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Weather conditions and time intervals to reduce the potential for off-target movement of spray due to temperature inversions – An Update

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Abstract. *A study was conducted to determine atmospheric conditions favorable for long-distance movement of spray deleterious to susceptible crops downwind from a spray application. The goal of this study was to incorporate this information into new guidelines for pilots on the weather conditions and times of the day in the Mid-south U.S. when potential for off-target movement of spray are highest due to temperature inversions. In the present study, a brief survey of some U.S. spraying regulations was made that consider temperature inversions. An Arkansas regulation suggests that a 3ºF air temperature increase is needed in the morning before spraying can commence and a 3ºF air temperature decrease in the evening signals when spraying should be stopped. This guideline was used as a comparison in this study. Our data showed that inversion conditions and 'stable atmosphere' occur between the hours of 1800 and 0600 hours during the summer months, and on clear days. During periods of cooler temperatures or cloud cover, inversions and stable atmosphere persisted longer. Results of this study indicated a good agreement with the Arkansas guidelines for most months studied.*

Keywords. Aerial application, spray drift, temperature inversion, atmospheric stability

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Introduction

Temperature inversions unfavorable for spraying can occur between the evening hours of surface cooling and the morning hours of surface heating. A temperature inversion is one factor (the other wind speed) in 'stable' atmospheric conditions. Spraying should be avoided during these periods to prevent off-target movement that can damage off-site crops (Bennett, 2006; Thomson et al., 2010). Typically these conditions occur between sunset to just after sunrise, during windless to low wind conditions and under clear to partly cloudy skies. Other indicators of this phenomenon are the presence of ground fog, dust hanging over a roadway, smoke from a chimney forming a layer, or dew or frost (if sufficient humidity exists). Although these indicators illustrate the 'potential' for a temperature inversion, these events can be highly variable. Fritz et al. (2008) indicated that stable atmospheric conditions (unfavorable for spraying) occurred when wind speeds were 2.0 m s^{-1} or below at College Station TX. The authors also documented that daytime (6:00 AM to 6:30 PM) temperature inversions occurred for 57% and 65% of the monitored days. Thomson et al. (2010) documented that 'stable' atmospheric conditions unfavorable for spraying occurred primarily between the hours of 6:00 PM and 6:00 AM during clear conditions in hot summer months. Wind conditions between 1.25 ms^{-1} to 1.60 ms^{-1} (2.8 and 3.6 mph) in the morning indicated a transition from a stable to unstable condition, which was more suitable for spraying.

Some States in the U.S. where aerial application is prevalent have adopted guidelines for the management of spray drift from ground and aerial applicators, but recommendations vary widely regarding the detectable conditions favorable for temperature inversion or 'stable atmosphere.' Section 219.06 of Mississippi applicators licensing rule (MDAC, 2011) states "*Smoke and/or other suitable means shall be used to detect inversion conditions and determine wind direction and speed*." This refers to the direction of smoke as an indicator of whether it is safe to spray. If smoke travels vertically, unstable atmospheric conditions exist and conditions are favorable for spraying. A regulation from Canada (Alberta, 2011) indicates that applicators may use "smokers" on their planes to determine how spray droplets will disperse and a guideline from Australia (CSIRO, 2002) indicates that the presence of an inversion can also be indicated by driving a vehicle along a dusty track and observing the movement of dust.

Because of concerns such as those outlined by Bennett (2006), guidelines in Arkansas have been revised to include very specific language concerning conditions where atmospheric temperature inversion can occur and spraying should not occur. A rule from the Arkansas State Plant Board (ASPB, 2008) states that "*Herbicide applications may not be made under conditions where the spray may possibly be entrained in an inversion layer*." The regulation goes on to state "*As an indicator that an inversion is unlikely to exist, the applicator shall record the ambient temperature measured at the field of application for each application. Inversions are much less likely to exist if the temperature has increased three (3) degrees Fahrenheit from the morning low at the time of application for applications made before noon or has not decreased more than three (3) degrees Fahrenheit from the afternoon high for applications made after noon*." The study presented herein attempts to verify the latter rule with field data for the Mid-south.

Objective

The objective of this study was to verify the validity of the Arkansas guidelines regarding air temperature change as a suitable method to assure conditions are favorable for spraying and stable atmospheric conditions do not exist.

Materials and Methods

A tall weather tower was set up at the USDA ARS CPSRU Mechanization Research Farms, Stoneville, MS. The equipment setup and data acquisition method are outlined in Thomson et al. (2010). The tower was equipped with precision thermistors to measure air temperature and anemometers to measure wind speed. These sensors were placed at vertical levels of 4.6, 9, 14, 18.3, 23, and 27.4 m (15, 30, 45, 60, 75, 90 feet) for the temperature sensors and 4.6, 12, 20, and 27.4 m (15, 40, 65, and 90 feet) for the wind sensors.

Using the collected meteorological data, the Stability Ratio (SR) was calculated as

$$SR = \frac{T_{z_2} - T_{z_1}}{WS_{z_3}^2} \cdot 10^5 \qquad (1) \qquad \text{(Munn, 1966)}$$

where:

T_{Z_1} and T_{Z_2} are temperature (^oC) at height z_1 and z_2 and WS_{Z_3} the wind speed (cm/sec) measured at a height of z_3 between z_1 and z_2, (which is the measured equidistant between z_1 and z_2 on a log scale). Yates et al. (1974) used heights of 2.4 and 9.8 m (8 and 32 feet) for z_1 and z_2, respectively, and a wind speed measurement height of 4.9 m (16 ft).

To calculate an SR in this study, the 4.6 m (15 ft) and 9 m (30 ft) temperatures were used for for T_{Z_1} and T_{Z_2} . The WS_{Z_3} wind speed was measured at 4.6 m (15 ft) height, which is not equidistant between the two temperature levels for strict application of Eq. 1 (but this irregularity did not appreciably affect the stability calculations on an hourly basis and will be addressed later in the paper).

Using this equation, atmospheric stability classes were setup and illustrated in Table 1 (Thomson et al., 2010).

Table 1. Atmospheric stability categories as a function of stability ratio (SR) ranges (from Yates et al., 1974)

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

Thomson et al. (2010) illustrates stability charts with diurnal changes, and an example is illustrated in Fig. 1.

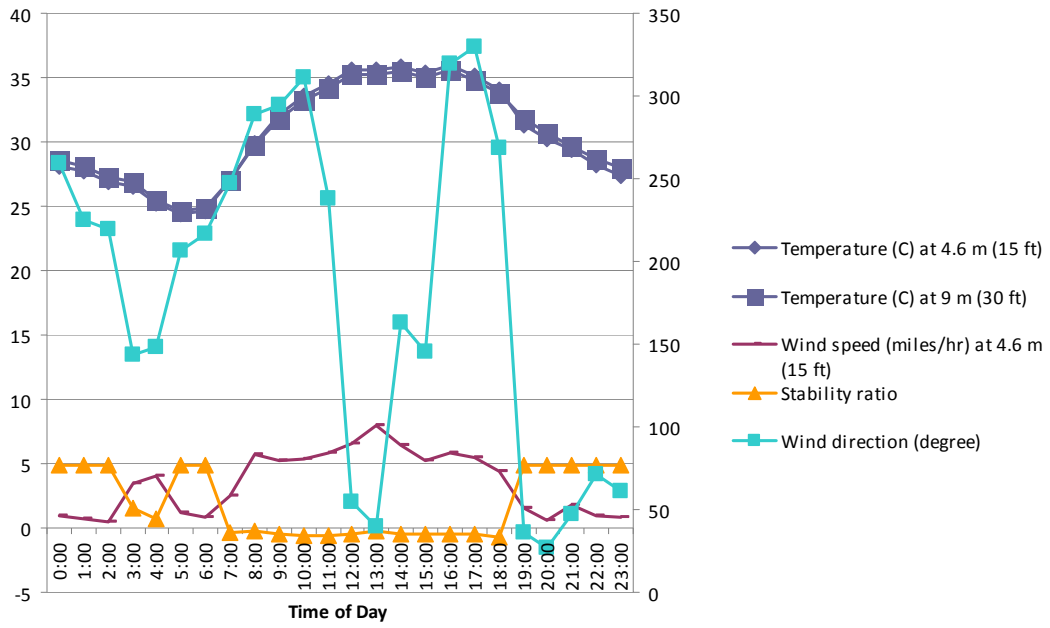

Figure 1. Stability ratios, temperatures, and wind for 15 July, 2004. Secondary axis is the scale for wind direction. 1 mile/hr = 0.447 m/s

Stability factors and temperature differences were calculated for comparison with the recommendations made by ASPB (2008) as shown in Table 2. The ASPB rule of stopping spraying when a 3ºF (1.67 C) temperature decrease occurs is exceeded for all example dates shown in Table 2 except April. However, an unstable condition was still indicated on 15 July when this value was exceeded indicating that a 3º F (1.67 C) reduction was rather conservative. Likewise, the temperature reduction result almost matched a 3º F (1.67 C) for 15 August while unstable conditions still prevailed.

Table 2. Atmospheric stability ratios for five selected dates using air temperatures measured at 4.6 m and 9.8 m elevations. Temperature change indicated in **bold** due to change of state can be compared with the guidelines for the required 1.67 C temperature difference (increasing in the morning; decreasing at night) to assure unstable conditions.

Julian Day	Date	Time	Stability Classification	Stability Ratio	Wind Speed (m/s)	Air Temperature (C), 4.6m	Temperature Change (C)
106	15-Apr	0600	V-stable	3.67	1.23	9.50	0.40
		0700	Stable	0.76	1.64	11.20	2.10
		0800	Neutral	-0.08	2.73	13.70	**4.60**
		1700	Unstable	-1.70	0.23	24.20	-0.05
		1800	V-stable	4.90	0.23	23.30	**-0.92**
197	15-Jul	0600	V-stable	4.90	0.39	24.70	0.33
		0700	Unstable	-0.39	1.13	27.00	**2.69**
		1800	Unstable	-0.40	1.98	34.00	-1.94
		1900	V-stable	4.90	0.67	31.60	**-4.34**
229	16-Aug	0600	V-stable	4.90	0.23	14.90	0.03
		0700	Unstable	-1.70	0.23	17.20	**2.30**
		0800	Unstable	-1.70	1.22	22.00	7.14
		1800	Unstable	-0.41	2.26	29.00	-1.62
		1900	Stable	1.06	1.52	26.30	**-4.34**
259	15-Sep	0700	V-stable	2.66	0.97	21.50	0.83
		0800	Neutral	-0.08	3.76	24.40	**3.51**
289	15-Oct	0700	Stable	0.63	1.93	7.82	0.44
		0800	Neutral	0.03	2.11	10.11	**2.72**
		1700	Neutral	-0.05	2.86	21.91	0.51
		1800	Stable	0.99	3.76	19.49	**-2.66**

Weather Considerations and Strict Application of the Stability Equation

The study presented herein measured wind speed within 0.4 m of the specified height (4.6 m) but the air temperature at the lower height for application of Eq. 1 was measured at the same height as the wind speed. Strict application of Eq. 1 requires that wind speed be measured at an elevation between the two temperatures. For this reason, a 2.5 m height temperature was extrapolated from the data using curve fits based on the other temperature readings. This extrapolation allowed application of Eq. 1 within the correct layer (Yates et al., 1974), and the data could be compared to determine if Eq. 1 still gave acceptable results using the heights in our study. Table 3 shows that stability classifications on an hourly basis (using 2.5 m height) were not appreciably different than those from the 4.6 m height (Table 2).

Table 3. Atmospheric stability ratios for five selected dates using air temperature extrapolated to 2.5m and temperature measured at 9.8m in the stability equation.

Julian Day	Date	Time	Stability Classification	Stability Ratio	Wind Speed (m/s)	Air Temperature (C) extrapolated to 2.5m
106	15-Apr	0600	V-stable	4.90	1.23	9.04
		0700	V-stable	1.42	1.64	11.03
		0800	Neutral	0.00	2.73	13.70
		1700	Unstable	-1.70	0.23	24.22
		1800	V-stable	4.90	0.23	23.15
197	15-Jul	0600	V-stable	4.90	0.39	24.65
		0700	Unstable	-1.69	1.13	27.21
		1800	Unstable	-0.72	1.98	34.09
		1900	V-stable	4.90	0.67	31.30
229	16-Aug	0600	V-stable	4.90	0.23	14.72
		0700	Unstable	-1.70	0.23	17.18
		0800	Unstable	-1.70	1.22	22.56
		1800	Unstable	-0.71	2.26	29.20
		1900	V-stable	2.73	1.52	25.94
259	15-Sep	0700	V-stable	3.77	0.97	21.43
		0800	Unstable	-0.31	3.76	24.78
289	15-Oct	0700	Stable	1.05	1.93	7.67
		0800	Neutral	0.00	2.11	10.13
		1700	Unstable/neutral	-0.11	2.86	21.96
		1800	V-stable	1.79	3.76	19.35

Conclusions

Results of this study conclude that the ASPB (2008) recommendations for temperature rise and fall required to begin and terminate spraying, respectively, are robust and valid recommendations for the summer months. These recommendations should be followed to avoid spraying during temperature inversions and ‘stable’ atmospheric conditions.

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