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			✓

Indicate (X) client(s) to whom this final report is submitted.
Replace any of these with other relevant clients if required.

FINAL REPORT
FOR 2012

PROGRAMME & PROJECT LEADER INFORMATION

	Programme leader	Project leader
Title, initials, surname		Dr VA Carey
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PROJECT INFORMATION

Project number	US B/C
Project title	Agroclimatic analyses for viticultural terroir studies
Project Keywords	Climate; Stellenbosch, Viticulture,

Industry programme	**CFPA**	
	Deciduous	
	DFTS	
	Winetech	Cultivation (Terroir)
	Other	

Fruit kind(s)	Grapes
Start date (dd/mm/yyyy)	01/01/2005
End date (dd/mm/yyyy)	31/12/2011

FINAL REPORT

(Completion of points 1-5 is compulsory)

1. Executive summary

Give an executive summary of the *total* project in no more than 250 words

The aim of this project was to obtain the services of Dr V Bonnardot to provide expert climatological support to terroir projects registered with Winetech. However, her work sometimes went beyond the terroir projects, responding to issues of growing concern (climatic change) or giving assistance to number of students at the DVO. She performed quality control of, and analysed, hourly data from the mesoclimatic databank (automatic weather stations and tintytag temperature sensors), as well as providing expert climatic interpretation.

Climatic data were analysed at three climatic scales (macro, meso and local scales) in order to:

- highlight the cooler macro climatic conditions that South Africa experiences compared to those experienced by other wine regions at similar latitudes worldwide.
- describe the climatic potential of each wine region of South Africa
- investigate climate change using long time series
- investigate seasonal climatic variability within the Stellenbosch district
- increase knowledge of spatial variability within the Stellenbosch district.

The six seasons included in this project can be characterized briefly as follows: the 2008/2009 season was the coolest season (upper level of Region III) of the study period; the 2005/2006 season was the driest growing season of the study period; the 2004/2005 and 2009/2010 seasons had the warmest and the wettest growing seasons of the study period and the 2006/07 and 2007/08 seasons could be considered as representative of the average conditions over the study period.

Comparison of the Winkler index values for sites and seasons showed that spatial variability in the Stellenbosch Wine of Origin District was greater than temporal variability. Investigation of minimum temperatures during the period January to March 2009 showed that the temperature differential with change in elevation was greater during radiative weather conditions, with well-known inversion phenomena and downslope cold air drainage, while under advective (cloudy) conditions, the relationship was poorly defined. The frequency with which these different events occur will determine the mean minimum temperature and the relationship of this mean with altitude. Multicriteria statistical modelling, which also took environmental factors into account showed that the range of minimum temperatures varied as a function of geographical factors and synoptic weather conditions but that these modelled maps best represented radiative weather conditions, while regional atmospheric modelling also performed well under advective conditions.

It is necessary to assess climate at fine scales (spatially and temporally) in order to characterise the climatic potential of locations for viticulture.

The results have been largely released under the form of various publications (scientific and popular) and various presentations (oral communication or posters) at local workshops, national and international congresses.

2. Problem identification and objectives

State the problem being addressed and the ultimate aim of the project.

Terroir is a complex concept that requires multidisciplinary study. An integral component of terroir studies is climate, and a climatologist thus forms an integral part of a terroir research team. There are no expert agroclimatologists, with a viticulture specialisation, currently in South Africa. Dr Valérie Bonnardot, an agroclimatologist who has specialised in viticultural applications in South Africa since 1996, returned to France in 2004. Her absence leaves a gap in the multidisciplinary terroir research team which is not easily filled.

The aim of this project will be to obtain the services of Dr V Bonnardot to provide expert climatological support to terroir projects registered with Winetech.

Objectives

1. Analysis of data from mesoclimatic databank.
2. Expert climatic interpretation (this will entail at least a three week visit to South Africa, annually).

3. Workplan (materials & methods)

List trial sites, treatments, experimental layout and statistical detail, sampling detail, cold storage and examination stages and parameters.

Automatic weather stations

Hourly data from eleven automatic weather stations related to WW13/12; namely, Nietvoorbij, Elsenburg, Alto, Bonfoi, Goedehoop, Groenland (destroyed in 2011), Jacobsdal (replaced by Amani in 2009/2010), Le Bonheur, Rustenhof, Thelema and Meerlust for the period 2005 to 2011 were obtained from the ISCW mesoclimatic databank.

Hourly data from automatic weather stations related to WW13/13; namely, Cordoba, Uvamira, Lusthof for the period 2005 to 2009 were obtained from the ISCW mesoclimatic databank.

Hourly data from automatic weather stations related to WW13/16; namely Oak Valley, Beaulieu, Shannon, Eikenhof, Smarag, for the period 2006 to 2010 were obtained from the ISCW mesoclimatic databank.

Analysis of data from mesoclimatic databank

Hourly climatic data were quality controlled and relevant climatic variables and indices were calculated. During the quality control, hourly climatic data was checked for missing and suspicious values. No checks were performed on drifting of the data.

Seasonal data reports and reports on quality of the data were prepared annually.

Analysis of data from Tinytag dataloggers

Twenty Gemini Tinytag Ultra 2 TGU-4500 data loggers were situated in grapevine rows at 1.5 m above the ground at a similar height to the grapevine canopy in a ACS-5050 Stevenson type screen in December 2005 / January 2006. A further twenty Gemini Tinytag Talk 2 TK-4023 data loggers were installed in vineyards in 2008 under the TerViClim international collaborative project. Standardization between loggers was ensured as best as possible (e.g. removal of canopy growth around loggers) to reduce any data alteration. Hourly data was analyzed as for data from the automatic weather station network.

4. Results and discussion

State results obtained and list any benefits to the industry. Include a short discussion if applicable to your results. This final discussion must cover ALL accumulated results from the start of the project, but please limit it to *essential* information.

Milestone	**Achievement**
1. Analysis of data from mesoclimatic databank	Dr Valerie Bonnardot visited South Africa for the periods 13 April 2005 to 6 May 2005; 23 April 2006 to 11 May 2006; 02 November 2006 to 17 November 2006; 3 November 2008 to 21 November 2008; 25 May 2009 to 12 June 2009; 3 November 2008 to 21 November 2008; 25 May 2009 to 12 June 2009, and 5 to 20 February 2012. During these visits she examined the data from the terroir automatic weather stations, calculated the relevant indices and compared each season to the long-term average using data from 1 weather station. Climatic data reports were compiled for each of the three projects (WW13/12, WW13/13, WW13/16). When problems were discovered with the data, these issues were raised with ISCW. When weather stations had to be moved due to vandalism, Dr Bonnardot advised as to new placement of the weather stations.
2. Expert climatic interpretation	Dr Bonnardot gave advice and published on Regional Atmospheric Modelling of the sea breeze influence in the Western Cape (2005; 2009), worked on data for publications resulting from WW13/01 with Dr WJ Conradie, analyzed the long-term climate change in South African wine producing areas, attended a meeting in November 2008, chaired by WINETECH, concerning the climate modeling project of ARC ISCW, where she was able to make contributions,

	assisted Prof A Deloire and students with statistical climatic analyses for their research on Sauvignon blanc and Cabernet Sauvignon (2009).

Highlighted results (compiled from extracts from papers and reports authored by Valerie Bonnardot)

Comparison between the climates of South African wine producing regions and worldwide locations situated at similar latitudes **(Bonnardot, 2005; Bonnardot, 2006,)**

The main factors that control the climate of any place on earth are latitude, the position relative to the distribution of land and sea, height above sea level, topography, general circulation of the atmosphere, perturbations and ocean currents. Bonnardot (2005, 2006) examined each of these factors for South Africa in order to aid in understanding the climate of the wine-producing regions in comparison to locations at similar latitudes in the southern and northern hemispheres. At latitude 30°S, South Africa is narrower than South America or Australia and thus largely under the influence of maritime air. Due to the prevailing ocean surface and the land / sea ratio, the coastal wine region of South Africa experiences cooler conditions than the latitude might suggest compared to other wine regions at similar latitudes, especially to those in the northern hemisphere. The maritime influence, however, decreases rapidly with the distance from the sea due to the physical configuration. The climate also depends on the general circulation of the atmosphere over the continent. South Africa is situated within the high-pressure belt (centred on 30°S approximately) and skirted by the circumpolar westerly air stream to the south. It is thus almost entirely under the influence of the westerly circulation, especially in winter when the high-pressure system moves 3 to 4° more to the north. At surface, the weather is characterized by a succession of cyclones and anticyclones moving eastwards across the country, while, in summer, there is an equatorial low-pressure tongue over the interior. According to the Köppen climatic classification, South Africa experiences different types of climate, from temperate humid (Cbs) to arid (Bw) (Thackrah et al., 2003). The extreme South Western Cape, where traditionally vineyards are situated, has a Mediterranean type of climate (nontropical winter rainfall, warm and dry summer), which is a temperate climate (type C) characterized by a more pronounced drought in summer, while the rest of the country passes progressively under the subtropical influence (aridity and summer rainfall of tropical origin).

In the Stellenbosch district, the annual amount of rainfall varies from approximately 600 mm to 900 mm, with orographic rainfall resulting in larger amounts closer to the mountains. Drought lasts for four to five months, from November-December to March. The annual mean temperature is around 17°C. The annual thermal amplitude is small (less than 10°C) and increases with distance from the Ocean (from 8.4°C at Nooitgedacht to 9.7°C at Elsenburg and Rustenburg). Winters are cool with a mean temperature above 13°C, slightly cooler inland or at altitude (above 12°C at Elsenburg and Rustenburg). The minimum July temperature is above 7°C. Spring is cool. The pre-véraison period is warm inland but remains cool in proximity to the sea or at high altitude. Summer and post-véraison are warm, but not exceedingly (mean and maximum February temperatures are below 22°C and 29°C respectively). A comparison between the climate of Stellenbosch, Robertson and Upington showed that pre and post-véraison climatic conditions are best suited in Stellenbosch for colour expression and flavour development and maintenance compared to the other two locations (Hunter & Bonnardot, 2002).

The Stellenbosch district vineyards lie as close as 6 km from the coast and up to 500 m high on the slopes of the mountains. They are subject to local climatic aspects resulting from the proximity of the Ocean and the complex topography. In addition to the general moderating influence of the oceans, the vineyards closest to the coast and facing south and west experience beneficial breezes blowing in from the sea, especially in summer when the difference between the sea/land surface temperatures is at maximum (Bonnardot, 2002; Bonnardot et al., 2001, 2002, 2005). The associated increase in wind velocity in the afternoon and concomitant increase in relative humidity and reduction in temperature is of particular interest for the wine industry due to the significant effects of temperature, relative humidity and wind on grapevine functioning and thus on potential wine character and quality (Carey, 2001; Conradie et al., 2002; Hunter & Bonnardot, 2002; Carey et al., 2003). With respect to the Mean February Temperature index, Lourensford in the Helderberg basin falls into the cool category, the remaining stations into the moderate category, suggesting that the area is suitable for the production of high quality red and white table wine (De Villiers et al., 1996), as shown in the spatial characterisation of natural terroir units for viticulture in the Bottelaryberg-Simonsberg-Helderberg wine producing area (Carey, 2001). Calculation of the growing degree-days placed the stations of the district into Region III (some near the coast at upper limit of Region II and the inland stations at the lower limit of Region IV). According to the Huglin index and the MCC system, the district has a warm temperate climate with no heliothermic constraint for the ripening of cultivar (HI+1), similar to Montpellier (France), Ravenna (Italy), Madrid (Spain), Evora (Portugal), Santiago (Chile), Napa (USA) and Nuriootpa (Australia). The coolest station has a temperate climate (HI-1), where late cultivars can reach maturity, similar to Pau, Toulouse, Bordeaux and Carcassonne (France). The minimum March temperature (Cold night index) indicates cool to temperate conditions for the ripening of cultivars (cooler than Santiago, Napa and Nuriootpa) and the aridity index indicates a severe to very severe drought (DI+1 and DI+2), the Stellenbosch district being drier than Madrid, Evora, Santiago, Napa or Nuriootpa.

BONNARDOT V., CAREY V.A., PLANCHON O., CAUTENET S., 2001. Sea breeze mechanism and observations of its effects in the Stellenbosch wine producing area. Wynboer 147, 10-14.

BONNARDOT V., 2002. The sea breeze: a significant climatic factor for viticultural zoning in coastal wine growing areas. In: Proc. 4th Int. Sym. Viticultural zoning, 17 – 20 June 2002, Avignon, France, p.339-348.

BONNARDOT V., PLANCHON O., CAREY V.A., CAUTENET S., 2002. Diurnal wind, relative humidity and temperature variation in the Stellenbosch-Groot Drakenstein wine producing area. S. Afr. J. Enol. Vitic., Vol, 23,No.2, 62-71.

BONNARDOT V., PLANCHON O., CAUTENET S., 2005. Sea breeze development under an offshore synoptic wind in the South-Western Cape and implications for the Stellenbosch wine-producing area. Theo. Appl. Clim. Vol 81, No 3-4, 203-218.

CAREY V.A., 2001. Spatial characterisation of terrain units in the Bottelaryberg /Simonsberg/Helderberg winegrowing area. MSc Agric (Viticulture), Univ. of Stellenbosch. Private Bag X1, Matieland 7602, South Africa.

CAREY V.A., BONNARDOT V., SCHMIDT A. and THERON J.C.D., 2003. The interaction between vintage, vineyard site (mesoclimate) and wine aroma of Vitis vinifera L. cvs.

Sauvignon blanc, Chardonnay and Cabernet Sauvignon in the Stellenbosch-Klein Drakenstein wine producing area. OIV Bull., 76 (863-864), 4-29.

CONRADIE W.J., CAREY V.A., BONNARDOT V., SAAYMAN D. and VAN SCHOOR L.H., 2002. Effect of Natural "Terroir" Units on the Performance of Sauvignon Blanc Grapevines in the Stellenbosch/Durbanville Districts of South Africa. I. Geology, Soil, Climate, Phenology and Grape Composition. S. Afr. J. Enol. Vitic., 23, 78-91.

DE VILLIERS F.S., SCHMIDT A., THERON J.C.D. & TALJAARD R. 1996. Onderverdeling van die Wes-Kaapse wynbougebiede volgens bestaande klimaatskriteria. Wynboer Tegnies 78, 10-12.

HUNTER J.J. and BONNARDOT V., 2002. Climatic requirements for optimal physiological processes: A factor in viticultural zoning. In: Proc. 4th International Symposium on Viticultural Zoning, 17 – 20 June 2002, Avignon, France, p.553-565.

THACKRAH A., BOUWMAN B. & KUSCHKE R., 2003. New Köppen Climate Map for South Africa and Possible Uses. In Proc. Golden Jubilee Congress of the Soil Science Society of South Africa. 20-23 January 2003, Stellenbosch, South Africa.

The current climate of the Stellenbosch wine producing district compared to historical climate (Bonnardot et al., 2006; Bonnardot et al., 2011)

Daily data from the Nietvoorbij mechanical (1967-1995) and automatic (1996-2010) weather stations (source : AgroMet ARC-ISCW) were analysed. The Pettitt statistical test was applied to depict significant breaking points in the 44-year annual, seasonal and monthly data series. It must be noted that upgrading of the weather station from mechanical to automatic did not affect the cohesiveness of the data and the 1967-2010 data series was therefore used as if it was one single station. The trend in mean annual temperatures for the period 1967-2010 at Nietvoorbij weather station (Stellenbosch) was an increase of 0.02°C.yr-1. The year 1983 was determined as breaking point within a significant upward trend ($p = 0.0001$). Beyond this breaking point, the mean annual temperature can be considered to be significantly warmer than before this breaking point.

Of the 10 warmest years over the 1967-2010 study period at Nietvoorbij, nine of them occurred from the 1990's onwards and six occurred within the last decade. This is in line with the published impacts of global warming, where it is been found that globally the 10 warmest years have occurred since 1997 (IPCC, 2007). The most recent vintages (years 2009 & 2010) were the second and fourth warmest years in the time series.

Climatic variability is natural and is expected to vary from one decade to another and one season to another. Data from Nietvoorbij shows us natural variability between years (12th warmest season on record being 1973/1974, and coolest season on record being 1996/1997), but, importantly, it must be noted that this variability occurs within a significant upward temperature trend over the 43-year period.

A total increase of 1°C in mean annual temperatures was calculated for the period 1967-2010. The most significant trend was found during the growing period, especially during February. The increase in mean temperature was calculated as 1.8°C for the months of February and July and the increase in growing season mean temperature was calculated as +0.7°C for this same time period.

As a result of increasing February minimum temperatures, warm and hot (> 16°C) nocturnal temperature conditions occurred more often (a frequency of 52%) during the period 1983-2010, than over the 1967-1982 period (a frequency of 35%).

This warming has also been observed in other wine-producing regions of the Western Cape. The annual temperature increase ranges from 0.5°C to 1.7°C, depending on the region and the record period.

Perspective:

On suggestion of Distell (meeting 13 Feb 2012), climate change should be further investigated in SA. Observed climatic trends such as those published in the Wynboer July 2011 issue (Bonnardot, Carey, Rowswell, 2011) should be realized for each wine region of South Africa. After a meeting with Jan Booysen on 15 Feb 2012, it was decided to start a series of articles on observed climate trends for each wine region of SA, one region per month during the course of 2012 with a compilation of the series in the technical yearbook 2012 (to be published early 2013). This work will be possible with the collaboration of ARC-ISCW, Dudley Rowswell and Gert Nyschen, who are gathering the data for Dr Bonnardot.

Inter-annual climatic variation in the Stellenbosch wine producing district (2004-2010)

Considering the long time (1967-2011) series of annual temperatures recorded at Nietvoorbij, it can be noted that the 6-year study period (2004-2010) follows the upward trend in temperature. However, the variability during the study period was not important in terms of annual mean temperature (Fig. 1).

Looking at the growing season with the Winkler index and the total amount of rainfall over September-March period (Fig. 2), the seasons can be characterized briefly as follows:

- The 2008/2009 season was the coolest season (upper level of Region III) of the study period.
- The 2005/2006 season was the driest growing season of the study period.
- The two seasons of 2004/2005 and 2009/2010 were the warmest and the wettest growing seasons of the study period.
- The 2006/07 and 2007/08 seasons are representative of the average conditions over the study period.

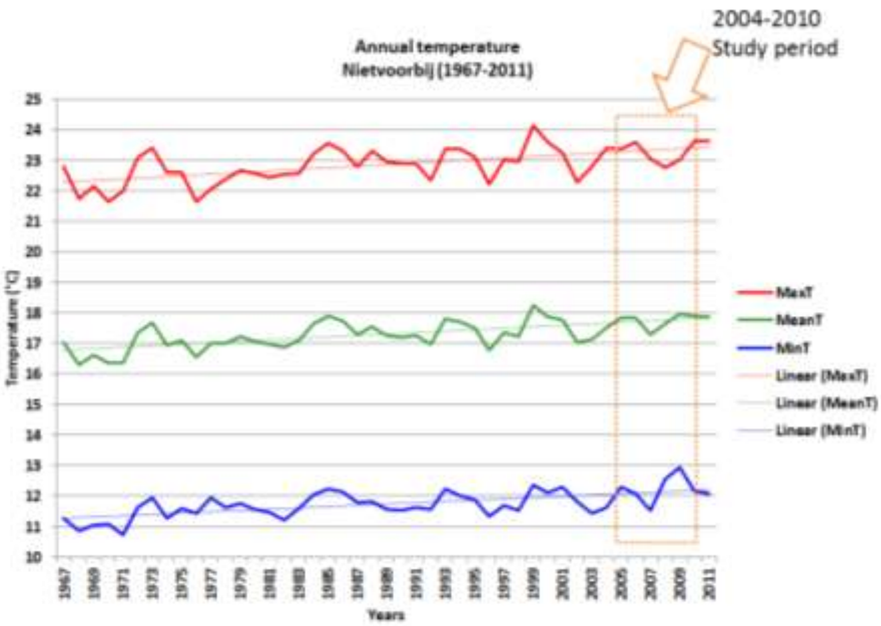


Figure 1: Annual temperatures at Nietvoorbij weather station from 1967-2011.

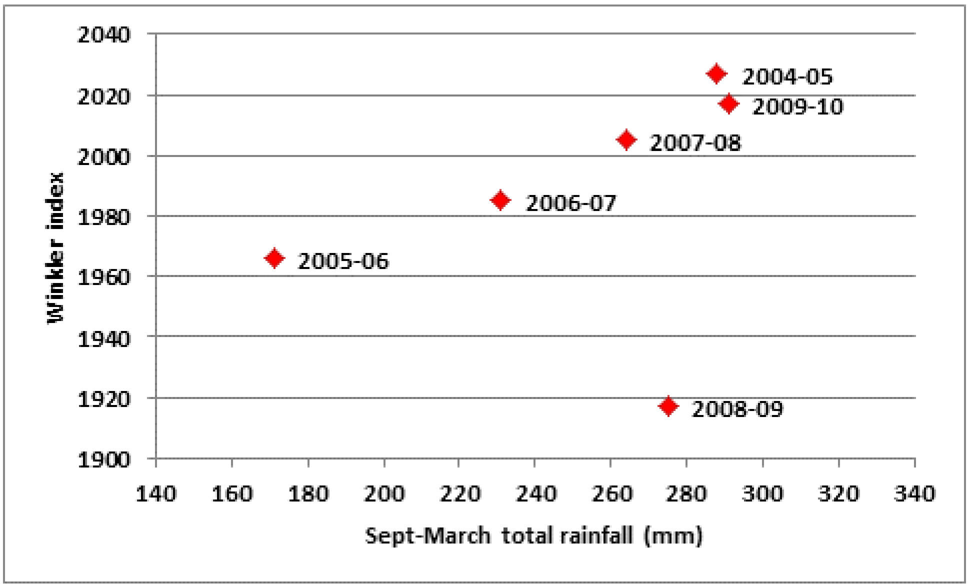


Figure 2: Winkler index and rainfall amount (mm) for the September-March period for six seasons (2004/2005 to 2009/2010) at Nietvoorbij.

The **2004/2005** season had the highest Winkler index (2027), but similar to that for the 2009/2010 season. The growing season was characterized by wetter than average conditions in October and January (Fig. 3).

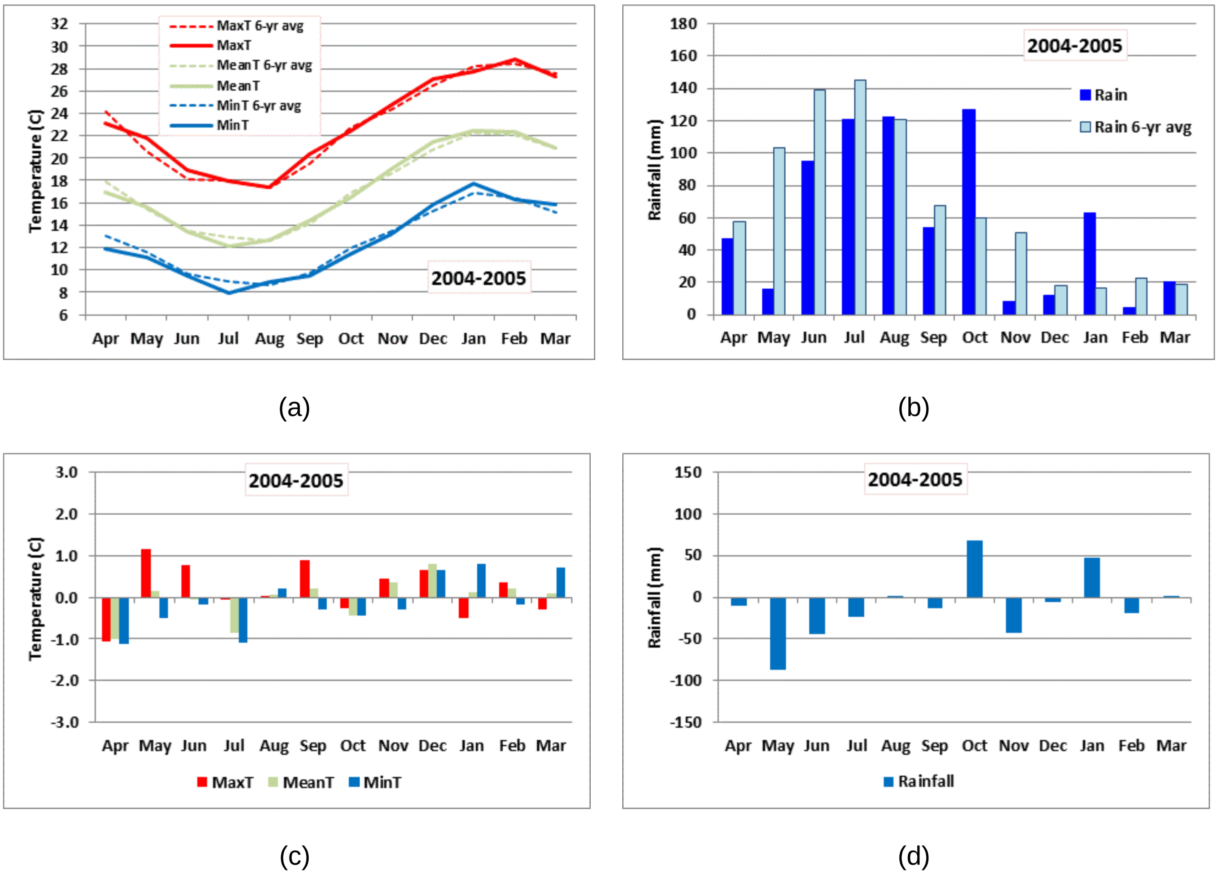
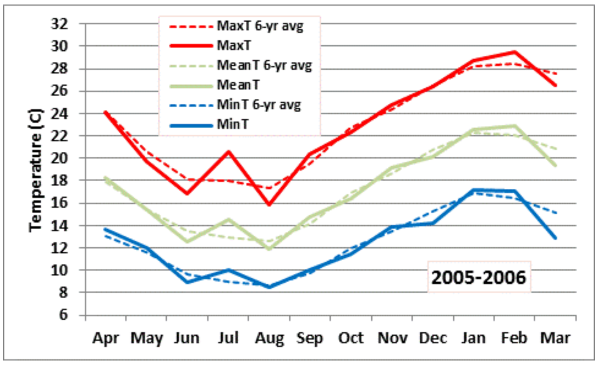


Figure 3: Monthly mean temperature (a) and total monthly rainfall (b) from April 2004 to March 2005 compared to the 6-year average (2004/2005 to 2009/2010). Deviation of monthly mean temperature (c) and monthly total rainfall (d) from the 6-year average for each month for the 2004/2005 season.

The **2005/2006** season was the driest growing season of the study period. Rainfall was lower than average from September to March (171 mm in total) (Fig. 4). There was no rain recorded in January. February temperatures were higher than the 6-year average and as a result, the MFT (22.9°C) was the highest of the study period. However, the 2005/2006 season ranked 5th in terms of the Winkler index (1966) and it was the second coolest season after 2008-2009. It was also characterized by warmer and drier weather conditions than average during July.



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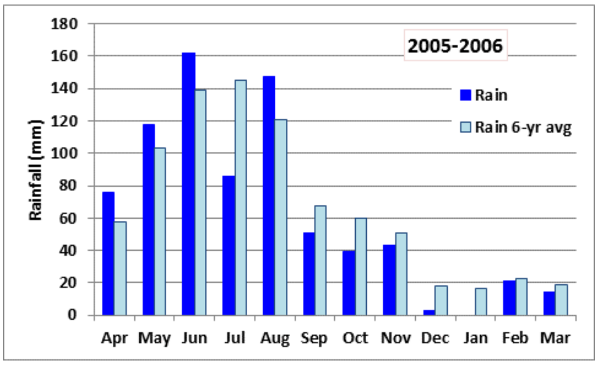

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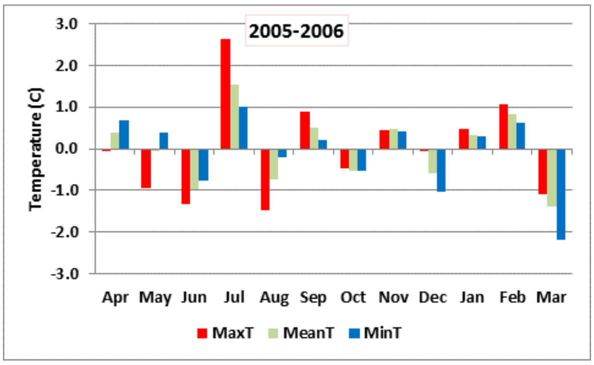

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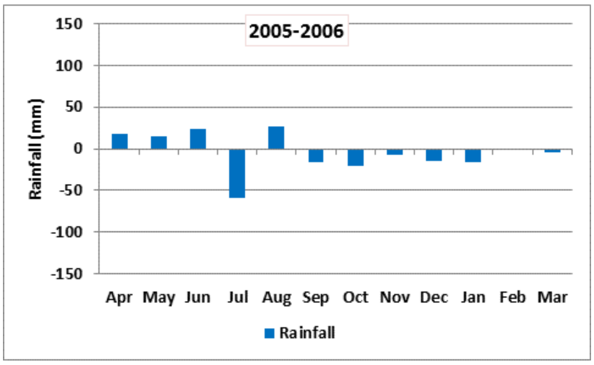
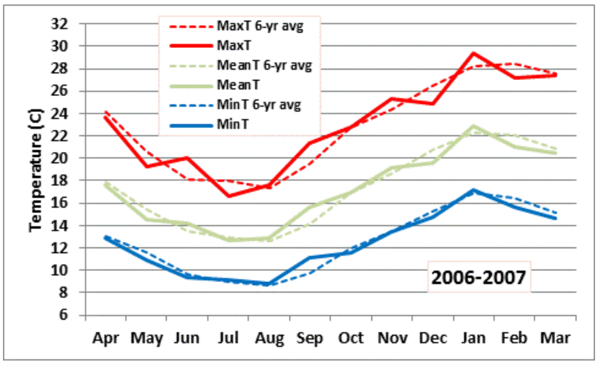


(d)

Figure 4: Monthly mean temperature (a) and total monthly rainfall (b) from April 2005 to March 2006 compared to the 6-year average (2004/2005 to 2009/2010). Deviation of monthly mean temperature (c) and monthly total rainfall (d) from the 6-year average for each month for the 2005/2006 season.

The **2006/2007** season had average conditions with a mean Winkler index value of 1985. It was characterized by a more temperate winter (July-August). Sufficient cold units were realized at the end of May for most of the stations. May was the wettest month of the season due to heavy rainfall. Spring was warm, with maximum temperatures in September and November being nearly 2°C and 1°C, respectively, above average (Fig. 5). Summer was characterized by warm conditions during January but cool conditions during December and February. The MFT index of the season (21°C) was the lowest of the six seasons that were studied. February and March received more rain than average.



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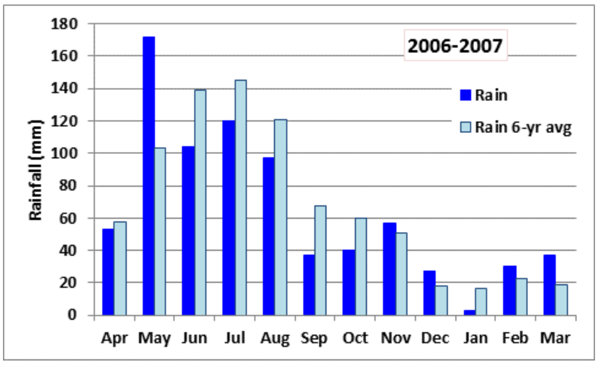

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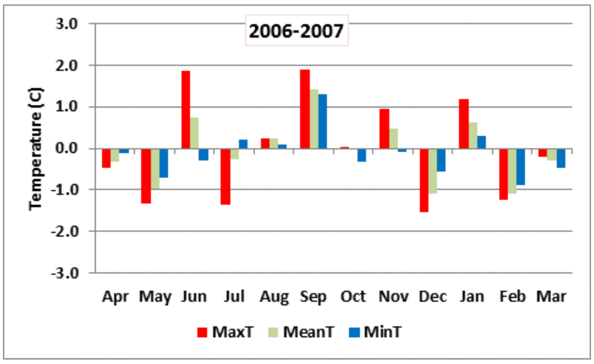

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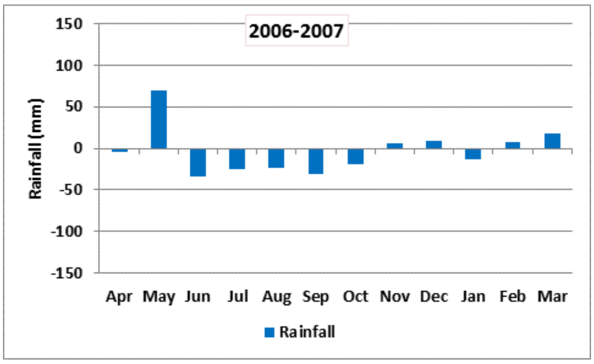
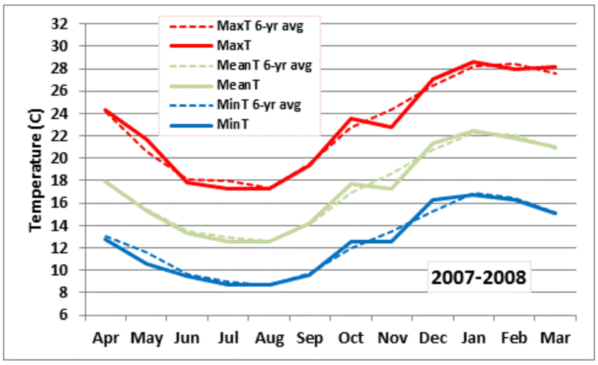


(d)

Figure 5: Monthly mean temperature (a) and total monthly rainfall (b) from April 2006 to March 2007 compared to the 6-year average (2004/2005 to 2009/2010). Deviation of monthly mean temperature (c) and monthly total rainfall (d) from the 6-year average for each month for the 2006/2007 season.

The **2007/2008** season was also characterized by average conditions. The Winkler index value was 2005 GDD. The season was characterized by a small amount of rainfall in September and cool conditions in November; otherwise temperature and rainfall were representative of the 6-year average (Fig. 6).



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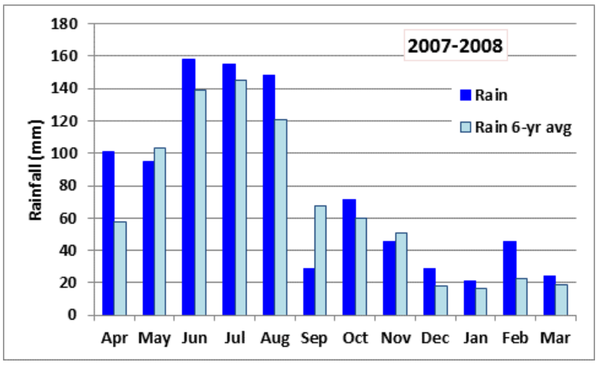

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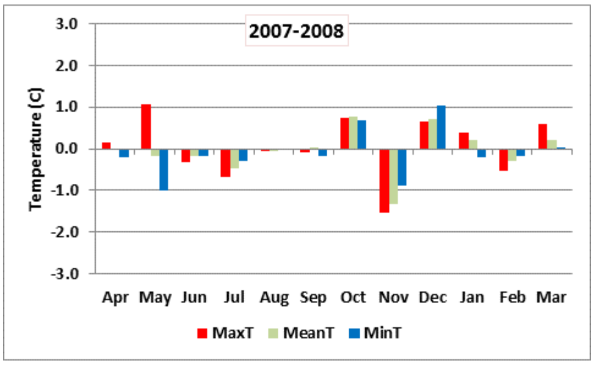

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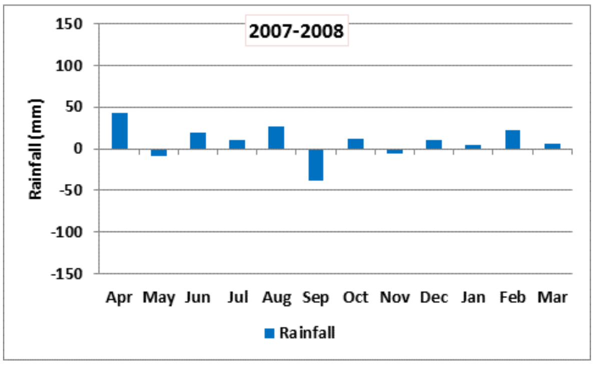


(d)

Figure 6: Monthly mean temperature (a) and total monthly rainfall (b) from April 2007 to March 2008 compared to the 6-year average (2004/2005 to 2009/2010). Deviation of monthly mean temperature (c) and monthly total rainfall (d) from the 6-year average for each month for the 2007/2008 season.

The **2008/2009** season was the coolest season of the study period. The Winkler index was 1917 GDD (upper level of Region III). Winter temperatures were the lowest of the study period and a large amount of rain fell during July (260 mm) (Fig. 7). September was cold (mean temperature 2°C below average) and rainy (140 mm), while one third of the monthly mean total rainfall fell during October. Summer was characterized by cool conditions in January but February and March were warm. Indeed, the MFT index was the second highest (22.6°C) of the study period.

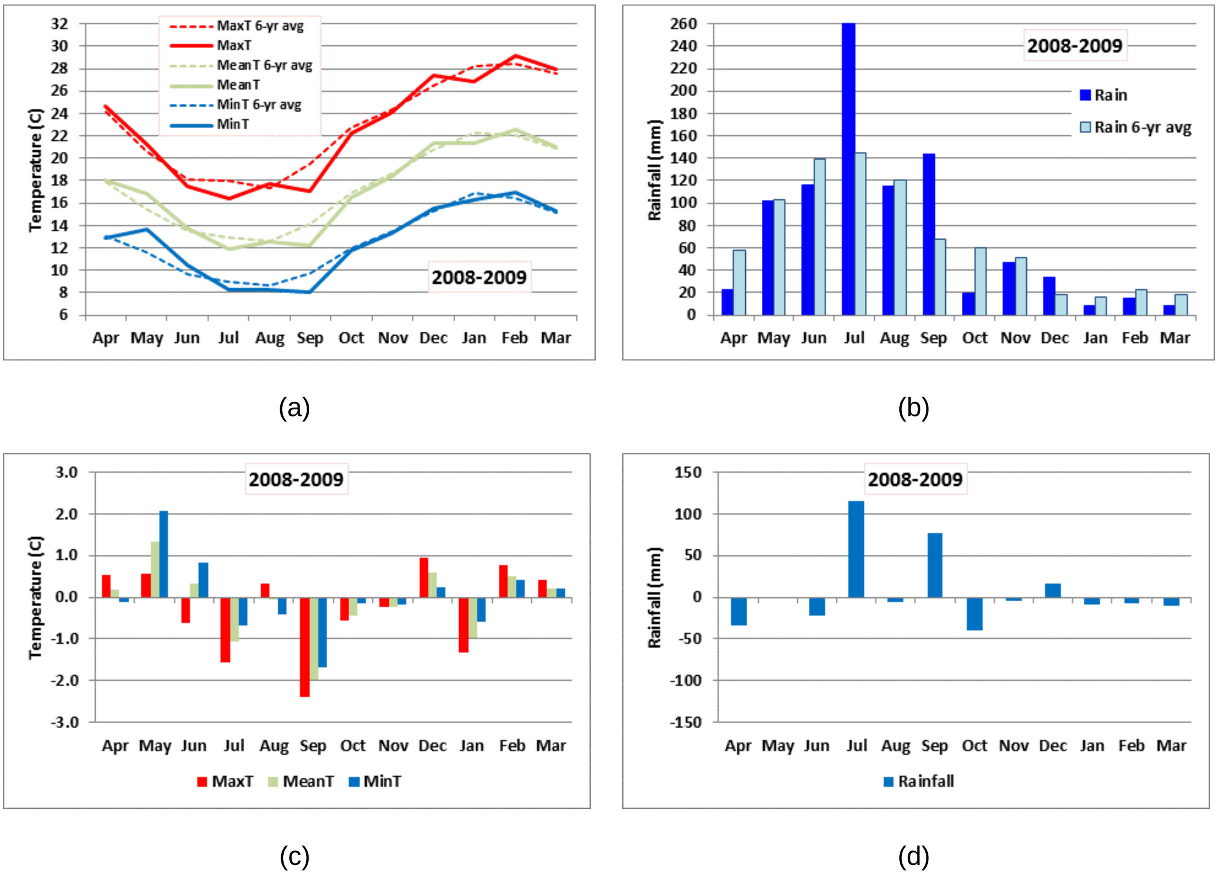
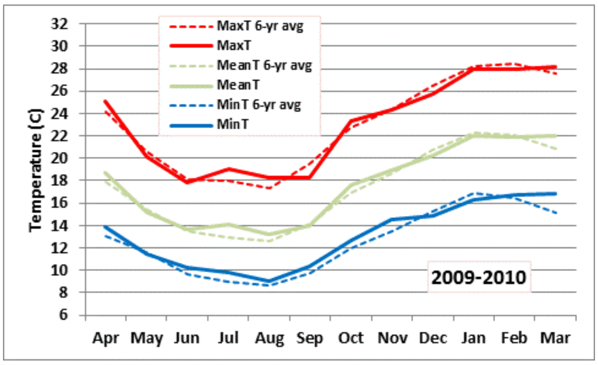
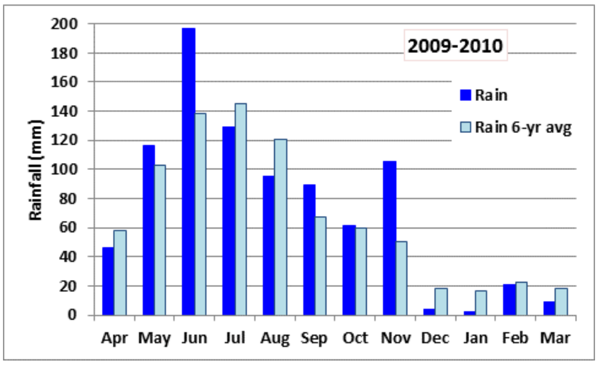


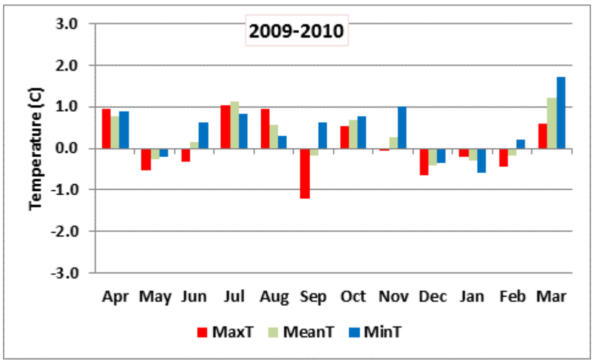
Figure 7: Monthly mean temperature (a) and total monthly rainfall (b) from April 2008 to March 2009 compared to the 6-year average (2004/2005 to 2009/2010). Deviation of monthly mean temperature (c) and monthly total rainfall (d) from the 6-year average for each month for the 2008/2009 season.

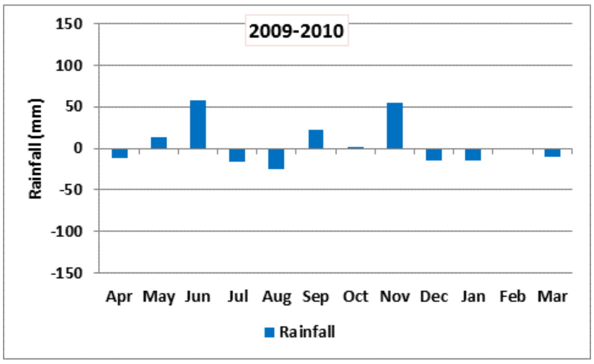
The **2009/2010** season was the second warmest growing season of the study period with a Winkler index reaching a value of 2017 GDD. Winter and Spring temperatures were above average. November experienced lower than average minimum temperatures and more rain than average (Fig. 8). The growing season of 2009/2010 received the most rainfall (nearly 300 mm during September-March) but the December and January were drier than average. March was also much warmer than average. In general, this season can be considered to be similar to the 2004/2005 season.





(a) (b)





(c) (d)

Figure 8: Monthly mean temperature (a) and total monthly rainfall (b) from April 2009 to March 2010 compared to the 6-year average (2004/2005 to 2009/2010). Deviation of monthly mean temperature (c) and monthly total rainfall (d) from the 6-year average for each month for the 2009/2010 season.

Spatial climatic variation in the Stelllenbosch wine producing district **(Bonnardot et al., 2006a, Bonnardot & Cautenet, 2009, Bonnardot et al., 2010; Bonnardot et al.; 2012)**

Climatic modelling - The Regional Atmospheric Modeling System (RAMS) was used to assess local air circulation patterns over the wine-producing Stellenbosch region of South Africa under project WW13/02 and GW50-031. Further interpretation and statistical analyses of the data for publication were performed under project US B/C and published in Bonnardot & Cautenet (2009). Under GW50-031, numerical simulations using four nested grids (25, 5, and 1 km, and 200 m of horizontal resolution) were performed for each day of February 2000 (during the grape-ripening period) over southern Western Cape Province. Modeled hourly data were extracted from the analysis files and used to produce mean hourly fields (temperature, relative humidity, wind speed, and radiation). Three runs with increasing horizontal resolutions for the finer grid were performed (run 1 with two nested grids of 25 and

5 km; run 2 with three nested grids of 25, 5, and 1 km; run 3 with four nested grids of 25, 5, and 1 km, and 200 m). Four stations (Alto, Bonfoi, Goedehoop and Jacobsdal) were used to compare modelled and observed data for three different climatic situations (strong sea-breeze development but with weak southerly flow; strong southerly flow, which enhanced the sea-breeze development; and a warm offshore airflow (Berg winds). As a whole, the observed differences in temperature and relative humidity between the four stations were reduced during the events with a strong synoptic flow, whereas differences between stations were noted for the days where local air circulations were controlled by sea and slope breezes. For each event, it was noted that the wind speeds and direction recorded at Alto were not associated with those recorded at the other stations (due to differences in aspect, in that it did not face the sea). For each event, the simulations of 1 km and 200 m resolution were statistically superior to the 5-km-resolution simulation, especially in reproducing the local air circulations (sea and slopes breezes) because of a better representation of the local terrain (topography and vegetation cover). With a strong synoptic flow, the increasing horizontal resolution of the grid did not necessarily give more information, and the results of the 1-km-resolution simulation often seemed sufficient to describe the different local air circulations. On the other hand, with a weak synoptic flow and prevailing local air circulations, as often occurs during the month of February, the high horizontal resolution (200 m) displayed relevant meteorological information for viticultural applications. Furthermore, with the high resolution (200 m), Bonnardot & Cautenet (2009) showed that the increase in vapor pressure in the morning was associated with the change in wind direction as the sea breeze occurred and that the maximum values of vapor pressure at around 1200–1500 SAST were associated with a southerly to southwesterly wind (sea breeze), just as for the observations and for all stations. Generally, the timing of the sea-breeze frontal movement was well retrieved in this region by the model. Moreover, in view of viticultural applications, the model correctly reproduced the extreme values of temperature (those exceeding 308C), wind speed (those exceeding 5 $m.s^{-1}$), and relative humidity (those below 60%). The model had difficulties in reproducing the low wind speed values, which, indeed, does not diminish its application in viticultural studies.

Wind speed - An index of openness of the landscape, which describes the proportion of the sky obstructed by masking features, established in Alsace and the Loire Valley, was calculated for eleven automatic agroclimatic weather stations in the Stellenbosch Wine of Origin District and statistical analysis of wind data was carried out for the 2004/2005 and 2005/2006 seasons in order to determine the prevailing wind and its strength at each site. Mean monthly percentage occurrence of wind from eight (8) compass directions, number of hours with a wind speed greater than 4 $m.s^{-1}$ and mean monthly wind speed for the growing season were calculated for each weather station. Data was then correlated to the index of openness to determine the wind exposure of each site. According to the IOP, the landscape of most of the studied sites varied from “relatively open” to “very open”, which favours air circulation in any direction. Mean wind speed varied from 2.5 to 3.5 $m.s^{-1}$ and the percentage of wind speed greater than 4 m.s-1 varied from 15 to 40%. The prevailing directions for moderate and strong winds were South and South West (sea origin) for most of the stations, enhancing the effect of the sea breeze circulation. Goedehoop, a fully exposed open site on top of a hill, and Jacobsdal, Meerlust and Rustenhof, open sites on flat land near the sea, were the windiest sites. At Thelema, site with a very closed landscape, wind speed was reduced. It had the lowest percentage of wind speed greater than 4 $m.s^{-1}$ (less than 10%). The directions for which it was the highest were E and SE, which were also amongst the least sheltered wind directions of the site. Prevailing masking features in any direction reduced the percentage wind speed greater than 4 $m.s^{-1}$. The significant correlation result showed that 25% of the variance of the percentage of wind speed greater than 4 $m.s^{-1}$ can be explained by the IOP.

Temperature indices – The Winkler Index values for the coolest and warmest sites and seasons are shown in Table 1, from which it can be seen that spatial variability was greater than temporal variability (Bonnardot & Carey, 2011). This can also be seen in Fig. 1, where the Winkler and Huglin Indices calculated for data recorded with the Tinytag network were compared for 4 seasons. Indices for each of the automatic weather stations for each year of the project are provided in Tables 2 to 7.

Table 1. Spatial and temporal variability Stellenbosch wine of origin district

Weather stations	**1995/1996 season**	**1999/2000 season**	**Difference between the 2 seasons**
T02	1637 **(II)**	1916 **(III)**	**279 units**
T20	2083 **(IV)**	2380 **(V)**	**297 units**
Difference between the 2 stations	**446 units**	**464 units**	

Table 2: 2004-2005 seasonal indices for the different locations. *Values in italics indicate that daily mean and daily maximum temperatures were estimated for up to five days in the calculation of Winkler and Huglin indices*.

Stations	**MFT**	**Winkler**	**Huglin**	**IF**
Alto	22.2	*2060*	*2382*	16.7
Bonfoi	21.4			15.6
Groenland	21.6	*1992*	*2402*	15
Goedehoop	21.1	*1932*	*2244*	15.9
Jacobsdal	20.9	*1892*	*2234*	15
Le Bonheur	22.4	*2074*	*2416*	17.1
Meerlust1	21.2	*1880*	*2290*	13.5
Rustenhof	21.6	*1969*	*2315*	15
Thelema1				
Nietvoorbij	22.3	*2028*	*2431*	15.8
Elsenburg	21.4	1927	2432	13.8

Table 3: 2005-2006 seasonal indices for the different locations. *Values in italics indicate that daily mean and daily maximum temperatures were estimated for up to five days in the calculation of Winkler and Huglin indices*.

Stations	**MFT**	**Winkler**	**Huglin**	**IF**
Alto	22.1	1846	2176	15.5
Bonfoi	22.4	1878	2258	14.3
Elsenburg	22.2	1841	2384	12.4
Goedehoop	21.6	1792	2149	14.8
Groenland	21.7	1853	2282	14.0
Jacobsdal	21.5	1777	2080	14.1
Meerlust	21.6	*1489*	*1853*	*11.6*
Nietvoorbij	22.9	1967	2399	12.9
Le Bonheur	23.1	*1958**	*2422**	15.7

Table 4: 2007-2008 seasonal indices for the different locations.

Stations	**MFT**	**Winkler**	**Huglin**	**IF**
Alto	21.0	2014	2311	16.5
Bonfoi	21.0	1987	2311	15.6
Elsenburg	20.5	1868	2348	13.4
Goedehoop	20.4	1907	2205	15.9
Groenland	21.2	1997	2402	14.8
Jacobsdal	20.5	1893	2221	14.9
Le Bonheur	21.3	2103	2412	17.0
Meerlust	21.0	1905	2325	13.1
Nietvoorbij	21.0	1983	2378	14.6
Rustenhof	21.1	1959	2291	14.4
Thelema	20.3	1944	2241	15.6

Table 5: 2007-2008 seasonal indices for the different locations.

Stations	**MFT**	**Winkler**	**Huglin**	**IF**
Alto	22.2	2030	2409	16.8
Bonfoi	21.8	2009	2384	15.7
Elsenburg	21.1	1884	2428	13.5
Goedehoop	21.3	1912	2280	16.0
Groenland	21.8	1990	2439	15.0
Jacobsdal	21.1	1877	2261	15.1
Le Bonheur	22.4	2129	2496	17.6
Meerlust	21.7	1942	2388	13.4
Nietvoorbij	21.8	2005	2437	15.1
Rustenhof	21.9	1997	2371	14.7
Thelema	21.8	1916	2275	16.6

Table 6: 2008-2009 seasonal indices for the different locations.

Stations	MFT	Winkler	Huglin	IF
Alto	22.9	1936	2362	16.7
Bonfoi	22.5	1926	2348	16.3
Elsenburg	22.4	1817	2382	14.6
Goedehoop	22.3	1826	2238	16.6
Groenland	22.6	1921	2431	15.9
Jacobsdal	21.9	1813	2231	15.9
Le Bonheur	23.2	2011	2447	17.3
Meerlust	22.1	1853	2333	14.2
Nietvoorbij	22.6	1917	2406	15.3
Rustenhof	22.2	1905	2320	15.4
Thelema	22.4	1817	2248	16.3

Table 7: 2009-2010 seasonal indices for the different locations.

Stations	MFT	Winkler	Huglin	IF
Alto	22.1	2021	2403	18.0
Amani	21.6	1931	2303	16.5
Bonfoi	22.0	2005	2377	17.1
Elsenburg	21.6	1915	2433	15.3
Goedehoop	21.4	1886	2257	16.9
Groenland	22.0	2013	2461	16.2
Le Bonheur	22.2	2063	2456	18.5
Meerlust	21.9	1964	2374	15.1
Nietvoorbij	21.9	2017	2427	16.8
Rustenhof	21.6	/	/	16.2
Thelema	21.5	1872	2248	17.8

Mean February Temperature index:
Cool: between 19°C and 20.9°C
Temperate: between 21°C and 22.9°C
Warm: between 23°C and 24.9°C

Winkler:
Region III (1667-1943)
Region IV (1944-2220)

Huglin Index:
Temperate: between 1800 and 2100
Warm temperate: between 2100 and 2400
Warm: between 2400 and 3000

Night temperature index (IF) (Minimum March temperature):
Cool: between 12°C and 14°C
Temperate: between 14°C and 18°C

In a warm season (2010/2011), three significant classes could be recognised for the Winkler index determined from data recorded at 40 data loggers (combined WW13/12 and TerViClim projects - WW13/12 data analysed under US B/C) by means of ascending hierarchical classification (Bonnardot & Carey, 2011) (Fig. 2). The warmest group (to the left of the dendrogram) represents inland and/or NW slopes while the cooler group (to the right of the figure) represents sits that are situated closer to the coast, SW slopes and/or at altitude.

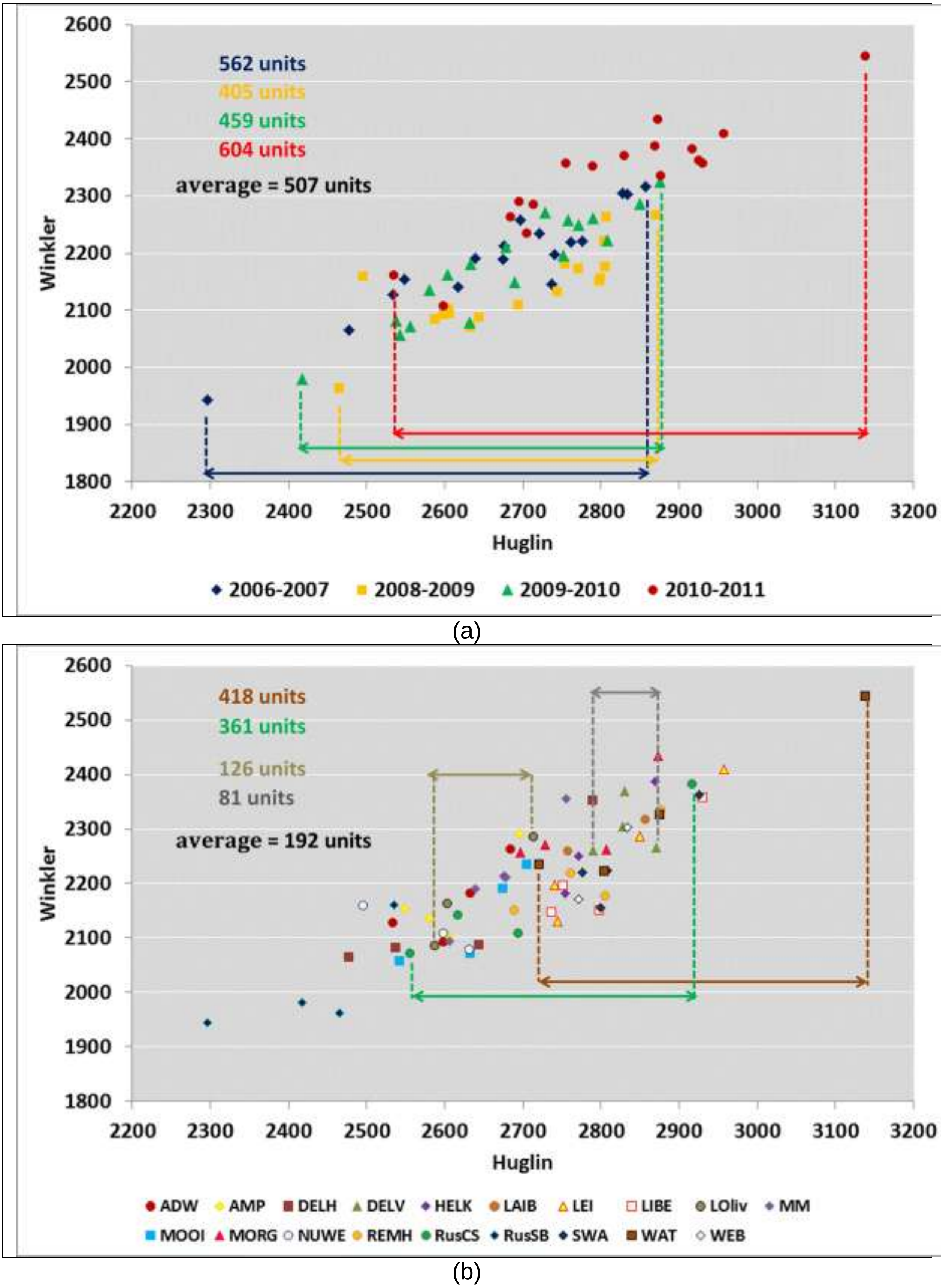


Figure 9: Comparison of Winkler and Huglin Indices for the Tinytag network in the Stellenbosch Wine of origin District for four seasons, labelled by season (a) and by site (b).

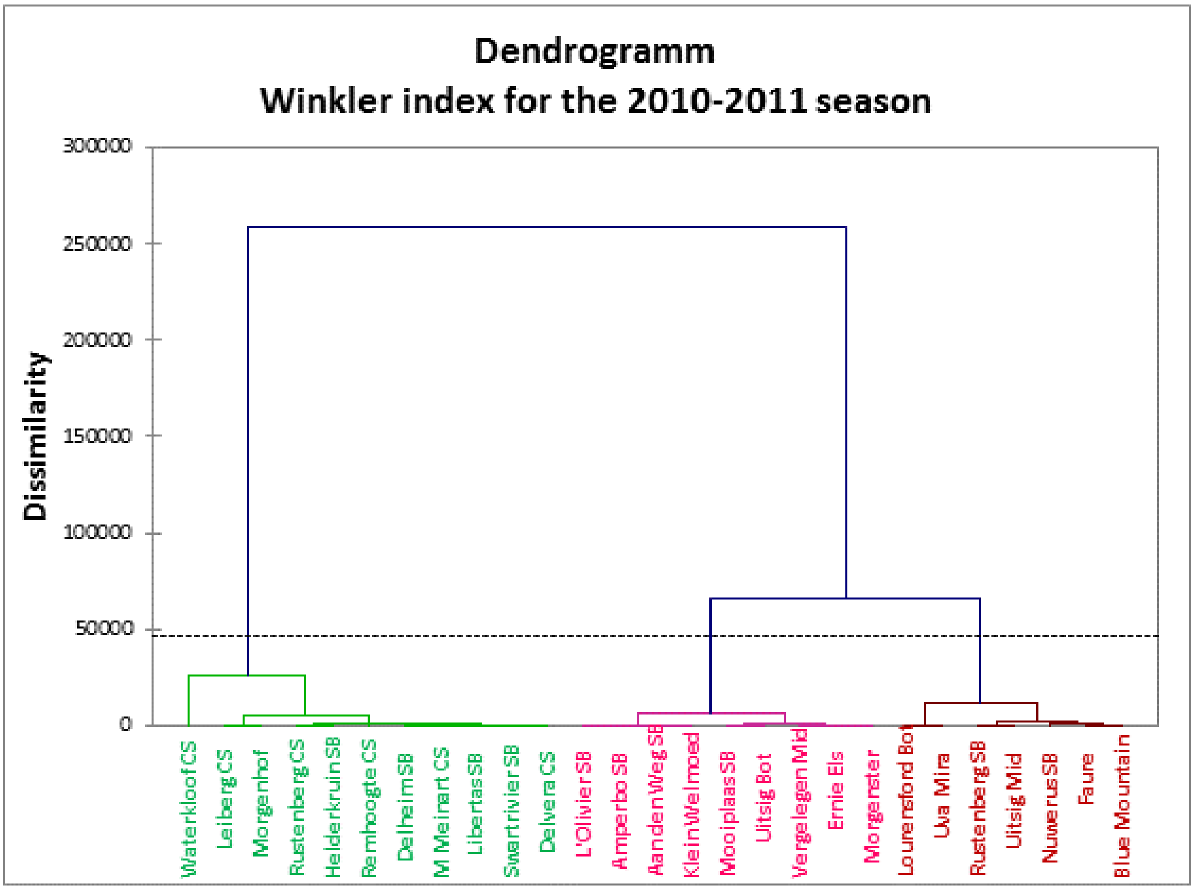


Figure 10: Dendrogramm for the Ascending Hierarchical classification of Winkler Index values for the Stellenbosch Wine of Origin Network for the 2010/2011 season.

Minimum Temperature - Looking at the cool night index (which is restricted to the Minimum of March for South Africa -Tonietto and Carbonneau, 2004), the variation within the Stellenbosch district was not significant using results of calculations for the 11 AWS and 7 seasons (Table 2 to 7), It suggested to investigate further at finer scales (both time and space).

Night temperatures recorded at 40 data loggers (combined WW13/12 and TerViClim projects - WW13/12 data analysed under US B/C) that were located in vineyards of the Stellenbosch Wine of Origin District were monitored during different weather conditions during the 2009 grape ripening period (January-March) (Bonnardot et al, 2010 (presentation at Soave), Bonnardot et al, 2012 IJSVV paper). The daily maximum difference between the coolest and warmest sites was, on average, 3.2°C for the 3-month period while it reached a difference of 14°C under radiative conditions (a difference of approximately 1°C to 2°C per km and 3°C per 100 m elevation). The temperature gradient limits varied as a function of elevation as well as atmospheric conditions. Temperature differential with change in elevation was greater during radiative weather conditions (Fig. 11) and showed well-known (although it has never been quantified before) inversion phenomena and downslope cold air drainage, while under advective (cloudy) conditions, the relationship was poorly defined. The frequency and intensity with which these different events occur may be of better relevance when studying the cool night index (of importance for the developpement of aromas) than a monthly minimum value. The study of frequency and intensity with different climatic thresholds have been suggested already by Hunter and Bonnardot (2011) and require further investigation.

Under TerViClim, numerical simulations of night temperatures, using a mesoscale atmospheric model, were performed for two weather events (27th, 28th and 29th January 2009 and the 5th and 6th March 2009) over this period. Night temperature fields at 200 m resolution were generated, taking large scale weather conditions into account. Data from 16 automatic weather stations (including those of WW13/12 and analysed under US B/C) were used for validation. Temperature data from the data loggers that were located in the vineyards (both from TerViClim and WW13/12) were used to produce maps of spatial distribution of the daily minimum temperature at a 90 m scale by means of multicriteria statistical modelling, which concomitantly took environmental factors into account. The range of minimum temperatures varied as a function of geographical factors and synoptic weather conditions. These modelled maps best represented radiative weather conditions, while regional atmospheric modelling also performed well under advective conditions.

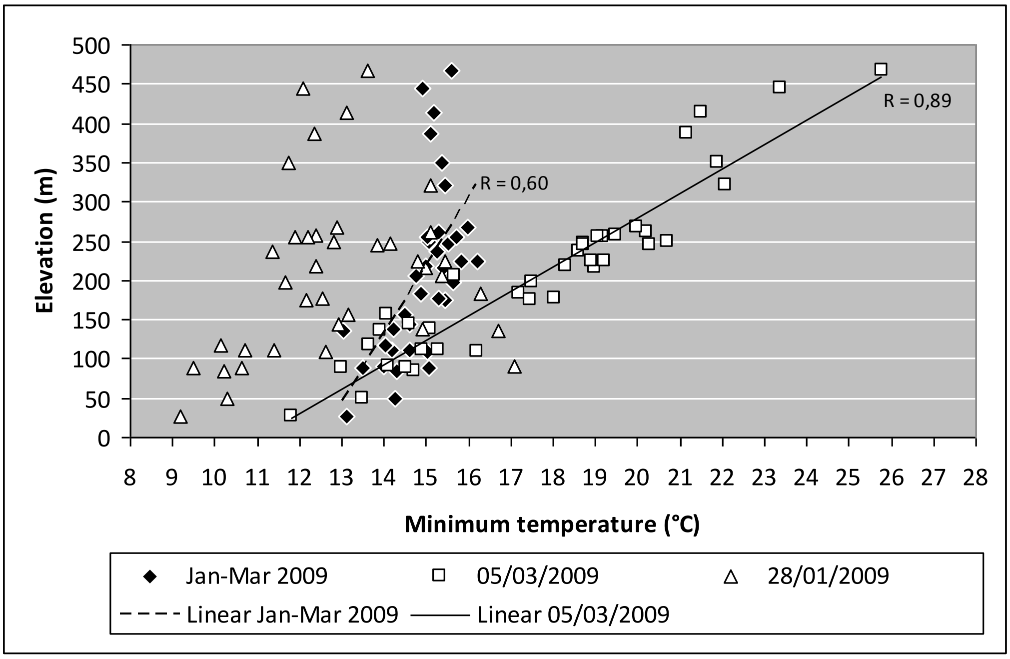


Figure 11: Minimum temperature (°C) in the vineyards of the Stellenbosch Wine of Origin District; mean value for 01/01/2009 to 31/03/2009, and values measured on 05/03/2009 and on 28/01/2009 *vs* elevation (m).

The results from the WW12/13 project showed the importance and relevance of increasing resolution to refine studies on climate spatial variability and to perform climate modelling based on distinguished weather types.

In the context of climate change, it is crucial to improve knowledge of current climatic conditions at fine scale during periods of grapevine growth and berry ripening in order to have a baseline from which to work when discussing and considering future local adaptations to accommodate to a warmer environment.

5. Accumulated outputs

List ALL the outputs from the start of the project.
The year of each output must also be indicated.

Technology development, products and patents

Indicate the commercial potential of this project (intellectual property rights or a commercial product(s)).

Monthly, Daily and Hourly database of climatic data from eleven automatic weather stations related to WW13/12; namely, Nietvoorbij, Elsenburg, Alto, Bonfoi, Goedehoop, Groenland (destroyed in 2011), Jacobsdal (replaced by Amani in 2009/2010), Le Bonheur, Rustenhof, Thelema and Meerlust from 2005 to 2011.

Monthly, Daily and Hourly database of climatic data from automatic weather stations related to WW13/13; namely, Cordoba, Uvamira, Lusthof from 2005 to 2009.

Monthly, Daily and Hourly database of climatic data from automatic weather stations related to WW13/16; namely Oak Valley, Beaulieu, Shannon, Eikenhof, Smarag, from 2006 to 2010 were obtained from the ISCW mesoclimatic databank.

Human resources development/training

Indicate the number and level (e.g. MSc, PhD, post doc) of students/support personnel that were trained as well as their cost to industry through this project. Add in more lines if necessary.

Although no students have been registered directly with this project, a number of students have benefited from consultation or collaboration with Dr Valerie Bonnardot, including, Philisiwe Shange (MScAgric Soil Science 2009), Zelmari Coetzee (Current MScAgric Viticulture), Chrisna du Preez (MSc Meteorology 2006), Carolyn Howell (PhD Agric Viticulture – abandoned), Wilhelm Pienaar (MScAgric Viticulture 2005), Alessandro Craparo (MSc WITS 2009), Leonardo Erazo-Lynch (MScAgric Viticulture 2011), Tara Mehmel (PhD Agric current).

Publications (popular, press releases, semi-scientific, scientific)

Deloire A. Vaudour E. Carey V. Bonnardot V. & Van Leeuwen C., 2005. Grapevine responses and terroir : a global approach.. *Journal International des Sciences de la Vigne et du Vin* **39** (4), 149-162.

Bonnardot V and Cautenet S, 2009. Mesoscale modeling of a complex coastal terrain in the South-Western Cape using a high horizontal grid resolution for viticultural applications. *Journal of Applied Meteorology and Climatology*, **48**(2), 330-348.

Bonnardot, V., V.A. Carey & D.I. Rowswell. 2011. Klimaatstendense in Stellenbosch: Nuutste waarnemings en kort oorsig. *Wynboer*, **263**: 95-99.

Bonnardot V, Carey V, Madelin M, Cautenet S, Coetzee Z & Quénol, H, 2012. Spatial variability of night temperatures at a fine scale over the Stellenbosch wine district, South Africa. *Journal International de la Vigne et du Vin*. In Press.

A series on observed climate trends for each wine region of SA is in preparation for publication in the Wynboer during the course of 2012. A Compilation of the series will be published in early 2013 in the technical yearbook 2012. (Collaboration with ARC-ISCW)

Presentations/papers delivered

Bonnardot V., 2005. Some climatic characteristics of the South African wine producing regions. In : Proc. Bacchus in Bourgogne, IInd Interdisciplinary and International Wine

Conference, November 2005, Beaune-Dijon, France, pp 144-167. Available on CD, Burgundy School of Business, Paris, Dijon.

Bonnardot V., 2006. Understanding large-scale factors that control the climate of South Africa: comparison between the climates of South African wine producing regions and worldwide locations situated at similar latitudes. Paper presented at at 3rd South African Society of Oenology and Viticulture International Congress. November 2006, Somerset West, South Africa.

Bonnardot V & Carey V, 2006a. Wind exposure of vineyards: a method of calculation. Poster presented at 3rd South African Society of Oenology and Viticulture International Congress. November 2006, Somerset West, South Africa.

Bonnardot V & Carey V, 2006b. Climate change: observed trends, simulations, impacts and response strategy for the South African vineyards. Paper presented at the International and Multi-disciplinary colloquium on Global warming, which potential impacts on the vineyards? March 2007, Dijon, France.

Bonnardot V, 2007. Temperature analysis and calculation of the Winkler index for the South African wine regions (1942-2005): Climate variabilty or climate change? SASEV Climate change workshop, November 2007, Stellenbosch, South Africa.

Bonnardot V & Carey V, 2008. Observed climatic trends in South African wine regions and potential implications for viticulture. In. Proc. VIIth International terroir congress, May 2008, Nyon, Switzerland.

Bonnardot V, 2008. South African wine regions temperature analysis (1965-2007): variability and/or change? SASEV conference, November 2008, Somerset West, South Africa

Bonnardot, V., C.L. Howell & A.J. Deloire. 2009. Preliminary consideration of the climatic wine regions concept within the context of climate change as regards to berry ripening in South Africa. Fourth International Viticultural and Oenology Conference, July 2009, Cape Town, South Africa (**POSTER**)

Deloire, A.J., C.L. Howell, I. Habets, M.P. Botes, V. Bonnardot & M.G. Lambrechts. 2009. Preliminary results on the effect of macro climatic temperatures on Sauvignon blanc (*Vitis vinifera* L.) berry ripening. Comparison of different wine regions of the Western Cape Coastal area of South Africa. Fourth International Viticultural and Oenology Conference, July 2009, Cape Town, South Africa. (**POSTER**)

Howell, C.L., I. Habets, M.P. Botes, V. Bonnardot, M.G. Lambrechts & A.J. Deloire. 2009. Progression of Sauvignon blanc (*Vitis vinifera* L.) ripening for two regions of the Western Cape Coastal area of South Africa. Preliminary results on berry colour, malic acid and sucrose evolution in relation to temperature. Sixteenth International Symposium GESCO 2009, July 2009, California, U.S.A. (**POSTER**)

Bonnardot, V.M.F., V.A. Carey, M. Madelin, S. Cautenet, Z.A. Coetzee & H. Quénol. 2010. 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. Proceedings of the Eighth International Terroir Zoning Congress, VR, Soave, Italy. pp 2-14 – 2-19, CD Rom ISBN 978-88-97081-05-0. (14-18 June) [Proceedings on-line at http://terroir2010.entecra.it/atti/index.html]

Bonnardot V. & Carey V, 2011. Spatial and temporal variability in temperature in the Stellenbosch Wine of Origin District, South Africa. Presentation at International TerViClim

meeting "Impact du changement climatique a l'echelle des terroirs viticoles", Nov 2011, Valparaiso, Chile and Mendoza, Argentina. (Paper currently being prepared for publication in 2012)

4. Total cost summary of project

	Year	CFPA	Deciduous	DFTS	Winetech	THRIP	Other	TOTAL
Total cost in real terms for year 1	2005				R63 766			**R63 766**
Total cost in real terms for year 2	2006				R76 985			**R76 985**
Total cost in real terms for year 3	2007				R50 000			**R50 000**
Total cost in real terms for year 4	2008				R128 684			**R128 684**
Total cost in real terms for year 5	2009							
Total cost in real terms for year 6	2010							
Total cost in real terms for year 7	2011							
TOTAL								