Towards numerical simulation of a wind machine during spring frost calibrated with field measurements

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Liberté Égalité Fraternité

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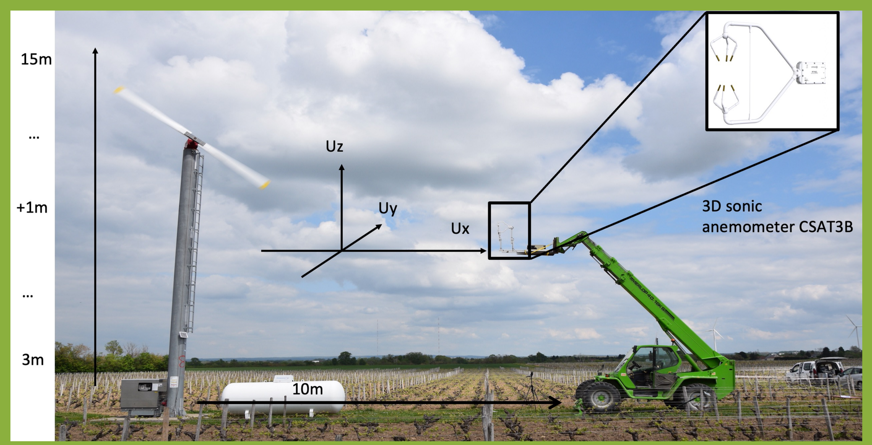
INTRODUCTION

Spring frost has been recognized as the most harmful weather hazard for agriculture. One way to fight it back is using a wind machine (WM). The most common design of a wind machine is a 10-m high fan with 2 blades of 6-m span and a speed of 600 rpm. It rotates on itself in approximately 4 min 30 s and blows a slightly positive air using the strength of the nocturnal thermal inversion to mix cold air near the ground with warmer air above (Brooks et al., 1948). In the Quincy vineyard in France, wind machines have been used for about 20 years. However, questions remain about the properties of the jet generated by the tower and the optimisation of its use alone or with additional heating (Le Cap et al., 2022). While field measurements are currently insufficient to understand all the mechanisms involved, numerical simulation should nevertheless help to overcome these barriers. A numerical model of a WM during a radiative frost with PALM (Maronga et al., 2015) is initialized from the field measurements and allows to explore its potential in improving frost control.

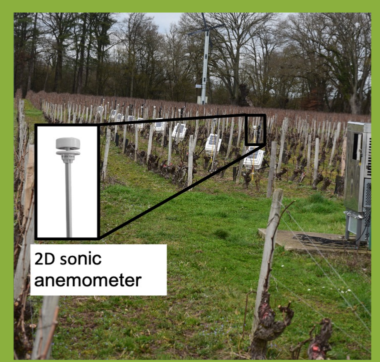
1 MATERIAL AND METHODS

Field measurements to asses the mass flow rate and flux momentum:

A Campbell Scientific® CSAT3B 3D sonic anemometer is placed 10 m away from the WM and mounted on a telescopic handler. 3 rotations per height were recorded (freq 100 Hz). The device recorded the jet's profile from 3 m to 15 m every 1 m.



8 LCJ® 2D ultrasonic anemometers are placed every 10 m from 20 m to 100 m in the row (freq 4 Hz) at vine-height (1.5 m).

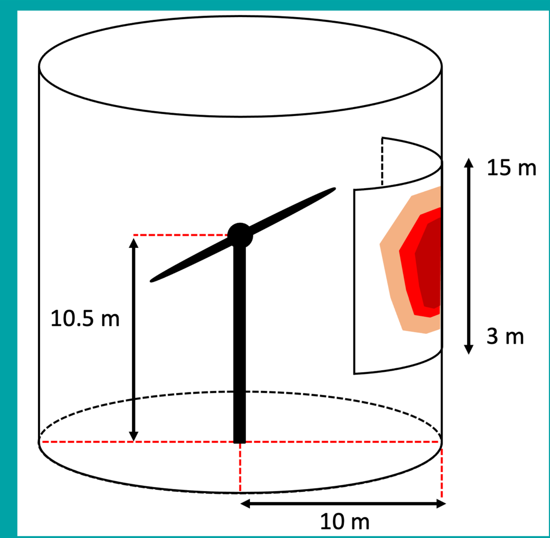


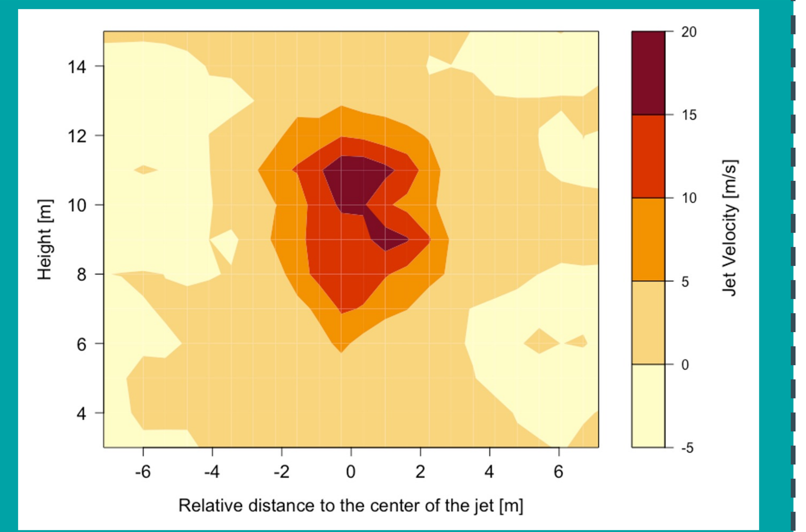
LES model of a WM with PALM :

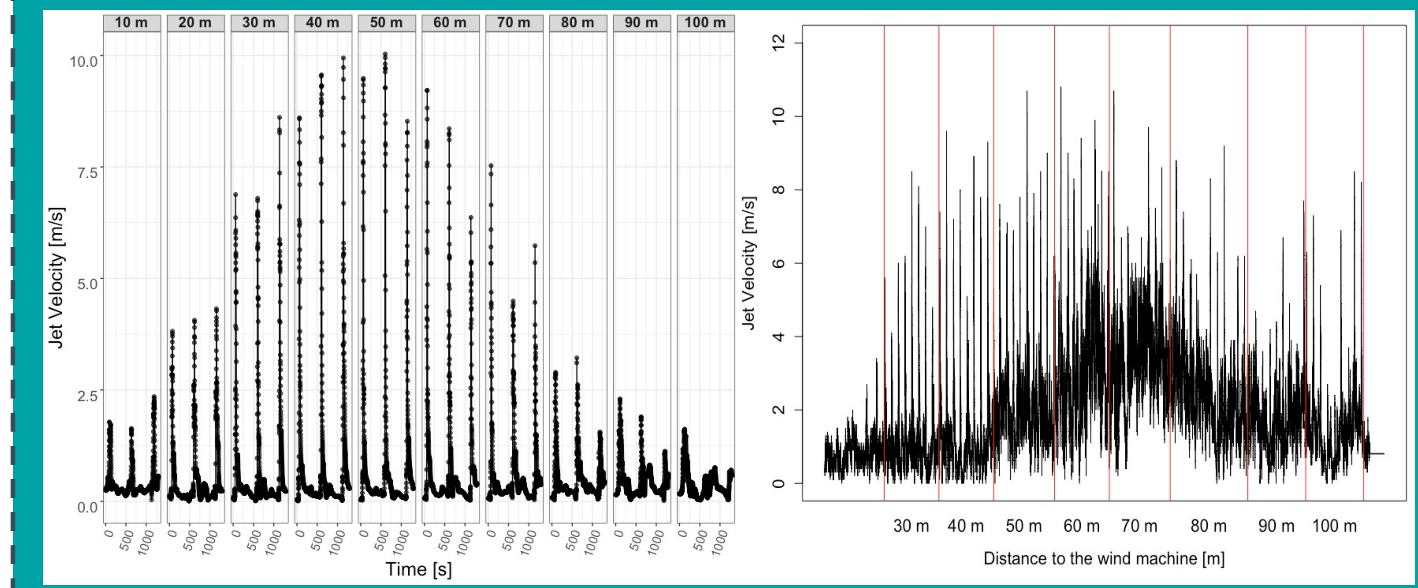
- Period of simulation: 2.5 d. Output every 15 s.
- Cyclic lateral boundary conditions
- 3 nested domains:
  - 512 m × 512 m × 1977 m. $\Delta_{x,y,z}$ = 4 m;
  - 256 m × 256 m × 256 m. $\Delta_{x,y,z}$ = 2 m;
  - 64 m × 64 m × 64 m. $\Delta_{x,y,z}$ = 1 m.
- Actuator disk (AD) to imitate the WM operating between 05:00 and 07:00 the last night.
- Land surface and clear sky radiation schemes to simulate a radiative frost night

2 RESULTS

The 2D image of an average blow is reconstructed from the successive local measurements in time and space. Each signal represents a gust of duration t equals to one rotation of the wind machine on itself, i.e. an angle of 2 π. The gust duration is transformed into an angular sector of 2 π covered by the machine. As the anemometer is 10 m away from the wind machine, we can then obtain an image of the Ux component of the gust as shown in the figure on the right. For each cell of this plot, elementary flow rate and momentum flux are calculated to estimate the total production by the tower.

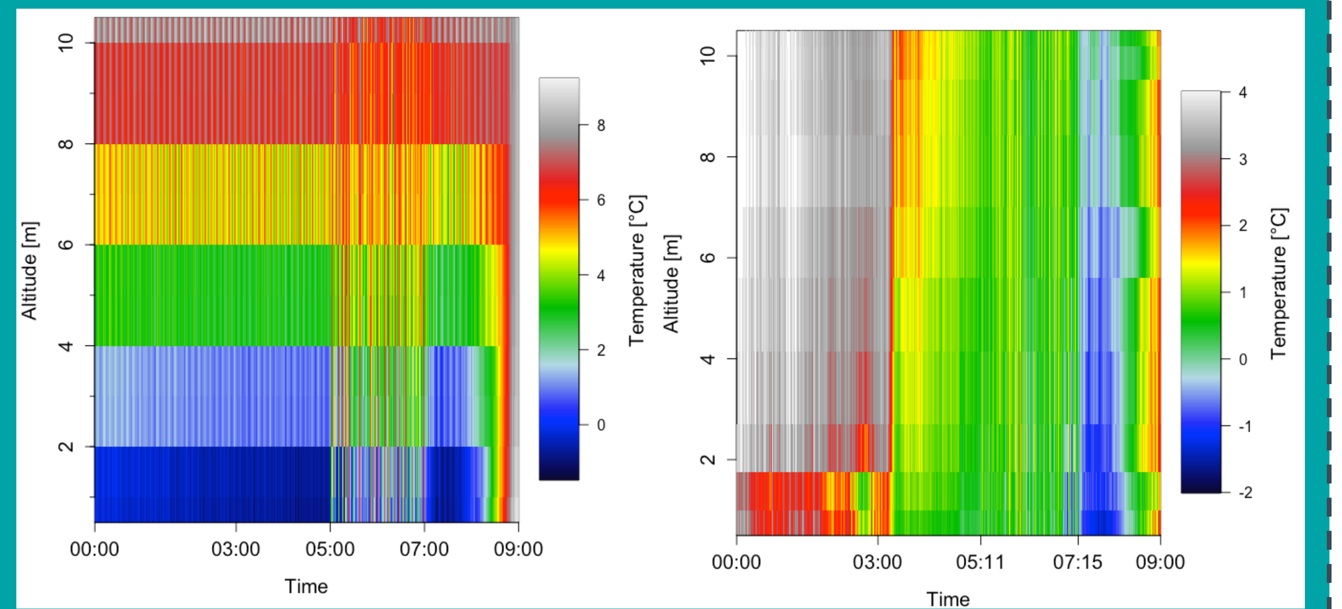


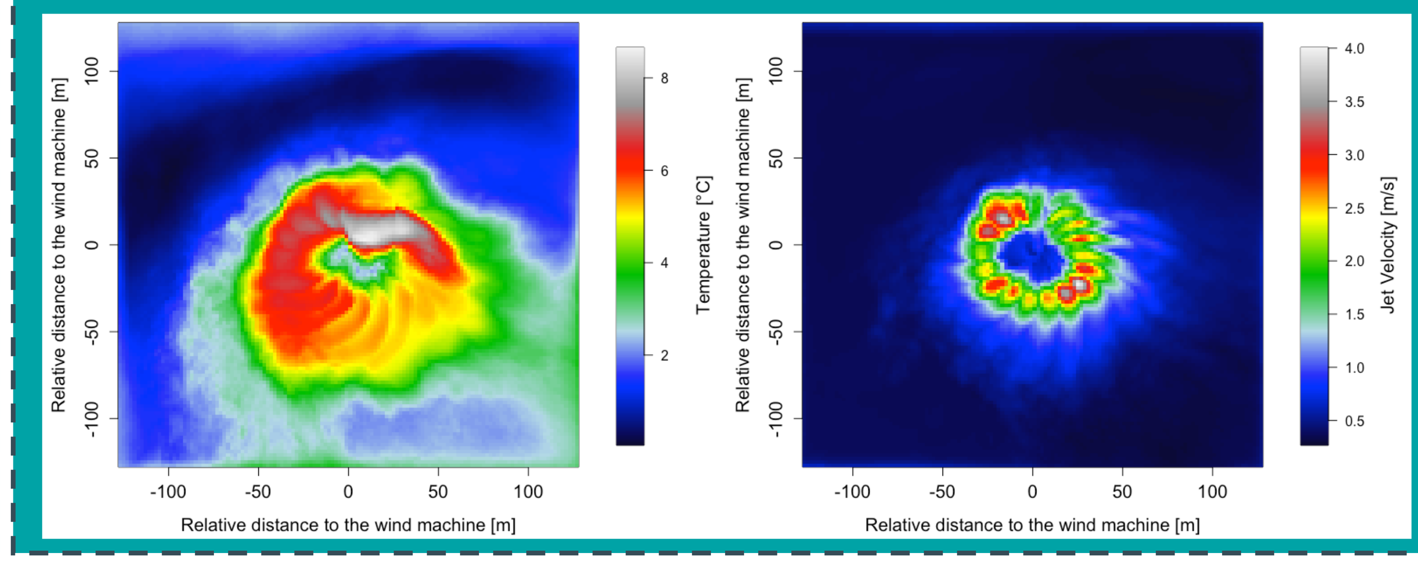




The jet's characteristics were then input to the AD to simulate the WM. Although there are still inconsistencies in the expansion and profile of the jet, the profiles obtained at 1.5 m height (vine height) in the left figure are close to those obtained in the field displayed in the right figure. The evolution of the amplitude of the velocity peaks according to the distance to the tower is consistent with observations. The AD manages to reproduce the residual velocity observed in the field that remains just after the WM passage. This residual velocity is present at every distances and gradually decreases until a second gust arrives. As the AD requires further work, the following results should not be interpreted as a consistent representation of reality but rather an exploration with the aim of improvement.

A night of frost measured in Quincy was used to initiate the weather conditions of the numerical model. However, the thermal inversion is overestimated compared to the measurements. In the field, the WM was switched on between 05:11 and 07:15. The figures show the temperature distribution with altitude through time. Results of the numerical model at 30 m from the AD are shown in the figure on the left, and those of the field measurements at 40 m in the figure on the right. Driven by the strong thermal inversion, the WM in the numerical model is much more efficient than in reality, each vertical line corresponding to a passage of the machine. While in the field the WM allowed to obtain peaks of 1°C or 2°C, in the numerical model, the temperature peaks are of the order of 5-6°C.





At a height of 1 m, the WM significantly warms up its vicinity up to a distance of at least 100 m. The resulting potato shape is however not uniform in space. The prevailing wind comes from the northwest. As a result the temperature potato shape extends downwind. Regarding the jet velocity, the pattern appears more uniform, although there are overspeed on both windward and leeward sides. However, one would have expected a spread out area on the leeward side with overspeed, and a reduced coverage on the windward side with a lower velocity.

3 CONCLUSIONS

The field measurements resulted in the following jet properties being measured:

Flow rate [m³\s]	Momentum Flux [N]
300	3000

A numerical model with PALM is initiated from the field measurements to initiate further analysis.

It is able to reproduce a night of radiative frost. However, adjustments are still needed to model a frost event more accurately following the field measurement, especially on soil moisture and vegetation properties.

The actuator disk simulates a rotating wind machine that significantly protects its vicinity within a radius of 100 m and beyond depending on the wind direction.

At a height of 1.5m, the module reproduces the velocity peaks observed in the field.

The actuator disk module still needs some work as it does not yet correctly reproduce the expansion and vertical profile of the jet.

Once calibrated, the numerical model will allow investigations into the influence of parameters usually encountered during field measurements:
- topography;
- weather conditions;
- urban and vegetation landscapes.

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