A Real-time Web Tool for Safe Aerial Application to Avoid Off-target Movement of Spray Induced by Stable Atmospheric Conditions in the Mississippi Delta

Y. Huang, D. K. Fisher, M. Silva, S. J. Thomson

Abstract. *Susceptible crops can be injured far downwind if proper application spray procedure is not followed. Avoidance of stable atmospheric conditions while spraying is important to prevent surface temperature inversion-induced off-target drift of crop protection materials. Our previous studies consistently indicated high likelihood (>90%) of stable atmospheric conditions (unfavorable for spraying) primarily between the hours of 6:00 PM and 6:00 AM during clear conditions in the hot summer months at the Mississippi Delta. With the requirement of timely farm operations, a web application has been developed to provide real-time determination of atmospheric stability and to recommend whether aerial applications are appropriate for a particular location and time. An algorithm was developed to determine atmospheric conditions likely for occurrence of a temperature inversion. This algorithm was programmed using the Python programming language and uploaded to an internet-cloud application platform for publication via HTML. The algorithm calculates the potential of a temperature inversion every hour based on air temperature and wind speed data measured at weather stations deployed over the Mississippi Delta and surrounding areas. The web application is adapted for mobile terminals, such as smartphones and tablets, and can provide timely guidance for aerial applicators and producers to avoid crop damage and air quality issues long distances downwind.*

Keywords. *Aerial application, Spray drift, Temperature inversion, Atmospheric stability, Crop protection, Web application, Mobile terminal.*

See off-target drift of crop production and protection materials applied from sprayers on aircraft is typically a function of controllable factors such as boom setup, nozzle type and orientation, spray pressure, and application height, and uncontrollable factors including air temperature, relative humidity, wind speed, and wind direction (Huang et al., 2010, 2012). Another important factor that causes off-target movement is "stable" atmospheric conditions, i.e., when a temperature inversion is likely to occur. Temperature inversion will result in a layer of cool and still air being trapped below warmer air. If pesticides are sprayed during an inversion, fine droplets of the chemical can be concentrated in the cool layer near the ground and isolated from the surrounding weather conditions. The direction and distance which the droplets can then move becomes unpredictable and the chemical may be transported away from the target area (Agriculture Victoria, 2017). Therefore, spraying should not be conducted at places where a temperature inversion prevents the spray cloud settling within the treated area (FAO, 2001).

It is important to study and document the time and duration of periods of stable and unstable temperature profiles to advise aerial applicators to avoid off-target drift caused by surface temperature inversions. The fundamental study can be traced back to 50 years ago on the dispersion of windborne material from industrial and other sources and an atmospheric stability classification scheme has been created (Pasquill, 1974). For pesticide droplet dispersion characterization, Thistle (2000) reviewed the physical concepts of atmospheric stability in fine pesticide droplet dispersion. Fritz et al. (2008) further indicated that stable atmospheric conditions (unfavorable for spraying) occurred in College Station, Texas, when wind speeds were 2.0 m s^{-1} or lower. The authors also documented that temperature inversions occurred between 57% and 65% of the monitored days.

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We conducted analyses using data collected on an instrumented 30-m tower to measure temperature and wind profiles at different heights to indicate both the presence of surface and aloft temperature inversions (Thomson et al., 2010, 2017). The study analyzed data collected from the tower and calculated the stability ratio (SR) to classify atmospheric stability for the likelihood of temperature inversion occurrence during a day. The results were organized as guidelines to recommend times of day that are likely to be of concern for spraying crop protection materials. In the study, hourly data indicated stable conditions (unfavorable for spraying) primarily between the hours of 6:00 PM and 6:00 AM during clear conditions in the hot summer months at the Mississippi Delta. The data were collected originally at 5-min intervals. The question remained if analysis from the resampled hourly data was consistent with the analysis from the original data. Huang and Thomson (2016) conducted a study to compare analytical results from the original data and resampled hourly and 15-min data, the latter being one of the time intervals used at the weather stations. Results indicated that all analytical results from hourly and sub-hourly intervals concluded (consistently) a high likelihood (>90%) of stable atmospheric conditions primarily between the hours of 6:00 PM and 6:00 AM during clear conditions in the hot summer months at the Mississippi.

Based on these previous studies, we worked to organize and disseminate the information via the internet on the web and mobile platforms to provide effective guidelines based on real-time data for aerial applicators and producers. The objective of this project was to develop a web-based interface, and data acquisition, processing, analysis and communication structure for developing a mobile interface to provide timely information in the hands of aerial applicators and farmers.

MATERIALS AND METHODS

RESEARCH SITE, DEVICES, DATA, AND OUTCOME

A tall tower was set up at the United States Department of Agriculture (USDA), Agricultural Research Service (ARS), Crop Production Systems Research Unit (CPSRU) Mechanization Research Farms, Stoneville, Mississippi. The tower was equipped with Omega 44000 series precision thermistors (Omega Engineering, Inc., Norwalk, Conn.) of ±0.2°C Interchangeability, 2,252 Ω @ 25°C to measure air temperatures, Qualimetrics model 2030 anemometers (All Weather, Inc., Sacramento, Calif.) of ±0.15 mph (0.067 mps) to measure wind speed, and a Met-One 024A sensor (Met One Instruments, Inc., Grants Pass, Ore.) of ±5° to measure wind direction. The temperature sensors were placed at heights of 4.6, 9, 14, 18.3, 23, and 27.4 m, similarly, anemometers and wind vanes were placed at heights of 4.6, 12, 20, and 27.4 m. The weather data were measured every 5 min from April through October in 2004 and 2005 during the crop growth period. The data measured in 2004 were used to calculate the Stability Ratio (SR) (Munn, 1966) using the temperatures measured at 4.6 and 9 m and the wind speeds measured at 4.6 m to determine atmospheric stability classes for likelihood of surface temperature inversion. Using the collected meteorological data, the SR was calculated as:

$$SR = \frac{T_{Z_2} - T_{Z_1}}{WS_{Z_3}^2} \cdot 10^5 \quad (1)$$

where T_{Z_1} and T_{Z_2} are temperature (°C) 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, temperatures were measured at 4.6 m and 9 m for T_{Z_1} and T_{Z_2}. Wind speed WS_{Z_3} was measured at 4.6 m. This height was not equidistant between the two temperature levels for strict application of equation 1, but this discrepancy will be addressed later. Diurnal atmospheric stability can be determined based atmospheric stability classes as illustrated table 1 for calculation of stability ratio.

This work has been conducted to characterize shallow surface temperature inversion layer above and below 4.6 m. Using the instrumented tall tower, temperature and wind profiles that indicate both the presence of surface and aloft temperature inversions and ultimately, atmospheric stability known to influence off-target movement of spray, could be determined. This research focuses on the surface inversion that happens to influence typical aerial application with the release altitude at around 4.6 m (15 ft).

Figure 1 shows the probability of daily atmospheric stability classified with SR calculations. The figure illustrates a 91.7% average probability of either stable or strongly stable conditions occurring 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, indicating a high likelihood of temperature inversion during which aerial application is not recommended (Huang and Thomson, 2016). This research provided a general guideline, but for specific days, the timing varied depending on actual weather conditions.

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." This rule was meant to provide a simple but accurate way of determin-

Table 1. Atmospheric stability categories as a functiomn of stability ration (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

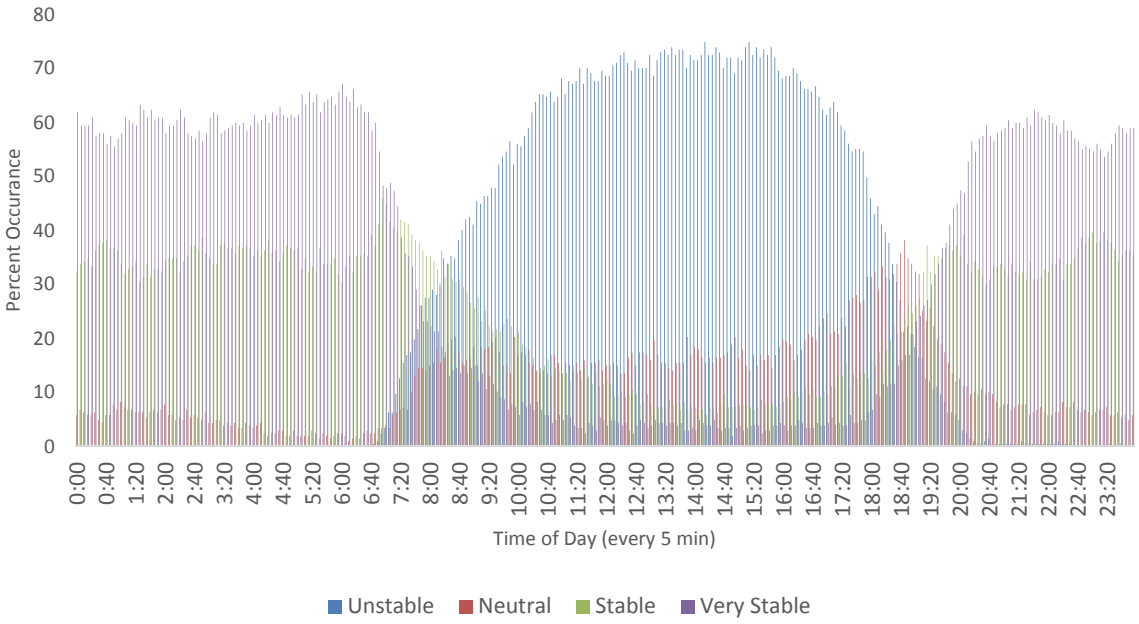


Figure 1. Daily probability distribution of atmospheric stability classified based on the SR calculation with data measured between April and October 2004 (Huang and Thomson, 2016).

ing stability with only wind speed and temperature measurements at a single height (Dennis Gardisser, personal communication, 5 December 2010). Timing of the recommendation was evaluated to see how well it matched the likelihoods we calculated with measured temperatures at several heights and wind speed data (Thomson et al., 2017). It was determined that the "Arkansas Rule" can be a valid reference to determine the timing of spray application to avoid off-target spray movement for any specific day during the period of crop growth on sunny days between approximately April to September in the Mississippi Delta. The weather data needed to implement the rule include air temperature and wind speed throughout the day. The data should be acquired from weather stations geo-spatially distributed in the area. The Delta Research and Extension Center of Mississippi State University provides hourly data measured in the Mississippi Delta and surrounding areas.

Web Calculation Algorithm

Our research data validated the "Arkansas Rule" during the summer months. We further validated an alternate form (Thomson et al., 2010) that states "…or has not decreased more than FIVE (5) degrees Fahrenheit from the afternoon high for applications made after noon." Our data has also shown that even if a very slight inversion exists, spraying may be allowed if wind speed is greater than 4 mph. This causes enough mixing and atmospheric conditions move towards neutral stability, during which it is safe to spray (Thomson et al., 2017). The logic of calculation algorithm described above for the web-based online guide is outlined in table 2.

Computing Platforms

The algorithm of the web calculation logic was programmed using Python, a widely used high-level programming language for general-purpose programming. The web

Table 2. Web calculation algorithm logic.

Before Noon	Is $T - T_{low} \geq 3$ °F? where T is the current temperature and T_{low} is the lowest temperature observed in the morning.	Yes	No Inversion and spraying is permitted			
		No	$T - T_{low} \leq T_{th}$ T_{th} is the temperature increase threshold, for example 2 °F	Yes	Strong inversion and no spray suggested	
				No, but WS > 4 mph? where WS is the wind speed	Yes	Spray OK
					No	No spray
After Noon	Is $T_{high} - T \leq 5$ °F? where T is the current temperature and T_{high} is the highest temperature observed in the afternoon.	Yes	No Inversion and spraying is permitted			
		No	$T_{high} - T \geq T_{th}$ T_{th} is the temperature increase threshold, for example 7 °F	Yes	Strong inversion and no spray suggested	
				No, but WS > 4 mph? where WS is also the wind speed	Yes	Spray OK
					No	No spray

interface was built using HTML (HyperText Markup Language). In the HTML program, with the Maps JavaScript API the Google Map with weather station marker was embedded in the web page. The web interface is a web application that extracts calculation results from the Python program, with the website hosted on a cloud-based web server (https://www.heroku.com) through GitHub (https://github.com/). Figure 2 shows the work flowchart of the web calculation and publication process. In the flowchart the weather data hub is created by Delta Research and Extension Center, Mississippi State University. The Python program interfaces with the hub through an intermediate website which publishes the weather data real time.

Mobile Platforms

As long as the website is activated and published, a web browser such as Google Chrome can be used to view the page on a smartphone or tablet computer. As shown in figure 3, Google Chrome provides an Inspect function to show the layout of the web page on each mobile platform. If any of the layout is not satisfactory, the web page HTML program can be adjusted until the layout is satisfactory.

Results

Figure 4 shows the web page viewed with Internet Explorer and demonstrates hourly determination of temperature inversion occurrence for 12 locations geographically distributed in the Mississippi Delta and surrounding areas. As the page shows, in the second column, the latest temperature measurements are displayed along with a color to indicate conditions for aerial application. Green indicates a low potential for temperature inversion based on background calculations, and conditions are favorable for aerial application currently at that location. Red indicates a high potential for temperature inversion, and aerial application is not recommended currently at that location. With this information, aerial applicators and producers in these regions can access real-time online advice on the timing of spray applications to avoid off-target drift.

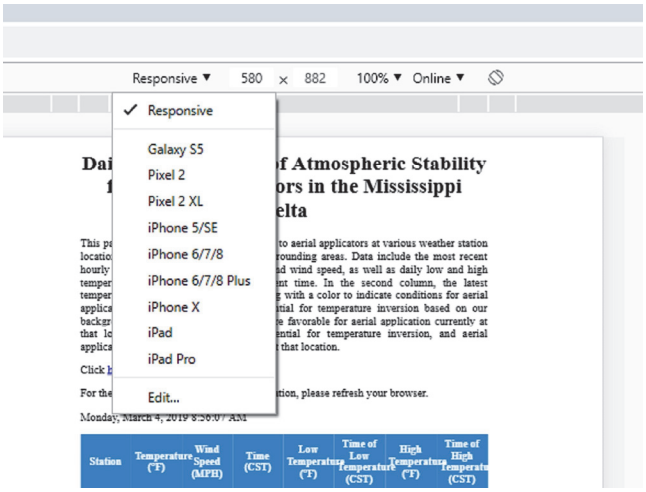


Figure 3. Google Chrome for visualization of web page layouts on mobile platforms.

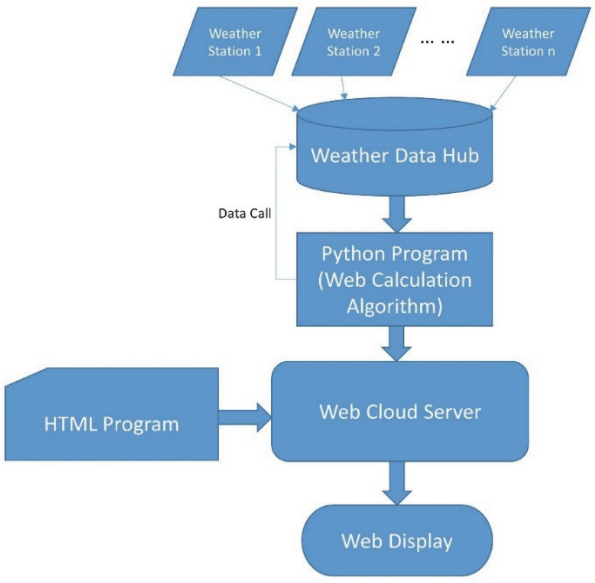
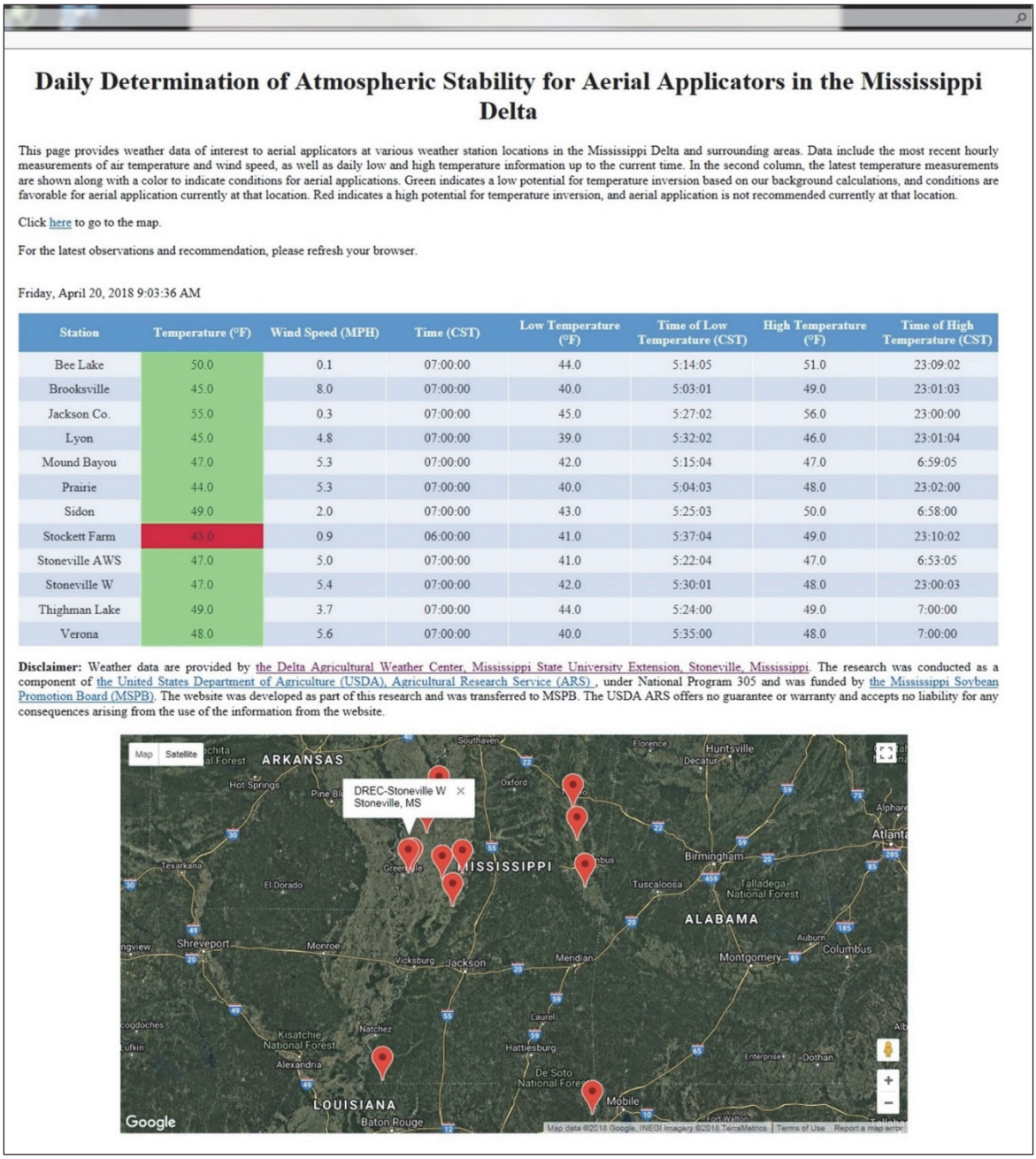


Figure 2. Flowchart of the web calculation and publication.

Figure 5 shows a series of web pages using the Safari web browser on an iPhone throughout a day from early morning to late afternoon. At 6:00 AM Central Standard Time (CST), all locations indicated a high potential for temperature inversion and aerial application was not recommended at any of the locations. At 7:00 AM CST, three locations still had a high potential for temperature inversion, and with the other nine locations showing a low potential for temperature inversion and, therefore, acceptable conditions for aerial application. At 8:00 AM CST, all 12 locations showed low potential for temperature inversion and aerial application was recommended. The low potential of temperature inversion remained at all locations until 5:00 PM CST, after which one location indicated high potential of temperature inversion. At 6:00 PM CST, three locations showed a high potential of temperature inversion, and at 7:00 PM CST, all 12 locations showed high potential of temperature inversion and recommended against aerial application. So, aerial application can be conducted at most of the locations from 7:00 AM CST to 6:00 PM CST on that day. Exceptions are that Brooksville and Verona are good for aerial application from 8:00 AM CST to 6:00 PM CST, Prairie from 9:00 AM CST to 6:00 PM CST, Jackson Co. from 7:00 AM CST to 4:00 PM CST, and Sidon and Stockett Farm from 7:00 AM CST to 5:00 PM CST.

Figure 5 illustrates how the web application works and the general timing of the occurrence of temperature inversion during one particular day. For other days, the timing may vary due to temperature and wind speed. Based on the statistical analysis of the weather data from 12 spatially distributed locations, in general, temperature inversions were often indicated between 6:00 PM CST and 7:00 PM CST until the following 7:00 AM CST on the days when air temperatures were relatively high in clear conditions. Cooler or cloudy conditions delayed the time of low potential of temperature inversion so that aerial applications could take place safely by about one hour late in the morning and moved back the time when the spray should be halted by one hour in the



Daily Determination of Atmospheric Stability for Aerial Applicators in the Mississippi Delta

This page provides weather data of interest to aerial applicators at various weather station locations in the Mississippi Delta and surrounding areas. Data include the most recent hourly measurements of air temperature and wind speed, as well as daily low and high temperature information up to the current time. In the second column, the latest temperature measurements are shown along with a color to indicate conditions for aerial applications. Green indicates a low potential for temperature inversion based on our background calculations, and conditions are favorable for aerial application currently at that location. Red indicates a high potential for temperature inversion, and aerial application is not recommended currently at that location.

Click here to go to the map.

For the latest observations and recommendation, please refresh your browser.

Friday, April 20, 2018 9:03:36 AM

Station	Temperature (°F)	Wind Speed (MPH)	Time (CST)	Low Temperature (°F)	Time of Low Temperature (CST)	High Temperature (°F)	Time of High Temperature (CST)
Bee Lake	50.0	0.1	07:00:00	44.0	5:14:05	51.0	23:09:02
Brooksville	45.0	8.0	07:00:00	40.0	5:03:01	49.0	23:01:03
Jackson Co.	55.0	0.3	07:00:00	45.0	5:27:02	56.0	23:00:00
Lyon	45.0	4.8	07:00:00	39.0	5:32:02	46.0	23:01:04
Mound Bayou	47.0	5.3	07:00:00	42.0	5:15:04	47.0	6:59:05
Prairie	44.0	5.3	07:00:00	40.0	5:04:03	48.0	23:02:00
Sidon	49.0	2.0	07:00:00	43.0	5:25:03	50.0	6:58:00
Stockett Farm	43.0	0.9	06:00:00	41.0	5:37:04	49.0	23:10:02
Stoneville AWS	47.0	5.0	07:00:00	41.0	5:22:04	47.0	6:53:05
Stoneville W	47.0	5.4	07:00:00	42.0	5:30:01	48.0	23:00:03
Thighman Lake	49.0	3.7	07:00:00	44.0	5:24:00	49.0	7:00:00
Verona	48.0	5.6	07:00:00	40.0	5:35:00	48.0	7:00:00

Disclaimer: Weather data are provided by the Delta Agricultural Weather Center, Mississippi State University Extension, Stoneville, Mississippi. The research was conducted as a component of the United States Department of Agriculture (USDA), Agricultural Research Service (ARS) , under National Program 305 and was funded by the Mississippi Soybean Promotion Board (MSPB). The website was developed as part of this research and was transferred to MSPB. The USDA ARS offers no guarantee or warranty and accepts no liability for any consequences arising from the use of the information from the website.

Figure 4. Web page showing daily temperature inversion information at 7:00 CST on 20 April 2018 (Internet Explorer), (upper), and locations of weather stations (lower).

late afternoon. As indicated in our early work (Thomson el al., 2017), wind speed influenced the degree of atmospheric stability in concert with vertical temperature gradients. Relatively high wind speed may shorten the period of the occurrence of temperature inversion to potentially give more spray time during the day although the applicator must still be aware of potential downwind drift of their spray.

Conclusion

This study demonstrates a web application prototype that can be useful for aerial applicators and farmers by providing online advice from an Internet website and mobile platforms to determine suitable times during a day to spray the field to avoid off-target downwind movement of spray. This is especially useful with the weather data that can be provided real time.

Acknowledgements

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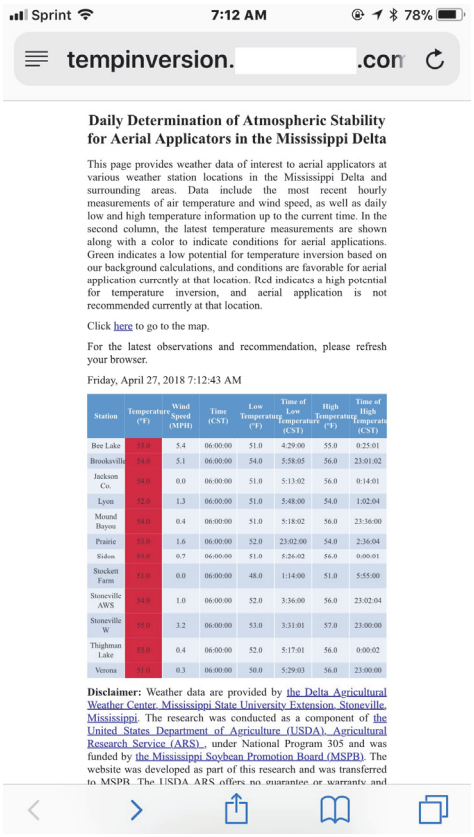
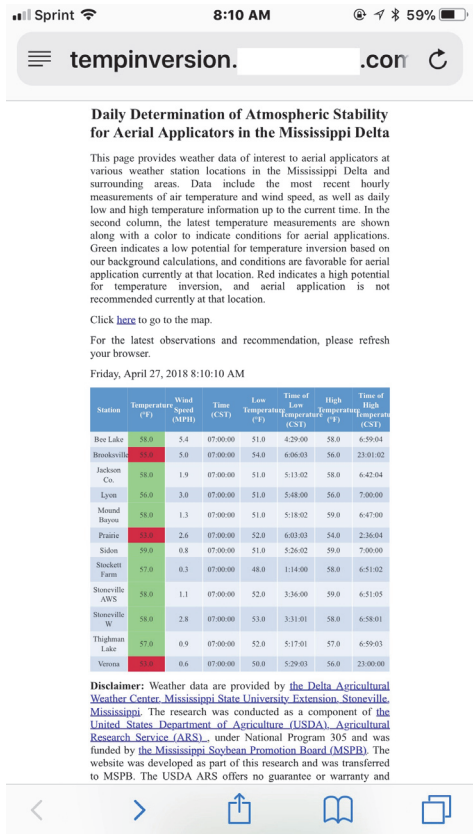
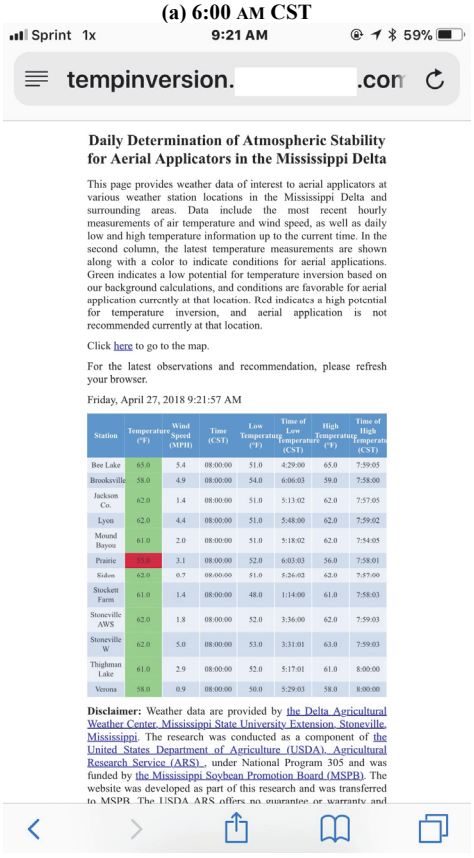


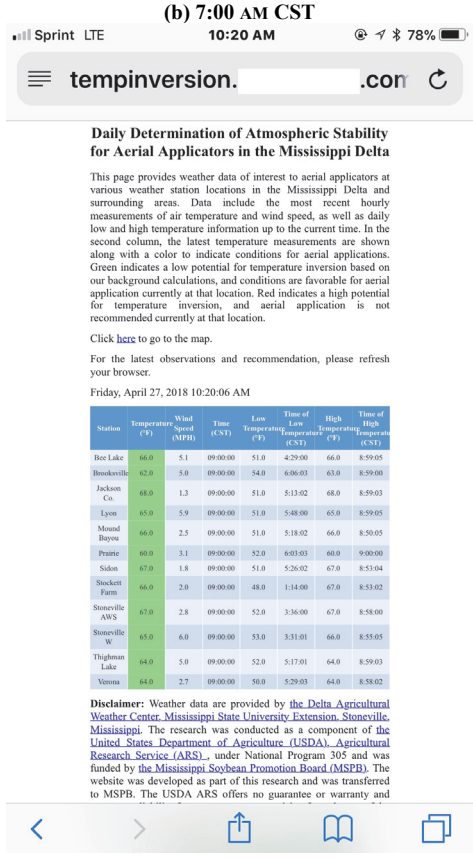
(a) 6:00 AM CST



(b) 7:00 AM CST



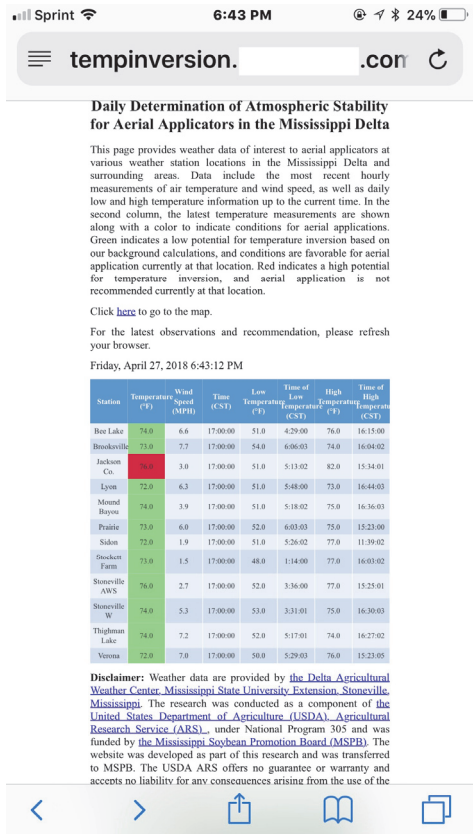
(c) 8:00 AM CST



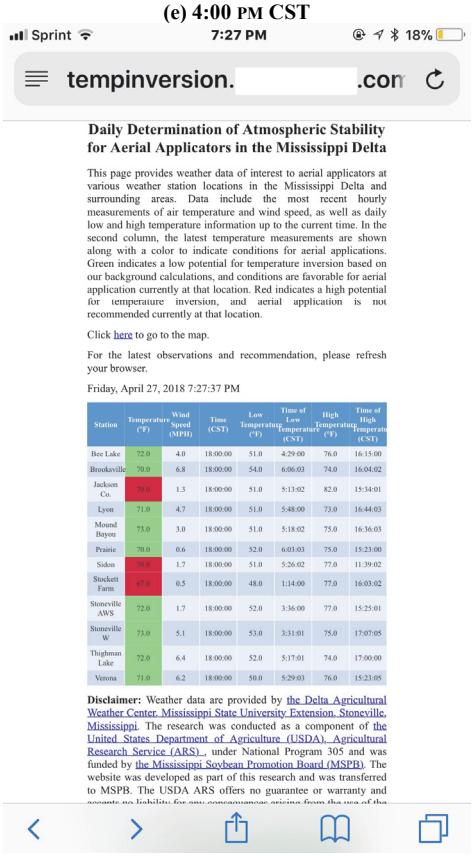
(d) 9:00 AM CST

Figure 5. Web pages of daily temperature inversion timing from early morning to late afternoon on 27 April 2018 (iPhone and Safari web browser).

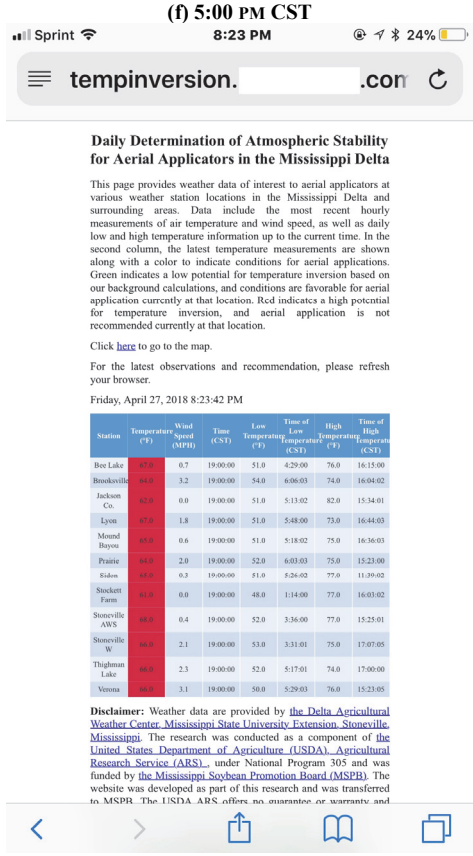
(e) 4:00 PM CST



(f) 5:00 PM CST



(g) 6:00 PM CST



(h) 7:00 PM CST

Figure 5 (con't). Web pages of daily temperature inversion timing from early morning to late afternoon on 27 April 2018 (iPhone and Safari web browser).

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