Homogenization of the global radiosonde temperature and wind dataset using innovation statistics from reanalyses

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Radiosonde temperature and wind data have been the backbone of the global upper air observing system at least until the 1990s. However, shifts in the raw radiosonde records due to changes in observing practice limit their use for climate analysis or as input in reanalyses.

During the past four years an automatic homogenization method (RAdiosonde OBservation COrrection using REanalyses, RAOBCORE, Haimberger 2007a, current version is 1.4) for the global radiosonde dataset has been developed. RAOBCORE analyzes time series of differences between observations and ERA-40 and the operational ECMWF background (BG) forecasts. These differences are called innovations and are used for detection and adjustment of inhomogeneities in temperature and wind. The ERA-40 background is therefore used as reference for homogenization.

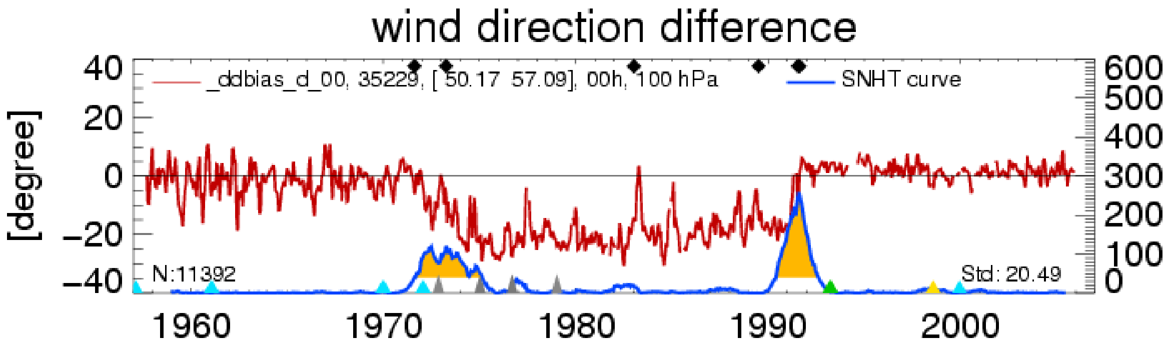

Fig. 1: Time series of 100 hPa wind direction innovations (obs-ERA-40 up to 2000, obs-ECMWF operational model from 2001 onwards, red curve) at Russian station Aktjubinsk and test statistic of Standard Normal Homogeneity Test (blue curve, right axis, values above 20 significant). Breaks are caused by erroneous north alignment of station between 1973 and 1991.

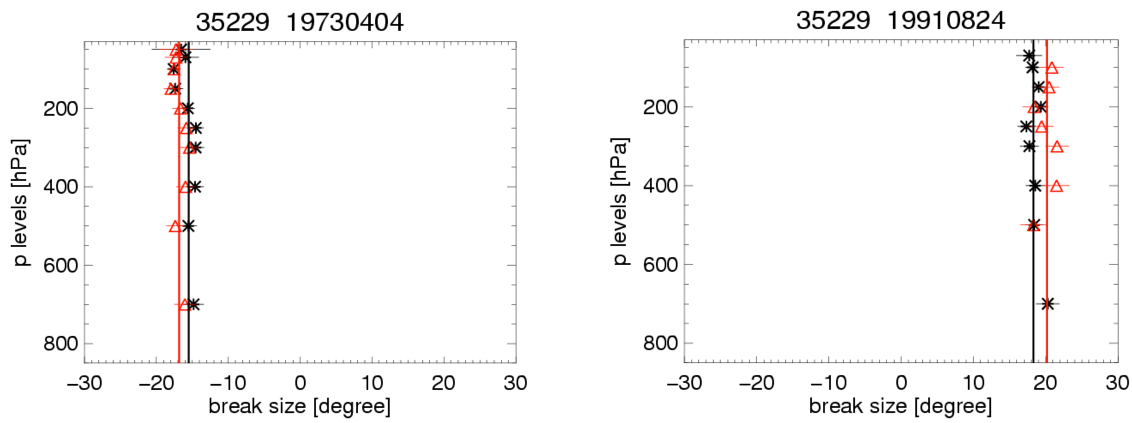

Fig. 2: Vertical profiles of break estimates in wind direction at breakpoints in 1973, 1991 detected in Fig. 1. Black: 00GMT, Red: 12GMT, Symbols: Values at individual levels, Lines: vertical averages.

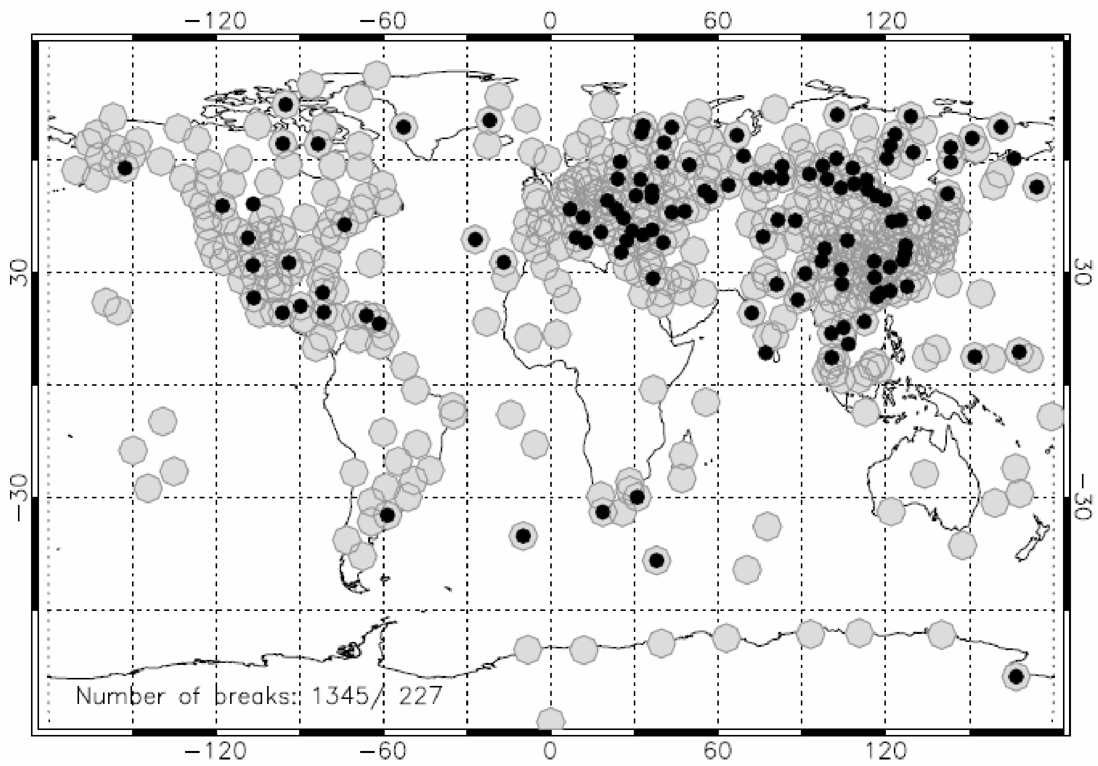

Fig. 3: Map of radiosonde stations with detected wind inhomogeneities during period 1958-2001. Black: Stations with breaks in north alignment, Grey: Stations with breaks in other wind parameters, e.g. wind speed. From Gruber and Haimberger (2008)

Recently we have also tried to homogenize the global radiosonde wind dataset (see Gruber and Haimberger, 2008 for details). Figs. 1 and 2 illustrate an example of breaks in observed radiosonde wind data. The direction bias estimate shown in Fig. 2 is vertically constant, which indicates that the shifts are caused due to changes in the station north alignment. More than 200 cases of stations north alignment shifts of at least 3 degrees could be detected and adjusted during the period 1958-2001. Breaks in *u*,*v* or wind speed could be also detected (in more than 1000 cases, see Fig. 3) and adjusted. There are only few indications of inhomogeneities in the ERA-40 background wind, so that we have much confidence in the wind homogenization. Despite the relatively large number of breaks, no systematic effect of the adjustments on the global mean wind climatology could be detected so far. Wind direction errors seem a good candidate for online bias estimation since vertically constant systematic forecast model errors in wind direction are unlikely.

When applied to temperature, RAOBCORE leads to improved spatiotemporal consistency of the homogenized observations, but care is needed during some periods when the homogeneity of the background forecast time series is questionable, especially around 1975, in the early 1980s and 1986. Nevertheless large and pervasive biases in the radiosonde temperature dataset, especially before the mid-1990s, could be safely detected and adjusted. Comparisons with MSU-derived layer mean temperature records also show the robustness of the method (Haimberger et al, 2008). The MSU-4 and MSU-3 equivalent anomaly difference time series of station Yap (91413) in Fig. 4 are an example. They show a large break at the end of 1995 caused by a change from VIZ-B to Vaisala RS80. RAOBCORE v1.4 adjusted time series shows good agreement with ERA-40 bg and satellite time series. In order to eliminate the formal dependency of the break size estimation on the ERA-40 background, a neighbor intercomparison method (RICH = Radiosonde innovation composite homogenization, see HTS08) has also been implemented.

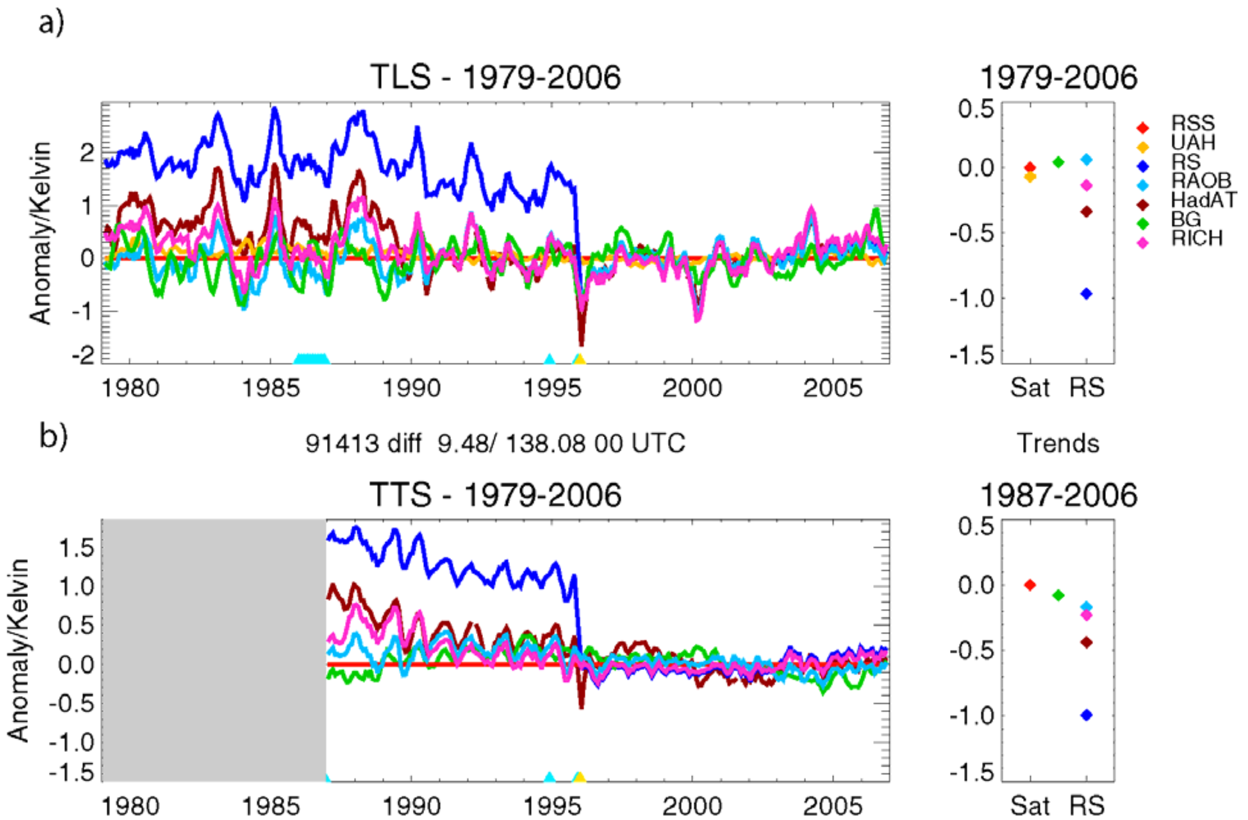

Fig. 4: Time series of monthly mean 00GMT temperature *anomaly differences* with respect to RSS MSU satellite data, a) for the LS (MSU4) and b) for the TS (MSU3) layer at station Yap (91413, tropical west Pacific). Differences are: RAOBCORE-RSS (light blue), UAH-RSS (orange), BG-RSS (green), RICH-RSS (pink), HadAT2-RSS (dark red) and unadjusted (RS) data-RSS (dark blue). Triangles at bottom of panels indicate documented radiosonde instrumentation changes. Corresponding decadal trend differences 1979-2006 (LS) and 1987-2006 (TS) are plotted in the right panels. From Haimberger et al. (2008).

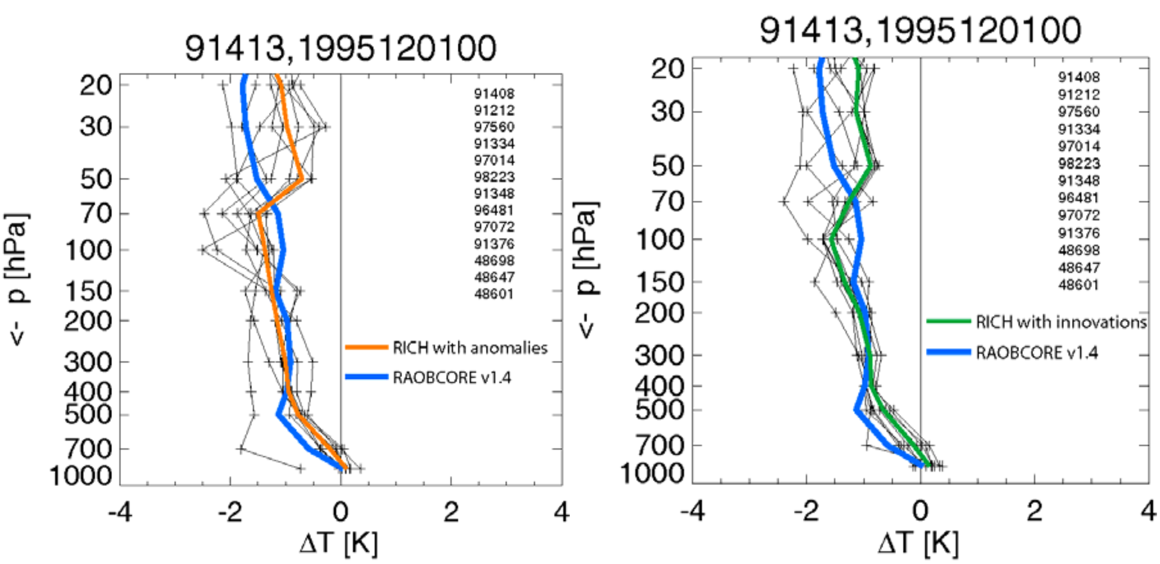

Fig. 5: Estimates of break profile caused by change from VIZ-B to Vaisala RS80 at Pacific station Yap in the western tropical Pacific. Blue curve in both panels: RAOBCORE v1.4 estimate, Orange curve: Weighted mean of break estimates gained by comparison of temperature anomalies at Yap with neighboring reference stations (WMO IDs in upper right corner). Green curve: Weighted mean of break estimates gained by comparison of temperature *innovations* (obs-ERA-40 background) with the same neighboring stations. Black lines are individual break size estimates from neighboring stations. Note smaller variance in right panel.

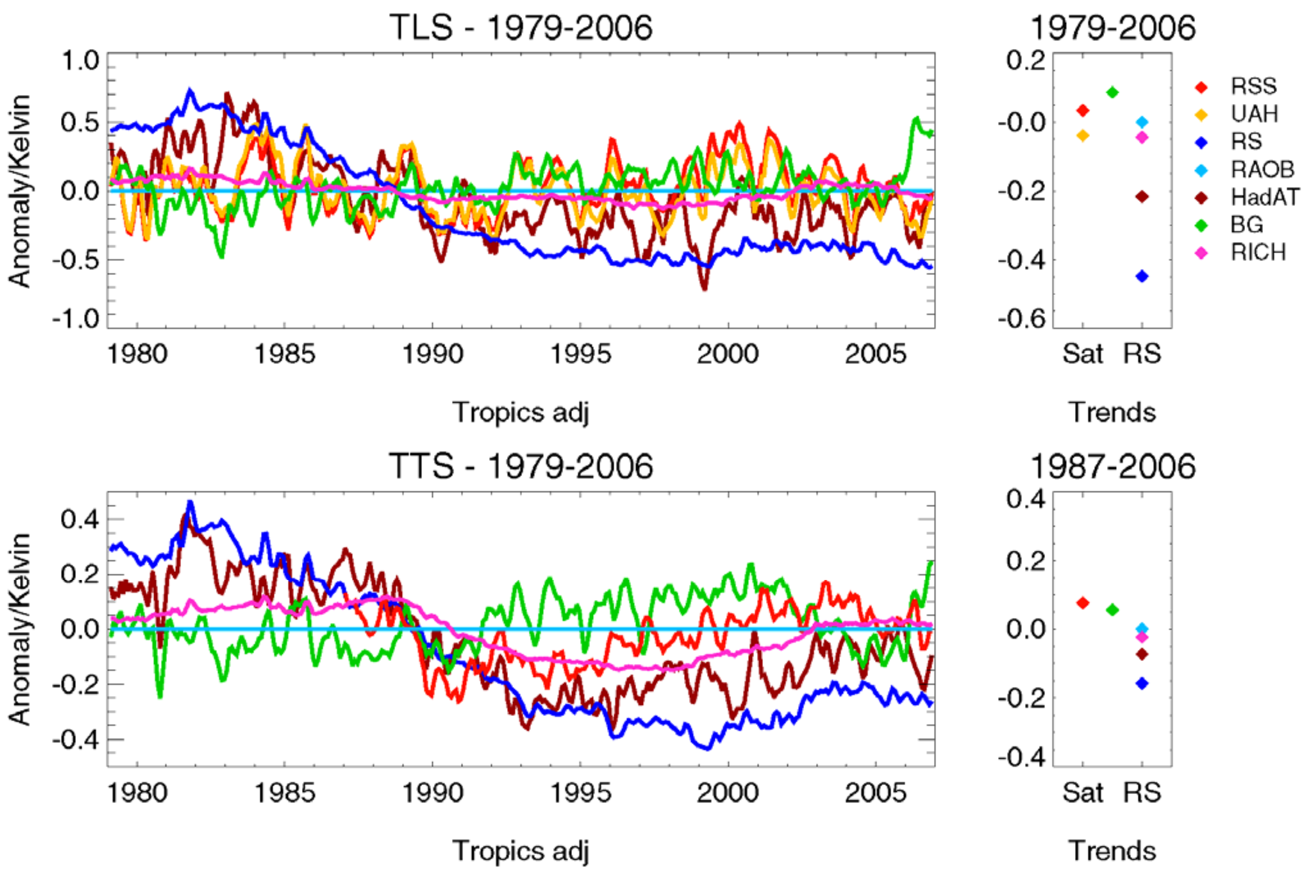

Fig. 6: Time series of tropical (20S-20N) mean MSU LS/TS temperature anomaly differences RSS-RAOBCORE (red), UAH-RAOBCORE (orange), ERA-40 bg-RAOBCORE (green), RICH-RAOBCORE (pink), HadAT2-RAOBCORE (dark red) and unadjusted radiosonde (RS) minus RAOBCORE (dark blue). Corresponding trend differences are shown in the right panels. All means are from data subsampled at radiosonde stations. RAOBCORE trends for the LS and TS layers are -0.4K/decade and -0.04K/decade, respectively.

Fig. 5 gives an example how comparison with temperature anomalies or temperature innovations from neighboring stations can yield a sensible break estimate. Using innovations yields smaller variance but is not strictly independent of BG. Therefore anomalies are used in all other figures shown. RICH estimates show good agreement with the RAOBCORE estimates in the case of Fig. 4 but also for most other individual stations, except in the southern extratropcics. As is shown in Figs 6, the RAOBCORE and RICH estimates agree much better with satellite data than unadjusted radiosonde data and also better than HadAT in the MSU4 and MSU3 equivalent layers. The agreement is also better in the MSU2 and MSU2LT layers (not shown). The vertical profiles of temperature trends derived from both RAOBCORE and RICH also show better agreement with climate model predictions than earlier radiosonde datasets (Santer et al. 2008, to be submitted to Int. J. Climatology).

The present temperature adjustment dataset (RAOBCORE v1.4) is available for climate studies and as input in future reanalyses from 1958 onwards. It is successfully used in ERA-Interim and MERRA (see articles by Uppala and Schubert in this volume). Fig. 7 summarizes the tropical mean departure statistics of radiosonde temperature compared to the ERA-Interim background forecasts in January 1989. Mean as well as rms departures are smaller when using RAOBCORE adjustments. Also the number of assimilated observations is increased. Using RAOBCORE adjustments leads to about 0.3-0.4K cooler analyses in the lower stratosphere (not shown, see Haimberger, 2007b).

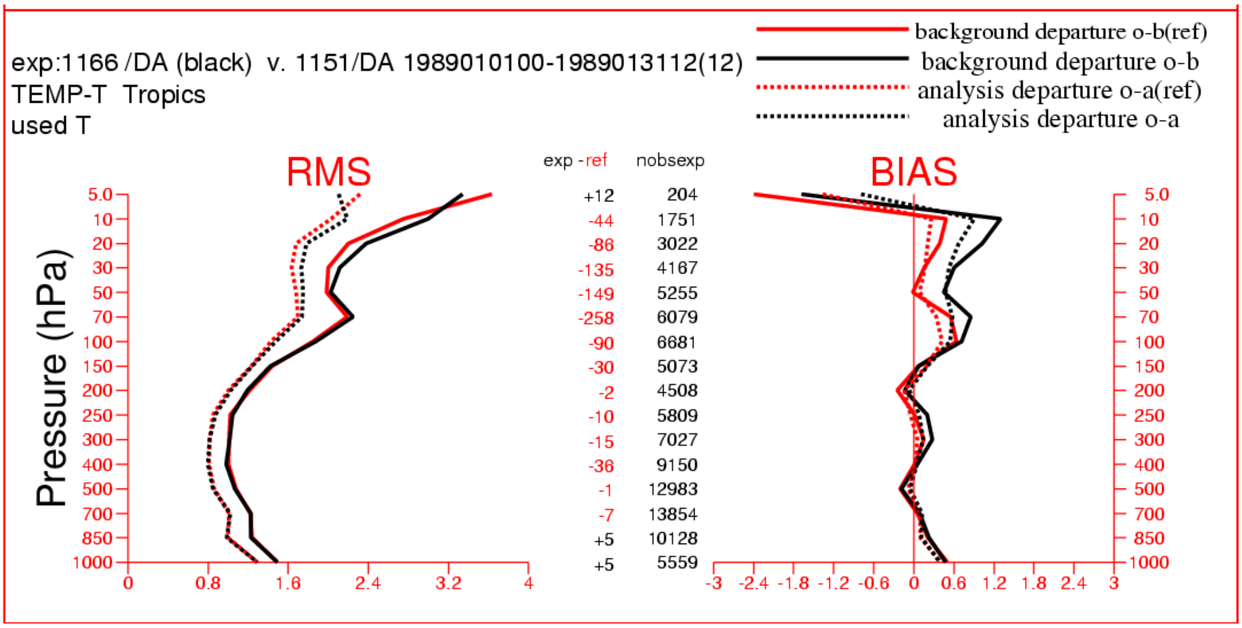

Fig. 7: Radiosonde temperature background departure (=innovation, solid) and analysis departure (dotted) statistics from ERA-Interim assimilation experiments 1151 (red, with RAOBCORE bias correction) and 1166 (black, without radiosonde temperature bias correction). "*nobsexp*" is number of observations accepted by the DA system, "*exp-ref*" is negative if more observations are assimilated by 1151.

The RAOBCORE/RICH approach needs a pilot climate data assimilation that generates background forecasts before it can be applied to the pre-1958 period. Surface pressure only reanalysis (Compo, this volume) background forecasts could be used as reference for this purpose. This would allow homogenization of upper air data from the 1938-1958 period as provided by NCAR, IGRA, or Bronnimann (2003). A homogenized upper air dataset could be quite useful for a future full extended reanalysis from 1938 onwards. It is also intended to use ERA-Interim and JRA25 (Onogi et al. 2007) innovation to check the sensitivity of RAOBCORE to the background forecast time series used.

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