7.1 TERRAIN AND AMBIENT WIND EFFECTS ON THE WARMING FOOTPRINT OF A WIND MACHINE

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1. INTRODUCTION

Frost can cause significant damage to plants that translates into losses in agricultural production. Freeze events in 1983 and 1985 cost the Florida citrus industry an estimated $2 billion (Kalma et al. 1992). Growers go to considerable expense to prevent frost damage to their crops. Wind machines are a popular form of active frost protection that consist of a 4 m diameter propeller blade mounted on top of a ~10 m mast. When activated the blade rotates at a high rate of speed to produce a jet of air that mixes warm air from aloft to the surface, warming the air surrounding the vegetation by several degrees under most circumstances. The assembly rotates around the mast axis to provide the greatest area of protection. The area warmed by the wind machine (the warming footprint) is affected by the ambient wind direction and the terrain surrounding the wind machine.

In this paper, we present data for horizontal and vertical temperature distribution in the nocturnal boundary layer for a region surrounding a wind machine located in a Columbia Basin vineyard. Previous studies have investigated the warming footprint of wind machines. Our goal is to better quantify and describe the horizontal temperature distribution using a network of temperature sensors in order to determine effects of terrain as well as ambient wind on the warming footprint.

2. EXPERIMENTAL DETAILS

The experiment was conducted on the night of 7-8 August 2001 at the Monson Ranches vineyard, located approximately 5 km southwest of Richland, WA. The wind machine was manufactured by Orchard-Rite Ltd. and was powered by a 454 Chevrolet engine using propane for fuel. The blades rotated about a quasi-horizontal axis that was tilted 6º downward. The hub height was 10 m. The spinning blades on the near-horizontal axis also rotated about the vertical axis at the rate of one revolution every 4 minutes.

2.1 *Site characteristics*

The Monson Ranches vineyard is situated on an elevated plateau with significantly lower-lying topography to the north and south. To the north, water drains toward West Richland and the Yakima River. To the south, water drains into Badger Canyon. The vineyard lies on gently rolling terrain, which is intersected by several gullies that drain to the north and south. The wind machine selected for study was located in a flatter area of the vineyard, but the land still sloped gently (1-2°) to the south. The vines themselves were aligned in rows 8 ft apart running north-south and were about 1.8 m tall. The vines were mature with fully developed foliage, which was densest between 1 and 1.5 m above ground.

2.2 *Instrumentation*

Temperatures at the canopy height were recorded by a set of approximately 40 small temperature data loggers (Hobos®, Onset Computer Inc., Bourne, Massachusetts, USA), which were fitted with radiation shields (RM Young, Traverse City, Michigan, USA). Vertical temperature and wind profiles were acquired with a Tethered Meteorological Tower® (TMT, Vaisala Inc., Boulder, Colorado, USA). The TMT was a helium filled balloon which supported a line carrying four meteorological sondes that transmitted data continuously to a ground-based radio receiver. Six RM Young weather stations recorded wind speed, wind direction, temperature and relative humidity near the ground. A 2-D sonic anemometer (Handar 625, Vaisala Inc., Boulder, Colorado, USA) was used to measure wind speed and direction nearer to the ground at a faster rate than the other wind sensors used in the experiment.

3. RESULTS

Ambient wind conditions allowed for two periods of wind machine activation. During these times the wind machine produced warming at canopy height of up to 5 C depending on distance from the wind machine. In general, warming was limited to a radius of about 150 m from the wind machine. In some cases, however, areas downwind or down-slope up to 200 m away from the machine were still warmed by 1-2 ºC. Before wind machine operation, an inversion of approximately 3.5 ºC between 12 m (wind machine hub height) and 3 m was recorded.

Data from the network of HOBO temperature sensors were interpolated by computer to create a series of horizontal temperature maps for the entire evening at 30 s intervals. Two examples of the maps are represented in figures 1a and 2a. The two plots indicate examples of horizontal temperature distribution under different ambient wind conditions during the night. Figure 1 presents a low ambient wind speed case in

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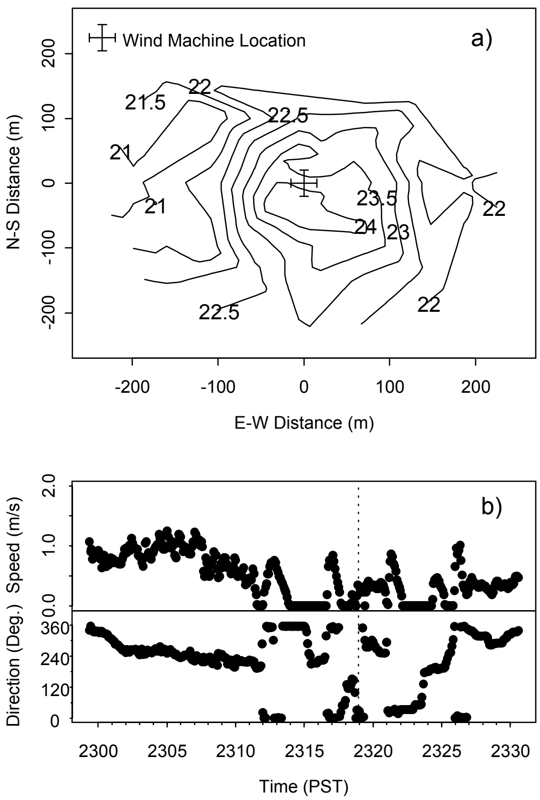

Figure 1. a) Isotherms surrounding the wind machine at approximately 2320 PST 7 August 2001. b) Wind data from a location 210 m south of the wind machine. The time of the temperature map in a) is indicated by the dotted vertical line.

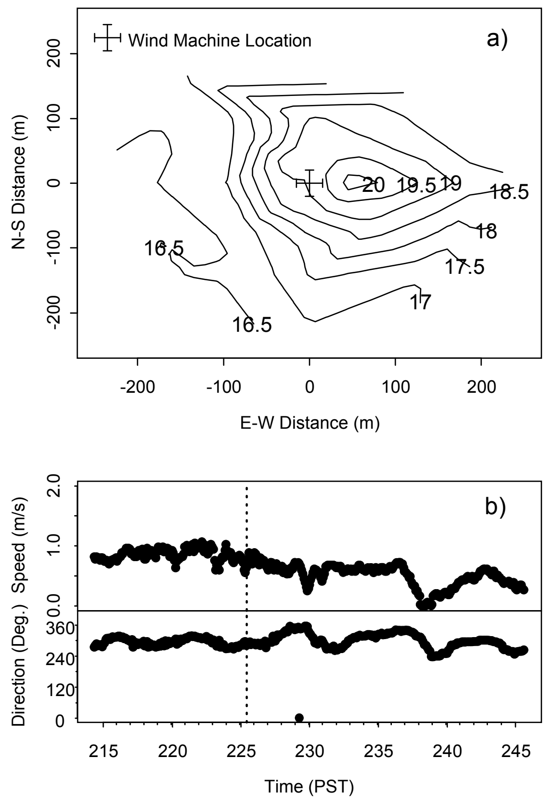

Figure 2. Same as Fig. 1, but for 225 PST 8 August 2001.

which drainage of the air appears to be the dominant process controlling the warming footprint orientation. In this case, the absence of a significant ambient wind allowed the air to drain south from the wind machine towards Badger Canyon. The inverted v's evident in the wind speed plot are gusts of wind associated with the passage of a jet of air from the wind machine. Figure 2 represents a case where a light ambient wind with a westerly component shifted the warm air footprint eastward. Inverted v's do not appear in the 0225 case because they are washed out by the background wind.

4. DISCUSSION AND CONCLUSIONS

It should be noted that this study did not occur during conditions associated with frost events. We assume that the temperature increase and warming pattern we observe when the wind machine is operated during a clear summer night is analogous to that for a clear cooler night. The wind machine's warming power is dependent on inversion strength, not the absolute temperature, so we can expect a similar amount of warming for conditions with similar inversion strengths. Radiative cooling rates should be roughly equivalent given the same wind and cloud conditions regardless of the temperature.

To date, most studies of the frost protection effectiveness of wind machines have taken place in orchards located in Florida and California. In these cases flat terrain and a rough canopy may have prevented or lessened the impact of terrain induced flows. In planning the usage of wind machines in vineyards, which frequently lie on complex terrain and have a smoother canopy than that of an orchard, the effects of slope flows on the warming footprint should be carefully considered.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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