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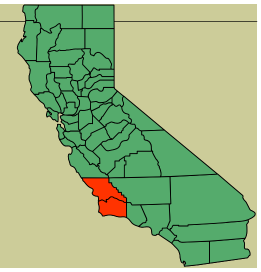
University of California Cooperative Extension

Grape Notes

San Luis Obispo & Santa Barbara Counties



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Improved information on temperature inversion conditions helps guide frost protection decisions

This project demonstrates the benefits of measuring springtime temperature inversion conditions on a farm scale, particularly with respect to assessing the potential of wind machines for frost protection. Current technology now makes it practical to assess inversion conditions in such detail.

Background

Without adequate frost protection measures, the production of frost-sensitive crops such as winegrapes would not be economically viable in many parts of California. Frost protection measures include passive practices such as appropriate site selection and vineyard floor management, and active measures such as wind machines, sprinklers or heaters. Sprinklers, while having proven efficacy, may not be possible in all areas due to limitations of local water supplies, while air pollution regulations and high fuel and labor costs may limit the use of fuel-burning heaters. For these reasons, there may be increasing interest in the potential of wind machines for frost protection in California and elsewhere.

The ability of wind machines to provide adequate frost protection depends upon having temperature inversions of sufficient strength such that crop temperatures can be maintained above their critical levels (Gerber 1979). Temperature inversions often form at night under conditions of clear skies and very low winds; the earth surface radiates heat rapidly towards outer space in the form of long-wave radiation, cooling the air adjacent to the surface. Because still air is a poor conductor of heat, in the absence of mixing by winds the cooler air forms a stratified layer near the ground surface. This cooler air, being denser than the warmer air above the surface, tends to flow downslope and accumulates in the lowest areas of the landscape (Shaw 2002). The likelihood and strength of inversion conditions are not always apparent by evaluating regional topography, and surface measurements of common meteorological variables often provide only limited insight into the inversion conditions (Doesken et al. 1988). Therefore, growers who are considering investing in wind machines for frost protection should ideally collect detailed information about their local inversion conditions *beforehand* in order to make the most informed decision possible (Evans 2000).

However, measuring inversion conditions has often been a challenge in itself. Past assessments of temperature inversions in vineyard and orchard regions have used a variety of techniques based on the measurement technology and resources available at the time. Due to the high cost of equipment and difficulty in erecting tall meteorological towers, measurements have usually been taken at a single location with the results being extrapolated over a broader region, generally with little understanding of the variability of the inversion conditions throughout the region (Schultz 1961; Bates 1972; Bates and Lombard 1978; Doesken et al. 1988; Shaw 2002). Having more detailed measurements on a farm scale could significantly improve the information available to a grower for determining the potential usefulness of wind machines at their specific location.

The goals of this project were to evaluate the strength and variability of the temperature inversion conditions on a farm scale using high-density measurements, and to characterize the suitability of the conditions for providing springtime frost protection with wind machines. The ultimate goal of this work is to demonstrate the usefulness that such detailed measurements can have for helping growers make the most informed frost-protection decisions possible, and in particular ensure that any investments in wind machines provide a predictable benefit.

Temperature measurements

Measurements were made in the spring of 2011 at two locations on the Central Coast; spring frosts are common concerns for both sites. One location was a future vineyard site in San Luis Obispo County, located several miles southwest of Paso Robles, while the second was an existing vineyard site with adjacent undeveloped property near Cuyama in Santa Barbara County. The Paso Robles site was fairly representative of much of that winegrape region, with rolling hills and sparse native oak trees. The property was formerly a dryfarmed grain field which had been cultivated in the fall of 2010 in preparation for future vineyard planting. Vegetation on the property during the study period consisted of a sparse mixture of volunteer barley, annual grasses, and various weed species. The Cuyama site included measurements within the established mature vineyard and as well as the adjacent unplanted acreage with sparse vegetation.

At the Paso Robles site, eleven 35 ft. tall meteorological towers were installed throughout the lowest areas of the property, similar to where wind machines could potentially be installed (Fig. 1). The towers were large flexible masts made of fiberglass and aluminum sourced from a local hardware store, and resembled tall fishing poles. The towers were approximately 400-500 ft. apart from each other along the lowest elevations. On each tower precision temperature dataloggers were installed at heights of 5 ft. and 35 ft., and recorded temperatures every 5 minutes. At the Cuyama site, five similar towers were installed, with three in the existing vineyard and two in the adjacent undeveloped area (Fig. 2). Temperatures were measured from late March through May 2011 at both sites.

Assessment of the temperature conditions

The 2011 spring frost season on the Central Coast was the most severe of the past 30 years, causing extensive damage to area vineyards (Battany 2011). In particular, the frost events on the early mornings of April 8 and 9 were characterized by extended periods of sub-freezing temperatures which led to large crop losses. As such, the season studied in this project represents the temperature conditions under some of the most severe circumstances likely to ever affect the area.

Past research has shown that a conventional-style wind machine can be expected to raise the temperature at the 5 ft. level by about 50% of the difference in temperature between the 5 ft. and 35 ft. heights (Ribeiro et al. 2006). For example, if the 35 ft. temperature was 4 °F warmer than the 5 ft. temperature, the operation of a conventional wind machine would be expected to raise the temperature at 5 ft. by about 2 °F. From this relationship, we can define a "useful" temperature inversion strength as a difference in temperature of about 2 °F or more measured between the 5 ft. and 35 ft. heights. If the inversion strength is less than 2 °F, then this can be considered "non-useful" as crop level temperatures would be raised by

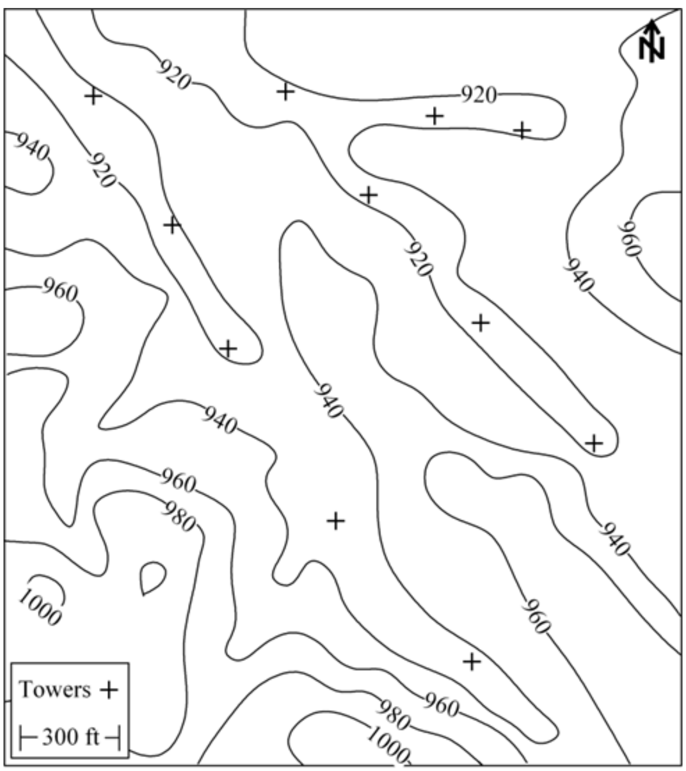


Figure 1. Topographic map of the Paso Robles study site. The eleven meteorological towers are indicated by (+).

Figure 2. The author installing one of the 35 ft. meteorological towers at the Cuyama site.

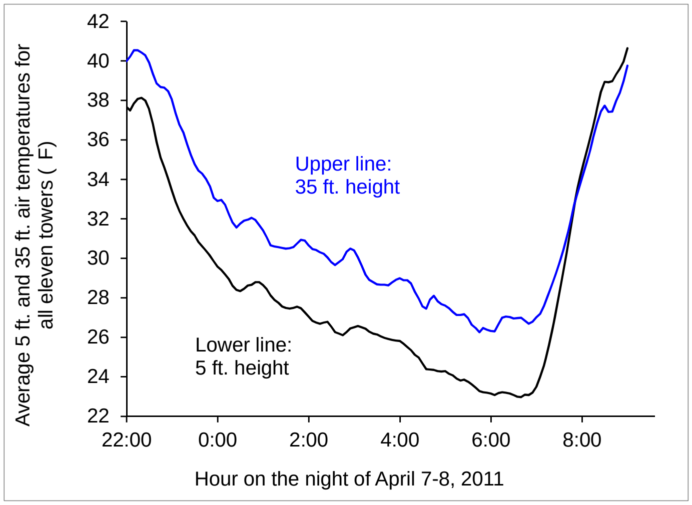


Figure 3. Average temperatures of all 11 towers at the 5 ft. and 35 ft. height through the night of April 7-8, 2011 at the Paso Robles site. If a conventional-style wind machine was operating under these conditions, the 5 ft. temperature would have been expected to be raised about halfway between the two drawn lines.

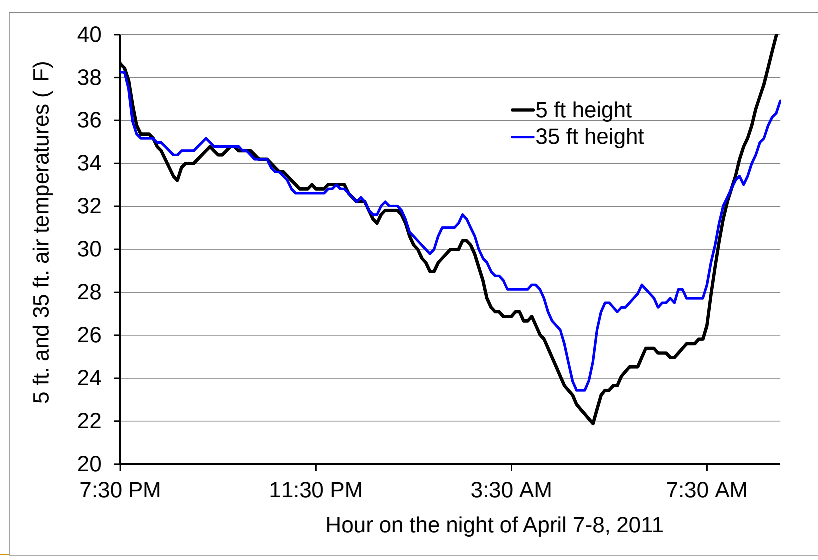
less than 1 °F. The stronger the inversion strength, the greater the potential warming that can be achieved, and hence the importance of measuring local inversions.

Ten frost events were recorded at the Paso Robles site during the spring 2011 measurements. Useful inversion conditions existed throughout the night of the coldest frost event on April 8, but the air temperature had dropped so low that the warming that would have been expected by the operation of wind machines would still have been insufficient to prevent crop damage (Fig. 3). Brief periods of non-useful inversions did occur on several frost nights of April 8, 9, 10, and 30. These periods were generally very short with the exception of the night of April 9, when the longest periods of non-useful inversions occurred. With the exception of the coldest frosts on the nights of April 8 and 9, the temperature inversion conditions on the remaining frost nights at the Paso Robles site would have enabled wind machines to provide sufficient warming at the crop to have prevented or significantly reduced crop damage.

Nine frost events were recorded at the Cuyama site. The April 8 and April 9 frosts both had the very weak inversions which are generally characteristic of advective frost events; indeed much of the damage observed in that county was consistent with an advective frost event. Figure 4 below shows the temperatures for a single Cuyama tower through the night of April 7-8, which was the coldest frost event at this location. Throughout much of this night the inversion strength was non-existent or very weak, likely a consequence of cold breezy conditions early in the night. During the last hours of the night stronger inversions finally began to form. The frost event on April 9 was also characterized by extended periods of non-useful inversion conditions at this site. The remaining frost events had useful inversions and minimum temperatures within the range that wind machines would have provided significant protection.

The fine spatial coverage of the measurements at the Paso Robles site gives us a very comprehensive picture of how crop-level air temperature and temperature inversion conditions varied throughout the study area during frost events. The temperature inversion conditions during the hour before sunrise, generally the coldest hour of the night under radiation frost conditions, indicates a range of values for the 11 tower locations on the severe frost morning of April 8. These values are shown over an area representing the primary coverage zones of wind machines in Figure 5. These inversion patterns do not necessarily correlate to the topographic elevations, which indicates the influence that the larger surrounding landscape can have on

Figure 4. The temperatures for one tower at the Cuyama site through the night of April 7-8, 2011. Temperature inversions were non-existent between 7:30 pm on April 7 and 1:30 am April 8, likely a consequence of windy advective frost conditions during this period.



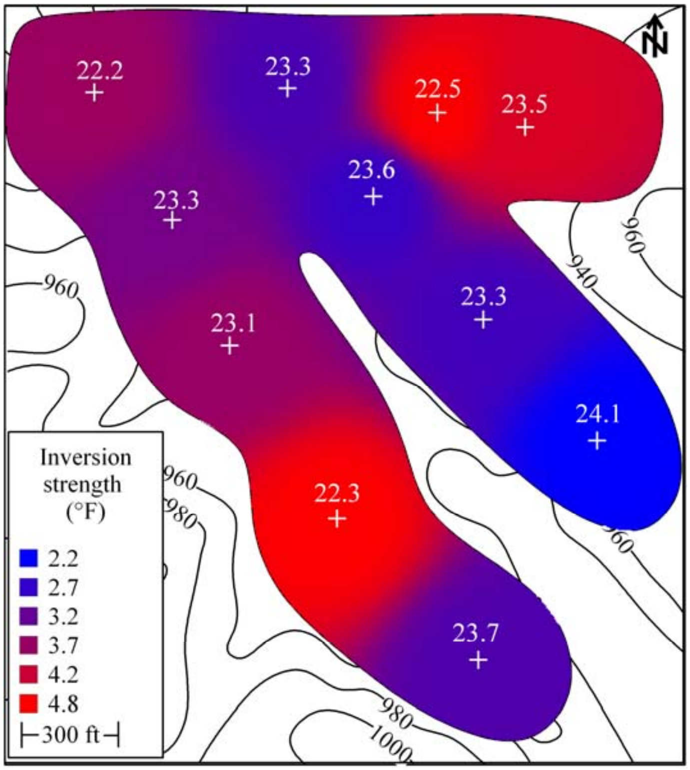


Figure 5. The average inversion strength during the hour before sunrise for the severe frost event of April 8, 2011 at the Paso Robles site. Tower locations are indicated by (+). The shaded area represents the primary coverage area for wind machines. The average 5 ft. temperature value during the hour before sunrise is indicated directly above each corresponding tower marker.

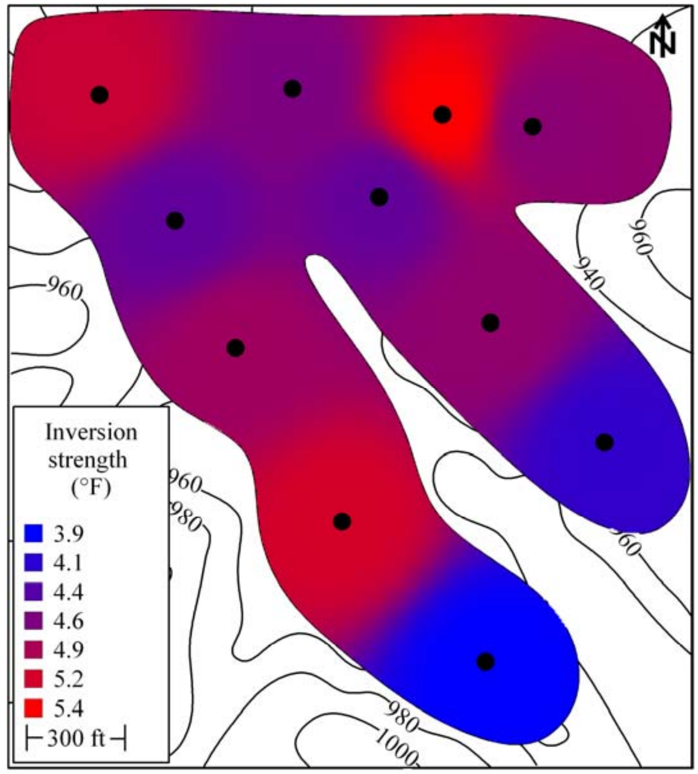


Figure 6. The average inversion strength between the 5 ft. and 35 ft. heights during the hour before sunrise for all ten frost events at the Paso Robles site.

the movement of cold air. The average values of the 5 ft. air temperature during the hour before sunrise on this same morning are also indicated on the map for each tower location. The average inversion strength for all ten frost events, again measured during the hour before sunrise, shows a fairly similar pattern when mapped over the same area (Fig. 6).

During all frost events at the Paso Robles site, the locations with the coldest 5 ft. temperatures consistently had the strongest inversion conditions. This relationship is indicated in Figure 7. For each frost event, the values of the 5 ft. temperature and the inversion strength are plotting for all 11 towers, and a regression line was fitted to each data set. The slopes of these regression lines indicate that colder locations consistently had stronger inversions, and that this pattern was observed for all frost events. Only six of the ten frost events are shown in Figure 7 for clarity, but the relationship was similar for all ten events. Knowing that there is a strong degree of consistency for these temperature characteristics over time is useful from a practical standpoint. If these relationships are developed over a single season by taking very detailed and comprehensive

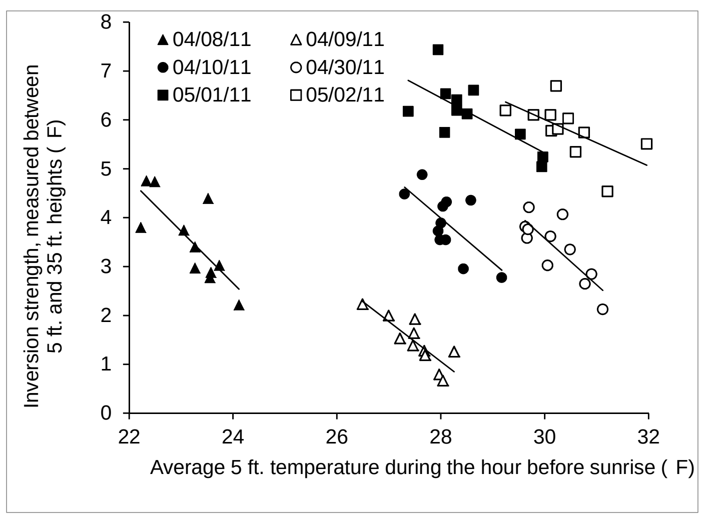


Figure 7. Relationship between the 5 ft. temperature and the inversion strength during the hour before sunrise at the Paso Robles study site. Values for all eleven towers are plotted individually for each frost event, and a linear regression line is fitted to each set. Only six of the ten frost events are shown for clarity, but the patterns for all ten events were similar. The coldest areas of the study site consistently had the strongest inversion conditions.

readings as was done in this study, the resulting patterns can likely be expected to remain fairly constant into the future provided that the general landscape conditions that control the flow of cold air remain unchanged. If intentional or unintentional changes are made to these landscape conditions, such as adding or removing a hedgerow or other airflow barrier, their impact on inversion conditions could be assessed by this type of monitoring before and after such changes occur.

The type of chart used in Figure 7 also provides a very simple way to graphically depict the conditions under which wind machines will be effective, based on measurements of the temperatures at 5 ft. and 35 ft. heights. Figure 8 below shows the theoretical crop temperatures attained under wind machine operation, as a function of the 5 ft. air temperature and inversion strength. For example, with a 5 ft. air temperature of 26 °F, an inversion strength of 6 °F will be needed in order for a wind machine to raise the crop temperature up to 29°F. As the 5 ft. air temperature decreases, a correspondingly larger inversion strength is required in order for a wind machine to maintain the desired crop temperature.

If these same crop temperature lines are drawn onto Figure 7, this would then provide a concise picture of how the temperature conditions would have affected wind machine frost protection throughout the spring period. Figure 9 shows these two combined, again with data from six of the ten frost events displayed. Because the April 8 points lie far to the left of the crop temperature lines, this indicates that wind machine operation would not have been able to raise the crop temperatures anywhere close to those target values. The April 9 points are marginal, while the points for the remaining frost events (as well as the four similar events which are not shown on this chart) were all within temperature ranges where wind machines would have provided adequate protection.

The temperature values in Figures 7 and 9 were calculated using the averages of the hour before sunrise, which under typical radiation frost conditions is the coldest period of the night. One can also use the same type of chart and look at how the temperature conditions evolved throughout the entire frost night, and thus estimate what the crop temperatures would have in theory been if wind machines had been operating during the night. This was done using the values of all 11 Paso Robles towers on the night of April 7-8 (the same data and time frame as in Fig. 3). Figure 10 on the following page shows how these conditions varied throughout the night; the black line indicates the 5 ft. air temperature and inversion conditions, measured at 5-minute intervals throughout the night. The blue crop temperature lines indicate the predicted crop temperatures if wind machines were operating. For example, at 4:00 am the crop temperature would have been expected to be between 27 °F and 28 °F under those conditions if a wind machine was operating, while the 5 ft. air temperature was itself just under 26 °F at that same time.

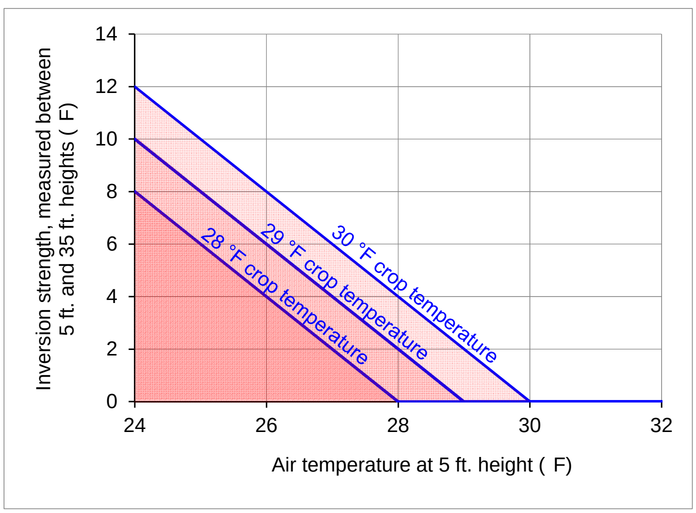


Figure 8. Theoretical crop temperatures attained through wind machine operation, as a function of the 5 ft. air temperature and the inversion strength. This assumes that the wind machine will raise the 5 ft. air temperature by 50% of the inversion strength as measured between 5 ft. and 35 ft. heights. Combinations in the shaded zone would not see the crop temperature raised up to the corresponding crop temperature of interest.

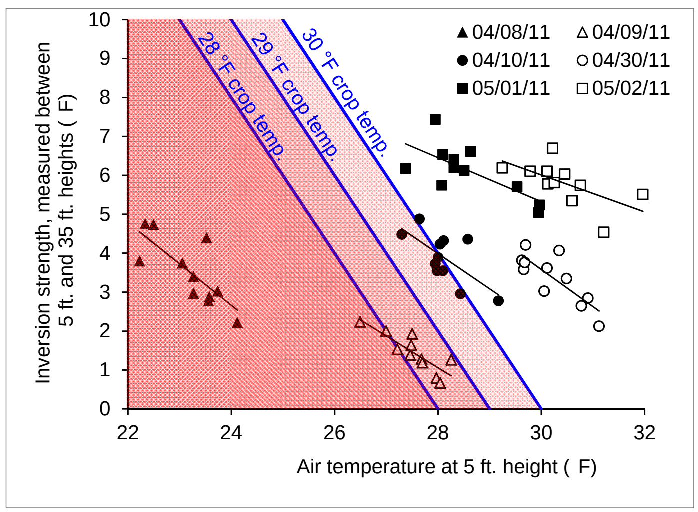
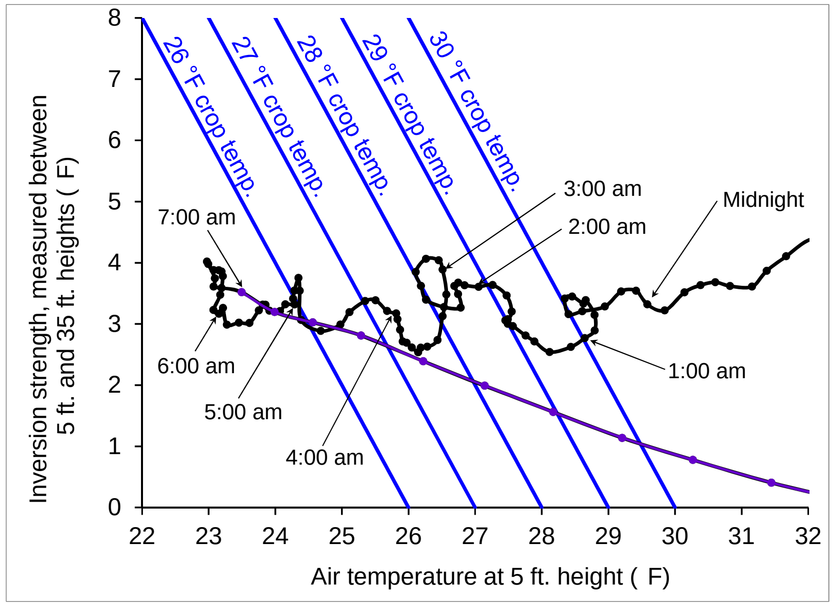


Figure 9. Average 5 ft. air temperature and inversion strength values during the hour before sunrise, overlaid with the diagram showing theoretical crop temperatures attained with wind machine operation. Temperature values are from the Paso Robles site in 2011, showing six of the ten frost events.

Figure 10. The crop-level air temperature and inversion strength throughout the night of April 7-8 at the Paso Robles site. The temperatures are the average values for all 11 towers. As the night progressed, the plotted values gradually fell lower with respect to the crop temperatures which would theoretically be attained if wind machines had been operating (indicated with the blue lines). The temperatures after sunrise are indicated with the purple color line.



Aiding frost protection decisions

This type of evaluation demonstrates the usefulness and importance of having detailed information about the temperature inversion conditions. The typical crop-level temperatures which are routinely measured only tell half of the story. The method demonstrated in this study can have significant practical benefits for assessing the potential suitability of wind machines for frost protection in a given location. These measurements can be accomplished at relatively low cost, and provide a great deal of insight into conditions which heretofore have been largely unknown. Critical planning decisions for frost protection may often need to be made with data gathered over short periods; the consistent spatial patterns of inversion strengths demonstrated in this study suggest that even such short-term measurements are still useful for site characterization. Indeed it may prove useful to map the temperature inversion characteristics as a routine part of vineyard site development, much in the same way that soils are mapped. For the purposes of estimating frost probabilities for a given location, longer term measurements will be required.

Conducting this type of detailed temperature inversion assessment will help ensure that the frost protection method chosen for a given location will provide a predictable level of protection. Given the high value of the winegrape crops at risk and the high costs associated with all active frost protection measures, the potential return on investment for measuring this type of detailed temperature information may be substantial.

Upcoming regional inversion assessment

The author will be working with Rhonda Smith (UCCE Viticulture Farm Advisor, Sonoma County) and Richard Snyder (UCCE Biometeorolgy Specialist) to conduct a three-year survey of springtime temperature inversion conditions throughout the vineyard regions of San Luis Obispo, Santa Barbara, and Sonoma Counties beginning in the spring of 2012. It is expected that the results of this large-scale regional study will significantly improve the information available to the grape industry with regards to inversion conditions and the suitability of wind machines for frost protection in these areas. This upcoming work is being supported by grants from the American Vineyard Foundation and the CDFA Specialty Crops Block Grant program.

References - see next page

Acknowledgements

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Making a Difference for California

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Upcoming UC Davis Central Coast Winegrape Grower Survey

The UC Davis Central Coast Winegrape Grower Survey will be mailed to Central Coast winegrape growers during winter of 2012.

The survey will ask for growers' perspectives on vineyard management practices, regional and state outreach and education programs, and information resources.

The survey is funded by the National Science Foundation and was designed by UC Davis researchers, California winegrape growers, and grower organization leaders.

The information collected by this survey will be used by UC Davis and viticulture organizations to better serve the needs of winegrape growers.

Thank you in advance for completing the survey, and for helping shape the future of California's viticulture and wine industry.

Your opinion is important **Your answers are anonymous**

If you have any questions please contact the project director:
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