

The Effects of Climate Change on Grape Production in Hungary

Ildikó Mesterházy, Róbert Mészáros, Rita Pongrácz

Department of Meteorology, Eötvös Loránd University,

Pázmány P. sétány 1/A, H-1117 Budapest, Hungary

E-mail: mesildiko@caesar.elte.hu

Abstract

The spacial distributions of several indices characterizing wine production in Hungary are analysed in this paper using the bias-corrected outputs of three different regional climate models: RegCM, ALADIN, and PRECIS. For this purpose the daily minimum, maximum, and mean temperature, and daily precipitation time series are used. The indices include the active degree days, Huglin's heliothermal index, the length of vegetation period according to thermal conditions, precipitation-temperature index, hydrothermal coefficient, and frequencies of extreme temperature events. In the study first the past changes of these indice are evaluated, and than the main focus is on the projected changes until the end of the 21st century. Our results suggest that white wine grapes are very likely to lose their dominance over red wine grapes in Hungary in the next few decades. At the same time, the ripening of late-ripening and very-late-ripening grape varieties will become more likely. Extreme high summer temperatures will become more frequent, while the risk of frost damage in the reproductive cycle is projected to decrease.

Keywords: *Vitis vinifera*, RegCM, ALADIN, PRECIS, Hungarian wine region

1. Introduction

Wine grape production is a segment of major importance in Hungarian agriculture. The life cycle of the grape is influenced by climatic, edaphic, and biotic factors, from which climatic factors are the most dominant and dynamically changing ones (*Kozma*, 2002). As vineyards in Hungary produce grapes for 25–30 years, predicting these climatic factors for the next decades has a very importance.

In this work we analyze the temporal trends of selected climatic factors, and use several indices to identify grape varieties in Hungary that are more suitable for the projected climatic changes. Additionally, we predict the trend of change in the probability of disease development for the next decades. Although there has been a recent work studying the future changes of ecological factors affecting Hungarian grape fields (*Szenteleki*, 2011), our work is the first climatic

study of the entire Hungarian region focusing specifically on grape and wine production.

2. Studied regions and applied methods

2.1. Studied regions

The wine regions of Hungary belong to the Northern territories of grape production. Grape production is made possible primarily by the diverse microregions of the country and their specific meso- and microclimate. Based on microclimatic similarities, the 22 Hungarian wine regions are categorized to 5 macroregions, covering the Great Hungarian Plain (Alföld), the North Hungarian Mountains (Északi-középhegység), the Transdanubian Mountains (Dunántúli-középhegység), the Transdanubian Hills (Dunántúli-dombvidék), and Alpokalja. On these wine regions, the wine grape production is dominated by white wine grapes, however in the Alpokalja and Transdanubian Hills regions red grape production is also important. From the grape varieties, both early-, medium-, and late-ripening ones are produced in the different regions (Hajdú, 2003).

2.2. Applied regional climate models

Results provided by global climate models (GCMs) cannot be applied to small regions like the Carpathian Basin and Hungary. Therefore in our analysis we applied regional climate models (RCMs) nested in GCMs. The RCMs have finer spatial resolution than GCM, thus they can take into account local scale landscape features and topography.

We used the outputs of the following model simulations carried out in the framework of the European ENSEMBLES project (van der Linden & Mitchell, 2009): RegCM and the ALADIN regional climate model (Pongrácz *et al.*, 2011), and the PRECIS regional climate model developed by the UK Met Office Hadley Centre for Climate Prediction and Research (Wilson *et al.*, 2007) and applied specifically to the Carpathian Basin (Pieczka, 2012). One to the raw outputs the general overestimation of summer temperature and annual precipitation (Pieczka *et al.*, 2011) were corrected using a percentile-based bias correction (Formayer & Haas, 2009) consisting of correcting the simulated daily outputs on the basis of the monthly distributions of observed meteorological data. Observations are available from the gridded E-OBS database (Haylock *et al.*, 2008) to a discrete spatial grid. The RCM simulations use the moderate A1B scenario (Nakicenovic & Swart, 2000) for the 21st century. This scenario assumes a slowly growing trend of atmospheric carbon-dioxide concentration, which is likely to exceed 700 ppm by the end of the century.

All RCMs applied a horizontal resolution of 25 kilometers. This resolution is still too coarse for detailed studies on the changing microclimatic conditions of

vineyards, but it enable us to estimate some general tendencies. The simulated model data we used cover the geographic region between latitudes 44°–50° N and longitudes 14°–26° E, and contain the time interval 1951–2100 (except for the PRECIS simulation, where the time interval was 1951–2098). The applied RCM outputs are the daily minimum, maximum, and mean temperature, as well as the daily precipitation, which are used to calculate past and future time series of various indices described in section 2.3, and derive conclusion on their effect on wine grape production in Hungary in the *short term* (for the period 2021–2050) and in the *long term* (for the period 2071–2100; or between 2069–2098 for the PRECIS model due to shorter simulation time range). We defined the years 1961–1990 is defined as the *reference period*.

2.3. The applied indices

The indices that we analyse in this paper are the following.

Active degree days (ADD). This can be easily calculated from the daily mean temperatures, and can be used to determine the grape varieties that the given region is suitable for (see Table 1). The calculation is carried out by summing the residual above 10 °C of the daily mean temperatures throughout the growing season (Davitaja, 1959; Kozma, 2002). Note, that in all our calculations we defined the growing season as the period of a year when the daily mean temperature is above 10 °C for at least three consecutive days (Kozma, 2002). This practice ally corresponds to the time beginning with budburst and ending with leaf-fall, and thus covers a longer interval of the year then the one discusses in Table 1.

Ripening categories	Active degree days	Number of days
	(from budburst to full ripening of berries)	
very-early-ripening varieties	690–850 °C	110–120 days
early-ripening varieties	850–1150 °C	120–130 days
medium-ripening varieties	1150–1350 °C	130–145 days
late- & very-late-ripening varieties	>1350 °C	>145 days

Table 1: Grouping of grape varieties based on the active degree days (Davitaja, 1959; Kozma, 2002).

Huglin’s heliothermal index (HI) (Huglin, 1978). This gives a measure of the goodness of a region for different grape varieties based on the daily mean- and maximum temperatures of the region, and on a factor denoted as d which depends on the geographic latitude of the region (and thus the average length of the days during the growing season). Huglin’s heliothermal index can be written as:

$$HI = d \sum \frac{[(T - 10^{\circ}\text{C}) + (T_x - 10^{\circ}\text{C})]}{2}, \quad (1)$$

where d is the *latitude coefficient* increasing monotonically from $d_{40}=1.02$ at latitude 40° N to $d_{50}=1.06$ at latitude 50° N; T is the daily mean temperature, and T_x is the daily maximum temperature, both measured in °C. In equation (1.), each term of the sum corresponds to one day in the growing season, and thus the sum goes through all the days of the growing season. The optimal values of HI for selected grape varieties are given in Table 2.

Huglin's Heliothermal Index (HI; in °C)	Grape varieties
2300	<i>Aramon</i>
2200	<i>Carignan</i>
2100	<i>Cinsaut, Grenache, Syrah</i>
2000	Ugni blanc
1900	Chenin blanc, Welschriesling, Merlot, Cabernet Sauvignon
1800	<i>Cabernet franc, Blaufränkisch</i>
1700	Chardonnay, Rhine Riesling, Silvaner, Sauvignon blanc, Pinot noir
1600	Pinot blanc, Gewürztraminer, Gamay
1500	Müller-Thurgau
1400	Irsai Olivér

Table 2: The optimal values for Huglin's heliothermal index (HI) for selected white (normal fonts) and red (italic fonts) wine grape varieties. (Huglin, 1978; Kozma, 2002)

Occurrences of extreme temperature episodes. We used the following measures in studying the occurrences of extreme temperatures (Dunkel & Kozma, 1981; Kozma, 2002):

- ◇ daily minimum temperature is below −17 °C in the reproductive cycle,
- ◇ daily minimum temperature is below −21 °C in the reproductive cycle,
- ◇ daily maximum temperature is above 35 °C in the vegetative cycle.

Precipitation-temperature index. One can measure the risk of peronospora infection by taking into account the relationship between precipitation and temperature. For this purpose the *precipitation-temperature index* (I_P) is calculated for the five-month long growing season (from April to August):

$$I_P = 10^{-5} XP, \quad (2)$$

where X is the active degree days in °C, and P is the precipitation (in mm) in the corresponding months of the season. Seasons with $I_P > 4$ are considered as having a high risk of a peronospora epidemic outbreak. In Hungary $I_P = 2.5-3.5$ during seasons with no occurrence of peronospora infection (Kozma, 2002).

Hydrothermal coefficient (HTC). We can characterize the combined effect of precipitation and temperature on grapes using the *hydrothermal coefficient* (HTC). This characteristic number, which measures the water supply of a vegetation, is calculated as:

$$HTC=10P/T_0, \quad (3)$$

where P is the precipitation during the growing season in mm, and T_0 is the effective degree days in °C (which is the sum of daily mean temperatures for days of the growing season when this temperature is above 10 °C). In areas, where the HTC is below 0.5, grape production is only possible if the humidity is high or if irrigation is applied. The maximum value of the HTC is in the range of 1.5-2.5, while its optimal value is around 1 (Szeljanyinov, 1928; Kozma, 2002).

3. Results and discussion

According to the climatic models, the ADD was in the range of 1200–1400 °C* in Hungarian wine regions during the 1961-1990 reference time interval (see Figure 1). These results suggest that climatic conditions were in favor of early- and medium-ripening grape varieties at the end of the 20th century. However, there are certain regions where late-ripening varieties are also produced (Hajdú, 2003). The reason for this is that models do not take into account the extra heat the grapes are subjected to when they are grown on hill- and mountainsides and are being exposed to sunlight at lower angles of incidence. Thus, heatmaps are falsely biased to lower-than-actual heat supply conditions at hilly terrains (such as the Alpokalja regions), falsely suggesting that these regions are only suitable for low heat demanding grape varieties. As it can be seen in Figure 2, based on HI, we could think that heat conditions in Alpokalja wine regions can only support less heat demanding varieties, and only the Alföld regions are optimal for more heat demanding ones. In practice the Alpokalja regions are known to be optimal for more heat demanding varieties, which can be explained by taking into account the extra heat the regions are obtaining from sunlight arriving at low angles of incidence.

We found the length of the growing season allowed by the thermal conditions in Hungary to be between 160–190 days within the reference time interval. This is about 1 month longer than what is necessary for early- and medium-ripening varieties (see Table 1 and Figure 3). Thus we can conclude that the projected thermal conditions by the end of the 21st century are optimal for late-ripening and very-late-ripening grape varieties.

Results obtained with the ALADIN and RegCM data have a short-term correlation with each other. Based on these, the ADD will increase up to 1400–1700 °C in the short term. The value of HI is expected to rise up to 1800 °C, however within the Alföld region values above 2300 °C are also possible.

* These values are only averages, i.e. in some years the ADD can be lower or higher. Negative deviations from these averages can lead to an insufficient amount of heat for the ripening of grape varieties that require a longer growing season.

The value of HI increases more steeply from the 1980s in every wine region, as shown in Figure 2.

The PRECIS model suggests a much more significant rise in the index values. The ADD can increase up to 1600–2000 °C in the short term. HI will reach 2300 °C in the whole country. In Figure 2, graphs corresponding to the PRECIS model increase with the highest steepness, which shows that this is the model that predicts the biggest change in the local climate by the middle of the century.

All three models predict the elongation of the growing season in the short-term (see Figure 3). By the middle of the 21st century, the vegetative cycle length allowed by thermal conditions can be as long as 180–210 days, however, the change will not be this significant (180–200 days) according to the ALADIN model.

We expect the same tendencies to occur in the long term. Based on the ALADIN and RegCM models, the ADD can be as high as 1700–2200 °C. Similar to the short-term results, PRECIS predicts a more significant change: according to this model, ADD can be between 2000–2500 °C. In the long term, all three models predict HI to be above 2300 °C throughout the whole country.

The vegetative cycle length allowed by thermal conditions can be even longer in the long term (see Figure 3). Its duration can reach 200–220 days, or 210–230 days according to the PRECIS model.

All these suggest that certain regions will allow the ripening of late-ripening grape varieties by the middle of the 21st century. As the increased heat allows the development of color- and aroma essences, growing a higher ratio of red wine grapes will be feasible in several wine regions. According to results corresponding to the end of the 21st century, the thermal conditions of Hungarian wine regions will allow the growing of mediterranean red wine grapes.

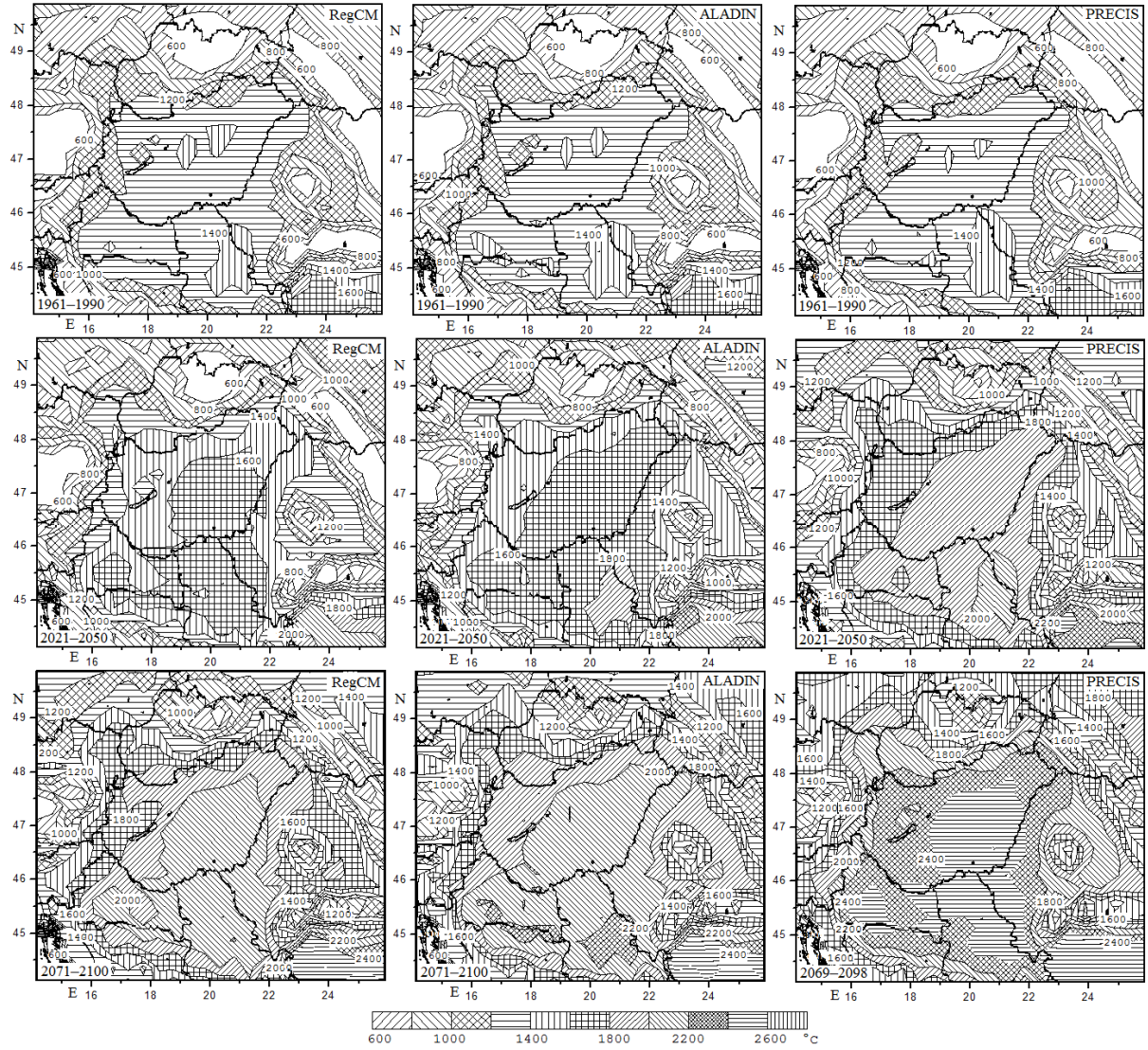


Figure 1: The values of active degree days in the Carpathian Basin. The upper row corresponds to the reference time interval, while the middle and lower row correspond to the predicted short-term and long-term future, respectively. The three columns show our results for the RegCM (left), the ALADIN (middle), and the PRECIS (right) regional climate models.

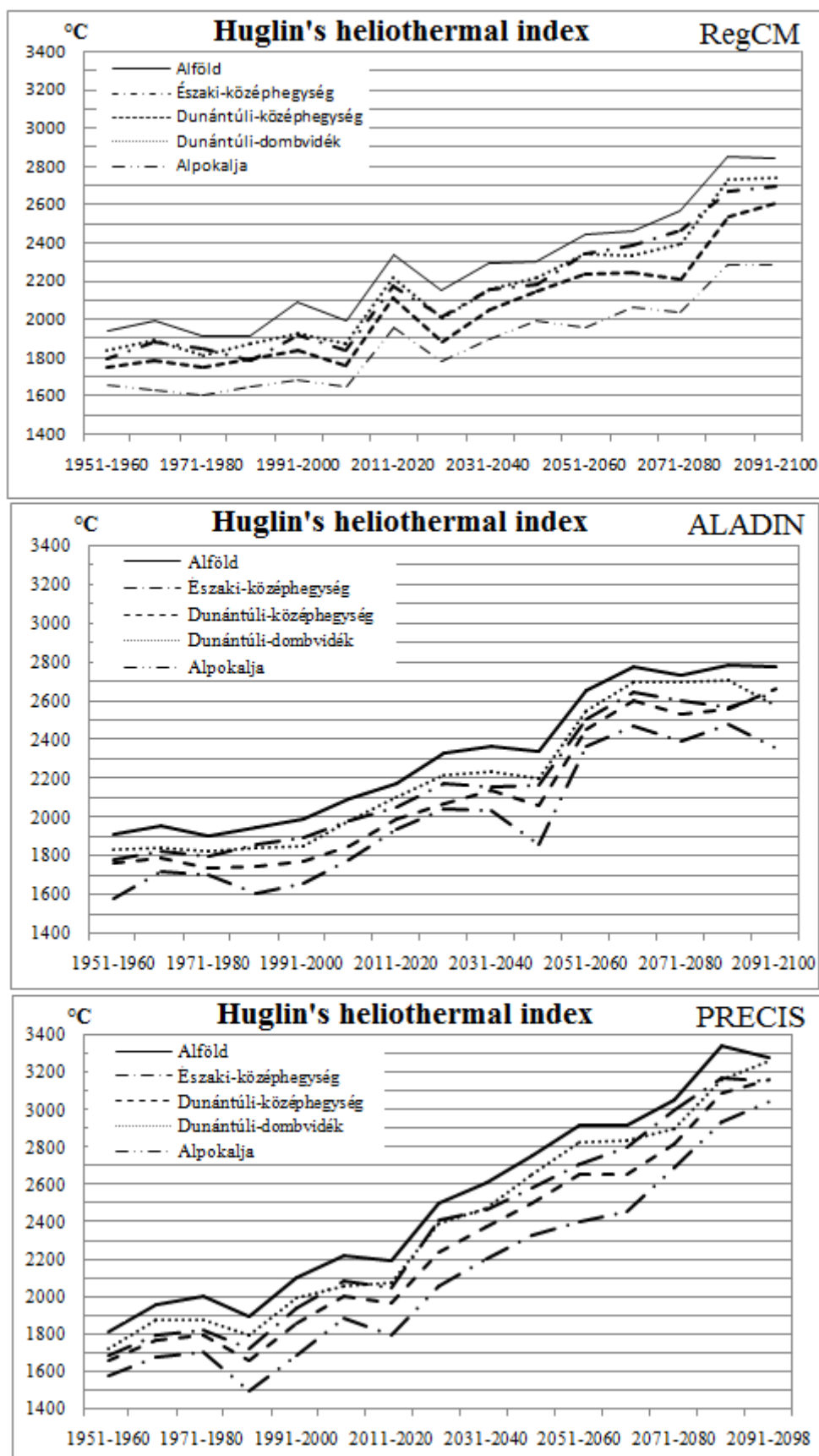


Figure 2: The temporal evolution of Huglin's heliothermal index (HI) in the Carpathian Basin based on the RegCM (upper), the ALADIN (middle), and the PRECIS (lower) regional climate models.

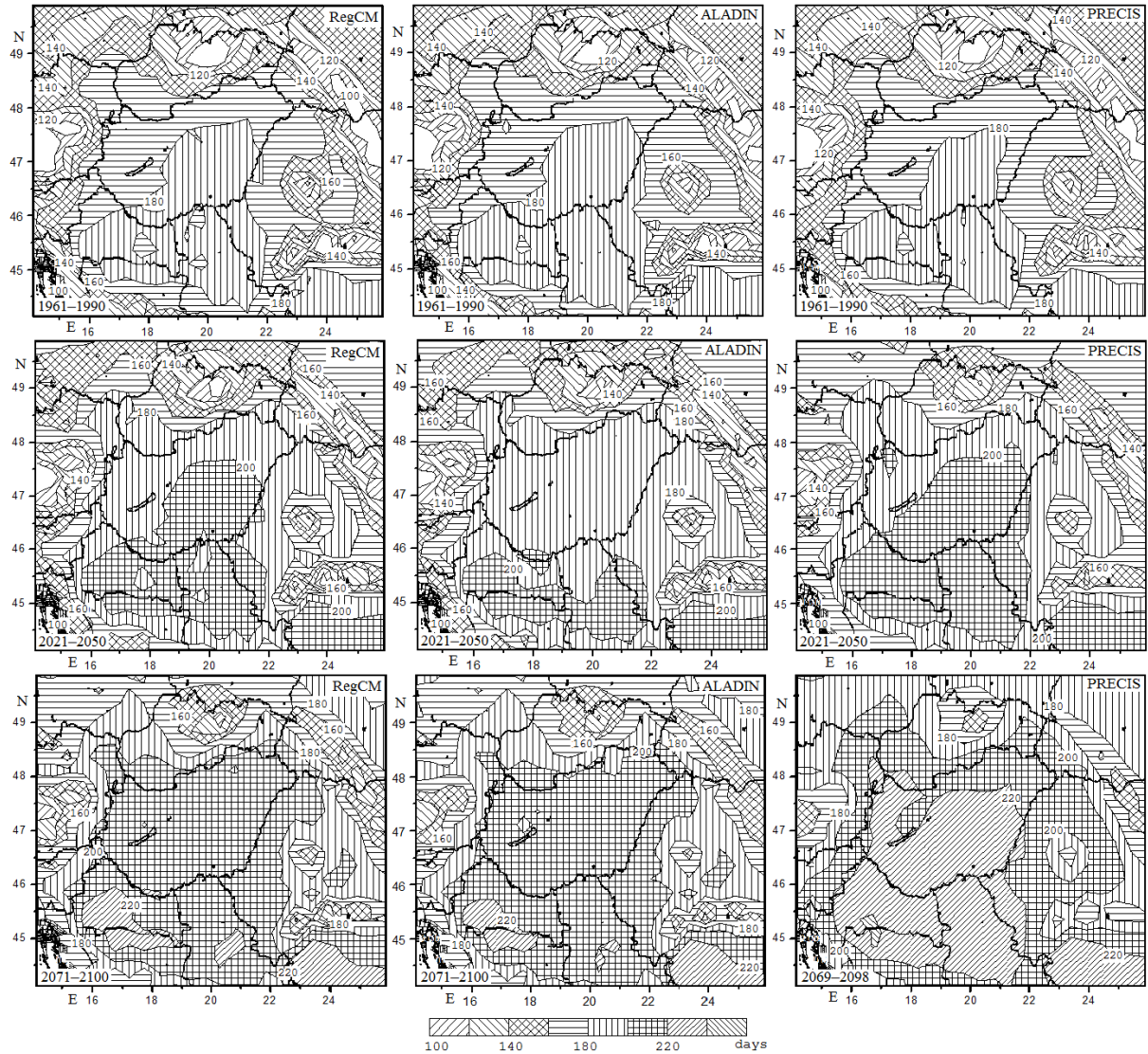


Figure 3: The length of the growing season in days allowed by thermal conditions. The upper row corresponds to the reference time interval, while the middle and lower row correspond to the predicted short-term and long-term future, respectively. The three columns show our results for the RegCM (left), the ALADIN (middle), and the PRECIS (right) regional climate models.

The prevalence of extreme temperatures in the reproductive and vegetative cycles also have a significant role beside the averages. As there were no minimum temperatures below -17°C in the PRECIS model, we only analyzed the extremes in the two other climatic models.

The regional distribution of the number of days with minimum temperatures below -17°C (as obtained with the RegCM and ALADIN models) is in a good agreement with the results presented in Dunkel & Kozma, 1981 (see Figure 5). However note, that the time interval investigated in Dunkel & Kozma (1981) is

slightly different from our reference time interval.

We found that the less frost-tolerant grape varieties suffered frost damage in every 2–3 years within the reference time interval (see Table 3). This prevalence will decrease by the middle of the century down to a prevalence of one major frost damage in the winter season in every 4–10 years. The danger of frost damage will become almost insignificant in the long-term.

The models underestimate the number of days with a minimum temperature below -21°C if we consider the investigations in *Dunkel & Kozma* (1981). This error can be related to the slight difference in the two time intervals in question. Independently from this fact, the prevalence of extreme cold temperatures will decrease in the short term, and days with extreme cold temperatures will almost completely disappear in the longer term.

The plants become damaged by extreme hot days in the growing season as well. In the reference time interval, the prevalence of days with maximum temperature above 35°C was one per 2–10 years according to model results (see Figure 5). Such years had higher prevalence in the RegCM model, and lower prevalence in the ALADIN model. On average there were 1–4 days when the maximum temperature rose above 35°C in all years when such days occurred.

There will be a drastic rise in the number of years with extreme high temperature both in the short and long term. All three models predict such days to occur in every two years in the short term, and in every year in the long term. In years when there is at least one day with a maximum temperature above 35°C , there will be rise in the number of such days both in the short and long term. We expect to have the highest prevalence of such days in the Alföld region. According to the RegCM predictions, there will be 2–4 days with extreme hot temperatures in the given years in the short term, and can be as many as 5–13 such days per year in the long term. The rise in the number of extreme hot days is even more drastic in the ALADIN and PRECIS models. Based on these models, we expect 8–16 extreme hot days per year in the short term, and 27–40 such days per year in the long term.

	Great Hungarian Plains (Alföld)		North Hungarian Mountains (Északi-középhegység)		Transdanubian Mountains (Dunántúli-középhegység)		Transdanubian Hills (Dunántúli-dombvidék)		Alpokalja	
	Re	AL	Re	AL	Re	AL	Re	AL	Re	AL
Reference time interval	17	15	22	18	17	17	15	12	7	5
Short term	3	6	7	8	8	3	5	2	1	1
Long term	1	1	1	2	3	2	1	1	0	1

Table 3: The number of years having at least one day in the reproductive cycle with minimum temperature below -17°C . The numbers are given for the different Hungarian wine regions, and for the RegCM (Re) and ALADIN (AL) climatic models.

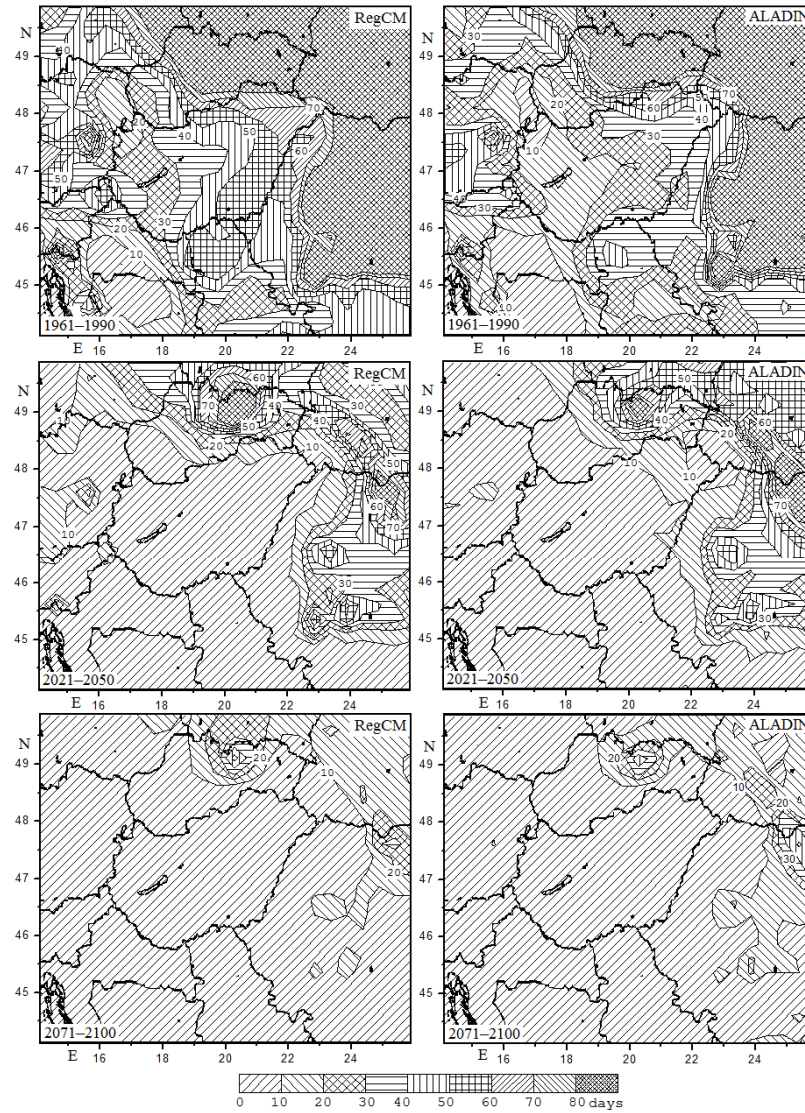


Figure 4: The number of days in the reproductive cycle with minimum temperature below -17°C . The two columns correspond to the RegCM (left) and the ALADIN (right) climatic models. The rows of the figure show the model results for the reference time interval (upper), and the predictions for the short (middle) and long (lower) term intervals.

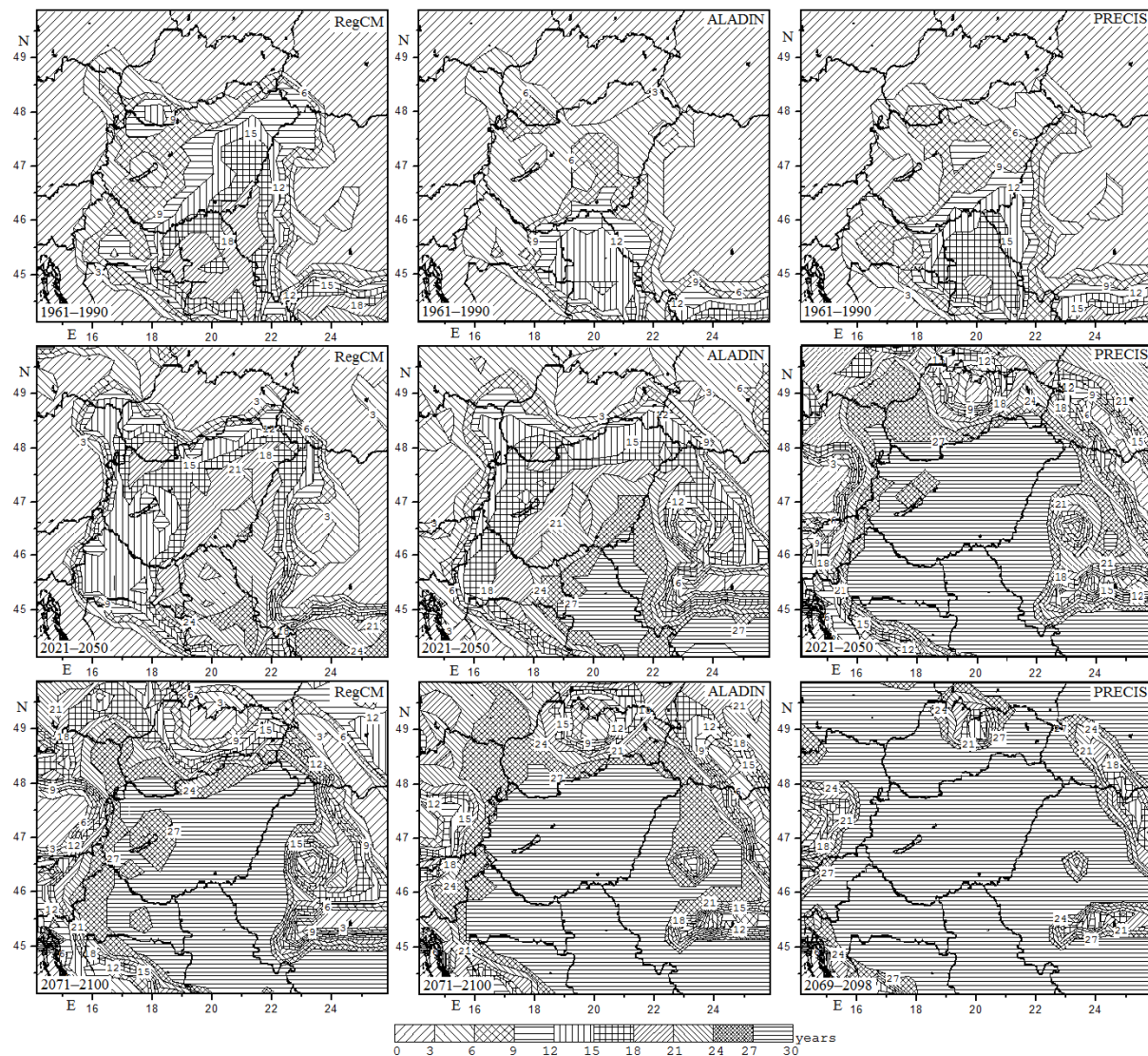


Figure 5: The number of days in the vegetative cycle with maximum temperature above 35 °C. The two columns correspond to the RegCM (left) and the ALADIN (right) climatic models. The two columns correspond to the RegCM (left) and the ALADIN (right) climatic models. The rows of the figure show the model results for the reference time interval (upper), and the predictions for the short (middle) and long (lower) term intervals.

Our studies based on the three climatic models showed (see Table 4) that the HTC will not reach the critical value of 0.5 neither in the short nor in the long term. This means that the climatic conditions will be suitable for wine production in the Hungarian wine regions. It depends on the deviation of the HTC from 1 whether these conditions move closer to or away from the optimum in given regions.

In the reference time interval, all three models showed excess heat in the Alföld regions, and excess precipitation in the North Hungarian Mountains (Északi-középhegység), Transdanubian Mountains (Dunántúli-középhegység), and Alpokalja regions. ALADIN resulted with the Transdanubian Hills

(Dunántúli-dombvidék) region being thermally optimal, while the RegCM and PRECIS showed excess heat in the region.

The changes in the short term are not unambiguous. RegCM does not show any change for the Alföld region, while for the Transdanubian Mountains and for the Alpokalja region it predicts an increase in excess precipitation. The climatic conditions are expected to become more suitable for grape production in the North Hungarian Mountains and Transdanubian Hills regions. ALADIN predicts a decrease in excess precipitation or an increase in excess heat for all regions, which does not lead to major changes in the Alpokalja region. This could lead to worse climatic conditions in the Alföld and Transdanubian Hills regions, and to better conditions in the North Hungarian Mountains and Transdanubian Mountains. Similarly to ALADIN, PRECIS shows a decrease in excess precipitation or an increase in excess heat for all wine regions, which means an improvement in the Alpokalja region, and worse conditions in all the other regions.

All three models give similar predictions for the long term future, which means that we expect a decrease in excess precipitation or an increase in excess heat in all regions compared to the reference interval. This again means better conditions for the Alpokalja region and worse for all other regions compared to the conditions in the reference time interval.

	Great Hungarian Plains (Alföld)			North Hungarian Mountains (Északi-középhegység)			Transdanubian Mountains (Dunántúli-középhegység)			Transdanubian Hills (Dunántúli-dombvidék)			Alpokalja		
	Re	AL	PR	Re	AL	PR	Re	AL	PR	Re	AL	PR	Re	AL	PR
Reference time interval	0.90	0.93	0.89	1.09	1.11	1.07	1.06	1.13	1.09	0.95	1.01	0.96	1.17	1.23	1.22
Short term	0.90	0.83	0.71	1.06	0.97	0.74	1.10	1.07	0.87	0.99	0.93	0.81	1.21	1.22	0.96
Long term	0.75	0.71	0.59	0.87	0.79	0.60	0.95	0.83	0.71	0.85	0.76	0.69	1.09	0.96	0.79

Table 4: The values of the Hydrothermal coefficient (HTC) in the different Hungarian wine regions based on RegCM (Re), ALADIN (AL), and PRECIS (PR) model predictions.

An increase in humidity results with a higher risk of fungal infections in the vineyard. The precipitation-temperature index gives a good measure of the risk of peronospora infection. There was a negligible risk of a preonospora epidemic in the reference time interval, although there were such epidemics in every 10 years in the mountain regions (see Figure 6).

Models predict a higher prevalence of peronospora epidemics both in the short and term intervals. The prevalence can be as high as one per every 2–4 years in the short term, and one per every 2 years in the long term. All three models predicted that the Alpokalja region will have the highest risk of fungal infections. However, we must note that the climatic models do not take into

account the microclimate of the different local wine regions, and thus the predictions should be treated as estimated averages for larger areas.

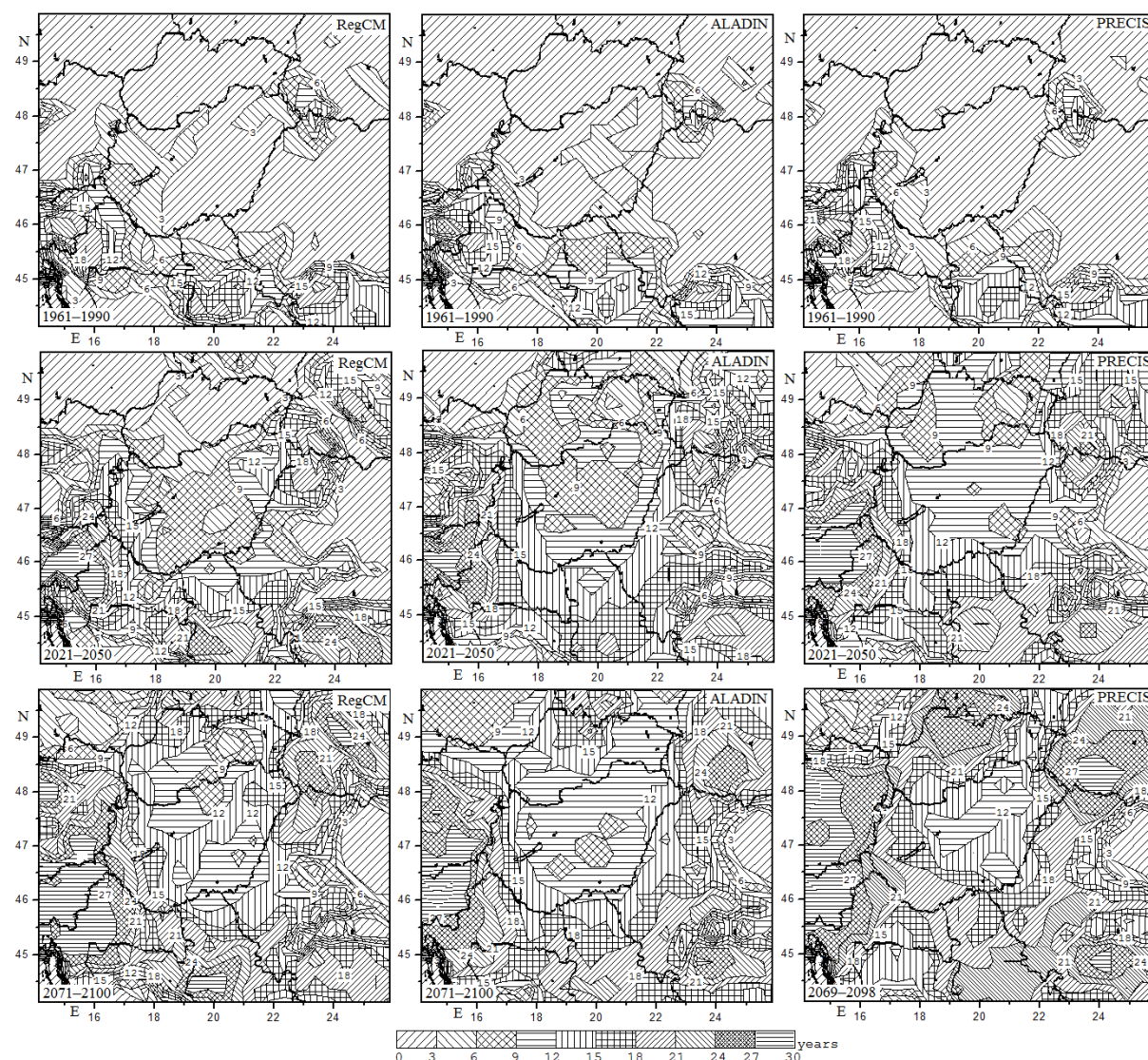


Figure 6: The number of years with high risk of peronospora epidemic outbreak. The columns correspond to the RegCM (left), the ALADIN (middle), and PRECIS (right) climatic models. The rows of the figure show the model predictions for the 1961–1990 reference time interval (upper), and for the 2021–2050 short (middle) and 2071–2100 long (lower) term intervals.*

4. Conclusions

Our investigations showed that in terms of heat conditions the 21st century will favor red wine grape and late-ripening varieties. We can derive this conclusion from the increasing tendency of active degree days and of Huglin's heliothermal index. At the same time, we expect the elongation of the growing season allowed by the climatic conditions.

Frost-damages in the dormancy periods will become more rare due to the warming climate. However, the number of days with maximum temperature above 35 °C will increase, which could lead to serious heat damages. There should be more care spent on preventing and mitigating damages due to increased heat stress using adequate horticultural practices.

The increase in the precipitation-temperature index suggests that there will be a drastic increase in the number of years with high risk of peronospora infection. However in contrast with this, we expect a decrease in the hydrothermal coefficient in all regions, which should counteract the former effect, and should lower the risk of fungal infections. In order to decide whether the net effect is an increase or decrease in the risk of fungal infections, we propose more detailed studies that should also take into account more parameters, such as the heat and water conserving characteristics of the soil in the region.

Acknowledgments

Simulation of the PRECIS regional climate model was supported by grant OTKA K-78125. The authors are grateful for Ildikó Pieczka for providing bias-corrected model outputs. The RegCM and ALADIN simulations were developed within the ENSEMBLES project (505539) which was funded by the EU FP6 integrated program. The E-OBS database was provided by the ENSEMBLES and ECA&D projects. This work has been supported by OTKA grants K81933 and K81975. The project was supported by the European Union and the European Social Fund (TÁMOP-4.2.1/B-09/1/KMR). We would also like to thank Peter Raffai for his valuable help with the English translation.

References

- Davitaja, F., F. (Давитая, Ф., Ф.), 1959: Климатические показатели сырьевой базы виноградо-винодельческой промышленности. Труды ВНИИВИВ „Магарач”, 6(1) 12–32. (in Russian)*
- Dunkel, Z., Kozma, F., 1981: A szőlő téli kritikus hőmérsékleti értékeinek területi eloszlása és gyakorisága Magyarországon. Légekör 26. 2., 13–15. (in Hungarian)*
- Formayer, H., Haas, P., 2009: Correction of RegCM3 model output data using a rank matching approach applied on various meteorological parameters. Deliverable D3.2 RCM output localization methods (BOKU-contribution of the FP6 CECILIA project)*
- Hajdú, E., 2003: Magyar szőlőfajták, Mezőgazda Kiadó, 11–223. (in Hungarian)*
- Haylock, M. R., Hofstra, N., Klein Tank, A. M. G., Klok, E. J., Jones, P. D., New, M., 2008: A European daily highresolution gridded data set of surface temperature and precipitation for 1950-2006., J. Geophys. Res., 113, D20119, doi:10.1029/2008JD010201, 1–12.*

- Huglin, P., 1978: Nouveau mode d'évaluation des possibilites héliothermiques d'un milieo viticole. *Proceedings of the Symposium International sur l'ecologie de la Vigne. Ministère de l'Agriculture et de l'Industrie Alimentaire, Contanca*, 89–98. (in French)
- Kozma, P., 2002: A szőlő és termesztése I. *Akadémiai Kiadó*, 13–19., 213–272. (in Hungarian)
- van der Linden, P., Mitchell, J.F.B., 2009: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, Exeter, UK. 164p.
- Nakicenovic, N., Swart, R.J., 2000: Emissions Scenarios 2000 – Special Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press, Cambridge*. 570p.
- Pieczka, I., Pongrácz, R., Bartholy, J., Kis, A., Miklós, E., 2011: A szélsőségek várható alakulása a Kárpát-medence térségében az ENSEMBLES projekt eredményei alapján. In: 36. *Meteorológiai Tudományos Napok - Változó éghajlat és következményei a Kárpát-medencében. (Szerk.: Lakatos M.) Országos Meteorológiai Szolgálat, Budapest*. 77–87. (in Hungarian)
- Pieczka I., 2012: A Kárpát-medence térségére vonatkozó éghajlati szcenáriók elemzése a PRECIS finom felbontású regionális klímamodell felhasználásával. *PhD értekezés. ELTE Meteorológiai Tanszék, Budapest*. 1–95. (in Hungarian)
- Pongrácz, R., Bartholy, J., Miklós, E., 2011: Analysis of projected climate change for Hungary using ENSEMBLES simulations. *Applied Ecology and Environmental Research*, 9, 387–398.
- Szeljanyinov, G., T., 1928: On agricultural climate valuation. *Proceedings of Agricultural Meteorology*, 20, 165–177.
- Szenteleki, K., Ladányi, M., Gaál, M., Zanathy, G., Bisztray, Gy. D., 2012: Climatic risk factors of Central Hungarian grape growing regions. *Applied Ecology and Environmental Research* 1, 87-105.
- Wilson, S., Hassell, D., Hein, D., Jones, R., Taylor, R., 2007: Installing and using the Hadley Centre regional climate modelling system, PRECIS. Version 1.5.1. *UK Met Office Hadley Centre, Exeter*. 131p.