USING ATMOSPHERIC AND STATISTICAL MODELS TO UNDERSTAND LOCAL CLIMATE AND ASSESS SPATIAL TEMPERATURE VARIABILITY AT A FINE SCALE OVER THE STELLENBOSCH WINE DISTRICT, SOUTH AFRICA.

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ABSTRACT

Atmospheric and statistical models were used to increase understanding of potential climatic impacts, resulting from mesoscale physical processes that cause significant temperature variability for viticulture within the Stellenbosch Wine of Origin district. Hourly temperature values from 16 automatic weather stations and 40 tinytag data loggers located in the vineyards were analysed. The 5th of March 2009 was selected as an example to study the cooling potential of the *terroirs* in radiative weather conditions during grape ripening time. Differences reached more than 10°C between vineyards and can be considered as significant for viticulture. Numerical simulations using the Regional Atmospheric Modeling System were performed. Results for a horizontal grid resolution of 200 m over the Stellenbosch wine region for the 5th of March 2009 showed that the temperature difference was due to cool air accumulation with land and downslope breezes. Surface temperature data recorded in the vineyards were used to produce, by means of multicriteria statistical modelling, which took environmental factors into account, a map of spatial distribution of the daily minimum temperature at a fine scale (90 m). The use of the two models represented an interesting tool to help in identifying the cooling potential of locations for viticulture and, at a later stage, studying the impacts of climate change at fine scales.

KEYWORDS

Atmospheric modelling, statistical modelling, cooling potential, vineyard, South Africa.

INTRODUCTION

Identification and characterisation of diverse environments for viticulture (viticultural *terroirs*) at different scales are of importance for the South African Wine Industry and a focal point of the South African viticultural research. Among environmental factors contributing to viticultural *terroirs*, climate, and especially temperature, has an important effect on grapevine growth, wine quality and character (Coombe, 1987). Various *terroir* studies undertaken in the Stellenbosch Wine of Origin district have shown significant mesoclimatic differences over short distances due to the proximity of the Atlantic Ocean and complex topography (Carey, 2001; Conradie *et al.*, 2002; Hunter and Bonnardot, 2004). Analyses of climatic surface data from the mesoscale *terroir* network of weather stations showed that local air circulation (sea breeze) in this coastal region played a significant role in maximum temperature differences. The sea-breeze induced patterns and the contributing effects of topography to local air circulation were ascertained at 5 km and 1 km scales with numerical simulations performed over this wine-producing region using a mesoscale atmospheric modelling system (Bonnardot *et al.*, 2002; 2005). More recent simulations (Bonnardot and Cautenet, 2009) have shown that, for local circulations forced by topography and surface contrasts, the use of a high horizontal resolution (200 m) was of greater value in the characterisation of viticultural *terroir*.

Increasing resolution is therefore necessary to fully represent the vineyard-site climate. In this regard, a terroir project piloted by the Department of Viticulture and Oenology of the Stellenbosch University is making use of a network of tinytag data loggers together with a mesoclimatic network of automatic weather stations to characterize surface temperature variation in the Cabernet Sauvignon and Sauvignon blanc *terroirs* of the Stellenbosch Wine of Origin district since 2004 (Carey, 2009). The fine scale network consists of 20 tinytag data loggers situated in rows of Cabernet Sauvignon and Sauvignon blanc vineyards and the mesoclimatic network consists of 10 automatic weather stations situated in the same study area. Both networks are included within an approximately 20 km × 20 km surface. On the other hand, the ANR-TERVICLIM program undertaken in 2008, which aims at mapping climatic parameters at a fine scale in different worldwide wine regions in the context of climate change, suggests, as a first step, a methodology which helps in understanding local climate keys. Thermal measurements using tinytag data loggers located in vineyard rows are also used to study the thermal variability, in space and time, along with phenological monitoring (Coulon *et al*., 2009; Bonnefoy *et al.*, 2009). Within the TERVICLIM program, thermal measurements are then used to produce spatial distribution of temperatures at 90 m fine scale by means of multicriteria statistical modelling. Atmospheric modelling is used in parallel to map mesoscale and local physical processes causing temperature variability, similarly to what was done in South Africa (Bonnardot *et al*., 2002, 2005; Bonnardot and Cautenet, 2009). The last step of the TERVICLIM program is to generate a range of regional climatic impacts using IPCC emissions scenarios from global climate models, thus providing guidance to decision-makers in the wine industries for short and long-term strategy.

Since the Stellenbosch Wine of Origin district has joined other world wine regions investigated in the TERVICLIM program, a 20-data logger network was installed in 2008 in addition to the existing network of the *terroir* project. The resulting 40-tinytag data logger network enables us to fill in gaps in weather data over the study period. Along with atmospheric and statistical models, it enables understanding of local climate keys and the assessement of spatial temperature variability at a fine scale within the study domain.

MATERIALS AND METHODS

The study domain covers a 41 km × 41 km large area within the Stellenbosch Wine of Origin district (Fig.1) in the Western Cape Province of South Africa. The proximity of the Ocean and the complex topography including coastal dunes, a coastal plain, inland hills and steep mountain ranges cause the developpment and the interaction of interesting meso and local scale air circulations, resulting in significant climatic variations for viticulture.

Version 6.0 of the Regional Atmospheric Modelling System (RAMS) (information online at http://www.atmet.com) was used to perform numerical simulations. RAMS is a numerical model based on the basic physical equations which govern the processes operating in the atmosphere. It assimilates observed data to adjust the model state towards observations. It takes surface data (climate, landcover, topography, soil texture) and large scale atmospheric data into account. RAMS uses nested grids to provide high spatial resolution while covering a large domain at lower resolution. In this study, four grids were used. A 25 km coarse grid resolution was devoted to synoptic circulations. The second grid represented an intermediate scale with a horizontal resolution of 5 km. Grids 3 and 4 with horizontal resolutions of 1 km and 200 m were the investigated domains for local air circulations over the Stellenbosch vineyards. Simulations were performed for the 5 and 6th of March 2009 in order to study the cooling potential of the *terroirs* in radiative weather conditions during grape ripening time.

Results for the 200 m grid resolution (Fig.1a) are shown, as an example, for the 5th of March 2009. Climatic data (temperature, relative humidity and wind) from Campbell automatic weather stations of the ARC-ISCW network and situated in proximity to studied vineyards (Fig.1b) were used to validate the ouput modelled data.

In order to reconstruct a fine-scale temperature field, a second approach was used based on multicriteria statistical modelling taking environmental factors into account (Carrega, 1995; Madelin and Beltrando, 2005). Minimum temperature values of the 40 tinytag data loggers located in vineyard rows (Fig.1b) and a stepwise linear multiple regression were used to produce a map of the spatial distribution of minimum temperatures for the 5th of March 2009 as a function of geographical (coordinates) and topographical (elevation, slope, aspect) data, provided by the SRTM 90 m Digital Elevation Model.

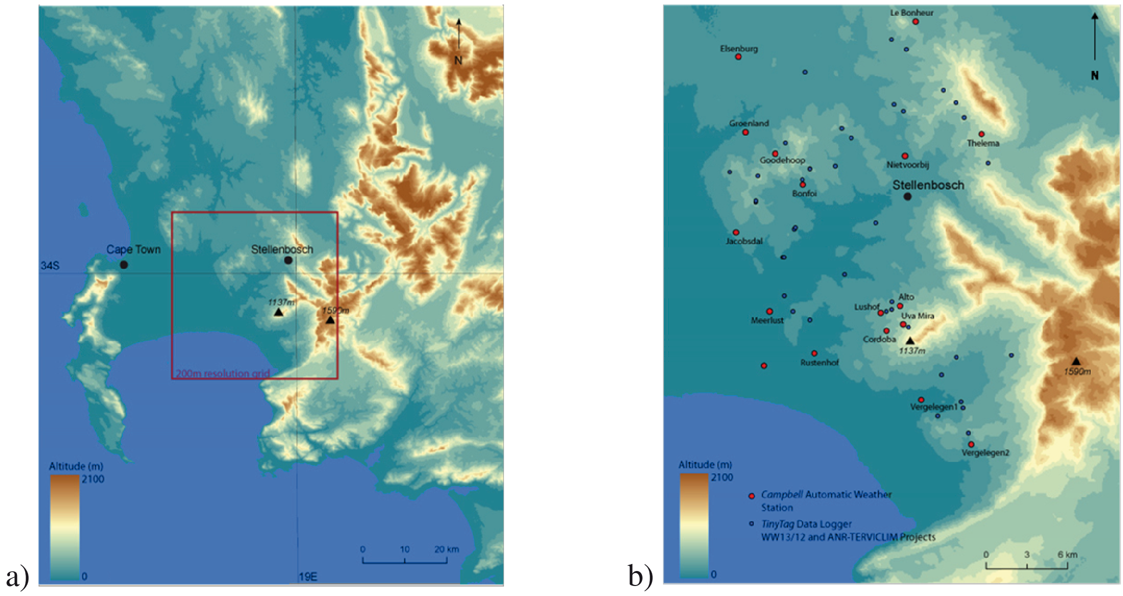

Fig. 1: Study domain in the Western Cape Province of South Africa. The red frame represents the high resolution grid (200 m) for atmospheric modelling (a). Location of automatic weather stations and tinytag data loggers in the vineyards of the Stellenbosch Wine of Origin district (b).

RESULTS AND DISCUSSION

Using daily minimum temperature values of the 5th of March 2009 from the 40 tinytag data loggers, the highest minimum temperature values (23.8°C and 23.4°C) were recorded in vineyards situated at 465 m above sea level (asl) on the southwestern slope of Simonsberg and at 445 m asl on the northwestern slope of Helderberg respectively (Fig. 2a). The lowest value for minimum temperature (11.8°C) was recorded in a vineyard situated at 25 m asl in the Eerste river valley. This represented a difference of 11.6°C over a 12 km distance between the Eerste river valley and the Helderberg slopes. A 10.6°C (12.2°C) temperature difference was observed over a 6 km (12 km) distance on the western slope of Simonsberg. In the Helderberg basin, the maximum temperature difference reached 8.2°C between the highest (320 m) and the lowest (135 m) locations, recording 22.1°C and 13.9°C respectively. For this date, as for others with similar anticyclonic weather conditions, a strong correlation was observed between altitude and minimum temperature recorded in vineyards (Fig.2b), with warmer conditions at higher altitudes and cooler conditions at lower altitudes. The highest vineyard's location for our study was 467 m.

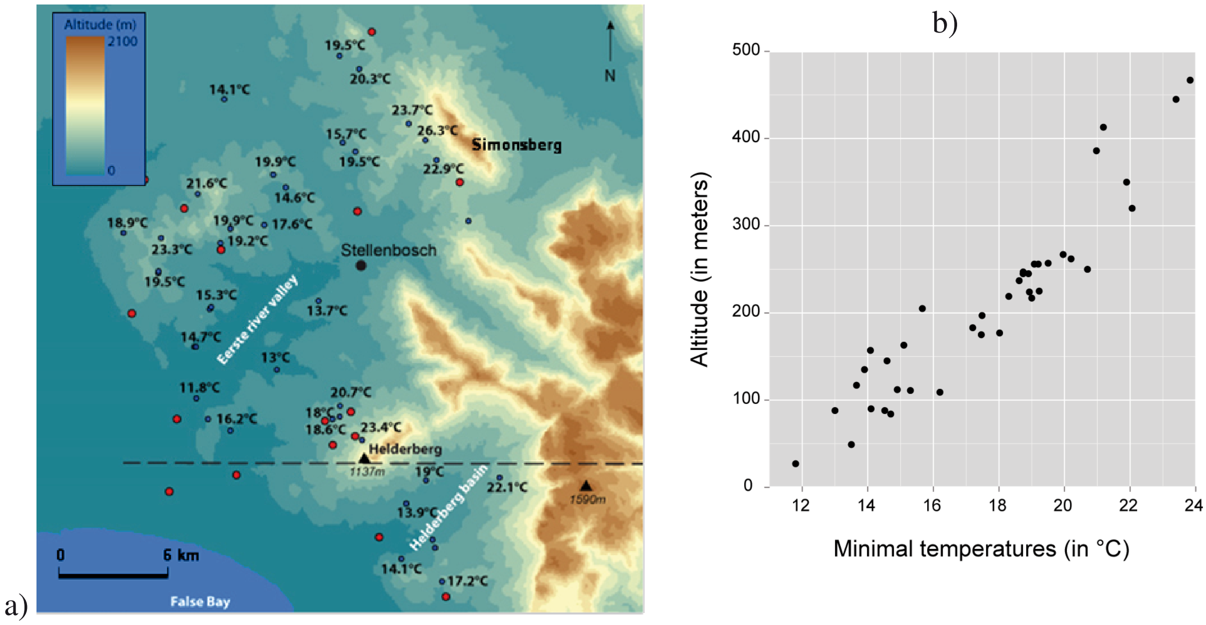

Fig.2: a) Minimum temperature as recorded by the tinytag data loggers on 5/03/2009 in the Stellenbosch Wine of Origin District (dashed line = location of a West-East cross section used in Fig.3) ; b) Corresponding correlation between altitude and minimum temperature ($R^2 = 0.88$).

Analysis of the synoptic weather conditions for the 5th of March 2009 showed that upper (1000 m) winds had a northerly component, corresponding to winds to the west of a high pressure system over the interior (results not shown). Physical processes in the lower atmosphere causing such a temperature variation in the vineyards were investigated using the mesoscale atmospheric modelling outputs. A West-East cross section (Fig.2a) of wind (Fig. 3a) over the study domain at 06:00 South African local time, time at which minimum temperature is usually recorded, showed light (< 2 m/s) land and downslope air circulations (in green) on the westernslope of Helderberg and stable air in the Helderberg basin and valleys to the East. This resulted in cool air accumulation at the end of night at lowest positions in valleys and on lower slopes (Fig. 3b). As shown in Fig.3b, modelled temperature values in the Eerste river valley were the lowest and those on mid westernslopes of Helderberg were the highest as recorded in the vineyards by the tinytags. The thermal inversion represented an approximately 500 m thick layer above the flat terrain of Eerste river valley (Fig.3b), explaining the significant positive correlation between altitude and observed minimum temperature up to an altitude of 500 m (Fig.2b).

Minimum temperature values of the 5th of March 2009 from the 40 tinytag loggers and multicriteria statistical modelling were then used to determine the final model : a stepwise linear multiple regression taking altitude and slope into account (91% of the initial information was explained). Using this model, the daily minimum temperature value was estimated for each point of the DEM grid at a 90 m scale (Fig.4). Due to altitude being the most significant factor (Fig.2b), spatial distribution of minimum temperatures very logically reflected the altitude variation. The estimation of minimum temperature was restricted to areas situated below 600 m asl, as there is no vineyard beyond this altitude. The statistical and atmospheric models outputs displayed complementary information, showing that bottom slopes are cooler than top slopes due to cold wind gravity flow along the slope (Mahrt, 1986).

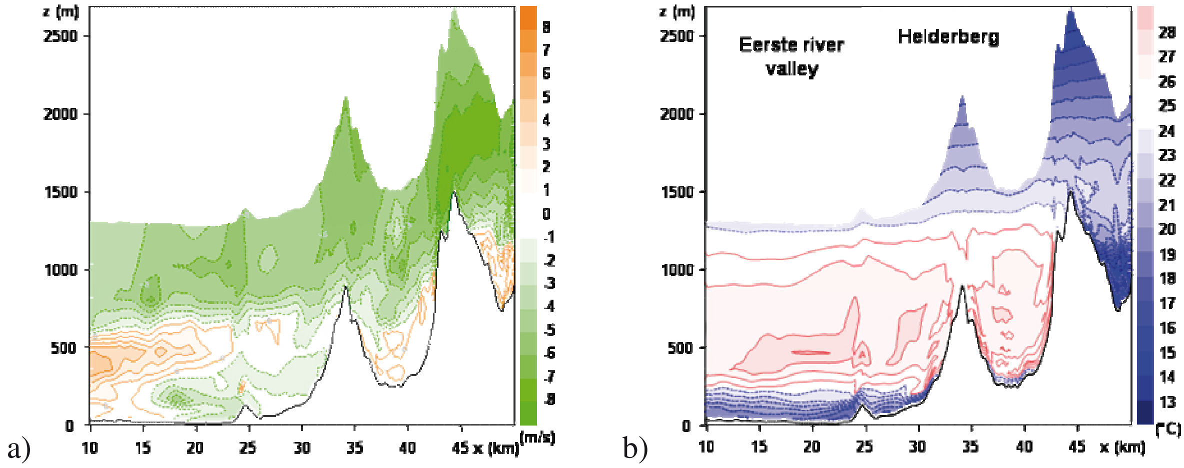

Fig.3: RAMS modelled a) zonal component of wind (m/s) (east in green and west in orange); b) temperature (°C) on 5/03/2009 at 04:00 UTC (06:00 South African time). West-East cross-sections at 34°01’43’’S over the Stellenbosch Wine of Origin district (Fig.2a).

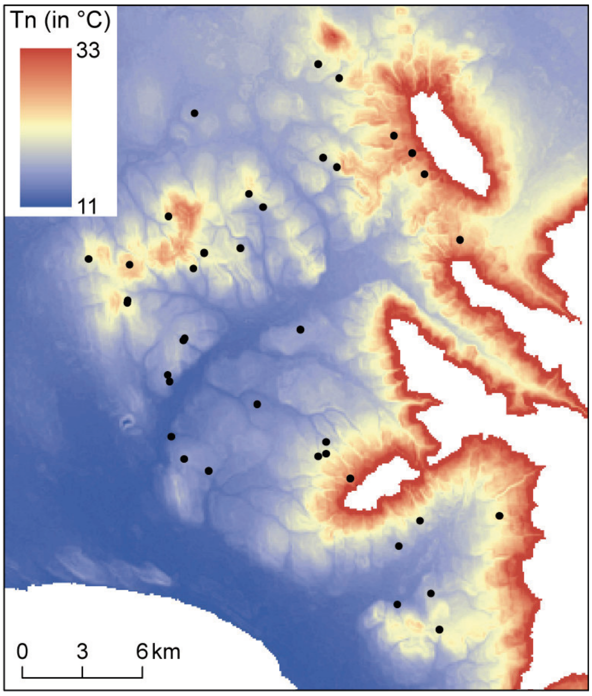

Fig.4: Modelled minimum temperature (Tn) for 5/03/2009 over the Stellenbosch vineyards (WW13/12 and ANR-TERVICLIM projects) using multicriteria statistical modelling.

CONCLUSION

Although the results are based on spatial minimum temperature variability for one particular day, and are thus not necessarily representative of all aspects of minimum temperature variability and night cooling potential during the ripening period, they show that fine scale measurements in vineyards as well as both atmospheric and statistical models represent interesting tools to help in understanding local climatic keys. This can aid in identifying climatic potential of locations for viticulture, providing valuable information for the seeking of ideal cultivar x *terroir* combination. Carried out at fine scales and knowing the interaction with larger scales, this climatic research extends the South African *terroir* knowledge and represents an important step towards quality and sustainable wine production.

Further atmospheric and statistical modelling investigations are in progress for different weather conditions during the growing and ripening period. Observed soil and land cover characteristics for the high resolution grid (200 m) are being assimilated into RAMS in order to better adjust the model state towards observations. It is expected that in the furture this work will contribute to studying the impacts of climate change at fine scales.

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