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SPACE-TIME VARIABILITY OF SPRING MINIMUM TEMPERATURES IN THE CHAMPAGNE VINEYARD (NE FRANCE)

ABSTRACT: MADELIN M. & BELTRANDO G., *Space-time variability of spring minimum temperatures in the Champagne vineyard (NE France)*. (IT ISSN 0391-9838, 2013).

Spring frost damage in Champagne vineyard (NE France) is a major issue among growers. When this natural hazard is due to a cold air mass advection, frost protection methods are generally inefficient because low temperatures occur over the entire region. In contrast, this is not the case when freezing occurs in radiative conditions (clear sky and calm wind), when marked temperatures differentiation can be observed due to a complex interplay between wind, topography, land cover, etc. To better understand the spatial and temporal distribution of nocturnal minimum temperatures during radiative conditions, we applied the numerical model MesoNH and confronted its results to observed data (network of weather stations). In this paper, a particular night in March 2003 is examined, a period during which frost was particularly intense. We find that the model reproduces quite well the direction of wind flow, but it tends to overestimate the minimum temperatures for the coldest sites. Moreover, it gives a clear illustration of the interaction between calm regional wind and local breeze, and its influence on spatial temperature distribution.

KEY WORDS: Frost, Champagne vineyard, MesoNH model, Minimal temperatures, Space-time variability, NE France.

INTRODUCTION

The Champagne vineyard, one of the most northerly in the World, covers about 33,600 ha, two thirds of which being located in the department (*i.e.*, administrative subdivision in France) of Marne, and correspond to the area studied in this article (fig. 1). It develops on hills with

moderate slopes (average of 12%), between 90 and 300 m (a.s.l.), mainly on the south, southeast and east slopes (fig. 1). The region is bordered on the west by limestone plateau covered with forests, in the centre by a curved cuesta overlooking the agricultural plain, in the east (wheat, beet). The vineyard of this region is concentrated on a cuesta and on both sides of the Marne Valley.

Located at the north limit of the «world of wine» (49.5 °N in Reims), the climate of this region is called «transition oceanic climate» and has a double influence, oceanic from the west and continental from the east. These conditions for vineyard are modulated by two characteristics: (i) a deep underground chalk, which allows good drainage and planting on slopes, so that (ii) the best vineyards are exposed to solar radiation in order to reduce the stagnation of cold air (which is drained down the hill outside the cultivated area). Collectively, temperate oceanic climate, continental influence and latitudinal position explain spring frost episodes that may be harmful to the vines, especially when they occur after the restart of vegetation growth (budburst). During this period (late March to early May), as the sap rises in the aerial parts, the plant becomes very sensitive to frost, especially when the bud appears. Air temperatures below -2 °C (at 2 m a.g.l.) are enough to cause the destruction of the primary buds, located near the surface (at 50 cm a.g.l.). In April 2003, 48% of the potential harvest froze during a cold episode that lasted only 3 days (CIVC, 2013a).

Due to this frost hazard and the high economical stakes (323 million bottles of Champagne sold in 2011 and 4.4 billion euro; CIVC, 2013b) associated with the Champagne vineyard, the Comité Interprofessionnel du Vin de Champagne (CIVC) has commissioned several studies, in particular to Météo-France and Umr Prodig/University Paris-Diderot, in order to improve local frost forecasting in susceptible areas for a variety of weather conditions and eventually to better organise the frost protection. As a former example, Météo-France proposes, during the spring

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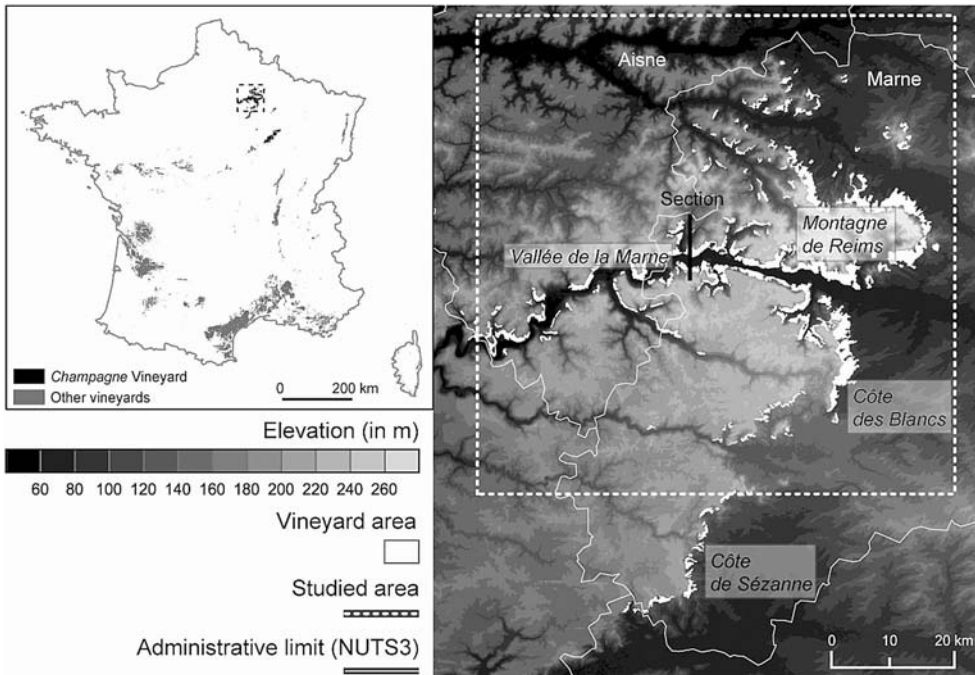


FIG. 1 - Vineyard location and topography of the studied area (data: SRTM, CLC).

period, a daily operable forecast (at 5 p.m.) of the minimum temperature for the night ahead for twenty vineyard sites (weather stations) in the Marne vineyard. This local estimate is based on a simplified physical model (Cellier, 1993) and a statistical analysis of past meteorological series, it also takes into account the forecasted atmospheric conditions for the night (wind and cloud cover).

When a very cold air mass, coming mainly from north to east, reaches the region, the temperatures tend to be low and there is little difference from one point to another within the vineyard. These conditions, related to large-scale atmospheric circulation, can lead to advection frosts, called «black frosts», for which protection methods have virtually no effect. In contrast, during the nights with clear sky and calm wind (radiative conditions), the spatial distribution of minimum temperatures presents a high variability and is strongly influenced by local parameters, in particular topography. A twenty-point estimate for the whole Marne vineyard is thus insufficient.

Under these nocturnal radiative conditions, the ground surface energy loss by infrared radiation is not compensated for soil conduction, atmospheric infrared radiation and turbulent convection. Ground and plant surfaces cool by several degrees. The cold air, denser than the neighbouring air, flows by gravity towards the low elevation areas (which generally are not planted with vines). Many publications have addressed this issue for over forty years (Geiger, 1968; Yoshino, 1975; André & Mahrt, 1982; Beltrando, 1998; Bridier, 2001; Quéno, 2002; Madelin, 2004; Madelin & Beltrando, 2005; Briche, 2011) and winegrowers have an empirical knowledge of the frost sensitive areas in the vineyard.

Several researches based upon *in situ* measurements in the Champagne vineyard have focused on the relationships between synoptic winds, slope breezes, and temperatures

(Beltrando & *alii*, 1992; Bridier, 2001; Quéno, 2002). The results clearly show that beyond 4 to 5 m/s, winds mix the air near the surface yielding a more uniform temperature spatial distribution. *Per contra*, when the winds are low (<2-3 m/s), cold air tends to accumulate in hill bottoms. Temperature differences of several degrees can in turn be observed for close sites (*e.g.*, distance of a few hundred metres). This phenomenon is disrupted by the interaction between the nocturnal slope breezes and the calm regional winds: cold air accumulation occurs when their directions are anti-parallel while air evacuation occurs when they are perpendicular (fig. 2).

The aim of this paper is to study in more details the space-time variability of minimum temperatures in the Marne vineyard by using the results of the MesoNH numerical model. The very rich outputs of the simulation provide a unique opportunity to illustrate the spatial rela-

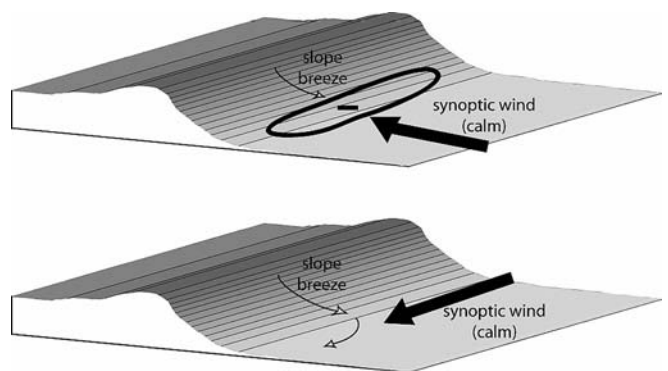


FIG. 2 - Interaction between synoptic wind and slope breeze (from Madelin, 2004).

tionship between minimum temperatures and airflows. This study is focused here on the example of Spring 2003 and the simulation results are compared to *in situ* observations from meteorological stations.

THE USE OF MESONH MODEL TO SIMULATE A RADIATIVE NIGHT

MesoNH model

Numerical modelling is a great tool to simulate the space and time evolution of surface climate variables that gives access to space-time distributions. In this study, we used the MesoNH model that is an atmospheric mesoscale non-hydrostatic model, developed jointly by Météo-France and the CNRS Aerology laboratory in Toulouse (Lafore & alii, 1998). This type of models rejects the hydrostatic assumption, *i.e.* volume and mass of air particles fixed over time, and is used to better understand the influence of elevation. It simulates the movements of the atmosphere over a wide range of scales ranging from synoptic scale to the micro-climatic scale. Its spatial resolution (250 m to 10 km), much finer than traditional weather patterns used for short-term forecasts, allows to better understand the interactions between the land surface (*e.g.*, topography and land cover/use) and the atmosphere. Many input data are needed by MesoNH to properly take into account the earth surface characteristics (*i.e.*, elevation, vegetation type, clay and sand proportions, soil moisture content) and used by three sub-models: (i) the Safran mesoscale analysis sys-

tem that gives atmospheric variables near the ground surfaces, (ii) the ISBA land-surface parameterisation model (Interaction Soil-Biosphere-Atmosphere; Noilhan & Planton, 1989), and (iii) the MODCOU hydrogeological model (MODélisation COUplée). The spatial resolution of the model inputs varies here from 1 to 10 km. Another feature of the MesoNH model is the ability to simulate nested domains having different spatial resolutions, which allows to refine the simulation of a given area within a larger domain (here 3 nested domains: 300 x 300 km with a resolution of 5 km, 70 x 70 km with a resolution of 1 km, and two zooms 15 x 15 km with a resolution of 250 m). The initial and lateral atmospheric boundary conditions (of the largest domain) are defined from the outputs of the Aladin meteorological model (resolution: 12 km). The vertical dimension is divided into 60 levels, with finer subdivisions near the surface.

The implementation of this model being relatively heavy, logistically and financially, this simulation has been carried out only for the night of March 16 to 17, 2003. Despite this, the outputs are abounding: various meteorological parameters are available at different times, for several simulation areas and at different heights above ground surface in order to capture the vertical dimension.

Atmospheric conditions on the night of March 16 to 17, 2003

Sunday 16 March 2003, France is under the influence of a large anticyclone centred over northern Europe, leading to a very dry synoptic north-northeast flow (fig. 3).

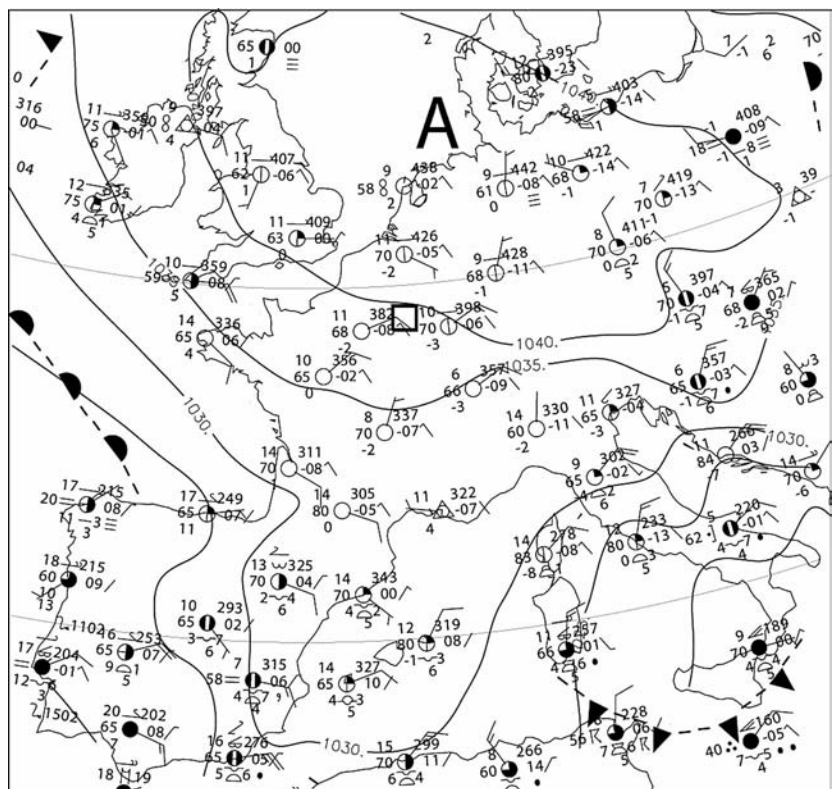


FIG. 3 - Surface weather analysis on March 16, 2003 at 12:00 UTC (extract from Météo-France Bulletin).

This flow direction is also found at 500 hPa, in conjunction with the high geopotential over the British Isles. During the day, the weather is characterised by a heavy sunshine and temperatures above normal. During the night, the anticyclonic conditions are maintained. The clear sky then leads to a strong night cooling. Reims, like many weather stations in France, particularly in the northeast quarter, records frost temperatures, with temperatures as low as $-3\text{ }^{\circ}\text{C}$. From 18:00 UTC on 16 March, the wind speed drops down to 2 m/s (sunset) and remained low throughout the night. The calm wind comes first from the east and then from the north (3/17, 3:00 and 12:00 UTC). The sky is then completely clear until 6:00 UTC on 17 March. The western side of a trough extending from Scandinavia to Italy creates an upper level front.

Observed temperatures in the vineyard

A network of measurement stations were set up in the 1990s in order to improve the climatic knowledge of the Champagne vineyard, in particular the frost events. These stations belong to two institutions: the French national meteorological agency Météo-France (www.meteo.fr) and the Champagne wine growers association Comité Interprofessionnel du Vin de Champagne (CIVC www.civc.fr). By using climatic data from the 23 local meteorological stations in the Marne vineyard, we can observe a marked variability, with a maximum variation of nearly $10\text{ }^{\circ}\text{C}$ (fig.

4). This temperature variation, at a local scale, is larger than the corresponding one between synoptic stations at a regional scale. Down hill stations are often colder (e.g., $-5.1\text{ }^{\circ}\text{C}$ in Chambrecy) than mid slope (e.g., $4.7\text{ }^{\circ}\text{C}$ in Bouzy). Beyond the influence of the relative altitude, northern stations are cooler. This observation can be explained by the northeast origin of the synoptic wind: stations oriented toward the streams are colder and, conversely, the temperatures are milder in sheltered sites.

Before the occurrence of these minima (around 5:00-6:00, before sunrise at 5:52 UTC), the evolution of temperatures through time varies from one station to another. Indeed, from sunset (17:51 UTC), the speed and intensity of cooling, which started around 15:00 UTC, fluctuate greatly from one station to another. For example, the stations of Germaine, Chambrecy, and Orbais-L'Abbaye record a marked temperature decrease during the night, unlike Bouzy, Nogent-l'Abbesse, and Plumecoq. In general, the stations located at low relative elevation exhibit a greater cooling, due to the stagnation of cold air coming down from the hills (slope breeze).

This brief overview of the weather data measured in the Marne vineyard during this night clearly illustrates the high spatial variability of nocturnal temperatures during stable atmospheric conditions. Since the winds were generally calm during the night of March 16 to 17, 2003, such a heterogeneous spatial distribution of minimal temperatures is likely to be a consequence of local settings (influ-

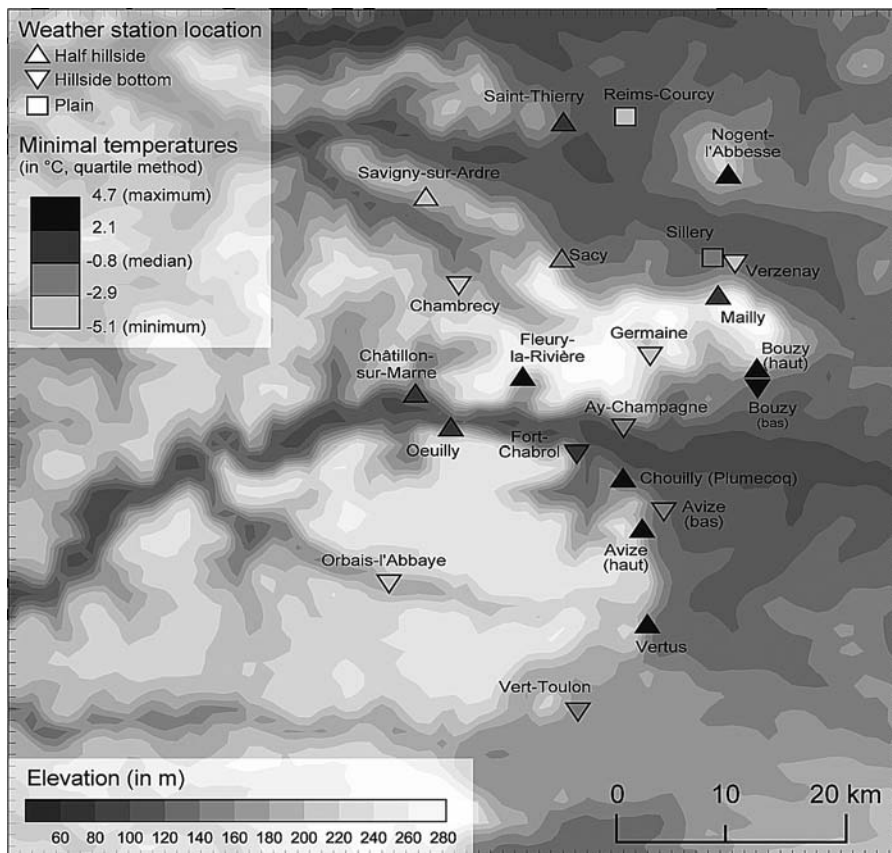


FIG. 4 - Minimal temperatures recorded by 23 weather stations of the Marne vineyard during the night of March 16 to 17, 2003 (data: CIVC, Météo-France, SRTM).

ence of topography, slope breezes interacting with the synoptic wind, etc.). The use of MesoNH simulations for this particular date may therefore provide further insights into the complex interaction of local effects with the temperature field.

SIMULATIONS OF WIND AND TEMPERATURE FIELDS

To highlight the relationship between airflows and temperatures, we chose to show the results of the simulation for only two parameters, wind (speed and direction) and temperature, in a vertical section crossing the Marne Valley with a north-south aspect (fig. 1) on one hand and by overlaying wind and temperature fields near the surface level on the other hand.

The vertical section of the Marne Valley

At 18:00 UTC, the MesoNH results for the Marne Valley (fig. 5) highlight that the valley bottoms are warm and

that the air flows occur mainly from north to south either near the surface or at 500 m a.s.l. We also observe the occurrence of slight ascending and descending movements. As expected, a lower speed is found near the surface, due to ground friction. The wind speed is also higher when the flow is directed down to the hill, due to the effect of gravity (and the other way around).

During the night, the winds at 500 m a.s.l. come from the east and blow to the west (results not shown here) and thus appear weak in this S-N section. Near the ground surface, air flows down the south-facing hillslope and this slope breeze seems to add up with the general wind. In contrast, on the north-facing hillslope, at 3:00 UTC, a slight slope breeze is visible. Both breezes are associated with thermal inversions. However, the cooling seems more pronounced on the north-facing slope, which can be clearly seen at 7:00 UTC. The end of the night is characterised by a dichotomy between the two hillsides. Areas of convergence and accumulation of cold air are located on the north-facing hillside, especially at the small ledge located at about 2 km of the cross section (the vertical profile shows then ascending movements). In contrast, the south-

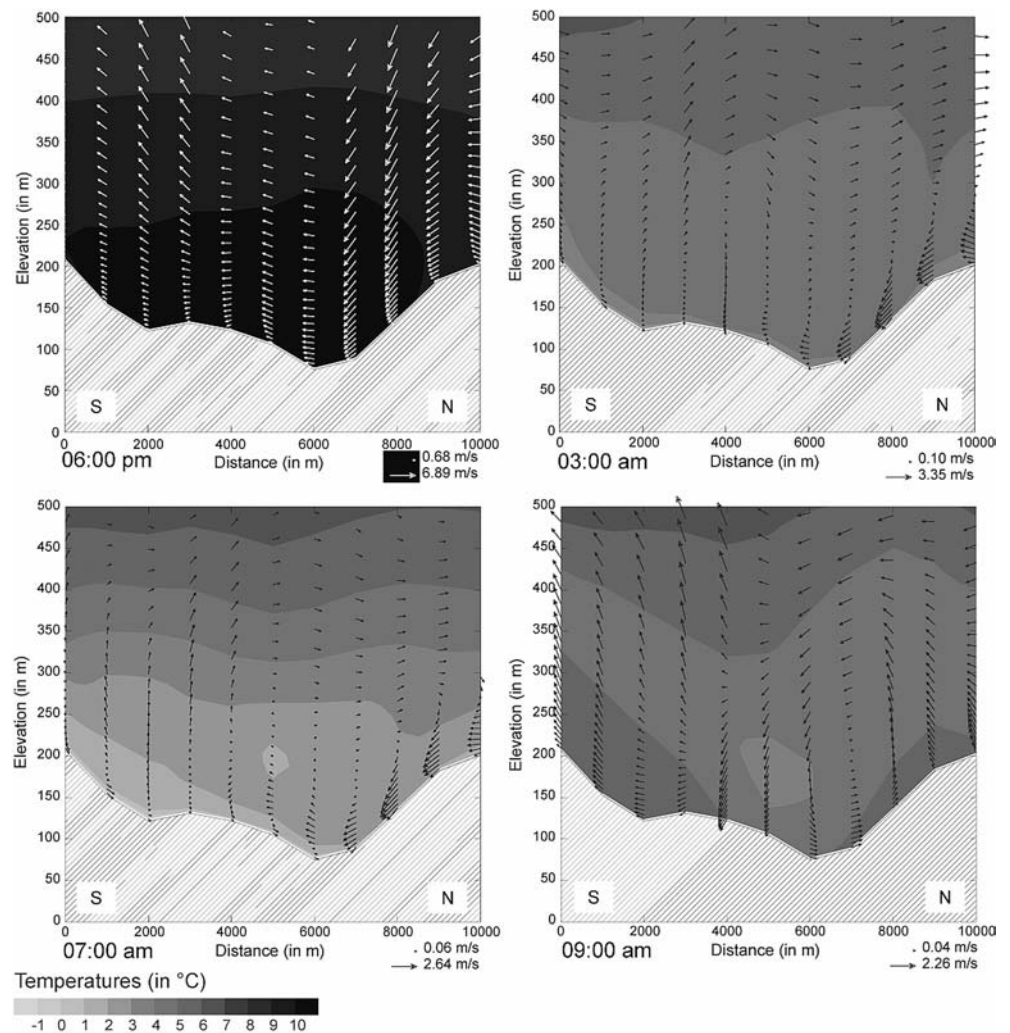


FIG. 5 - MesoNH simulation results for wind and temperature at the section of the Marne Valley, during the night of March 16 to 17, 2003 (18:00, 3:00, 7:00 and 9:00 UTC; data: MesoNH - Météo-France; resolution: 1 km).

facing hillside is mainly characterised by a flow that is strong enough to block the inverse flow coming from the other side of the valley, even to throw out the cold air toward the north-faced hillside (fig. 5).

At 9:00 UTC, the model simulates the upward slope breezes associated with ground surface heating. In the atmospheric layers at 500 m a.s.l., we can observe a north-south flow the same pattern as during the day before.

Overlaying wind and temperature fields

Figure 6 shows wind and temperature fields at 6:00 UTC (*ca.* thermal minima), near the surface level, overlaid on the same map. The areas where wind intensity is low are characterised by cold temperatures evidencing cold air accumulation due to gravity. Thus, the simulated cold areas are located in the valley bottoms and valleys, except the Marne Valley and in the plains of the north and east of the studied area: estimated temperatures are negative.

The results of MesoNH simulation corroborate the *in situ* measurements discussed in previous works (Beltrando & alii, 1992), revealing an interaction between slope breezes and the synoptic wind that affects cold air accumulation. The example of the Montagne de Reims (fig. 1) is particularly illustrative: (i) north slope breezes flow against the synoptic wind, in hill bottoms, and yielding a trapping of cold air; (ii) *per contra*, to the east, the simulation shows only a north wind, which is strong enough to suppress the accu-

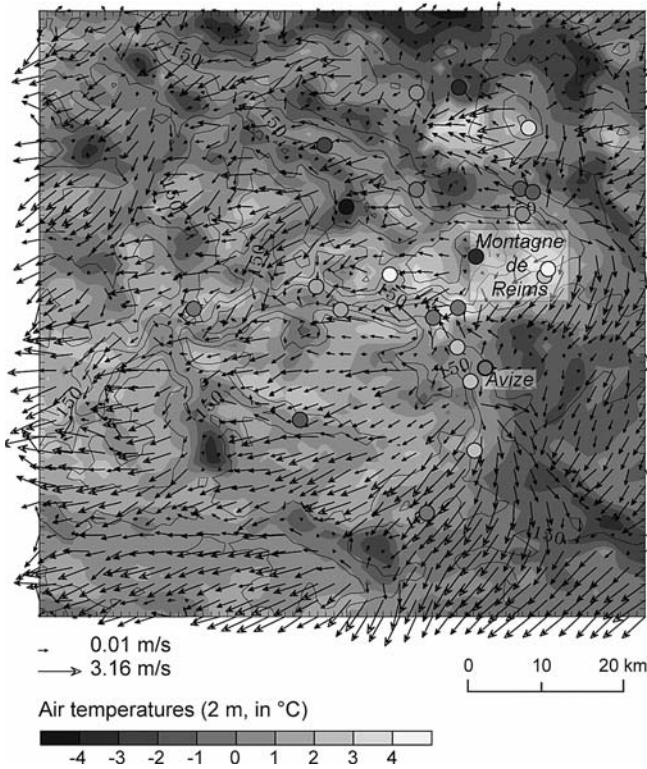


FIG. 6 - Wind and temperature fields from MesoNH simulation at 6:00 UTC on March 17, 2003 (data: MesoNH - Météo-France; resolution: 1 km).

mulation of cold air at this location; (iii) to the south, a very cold area, that may originate from a blocking of the cold air flows, from Avize hillside by the northerly flow. In general, to the north and east of the study area, the windward slopes are much colder than the leeward ones. Further west, the topography of the cuesta Île-de-France, though less differentiated, exhibits a more complex behaviour.

In figure 6, we also added the temperatures measured at the different weather stations. The comparison shows that the simulated temperatures are mostly consistent with the local observations (fig. 7), even if we compare point observations (weather stations) and grid simulations (with a resolution of 1 km). The simulated temperatures are rather underestimated for stations under relatively high temperatures (-3.0 °C between observation and simulation in Fleury-la-Riviere, -2.2 °C in Bouzy) and overestimated for cold stations (for example, 2.7 °C in Chambrecy to 2.2 °C in Germaine).

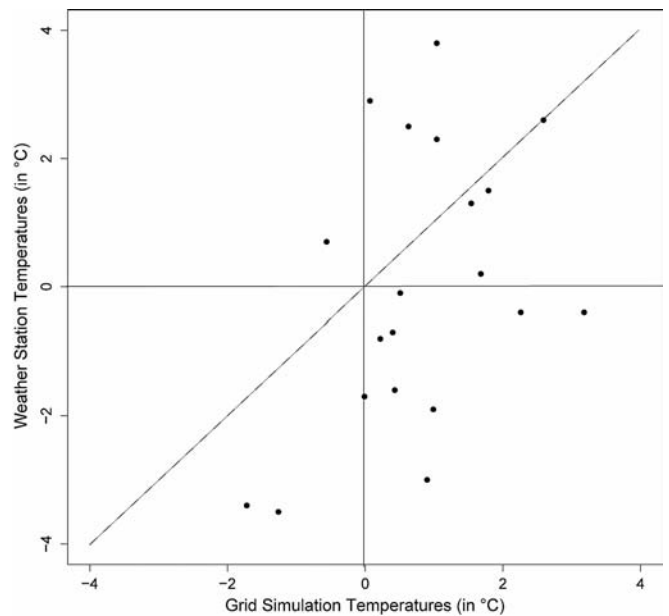


FIG. 7 - MesoNH simulated temperatures *vs.* weather station observations (data: MesoNH - Météo-France, CIVC).

CONCLUSION

The MesoNH numerical model gives results consistent with *in situ* measurements on various types of local settings (upper parts of hills, valley bottoms, etc.). Output results show a spatial temperature distribution in the lower layers of the troposphere, consistent with the observations and coherent with the literature. The quality of the results depends mainly on the quality of input data of the model (the nature of the surface, the initial state of the lower troposphere...). The results presented here (valley section and overlaying map) are very informative and give support to the theoretical schemes.

We have observed the phenomenon of thermal inversion and slope breezes causing cold air to the lower areas (bottom of hill or ledge). A cross section of the Marne Valley has also highlighted another interaction between airflow and topography, due to the orientation of the slopes. Areas appear more or less cold, especially depending on their windward (favouring a cold air trapping) or leeward situations (favouring an evacuation of cold air). This highlights the role of topography in the spatial variation of nocturnal temperatures. A better understanding of the temperature distribution, and especially its relationships with airflows, will improve the confidence of growers in the frost estimation.

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