

# Chapter 2

## Climate Change in Central and Eastern Europe

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### 2.1 Preface and Definitions

Along with the increasing world population and the technological advancement during the last centuries both energy consumption and the demand for land have increased simultaneously. Climate change at its estimated pace poses serious challenges for society, policy, and the economy. In order to develop suitable strategies for adaptation, fundamental knowledge about the climate in the past, present, and potentially in the future is required on a global and a regional scale. Thus, a scientific assessment of observed and projected changes of climate variables and indices is an inevitable precondition for appropriate adaptation and mitigation measures.

Because the terms “weather” and “climate” are often misunderstood, a few general definitions have to be explained first. While “weather” means the state of the atmosphere in a certain moment, hour, day, or week, “climate” is defined as the statistical description of weather, including averages and variability as well as the return intervals of extremes over a period of at least 30 years [defined by the World Meteorological Organisation (WMO)] (WMO 2011). The most relevant climate parameters characterising this period are surface variables- air temperature, precipitation, radiation, humidity, cloud cover and wind. Closely related to this definition

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is the term “climate change” as used by the Intergovernmental Panel on Climate Change (IPCC). Climate change is defined as a statistically significant change in the mean state or the temporal variability of the climate due to natural variation of external forcing, anthropogenic changes in the atmosphere’s composition, or changes in land use (IPCC 2007). In this chapter possible sources of climate information are summarised including an overview of uncertainties. The main focus is on climate change signal in Central and Eastern Europe.

## 2.2 Measurements, Climate Models and Sources of Uncertainties

### 2.2.1 Observations

One traditional way to observe past climate change is through measurement and analysis of instrumental climate series, as currently performed by national weather services. The first international measurement network was built in 1781 and included 39 stations from North America to the Urals, with most in Europe (Schönwiese 2003). Based on these observations institutes like the Met Office Hadley Centre,<sup>1</sup> the Climatic Research Unit,<sup>2</sup> and others have calculated the global temperature since 1850. For periods before 1850, scientists use climate reconstructions based on natural archives. They extract data from ice cores, tree rings, speleothems, varved sediments, and subsurface temperature profiles which are obtained from boreholes or proxy data like historical references, harvest numbers, phenological phases, icing and flooding information, conclusions about the prehistoric climate, or to past states of the atmosphere (Esper et al. 2002; Luterbacher et al. 2004; Wanner et al. 2008). Figure 2.1 shows on the left a slice of a stalagmite which has been used to reconstruct precipitation. The tree ring on the right could be dated back to 1746 and gives information about environmental conditions in each year of the tree’s life.

A historical monthly precipitation data set since 1900 for global land areas has been constructed by the Climatic Research Unit, gridded at two different resolutions (2.5° latitude by 3.75° longitude and 5° latitude/longitude). For Central and Eastern Europe a number of regional data sets have been developed for manifold applications. A sufficient length of time, sufficient spatial density, and high data quality without any inhomogeneities are the requirements of the data used for climate variability studies. Inhomogeneities are artificial breaks or trends in time series caused by manifold non-climatic perturbations like station relocations, changes of instruments or observation hours, altering of regulations for means calculations,

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<sup>1</sup> <http://www.metoffice.gov.uk/hadobs/hadcrut3/diagnostics/comparison.html>

<sup>2</sup> <http://www.cru.uea.ac.uk/>



**Fig. 2.1** *Left:* Slice of a stalagmite from a cave in Austria; *Right:* Horizontal cross section of a tree (*Larix decidua*) in Savoyen grown in 1746, cut in 1999

urban trends and many other disturbances (Aguilar et al. 2003). Different tests and correction procedures have been developed to remove inhomogeneities; however these tests concentrate mainly on monthly temperature and precipitation data. Daily data requires more sophisticated methods, taking not only the mean but the whole frequency distribution of an element into account (cf. Della-Marta and Wanner 2006; Mestre et al. 2009).

Nevertheless, some groups have expended great efforts to create and analyse regional long-term data sets. For the southern part of Central Europe [called the Greater Alpine Region (GAR)] the Historical Instrumental Time Series for the Greater Alpine Region (HISTALP) database<sup>3</sup> has been developed. Its temperature and air pressure series date back to 1760, precipitation to 1800, cloudiness to the 1840s and sunshine to the 1880s. In those earlier times the network density was rather sparse; only since national weather services have been founded in the mid-nineteenth century the number of stations has been steadily increasing. This growth allows for extensive climate information during the twentieth century.

Not all measured or observed climatological data has been made available for research or practical applications. Some of the data has been lost forever destroyed during wars or other misfortunes, some other data is still left in archives, libraries or other locations in its original paper sheets, some data has been printed in yearbooks or newspapers that have not been digitised until now. That is why a number of countries and institutions have started data recovery/rescue activities to make as much data available as possible. Such efforts have recently begun in 2011 for the Carpathian region; Hungary, Poland, Romania, Serbia, Slovakia and Ukraine have made great efforts to improve their database over the last 50 years. However, particularly in Eastern European countries, there has been a decline in the number of meteorological observation stations after the political changes of the early 90s. In some cases, the number decreased to the same level as during the 60s. For the Mediterranean Region the initiative WMO-MEDARE<sup>4</sup> was born under the auspice

<sup>3</sup> <http://www.zamg.ac.at/histalp>

<sup>4</sup> <http://www.omm.urv.cat/MEDARE/index.html>

of the World Meteorological Organisation in order to develop climate data and metadata rescue activities across the Greater Mediterranean Region.

### 2.2.2 *Models*

Measurements provide information on the past and recent climate. To estimate possible changes of climate parameters, perspective climate models can be applied. These models can be divided into two main approaches- dynamical and statistical climate models. Dynamical climate models can be grouped into Global Climate Models or Global Circulation Models (GCMs), Regional Climate Models (RCMs), Earth System Models (ESMs), Coupled Atmosphere Ocean Global Climate Models (AOGCMs), and others. GCMs and AOGCMs are strongly simplified but contain the most important physical processes describing our climate system. They are limited to the representation of large scale effects on the global climate due to changes in greenhouse gas concentration, eruptive volcanoes etc. Their spatial resolution for the whole globe is from  $3^\circ$  down to  $1.2^\circ$ . RCMs use model output from GCMs as forcing to simulate the climate at smaller scales for certain regions. They contain complex model physics and due to their high spatial resolution from 50 km down to 3 km ( $0.5^\circ$ – $0.025^\circ$ ) it is possible to reproduce regional and local effects through the integration of orography and land use. The second group of climate models follows a statistical approach. Statistical relationships between large scale processes and local measurements are extended to estimate future climate and possible changes can be derived very locally. Typical statistical models are a weather generator, Markov chains, linear regression, or principle component analysis. Dynamical and statistical models both have their advantages and disadvantages and the decision of what kind of climate model to use depends on the application and the specific question to be answered in relation to future climate change.

For the interpretation of climate change scenarios and a consequent impact assessment, the consideration of given uncertainties is a fundamental task. Uncertainties arise from imperfect knowledge of physical processes of the climate system as well as from model limitations due to the numerical approximation of the physical equations. Many physical processes which operate at scales below the model resolution are integrated into the climate and impact models as assumptions, simplifications and parameterisations. Furthermore the internal model variability is a reason for uncertainties in the simulation of climate responses to given forcings (Christensen et al. 2001). Moreover, uncertainties arise from the internal variability of the climate system, which is characterised by natural fluctuations in the absence of any radiative forcing (Hawkins and Sutton 2009). Additionally, a high level of uncertainty of the observed climate is implied due to measurement errors and sparse station networks as already described in the previous section. The development of climate scenarios involves uncertainties due to the estimation of future greenhouse gas and aerosol emissions, the conversion of emissions to concentrations, the conversion of

concentrations to radiative forcing, the modelling of the climate response to a given forcing, and the conversion of model response into inputs for impact studies (Houghton et al. 2001).

Each step in the development of climate change scenarios leads to a range of probable results followed by a plenitude of uncertainty. The challenge is to assess and to quantify uncertainties about climate scenarios and their consideration in climate change and impact studies. The use of a range of emissions scenarios to force a number of different GCMs and to take into account the range of possible socio-economic futures for the development of regional climate change scenarios is recommended.

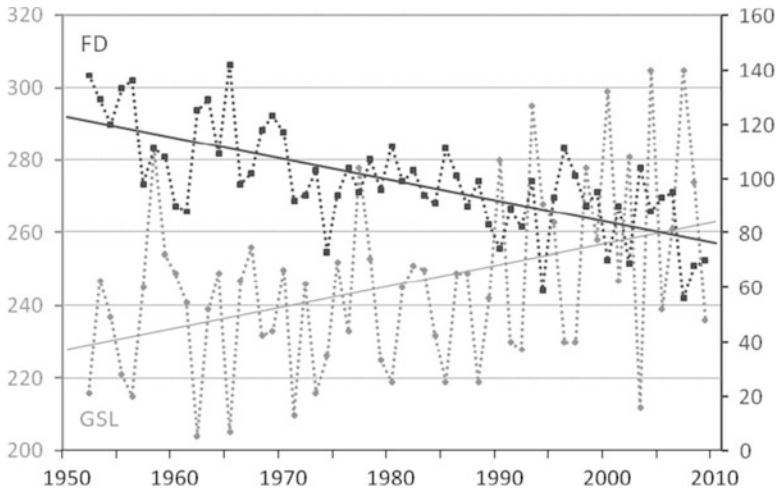
### 2.3 Temperature and Precipitation Change in the Past 50–150 Years

Because climate analyses are often carried out for specific regions or for specific countries, the following section summarises past climate change information based on given literature for each different region separately.

The climate of the twentieth century in Central and Eastern Europe is marked by an overall temperature increase, although more pronounced in the Alps and their surroundings than elsewhere in this region. Other climate elements, like precipitation have developed diversely with regional increases and decreases of smaller distances. For the HISTALP area (GAR) covering the *southern part of Central Europe* (4–19°E, 43–49°N, 0–3500 m asl) temperature increased significantly by about 1.2 °C during the twentieth century. This increase was similar in all of the subregions (Auer et al. 2007). Warming at the high mountain observatories in the Alps did not differentiate significantly from that in the lowlands. The respective numbers for the seasons are 1.1 °C for spring, 1.3 °C for summer, 1.2 °C for autumn and 1.3 °C for winter. The strongest warming occurred in the 1980s and 1990s. Thus, focusing on a shorter time period of the last 30 years, a much more severe warming can be found in the series. Together with the higher mean temperature level, a number of extremes derived from daily maximum and minimum temperature are expected to have increased as well.

For the Austrian territory Nemeč et al. (2012) found a widespread warming trend in both maximum and minimum temperature meaning an increase of warm days and warm nights. Cold days and nights, on the other hand, have been decreasing during the past 40 years. Climate impacts are easy to detect in nature, shrinking glaciers, elongated growing season lengths, thawing of permafrost, etc. Frost has decreased, above all in the lowlands in spring and autumn. In the high mountains the summer season is affected most by frost reduction (cf. Fig. 2.2).

For precipitation no general trend was detected for the HISTALP region, but regional features have to be taken into account. An increase of about 9 % in the north-western part matches a decrease of the same magnitude in the south-eastern part. Some stations in the south of *Austria* recorded a reduction of up to 20 %. Extreme



**Fig. 2.2** Growing season length (*GSL*) and number of frost days (*FD*) in Laa an der Thaya, near the National park Thayatal in Austria for the time period 1952–2009. The prolongation of the growing season of approximately 1 month is documented as well as the reduction of frost days by about 45 days during the past 60 years (Data source: ZAMG, homogenised daily extreme temperatures of Laa an der Thaya)

precipitation events display an overwhelmingly heterogeneous picture. Only a statistical, not strongly significant tendency towards weaker 1-day and 5-day precipitation events is found in the south-eastern parts of Austria. In eastern and south-eastern Austria an intensification of precipitation events larger than 20 mm/day can be identified. On the other hand, consecutive dry days show a clear geographic pattern south of the alpine divide with a trend towards longer dry periods.

Warmer temperatures should result in a reduced amount of solid precipitation, which means less snow during the cold season in relation to the annual total precipitation amount. A pronounced difference between mountains and valleys can be expected due to the different temperature level. In the lowlands, winters have experienced more and more rain rather than snow, whereas core months of winter in the high Alps have not had much change. The snow deficit comes into effect in summer with negative consequences for Alpine glaciers.

Measurements of 51 stations evenly distributed, homogenised and averaged over the territory of *Poland* confirmed the rising of annual temperature for the second half of the twentieth century (Degirmendzic et al. 2004). It is obvious that not all months contributed to the annual temperature increase of approximately 1 °C; however, the most pronounced warming was found in spring. Extreme temperatures have been studied by Wibig and Glowicki (2002). Poland belongs to the group of countries in which a stronger increase of minimum temperature than maximum temperature caused a decrease of the daily temperature range (DTR) at most stations. This effect correlated with increasing cloudiness, however could not be found in the GAR. With rising minimum temperature, Poland experienced a prolongation of the frost-free season. At the same time warmer temperatures and the frequency of hot weather

events in summer have been increasing. Wibig (2012) recorded a strong relationship between hot weather and lack of precipitation. Over the year no significant changes have been observed in the annual amounts of precipitation, but more interestingly, a decreasing summer precipitation trend has been found. March is the only month where a significant precipitation increase was detected.

In *Hungary* the general annual twentieth century warming of about 0.8 °C (most expressed in summer by increase of about 1 °C) initiated an extended calculation of extreme temperature and precipitation indices for the whole country using grids of the basic variables daily temperature and precipitation (Lakatos et al. 2011). Countrywide the grid point average of hot days ( $T_{\max} \geq 30$  °C) and warm nights ( $T_{\min} \geq 20$  °C) showed a remarkable increase beginning in the 1980s. Maps allow for a better identification of the most sensitive regions of the country. These maps coincide with the Austrian studies (Nemec et al. 2012) which state that warming does not necessarily cause more heavy precipitation. Changes of the annually greatest 1-day total rainfall between 1961 and 2009 vary from -15 to +10 mm. This increase could be detected mainly in the regions east of the Danube. Precipitation in general has decreased by 11 % in Hungary since 1901, especially since the 1970s. This decrease in precipitation is especially pronounced in spring. Although summer precipitation does not display a special negative trend drought events with dry and warm months are immanent in the climate of Hungary. The Hungarian plains are most affected, with drying occurring in late spring/early summer and during late autumn.

*Romania* has experienced a warming of about 0.5 °C in annual mean temperature since 1901, and in the south eastern region trends up to 1 °C have been estimated. Summer temperatures have been increasing since the 1970s with highest positive anomalies in the Northeast and Southwest of the country. During the hot summer of 2007 temperatures above 40 °C have been recorded during periods with maximum temperatures of 35 °C (Busuioc et al. 2007). Winter temperatures have been increasing more steadily during the last century leading to the warmest winter in 2006/2007 with an anomaly of about +6 °C. As stated previously, no uniform long-term precipitation change pattern was detected in Romania. There are some smaller regions with increases and decreases in other regions. Extreme precipitation events and their variability have been studied by Cazacioc (2007) for 1961–1996. On average, the daily maximum precipitation amount is highest in the south-western mountainous region (up to 68 mm) whereas in central Romania rather low rainfall of around 30 mm can be experienced. Maximum daily precipitation has mainly decreased during this period, most significantly more or less only in the south-western mountain region. On the other hand slight growing trends have been found partly in western and north-western regions of Romania.

### 2.3.1 Global and European Trends

For at least the last 500 years, European winters were generally colder than those of the twentieth century, except for two short periods around 1530 and 1730

(Luterbacher et al. 2004). The coldest winter periods occurred during the late sixteenth century, during the last decades of the seventeenth century, and at the end of the nineteenth century (Jones et al. 2001; Luterbacher et al. 2004).

Since the middle of the nineteenth century the annual average temperatures of the northern hemisphere have increased by 0.6 °C (Jones et al. 2001). Winters have warmed by nearly 0.8 °C and summers by only 0.4 °C in which the warming has occurred in two phases from about 1920–1945 and from 1975 to 2001 (Jones et al. 1999). On a global scale the minimum temperatures have increased more significantly than the maximum temperatures for the period of 1950–1993 (Jones et al. 1999). This leads to a decrease of the diurnal temperature range by 0.08 °C per decade.

A statistical trend analysis of temperature and precipitation of more than 600 stations across Europe shows a “warming band” of mean annual temperatures which extends from south-western to north-eastern Europe for the time period of 1951–2000 (Schönwiese and Janoschitz 2008). The seasonal examination of the data indicates that the temperature trends of the winter months are higher and clearer than the temperature trends of the summer months. Highest warming trends were found in the Baltic region with about 3 °C and in the western parts of Russia and the Alps with about 2 °C. For Eastern Europe (east of about 20°E) the summer temperature trends show small negative values (moderate cooling) and for Central Europe there are positive trends (warming).

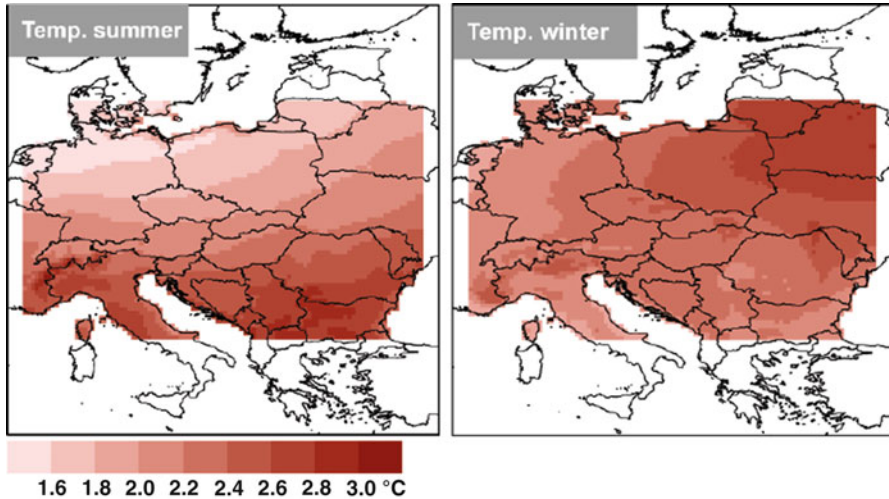
The spatial precipitation pattern for Europe displays increasing annual trends for parts of North Europe, no trends for Central and Eastern Europe, and a clear negative trend for South Europe for the period of 1951–2000 (Schönwiese and Janoschitz 2008). In summer, precipitation increases in most parts of Europe, except areas east around 25°E and south around 60°N (East and Southeast Europe), in which a precipitation decline was observed. In winter months, the precipitation trends over Europe are divided into two parts. In the Mediterranean countries and in some countries of Eastern Europe precipitation has declined and in other parts of Europe precipitation has increased with observed maximum values of about 40 %.

## **2.4 Projected Climate Change in the Near and Far Future in Europe**

### ***2.4.1 Temperature***

In Central and Eastern Europe the mean annual temperature is projected to increase between 1 and 3 °C until the middle of the century and up to 5 °C by the end of the century (Giorgi et al. 2004; Räisänen et al. 2004; Rowell 2005; Christensen et al. 2007; Déqué et al. 2007; Kjellström et al. 2007), if no policy measure is taken (IPCC 2007). Figure 2.3 illustrates the projected change in temperature as a result of a multi-model average for the middle of the twenty-first century.





**Fig. 2.3** Change of simulated mean temperature in Central and Eastern Europe in winter and summer as the multi-model mean 2036–2065 relative to 1971–2000 for the A1B greenhouse gas emission scenario

The model output is taken from various regional model simulations driven by different European Global Climate Models produced in the European project ENSEMBLES (van der Linden and Mitchell 2009). The projections up to 2100 use a common forcing under A1B greenhouse gas emission scenario. The European warming will be higher than the global mean temperature increase. As can be seen in Fig. 2.3 this temperature increase is different from region to region and season to season. In the autumn and winter months the temperature change in North and Eastern Europe will be higher (up to 3 °C) compared to South Europe (1–1.5 °C).

The warming in winter increases from the western coastal regions of Europe to the eastern continental interiors (Giorgi et al. 2004; Rowell 2005). This can be mainly explained through two mechanisms. The first is the influence of the rather modest warming of the ocean on the climate of the western parts of Europe (Rowell 2005), and the second is the snow albedo feedback mechanism. If the warming depletes the snow cover, the albedo decreases and more solar radiation reaches the surface, which in turn enhances the surface warming, accelerates the snow depletion, and sustains a positive feedback mechanism (Giorgi et al. 2004; Rowell 2005; Kjellström et al. 2007). Furthermore, the minimum temperatures have risen most, leading to decreased winter temperature variability (Räisänen et al. 2004). Adversely, in summer the increase in the south of up to 2.5 °C is larger than in the north with an increase of less than 2 °C.

The projected increase in daily mean temperature varies overall. The model projections show a clear warming trend for the future, although there are regional and seasonal differences in the magnitude of the projected temperature increase. The changes in temperature as multi-model mean for the period 2036–2065 relative

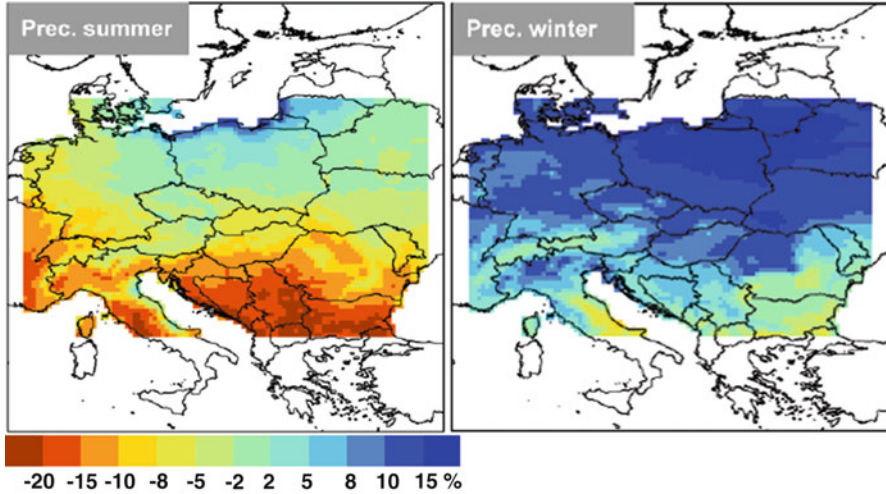
to 1971–2000 show a steady rise of the summer temperature of 1.5 °C in the northern parts of Germany and Poland and up to 3 °C in Southeast Europe. For the winter months the projected increase is the highest in the north-eastern region (~3 °C) and lowest in the western parts of Central Europe (~1.8 °C). Thereby, the spread of the model projections for temperature is high in the summer months, especially in the southern parts of Central Europe with a coefficient of variation up to 50 % (not shown).

For all of Central and Eastern Europe a clear temperature rise is visible for the future which is projected to become more distinct at the end of the century. A general pattern is that the projected increase of temperature is highest during summer and lower during winter. For most areas, a comparison of the projections shows a high uncertainty range, especially during summer. The range of uncertainty results from different potential pathways of technological, economic, and demographic development leading to different emissions of greenhouse gases and the related response of the climate system.

## **2.4.2 Precipitation**

The projections for precipitation show a more complex picture. The spatial heterogeneity of precipitation is generally larger than the special heterogeneity of temperature. The projected changes for precipitation vary seasonally and across regions in response to changes in large scale circulations and water vapour loadings. With regard to the nearer future the evaluation of various climate models does not show a distinct trend for precipitation in most of the area, especially due to the highest uncertainties in simulated precipitation trends existing for Eastern Europe. Nevertheless, trends on future precipitation become clearer for the end of the century, where a shift of precipitation from summer to winter becomes visible. A general assumption is that the summer precipitation all over Central Europe (except along the coast of the Baltic Sea) will decrease, while in most cases Central Europe will most likely become wetter in the winter season. Despite these precipitation increases, the amount of snow and area covered by snow are expected to decline due to warming. In contrast, the projections for the summer months show tendencies for a decrease in precipitation especially in the southern parts of Central Europe. The multi-model mean (cf. Fig. 2.4) shows a decrease up to 25 % in the summer months for southern Central Europe and an increase in the amount of precipitation up to 20 % for northern Central Europe in the winter months.

Due to the high spatial and temporal variability of precipitation and the complexity of its development processes, the changes in precipitation show more regional and seasonal differences than temperature shows. In spring and autumn the precipitation amount decreases in South and Southeast Europe. In North and Northeast Europe an increase can be detected. In winter Central and Southeast Europe show small changes in precipitation sums. Several climate change studies show a south-north contrast in precipitation, with an increase in North Europe



**Fig. 2.4** Change of simulated mean precipitation in Central and Eastern Europe in winter and summer as the multi-model mean 2036–2065 relative to 1971–2000 for the A1B greenhouse gas emission scenario

and a decrease in South Europe. The border between increasing and decreasing precipitation moves with the season and shows a northwards shift in summer (Christensen and Christensen 2007; Christensen et al. 2007). This transition line extends from the Iberian, Italian, and Balkan peninsulas (Giorgi et al. 2004) and is located at about 40°N in winter, 45°N in spring, 60°N in summer, and 55°N in autumn (Rowell 2005). Missing precipitation in spring can increase the probability of the occurrence of heat waves in Central Europe (like e.g. in 2003) (Fischer and Schär 2009; Fischer et al. 2007).

## 2.5 Need for Research

Meteorological measurements provide essential information about past and present climate conditions. Data recovery initiatives contribute to a reduction of deficiencies and thus an enhanced knowledge of regional climate variability. To assess future changes in temperature, precipitation, and other climatic parameters, Global Circulation Models, Regional Climate Models, and statistical downscaling methods are utilised to simulate climate variations for the upcoming decades.

During the last century the global air temperature has increased by about 0.7 °C (IPCC 2007). Central and Eastern Europe have turned out to be more sensitive to climate change than other regions, facing a temperature rise of a little more than twice the global mean (Auer et al. 2007). The research community in Europe is very big and intensive investigations are carried out to assess climate change in mean

and variability of common parameters, but also in their extreme values. Central Europe is located in a climatic transition zone of precipitation increase and decrease. Estimating the changes is difficult. This fact results in a high uncertainty in the expected future change. These uncertainties from observations and similarly from models need to be taken into account in all fields of climate change related decisions.

Climate researcher can give a hint of possible future changes but also have to communicate the range of uncertainty and the limitation of measures. The challenge in climate research tends to focus more and more to a very local scale. In all fields of applications strategies have to be developed that take a wide range of possible future developments into account and are adapted regularly by updated climate data.

**Acknowledgements** The analysis of the climate change signal in Central and Eastern Europe is based on regional climate model simulations for all of Europe, and the A1B emissions scenario is based on regional climate model simulations carried out in the European Union-funded Project ENSEMBLES (GOCE-CT-2003-505539). We are very grateful to Sorin Cheval, Joanna Wibig and Zita Bihari for supplying information on national observation systems and climate change information and to Michael Grabner and Bernhard Hynek for photos.

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## References

- Aguilar, E., Auer, I., Brunet, M., Peterson, T. C., Wieringa, J. (2003). *Guidelines on climate metadata and homogenization* (WCDMP-No.53. WMO-TD No. 1186), 51 pp.
- Auer, I., Böhm, R., Jurkovic, A., Lipa, W., Orlik, A., Potzmann, R., Schöner, W., Ungersböck, M., Matulla, C., Briffa, K., Jones, P., Efthymiadis, D., Brunetti, M., Nanni, T., Maugeri, M., Mercalli, L., Mestre, O., Moisseline, J. M., Begert, M., Müller-Westermeier, G., Kveton, V., Bochnicek, O., Stastny, P., Lapin, M., Szalai, S., Szentimrey, T., Cegnar, T., Dolinar, M., Gajic-Capka, M., Zaninovic, K., Majstorovic, Z., & Nieplova, E. (2007). HISTALP – Historical instrumental climatological surface time series of the Greater Alpine Region. *International Journal of Climatology*, 27, 17–46.
- Busuioc, A., Dumitrescu, A., Soare, E., & Orzan, A. (2007). Summer anomalies in 2007 in the context of extremely hot and dry summers in Romania. *Romanian Journal of Meteorology*, 9(1–2), 1–17.
- Cazacioc, L. (2007). Spatial and temporal variability of extreme daily precipitation amounts in Romania. *Romanian Journal of Meteorology*, 9, 34–46.
- Christensen, J. H., & Christensen, O. B. (2007). A summary of the PRUDENCE model projections of changes in European climate by the end of this century. *Climatic Change*, 81, 7–30. doi:10.1007/s10584-006-9210-7.
- Christensen, O. B., Gaertner, M. A., Prego, J. A., & Polcher, J. (2001). Internal variability of regional climate models. *Climate Dynamics*, 17, 875–887.
- Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R. K., Kwon, W.-T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C. G., Räisänen, J.,

- Rinke, A., Sarr, A., & Whetton, P. (2007). Regional climate projections. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, & H. L. Miller (Eds.), *Climate change (2007): The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 847–940). Cambridge/New York: Cambridge University Press.
- Degirmendzic, J., Rozuchowski, K., & Zmudzka, E. (2004). Changes of air temperature and precipitation in Poland in the period 1951–2000 and their relationship to atmospheric circulation. *International Journal on Climatology*, *24*, 291–310.
- Della-Marta, P. M., & Wanner, H. (2006). A method for homogenising the extremes and mean of daily temperature measurements. *Journal of Climate*, *19*, 4179–4197.
- Déqué, M., Rowell, D. P., Lüthi, D., Giorgi, F., Christensen, J. H., Rockel, B., Jacob, D., Kjellström, E., de Castro, M., & van den Hurk, B. (2007). An intercomparison of regional climate simulations for Europe: Assessing uncertainties in model projections. *Climatic Change*, *81*, 53–70. doi:10.1007/s10584-006-9228-x.
- Esper, J., Cook, E. R., & Schweingruber, F. H. (2002). Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability. *Science*, *295*, 2250–2253. doi:10.1126/science.1066208.
- Fischer, E. M., & Schär, C. (2009). Future changes in daily summer temperature variability: Driving processes and role for temperature extremes. *Climate Dynamics*, *33*, 917–935. doi:10.1007/s00382-008-0473-8.
- Fischer, E. M., Seneviratne, S. I., Vidale, P. L., Lüthi, D., & Schär, C. (2007). Soil moisture – Atmosphere interactions during the 2003 European summer heat wave. *Journal of Climate*, *20*, 5081–5099.
- Giorgi, F., Bi, X., & Pal, J. (2004). Mean, interannual variability and trends in a regional climate change experiment over Europe. II: Climate change scenarios (2071–2100). *Climate Dynamics*, *23*, 839–858. doi:10.1007/s00382-004-0467-0.
- Hawkins, E., & Sutton, R. (2009). The potential to narrow uncertainty in regional climate predictions. *Bulletin of the American Meteorological Society*, *90*, 1095–1107.
- Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. M., & Xiaosu, D. (2001). *Climate change 2001: The scientific basis: Contributions of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press. 881 pp.
- IPCC. (2007). Summary for policymakers. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, & H. L. Miller (Eds.), *Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge/New York: Cambridge University Press.
- Jones, P. D., New, M., Parker, D. E., Martin, S., & Rigor, I. G. (1999). Surface air temperature and its changes over the past 150 years. *Reviews of Geophysics*, *37*, 173–199. doi:10.1029/1999RG900002.
- Jones, P. D., Osborn, T. J., & Briffa, K. R. (2001). The evolution of climate over the last millennium. *Science*, *292*, 662–667. doi:10.1126/science.1059126.
- Kjellström, E., Bärring, L., Jacob, D., Jones, R., Lenderink, G., & Schär, C. (2007). Modelling daily temperature extremes: Recent climate and future changes over Europe. *Climatic Change*, *81*, 249–265. doi:10.1007/s10584-006-9220-5.
- Lakatos, M., Szentimrey, T., & Bihari, Z. (2011). Application of gridded daily data series for calculation of extreme temperature and precipitation indices in Hungary. *Időjárás*, *115*, 99–109.
- Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., & Wanner, H. (2004). European seasonal and annual temperature variability, trends, and extremes since 1500. *Science*, *30*, 1499–1503. doi:10.1126/science.1093877.
- Mestre, O., Prieur, C., Gruber, C., Caussinus, H., & Jourdain, S. (2009). A method for homogenization of daily temperature observations. *Journal of Applied Meteorology and Climatology*, *50*, 2343–2358.

- Nemec, J., Gruber, C., Chimani, B., & Auer, I. (2012). Trends in extreme temperature indices in Austria based on a new homogenised dataset. *International Journal of Climatology*. doi:[10.1002/joc.3532](https://doi.org/10.1002/joc.3532).
- Räisänen, J., Hansson, U., Ullerstig, A., Döscher, R., Graham, L. P., Jones, C., Meier, H. E. M., Samuelsson, P., & Willén, U. (2004). European climate in the late twenty-first century: Regional simulations with two driving global models and two forcing scenarios. *Climate Dynamics*, 22, 13–31. doi:[10.1007/s00382-003-0365-x](https://doi.org/10.1007/s00382-003-0365-x).
- Rowell, D. P. (2005). A scenario of European climate change for the late twenty-first century: Seasonal means and interannual variability. *Climate Dynamics*, 25, 837–849. doi:[10.1007/s00382-005-0068-6](https://doi.org/10.1007/s00382-005-0068-6).
- Schönwiese, C.-D. (2003). *Klimatologie*. Stuttgart: UTB.
- Schönwiese, C.-D., & Janoschitz, R. (2008). *Klima-Trendatlas Europa 1901–2000*. Frankfurt/Main: Berichte des Instituts für Atmosphäre und Umwelt der Universität Frankfurt.
- van der Linden, P., Mitchell, J. F. B. (Eds.). (2009). *ENSEMBLES: Climate change and its impacts: Summary of research and results from the ENSEMBLES project*. Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK.
- Wanner, H., Beer, J., Bütikofer, J., Crowley, T. J., Cubasch, U., Flückiger, J., Goosse, H., Grosjean, M., Joos, F., Kaplan, J. O., Küttel, M., Müller, S. A., Prentice, I. C., Solomina, O., Stocker, T. F., Tarasov, P., Wagner, M., & Widmann, M. (2008). Mid- to Late Holocene climate change: An overview. *Quaternary Science Reviews*, 27, 1791–1828. doi:[10.1016/j.quascirev.2008.06.013](https://doi.org/10.1016/j.quascirev.2008.06.013).
- Wibig, J. (2012). Has the frequency or intensity of hot weather events changed in Poland since 1950? *Advances in Science and Research*, 8, 87–91.
- Wibig, J., & Glowicki, B. (2002). Trends of maximum and minimum temperature in Poland. *Climate Research*, 20, 123–133.
- World Meteorological Organization (2011). *Guide to climatological practices* (3rd ed.). (WMO-No. 100), Geneva.