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Measuring Surface Wind Velocity Changes

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Measuring Surface Wind Velocity Changes

Abstract

Agricultural spray drift is affected by many factors ranging from current weather conditions and the topography of the surrounding area, to the properties at the nozzle and the height at which the spray is released. Wind direction, speed, and solar radiation during the late spring/summer spray season of 2014 was measured at 10 Hz. Instrumentation was placed one meter off the ground to simulate conditions of a sprayer. Data was used to measure wind changes as it moved from one sensor to another, and to evaluate under what conditions wind may be most likely to have a significant direction or speed change. The data suggests that little to no linear correlation exists between an upwind and downwind sensors when measured in one minute segments, after adjusting for lag between the two sensors. The linear correlation values for wind direction and speed were 0.28 and 0.20 respectively. The downwind sensor measured a wind direction greater than 20 degrees different from the upwind sensors 16% of the time. The downwind sensor measured 1 m/s different wind speed from the upwind sensor 40% of the time. Histograms of wind big change events, where the difference in wind direction 30 seconds in the future and the current wind direction was greater than a set tolerance, were created for tolerances of 5, 25, and 45 degrees. For all tolerances, lower wind speeds (< 3 m/s) gave rise to more wind change events.

Keywords

sprayers, spray drift, data collection, wind effects, turbulence, simulation parameters

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

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Abstract

Agricultural spray drift is affected by many factors ranging from current weather conditions and the topography of the surrounding area, to the properties at the nozzle and the height at which the spray is released. Wind direction, speed, and solar radiation during the late spring/summer spray season of 2014 was measured at 10 Hz. Instrumentation was placed one meter off the ground to simulate conditions of a sprayer. Data was used to measure wind changes as it moved from one sensor to another, and to evaluate under what conditions wind may be most likely to have a significant direction or speed change.

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Histograms of wind big change events, where the difference in wind direction 30 seconds in the future and the current wind direction was greater than a set tolerance, were created for tolerances of 5, 25, and 45 degrees. For all tolerances, lower wind speeds (< 3 m/s) gave rise to more wind change events.

Keywords. *sprayers, spray drift, data collection, wind effects, turbulence, simulation parameters*

1. Introduction

Agriculture sprayers are used in providing crops necessary chemicals to protect and improve crop plant health. However, off-site drift of these chemicals can be detrimental to adjacent crops or other forms of life. Spray drift has many factors ranging from the topography of the land and current weather conditions to the size of the droplets and the height at which the droplets are released. Spray technology includes capabilities to mitigate spray drift by affecting droplet size for wind conditions (Nordby & Skuterud, 1974; Smith, Harris, & Goering, 1982). Boom height, temperature, humidity, droplet size, droplet release pressure, air pressure, and wind conditions are just some of the factors that control spray drift. Instrumentation placed on a sprayer may be used to control droplet size dependent upon current weather conditions. This strategy may be defeated by any unforeseen changes in wind direction or speed after the droplet has left the nozzle.

Spray drift models have been developed. Many models use Gaussian Distributions and random walks to simulate the droplets (Craig, 2004; Holterman, Van de Zande, Porskamp, & Huijsmans, 1997). With these models, buffer zones can be calculated to help insure that spray will remain in the field it was sprayed (Craig, 2004; Brown, Carter, & Stephenson, 2004). While high sophistication is used for the droplets and how the droplets are deposited down wind, less attention is given to the wind. The models use an average wind velocity with random disturbances for both direction and speed (Holterman, Van de Zande, Porskamp, & Huijsmans, 1997). Measurement and analysis of transient wind changes could help mitigate spray drift.

Objectives

- To measure changes in transient wind velocity (direction and speed) near the ground surface at a typical ground sprayer boom height
- To evaluate under what conditions wind may be most likely to have a significant velocity change or be more turbulent.

2. Methods and Materials

2.1 Experimental Design and Apparatus

Data was collected during the late spring/summer spraying season of 2014 using instrumentation set into a field of growing oats under seeded with grass. The field was located at the Iowa State University Research Farm's Bruner Farm field F1 (Figure 1). Field dimensions are 880 feet long by 348 feet wide. This allowed spacing from surrounding fields or other obstructions for the wind to "smooth" itself before reaching the sensors.

Figure 1: Bruner Farm field F1 (42.014911 N 93.731241 W) (Google, 2015)

Instrumentation included four ultrasonic anemometers (model: WindMaster 3d, Gill Instruments, Lymington, Hampshire), which measures the wind speed in the 3 cardinal directions (Figure 2), and a pyranometer (model: SP-212, Apogee Instruments, Logan, UT) to measure solar radiation. Each anemometer was supplied power by its own charging station located next to the sensors 2-3 meters away. The sensor configuration is as follows;

1. Sensors were placed in a cross pattern with 15.2 m (50 ft) spacing from a center point (Figure 3).
2. Anemometers were placed one meter above the ground surface to collect wind measurements.
3. Data was acquired at ten samples per second (10 Hz).
4. The pyranometer was placed adjacent to the western most sensor located on the charging station near the anemometer.

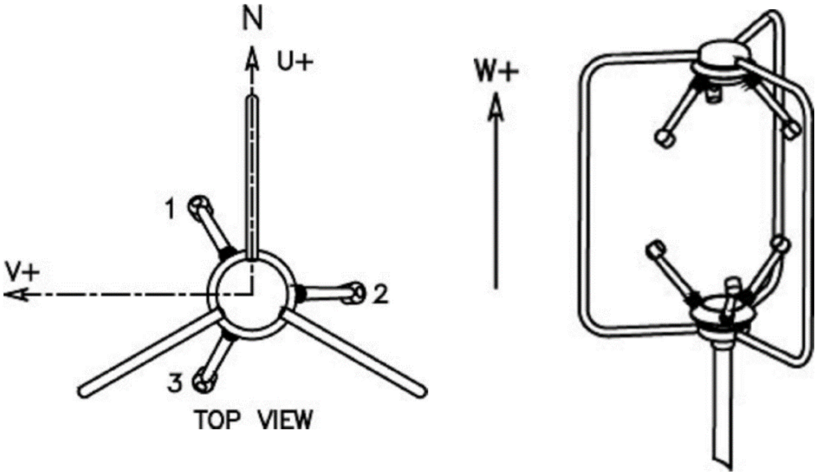

Figure 2: Ultrasonic Anemometer measuring velocity in U, V, and W component directions

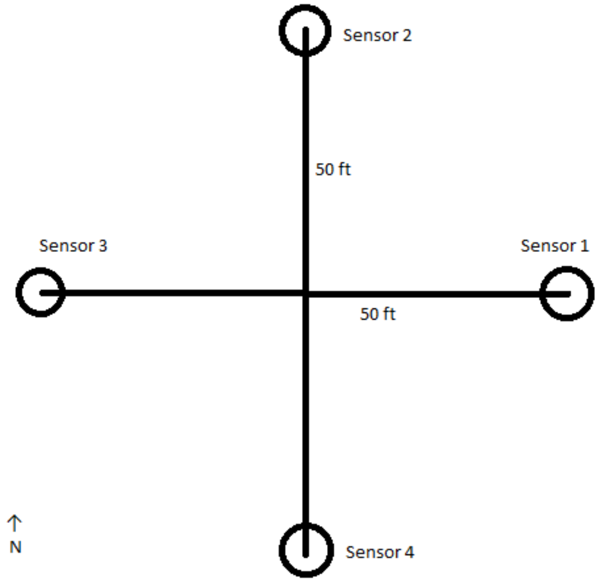

Figure 3: Sensor Positioning

Each charging station housed a 12 volt battery and data recorder. The stations were solar powered. The data recorder consisted of an open source microcontroller (model: Arduino Uno with GPS shield). The GPS shield was used to log the location of the sensor and to supply an accurate time base for both data logging and post processing synchronization of the multiple sites.

2.2 Data Analysis

After data was collected, wind direction was determined using trigonometry. A wraparound method to achieve a semi-continuous wind direction data set (Wraparound refers to the convention of allowing the wind direction to go above 360 degrees and below 0 degrees, i.e., 12 degrees = 372 degrees. Interpolation was needed because data acquisition equipment are not perfect and will record data at their own rate, and that rate is not exactly the same for all systems. This comes down to the microcontrollers 16 MHz clock. The gps shield helps in this aspect but does not insure that the data loggers all log data at the same time. A linear spline was used to interpolate the data in order to compare the sensors with one another. (Faires, 2011).

3. Results and Discussion

Linear correlation

Unless noted, data shown is from a sample five hour period typical of daytime sprayer operation from the hours of 7:30 am and 12:30pm (Figure 4). The five hour period was chosen due to, on average, the wind direction passes over two sensors. Allowing for both upwind and downwind measurements. Initial analysis checked for a linear correlation from the upwind sensor to the downwind sensor. However, due to the high number of points, it is unclear graphically if there is a correlation (Figure 5) but the linear correlation between the sensors were 0.41 and 0.33 for wind direction and speed, respectively.

To graphically see the structure of the data better, two-dimensional natural logarithmic histograms were used (Figure 6). The areas that are lighter represent where the highest density of points occurred. These values are the natural logarithmic values of points that are located in a certain bin. This was done to see smaller structures in the data. The bar graph to the right of the graphs show the shading equivalents to the natural log values. This shows how the data grouped around the mean and how the data gives no apparent structure to linear dependency. This is further shown by taking correlation values on shorter time scales of one minute segments. Here the entire data set was separated into multiple one minute data sets. Correlation values were then found on these smaller data sets and then averaged over the five hour period, giving an adjusted correlation value. This better represents what will be seen during spraying. For these shorter time scale measurements, the correlation values for wind direction and speed were 0.02 and 0.03 respectively.

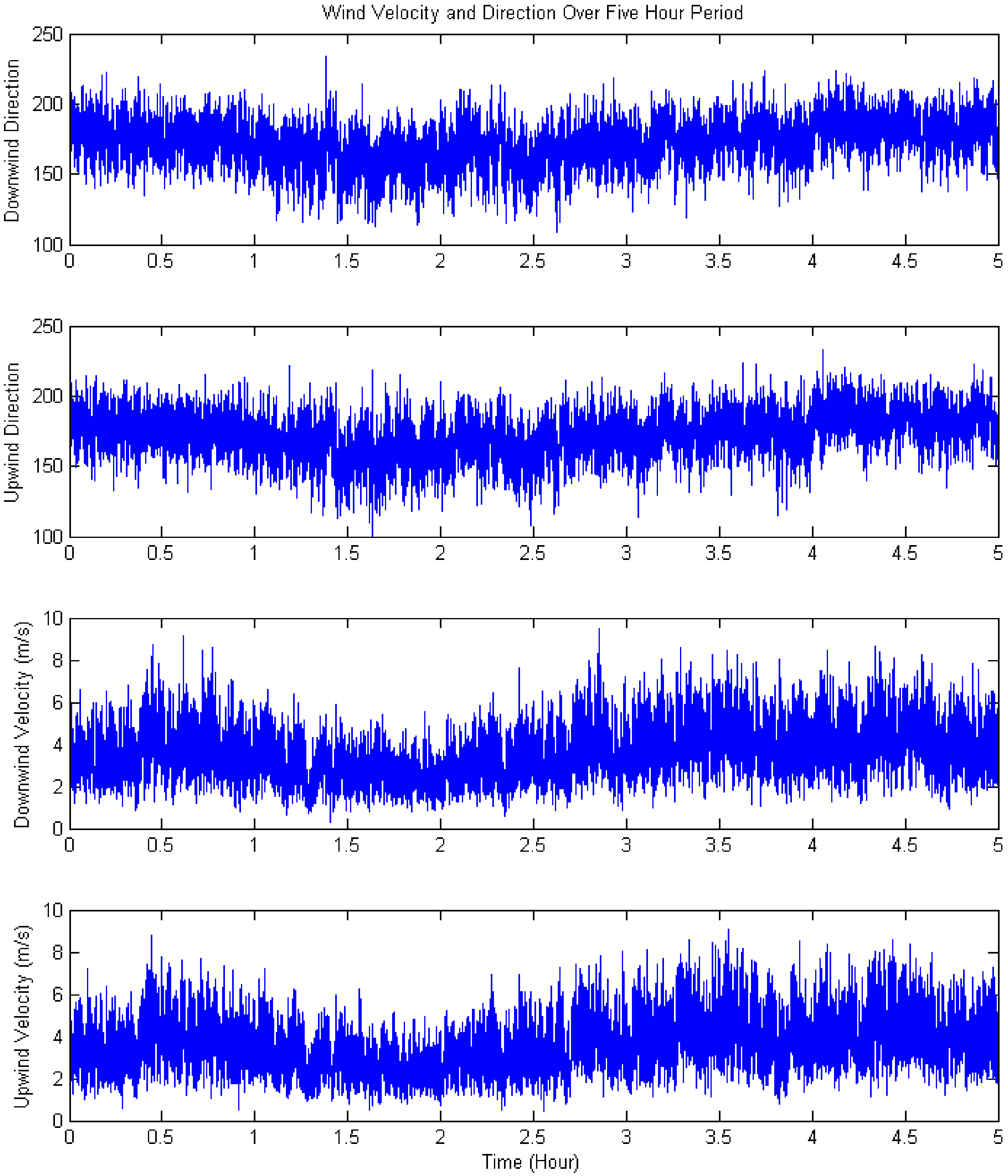

Figure 4: Five hour period of upwind/downwind sensors for both wind velocity and wind direction

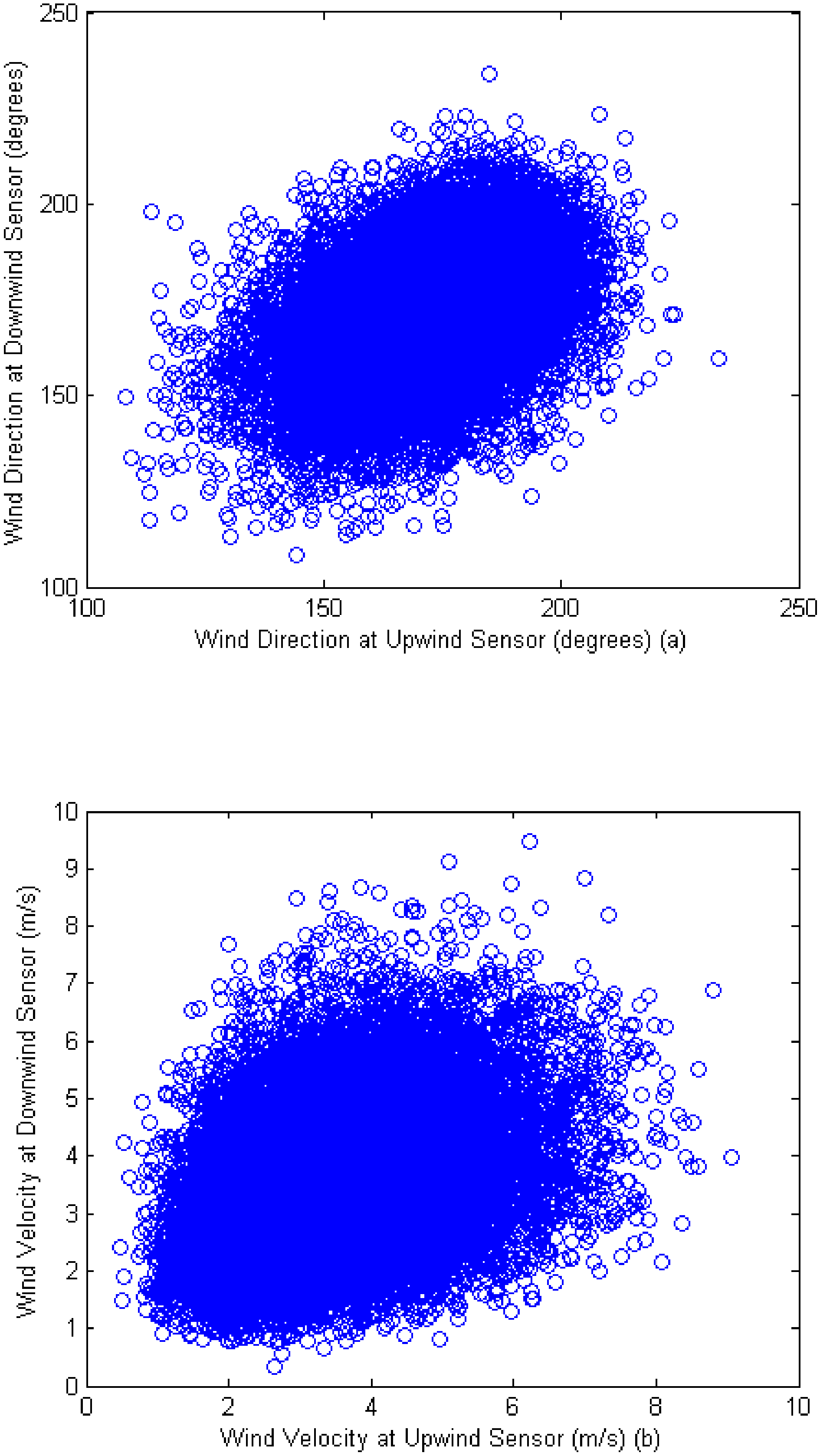

Figure 5: Scatter plot showing downwind direction (a) and downwind velocity (b) as a function of upwind conditions

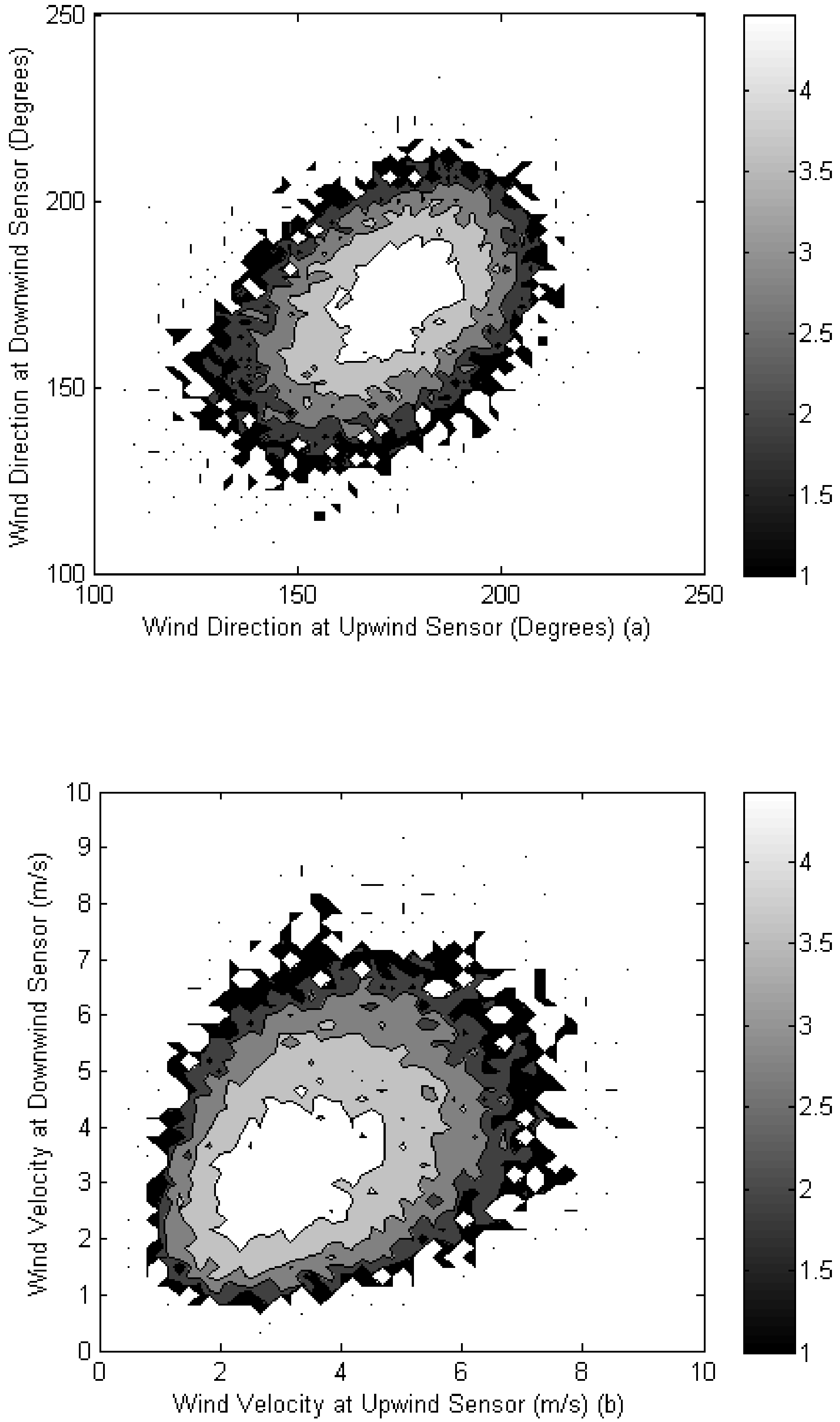

Figure 6: Density plots of point grouping for downwind direction (a) and downwind velocity (b) as a function of upwind conditions. The range was divided into sectors (for wind direction, grid spacing of 1x1 degree were used) and the number of points were then counted for each sector. The natural log was then applied to the counts to show underlying structure. Since ln(1) = 0, a value of 1 was added to all sectors that originally had a value of at least one.

Using smaller segments of data, the time it takes for the wind change to travel to the next sensor can be included. During the five hour period, there was a 3.6 m/s (8 mi/h) average wind speed and the sensors were spaced 30.5 m (100 ft) apart. Average wind speed implies a lag of about 8.5 seconds, (taking the distance separated by the sensors and dividing by the average wind speed), before similar conditions would be observed downwind. However, maximum correlation occurs at 12 seconds (Figure 7) with correlation values of 0.28 and 0.20 for wind direction and velocity respectively.

From investigating the five hour segment of data, wind direction and wind speed cannot be considered to remain constant after leaving the upwind sensor/ boom arm. This is especially true when dealing with shorter timescales as is reflected in Figure 7 at the 0 Lag term. Figure 7 shows the breakdown of Taylors Hypothesis (Frozen Turbulence) on these small size and time scales. The Frozen Turbulence Hypotheses states that turbulence can be considered “frozen” as eddies (turbulent motion of wind) advects pass a sensor(s) (Stull, 2009).

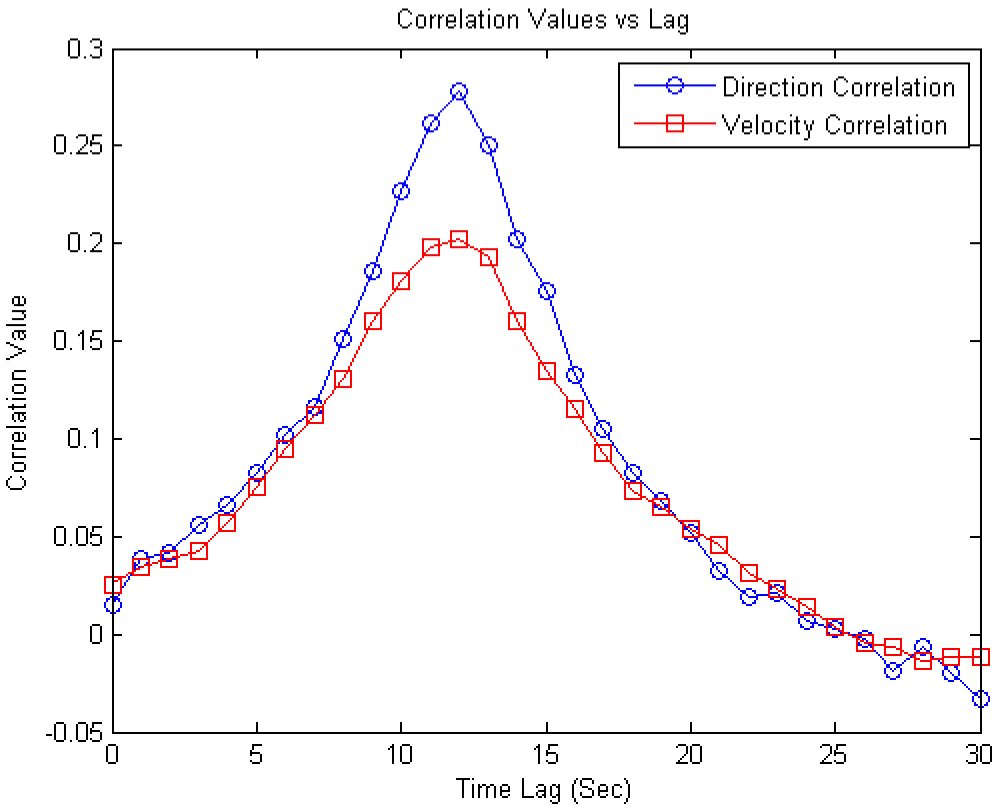

Figure 7: Correlation plot as a function of lag between the upwind and downwind sensors for both wind direction and velocity

Probability that downwind velocity is within range of upwind velocity

To anticipate an unexpected change in wind direction or speed after spray is released from the nozzle, it would be desirable to know what the probability is of the downwind sensor being within a given tolerance range of an upwind sensor. From Figure 7, an adjusted lag value of 12 seconds was used in this analysis. The percentage of time that the downwind sensor is outside a given tolerance of the upwind sensor is shown in Figure 8. This was done by comparing the difference between the upwind and downwind sensors and counting how many data points fell outside of a tolerance. This count was then divided by the total number of points. For example, if the Velocity Tolerance was set to ± 1 m/s, then about 40% of the time the absolute value of the difference between the upwind and downwind sensor would be greater than 1 m/s. Figure 8 gives insight on the range of random fluctuations in both wind velocity and direction.

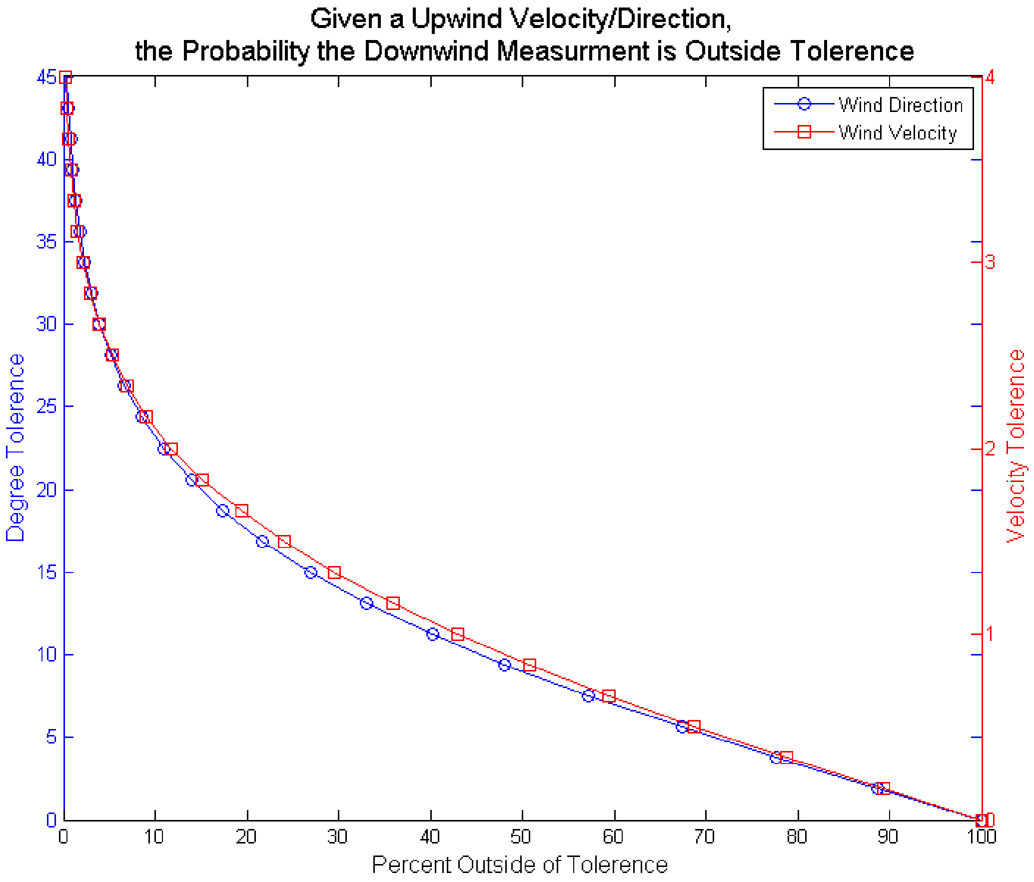

Figure 8: Probability that the downwind sensor will be outside a given tolerance to the upwind sensor

Parameters related to wind changes

To gain greater understanding of what occurs after the droplet has left the spray boom, data collected over a range of days during late spring and summer were analyzed to see when it was more likely to see a change in the wind direction 30 seconds into the future. As data was processed, if the value for wind direction at a sensor, thirty seconds into the future, was greater than a given tolerance (45, 25, or 5 degrees), the current wind direction, velocity, solar radiation, and time of day were recorded. This yields the Figures 9, 10, and 11.

The figures 9, 10, and 11 show how Wind Change Events are distributed. As the sun heats the earth, increasing the surface energy, the weather becomes turbulent (Stull, 2009) as is seen in Figure 9. As the tolerance is tightened, the distributions for Time of Day and Solar Radiation becomes uniform. However, the Wind Velocity remains relatively unchanged. This shows that most unstable events occur below 3 m/s winds. This may be problematic due to most manufactures and model makers of spray drift recommend spraying in conditions similar to this. More data is needed to confirm due to the data being only from one season and may change.

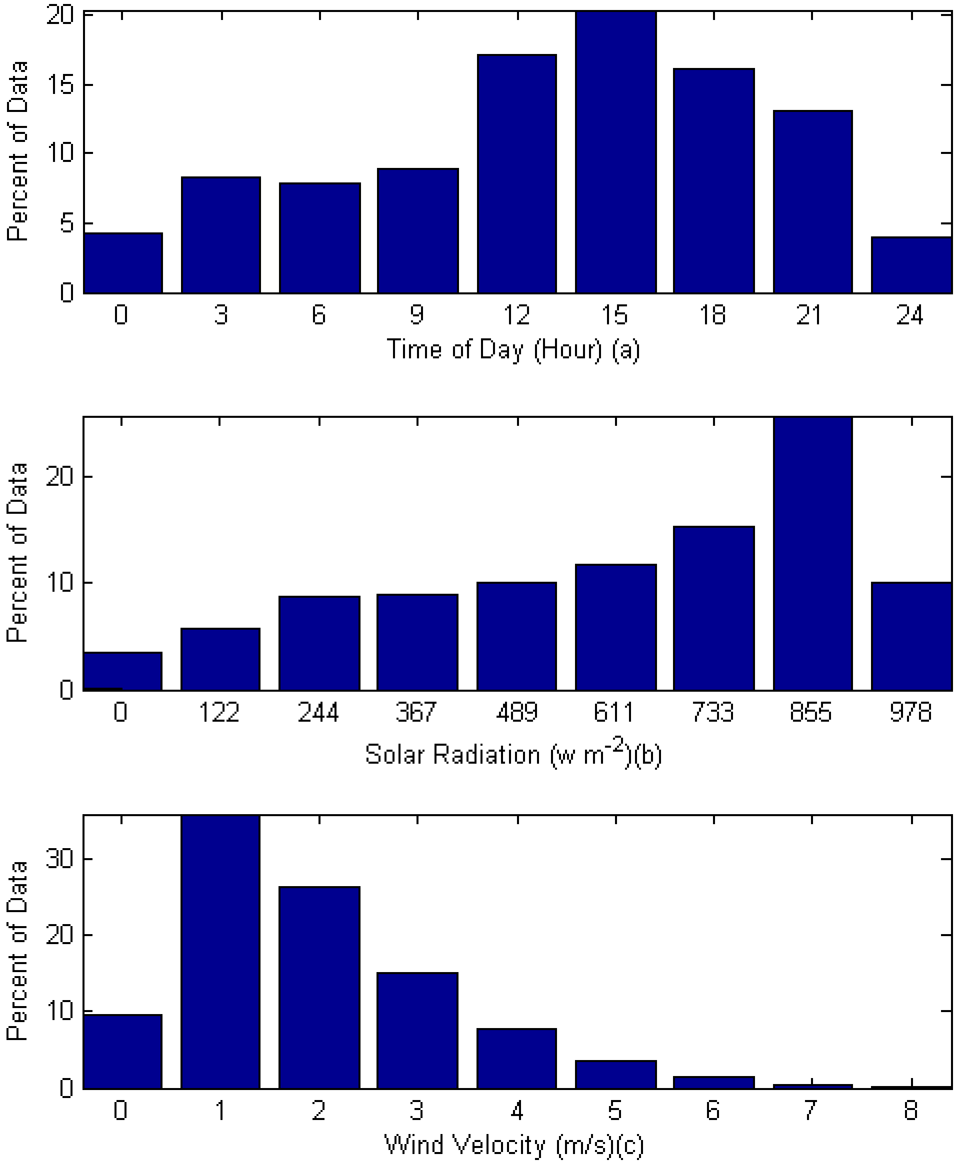

Figure 9: Histogram of data where a wind change greater than 45 degrees occurred 30 seconds in the future, showing the distribution of occurrences for Time of Day (a), Solar Radiation (b), and Wind Velocity (c)

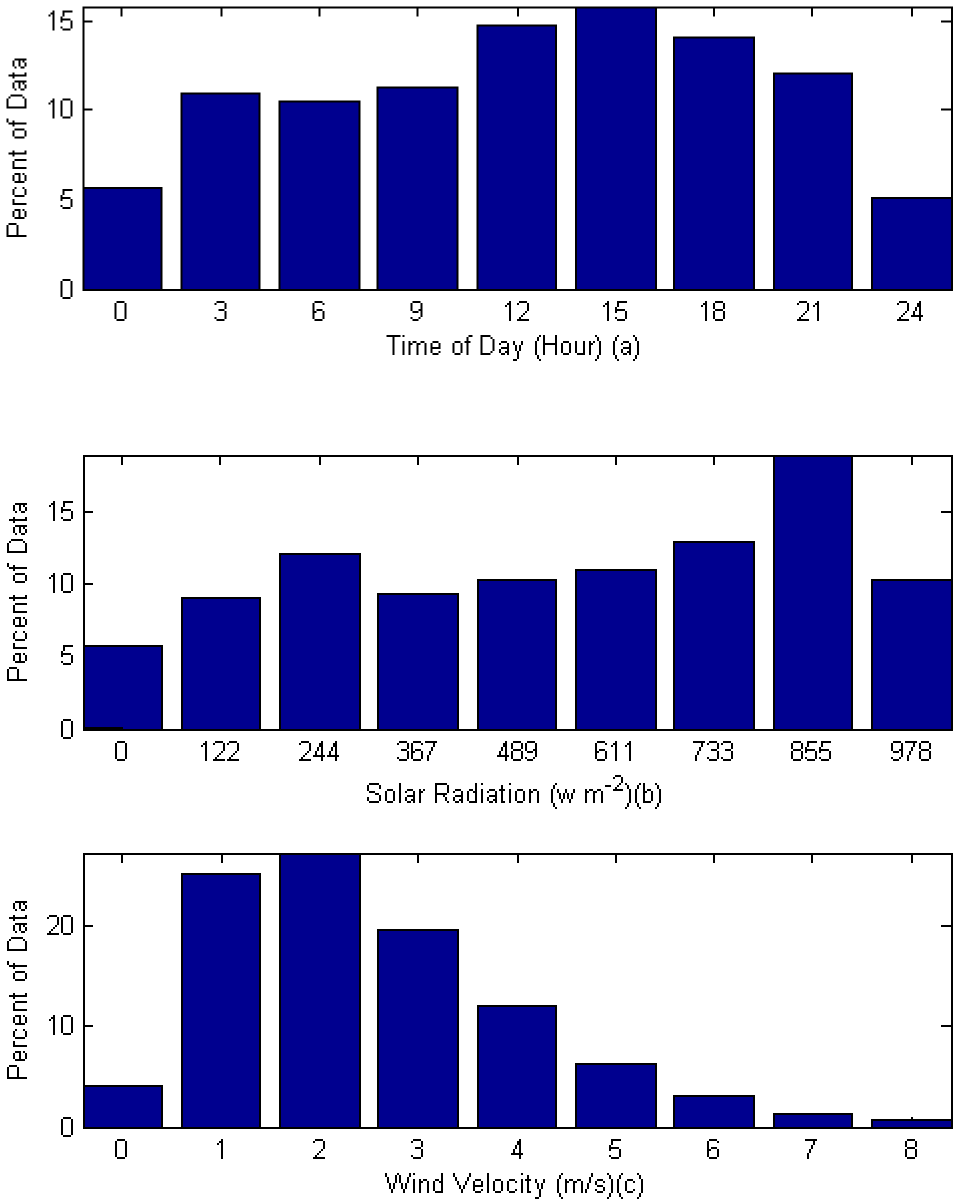

Figure 10: Histogram of data where a wind change greater than 25 degrees occurred 30 seconds in the future, showing the distribution of occurrences for Time of Day (a), Solar Radiation (b), and Wind Velocity (c)

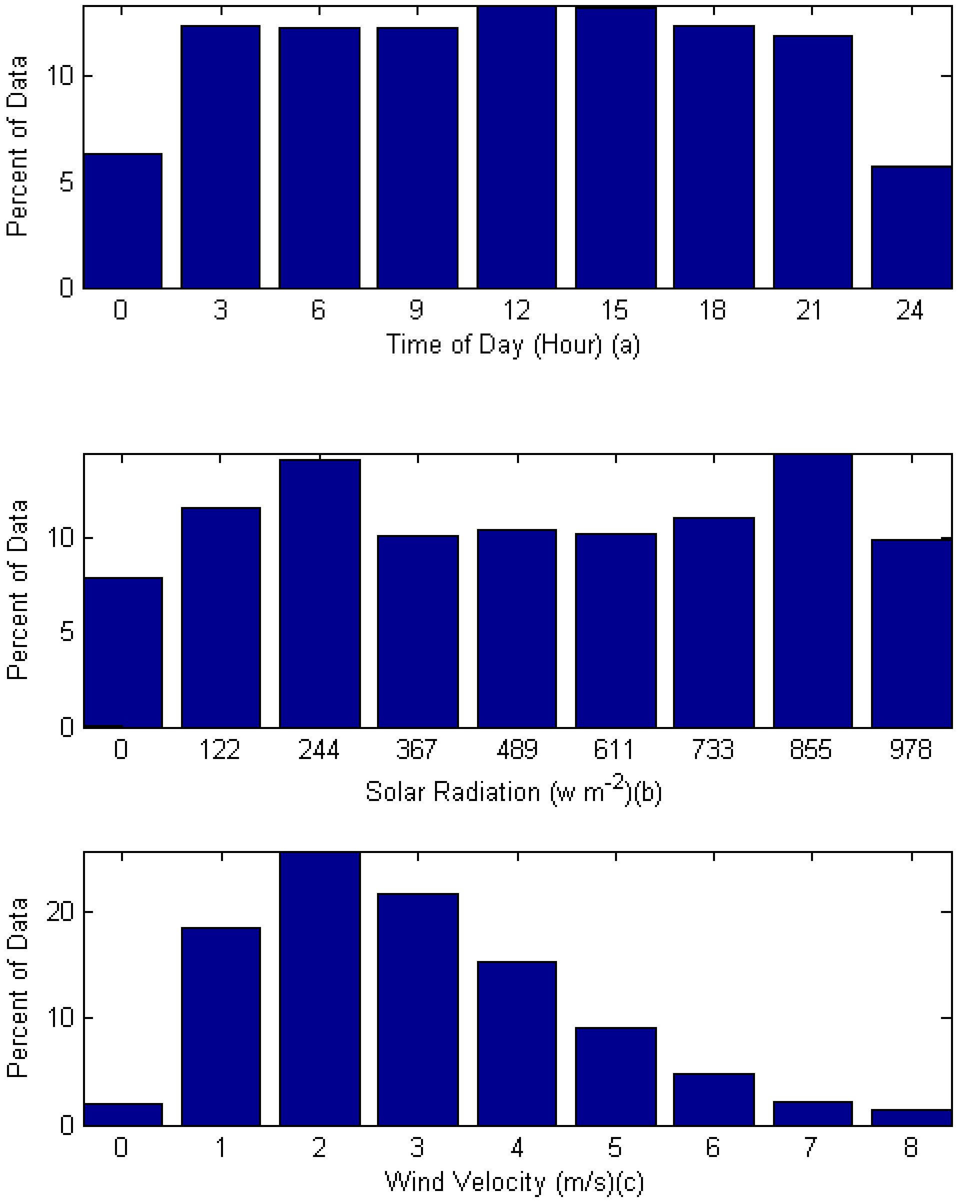

Figure 11: Histogram of data where a wind change greater than 5 degrees occurred 30 seconds in the future, showing the distribution of occurrences for Time of Day (a), Solar Radiation (b), and Wind Velocity (c)

4. Conclusion

Data support the following conclusions:

- Random fluctuations of wind direction and speed had correlation coefficients of 0.41 and 0.33, over a five hour period (Figures 5 and 6).
- The relationship between upwind and downwind sensors of wind speed and direction averaged over one-minute time periods improved if a lag time was used to allow for downwind movement of airflow patterns (Figure 7).
- Using an adjusted lag time, downwind direction was greater than 20 degrees different from upwind direction about 16% of the time and downwind speed was greater than 1 m/s different than upwind speed about 40% of the time (Figure 8).
- Changes in wind direction of 5, 25, or 45 degrees more frequently occurred at wind speeds of 1 – 3 m/s rather than at greater wind speeds (Figures 9 – 11). Time-of-day and solar radiation may affect wind changes of 45 or 25 degrees, but these factors did affect wind changes of 5 degrees as much as lighter overall wind speed.

Larger data sets will be analyzed in the future to gather a better understanding on the bounds of the random nature of wind direction and speed. Difficulties with this process come in the form of finding data sets in which the wind direction passes over aligned sensors.

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