EVALUATION OF OPERATIONAL INSAT-3D UTH PRODUCT USING RADIOSONDE AND METEOSAT-7

I. Dey [a], M. V. Shukla [a], P. K. Thapliyal [a], C.M. Kishtawal [a]

[a]Atmospheric and Oceanic Sciences Group, Space Applications Centre, Indian Space Research Organization, Ahmedabad, India – (ipshita, munnvinayak, pkthapliyal, chandra_k)@sac.isro.gov.in

KEY WORDS: Water Vapor, Upper Tropospheric Humidity, INSAT-3D, Radiosonde, Meteosat-7

ABSTRACT:

Recently available satellite observations from the water vapor channel (6.5-7.1 µm) of the Imager on-board India's geostationary satellite, INSAT-3D have been used to estimate Upper Tropospheric Humidity (UTH). In this study, operationally retrieved UTH product has been compared and validated for the period of Jan-Jun, 2014, using in-situ and satellite measurements. In-situ measurements of UTH have been indirectly derived using humidity profiles obtained from a network of radiosonde stations from NOAA/ESRL database. Meteosat-7 UTH products have been used as satellite measurements. The validation of INSAT-3D UTH against UTH derived from radiosonde profiles shows reasonable agreement, with linear correlation coefficients ranging from 0.78 to 0.87 and the slope of the regression line ranging from 0.52 to 0.77. The UTH tends to overestimate observed humidity by ~4% with RMS difference of ~12%. Comparison of INSAT-3D UTH product with Meteosat-7 UTH product suggests a good match with RMS difference of 7.61% and a mean bias of -0.43%, linear correlation coefficients varying from 0.88 to 0.93 and slope of the regression line varying from 0.64 to 1.08. The UTH products from INSAT-3D and Meteosat-7 have also been inter-compared by validating the two against the UTH derived from a set of collocated radiosonde observations. INSAT-3D UTH shows a RMSD of 10.65% and bias of 0.78% which matches very well with Meteosat-7 UTH with a RMSD of 10.31% and bias of -0.53%.

1. INTRODUCTION

Water vapor in the atmosphere plays an important role in the Earth's climate system because of its strong absorption of longwave radiation and through its coupling with other components of the hydrological cycle. Perhaps the most important feedback in the earth's climate system is the climate feedback due to upper-tropospheric water vapor, especially in the tropical region which is dominated by deep convective systems. Such tropical convective systems can increase the relative humidity in the upper troposphere over a wide range of space and time scales [Soden and Fu, 1995]. Upper Tropospheric Humidity (UTH), a weighted average of relative humidity in the 200–500 hPa layers, therefore becomes an important parameter that could help in the diagnosis of convective processes in the atmospheric model simulations.

Conventionally, UTH measurements can be derived from radiosonde observations that are taken routinely at synoptic hours, 0000 and 1200 UT, over various meteorological observatories. However, radiosonde humidity measurements tend to be unreliable under the dry and cold conditions in the upper troposphere [Elliot and Gaffen, 1991]. Furthermore, the radiosonde network coverage is sparse, particularly over the oceans and in the equatorial regions. Thus the only global upper tropospheric humidity measurements come from satellites. Infrared data at 6.7µm from geostationary and polar orbiting satellites have been used extensively for this purpose. A number of studies have developed and discussed the algorithms for UTH estimation from the clear-sky radiances in the water vapor channel (6.7µm) onboard geostationary [Soden and Bretherton, 1993; Thapliyal et al., 2011] and polar orbiting [Wu et al., 1993; Soden and Bretherton, 1996] satellites. Soden and Bretherton [1993, hereafter SB93] developed a simple regression equation using the European Centre for Medium Range Weather Forecast (ECMWF) analysis between UTH and the simulated brightness temperature of GOES water vapor channel, in the following form:

$$\ln[UTH/\cos(\theta)]=a+b.Tb_{wv} \quad (1)$$

where UTH is the weighted mean relative humidity in the vertical atmospheric column, θ is the viewing zenith angle, Tb_{wv} is the brightness temperature in the water vapor channel, and a, b are the regression coefficients. The weights to compute the UTH are derived using sensitivity of the water vapor channel to the changes in the relative humidity at different atmospheric levels. The relationship (1) was further modified by Soden and Bretherton [1996, hereafter SB96], with following analytical expression:

$$\ln[UTH \,.\, p_o/\cos(\theta)]=a+b.Tb_{wv} \quad (2)$$

where, p_o is the normalized or scaled reference pressure and is equal to the pressure of the level at temperature 240 K divided by 300 hPa, i.e., $p_o = p(T = 240\ K)/300$. The values of p_o were shown to have latitudinal and seasonal dependency varying between 0.9 in the tropics to 1.5 in the mid-latitudes. Thapliyal et al. [2006] presented a simple methodology to estimate the UTH from Kalpana observations that was based on SB93 using the value of p_o as 1.0, an assumption that is valid only for narrow tropical region. This was followed up by an improved algorithm based on SB96 where p_o was computed using an empirical functions of latitude and month [Thapliyal et al., 2011].The improved algorithm for the UTH estimation [Thapliyal et al., 2011] from INSAT-3D observations has been developed at the Space Applications Center (SAC). This algorithm is installed in the INSAT Meteorological Data Processing System (IMDPS) and is operational at SAC and India Meteorological Department

(IMD). In this study operationally retrieved UTH product has been compared and validated for the period of Jan-June, 2014 using in-situ observations and satellite measurements.

2. DATA AND METHODOLOGY

INSAT-3D, a geostationary satellite located at 82°E, was launched by the Indian Space Research Organization (ISRO) in July 2013. INSAT-3D has an Imager onboard that takes observations at 30 min interval in six spectral channels: Visible (VIS, 0.6μm), Short-Wave Infra-red (SWIR, 1.6μm), Mid-Wave Infra-Red (MWIR, 3.9μm), and Infra-Red (WV 6.7μm, TIR-1 10.8μm, TIR-2 12.0μm). The spatial resolution of Imager is 1 km in VIS and SWIR; 4 km in MWIR, TIR-1 and TIR-2 and 8 km in WV channels for nadir observation. Figure 1a shows the spectral sensor response function (SRF) of INSAT-3D WV channel and Figure 1b shows the weighting function of INSAT-3D WV channel derived using radiative transfer model SBDART (Santa Barbara DISORT Atmospheric Radiative Transfer [Ricchiazzi et al., 1998]). These weights are computed as sensitivity of water vapor channel brightness temperatures to the small perturbations in the relative humidity in thin layers equally spaced in the logarithm of pressure, i.e., equal spacing of *d(ln(p))* or *dp/p* [Soden and Bretherton, 1996; Soden and Fu, 1995]. From Figure 1b it may be observed that INSAT-3D WV channel is sensitive to the relative humidity changes in broad layer between 500 and 200 hPa with peak sensitivity at ~300 hPa. These weights are used to compute UTH values from the relative humidity profiles observed by a radiosonde. The improved algorithm for UTH estimation from INSAT-3D WV channel employs a bilinear regression relationship between $ln[UTH.p_o/cos(\theta)]$ and water vapor channel brightness temperature Tb_{wv} in the following form:

$$UTH = (1/p_o)[cos(\theta)*exp(-a_1*Tb_{wv} + b_1)] \quad (1)$$
$$[Tb_{wv} < 245.0] \quad (with\ R^2 = 0.9965)$$
And,
$$UTH = (1/p_o)[cos(\theta)*exp(-a_2* Tb_{wv} + b_2)] \quad (2)$$
$$[Tb_{wv} > 245.0] \quad (with\ R^2 = 0.9989)$$

The regression coefficients a_1 and b_1 were determined to be -0.1354 and 36.81 respectively, and a_2 and b_2 were found to be -0.119 and 32.79 respectively. The UTH products from INSAT-3D are generated at 8km × 8km resolution at sub-satellite point (per pixel) operationally at 30 min interval by IMDPS at the India Meteorological Department (IMD, http://www.imd.gov.in). These products are also available from the Meteorological and Oceanographic Satellite Data Archival Center (MOSDAC, http://www.mosdac.gov.in) at SAC/ISRO. In this study, operationally retrieved INSAT-3D UTH product has been compared and validated for the period of January to June 2014, using in-situ and satellite measurements.

In-situ measurements of UTH have been computed from radiosonde humidity profiles obtained at 0000 and 1200 UT from the NOAA/Earth System Research Laboratory (ESRL) database (http://www.noaa.esrl.gov.in).The radiosonde data includes temperature, humidity, and wind profiles at 22 mandatory levels (including surface). For quality control of the radiosonde data, the observed profiles are checked to see whether temperature and dewpoint depression are within two standard deviations of the 6-month mean profiles at any given pressure level from the surface to 100 hPa.

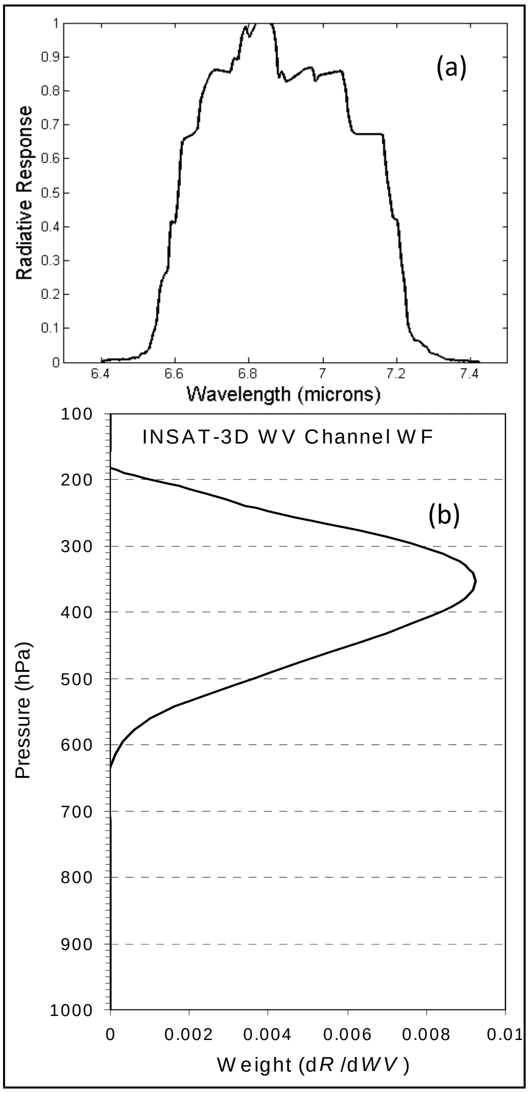

Figure 1. (a) Spectral sensor response function (SRF) and (b) sensitivity of INSAT-3D WV channel Tb to local perturbations in relative humidity in thin layers equally spaced in the logarithm of pressure (weights are normalized).

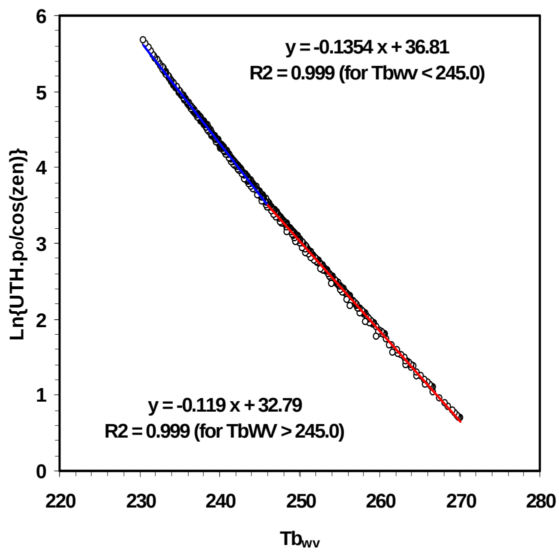

Figure 2. Bilinear regression relationship between $ln[UTH.p_o/cos(\theta)]$ and INSAT-3D water vapor channel brightness temperature Tb_{wv}..

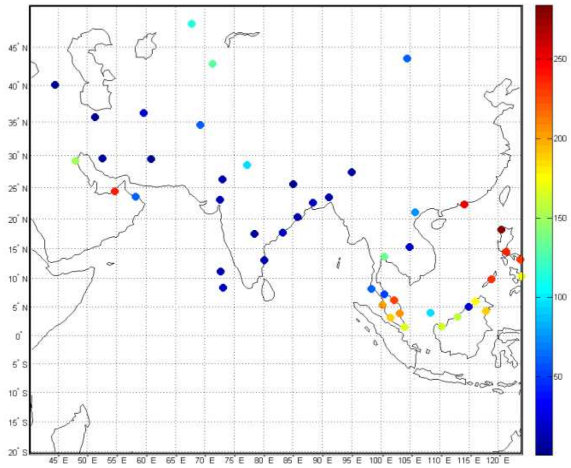

Figure 3. Radiosonde stations used for constructing the collocated data. The color scale given at each station represents the number of INSAT-3D–radiosonde matchups.

The collocated INSAT-3D and radiosonde data is constructed over the Indian subcontinent (0^0N – 50^0N, 80^0E – 130^0E; Refer Fig. 3 for the geographical location of the study domain). UTH from the quality controlled radiosonde profiles are calculated by taking the weighted average of relative humidity over water vapor weighting function.

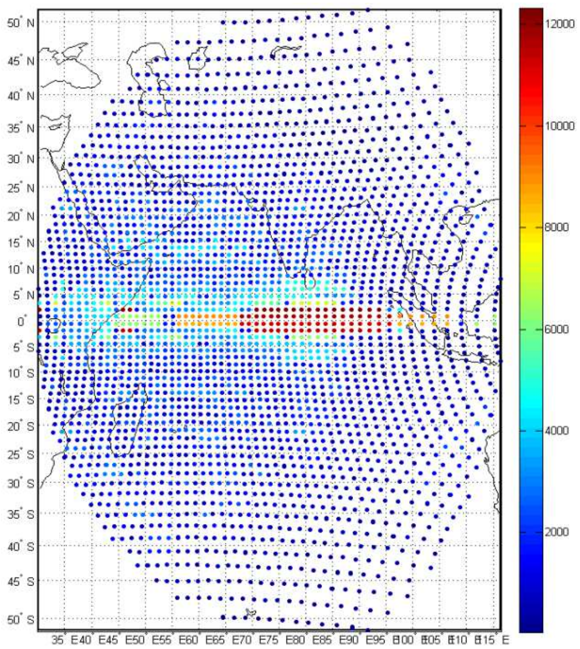

Figure 4. Meteosat-7 and INSAT-3D collocated points. The color scale given at each station represents the frequency of INSAT-3D–METEOSAT-7 observations.

It is be noted that the measurement errors of radiosonde water vapor are substantial and complicated in the upper troposphere and lower stratosphere because of the slow sensor response to the humidity changes at low temperatures. The water vapor measurements from radiosondes are therefore restricted to below 100 hPa and validation results obtained should be interpreted with caution. Operational meteorological product of UTH from Meteosat-7 (Indian Ocean coverage) available from EUMETSAT has also been used for comparison of INSAT-3D UTH product. Both INSAT-3D and Meteosat-7 UTH product are available at half hour interval but with different spatial resolution. Meteosat-7 UTH products are generated at 1.5° × 1.5° resolution (segments of 32 × 32 pixels), whereas, INSAT-3D UTH products are generated at 0.5° × 0.5° resolution. We have used UTH products at 3 hr interval (0000, 0300, 0600, 0900, 1200, 1500, 1800, 2100 UT) for the purpose of comparison and validation. For collocation, data are kept if the time and spatial differences between the reference observations (Radiosonde or Meteosat-7) and the INSAT-3D measurements are within 1 hr and 50 km, respectively.

3. RESULTS AND DISCUSSIONS

The best source to validate products relating to UTH is the upper air observations from the radiosonde. The radiosonde measurements of relative humidity have been used by various researchers to validate the satellite estimated UTH products [Schmetz and Turpeinen, 1988; Turpeinen and Schmetz, 1989; Heinemann, 2004; Jethva and Srinivasan, 2004; Thapliyal et al., 2011]. The INSAT-3D UTH product computed for pixels free from middle and upper level clouds has been compared and validated with UTH computed from radiosonde profiles, collocated in time and space. The total number of collocated points is 4160. Figure 5 shows the monthly comparison of INSAT-3D UTH and UTH computed from radiosonde profiles. Table 1 depicts the monthly statistics of the collocated points. It was observed that during Jan-Feb, the UTH biases were very high for 1200 UT which is also reflecting in the statistics of Jan-Feb. The calibration coefficients were modified in the L1B data product which improved the UTH biases from March 2014.

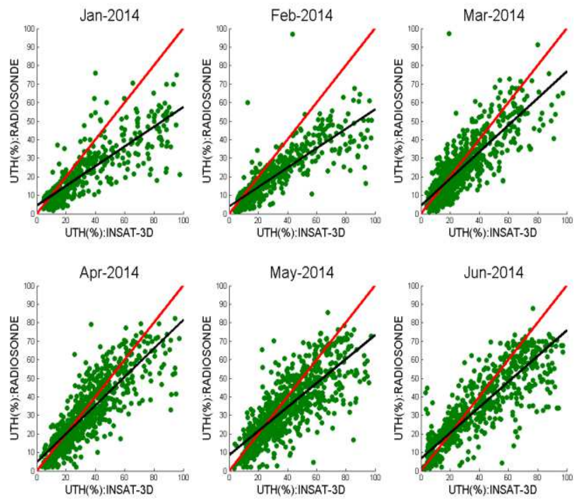

Figure 5. Monthly scatter plots of INSAT-3D UTH vs. Radiosonde UTH at 00 and 12 UT for the period Jan-Jun 2014

The combined statistics is therefore presented only for March-June 2014. INSAT-3D UTH shows reasonable agreement with radiosonde observations with a mean bias of 3.91%, RMSD of 12.18% and correlation coefficient of 0.84. Figure 6 shows the time series of Mean Bias, RMSD and correlation coefficients obtained from comparison of INSAT-3D UTH and radiosonde UTH for the months of Feb-Apr 2014. Figure 7 shows the comparison of INSAT-3D UTH with Meteosat-7 UTH at 00 and 12 UTC, for the months of Jan-Jun 2014. The collocation of UTH products from INSAT-3D and Meteosat-7 results in a very large number of matchup points (~1.9 million); hence, for the ease of documentation we present the validation results for 00 and 12 UT only. Total number of collocated points is 624365.

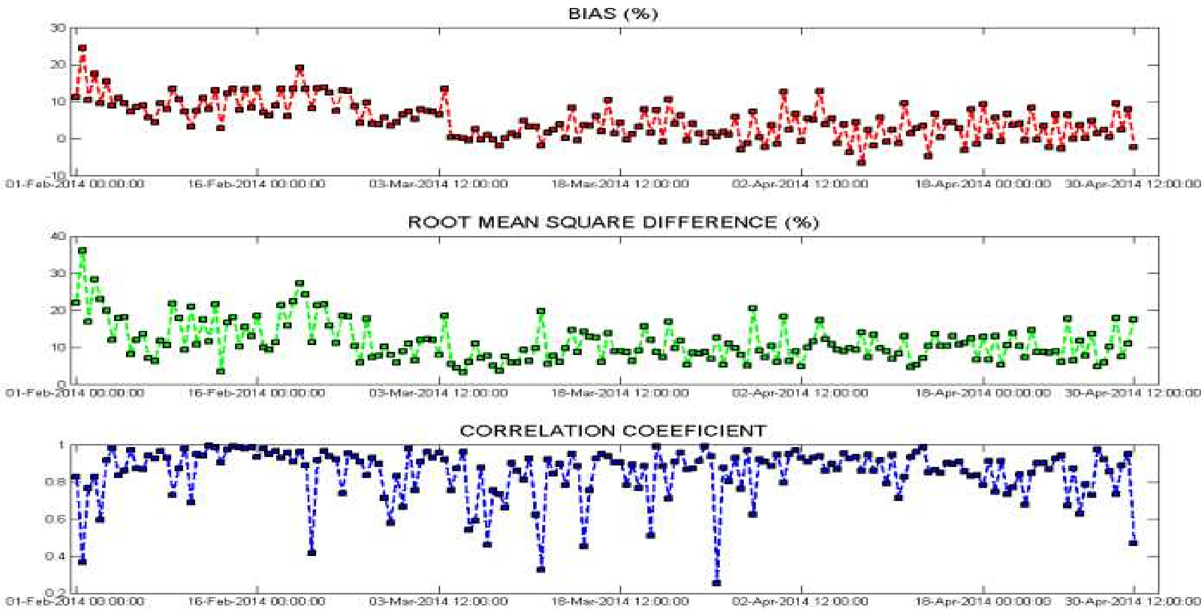

Figure 6. Time series of UTH statistics, with radiosonde used as reference observations.

Mon	Mean Bias (%)	RMSD (%)	Slope	Correlation Coefficient
Jan	10.95	18.18	0.53	0.84
Feb	9.53	16.07	0.52	0.86
Mar	2.49	9.69	0.72	0.84
Apr	3.21	11.02	0.77	0.84
May	5.33	13.84	0.65	0.78
Jun	4.92	14.16	0.69	0.87

Table 1. Monthly averaged statistics of comparison between INSAT-3D UTH and UTH derived from Radiosonde observations.

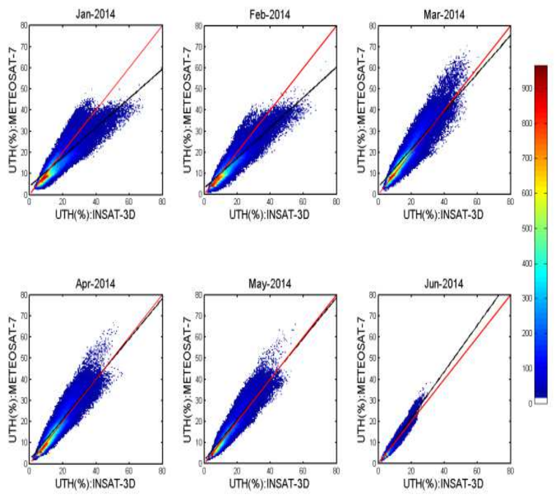

Figure 7. Monthly scatter plots of INSAT-3D UTH vs. Meteosat-7 UTH at 00 and 12 UT for the period Jan-Jun, 2014

Mon	Mean Bias (%)	RMSD (%)	Slope	Correlation Coefficient
Jan	8.42	12.73	0.64	0.92
Feb	6.67	11.04	0.70	0.92
Mar	0.12	7.90	0.87	0.88
Apr	-0.49	6.62	0.95	0.91
May	-0.21	7.12	0.95	0.91
Jun	-1.13	6.94	1.08	0.93

Table 2. Monthly averaged statistics of comparison between INSAT-3D UTH and Meteosat-7 UTH

As is observed, INSAT-3D UTH matches very well with Meteosat-7 UTH, particularly in the months of Apr-Jun, with a mean bias of -0.43%, RMSD of 7.16% and a correlation coefficient of 0.91 for the four months. As predicted, there is a sharp decrease observed in RMSD and Bias during the month of March due to the calibration correction in the L1B WV radiances. The monthly statistics has been shown in Table 2.

Time series of mean UTH derived from Radiosonde, INSAT-3D as well as Meteosat-7 at different radiosonde locations (Refer Figure 10) reveals that the overall pattern of INSAT-3D UTH matches very well with regions of low/high UTH coinciding with low/high UTH values from Radiosonde as well as Meteosat-7. The UTH products from INSAT-3D and Meteosat-7 have also been inter-compared by validating the two against the UTH derived from collocated radiosonde observations. The total number of collocated observations of radiosonde, INSAT-3D and Meteosat-7 is 857. Figure 9a shows the scatter plot between collocated INSAT-3D and Radiosonde UTH with RMSD of 10.65% and bias of -0.78% (UTH greater for Radiosonde).

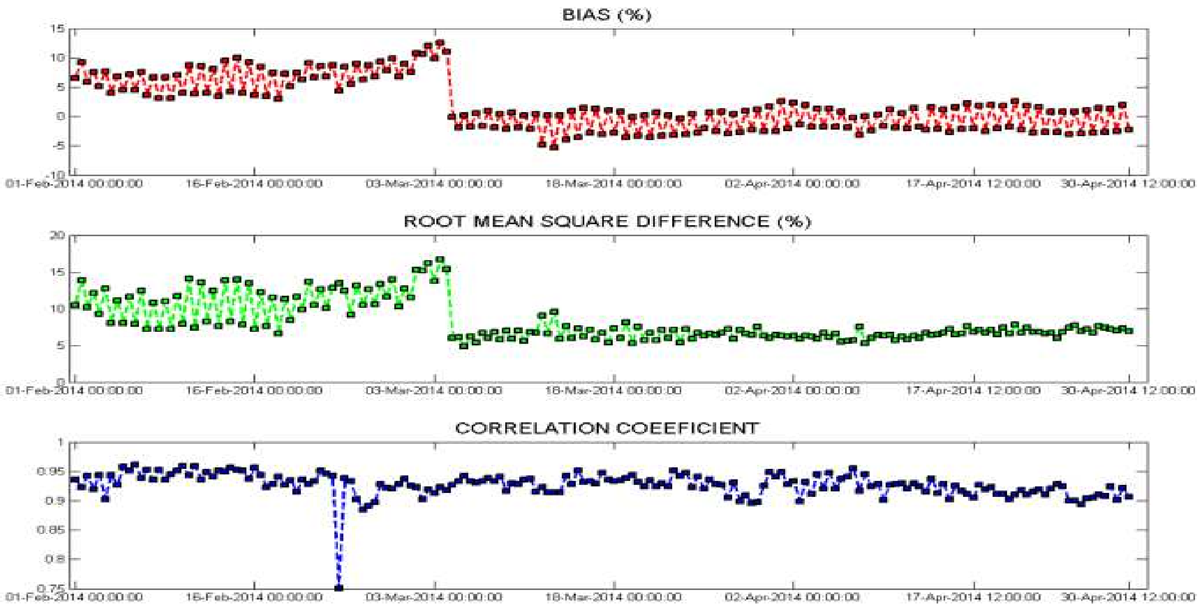

Figure 8. Time series of UTH statistics, with Meteosat-7 used as reference observations.

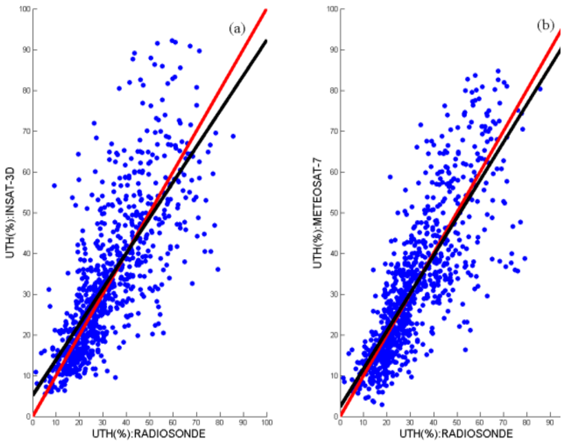

Figure 9. (a) Scatter plot of INSAT-3D UTH vs. Radiosonde UTH (b) Scatter plot of Meteosat-7 UTH vs. Radiosonde UTH at 00 and 12 UT for Mar-Jun 2014.

Similar validation of Meteosat-7 UTH product with radiosonde UTH is shown in Figure 9b with RMSE = 10.31% and bias = −0.53%. This shows a fairly good agreement between INSAT-3D and Meteosat-7 UTH values. In addition, over these locations the mean UTH values for radiosonde observations, INSAT-3D, and Meteosat-7 are 32.08%, 31.30% and 31.83% respectively, and the standard deviation of the UTH values are 15.46%, 15.98%, and 17.71%, respectively. It is obvious that the mean and standard deviation of INSAT-3D UTH values over these locations agree better with the Meteosat-7 UTH values.

4. CONCLUSIONS

In the present study, the INSAT-3D UTH products were compared with the Meteosat-7 products that use a look-up table based algorithm for UTH estimation and validated with the UTH computed from the radiosonde observations of relative humidity for the period of January-June 2014. The validation of INSAT-3D UTH carried out with the collocated high-quality radiosonde observations for Mar-Jun shows that the RMSE of INSAT-3D UTH with respect to radiosonde UTH is around 12.18% with bias of 3.91%. Mean monthly products of INSAT-3D UTH were compared with corresponding Meteosat-7 UTH products. Comparisons show that spatial and temporal RMS difference of INSAT-3D UTH from Meteosat-7 UTH lies within 8% for most of the time period. The combined RMSD for entire period and spatial domain is around 7.16% with mean bias of around −0.43%. Time series plot of UTH at various locations also show one-to-one correspondence of UTH from INSAT-3D, Radiosonde and Meteosat-7 UTH. It has been noted that the RMSD and mean bias values for individual months as well as for combined data set are maximum at 12 UT and minimum at 00 UT. A detailed comparison with the UTH estimated from the relative humidity profiles of radiosonde shows that the RMS difference of INSAT-3D operational UTH products is 10.65% as against 10.31% Meteosat-7 UTH products. This indicates an overall good matching between INSAT-3D UTH with Meteosat-7 UTH.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. A. S. Kiran Kumar, Director, SAC; and Dr. P. K. Pal, Deputy Director, EPSA/SAC for constant encouragement and guidance. The authors would like to acknowledge EUMETSAT for providing Meteosat-7 products, NOAA/CLASS for radiosonde observations, and IMD and MOSDAC for providing INSAT-3D products. The authors would like to thank Dr. B. S. Gohil, Dr. Nitant Dube and other anonymous reviewers for giving important comments and suggestions that have improved the quality of the paper.

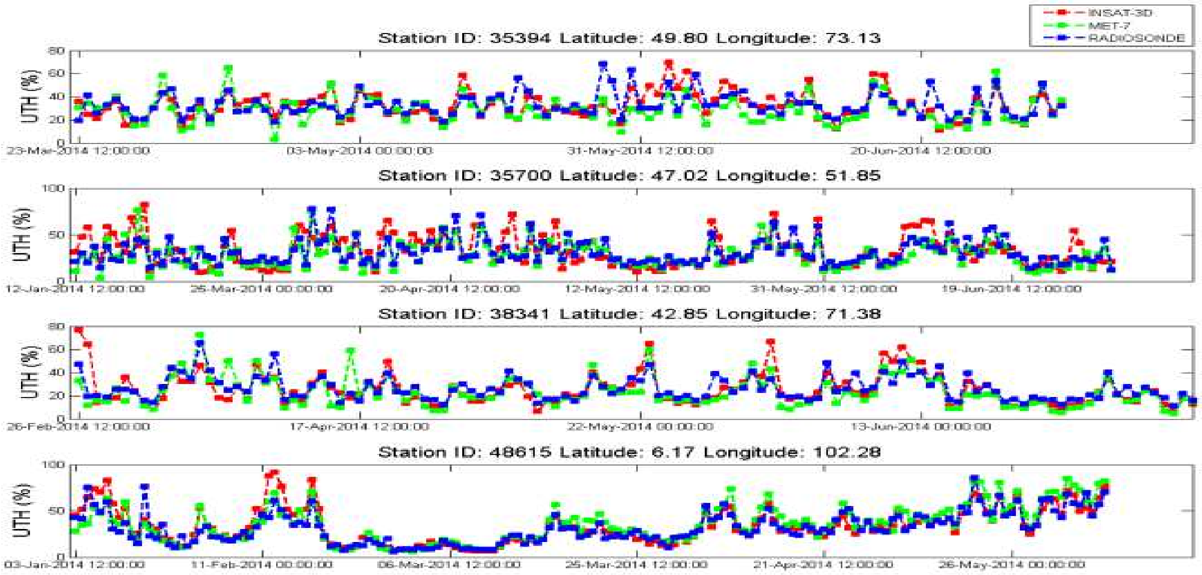

Figure 10. Time series of UTH from Radiosonde, INSAT-3D and Meteosat-7 at four different stations.

REFERENCES

Elliott, W. P., and D. J. Gaffen (1991), On the utility of radiosonde humidity archives for climate studies, Bull. Am. Meteorol. Soc., 72, 1507–1520,doi:10.1175/1520-0477(1991) 072<1507: OTUORH>2.0.CO;2.

Heinemann, T. (2004), MSG meteorological products extraction facility: Algorithm specification document, Rep. EUM/MSG/SPE/022, 212 pp., Eur. Organ. for the Exploit. of Meteorol. Satell., Darmstadt, Germany.

Jethva, H., and J. Srinivasan (2004), Role of variations in vertical profiles of relative humidity on the retrieval of humidity from AMSU-B data, Geophys. Res. Lett., 31, L23109, doi:10.1029/2004GL021098.

Schmetz, J., and O. M. Turpeinen (1988), Estimation of the upper tropospheric relative humidity field from METEOSAT water vapour image data, J. Appl. Meteorol., 27, 889–899, doi:10.1175/1520-0450(1988)027<0889: EOTUTR >2.0.CO;2.

Soden, B. J., and F. P. Bretherton (1993), Upper tropo. rel. hum. from GOES 6.7µm channel: Method and climate. for July 1987, J. Geophys. Res. 98, 16669-16688,doi:10.1029/93JD01283.

Soden, B. J., and F. P. Bretherton (1994), Evaluation of the water vapor distribution in GCMs using satellite observations, J. Geophys. Res., 99, 1187–1210, doi:10.1029/93JD02912.

Soden, B. J., and R. Fu (1995), A satellite analysis of deep convection, upper tropospheric humidity and the greenhouse effect, J. Clim., 8, 2333–2351,doi:10.1175/1520-0442(1995) 008<2333: ASAODC>2.0. CO;2.

Soden, B. J., and F. P. Bretherton (1996), Interpretation of TOVS water vapor radiances in terms of layer-average humidities: Method and climatology for the upper, middle and lower troposphere, J. Geophys. Res., 101, 9333–9343, doi:10.1029/96JD00280.

Wu, X., J. J. Bates, and S. J. S. Khalsa (1993), A climatology of water vapor band brightness temperature from NOAA operational satellite, J. Clim., 6, 1282–1300, doi:10.1175/1520-0442(1993)006<1282: ACOTWV>2.0.CO;2.

Thapliyal, P. K., M. Vinayak, K. S. Ajil, S. Shah, P. K. Pal, and P. C. Joshi (2006), Estimation of upper tropospheric humidity from water vapor channel of very high resolution radiometer onboard INSAT-3A and Kalpana satellites, Proc. SPIE Int. Soc. Opt. Eng., 6408, 1–7.

Thapliyal, P. K., M. V. Shukla, S. Shah, P. C. Joshi, P. K. Pal, and K. S. Ajil (2011), An algorithm for the estimation of upper tropospheric humidity from Kalpana observations: Methodology and validation, J. Geophys. Res., 116, D01108, doi: 10.1029/2010JD014291.

Turpeinen, O. M., and J. Schmetz (1989), Validation of upper tropospheric relative humidity determined from Meteosat data, J. Atmos. Oceanic Technol., 6, 359–364, doi:10.1175/1520-0426(1989)006<0359:VO-TUTR>2.0.CO;2.