THE SEA BREEZE: A SIGNIFICANT CLIMATIC FACTOR FOR VITICULTURAL ZONING IN COASTAL WINE GROWING AREAS

LA BRISE DE MER : UN FACTEUR CLIMATIQUE IMPORTANT POUR LE ZONAGE VITICOLE DANS LES RÉGIONS VITICOLES COTIÈRES

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ABSTRACT

The sea breeze is an important climatic factor for viticultural zoning in coastal wine producing areas as the associated increase in wind velocity in the afternoon and concomitant increase in relative humidity and reduction in temperature is of significance for vine functioning and, therefore, grape and wine quality. Wind, relative humidity and temperature were studied with the aid of surface data from automatic weather stations in the South Western Cape wine growing area of South Africa as well as numerical simulations over the study domain in order to ascertain the degree of penetration of the sea breeze and to assess the "limit" of its influence. Simulations were performed using the Regional Atmospheric Modelling System (RAMS) for three synoptic conditions during the grape maturation period: a southerly large-scale flow associated with warm temperature (3/02/2000), a northerly large-scale flow associated with hot and dry conditions (18/02/2000) and north-westerly large-scale flow associated with cool and humid conditions (19/02/2000). Results of the numerical simulations performed at a 1-km resolution showed that the warmer the temperature, the greater the temperature decrease induced by the sea breeze. The sea breeze originating from the Atlantic (Table Bay) on 18/02/2000 generated a maximum temperature decrease of 6°C, while that originating from False Bay on 3/02/2000 generated a maximum temperature decrease of 2°C in the Stellenbosch wine producing area. A maximum temperature decrease of only 1°C was recorded on an overcast day (19/02/2000).

RESUME

La brise de mer est un facteur climatique important pour le zonage viticole des régions viticoles côtières car l'accélération du vent qui lui est associée l'après midi ainsi que l'augmentation de l'humidité relative et la réduction de la température concomitantes sont significatives pour le fonctionnement de la vigne et, par conséquent, la qualité du raisin et du vin. Le vent, l'humidité relative et la température sont étudiés à partir de données de surface issues de stations météorologiques automatiques situées dans le vignoble au sud ouest de la région du Cap en Afrique du Sud et de simulations numériques sur l'espace étudié afin d'évaluer le degré de pénétration de la brise de mer et la "limite" de son influence. Les simulations ont été réalisées avec le Regional Atmospheric Modelling System (RAMS) pour trois conditions synoptiques au cours de la période de maturation: un flux à grande échelle de sud, chaud (3/02/2000), un flux de nord très chaud et sec (18/02/2000) et un flux de nord-ouest frais et humide (19/02/2000). Les résultats des simulations numériques avec une résolution de 1 km montrent que plus les températures sont élevées, plus la baisse des températures générée par la brise de mer est importante. La brise de mer venant de l'Atlantique (Table Bay) le 18/02/2000 a généré une baisse maximale des températures de 6°C tandis que celle de la False Bay le 3/02/2000 une baisse maximale de 2°C dans la région viticole de Stellenbosch. Une baisse maximale de 1°C seulement a été enregistrée lors d'un jour nuageux (19/02/2000).

INTRODUCTION

Sea breeze circulations are due to the contrasting land and water properties and energy balances. The land-water temperature difference produces a land-water pressure difference in the lower atmospheric layer, which results in a system of breezes along a coastline with land breezes at night and sea breezes during the day (ABBS & PHYSICK, 1992). The sea breeze development and circulation have meso-climatic implications in the coastal regions: increase in wind velocity in the late morning and afternoon with concomitant increase in relative humidity and reduction in temperature (usually recorded at the time for maximum temperature), which are of particular interest for the wine industry due to significant effects of wind velocity (CAMPBELL-CLAUSE, 1988), relative humidity (DURING, 1976) and temperature (COOMBE, 1987) on grapevine functioning and thus potential wine quality. Cool temperatures favour the development of grape aromas, especially for white cultivars, e.g. a high concentration of methoxypyrazines responsible for typical green pepper and grassy aroma in Sauvignon blanc (MARAIS *et al.*, 1999). Therefore, the cooling effect of the sea breeze may result in higher wine quality.

The sea breeze is an element of the climate in the South Western Cape region, but there is a lack of knowledge concerning its interaction with prevailing synoptic winds and topography and its precise effect on relative humidity, wind and temperature in this wine producing area. Sea breeze studies were initiated in order to determine how far inland the wine growing areas are influenced by this climatic factor. Climatic observations using surface data obtained from weather stations located in vineyards indicated a sea breeze presence during February (ripening period of most cultivars in the Cape) (BONNARDOT, 1999), but modelling methods appeared necessary in order to study the atmospheric profiles and the sea breeze origin and characteristics (BONNARDOT *et al.*, 2002). The aim of this paper is to show the variation in time and distance of the sea breeze and its influence in the South Western Cape wine-producing region during the ripening period of the grapes using results of an atmospheric modelling system.

MATERIAL AND METHOD

Hourly surface data from five automatic weather stations of the ARC Infruitec-Nietvoorbij network situated in the Stellenbosch and Paarl wine districts at different distances from Table Bay and False Bay (Table 1) were analysed during February 2000. An analysis of variance was performed using ANOVA (SAS, version 8.2) with the Duncan's Multiple Range Test in order to compare temperature means between stations. Upper air and surface data from Cape Town International Airport were also analysed in order to study different synoptic conditions. Three days, each having a different synoptic condition, were used for numerical simulations (3/02/2000, 18/02/2000 and 19/02/2000). These simulations were performed with the aid of the Regional Atmospheric Modelling System (RAMS, the non-hydrostatic, paralleled & 4.3 version) (PIELKE *et al.*, 1992) using four nested grids at resolutions of 25 km, 5 km, 1 km and 200 m. The methodology was largely described by BONNARDOT *et al.* (2002). Results are presented for the 1 km resolution grid covering the South Western Cape and using horizontal and vertical cross-sections over the Stellenbosch and Paarl wine districts (Fig.1). Distances (km) are given as distance from the centre Grid 1 (33°5'S/18°5'E) and time is given as South African Standard Time (SAST), i.e. Greenwich Meridian Time +02:00.

RESULTS AND DISCUSSION

The mean weather conditions for February 2000 clearly indicated that the coastal weather stations recorded cooler temperatures. Their maximum temperatures also occurred earlier than those recorded at inland stations (Table 2). Even though the wind velocity increased in the afternoon, the associated increase in humidity and reduction in temperature due to the sea breeze penetration were not very noticeable when averaged data were used (Fig.2). The study of specific days with different synoptic conditions led to greater evidence of the sea breeze development and its effect on general weather patterns. The description of weather conditions for Cape Town (on average) for February 2000 as well as for the three selected days is given in Table 3. On 3/02/2000, a southerly wind flow (sea origin) in the boundary layer (at 1000 hPa) and a weak northerly wind at the altitude of 1039 m occurred. It was slightly warmer and drier than the monthly average, but was the most representative of the weather conditions during the ripening period. On 18/02/2000, there was a strong (> 10 m.s^{-1}) offshore synoptic wind with warm (24.2°C) and dry (27%) conditions at 850 hPa and resulting in very hot and dry conditions at surface level. A maximum temperature of 37.4°C (highest of the month) was recorded at Cape Town Airport, which was 9.9°C above the monthly average. On the contrary, on 19/02/2000, the westerly synoptic wind brought in cool and humid air upon a thick layer of the atmosphere up to at least 850 hPa. It was one of the coolest days of the month with a maximum temperature of 24.9°C at surface. Relative humidity recorded at surface level at 14:00 (70%) was the highest of the month (20% above average). The frequency analysis of the winds above Cape Town International Airport between 12:00 and 13:00 for February 2000 (Table 4) showed that 93% of the recorded winds at 1000 hPa in the boundary layer (atmospheric layer, through which the sea breeze is moving) had a southerly, southwesterly, westerly or northwesterly component (onshore), and that 14% of the recorded winds at 900 hPa and 31% at 850 hPa had a northerly, northeasterly or easterly component (offshore).

Results of the numerical simulations clearly showed the southerly large-scale flow in the boundary layer on 3/02/2000 and 19/02/2000, which strengthened the sea breeze, and the northerly large-scale flow on 18/02/2000, which deviated the sea breeze from Table Bay southwards and prevented the sea breeze from False Bay to penetrate inland (Fig.3). The southerly winds favoured the sea breeze penetration from False Bay on 3/02/2000. A thin layer (50 - 100 m) of high humidity (> 80%) was observed above False Bay and started to penetrate up to 5 km inland on the southern slope of the first hill (Fig.4a, X2). The humidity decreased progressively onwards depending on the relief. A value of 60% was recorded at the southern slopes of Bottelaryberg and Tygerberg hills (Fig.4a). The offshore synoptic wind (18/02/2000) prevented the sea breeze that developed over False Bay from penetrating inland at 14:00 (Fig.4b, X2), while the sea breeze that originated from the Table Bay (300 m thick layer) penetrated from the west up to the Tygerberg hills (Fig.4b, Y1). The sea breeze originating from False Bay (200 m thick layer with humidity > 60%) developed later, at 17:00 (Fig.4c, X2), and penetrated inland up to 10 km from the coast, converging with the one from Table Bay over the wine growing area (Fig.4c, left). The humid air associated with the sea breeze on 19/02/2000 combined with the humid air brought by the westerly wind (Fig.4d).

At 14:00, the usual time recorded for maximum temperature, temperature increased from south to north along with the southerly synoptic wind (Fig.5a, left), while it increased from west to east along with the northerly synoptic flow (Fig.5b, left). In both cases, a steep temperature gradient occurred at the interface between maritime and inland air (situated at the coastline, at the first km inland or out at sea). A thermal inversion in the lower atmospheric layers with cool and humid air associated with the sea breeze passing below the warmer inland air was located as far as 6 km from False Bay on 3/02/2000 (Fig.5a, X2) and from Table Bay on 18/02/2000 (Fig.5b, Y1). Significant temperature differences between slopes were noticed, decreasing with distance from the sea. A 4°C difference between the south facing and north facing slopes of the hill near Faure and a 2°C difference between the south facing and north facing slopes of the Bottelaryberg hill occurred on 3/02/2000 (Fig.5a, X2). A 4°C difference between the west facing and east facing slopes of the Tygerberg hill occurred on 18/02/2000 (Fig.5b, Y1). On 19/02/2000, the contrast between maritime and inland air was not as important as during the two previous warmer conditions. The temperature gradient at the coast (False Bay) was reduced. Temperature increased with distance from the sea (Fig.5c). The cooling effect of the sea breeze was nullified by the general cool and humid conditions of the day.

The corresponding surface observations in the vineyards (Fig.6) confirmed the results of the simulation. On 3/02/2000, an increase in humidity (up to 10%) and decrease in temperature (up to 2°C) were noticed between 13:00 and 14:00 or between 14:00 and 15:00 depending on the location (Fig.6a). The situation on 18/02/2000 was more complicated due to the penetration of 2 sea breezes, from Table Bay at 14:00 and from False Bay at 17:00. The minimum relative humidity was recorded at 12:00 at the coastal stations (T07, T10) and 13:00 at stations located between 15 and 30 km from False Bay or between 28 and 35 km from Table Bay (T01 and T16) (Fig.6b). Even though relative humidity values remained low (between 25 and 55%) due to the dry synoptic conditions, a slight humidity increase (10%) due to the sea breeze penetration from Table Bay (Fig.4b) was recorded at stations close to the sea between 12:00 and 13:00 for T10 and T07, an hour later, between 13:00 and 14:00 for T01 and T16, where after it remained constant until 15:00. The relative humidity values decreased slightly at 15:00 (a second minimum was recorded at 16:00) and increased again from 16:00 onwards (penetration of the sea breeze from False Bay, Fig.4c). Despite warm conditions (maximum temperature above 30°C in the vineyards), both time periods of increased relative humidity corresponded to decreases in temperature. This became less significant with distance from the coast (Fig.6b). T07 and T10 recorded early maximum temperature at 11:00. The temperatures dropped from 34-36°C to 30-32°C, respectively, between 11:00 and 13:00 with a "minimum" of 28-32°C at 14:00 (the usual time recorded for maximum temperature), which represented a temperature decrease of 6°C in 3 hours. T01 and T16 located at 16, 20 and 30 km from False Bay, respectively, recorded their maximum temperature 2 hours later than T07 and T10. The temperature decrease was not as important (only 3°C) compared to that recorded at the previous stations. There was no sign of temperature decrease further inland (T28) and a difference of 9°C at 14:00 with the coolest location (T07), 28 km away. On 19/02/2000, the cooling effect of the sea breeze was reduced (maximum temperature decrease of 1°C).

The maximum temperature difference between stations was also reduced (5°C at 14:00) due to general humid and cool conditions associated with a prevailing westerly wind (Fig.6c).

CONCLUSION

The temperature reduction in the South Western Cape wine-growing region is pronounced due to the combined effect of the sea breezes originating from False Bay and Table Bay, with the additional contributing climatic effects of the complex topography of the area. The development, inland penetration and effects of the sea breeze varied from day to day depending on the synoptic weather conditions. The warmer the temperature, the greater the temperature decrease induced by the sea breeze. Under dry and hot climatic conditions due to an offshore synoptic wind, the sea breeze generated greater temperature decreases in the Stellenbosch and Paarl wine districts than under warm conditions associated with an onshore synoptic wind. The cooling effect of the sea breeze under these conditions may drastically reduce the duration and intensity of thermal stress for grapevine functioning at some locations. Temperature differences between slopes may have potential implications for viticulture.

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(http://rams.atmos.colostate.edu/detailed.html)

Table 1: Attributes of the automatic weather stations within the Stellenbosch and Paarl wine districts. * T28 is situated outside the limit of the domain for simulation.

Locations	Altitude (m)	Aspect	Slope (%)	Distance from Table Bay or the West Coast (km)	Distance from False Bay (km)
T01	148	SSW	1.68	35	20
T07	230	SE	8.62	12	27
T10	130	SW	5.73	24	12
T16	260	NE	7.49	30	35
T28*	187	ENE	5.56	55	55

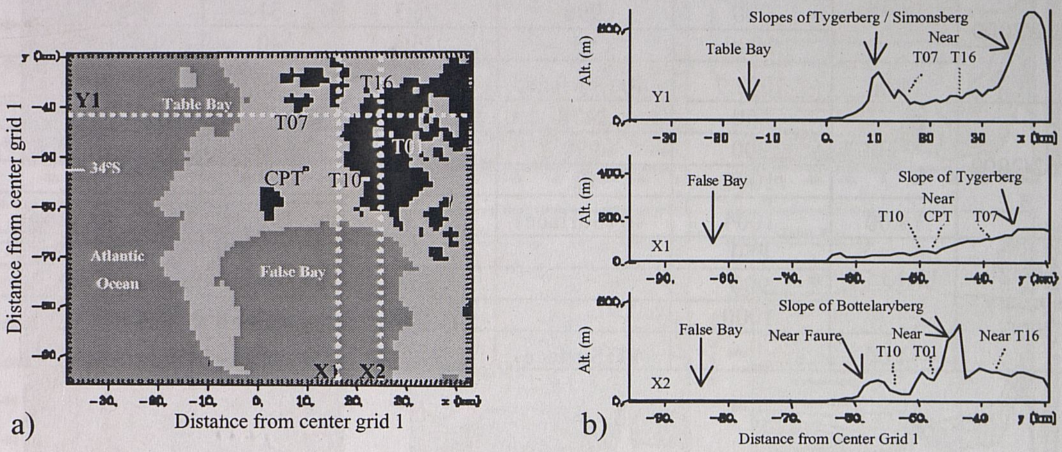

Figure 1: a) Study domain for simulation (Grid 3, 1 km resolution). Center grid 1 is 33°5'S/18°5'E. Location of the automatic weather stations (T01, T07, T10, T16) in the vineyards (in black) and cross sections (Y1, X1 and X2); b) Topography along the three cross-sections.

Table 2: Temperature (°C) at 14:00 and 15:00 recorded at five the automatic weather stations situated in the Stellenbosch and Paarl wine districts. Means with the same letter are not significantly different (Duncan's Test).

	Temperature (°C) at				
Time	T01	T07	T10	T16	T28
14:00	27.8 ab	25.7 c	26.1 c	27.5 bc	29.7 a
15:00	27.9 ab	25.7 c	26.0 cb	27.6 b	29.9 a
Difference	+ 0.1	=	- 0.1	+ 0.2	+ 0.2

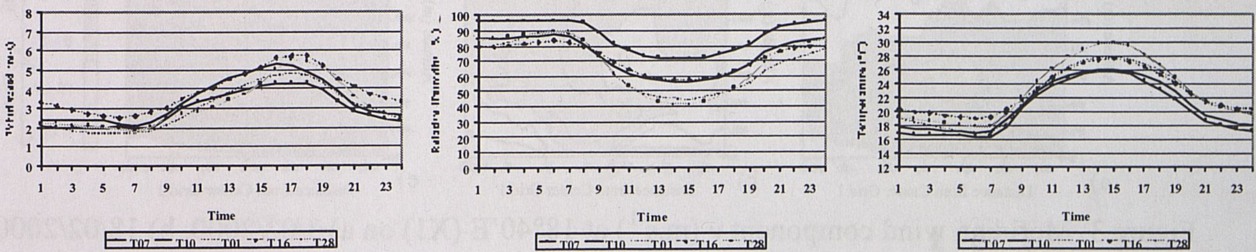

Figure 2: Mean hourly surface data (February 2000) at five weather stations in the Stellenbosch and Paarl wine districts: a) wind speed (m/s), b) relative humidity (%) and c) temperature (°C).

Table 3: Upper air data at 850, 900 and 1000 hPa and surface data at Cape Town International Airport during February 2000 (*Value represents the maximum temperature for the day, which was not necessarily recorded at 14:00).

Date	Time (SAST)	Air pressure (hPa)	Altitude (m)	Temperature (°C)	Humidity (%)	Wind direction	Windspeed (m/s)
3/02/2000	13:05	850	1528	16.2	41	5° (N)	4.8
		900	1039	20.4	41	5° (N)	2.2
		1000	122	25.5	40	190° (SSW)	5.0
	14:00	1008.3	40 (Surface)	30.1*	40	190° (SSW)	6.0
18/02/2000	12:38	850	1497	24.2	27	350° (N)	10.9
		900	996	25.3	31	360° (N)	10.6
		1000	65	26.3	40	300° (NW)	10.5
	14:00	1002.7	40 (Surface)	37.4*	47	340° (NW)	10.0
19/02/2000	12:50	850	1478	15.6	72	290° (WNW)	3.8
		900	990	17.0	85	245° (WNW)	3.1
		1000	82	22.4	73	180° (S)	3.5
	14:00	1004	40 (Surface)	24.9*	70	180° (S)	4.0
Average February 2000	12-13:00	850		16.3	35		3.7
		900		18.0	53		4.6
		1000		22.8	52		7.7
	14:00		40 (Surface)	27.5*	50		8.0

Table 4: Frequency of wind (%) at 850, 900 and 1000 hPa above Cape Town International Airport (February 2000). (*Missing values: 14% at 850 and 900hPa; 7% at 1000 hPa)

Air pressure levels	Frequency of the wind direction (%)							
	Land origin			Sea origin				
	North	Northeast	East	Southeast	South	Southwest	West	Northwest
850 hPa* (≈ 1500 m)	14	3	14	0	17	7	14	21
900 hPa* (≈ 1000 m)	7	0	7	17	34	7	7	7
1000 hPa* (≈ 100 m)	0	0	0	0	69	14	3	7

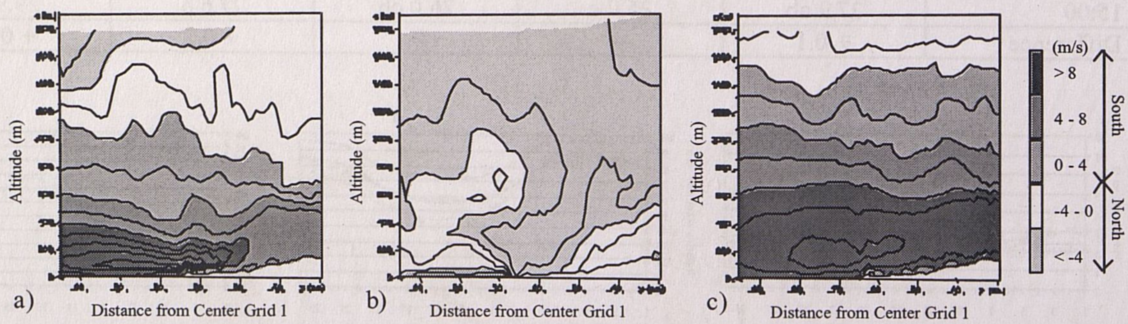

Figure 3: Meridian wind component v (m.s^{-1}) at 18°40'E (X1) on a) 3/02/2000, b) 18/02/2000 and c) 19/02/2000. Centre Grid 1 is 33°5'S/18°5'E.

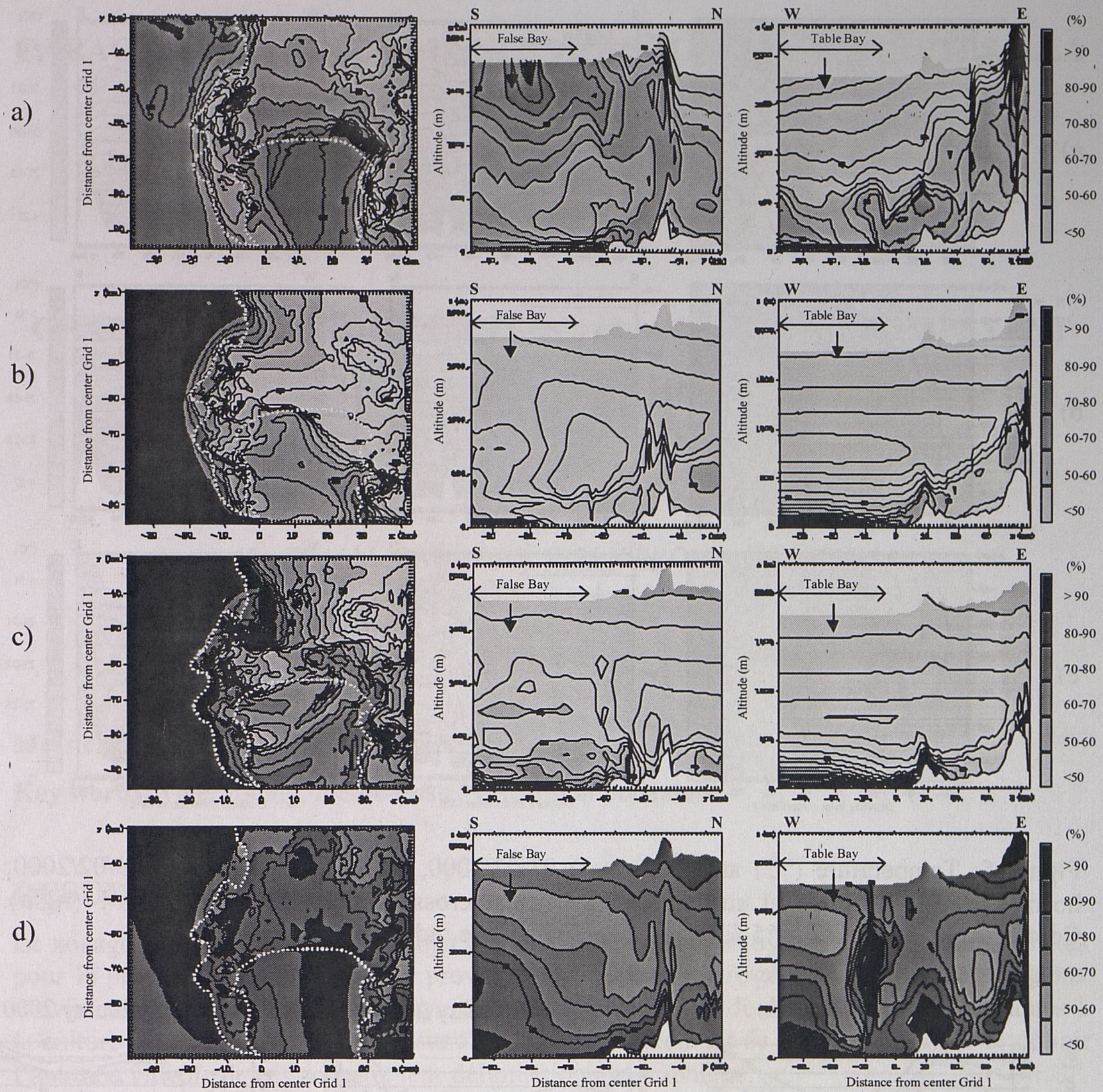

Figure 4: Relative Humidity (%) on a) 03/02/2000 at 14:00, b) 18/02/2000 at 14:00 and c) 17:00, d) 19/02/2000 at 14:00. Horizontal cross section at surface (left), vertical cross section X2 (middle), Y1 (right). Centre Grid 1 is 33°5'S/18°5'E. The dotted white line indicates the coastline.

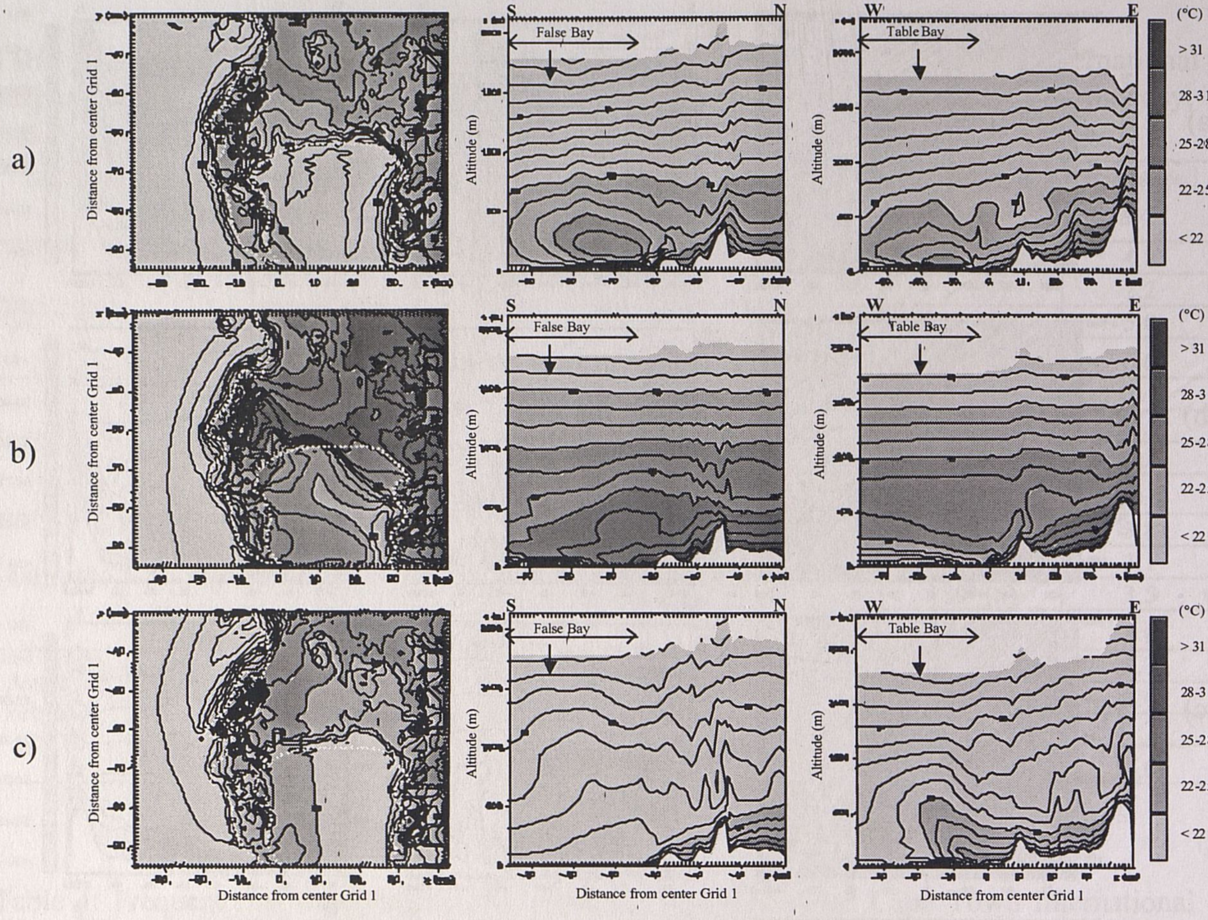

Figure 5: Temperature (°C) at 14:00 on a) 03/02/2000, b) 18/02/2000 and c) 19/02/2000; horizontal cross section at surface (left), vertical cross section X2 (middle), Y1 (right). Centre Grid 1 is 33°5'S/18°5'E. The dotted white line indicates the coastline.

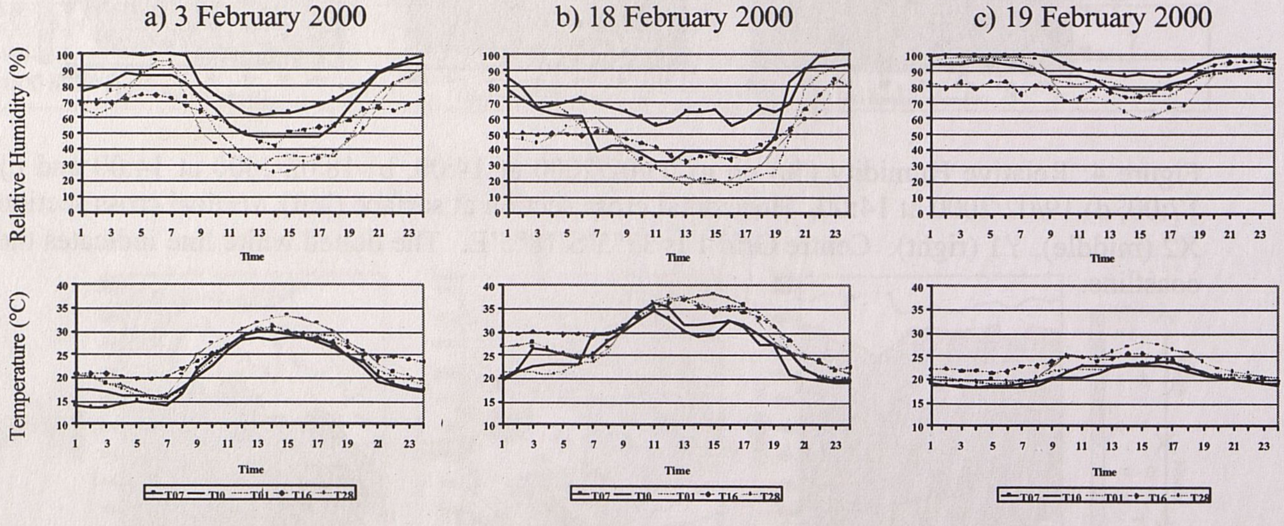

Figure 6: Relative humidity (%) and temperature (°C) on a) 3/02/2000, b) 18/02/2000 and c) 19/02/2000 at five weather stations in the Stellenbosch and Paarl wine districts.