

A FINE-SCALE APPROACH TO MAP BIOCLIMATIC INDICES USING AND COMPARING DYNAMICAL AND GEOSTATISTICAL METHODS

Renan Le Roux¹, Marwan Katurji², PeymanZawar-Reza², Laure de Ressaiguier³, Andrew Sturman², Cornelis van Leeuwen³, Amber Parker⁴, Mike Trought⁵ and Hervé Quéno¹

¹ LETG-COSTEL, UMR 6554 CNRS, Université de Rennes 2, Place du Recteur Henri Le Moal, Rennes, France

² Centre for Atmospheric Research, University of Canterbury, Christchurch, New Zealand

³ EGFV, Bordeaux Sciences Agro, INRA, Univ. Bordeaux, ISVV, F-33140 Villenave d'Ornon, France

⁴ Lincoln University, P O Box 85084, Lincoln, Christchurch, New Zealand

⁵ New Zealand Institute for Plant and Food Research Ltd, Blenheim, Marlborough, New Zealand

Corresponding author: Le Roux. E-mail: renan.leroux@uhb.fr

Abstract

Climate, especially temperature, plays a major role in grapevine development. Several bioclimatic indices have been created to relate temperature to grapevine phenology (e.g. Winkler Index, Huglin Index, Grapevine Flowering Veraison model [GFV]). However, temperature variability can be significant at vineyard scale, so knowledge of the various climatic mechanisms leading to this variability is essential in order to improve local management of vineyards in response to climate change. Indeed, current climate change models are not accurate enough to take into account temperature variability at the vineyard scale (Dunn et al., 2015). This study therefore proposes a method for compare regional modelling and fine-scale observations to map temperatures and bioclimatic indices at fine spatial resolution for some recent growing seasons. This study focuses on two vineyard areas, the Saint-Emilion and Pomerol region in France and the Marlborough vineyard region in New Zealand. A regression model using temperature from networks of measurements has been created in order to map temperature and bioclimatic indices at vineyard scale (100 metres for Marlborough and 25 metres for Saint-Emilion and Pomerol). To complement the field measurements, the advanced physics-based three-dimensional numerical weather model Weather Research and Forecasting ó WRF (<http://wrf-model.org/index.php>) has been used, providing hourly meteorological parameters over a complete growing season for each site at 1, 3 and 9 and 27 kilometre resolution. The output of the WRF model provides temperature, wind speed and direction, pressure, and solar radiation data at these different resolutions. The application of different scales of modelling allows improvement in understanding the climate component of the specific terroirs of the study areas.

Keywords: *Climate, phenology, grapevine, bioclimatic indices, modelling*

1 INTRODUCTION

Viticulture is an important practice across many regions of the world, representing a key economic and cultural activity. Within wine growing regions, climate has a central role in the characterization of a specific vineyard terroir (van Leeuwen et al. 2004; Jones et al. 2006). As the grapevine is highly sensitive to climate variations, both spatially and temporally, climate change is one of the most important challenges facing the viticultural sector. Over the coming decades, wine growing regions will be confronted by a modification of regional climate characteristics that may lead to significant impacts on wine quality and typicality (Beltrando and Briche, 2010; Neethling et al., 2012; Quéno, 2014). As temperature variability can be significant at vineyard scale, several bioclimatic indices have been created to relate temperature and grapevine phenology (e.g. Winkler (Amerine and Winkler. 1944), Huglin (Huglin. 1978), Grapevine Flowering Veraison model [GFV] (Parker et al., 2013, 2011)). Knowledge of the different climatic mechanisms leading to this variability is essential in order to improve local management of vineyards in response to climate change. Indeed, current climate change models are not accurate enough to take account of temperature variability at the local scale. This study therefore proposes to map temperature-based bioclimatic indices at various climatic scales for some recent growing seasons over two very different vineyard areas, the Saint-Emilion and Pomerol area in France and Marlborough region in New Zealand. We used the advanced physics-based three-dimensional numerical weather model (Weather Research and Forecasting ó WRF (Skamarock, et al., 2008)) to create maps at 1,3,9 and 27 kilometre resolution. To create maps with finer horizontal resolution (25 to 100 metres), observation networks have been set up and geostatistical models were applied. Regression of temperature on a range of terrain characteristics derived from a DEM was undertaken, as has been carried out in previous studies (Joly et al., 2003; Madelin, 2004; Stahl et al., 2006; Bois, 2007; Bonnardot et al., 2012; Bonnefoy, 2013). A non-linear model, Support Vector Regression (SVR ó Cortes and Vapnik, 1995), was used as it showed better performance compared to linear models.

2 MATERIALS AND METHODS

The two study sites selected for this research are vineyard areas with very different environmental characteristics. The first one is a famous sub-appellation of the Bordeaux area in France, including the Saint-Emilion and Pomerol appellations, where the altitude varies between 10 and 100 metres across a succession of hills and valleys. Several rivers and creeks are located in the study area, the main one being the Dordogne River in the south. The general climate of the region is oceanic with precipitation evenly distributed over the year, even during the relatively warm summers. The main varieties grown are Merlot, Cabernet franc and Cabernet Sauvignon. The second study site is the largest wine production area in New Zealand, the Marlborough vineyard region, which mainly produces wine from Sauvignon blanc grapes. The area is surrounded by high mountains (some of which reach over 2000 metres) and is bordered by the Pacific Ocean on the eastern side. The complex terrain, combined with the oceanic influence, creates a very specific and complicated local climate influenced by both mountain-valley and land-sea breeze circulations. At the Saint-Emilion and Pomerol site, 90 temperature sensors have been used to collect hourly air temperatures inside the vine canopy since 2012. For Marlborough, 37 automatic weather stations were established, recording climatic data such as air temperature, wind speed and solar radiation (Figure 1).

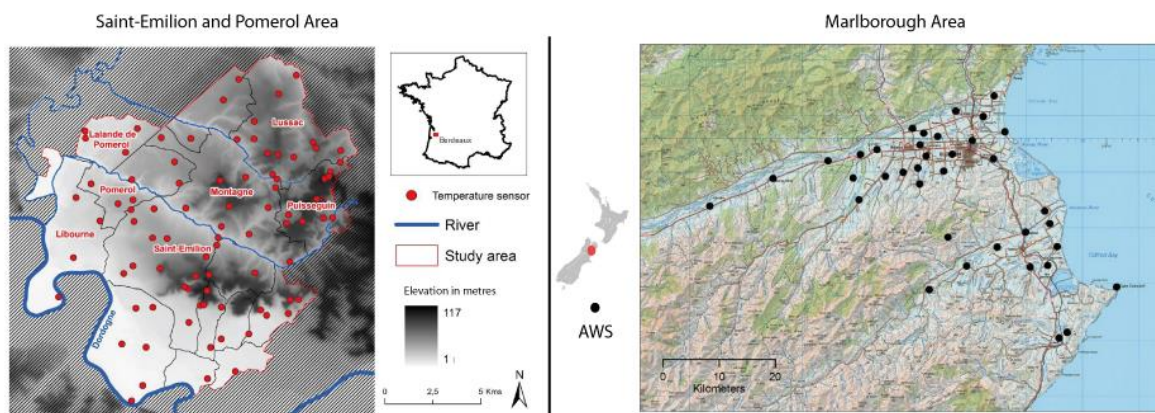


Figure 1: Studies sites and the location of the observation networks.

Two different sets of data were used to obtain maps of temperature at different scales. The first dataset was output from a geostatistical/interpolation model that provided maps at the DEM resolution (25 metres for Saint-Emilion and Pomerol and 100 metres for Marlborough). Using data extracted from the temperature sensors and weather stations, regression models (SVR) were used to relate air temperature to several environmental predictors (elevation, slope, aspect and position), with the aim of producing the fine-scale temperature maps. The second dataset was obtained from the WRF model. It provided climate variables (e.g. temperature and wind speed) at different spatial scales (1, 3, 9, and 27km) at hourly intervals throughout the growing season. Hence, temperature maps were available from the synoptic to the local scale for the two different regions for one full growing season (2014 for Saint-Emilion and Pomerol, 2013-2014 for Marlborough). Using these different scales, it has been possible to characterize temperature variability and bioclimatic indices for each vineyard region.

3 RESULTS AND DISCUSSION

The Winkler index was calculated to create daily maps of each models' outputs, and results compared to the average Winkler index over the whole area (Figure 2). We used the average over each area to reduce bias introduced by comparing the output of different kinds of model. Results show that at larger scales, the effect of the proximity of water bodies (Garonne and Dordogne rivers, Gironde estuary) are important for temperature distribution in the Bordeaux area, while the deep valleys and oceanic influence are the main influences on temperature variability in the Marlborough region (Figure 2).

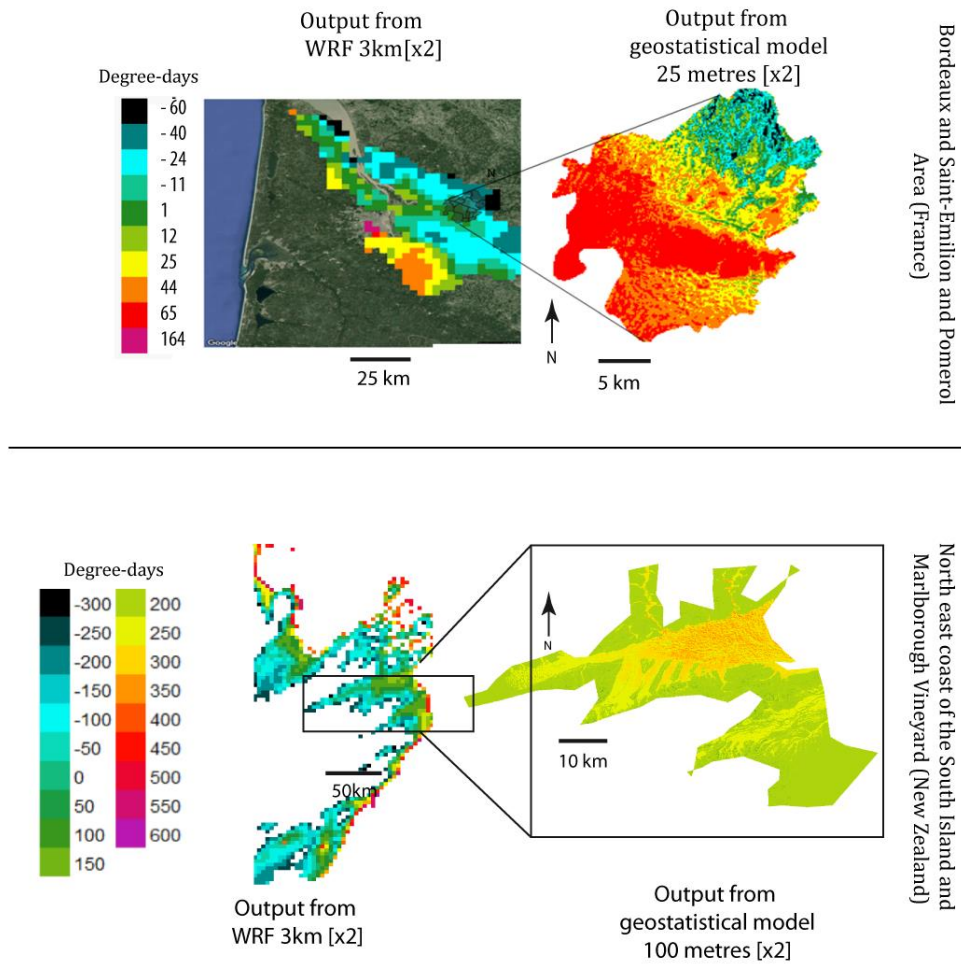


Figure 2 :Maps of the difference from mean across the region of the Winkler index (in degree-days) mapped at 3 km resolution and 25/100 metre resolution over the two vineyard areas based on the output of WRF and the regression model (2014 growing season for St Emilion at the top and 2013-2014 for Marlborough at the bottom).

Figure 2 also shows that at the finer scale the variability is more complex and some localized spatial patterns are identified that reflect development of such small-scale phenomena as cool air pools, slope heating, and coastal effects. Comparison of these different scales shows that temperature range appears to be smaller in magnitude at the regional and local scales in the Bordeaux area where the terrain is significantly smoother than in New Zealand. For Bordeaux we can also note that the spatial variability is similar at both the local and regional scales. These two different scales of modeling are important to understand the range of climatic variability and its drivers. In a context of climate change it is also critical to measure the impact of temperature differences on vine development. It should also be noted that in larger scale future climate models (in France we used the ALADIN model (Bubnová et al., 1995; Radnóti et al., 1995)), vineyard areas such as our study sites represent just one or a small number of pixels (Figure 3), so that their usefulness for developing regional and local adaptation strategies is limited. Further work would involve downscaling this future climate model to the local scale. In particular, because temperature has been shown to strongly influence grapevine growth, the date of occurrence of phenological stages shows similar variability at the vineyard scale. For example, fine-scale maps of the estimated date of 50% flowering obtained using the GFV model and the temperatures obtained from the geostatistical modelling reveal that the timing of phenology can exhibit significant spatial variability over small distances (Figure 4).

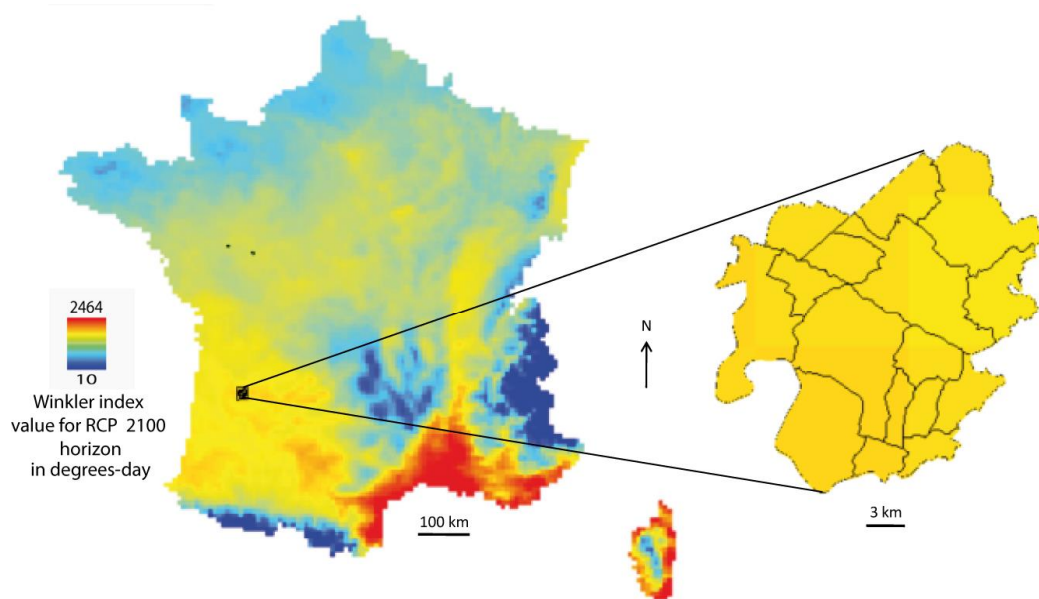


Figure 3: Winkler index for the year 2100 for France and the Saint-Emilion and Pomerol area at 8 km resolution based on the RCP 4.5 scenario. Data: DRIAS project from the ALADIN model.

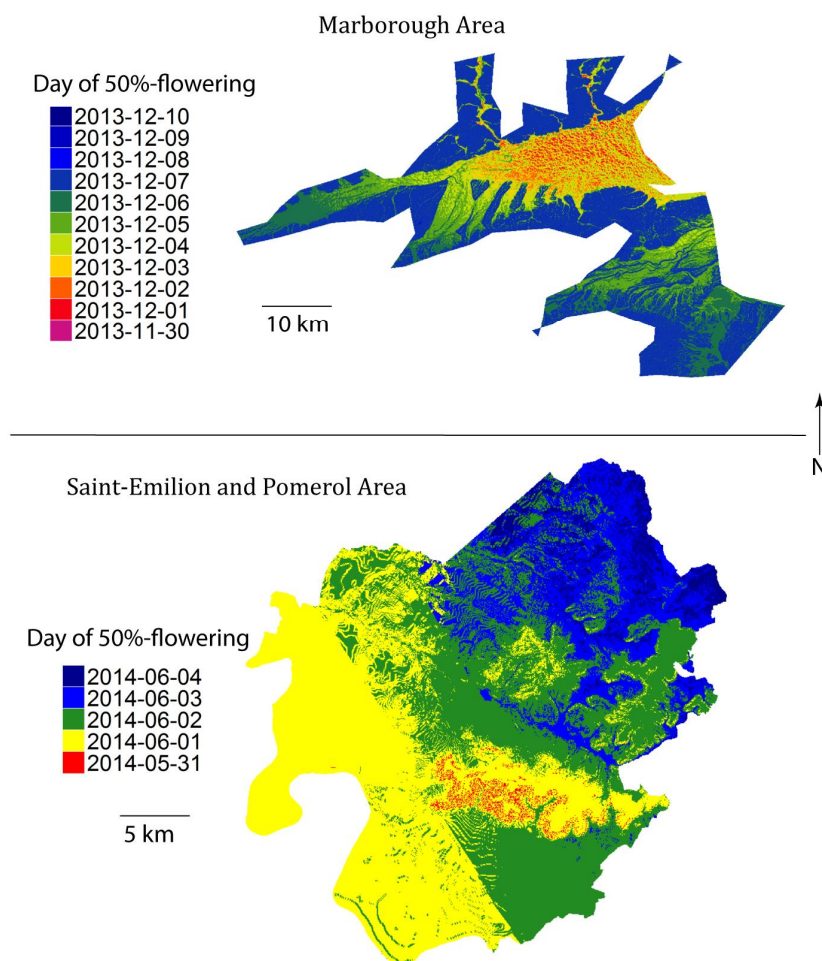


Figure 4: Isochrones maps of the date on which accumulated degree day values derived from the Grapevine Flowering Véraison model achieved $F^* = 1282$ (value for Sauvignon blanc) across the Marlborough region and $F^* = 1269$ (value for Merlot) across the St Emilion and Pomerol region, based on the geostatistical model output at 25/100 metres spatial resolution. (2013-2014 growing season for Marlborough at the top and 2014 for Saint-Emilion and Pomerol at the bottom).

4 CONCLUSION

The multiple scale approach presented in this study could be reproduced anywhere where high-resolution mesoscale models are available, on the condition that a temperature logger or weather station network has to be set-up. It allows a comprehensive analysis of temperature distribution over vineyard areas across a range of different spatial scales. Moreover, being able to map the fine-scale spatial variation of phenological stages provides valuable information for vine growers to help with vineyard management decisions. Improved optimization of wine-grape production through better knowledge of climate at high resolution within vineyard regions will contribute to the future sustainability of high quality wine production in the context of climate change. Understanding relationships between these different scales is the next step to linking general synoptic weather situations to local effects. Then using this relationship we might be able to provide fine scale adaptation for future climate model presented in the DRIAS project.

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5 LITERATURE CITED

- Amerine MA, Winkler AJ. 1944. Composition and quality of musts and wines of California grapes. University of California.
- Beltrando G, Briche E. 2010. Changement climatique et viticulture en Champagne : du constat actuel aux prévisions du modèle ARPEGE-Climat sur l'évolution des températures pour le XXI^e siècle. *EchoGéo* (14).
- Bois B. 2007. Cartographie agroclimatique a meso-echelle : methodologie et application a la variabilite spatiale du climat en gironde viticole. Conséquences pour le développement de la vigne et la maturation du raisin. Université Sciences et Technologies - Bordeaux I.
- Bonnardot V, Carey VA, Madelin M, Cautenet S, Coetzee Z, QuénoI H. 2012. Spatial variability of night temperatures at a fine scale over the Stellenbosch wine district, South Africa. *Journal International des Sciences de la Vigne et du Vin*46(1): 1613.
- Bonnefoy C. 2013. Observation et modélisation spatiale de la température dans les terroirs viticoles du Val de Loire dans le contexte du changement climatique. Université Rennes 2.
- Bubnová R, Hello G, Bénard P, Geleyn J-F. 1995. Integration of the Fully Elastic Equations Cast in the Hydrostatic Pressure Terrain-Following Coordinate in the Framework of the ARPEGE/Aladin NWP System. *Monthly Weather Review*123(2): 5156535. DOI: 10.1175/1520-0493(1995)123<0515:IOTFEE>2.0.CO;2.
- Cortes C, Vapnik V. 1995. Support-vector networks. *Machine learning*20(3): 2736297.
- Dunn M, Lindsay J, Howden M. 2015. Spatial and temporal scales of future climate information for climate change adaptation in viticulture: a case study of User needs in the Australian winegrape sector. *Australian Journal of Grape and Wine Research*.
- Huglin P. 1978. Nouveau mode d'évaluation des possibilites heliothermiques d'un milieu viticole. *Comptes rendus des seances*.
- Joly D, Nilsen L, Fury R, Elvebakk A, Brossard T. 2003. Temperature interpolation at a large scale: test on a small area in Svalbard. *International Journal of Climatology*23(13): 163761654. DOI: 10.1002/joc.949.
- Jones GV, Reid R, Vilks A. 2012. Climate, Grapes, and Wine: Structure and Suitability in a Variable and Changing Climate. In: Dougherty PH (ed) *The Geography of Wine*. Springer Netherlands, 1096133.
- Madelin M. 2004. L'aléa gélif printanier dans le vignoble marnais en Champagne. Modélisation spatiale à une échelle fine des écoulements de l'air et des températures minimales. Université Paris-Diderot - Paris VII.
- Neethling E, Barbeau G, Bonnefoy C, Quinol H. 2012. Change in climate and berry composition for grapevine varieties cultivated in the Loire Valley. *Climate Research*53(2): 896101. DOI: 10.3354/cr01094.
- Parker A, de Cortázar-Atauri IG, Chuine I, Barbeau G, Bois B, Boursiquot J-M, Cahurel J-Y, Claverie M, Dufourcq T, GénY L. 2013. Classification of varieties for their timing of flowering and veraison using a modelling approach: A case study for the grapevine species *Vitis vinifera* L. *Agricultural and Forest Meteorology*180: 2496264.
- Parker A k., De Cortázar-Atauri I g., Van Leeuwen C, Chuine I. 2011. General phenological model to characterise the timing of flowering and veraison of *Vitis vinifera* L. *Australian Journal of Grape and Wine Research*17(2): 2066216. DOI: 10.1111/j.1755-0238.2011.00140.x.
- QuénoI H. 2014. Changement climatique et terroirs viticoles. Lavoisier Tec&doc.444p
- Radnóti G, Ajjaji R, Bubnová R, Caian M, Cordoneanu E, Von Der Emde K, Gril J, Hoffman J, Horányi A, Issara S. 1995. The spectral limited area model ARPEGE-ALADIN. PWPR report series (7): 1116117.

Skamarock, W, Klemp, Joseph, Dudhia, Jimy, Gill, David, Barker, Dale, Wang, Wei, Huang, Xiang-yu, Duda, Michael. 2008. A Description of the Advanced Research WRF Version 3. . DOI: 10.5065/D68S4MVH.

Stahl K, Moore RD, Floyer JA, Asplin MG, McKendry IG. 2006. Comparison of approaches for spatial interpolation of daily air temperature in a large region with complex topography and highly variable station density. *Agricultural and Forest Meteorology*139(364): 2246236. DOI: 10.1016/j.agrformet.2006.07.004.

van Leeuwen C, Friant P, Choné X, Tregoat O, Koundouras S, Dubourdieu D. 2004. Influence of Climate, Soil, and Cultivar on Terroir. *American Journal of Enology and Viticulture*55(3): 2076217.