

THE WATER VAPOR VARIABILITY – SATELLITE/SONDES (WAVES) FIELD CAMPAIGNS

D. N. Whiteman¹, M. Adam², C. Barnet¹³, B. Bojkov³, R. Delgado³, B. Demoz², J. Fitzgibbon⁴, R. Forno¹², R. Herman⁸, R. Hoff³, E. Joseph², E. Landolfo¹¹, K. McCann³, T. McGee¹, L. Miloshevich⁵, I. Restrepo¹⁰, F. J. Schmidlin¹, B. Taubman¹⁴, A. Thompson⁷, L. Twigg¹⁵, D. Venable², H. Vömel⁶, C. Walthall⁹

¹ NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771, david.n.whiteman@nasa.gov

² Howard University, Washington, DC, 20059

³ University of Maryland, Baltimore County, Baltimore, MD 21250

⁴ NOAA/National Weather Service, Sterling, Virginia 20166

⁵ National Center for Atmospheric Research, Boulder, CO 80305

⁶ University of Colorado (CIRES), Boulder, CO 80309

⁷ Pennsylvania State University, University Park, PA 16802

⁸ Jet Propulsion Laboratory, Pasadena, CA 91109

⁹ U. S. Department of Agriculture, Beltsville, MD 20705

¹⁰ Trinity University, Washington, DC 20017

¹¹ Instituto de Pesquisas Energeticas e Nucleares (IPEN), São Paulo, Brazil

¹² Universidad Mayor de San Andrés., La Paz, Bolivia

¹³ NOAA/NESDIS, Camp Springs, MD 20746

¹⁴ Appalachian State University, Boone, NC 28608

¹⁵ Science Systems Applications, Inc., Lanham, MD 20706

ABSTRACT

Three NASA-funded field campaigns have been hosted at the Howard University Research Campus in Beltsville, MD. In each of the years 2006, 2007 and 2008, WAVES field campaigns have coordinated ozonesonde launches, lidar operations and other measurements with A-train satellite overpasses for the purposes of satellite validation. The unique mix of measurement systems, physical location and the inter-agency, international group of researchers and students has permitted other objectives, such as mesoscale meteorological studies, to be addressed as well. We review the goals and accomplishments of the three WAVES missions with the emphasis on the non-

satellite validation component of WAVES, as the satellite validation activities have been reported elsewhere.

1. BACKGROUND

The WAVES_2006 and _2007 campaigns were staged from July 7 to August 10, 2006 and July 14 to August 8, 2007, respectively. WAVES_2008 began operations February 9, 2008 and, at the time of this writing, is still in progress. The Beltsville, MD site of Howard University is a 110-acre forested facility located in a mixed suburban, light-industrial area on the periphery of Washington, DC. As such it offers a wide range of meteorological and air quality conditions from hot and

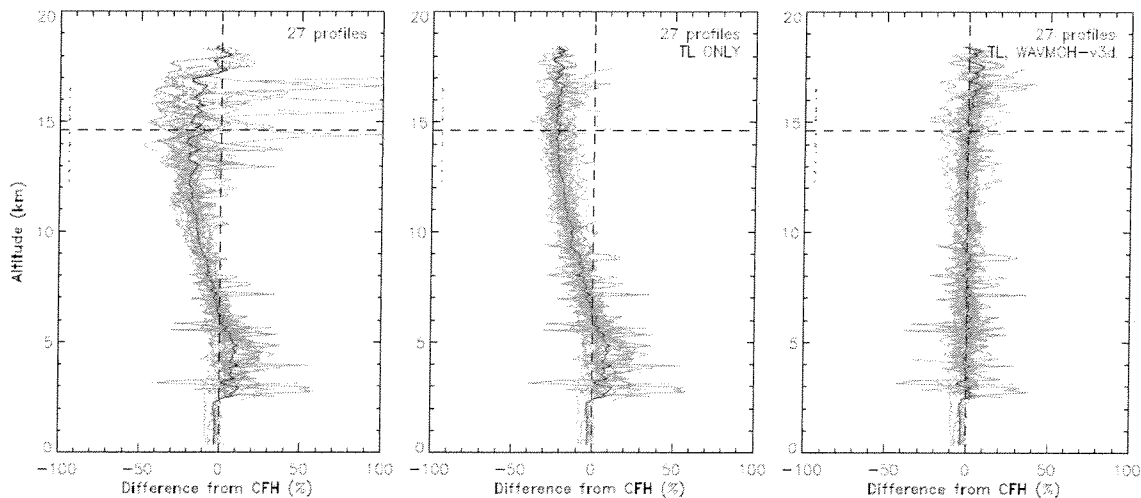


Figure 1 left: Percentage difference in relative humidity measurements of uncorrected Vaisala RS-92 and CFH. Middle: Same comparison after correction for the increasing response time of the Vaisala sensor with altitude. Right: Same comparison after application of the empirical correction to RS-92 data.

polluted in the summer to cold and pristine in the winter. This makes the Beltsville location of particular interest to satellite validation (e.g. see Adam et. al., this conference) by permitting retrieval studies under varying atmospheric conditions. During the first two WAVES campaigns, measurements of various sensors were coordinated with more than 50 Aura overpasses. The measurement systems involved included Vaisala RS-92 radiosonde, ENSCI ozonesonde, Cryogenic Frostpoint Hygrometer (CFH), Raman and backscatter lidars from NASA/GSFC, Howard University, University of Maryland, Baltimore County and Penn State University. These episodic measurements were supported by the large number of sensors permanently sited at the Howard University facility including a 31-m instrumented tower, various broad-band and spectral radiometers, microwave radiometer, GPS, whole sky imager, Doppler C-band radar, research level air quality monitoring instruments, wind profiler and RASS (Radio Acoustic Sounding System) system.

2. VAISALA RADIOSONDE EMPIRICAL CORRECTION

Outside of the pure satellite validation, one of the core activities of the WAVES efforts has been to extend the research in radiosonde and Raman lidar corrections that was initiated during the AWEX-G field campaign in 2003 [1][2]. Of particular interest to the satellite overpass coordinated radiosonde measurements provided by WAVES is the empirical correction of Vaisala RS-92 radiosonde relative humidity data based on same balloon launches with the CFH. An example of that correction is shown in figure 1.

The left panel of figure 1 shows the percentage difference between the original Vaisala RS-92 measurements and those of the CFH. A moist bias in the middle troposphere and a distinct dry bias that increases with altitude in the upper troposphere is observed in the Vaisala sensor. The middle panel shows the same comparison after correction for the increase in response time of the relative humidity sensor due to the decreasing temperatures at higher altitudes. A dry bias in the UT is still observed however the variability in the comparisons with CFH is greatly reduced. The right-most panel shows the comparison of the RS-92 with the CFH after application of the empirical correction to the RS-92 measurements. This empirical correction has been derived using all available RS-92 CFH comparisons including from other field campaigns such as MOHAVE (see Leblanc et. al, this conference) and

TC4. In the mean, the two measurements agree within less than +/- 10% to well above the tropopause, the mean height of which is indicated by the dashed horizontal line at an altitude of approximately 15 km, permitting the corrected RS-92s to be used for accurate validation purposes into the lower stratosphere.

3. TOTAL COLUMN WATER CALIBRATION COMPARISON

One method of comparing the overall calibration of various water vapor sensors is to compare the total precipitable water measured by each system. The total column water measurements from several instruments including CFH and RS-92 were compared for total column water vapor amounts from the WAVES_2006 campaign. That comparison is shown in figure 2. The reference instrument for this figure is a 2-channel Radiometrics microwave radiometer, the instrument that has become the "gold standard" for total column water measurements within the Department of Energy's Atmospheric Radiation Measurements (ARM) program. The instruments that are compared with the MWR for total column water amounts are the Suominet GPS, the TES instrument on Aura, the AIRS instrument on Aqua, the CFH, the RS-92 with empirical correction (ECNT) and the RS-92 with time lag correction only (TLNT). The range of PW calibrations covers almost 20% with the GPS retrievals being on average ~ 3% dry of the MWR and the AIRS retrievals being ~ 15% wet. This large range in PW measurements exceeds the claimed accuracy of all the individual measurement systems and indicates the need for further work in this area.

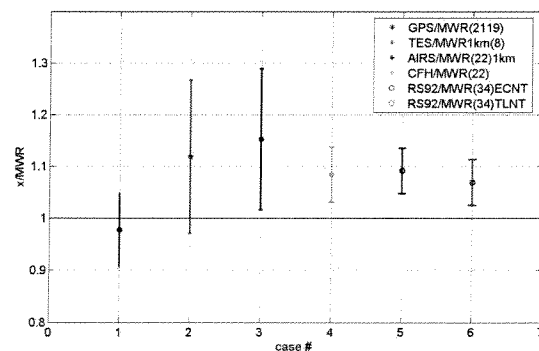


Figure 2 Comparison of precipitable water amounts measured by microwave radiometer, GPS, TEX on Aura, AIRS on Aqua, CFH and Vaisala-92.

It is interesting to note from figure 2 that the CFH and corrected RS-92 are, as expected, in good agreement

and exchange between the boundary layer and the free troposphere is needed. Figure 3 presents a 5-day

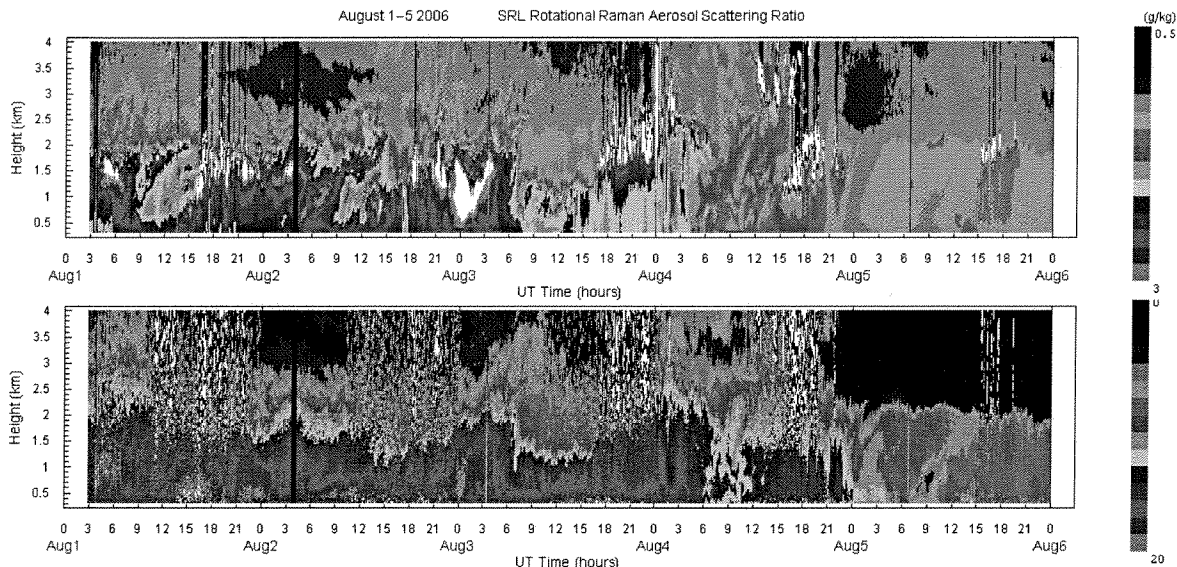


Figure 3 Aerosol scattering ratio and water vapor mixing ratio measurements over a 5-day period measured by the NASA/GSFC Scanning Raman and the Howard University Raman Lidars.

with each other but are significantly moist of the MWR. They are also moister than the RS-92 measurements that have only received a time-lag correction. This result prompted a re-analysis of the CFH and RS-92 data using Raman water vapor lidar and other measurements to help study this discrepancy. The conclusion was that under the moist, polluted conditions of WAVES_2006 – conditions under which the CFH had not previously been tested - the CFH was measuring artificially moist in lower troposphere. This moistness of the CFH results caused the empirical correction derived for Vaisala RS-92 from WAVES-2006 to also be significantly moist. A complete re-analysis of CFH/RS-92 dual sensor launches from WAVES and MOHAVE, lidar data from WAVES and data acquired by the ARM program is now being performed in order to derive a new empirical correction to the RS-92 data that does not rely on the CFH for pressures greater than 700 mb. This new correction will be one of the major achievements of the WAVES campaigns.

4. MEASUREMENTS DURING A HEAT-WAVE/POLLUTION OUTBREAK PERIOD

One of the challenges for satellite remote sensing is how to use such data to aid in the understanding and prediction of local pollution events. In order to couple measurements of pollutants aloft, such as available from passive satellite, and the human experience on the ground, accurate modeling of boundary layer evolution

sequence of water vapor mixing ratio and aerosol scattering ratio data acquired by the NASA/GSFC Scanning Raman Lidar and the Howard University Raman Lidars during the August 1-5, 2006 period that is being used as a case study for the purposes of tuning chemical transport models. This was a period characterized by a heat advisory and poor air quality which was finally swept out by a frontal passage that occurred on August 4-5. Supporting data for this case include 10 ozonesondes and ground level chemistry.

5. AIRBORNE AND GROUND-BASED RAMAN WATER VAPOR LIDAR COMPARISONS

WAVES_2007 provided the opportunity for ground-based validation of the new airborne Raman lidar called RASL (Whiteman et. al., this conference). On the night of August 3, 2007 RASL overflew the Beltsville site on several occasions. The comparison of airborne RASL data with Vaisala RS-92 and ground-based HURL (Adam et. al., this conference) is shown in figure 4. RASL averaging time is 10 sec (1 km horizontal resolution) while HURL averaging time is 60 secs. The RASL random error remains below 10% throughout the profile while the HURL random errors range from ~ 1% at 1 km to 30-100% at 6-8km. The ability to maintain a nearly constant random error illustrates the signal to noise advantage of measuring water vapor mixing ratio using a Raman lidar from the air looking

downward versus from the ground looking upward.

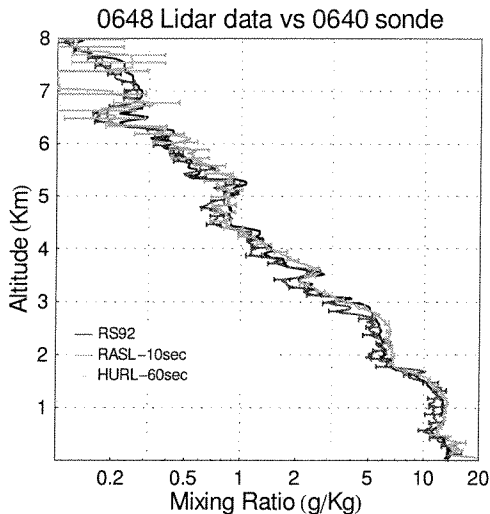


Figure 4 Comparison of airborne RASL, Vaisala RS-92 and ground-based HURL water vapor mixing ratio measurements

6. CHARACTERIZATION OF HIGH ALTITUDE RAMAN LIDAR WATER VAPOR MIXING RATIO MEASUREMENTS

WAVES_2008 is currently in progress. One of the main goals is the continuation of the study of high altitude Raman lidar measurements of water vapor mixing ratio that has been the focus of the two MOHAVE (Leblanc et. al, this conference) campaigns. Four Raman lidar systems are participating: 2 from NASA/GSFC, one

each from Howard University and UMBC. Figure 5 shows a comparison of 2 1-hour summations of upward-looking RASL measurements (termed ALVICE in this configuration) with those of corrected Vaisala RS-92 radiosondes. The second configuration of ALVICE uses a reflective blocker to reduce significantly the amount of 354.7 nm light that enters the optical system and thus to reduce any fluorescence that may be caused by the intense 354.7 light. In this one comparison there is no indication of a significant fluorescence component to the signal. One of the goals of WAVES_2008 is to acquire a statistically robust set of such measurements for characterizing UT/LS measurements of Raman lidar.

7. SUMMARY AND OUTLOOK

The WAVES field campaigns have permitted numerous research topics to be studied. Here we presented progress reports on Vaisala radiosonde empirical correction, total precipitable water calibration of various sensors, lidar measurements during pollution outbreak and Raman lidar water vapor mixing ratio comparisons for airborne and ground-based systems. This research has involved graduate students and researchers from numerous government agencies, universities and foreign institutions permitting a large body of collaborative activity at the HU/Beltsville campus. WAVES_2008 is currently in progress with the goal of extending these collaborative efforts.

We gratefully acknowledge the support of NASA's Atmospheric Chemistry and Dynamics Program.

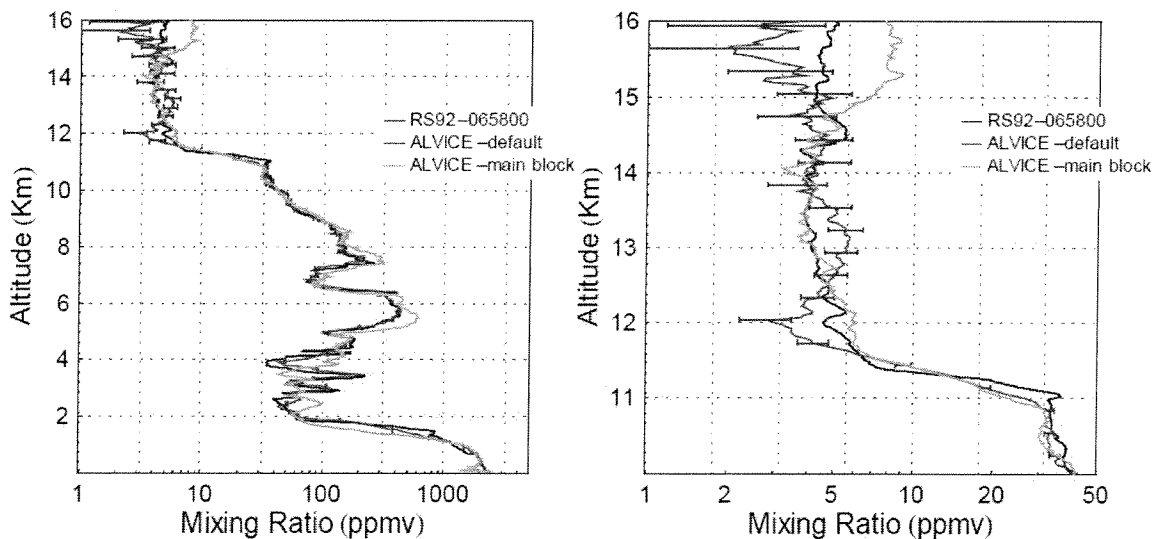


Figure 5 Comparison of corrected Vaisala RS-92 radiosonde and two configurations of the ground-based ALVICE Raman lidar measurements of water vapor mixing ratio.