5.5 AN OVERVIEW OF THE OKLAHOMA CITY URBAN MICRONET TEST FACILITY

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1. INTRODUCTION

In late 1999, the world's population exceeded 6 billion people with an expected 9 billion by the year 2050. At the same time, the world is becoming more urbanized than ever before. Every week, the world's urban population increases by about one million people. The United Nations projects that by the year 2015; there will be 21 mega-cities with populations exceeding 10 million people (Hinrichsen et al. 2002). The impact of this growth will lead to increased urban sprawl already prevalent during the last few decades. As such, it is of increased importance that meteorologists have the necessary tools to study and quantify the impacts of urban areas on meso-, micro-, and local scale environments.

In order to monitor the urban atmosphere in Oklahoma City, the Oklahoma Climatological Survey (OCS) is in the early stages of developing and deploying The Oklahoma City Urban Micronet (OKCNET). The goals of the OKCNET project include: 1) operate a city–wide network of weather stations that measure core variables and transmit data in near real time, and at temporal resolution of one-minute; 2) relay the data via the Oklahoma City WiFi network used by city police, emergency managers, and first responders; 3) share aforementioned data with local, state, and federal governments; as well as, both public and private education institutions, private businesses and research communities.

When operational, the OKCNET will consist of 30 – 40 stations deployed across Oklahoma City (with a higher density near the central business district) that will measure weather variables such as wind speed and direction, precipitation, barometric pressure, temperature and humidity In addition, there will be three to five Oklahoma Mesonet stations (Brock et al. 1995) strategically located within the metro area.

Many individuals and agencies will benefit from the data collected by the Oklahoma City urban micronet. For example, the data information will be used to further study the process of urban dispersion, urban wind fields, and the impacts of the urban heat island on local and microclimate scale. Furthermore, the data can be used to increase the accuracy of local forecasts, monitor severe weather in and around urban areas, and provide improved road weather conditions.

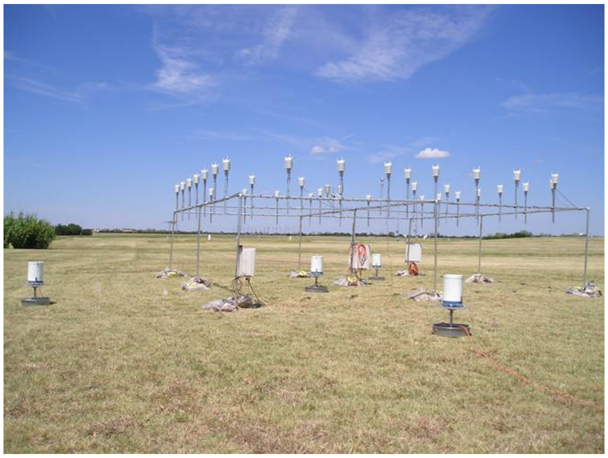

Figure 1. The Oklahoma City Urban Micronet Intercomparison Facility.

2. SENSORS AND EQUIPMENT

2.1 The Vaisala *WXT510 Weather Transmitter*

The sensor chosen for use in the OKCNet project is the Weather Transmitter WXT510 manufactured by Vaisala Oyj. The WXT510 collects observations of air temperature, relative humidity, pressure, wind speed, wind direction, and precipitation. The sensor package requires little maintenance once deployed, uses minimal power to collect observations, and has no moving parts. It is these qualities that make the WXT510 an ideal instrument package for OKCNet.

Figure 2. The Vaisala WXT510 Weather Transmitter

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2.1.1 Vaisala PTU module

The Vaisala WXT510 Weather Transmitter measures air temperature, barometric pressure and relative humidity via a replaceable PTU module. Barometric pressure measurements are taken with a capacitive silicon BAROCAP sensor that has a range of 600 to 1000 hPa with accuracy of 0.5 hPa from 0 to 30°C and an output resolution of 1.0 hPa from -52 to 60°C. Relative humidity is measured by a capacitive thin film polymer HUMICAP 180 sensor with a range of 0 to 100% RH and accuracy of ±3% RH from 0 – 90% RH and ±5% from 90 – 100% RH with an output resolution of 0.1%. Air Temperature is measured in a range of -52 to 60°C with an accuracy of ±0.3°C and an output resolution of 0.1°C.

2.1.2 Vaisala WINDCAP wind sensor

The Vaisala WINDCAP sensor uses ultrasonic technology to measure wind speed by utilizing three evenly spaced transducers. By using the sound waves time of travel between each transducer and the distance between transducers in a formula, the wind speed and direction is calculated. Wind speed is measured with a range of 0 to 60 ms^{-1} and an accuracy of 0.3 ms^{-1} or 2% (whichever is greater) with a resolution of 0.1 ms^{-1}. Wind direction is measured with a range of 0 to 360 degrees and an accuracy of ±2% with a resolution of 1°.

2.1.3 Vaisala RAINCAP sensor

The RAINCAP precipitation sensor utilizes acoustic rain/hail impact measurement technology that is at the forefront of precipitation measurement technology. Precipitation accumulation is measured as a function of the voltage signal of the raindrops as they impact the sensor. Each voltage signal is proportional to the volume of a specific raindrop, which is subsequently converted to accumulated precipitation. The RAINCAP sensors are advantageous over tipping bucket rain gauges in that they incur a less chance for error due to evaporation, flooding, wind, and splash out. In addition, the RAINCAP and WINDCAP sensors contain internal heating elements controlled by a heating temperature sensor located under the RAINCAP component. The heating element will keep the sensors clear of ice buildup, which would affect data quality, in the event of winter precipitation. Output resolution for rain is 0.01 mm with a field accuracy of better than 5%. The resolution for hail is 0.1 $\mathrm{hits/cm}^2$.

2.1.4 WXT510 Deployment

The siting and exposure of the WXT510 is the biggest challenge of the micronet because in most instances the WMO Guidelines are not applicable in an urban setting (Oke 2004). Because the goal of the micronet is to document the atmospheric conditions within the urban canopy layer (UCL), the sensors need to be located so they can properly record data relevant to urban conditions (i.e. traffic signals, street lights, and building surfaces).

When dealing with sensors and the components they measure, there are locations that are specifically discouraged due to the tendency to return data that is not representative of a general urban area. It is not recommended to measure air temperature or humidity from the rooftop of a building. Such locations create microclimates that are overexposed to incoming solar radiation resulting in an over stating of a temperature that can not be extrapolated vertically or horizontally.

The WMO guidelines for wind speed and direction sensors suggest a height of ten meters which is the height of many obstacles in an urban setting. An example of this is referenced in Oke (2004) which states that an acceptable height for an anemometer in an urban setting is 15 meters above the surface. Rooftops are also poor locations for wind sensors, because they will modify wind fields; thus requiring the use of a very tall mast for the sensor. Wind sensors must be placed at heights sufficient to ensure they are representative of upstream surface roughness at the local scales and are as free from micro or local scale climate anomalies as possible (Oke 2004).

2.2 Oklahoma Mesonet Stations

The perimeter stations will be standard Oklahoma Mesonet stations (McPhearson et al. 2006) with the full compliment of sensors. These stations will be installed within 15 km of the central business district and will be essential in providing transition observations from the rural environment to the urban district. These measurements will give insight to the impacts that the urban area has on the surrounding areas.

2.3 Intercomparison Facility

Before the micronet sensors are deployed in Oklahoma City, they are first installed at the Urban Micronet Intercomparison Facility. The WXT510s are mounted at a height of 2 meters in a 10 meter square test grid. This allows measurements to be compared under the same conditions to other micronet sensors and various control sensors.

In the event that any of the WXT510s deployed in Oklahoma City collect suspect data, they will be replaced with an identical sensor and the suspect sensor will be relocated to the intercomparison site in Norman. The suspect sensor’s measurements will then be monitored to verify if the suspect data is due to a sensor malfunction or if the anomaly is site specific. Data from the intercomparison facility will, in some instances, also be compared to data from the Norman Mesonet station (NRMN) which is approximately 160 meters NNW of the test facility.

2.3.1 Intercomparison Control Sensors

The control sensor for relative humidity is the Vaisala HMP45C, installed on 27 July 2006, which has manufacturer calibrated accuracy of ±2% for RH between 0 – 90% and ±3% between 90 – 100% with an overall resolution of 0.1% (McPhearson et al. 2006). The HMP45C also measures air temperature (TSLO) within a range of -39.2 to 60°C. The relative humidity measurement has a temperature sensitivity of 0.05% RH/°C.

Temperature is also measured with the Thermometric FastTherm (FastTherm) which was installed on 20 July 2006. This sensor has a range of -30 to 50°C with an accuracy of ±0.35°C, which in conditions of extreme radiation and light winds can vary as much as ±1°C.

The precipitation measurement control is the MetOne tipping bucket rain gauge. It has a resolution of 0.25 mm and accuracy varies depending on tip capacity.

Wind is measured with a Vaisala 2-D sonic anemometer with a resolution of 0.1 ms^{-1} and an accuracy of 0.135 ms^{-1} or 3% of the reading, whichever is greater. An R.M. Young 3101 Wind Sentry cup anemometer with a range of 0 to 45 ms^{-1} and accuracy of ±0.5% is also installed. The purpose of the cup anemometer is not only for a comparison with the WXT510, but also comparison to the 2-D sonic anemometer to note the differences between the two wind sensor technologies. Because the wind measurement technology used by the WXT510 is innovative, it is beneficial to compare measurements by accepted technology with regard to wind measurement values.

2.1.4 Datalogger

The datalogger used at the intercomparison facility is the Campbell Scientific CR1000. All communications between the WXT510 and dataloggers are performed via Serial Digital Interface Protocol (SDI-12), which allows for multiple sensors to be wired to one datalogger with minimal signal interference. SDI-12 interfacing allows sensors to be added or removed without disruption of the others and a single cable to supply power to all of the connected sensors.

When deployed, the micronet sensors will use the CR 200 data logger in place of the larger CR 1000 that is used at the intercomparison site. Because there will only be one sensor per datalogger, the necessary storage capacity will be less, and will only need to hold the data until it is transmitted via the Oklahoma City wireless network.

3. INITIAL RESULTS

3.1 Air Temperature

The overall comparison of air temperature between the WXT510, FastTherm, TSLO, and Norman Mesonet Station (NRMN) all had correlation coefficients greater than 0.70. However, the FastTherm had the closest comparison to the WXT510 with a correlation of 0.99. The comparison among the WXT510's throughout the test period was very favorable also. The average variance, a value calculated with the daily average of all 33 WXT510's, ranged from 0.005 to 0.01°C for the entire test period (45 days).

When all of the temperature sensors, WXT510, FastTherm, HMP45C, were recording data over the last twelve days of the test period, the average temperature range between them was 1.4ºC, with a variance calculated to be 0.7°C. Figure 3 is a graph of the average daily air temperature of all four temperature sensors installed at the intercomparison test facility and the Norman Mesonet station during the summer of 2006.

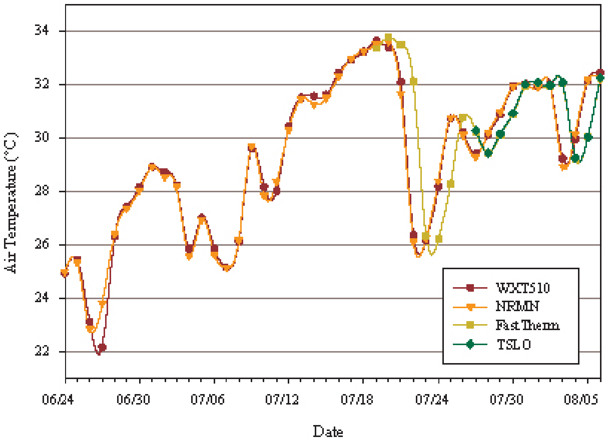

Figure 3. Comparison of the average daily air temperature for the WXT510, NRMN, TSLO, and FastTherm for 24 June 2006 to 7 August 2006.

3.2 Dew Point Temperature

The dew point temperature measurement was compared to NRMN and also showed similar average daily measurements with the highest difference between the two at approximately one degree Celsius in each case with an average difference of approximately 0.5°C Because the WXT510 dew point temperature is a value that is not measured directly but calculated using the air temperature and pressure measurements, the corresponding value will depend on the accuracy of the two weighted by the amount each is used to calculate the dew point temperature value.

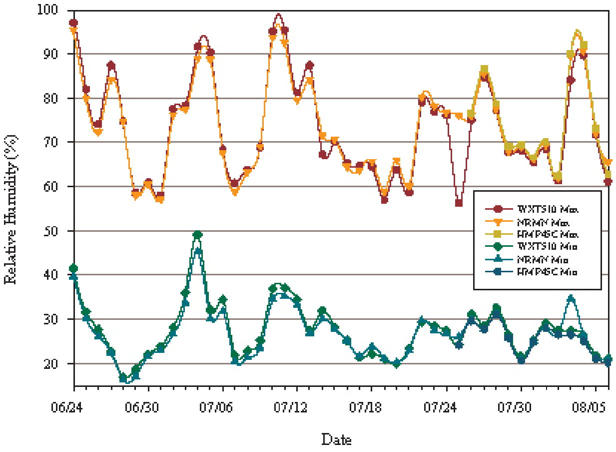

Figure 4. Comparison of the average maximum and minimum relative humidity for the WXT510, NRMN, and HMP54C for 24 June 2006 to 7 August 2006.

3.3 Relative Humidity

In addition to the WXT510, the intercomparison site was also equipped with a Vaisala HMP45C that measured relative humidity. Of the four parameters measured by the PTU (Section 2.1.3) module, relative humidity had a variance of 0.08%. The maximum variance of any daily average from the WXT510 was 0.4% and the minimum variance was 0.02%. That being said, Figure 4 shows the plot of the maximum and minimum values from the Norman Mesonet, WXT510, and HMP45C, together follow the same overall contours.

3.4 Barometric Pressure

The pressure measurement had an overall variance of 0.029 hPa^2 among all 33 WXT510s. During the 45 day test period, the WXT510 pressure measurements were compared to the Norman Mesonet station. During this time, the average difference between the two pressure measurements was about 1.62 hPa. This difference can be explained, in part, by fact that during the test period, the WXT510's were programmed to round measurement to the nearest whole number. The pressure range during the experiment period was from approximately 967 hPa to 981 hPa. The correlation coefficient between NRMN and the WXT test facility was calculated to be 0.79.

3.5 Wind Speed

When compared to NRMN, the WXT510 showed lower overall speeds when comparing the average or maximum and minimum (Fig. 5). Comparing the variances of all of the WXT510 average daily wind speeds, the wind measurements showed a variance of 0.0065 m^2s^{-2}. It should be noted that there is an obstruction about 50 meters directly to the south of the test facility that could be part of the reason for the difference. Another possible explanation for the discrepancy is that the NRMN measurements are taken with a cup anemometer. For future statistical comparisons, a Vaisala 2-D sonic anemometer as well as a cup anemometer has been installed within the test facility grid.

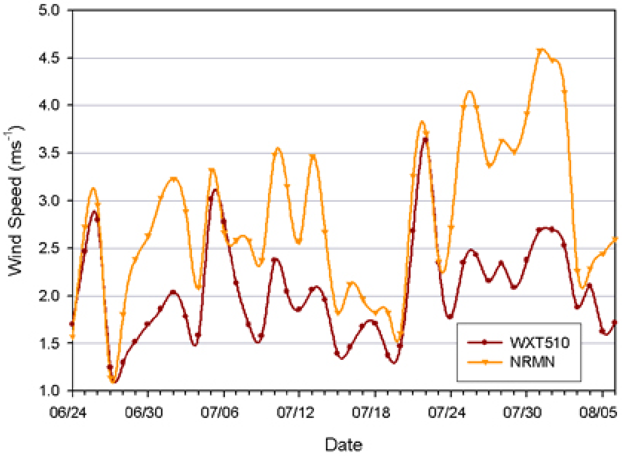

Figure 5. Comparison of the average daily wind speed for the WXT510 and NRMN for 24 June 2006 to 7 August 2006.

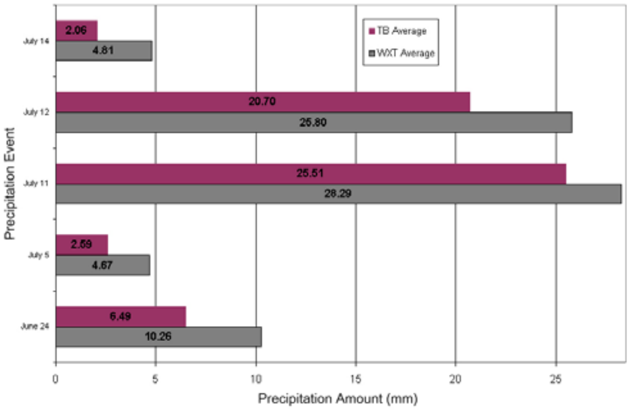

Figure 6. Comparison of the precipitation measurement for the WXT510 and MetOne tipping bucket rain gauge for 24 June 2006 to 7 August 2006.

3.6 Precipitation

The most noticeable differences between the WXT510s and control sensors were measured during light precipitation events. Figure 6 shows that for the seven rain events during the observation period of 24 June 2006 to 7 August 2006, the average difference between the tipping bucket rain gauge and the WXT510's RAINCAP was about 3.3 mm. This implies that, on average, the WXT's precipitation measurement was about 12% higher than the measurements from the tipping bucket rain gauges. One point of interest though is that the measurement differences between the two types of sensors appear to decrease with respect to the amount of rain in each event. Figure 6 illustrates this point with the events on 11 July 2006 and 14 July 2006. During the event on 11 July 2006, the WXT was only about 10% higher than the tipping bucket; whereas during the event on 14 July 2006, the WXT measures more than 200% higher than that of the tipping bucket.

4. CONCLUSIONS

The purpose of the intercomparison site is to gauge the variability of the parameters the WXT510 measures. It is important to know how much the measurements vary from sensor to sensor under the same conditions, before they are deployed to measure different conditions. The initial results are promising with temperature, pressure, relative humidity, and wind speed showing average variances of 0.07°C^2, 0.03 hPa^2, 0.08$\%^2$, and 0.0065 m^2s^{-2} respectively.

The WXT510 measurements compared quite well to the control sensors. When compared to the control sensors within the test facility grid, there were very high correlations between sensors and the plotted measurement values followed the same overall contours.

The comparison of accumulated precipitation between the WXT510 and tipping bucket rain gauges showed that differences increased in the occurrence of lighter rain events. The 5 July 2006 event showed a tipping bucket average accumulated precipitation of 2.59 mm compared to the WXT510 average of 4.67 mm, which is a difference of about 55%. During the 11 July 2006 event, a heavier rainfall event, the tipping bucket rain gauges averaged an average accumulated precipitation of 25.51 mm when the WXT510's returned an average of 28.29 mm; a difference of only about 10%.

Relative humidity measurements returned a correlation of 0.99 between the WXT510's average and the HMP45C located at the test facility. Wind speed varied more than the other parameters, but when the WXT510 average and NRMN are graphed together; it shows that although the wind speeds might be different, they still follow the same general patterns.

The majority of the cases where there is a discrepancy, it is within the combined error range of the displayed sensors. As research at the test site continues, so will the understanding of the accuracy of the WXT510 sensors with respect to currently used control instruments. At this stage of the development of the Oklahoma City Urban Micronet, the WXT510 sensor appears to be an acceptable sensor for use in an urban monitoring network.

5. ACKNOWLEDGEMENTS

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