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METHODS FOR THE DESIGN OF CLIMATE CHANGE SCENARIO IN SLOVAKIA FOR THE 21ST CENTURY

Abstract: In this paper methods of climate-change scenario projection in Slovakia for the 21st century are outlined. Temperature and precipitation time series of the Hurbanovo Observatory in 1871–2007 (Slovak Hydrometeorological Institute) and data from four global GCMs (GISS 1998, CGCM1, CGCM2, HadCM3) are utilized for the design of climate change scenarios. Selected results of different climate change scenarios (based on different methods) for the region of Slovakia (up to 2100) are presented. The increase in annual mean temperature is about 3°C, though the results are ambiguous in the case of precipitation. These scenarios are required by users in impact studies, mainly from the hydrology, agriculture and forestry sectors.

Key words: trends, climate change, climate scenarios, Slovakia

Introduction

Climatic change issues and analyses on local and global scales have become very frequently discussed topics recently. Global mean surface temperatures have risen by 0.74°C ± 0.18°C when estimated according to a linear trend over the last 100 years (1906–2005) (IPCC 2007). The air-temperature increase in Slovakia in 1880–2007 is illustrated as an example of Hurbanovo time series in Figure 1. The Hurbanovo Observatory (115 m a.s.l.) is a representative site for the region of the southwest part of Slovakia and it ranks among the best meteorological stations in Central Europe with sufficiently long, high quality observations. Temperature measurements at Hurbanovo are available from 1871 onwards, though the quality of measurements from the first ten years of observations is less reliable (Lapin 2004). Air temperature has increased almost continuously at Hurbanovo within this period to a level of significance of 0.01 (Fig. 1). There is an increase of about 1.6°C in the linear temperature trend in the period 1880–2007. Temperature series show an increasing trend in all seasons, particularly in spring. The precipitation series (annual precipitation totals) have a decreasing linear trend at Hurbanovo by about 13% in the same period, though to a slightly lower degree of significance of around 0.05 (Fig. 1). From Figure 1 it is also apparent that there has been a slightly increasing trend since 1980.

Continued greenhouse gas emissions at or above the current rates will cause further warming and induce many changes in the global climate system during the 21st century that will be very likely larger than those observed during the 20th century (IPCC 2007). In the present paper we have turned our attention to possible future climatic patterns in Slovakia. The first climate change scenarios were prepared for Slovakia within the Slovak National Climate Program studies in 1991 by a very simple analogue method. Since then several new generations of climate scenarios have been designed and published. A number of studies have been issued also by the Comenius University team (e.g. Lapin 1992, 1995; Lapin et al. 1995, 2000, 2001a, b, 2003, 2006a, b; Lapin and Melo 1999, 2004; Melo and Lapin 2000, 2005; Damborska et al. 2002; Melo 2005). The aim of this contribution is to present briefly the methods and results of the climate change scenarios designed in Slovakia for the 21st century (up to 2100), predominantly those provided by the Comenius University team.

Methods used in Slovakia for the design of climatic scenarios

Our team used three basic methods for the design of regional climate change scenarios in Slovakia between 1991 and 2008: incremental scenarios (since 1991; Lapin et al. 1995), historical analogues (since 1991; Lapin et al. 1995), and the downscaling and statistical modification of general circulation models (GCMs) (since 1995).

The simplest method of climate-change scenario design is the incremental one. The incremental method is the simplest way of designing climate change scenarios. This method is based on a simple combination of selected

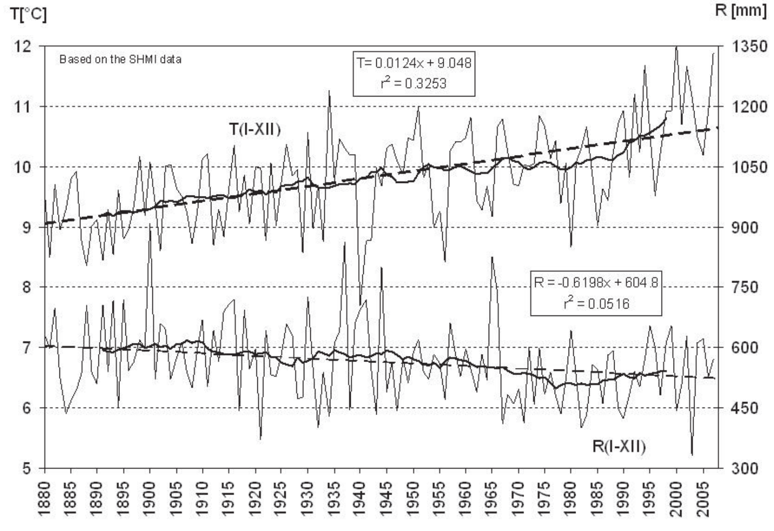


Fig. 1. Annual air temperature means (T) and annual precipitation totals (R) at Hurbanovo in the period 1880–2007 (including 20-year moving averages and linear trends). Linear trend indicates 1.6°C T increase and 79.3 mm (13%) R decreases in this 128-year period

air temperature (T) and precipitation (R) differences. The usual monthly temperature increments (dT) range is from 0.5°C to 6.0°C warming and the usual monthly precipitation increments (dR) range is from –20% to +20% deviations from the long-term average (norm). These scenarios were very popular among users in the early 1990s. However, because of the poor physical reliability among variables in such scenarios the values of some selected combinations (e.g. relative air humidity, snow cover, wind speed, evaporation) were unrealistic. At present, these types of scenarios are used in Slovakia only for the purposes of testing impact models.

Another way of designing regional climate change scenarios is the use of the analogue method. According to IPCC (2001), temporal analogues make use of climatic information from the past as an analogue for a possible future climate. The most suitable analogues are those based on historical instrumental measurements. Data from the period before regular instrumental observations are only partially appropriate for the analogue studies. The problem with paleoclimatic data is whether the weather and climate it reflects are representative of a global climate change driven by the increased greenhouse effect. Historical analogues have been used in Slovakia since 1991 as an alternative to the downscaled GCM outputs. Some warmer periods from the past have been selected according to specific methods and applied as the analogues of a possible future climate and for analysis of the interrelations among several climatic elements. The relatively warmer periods in the past (compared to the long-term average) were usually connected with a significant decrease in snow cover in the winter months (especially in the lowlands), a decrease in precipitation and relative air humidity from the spring to the autumn (Lapin et al. 1994).

The aim of the analogue method is to find warmer/colder periods or seasons in the existing time series and to characterize their climatic patterns using the mean monthly values of selected climatic elements. The problem is solved by two different methods.In the first case we applied the method based on warmer season, where this warmer period exists continually for at least five years and the average seasonal temperature is higher in all the years than the 1951–1980 norm. This normal period was chosen as one which was not influenced by climate change to any statistically significant degree, according to the IPCC recommendation. If any individual year (or several years) occurring in this continual series does not fulfil our requirements, we have taken it (them) into account only if this requirement was fulfilled as 5-year simple weighting moving average with centre in this particular year.

In the second case the warmer/colder periods have been selected as series from individual years, where each one was classified as relatively warm/cold. All the individual years which had higher/lower values of air temperature in the considered season than the 1951–1980 norm were included into the series of warmer/colder seasons.

The seasonal means and totals of several climatologic elements (air temperature, precipitation totals, relative air humidity means, sunshine duration,...) have been calculated for these chosen periods.The selected relatively warmer summer seasons in the Danubian lowland (Hurbanovo) in Slovakia in the limited 1951–2003 series are characterized by a decrease in precipitation totals and in relative humidity means and by an increase in global solar radiation flux density (Melo 2005). The advantage of the analogue approach is that the changes in climate have actually been observed and so, by definition, they are internally consistent and physically plausible (IPCC 2001).

Climatic models are the most important source of information for the behavior of a climatic system under changed conditions in the global climate system. Climate change experiments which have been carried out include Boer et al. (1992), McFarlane et al. (1992), Murphy and Mitchell (1995), Russell and Rind (1999), Flato and Boer (2001). At present, the most highly developed tools are the coupled atmospheric and oceanic general circulation models (GCMs). In Slovakia, we have utilized the global GCM outputs from the Canadian Centre for Climate Modeling and Analysis in Victoria, B.C., from the Goddard Institute for Space Studies in New York, from the Geophysical Fluid Dynamics Laboratory in Princeton and from the United Kingdom Meteorological Office in Bracknell. Recently new climate model outputs from the Max-Planck-Institute for Meteorology in Hamburg have been made available to our team, though the results from this model are not yet ready. The first model outputs were only in the form of monthly values for individual climatic elements (characteristics). The newest GCM outputs offer tens of variables in the form of daily means, extremes and sums.

For the design of regional climate change scenarios we have taken into account model outputs from the nearest GCM gridpoints around Slovakia in the Central European region. The gridpoint resolution of these global GCMs is approximately 250 to 300 km (the newest CGCM3.1 model has a resolution of about 140 km). Many smaller mountains, individual mountain ridges, small valleys and hollows are not visible in such a topography. Precipitation totals in the model outputs in Central Europe are much higher and the run-off is very slow, which results in relatively high evaporation (only slightly lower than the potential evaporation). The global climatic model (GCM) resolution is not sufficient for detailed regional climatic analysis. As a solution to this problem, regional GCM output modification (downscaling) was carried out. The statistical downscaling involves the development of statistical relationships among the locally observed climatic variables and outputs of the global GCM experiments (both the means and variability). Dynamic downscaling uses a detailed regional meteorological model nested into the global model system. It was mainly the statistically – based method which was applied by our team. This method is based on the measured data from the meteorological stations in the control period (i.e. the periods 1951–1980 or 1951–2000 during the 20th century). The selection of a representative past reference period is highly important. Currently the dynamic downscaling methods are being developed by our team though as yet we only have preliminary results (Lapin et al. 2006a).

Selected results of the GCM-based climate change scenarios for Hurbanovo

Climate change scenarios designed in the form of air-temperature and precipitation totals time series for Hurbanovo and the 21st century are presented here as the next step. These scenarios are based on the outputs of three different global coupled (atmosphere-ocean) general circulation models (GCMs):

- model data from the Goddard Institute for Space Studies in New York (GISS 1998 model under compounded of 1% CO_2 increase experiment with tropospheric sulfate aerosol changes),
- model data from the Canadian Centre for Climate Modelling and Analysis in Victoria, B.C. (CGCM2 model under two SRES emissions scenarios, A2 and B2, and one emissions scenario IS92a),
- model data from the Met Office Hadley Centre in Exeter, UK (HadCM3 model under emissions scenario IS92a).

The topography applied in these GCMs for Central Europe is simplified, smooth and unrealistic. The Alps and the Carpathians are presented there as one flat hill in Central Europe without the Danubian hollow in Panonia. Therefore, climatic values in the individual gridpoints represent some areal mean values over an area of about 100,000. sq km. The series of monthly or daily data from the outputs of these models have been used to elaborate and design climate change scenarios for the conditions of a strengthened greenhouse effect on the territory of south-western Slovakia in the 21st century. The CGCM3.1 model with A2 and B1 SRES emission scenarios and a more detailed topography was analyzed in 2008.

The GCM outputs offer data representing a sort of areal average around the grid points. These data are less variable in spatial and temporal terms than those measured at meteorological stations. As a first step, the interpolation from the GCM gridpoint data round Slovakia to the locality of Hurbanovo (the weights with respect to the distance from this locality) was applied. Downscaling of the model outputs for the selected locality (Hurbanovo) was achieved by the use of measured data from the meteorological station (Hurbanovo) in the “control” or “reference” period (1951–2000). The modified model outputs according to the means and variability (standard deviations in the case of air temperature, variation coefficients in the case of precipitation totals) are then correspond relatively well with the observed data series. Assuming only insignificant changes in the transforming relation between measured and modeled data (means and variability), we can similarly modify the model outputs for the near future (up to the year 2100). Some modification of this method has already been applied in studies such as Lapin and Melo (1999, 2004), Lapin et al. (2001a, b), Melo (2005).

We can state on the basis of all the GCM outputs studied that the climate at Hurbanovo will continue to experience an increase in temperature in the 21st century. The temperature, according to the GISS 1998 model, is characterized by the lowest growth rate of the three selected GCMs. On the other hand, the most noticeable air-temperature increase is that projected by the HadCM3 model. The temperature increase resulting from the new B2-SRES emission scenario is lower than that from the older IS92a scenario according to the same model (CGCM2). The result of A2-SRES is similar to IS92a in the case of the air-temperature increase based on the same model CGCM2 (Fig. 2).

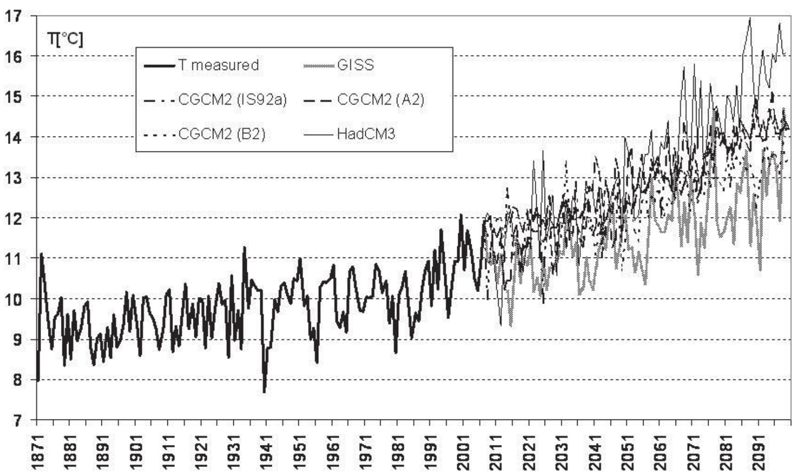
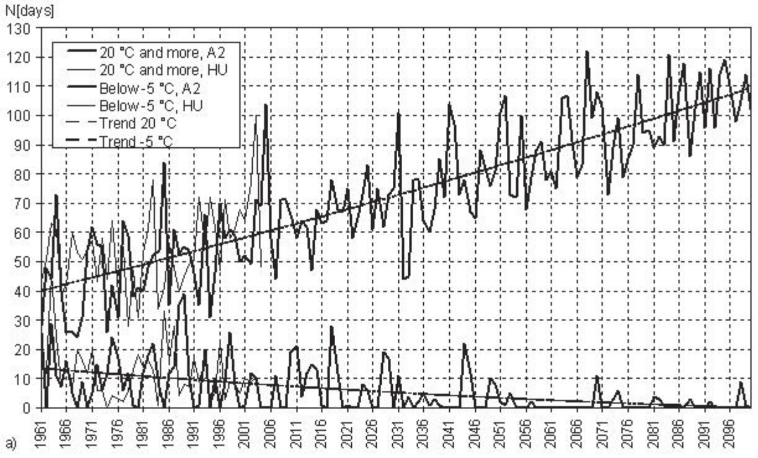


Fig. 2. Annual air temperature means (T) in Hurbanovo measured in 1871–2007 and scenarios based on 5 different GCMs in 2008–2100 (after modification)

The downscaling method was completed by testing the range of mean temperature (T) occurrences, i.e. the number of days within the selected daily temperature means in intervals with a 5°C step. A selection of such elaborations is shown in Figure 3 for T <-5°C and T ≥20°C. With the exception of the relatively good correlation with the statistics of the data measured at Hurbanovo in the period 1961–2005, some change in variability in future periods compared to the past can be noted. The increasing trend in the number of days with T ≥20°C is significant both in the SRES-A2 and SRES-B2 scenarios (around 42 in 1961, 59 in 2001 and 110 or 92 in 2100). On the other hand, the number of days with T <-5°C is significantly decreasing (about 12 in 1961, 8 or 10 in 2001 and nearly zero in 2100).

In the case of precipitation the results obtained by these climate models are rather different (Fig. 4). According to the GISS 1998, HadCM3 and CGCM2 (A2-SRES) models we can expect some decrease in annual precipitation totals at Hurbanovo in the 21st century, while the CGCM2 (B2-SRES) and CGCM2 (IS92a) model outputs suggest there may be an increase. It needs to be stressed that slightly different precipitation scenarios are projected for northern Slovakia. There we expect a general increase in the annual precipitation totals, more in the winter totals – up to a 30% rise compared to the 1901–1990 long-term average totals. According to the results shown in Figure 5, the projected precipitation scenarios for central Slovakia show a decrease in the summer monthly totals by about 2% to 16% and an increase in the winter monthly totals by about 10% to 27% in the period 2061–2090 in comparison with 1951–1980. These results are similar to the IPCC (2007) findings. Annual precipitation is very likely to increase in most of northern Europe and to decrease in most of the Mediterranean area in the 21st century. In Central Europe, precipitation is likely to increase in the winter but decrease in the summer (IPCC 2007). On the other hand the monthly temperature scenarios for central Slovakia show a general increase all year round (Fig. 5).

Climate scenarios for Slovakia based on GCM downscaling and statistical modification are in general agreement with the current European climate change results based on the regional modeling efforts in the PRUDENCE project. The primary objectives of this project, which involved 21 European research institutes and universities, are to provide high resolution (50 km x 50 km) climate change scenarios for Europe for the period 2071–2100 using the dynamic downscaling methods with regional climate models and to ex-



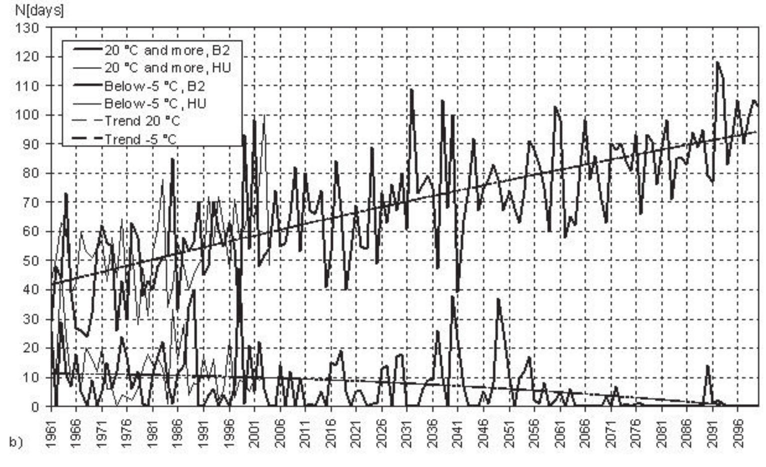


Fig. 3. Trend of number of days with mean air temperature T< -5°C – lower line and T ≥20°C – upper line based on the CGCM2 (CCCM2000) and SRES-A2 (upper Figure 3a) and SRES-B2 (lower Fig. 3b) downscaling in 1961–2100 and comparison with statistics of temperatures measured at Hurbanovo in 1961–2005 (thin lines); CGCM2 (CCCM2000) output modified by 11-day running means at variability

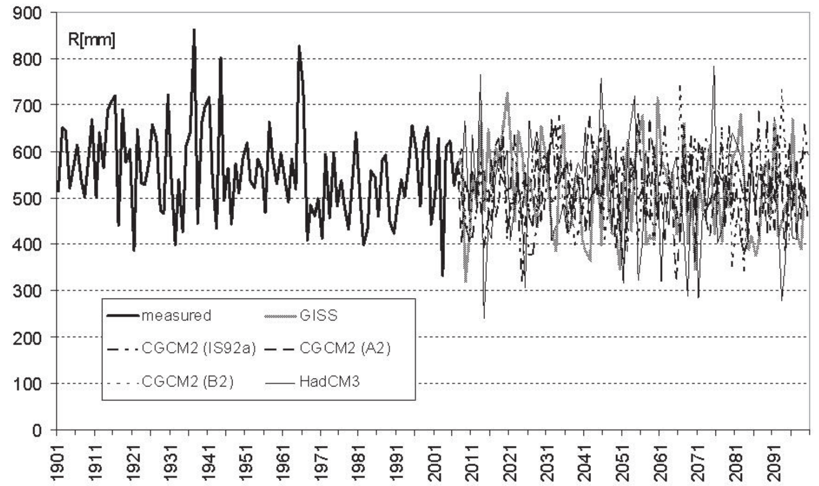


Fig. 4. Annual precipitation totals (R) at Hurbanovo measured in the period 1901–2007 and scenarios based on 5 different GCMs in the period 2008–2100 (after modification)

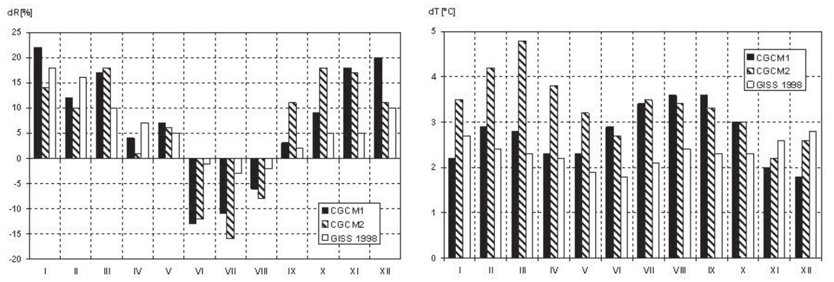


Fig. 5. Annual course of scenarios for monthly precipitation totals (left) and monthly air temperature means (right) for central Slovakia in the period 2061–2090 compared to the period 1951–1980 according to three GCMs (CGCM1 (IS92a), CGCM2 (IS92a) and GISS 1998)

plore the uncertainty in these projections. The results of the project suggest that, in the case of temperature, a warming trend is evident for the whole Central European region.

Based on the different regional climate model results of the PRUDENCE project, expected climate change estimations for the Carpathian basin and especially for Hungary are summarized and discussed for the 2071–2100 period in Bartholy et al. (2007). For all four seasons and for both emission scenarios (A2-SRES and B2-SRES), the expected warming by 2071–2100 in Hungary is between 2.5°C and 4.8°C. The largest temperature increase is projected for the summer (4.8°C (A2-SRES) and 4.0°C (B2-SRES)) while the lowest seasonal warming is expected in the spring (3.1°C (A2-SRES) and 2.5°C (B2-SRES)). The expected change in annual precipitation totals in this region is not significant. However, significantly large and opposite trends are expected in different seasons. The seasonal precipitation total is very likely to increase in the winter, while it is expected to decrease in the summer.

Conclusion

The climate change scenarios projected in Slovakia are based mainly on global climatic model outputs. Climate models are generally considered to be the best tools for assessing the response of the climate system to changes in radiative forcing. It is known that the GCM-based scenarios of some important climatic elements are not very reliable (particularly unreliable are the scenarios for evaporation, relative humidity, runoff, snow cover, extreme weather events etc.). Therefore, our team is investigating the design of combined GCM-analogue scenarios. These scenarios combine both the good quality of mean air temperature, precipitation, solar radiation and specific humidity scenarios based on the GCM outputs on one hand, and the physically plausible relations among other climatic characteristics on the other. Regional climate change scenarios for Slovakia are usually based on monthly GCM outputs (air temperature and precipitation totals) and on historical analogues (statistical structure of the data series, extreme weather events, and other elements). Scenarios based on three applied GCMs show the additional warming in this territory by the end of the 21^{st} century to be roughly from 2 to 4°C in 2071–2100 compared to the 1951–1980 norm. These scenarios have been applied in many impact studies in Slovakia in several socio-economic sectors since 1993 (e.g. Siska and Malis 1997; Szolgay et al. 2002; Skvarenina et al. 2004; Pekarova and Szolgay 2005; Hlavcova et al. 2006).

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