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Atmosphere Humidity Measurements in the Brazilian Equatorial Region: Intercomparison from Radiosonde, GPS and Radiometers.

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Abstract: The Brazilian equatorial region is characterized by large space-time variability in the atmosphere humidity fields associated with the great humidity potential generated by high temperatures. The knowledge of the vertical distribution of humidity field is very important in meteorology due to the crucial role that water vapor plays in the Earth's energy budget. Radiosonde is the operational meteorological instrument employed to measure the atmospheric humidity profile at high vertical resolution. This study presents the results from two experiments, one, held in October 2001 at Alcantara Brazilian Space Flight Center, designed to intercompare radiosondes from several commercial radiosonde manufacturer. The second experiment, held in September 2002, in the Amazon region, was designed to perform a comparison of the integrated water vapor content (IWV) from radiosondes, GPS receiver, solar radiometer and the radiometers sensor carried by the AQUA satellite. The radiosonde intercomparison experiment evaluated the performance of the different humidity sensors in a tropical region and showed that the humidity measurements achieved by the different sensors were quite similar in the low troposphere and quite dispersed in the higher layers. The IWV comparison showed that all indirect measurements tend to overestimate the atmospheric humidity when compared with values from radiosondes.

Key words: Intercomparison experiments; Radiosondes; Integrated Water Vapor.

1. INTRODUCTION

Water vapor is an atmospheric component of major interest in the atmospheric sciences, because it affects the energy budget and plays a key role in the several atmospheric processes. The measurements quality of the vertical distribution of humidity in the atmosphere is very important in meteorology. Low precision and a lack of continuous water vapor measurement is one of the major error sources in short-term precipitation forecasts [1]. Although there are several techniques for measuring the profile of atmospheric humidity, the radiosonde is one of the techniques that perform direct measurements, unlike other remote sensing-based techniques.

Radiosonde is the humidity measurement device that provides the best vertical resolution and one of the few devices performing direct measurements of the atmosphere profile. Also, radiosondes are the operational devices used to measure the vertical profile of atmospheric water vapor. The intercomparison experiments among several radiosondes from different manufacturers have allowed the potential of this instrument to be verified. Turner et al. 2003, Miller et al. 1999, Guichard et al. 2000, Miloshevich et al. 2001 and Wang et al. 2002 suggested the usage altitude-independent scale factor and corrections in the humidity measurement from Vaisala RS80H radiosonde. As in nowadays, RS80 is the most used device; its performance was evaluated in operational usage comparing with more sophisticated humidity sensor [2-4]. Radiosondes, radiometers and GPS receivers have been used in the validation of the new techniques of humidity measurement, as solar radiometer [5] and humidity sounding satellite [6] and are used in experiments with intensive water vapor observation periods [7] to characterize and improve the accuracy of the water vapor measurements.

The main goal of this study is to characterize the quality of humidity measurements from radiosondes and analyze the quality of the IWV content obtained from remote sensing techniques with relation to the radiosonde measurement.

Section 2 describes the two experiments and section 3 presents the intercomparison results from the radiosonde and IWV contents from different remote sensing techniques. Section 4 summarizes the main results.

2. DETAILS OF THE EXPERIMENTS

2.1 Radiosondes Intercomparison Experiment

The radiosonde humidity sensor intercomparison was carried out under the WMO experiment at the Brazilian Air Force Satellite/Rocket Launch Center (CLA), which is located at latitude 2°18'S and longitude 44°22'W and 49 MSL. The experiment lasted 18 days, beginning on May 21st and finishing on June 7th, 2001, which 3 or 4 radiosondes were launched all together 4 times a day in each one of the 43 flights made during the experiment. The arrangements for launching of the radiosondes were done in order to compare the measurements from different sensors available operational radiosondes. The radiosondes participating in this experiment were: RS80 and RS90 Radiosondes (Vaisala Oyj-Finland) using a sensor of type thin-film capacitive; MKII Radiosonde (Sippican Inc.-USA) applying an humidity sensor called “hygristor”; GL-98 Radiosonde (MODEM-France) with humidity sensor of the capacitor type; DFM-97 Radiosonde (Graw Radiosondes GmbH & Co. KG-Germany) using capacitive polymer chip-sensor; and SW humidity Sensor (Meteolabor-Switzerland), which is based on the physically chilled-mirror principle to measure water vapor concentrations. The flights were arranged in such a way that GL-98 and DFM-97 were placed with MKII, RS80 or RS90. The SW humidity sensor was launched attached to the MKII radiosonde. Additional details of this experiment and data processing can be obtained from [8].

2.2. IWV Intercomparison from Multi-Sensor Experiment

The IWV intercomparison experiment began on September 12th and finished on November 3rd, 2002. This experiment was part of the RACCI/LBA experiment [9]. The sites involved in the IWV comparison experiment are denominated by Abracos (latitude 10°45’S and longitude 62°21’W and 281 MSL), Guajará Mirim (latitude 08°42’S and longitude 63°53’W and 182 MSL) and Porto Velho (latitude 10°45’S and longitude 65°18’W and 116 MSL), hereafter called ABRA, GJMI and PTVE station, respectively. 467 radiosondes RS80 (Vaisala Oyj-Finland) were released in the IWV comparison experiment, which 214 launched in ABRA, 143 in GJMI and 110 in PTVE. The CIMEL CE-318, Sun-Sky photometer from AERONET (AErosol RObotic NETwork) was installed in ABRA station [11]. The humidity values from the satellite were obtained from the Humidity Sounder for Brazil (HSB) [12] flying on board AQUA satellite. The GPS receivers were distributed as follow: the ASHTECH brand, ZXII model was installed in ABRA station and two TOPCON brand, LEGACY model were installed in GJMI and PTVE stations. Additional details of this comparison experiment and collected data processing can be obtained from [10].

3. Analysis of the Results

Basically we have used the tendency and dispersion to analyze the consistency of the radiosonde measurements from intercomparison experiment and for the IWV analysis from multi sensor comparison experiment.

3.1 Results from the radiosondes intercomparison experiment

Due to the absence of a reference humidity data, the sensor’s performances are presented as a function of the RS80 values. The RS80 was chosen because it is currently the most used radiosonde for operational purposes. Besides, it participated in all flights accomplished in the experiment. In this analysis three layers were defined: the first layer includes the lower levels of the troposphere (from the surface to 3 km); the second layer includes the medium levels of the troposphere, between 3 and 8 km; the third layer includes the highest levels of the troposphere and the beginning of the stratosphere, starting at 8 km up to the end of the vertical profile.

Figure 1 gives the bias and RMS values of the RH sensors as a function of the RS80 sensor values. The number of samples considered in each comparison is presented in the Table 1.

In the first layer the RS80 RH mean value is smaller than those from other sensors (Figures 1a, 1b, 1c and 1e), with the exception of the DFM-97 sensor values (Figure 1d). In this layer GL-98 has nearly no bias (Figure 1c);

In the second layer, the low bias values indicate the lack of tendency among the different radiosondes. An exception is observed between the RS80 and MKII, where the latter presents smaller values than the RS80 in that layer. However, a large dispersion is observed between such radiosondes (Figure 1b). Despite the tendency among these radiosondes being small, the RMS values in this layer indicate a larger dispersion than those observed in the first layer;

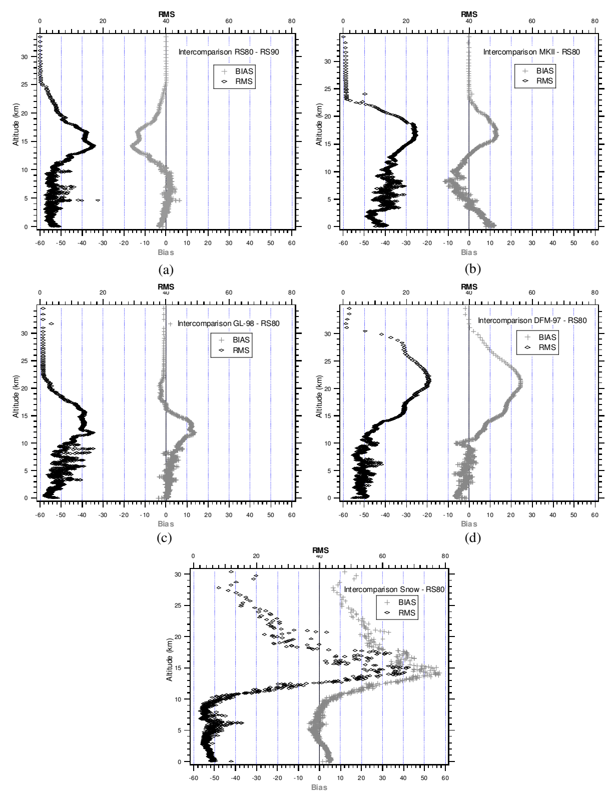

Figure 1 - Bias and RMS values for different altitude as a function of the RS80 RH values.

The largest dispersion of the RH is noticed in the third layer. In this layer, the RS80 RH mean value presents a tendency to underestimate the RH. It presents smaller values than those generated by the other sensors.

Table 1 shows a quantitative analysis of the bias and RMS values (given in %RH) concerning the RS80 and in comparison to the other sensors as well as of all the possible combinations of radiosonde sensors. In summary, the values presented in Figure 1 and Table 1 suggest the following: (1) the RS80 RH sensor presents a tendency to underestimate

Table 1 - Bias and RMS (%RH) for the vertical profile of radiosonde measurements, at the three selected layers.

Comparison	Flight Number	Bias (%RH)			RMS (%RH)		
		1st layer	2nd layer	3rd layer	1st layer	2nd layer	3rd layer
RS90 - RS80	18	+1.47	-1.12	+5.57	3.49	4.37	8.01
MKII - RS80	33	+7.44	-2.47	+0.33	10.18	14.03	15.29
GL-98 - RS80	20	+0.82	+1.89	+5.27	4.12	7.23	9.96
DFM-97 - RS80	16	-3.95	-1.34	+8.10	5.89	6.23	12.95
SW - RS80	16	+3.57	-1.11	+22.24	5.05	5.30	28.32
MKII - RS90	19	+7.26	-2.52	-4.37	9.89	14.09	14.54
GL-98 - RS90	13	-1.49	+1.32	-2.58	3.82	5.34	8.61
DFM-97 - RS90	8	-4.06	+0.19	+3.15	6.96	7.33	12.01
SW - RS90	18	+1.98	-0.08	+14.97	4.63	7.77	22.63
GL-98 - MKII	19	-7.43	+3.86	-5.31	10.09	12.53	17.73
DFM-97 - MKII	15	-9.56	+2.15	+5.37	12.91	16.88	15.67
SW - MKII	16	-5.32	+2.58	+20.82	8.39	16.79	29.16
SW – GL-98	10	+5.58	-0.30	+22.75	7.44	9.98	30.36
SW - DFM-97	7	+4.59	-2.59	+7.97	6.05	7.93	19.78

the humidity in the low and high troposphere and the layer above the latter; (2) the RS90 presents RH values which are more similar to most sensors available than the RS80; (3) the MKII overestimates RH in the low troposphere and presents quite dispersive RH values in the low and medium troposphere; (4) the RS80, RS90 and GL-98 presented RH values with good agreement in the three layers; and (5) the SW sensor values presented good agreement with these radiosondes below 10 km and the largest tendency and dispersion above this layer.

Sapucci et al 2005 performed a comparison separating the radiosonde into day and night periods, in order to evaluate the humidity sensor's sensitivity to solar radiation heating. The results obtained show that the RS80 during the night underestimates the RH in relation to the other radiosondes for higher RH values (larger than 75 %). Solar radiation is an important factor that needs special consideration in the humidity sensors' measurements and the radiosonde manufactures have studied a strategy to eliminate its effects on RH values [2]. The solar radiation effects are clearly seen in the day and night analysis and they are probably responsible for most of this behavior. IWV values analysis during day and night period carried out in the ARM experiment using microwave radiometer and RS80 radiosonde suggested that daytime radiosondes are typically 3%-4% drier than nighttime radiosondes [13]. If we consider differences between the traditional radiosonde measurements and the SW, that measures humidity in a completely different way (it uses chilled mirrors) and the good performance of SW in the lowers layers where mostly humidity is concentrated, we observe a diurnal drier behavior of order of 5.9% for RS80, 4.5 % for RS90, 1.4 % for MKII and 7.1 % for GL-98.

3.2. Results from IWV intercomparison techniques from multi-sensor

Different IWV quantification techniques were intercompared, except for the HSB vs CIMEL, because only few measurements were coincident between satellite and AERONET. Also, HSB vs RS80 was not intercompared because radiosondes were used to adjust regression from IWV and HSB.

CIMEL solar radiometer comparison with RS80 radiosondes. In order to know the dispersion between IWV values from CIMEL and RS80 radiosonde, Figure 2 presents the scattering diagram of 37 data pairs obtained in ABRA station. We clearly see an overestimation of the IWV values derived by CIMEL when compared with RS80 values. The Standard Deviation (S.D.) (2.0 kg m^{-2}) values is much smaller than bias (+6.4 kg m^{-2}) value, which reveal that systematic error is present in this comparison. The good agreement between both measurements is well described by the high correlation coefficient (r) of 0.93. The reason for such a large bias is probably related to the worst performance of the sun photometer instruments to derive IWV values in cloudy condition, very typical situation in Amazon region. This instrument operates better in conditions with direct sunlight under clear-sky [5].

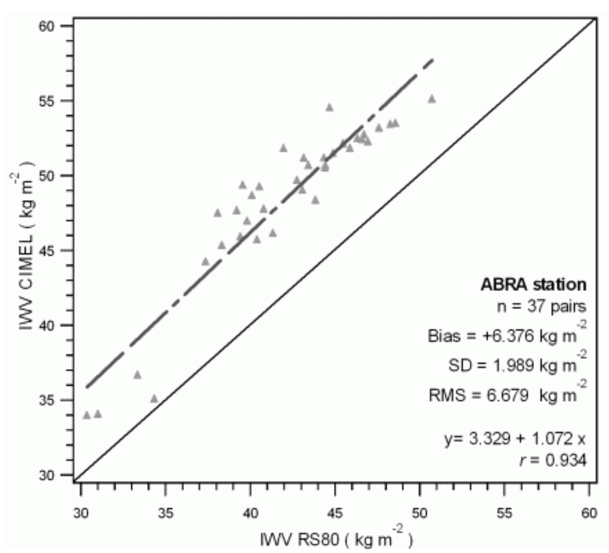

Figure 2 - Scattering diagrams of the CIMEL IWV values as function of the RS80 IWV values in ABRA station.

GPS comparison with CIMEL. Figure 3 presents the scattering diagram for GPS and CIMEL solar radiometer.

This figure shows that IWV values from GPS tends to generate smaller absolute values than those obtained with solar radiometer (bias of -2.33 kg m^{-2} or 4.5 %) as suggested by the former intercomparison. One can note that this tendency increases when IWV become larger. When the IWV values are smaller than around 38 kg m^{-2}, there is nearly no tendency and the dispersion is very low. The possible explanation for this behavior is that the situations of low IWV values are strongly correlated with clear sky situation when sun photometer has the best performance to measure the IWV. However, as IWV increase, increases the probability to have more clouds and the IWV measurement by SIMEL is successively degraded. Figure 2, also shows the same behavior, with lower bias for low IWV values.

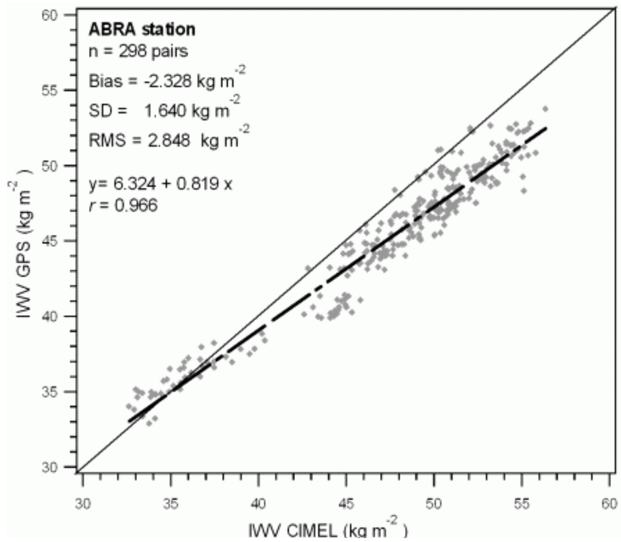

Figure 3 - Scattering diagrams of the GPS IWV values as function of the CIMEL IWV values in ABRA station.

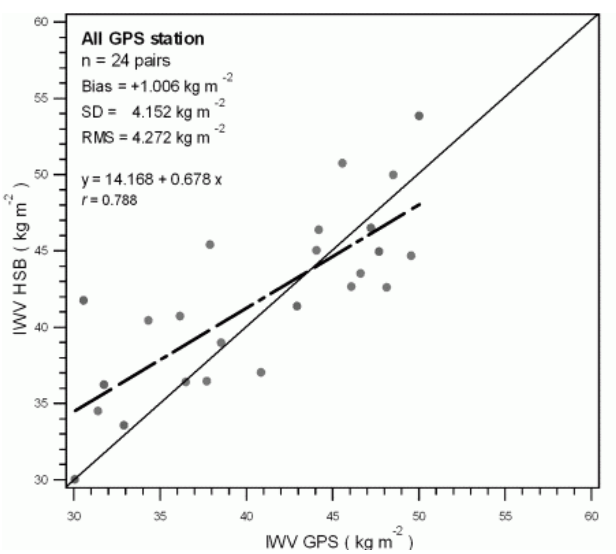

Figure 4 - Scattering diagrams of the HSB IWV values as function of the GPS IWV values in the RACCI GPS stations.

HSB sensor comparison with GPS. The results obtained in the comparison between IWV values from GPS and HSB sensor are presented in the Figure 4. HSB IWV values are slight higher than GPS IWV (bias of 1.0 kg m^{-2} or 2%), however, the dispersion is very large (S.D. of 4.15 kg m^{-2} or 8.1 %). The correlation between both values is 0.78 revealing this larger dispersion discussed before. The HSB can give a very good precision in the description of the humidity value in the higher atmosphere, however, the precision to describe the humidity field in the lower levels, where the large amount of water vapor is found, is very compromised due to the HSB channel sensibility to the ground emissivity and temperature.

GPS receiver comparison with RS80 radiosondes. The Figure 5 shows the GPS IWV content vs. IWV RS80 scattering diagram. This figure reveals that GPS technique to quantify IWV content also overestimate with relation to the RS80 radiosonde. The bias values is 2.83 kg m^{-2}, the RMS is 3.75 kg m^{-2} and the correlation equal to 0.87. This diagram shows the results for all GPS station and differences in the Bias and RMS was found, but in this study we will not explore this feature. These results show that all remote sensing technique overestimate the IWV, GPS seems to be the best indirect technique to describe IWV. Preliminary results show better results during the nighttime than during the daytime. It is probably because GPS signal is more affected by Ionospheric effects, during daytime due to the solar radiation. This effect tends to dryer the IWV GPS value. Even though, when the analysis is performed only for nighttime a smaller but still dryer bias is observed. Table 2 summarizes the results from all techniques described in this study for measuring IWV. This table shows that the lowest tendency was found in the HSB sensor and GPS receiver (1.0 kg m^{-2}) and the lowest dispersion was found in the comparison between GPS and RS80 (2.9 kg m^{-2}) in PTVE station and also GPS and CIMEL (2.8 kg m^{-2}), in which the largest correlation coefficient was obtained (0.966).

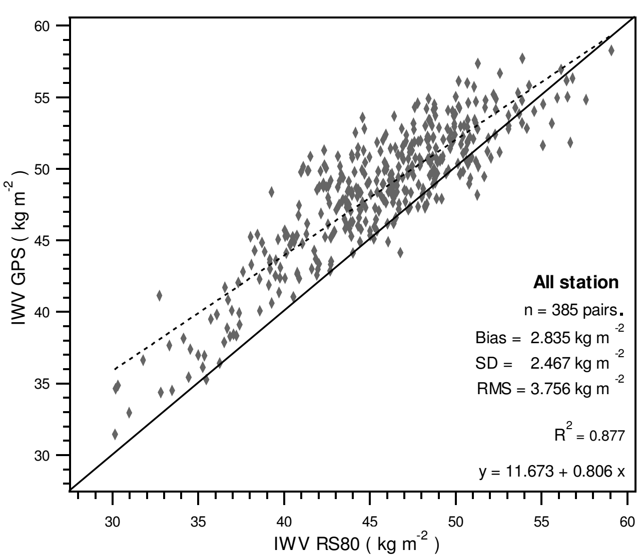

Figure 5 - Scattering diagrams of the GPS IWV values

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Table 2 - Statistical measurements and coefficients values generated in the several comparisons between different IWV quantification techniques used in the RACCI experiment.

Comparison	Number of considered data pairs	Statistical measurement (kg m^{-2})			Coefficient		
		Bias	*S. D.*	RMS	Correlation	Slope	Intercept
CIMEL – RS80 ABRA	37	+6.376	1.989	6.679	0.934	**1.072**	**+3.329**
GPS – CIMEL ABRA	298	-2.328	**1.640**	**2.848**	**0.966**	0.819	+6.328
HSB – GPS All station	24	**+1.006**	4.152	4.272	0.788	0.678	+14.168
GPS – RS80 ABRA	167	+3.167	2.463	4.012	0.857	0.784	+12.826
GPS – RS80 GJMI	121	+3.279	2.354	4.037	0.902	0.948	+5.545
GPS – RS80 PTVE	97	+1.710	2.281	**2.851**	0.791	0.678	+17.597

4. SUMMARY AND CONCLUSIONS

In order to characterize the quality of humidity measurements in the Brazilian equatorial region, this paper presents results from radiosondes intercomparison experiment, held in October 2001 in Alcantara, Maranhão state, and an intercomparison experiment of the different IWV quantification techniques, held in Amazonia region in September 2002.

The results of radiosonde intercomparison experiment show the RH sensors presenting similar results with small tendency and low dispersion where humidity concentration is larger (up to 3 km). In intermediate layers, from 3 to 8 km, the humidity sensors present a small bias, but larger dispersion than in the first layer. However, in the layer above 8 km the largest disagreement among the humidity measurements is observed, due to the dispersion and tendency of the measurements being very high. The RS80 RH sensor presents a tendency to underestimate the humidity in the low and high troposphere and the SW sensor values presented good agreement with these radiosondes below 10 km and the largest tendency and dispersion above this layer.

Related to the IWV content intercomparison, results show that all remote sensing techniques overestimate the values obtained by RS80 radiossonde. IWV from GPS values overestimates the IWV by 2.3 kg m^{-2} with relation to the CIMEL photometer (4.5 %). HSB sensor IWV results are higher by 1.0 kg m^{-2} (1.9 %) when compared with GPS IWV tecnhique. The bias values generated in the comparison between GPS and RS80 reveal the GPS receivers overestimate humidity. The radiosonde intercomparison results shows that RS 80 normally underestimate the RH, therefore, it is possible that the performance observed above is reason of the RS 80 dryer behavior.

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