Original Article
Journal of Biosystems Engineering
J. of Biosystems Eng. 41(4):337-341. (2016. 12)
https://doi.org/10.5307/JBE.2016.41.4.337
eISSN : 2234-1862
pISSN : 1738-1266

Atmospheric Stability Evaluation at Different Time Intervals for Determination of Aerial Spray Application Timing

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Received: November 1st, 2016; Revised: November 16th, 2016; Accepted: November 28th, 2016

Abstract

Purpose: Evaluation of atmospheric conditions for proper timing of spray application is important to prevent off-target movement of crop protection materials. Susceptible crops can be damaged downwind if proper application procedure is not followed. In our previous study, hourly data indicated unfavorable conditions, primarily between evening 18:00 hrs in the evening and 6:00 hrs next morning, during clear conditions in the hot summer months in the Mississippi delta. With the requirement of timely farm operations, sub-hourly data are required to provide better guidelines for pilots, as conditions of atmospheric stability can change rapidly. Although hourly data can be interpolated to some degree, finer resolution for data acquisition of the order of 15 min would provide pilots with more accurate recommendations to match the data recording frequency of local weather stations. **Methods:** In the present study, temperature and wind speed data obtained at a meteorological tower were re-sampled to calculate the atmospheric stability ratio for sub-hour and hourly recommendations. High-precision evaluation of temperature inversion periods influencing atmospheric stability was made considering strength, time of occurrence, and duration of temperature inversion. **Results and Discussion:** The results indicated that atmospheric stability could be determined at different time intervals providing consistent recommendations to aerial applicators, thereby avoiding temperature inversion with minimal off-target drift of the sprayed liquid.

Keywords: Aerial application, Atmospheric stability, Temperature inversion

Introduction

Crop production and protection materials applied from the sprayers of aircraft can drift off-target because of various factors, including controllable factors, such as boom setup, nozzle type and orientation, spray pressure, and application height, and uncontrollable weather factors such as air temperature, relative humidity, wind speed, and wind direction.

One important method to prevent off-target movement is to avoid application under "stable" atmospheric conditions, i.e., when a temperature inversion is likely to occur. Spraying should not be conducted at places where there is an upward air movement, or where a temperature inversion prevents the spray cloud settling within the treated area (FAO, 2001). The detrimental effects of spraying 2, 4-D to rice or pastures under conditions of a temperature inversion have been documented (Bennett, 2006). The complaints regarding drift in East Arkansas indicated that the problem was most likely due to multiple applications of 2, 4-D under stable atmospheric conditions. Under these conditions, air parcels cannot rise and disperse, but it can move laterally in light variable winds, typically observed during a surface inversion (Ramsey, 2002). A spray layer applied under stable conditions is hence "ready to move" off target when the wind picks up, and the same was concluded to occur in East Arkansas (Bennett, 2006).

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Surface temperature inversions occur during surface cooling in the nighttime and surface heating until morning (Beychock, 1994; Ramsey, 2002). These conditions usually occur in the interval between sunset and soon after sunrise, under windless to low wind conditions, and when clear to partly cloudy skies exist. Other indicators are the presence of ground fog (if sufficient humidity exists), dust hanging over a roadway, smoke from a chimney forming a layer, and dew or frost (if sufficient humidity exists). However, many of these indicators demonstrate the "potential" for temperature inversions and duration of these events vary drastically. Hence, it would be instructive to document the time and duration of periods of stable and unstable temperature profiles. In College Station, Texas, Fritz et al. (2008) indicated that stable conditions (unfavorable for spraying) occurred when wind speeds were 2.0 m s^{-1} or below when temperature differences with height also indicated such. The authors also documented that temperature inversions occurred between 57% and 65% of the monitored days.

In this study, conducted in Stoneville, MS, by using an instrumented tall tower, temperature and wind profiles were determined with measurements at different heights to indicate both the presence of surface and aloft temperature inversions. This paper presents data from towers and the calculation result of stability ratios (SRs) to classify atmospheric stability. The results can be used to make recommendations on the times of day that are likely to be of concern for spraying crop protection materials.

In our previous study, hourly data indicated stable conditions (unfavorable for spraying) primarily between the hours of 18:00 and 6:00 during clear conditions in the hot summer months in the Mississippi Delta (Thomson et al., 2010). With the requirement of timely farm operations, sub-hourly data are required to provide better guidelines for pilots, as conditions of atmospheric stability can change rapidly. Although hourly data can be interpolated to some degree, finer resolution for data acquisition in the order of 15 min would provide pilots with more accurate recommendations to match the data recording frequency of local weather stations. In the present study, temperature and wind speed data obtained at a meteorological tower are re-sampled to calculate the SR for sub-hour and hourly recommendations. High-precision evaluation of temperature inversion periods influencing atmospheric stability is made considering strength, time of occurrence, and duration of temperature inversion.

Material and Methods

A 30 m tower was set up at the Mechanization Research Farm (latitude: 33.446526°, longitude: -90.876501°) of the United States Department of Agriculture, Agricultural Research Service, Crop Production Systems Research Unit in Stoneville, MS (Figure 1). The tower was equipped with Omega 44000 series precision thermistors (Omega Engineering, Inc., Stamford, CT) to measure air temperatures, Qualimetrics model 2030 anemometers (All Weather Inc, Sacramento, CA) to measure wind speed, and a Met-One 024A sensor (Campbell Scientific, Logan, UT) to measure wind direction. These sensors were placed at 4.6 m, 9 m, 14 m, 18.3 m, 23 m, and 27.4 m for measuring temperatures and 4.6 m, 12 m, 20 m, and 27.4 m for monitoring wind speeds.

A Campbell CR-21X micrologger (Campbell Scientific, Logan, UT) was used for data acquisition and was setup in pulse counting mode for the wind speed sensors. For the thermistors reading temperature, the CR-21X was programmed in a half-bridge mode with excitation output from the CR-21X. The wind direction sensor also utilized a precise excitation voltage supplied by the CR-21X. Weather data were obtained from April to October in 2004 and read every five minutes. These data were periodically downloaded from data scans for further processing using a customdesigned program written in SAS. This program created a spreadsheet file from raw data for each block of downloaded data, and data files for each month were created.

In this study, data read every five minutes were averaged

Figure 1. A 30 m tower installed with sensors at different heights to measure air temperature, wind speed, and wind direction.

over a one-hour period to obtain hourly readings. Sub-hourly data were also created to match the data-recording interval of local weather stations for more timely guidance to pilots. Although hourly data could be used for determining atmospheric stability in some way, higher resolution of data acquisition in the order of 15 min would provide pilots with more accurate recommendations. In this study, temperature and wind speed data obtained at the meteorological tower were re-sampled to calculate SR using different time steps for sub-hour and hourly recommendations.

With the meteorological data, SR can be calculated to determine daily atmospheric stability. Table 1 lists atmospheric stability classes determined from the SR (Yates et al., 1974). Under stable atmospheric conditions, spraying process should not be conducted.

$$SR = \frac{T_{z_2} - T_{z_1}}{WS_{z_3}^2} \cdot 10^5 \quad (1)$$

The SR can be calculated as follows (Munn, 1966): where T_{z_1} and T_{z_2} are the temperatures (°C) at heights z_1 and z_2, respectively, and WS_{z_3} is the wind speed (m/s) measured at a height of z_3 between z_1 and z_2, which is measured equidistantly between z_1 and z_2 on a log scale.

To calculate the SR to determine the surface atmospheric stability, the temperatures measured at 4.6 m and 9 m were used for T_{z_1} and T_{z_2}, and the wind speed measured at 4.6 m was used for WS_{z_3}. Although this height for wind speed measurement is not equidistant between the two temperature levels for strict application requirement of the above equation, wind speeds and air temperatures were measured at these heights to indicate daily trend of forerunning surface temperature inversions. Measuring wind at this height was not found to cause significant differences in SR at different time steps.

Table 1. Atmospheric stability classified from SR ranges

Atmospheric Stability Category	SR Range
Unstable	-1.7 to -0.1
Neutral	-0.1 to 0.1
Stable	0.1 to 1.2
Very Stable	1.2 to 4.9

Results and Discussion

Figures 2, 3, and 4 show the probability of daily atmospheric stability in the intervals of 5 -min, 15 min, and 1 h, respectively. The probabilities were calculated for each class of daily atmospheric stability by dividing the number of occurrences in 5 min, 15 min and 1 h, respectively, with the total number of occurrences in a day considering all the daily data from April to October in a year.

Figure 2 shows the probability of daily atmospheric stability calculated using original data at an interval of 5 min measured from the tower over the period from April 15 to October 25, 2004. The figure shows an average probability of 91.7% for the occurrence of either stable or strongly stable conditions between 19:00 in the evening and 6:00 in the morning. Neutral conditions occurred 7.1% of the time and unstable conditions occurred 1.2% of the time, which implies that application is not recommended during daytime.

Figure 3 shows the probability of daily atmospheric stability calculated using original data at an interval of 15

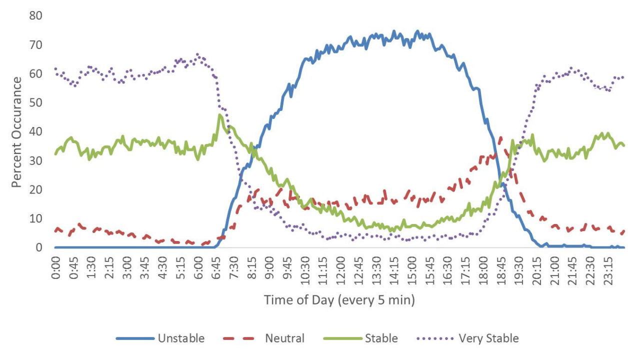

Figure 2. Daily probability distribution of atmospheric stability classification from April to October, 2004, calculated from original 5 min data.

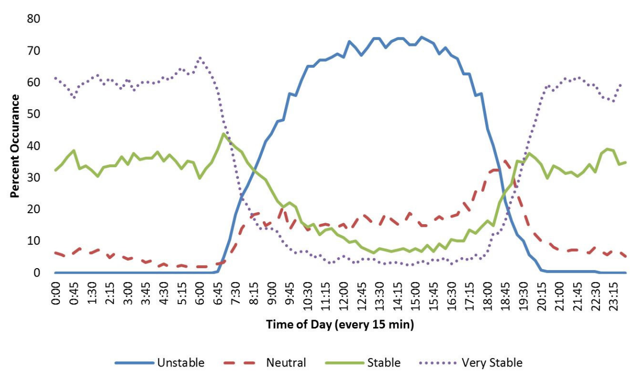

Figure 3. Daily probability distribution of atmospheric stability classification from April to October, 2004, calculated from 15 min data.

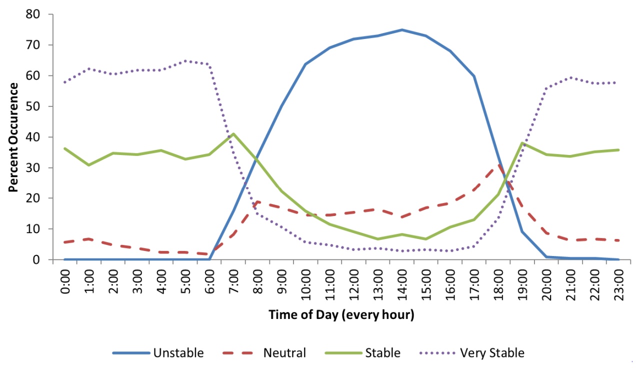

Figure 4. Daily probability distribution of atmospheric stability classification from April to October, 2004, calculated from hourly data.

min averaged from the original data of 5 min over the same period in 2004. The figure shows an average probability of 91.5% for the occurrence of either stable or strongly stable conditions between 19:00 in the evening and 6:00 in the morning. Neutral conditions occurred 7.3% of the time and unstable conditions occurred 1.2% of the time. The results are consistent with the results from the 5 min data.

Figure 4 shows the probability of daily atmospheric stability calculated with hourly data averaged from the 15 min data over the same period in 2004. The figure shows an average probability of 93% for the occurrence of either stable or strongly stable conditions between 19:00 in the evening and 6:00 in the morning. Neutral conditions occurred 6.1% of the time and unstable conditions occurred 0.9% of the time. In general, the results are still consistent with the results from the data obtained in the 5 min and 15 min intervals, even though they increased the difference between the stable and unstable conditions.

The three figures show a high average probability (92.1%) for the occurenceoccurrence of either stable or strongly stable conditions between 19:00 hrs and 6:00 hrs over the period from April to October, 2004. Neutral conditions occurred 6.8% of the time on an average and unstable conditions occurred 1.1 % of the time. In this wayHence, it would not be suggested for aerial applicators to spray between 19:00 and 6:00 hrs oin any of their working days over the period offrom April to October in the area of under study.

The data presented in this study showed consistent patterns of atmospheric stability occurring primarily between the hours of 18:00 and 6:00 regardless of data time intervals from 5 min to 1 h. With the recommendation of the likelihood of temperature inversion occurrence, an applicator should judge to balance between conditions that are quite stable, in which case spray does not disperse (with potential to move off-site), and conditions that are quite unstable and windy, in which case spray is quickly dispersed and moved off-site without reaching the target. The results of this study suggest applicators to identify these conditions. It should be further noted that typically during the day, with the cycle of changing atmospheric conditions, temperature inversion occurring late in the afternoon is likely to persist throughout the remainder of the day.

Conclusion

This study calculated the SR at different time intervals to determine the daily atmospheric conditions and recommend the spray timing for aerial applicators such that they avoid spraying during temperature inversions. The comparison indicates that the calculations provided consistent information in suggesting to not apply the spray from 19:00 hrs in the evening to 6:00 hrs in the morning. In practice, 15 min and hourly data are more useful than the original 5 min data to match the data from local weather stations and provide timely recommendations for aerial applicators. Although the data used in this study are from 2004 measurement in Stoneville, MS, the methods and the information derived from the data can be adapted for other years and other locations. For comparison at other locations and latitudes, time intervals, where changes in atmospheric state occur, should be referenced to sunrise and sunset.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgements

In memory of Dr. Lowrey A. Smith for his original contributions in building the measurement tower and acquisition of the first data sets.

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