Detection of climatic trends and variability at Hurbanovo

M. Melo, M. Lapin and I. Damborská

Department of Astronomy, Physics of the Earth and Meteorology, Comenius University, Bratislava, Slovak Republic
(e-mail: melo@fmph.uniba.sk, lapin@fmph.uniba.sk, damborska@fmph.uniba.sk)

Abstract The global climate becomes warmer recently. In this contribution the tendency of climate regime change in the region of the Danubian lowland in Slovakia is studied. In the first part of this paper the detection of climatic trends and variability at the Hurbanovo Observatory in 1871-2006 is analyzed and in the second one the climate scenarios for the 21st century are outlined. These scenarios are based on the global climatic General Circulation Models outputs.

Key words: *climatic trends, air temperature, precipitation total, climate change, climate models, climate scenarios*

1. Introduction

Climatic conditions are non-stationary. The climate has varied on many time scales in history. Many processes have impacts on the climate system. During the last two-three centuries also human action has had an impact on that climate. Climatic change on local and global scales has become a reality. The aim of this contribution is to detect observed variability and changes in the Danubian region in Slovakia in the twentieth century and to outline projected future trends in the twenty-first century. The Hurbanovo Observatory (115 m a.s.l.) is representative site for this region (south-western part of Slovakia) and it ranks among the best meteorological stations in central Europe with sufficiently long and good-quality observations. Previous study about detection of some expected changes in the climatological regime due to climate change was introduced by Lapin (2004).

2. Climatic trends

Air temperature trend is significant at Hurbanovo (Fig. 1). The result showed increase in annual air temperature means by about 1.4°C (according to linear trend) in 1871-2006. Temperature series show increasing trend in all seasons, the greatest one in spring period. The precipitation series (annual precipitation totals) have decreasing trend by about 13% (by linear trend) at Hurbanovo in 1901-2006 (Fig. 2).

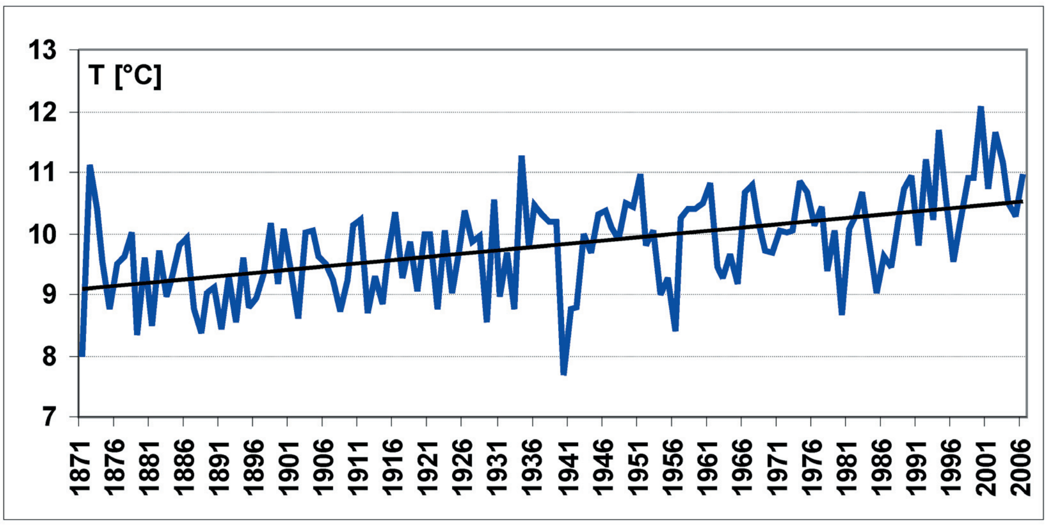

Fig. 1. Annual air temperature means at Hurbanovo in 1871-2006 (with its linear trend).

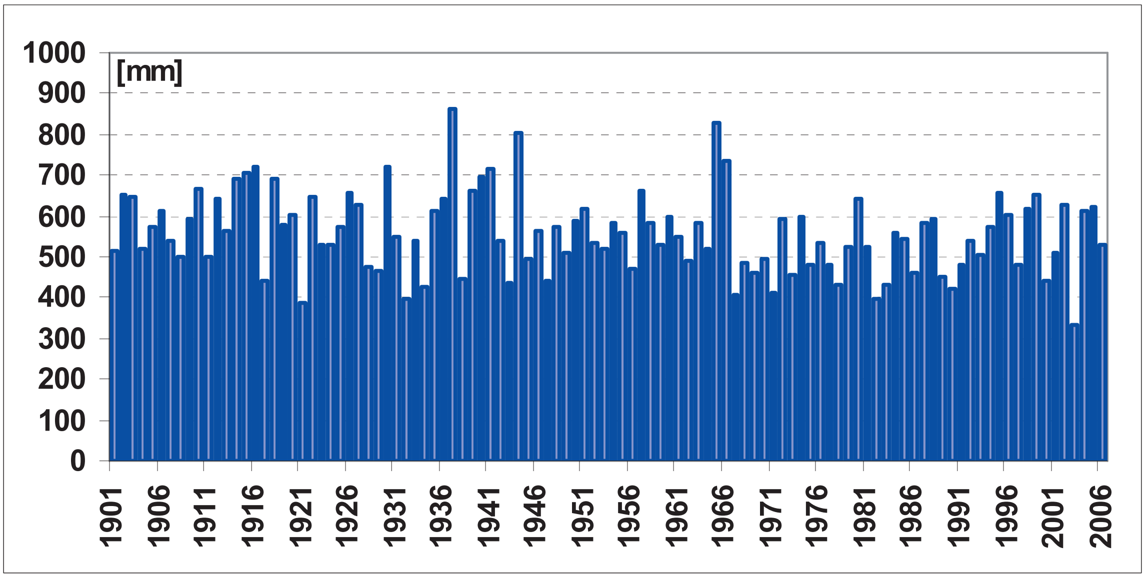

Fig. 2. Annual precipitation totals at Hurbanovo in 1901-2006.

3. Singularities and duration of some typical air temperatures spells

The tendency for a certain type of weather to recur with reasonable regularity around the same date is termed a singularity (Barry and Chorley 2003).
Some of the central European singularities that occur most regularly are as follows (Fig. 3):

- Recurrence of winter in February when cold anticyclonic weather originated from Siberia influences European climates and this anticyclone extends also in our region. Probability of recurrence of winter in Hurbanovo is namely from 5th to 15th of February in 1901-1950 period. In the 1992-2006 this singularity is not so much significant.
- Penetration of cold arctic air from the north of Europe (Scandinavia) to the central Europe is often typical in spring (between 5th and 18th of March). This singularity is less significant in new periods 1951-2000 and 1992-2006. On the contrary in these both periods (1951-2000 and 1992-2006) is more typical penetration of cold arctic air from the northwest of Europe to the central Europe in April (between 4th to 12th of April). In this case the arctic air is very cold only in higher altitudes.
- Air temperature decrease connected together with invasions of westerly maritime air (precipitation occurrence and total increase) over Slovakia takes place in about early mid-June (this period marks the beginning of the European summer monsoon "Medard in Slovakia"). This wet spell ends about middle July. This is the most important singularity in the central European region (probability of occurrence is approximately 90% in all studied periods).
- Around at the end of September and during early October central Europe is affected by an anticyclonic weather spell with typical relative warm and dry weather (late summer "Babie leto in Slovakia"). Particularly relative high values of daily maximal temperatures in this period are reached. Daily air temperature means do not show any important deviation from the optimal curve because in this period there are significant also relative low values of daily minimal temperatures. However, in the newer studied period (1992-2006) a moderate deviation from the optimal curve of daily air temperature means annual course have been reached in comparison to previous periods. These daily air temperature means have reached higher values contrary to low values of daily minimal temperatures. Recently the significance of this singularity increases and at present this singularity (late summer) reaches probability of occurrence comparable with the European summer monsoon.

- In late December (between 20th of December and 5th of January) there is typical a cyclonic type of weather, when Genova depressions (from Genova gulf) frequently move towards the central Europe and partially affect also south of Slovakia. Weather is warmer and wetter during so called "Christmas warming".

We prepared the annual course of air temperature climate scenario based on the Canadian climate model CGCM2 (SRES-A2) for the period 2051-2100 (Fig. 3). According to this scenario we can await increase in daily air temperature during all year round (mean increase about 3.5 °C in 2051-2100 in comparison to 1951-2000), particularly in spring period (increase in March by about 5.2 °C and in April by about 5.3 °C in 2051-2100 in comparison to 1951-2000). The most significant singularity according to these results (CGCM2 model) is that the European summer monsoon ("Medard") will remain in central European region, evident is also the recurrence of winter in February, late summer ("Babie leto") and Christmas warming. Penetrations of cold arctic air from the north and northwest Europe to central Europe will remain typical also according to the CGCM2 model only in April, similar singularity in March is not established in the late 21st century.

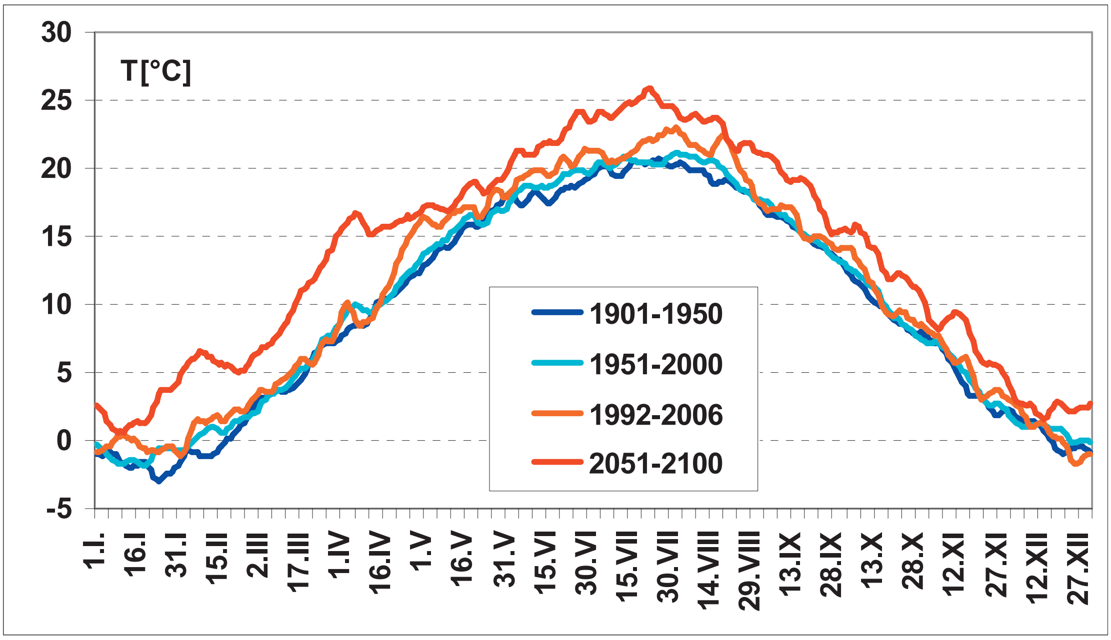

Fig. 3. Annual course of air temperature [°C] (its 5-days simple weighting moving average) at Hurbanovo for periods 1901-1950, 1951-2000, 1992-2006 and the climate scenario based on the CGCM2 (SRES-A2) in 2051-2100.

As the next step we studied duration of some typical air temperatures spells. Particularly spells with duration of air temperatures ≤ 0ºC, ≥ 5ºC, ≥ 10ºC, ≥ 15°C are interesting. These air temperatures have relation mainly to living nature. Spell with air temperatures ≤ 0ºC characterises winter period with freeze, ≥ 5ºC means large vegetation period, ≥ 10ºC means small vegetation period, ≥ 15ºC means pure summer period. We added also the spells with air temperatures ≥ 20°C and ≥ 25°C. We studied date of the beginning and the ending of these spells and also total number of days with these temperatures. These spells are determined on the base of 5-days simple weighting moving average for the next periods: 1901-1950, 1951-2000 and 1992-2006 (Fig. 3). Period 1992-2006 was chosen for its unusually warm character (at Hurbanovo the winters were warmer from 1988 and from 1992 also summers are warmer). We applied two methods at the analysis – selection of all periods and also the longest continuous periods with required temperatures without interruption.

Difference between both used methods is insignificant. Major part of results according to both methods is the same (Tab. 1). Climate at Hurbanovo is warming. Total number of days with positive air temperatures increases, in the meanwhile total number of days with negative temperatures decreases (Fig. 3, Tab. 1). Although differences among particular studied periods in case of total number of days with air temperatures ≥ 5 ºC and ≥ 10 ºC are no significant, on the contrary the most significant differences have been reached in case of total number of days with low (≤ 0 ºC) and high values of air temperatures (≥ 15°C and ≥ 20°C). Even we can state that longer continuous lasting periods with air temperatures lower or equal than 0 ºC not exist at present. In the period 1992 –2006 we ascertain only two shorter periods approximately with the same value of duration. In this case we propose to change this method. In the future we can consider total number of days with air temperatures lower or equal than 5 ºC as a characteristic of winter spell in the Slovak lowlands. Significant increase of total number of days with air temperature higher or equal than 15 °C and 20 °C is recognized. In case of total number of days with T ≥ 15 °C this increase is about 20 days and in case of T ≥ 20 °C this increase is even more than 40 days between periods 1901-1950 and 1992-2006.

Climate scenarios of air temperature for period 2051-2100 on the base of the CGCM2 (SRES-A2) model have been prepared. According to these scenario results the spells with air temperatures ≤ 0 ºC (winter period with freeze) already will not exist at Hurbanovo at the end of the 21st century. On the contrary in the Danubian lowland we can await appearance of new temperature characteristic – spells with T ≥ 25 °C (Fig. 3, Tab. 1).

Tab. 1: Duration (date of the beginning and the ending and total number of days) of some typical air temperatures spells (T ≤ 0 ºC, T ≥ 5 ºC, T ≥ 10 ºC, T ≥ 15 °C, T ≥ 20 ºC, T ≥ 25 ºC) at Hurbanovo in periods 1901-1950, 1951-2000, 1992-2006 and climate scenario based on the CGCM2 (SRES-A2) model for period 2051-2100. (A means the longest continuous lasting periods and B means total periods with required temperatures).

		1901-1950		**1951-2000**		**1992-2006**		**2051-2100**	
		from - to	**days**	**from - to**	**days**	**from - to**	**days**	**from – to**	**days**
≤ 0º	A	17.12.-17.2.	63	30.12.-6.2.	39	21.12.-7.1. 16.1.-4.2.	18 20	-	0
	B	17.12.-17.2.	63	24.12.-6.2.	42	21.12.-4.2.	38	-	0
≥ 5º	A	19.3.-12.11.	239	16.3.-15.11.	245	14.3.-17.11.	249	1.2.-29.11.	302
	B	19.3.-12.11.	239	16.3.-15.11.	245	14.3.-17.11.	249	1.2.-29.11.	302
≥ 10º	A	14.4.-14.10.	184	15.4.-16.10.	185	15.4.-16.10.	185	15.3.-31.10.	231
	B	14.4.-14.10.	184	6.4.-16.10.	186	3.4.-16.10.	186	15.3.-31.10.	231
≥ 15º	A	14.5.-17.9.	127	10.5.-18.9.	132	26.4.-17.9.	145	30.3.-9.10.	164
	B	14.5.-17.9.	127	10.5.-18.9.	132	26.4.-22.9.	147	30.3.-9.10.	164
≥ 20º	A	15.7.-5.8.	22	2.7.-18.8.	48	19.6.-24.8.	67	1.6.- 8.9.	100
	B	5.7.-5.8.	25	2.7.-18.8.	48	19.6.-24.8.	67	1.6.- 8.9.	100
≥ 25º	A	-	0	-	0	-	0	18.7.-26.7.	9
	B	-	0	-	0	-	0	18.7.-26.7.	9

4. Changes in daily climatic data frequency distribution after 1950 and climate scenarios up to 2100

Climate change detection in Slovakia using daily data frequency distribution analysis was analyzed by Lapin (2004). The IPCC (2001) presented four dominant types of possible change in precipitation and air temperature frequency distribution change (Fig. 4).

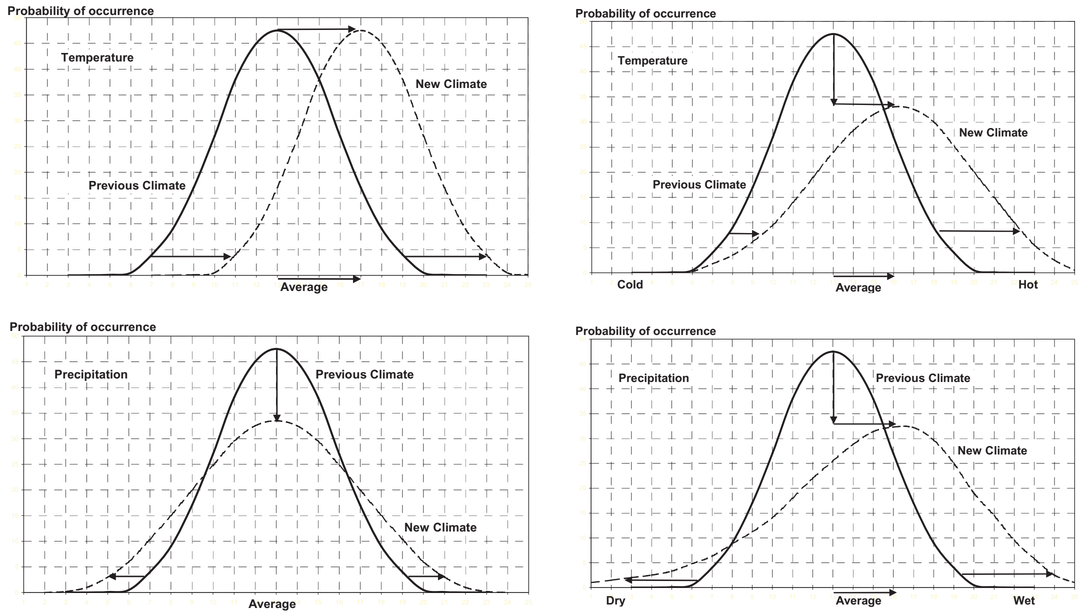

Fig. 4. Possible changes in mean and variability of air temperature (top) and precipitation totals (bottom) – modified according to IPCC (2001).

Frequency distribution of daily mean normalised temperatures T_N for Hurbanovo (for the April – August season) in 1991-2004 and climate scenarios in 2051-2080 and 2071-2100 based on the CGCM2 (SRES-A2) model outputs (modified for Hurbanovo) are outlined in the Fig. 5. A linear shift to higher air temperatures values by about 3-4 °C without any change of variability is the most probable up to the year 2100. Up to present, scenarios of precipitation regime change indicate only small changes in precipitation long-terms means, increase in precipitation variability is very probable.

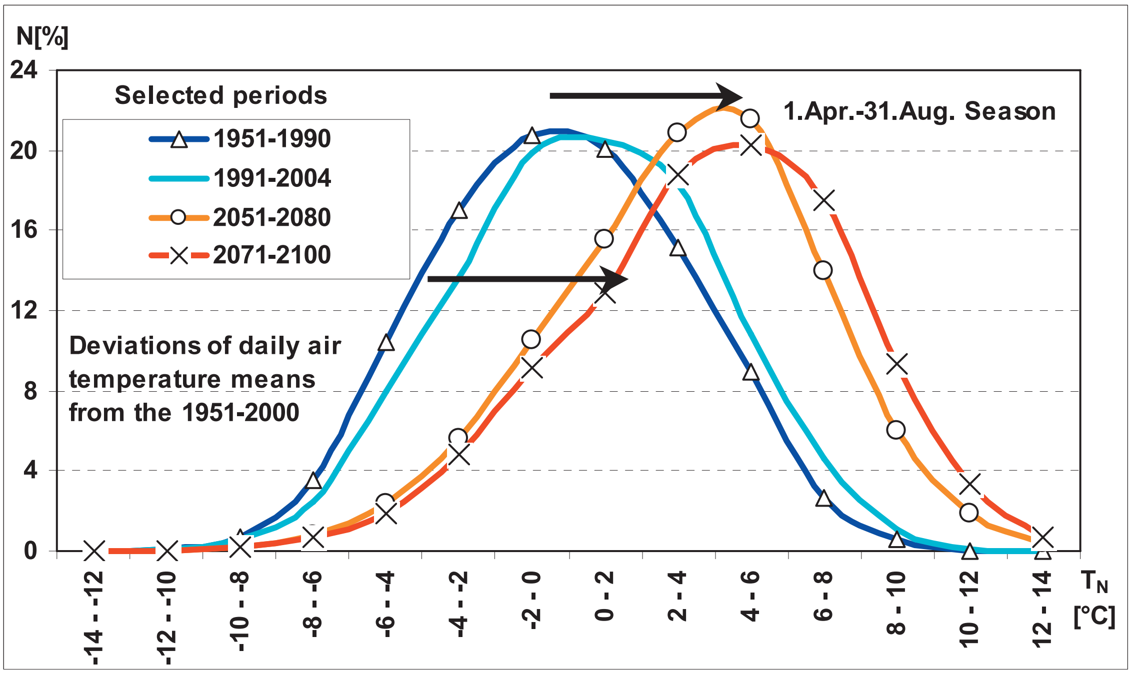

Fig. 5. Frequency distribution of daily mean normalised temperatures T_N for Hurbanovo in 1991-2004 and climate scenarios in 2051-2100 based on CGCM2 (SRES-A2) model outputs.

5. Konček's moisture index

Konček's moisture index is important climatic characteristic. Its value is calculated by this formula:

$$Iz = 0{,}5.R + r - 10.T - (30+v)$$

where R [mm] – means precipitation total in the vegetation period (Apr.-Sep),
r [mm] – precipitation total exceeded in average 105 mm for winter (Dec.-Feb.),
T [°C] - mean air temperature in the vegetation period,
v [$m.s^{-1}$] – mean wind speed measured at 14 h in the vegetation period.

Value Iz > 120 means very moist region, Iz = 60-120 means moist region, Iz = 0-60 means moderately moist region, Iz = -20-0 means moderately dry region, Iz = -40 - -20 means dry region, Iz < -40 means very dry region.

On the base of these values (Konček's moisture index) together with some air temperature characteristics climatic regions in Slovakia were elaborated (Konček 1980, Lapin et al. 2002). Three regions are divided by this method (warm, moderately warm and cool regions). Warm region has 50 or more so called summer days annually in average (with daily maximum air temperature ≥25 °C), moderately warm region has less than 50 summer days annually in average (with daily maximum air temperature ≥25 °C) and the July mean temperature is 16 °C or more. Cool region has the July mean temperature < 16 °C. Warm region has 7 subregions (differences are in values of January air temperature and in values of Iz. Moderately warm region has 7 subregions (differences are in values of January and July air temperatures and in values of Iz). Cool region has 3 subregions (all three subregions are considered as very humid (differences are in July temperature) (more in Lapin et al. 2002).

Tab. 2: Values of Konček's moisture index Iz for different periods (1901-1950, 1931-1960, 1951-1980, 1961-1990 and 1991-2006) and climate scenario on the base of the CGCM2 (SRES-A2) model for 2051-2100 at Hurbanovo.

Periods	1901-1950	1931-1960	1951-1980	1961-1990	1991-2006	2051-2100
I_z	-22.9	-29.6	-37.3	-46.8	-48.9	-105.3

Calculations for different periods at Hurbanovo have been carried out using measured and model data. Precipitation totals decrease and air temperature increase cause growth of aridization in landscape. We can state that aridization trends appear in the Danubian lowland in the whole 20th century (values of Iz decrease continuously in the 20th century) (Tab. 2). Even new climatic subregion arose in the Danubian lowland in 1961-1990. In 1901-1950 (Iz = -22.9) likewise in 1931-1960 (Iz = -29.6) was typical for this region warm and dry climate (warm region and dry subregion) (Konček 1980). Boundary value Iz = -40 was adjusted in the period 1961-1990 (Iz = -46.8) and from this time in the Danubian lowland we have warm and very dry climate (warm region and very dry subregion) (Lapin et al. 2002). Also other shifts of climatic regions and subregions were registered in Slovakia in the 20th century (Konček 1980, Lapin et al. 2002). In the period 1991-2006 the value of Iz is –48.9 (especially because of higher mean air temperature; precipitation total is slightly higher in this period as well). This value does not give a completely true picture on real climate in the Danubian lowland in the recent years because of precipitation distribution changed during the year. Annual precipitation total is similar to previous periods but we have less number of days with precipitation on the one hand and precipitation intensity is higher on the other hand. Major part of precipitation runoffs and so less influences the soil moisture in this region. Konček's moisture index is appropriate to modify according to this reality in the future. In 2051-2100 the approximate value (climate scenario) of Iz = -105.3 according to the CGCM2 (SRES-A2) model (especially because of higher mean air temperature and lower values of precipitation total in the vegetation period (IV-IX) in the 21st century by model). It means this region will be still more aride.

6. Appearance of new species in the Danubian lowland as an indicator of the aridization trends

The effects of the twentieth-century climate change affect on all landscape components. Responses are different in timescales, firstly responds fauna and afterwards vegetation. However, species migrate only slowly. For instance surveys of plant species on peaks in the European Alps indicate an upward migration of alpine plants by 1 to 4 m per decade during the twentieth century (Barry and Chorley 2003). Is there any evidence of changing Danubian climate in its fauna or vegetation structure?

The best indicator of the climate change is appearance of new species in the study locality. Halgoš and Bulánková (2001) describe the influence of climatic changes on the structure of zoocenoses in aquatic and terrestric ecosystem. In terrestric ecosystem climatic changes manifestate in penetration of thermophilous and invasive species such as Anodonta woodiana (Mollusca, Bivalvia), Crocothemis erythraea (Insecta, Odonata), Diuraphis noxia (Insecta, Homoptera), Cameraria ohridella (Insecta, Lepidoptera), Neogobius kessleri (Pisces, Gobiidae).

Recently we are the observers of animal spreading originate from the Mediterranean to the Central Europe. Aphid Diuraphis noxia spreads out towards north to Central and Eastern Europe. First record of this species in Slovakia was found in 2000 and in 2001, this aphid already belongs to the dominant species of corn pests (Halgoš and Bulánková 2001).

Bulánková (1999) points out shift of habitat border of some Mediterranean species (dragonfly (Odonata)) to the north (Danubian lowland). Abundance of some rare Mediterranean species (e.g dragonfly Crocothemis erythraea) increases in Danubian lowland.

In consequence of global warming prevalence of new species of mosquito (Anopheles) in south - western Slovakia is observed. Halgoš and Benková (2004) recorded first appearance of Anopheles hyrcanus (Cilicidae, Diptera) in Slovakia (in Danubian lowland). Two years before this species of Anopheles was recorded in surroundings of Balaton lake in Hungary. This mosquito (Anopheles hyrcanus) is able to disseminate malaria in this region. In Slovakia we have now already together six species of mosquito, which can disseminate this disease (malaria) (Halgoš, personal communication 2007).

Last years gradually we appear new species of fishes (Neogobius kessleri) originated from lower part of Danube (Halgoš and Bulánková 2001).

Fedor and Majzlan (2001) studied the selected species of Orthopterous insects in the Danube region (Slovakia). Some xerothermophilous species such as Oecanthus pellucens, Oedipoda caerulescens, Psophus stridulus, Euchorthippus declivus are seemed to be able to indicate aridization trends. On the contrary, presence of several hygrophilous Orthopterous insects, for example Pholidoptera griseoaptera and Omocestus viridulus, refer to a less significant influence of aridization and relatively untouched wetland biotopes of the Danube region. Aridization, which influence onto the Danube region landscape has been already proved, markedly hints at the changes in the Orthopterous insect communities structure. Biomonitoring of the orthopterocoenoses emphasizes a decrease in domination of hygrophilous species that are continuously replaced by xerotermophilous taxones (Fedor and Majzlan 2001).

The first results show that fauna structure in the Danubian lowland gradually begins to change. New species come from the Mediterranean like that climate in the Danubian lowland begins to show some features typical for the Mediterranean region with its warmer days and aridization trends.

7. Climate scenarios

Climatic scenarios are at present based mainly on global climate models outputs. Climate models are the best tools for assessing the response of the climate system to changes in radiative forcing. Climate change experiments have been carried out by e.g. Boer et al. 1992, McFarlane et al. 1992, Murphy and Mitchell 1995, Russell and Rind 1999, Flato and Boer 2001.

In this contribution we prepared climate change scenarios in form of time series of air temperature and precipitation totals for Hurbanovo in the 21st century based on three global climate model outputs. Model data from the next three different global coupled (atmosphere-ocean) general circulation models (GCMs) have been utilized:

- 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).

Present horizontal resolution of the GCMs does not allow make out some regional climate features. Two principally different approaches have been applied for solution of this problem: statistical methods (statistical downscaling) and dynamical methods (dynamical downscaling) that use a detailed regional meteorological model nested into the global model system. Statistical downscaling consists from development of statistical relationships between locally observed climate variables and outputs of global GCM experiments. A set of statistical downscaling techniques has been developed up to present (IPCC, 2001). Also in this contribution statistical downscaling is used. Statistical method for downscaling of global GCMs outputs to the regional level is applied.

7.1. Model data

The temperature and precipitation time series of Slovak station Hurbanovo for 1871-2006 (data from the Slovak Hydrometeorological Institute) and data from the next three global GCMs (GISS 1998, CGCM2, HadCM3) are utilized.

Coupled atmosphere-ocean model GISS 1998 from the NASA / Goddard Institute for Space Studies in New York was developed for climate studies in 1998 (for 1990-2099 period). C085 is control simulation with constant 1989 atmospheric composition, C086 is compounded 1% CO_2 increase experiment and C087 is compounded 1% CO_2 with tropospheric sulfate aerosol changes. We used C085 and C087 simulations here. This model has 4° x 5° horizontal resolution with 9 vertical layers for the atmosphere and 13 layers for the ocean (Russell and Rind, 1999). We took into account the model outputs from 4 gridpoints near to Slovakia (gridpoint 1 – 46° N, 17,5° E, 361 m a.s.l., gridpoint 2 – 46 °N, 22,5° E, 386 m a.s.l., gridpoint 3 – 50° N, 17,5° E, 366 m a.s.l. and gridpoint 4 – 50° N, 22,5° E, 345 m a.s.l.).

CGCM2 is the second version of the Canadian Centre for Climate Modelling and Analysis coupled global climate model. Model was developed in 2000. This model is based on the earlier CGCM1, but with some improvements (Flato and Boer, 2001). CGCM2 has been used to produce ensemble climate change projections (for period 1900-2100) using the older IS92a forcing scenario, as well as the newer IPCC SRES A2 and B2 scenarios. For the regional downscaling the CGCM2 outputs of 6 gridpoints near to Slovakia were selected: gridpoint 1 – 46,39° N; 15,00° E; 597 m a.s.l., gridpoint 2 – 49,39° N; 18,75° E; 616 m a.s.l., gridpoint 3 – 46,39° N; 22,50° E; 554 m a.s.l., gridpoint 4 – 50,10° N; 15,00° E; 442 m a.s.l., gridpoint 5 – 50,10° N; 18,75° E; 531 m a.s.l., gridpoint 6 – 50,10° N; 22,50° E, 566 m a.s.l..

HadCM3 is a coupled atmosphere - ocean model from the Met Office Hadley Centre in Exeter, UK. This model was developed in 1998. Atmosphere part of this GCM has 19 vertical layers and horizontal resolution 2,5° x 3,75°, oceanic GCM has 20 vertical layers and horizontal resolution 1,25° x 1,25°. We took into account model outputs from 6 gridpoints near to Slovakia (gridpoint 1 – 50°N, 15°E, 734 m a.s.l.; gridpoint 2 – 50°N, 18.75°E, 218 m a.s.l.; gridpoint 3 – 50°N, 22.5°E 371 m a.s.l.; gridpoint 4 – 47.5°N,15°E 371 m a.s.l.; gridpoint 5 – 47.5°N, 18.75°E 394 m a.s.l.; gridpoint 6 – 47.5°N, 22.5°E, 418 m a.s.l.) for the period 1950-2099.

Topography in central Europe is very smooth in all these models. The Alps and the Carpathians are presented in these GCMs as one flat hill in, without the Danubian hollow in Panonia. The values in individual gridpoints represent some areal mean values. Outputs of these models have been used to elaborate climate scenarios for the climate of strengthened greenhouse effect on the territory of south - western Slovakia in the 21st century.

Firstly the interpolation from the GCMs gridpoints data near to Slovakia to the locality of Hurbanovo (the weights with respect to the distance from this locality) was used. Downscaling of the model outputs for selected locality (Hurbanovo) was realized by use of 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 case of air temperature, variation coefficients in case of precipitation amount) are then in relatively good accordance with the observed data series. Supposing only insignificant changes in the transforming relation between measured and modeled data we can similarly modify the model outputs also in the close future (up to the year 2100). This method was applied in Lapin and Melo 1999, Lapin et al. 2001a, Lapin et al. 2001b, Lapin and Melo 2004, Melo 2005, Melo 2007.

7.2. Model results

In 1871-2006 we have achieved moderate air temperature increase (annual mean) in Hurbanovo (according to linear trend about 1.4 °C in this period). Firstly we compared real (measured) annual air temperature means at Hurbanovo in 1901-2006 and modeled annual air temperature means according to three different GCMs in the same locality in the 20th and 21st centuries (without modification). Means and variability among the GCMs outputs and measured data are different. Modification of means and variability of these GCMs outputs is needed according to the standard deviation (variation coefficients in case of precipitation) obtained from the measured series. The result in form of air temperature scenarios for the 21st century can be seen in Fig. 6. On the base of all studied GCMs outputs we can state that climate at Hurbanovo will continue in increase also in the 21st century. Temperature growth according to the model GISS 1998 is characterized by the lowest values. On the contrary the most expressive air temperature increase on this territory is projected by the model HadCM3. Temperature increase resulted by new B2-SRES emission scenario is smaller than the result with older IS92a one according the same model (CGCM2). Result of A2-SRES is similar to IS92a in case of air temperature increase based on the same model CGCM2.

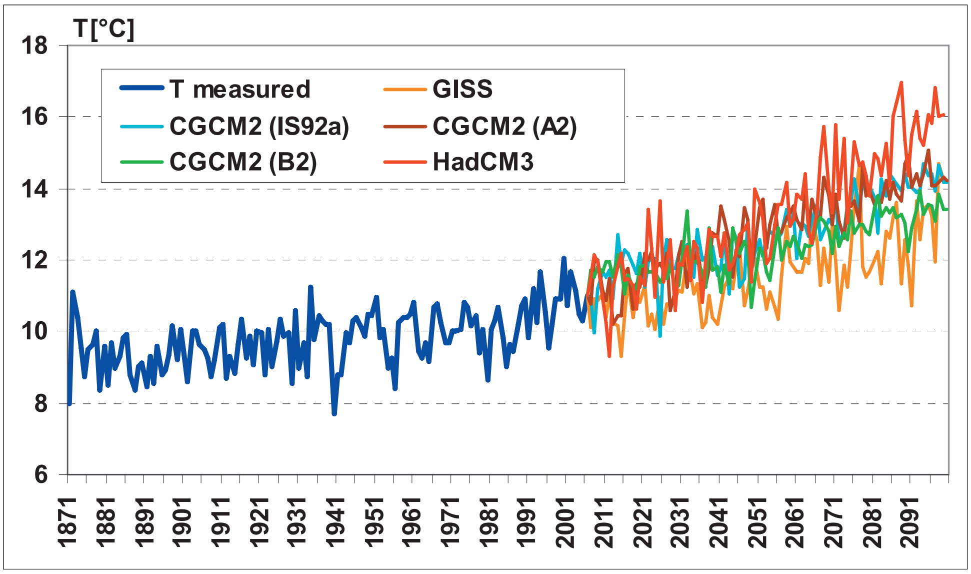

Fig. 6. Annual air temperature means [°C] in Hurbanovo – measured in 1871-2006 and scenarios based on different GCMs in 2007-2100 (after modification).

Precipitation trend at Hurbanovo in 1901-2006 shows 13% decrease (by linear trend). Atmospheric precipitation scenarios according to three GCMs after modification (means and variability) can be seen in Fig. 7. The results obtained by these climate models (in case of precipitation) are rather different. In the 21st century we can await decrease in annual precipitation totals at Hurbanovo according to next models: GISS 1998, HadCM3, CGCM2 (A2-SRES), and some increase in annual precipitation total at Hurbanovo according to the CGCM2 (B2-SRES) and CGCM2 (IS92a).

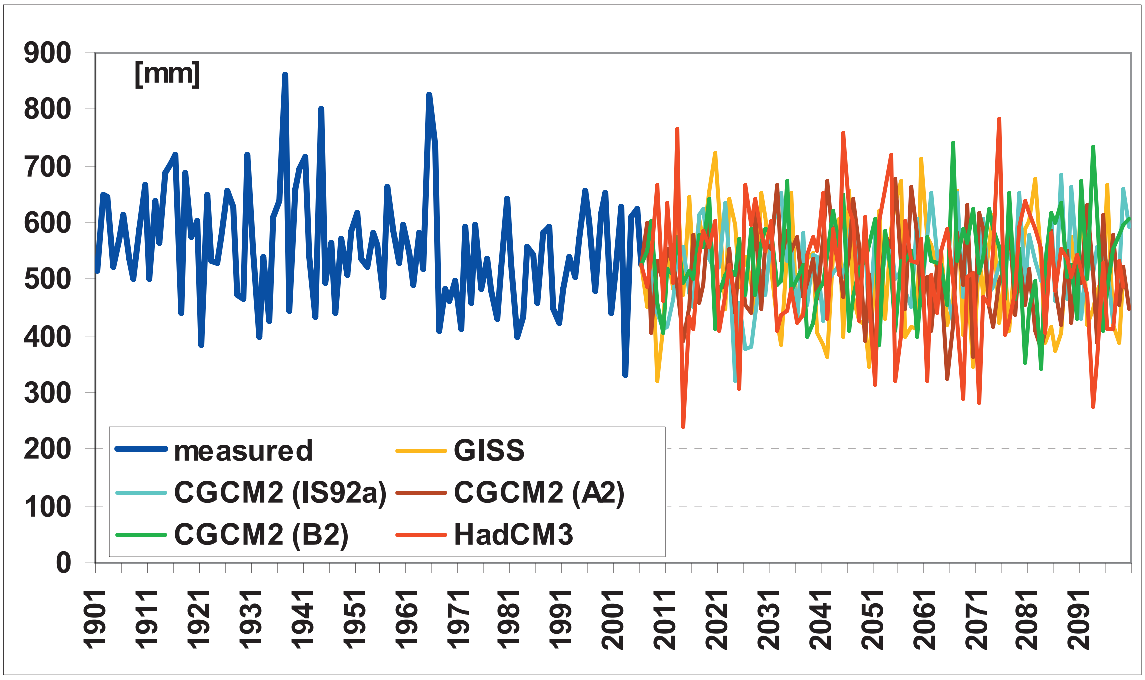

Fig. 7. Annual precipitation total [mm] at Hurbanovo – measured in 1901-2006 and scenarios based on different GCMs in 2007-2100 (after modification).

8. Conclusion

Climate is changing in the central European region. At present we do not know exactly to determine a proportion of human contribution to this climate change. Certainly the climate has become warmer in the Danubian lowland (SW Slovakia) in 1871-2006. Recently (in the warmest 15-years period 1992-2006) this climate begins to show some features typical for the Mediterranean region with its warmer spells and aridization trends. The first records of new species of fauna introduction into the Danubian lowland are a reality. New species come mainly from the Mediterranean to this locality. Scenarios based on three GCMs show additional warming on this territory at the end of the 21st century.

Acknowledgements

The Science and Technology Agency (Slovakia) under contract No. APVT-51-017804 and the Grant Agency of the Slovak Republic under the Project VEGA No. 1/4033/07 supported this study. In this contribution model data from the Canadian Centre for Climate Modelling and Analysis in Victoria, B.C., from the Goddard Institute for Space Studies in New York, from the Met Office Hadley Centre in Exeter, UK and measured data from the Slovak Hydrometeorological Institute in Bratislava are used.

References

[1] Barry, R.G., Chorley, R.J. (2003): Atmosphere, weather and climate. Routledge, London and New York, eighth edition, 424p, ISBN 0-415-27171-1.

[2] Boer, G.J., McFarlane, N.A., Lazare, M. (1992): Greenhouse Gas-induced Climate Change Simulated with the CCC Second-Generation General Circulation Model. *J.Climate*, 5, 1045-1077.

[3] Bulánková, E. (1999): Zmeny v druhovom zložení vážok (Odonata) Podunajskej roviny za posledných tridsať rokov. *Entomofauna Carpathica*, 11/1, 1-5.

[4] Fedor, P.J., Majzlan, O. (2001): Orthopterous Insects (Ensifera et Caelifera) as an Indicator of the Aridization Trends in the Danube Region (Slovakia). *National climate programme of the Slovak republic*, 10, VI, 42-53.

[5] Flato, G. M., Boer, G. J. (2001): Warming asymmetry in climate change simulations. *Geophysical Research Letters*, 28, 1, 195-198.

[6] Halgoš, J., Benková (2004): First record of Anopheles hyrcanus (Cilicidae, Diptera) from Slovakia. *Biologia*, Vol.59, Suppl. 15, p.67.

[7] Halgoš, J., Bulánková, E. (2001): The influence of climatic changes on the structure of zoocenoses. *National climate programme of the Slovak republic* 11, VI, 83-87.

[8] IPCC (2001): Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Xiaosu, D. (eds.). *Cambridge Univ. Press*, UK, 944 pp.

[9] Konček, M. (1980): Climatic regions. In: Atlas Slovenskej socialistickej republiky. SAV, Bratislava, map number 42, p.64.

[10] Lapin, M. (2004): Detection of changes in the regime of selected climatological elements at Hurbanovo. Contributions to Geophysics and Geodesy, Vol. 34/2, 169-193.

[11] Lapin, M., Damborská, I., Melo, M. (2001a): Downscaling of GCM outputs for precipitation time series in Slovakia. *Meteorologický časopis*, 4, 3, 29-40.

[12] Lapin, M., Melo, M. (1999): Climatic Changes and Climate Change Scenarios in Slovakia. *Meteorologický časopis*, 2, 4, pp. 5-15.

[13] Lapin, M., Melo, M. (2004): Methods of climate change scenarios projection in Slovakia and selected results. *J. Hydrol. Hydromech.*, 52, 4, 224-238.

[14] Lapin, M., Melo, M., Damborská, I. (2001b): Scenarios of several physically plausible climatic elements. *NKP SR, VI, zv.11/01*. MŽP SR, SHMÚ, Bratislava, 5-30.

[15] Lapin, M., Faško, P., Melo, M., Šťastný, P., Tomlain, J. (2002): Climatic regions. In: Landscape Atlas of the Slovak Republic. Ministry of Environment of the Slovak Republic Bratislava, Slovak Environmental Agency Banská Bystrica, ISBN 80-88833-27-2, map number 27, p.95.

[16] McFarlane, N.A., Boer, G.J., Blanchet, J.-P., Lazare, M. (1992): The Canadian Climate Centre Second-Generation General Circulation Model and Its Equilibrium Climate. *J.Climate*, 5, 1013-1044.

[17] Melo, M. (2005): Warmer periods in the Slovak mountains according to analogue method and coupled GCM. *Croatian Meteorological Journal*, 40, 589-592.

[18] Melo, M. (2007): Regional climatic scenarios for Slovak mountain region based on three global GCMs. *29th International Conference on Alpine Meteorology*, Chambéry, France, 4-8 June, 2007, Extended abstracts, poster sessions – Volume 2, Météo – France, 437-440.

[19] Murphy, J.M., Mitchell, J.F.B. (1995): Transient Response of the Hadley Centre Coupled Ocean-Atmosphere Model to Increasing Carbon Dioxide. Part II: Spatial and Temporal Structure of Response. *J.Climate*, 8, 57-80.

[20] Russell, G.L., Rind, D. (1999): Response to CO_2 Transient Increase in the GISS Coupled Model: Regional Coolings in a Warming Climate. *J. Climate*, 12, 531-539.