Investigation of grapevine areas under climatic stress using high-resolution atmospheric modelling: case studies in South Africa and New Zealand

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Abstract

High-resolution atmospheric simulations (500 m) were used to assess viticultural areas under climatic stress in South Africa and New Zealand. The potential areas in which high daytime temperature stress was likely to affect grapevine photosynthesis and grape composition were identified. Results indicated different diurnal temperature variations within the two areas due to synoptic and local environmental factors, often associated with the influence of terrain.

1. Introduction

Identification and characterisation of viticultural environments are of importance for the expanding wine industries of 'New World' countries such as South Africa (Carey et al., 2008) and New Zealand (Tesic et al., 2002). Among environmental factors contributing to successful vineyard areas, climate variables, especially temperature, have an important effect on grapevine growth and on the development of grape aromas and thus wine quality (Coombe, 1987). In some regions of the world, excessive temperatures can create significant stress for the vine, resulting in sub-optimal conditions for wine production (White et al., 2006). Climate monitoring networks are frequently of insufficient spatial resolution to provide a clear picture of the temperature patterns in regions of complex terrain, so that it is not possible to identify sections of a vineyard region that are more susceptible to temperature increases that may result from possible global warming. Spatial mapping of temperature by means of mesoscale atmospheric modelling has therefore been performed over several wine-producing regions. The Regional Atmospheric Modelling System (RAMS) has been used to investigate sea breeze circulations over the vineyards of the South Western Cape in South Africa (Bonnardot et al., 2005). These numerical simulations showed that, for local circulations forced by topography and surface contrasts, the use of a high horizontal resolution (< 1 km) was of great value in characterising the climate potential of viticultural environments (Bonnardot and Cautenet, 2009). Increasing resolution is therefore considered necessary to properly identify and characterize the climate of wine-producing regions and to determine their vulnerability. The CCAM (Cubic Conformal Atmospheric Model) has been used to produce a 200 m climatology over the Stellenbosch district (Roux, 2009), while the Advanced Research Weather Research and Forecasting (ARW-WRF) model has been used to investigate climate variability over the Burgundy wine region (Bonnefoy et al., 2010). Similar modelling of wine-producing areas has been conducted in Australia (Lyons and Considine, 2007). This paper shows how advanced high-resolution (500 m) three-dimensional atmospheric numerical models can be used to map spatial and temporal variation of temperature in the wine-producing regions of the Western Cape Province in South Africa and Marlborough in New Zealand.

2. Data and Methods

The WRF-ARW model (Version 3.2.1) used in this study is an open-source model that was developed principally by the National Center for Atmospheric Research (NCAR) and the United States National Oceanic and Atmospheric Administration (NOAA) (Skamarock et al., 2008). It is a regional, state-of-the-art, non-hydrostatic model, based on the physical equations that govern the processes operating in the atmosphere, taking surface information (such as land cover, and soil moisture and temperature) and large-scale atmospheric data (in this case, NCEP FNL Operational Global Analysis data) into account. A series of nested grids was used to reduce computational costs (Jacobson, 2005), while at the same time providing a sufficient spatial resolution. Implementation of the WRF-ARW model consisted of four domains over the wine-producing regions of the Western Cape (South Africa) and Marlborough (New Zealand) (Figure 1).

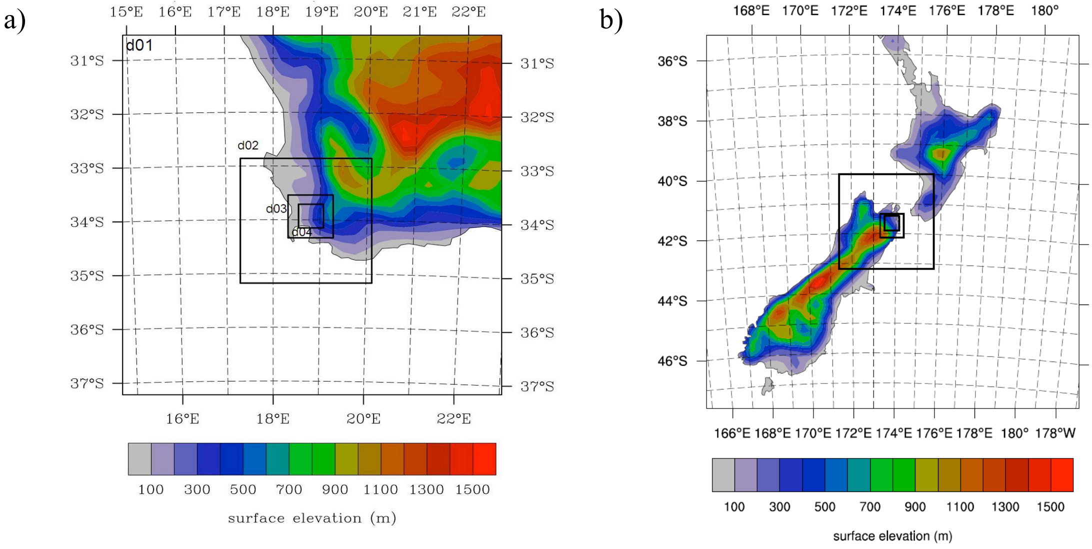

Fig. 1: Grid domains for WRF simulations over a) South Africa, and b) New Zealand.

For simulations over South Africa (Figure 1a), the computational domains represent synoptic circulations (d01), covering much of southwestern Africa and the eastern South Atlantic Ocean, with a coarse horizontal grid spacing of 24 km. The second grid (d02) represents an intermediate scale with a horizontal resolution of 6 km. Domain 3 (d03) is a higher resolution grid (1.5 km) used for investigating local air circulations. The innermost domain (d04) with a horizontal grid spacing of 500 m covers the Stellenbosch wine-producing district, part of False Bay to the southwest corner, and the mountain ranges of Helderberg and Simonsberg, reaching above 1000 m (Figure 2a). The same grid resolutions were used for the New Zealand case (Figure 1b), with d01 covering almost the entire country (24 km), while d02 is located over the northern end of the South Island and part of the North Island (6 km), ensuring that effects of the regional topography are represented. This includes the funnelling effect of Cook Strait between the two islands, the orographic effects of the mountains to the west, and land-sea breeze circulations. The more local terrain effects are captured by d03, which covers the wider Marlborough region (1.5 km), and d04 that is limited to the area immediately surrounding the vineyards (500 m). The four domains for each study region had 38 vertical levels, and the model was run for 72 hours in both cases. The WRF model was initialized at 0000 UTC using NCEP FNL data, which also provided lateral boundary conditions every 6 hours. Physical parameterisations are listed in Table 1.

Numerical simulations of mesoscale meteorology were performed for several periods during the grape ripening season of 2009: 27-29 January and 5-7 March for South Africa, and 8-11 February and 22-25 March for New Zealand. Output data were provided at hourly intervals, and validated against observations obtained from several available meteorological stations. Climate data from the automatic weather station network of the Institute for Soil, Climate and Water of the Agricultural Research Council (ARC-ISCW), situated in close proximity to the vineyards (Figure 2), were used to validate the model output data of South Africa, while meteorological data from the national climate database (managed by the National Institute for Water and Atmospheric Research - NIWA) were used in the New Zealand case.

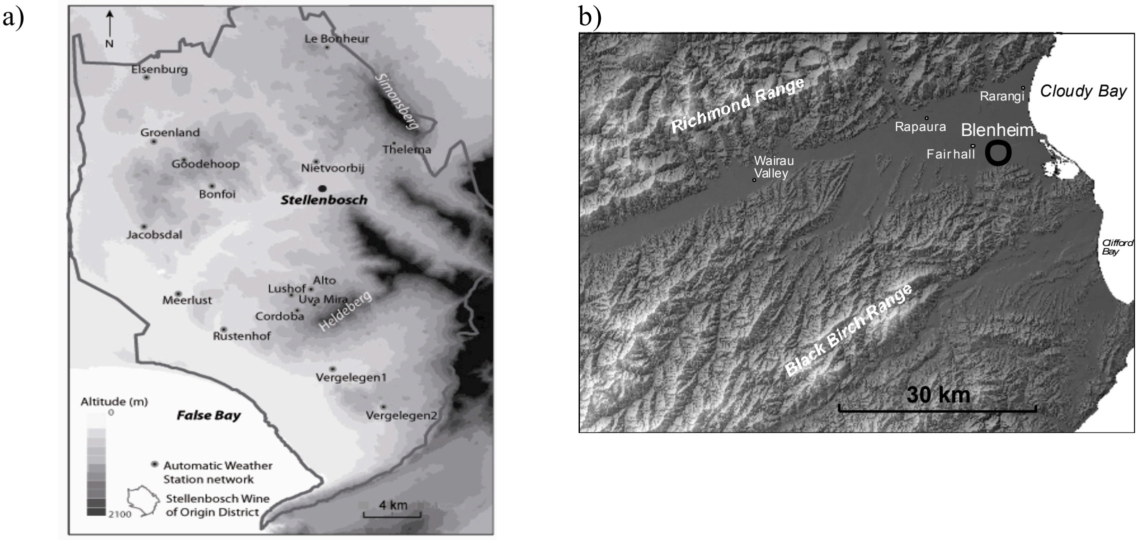

Fig. 2: Location of the automatic weather stations used for WRF model validation within: a) the Stellenbosch wine region of South Africa (ARC-ISCW network); and b) the Marlborough region in New Zealand (data provided by NIWA).

Tab. 1: Parameterisation schemes used in the WRF model runs.

	Scheme used	**Source**
Microphysics	WRF Single-Moment 6-class scheme	Hong and Lim (2006)
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 (for d01 and d02)	Kain (2004)

3. Results

Examples of spatial and temporal variation of temperature at 500 m resolution for South Africa and New Zealand are displayed in Figures 3 and 4, respectively. Figure 3a shows an example of extremely high temperatures over the Stellenbosch wine district. On this day, the vineyards would have experienced high daytime temperature stress for leaf photosynthesis (> 35°C) and for grape colour and flavour (> 25°C), with potential detrimental implications for sugar/organic acid levels in the grapes (Hunter and Bonnardot, 2011). As the southerly winds from False Bay and westerly winds from Table Bay penetrated inland as sea breeze, cooler temperatures progressively released vineyards nearer to the coast from the temperature stress, resulting in moderate climate conditions (Figure 3b).

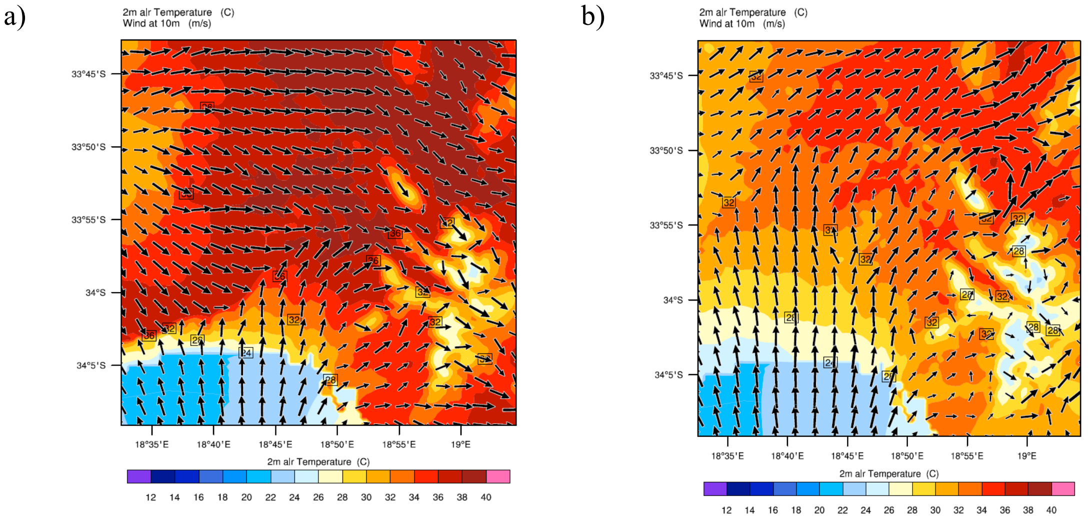

Fig. 3: Air temperature (°C) at 2 m and wind (m s^{-1}) at 10 m over d04 (500 m resolution) and the Stellenbosch region (RSA) on 6 March 2009 at a) 1200 UTC; and b) 1600 UTC.

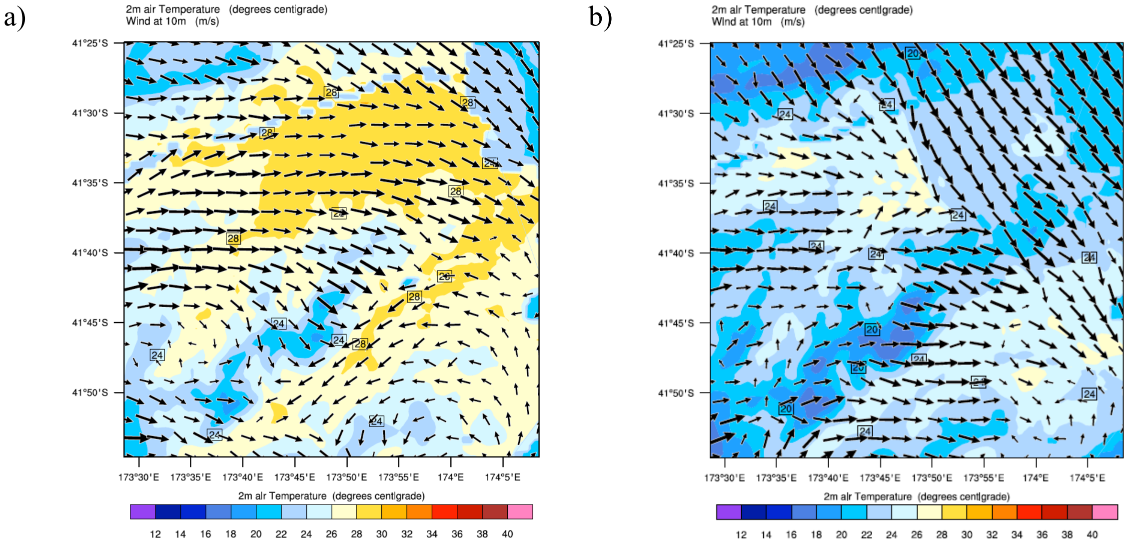

Fig. 4: Air temperature (°C) at 2 m and wind (m s^{-1}) at 10 m over d04 (500 m resolution) and the Marlborough region (NZ) on 9 February 2009 at a) 1200 NZST; and b) 1600 NZST.

The New Zealand case shown in Figure 4 involved a foehn situation with observed temperatures reaching 34°C (30°C modelled temperatures). Westerly winds dominated over the northern part of the area, with evidence of channelling of the wind through

Cook Strait in the northeastern corner of the domain. Onshore winds, which appear to be a local sea breeze, are evident in the lower right section of the domain, penetrating up the Awatere Valley. Comparison of observed and modelled temperatures indicates a relatively good agreement, particularly for the Stellenbosch region (Figure 5).

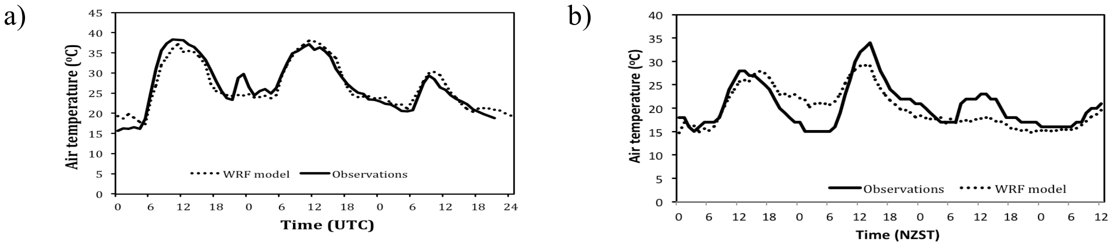

Fig. 5: Comparison between observed and modelled temperature data for a) 5-7 March 2009 at Elsenburg (RSA), and b) 8-11 February 2009 at Blenheim (NZ).

4. Conclusions

On a daily basis, grapevines in the two study areas experienced a range of thermal conditions that would have impacted on vine growth and the development of primary (e.g. sugar and organic acids) and secondary (e.g. colour and aroma) grape quality compounds. These conditions were largely controlled by the prevailing large-scale weather conditions and complexity of the local terrain. The areas in which the vines are likely to be under significant climatic stress were identified in relation to the large-scale weather conditions and for both regions. In particular, areas in which low/high night temperature stress was likely to affect grape composition, and where low/high day temperature stress is likely to affect grapevine photosynthesis, were identified. Results illustrated different diurnal temperature variations due to the inland penetration of the sea breeze, and other local effects (e.g. foehn conditions). These depended on environmental factors, such as the synoptic wind, topography, coastline orientation and slope angle and aspect, with each playing different roles in the thermal regime of the two vineyard regions.

Acknowledgements

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