Joint study of spatial variability of temperatures and wind machine performance in the Quincy vineyard to improve fight against spring frost events

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JOINT STUDY OF SPATIAL VARIABILITY OF TEMPERATURES AND WIND MACHINE PERFORMANCE IN THE QUINCY VINEYARD TO IMPROVE FIGHT AGAINST SPRING FROST EVENTS

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Résumé : *Les gelées printanières survenant après le débourrement des bourgeons sont particulièrement dévastatrices et conduisent pour les vignerons à une perte économique importante. Les tours antigel sont un des moyens existants permettant de lutter contre ces gelées. Cependant, l'efficacité d'un parc de tours dépend de leur positionnement, déterminé par les performances de la tour et de la variabilité spatiale de la température durant ces évènements gélifs. L'objectif de cette étude est de caractériser les performances des tours antigel et la variabilité de la température, permettant ainsi de proposer une méthodologie pour un positionnement a priori des tours antigel dans le vignoble de Quincy. Afin de faire face à cet enjeu, la CUMA du vignoble de Quincy s'est associée avec différents partenaires afin de former le projet SICTAG (« Système Innovant d'aide à la décision Connecté et de gestion efficiente en temps réel des Tours Antigel du Centre-Val de Loire »).*

Mots-clés : *gel ; tour antigel ; vignoble de Quincy ; gelées printanières*

Abstract: *Spring frosts occurring after budburst constitute a significant risk for winegrowers and can lead to severe yield losses. Wind machines can contribute to protecting vineyards against these frost events. However, the efficiency of wind machine parks depends on the locations of wind machines concerning their performance and spatial variability of temperature during these frost events. This study aims to characterize wind machine performance and spatial variability of temperature, and propose a methodology for an a priori positioning wind machines on the vineyard of Quincy. To face this stake, the CUMA of Quincy vineyard came up with several partners in the SICTAG project ("Innovant System of Connected decision support and efficient real-time management of wind machine of the Centre Val de Loire").*

Keywords: *frost; wind machine; vineyard of Quincy; spring frosts*

1 Introduction

Frosts can be distinguished as advective frosts and radiative frosts. Radiative frosts are characterized by clear skies and very low winds, which results in energy loss near the ground. Consequently, in the low part of the atmosphere (from a few meters to several hundreds of meters above the ground), this radiative loss produces a thermal inversion meaning the highest altitudes get the highest temperatures. Although no adequate solution exists to fight the advective frost, many solutions appeared to fight radiative frost occurrences. Some are passive solutions like soil management, while others are active solutions like wind machines (WM) on which this paper focuses (Kalma *et al.*, 1992).

A wind machine is commonly composed of a 10m-mast and a 2-blade-hub blowing fan at its peak. The wind machine turns on itself for 4-5min. The use of the wind machine, illustrated in figure 1, is conditioned by the state of the atmosphere (Kalma *et al.*, 1992; Snyder and Melo-Abreu, 2005). Indeed, it is remarkably efficient with a thermal inversion of about 1.5°C and 2°C between 1.5m and 15m high (Kalma *et al.*, 1992) and for a weak wind. The blowing fan sweeps the crop by blending quickly warm air above with the cold air (of few degrees below 0) near the ground. Hence the thermal stratification is suppressed. The air temperature is slightly positive and homogeneous and the frost injury is momentarily avoided. Multiple wind machines can also work together to fight the frost by covering a more expanded area and using a synergy effect to enhance efficiency (Snyder and Melo-Abreu, 2005). Some previous studies showed the positive effect of wind machine use in an orchard by leading field measurements and also tries characterizing the airflow pattern. While there is no need to start wind machines long in advance to observe a benefit, (Ribeiro *et al.*, 2006), the thermal effect can be felt until an average of 100m also depending on the natural drift (Beyá-Marshall *et al.*, 2019; Ribeiro *et al.*, 2006). Indeed, the natural drift tends to extend the range of the current in the wind direction and shorten it perpendicularly and oppositely (Beyá-Marshall *et al.*, 2019; Ribeiro *et al.*, 2006). Both studies noted the capacity of wind machines to increase the temperature in height and distance and observed slight differences in the magnitude of this gain depending on the inversion strength (Beyá-Marshall *et al.*, 2019; Ribeiro *et al.*, 2006). The utility of wind machines is then conditioned by a climatological assessment where minimum temperature and inversion strength are cornerstones (Doesken and McKee, 1988). At the vineyard scale, one can observe a spatial variability of the temperature, depending on the meteorological situation and the topography of the crop, thus influencing the efficiency of wind machines. In the Quincy vineyard, nearly 60 wind machines are disseminated offering protection against spring frost for 85% of the crop. However, their efficiency is acceptable but not noteworthy enough. Hence wine-growers gathered different kinds of partners such as industrials, and scientific researchers in the SICTAG[1] project to investigate how the wind machine warms the crops and the most efficient way to use it.

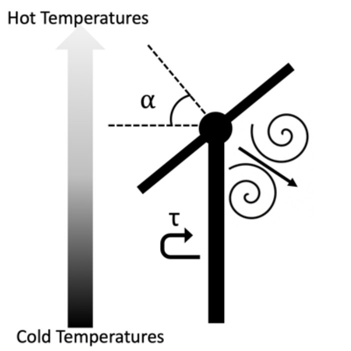

Figure 1: Schematic of the operation of the wind machine. τ is the rotation time and α is the rotor tilt angle. Adapted from (Heusinkveld *et al.*, 2020)

The present study aims to describe the temperature spatial variability during radiative frost across the Quincy vineyard and to characterize the wind machine temperature effect and jet stream through field measurements analysis. It is a preliminary part of the wind machine location improvement across the Quincy vineyard. In section 2 we present an overview of the site and methods. The results are shown and analyzed in section 3. Finally, we draw some conclusions and perspectives in section 4.

2 Site and Methods

The study was conducted in the Quincy vineyard located in the Centre Loire region, in the middle of France covering a delimited zone of 700Ha. The soil type is sandy, gravelly soil settled in old alluvial earthworks, perched on riparian limestone hillsides. Vine stocks are planted with a spacing of 1m to 1.15m between plants and 1.5m between rows. The vineyard of Quincy is relatively flat. Indeed, its slope varies between 0° and 6° with a majority of values between 0° and 3°.

[1]Innovant System of Connected decision support and efficient real-time management of wind machine of the Centre Val de Loire

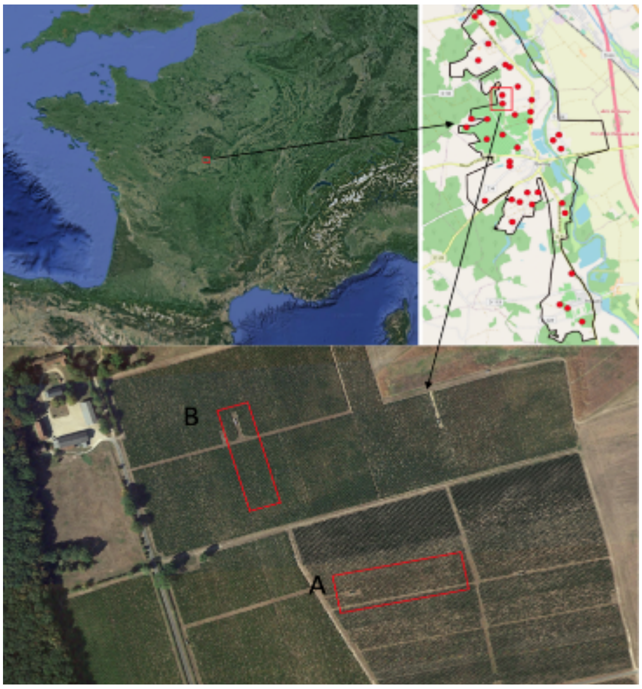

Figure 2: Location of the Quincy vineyard in France. The border of the vineyard is delimited by black lines. Temperature sensors are represented by red dots. Finally, field experiments were conducted in one single plot, at two different locations and using two different wind machines.

2.1 *Spatial variability of temperature*

Each plot of the vineyard includes a temperature sensor from the "Weenat" company. The number of sensors is 38 and are spread in the whole vineyard to measure hourly temperature day after day. The entirety of the sensors is in use since December 2019. The locations of these sensors are shown below in figure 2, represented by red dots.

The study focuses on three different scales, as it is tried to establish a connection between them. Different kinds of data are available at several scales:

- Synoptic data corresponds to meteorologic data at a large scale such as low-pressure and high-pressure areas. Also, meteorologic regional variables are considered.
- Topographic data described by Digital Elevation Model (DEM) contains geographic data like elevation, slope, or exposure. DEM used in this study is 5m accurate.
- Lastly, micro-scale data represent the temperature across the vineyard of Quincy. By retrieving the hourly temperatures of the Weenat remote sensors, the daily minimum temperature can be extracted, which is defined as the minimum temperature measurement between 6 pm the day before and 6 pm the same day. The dry temperature is considered in this study due to the lack of trust in the wet temperature.

At different scales, Hierarchical Clustering (HC) is used to group individuals according to observed variables (temperatures, topographic data, meteorologic data) to visualize similar days and plots (Bonnefoy, 2013; Madelin, 2005).

2.2 *Wind machine performance*

The field measurements were conducted on two different wind machines, in a flat zone of the vineyard where the slope is quasi-inexistent. The first experiment conducted on site A (called experiment A) in figure 2 used a Mecagri wind machine. The double-blade span is 5.4m meters moving at 590rpm and the mast is 10.5 meters high. The hub is tilted with an angle of approximately 7° to the ground. The wind machine turns on itself for 4min30s. The second experiment (experiment B) was conducted on site B using an Orchard Rite wind machine providing a double-bladed fan of 6.04m diameter with a mast of 10.7m high and the same rotation specifications as the Mecagri wind machine. For both experiments, the air temperature was measured using T-type thermocouples. Wind speed and direction were measured using sonic anemometers (LCJ, Vertou, France). Data were collected using two CR310 data loggers for experiment A and one CR1000X data logger for experiment B (Campbell Scientific Inc., Logan, UT, USA). The measuring frequency was 2Hz during experiment A and 4Hz during experiment B.

3 Results

3.1 *Spatial variability of temperatures*

During March and April 2020, the vineyard faced several frost events. The statistical study focuses on this period, divided into three distinct cycles : from 24/03 to 29/03 first frost event ; from 29/03 to 31/03 no frost ; from 31/03 to 05/04 2nd frost event. In Table 1, groups are presented following their meteorological characteristics. Besides, average tendencies of anticyclones (H) and depressions (L) positions are detailed. With this quick analysis, we can conclude what type of frost one could face depending on anticyclones and depressions positions and on the meteorological variables observed by regional captors.

Table 1 Characteristics of meteorological situations observed on each group of the classification

	Group 1	Group 2	Group 3	Group 4
Group's characteristics	Clear sky, low humidity, weak wind, high pressure	Cloudy sky, very low humidity, strong wind, low pressure	Cloudy sky, very low wind, high humidity, low pressures	Cloudy sky, very strong wind, very high humidity, very high pressure
Type of frost	Radiative frost	Advective frost	Weak radiative frost	No frost
Mean minimal temperature	-1.86°C	-1.56°C	-0.86°C	3.36°C
Position of H and L	H in Eastern Europe. L in Scandinavia	Depression near France	No tendency	H in the North. L in Eastern Europe

Through those results, it has been observed that different kinds of frost occurred in the vineyard during the studied period. However, wind machines are only efficient in fighting radiative frost. Hence, a clustering method following the minimum temperatures was applied on days from the previously established radiative frost cluster. Moreover, several classifications were applied to topographic data. Matching classes from minimal temperatures and topographic parameters clusters enabled determining prevailing topographic parameters in the spatial variability of temperatures. It appears that topographic parameters governing temperature variability are mainly altitude and slope. Indeed, during radiative frost, high altitudes recorded higher temperatures (83,33% of the highest minimum temperature class from the temperature cluster are made up of the low altitudes class from the topographic cluster). In contrast, low altitudes provide low temperatures (50% of the lowest minimum temperature class). This statement is in line with the fact that radiative frost occurs mainly at low altitudes. As cold air is denser than ambient air, it flows slowly downward along the slope and accumulates in the bottom areas, hence creating lakes of cold air. It explains the strong spatial variability of minimum temperatures generated by the topography. Besides, high rates of slope do not enhance any extreme range of the temperature. Indeed, low slopes recorded the lowest temperatures (60% of the lowest minimum temperatures class are made up of the lowest slopes class from the topographic cluster). On the contrary, neither high nor low temperatures are ever measured on plots where the slope is significant. Therefore, while the slope has a role to play, altitude remains the primary topographic parameter to take into account to explain temperature spreading.

3.2 *Wind machine performance*

By leading some field measurements, it has been possible to verify the benefit of wind machines on crops. Field measurements were carried out during winter 2020. Even if experiments were not conducted at night time during a frost occurrence, some wind machine effects had been caught.

The first experiment (experiment A) allows characterizing the impact of a WM on its environment by evaluating the covered area and the level of intensity. Two masts (1.5m high) were placed in front of the Mecagri WM. One stayed at 40m, the other one was mobile and moved every 4m at each revolution of the WM, covering distances from 12m to 96m from the WM. For each mast, the air temperature was measured at 0.1m, 0.5m, and 1.5m high, while wind speed and direction were measured at 1.5m high.

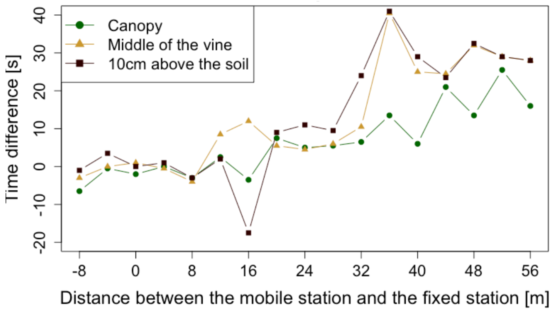

Figure 3: Evolution of the 3 maximum temperature time differences between the mobile and fixed stations for each revolution of the WM, according to the relative position of the mobile and fixed station (fixed station at 40m from the WM)

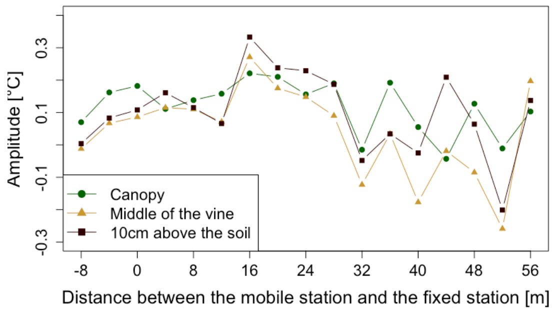

Figure 4: Evolution of the 3 maximum temperature amplitudes between the mobile and fixed stations for each revolution of the WM, according to the relative position of the mobile and fixed station (fixed station at 40m from the WM)

Figure 3 shows that for each measurement height, the longer the distance was from the WM, the longer the delay was to measure a temperature spike and catch the flow of the wind machine. This result suggests a spiral shape of the jet due to the rotation of the WM. In figure 4, one can see that the first half portion of the line increases while the second part decreases. It seems that until 24m backward the fixed station, the heat gain was slightly higher, whereas from 24m to 56m backward, the wind machine effect decreased. One can assume that the wind machine did not deserve the plots equally. Those first experiments aimed to study the operation of the WM and were not conducted during a frost event. This can be a plausible explanation for the temperature amplitude being low. Thus, the amplitude would probably be more significant during a frost event with a thermal inversion.

The second experiment (experiment B) was conducted when temperatures did not drop below 4°C. It was similar to the previous one, aiming to characterize the impact of a wind machine on its environment but on higher altitudes. A 10m high mast was moved in front of the Orchard Rite WM, measuring wind and temperatures at 100, 80, 60, and 30m from it. The air temperature was measured at 0.1m, 0.5m, 1.5m, 2m, 3.40m, 4.90m, 6.30m, 7.70m, 9.10m, 9.85m, 10.5m high. Wind speed and direction were measured at 2m, 5m, 7m, and 10m high. This experiment allowed figuring out that the mixing of air is strongly dependent on the height in the mixing layer and the distance from the wind machine, thus, chaining to a difference in the heat provided. Indeed, the stream did not reach or toughly a 100m distance, questioning the real reach of the stream depending on the climatic situation. Thus, in the following, results focus on the vertical wind profile of the wind machine stream for distances up to 80m. Figure 5 shows that the maximum speeds were reached by the highest anemometers near the wind machine, whereas far from the WM it tended to the contrary. It indicates that the shape of the stream was complex. The tilt angle of the blades must have influenced the shape and range of the stream, influencing the effect of the wind machine depending on the distance. Figure 6 shows that in the WM vicinity, the airflow was not homogeneous regarding the altitude, with a velocity difference of 3 m/s, the highest heights catching the maximum values. In contrast, far from the WM, the four anemometers on the mast nearly similar values with a velocity difference of less than 1m/s. These preliminary results provide a first view of a WM spatial impact.

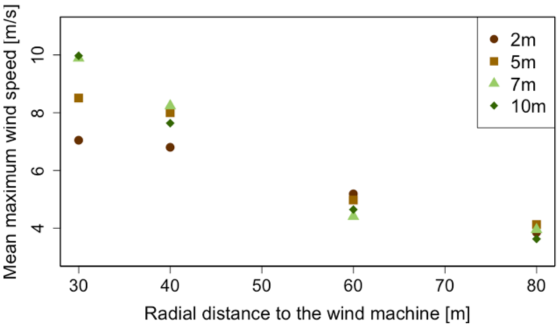

Figure **5**: Mean maximum wind speed following the radial distance for a WM revolution period.

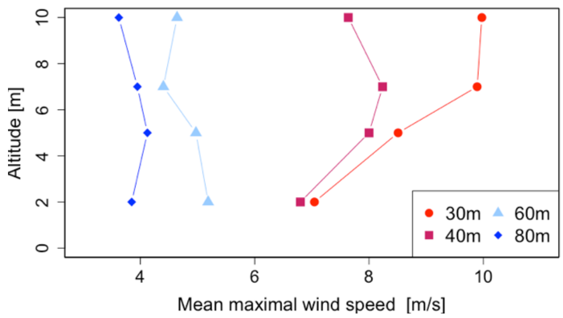

Figure **6**: Vertical profile of the mean maximum wind speed

4 Discussion and Conclusion

This paper aimed to characterize the spatial variability of temperatures during radiative frost across the Quincy vineyard and to analyze field measurements to characterize the wind machine on its temperature effect and its jet stream through high-frequency measurements. The temperature variability is highly correlated with altitude and slope, highlighting colder plots than the average where wind machine use should be considered with great attention. The wind machine provided a thermal gain even if not use in optimal thermal stratification conditions. Further investigations shall be conducted regarding whether or not burner use during wind machine operation provides extra efficiency. Besides, newly acquired data during last frost occurrences shall strengthen the behavior of temperature variability respecting the climatologic situation and topographic parameters.

5 References

Beyá-Marshall, V., Herrera, J., Santibáñez, F., Fichet, T., 2019. Microclimate modification under the effect of stationary and portable wind machines. *Agric. For. Meteorol.* **269–270**, 351–363

Bonnefoy, C., 2013. Observation et modélisation spatiale de la température dans les terroirs viticoles du Val de Loire dans le contexte du changement climatique*, Université Rennes 2*, 305p.

Doesken, N.J., McKee, T.B., 1988. A climatological assessment of the utility of wind machine for freeze protection in mountain valleys. *J. Appl. Meteorol*. **28**, 194-205

Heusinkveld, V.W.J., van Hooft, J., Schilperoort, B., Baas, P., Veldhuis, M. ten, van de Wiel, B.J.H., 2020. Towards a physics-based understanding of fruit frost protection using wind machines. *Agric. For. Meteorol.* **282–283**, 107868.

Kalma, J.D., Laughlin, G.P., Caprio, J.M., Hamer, P.J.C., 1992. The Bioclimatology of Frost: Its Occurrence,Impact and Protection*, Advances in Bioclimatology*. G. Stanhill,139p.

Madelin, M., 2005. L'aléa gélif printanier dans le vignoble marnais en Champagne . Modélisation spatiale à une échelle fine des écoulements de l'air et des températures minimales, *Université Paris-Diderot - Paris VII*, 307p.

Ribeiro, A.C., De Melo-Abreu, J.P., Snyder, R.L., 2006. Apple orchard frost protection with wind machine operation. *Agric. For. Meteorol.* **141**, 71–81

Snyder, R.L., Melo-Abreu, J.P. de, 2005. Frost protection: fundamentals, practice and economics, Environment and natural resources series. *Food and Agriculture Organization of the United Nations*, 240p.