American Society of
Agricultural and Biological Engineers

An ASABE Section Meeting Presentation

Paper Number: AA10-10

Temporal Indications of Atmospheric Stability Affecting Off-Target Movement of Spray in the Midsouth U.S.

Steven J. Thomson

USDA ARS CPSRU, Stoneville, MS USA, steve.thomson@ars.usda.gov

Yanbo Huang

USDA ARS CPSRU, Stoneville, MS USA

Bradley K. Fritz

USDA ARS APMRU, College Station, TX USA

Written for presentation at the
2010 ASABE/NAAA Technical Session
Sponsored by ASABE Technical Committee PM-23/6/2
44th Annual Convention & Exposition
Savannah International Trade & Convention Center, Savannah, GA
December 6, 2010

Abstract. *This study was designed to determine atmospheric conditions favorable for off target movement of spray deleterious to susceptible crops. A tall meteorological monitoring tower equipped with six precision (and periodically calibrated) thermistors at six heights to 27.4 m and wind speed anemometers at four heights to 27.4 m was logged continuously throughout the day during the growing season. Wind speed and temperature data were used to calculate atmospheric stability ratios, and temporal and temperature gradient patterns at different altitudes were determined. Periods when wind patterns and stable air conditions occur that are known to favor off-target drift were determined from tower data. Temperature inversion periods influencing atmospheric stability were examined for strength, time of occurrence, and duration. The data presented in this study showed 'stable' conditions (unfavorable for spraying) occurring primarily between the hours of 6:00 PM and 6:00 AM during clear conditions in the hot summer months. Wind conditions in the morning transition from stable to unstable atmosphere ranged between 1.25 to 1.60 m s^{-1} (2.8 and 3.6 mph). The ultimate goal is to incorporate this information into new guidelines for pilots on weather conditions and times of the day not to spray to reduce the potential for far-field off-target drift in the Mid-south.*

The authors are solely responsible for the content of this technical presentation. The technical presentation does not necessarily reflect the official position of ASABE, and its printing and distribution does not constitute an endorsement of views which may be expressed. Technical presentations are not subject to the formal peer review process, therefore, they are not to be presented as refereed publications. Citation of this work should state that it is from an ASABE Section Meeting paper. EXAMPLE: Author's Last Name, Initials. Title of Presentation. ASABE Section Meeting Paper No. xxxx. St. Joseph, Mich.: ASABE. For information about securing permission to reprint or reproduce a technical presentation, please contact ASABE at rutter@asabe.org or 269-429-0300

(2950 Niles Road, St. Joseph, MI 49085-9659 USA).

Keywords: aerial application, spray drift, temperature inversion

The authors are solely responsible for the content of this technical presentation. The technical presentation does not necessarily reflect the official position of ASABE, and its printing and distribution does not constitute an endorsement of views which may be expressed. Technical presentations are not subject to the formal peer review process, therefore, they are not to be presented as refereed publications. Citation of this work should state that it is from an ASABE Section Meeting paper. EXAMPLE: Author's Last Name, Initials. Title of Presentation. ASABE Section Meeting Paper No. xxxx. St. Joseph, Mich.: ASABE. For information about securing permission to reprint or reproduce a technical presentation, please contact ASABE at rutter@asabe.org or 269-429-0300

(2950 Niles Road, St. Joseph, MI 49085-9659 USA).

Introduction

Crop protection materials and harvest aids applied from both aircraft and ground sprayers can drift off-target due to many factors such as nozzle type and orientation, spray pressure, and application height. Droplet size, which is influenced by nozzle and adjuvant interaction is a significant factor for near-field off-target drift (Ozkan, 1998). Uncontrollable weather factors must also be considered, and it is incumbent on the applicator to schedule application during periods that do not exacerbate off-target drift.

For good environmental stewardship from aerial application of crop protection materials, a major goal is to avoid application under 'stable' atmospheric conditions when a temperature inversion is likely to occur. Spraying must not occur where there is upward air movement or where a temperature inversion prevents the spray cloud settling within the treated area (FAO, 2001). The detrimental effects on cotton of spraying 2, 4-D to rice or pastures under conditions of a temperature inversion have been documented (Bennett, 2006). The number of drift complaints increased in East Arkansas and based on field and extension reports, the problem was most likely the result of multiple applications of 2, 4-D under stable atmospheric conditions. Under those conditions, a parcel of air can't rise and disperse, but it can move laterally in the light variable winds typical of a surface inversion (Ramsey, 2001). A spray layer applied under stable conditions is thus "ready to move" off target when the wind picks up, and this is what was surmised to occur in East Arkansas (Bennett, 2006).

Surface temperature inversions occur during nighttime surface cooling and until morning surface heating (Beychock, 1994; Ramsey, 2001). These conditions usually occur at sunset to just after sunrise, under windless to low wind conditions, and when there are clear to partly cloudy skies. 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 (also if sufficient humidity exists). However, many of these indicators illustrate the 'potential' for temperature inversions and duration of these events can be highly variable. It would thus be instructive to document the time and duration of periods of stable and unstable temperature profiles. For an environment in College Station, TX, Fritz et al. (2008) indicated that stable or unstable conditions (unfavorable for spraying) occurred when wind speeds were 2.0 m s^{-1} or below. The authors also documented that temperature inversions occurred between 57 and 65% of the monitored days.

By using an instrumented tall tower, temperature and wind profiles that indicate both the presence of surface and aloft temperature inversions can be determined. This study presents data from towers that were used to calculate stability ratios. These data can be used to make recommendations on the times of day that are likely to be of concern when spraying crop protection materials.

Materials and Methods

A tall tower was set up at the USDA ARS CPSRU Mechanization Research Farms, Stoneville, MS. The tower was equipped with Omega 44000 series precision thermistors to measure air temperatures, Qualimetrics model 2030 anemometers to measure wind speed, and a Met-One 024A wind direction sensor. The temperature sensors were placed at 4.6, 9, 14, 18.3, 23, and 27.4 m (15, 30, 45, 60, 75, 90 feet) for temperature; 4.6, 12, 20, and 27.4 m (15, 40, 65, and 90 ft) for monitoring wind speeds.

A Campbell CR-21X micrologger 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 through October 2004 and read every five minutes. These data were periodically downloaded from data cans for further processing using a custom-designed 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. Data read every five minutes were averaged over a one hour period to obtain hourly readings, plotted herein.

For calculation from 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.

To calculate SR, the temperatures were measured at 4.6 m (15 ft) and 9 m (30 ft) for T_{Z_1} and T_{Z_2}. Wind speed WS_{Z_3} was measured at 4.6 m (15 ft) for presentation of results, but this height is not equidistant between the two temperature levels for strict application of Eq. 1. However, wind speeds and air temperatures were measured at several different heights, so diurnal trends indicating aloft temperature inversions can be indicated.

For calculation of the stability ratio (SR), diurnal atmospheric stability can be determined based atmospheric stability classes as illustrated Table 1.

Table 1 Atmospheric stability categories as a function of stability ratio (SR) ranges (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

Figures 1 through 3 illustrate weather data and stability ratios for three select days of the year. Data for the plots were averaged over one hour intervals. For 15 April, 2004, the transition point from stable (unfavorable for flying) to unstable conditions in the morning hours occurred between about 6:00 and 7:00 AM. This response characterizes a typically smooth transition between states as categorized in Table 1. It is interesting to note that stable or very stable conditions were still prevalent at wind speeds sometimes indicated as suitable for spraying (between 1.25 to 1.60 m s^{-1} or 2.8 and 3.6 mph). In the evening, stable conditions began to occur after about 18:00 at very low wind speed (0.23 m s^{-1} or 0.52 mph) at the 4.6 m (15 ft) height. Figure 2 (15 July, 2004) indicates more variable wind, although diurnal temperature cycles followed a similar smooth pattern as the 15 April plot. Within the morning hours normally

indicating stable conditions, fluctuations between stable and unstable conditions inversely tracked wind speed fluctuations as would be expected. The evening hours showed transition to stable conditions after 18:00 as in the 15 April plot (Fig.1), and stable conditions were clearly in place when wind speed was down to 0.67 m s^{-1} or 1.5 mph. The 15 October plot of Fig. 3 shows more weakly stable conditions during the early morning hours after midnight because of higher wind speeds hovering in the 1.11 m s^{-1} (2.5 mph) range. The transition to stable conditions in the evening occurred after 18:00 as the wind speed measured at 4.6 m (15 feet) dipped to 0.89 m s^{-1} (2.0 mph). Figure 4 illustrates a 62% average probability of either stable or strongly stable conditions occurring between 19:00 and 6:00 over the period of 14 April to 6 November, 2004. Neutral conditions occurred 23% of the time and unstable conditions occurred 15% of the time.

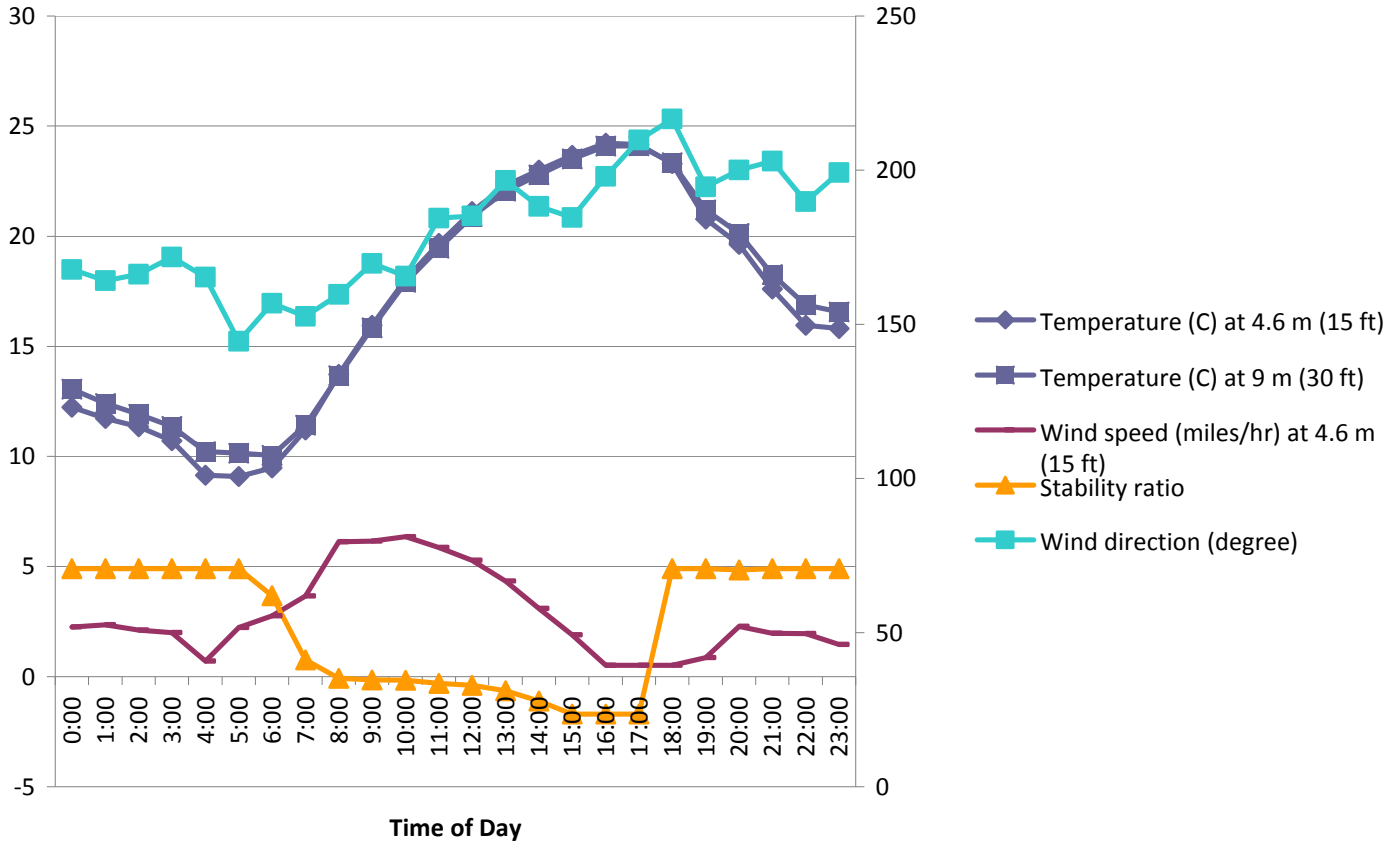

Fig. 1. Stability ratios, temperatures, and wind for 15 April, 2004. Right axis is the scale for wind direction. 1 mile/hr = 0.447 m/s

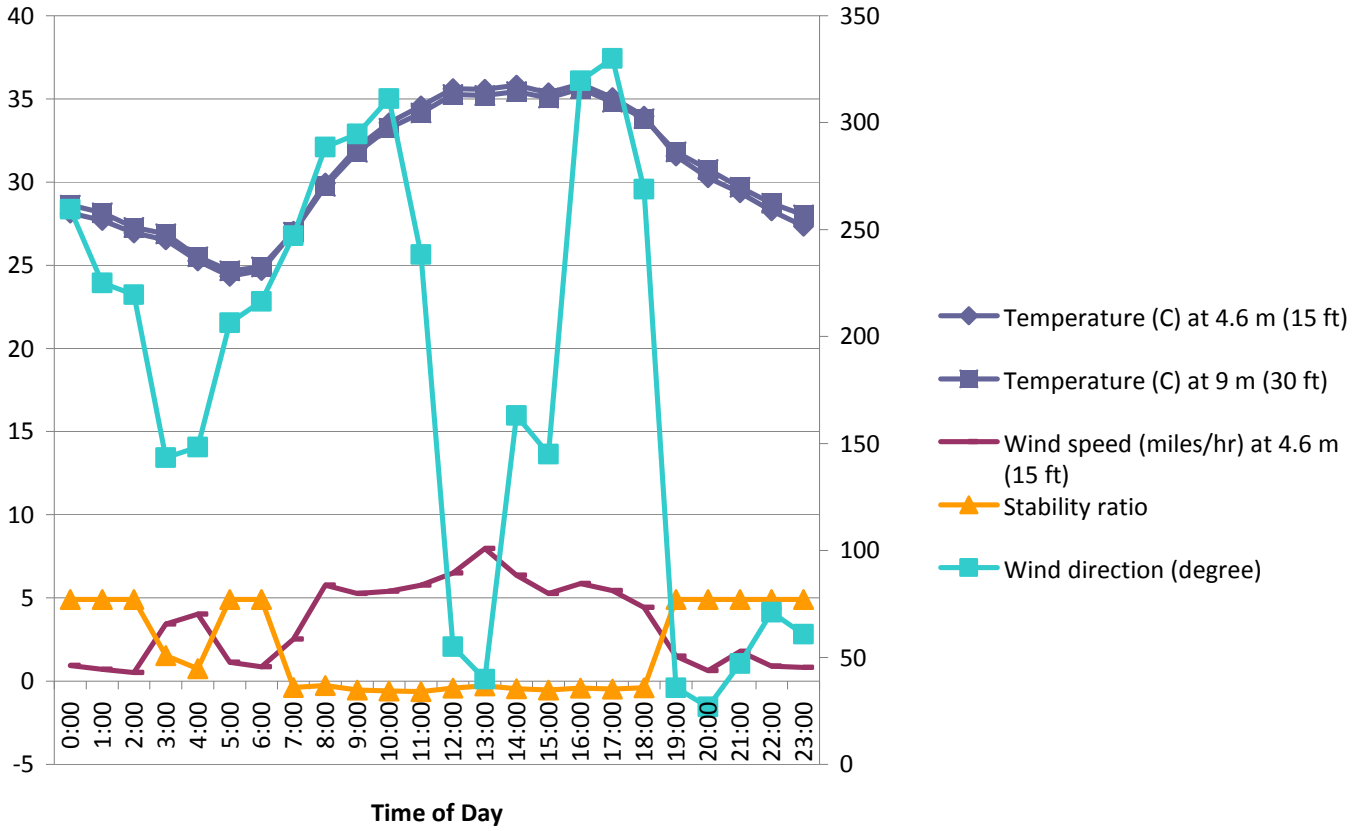

Fig. 2. Stability ratios, temperatures, and wind for 15 July, 2004. Right axis is the scale for wind direction. 1 mile/hr = 0.447 m/s

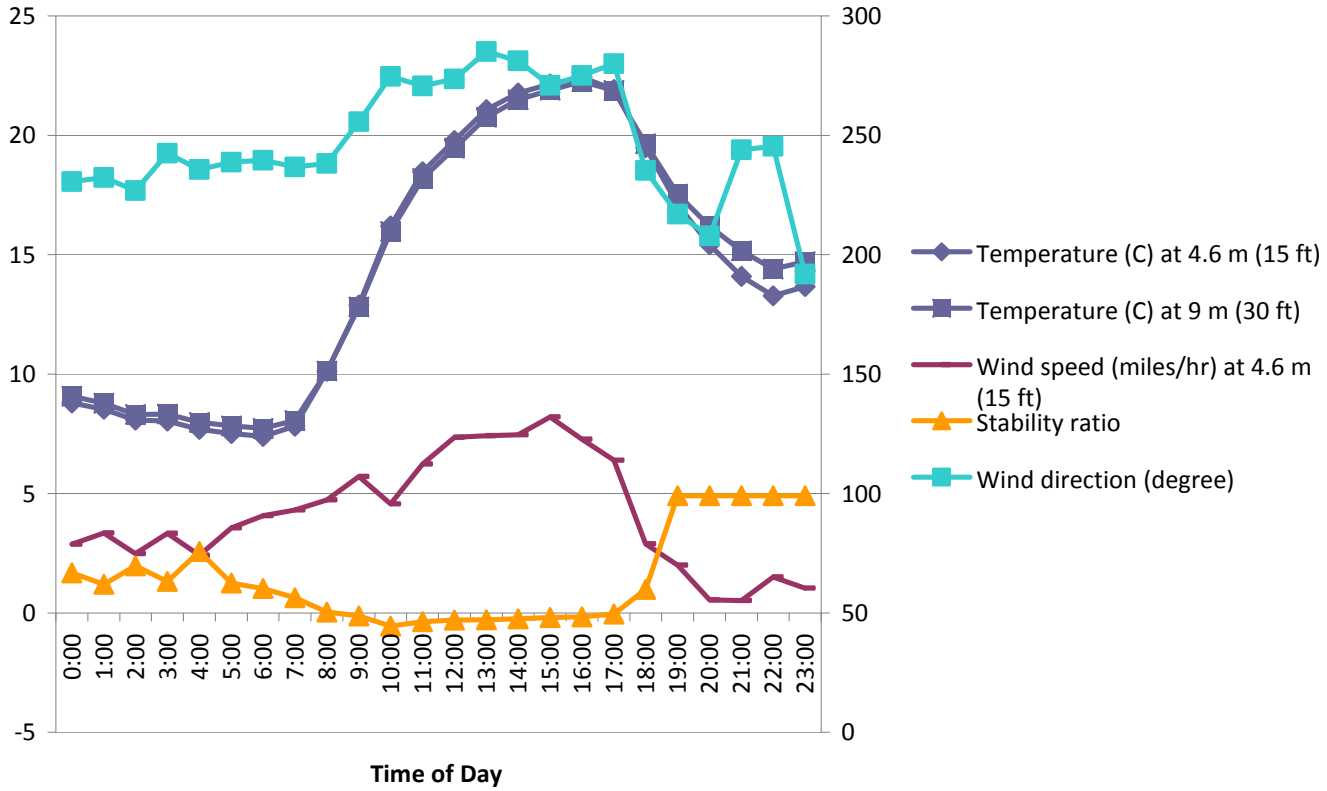

Fig. 3. Stability ratios, temperatures, and wind for 15 October, 2004. Right axis is the scale for wind direction. 1 mile/hr = 0.447 m/s

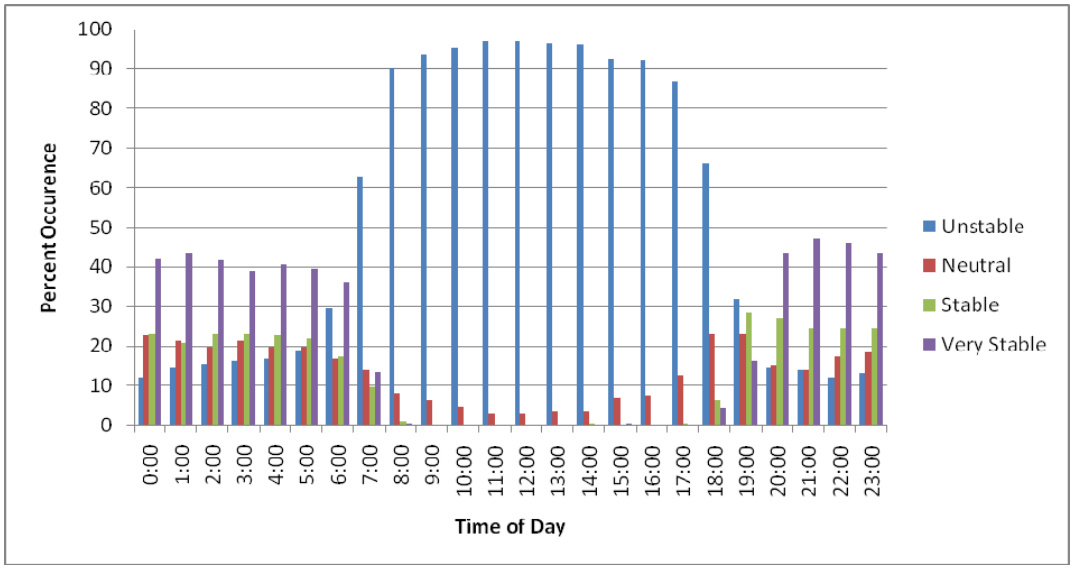

Fig. 4. Probability distribution of atmospheric stability classification by time of the day between 14 April, 2004 and 6 November, 2004.

The data presented in this study showed consistent patterns of atmospheric stability occurring primarily between the hours of 6:00 PM and 6:00 AM, which is also consistent with what was observed from the study in College Station, TX (Fritz et al., 2008). Probability of either stable or

stongly stable conditions over the logging period was 62%, which compares well with 57 % and 65% of days monitored in Texas over two different stations.

An applicator should use judgment to find a balance between conditions that are so stable that spray does not disperse (with potential to move off-site), and conditions that are so unstable and windy that spray is quickly dispersed and moved off-site without reaching the target. The results of this study, coupled with a previous study that indicated similar results, suggest some "rules-of-thumb" a pilot can use to identify these conditions. It should be noted that during the daily cycle of atmospheric conditions, inversions occuring late in the afternoon are likely to persist through the remainder of the day.

References

Bennett, D. 2006. 2,4-D herbicide drift damage stuns east Arkansas cotton. Delta Farm Press. Aug 11, 2006. Available at: http://deltafarmpress.com/24-d-herbicide-drift-damage-stuns-east-arkansas-cotton Accessed 3 January 2011.

Beychok, M. R. 1994. *Fundamentals of Stack Gas Dispersion*. 3rd Ed., Newport Beach, CA: M.R. Beychock.

FAO, 2001. Guidelines on Good Practice for Aerial Application of Pesticides. Food and Agriculture Organization of the United Nations, Rome, 2001. Available at http://www.fao.org/docrep/006/y2766e/y2766e00.htm Accessed 3, January 2011.

Fritz, B.L., W. C. Hoffmann, Y. Lan, S. J. Thomson, and Y. Huang. 2008. Low-Level Atmospheric Temperature Inversions: Characteristics and Impacts on Aerial Applications. Agricultural Engineering International: the CIGR Ejournal. Manuscript PM 08 001. Vol. X.

Munn, R. E. 1966. *Descriptive Meteorology – Advances in Geophysics Supplement 1.* New York: Academic Press.

Ozkan, H.E. 1998. New nozzles for spray drift reduction. Ohio State University Extension Fact Sheet AEX-523-98. Available at http://ohioline.osu.edu/aex-fact/0523.html Accessed 3 January 2011.

Ramsey, G. 2001. Surface inversions, atmospheric stability, and spray drift. Pesticide Spray Drift Conference, Sacramento, California, Sept 5-6, 2002. Available at http://www.cdpr.ca.gov/docs/enforce/drftinit/confs/2001/ramsey.ppt. Accessed 03 December 2010.

Yates, W. E., N. B. Akesson, and R. E. Cowden. 1974. Criteria for minimizing drift residues on crops downwind from aerial applications. *Transactions of the ASAE* 17(4): 637-632.