INTERCOMPARISONS BETWEEN SONDES RS80 VAISALA AND MKII SIPPICAN USED IN BRAZIL

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Abstract

The sondes RS80 from Vaisala Oy (FInland) and MKII Sippican (Mexico) are used in Brazil to collect data from upper air. The operational network consists of about 50 upper air stations, most of them using Vaisala sondes. During LBA/TRMM 1999 (held at a tropical forest site) and RSO/2001 (at the coast site) field campaigns, simultaneous soundings were made to collect data in the tropics in order to quantify the difference between the sensors used. A total of 40 simultaneous sounding (10 during LBA and 30 during RSO) were available. The individual profiles were extrapolated for each 50 m and average properties in intervals of 500 m were computed for comparisons. In general, the differences between RS80 and MKII presented a negative bias for temperature (around 0.1 or 0.2 C); negative bias for relative humidity (around 5-7%); negative bias for pressure (around 0.2-0.3 hPa). The difference in winds is less than 1 m/s for the winds components. The relative humidity data were also compared to a reference (Snow White, Meteor Labor) during RSO and the winds were compared with radar tracking.

1. Introduction

The Upper Air Brazilian network comprises about 50 radiosonde stations, which are either Vaisala RS80 or Sippican MKII, distributed over the country. The main purpose of this station network is to provide vertical profiles of temperature, humidity, pressure and wind from the atmosphere for either assimilation into NWP models or for operational purposes at Air Force or Navy. The main concern of the network managers is regarding to the reformulation of it, by either adding new locations or replacing the station equipments. Therefore, in the past 10

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years several field campaigns were taken to investigate the quality of radiosondes that are used in operational basis. In this regard, two special experiments involved comparisons between Vaisala RS80 and Sippican MKII, which were the first phase of the Large Scale Biosphere Amazon in conjunction with the Tropical Rainfall Measurement Mission (LBA/TRMM) (*Silva Dias et al.*, 2001), held on the Brazilian Amazon Rainforest on 1999, and the WMO Radiosonde Intercomparison Experiment (*Silveira, et al*., 2003), held on Alcantara, Maranhão, Brazil, on 2001. Both field campaigns were performed close to the equator and, though they were designed to attend different goals, the results give good examples of performance of these two equipments. Thus, we shall summarize both experiments and discusses the individual results.

Field Experiments

As a part of the LBA/TRMM strategy design, an intercomparison of the radiosonde systems was performed at the end of experiment (Feb 22-24, 1999) at the pasture site. During these 3 days (1 launching each 3 hours), 17 flights were made with VIZ (MKII) and Vaisala (RS80) sondes attached to the same balloon. The ascension rate was close to 5 m.s-1. The same surface observation was given as input for both sondes. The goal was to compare the data from both systems in order to observe the differences for the profiles (temperature, humidity and winds) resulting from the different sensors and algorithm procedures. The VIZ system used the 3-D differential GPS (Global Positioning System) capability which means that it measures the height of the sonde and the pressure is computed using the hydrostatic equation with the surface pressure given as an initial condition. This procedure also gives the winds, where the components of the winds are determined cumulatively from the surface value. The Vaisala uses the standard pressure/height relationships (e.g. measures the atmospheric pressure and computes the height). The times of soundings were 2, 5, 8, 11, 14, 17, 20 and 23 Local Time (LT). The essential characteristics of the two sounding systems are summarized in Table I.

Table I: Technical characteristics of the sondes Vaisala (RS80-15G) and Viz (Mark II LOS).

VARIABLE	**RS80-15G (SENSOR AND RESOLUTION)**	**MARK II – LOS (SENSOR AND RESOLUTION)**
Pressure (hPa)	Capacitive aneroid (0.1)	Computed by GPS
Temperature (°C)	bead thermistor (0.1)	Rod thermistor (0.1)
Humidity (%)	Film capacitor (1)	Carbon hygristor (1)
Winds ($m.s^{-1}$)	0.15	0.3
Sampling rate (s)	0.15	1

The pasture site (hereafter Fazenda N.S. Aparecida) is located at 10° 45´S, 62° 21´W, 290 MSL and this experimental site is a farm originally formed in the 80s. The vegetation is covered by grass. The ranch is situated in a strip of cleared area about 4 km wide and several tens of kilometers long, in the centre of na area of about 50 km in radius which has undergone large scale clearance. More details about the landscape are in *Gash and Nobre* [1997] and *Silva Dias et al.* [2001].

The WMO Intercomparison Radiosonde experiment was carried out from 21 May to 7 June 2001, at Alcantara, Maranhão, Brazil (at the latitude 2° 18' South and longitude of 44° 22' West), for evaluating GPS, humidity, temperature and pressure measurements from 5 radiosonde types, as described at table II. 43 flights were carried during this period. The launch times were 00, 06, 12 and 18 UTC. Four additional flights were carried out on 30 May, 14 UTC; 31 May, 02 UTC and 14 UTC; and on 1 June, 02 UTC.

In addition to the data generated by the radiosondes, environmental data were measured and archived, such as surface temperature, precipitation, relative humidity, clouds, pressure and wind, as well as a C-Band radar data for evaluating the GPS data. The data archive of the

RSO was built by sampling all flights every two seconds. GL-98 and MKII measurements, which sampled at a rate of one second, were linearly interpolated.

Table II: equipment description for the WMO Radiosonde Intercomparison in Brazil.

EQUIPMENT	TYPE	MANUFACTURER	PARAMETER
RS80	Radiosonde	Vaisala Oyj, Finland	P, T, RH, GPS wind
RS90	Radiosonde	Vaisala Oyj, Finland	P, T, RH, GPS wind
MKII	Radiosonde	Sippican, USA	T, RH GPS wind and heights
GL-98	Radiosonde	Modem, France	T, RH, GPS wind and heights
DFM-97	Radiosonde	Dr. Graw, Germany	P, T, RH, GPS wind
SNOW WHITE	Humidity sensor	MeteoLabor, Switzerland	Relative Humidity
CEILOMETER Laser CT75K	Cloud detector	Vaisala Oyj, Finland	Cloud height and cover
RADAR	Doppler Radar C-Band (5.8 GHz)	Thomson, France	Balloon tracking wind components
MILLOS 500	Meteorological automatic station	Vaisala Oyj, Finland	P,T,RH, wind, solar radiation and rain
THYGAN	Humidity check sensor	MeteoLabor, Switzerland	Relative humidity

Results from the experiments

For each of the 17 flights on LBA/TRMM experiment, the variables measured by the radiosoundings were: air temperature, relative humidity, pressure (Vaisala only) and wind components. These variables were extracted from the raw data and have been linearly interpolated at 50 m intervals up to 5000 m. The Vaisala software has a special function (STATUS) which shows the percentage of good data used for the 10 s data and for PTU this percentage is always higher than 98 % and for winds it was 85 %. As the comparison has been done up to a height of 5000 m and the lack of good data increases with the height, this percentage should be higher. Some basic statistics (mean and standard deviation - SD) were computed for all flights and their layer average is presented at Table III.

Table III: Statistics of the mean differences (RS80 minus MKII measurements) and the standard-deviation (in brackets) for pressure (P), air temperature (T), specific humidity (Q), zonal (U) and meridional winds (V) and windspeed (WS).

Height (m)	P (hPa)	T (°C)	Q ($g.kg^{-1}$)	U ($m.s^{-1}$)	V ($m.s^{-1}$)	WS ($m.s^{-1}$)
500	0.0(0.1)	-0.1(0.5)	-1.2(0.9)	-0.3(1.4)	-0.1(1.6)	0.3
1000	-0.1(0.2)	-0.2(0.4)	-1.6(0.8)	-0.8(1.6)	0.1(0.9)	0.8
1500	0.2(0.3)	-0.3(0.4)	-1.4(0.6)	-0.4(1.4)	0.2(0.7)	0.4
2000	-0.3(0.3)	-0.3(0.4)	-1.2(0.5)	-0.7(1.0)	0.3(0.9)	0.7
2500	-0.4(0.3)	-0.3(0.4)	-0.9(0.5)	-0.7(1.6)	0.2(1.2)	0.8
3000	-0.4(0.4)	-0.3(0.4)	-0.8(0.5)	-0.5(0.8)	0.2(0.9)	0.5
3500	-0.5(0.4)	-0.3(0.5)	-0.6(0.5)	-0.7(1.0)	0.0(0.9)	0.7
4000	-0.6(0.5)	-0.3(0.5)	-0.4(0.4)	-0.2(1.2)	0.7(1.2)	0.7
4500	-0.6(0.5)	-0.3(0.5)	-0.4(0.4)	-0.5(1.2)	0.6(1.2)	0.8
5000	-0.6(0.5)	-0.5(0.4)	-0.3(0.3)	-0.4(1.5)	0.3(1.0)	0.5

The first layer consists of measurements from surface (300 m) up to 500 m and the others levels were 10 points averaged (500 m height interval). The variables computed are always the RS80 minus MKII measurements.

For the pressure variable, the differences are close to zero in the first layer but increase slightly with the height, reaching a maximum value around -0.6 hPa at 5000 m. The SD ranged from 0.1 at the surface up to 0.5 at the top. This increase of the difference with height is probably due to the errors involved in the temperature determination and also by the MKII procedure, which uses the differential concept to compute the actual value. Also, the differences are of the same order as the accuracy of the measurements. For air temperature, there is a consistent negative bias during the whole profile, ranging from -0.1 °C at the first layer up to -0.5 °C at 5000 m. The SD is around 0.4 - 0.5 °C for all levels. The zonal wind component shows a negative difference ranging from -0.2 $m.s^{-1}$ up to -0.8 $m.s^{-1}$, but this difference varies with height. The SD is reasonable high, ranging from 0.8 $m.s^{-1}$ up to 1.5 $m.s^{-1}$. The higher values of SD are close to the surface (lower than 1500 m). This feature could be associated with the pendulum movement of the sondes. The meridional wind component shows similar features, although this difference is smaller than the zonal wind and also opposite in sign. The zonal flow was stronger than the meridional, which explains why the difference in the zonal component is higher. The windspeed differences (computed from the wind components) show values ranging from 0.3 up to 0.8 m.s^{-1}. Once the sonde is within the clouds, the strength of the signal gets weaker and the satellite synchronization may be lost, increasing the uncertainty of the position and winds. The humidity profile deserves a special attention, since one of the goals of the LBA/TRMM is to validate the algorithms applied to the data from the satellite TRMM. The humidity profiles (Figure 1) shows overall differences around 5 %, with Vaisala presenting the smaller values.

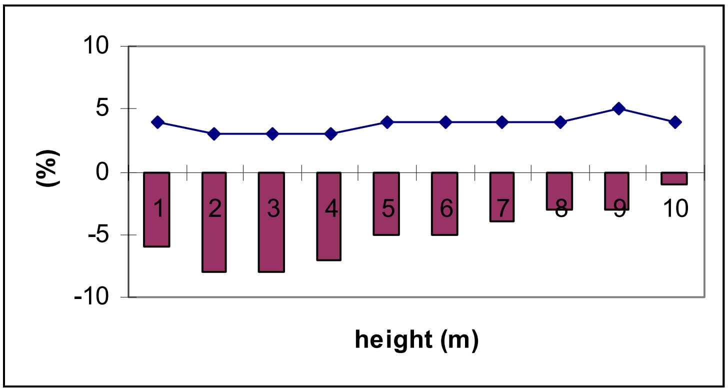

Figure 1: Profile of the mean (bar) and standard deviation (line) of the relative humidity differences between the RS80 and MKII measurements during LBA/TRMM experiment. Each level in the x-axis represents 500 m height.

The layer between 1000 and 2000 m (layers numbers 2 and 4) shows the largest differences (values around 8%). This layer is often the cloud layer and sometimes the sonde goes in and out cloud, not allowing enough time for the sensor to come into equilibrium with the environment (time constant of the sensors is around 1 s). Also, as point out by *Visscher and Kornet* [1994], the hysteris of the sensors can account for some uncertainty of the measurements. Detailed comparisons of humidity sensors made by these authors showed that a difference less than 1.5 % can not be detected using ordinary humidity probes. In their study, a humicap sensor (the same sensor used by Vaisala) was compared with a reference psychrometer (platinum resistance). The hysteris and time constant of the equipment contributes to an accuracy of around 2%. Others measurements in the tropics show differences between sensors around 5% (TOGA COARE Expedition in the Pacific Ocean) or slightly less around 3 – 4% at Ascention Island (Equatorial Atlantic Ocean). In the TOGA

COARE expeditions, Guichard et al. [2000] found that corrections up to 4% for the whole atmosphere should be applied in their data, in order to correct a dry bias caused by the dessicant. Previous discussions (*Zipser and Johnson*, 1998) suggested that this dry bias could be associated with the age of the sonde. In LBA/TRMM experiment, the sondes used were not older than 3-4 months. Close to the surface, an additional 1-2% error can result from heating related with radiation exposure of the sensor (*Guichard et al.*, 2000). That difference corresponds to a mixing ratio around 0.3 $g.kg^{-1}$. The specific humidity (shown in Table III) has been computed from the thermodynamics variables and shows the same features as the relative humidity: highest values around 1.5 $g.kg^{-1}$ in the cloudy layer (between 1000 and 2000 m). Because of the moisture decreases with the height, the specific humidity profile shows lower values at the end. Also, the accuracy and reliability of humidity measurements usually decrease as the concentration of the water vapor, temperature and pressure (*Miloshevich et al.,* 2001). At Table IV, it is shown basic statistics about the classification of the difference considering the absolute value or the relative humidity. In this analysis, the Vaisala´s measurement has been considered as the reference.

Table IV: Statistics of the intensity of the difference related with the absolute value of relative humidity (Vaisala was considered the reference measurement).

	50-60 %	**60-70 %**	**70 – 80%**	**80 – 90%**	**90 – 100%**
N	3	27	467	717	378
Mean	0	-4	-5	-6	-4
Mediana	0	-4	-5	-6	-3
Mode	0	-3	-5	-5	0

The results in the table IV show that the largest differences (values around 5 and 6%) are found for a range of relative humidity between 70-90 %. It is worthwhile to notice that for very high relative humidity measurements (90-100 %), the most common difference (mode) is 0. Figure 2 shows the scatter plot between differences and absolute value.

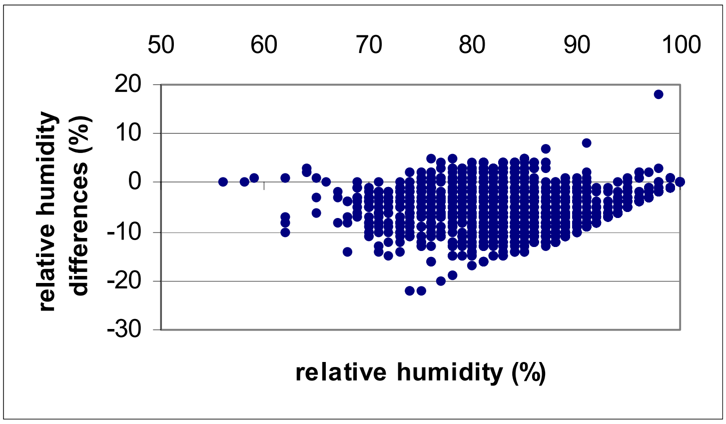

Figure 2: Dispersion diagram of the relative humidity differences against an absolute relative humidity (RS80 was considered the reference measurements).

These pairs of values have been plotted independently in figure 2 from the height and time of the day. There are few data showing positive differences and the largest differences (up to 20%) occur in the range of 65-80 % of relative humidity.

In order to study the influence of the solar radiation on the measurements of temperature and humidity, the data set has been separated in daytime (considering the soundings made at 12, 15, 18 and 21 LT) and nighttime (soundings at 24, 3,6 and 9 LT). The humidity data does not shown any significant difference between daytime and nighttime, presenting the same feature described above. For the temperature, however, there is a small difference (around 0.1 up to 0.2 °C) which could be assigned for the solar radiation heating. The temperature differences between RS80 and MKII are larger during daytime than during nighttime.

The results of the WMO radiosonde experiment were extensively discussed in the final report (still to be published by the WMO) and at the Executive summary (Silveira et al. 2003). Moreover *Sappuci, et. al*. (2005) presents a reviewed analysis of the experiment, regarding humidity measurements.

This WMO intercomparison phase had the participation of 5 radiosondes on over 40 flights. The results were examined as a group or in pairs, were there was possible to have coincidently flights for a given pair of radiosondes. Nevertheless, that was possible to obtain some conclusions for MKII and RS80, which participate on most of flights. Figure 3 and table

V, show results for relative humidity comparisons and table VI brings results of temperature analysis.

As matter of clarification, a RMS error and dispersion analysis was carried out to verify the accuracy of all measurements. The analysis was based on the three vertical layers:

- Surface to 3000 meters;
- 3000 to 8000 meters;
- 8000 meters to the top.

Thus, following such atmosphere layers division, the MKII radiosonde presented, at low levels, where there is high concentration of water vapor, humidity values higher than those measured by the RS80.

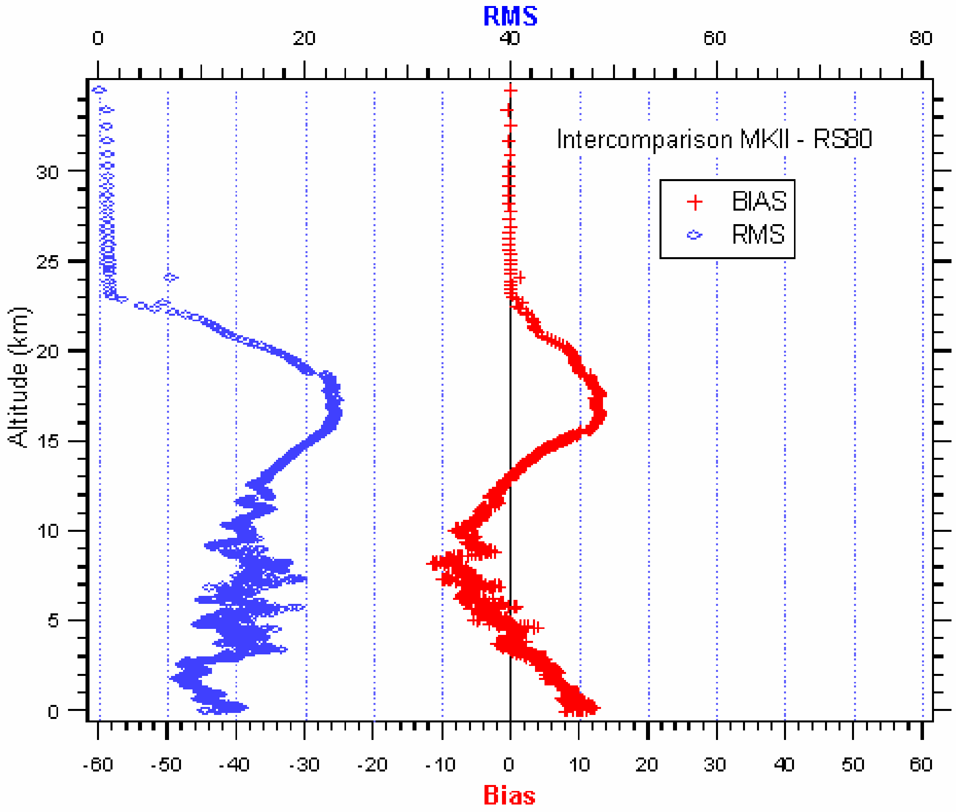

Figure 3: Comparison of relative humidity between MKII and RS80, during WMO RSO intercomparison.

Table V. Average of bias and RMS for the vertical profile of radiosonde measurements, at the three selected layers.

Comparison	Average figures BIAS (%)			RMS (%)		
	1st layer	2nd layer	3rd layer	1st layer	2nd layer	3rd layer
MKII –RS80	+7.44	-2.47	+0.33	10.18	14.03	15.29

Table V shows a quantitative analysis of the bias and RMS values (given in %RH) concerning the RS80 and in comparison to MKII, which shows a positive bias and strong dispersion in the first two layers. Moreover, the values presented in Figure 3 and Table V suggest that the RS80 RH sensor presents a tendency to underestimate the humidity in the low and high troposphere and the layer above the latter, and the MKII overestimates RH in the low troposphere and presents quite dispersive RH values in the low and medium troposphere.
Regarding the RS80, it was chosen as a reference for the temperature analysis. Table VI shows the average bias and RMS for the three selected layers.

Table VI: Average of bias and RMS error for the vertical profile of radiosonde measurements at the three selected layers.

Comparison	BIAS (°C)			RMS (°C)		
	1st layer	2nd layer	3rd layer	1st layer	2nd layer	3rd layer
RS80-MKII	-0.03	-0.11	-0.65	0.20	0.30	1.20

The influence of the solar heating in the sensors was also analyzed by splitting up the data-set for daytime (soundings at 12 and 18 UTC) and nighttime (soundings at 00 and 06 UTC). The results show that at daytime conditions, up to an altitude with temperature higher than –30 °C, the absolute differences among the radiosondes are within the range from –0.5 °C to +0.5 °C. For temperatures lower than –35 °C, the difference between RS80 and MKII increased substantially to a value around 1.5 °C.

The GPS analysis consisted on the post-processing of radiosonde wind data, to compute the vector wind components; on the post-processing of radar data, by applying a Kalman filtering analysis on the data and on the computation of bias and RMS error to determine a comparison among pairs of radiosonde measurements. It was considered that the wind vector was computed by using the “codeless” (Vaisala) and decoded (others) Differential GPS Technique.

The GPS wind data were generated for different weather conditions and for day and night time. A typical operational resulted was obtained by reporting the number of flights that sustained GPS measurements up to 5000 s of ascent time. The recent WMO review of operational GPS performance indicated that 10 to 15% missing wind data were typical.

The different types of radiosondes produced wind data in excellent agreement. The results taken by comparing sonde winds and radar winds show very small differences among these measurements.

Concluding remarks

Analysis on temperature and humidity sensors was carried out for RS80 and MKII radiosondes, which are the major equipments used for operational basis in Brazil, on two distinct intercomparison campaigns held in Brazil, on 1999 (LBA) and 2001 (WMO RSO intercomparison). Moreover, GPS wind retrieval was also analyzed for both experiments.

For LBA/TRMM campaign, although the individual profiles presented some alternate patterns, on average the difference between Vaisala and MKII was about –0.3 °C for the temperature and –5 % for relative humidity (equivalent to 1.0 up to 1.5 $g.kg^{-1}$).

For WMO RSO Intercomparison, considering the relative humidity results, in general, all measurements were close together at temperature higher than -25°C. However, the MKII had a positive bias at high RH values and a negative bias at low RH values. At the lower temperatures, the dispersion between the different RH sensors increased. This resulted in the systematic differences. Regarding temperature, for daytime and nighttime flights, the range of the temperature differences in the troposphere between the radiosondes was mostly between –0.5°C and 0.5°C, with RS80 used as reference. The MKII temperature in daytime flights had a positive bias of about 1.5°C in the stratosphere.

GPS wind were shown to be in good agreement at both experiments, apart from some failures due lack of satellite synchronization.

Although both experiments were not carried out precisely on operational conditions, they were very useful to assess the quality of the radiosondes, as well as in terms of comparison with other equipments, as done during WMO RSO Intercomparison. It is suggested that such campaigns would be performed on regular basis, as way to constantly check the radiosondes, as well as to keep the improvements on such devices following the operational needs.

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