Reliability of Climate Change Impact Assessments for Viticulture

Manfred Stock, Friedrich-W. Gerstengarbe, Thomas Kartschall and Peter C. Werner
Potsdam Institute for Climate Impact Research
Potsdam
Germany

Keywords: adaptation, grapevine, model, phenology, regionalization, risks, vulnerability

Abstract

Current assessments of climate change effects on viticulture are primarily based on global climate models. With respect to temperature and temperature-based indices, this may produce reasonable first approximations. Recent studies indicate that several viticultural regions may become more successful, and others less so, as high-quality wine production areas. However, it is not only average temperature but also a variety of other climate parameters and their variability that the allocation of chances and risks in impact assessments depends on. In this respect, global model resolutions are of limited value. However, current methods of regionalization by statistical downscaling or embedded regional climate models also show deficiencies and uncertainties. This paper presents a new method for the evaluation of regional climate scenarios using the statistical regional model STAR. This model offers improved applicability and reliability concerning viticultural aspects and primarily aims at evaluating measures of adaptation rather than predictions. The results demonstrate the extent and effects of climate change on viticultural areas in Europe. Possible impact on grapevine phenology and wine quality for the Rheingau and pest risks for Sardinia is given as example.

INTRODUCTION

Historical records as well as present day observations have already shown a significant sensitivity of wine production to climate variability. There is a well-documented relation between a good or moderate vintage and good or bad annual weather conditions. The ongoing climate change adds a new element of uncertainty. Substantial phenological and economic alterations have already been observed and are expected to continue in the future. The annual dates of budbreak, flowering and fruit maturity of grapevines have been observed to take place earlier in various regions. In addition, the observed geographical relocation of various pests and pathogenic organisms are also influenced by climate change. Though viticulture may be well adjusted to changing weather patterns, this might not be the case for climate change.

Recently methods have been developed to assess climate change impacts with greater accuracy and increased reliability. This offers innovative opportunities to make use of additional chances which climate change might bring to viticultural regions as well as to diminish some of the associated risks.

DATA AND METHODS

Observational Data of Climate Change Effects

Any assessment of future climate developments and its effect on viticulture has to start with an analysis of the recent climate to be reliable. A validated series of observed meteorological parameters with high resolution in time and space are necessary for such an analysis using advanced regional climate models. In addition, well-documented data sets of the observed effects of climate variability on viticulture are the basis for reliable and validated models, which can be used to calculate possible future developments.

Significant shifts of the earth's climate zones have been observed in the last century, and particularly the last two decades (Fraedrich et al., 2001). Analysis of specific climate types and their changing geographical location reveals that Europe, with an area change of 13.5% of its total area, is the major ‘battle-field’ compared to other continents. Many wine-growing regions are afflicted to include the south of France and the Bordelaise, Northern Portugal, La Mancha and Rioja in Spain, the Tuscany region and Sardinia in Italy, and within Germany the Rhine River Valley and the north-east. It is worth mentioning that the wine-producing region in South Australia also exhibits significant climate change but the shift of climate zones in the superior Asia-Pacific areas are relatively minor.

Regional climate data for the reference period of 1951 to 2000 was needed as input for our regional climate model STAR and consisted of daily values of air temperature (daily maximum, minimum and mean), precipitation (24 hour total), relative humidity, water vapour pressure, air pressure, sunshine duration per day, global radiation (daily total), wind velocity (daily mean) and cloud cover (daily mean). The data sets for specific regions were compiled with support from the following institutions: Agrometeorological Service of Sardinia (SAR, www.sar.sardegna.it), Sassari, Italy (Alghero); Deutscher Wetterdienst (DWD, www.dwd.de), Offenbach, Germany (Potsdam and Geisenheim); Dipartimento di Biotecnologie Agrarie (www.unifi.it/unifi/distam), Firenze, Italy (Pisa); Zentralanstalt für Meteorologie und Geodynamik (ZAMG: www.zamg.ac.at/index.php3), Wien, Austria (Eisenstadt).

In addition to climate data, impact assessments also make use of observed phenological, physiological, and other viticultural data (e.g. dates of budbreak, anthesis, veraison, and harvest and yield, quality ratings, and pest damage). There is archival information dating as far back as 1700 (Johannisberg Castle near Geisenheim in Rheingau, Germany) in which the first day of harvest was recorded (Fig. 1). These archives are invaluable sources of information on relations between climate variability and viticultural data.

Assessment of Climate Change Scenarios

An assessment of climate change impacts on viticulture has to deal with the integrated system of climate and vineyard and is generally based on scenarios. A scenario represents the temporal and spatial characteristics of the system based on defined initial conditions and a number of parameters that describe the system. It is not a prediction, but a set of ‘if-then-else relations,’ i.e. ‘what might be if’ rather than ‘what will be’. Climate change scenarios are based on assumptions about the development of structure and strength of the global economy leading to different assumptions pertaining to the increase of CO_2 and other greenhouse gases. These emission scenarios are relevant input data for climate models calculating subsequent climate change. The state-of-the-art climate change scenarios and their associated methods are described in IPPC (2000, 2001).

1. Global Climate Scenarios and Models. Differing emission scenarios are related to the development of different global warming predictions (curves in Fig. 2), resulting in an annual global average surface temperature in 2100 ranging from 2 to 4.5°C increase compared to 1990. These curves are based upon the results of different global circulation climate models (GCM). They differ significantly, adding additional uncertainty to the range given above which expands to 1.5 to 5.8°C in 2100 (grey area in Fig. 2). A median scenario was chosen (A1B from IPCC, 2001) for the impact assessments up to the year 2050 based on the regional model STAR.

The aspect of scale has to be considered with respect to impacts of climate change, which may be another source of uncertainty. For example, what is the relationship of a parameter like the ‘annual global average surface temperature’ to the daily environmental conditions in a specific vineyard? How can global scenarios be transferred and scaled down into regionally relevant information? To solve this problem, all methods have to make use of sufficiently high-resolution GCM models. With respect to impact assessments for viticulture, these results are generally of limited usefulness and reliability. The calculated climate parameters such as precipitation and climate variability are insufficient for the demands of models concerning grapevine phenology and physiology.

Yet the GCM results are a reasonable input for calculating temperature-based indices (Huglin, 1986) in a first approximation and for methods of regionalization.

The assessment of the Huglin Index within Europe contains historical and future scenario data (CRU, 2003; Hulme et al., 2000). The historical data contain the major meteorological factors with a spatial resolution of 10’ for the time period between 1900 and 2000 with observations across Europe. The future projection is based on the A1FI (fuel intensive)-IPCC scenario using the output of the Parallel Climate Model (PCM) for the 2001-2100 AD period and can be viewed as a worst-case scenario. The PCM is a coupled GCM, ocean, and ice model (Dai et al., 2001) and it predicts a moderate global temperature increase of 1.6°C between 2000 and 2050 and 3.4°C between 2000 and 2100 compared to higher increases using other GCMs (Hadley Centre-HadCM3, CSIRO CSIRO-Mk2, Canadian Center for Climate Modelling and Analysis CGCM2).

2. Regional Climate Models. Regional climate models in general are embedded in a global model. The global model supplies the regional model with all large-scale information. This has the advantage of physically coupling large- and small-scale processes. Its disadvantage, however, lies in the fact that up to now it has been impossible to exactly reproduce the coupling and the processes. This leads to defects in the results, which do not allow their further being used in small scale impact studies. Moreover, the computer time needed for calculating such models is too great to simulate long-term runs.

3. Statistical Downscaling. Most statistical downscaling methods are based on climate model results transformed to a smaller scale using statistical algorithms. Using these methods, the results of the GCM can be directly adopted so that the physical propagation of defects into a regional model is avoided but the defects of the GCM are transmitted directly into the regional scenario.

4. Statistical Regional Climate Model STAR. The model STAR is based on the fact that GCM results reflect average large-scale climate changes for a defined region more exactly than for a number of grid points. This reduces the number of defects of the GCM to a minimum. A regional scenario is constructed by observed time series of meteorological parameters, on the one hand, and by information calculated by the GCM about the future development of climate (expressed by a selected climate parameter), on the other hand. For the regional study presented herein, the temperature trend calculated by the global model ECHAM4/OPYC3 (MPI Hamburg) was used. According to these conditions the expected changes are imposed on the observed values of the climate parameter (Werner and Gerstengarbe, 1997). Using a special cluster algorithm (Gerstengarbe et al., 1999), the other observed meteorological parameters are consistently adapted to these changes. The application of a Monte-Carlo Algorithm allows the calculation of a number of scenario runs to estimate the most probable future development.

Validation of Simulated Results

Simulated results on observed data from the past are used to test the usefulness of methods of regionalization (validation). In comparative studies of different models of regionalization, the best results were attained by the model STAR, which made it our preferred model. With regard to the reliability of simulated results the following may be said:

Climate simulation results of the model STAR differ significantly in reliability with respect to different climate parameters, listed in decreasing order: the reliability of simulated future trends in temperature is very high and that of precipitation is also high. The simulated number of days and simulated trends for special meteorological factors such as hot days, days with frost, sunshine or precipitation show satisfactory reliability. Climate variability concerning extremes of temperature or precipitation can be simulated with limited reliability, whereas simulated trends of extreme events like storms, floods, hail etc. show poor or no reliability. It should be emphasised that a simulated climate scenario does not give reliable information about exact future dates of specific meteorological events, it is not a prediction.

RESULTS AND DISCUSSIONS

Regionalized Climate Change Impact Assessments – Rheingau Study

The average annual temperature in the wine-growing regions of the Rheingau, currently range from 9 to 11°C. (note - in the last 50 years average temperature has risen approximately 1°C). Average annual precipitation varies between 500 and 700 mm, except the low mountain ranges surrounding the area. An additional increase in temperature from 1.2 to 1.6°C, compared to the current temperature conditions, is to be expected, most markedly in the South and least in the North (Fig. 3). Changes in precipitation will be less in the North and more in the South.

The phenological development of the grapevine will be hastened in the future (2055) as already observed for the reference period from 1951 to 2000 (Hoppmann, pers. commun., 2004). Currently, budbreak and anthesis take place 8-10 days earlier than 50 years ago and in the future this span of time will be earlier by another 12 days for budbreak and 16 days for anthesis. By 2050, veraison, having moved forward 18 to 23 days in the past 5 decades, is expected to occur 30 days earlier than in 1950. The earlier occurrence of these phenological stages was projected onto harvest using a simple linear relation (broken line in Fig. 1).

A multi-year (1955–1997) data set characterizing quality of 'Riesling' (sugar and acid contents) and vine phenological stages were recently published (Berend, 1998). These data were correlated with six climate parameters from each year using multiple linear regression analysis (Stock et al., 2003). Quality ratings (Q: 1 to 6) were positively (higher quality) correlated with three parameters and negatively correlated with the other three (Table 1). This would indicate that rising temperature, due to climate change, may not necessarily have only a positive effect on 'Riesling' quality. High average daily temperatures, while advantageous for ripening the fruit, may be harmful during the period between anthesis and maturation. This also holds true of very warm temperatures during veraison, when higher night temperatures may reduce acid affecting wine quality.

Global Warming Effects on European Viticulture – a Comparative Assessment

The scenario model was used to compute the Huglin Index for different European wine-growing regions over the period from 1950 to 2050 (Fig. 5). In each region the Huglin Index increases up to 2050. The increase is somewhat lower for the Mediterranean regions (Pisa, Tuscany, and at Alghero on Sardinia) in comparison with the more northern regions (Eisenstadt, Austria and Geisenheim and Potsdam in Germany). A trend away from white wine towards red wines of high quality is already occurring in the Burgenland (Eisenstadt). In the Rheingau (Geisenheim), there is a trend towards producing 'Cabernet Sauvignon' and near Potsdam, the trend towards producing high quality 'Riesling' and 'Chardonnay' or 'Cabernet franc' is gaining ground.

Huglin Index calculations for Europe at a medium resolution (10') were compared with the results of the high-resolution regional model STAR (Fig. 4). While the global emission scenarios as well as the global climate model used differed in both cases, the calculated global warming effect was similar. The Huglin indices in both cases (CRU-Europe, PIK-eastern Germany) clearly show visible effects between 1951 and 2050. In general, a shift of viticultural areas to the north in Europe can be seen, with temporary cooling-off and delays in the 1970s and 2030s. Greater changes appear after 2030. For eastern Germany, a growth of the isolated, potential viticultural area near Potsdam (the northern-most qualified European vineyard 'Wachtelberg, Werder', located at 52° 22' N, 12° 56' E) is visible with similar effects during the 1970s and 2030s. Around the middle of this century, more 'southern' cultivars like 'Cabernet franc' will appear beside the major cultivar presently cultivated, 'Müller-Thurgau'.

Phenology of Grapevine versus Phenology of Pests

While climate change will impact grapevine phenology it will also impact the phenology of pests. A study of the damage to grapevines on Sardinia by the grape moth

(*Lobesia botrana*) offers a good example of this interrelationship. The probable scenario of the future climate from 2001 to 2055 was computed using regional climate data over the period of 1951 to 2000 and the climate model STAR. Temperature parameters from the past and for future scenarios were used as input for a grapevine phenology model (Bindi et al., 1997) and of the Sardinian grape moth (Cossu et al., 1999). Periods of increasing temperature resulted in different developmental changes for the vines, its pest, and the associated risk (Cossu et al., 2004). The average annual increase in temperature from 1951 to 2055 was 1°C (from 15.9 to 16.9°C).

Results indicate that there may be four generations of grape moth between spring (April, 1) and autumn (end of October) (Fig. 6, Table 2). For grapes to be damaged the fourth generation of adult moths must be present during fruit maturation to harvest. The probability of this occurring is demonstrated from 1951 (observed) to 2055 (future scenario) via an increase in temperature, which hastens the ripening of grapes and appearance of the fourth generation of grape moths. At the beginning of the simulation period both factors were observed to co-occur approximately two days 80% of the years. This may increase in the future to ~10 days every year. As a result, the cost of pest management will increase and the economic yield will be diminished.

Reducing Vulnerability by Adaptation

The methods presented here for assessing the impact of climate change will not produce predictions but scenarios for assessing the vulnerability of present-day viticulture. These scenarios describe a region's exposure to climate change with regard to the prevailing specific sensitivity. The potential impacts can be calculated with the help of suitable phenological and physiological models. This is an essential portion of the scientific program, which will find its completion, however, in the co-operation with the wine-producers affected and conscious of the risks and chances of climate change, and in the common assessment of the perceived adaptive capacity with regard to reducing the remaining vulnerability. Socio-economic methods like questionnaires and stakeholder dialogues will be used. For a beginning, the potentialities and limitations of an adaptive choice of vines in the different wine-growing regions of Europe are being studied. Further steps towards adaptation to the climate change will concern for instance use and cultivation of land and sophisticated pest and water management strategies.

CONCLUSIONS

Climate change may bring opportunities to viticulture as well as potential risks as summarized below:

- New viticultural regions may appear, increasing competition for the old ones.
- A wider choice of cultivars may be necessary in established wine regions, which may change their traditional character.
- Earlier dates of phenological events will accelerate the growth of grapevines, but pests and diseases will increase as well.
- Greater solar radiation will enhance the maturation of grapes but it may also increase sunburn.
- Good vintages will bring higher yields which mean diminishing returns.
- High quality wine produced in good vintages may contrast with serious losses in other years; climatic variability and uncertainties may decrease the benefits while increasing economic risks.

Climate impact assessments are a necessary and important tool to identify risks and possible strategies in order to reduce the vulnerability of viticulture to climate change. To match these objectives, regional climate change scenarios have to be developed with increased spatial and temporal resolution while reducing the influence of uncertainties. Reliability of such assessments depends on the pertinent selection of climate scenarios and the Global Climate Model, the chosen method of regionalization ("downscaling"), the identification of errors in applied data sets by validation methods, and lastly, the reliability of phenological and physiological models using the regional scenarios.

ACKNOWLEDGEMENTS

Thanks to Forschungsring des Deutschen Weinbaus, Germany, for financial support, to Franz Badeck for scientific advice, and to Lilly Stock and Martin Wodinski for technical assistance.

Literature Cited

Berend, K. 1998. Die Weinjahrgänge im Rheingau. Eltville, 98 pp.

Bindi, M., Miglietta, F., Gozzini, B., Orlandini, S. and Seghi, L. 1997. A simple model for simulation of growth in grapevine (*Vitis vinifera* L.). I Model development. Vitis 36:67-71.

Bindi, M., Miglietta, F., Gozzini, B., Orlandini, S. and Seghi, L. 1997. A simple model for simulation of growth in grapevine (*Vitis vinifera* L.). II Model validation. Vitis 36:73-76.

Cossu, Q.A., Delrio, G., Di Cola, G. and Gilioli, G. 1999. Modelli matematici nella protezione integrata delle colture in Sardegna. Collana di Agrometeorologia per la Sardegna, Nota Tecnica. 3:28-38.

Cossu, Q.A., Battaglini, A. and Bindi, M. 2004. Informatore Agrario, Milano (in press).

CRU. 2003. Climatic Research Unit, www.cru.uea.ac.uk.

Dai, A., Wigley, T.M.L., Boville, B.A., Kiehl, J.T. and Buja, L.E. 2001. Climates of the 20th and 21st Centuries Simulated by the NCAR Climate System Model. J. Climate 14:485-519.

Fraedrich, K., Gerstengarbe, F.-W. and Werner, P.C. 2001. Climate shift during the last century. Climatic Change 50:405-417.

Gerstengarbe, F.-W., Werner, P.C. and Fraedrich, K. 1999. Applying non-hierarchical cluster analysis algorithms to climate classification: some problems and their solution. Intern. J. Climatol. 64:143-150.

Huglin, P. 1986. Biologie et ecologie de la vigne. Payot Lausanne. París.

Hulme, M., Crossley, J., Lister, D., Briffa, K.R. and Jones, P.D. 2000. Climate observations and GCM validation Interim Annual Report to the Department of the Environment; April 1999 to March 2000. CRU, Norwich, UK.

IPCC. 2000. Special Report on Emission Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC).

IPCC. 2001. Climate Change 2001, Third Assessment Report of IPCC, Working Group I: The Scientific Basis; WG II: Impacts, Adaptation, and Vulnerability; Cambridge University Press, www.ipcc.ch.

Stock, M., Badeck, F., Gerstengarbe, F.-W., Kartschall, T. and Werner, P.C. 2003. Weinbau und Klima – eine Beziehung wechselseitiger Variabilität. Terra Nostra 6, 6. Deutsche Klimatagung, S. 422-426.

Werner, P.C. and Gerstengarbe, F.-W. 1997. Proposal for the development of climate scenarios. Clim. Res. 8:171-182.

Tables

Table 1. Result of a multiple regression analysis of the relation between climate parameters P_i and quality ratings (1 to 6) of Rheingau Riesling: $Q = \Sigma\, r_i * P_i$, $R^2 = 0.83$. The sign of r_i denotes positive or negative effects on quality (Stock et al., 2003).

Climate Parameter	Pi	r_i	R_i^2
Average daily Radiation - Flowering to Veraison	R_{FV}	1.06	0.54
Number of hot days – Budbreak to Flowering	N_{BF}	0.09	0.11
Average mean daily Temperature - Veraison to Harvest	T_{VH}	0.36	0.07
Average mean daily Temperature - Flowering to Veraison	T_{FV}	-0,83	0.06
Average Precipitation - Veraison to Harvest	P_{VH}	-0.51	0.03
Number of very hot days - Veraison to Harvest	N_{VH}	-0.23	0.02

Table 2. Interference in numbers of years and days between grapes in the final phase of maturation before harvest and the fourth generation of adult grape moths (*Lobesia botrana*), Alghero, Sardinia, Italy, from 1951 to 2055 (based on Cossu et al., 2004).

Period of Interference	observed 1951 – 1975	observed 1976 – 2000	simulated 2001 – 2025	simulated 2026 -2055
Number of years	80%	88%	97%	100%
Number of days	2	~ 5	~ 8	10

Figures

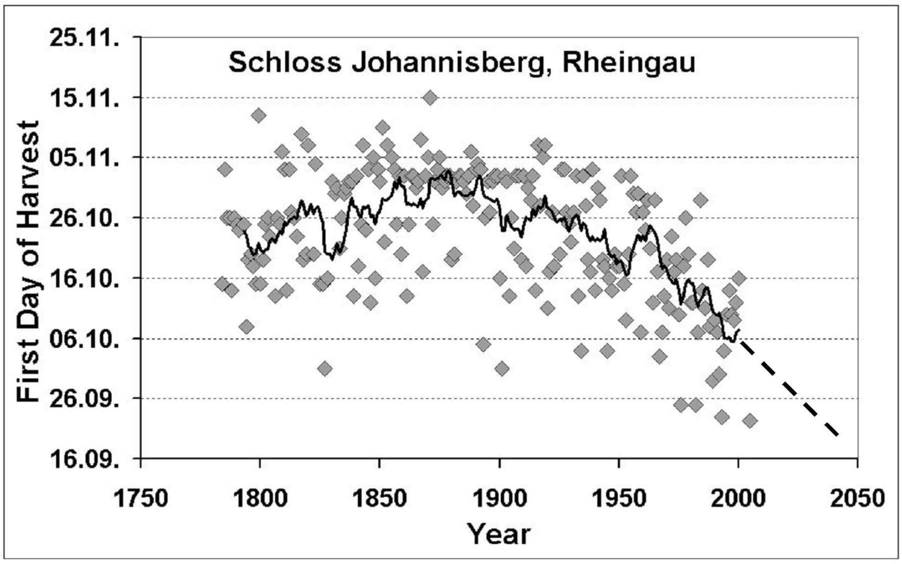

Fig. 1. First date of harvest of 'Riesling' from 1784 to 2003 at Schloss Johannisberg, Rheingau and estimated first date of harvest up to 2050.

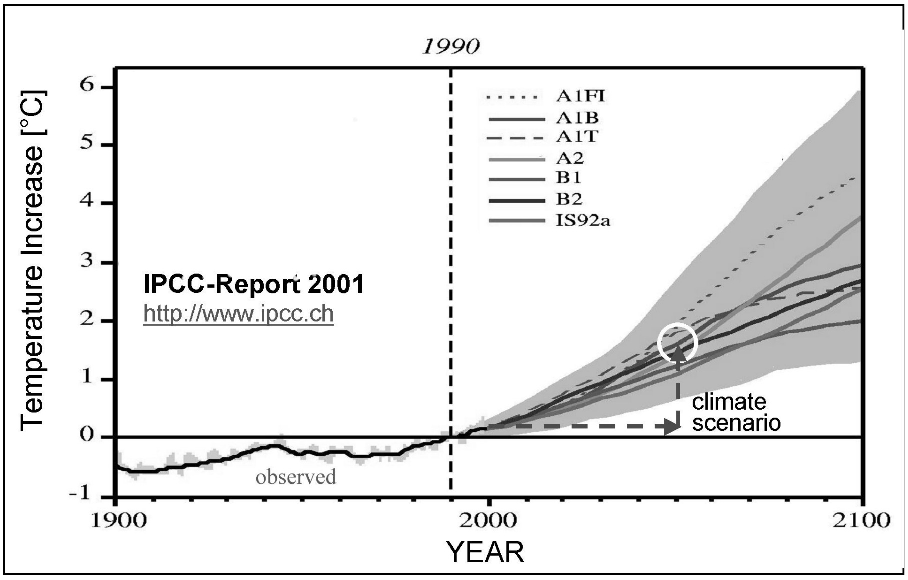

Fig. 2. The change in the global average surface temperature with time relative to 1990 (1900 – 1990 observed; 1990 – 2100 estimated). The temperature increase from 1990 to 2100 lies between 1.5 and 5.8°C, depending on different gaseous emission scenarios (curves) and the climate model used (grey area), according to (IPCC, 2001).

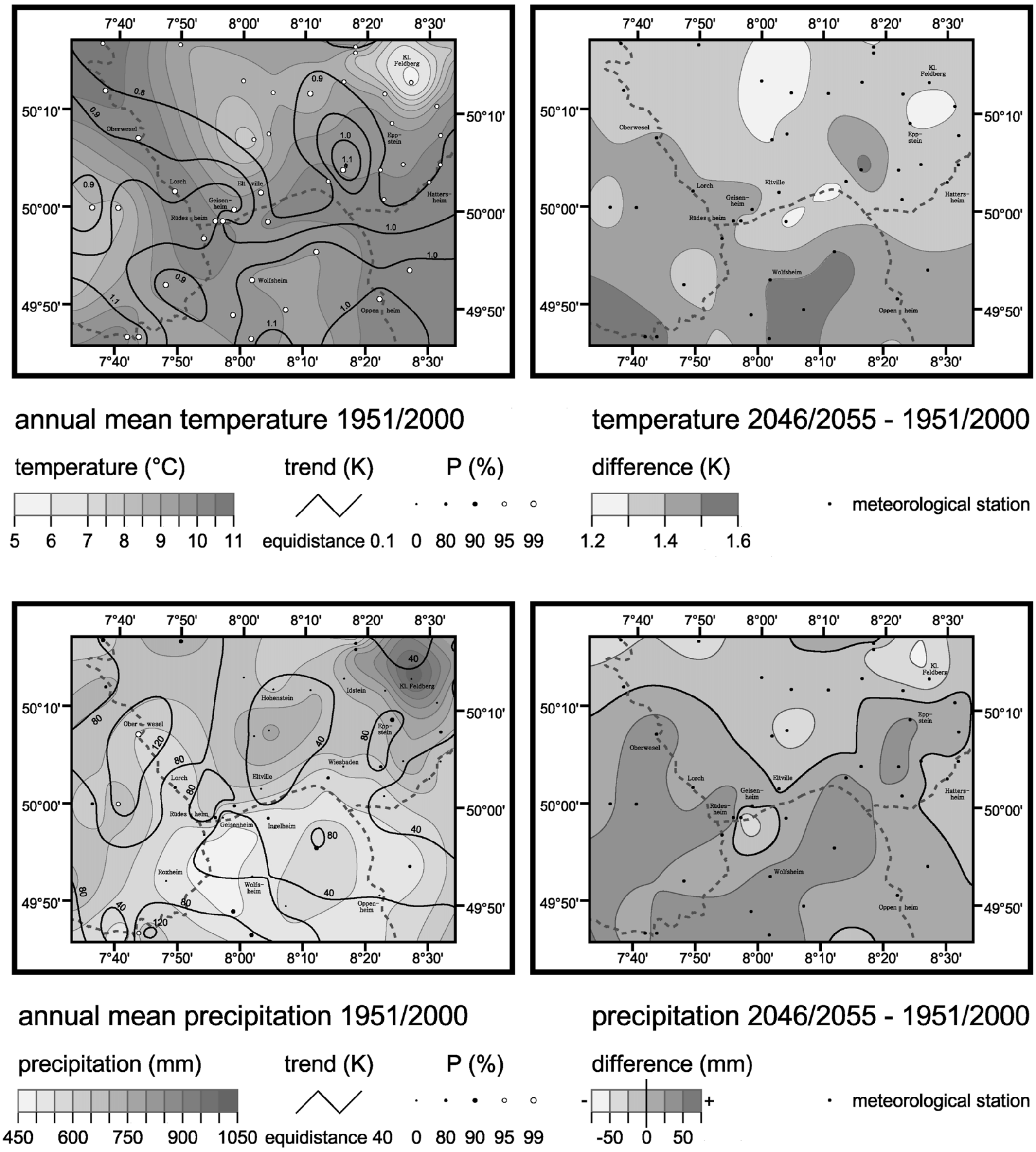

Fig. 3. Maps of the Rhine Valley and the Rheingau in Germany showing distributions of annual mean temperature and precipitation for the period 1951 to 2000 (left, upper and lower) and their projections for the years 2046 to 2055 (expressed as the difference between the reference period and the future) (right).

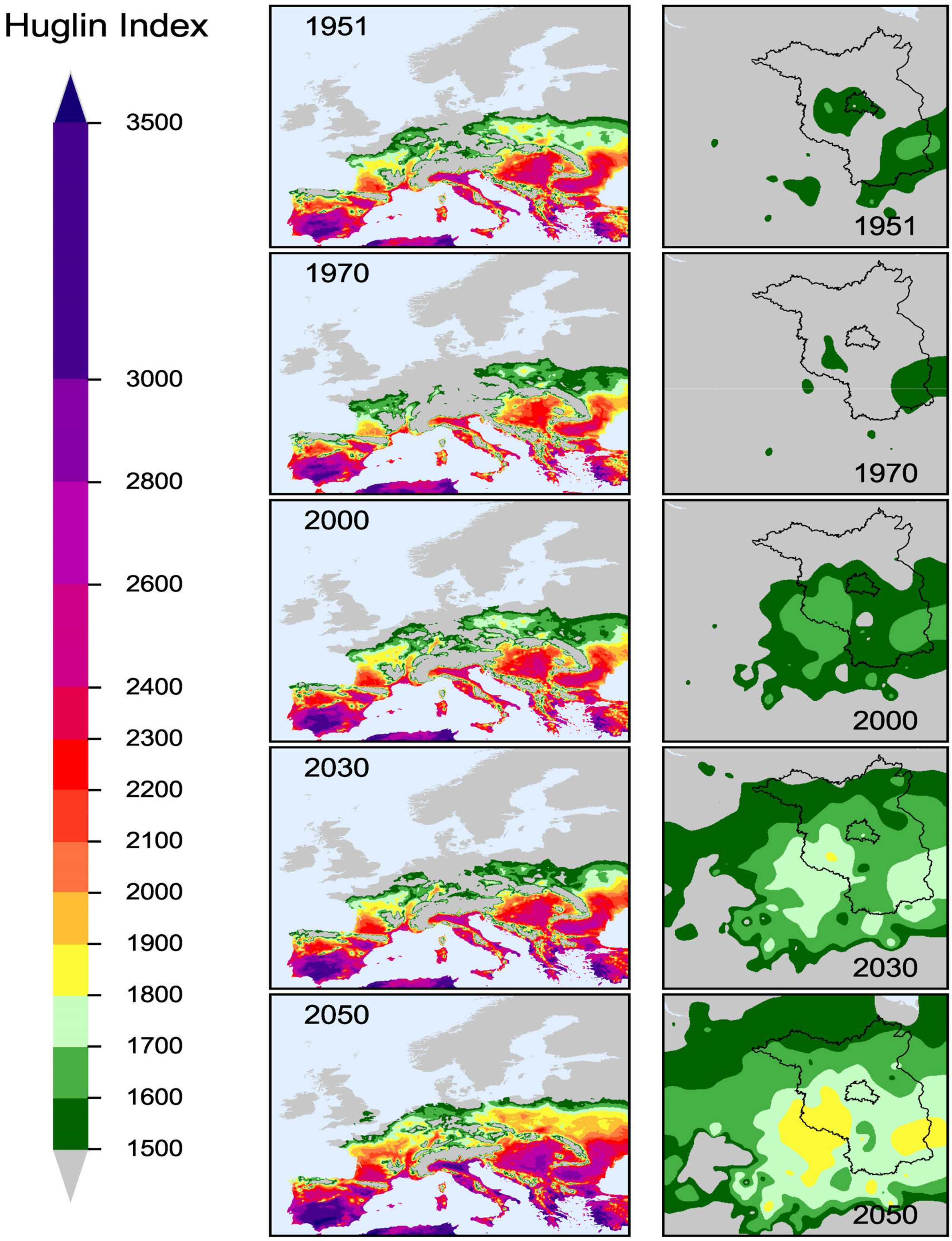

Fig. 4. The Huglin Index throughout Europe from 1951 to 2000 (observed meteorological data) and model calculations up to 2050. The CRU data and the PCM results were used for the European map (left). Results with high regional resolution for eastern Germany (right) were obtained using PIK/DWD data and the model STAR.

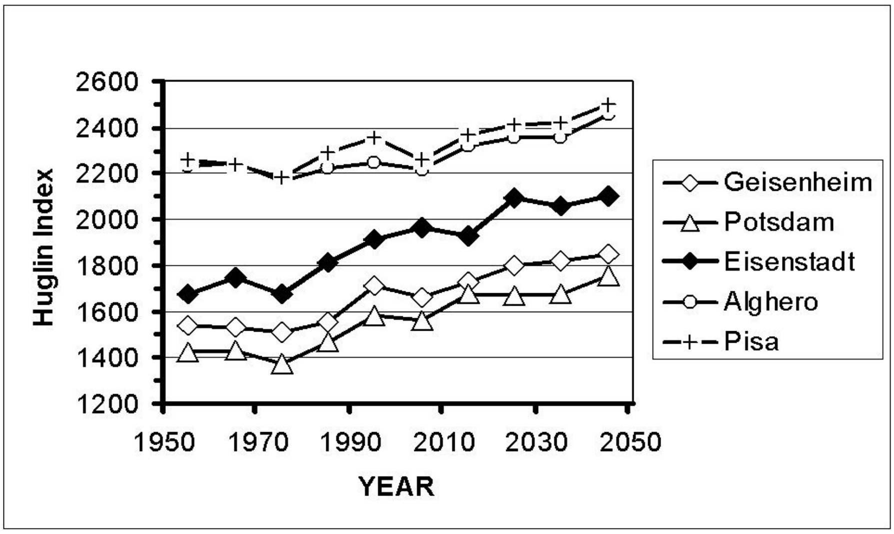

Fig. 5. Past and projected Huglin Index (ten year average, between 1950 and 2050 for five European viticultural regions; Germany - Geisenheim and Potsdam; Austria - Eisenstadt (Burgenland); Italy - Alghero (Sardinia) and Pisa (Tuscany)).

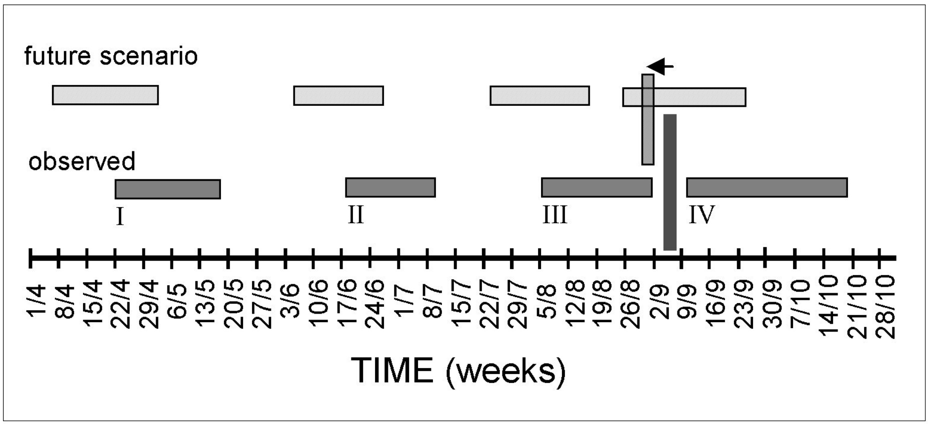

Fig. 6. Developmental sequence of four generations of the adult grape moth (*Lobesia botrana*) projected between April 1 and end of October in Alghero, Italy (horizontal bars). The moth will develop earlier in the future climate scenario (above) compared to the observed situation (below). The risk of co-occurrence between the pest and grapes in their final phase of maturity before harvest (vertical bars) will be much higher in the future than in the past (based on Cossu et al., 2004).