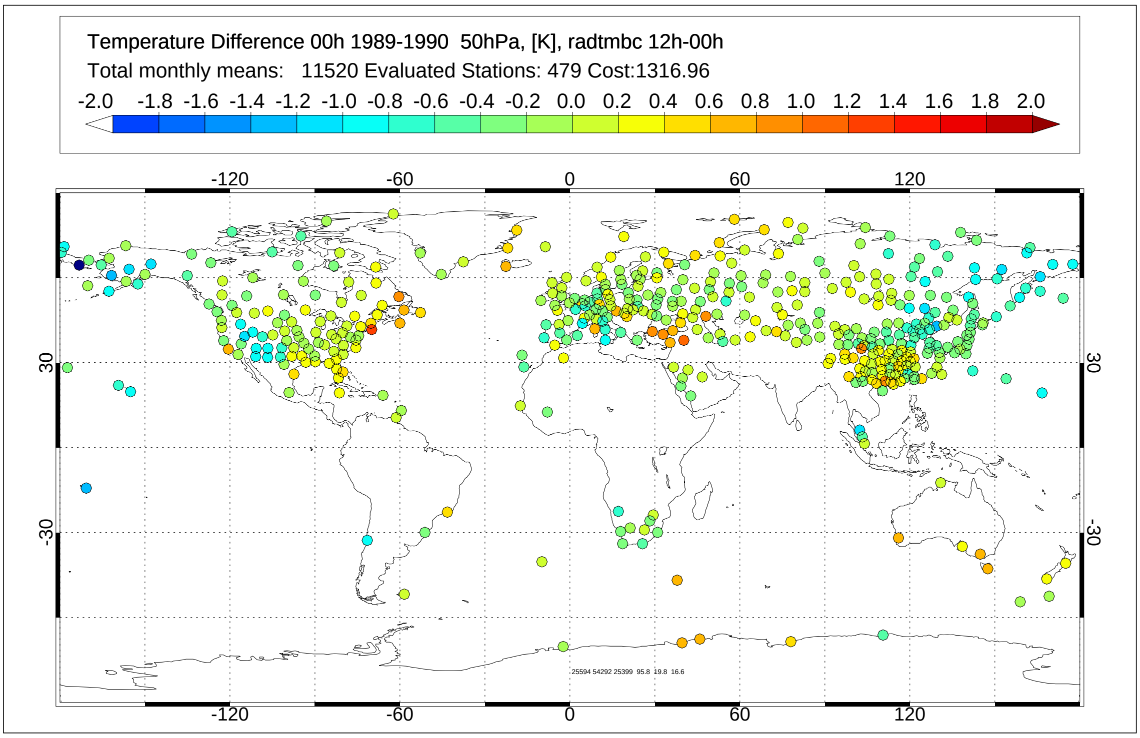


*Figure 19: Map of 12GMT-00GMT differences at 50 hPa with solar elevation dependent adjustment only. The inconsistencies over U.S., Alaska are only partly removed.*

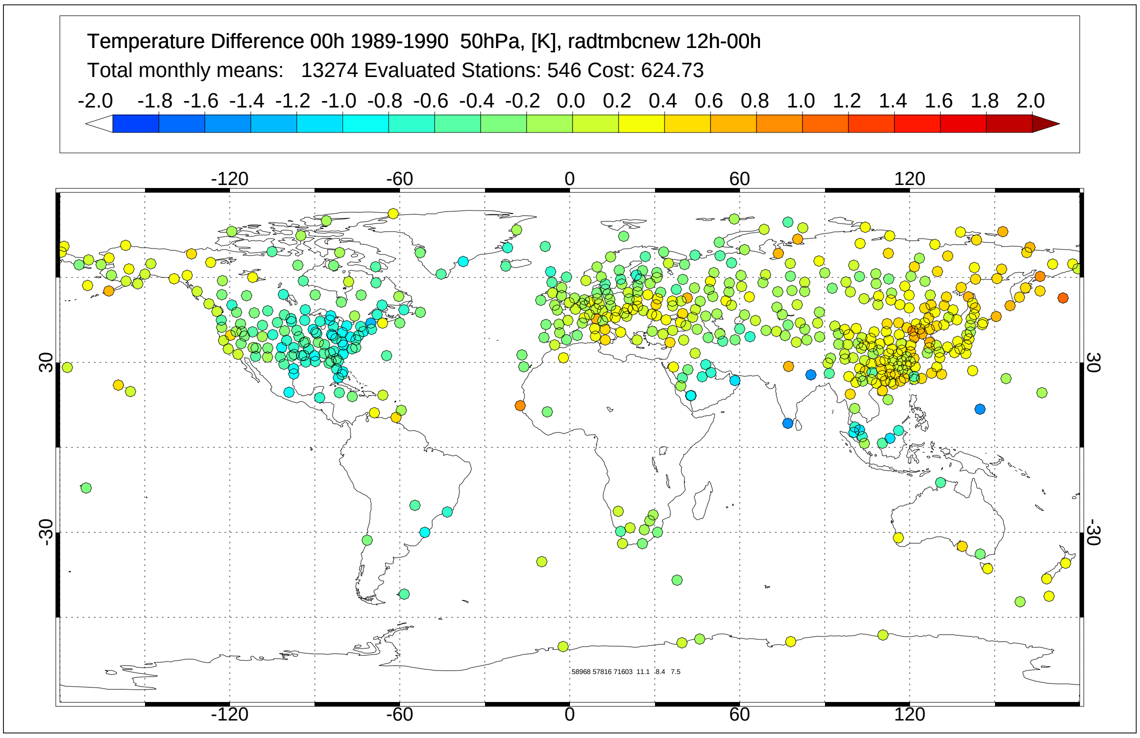


*Figure 20: Map of 12GMT-00GMT differences at 50 hPa, adjusted with combined RAOBCORE plus solar elevation dependent RASE correction.*

The mean effect of the adjustments, which are in most cases toward lower temperatures, is largest in the 1989 and the early 1990s due to the then larger radiosonde temperature biases and goes towards zero in 2009, when the RAOBCORE adjustments are no longer considered valid. From 2009 onward, only the solar elevation dependent adjustment scheme is active. Due to improved radiosonde and satellite observations, also the solar elevation dependent adjustments have become substantially smaller over time.

## 5 Conclusions

The combined RASE adjustment has been adopted for ERA-Interim in 2006 and its overall effect has been as expected, both on departure statistics and trends, with the notable exception of very high latitudes in the Antarctic where the RAOBCORE temperature adjustments were affected by shifts in the ERA-40 background.

Whereas RAOBCORE adjustments are available back to 1958, the RASE adjustments are recommended only back to 1979. Before then, the solar elevation dependent bias correction is considered unreliable since the diurnal cycle of the ERA-40 background is unreliable. There are, however, also issues with RAOBCORE-adjustments in the mid-troposphere prior to 1992 that need attention. They are larger than would be suggested by adjustments based on comparison with neighboring radiosondes Haimberger *et al.*(2008).

Revised radiosonde bias corrections that go further back in time will be required for satisfactory performance of a multi-decadal European reanalysis that is planned in the near- and mid term.

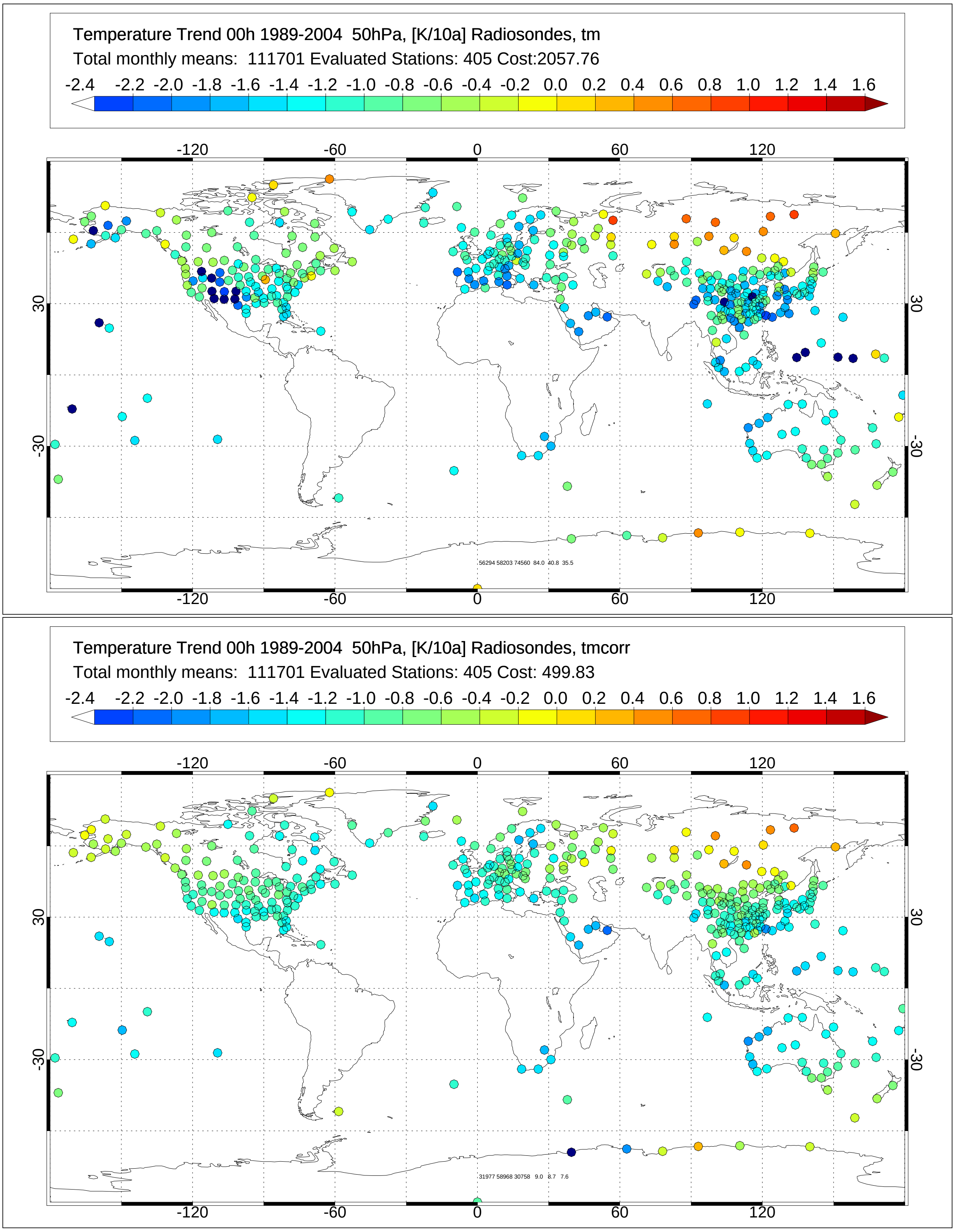


*Figure 21: Map of temperature trends 1989-2004 at the 50 hPa level, a) before, b) after RASE adjustment. Note improved spatial consistency of trends, especially over the U.S., China and the Western Pacific.*

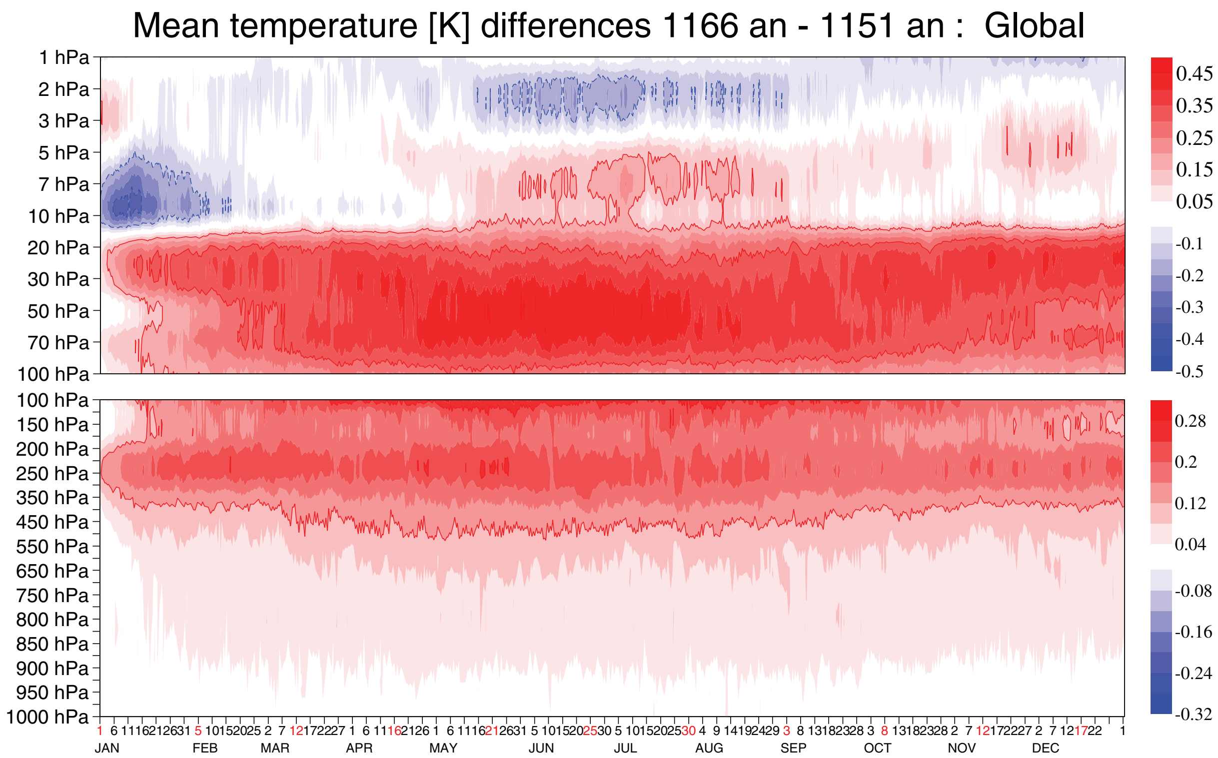


*Figure 22: Standard Temperature Departure statics between ERA-Interim experiments 1166 (no radiosonde bias correction) and 1151 (using the biascorrection described in this document)*

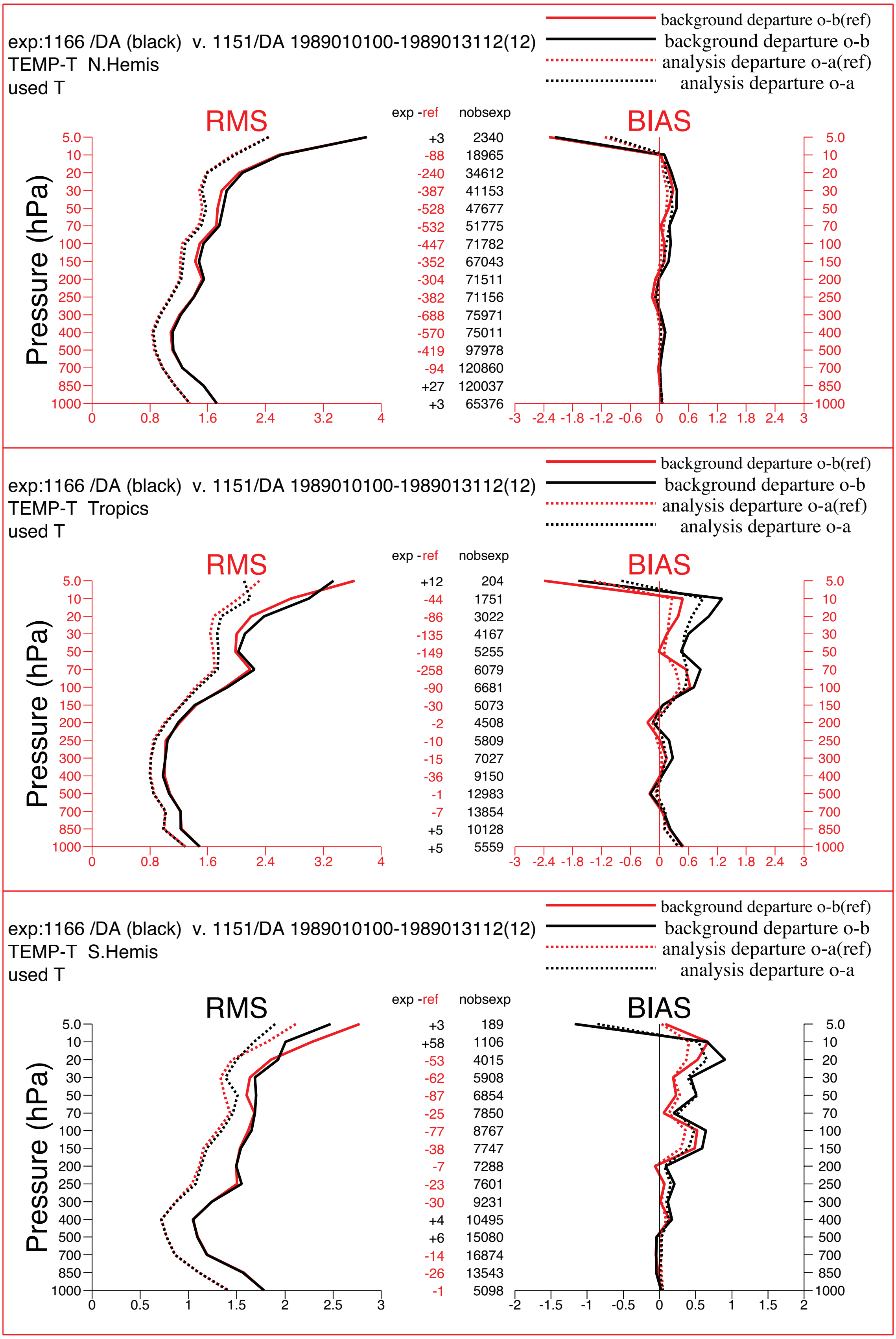


*Figure 23: Standard Temperature Departure statics between ERA-Interim experiments 1166 (no radiosonde bias correction) and 1151 (using the biascorrection described in this document)*

**APPENDIX**

## A Using the combined adjustment within the ERA-Interim

This is a rudimentary description of tables and flags needed for using the three different version of radiosonde bias corrections for ERA-Interim.

The RAOBCORE adjustments for the ERA-Interim are read by the IFS from
`/home/rd/rdx/data/31r1/era40/rsbias/biascor.t`
This table can be downloaded from http://www.univie.ac.at/theoret-met/research/RAOBCORE and updates will be available from this web site as well. Adjustments are available from 1958-2005. The software is installed at the Department of Meteorology, University of Vienna and is maintained by Leopold Haimberger.

The split solar elevation dependent tables for the RASE adjustment are read by the IFS from
`/home/rd/rdx/data/31r1/era40/rsbias/T_correct_00_YYYY010100`
`/home/rd/rdx/data/31r1/era40/rsbias/T_correct_12_YYYY010100`
and are available for the period 1988-2008.

The solar elevation dependent tables for the SE adjustment only are read by the IFS from
`/home/rd/rdx/data/31r1/era40/rsbias_solaronly/T_correct_YYYY010100`
and are available for the period 1988-2008.

All solar elevation dependent tables are calculated by a program package at ECMWF that is maintained by Ulf Andrae (SMHI).

From there the tables may be read into an ODB database (Maintainer of the database: Drasko Vasiljevic). To use the ODB bias tables, the switch LRSTBIAS_ODB must be set to true. At the time of writing, the tables are read directly, however. The actual bias corrections for the individual radiosonde records are calculated in the IFS routine `biascor_era40.F90`.

In order to use the adjustments, the following switches must be set in PrepIFS:

- No adjustment: RSTBIAS=false
- SE adjustment (the default): RSTBIAS=true; RSTBIAS_SE=true ; RSTBIAS_TS=false
- RAOBCORE adjustment: RSTBIAS=true; RSTBIAS_SE=false ; RSTBIAS_TS=true
- RASE-adjustment: RSTBIAS=true; RSTBIAS_SE=true ; RSTBIAS_TS=true

In the logfile of the IFS script uptraj0 one can verify which table entries have been read for a given station.

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