APPLICATION OF HIGH-RESOLUTION CLIMATE MEASUREMENT AND MODELLING TO THE ADAPTATION OF NEW ZEALAND VINEYARD REGIONS TO CLIMATE VARIABILITY

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Abstract
Initial results are presented of research into the relationship between climate variability and viticulture in New Zealand vineyards. Atmospheric modelling and analytical tools are being developed to improve adaptation of viticultural practices and grape varieties to current and future climate. The research involves application of advanced local and regional scale weather and climate models, and their integration with grapevine phenological and crop models. The key aims are to improve adaptation of grape varieties to fine scale spatial variations of climate, and reduce the impact of climate variation and risk factors such as frost, cool spells and high temperatures. Improved optimization of wine-grape production through better knowledge of climate at high resolution within vineyard regions will contribute to the future sustainability of high quality wine production. An enhanced network of automatic weather stations (AWS) has been installed in New Zealand's premier vineyard region (Marlborough) and the Weather Research and Forecasting (WRF) model has been set up to run twice daily at 1 km resolution through the growing season. Model performance has been assessed using AWS data and the model output is being used to derive high-resolution maps and graphs of bioclimatic indices for the vineyard region. Initial assessment of model performance suggested that WRF had a cold bias, but this was found to be due to errors in the default surface characteristics. Spatial patterns of predicted air temperature and bioclimatic indices appear to accurately represent the significant spatial variability caused by the complex terrain of the Marlborough region. An automated web page is being developed to provide wine-producers with daily up-dates of observed and modelled information for the vineyard region. Latest results of this research will be provided along with a review of the 2013-14 growing season, using data from both the climate station network and WRF model output.

Keywords: climate variability, viticulture, meteorological network, high-resolution climate modelling, Marlborough, New Zealand

1 INTRODUCTION

The wine industry is highly sensitive to variations in weather and climate, which can significantly affect both the quantity and quality of wine produced in a given year (Trought 2005). An inter-disciplinary research programme is underway, applying climate measurement and modelling techniques at high resolution in key wine-producing regions of New Zealand to evaluate the risks posed by short and longer-term climate variability. These atmospheric models are being integrated with new phenological and crop models to help develop appropriate adaptation strategies to ensure long-term sustainability of the industry.

The cool, temperate conditions found in New Zealand result in fine, flavoursome wines, but small fluctuations in temperature can significantly affect grapevine yield and wine aromas. In Marlborough, New Zealand's most important vineyard region by area and volume of wine produced, this problem is accentuated as marked spatial variations of temperature are often observed. As a result, spatial differences in grapevine development have to be managed at harvest to maintain consistency of supply and wine style (Trought 2011). Methods are needed to quantify seasonal fluctuations in grapevine phenology and yield across vineyard regions in complex terrain, as managing yields year-to-year is important if a consistency of wine style is to be achieved. Geographic factors produce significant spatial climate variability to which many vineyard areas have become adapted. This spatial variability of climate affects the robustness of a vineyard region to long-term climate change, because as some parts of the region may become unsuitable for specific grape varieties, other parts may take their place (Jones et al, 2009; Seguin and Garcia de Cortazar-Atauri, 2005). Investigation of small-scale climate variations within existing vineyard areas is therefore an important first step in developing a strategy for adapting to climate change. The current research adopts a multi-scale approach that has been developed to address this problem by integrating measurement and modelling techniques at a range of time and space scales.

The current research includes measurement of climate at the local scale using enhanced networks of sensors and data loggers located to capture the range of topographic situations within the Marlborough region, and application of high-resolution weather and climate and phenological models to map the climate and potential plant response at vineyard (~100 m) scales, validated using the available measurements. Investigation of temporal trends of air temperature in the vineyard region using pre-existing data has already identified a strong relationship between local climate and larger scale atmospheric processes (Sturman and Quénol 2013). The current paper outlines recent progress made in the high resolution monitoring and modelling of temperature and phenology within the region, and provides some initial results of the work completed to date.

2 MATERIALS AND METHODS

An enhanced network of climate sensors and data loggers has been established in the Marlborough vineyard region through the addition of 11 new automatic weather stations (AWS), bringing the total number of AWS in the region to 37 (Figure 1). The 11 new AWS record data every 10 minutes, in addition to pictures of the vineyard collected using time-lapse cameras every 3 hours between 7 am and 7 pm. AWS sensors include wind speed and direction at 5 m, air temperature at 1.5 and 5 m, relative humidity at 1.5 m, solar radiation, atmospheric pressure, soil moisture at -2 cm, soil temperature at -2 cm and -30 cm, and a time-lapse camera (facing north, taking pictures of vineyard) mounted at 3 m. A quality controlled database has been established since mid-2013.

To complement the field measurements, the advanced physics-based three-dimensional numerical weather model (Weather Research and Forecasting – WRF; http://wrf-model.org/index.php) is being used to represent high-resolution spatial variation of the meteorology over complex terrain within the vineyard region over a time frame from hours to years, and model output is being validated using data from the enhanced measurement network. The WRF model runs use a set of nested grids to allow the downscaling of larger scale atmospheric processes to the local scale, where the influence of complex terrain can be represented by the high-resolution grid (Figure 2). The nested grid approach is based on grid dimensions shown by the black boxes in Figure 2a. This approach allows enhanced model spatial resolution (27, 9, 3 and 1 km, respectively) while preserving practical computer run times. The model configuration was selected based on numerous experiments and optimizations aimed at properly resolving the variation of climate within the valley, and the key physics schemes used in the WRF model runs are listed in Table 1.

Hourly meteorological data are currently obtained operationally at 1 km resolution over the Marlborough region from the WRF model to allow reasonably high resolution mapping of variables that are important to viticulture (as shown in Figure 3). Bioclimatic indices that reflect the response of the grapevine to its environment, such as the Grapevine Flowering Veraison model (GFV) (Parker et al. 2011), are also being derived from mean daily air temperature data.

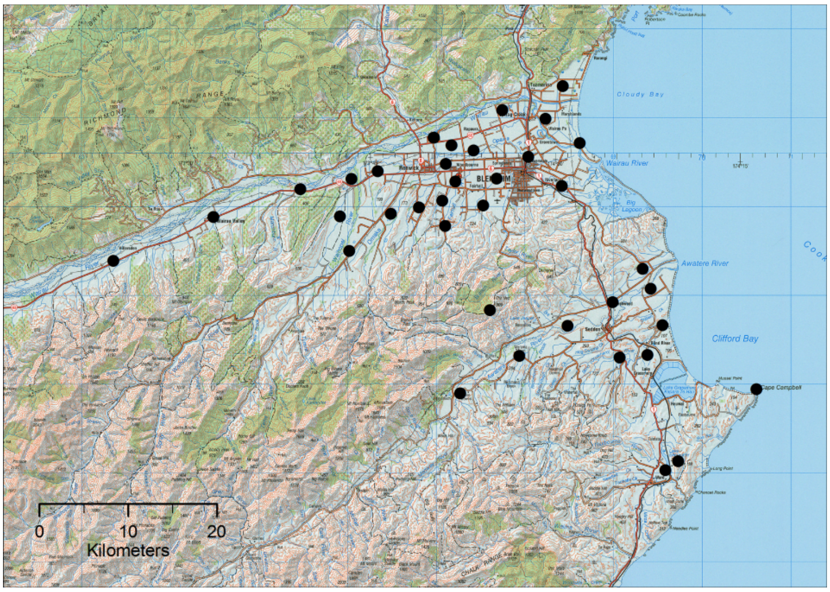

Figure 1: The location of automatic weather stations in the Marlborough vineyard region.

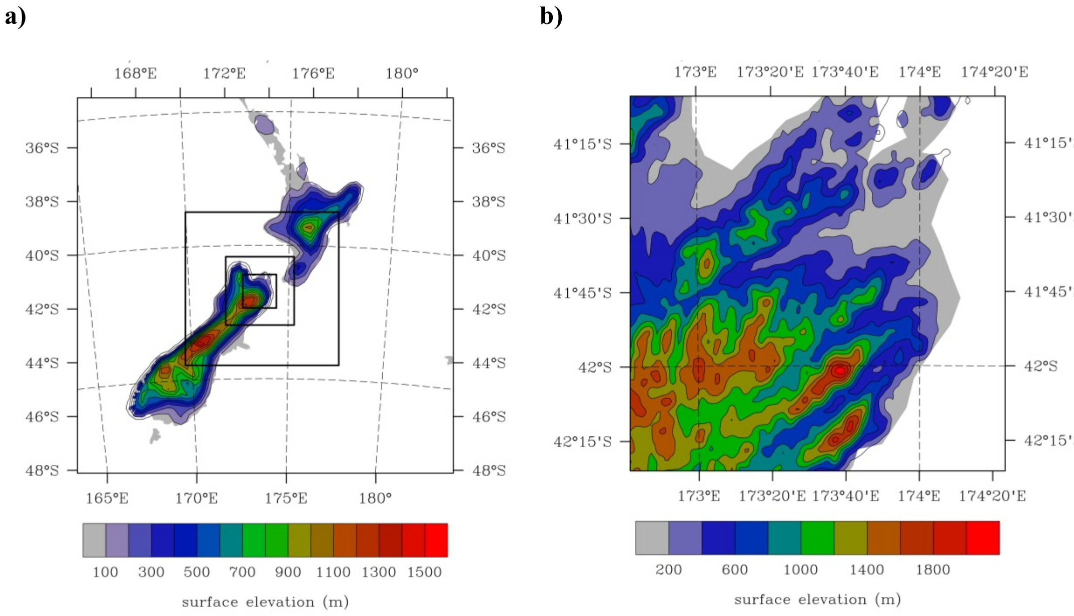

Figure 2: Weather Research and Forecasting model nested grid configuration, showing terrain height, a) for all four grid domains, and b) the high-resolution domain (grid 4).

Table 1: Physics schemes used in the Weather Research and Forecasting model runs.

	Scheme used	**Source**
Microphysics	Kessler	Kessler (1969)
Long-wave radiation	RRTM	Mlawer et al. (1997)
Short-wave radiation	Dudhia	Dudhia (1989)
Surface layer	Monin-Obukhov	Janjic (1994)
Land surface scheme	NOAH LSM with four soil layers	Ek et al. (2003)
Boundary layer scheme	Yonsei University (YSU)	Hong et al. (2006)
Cumulus parameterisation	Updated Kain-Fritsch scheme (domains 1 and 2 only)	Kain (2004)

3 RESULTS AND DISCUSSION

The network of AWS in the Marlborough region was expanded to 37 in April/May 2013 by the addition of 11 sites, and meteorological data have been collected from all sites since then. The data have been used for validating model output, based on both raw data and derived bioclimatic indices. In the latter case, the Grapevine Flowering Veraison (GFV) growing degree day (GDD) model (Parker et al. 2011, Parker et al. 2013) was applied using a base temperature of 0°C to derive accumulated GDD totals from the model-derived temperature data which were then compared with values obtained from the AWS sites. An end-of-season example of a GFV growing degree day map is provided in Figure 4, clearly showing the effect of topographic factors on accumulated growing degree days, including altitude and distance from sea.

Preliminary model calibration and validation tests have been conducted for the first part of the growing season (September to December 2013) using a range of meteorological variables including pressure at mean sea level, relative humidity, air temperature and wind components. Output data from the 4th domain of the WRF model with 1-km horizontal resolution were used to evaluate the meteorological model performance. For the Marlborough vineyard region, data from the nearest grid points to the geographic location of selected automatic weather stations were extracted for comparison with observed data for the initial period of analysis. Modelled mean daily temperatures at approximately two thirds of the AWS were found to be within 1.5ºC of observed values, with a consistent cold bias across the vineyard area. Figure 5 provides a comparison of GFV-based growing degree day totals derived from WRF-predicted temperatures with those derived from automatic weather stations observations, reflecting the cold bias in the model output. Statistical analysis shown in Table 2 provides an assessment of model performance in representing air temperature at the Blenheim Airport site.

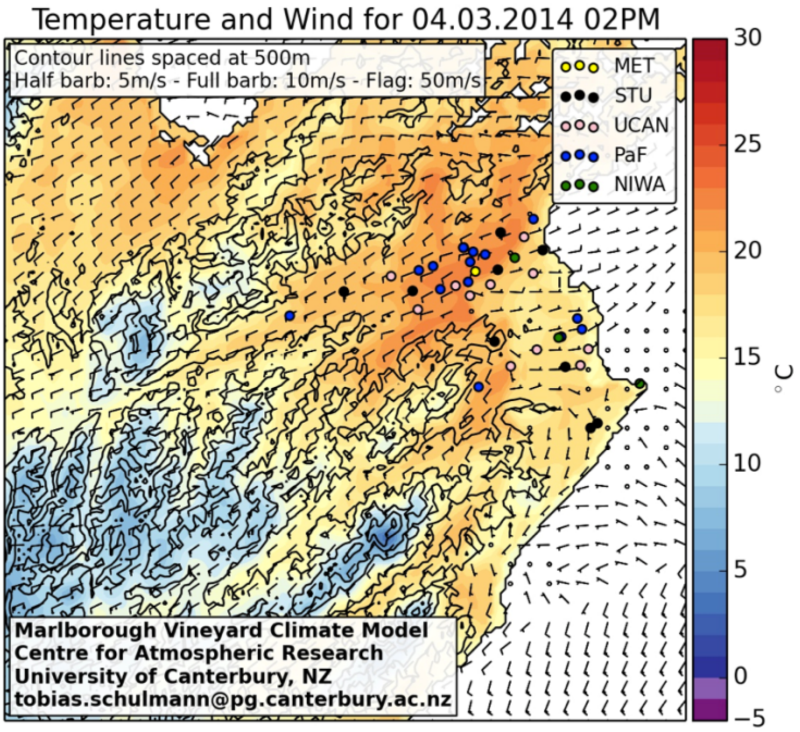

Figure 3: Example of the operational output of hourly temperature and wind from the Weather Research and Forecasting model for the Marlborough region, 1400h on 4 March 2014.

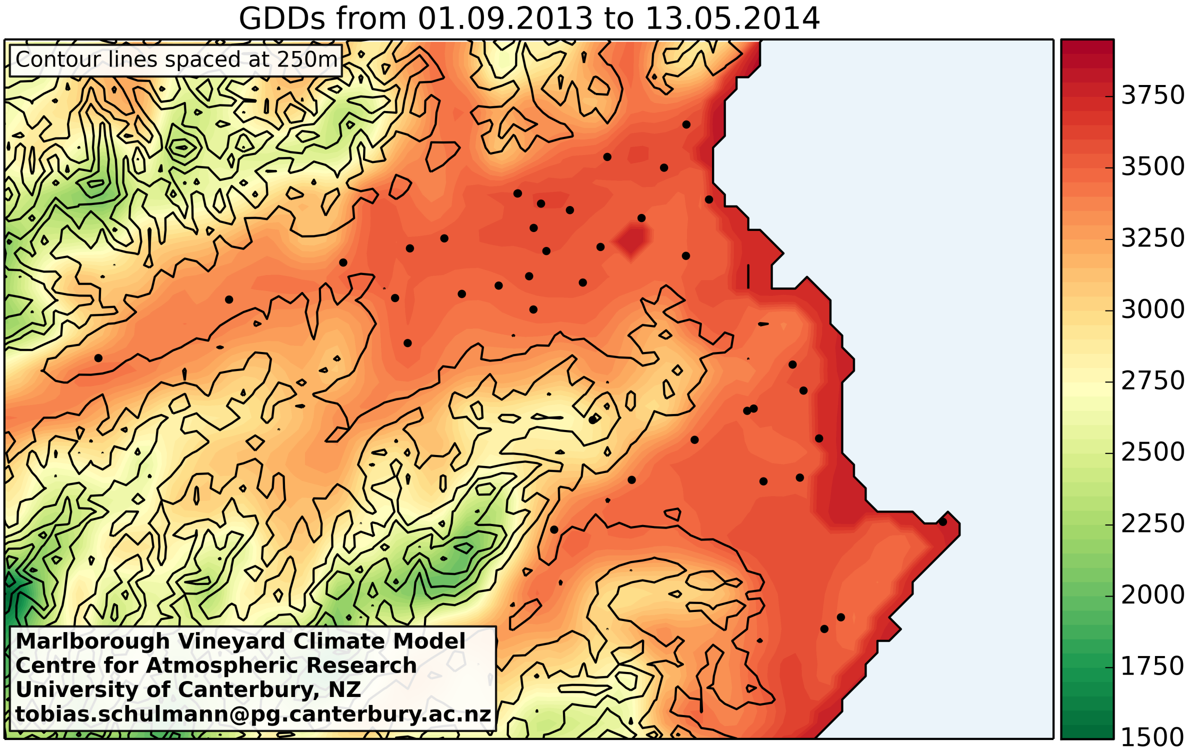

Figure 4: Example of growing degree day map of the Marlborough vineyard region derived using the Grapevine Flowering Veraison model based on Weather Research and Forecasting model temperatures, 1 September 2013 to 13 May 2014. Black dots indicate AWS locations.

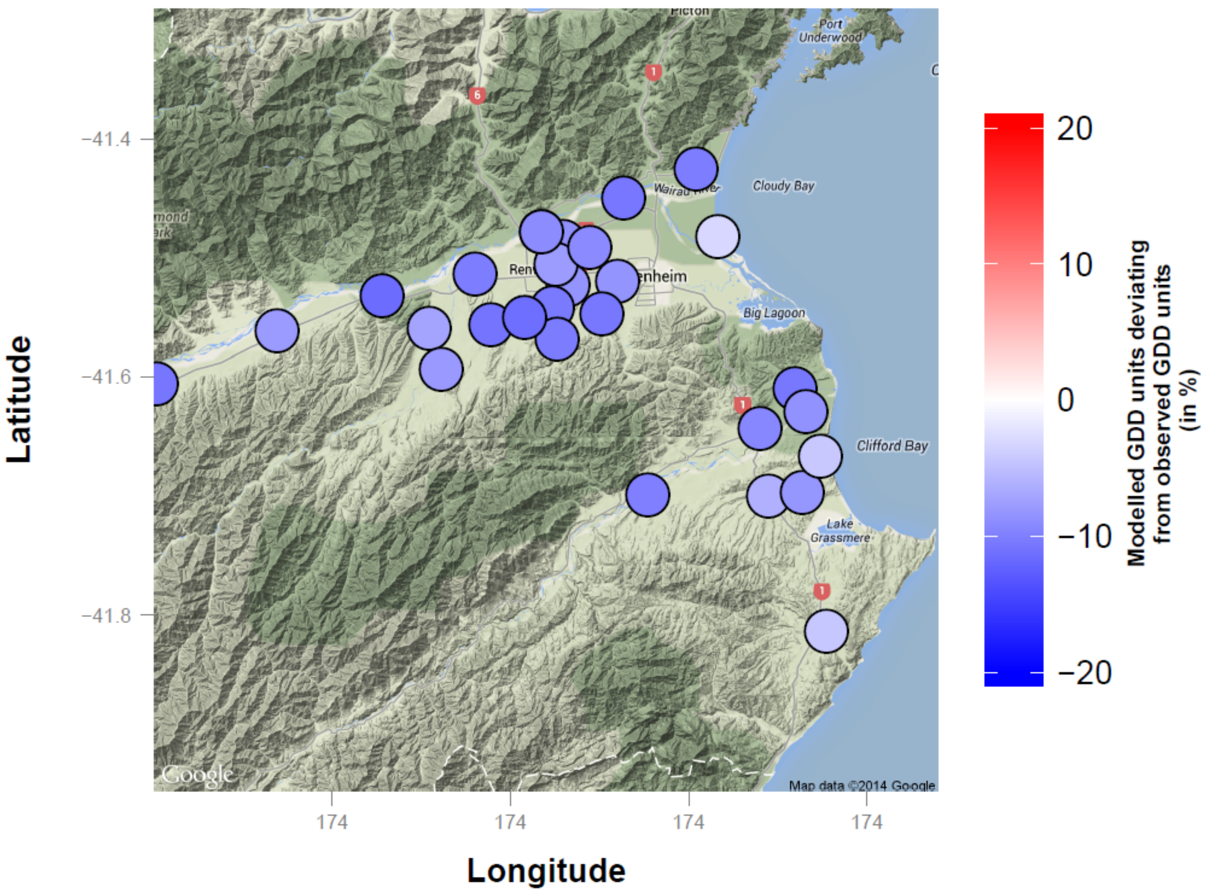

Figure 5: Percentage difference between Grapevine Flowering Veraison growing degree day accumulation based on Weather Research and Forecasting model temperatures and values obtained from the automatic weather station network, for 1 September to 31 December 2013.

Table 2: Statistical analysis of mean daily air temperature obtained from the Weather Research and Forecasting model and automatic weather station observations for Blenheim Airport for 1 September to 31 December 2013. R = correlation coefficient, IOA = index of agreement, RMSE = root mean square error.

Mean		Standard deviation		Number of observations		Statistics			
Observed	**Modelled**	**Observed**	**Modelled**	**Observed**	**Modelled**	**R**	**IOA**	**RMSE**	**Bias**
14.2	13.0	5.2	4.2	2922	2928	0.81	0.99	1.09	-1.18

4 CONCLUSION

The research results presented here are derived from an innovative combination of meteorological and phenological measurements with the high-resolution WRF weather prediction model and the recently developed GFV phenological model (Parker et al. 2011). They demonstrate the feasibility of applying advanced weather/climate modelling techniques to improve understanding of the relationship between viticulture and the climatic environment, so that wine production can be better adapted to climate variability.

During early stages of the 2013-2014 growing season the WRF model demonstrated a weak but consistent cold bias across the Marlborough region, resulting in a ~10% reduction in GFV growing degree days when compared with values obtained from the AWS network. Further work will investigate the cause of the cold bias and identify possible changes to model settings required to eliminate it. WRF model runs for five growing seasons (2008-2014 at 1 km resolution) will be completed and downscaled to finer spatial resolution (<100 m) using the ANUSPLIN interpolation software (Hutchinson and Gessler 1994), with the aim of representing sub-WRF model-grid scale variations in air temperature by accounting for higher resolution terrain elevation. The WRF model has been running in operational mode during the 2013-2014 growing season with accumulated GDD values being updated daily on a prototype web site. The bias-corrected results are already being applied to an improved understanding grapevine phenology in the Marlborough region (Parker et al. 2014), and will be extended to other areas of New Zealand.

Understanding microclimate variability at high resolution within the Marlborough region has implications for optimal grape variety selection, as well as evaluation of impacts on vineyard operation and wine production. A long term aim is to create a strategic decision-making tool to assist wine-producers to adapt to current and future climate variability, both in New Zealand vineyards and elsewhere in the world.

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