Relative Humidity Sensor Intercomparison in Tropical Region

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ABSTRACT

The quality of the humidity vertical distribution measurements in the atmosphere has essential importance due to crucial role that the water vapor plays in the energy swinging on Earth. The radiosonde, among the available humidity measurement techniques, is the unique direct measurement technique and is the one that supplies the best vertical resolution. Several intercomparison experiments have been carried out by WMO (World Meteorological Organization) with the aim of investigating the potential of this technique in different climatic areas. This article presents the results of one experiment accomplished in Brazil, in which the main radiosonde manufacturers were involved. The main goal of this experiment is to evaluate the different humidity sensors performance in tropical areas. The results showed that the humidity measures accomplished by the different sensors are quite similar in the low troposphere and quite disperse in the superior layers. Moreover, the absence of humidity values that may be considered as reference turned out the evaluation of the humidity sensors performance very difficult in the high troposphere.

1. Introduction

The low latitude areas present low temperature space variation and low pressure space variation and great variety in the humidity fields due to the intense convective processes in those areas associated to the great humidity potential generated by high temperatures. This high concentration and variety of the water vapor in the tropical atmosphere make the quality of the humidity measurement to have special importance to climatic change studies and weather forecasts. The atmospheric water vapor is associated to latent heat liberation and plays an important role in the atmosphere general circulation, hydrologic cycle and in the cloud formations, besides being involved in the main atmospheric phenomena.

Although there are several measurement air humidity profile techniques, the radiosonde is still the only technique that accomplishes the measurements in a direct way, unlike the other remote sensing based techniques. The intercomparison experiments among several radiosondes of different manufacturers permit verifying the potential of this instrument. At world level, the radiosondes are the operational devices used to measure the atmospheric water vapor vertical profile. Several intercomparison experiments of different radiosonde manufacturers were accomplished with the objective of evaluating the humidity measurement quality of the different sensors (Ivanov et al., 1991; Yagi et al., 1996; Schimidlin, 1998).

An experiment was accomplished in the Virginia State (USA) during September 1995, where main radiosonde manufacturers were involved (Schimidlin, 1998). In that experiment, several recommendations were made for the radiosonde manufacturers and users with the aim of providing improvements in the production and a better performance in usage. The results obtained turned out evident the importance of intercomparison experiment for the improvement of that technique. Experiments with intensive water vapor observation periods in 1996 and 1997 involving several techniques of relative humidity measurements were accomplished inside the ARM Program’s (Atmospheric Radiation Measurement Program) (Revercomb et al., 2003). These experiments main goal was to characterize and improve the accuracy of the water vapor measurements. ARM Program’s experiments used the radiosondes together with a dual-channel microwave radiometer, solar and infrared radiometer and spectrometers and a two-frequency Global Positioning System (GPS) receiver for providing absolute water vapor measurements. The results showed a significant variability in the Vaisala RS80H radiosonde measurements of same calibration batches and that an altitude-independent scale factor in the low troposphere can be used to reduce this variability. The RS80 radiosonde was object of several research paper studies to evaluate the needs for corrections in their results due to the contamination of the capacitive element humidity sensor by chemical substances (Wang et al. 2002;

Meloshevich et al., 2001; Guichard et al. 2000; Miller et al. 1999). Other research papers sought to evaluate the humidity sensor performance of the RS80 after applying corrections in their results and the accuracy and performance of the Vaisala RS90 radiosonde during operational use (Wang et al., 2001; Paukkunen et al., 2001). RS80 was also used to evaluate the performance of "Snow White" sensor in an intercomparison experiment accomplished at five tropical stations during different seasons in 2000-2001 (Fujiwara et al., 2003). The Snow White and RS80 sensors showed reasonable agreement only in the middle troposphere. In the other layers there was a bias characterizing the dry bias error of RS80 due to the sensor humidity contamination.

A radiosonde intercomparison experiment promoted by WMO was accomplished in Brazil during 2001 aiming to study the humidity sensor peformance in the tropical areas. The main radiosonde manufacturers participated in the experiment: Dr. Graw Messgeraete GmbH&CO (Germany), Geolink (France), Sippican Inc. (USA) and Vaisala (Finland). Vaisala participated with two radiosonde models: RS80 and RS90. The humidity sensor Meteolabor "Snow White" (Switzerland) also was used in this experiment because it presents the chilled-mirror technique to measure water vapor with the intention of supplying the reference values to evaluate the radiosonde performance. The aim of this work is to evaluate the performance of the different humidity sensors in tropical regions. This evaluation was performed in different atmospheric layers and in different periods of the day.

2. Experiment

The Humidity Sensor RSO Intercomparison was carried out at the Brazilian Air Force Satellite/Rocket Launch Center (CLA), at the Alcântara City, situated in Maranhão State, Brazil. The experiment was performed at the meteorological station of CLA, which is located at the latitude 2° 18’ South and longitude of 44° 22’ West.

The experiment lasted 21 days, beginning on May 21st and finishing on June 7th, 2001. The official flights occurred 4 times a day, at 00 UTC, 06 UTC, 12 UTC and 18 UTC, as indicated in Table 1. This table shows radiosonde combinations accomplished in each one of the 43 flights made during the experiment. The Snow White humidity sensor was launched attached to the MKII radiosonde.

To hold up the balloon, unwinder, a parachute and 3 or 4 radiosondes flying all together were used with a rig structure consisting of 1 or 2 PVC pipes. These rig structures are shown in the Figure 1. The rig varies according to the launchings with 3 or 4 radiosondes. Additional details of this experiment can be obtained from SILVEIRA *et al.*, 2003.

2.1. Humidity sensor details

A brief description of each relative humidity sensor participating in this experiment is given below, in which is presented the most important details of the involved radiosondes.

RS80 Radiosonde (Vaisala Oyj-Finland): the relative humidity sensor is the Vaisala H-Humicap. This sensor is a thin-film capacitive using a highly porous polymer electrode, which capacitance depends on the amount of water vapor and on air temperature. The measurement range humidity is, given by manufacturer, of from 0 to 100 %. Typically, the RS80 samples relative humidity data is given at intervals of approximately 1-2 seconds;

RS90 Radiosonde (Vaisala Oyj-Finland): the RS90 relative humidity sensor is the Vaisala H-Humicap, the same RS80 sensor, but the measurement method is different. The humidity sensor RS90 consists of two sensor elements alternately heated and cooled during the flight. This sensor is heated to eliminate moisture that may form on the polymer surface when the radiosonde crosses the clouds. While an element is heated, the other measures the relative humidity alternating during the flight. The measurement range is from 0 to 100 % with a resolution of 1 %;

MKII Radiosonde (Sippican Inc.-USA): the relative humidity sensor is a polymer strip coated with a carbon slurry called “hygristor”. The MKII sensor operates on the resistance principle whereby increases as atmospheric moisture decreases. The space between the carbon molecules increases or decreases as the relative humidity changes, leading to a change in resistance. The hydristor measures between 5 to 100 %. The humidity data are available approximately every 1.3 seconds;

GL-98 Radiosonde (Geolink -France): the relative humidity sensor is a capacitor type with measurement range from 0 to 100 %. The measurement humidity GL-98 resolution and absolute accuracy are 0.1% and 5%, respectively. The response time of this sensor is smaller than 2 seconds;

DFM-97 Radiosonde (Dr. Graw Messgeräte GmbH & CO-Germany): the DFM-97 relative humidity sensor is a capacitive polymer chip-sensor protected against heating and water ingress by a mirrored capsule. This sensor presents humidity measurement error smaller than 5% with a resolution of 1%.

SW Relative Humidity Sensor (Meteolabor-Switzerland): this sensor is a hydrometer named Snow White, based on the physically chilled-mirror principle to measure water vapor concentrations. There is an electric system to maintain the mirror temperature at the dew-point temperature of the environment. The SW flew connected to other radiosonde to share the data transmitter and temperature measurements.

3. Data processing and method

This section describes the procedures used in the experiment at the post-processing stage. The first step was to set up a data set sampling at 2 seconds rate for all flights. These observations were linearly interpolated to this value. Thus, the GL-98 and the MKII observations, which were at a rate of 1.0 second, were interpolated. The second pre-processing step was the offset adjustment time of all observation. As the radiosondes committees the time is the parameter common to all of the equipments participating in the same flight. Therefore, the intercomparison analyses are realized as function of time. However, due to the specific system of the each radiosonde, the start of the flight is not even for all sensors, a small offset adjustment time was necessary. This adjustment is described as follows.

An objective technique was used to adjust the time setup of all set of radiosondes. This technique considers the following points:

- The temperature is the radiosonde measurements that better agree among the different types of radiosondes. Thus, it was decided to use the temperature as the parameter to guide the offset time adjustment;

- The Vaisala RS80 was the radiosonde that participated in all flights. Then, the RS80 temperature profile was used as reference to adjust the time offset of the other radiosondes. Considering that, this procedure only adjusts the time offset, there is no implication in the results of the radiosonde comparison due to the consideration of RS80 as a reference;

– The maximum time offset was considered in the time interval of about to be at maximum 20 seconds. This time step value was defined to be larger than the largest time offset occurring during the radiosonde trial, in order to assure the best adjustment;

– The time offset was adjusted considering only the average time to the radiosonde to cross a layer slightly larger than the mixed layer, i.e., 160 seconds. The layer included the mixed layer and few meters higher has a larger temperature dynamics (temperature changes with height). The use of this layer assures to have a good adjustment without including all the radiosonde patches that probably add time offset due to the specific radiosonde system.

Based in the methods described above it was applied a mean squared error algorithm to the temperature profile, with about 20 seconds lag, for each flight between RS80 and each other radiosonde participating of the flight. The minimum time lag absolute error was considered as the time offset of each sonde with relation to the RS80 flight. An example of this approach applied to one of the flights is shown in figure 2.

The relative humidity measurements from SW were pos-processed using RS90 temperature. Moreover, it was applied a quality control process to exclude spurious values. This pos-process SW data were carried out by the UK office.

The comparisons among the different radiosondes launched in the same flight were accomplished using as reference the ascension time. However, that reference cannot be used to accomplish a single analyzis which contains the humidity values obtained in different flights. That is due to the fact that in a same ascension time the altitude cannot be the same among the different flights, because the ascension rate of the balloons are not equal. To solve this problem, the humidity values from different sensors were referred in the pressure values before to be compared with the generated results by other flights. The humidity measures were interpolated for the vertical profile pressure values with intervals of 1mBar. In the above levels, not only the medium values were calculated but also the measures of tendency (Bias) and measures of dispersion (RMS). Such measures were associated to the RS80 radiosonde altitude values, because that radiosonde participated in all flights.

3.1. Available data

From the 43 radiosondes flights only two flights were cancelled. Flight 33 with RS80, RS90, MKII, DFM-97 and SW sensor was cancelled because just 2 minutes prior to the launching, a heavy storm happened and the balloon was not able to be lifted with the radiosondes. Flight 37 balloon with RS80, RS90, MKII, DFM-97 and SW sensor did not ascend properly, staying between 200 and 400m for 20 minutes due to strong rainfall that happened prior to launching. This flight was also cancelled. Some of the RS80, RS90, MKII and SW humidity data presented clear technical problems and they were excluded in order to not commit the statistic analyzes (see Silveira et al. (2003) for specific details).

A reference humidity sensor was employed to evaluate the performance of the different radiosonde systems. Therefore the SW chilled mirror hygrometer sensor was used in the RSO experiment and flew interfaced to MKII, as a way to obtain reference values for the humidity. However, as we shall observe, this sensor presented large dispersion and bias at high levels, when compared to the radiosonde measurements. This disagreement could be an indication that it would be capable of detecting small variations on humidity, unnoticeable to the radiosondes. But, it could also be due to technical problems. Therefore, it is important to stress that this fact put in risk the use of the chosen reference, mainly at high levels, as its values are doubt.

Due to the absence of a reference humidity data, the other sensor performances are presented as function of RS80 values. The RS80 was chosen because it participated in all flights accomplished in that experiment. Besides this, nowadays the RS80 is the most used radiosonde for operational purpose and many researches have been developed to reduce and eventually remove errors present in this sensor (Wang et al., 2003).

Table 2 describes the flights number available during this experiment for each radiosonde system, and it presents the number of flights available for an intercomparison. Table 2 shows that MKII humidity sensor presented the largest number of flight with technical problems than the other sensor. It was a problem because SW sensor flew attached to it.

Whereas the others radiosondes continually measured the humidity during most of the soundings, the MKII had a large amount of interruptions and it registered null values while the other radiosondes did not. This happened in the Flights 29, 30 and 32. These values were taking out of analyses.

4. Analyses of the Results

A first analyzis is regarding the medium profile of the relative humidity values from different sensors. In spite of the fact that the different radiosondes flights that have not occurred simultaneously and the amounts of flights have been different, the campaign medium profiles present a preliminary analysis of the medium behavior of the different humidity sensors involved in the experiment. Figure 3 presents the medium profiles of the relative humidity measured from different sensors as function of the altitude.

Figure 3 indicates that at low and medium levels of the troposphere (up to around 8000m), where the humidity concentration is relatively large, the sensors measurements presented low dispersion. This fact is not observed at high levels of the troposphere as the measurements are highly dispersed. Besides, at low levels, where there is high concentration of water vapor, the MKII radiosonde presents relative humidity values higher than those of the other radiosondes. Conversely, the DFM-97 radiosonde, presents values lower than the other. Summarily, for this first approach, MKII and DFM-97 overestimates and underestimates, respectively, the humidity with relation to the other radiosondes, at conditions of high concentration of water vapor. The point that draws attention in Figure 3 is the high dispersion at high levels, where it is clearly seen that there is no agreement amongst the radiosondes.

A tendency and dispersion analyses were applied to verify the accuracy of the radiosonde measurements. We have used the root mean squared error (RMS) as the dispersion measurement and the bias to account for possible tendencies. These statistical measurements were computed on level-to-level basis, for a combination of the available radiosondes, for the same flight and time and further converted to the RS80 pressure. The analysis was carried out using the height (converted from pressure using the average relationship). Moreover, in order to make the analysis easier, three layers were defined: The first layer comprising the low levels of the troposphere (from the surface to 3 km); The second layer comprising the medium levels of the troposphere, between 3 and 8km; The third layer comprising the high levels of the troposphere, starting at 8km till the end of the vertical profile.

Figure 4 gives the bias and RMS values of the relative humidity sensors as function of the RS80 sensor values. In the first layer, where humidity concentration is larger, the RS80 values are smaller than those from others sensor (GL-98 has nearly no bias in this layer); with exception of the DFM-97 sensor values. In the second layer, the bias values indicate the absence of tendency . An exception is observed between RS80 and MKII. MKII presents smaller values than RS80 in that layer. In spite of the tendency among these radiosondes to be small, the RMS values in this layer indicate a larger dispersion than those observed in the first one. The largest dispersion of the relative humidity is noticed in the third layer, where the RS80 values present a tendency of underestimating the relative humidity . It presents smaller values than those generated by the other sensors.

Table 3 gives a quantitative analysis of the mean bias and RMS values in comparison among RS80 and other sensors as well as of all possible combinations of radiosonde sensors. There is not any combination between GL-98 and DFM-97 because they were not launched together in any of the flights.

The values presented in the Table 3 show that radiosonde RS90 supplies more similar results to the other radiosondes than those obtained in the comparisons between RS80 and those same radiosondes. The bias values in the RS90 were smaller for the three appraised layers. The RMS values were also smaller in the comparisons that RS90 was involved, except for the comparison with the DFM-97 sensor, which presented smaller dispersion with RS80 in the first and second layer.

The numbers presented in Table 3 indicate that the MKII sensor, in the first two layers, presented a positive bias and the largest dispersion than values generated by the other radiosondes. In the third layer, the SW sensor presented larger tendency and larger dispersion. In the three layers the comparisons among RS80, RS90 and GL-98 sensors presented the smaller tendency and smaller dispersion. In spite of SW sensor present the largest bias and dispersion in the third layer, the BIAS and RMS values generated in the first and second layer, considering RS80, RS90 and GL-98, were too low.

In order to evaluate the humidity sensor sensitivity to solar radiation, the soundings were divided into day and night periods. This analysis was performed computing the average differences between RS80 and the other radiosondes in function to the relative humidity. Figure 5 brings the results of these comparisons. One can clearly note that RS80 during the night underestimates the relative humidity, in relation to the other radiosondes (except to the DFM-97) for higher values (larger than 75%). It is worthy to note that the dispersion from RS80 values is larger during the night than during the day. For values above 50% during the night and 70% during the day, the measurements were close to each other. As regarding to SW, for relative humidity values under those values, the sensor presented high dispersion in relation to the radiosonde measurements, regardless the period of the day.

Another analysis was to evaluate the humidity computations considering the variations of temperature. This is important as temperature is related to the maximum amount of humidity that an air porcion contains at the moment of the soundings and can also give additional information about the humidity sensors. Therefore, it was selected temperatures above 0°C as first analysis interval; temperatures between –25°C and 0°C as the second interval, and temperatures less than –25°C as the third interval. Figure 6 shows the bias as function of RS80 values for day and night periods, considering these selected intervals. Figures 6A and 6B show that for temperatures above –25°C during the day, the radiosondes RS90, RS80 and GL-98 provided values very close to each other, with the average bias close to zero. However, for low temperatures, below –25 °C, a higher dispersion is observed among the radiosondes. During the night, under temperatures above –25 °C, RS80, RS90 and SW measured the humidity very close and, as shown in Figure 6D, for temperatures above 0°C and close to 100% of humidity, the RS90 presented higher values. One reason for these high values did not appear during the day might be related to the radiation factor, which could compensate possible problems in the humidity sensor of RS90. As it was expected, at temperatures under –25°C, the radiosondes diverge more than any other levels. The humidity values computed by MKII and SW presented high dispersion, regardless the period of the day, and this fact is noticeable, as the temperature gets smaller.

Another analysis of the humidity sensor performance was regarding the integrated water vapor (IWV) total content in the atmospheric. The great divergencies in the relative humidity values presented in the dry layers have smaller significance to IWV values because it is an integrated measure. Consequently, the IWV values are less divergent. The IWV values were calculated from a numeric integration of radiosondes relative humidity values measured during the experiment. Flight 20 did not participate in this analysis due to technical problems in the humidity sensor in the levels close to the surface. This analysis was carried out for different atmospheric layers. A fourth layer was added to evidence the dispersion of the high levels. The third layer was subdivided in two layers, one between 8 and 15km and other above 15km.

Figure 7 presents the dispersion diagram among the IWV values from different radiosondes in function of the RS80 IWV values for the different appraised layers. The IWV values dispersion is gradually larger in the highest layers, as discussed previously. The scales of the different graphs of Figure 7 were altered to facilitate the result interpretations. The R^2 values indicate that the correlation among the IWV values generated from radiosondes humidity sensor is too high, mainly in the first three appraised layers. The R^2 values are above 0.9 in those first three layers, with exception of MKII radiosonde. In the fourth layer the R^2 values indicate low correlation among MKII, GL-98 and SW sensors. Only the RS90 and DFM-97 present correlation relatively good in that layer a.

Table 4 shows the IWV values among the humidity sensor of the evaluated radiosonde and RS80 humidity sensor for the four appraised layers. The tendency and dispersion measures show that the RS90 and RS80 humidity sensor present the most similar values, mainly in the first two layers where a humidity concentration is larger. In those layers the correlation factor is quite high and the BIAS and RMS values relatively low, in the order –0.6kg/m^2 and 1,3kg/m^2, respectively. The MKII sensor presented smallest correlation values with the RS80 sensor. In that comparison there was significant tendency and great dispersion, mainly in the first two layers. RMS generated to consider the whole profile was 4.6kg/m^2.

This value is three times larger than the dispersion resulting from the comparison between RS80 and RS90.

The GL-98, DFM-97 and SW sensors in comparison to RS80 values had performance intermediate to the two outstanding cases. Such sensors presented values with high correlation and RMS 2.2, 2.4 and 2.6kg/m^2 for the GL-98, SW and DFM-97 sensors, respectively. The GL-97 sensor generated a low BIAS in comparing to RS80 in the first layer. This fact should be noticed because this sensor presented smaller tendency in that first layer.

5. Conclusion

The results of this experiment show the sensors present similar results with small tendency and low dispersion where humidity concentration is larger (up to 3000m). In intermediate layers, from 3 to 8km, the humidity sensors present a small bias, but larger dispersion than in the first layer. However, in the layer above 8km it is observed a largest disagreement among the humidity measures, because the dispersion in the measures is very large and there is the absence of a reference value. Although this last layer present low humidity concentration, the radioactive effects turn out to have great relevance, because the small mass of water vapor present in those layers makes great impact in the infrared radiation absorption. Considering that fact, more sophisticated mechanisms should be used to evaluate the humidity measurement qualities in the atmosphere high layers. Experiments using such mechanisms should be accomplished in the future with the objective of providing improvements in the sensors sensibility in the small masses of water vapor and in the low temperature present in the high atmosphere.

In the first layer, the humidity measures from RS90 radiosonde and SW humidity sensors can be considered more reliable due to the low dispersion and tendency generated between these sensors. The more probable cause for this fact is the sophistication of the measurement mechanisms present in these sensors. If one considers those measurements as reference, it can be verified that the MKII sensor overestimates the humidity values in the first layer. Otherwise, the DFM-97, RS80 and GL-98 humidity sensors tend to supply values underestimated in those same circumstances. Among those, DFM-97 radiosondes is the one that presents the largest tendency of underestimating the measurements while RS80 and GL-98 present quite close values of RS90 in that layer.

In the analysis in the day and night periods was observed that the sensors present more similar measures during the day period and smaller bias values when the relative humidity was high. The largest tendencies, in both day and night period, were generated when the temperature was below -25° C.

In spite of the relative humidity values present great divergence, the integrated water vapor values presented small dispersion and small tendency, with exception just of the MKII sensor. The RS80 and RS90 sensors presented more similar results, with a RMS of only 1.3kg/m^2. The SW sensor presented low dispersion in the IWV values because the largest dispersion in the humidity values generated in this sensor occurred in the high levels, where the atmospheric water vapor amount is small.

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Figure Captions

Figure 1 - The rig structure used (a) for supporting 3 radiosondes and (b) used to sustain 4 radiosondes.

Figure 2 - Example of temperature profile without time offset adjustment (left side) and after time offset adjustment (right side).

Figure 3 - Average profiles of relative humidity computed from the radiosonde measurements.

Figure 4 - Bias and RMS values Vs altitude as function of RS80 relative humidity values.

Figure 5 - Average difference of relative humidity for day and night periods, as function of the RS80 relative humidity values.

Figure 6 - Average difference of relative humidity for day and night periods as function of RS80 humidity values considering temperatures above 0°C, from –25°C to 0°C and under -25°C.

Figure 7 - Correlation analyzes of the Integrated Water Vapor (*IWV*) values in the different layers of the radiosonde profile.

Tables

Table 1 - Launching times and radiosondes combination in the flight.

Launching times (UTC)			
0:00	6:00	12:00	18:00
RS80	RS80	RS80	RS80
MKII	MKII	MKII	MKII
SW	-	-	Snow
DFM-97	GL-98	DFM-97	GL-98
RS90	-	-	RS90

Table 2 - The comparisons available between RS80 and others humidity sensor.

Humidity sensor	Accomplished flight numbers	Canceled flight numbers	Flight numbers with sensor technical problems	Intercomparison number with RS80
RS80	40	2	1	…
RS90	25	2	1	18
MKII	43	2	6	33
SW	23	2	3	16
GL-98	23	0	0	20
DFM-97	19	2	0	16

Table 3 - BIAS and RMS average for the vertical profile of radiosonde measurements, at the three selected layers.

Comparison	BIAS (%)			RMS (%)		
	1st layer	2nd layer	3rd layer	1st layer	2nd layer	3rd layer
RS90-RS80	+1.47	-1.12	+5.57	3.49	4.37	8.01
MKII-RS80	+7.44	-2.47	+0.33	10.18	14.03	15.29
GL-98-RS80	+0.82	+1.89	+5.27	4.12	7.23	9.96
DFM97-RS80	-3.95	-1.34	+8.10	5.89	6.23	12.95
SW-RS80	+3.57	-1.11	+22.24	5.05	5.30	28.32
MKII-RS90	+7.26	-2.52	-4.37	9.89	14.09	14.54
GL-98-RS90	-1.49	+1.32	-2.58	3.82	5.34	8.61
DFM97-RS90	-4.06	+0.19	+3.15	6.96	7.33	12.01
SW-RS90	+1.98	-0.08	+14.97	4.63	7.77	22.63
GL-98-MKII	-7.43	+3.86	-5.31	10.09	12.53	17.73
DFM97-MKII	-9.56	+2.15	+5.37	12.91	16.88	15.67
SW-MKII	-5.32	+2.58	+20.82	8.39	16.79	29.16
SW-GL-98	+5.58	-0.30	+22.75	7.44	9.98	30.36
SW-DFM97	+4.59	-2.59	+7.97	6.05	7.93	19.78

Table 4 - BIAS and RMS values and correlation coefficients of the *IWV* regarding RS80 radiosonde in the different layers.

Radiosonde	Flight Numbers	Statistical Measurements	Layers (m)				Total Content
			0 to 3000	3000 to 8000	8000 to 15000	15000 to 30000	
RS90	18	BIAS	-0,787	0,186	0,012	-0,003	-0,591
		RMS	1,124	0,387	0,041	0,005	1,271
		R^2	0,973	0,994	0,993	0,879	0,976
MKII	33	BIAS	-3.497	0.159	0.113	-0.000	-3.229
		RMS	4.158	1.972	0.218	0.007	4.605
		R^2	0.823	0,896	0,791	0,487	0,867
GL-98	20	BIAS	-0.578	-0.187	-0.064	0.004	-0.822
		RMS	1.696	0.542	0.073	0.006	2.202
		R^2	0.947	0,990	0,995	0,461	0,907
DFM-97	16	BIAS	1.979	0.279	-0.006	-0.057	2.194
		RMS	2.198	0.547	0.029	0.112	2.565
		R^2	0,966	0,991	0,990	0,937	0,972
SW	16	BIAS	-1.725	0.197	-0.062	-0.025	-1.607
		RMS	2.186	0.594	0.080	0.047	2.413
		R^2	0,942	0,984	0,992	0,581	0,940

Figures

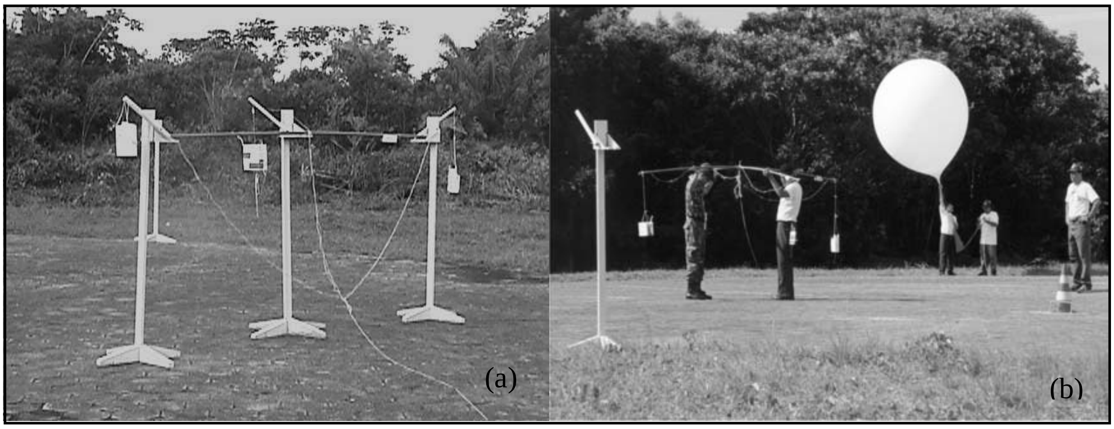

Figure 1

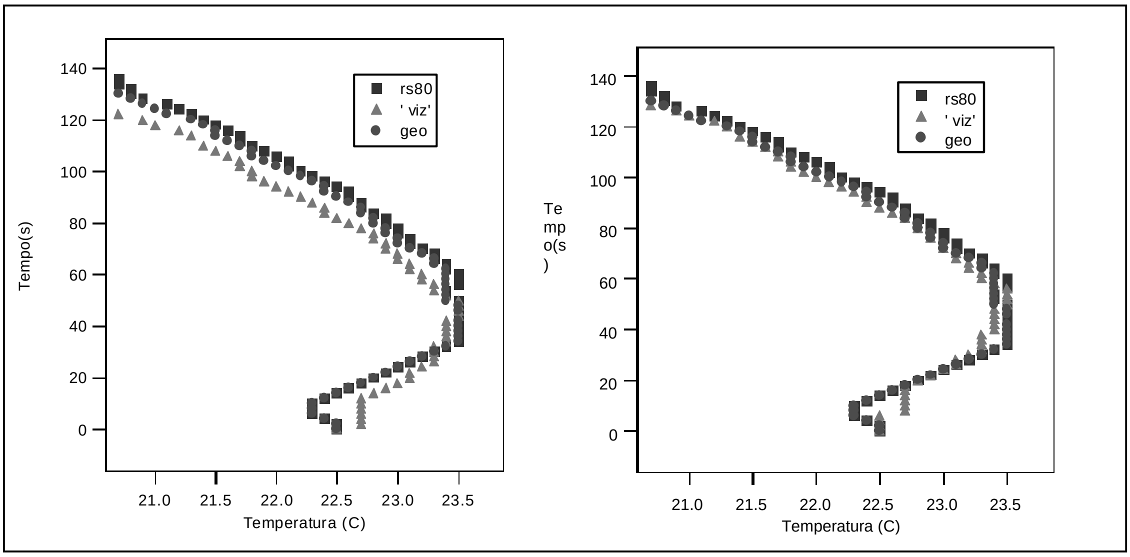

Figure 2

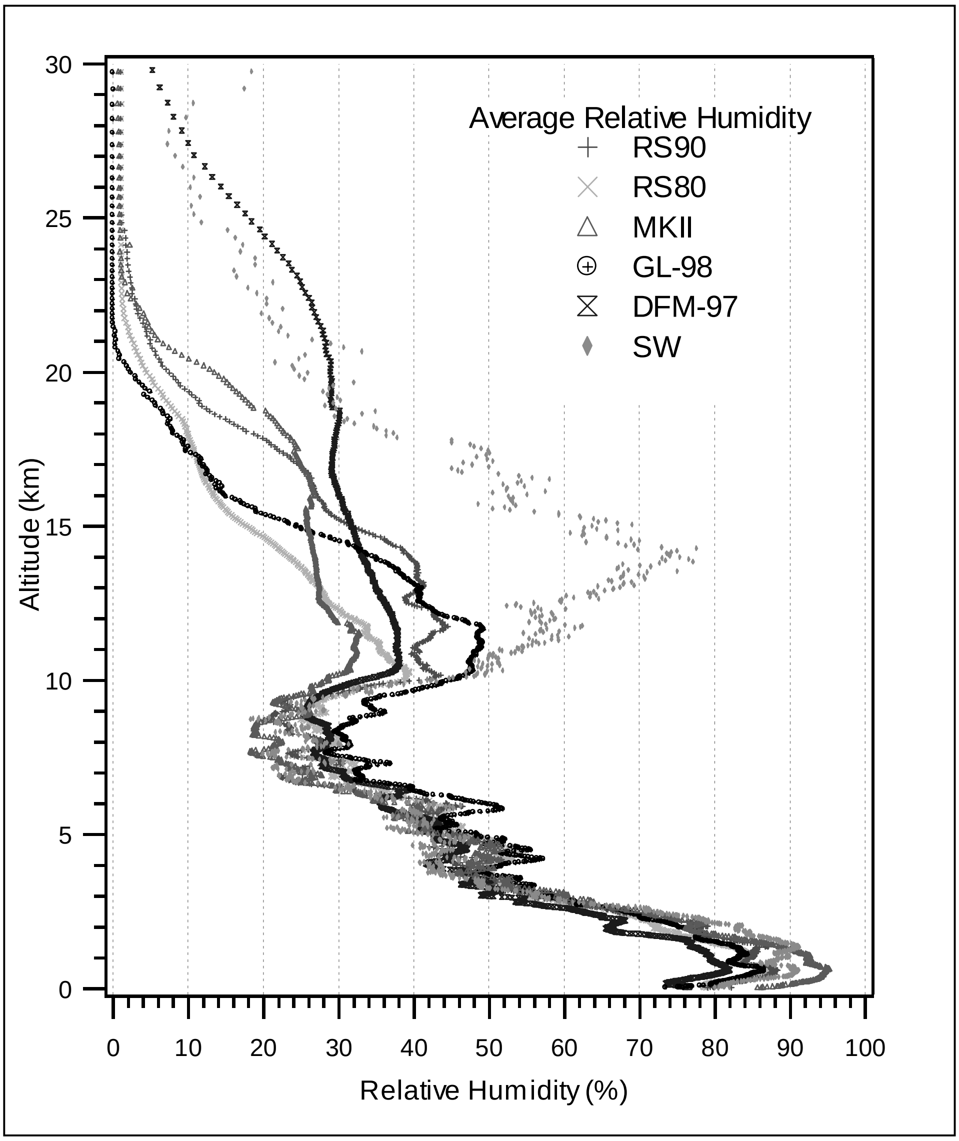
Average Relative Humidity
RS90
RS80
MKII
GL-98
DFM-97
SW
Altitude (km)
0
5
10
15
20
25
30
Relative Humidity (%)
0
10
20
30
40
50
60
70
80
90
100

Figure 3

Figura está em um arquivo doc separado.

Figure 4

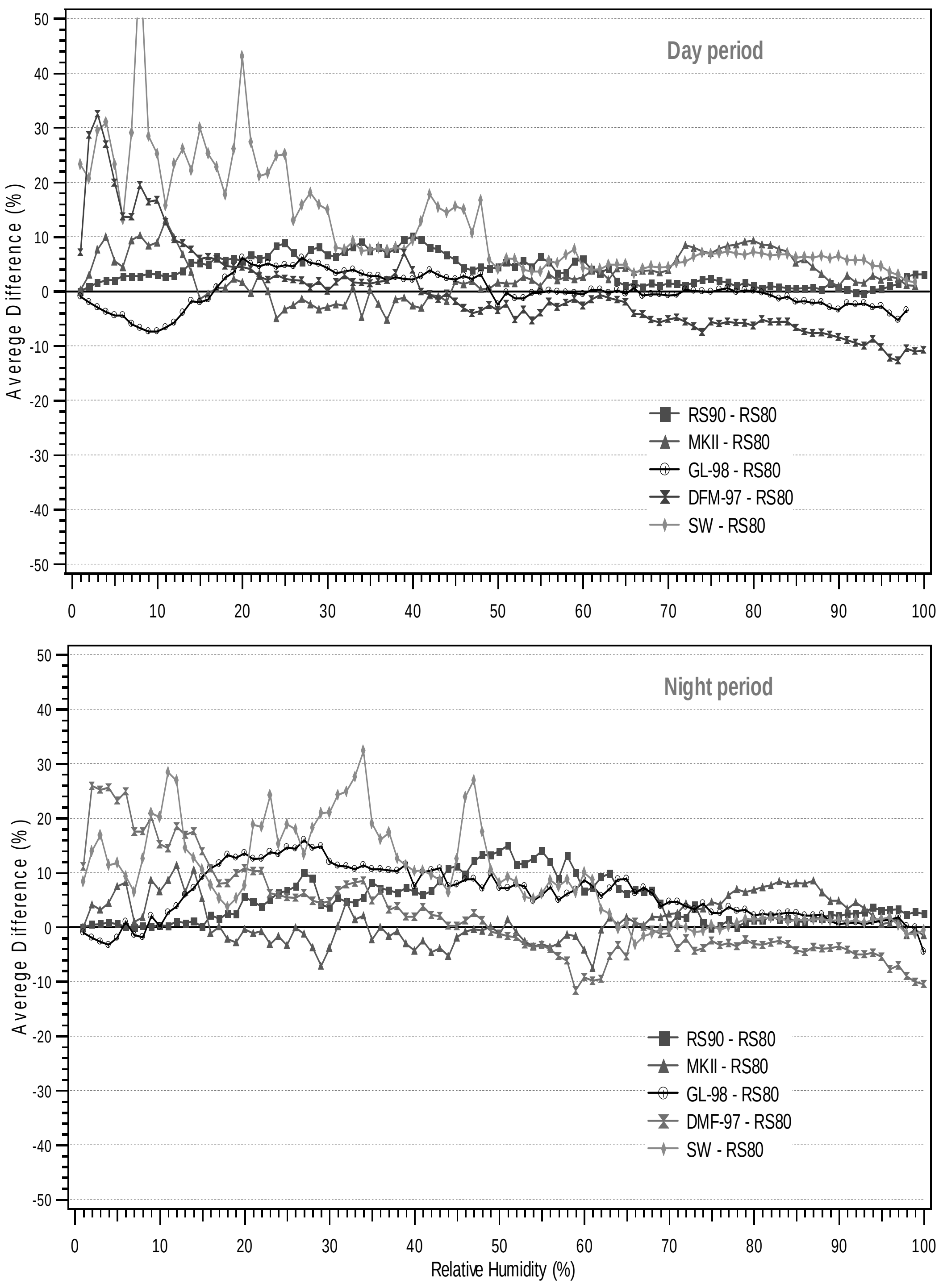
Day period
Averege Difference (%)
50
40
30
20
10
0
-10
-20
-30
-40
-50
RS90 - RS80
MKII - RS80
GL-98 - RS80
DFM-97 - RS80
SW - RS80
0
10
20
30
40
50
60
70
80
90
100
Night period
Averege Difference (%)
RS90 - RS80
MKII - RS80
GL-98 - RS80
DMF-97 - RS80
SW - RS80
Relative Humidity (%)

Figure 5

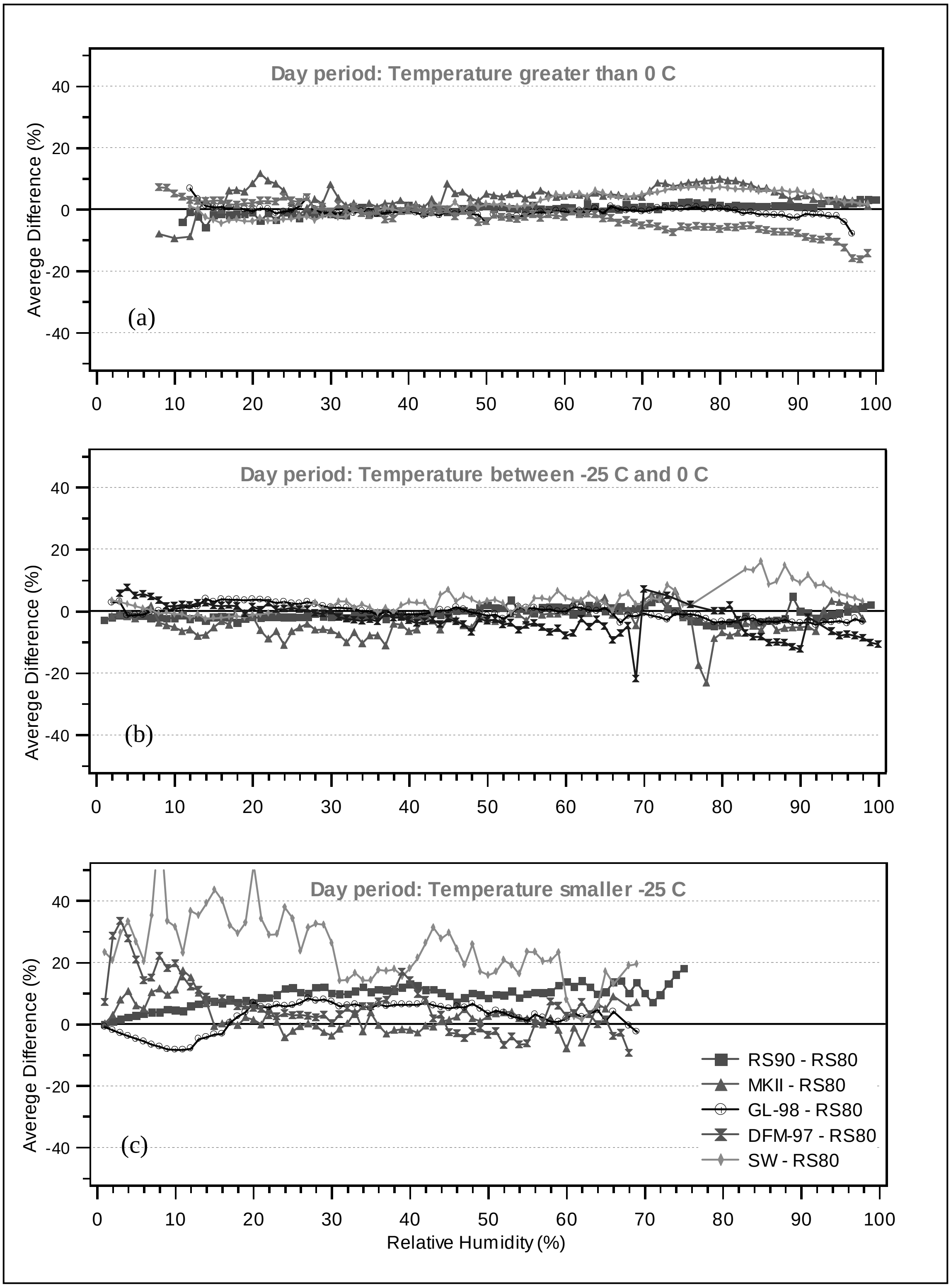

Figure 6 (a, b and c)

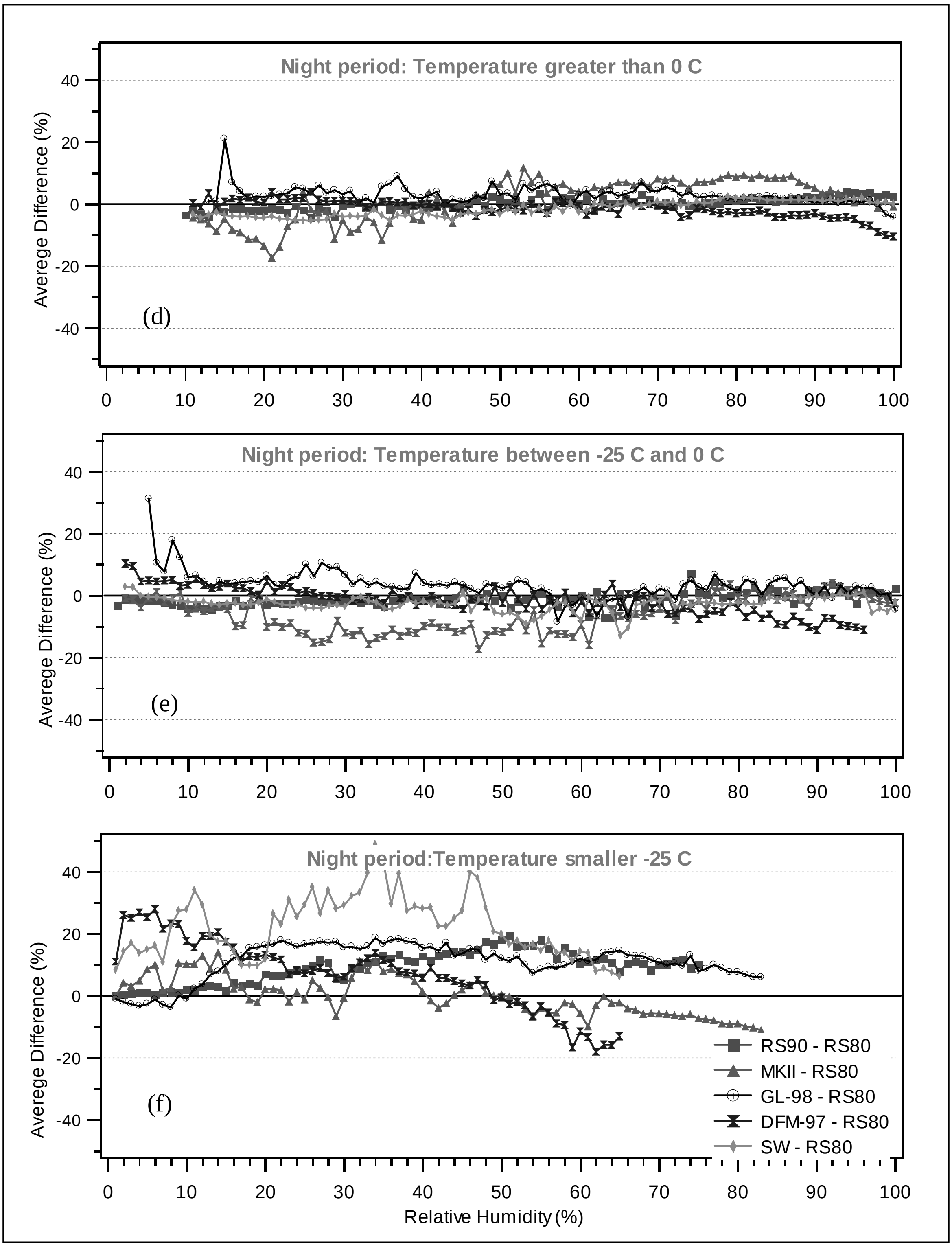

Figure 6 (d, e and f)

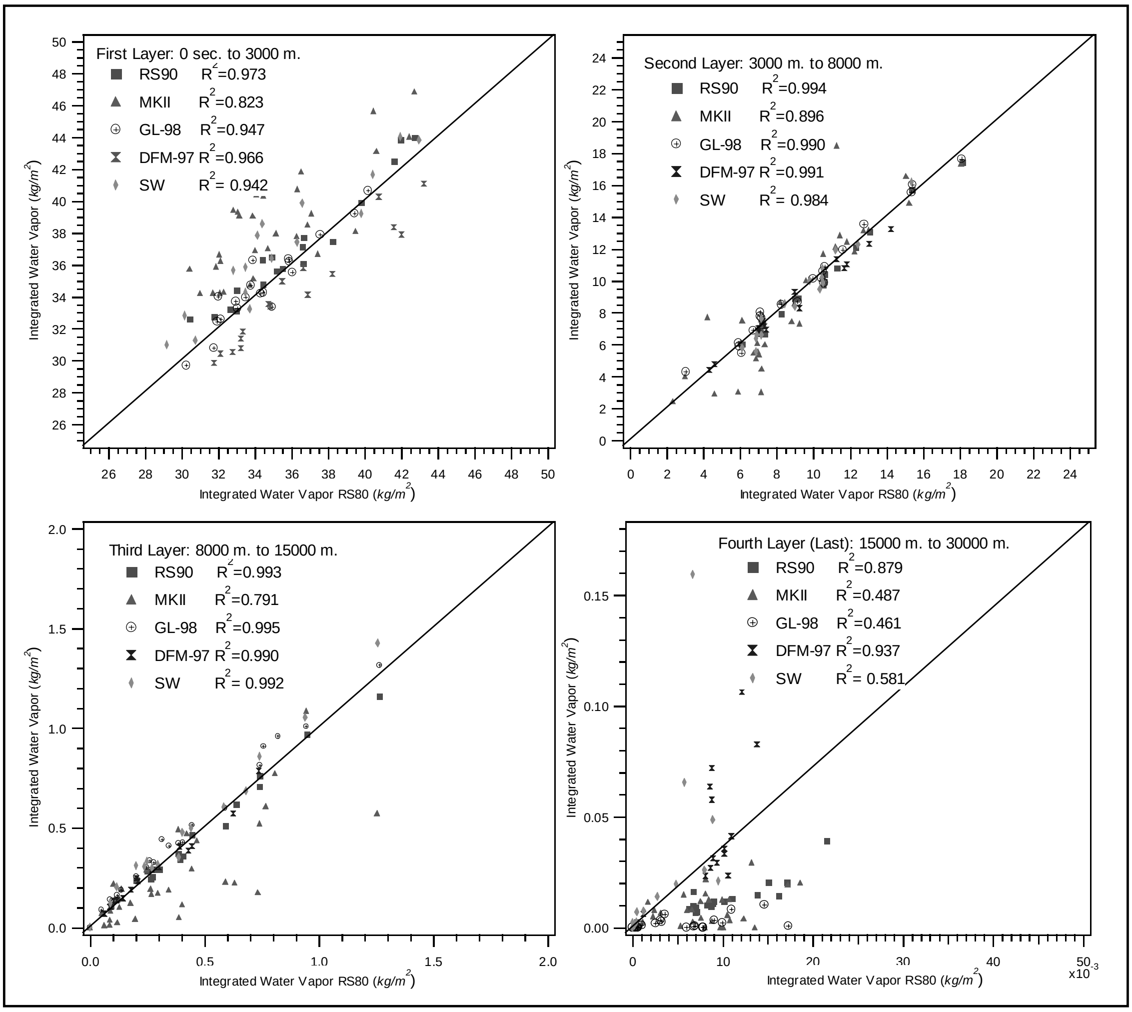
First Layer: 0 sec. to 3000 m.
RS90 R2=0.973
MKII R2=0.823
GL-98 R2=0.947
DFM-97 R2=0.966
SW R2= 0.942
Second Layer: 3000 m. to 8000 m.
RS90 R2=0.994
MKII R2=0.896
GL-98 R2=0.990
DFM-97 R2=0.991
SW R2= 0.984
Third Layer: 8000 m. to 15000 m.
RS90 R2=0.993
MKII R2=0.791
GL-98 R2=0.995
DFM-97 R2=0.990
SW R2= 0.992
Fourth Layer (Last): 15000 m. to 30000 m.
RS90 R2=0.879
MKII R2=0.487
GL-98 R2=0.461
DFM-97 R2=0.937
SW R2= 0.581
Integrated Water Vapor (kg/m2)
Integrated Water Vapor RS80 (kg/m2)
x10-3

Figure 7