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A Not So-Random Walk with Wind: Evaluating Wind Velocity Update Methods in Ground Based Spray Deposition Models

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Abstract

The notion that wind speed and direction can be approximated by adding a random fluctuation to the previous value was investigated. The data were recorded at one meter above a field to simulate conditions that are present at a ground sprayer's boom. Variance ratio tests were carried out to test the null hypothesis that wind possesses similar properties to a random walk versus the alternative that wind does not. More specifically, are the random fluctuations auto correlated with one another in time? This process was done to a 10Hz sample and averages of the measured wind data at 0.5, 1, 5, 10, 30, 60, 300, and 600 seconds. It was found that for all tests, except for the 300 and 600 second data samples, the null hypothesis was rejected at greater than 99.9% certainty. This indicates that there is evidence of autocorrelation (rather than randomness) in the measurements of wind speed and direction, associated with each other in time.

Keywords

Random Walk, Spray Drift, Model Verification

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

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ABSTRACT. *The notion that wind speed and direction can be approximated by adding a random fluctuation to the previous value was investigated. The data were recorded at one meter above a field to simulate conditions that are present at a ground sprayer's boom. Variance ratio tests were carried out to test the null hypothesis that wind possesses similar properties to a random walk versus the alternative that wind does not. More specifically, are the random fluctuations auto correlated with one another in time? This process was done to a 10Hz sample and averages of the measured wind data at 0.5, 1, 5, 10, 30, 60, 300, and 600 seconds. It was found that for all tests, except for the 300 and 600 second data samples, the null hypothesis was rejected at greater than 99.9% certainty. This indicates that there is evidence of autocorrelation (rather than randomness) in the measurements of wind speed and direction, associated with each other in time.*

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Introduction

Agricultural sprayers provide agricultural chemicals that protect and improve crop plant health, but the chemicals can be detrimental to adjacent crops or other forms of life. Understanding how spray propagates (through the use of models) is essential to provide the industry with the necessary information to keep the chemicals in the field. The EPA defines spray drift as follows, “Pesticide spray drift is the physical movement of a pesticide through air at the time of application or soon thereafter, to any site other than that intended for application” (EPA, 2014). Multiple models are available to calculate the physics of droplet movement including Lagrangian, Gaussian, Random Walk, Regression, and Computational Fluid Dynamic (CFD) models (Frederic, Verstraete, Schiffers, & Destain, 2009; Holterman, Van de Zande, Porskamp, & Huijsmans, 1997; Baetens, et al., 2007; Milton E. Teske, 2002; Ming-Yi Tsai, 2005; Frederic, Verstraete, Schiffers, & Destain, 2009; Smith, Harris, & Goering, 1982). Models apply random fluctuations to the mean wind to simulate the wind’s turbulent nature. Essentially, the wind takes a random walk. A popular application of random walks, is to use averaged wind velocities acquired from measurements and introduce random fluctuations to simulate turbulence (Holterman, Van de Zande, Porskamp, & Huijsmans, 1997; Thompson & Ley, 1983). Wind fluctuations may appear random but little information exists of short term, transient wind velocity changes that can confirm this property accurately near the surface in the vicinity of a ground sprayer boom.

A statistical method to test the random walk hypothesis that is used primarily for financial predictions is the variance ratio test (MathWorks, 2015; Ostasiewicz, 2000). The variance ratio test investigates the “random fluctuations” of a time series dataset and tests if changes in the time series are statistically independent or if these changes are correlated with one another. The variance ratio test has been primarily used to test the random walk hypothesis for market efficiencies in finance (Charles & Darné, 2003). The test is particularly useful for testing if the process eventually returns to the average (mean reversion) (Charles & Darné, 2003). The random walk model was first introduced in 1828 when the botanist Brown described his Brownian motion. Since then the model has gained ground in multiple fields from biology, physics, and finance (Codling, Plank, & Benhamou, 2008). The test devised by Lo and MacKinlay (1988) was directed at financial markets, though no assumptions were ever made that limit the test to only financial random walks (Lo & MacKinlay, 1988).

Objectives

The objectives of this research were to:

- Investigate changes in transient wind velocity near the ground surface at a typical ground sprayer boom height, and
- Evaluate the randomness of measured transient wind velocity changes for use in random walk models as applied to ground sprayers

Methods and Materials

Experimental Design and Apparatus

Field measurements of wind speed and direction were collected during the late spring/summer spraying season of 2014 using instrumentation set into a field of growing oats. The field was located at the Iowa State University Research Farm’s Bruner Farm field F1 near Ames, Iowa (Figure 1). The field dimensions were 268 m long by 105 m wide (880 by 348 ft). Wind speed and solar radiation measurements were acquired at 10 samples per second using ultrasonic anemometers (model: WindMaster 3d, Gill Instruments, Lymington, Hampshire, UK) and a pyranometer (model: SP-212, Apogee Instruments, Logan, UT). The anemometers measured the wind speed in the north-south, east-west, and vertical directions (Figure 2). Open source microcontrollers equipped with a GPS module (model: Arduino Uno, Arduino Inc; Ultimate GPS Shield, Adafruit, New York, USA) were used to log data to a micro SD data card. Using the GPS’s PPS (Pulse per Second) output, time correction was done to ensure accurate time recording of wind velocity measurements on the microcontroller. To reduce influences to wind velocity, the microcontrollers and their power supplies were located separate from the anemometers at a distance of approximately 2-3 meters. Anemometers were placed one meter above the ground’s surface to collect wind measurements. The pyranometer was placed on the charging station near the anemometer.

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

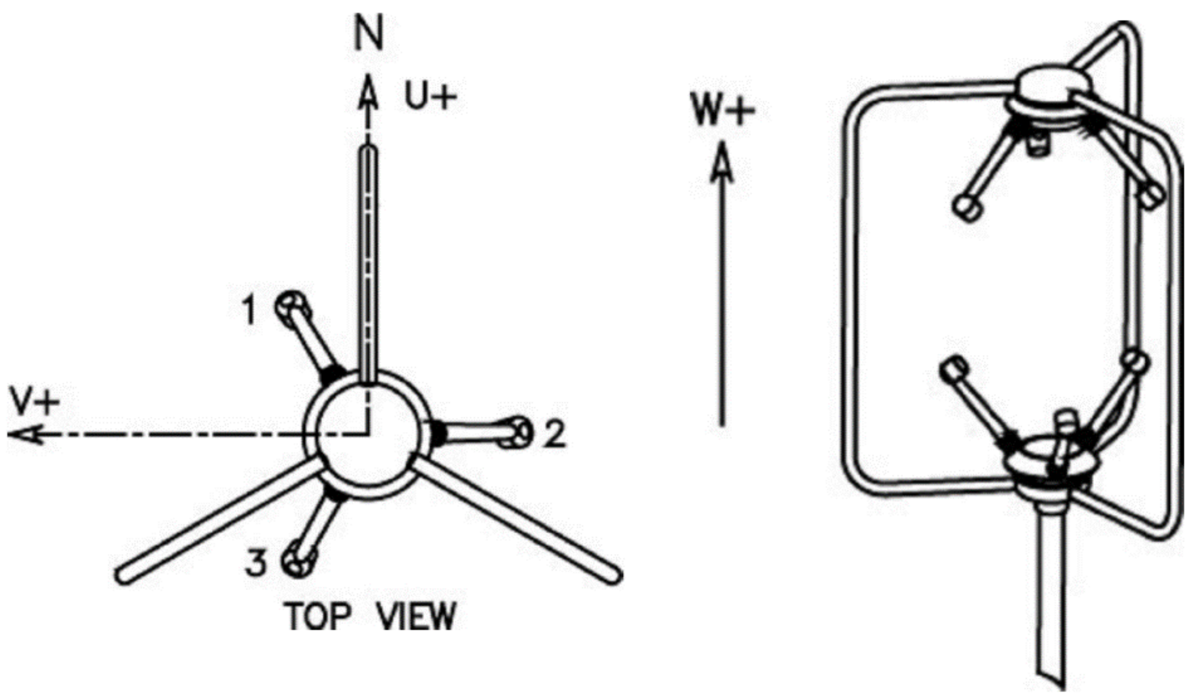

Figure 2: Ultrasonic Anemometer measuring velocity in U, V, and W component directions

Data Analysis

The data from a single sensor shown in figure 3 is from a five hour period, between 7:30 am to 12:30 pm during typical daytime spraying conditions, and will be used for the study. Wind direction was calculated from the wind speeds using trigonometric relationships. A wraparound method was used to produce a semi-continuous wind direction dataset. The wraparound method allowed wind direction to go above 359 degrees and below 0 degrees, e.g. 12 degrees = 372 degrees.

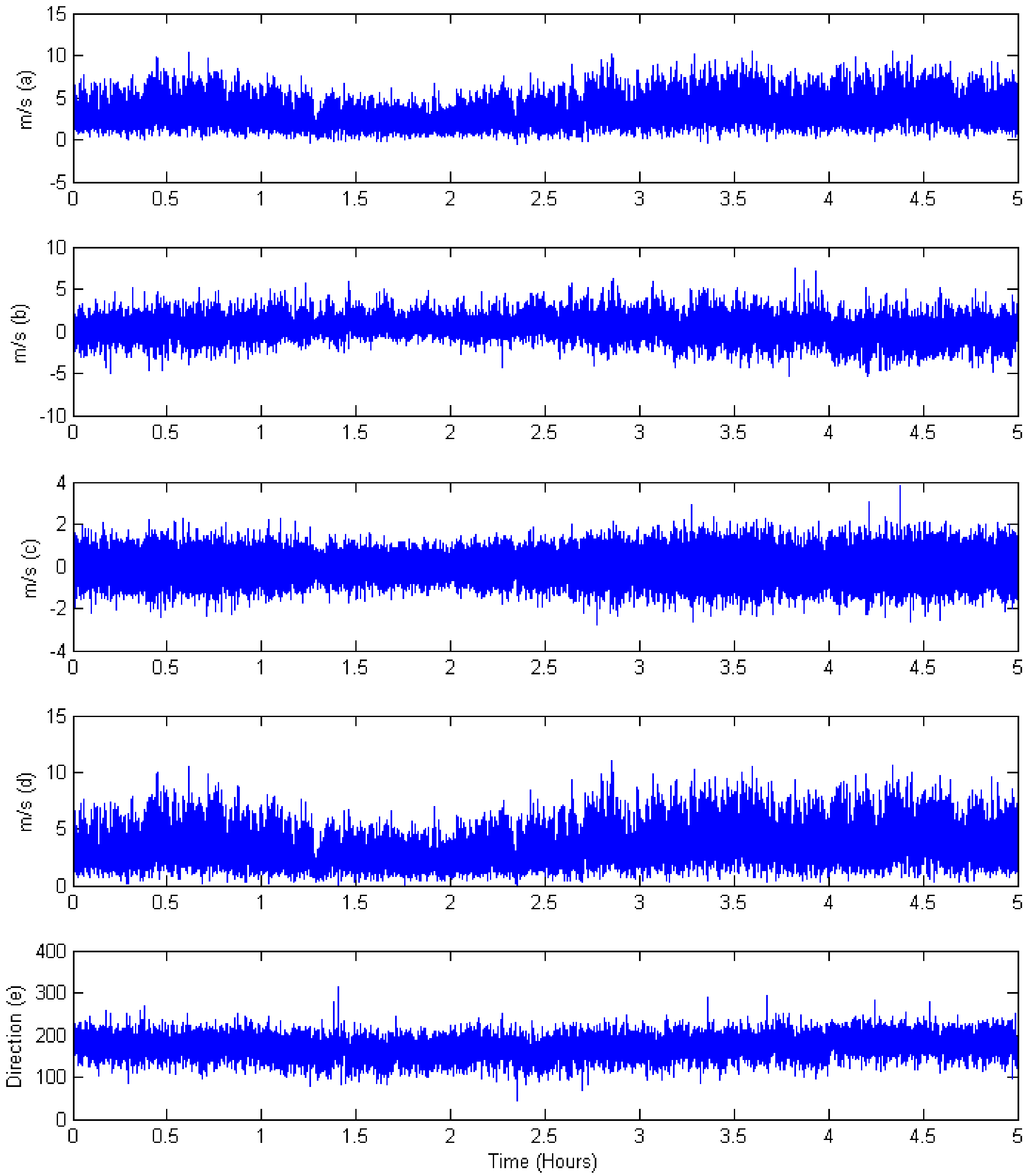

Figure 3: Data collected over a five hour period. (a) North-South, (b) East-West, (c) Vertical Wind, (d) Wind Magnitude, and (e) Wind Direction

The variance ratio test was used to test the null hypothesis (h_0) that a random walk (Equation 1) faithfully represents the statistical properties of the measured wind fluctuations. Specifically, the test is used to measure if the values of ϵ_t are correlated.

$$y_t = c + y_{t-1} + \epsilon_t \tag{1}$$

where

- y_t are the time series process
- c is a drift constant for the random walk model
- ϵ_t are random independent processes and are distributed with mean zero and variance σ^2 (Box, Jenkins, & Reinsel, 1994; Enders, 1995; MathWorks, 2015; Ostasiewicz, 2000)

This test was done for the wind speeds traveling in the north-south direction (Uwind), the east-west direction (Vwind), the vertical direction (Wwind), the magnitude of the north-south and east-west winds (MWind), and wind direction (DWind). In addition to testing individual readings each 0.1 s, multiple averages (1/2 s, 1 s, 5 s, 10 s, 30 s, 1 min, 5 min, and 10 min) were tested to determine if longer-term averaged readings eventually possessed properties of the random walk.

Variance ratio test statistics are calculated based upon the ratio of variance estimates from the time series' m-period returns (MathWorks, 2015; Box, Jenkins, & Reinsel, 1994; Enders, 1995; Ostasiewicz, 2000). The returns are calculated from the difference of terms in the series (Equation 2)

$$r_m = y_t - y_{t-m-1} \tag{2}$$

The variance ratio for period m is:

$$VarRatio_m = \left(\frac{1}{m+1}\right)\left(\frac{\text{var}(r_m)}{\text{var}(r_0)}\right) \tag{3}$$

The m parameter determines the period of the time difference. For example if the model that was being tested used the third previous value to predict the next value, m would equal 3. For the purposes of this paper, m will equal one to signify that the use of the previous step is used to predict the next step. This matches the form of the wind model shown in equation 1. This ratio indicates how the individual measurements behave, either by propagating to the mean (ratio less than one), or away from the mean (ratio greater than one).

With the variance ratio calculated, the test statistic is then calculated using Lo and MacKinlay's heteroscedasticity method (Charles & Darné, 2003) (Equation 4). Heteroscedasticity is needed because the assumption that ϵ_t are independently and identically distributed is not required for this test.

$$Tvr = \frac{VarRatio_m - 1}{\sqrt{\phi_m^*}}$$

$$\phi_m^* = \sum_{j=1}^{m}\left[\frac{2(m+1-j)}{m+1}\right]^2 \delta(j), \qquad \phi_1^* = \delta(1) \tag{4}$$

$$\delta(j) = \frac{\sum_{i=j+1}^{T}(y_i - \hat{y})^2\left(y_{i-j} - \hat{y}\right)^2}{\left(\sum_{i=1}^{T}(y_i - \hat{y})^2\right)^2}$$

Where y_i is the ith observed value in the time series, $\hat{y}$ is the average value in the time series, and T is the length of the time series, and as T approaches infinity, this test statistic approaches a normal distribution (Charles & Darné, 2003). Test statistics are used to calculate the p-values.

Results and Discussion

Table 1 summarizes the test results of all tests done. The statistical method was done at a 95% confidence level to determine if the null hypothesis was accepted or rejected.

		Sample Time								
		1/10 sec	1/2 Sec	1 Sec	5 Sec	10 Sec	30 Sec	1 Min	5 Min	10 Min
Test Results	Uwind	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Plausable	Reject
	Vwind	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Plausable
	Wwind	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Reject
	Mwind	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Plausable	Reject
	Dwind	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Reject	Plausable
P-Value	Uwind	0	0	0	0	0	1.20E-14	6.50E-09	0.132	0.006
	Vwind	0	0	0	0	0	6.00E-07	2.70E-08	0.015	0.205
	Wwind	0	0	0	0	0	5.90E-20	1.80E-10	0.003	0.027
	Mwind	0	0	0	0	0	8.50E-15	4.80E-09	0.069	0.007
	Dwind	0	0	0	0	0	3.60E-07	4.60E-08	0.028	0.429
Variance Ratio	Uwind	0.94	0.86	0.75	0.71	0.67	0.61	0.59	0.82	1.40
	Vwind	0.84	0.75	0.69	0.68	0.72	0.74	0.58	0.60	0.74
	Wwind	0.75	0.60	0.54	0.52	0.54	0.45	0.57	0.48	0.62
	Mwind	0.94	0.86	0.75	0.71	0.68	0.61	0.59	0.76	1.35
	Dwind	0.86	0.73	0.67	0.68	0.72	0.75	0.58	0.61	0.85

Table 1: Variance Ratio Test results at multiple averaging values in which the null hypothesis is accepted or rejected. (Uwind is the north-south wind speed, Vwind is the east-west wind speed, Wwind is the vertical wind speed, Mwind is the magnitude of the wind

From table 1 the null hypothesis of random data is rejected with greater than 99.9% certainty, except for longer periods when data is averaged over 5 or 10 minutes. This shows that the wind fluctuations are correlated with one another at short time steps, at one meter height near the ground surface, but may be considered to be randomly independent as the time between each step increases. Droplet sizes greater than 50 µm contain a larger total fraction of driftable spray volume than tinier droplets and unless displaced vertically upward a significant distance would be expected to deposit in these shorter time periods with non-random wind velocity. For models that incorporate random fluctuations, greater care is needed and simply adding a random fluctuation to the previous wind conditions is not completely correct. The exact relationship that should be used for modeling turbulent fluctuations is currently unknown.

Conclusions

It was found that wind velocity changes at one meter (near the height of a ground sprayer's boom) are not purely random when using sampling periods of less than five minutes. Greater care is needed in models that implement random numbers to simulate turbulence for ground spray applications. All tests below five minute averages yielded greater than a 99.9% confidence level that the pattern of wind velocity do not follow the model of a Random Walk. Exactly how these wind velocity values are correlated are currently unknown.

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