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The application of high-resolution atmospheric modelling to weather and climate variability in vineyard regions

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Abstract

Grapevines are highly sensitive to environmental conditions, with variability in weather and climate (particularly temperature) having a significant influence on wine quality, quantity and style. Improved knowledge of spatial and temporal variations in climate and their impact on grapevine response allows better decision-making to help maintain a sustainable wine industry in the context of medium to long term climate change. This paper describes recent research into the application of mesoscale weather and climate models that aims to improve our understanding of climate variability at high spatial (1 km and less) and temporal (hourly) resolution within vineyard regions of varying terrain complexity. The Weather Research and Forecasting (WRF) model has been used to simulate the weather and climate in the complex terrain of the Marlborough region of New Zealand. The performance of the WRF model in reproducing the temperature variability across vineyard regions is assessed through comparison with automatic weather stations. Coupling the atmospheric model with bioclimatic indices and phenological models (e.g. Huglin, cool nights, Grapevine Flowering Véraison model) also provides useful insights into grapevine response to spatial variability of climate during the growing season, as well as assessment of spatial variability in the optimal climate conditions for specific grape varieties.

Keywords: WRF model, weather and climate, grapevine response, Marlborough, New Zealand

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Introduction

It is well known that the temporal and spatial variability of weather and climate within vineyard regions has an important influence on grapevine response and therefore wine production (quality and quantity). To understand the potential consequences of climate change for viticulture in regions of complex terrain it is important to investigate this influence across a range of time and space scales in order to appropriately manage future risks to the local wine industry. However, many vineyard regions have a poor record of meteorological, as well as phenological, observations. We therefore need to explore other ways of investigating the variation of weather and climate across wine-producing regions and its influence on the grapevine at the vineyard scale. Physics-based mesoscale atmospheric numerical models are tools that can be used to provide a good understanding of the fine-scale variability of weather and climate across a vineyard area, even in regions of complex terrain (Bonnardot and Cautenet, 2009; Soltanzadeh *et al.*, 2016). These models have been used to address a range of other applied problems, including dust and air pollution dispersion, wild fire behaviour and wind energy resource assessment (Purcell and Gilbert, 2015; Alizadeh Choobari *et al.*, 2012; Simpson *et al.*, 2013; Sturman *et al.*, 2011; Titov *et al.*, 2007).

The key research question addressed in this paper is therefore: what can mesoscale numerical models tell us about weather/climate variability at vineyard scale and its influence on grapevine response? This question is addressed by applying an internationally well-known mesoscale atmospheric model to New Zealand's most important vineyard region.

Research methodology

The main feature of this research is the application of the Weather Research and Forecasting (WRF – Skamarock *et al.*, 2005) model to simulate local weather/climate in vineyard regions in complex terrain for both short term weather forecasting in support of frost protection and spraying activities, as well as longer term investigation of the spatial and temporal variability of vineyard scale climate. In the latter case, the aim is to demonstrate the usefulness of atmospheric mesoscale models for:

- identifying the major influences on local weather and climate (sea breezes, foehn effect, cold air drainage and ponding, etc.) in vineyard regions, essentially identifying the main contributions to the climate component of the terroir.

- investigating the influence of local and regional weather/climate on grapevine response and climate risk factors for viticulture through the coupling of mesoscale models with bioclimatic and crop models.

Marlborough region

Marlborough is the most important wine-producing region of New Zealand, producing more than 70 % of the wine exported from the country. It is located in the northeastern part of the South Island in a region of complex terrain, with significant relief and altitudes reaching more than 1500 m in a number of places (Figures 1 and 2). The main vineyard areas are mostly located on the lower-lying flood

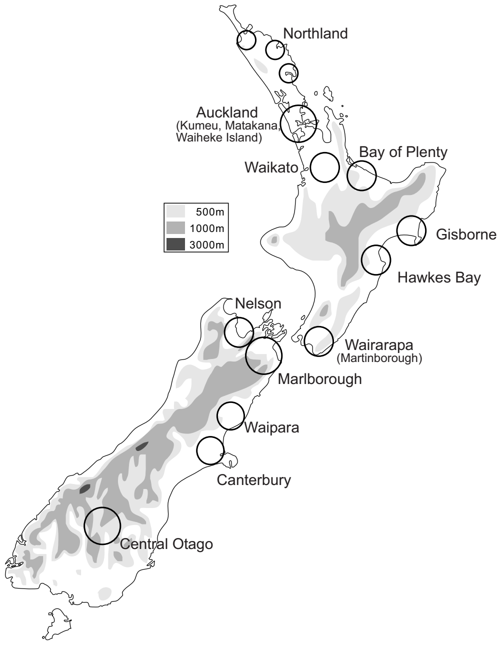

Figure 1 - The location of vineyard regions in New Zealand (after Sturman and Quénol 2013).
The size of the circles merely identifies the general locations of the vineyards.

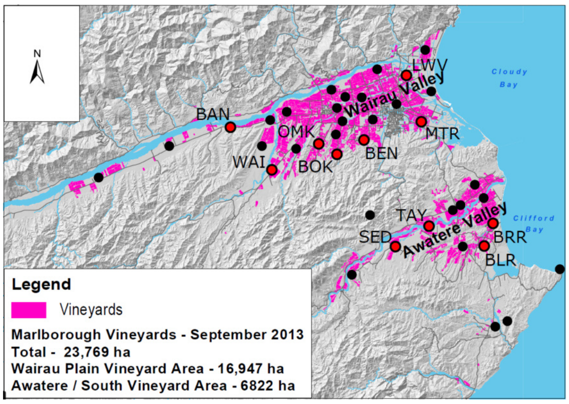

Figure 2 - Distribution of vineyards within the Marlborough region in 2011, with the locations of weather stations operating between 2013 and 2015.
The filled circles are sites of long-term records, these were supplemented by the red sites for the study period. Vineyard map provided by the Marlborough District Council.

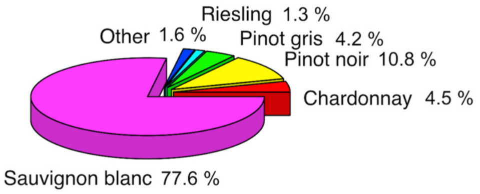

Figure 3 - The breakdown of vineyard area in the Marlborough region by grape variety in 2016.

plains of the two main valleys of the Wairau and Awatere rivers.

Sauvignon blanc is the dominant grape variety planted in the region, following by Pinot noir, Chardonnay and Pinot gris (Figure 3).

WRF model setup

The WRF was set up using a four-level nested grid configuration, as shown in Figure 4a, for computational efficiency. The model was run twice per day producing hourly predictions of meteorological parameters such as air temperature and pressure, wind speed and direction, and atmospheric humidity at 1 km resolution over the Marlborough region (Figure 4b).

Initial assessment of the WRF model performance through comparison with automatic weather station data in Marlborough suggests that there is a cold bias of between 0.5 and 1.0 °C. Potential cold bias of model predictions has previously been recognized (Steele *et al.*, 2014; Hu *et al.*, 2010), and needs to be allowed for when interpreting analysis of spatial patterns across the region. This cold bias will be the subject of further research so that appropriate adjustments can be made.

In addition to seasonal maps of key variables (average daily maximum, minimum and mean temperature), maps of accumulated degree-days were derived from hourly temperature predictions two metres above ground level and the Grapevine Flowering Véraison (GFV) model (Parker *et al.* 2011, 2013), as shown in Figure 5. Seasonal maps of using the parameters of the GFV model for a temperature summation (base temperature of 0 °C, start date of 29 April) and other bioclimatic indicators were also produced.

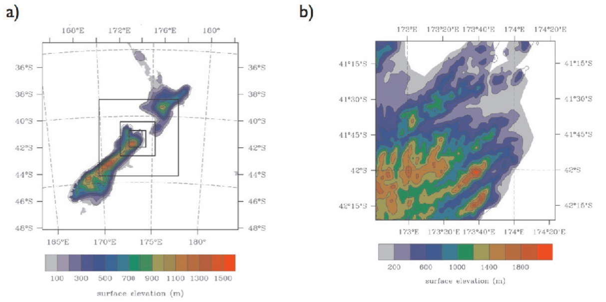

Figure 4 - The WRF nested grid configuration, showing terrain height, a) for all four grid domains (27, 9, 3 and 1 km resolution), and b) the high-resolution domain.

It should be mentioned that the GFV model was not developed to provide a degree-day accumulation over the whole growing season, but to set temperature sum thresholds at which a given grape variety reaches a given phenological stage (flowering or véraison). Although the results produced here do not strictly reflect the original rationale of the GFV model, it is still possible to derive a temperature summation for the growing season (as shown in Figure 5), allowing analysis of inter-annual and intra-regional patterns of heat accumulation.

Results

1. Coupling WRF model output with bioclimatic indices

By coupling the WRF model output with bioclimatic indices and phenological models it is possible to provide a spatial analysis of the suitability of a vineyard region to a range of different grapevine varieties. As shown in Figure 6, the key indices/models examined in this paper are:

- Mean growing season temperature (1 October to 30 April);
- Huglin index (1 October to 31 March);
- Grapevine Flowering Véraison model (29 August to 30 April).

The three maps in Figure 6 show significant commonality. For example, the influence of the complex terrain of the region is clearly evident in all three maps, with altitude and distance from sea having an important influence on the thermal environment of the region. However, some

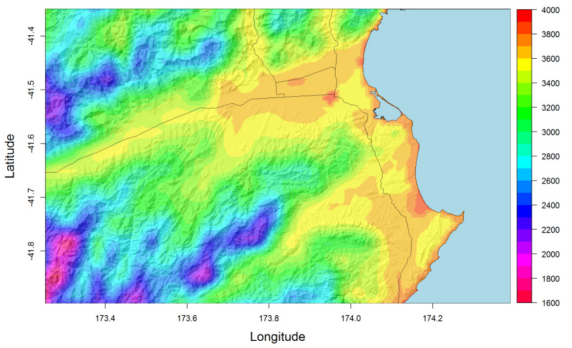

Figure 5 - Example map of temperature summation over the Marlborough region from 29 August 2013 to 30 April 2014 calculated according to the GFV model using a threshold of 0 °C and based on WRF model temperatures.

differences also occur between the maps, with the mean growing season temperature and the GFV temperature summation (Figures 6a and c) picking out the warming effect of the sea along a narrow strip near the coastline, while the Huglin index (Figure 6b) indicates greater accumulated heat in the central part of the Wairau Valley.

2. Integration of WRF with the GFV model: 50 % flowering/véraison dates

The GFV model has the following parameters (daily degree-day accumulations) that can be used for prediction of flowering and véraison for Sauvignon blanc: F* = 1282 (50 % flowering); 2528 (50 % véraison), where F* is the critical temperature sum (threshold = 0 °C, starting on the Northern Hemisphere 60th day of the year - 29 August in the Southern Hemisphere). The WRF model output can be used with the GFV model to map the timing of flowering and véraison across vineyard regions, as shown for Marlborough in Figure 7.

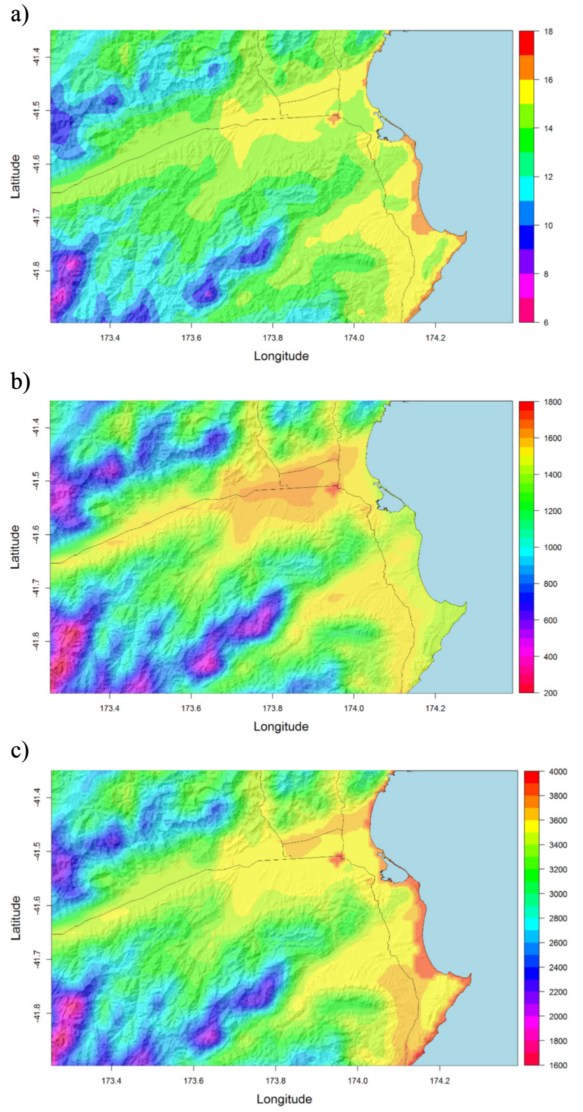

Figure 6 - Maps of: a) mean growing season temperature, b) Huglin index, and c) GFV temperature summation, based on the 2008-9 to 2013-14 growing seasons in the Marlborough region.

Figures 7a and b illustrate the extent of inter-seasonal variability in the development of flowering across the region. Using a combination of WRF model output and the GFV model, the development of key phenological phases can be mapped across a region of complex terrain like Marlborough, to provide the basis for predicting the magnitude and timing of harvest for different parts of the region.

3. Optimal mean growing season temperatures for key Marlborough grape varieties

The WRF-predicted spatial variation in mean growing season temperature (GST) can also be mapped and compared with published optimal ranges of values

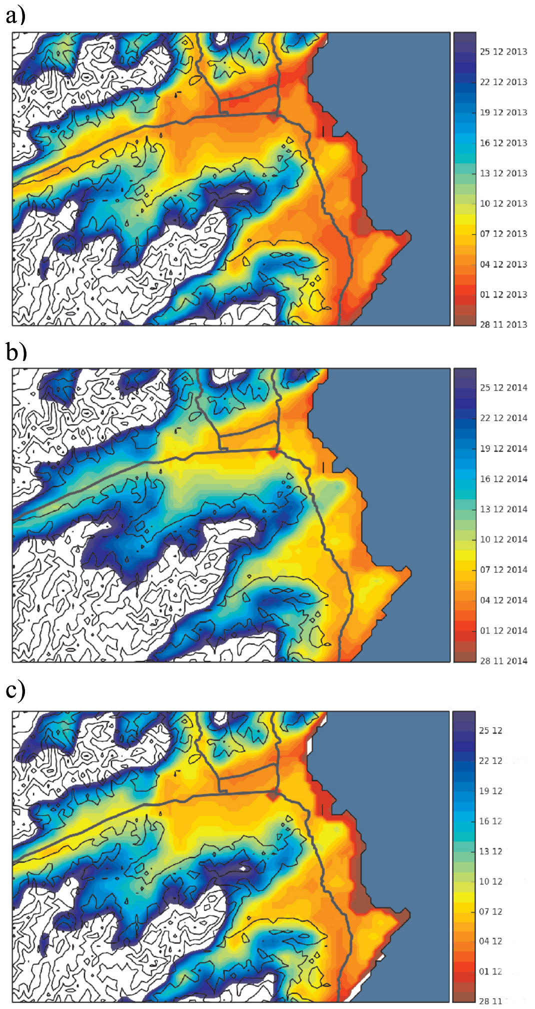

Figure 7 - Isochrone maps of 50 % flowering over the Marlborough region during the growing seasons of: a) 2013-14, b) 2014-15, and c) 2008-14. The key in c) indicates the average day and month of the year.

associated with different grape varieties (Jones, 2006 and 2007):

- Pinot gris [13 – 15.2 °C],
- Chardonnay [14.2 – 17.2 °C],
- Pinot noir [14 – 16.2 °C],
- Sauvignon blanc [14.8 – 18 °C].

(approximate values extracted from graphs in Jones, 2006 and 2007)

In Figure 8, the different mean growing season temperature ranges considered optimal for the four most important Marlborough grape varieties are plotted using the same colour scale, so that the red colours at either end of the scale indicate marginal regions, while the blues and greens represent the most optimal areas for each grape variety.

Based on the WRF-derived temperatures and published optimal temperature ranges for grape varieties, the most optimal grape variety for the Marlborough region appears to be Pinot noir, rather than Sauvignon blanc, which is by far the dominant variety in the region. There are three possible reasons for this anomalous result. First, the cold bias of the WRF model tends to suggest that both Sauvignon blanc and Chardonnay are less optimal than they really are, while Pinot noir and Pinot gris appear to be more optimal.

Second, the ranges of GST used to represent optimal growing conditions for the different grape varieties are based on typical values of GST obtained from regions where those varieties are currently successfully grown (Jones, 2006 and 2007). This rather assumes that the present-day thermal environment is the main reason for the grapes being located where they are, when in fact historical and cultural factors may also be important.

Third, Marlborough, and in particular the Awatere Valley, produces a grassy style Sauvignon blanc. The grapes are harvested at a lower level of ripeness (at a higher 3-isobutyl-2-methoxy-pyrazine content) than in other parts of the world where Sauvignon blanc is produced, and this creates a distinctive wine style.

Conclusions

The application of mesoscale weather/climate models to vineyard regions such as Marlborough (in New Zealand) provides improved knowledge of the unique features of the weather/climate (sea breezes, foehn winds, mountain/valley winds, cold air ponding, etc.) and their contribution to the local 'terroir'. Models such as WRF can also be used to investigate the relationship between weather/climate and key phases of grapevine development at vineyard scale within wine-producing regions. Variability of climate can be investigated across vineyard regions at high resolution using such models, allowing

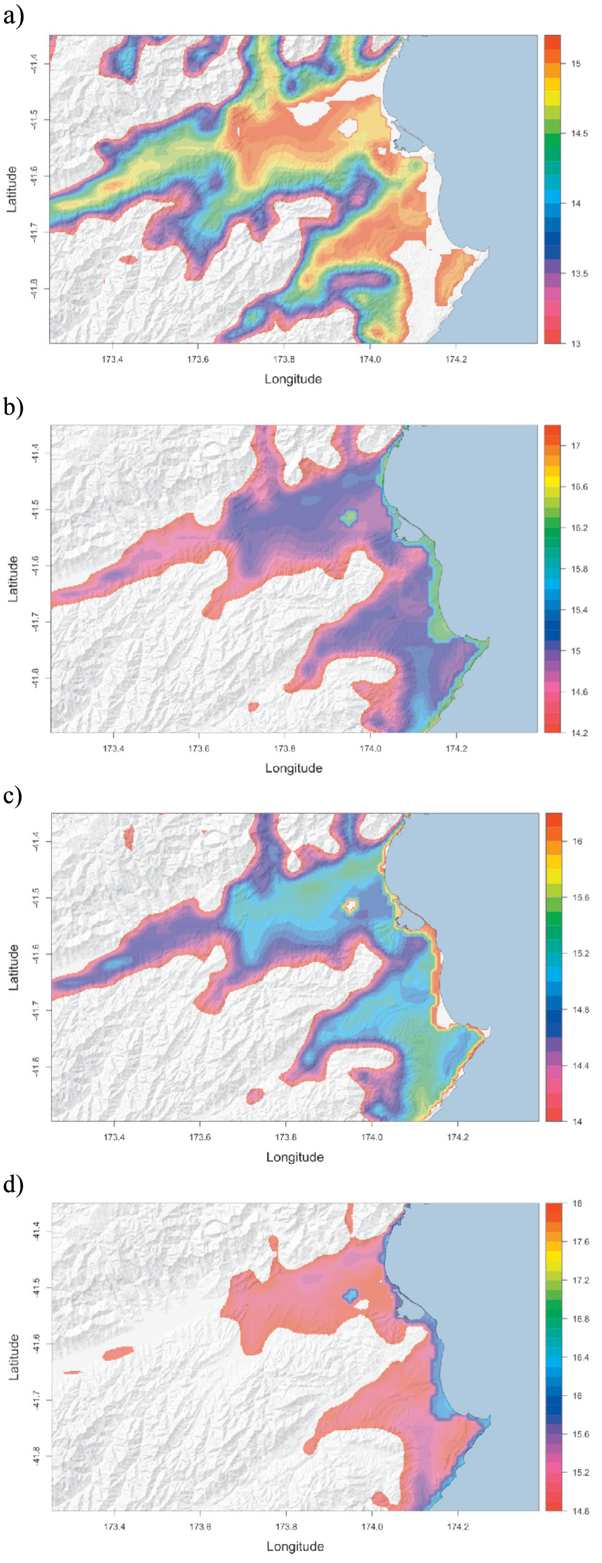

Figure 8 - Maps of optimal mean GST ranges for the main Marlborough grape varieties: a) Pinot gris, b) Chardonnay, c) Pinot noir and d) Sauvignon blanc, based on WRF model output for 2008-2014.

identification of optimal/marginal areas for winegrape production and climate risk assessment based on various bioclimatic indices. Such analysis can also be used to assess the robustness of vineyard regions to longer term climate change, including how much change would be required to make a region unsustainable with respect to specific grape varieties.

The use of the WRF model to assess the suitability of specific grape varieties in the Marlborough region suggests that we need to investigate the origin and nature of the cold bias in model predictions in order to provide more accurate simulations of near-surface temperatures and hence bioclimatic indices. It is also important to improve understanding of the relationship between climate parameters such as average growing season temperature and grapevine response to be able to better assess the future of quality wine production in specific areas in response to changing climate. It is therefore important that future work addresses the limitations identified in combining WRF modelled temperatures with bioclimatic indices by coupling WRF with phenophase models at a higher temporal and spatial resolution.

The suitability of grape varieties to specific areas also depends on the style of wine. For example, Marlborough Sauvignon blanc is generally harvested at a commercial soluble solids (SS) of 20.5 to 21.5 °Brix. Other regions and styles may require a higher SS and therefore take longer to achieve that target. It may therefore be more logical to base suitability of grape varieties on the temperature summation it takes to reach a particular SS target (based on the GFV model).

The effects of manipulation of the grapevine environment at vineyard scale should also be integrated into more comprehensive modelling systems, as the effects of variations in the regional climate could be offset by vineyard management techniques (Webb *et al.*, 2012).

In conclusion, it should be noted that Global Climate Models (GCMs) provide only a general idea of the larger-scale changes in climate likely to occur in vineyard regions over future decades (as discussed by Hannah *et al.*, 2012 and 2013, and van Leeuwen *et al.*, 2013). It is evident that downscaling GCM output to the regional and local scales is fraught with difficulty in regions of complex terrain as the interaction of hemispheric and synoptic scale processes with local and regional topography can introduce significant spatial variation in response to large scale forcing (Sturman and Quénol, 2013). It is therefore important that methods of dynamical and statistical downscaling be improved to allow more realistic assessment of the impacts of climate change on vineyard regions, in order to develop appropriate and effective adaptation strategies.

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