Analysis of radiosonde measurements by ground- and satellite-based simultaneous observations during the Water Vapor IOP 2004 experiment

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Introduction

Water vapor and clouds play a key role in controlling the earth's climate, through greenhouse trapping of radiation and the feedback on global sea surface temperature and ice coverage (Curry et al., 1996). Therefore, accurate measurements of the atmospheric water vapor (WV) and cloud properties are essential for the improvement in modelling radiation energy budget. On the other hand, there are still large uncertainties in the radiative properties of the atmosphere, often caused by lack of accurate observations. This is especially true for critical environments such the polar regions, which conversely are so important for climate change studies. Measurements during extremely dry conditions, as the Arctic winter, are particularly difficult, because of the poorer sensitivity of conventional instruments to such low amounts of WV. For these reasons, the Environmental Technology Laboratory (ETL) of the National Oceanic and Atmospheric Administration (NOAA) has developed a new instrument, the Ground-based Scanning Radiometer (GSR) (Cimini et al., 2005), and conducted a Water Vapor Intensive Operational Period (WVIOP) in March/April 2004 at the Atmospheric Radiation Measurement (ARM) Program site in Barrow (71° N, 156° W), AK, USA (Westwater et al., 2005). During the WVIOP2004, the GSR was installed on the deck of the ARM facility, called the Great White (GWT), joining the operational suite of ground-based instrumentation. In addition, frequent radiosonde launches and satellite overpasses provided independent sources of in situ and remote observations.

The goals of the WVIOP2004 experiment include, but are not limited to, the assessment of the accuracy of radiosonde humidity profiles in the Arctic environment, the performance evaluation of the technology recently developed at NOAA/ETL, the comparison of micro- and millimetre-wave radiometric sensitivity to low WV amounts, and finally the collection of a data set for atmospheric absorption model studies at frequencies ranging from microwave to infrared wavelengths.

Table 1: List of the instruments considered in this analysis.

INSTRUMENT	PLATFORM	CHANNELS	RANGE
MWR	GWT	2	23-31 GHz
MWRP	GWT	12	22-58 GHz
GSR	GWT	25	50-400 GHz
AERI-ER	GWT	5436	400-3020 cm^{-1}
MODIS	AQUA	36	620-14385 nm
AIRS	AQUA	2378	649-2665 cm^{-1}
AMSU-B	NOAA-17	5	89-190 GHz
RAOB	GWT, DPX, NWS	-	-

Radiosonde Comparison

In Table 1 are listed the instruments that are considered in the following analysis. During the WVIOP2004, the GSR was installed by NOAA/ETL on the ARM GWT deck, where the dual channel microwave radiometer (MWR), the 12-channel microwave radiometer profiler (MWRP), and the Atmospheric Emitted Radiation Interferometer Extended-Range (AERI-ER) are routinely operated. From the same site, one balloon-borne radiosonde (Vaisala RS90-A) per day is launched routinely. Moreover, two radiosondes (Sippican AIR VIZ) per day are launched independently at the National Weather Service (NWS) facility, as part of NWS operational task. Furthermore, during the WVIOP2004, four radiosondes (Vaisala RS90-A) per day were launched from the ARM duplex (DPX) site. Occasionally, three different radiosonde packages (Vaisala RS90-A, Meteolabor Snow White, and Sippican AIR VIZ) were attached at the same balloon and launched at the same time. Thus, in a few cases there were five independent radiosonde measurements at the same time. Figure 1 shows the first of these cases during the WVIOP2004. Differences in the temperature measurements seem fairly small, while we note significant differences in the humidity profiles. In particular, the two sondes carrying a carbon hygristor (CH) sensor (indicated by AIR VIZ-B2 and NASA Carbon Hygristor) show a smoother vertical structure with respect to both the Vaisala RS90-A and Meteolabor Snow White (indicated by NASA chilled mirror), using thin film capacitor and chilled mirror dew-point hygrometer sensors, respectively (Mattioli et al., 2005). The same CH sensors show also a 20% larger relative humidity (RH) with respect to the other sensors in the upper troposphere-lower stratosphere (8-15 km).

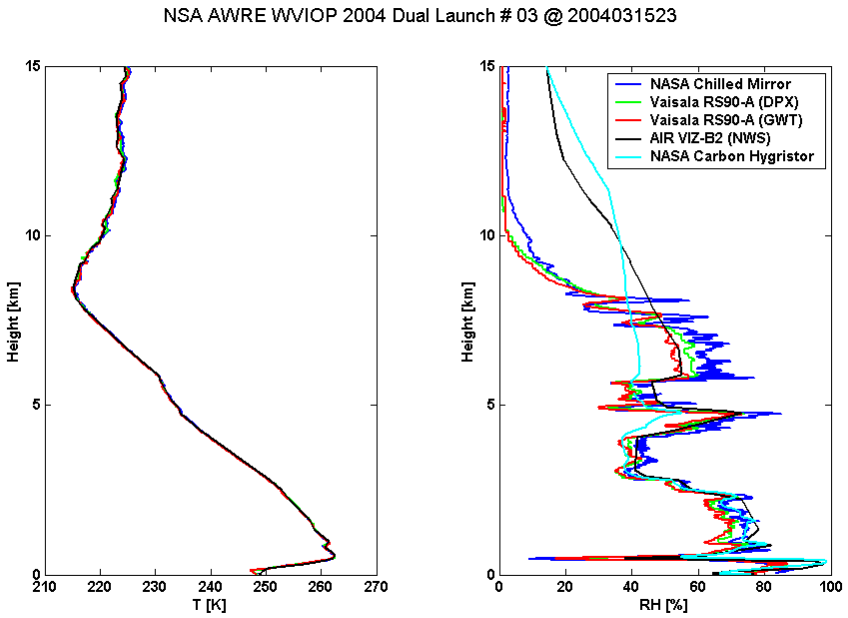

Figure 1: A case of multi-radiosonde launch. Three out of five radiosondes were attached at the same balloon and launched from DPX, while the other two were launched at NWS and GWT sites.

To extend this study to a statistically significant set, we computed the mean value and the standard deviation of the differences in temperature and humidity profiles for the set of radiosondes launched simultaneously from the NWS and GWT sites. The results are shown in Figure 2. The bias in the temperature profile is within 0.25 K, except for the first 500 m, where local effects due to environmental conditions might be important. In fact, the NWS site is located in the city of Barrow, which causes a surrounding heat island, while GWT is about 8 km away. This could explain the 0.5-1.0 K bias in the first few hundreds meters. On the other hand, above 10 km, NWS were found in average moister than GWT by about 18-20% in RH. This

analysis confirms the early results from the first case of multi-sonde launch. Moreover, there seem to be a 5% bias in the lower troposphere.

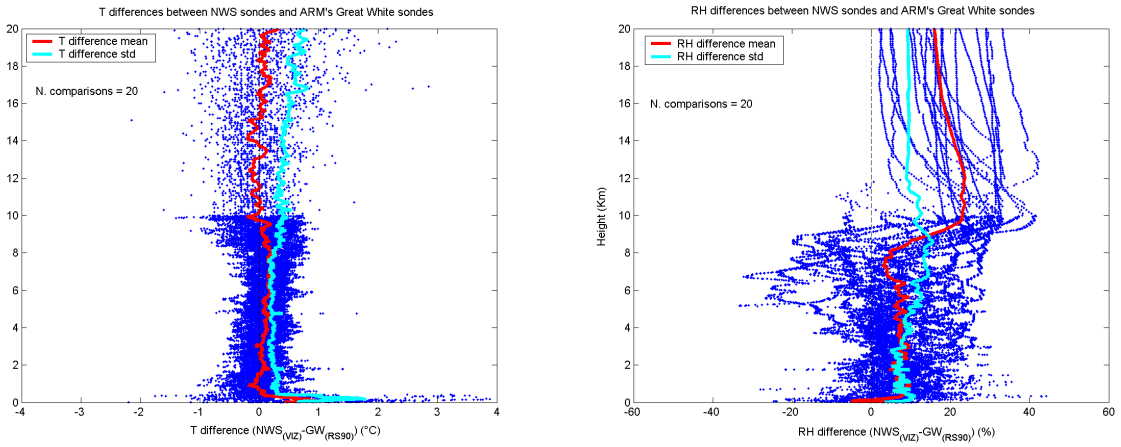

Figure 2: Difference in temperature (left) and relative humidity (right) profiles for the entire set of simultaneous soundings launched at NWS and GWT sites (blue dots). Mean value (red line) and standard deviation (cyan line) are also displayed.

Remote sensing observations

To investigate the effect of the humidity bias in Figure 2, we consider a comparison with remote sensing data from ground- and satellite-based instruments (Table 1). Thus, in addition to measurements taken from the ARM site, we collected observations from MODerate Resolution Imaging Spectroradiometer (MODIS), Atmospheric Infrared Sounder (AIRS), and Advanced Microwave Sounding Unit B (AMSU-B) taken from AQUA and NOAA-17 satellite overpasses. Via an analysis of the incremental Weighting Functions (WF), we selected channels that show a strong response to changes in the upper tropospheric and lower stratospheric humidity (UTH). This subset is for now formed by AIRS, GSR, and MWRP channels, although we plan to add some more to include AMSU-B and MODIS. Figure 3 shows water vapour normalized WF for the UTH AIRS channels (left) and a selection of GSR and MWRP channels that will be considered in the following. Then, down- and up-welling brightness temperatures (Tb) have been simulated from DPX, GWT, and NWS radiosonde measurements using recent versions of radiative tranfer models. For the microwave region, we used the model described by Rosenkranz (2003), while for the infrared we used version 9.4 of Line-by-line Radiative Tranfer Model (LBLRTM) (Clough et al. 2005).

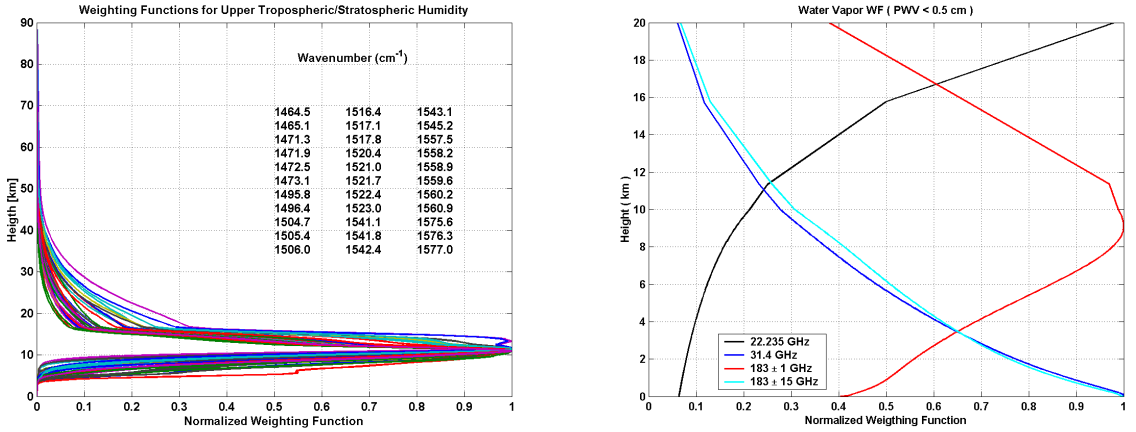

Figure 3: Normalized Weighting Functions for AIRS UTH sounding channels (left) and selected MWRP and GSR channels (right).

Comparison between radiosondes simulations and ground-based measurements for a 24-hour time series are shown in Figure 4. Note that GWT and DPX radiosondes, corresponding to Vaisala RS-90 package, agree with measurements within 1-2 K for all the considered channels. The NWS show a comparable agreement for 23.8, 31.4, 183±15 GHz channels, which are sensitive to the lower troposphere (Figure 3). On the other hand, NWS show large differences (5-10 K) at 22.235, 183±1, and 183±3 GHz, which are channels with high sensitivity to UTH, as shown in Figure 3.

Comparison between radiosondes simulations and satellite-based measurements is shown in Figure 5. Here, simulations obtained from NWS radiosonde in Figure 1 (20040315 23 UTC) are compared with the AIRS spectrum measured at the closest overpass time, within one AIRS field-of-view distance. This happened at 20040315 23:10 UTC; the observation zenith angle, 35.5 deg, has been considered in the simulations. Besides outliers, measurements and simulations show differences larger than 1-2 K in two spectral ranges: from 650 to 700 cm^{-1} and from 1470 to 1570 cm^{-1}. The first spectral range is located in the middle of the strong CO_2 complex, where most of the contribution comes from the high stratosphere and above. Unless of special kind, radiosonde balloons usually do not pass 20-25 km, and thus simulations in this region rely on the reference profile that was used to extrapolate the measurements up to the top of the atmosphere. On the other hand, differences in the 1470 to 1570 cm^{-1} spectral range are due to the UTH, as shown in Figure 3. In fact, for the selected UTH channels in Figure 3, Tb differences are as high as 5 K. By computing the statistics of NWS and GWT simulations against measured Tb for these UTH channels, we obtain the numbers shown in Figure 5. It is evident that GWT radiosondes agree better with measurements than the NWS ones, with a mean and root-mean-square (rms) difference three to four times smaller, and a linear fit slope of 0.8 instead of 0.3.

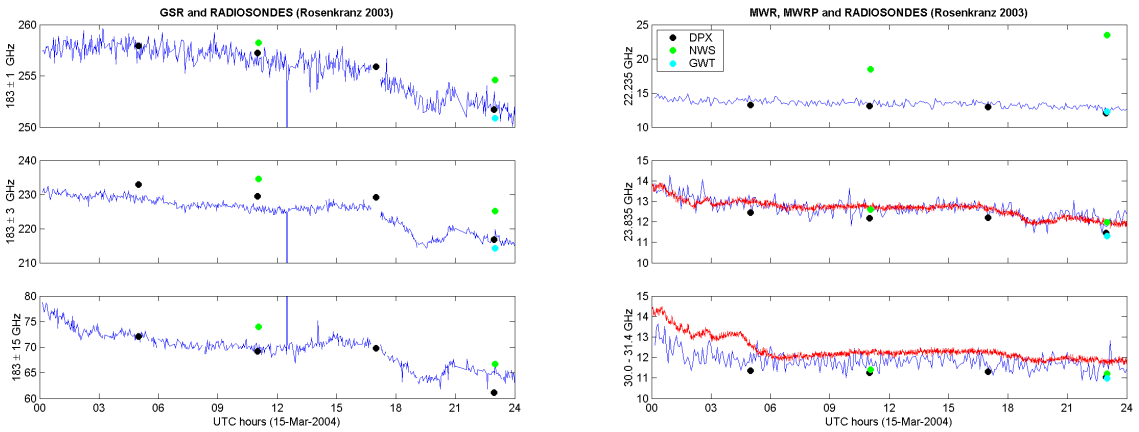

Figure 4: 24-hour time series of simulated and measured Tb at selected GSR, MWR, and MWRP channels.

Summary, conclusions, and future work

The WVIOP2004 provided a comprehensive data set for the study of the Arctic atmosphere. In the analysis of the radiosonde launched during the WVIOP2004, we found large discrepancies in humidity profiles, especially in the upper troposphere-lower stratosphere range. Preliminary results seem to indicate that NWS radiosondes might be biased above 10 km (about 20% in RH), although further investigation is needed. For example, we intend to extend the analysis to a statistically significant set including all the observations listed in Table 1. Because the NWS radiosondes are routinely launched at Barrow, and a long historic database is available to and used by the scientific community, the absolute accuracy is particularly important. In fact, any possible bias in these measurements needs to be taken into account into radiative and climate models studies, as well as in satellite observation calibration/validation efforts.

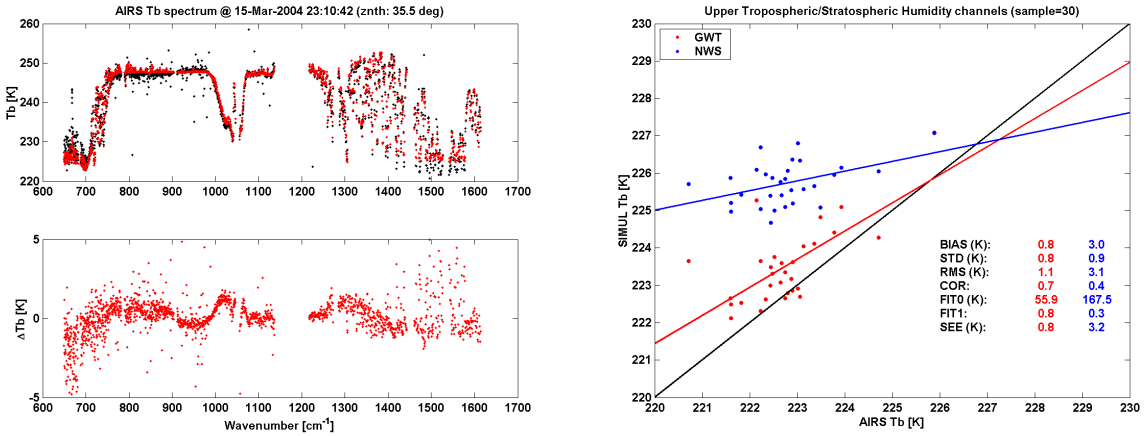

Figure 5: Left: Measurements (black) and NWS simulations (red) of AIRS Tb spectrum. The difference between the two is shown in the bottom panel. Right: scatter plot and statistics of simulated (blue: NWS; red: GWT) minus measured Tb considering only AIRS UTH channels.

Acknowledgments

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