P2.6 ON QUALITY CONTROL PROCEDURES BEING ADOPTED FOR TRMM LBA AND KWAJEX SOUNDINGS DATA SETS

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1. INTRODUCTION

During NASA's Tropical Rainfall Measuring Mission (TRMM) field campaigns Large Scale Biosphere Atmosphere (LBA) held in Amazonia (Brazil) in the period Januray-February, 1999, and the Kwajalein Experiment (KWAJEX) held in the Republic of Marshall Islands in the period between August-September, 1999, extensive radiosonde observations (raob) were collected using VIZ and Vaisala sondes which have different response characteristics. In all, 320 raob for LBA and 972 fixed raob for KWAJEX have been obtained and are being processed. Most atmospheric sensible heat source (Q1) and apparent moisture sink (Q2) budget studies are based on sounding data, and the accuracy of the raob is important especially in regions of deep moist convection. A data quality control (QC) project has been initiated at GSFC by the principal investigator (JBH), and this paper addresses some of the quantitative findings for the level I and II QC procedures. Based on these quantitative assessment of sensor (or system) biases associated with each type of sonde, the initial data repair work will be started. Evidence of moisture biases between the two different sondes (VIZ and Vaisala) has been shown earlier by Halverson et al. (2000). Vaisala humidity sensors are found to have a low-level dry bias in the boundary layer, whereas above 600 mb the VIZ sensor tends to register a dryer atmosphere (see Figure 1). All raob data were subjected to a limit check based on an algorithm already well tested for the raob data obtained during the Tropical Ocean Global Atmosphere (TOGA-COARE) (Loehrer et al. 1996).

For the purpose of profile comparison within the atmospheric Boundary Layer (ABL) a 30 m^3 tethersonde (TS) manufactured by Vaisala with an on-board data Acquisition System (DAS) was used at the station Abracos (TRMM LBA Pasture site) during LBA. The VIZ humidity and temperature sensors have been independently compared with the TS profiles and the biases are reported in this paper. The TS produced 2-second measurements that correspond to approximately 2-meter vertical resolution. The TS hygristor has a response time of 4.8 seconds. For the TS temperature sensor, the response time was found to be < 2 seconds by the University of Virginia investigators Jose Fuentes and Ryan Heitz (JFRH) using a laboratory technique. During profiling TS maintained an ascent/descent rate of 1 ms^{-1} and the sampling was performed at a rate of 1 Hz. A 10-m tower was used to acquire surface layer data. JFRH compared the 10 m tower data independently with the TS samples and performed a preliminary QC on the data-set by eliminating the pressure levels that exceeded a threshold value of 0.02 millibar (mb) and reported a correlation > 0.9. They also removed TS-tower biases due to TS sensor ventilation and radiational loading. Section 2 of this paper describes the raob data format adopted in the level I procedure and some preliminary results obtained by comparing the VIZ and Vaisala raob data after performing limit checks on the data. Section 3 describes the direct comparison TS-VIZ biases found in the ABL and VIZ-Vaisala biases in the ABL as well as for all levels from the surface through 150 mb. Section 4 describes the systematic time variation of TS-VIZ temperature (T) and specific humidity (q) biases, and the time constants derived for the VIZ thin rod thermistor, and carbon humidity sensor.

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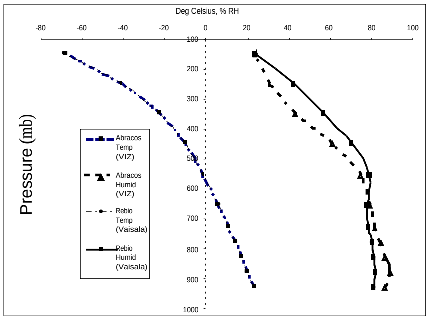

Figure 1: VIZ vs. Vaisala mean T, RH comparison using Abracos, and Rebio Jaru data obtained during the period January 24-February 24, 1999.

2. DATA FORMAT AND FILENAMES

A consistent data format and filenaming convention was adopted for the LBA as well as the KWAJEX raob data sets. The 4-station LBA network consisted of the Abracos (ra, VIZ), Rancho Grande (rg, VIZ), Rebio Jaru (RJ, Vaisala), and Rolim de Moura (RM, Vaisala) stations. The filenames for the station Abracos are given as 'raddmm.hra' where dd is the day of the month, mm is the month and hr is the raob sounding time in Universal Coordinated Time (UTC). An 'a' at the end means it is the processed data directly obtained from VIZ. Alan Betts and John Ball of Atmospheric Research, VT were instrumental in correction of the wind and surface data obtained using VIZ sondes during LBA at the Abracos pasture-site and Rancho Grande site. These data sets for LBA are renamed as version 'b' files. The 6-station KWAJEX data sets were obtained from Lae (lo, VIZ), Meck (me, MSS), Roi (ro), Kwajalein (kmr, MSS), mobile R/V Ron Brown (rb, Vaisala), and Woja (wo, VIZ). The MSS raobs are Orbital Sciences Corporation Meteorological Sounding Systems. MSS raob evaluation is beyond the scope of this paper. Table 1 shows the data format. It should be noted that in the case of VIZ version 'b' data files, the first data row (the 12th row in the file) contains the original uncorrected surface data, and the second row (13th row in the file) contains the Betts corrected data for the first level.

WETAMC stands for Wet Season Atmospheric Mesoscale Campaign. The surface reference data are obtained from the operator entry records, and the exact start time in UTC for the VIZ soundings are obtained from a journal text file that contain records of flight events and information about system operation and launch detection.

TABLE 1

KWAJEX - WETAMC/TRMM
Station : KMR, KWAJ.
Location : 8.27N, 167.7E Elev 6.0 m
RS TEST NUMBER: 990726
Ground Check: Ref RS Corr
Pressure: -999.9 -999.9 -999.9
Temperature: -999.9 -999.9 -999.9
Humidity: -999.9 -999.9 -999.9
Started at: 29 JUL 99 23:06 UTC

Hgt/MSL	Press	Temp	RH	Dir	Speed
m	hPa	C	%	deg	m/s
6.0	1014.2	23.5	84.3	230.0	1.5
4.0	1014.2	23.7	84.5	125.0	1.5

For VIZ soundings, humidity originally reported as dew points has been converted to RH%. The humidity is derived from the dew point temperature (DWPC) and the air temperature (TMPC) both in ^{0}C in the methods of Bolton (1980).

The VIZ sondes were Sippican Global Position System (GPS) Mark II microsonde operated at 403-406 MHz, with Pressure, Temperature, Humidity (PTU) channels and winds. Winds were computed using differential code-correlating GPS and both PTU and wind were sampled at 1 Hz. The approximate ascent rate of 5.5 - 7 m/s enabled measurement every 0.7 mb in the ABL. The Vaisala sondes also operated at 403-406 MHz and carried capacitive aneroid pressure sensor, capacitive bead temperature sensor, and humicap thin film capacitor humidity sensor with 1 sec lag time. The Vaisala PTU and wind were sampled every 1.5 seconds, and winds were computed with codeless GPS receiver, and an algorithm is used to carefully select the best geometry so as to avoid the dilution of GPS precision.

3. LIMIT CHECK ON ABRACOS DATA

The tropical atmosphere gross limit checks (based on Loehrer et al. 1996) were applied to the Abracos site VIZ data. In all, about 120,000 levels of data were subjected to limit checks and Figure 2 shows the percentage of questionable T and Dew Point (TD) levels

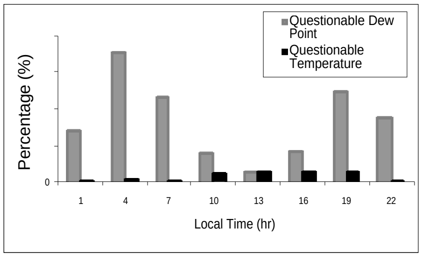

Figure 2: Shows Local Time variation of % questionable Temperature and Dew Point obtained for all Abracos soundings following Loehrer et al. (1996).

that were reported. From Figure 2 it is apparent that the percentage of questionable temperature and humidity data diminishes and becomes almost the same at 1300 LT when boundary layer convection is dominant. Otherwise humidity data quality worsens when the ABL is more or less stable (during early morning and evening hours). It is worthwhile to look at the VIZ humidity and temperature bias within the ABL with an independent sensor on the TS which is discussed in the next section.

4. SENSOR BIASES

The sampling rate of the VIZ and TS sensors are almost equal, hence a study has been done to asses the characteristic magnitude and distribution of error (TS minus VIZ) associated with the temperature and humidity sensors. Since TS data are good when compared with the 10 m tower data (as mentioned in section 1) we shall use the 1 sample/second TS data as a baseline and compare with the 27 VIZ raobs obtained between January 21-Feb 28, 1999 at Abracos pasture site with elevation 293 m.

4.1 *Temperature and Humidity Bias Between Tethersonde and VIZ Sonde*

The first step in identifying the temperature and specific humidity biases between the TS records and VIZ raob was to find out the exact start time in seconds elapsed from a reference time (in our case it is the 00 hour UTC January 01, 1999). Once we know the start time of the VIZ sonde as well as the TS, each observed level within the ABL (surface to 850 mb) is tagged with its observation time (delay in seconds from January 01 00 hour UTC) and then the comparison is performed. Equation 1 explains the time assignment for each level:

Total delay in sec. = start time + [x/(ds/dt)] (1)

where x is the difference between the current level and the preceding level in meters and ds/dt is the approximate VIZ ascent rate (6.85 ms^{-1}). Once the delay in seconds is known for each level then corresponding TS records are searched within a 5 mb (or approximately 50 meters) separation with a TS-VIZ time difference of 300 seconds (5 minutes) and another time within 1800 seconds (30 minutes). Since the ABL changes rapidly, hence for all practical purpose we shall consider comparisons in the time delay range of 300 seconds. Finally, histograms are formed for the biases. A typical TS-VIZ T bias histogram for a 5-minute delay at 1300 LT is shown in Figure 3 (a) and for specific humidity in Figure 3(b).

It is apparent from the above two plots that the bias distributions are skewed normal type. The specific humidity (q) for the TS as well as the VIZ cases was obtained using the method as mentioned in Bolton (1980) to obtain the mixing ratio (w) in kg/kg then q=w/(1+w), which is then converted to g/Kg. Using the histograms, the biases occurring at peak frequencies for each sounding time 1, 4, 7, 10, 13, 16, 19, and 22 hours LT and the average biases occurring at each of the above LT are plotted to see if there is any time variation of the bias. Figure 4 shows the time series of the T and q differences obtained from the Abracos site. From inspecting Figure 5 it is evident that there exists an anomaly in the humidity and temperature records obtained from the VIZ sondes since the sonde tends to register a drier atmosphere when compared with TS records at 13 LT when maximum surface heating is expected to occur but the sonde registers a moister atmosphere when surface temperatures fall between 16 and 20 LT. Another attempt was made to see if the T and q biases have any systematic variation with height.

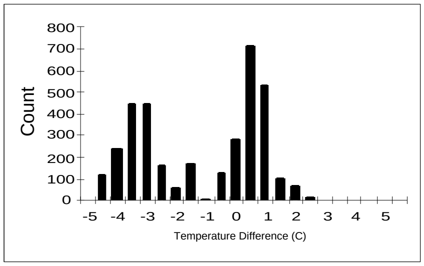

Figure 3(a): TS-VIZ T difference histogram for 1300 LT

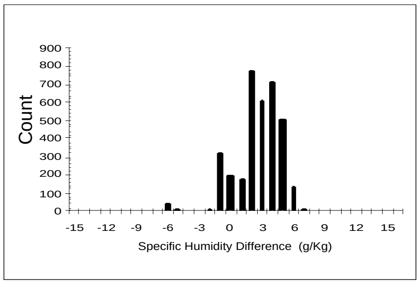

Figure 3(b) TS-VIZ q difference histogram for 1300 LT

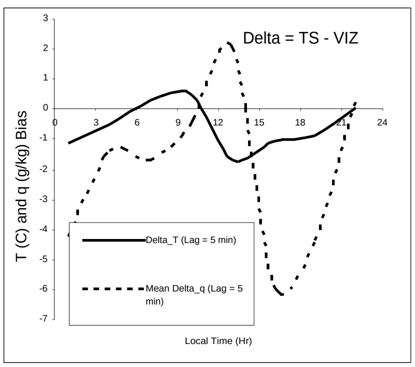

Figure 4: Mean T and q biases as function of LT (hrs). Note that sonde remains cold and dry during the convective periods 10 LT and 14 LT.

But surprisingly when the average bias at each pressure level was obtained and the time series plotted we found a similar variation pattern for the q. Figure 5 shows the biases with height.

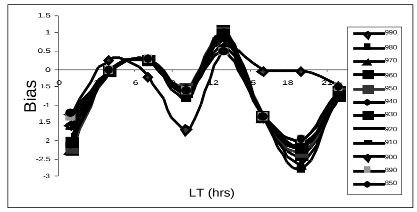

Figure 5: TS-VIZ sonde q bias in g/Kg at various pressure level shown as a function of LT.

The instantaneous TS-VIZ q and T biases have been used to finding the root mean square error *(rmse)* using the formula

$$rmse = \sqrt{\frac{(b - \bar{b})}{(n-1)}} \qquad (2)$$

where b is the instantaneous bias between the tethersonde and VIZ sonde data pairs and the over-bar indicates the average bias for n=31,498 samples used in this case. The *rmse* for the humidity was found to be 2.885 gkg^{-1}, and the *rmse* for the temperature bias was found to be 1.422 C for the boundary layer.

4.2 *Estimation of VIZ Hygristor Time Constant*

The interval required for a system to change a specified fraction from one state or condition to another is the time constant of the sensor. It is used in the expression:

$$A(t) = A(0)e^{-\frac{t}{a}} \qquad (3)$$

where A (t) is the value of the state at time t, A (0) is the value of the state at time t = 0, a is the time constant, and t is the time that has elapsed from the start of the exponential decay. When t = a, A (t)/A (0) = 1/e, or approximately 0.37, and the system has changed about 63% toward its new value in one time constant. A system is considered to have changed its state after the duration of three time constants, which corresponds to a 95% change in state. The time constant for the VIZ hygristor and thermistor have been found using the TS-VIZ bias data. The average ascent rate of the VIZ sonde is calculated to be 6.85 ms^{-1}, hence a minimum TS-VIZ bias is expected to occur at every 6.85*a meters in the vertical. With 'a' unknown in this case a vertical series of the magnitude of TS-VIZ biases has been plotted and from this plot it is distinctly seen that a minimum in q biases occurs at an average spacing of 74.2 meters and approximately 100 meters for the T biases. From these data we could infer that the a for the humidity sensor was of the order 10.8 seconds. This is comparable to the time constant for the VIZ Mark II microsonde humidity sensor found earlier by Mahesh et al. (1997) who reported 8 seconds using data obtained from a different experiment done at the South Pole *(personal commmunication)*. The temperature sensor time constant is yet to be ascertained.

4.3 *Temperature and Humidity Bias Between VIZ Sonde and Vaisala Sonde*

At the Abracos site there were also available 17 VIZ- and Vaisala raob data sets mostly taken in the period between February 21-24, 1999. The Vaisala sondes have been identified by their batch numbers 7044, 7472, 7473, and 7474. For instance the number 7472 signifies that the sonde was manufactured in 1997 on 2nd day of the 47th week. Hence we performed calculations of T and q biases between the VIZ-Vaisala sonde data pairs for 5-minute and 30-minute lag periods and for each batch separately. This approach is an attempt to ascertain a qualitative picture of the behavior of the sensor biases for each batch number to see whether the biases show any pattern. Since neither raob data sets is quality controlled we will hence not be finding the true biases. Considering most of the sensor biases to be systematic and varying with local time as discussed in section 4.1, we present a gross picture of the VIZ-Vaisala biases in terms of their batch identity (ID) numbers only. Figure 6 shows the variation of the ABL temperature and humidity biases plotted as batch series.

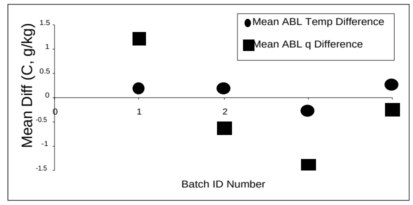

Figure 6: Shows the variation of the T and q biases for all the Vaisala batches identified 1=7044, 2=7472, 3=7473, 4=7474.

We also adopted a 1-way Analysis of Variance (ANOVA) procedure mentioned in the National Institute of Standards and Technology Engineering Statistics Handbook 'Product and Process Comparisons' chapter (more than 2 processes) on the web site, http://www.itl.nist.gov/div898/handbook to split the total variation in the data into a portion due to use of different instruments and a portion due to internal inconsistencies (random). Table 2 below gives the percentages of systematic and random errors occurring while using the VIZ-Vaisala q data computed for all possible levels (from the surface up to about 150 mb) and pairs formed by taking 5-min lag between the VIZ and Vaisala measurements.

TABLE 2

Batch	Error % Due to Use of different Instrument	Error % Due to Internal Inconsistencies
7044	58.6	41.4
7472	91.6	8.0
7473	70.0	30.0
7474	38.4	62.0

5. DISCUSSIONS AND CONCLUSIONS

The TRMM field campaign soundings data format has been explained and a brief procedure of re-formatting has been given. The accuracy of the TS-VIZ sounding bias study depends on how accurately the TS data have been quality controlled by JFRH of the University of Virginia. The VIZ raob limit check study provides us information about the questionable data occurrences at various time of the day. It may be concluded that the erroneous humidity data occur more strongly when the ABL is stable, and the amount of questionable data for the T and RH are small but similar during convective ABL conditions. This area needs further investigation to verify the result and to find out what is causing this discrepancy. For the TS-VIZ temperature and specific humidity bias study, a time lag of 300 seconds (5 min) proves to be sufficient for estimating the characteristic magnitude of the raob biases. The RH sensor time constant for the VIZ sonde was found to be about 10 seconds, and since it samples every 1 second for the PTU and wind, enough samples have been acquired, but use of individual values may yield misleading result. This means that with an ascent rate of 6.85 ms^{-1} we have good data every 70 meters. However, the TS-VIZ bias study yields an rms error of 2.8 gKg^{-1} in specific humidity and 1.4 ^{0}C for the temperature measurements taken within the ABL. These magnitudes could be used for removing the VIZ sonde bias, and a proper correction algorithm could be designed by taking into account the T and RH sensor time constants found in the approach mentioned here and in Miller (1993). It is evident from Figures 4 and 5 that there is a pressure-independent time variation of the T and q biases between the TS and VIZ raob data. It is possible that the VIZ humidity sensor has a heating problem causing it to register a lower q value when surface heating is large, and vice-versa. From Figure 6 it is noted that there is a variation of the VIZ-Vaisala T and q bias for all levels with the respective batch ID of the Vaisala sonde. This could also be done using the VIZ batch ID's and note if there is any time variation. The ANOVA technique could well be applied to find the percentages of random and systematic biases after the above corrections are applied. The preliminary heating and drying budgets are based on the raw data sets and these profiles will be again provided once the corrections are applied and the raob data are properly filtered based on the above discussions.

6. ACKNOWLEDGMENTS

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