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GEOGRAPHIC AND SEASONAL VARIABILITY IN ACCURACY IN WATER VAPOR MEASUREMENTS FROM WVSS-II

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1. INTRODUCTION

While radiosondes make up a large portion of the upper-air network, they have poor spatial and temporal resolution. Satellites have been used to fill in these spatial and temporal gaps but the data is limited in the lower troposphere. With the addition of the Water Vapor Sensing System II (WVSS-II) on commercial aircraft, aircraft-based profiles can be used to augment the existing radiosonde network with more frequent and spatially dense observations.

Previous studies have been conducted to validate the performance of the WVSS with specially launched radiosondes; these studies have been limited to individual locations and observation periods of a few weeks. This present study uses operational radiosondes from across the continental United States (CONUS) to validate WVSS-II performance in different seasons and geographical regions. By characterizing sensor performance in this way, it will ease its adoption into forecasting, models, and other areas of research.

2. DATA & METHODS

The WVSS-II is a reliable, low-maintenance sensor mounted on commercial airplanes. Currently, version three of WVSS-II is in deployment on approximately 100 planes within the United States, primarily aboard UPS 757's and Southwest 737's. The sensor weighs 3.5 kg, and uses the standard 28-volt power supply on the aircraft. The sensor also has a range of detectable signal of 50 ppmv to 40,000 ppmv with an accuracy of +/- 50 ppmv or +/- 5% of the reading (whichever is greater) in a pressure range from the surface to 200 hPa and in a temperature range of -65 °C to +50 °C (Spectra Sensors 2012).

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The WVSS-II data is transmitted via Aircraft Meteorological Data Reports (AMDAR) and the Aircraft Communications Addressing and Reporting System (ACARS) [ESRL/GSD]. The water vapor data collected from the WVSS-II was then compared with radiosondes launched as part of regular operations by the National Weather Service (NWS) throughout the CONUS for the entirety of 2015. Two different models are currently part of the radiosonde network: the LMS-6 by Lockheed Martin Sippican and the RS92-NGP by Vaisala. The WVSS-II measures water vapor mixing ratio directly while these radiosondes measure relative humidity and are post-processed to dew point temperature. To prevent any biases from using temperature from the aircraft, the radiosonde dew point temperatures were converted to water vapor mixing ratio.

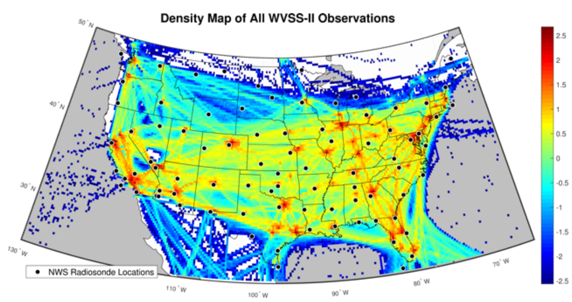

Figure 1: Density plot of the numbers of WVSS-II observations across the CONUS for 2015 with radiosonde locations plotted as well. (Note: color scale is base log 10).

Similar to past studies (e.g. Petersen et al. 2006), the following criteria were implemented to compare WVSS-II observations to radiosondes: the WVSS-II observations must be within 30 minutes, 10 hPa, and a 50 km radius of the radiosonde observation. These observations were then interpolated onto a vertical grid with a resolution of 10 hPa. Figure 1 shows the number

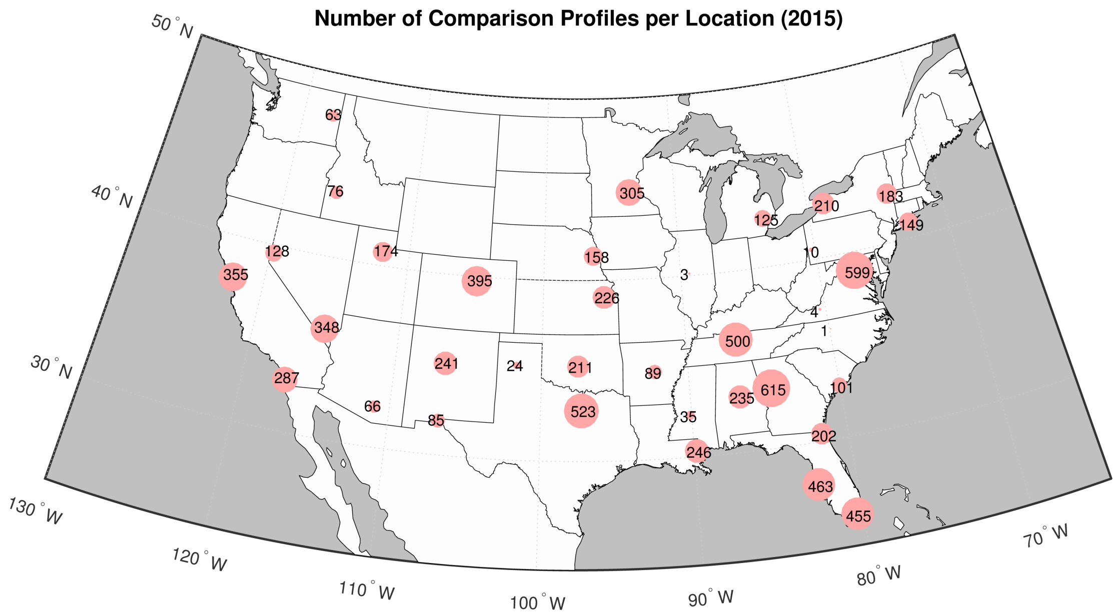

Figure 2: Locations used for comparison between WVSS-II and radiosondes with the number/size of circle indicating how many comparison profiles were present for 2015.

of observations across the CONUS for 2015 alongside radiosonde locations. It is apparent that the WVSS-II observations are clustered around cities with large airports where planes frequently take off and land. This helped determine which locations would be suitable for comparisons between the radiosondes and the WVSS-II.

3. RESULTS

Comparisons between the WVSS-II and radiosondes were made for two different ranges: 1050 hPa – 400 hPa and 700 hPa – 200 hPa. The range of 1050 – 400 hPa was chosen to examine where airplanes are taking off and landing from airports and creating a vertical profile of moisture observations. At this range, biases were found for ascending/descending aircraft, seasons, different regions across the CONUS, and two climatically different locations. The range of 700 hPa – 200 hPa was assessed as well to examine all WVSS observations from airplanes taking off and landing at airports but to also include observations from planes that were higher up in the atmosphere and at cruising altitude levels.

3.1 1050 hPa – 400 hPa Comparisons

For comparisons made in the range of 1050 hPa – 400 hPa, an additional criterion was implemented. The WVSS-II observation was required to be on an airplane that was taking off or landing at an airport near the radiosonde location which confirmed that the airplane was ascending or descending and creating a water vapor profile instead of merely overflying a location on its way to a more distant airport.

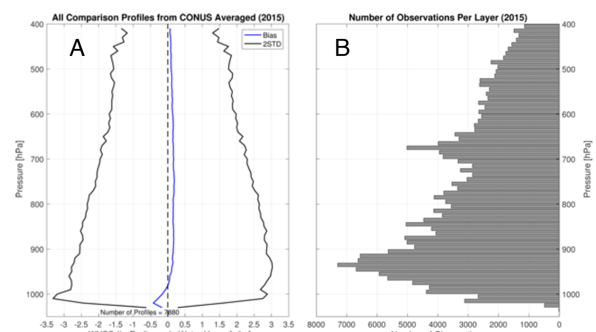

Figure 3: (A) CONUS composite of all comparison profiles for 2015 with bias and standard deviation. (B) Number of observations per layer for CONUS composite.

The number of comparison profiles from 1050 hPa – 400 hPa for each location are shown in Figure 2 (Note: a comparison profile must consist of at least two observations that meet the criteria, however most profiles contain many more observations). Similar to Figure 1, it is apparent that the north-central CONUS is lacking in observations while the southern portion of the country is very abundant.

By averaging all the comparison profiles from these locations by layer, the bias of the WVSS-II was found (Fig. 3A). There is a slight moist bias of less than 0.2 g/kg for the WVSS-II throughout most of the entire profile when compared to the radiosondes. The number of observations below 1000 hPa, decrease significantly which could explain the slight dry bias closest to the surface.

Past studies have shown slight differences in bias for WVSS-II on airplanes taking off and airplanes landing. Above approximately 950 hPa, the descent profile has less bias than the ascent profile (Fig. 4). Most notably, from 950 – 580 hPa, the descent profile has a bias of about half that of ascent. There is possible hysteresis happening with both the ascending observations, as the aircraft flies from moist to dry air, and the descending observations, as the aircraft flies from dry air to more moist air.

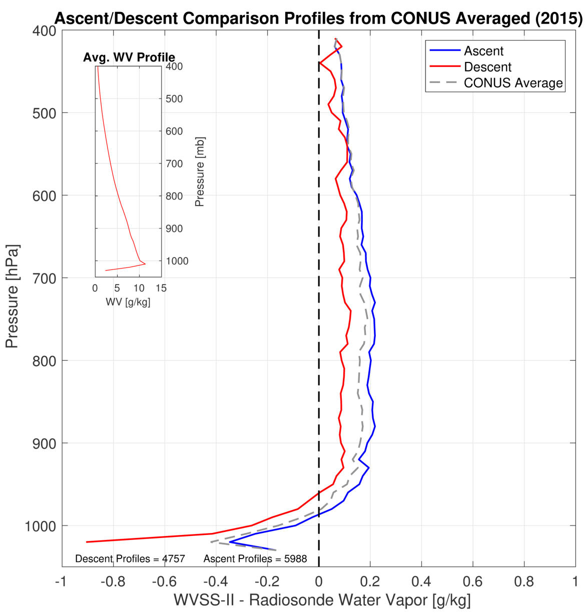

Figure 4: CONUS composite of WVSS-II observations from only ascending aircraft (blue), descending aircraft (red), and the CONUS average (gray dashed) for 2015. The inset shows the average water vapor profile from the radiosondes for 2015.

When aircraft ascend, the frequency in which observations are taken is three times greater than the descending observations (Fig. 5). In addition to the difference in observation frequency, the differences between flight patterns of ascending and descending aircraft could also be contributing to the differences in the number of observations.

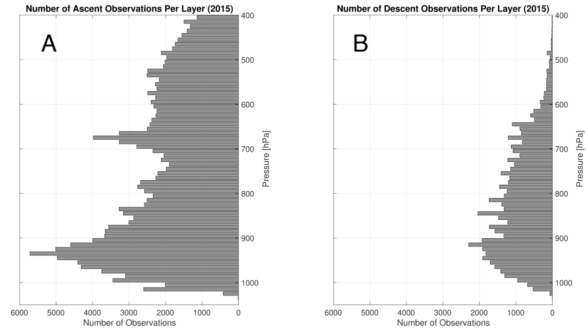

Figure 5: The number of WVSS-II observation per layer with ascending observations (A) and descending observations)

When considering seasons, winter has the least bias while summer has the highest (Fig. 6). This could be explained by the fact that cold air masses tend to typically be drier while warm air masses are typically more moist and the biases relate to the amount of moisture present.

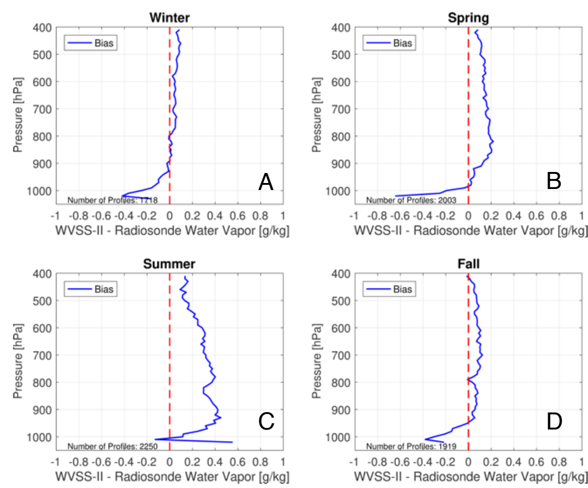

Figure 6: CONUS composite of comparison profiles for winter (A), spring (B), summer (C) and fall (D) for 2015.

3.2 Climate Regions

The Köppen-Geiger Climate Classification Map (available at http://koeppen-geiger.vu-wien.ac.at/usa.htm) was used to classify different locations into similar climates and determine how the WVSS-II responds in different climate regimes. There are six regions used with the available locations, warm temperate, fully humid, hot summers (Cfa); warm temperate, dry and hot summers (Csa); warm temperate, dry, warm summer / snow, dry, warm summer (Csb/Dsb); snow, fully humid, warm summer (Dfb); cold arid, steppe (BSk); and cold arid, desert (BWk). To calculate the bias for each region, the location with the smallest number of comparison profiles determined how many profiles were randomly chosen from each of the remaining locations to prevent any bias towards one location; all of these profiles were then averaged to find the region's bias.

The Cfa region contained most of the locations in the southern and eastern parts of the CONUS while also including the mid-Atlantic region (Fig. 7). Similar to the CONUS composite, the Cfa regional bias is slightly moist above 1000 hPa.

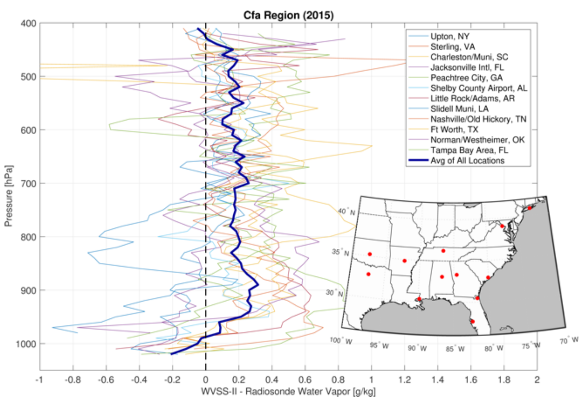

Figure 7: Regional bias composite for warm temperate, fully humid, with hot summers (Cfa) with the map inset showing the locations of where the comparison profiles came from.

The Dfb region (Fig. 8), is located in the northern part of the CONUS and contains fewer locations than the Cfa region. This region still has the slight moist bias above 1000 hPa similar to past bias composites.

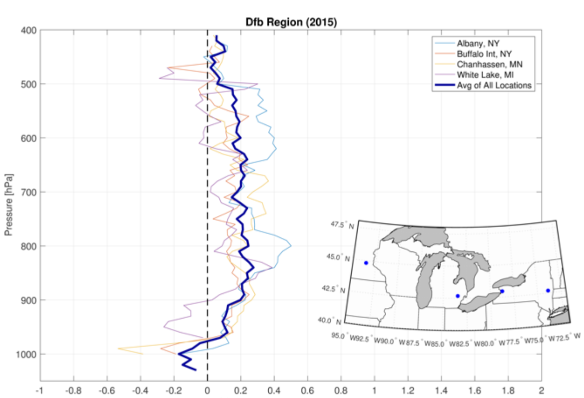

Figure 8: Same as Figure 6 but for the Dfb region.

When comparing all six regions to each other (Fig. 9), there is a moist bias present through most of the atmosphere similar to CONUS composite of comparison profiles (Fig. 3). The lower levels have a larger spread in bias differences but converge as altitude increases.

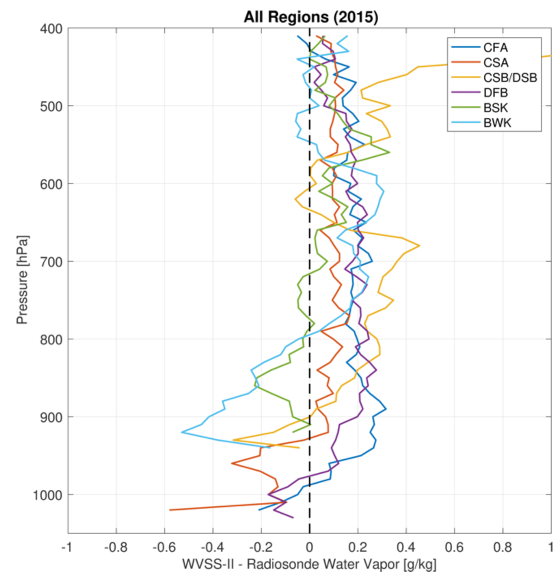

Figure 9: All six different regions for comparisons.

3.3 680 hPa – 200 hPa Comparisons

The second maximum in observations per layer observed at approximately 680 hPa was chosen as the lower bound of the range for mid/upper level comparisons. These comparisons do not include the ascending/descending into an airport criterion and allows for planes that are flying over a location while heading to a different destination to be included.

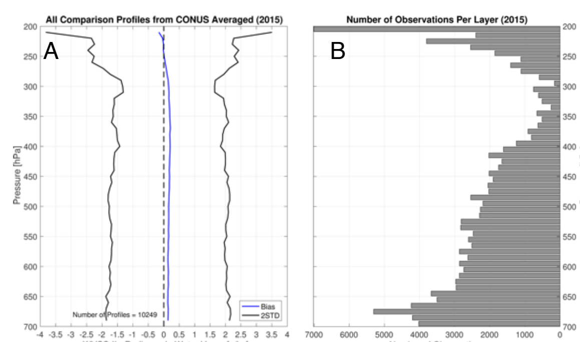

Figure 10: Comparison profiles for 700 hPa – 200 hPa with the CONUS differences composite for all comparison profiles (A) and the number of observations per layer (B).

Figure 10A shows the comparison profiles for the CONUS at these levels. Similar to the lower levels of the atmosphere, there is still the moist bias present throughout most of the column when compared with radiosondes. The number of observations decreases with height but then again increases near 200 hPa where many planes are flying at cruising altitude.

3.4 Individual Locations

Two climatically different locations with significant numbers of available comparisons were chosen for further investigation: Miami, Florida with a tropical moist climate, and Las Vegas, Nevada, in the desert. In Miami (Fig. 11), the bias is actually slightly dry at the lowest levels but the standard deviation is quite large. In comparison, Las Vegas (Fig. 12) similarly starts with a dry bias but higher up becomes a moist bias. The standard deviation for Las Vegas is much smaller than that of Miami as well. The insets in both Figure 11 and 12 show the average water vapor mixing ratio profile from each location. These show how Miami on average has over twice the amount of water vapor present than Las Vegas which could explain Miami's much larger variability and noisier seasonal comparison profiles.

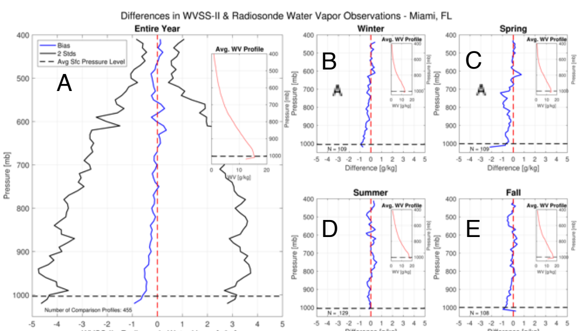

Figure 11: Comparison profile composite at Miami, FL for all of 2015 (A) with bias (blue) and standard deviation (black) and for the seasons winter (B), spring (C), summer (D), and fall (E) with each having the average water vapor mixing ratio profile from the radiosondes.

4. CONCLUSIONS

Overall, the WVSS-II were slightly more moist than operational radiosondes above 1000 hPa. The WVSS-II observations from descent profiles show slightly less difference than ascending profiles. Summer is the season with the largest differences while winter has the smallest. Different regions follow CONUS composites with the most spread at the lower levels and becoming more in agreement with each other at higher altitudes. Similar to lower level comparisons, the higher level comparisons are still slightly moist extending to nearly 250 hPa. The cause of these biases need to be investigated still but previous studies suggest that they could be due the distance between the radiosondes (Petersen et al. 2016) and the WVSS-II and due to the faster response time of the WVSS-II (Helms et al. 2010). Future work will examine differences by aircraft type and differences by temporal/spatial distance between WVSS-II observation and radiosondes.

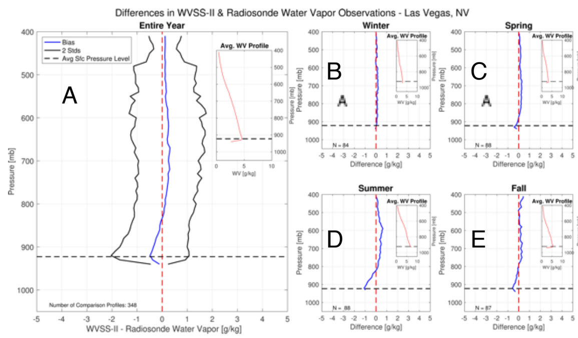

Figure 12: Same as Figure 10 but for Las Vegas, NV.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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