Investigating the adaptability of New Zealand's vineyard areas to changing climate using a multi-scale approach

Andrew Sturman[1], Hervé Quénol[2], Stuart Powell[1], Iman Soltanzadeh[1], Peyman Zawar-Reza[1] and Valérie Bonnardot[2]

[1] Centre for Atmospheric Research, Department of Geography, University of Canterbury, Christchurch, New Zealand.

[2] COSTEL Laboratory, UMR 6554 LETG of CNRS, Université Rennes 2, 2 Place du Recteur H. Le Moal, 35043 Rennes Cedex, France

Email: andrew.sturman@canterbury.ac.nz

Abstract

Grape vine growth and hence the wine industry are highly sensitive to variations in weather and climate. A collaborative international research programme is underway to investigate this sensitivity, and to help develop strategies for adapting to a changing climate. A multi-scale measurement and modelling approach is taken to determine the spatial and temporal variability of observed climate at the vineyard scale. Based on this knowledge, it is possible to evaluate the robustness of a vineyard region to change and also evaluate the options that are available for it to respond to future change using advanced regional scale climate models.

1. Introduction

The wine industry in New Zealand, as in other parts of the world, is highly sensitive to variations in weather and climate, which can significantly affect both the quantity and quality of wine produced. It is also an important contributor to the economy of the country due to the significant exports of high quality wine to a range of different overseas destinations. An international research programme (TERVICLIM/TERADCLIM) is therefore underway, applying climate measurement and modelling techniques at high resolution in key wine-producing regions of the world to evaluate the risks posed by longer term climate variability, and to help develop appropriate adaptation strategies to ensure long term sustainability of the industry. The New Zealand component of this research recently started an intensive study of the local and regional climate of Marlborough.

The growing cycle of the grape vine involves a series of stages (e.g. bud burst, flowering, fruit set, veraison, maturity, leaf fall and dormancy) that are largely dependent on the weather experienced at different times through the year. Phenology is the study of the relationship between these plant responses and the environment within which the plants are growing, particularly the climate. Climate change appears to be having an impact on grape vine phenology, with growing seasons advanced by several weeks in some parts of the world (Hall and Jones, 2009; Webb et al, 2007; De Cortazar, 2006; Chuine et al, 2004; Schultz, 2000). There are also specific weather hazards such as frost, high temperature or humidity, and strong winds that can have a significant impact on the vine and its productivity (Briche et al, 2011; Jones, 2006; Jones and Davis, 2000). The characteristics of the wines produced (e.g. acidity, alcohol content, development of aromas and sweetness), and therefore its quality, also depend strongly on the weather experienced during the growing season (Neethling et al, 2011; Van Leeuwen et al, 2004).

It should also be remembered that geographic factors can produced significant regional and local climate variability, to which many vineyard areas have become adapted over long periods of time. This climate spatial variability determines the intrinsic robustness of a given vineyard region to long term climate change, because as some parts of the region may become unsuitable for grape production other parts may take their place (Jones et al, 2009; Seguin and De Cortazar, 2005). It is therefore important to investigate the small scale climate variations within existing vineyard areas before developing a strategy for responding to climate change. It also needs to be recognised that improved knowledge of possible regional and local variations in climate depends on a better understanding of the relationship between large scale atmospheric circulation and processes that operate at a smaller scale. The current paper therefore illustrates a multi-scale approach that has been developed to address this problem by integrating measurement and modeling techniques at a range of time and space scales, using examples from the Marlborough area (Figure 1).

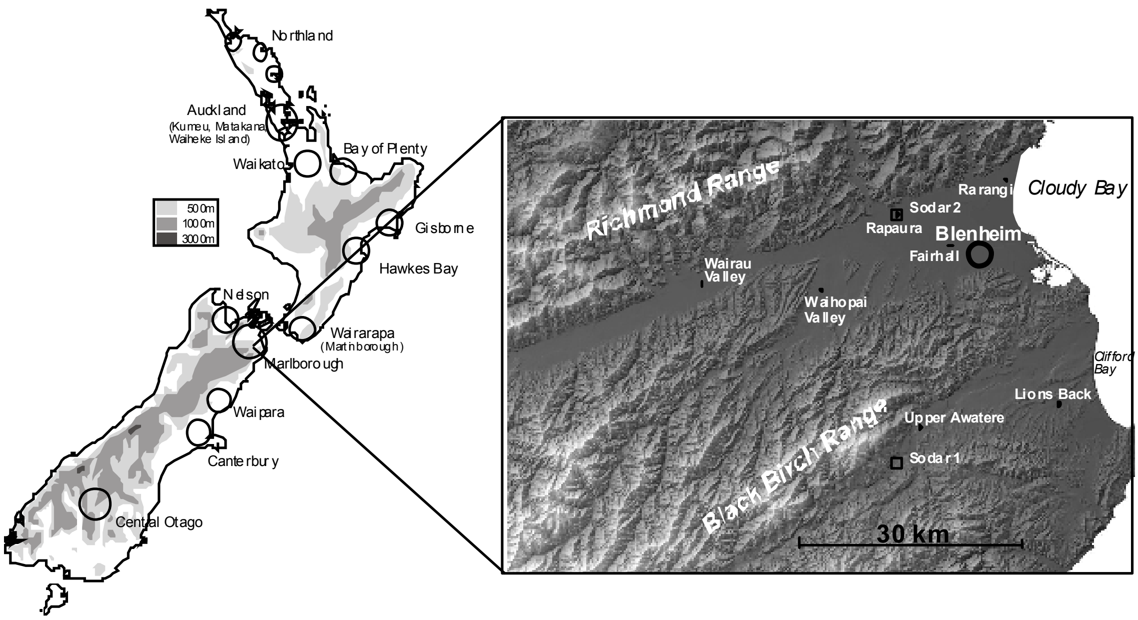

Fig. 1: The main vineyard regions of New Zealand, with a terrain map of the Marlborough region derived from digital elevation data. The locations of SODAR measurement sites and several automatic weather stations are indicated.

It is evident that not all vineyard regions of the world experience the same spatial and temporal variations in their local climate, so it is reasonable to expect that there should be significant variability in the way in which each region responds to future climates. The current research therefore aims to develop a strategy that can be applied anywhere in the world, starting with a detailed assessment of the present-day climate resource available to support viticulture in a given area, and involving the application of improved technology to both collect new data and to model climate variability at high spatial and temporal resolutions. The complex terrain in New Zealand provides an excellent natural laboratory within which to investigate the nature of small scale climate variability and the factors that control it, and it is this small scale variability that contributes to the robustness of a vineyard area in response to long term climate change.

2. Methods

The methodology used in this research includes several major components (Figure 2):

- Measure the climate at the regional scale (kilometres) using networks of sensors and data loggers located to capture the range of topographic situations in a given area (e.g. slope aspect and angle, soil type, altitude and location in the terrain).
- Model the climate at the regional (1-3 km) and vineyard (100s of metres) scales employing atmospheric numerical models, and using the measurements mentioned above for model validation.
- Relate the high-resolution spatial patterns of climate to potential effects on the grapevine using a range of bioclimatic indices, to assess the extent to which the vines are optimally (or marginally) located, and identify the extent of environmental risk (such as frost or extreme temperatures).
- Develop scenarios of future climate at fine scales in vineyard regions using regional modelling techniques (e.g. RegCM) to downscale the results from larger scale general circulation models (GCMs).
- Relate the fine scale assessment of future climates to the environmental requirements for sustainable grape production, to form the basis for developing effective adaptation strategies.

a) b)

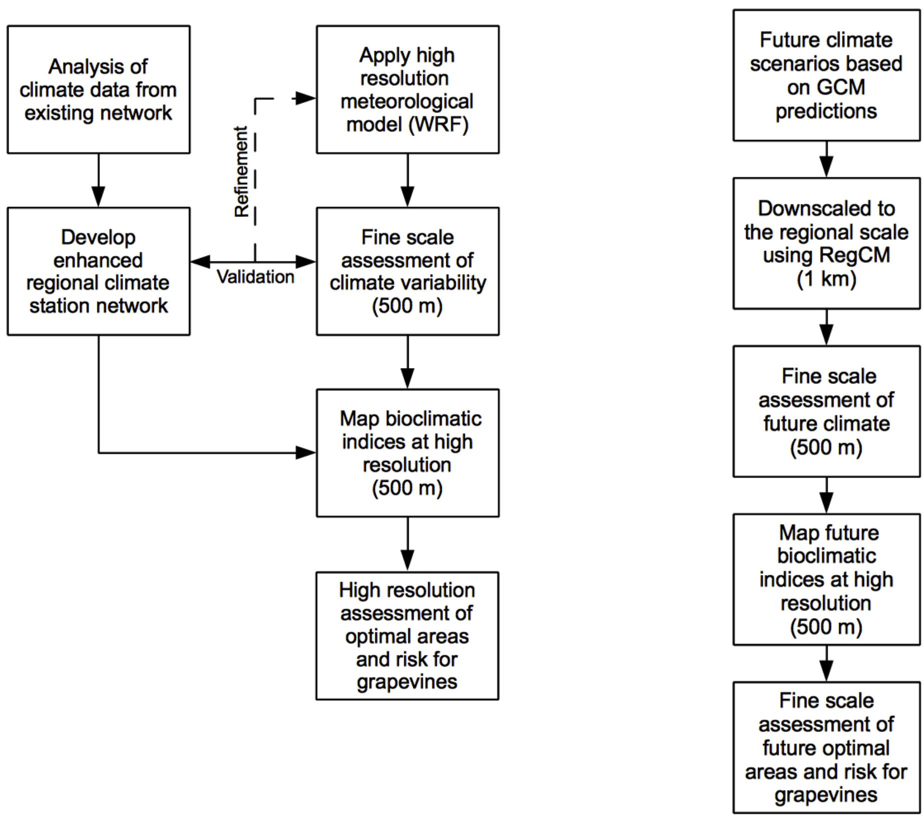

Fig. 2: Schematic illustration of the research strategy being used to assess a) the current status of vineyard areas from a microclimate point of view, and b) possible implications of future climate variations.

The main analysis tools used in this research therefore comprise field data collection, three-dimensional atmospheric numerical models, statistical and geostatistical techniques, and geographic information systems. To understand possible impacts of changing climate on viticulture, it is first important to obtain good knowledge of the local climate within a vineyard area and the atmospheric processes that control it, hence measurement of climate at a reasonably high resolution (kms to 100s of metres) in such areas is an important aspect of the research. Development of advanced computer modeling capability over recent decades allows high-resolution atmospheric modelling to complement measurement networks in helping to improve understanding of the processes responsible for local scale climate variability. The available data can be used to validate models, while the models themselves provide a much higher resolution view of the effects of the terrain on local climate. A combination of numerical and statistical modeling techniques can also be applied to evaluation of strategies for maintaining the long term sustainability of vineyard areas in a changing climate. These analysis tools can also be used to evaluate risk associated with the climate resource (e.g. from frost, wind, flood or drought), and its possible exacerbation due to predicted future climates.

3. Initial results

As a first stage of this research, climate variability over recent decades has been evaluated for Marlborough in comparison with other key vineyard areas of New Zealand, and recognized bioclimatic indices have been used to assess the significance of observed variations for viticulture. Initial analysis of trends of monthly mean, and mean monthly maximum and minimum, temperature suggests that the Marlborough and North Canterbury areas differ from other regions such as Nelson, Hawkes Bay and Central Otago in terms of observed trends (Sturman and Quenol, 2011; Powell et al, 2011). The long term warming trend shown in other regions appears to be largely absent and the temperature range in the two east coast South Island areas appears to have increased significantly. Analysis of changes in synoptic scale weather patterns over the same period suggests that this change in temperature regime has resulted from an increase in the frequency of anticyclones and westerly flow over the South Island.

Also, automatic weather stations and a vertical atmospheric profiler (SODAR – Sound Detection and Ranging) have been installed in the Marlborough region to investigate in more detail the local climatic environment of the vineyard area, with an initial focus on the particular characteristics of the frost risk. Information from these measurement systems has been complemented by three-dimensional numerical modelling of atmospheric processes using the Weather Research and Forecasting (WRF) model at a spatial resolution of 500 m over the region, to provide a better understanding of the controls of the spatial variability of frost risk. The nested grid setup used for the simulations is shown in Figure 3. Results from case studies indicate that the terrain interacts in a complex way with the larger scale weather patterns and local airflow generated by cold air drainage at night, creating low-level jets that interfere with surface cooling processes in some areas. Understanding the spatial pattern of frost over the vineyard area on cool nights therefore requires more knowledge than is typically available from existing surface observations alone, reinforcing the need to undertake three-dimensional modelling studies to fill the gaps.

The same three-dimensional atmospheric numerical model (WRF) has been run for a whole year with the aim of characterizing the spatial (3 km resolution) and temporal (hourly) variability of climate within the vineyard areas. Model runs have so far been limited to just one growing season (June 2008 to May 2009) because of the significant computer resources required. The results provide a good regional picture of climate variability across Marlborough. The enhanced climate station network has been used to validate the model results, with bioclimatic indices being derived at reasonably high resolution for the whole region. These model-derived indices provide the opportunity for developing and testing phenological models of vine development at high spatial resolution through the growing season, incorporating climatic data at a much higher resolution than are available from the existing climate station network.

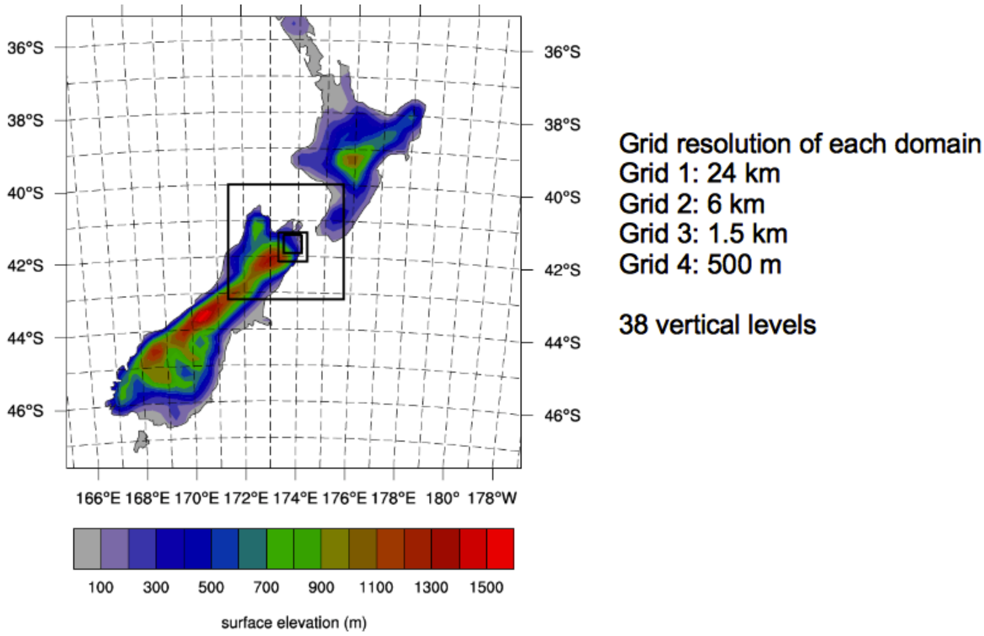

Fig. 3: Nested grid setup for the WRF model case study simulations for Marlborough.

4. Discussion and conclusions

The involvement of New Zealand scientists in the international collaborative climate-viticulture research programme TERVICLIM/TERADCLIM has provided an impetus for new investigations to be undertaken of the relationship between climate and the grapevine at a fine scale in this country, with the aim of improving the knowledge available to ensure viticultural activities respond appropriately to future variations in climate. Marlborough has been chosen as the initial study area in New Zealand because it is by far the most productive of the country's wine regions. Coincidentally, it appears that recent variations in the climate regime of this region differ significantly from other major wine-producing regions in New Zealand, which makes it even more interesting to study. Work completed so far has indicated that this difference is due to the interaction of changing atmospheric circulation patterns over the last several decades with the complex terrain of the South Island. Initial results of this research programme have already provided significant new insights into the relationship between the grapevine and local climate in one of New Zealand's iconic wine-producing areas.

Acknowledgments

This research has benefitted from funding provided by the International Mobility Fund managed by the Royal Society of New Zealand, as well as under the TERVICLIM Project "*Observation et Modelisation spatiale du climat a l'echelle des terroirs viticoles dans un contexte de changement climatique*", programme no. JC07_194103, CNRS, France. The authors are also grateful for continuing logistical support provided by the Department of Geography, University of Canterbury, New Zealand and the COSTEL Laboratory, University of Rennes 2, France.

References

Briche, E., H. Quénol, G. Beltrando, 2011: Changement climatique dans le vignoble champenois. L'année 2003, préfigure-t-elle les prévisions des modèles numériques pour le XXIe siècle? *L'Espace Géographique* 2/11: 164-175.

Chuine, I., P. Yiou, N. Viovy, B. Seguin, V. Daux, E. Leroy Ladurie, 2004: Grape ripening as a past climate indicator. *Nature* 432: 289–290.

Garcia de Cortazar, A. I., 2006: *Adaptation du modèle STICS à la vigne (Vitis vinifera L.). Utilisation dans le cadre d'une étude du changement climatique à l'échelle de la France*. Thèse de doctorat de L'Ecole Supérieure Nationale d' Agronomie, Montpellier, 175p.

Hall, A., G.V. Jones, 2009: Effect of potential atmospheric warming on temperature-based indices describing Australian winegrape growing conditions. *Australian Journal of Grape and Wine Research* 15: 97-119.

Jones ,G., 2006: Climate change and wine: observations, impacts and future implications. *Wine Industry Journal* 21: 21-26.

Jones, G.V., R.E. Davis, 2000. Using a synoptic climatological approach to understand climate/viticulture relationships. *International Journal of Climatology* 20: 813-837.

Jones, G.V., M. Moriondo, B. Bois, A. Hall, A. Duff, 2009: Analysis of the spatial climate structure in viticulture regions worldwide. *Bull. OIV* 944-946:507-518.

Neethling, E., G. Barbeau, H. Quénol, C. Bonnefoy, 2011: Evolution in climate and berry composition for the main grape varieties cultivated in the Loire Valley (France). (*submitted*)

Powell, S., A. Sturman, H. Quénol, 2011: Changement climatique et variabilité spatiale du climat dans les vignobles de Marlborough (Nouvelle Zélande). In Proc of *XXIVth Congress of Association Internationale de Climatologie*, *6-11 September 2011, Rovereto (Italy),* 486-491.

Schultz H.R., 2000: Climate change and viticulture: a European perspective on climatology, carbon dioxide and UV-B effects. *Australian Journal of Grape Wine Research* 6: 2-12.

Seguin, B., I.G. de Cortazar, 2005: Climate warming: Consequences for viticulture and the notion of `terroirs' in Europe. *Acta Horticulturae* 689: 61-69.

Sturman, A. and Quénol, H. 2011: The effect of changes in atmospheric circulation on temperature trends in the major vineyard region of Marlborough, New Zealand. *(submitted).*

Van Leeuwen, C., P. Friant, X. Choné, O. Tregoat, S. Koundouras, D. Dubourdieu, 2004: Influence of climate, soil, and cultivar on terroir. *American Journal of Enology and Viticulture* 55: 207-217.

Webb, L., P.H. Whetton, E.W.R. Barlow, 2007: Modelled impact of future climate change on the phenology of winegrapes in Australia. *Climate change and Grapevine Phenology* 13: 165-175.