Comparison of ECMWF Model Analyses with the Observed Upper-Air Temperature and Relative Humidity Climatology at the ARM NSA, SGP, and TWP Climate Research Facility Sites

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Introduction

Analyses of output from the European Centre for Medium-range Weather Forecasting (ECMWF 1994) model often are used for evaluating both observations (Ovarlez and van Velthoven 1997, Comstock and Jakob 2004) and the output of other models and satellite retrievals (Soden and Bretherton 1994). Although radiosonde observations are assimilated into the model forecasts, data collected above 300 hPa are not used, primarily because radiosondes are considered inaccurate at low temperatures and water vapor concentrations (Simmons et al. 1999). New technology has greatly improved radiosonde performance at low temperatures. Because some applications (e.g. satellite retrievals, calculations dependent on estimates of upper troposphere humidity) continue to use the ECMWF model analyses for validation instead of the observations, comparing the model analyses to data obtained from the new generation of radiosondes is of considerable interest. In this paper we present an analysis of the differences between ECMWF forecasts of temperature and humidity and observations from radiosonde soundings made at three of the Atmospheric Radiation Management (ARM) Climate Research Facility (ACRF) sites.

Data

We restricted our analysis to ARM soundings done using the Vaisala RS90 radiosonde. The RS90 radiosonde is more accurate than the earlier Vaisala RS80-H model used by ARM (Antikainen et al, 2002) and not subject to the dry bias that plagued the RS80 instrument. The ending date for the analysis was based on the availability of ECMWF analysis data. Table 1 shows the time periods and number of soundings we used in this study. All the sounding data were obtained from the ARM archive. The ECMWF analyses were obtained from ARM External Data Center (XDC).

Table 1. Radiosonde data matched with ECMWF analyses. Analysis period is limited by beginning of ACRF operations using RS90 radiosondes and by the availability of ECMWF data at the ARM external data center (XDC).

ACRF Site	Start Date	End Date	Number of Soundings
NSA	04/28/2002	11/30/2003	402
SGP	05/01/2001	11/30/2003	3147
TWP (C2)	06/01/2002	11/30/2003	1141

ECMWF model output

We used the diagnostic data derived from ECMWF model runs (XDC data platform name SSSecmwfvarX1.c1.YYYYMMDD.000000.cdf). These files consist of hourly profiles of atmospheric variables calculated on a 60-level grid ranging from the surface to 10 hPa. Water vapor is represented in the data by specific humidity (q) which is calculated by the model at each grid point. The data also includes relative humidity (U) as an output variable. U is derived from the modeled specific humidity and temperature and from estimates of saturation water vapor relative to an ice surface. The ECMWF uses a modified version of the Tetens saturation vapor pressure formula (Simmons et al. 1999). At temperatures above 0 °C the Buck (1981) coefficients are used. Below -23 °C the coefficients are taken from Alduchov and Eskridge (1996). Between 0 °C and -23 °C, the model uses a quadratic interpolation. Figure 1 compares the ECMWF representations of saturation with the familiar Goff-Gratch and Hyland-Wexler formulations.

Methods

For each radiosonde flight we determined the time of the sounding midpoint. We then found the hourly ECMWF analysis that most closely corresponded to this time. The ECMWF data include both cell-averaged (0.56 deg x 0.56 deg) and point estimates of the variable values closest to the ACRF sites. We found only small differences between the two and used the point estimates to avoid any variation between ARCF sites that might be due to averaging the model output over different areas. Although model and radiosonde temperatures can be compared directly, the water vapor variables are not directly matched- the model uses specific humidity, the radiosonde uses relative humidity over water. We converted both measures to mixing ratio. The conversion of model specific humidity to mixing ratio is algebraic; we used the Wexler-Hyland saturation curve and the radiosonde temperature to calculate mixing ratio from the radiosonde relative humidity. Figure 2 shows examples of matched model and radiosonde profiles for each of the ARCF sites. We determined the height of the tropopause from the radiosonde data by using the WMO definition based on lapse rate and layer thickness.

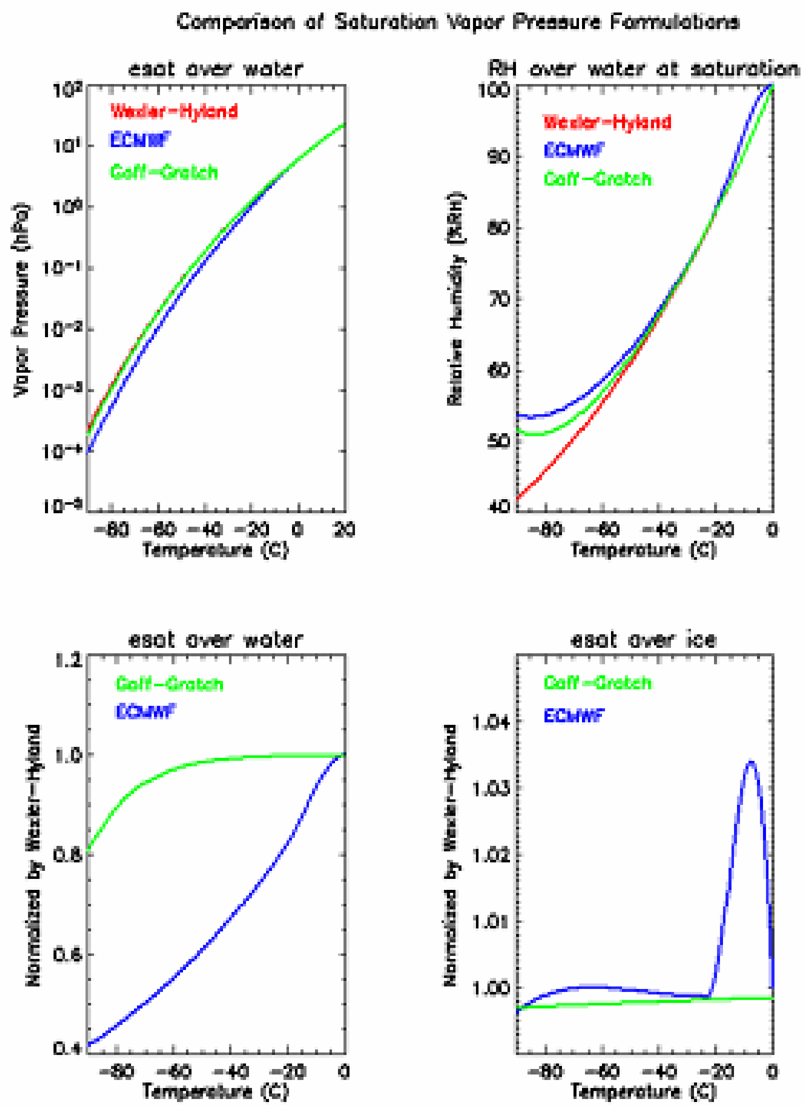

Figure 1. Comparison of ECMWF saturation water vapor formulation with Goff-Gratch and Wexler-Hyland formulations. Note that both ECMWF and Goff-Gratch depart from Wexler-Hyland at low temperatures typical of the upper troposphere. This is important for interpretation of the ECMWF model results because the model humidity is constrained to saturation above the tropopause.

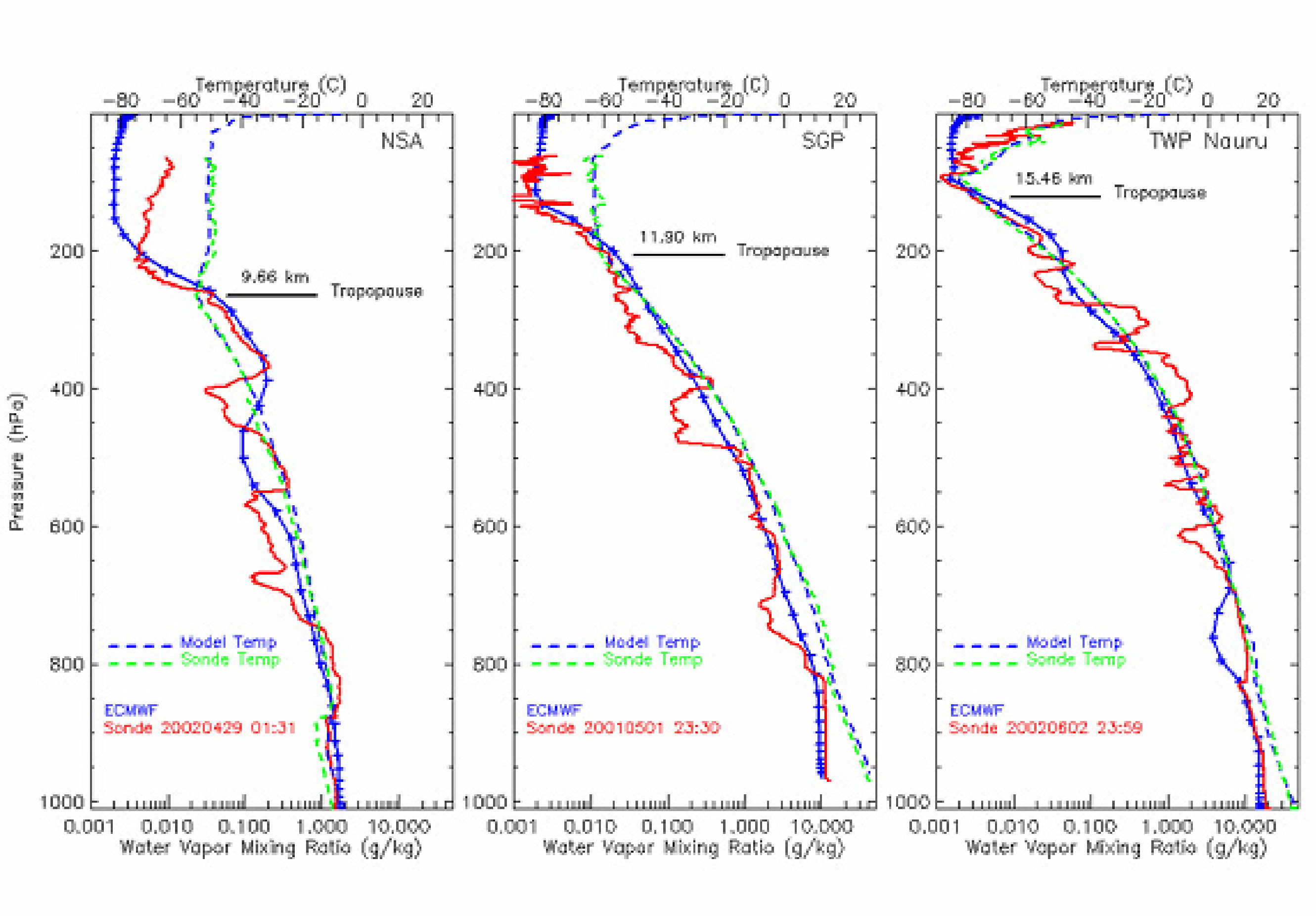

Figure 2. ARCF soundings matched in time with 60-layer ECMWF model profiles. Solid lines represent mixing ratio (red=sonde, blue=ECMWF), symbols show pressure mid-point of model vertical layers. Dashed lines represent temperature (green=sonde, blue=ECMWF). Although often penetrating the tropopause, ACRF soundings do not reach the 10 hPa level represented by the first ECMWF layer.

Results

Figures 3 and 4 show examples of monthly averages of the radiosonde and ECMWF model water vapor mixing ratio and temperature data. Both examples are taken from June 2003; Figure 3 data are from the SGP and Figure 4 data are from the TWP. In addition to the monthly averaged profiles we also have plotted the relative difference in mixing ratios.

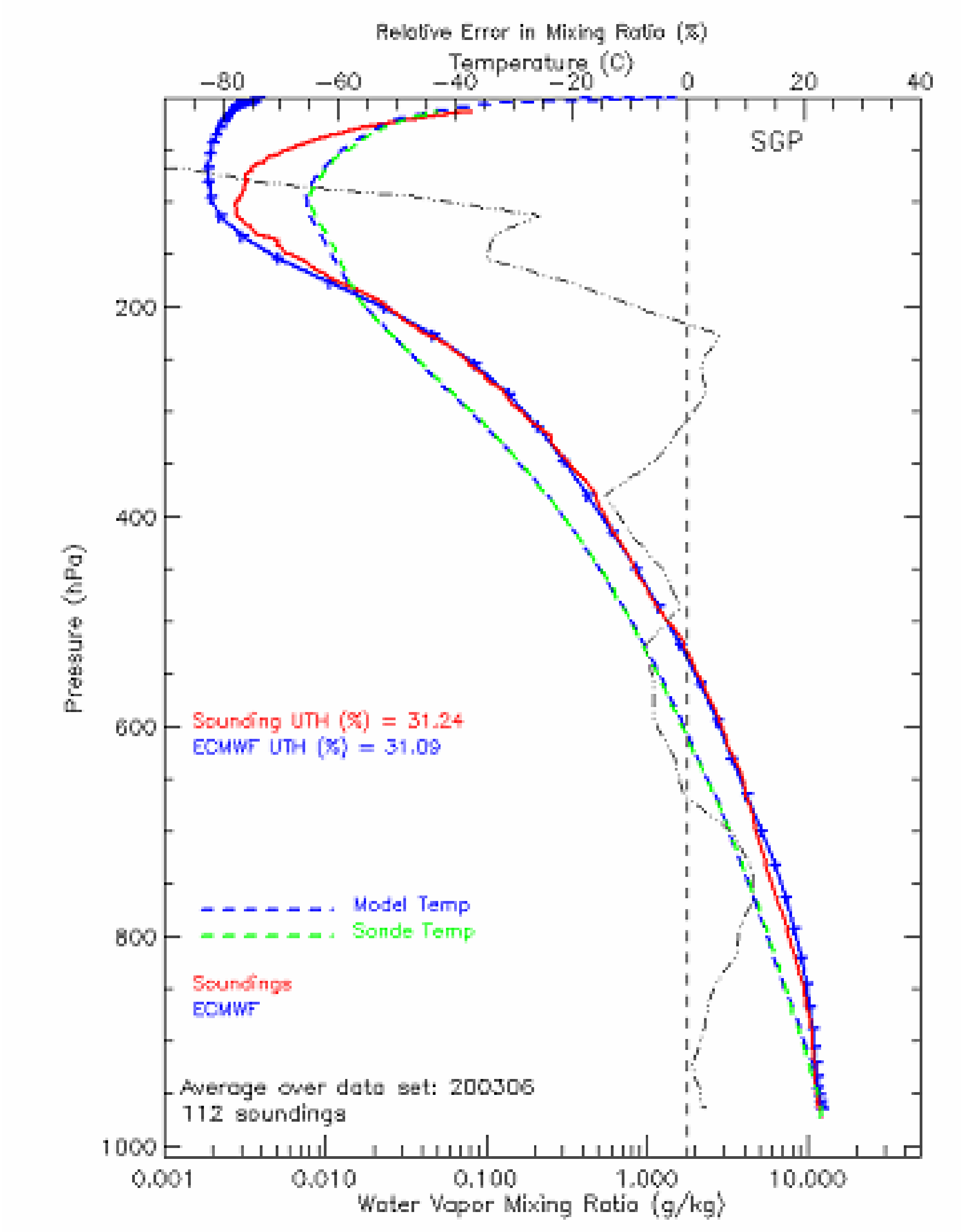

Figure 3. Average profiles of temperature (solid lines) and water vapor mixing ratio (dashed lines) obtained from the radiosonde observations (red) and the ECMWF forecasts (blue) for the SGP ACRF site during June 2003. The dash-dotted line is the relative difference (%) between the two mixing ratios. The monthly-average values of Upper Tropospheric Humidity (UTH) for the soundings and model analyses also are shown.

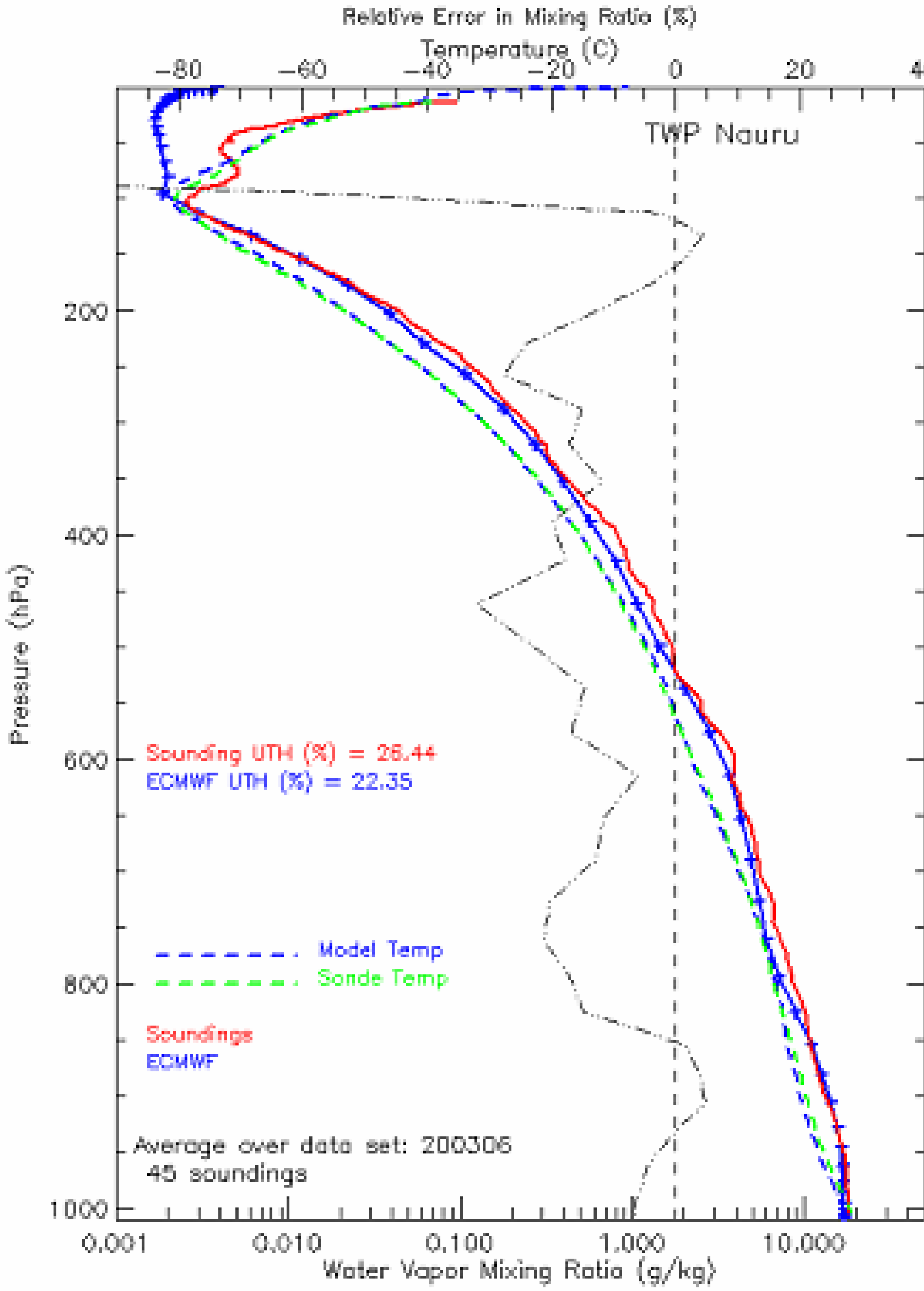

Figure 4. As in Figure 3 but for the TWP (C2) ACRF site on Nauru in June 2003.

In addition to the profiles, we calculated the value of upper tropospheric humidity (UTH), defined as the average relative humidity over water between 500 hPa and 200 hPa, for each sounding and model analyses pair. Figures 5 and 6 show how the observed and modeled UTH compare for the month of December 2002 at the SGP (Figure 5) and TWP (Figure 6) ACRF sites.

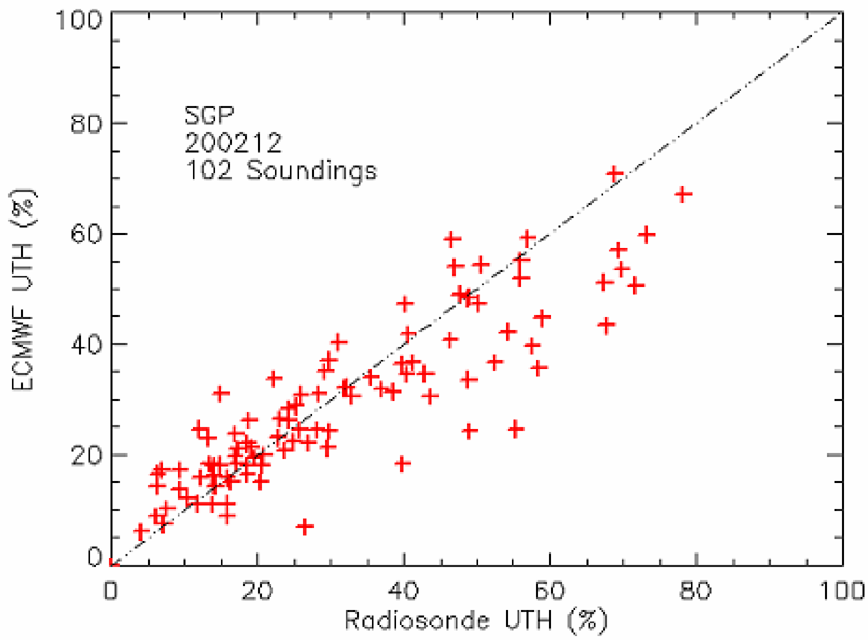

Figure 5. Upper tropospheric humidity (UTH) from the ECMWF model runs versus UTH from the matched radiosonde flights for December 2002 at the SGP ACRF site.

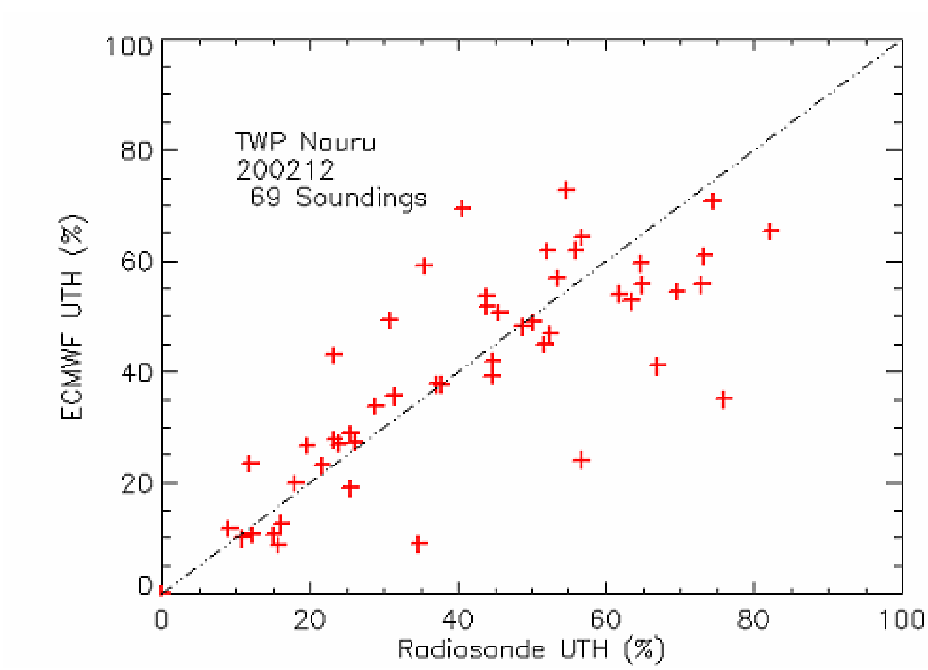

Figure 6. As in Figure 5 for December 2002 at the TWP (C2) ACRF site on Nauru.

Conclusions

Although temperature and water vapor profile measurements obtained from individual soundings can differ substantially from matched model forecasts, monthly average differences are less striking. However, comparisons of matched sounding and model forecasts (e.g. Figures 5 and 6) tend to show that the model UTH is lower than the sounding UTH at higher values of UTH. Whether this results from lag in the radiosonde humidity sensor as it approaches the dryer tropopause or from the model constraint of setting all super-saturated values of humidity above the tropopause down to saturation values remains to be determined.

Acknowledgements

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