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Meso-scale future climate modeling (5 km resolution): application over French wine regions under the SRES A2 scenario (2041-2050)

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ABSTRACT
In order to assess climate change at regional scales suitable to viticulture, the outputs of ARPEGE_Climat global model (resolution 0.5°) were downscaled using the Regional Atmospheric Modeling System (RAMS) and nested grids, providing downscaled datasets of 5 km resolution over France. Simulations were performed for two periods: 1991-2000, to assess the method against observations and quantify the large-scale induced biases; and 2041-2050 as near future climate projection under the SRES A2 scenario conditions. Results for July maximum temperatures, focussing on 6 wine regions, show RAMS contribution in reducing the large-scale bias, leading to a better assessment of climate change, yet with spatial differences.

Keywords: Mesoscale climate modeling, SRES A2 scenario, July maximum temperature, wine regions, France.

1 INTRODUCTION

Climate variability and trends are issues of growing concern at regional/local scales in the viticultural sector. The use of global climatic models (GCMs) ran under the different SRES emissions scenarios representing possible future evolution of greenhouse gases and aerosol precursor emissions during the 21st century (1), are necessary to simulate future climate. However, the outputs from GCMs are generally too broad-scale for viticultural purposes at regional scales (2, 3) and therefore downscaling methods (coarse to fine resolution) are necessary to translate changes at regional/local scales. Regional (or meso-scale) Climate Models (RCMs) driven by large-scale forcing generated by GCMs have been used for many years as a relevant downscaling tool (taking surface conditions and land-sea configuration into account, thus improving dynamical processes by means of nested grids (4) in order to study climate change at regional scales (5, 6). Many studies have shown the value of using different high-resolution three-dimensional atmospheric numerical models and increasing resolution to characterize the climate variability, potential and risks for viticultural environments (7-13). In this paper, the ARPEGE-Climat model of Météo-France (called ARPEGE thereafter) was used as the global driver for the Regional Atmospheric Modeling System (RAMS) and we show how RAMS contributed to deliver high resolution downscaled datasets (5 km) for recent past and near future climates, targeting some French wine regions.

2 DATA AND METHOD

The regional atmospheric modeling system RAMS (14) (v6.0) was initialized every 6 hours with the 3-D atmospheric fields of ARPEGE (4) (0.5° resolution), which simulated a succession of climatic conditions comparable to observations over Western Europe and reproduced the mean climatic characteristics of the 1971-2000 period (15). Two nested grids were used for downscaling (Fig. 1): Grid 1 corresponding to large scale forcing over the North Atlantic Ocean and Europe; Grid 2 with a 5 km resolution representing local circulations over France. The outputs of ARPEGE were downscaled for two periods of ten years in order to reduce computational costs (i.e. 1991-

2000 as reference period and 2041-2050 as near future climate projection). The 3-D fields used for the future period were those generated under the SRES A2 pessimistic scenario for the end of the century with CO_2 concentrations increasing from 350 ppm to 850 ppm between 2000 and 2100 (16). Data for the 1991-2000 period were analysed in order to (i) validate the method against observations at specific sites, (ii) assess the large scale induced biases, (iii) show spatial differences and (iv) assess the RCM contribution in reducing the large-scale biases. Results for July maximum temperature are presented in this paper to assess summer warming, holding implications for viticulture. Observed daily data were provided by Météo France. Focus was made on six wine regions of France, namely the Loire Valley, Champagne, Burgundy, Bordeaux, the low Rhône Valley and Languedoc using representative regional weather stations, Angers-Beaucouzé (Angers), Reims-Courcy (Reims), Savigny-lès-Beaune (Savigny), Bordeaux-Mérignac (Bordeaux), Montélimar and Nîmes respectively (Fig. 1). A descriptive statistical analysis was performed using simulated and observed temperatures datasets in order to assess the method against observations and assess the RCM contribution in providing detailed regional simulations. The Student *t* test was calculated to determine whether the differences between observed and simulated datasets were statistically significant. To estimate the errors between the simulated and observed values, the root mean square error (RMSE) was calculated.

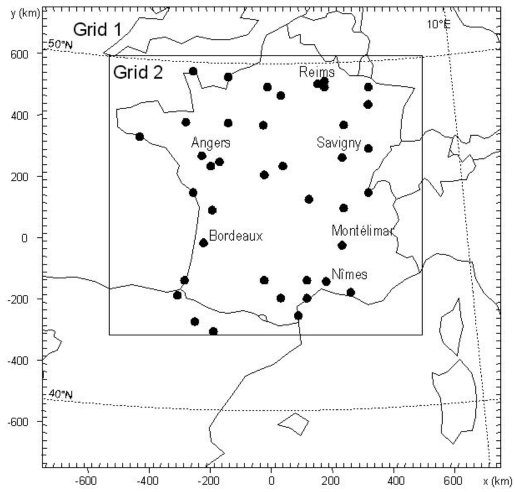


Figure 1. Domains for RAMS meso-scale simulations (Grid 1: 25 km horizontal resolution; Grid 2: 5 km horizontal resolution). Spatial distribution of the weather stations used for validation (black points) with names for those representatives of the six studied wine regions (Source Météo-France).

3 RESULTS

3.1 The 1991-2000 reference period

Due to the highest spatial resolution of RAMS, one can clearly see the adding value of the meso-scale model, highlighting spatial differences compared to the coarse resolution of ARPEGE (Fig. 2).

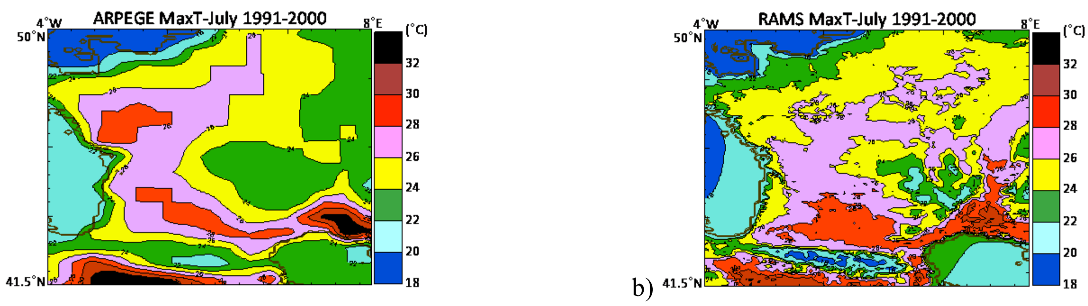


Figure 2. Simulated July Maximum temperature (Grid2) using a) ARPEGE (50 km resolution) and b) RAMS (5 km resolution), average for 1991-2000.

Considering statistical results between simulated and observed temperature values over the reference period (1991-2000) for the six studied wine regions (Table 1), it can be noted that biases of different magnitudes according to locations are induced by the large scale forcing and that the average error (RMSE) is smaller using the RAMS outputs.

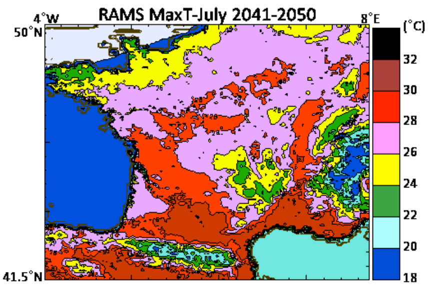
Table 1. Root Mean Square Error and Student *t* test between simulated temperatures by ARPEGE (50 km resolution) and RAMS (5 km resolution) and observed July maximum temperatures at 6 locations. Non significant differences between simulations and observations are indicated in bold (p-values > 0.05).

Location	Model	Mean difference (°C)	RMSE
Angers	ARPEGE	+3,9	7.15
	RAMS	**+0,6**	4.80
Reims	**ARPEGE**	**+1,6**	6.00
	RAMS	**+1,5**	5.54
Savigny	ARPEGE	-1,8	5.75
	RAMS	**-0,2**	5.59
Bordeaux	ARPEGE	+1,8	5.90
	RAMS	-1,3	5.34
Montélimar	**ARPEGE**	**-0,2**	5.37
	RAMS	**+0,1**	5.43
Nîmes	ARPEGE	+2,4	5.53
	RAMS	**-0,9**	4.44

Three cases highlighted significant spatial differences in the modeling (i) Temperature differences between simulations by both models and observations were significant (Bordeaux); (ii) Temperature differences between simulations by both models and observations were not significant i.e. ARPEGE and RAMS models reproduced the observations significantly (Montélimar and Reims, with a significant warm bias at Reims) ; (iii) Temperature differences between ARPEGE simulations and observations were significant whereas those between RAMS simulations and observations were not. Therefore RAMS contributed in reducing the ARPEGE warm bias significantly by more than 3°C at Angers and Nîmes, bringing the simulations closer to observations. Yet RAMS simulations resulted in a cold bias over the Languedoc. On the other hand, RAMS reduced the ARPEGE cold bias by 1.6°C at Savigny, lifting up simulations close to observations.

3.2 The 2041-2050 future period under the SRES A2 scenario

Simulated July maximum temperature for 2041-2050 at 5 km resolution and differences between the 2041-2050 and 1991-2000 periods are displayed in Figure 3 a and b respectively.

a) 

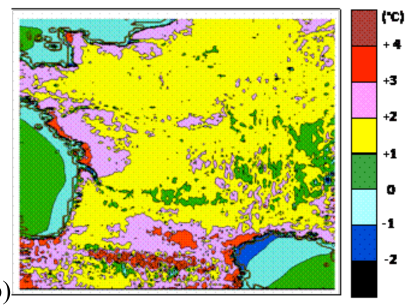
b) 

Figure 3. a) Simulated July maximum temperature for 2041-2050 (A2 SRES scenario) for Grid 2; b) Differences between 1991-2000 and 2041-2050.

Site-specific modeled data for 2041-2050 are provided in Table 2. The RAMS assimilation of the SRES A2 scenario for the 2041-2050 period resulted in temperature projected to rise in the range 0.4°C to 3.4°C. A significant increase of 3.4°C is simulated at Reims, but there was a warm bias over the control period of 1.5°C, leading to likely over estimation. The increase is of 2°C in the Loire Valley but there was a warm bias of 0.6°C over the control period. Results are also likely to be overestimated at Angers. A significant increase of 1.4°C was simulated in Burgundy and of 1°C in Montélimar. Finally, an increase of 0.4°C was simulated by RAMS at Nîmes for which, conversely, results are likely underestimated as there was a 0.9°C cold bias over the control period.

Table 2. Change in July temperature parameters between the 1991-2000 period and the 2041-2050 period (using RAMS simulation and the SRES A2 scenario). Results in bold are those for which simulations were validated over the reference period.

Location	Observation (1991-2000)		RAMS Simulation (2041-2050)		Mean differences between simulation and observation in	
	July Max T (°C)	#days with July Max. T> 35°C	July Max T (°C)	#days with July Max. T> 35°C	July Max T (°C)	#days with July Max. T> 35°C
Angers	25.2	0.2	**27.2**	**0.5**	**+2.0**	**+1.8**
Reims	24.4	0.1	**27.8**	**0.4**	**+3.4**	**+0.3**
Savigny	26.5	0.1	**27.9**	**0.9**	**+1.4**	**+0.8**
Bordeaux	26.7	0.7	27.6	0.6	+0.9	-0.1
Montélimar	29.0	1.4	**30.0**	**2.2**	**+1.0**	**+0.8**
Nîmes	30.6	2.6	**31.0**	**2.8**	**+0.4**	**+0.2**

4 CONCLUSIONS

The Regional Atmospheric Modeling System contributed to deliver high resolution downscaled datasets (5 km resolution) for recent past (1991-2000) and near future (2041-2050) climates. Taking the surface heterogeneity into account, it reduces the large-scale induced biases and leads to a better correlation between simulations and observations. The assimilation of the SRES A2 scenario for the 2041-2050 period resulted in temperature projected to rise in the range 0.4°C to 3.4°C for the maximum temperature of July, with some bias depending on the regions. Results are dependent on ARPEGE outputs used for the large-scale forcing and on the chosen reference period. They would probably be different with other runs using other scenarios and other control periods.

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