# Validation of the Upper Tropospheric Relative Humidity Determined from METEOSAT Data

OLLI M. TURPEINEN* AND JOHANNES SCHMETZ

*European Space Operations Centre, Darmstadt, Federal Republic of Germany*

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ABSTRACT

The purpose of this note is to "validate" the upper tropospheric humidity (UTH) operationally extracted from the 6.3 $\mu$m channel data of METEOSAT. The validation is carried out by comparing the satellite data with observed humidities from the conventional network of radiosondes. The validation is not an absolute error assessment of the UTH, but rather an intercomparison, because the upper-tropospheric radiosonde humidities may not be very accurate.

The results for three latitude belts indicate that the estimated humidity in the upper troposphere shows a fairly high linear correlation (coefficients 0.64–0.89) with the observed humidity and that the slope of the regression line ranges from 0.82–0.89. The rms-error of the UTH is generally less than 10%. The UTH tends to underestimate the observed humidity by about 4%. This relative bias is most pronounced in the midlatitude belts.

## 1. Introduction

The determination of the upper-tropospheric humidity (UTH) based on the data from the water-vapor channel on board METEOSAT has been described in detail in a paper by Schmetz and Turpeinen (1988) (hereafter ST). First results of comparisons with radiosondes were presented in ST; however, no attempt was made to validate the UTH. Those results indicated some shortcomings in the operational UTH product, which called for reconsideration before the UTH could be used as an input for numerical weather-prediction models. Therefore the present study was undertaken; its purpose is to validate the "satellite-based" UTH against the humidities from the radiosondes. Data from two phases are compared. For the first phase the physical retrieval method closely resembles that described in ST. Based on the results of the first phase, minor changes were made to the retrieval in order to alleviate the problems during the second phase.

## 2. Data

The validation took place in two phases: the first ran from 7 September until 23 September and the second from 5 October until 5 November 1987.

* Present affiliation: Recherche en Prevision Numerique, Dorval, Canada.

*Corresponding author address:* Dr. Johannes Schmetz, European Space Operations Center, Robert-Bosch-Strasse, 5 6100 Darmstadt, Federal Republic of Germany.



All the radiosonde data within the METEOSAT field of view were collected, but only the radiosonde data collocated with a valid UTH were considered. Altogether, 1052 and 1045 collocations were found during the first and second phases, respectively. The sample sizes for the two phases and for the various areas are depicted in Table 1. The total sample sizes are fairly large, but their geographical distributions are uneven: the dominance of the collocations from the latitude belt 20°N–55°N is very obvious. During the first phase, for example, 73% of the collocations were found in that belt. Only 14% of the stations originated from the tropical region bounded by the latitudes of 20°S and 20°N. The coverage was comparable in the Southern Hemispheric latitude from 20°S to 55°S, where 13% of the collocations were located.

The UTH is a measure of the mean column humidity in the layer between 600 and 300 hPa (ST). Therefore the radiosonde humidities had to be first converted into a compatible value. Only the radiosonde stations reporting humidity values from all the standard levels between 600 and 300 hPa, i.e., 500, 400 and 300 hPa were considered. In addition, the 700-hPa humidity was needed to estimate the 600-hPa value, which was approximated by simply averaging the 700 hPa and 500 hPa values. The mean layer humidity was computed with a weighting, which was derived by averaging the weights of two contribution functions: those of a standard midlatitude summer atmosphere with a satellite zenith angle of 45 degrees and those of a standard tropical atmosphere with a zenith angle of zero degrees. The weights were based on the results by Fischer et al. (1981). The use of a single set of weights is a simplification, as the contribution function varies with the

TABLE 1. Sample sizes as a function of the phase and area considered.

| | Region | | | |
|---|---|---|---|---|
| | 55°S–55°N | 20°N–55°N | 20°S–20°N | 20°S–55°S |
| Phase I | 1052 | 770 | 145 | 137 |
| Phase II | 1045 | 615 | 184 | 246 |

atmospheric temperature profile and the satellite viewing angle, but the average used in this study well represents the typical atmospheric conditions within the METEOSAT field of view. The fact that the midlatitude atmospheres are generally drier than the considered model atmospheres is compensated by the increased satellite zenith angle at those latitudes. Concerning the radiosonde humidities, it is important to note that values can be largely in error. This is especially true in the upper troposphere where absolute humidity is small. Therefore, the following intercomparison is a relative validation only, since the radiosonde humidities cannot constitute an absolute reference.

## 3. Results

The results are presented for two phases, since the determination of the UTH was slightly modified after the first phase in an attempt to improve the accuracy of the satellite humidity.

### *a. The first phase*

Scatter plots from the first phase for the various areas are displayed in Fig. 1. All the available radiosonde humidities are plotted in Fig. 1a against the UTH (satellite humidities). The results show that a fair agreement exists between the humidities whenever the observed humidity is between 10 and 30%. Two areas of disagreement can, however, be identified. First, with increasing humidity the UTH seems to systematically underestimate the observed values. In fact, few UTH-values occur above 50%. The absence of higher UTH-values may seem unnatural, but it can be largely attributed to the fact that the UTH is only determined for segments with no medium and high clouds, where the relative humidity is not likely to be very high (ST). Note also that the number of radiosonde humidities above 50% is small (about 20 out of 1052). Second, as the observed humidity becomes extremely low approaching the 5% limit, the UTH tends to remain higher. The same features are also evident in Fig. 1b, where the results from the 20°N–55°N latitude zone are presented.

Figures 1c and 1d depict the results from the tropics and the southern belt 20°S–55°S, respectively. The agreement seems to be somewhat superior to that discernible in the northern latitude zone. Two areas of discrepancies still exist: underestimation of the higher humidities and overestimation of the UTH values for very low observed humidities, thus indicating that the UTH covers too limited a range.

Note that in ST (Fig. 8) there were more UTH and radiosonde humidity values above 50%, but their dispersion was very large. The occurrence of higher UTH humidities was primarily due to a lower WV calibration coefficient, which related a calculated radiance, and hence relative humidity, to too high a count. As for the radiosonde humidity, a higher weight was given to lower-altitude measurements. As in the present study, the failure of the UTH retrieval to produce very low humidities was present in ST.

More-quantitative results are shown in Table 2, where a number of statistical parameters concerning the UTH and radiosonde humidities are displayed. The earlier results are confirmed: the UTH varies less than the observed humidity, as the standard deviation is systematically smaller for the satellite based estimates. The unduly limited range of the UTH-product is also reflected in the small slopes of the linear regression lines, which is only 0.47 for all data samples. Slopes and linear correlation coefficients are indicated in the Figs. 1a–d.

The underestimation of the higher humidities seems to be the dominant feature as the overall statistics indicate a bias of −4.4%, ranging from −0.6 to 8.2% (not shown). In spite of the above limitations, all the correlation coefficients calculated between the UTH and observed humidity remain fairly high. The results are especially encouraging for the tropical region and southern latitude zone.

The main shortcoming of the UTH, the too limited range, was first tackled by improving the scheme whenever the atmosphere is extremely dry. This was done by changing the relative humidity values for which the counts/radiances of the UTH-tables were computed. Previously, those values were evenly distributed over the full range, i.e., 1%, 20%, 40%, 60%, 80% and 100%. Values in between were found by linear interpolation. There is, however, a much higher sen-

TABLE 2. Statistics of the UTH and radiosonde humidity for the first phase of validation. Mean UTH = average UTH; s/d. UTH = standard deviation of the UTH; mean R/S = average radiosonde humidity; s/d. R/S = standard deviation of the radiosonde humidity; rms. UTH = root mean square difference between the UTH and radiosonde humidity; bias UTH = bias between the UTH and the radiosonde humidity.

| | Region | | | |
|---|---|---|---|---|
| Parameter | 55°S–55°N | 20°N–55°N | 20°S–20°N | 20°S–55°S |
| Mean UTH | 17.2 | 18.6 | 13.9 | 12.9 |
| s/d. UTH | 6.7 | 6.4 | 5.4 | 6.3 |
| Mean R/S | 21.6 | 23.9 | 15.8 | 14.7 |
| s/d. R/S | 14.9 | 15.5 | 11.9 | 9.3 |
| rms. UTH | 11.9 | 13.1 | 8.4 | 6.5 |
| Bias UTH | −4.4 | −5.3 | −1.9 | −1.8 |

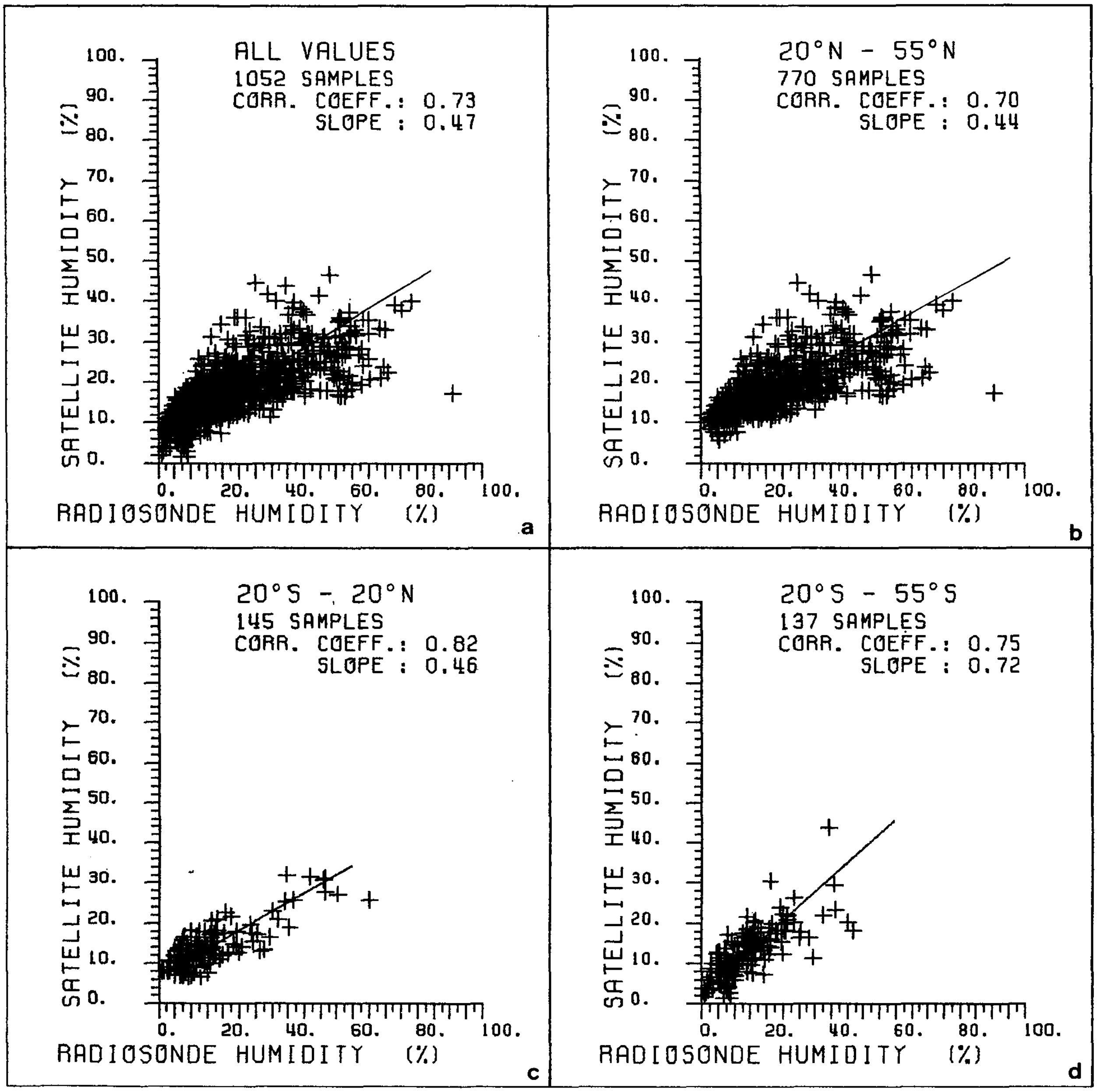


FIG. 1. The scatter plot of the UTH (satellite humidity) against the radiosonde humidity for the first phase of validation. The different panels show results for (a) all samples, (b) the northern latitude belt (20°N–55°N), (c) the tropical belt (20°N–20°S), and (d) the southern belt (20°S–55°S). Inside the panels the linear correlation coefficient and the slope of the regression line are indicated.

sitivity of the satellite measurements to a change at low relative humidities. This feature is illustrated in Fig. 2, where the variation of the relative humidity is depicted as a function of counts assuming a tropical standard atmosphere with a zenith angle of zero degrees. The previous set up of the UTH tables led to a systematic overestimation of very low humidities producing few humidities below 10% (Fig. 1) due to the nonlinearity of the relation. The improved resolution at the dry end of the UTH tables, with radiative transfer calculations for 1%, 5%, 10%, 20%, 40% and 100% relative humidities, no doubt alleviates the problem of overestimation in the very dry conditions. Meanwhile, it would result in an increased overall negative bias. Therefore, accompanying modifications have to be carried out to cut down the negative bias at the higher humidities.

To prevent the increase of the negative bias two avenues were followed. First, the quality control threshold, the maximum acceptable difference between the calculated and observed counts, described in detail by

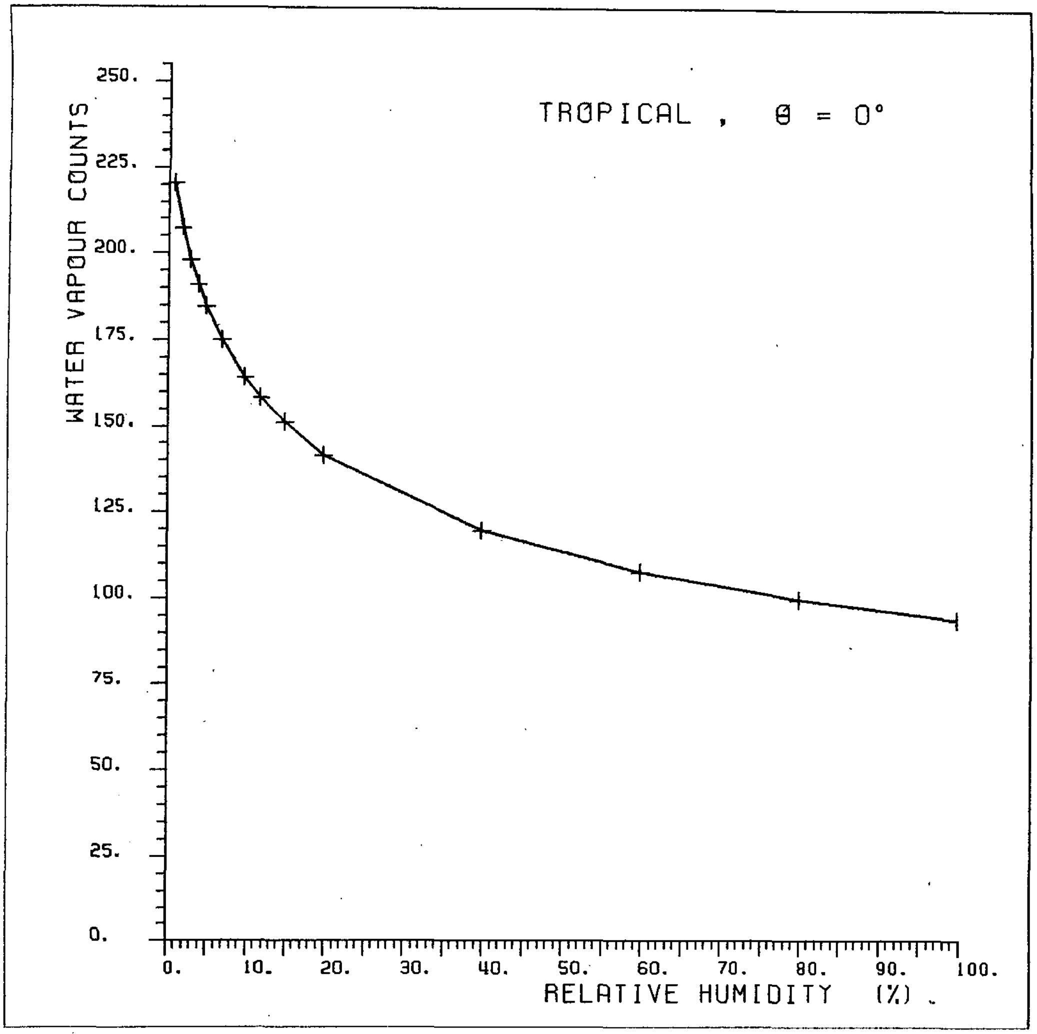


FIG. 2. The dependance of the UTH (relative humidity) on the water vapor counts for a standard tropical atmosphere and for a zenith angle of zero degrees. Note that the range of WV has been expanded from 64 to 256 counts.

ST, was decreased for the observed relative humidities higher than 50%. A tolerance of a discrepancy of 8 counts (on a 6 bit scale) that was accepted formerly was reduced to 4. If the collocated points exhibited a larger difference the collocated values were disregarded. This can be well justified because a minor change in counts (or radiances) leads to a major change in the humidity, if the atmosphere is moist. This behavior of the humidity is demonstrated in Fig. 2 and it implies that the margin of the uncertainty of the UTH increases considerably as the relative humidity approaches the saturation. Second, the UTH-tables used for the UTH retrieval (for details see ST) were slightly modified. The tables are no longer calculated for relative humidities fixed from 600 to 300 hPa, but to an upper boundary of 350 hPa. This is the simplest way to consider that the atmospheric relative humidity generally decreases with increasing height. A decreasing relative humidity profile yields, for the same mean column relative humidity, a higher radiance than the constant value profile, since the bulk of the moisture is placed at altitudes with higher temperatures.

*b. The second phase*

Scatter plots from the second phase for the various areas are displayed in the four panels of Fig. 3. The results for the whole METEOSAT field of view are shown in Fig. 3a. The figure indicates that the problem of overestimation of the UTH in the very dry conditions has been solved, while the underestimation of the humidity for moister atmospheres has not completely disappeared. The agreement seems to be better in the tropical (Fig. 3c) and in the southern belt (Fig. 3d) than in the northern latitude zone (Fig. 3b).

The statistics for the second phase are shown in Table

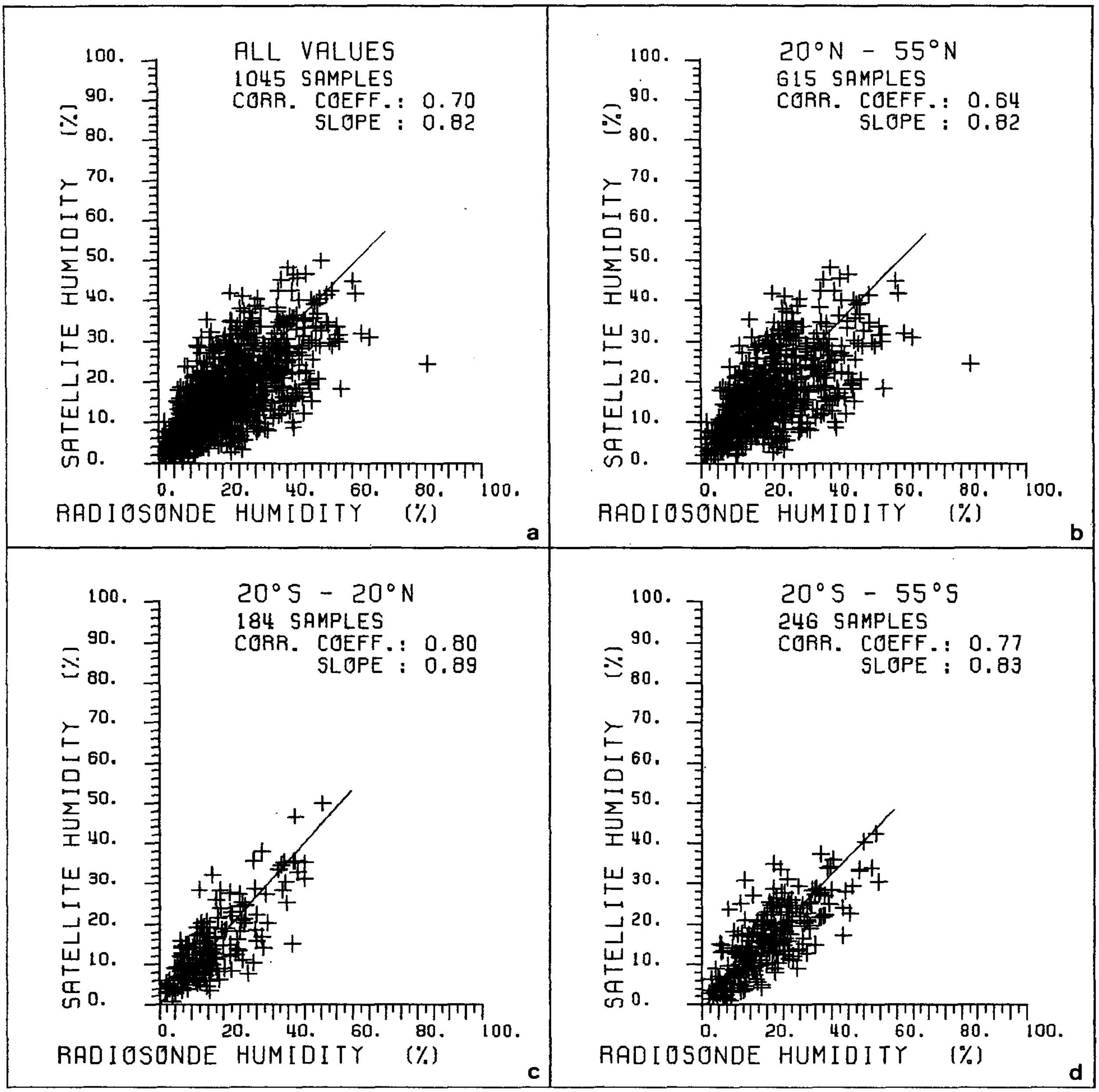


FIG. 3. As Fig. 1 but for the second phase.

3. Similar to the first phase, the best agreement between the estimated and observed humidity was found in the tropical regions. A number of improvements over the results of the first phase can be reported: (i) the range of the UTH has expanded and it exhibits a standard deviation which is more in line with the one of the observed humidity; (ii) the slopes of the regression lines are now much closer to one (0.82–0.89, see Fig. 3); and (iii) for the whole area between 55°N and 55°S the rms difference between the radiosonde humidity and the UTH has decreased by 2%. The other statistical parameters are comparable to the ones from the first phase. Both the correlation coefficients (0.64–0.80) and the negative relative bias of the UTH (−4.5%) remained unchanged. The reasons for the persistent bias may be attributed to the assumption of a constant layer humidity in the atmosphere between 600 and 350 hPa adapted in the UTH retrieval scheme. At least the pertaining change to the retrieval could potentially remove the bias.

## 4. Summary

A study to validate the UTH was undertaken to assess the accuracy of the satellite product. The work was

TABLE 3. As Table 2, but for the second phase of validation.

| | Region | | | |
|---|---|---|---|---|
| Parameter | 55°S–55°N | 20°N–55°N | 20°S–20°N | 20°S–55°S |
| mean UTH | 16.0 | 16.8 | 13.9 | 15.6 |
| s/d. UTH | 9.3 | 9.5 | 9.0 | 8.8 |
| mean R/S | 20.5 | 21.7 | 16.2 | 20.7 |
| s/d. R/S | 12.2 | 12.8 | 10.4 | 11.0 |
| rms. UTH | 9.9 | 11.1 | 6.7 | 8.6 |
| bias UTH | −4.5 | −4.9 | −2.3 | −5.1 |

carried out in two phases so that the retrieval scheme could be improved as a result of the experience gained during the first phase. The split in two phases should have no bearing on the comparison because the data are sampled quasi-globally and improvements are obvious in all latitude belts in the second phase. Thus, a possible influence of changed climatology can be ruled out.

The results were encouraging. The best agreement between the estimated and observed humidity was found in the tropics, where the linear correlation was 0.80 and the slope of the regression 0.89. The error statistics showed that the rms-difference of the UTH was less than 10%. The mean negative bias of the UTH was −4.5%. The systematic underestimation of the humidity may be attributable to the retrieval scheme. A definite value for a bias is difficult to state since the radiosonde humidities used for validation are averages over several discrete measuring points. That by itself and the approximate weighting with a mean contribution function may already introduce a bias. The upper tropospheric humidities from radiosonde may also be systematically in error since radiosonde measurements at low absolute humidities are difficult. The ultimate test for the UTH-product will be its use in the analysis of humidity fields.

## REFERENCES


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