SCENARIOS OF AIR HUMIDITY AND POTENTIAL EVAPOTRANSPIRATION CHANGE FOR HURBANOVO

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Abstract

Hurbanovo is the main Meteorological and Climatological Observatory in Slovakia, quite well representing a region of the Danubian lowlands. It lies in southwestern Slovakia (altitude 115 m a.s.l., established in 1871, all time uninterrupted professional observations). The paper presents detail air humidity, actual and potential evapotranspiration development in 1951-2007, including some information on air temperature and air humidity variability. In 2007 the newest Canadian CGCM3.1 model with daily data outputs have been analyzed, the emission scenarios SRES-A2 and B1 were selected. Based on the CGCM3.1 modified outputs for Hurbanovo the scenarios of daily air temperature and daily air humidity in 2001-2100 are presented in the paper as time series and distribution curves. The combined CGCM3.1 based scenarios of potential evapotranspiration are calculated using simple Zubenok formula and saturation deficit (difference between modeled saturated and actual water vapor pressure).

Key words: Climate Change, Evapotranspiration, Soil Moisture, Model Assessments

Introduction

Temperature increase by 1.6 °C and annual precipitation decrease by 24 mm (3.1 %) was registered in Slovakia the period 1881-2007 (based on 3 temperature series and double weighted average method of areal precipitation totals calculation from 203 stations). Details since 1901 can be seen in Fig. 1. On the other hand annual relative air humidity means (based on Hurbanovo data only) decreased by 5% and the April-September season by 6% since 1901 (Fig. 2). Water vapor pressure had insignificant linear trend in 1901-2007 in all year round with some lower values in 1976-1993, mainly in the April-September season (Fig. 3). Significant increase in air temperature and changes in precipitation occurred in Slovakia also during the period 1951-2007, predominantly after 1985.

These changes influenced regime of air humidity, potential and actual evapotranspiration, soil moisture and runoff predominantly in the southern half of Slovakia. For example, potential evapotranspiration sums increased at Hurbanovo by 17,5 % (by 17,7 % in the growing period April-September, Fig. 4). On the other hand, the actual evapotranspiration sums (calculated by modified Budyko method at the Division of Meteorology and Climatology (DMC), Faculty of Mathematics, Physics and Informatics (FMPhI) Comenius University) decreased in the growing period until 1993 by about 20% and then slightly increased (Fig. 5) probably under decreasing soil moisture. The growing period relative air humidity significantly decreased also in 1994-2007 period when water vapor pressure increased by about 1.0 hPa compared to 1976-1993 period. Decrease of relative air humidity (***U***) at Hurbanovo in the spring-summer season 1994-2007 was as follows (compared to 1901-1990 long-term averages): March by 2.4 %, April by 3.7 %, May by 3.3 %, June 4.0 %, July 3.0 % and August 2.0 % (based on the SHMI data at Hurbanovo).

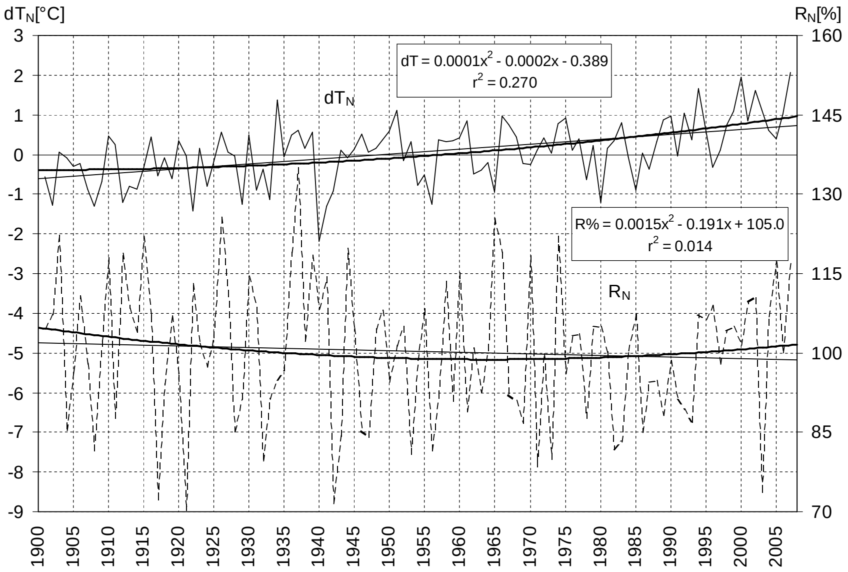

Figure 1: Deviation of annual air temperature means (*dT$_N$*) in Slovakia from 1951-1980 long-term average and % of areal annual precipitation totals (*R$_N$*) in Slovakia from 1901-1990 long-term averages in 1901-2007 (linear and power trends are included, data offered by the SHMI).

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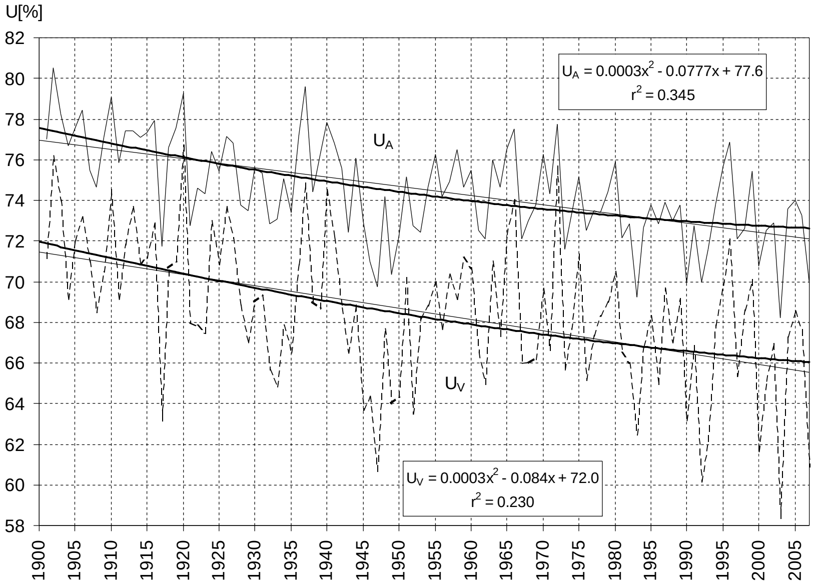

Figure 2: Annual (*U$_A$*) and seasonal (April-September, *U$_V$*) relative air humidity means at Hurbanovo in 2001-2007 (linear and power trends are included, data offered by the SHMI).

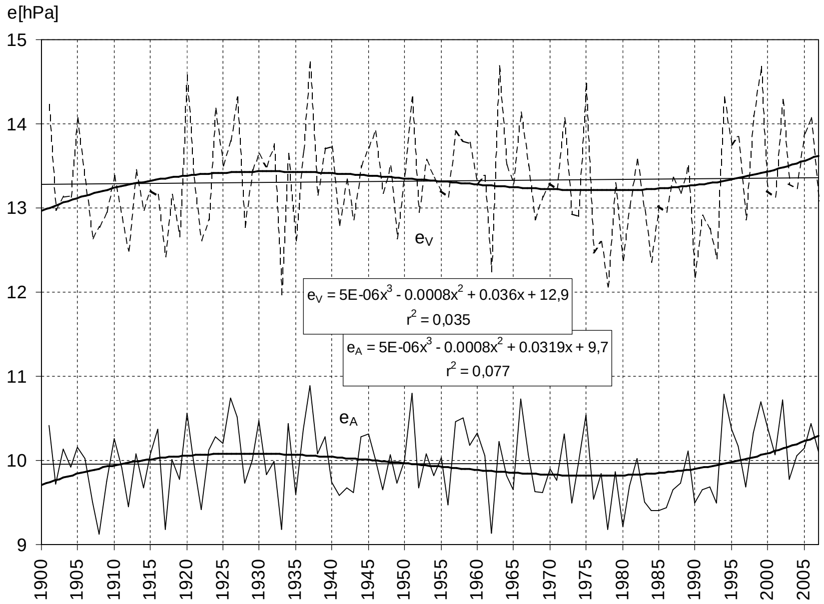

Figure 3: Annual (e_A) and seasonal (April-September, e_V) water vapor pressure means at Hurbanovo in 2001-2007 (linear and cubic trends are included, data offered by the SHMI).

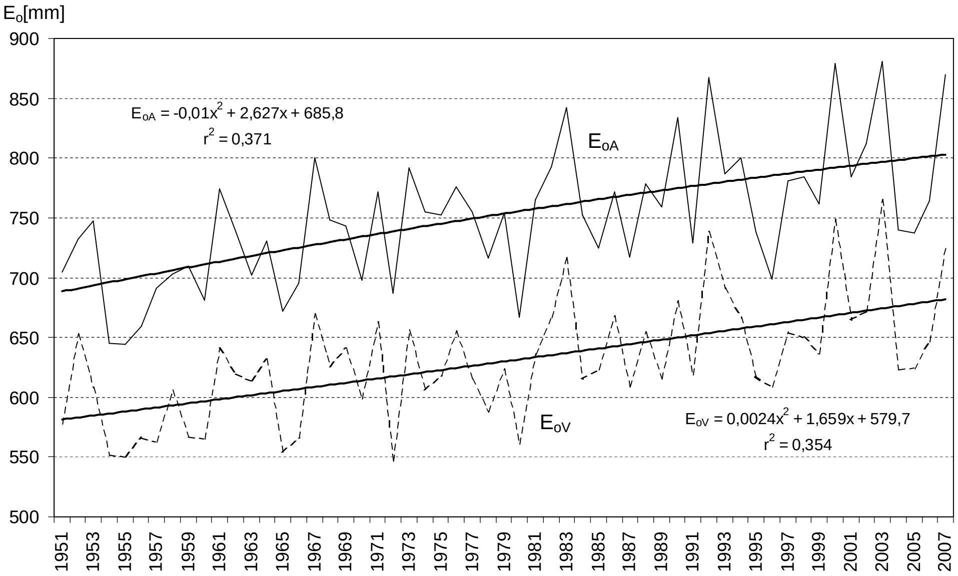

Figure 4: Annual (E_{oA}) and seasonal (April-September, E_{oV}) potential evapotranspiration sums at Hurbanovo in 2001-2007 (power trends are included, basic data offered by the SHMI, calculated by modified Budyko method at the DMC).

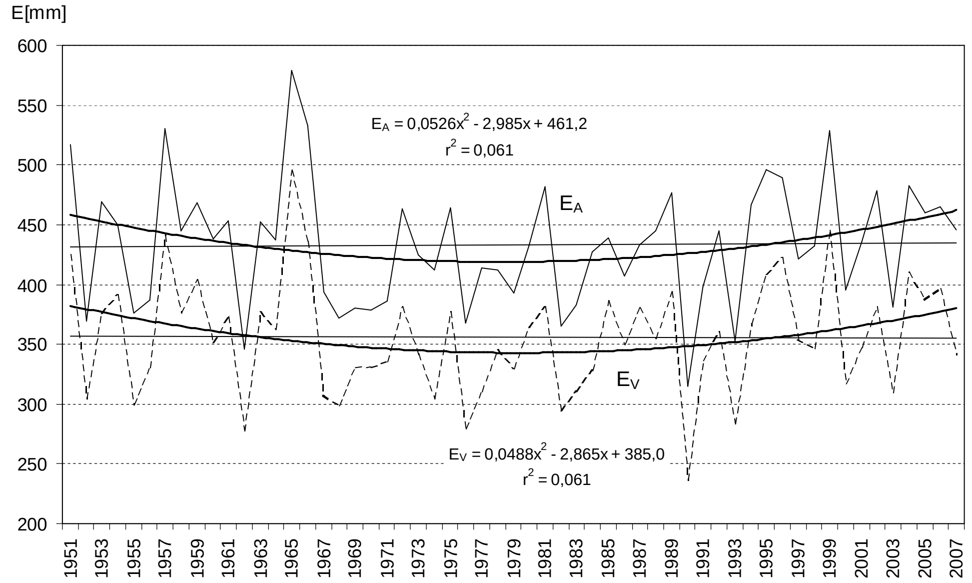

Figure 5: Annual (E_A) and seasonal (April-September, E_V) actual evapotranspiration sums at Hurbanovo in 2001-2007 (linear and power trends are included, basic data offered by the SHMI, calculated by modified Budyko method at the DMC).

These data represent a repetition, or appreciation and widen, of information published in our previous papers (Tomlain 1980, Hrvoľ et al. 2001, Lapin and Tomlain 2001, Lapin 2005). Some authors have stressed also a great importance of possible drought spells occurrence increase due to warming of climate in the next decades (IPCC 1998, 2001, 2007, Lapin 2005 etc.). This assumption is based mainly on the clear physical relation among air temperature, air humidity and precipitation changes resulting in changes of potential and actual evapotranspiration, and finally in changes of soil moisture. Slovakia belongs among countries with complex climate, including very different water balance conditions in the lowlands (mostly in southern Slovakia) and mountains (mostly in northern Slovakia). While for all Slovakia water balance this relation is app. as follows: 65 % of precipitation (R) is evaporated and 35 % of R creates runoff (Lapin and Tomlain 2001, Lapin 2005), the Danubian lowland round Hurbanovo is significant with greater share of evaporation (more than 80 %) compared to runoff (less than 20 %). So any increase in potential evapotranspiration, or any decrease in precipitation is very important in this territory.

2. Data

Hurbanovo is the main Meteorological and Climatological Observatory in Slovakia (belonging to the observation network of the Slovak Hydrometeorological Institute - SHMI), quite well representing a region of the Danubian lowlands not only in Slovakia but also in the significant part of the whole Pannonian Hollow. It lies in southwestern Slovakia (altitude 115 m a.s.l.). This Observatory was established in 1871, important is an uninterrupted professional observation all time since the beginning. For this study the SHMI offered us daily data in the period 1951-2007 and monthly data in the period 1871 (1881)-2007 (air humidity in 1901-2007). To prepare Fig. 1 we used also data from stations Košice (altitude 230 m a.s.l.) in southeastern Slovakia and Liptovský Hrádok (altitude 640 m a.s.l.) in northern Slovakia. More over we used also areal precipitation totals in whole Slovakia calculated by the double weighted averages method from 203 stations (presented data are since 1901, because of better quality). All mentioned data have been tested on homogeneity with positive result (Lapin and Tomlain 2001, Gaál 2006, Peterson 1998).

3. Method

Methods of statistical elaboration of daily and monthly climatological data are obvious. There are many sources of agreed procedures used widely all over the World (WMO Guide No.100 1983 and updates, Nosek 1972 etc.). Trends are significant at the level $\alpha = 95\%$ if the determination coefficient $r^2 > 0.04$ for 100 year series and $r^2 > 0.07$ at 50 year series (approximately only, Nosek 1972).

More sophisticated are the methods for calculation of evapotranspiration components. There are to disposal series of free water surface evaporation measurements by the GGI-3000 evaporimeters since 1969 (Lapin et al. 1987), these data are not fully suitable for water balance evaluation of river basins and agricultural fields. That is why a complex method was developed in Russia (Budyko 1978). This method was adopted and modified for Slovakia (Tomlain 1980, Hrvoľ et al. 2001, Atlas 2002).

Monthly potential evapotranspiration sums ($\boldsymbol{E_o}$) are denoted by the equation of water vapor diffusion in the atmosphere:

$$\boldsymbol{E_o} = \rho\, \mathrm{D}\, (\boldsymbol{s_o}^* - \boldsymbol{s_2}),$$

where ρ is the air density, D - integral diffusion coefficient, $\boldsymbol{s_o}^*$ - saturated specific humidity at the temperature of evaporating surface and $\boldsymbol{s_2}$ - specific humidity in meteorological shelter. The actual evapotranspiration sum ($\boldsymbol{E}$) is supposed to be proportional to the potential evapotranspiration sum ($\boldsymbol{E_o}$) as follows:

$$\mathrm{E} = \mathrm{E_o} \frac{\overline{\mathrm{W}}}{\mathrm{W_o}},$$

the storage $\overline{\mathrm{W}}$ is specified as the moisture stored in the upper soil layer of one m depth, $\boldsymbol{W_o}$ is critical value above which the $\boldsymbol{E}$ equals $\boldsymbol{E_o}$. The average soil moisture $\overline{\mathrm{W}} = (\boldsymbol{W_1} + \boldsymbol{W_2})/2$ is determined from the water balance equation by the method of step-by-step approximation ($\boldsymbol{W_1}$ is the moisture stored in the soil at the beginning of the month and $\boldsymbol{W_2}$ at the end). The $\boldsymbol{W_o}$ usually represents a layer of 100 to 200 mm water with seasonal and regional variations.

Downscaling of outputs from global and regional General Circulation Models (GCMs) is possible by use of two basic methods (Boer et al 2000, IPCC 2007, Lapin et al. 2004) – statistical (some interpolation procedure) and dynamic (regional or local model of atmosphere dynamics). We used statistical approach to modify outputs of the newest Canadian GCM (CGCM3.1) for any site in Slovakia. This procedure was described more in details in Lapin et al. (2001, 2004, 2006ab), only small changes have been made in this method recently.

As it can be seen from Table 2, the spatial resolution of CGCM3.1 grid points is linearly twice more dense than at the previous Canadian models CGCM1 and CGCM2, what results in better areal resolution of outputs. Also the topography complexity is much better, the Pannonian hollow and the Carpathians are clearly distinguished in this GCM (Boer et al. 2000, Lapin et al. 2004). At most of calculations only the nearest 4 grid points have been applied.

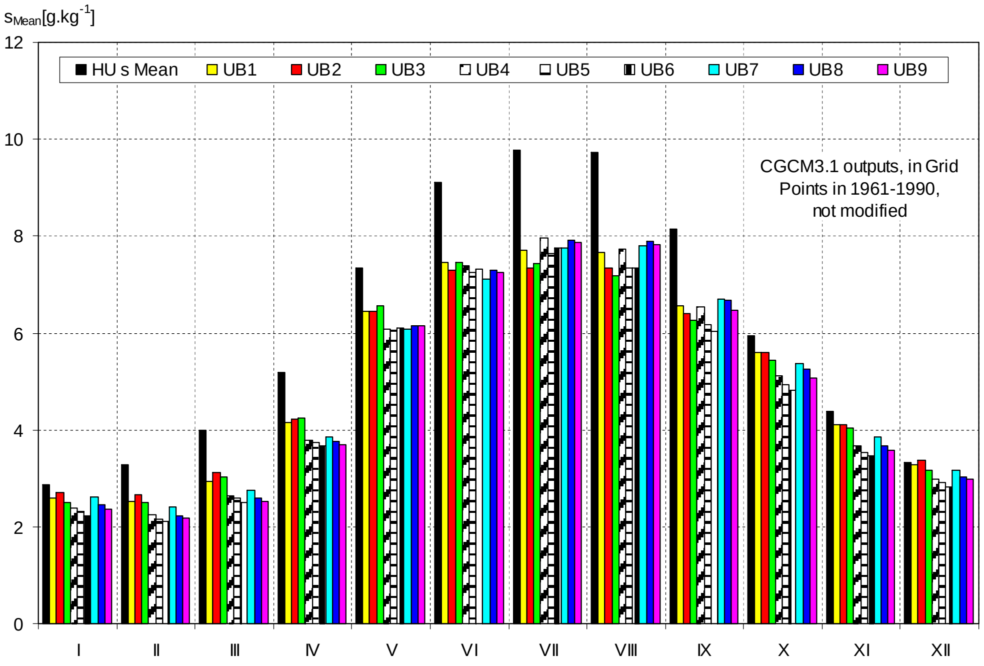

Figure 6. Comparison of monthly mean specific humidity measured at Hurbanovo (HU, black column) and modeled by CGCM3.1 model for the grid points (UB) 1 to 9 (Table 1) in 1961-1990, without any modification of CGCM outputs (UB 5 lies in the centre of Slovakia).

Because of detail evaluation of temperature and precipitation in the CGCM3.1 outputs by Lapin et al. 2006ab, only specific humidity analysis is presented here in Figs. 6 and 7. Especially in season March to July the specific humidity means are significantly lower than those measured at Hurbanovo in 1961-1990. This is caused mainly by two reasons – higher altitude and cooler spring in the CGCM3.1 outputs compared to observed climate. In spite of this the newest Canadian GCM results are much better than the previous ones. This can be seen also in comparison shown in Fig. 7, where very realistic annual course of deviations between southern and northern part of Central Europe is modeled.

Table 1: Geographical location of the grid points at the Canadian model CGCM3.1 in the close surrounding of Slovakia.

UB	Longitude (°)	Latitude (°)	Altitude (m)	Close City
1	16.88	46.04	306.5	Zagreb, Cro.
2	19.69	46.04	239.0	Subotica, Serb.
3	22.50	46.04	483.1	Hunedoara, Rom.
4	16.88	48.84	474.1	Břeclav, CZ
5	19.69	48.84	336.7	Brezno, SR
6	22.50	48.84	463.4	Ubľa, SR
7	16.88	51.62	193.3	Wroclaw, PL
8	19.69	51.62	199.7	Radomsko, PL
9	22.50	51.62	216.4	Lublin, PL

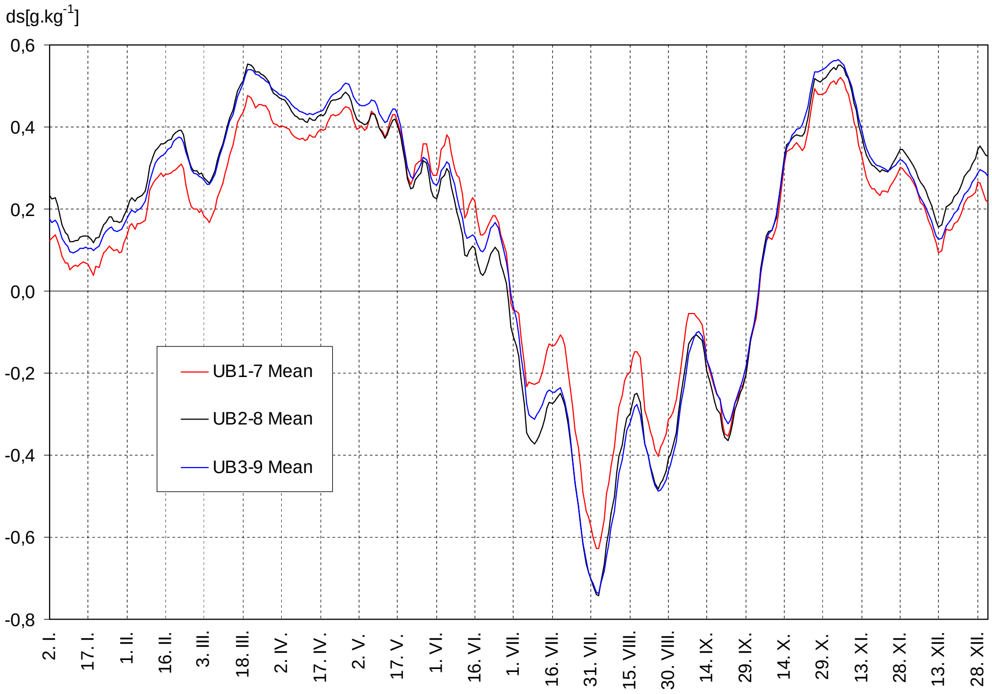

Figure 7. Comparison of daily mean specific humidity modeled by CGCM3.1, deviations (*ds*) of southern grid points (UB) 1, 2 and 3 data and the northern ones UB 7, 8 and 9 (Table 1) in 1961-1990, without any modification of CGCM outputs (smoothed by 15-day running average).

Scenarios of relative air humidity $U = e/e^*$, where e is actual water vapor pressure and e^* is saturated water vapor pressure for given air temperature, are very frequently required by the users. The GCMs outputs contain usually only one air humidity variable – specific humidity (s). This variable is in relation with e according to formula $s = 0.622 \,.\, e/(p - 0.378\, e)$, where p is air pressure for given altitude. This influences also calculation of relative humidity $U' = s/s^*$ is slightly different from $U = e/e^*$.

The accurate formula for calculating of relative humidity is: $U = (s/s^*) \,.\, (0.622 + 0.378 \,.\, s^*)/(0.622 + 0.378\, s)$, where s^* is saturated specific humidity. This quantity can be calculated according to formula: $s^* = 0.622\, e^*/(p - 0.378\, e^*)$, where p is air pressure (we applied 21-day running means of daily averages of measured values from the period of 30 years). Values of saturated water vapor pressure (e^*) can be obtained from the GCMs outputs of air temperature using Magnusson formula.

Then on the base of values of relative humidity and actual water vapor pressure the actual water vapor pressure and saturation deficit d can be calculated ($e = e^* . U$, $d = e^* - e$). Users usually do not need data on specific humidity, or water vapor pressure. They prefer data on relative air humidity, air temperature and saturation deficit for potential evapotranspiration (E_o) calculation by various formulae. We made some steps to evaluate several methods of mentioned variables calculation, also with assessment of possible errors. Details will be published in some of our next papers. Air humidity nonlinearly depends on air temperature and this brings many problems in designing of humidity scenarios. Our aim is to calculate all air humidity characteristics for users as precisely as possible.

Measured daily meteorological data at Hurbanovo in 1961-1990 have been used in the statistical downscaling procedure. This procedure is resulting in the time series of daily data as scenarios for the time frame 2001-2100. Not any value can be considered as forecast for given site and day, but it is considered that the 30-year series describe climatic conditions in selected 30-year periods (mean, extremes and variability). The air temperature scenarios can be applied also for wider area by adding a difference of monthly normals (only insignificant deviation have been recognized among temperature scenarios between the nearest grid points), precipitation scenarios are prepared for each station individually (the deviations among the nearest grid points are quite significant). Air humidity is considered as variable closer to air temperature areal variability than to the precipitation one. More about this problematic can be read in Lapin et al., 2006ab.

4. Results

The project solved in the DMC brought a huge amount of results, so only selected number of it are listed here. Firstly some changes in the humidity distribution curves can be expressed briefly in Fig. 8 showing the shift of patterns in the recent periods. Distribution of normalized daily relative humidity averages ($\boldsymbol{U_N}$, deviation from the normal 1961-1990) has shifted in the season April-August significantly to lower $\boldsymbol{U_N}$ (in fact lower $\boldsymbol{U}$) values, mainly in the last 8-year period 2000-2007.

Outputs of the CGCM3.1 model contain results by SRES A2 and SRES B1 emission scenarios assessments. The first one represent pessimistic supposition of mankind behavior up to 2100 and the second the optimistic one (IPCC 2000). Emission of CO_2 is supposed as 28.9 Gt by SRES A2 (cumulative 1773 Gt) and 5.2 Gt by SRES B1 (cumulative 989 Gt) in 2100. This difference is much more expressed in air temperature scenarios after 2040 (Fig. 10).

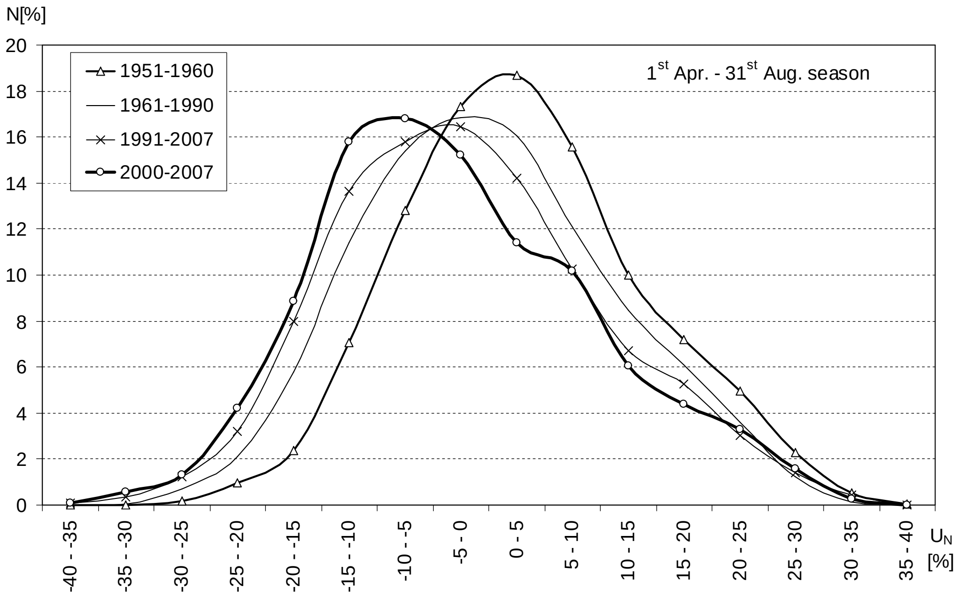

Figure 8. Comparison of normalized mean daily relative air humidity distribution curves at Hurbanovo (deviations of *U* from 1961-1990 long term averages, in 1951-1960, 1961-1990, 1991-2007, 2000-2007), a shift to lower *U* values is clearly seen (data offered by the SHMI).

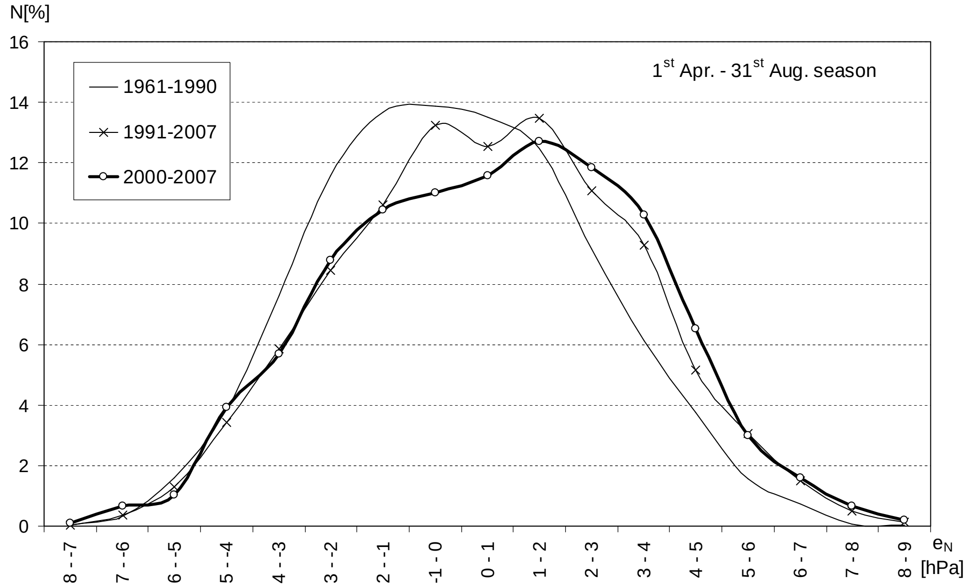

Figure 9. Comparison of normalized mean daily water vapor pressure distribution curves at Hurbanovo (deviations of *e* from 1961-1990 long term averages, in 1961-1990, 1991-2007, 2000-2007), a shift to higher *e* values is clearly seen (data offered by the SHMI).

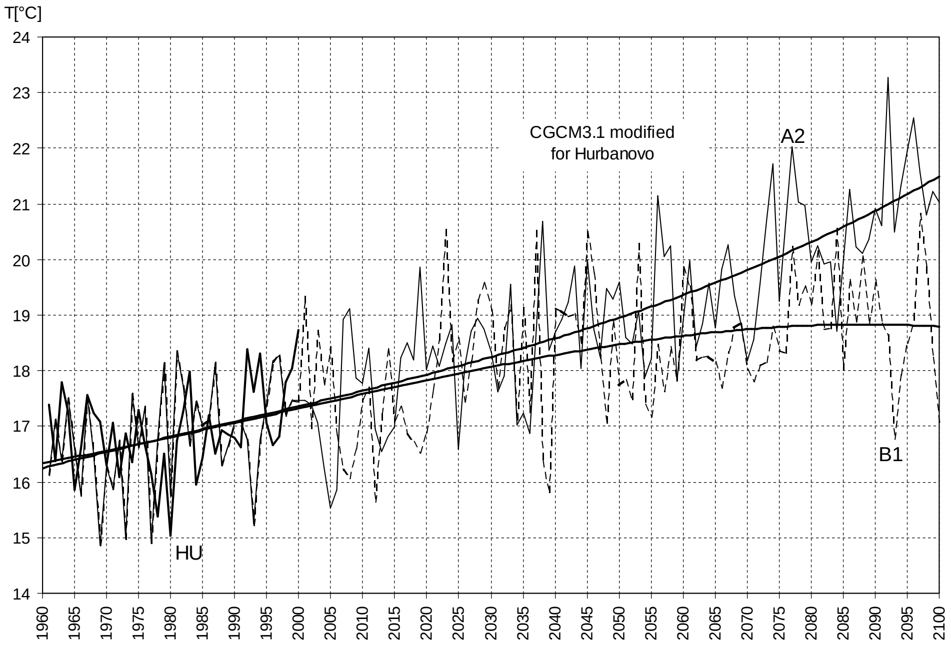

Figure 10. Comparison of mean April to September air temperature (*T*) by CGCM3.1 and SRES A2 and SRES B1 emission scenarios in 1961-2100, and measured data at Hurbanovo (HU, solid) in 1961-2000, CGCM3.1 data are modified model outputs (scenarios are different from measured data in selected years, but have the same average in 1961-1990).

The long-term patterns of air temperature (Fig. 10) influence also the patterns of water vapor pressure (***e***), because of clear physical relation between temperature and humidity of air in real conditions. In the next pages we will show that the model CGCM3.1 does not suppose any significant change in relative air humidity. This causes nearly the same behavior of water vapor pressure averages as the air temperature ones in the April to September season. Some details can be seen in Figs. 11 to 13.

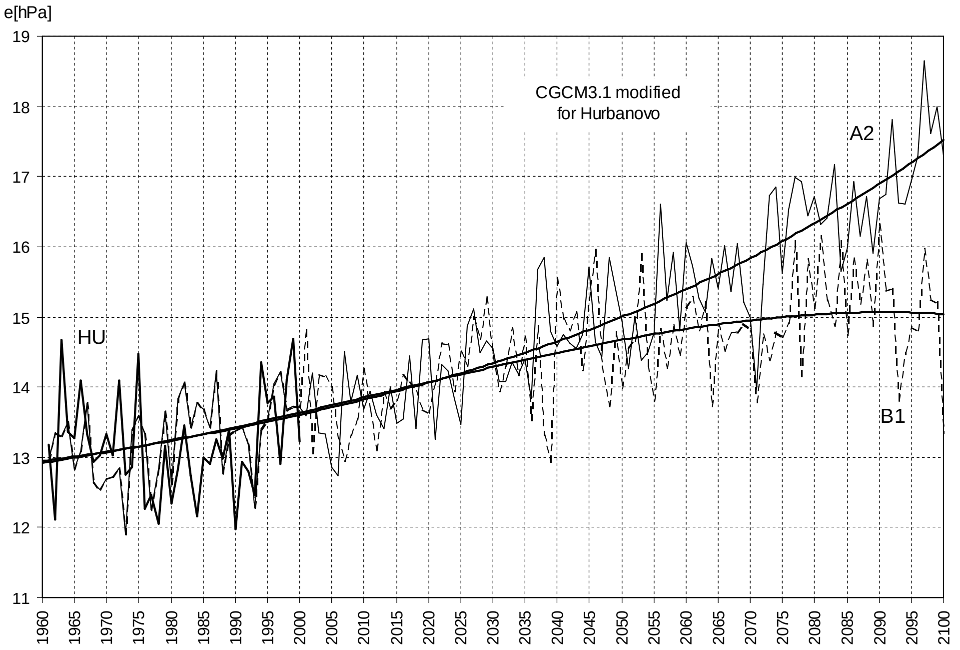

Figure 11. Comparison of mean April to September water vapor pressure (*e*) by CGCM3.1 (SRES A2 and SRES B1 emission scenarios) in 1961-2100 and measured data at Hurbanovo (HU, solid) in 1961-2000, CGCM3.1 data are modified model outputs (scenarios are different from measured data in selected years, but have the same average in 1961-1990).

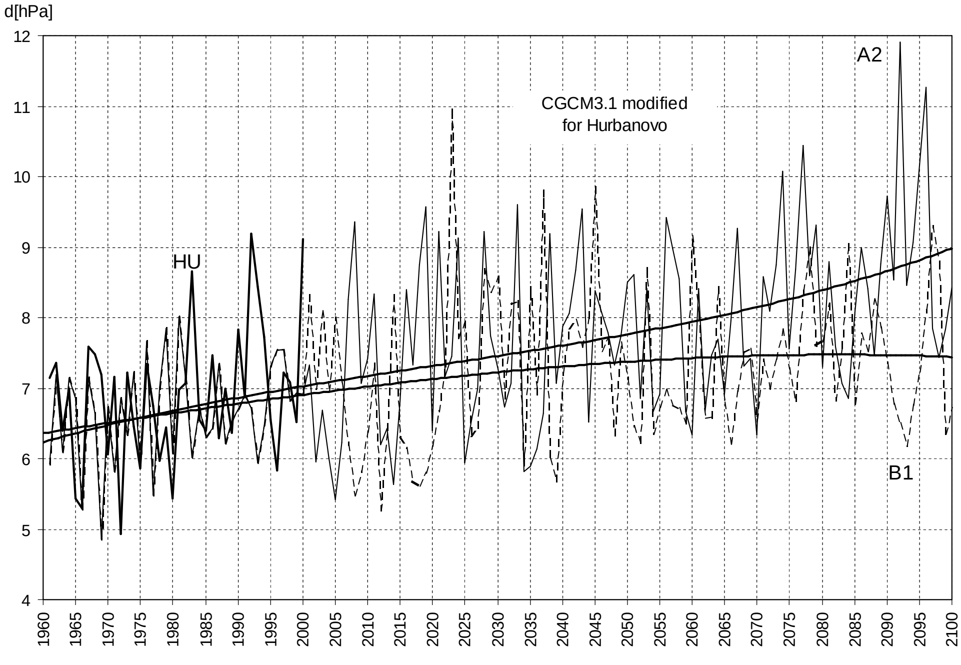

Figure 12. Comparison of mean April to September saturation deficit (*d*) by CGCM3.1 (SRES A2 and SRES B1 emission scenarios) in 1961-2100 and measured data at Hurbanovo (HU, solid) in 1961-2000, CGCM3.1 data are modified model outputs (scenarios are different from measured data in selected years, but have the same average in 1961-1990).

Modeled saturation deficit (***d***) will increase up to 2100, both at A2 and B1 emission scenarios (Fig. 12). More intense ***d*** increase is modeled for A2 scenario in the April to September season 2071-2100, by about 20% compared to period 2001-2030 (about 40% trend in 1961-2100), and only by 8% at the B1 scenario (about 17% trend in 1961-2100). Some stabilization of d values at the B1 scenario in 2070-2100 is caused by significant decrease of global greenhouse gases emission projected by this scenario after 2050.

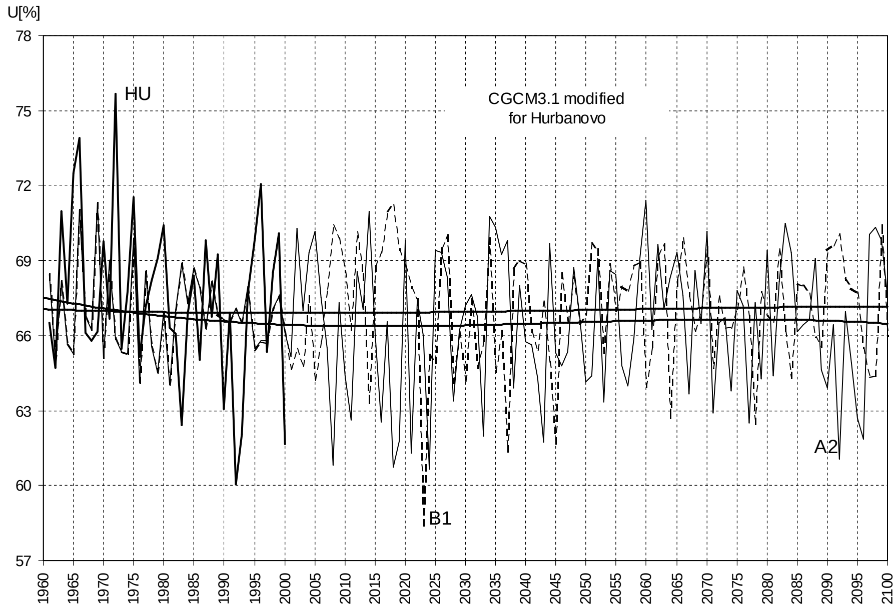

Figure 13. Comparison of mean April to September relative humidity (*U*) by CGCM3.1 (SRES A2 and SRES B1 emission scenarios) in 1961-2100 and measured data at Hurbanovo (HU, solid) in 1961-2000, CGCM3.1 data are modified model outputs (scenarios are different from measured data in selected years, but have the same average in 1961-1990).

It is interesting that after significant decrease of relative air humidity (***U***) in 1901-2007 both emission scenarios (A2, B1 at model CGCM3.1) suppose stabilization of lower ***U*** up to the end of the 21st century (Fig. 13). This will result in rise of evapotranspiration needs, because of higher air temperature and saturation deficit at the same relative air humidity. If this scenario will fulfill, the increase in potential evapotranspiration sums can reach up to 30% in the April to August season compared to 1951-1980 averages (Figs. 14 and 15, based on Zubenok method modified for Slovakia, Zubenok 1976, Recommendations 1976). Also the trend in seasonal potential evapotranspiration sums is significantly increasing (Figs. 16 and 17). Because of insignificant change in precipitation totals is supposed (some small decrease is more probable), it is expected a decrease in soil moisture at least by 25% and runoff decrease by more than 25% in the southern half of Slovakia. More detail evaluation of all water balance variables will be elaborated by the end of 2008. The results will be published in separate paper in English. The presented method of water balance related variables calculation will be applied also for other Slovak localities with sufficiently reliable data on air humidity (daily water vapor pressure) at least in 30-year period. In Hrvoľ et al. (2001), Atlas (2002) and Lapin (2005) a profound analysis of evapotranspiration condition in Slovakia is presented (based on Complex Budyko method modified for Slovakia). Slovak Hydrometeorological Institute is able to prepare input data for model evaluation of evapotranspiration scenarios at least from 30 meteorological stations in 1951-2000. This is enough great number of stations and data for complex spatial and temporal evaluation of possible changes in potential and actual evapotranspiration over the Slovak territory up to the end of the 21st century for any user.

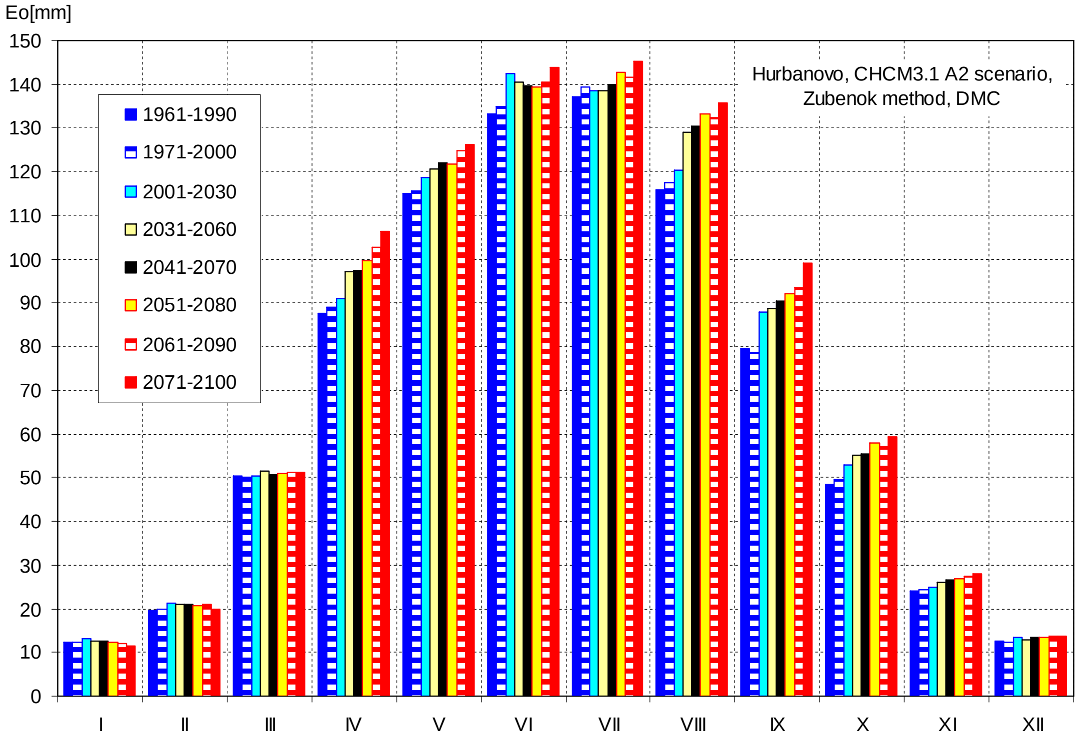

Figure 14. Comparison of mean monthly potential evapotranspiration sums E_0 calculated by the Zubenok method and the CGCM3.1 (SRES A2) modified model data for Hurbanovo and selected 30-year periods in 1961-2100.

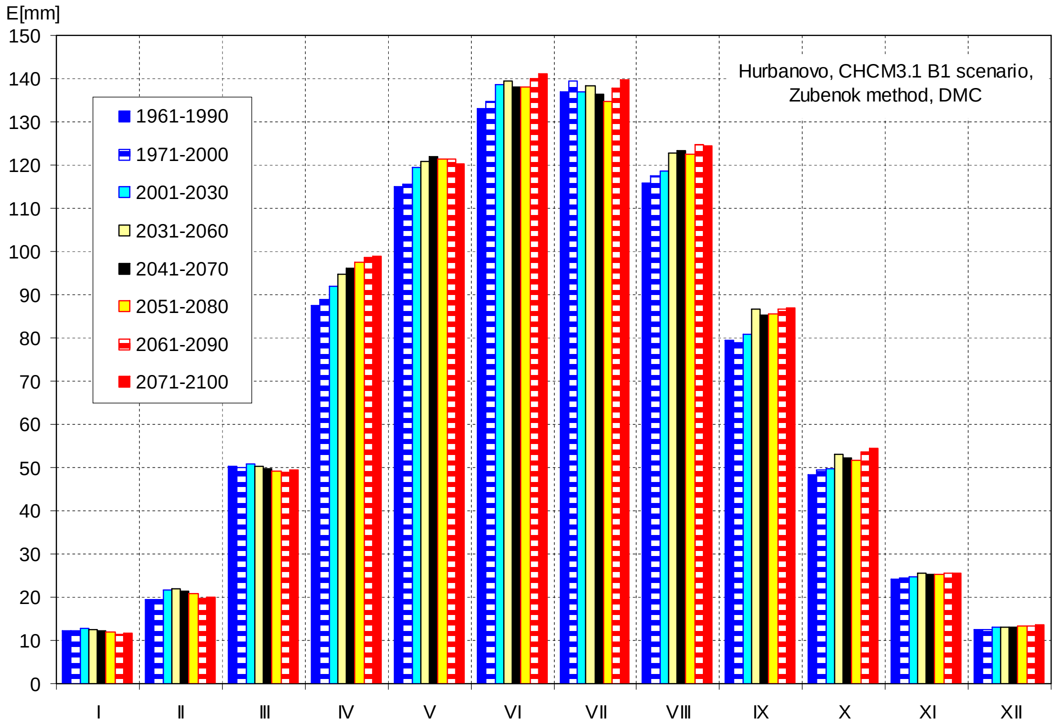

Figure 15. Comparison of mean monthly potential evapotranspiration sums E_0 calculated by the Zubenok method and the CGCM3.1 (SRES B1) modified model data for Hurbanovo and selected 30-year periods in 1961-2100.

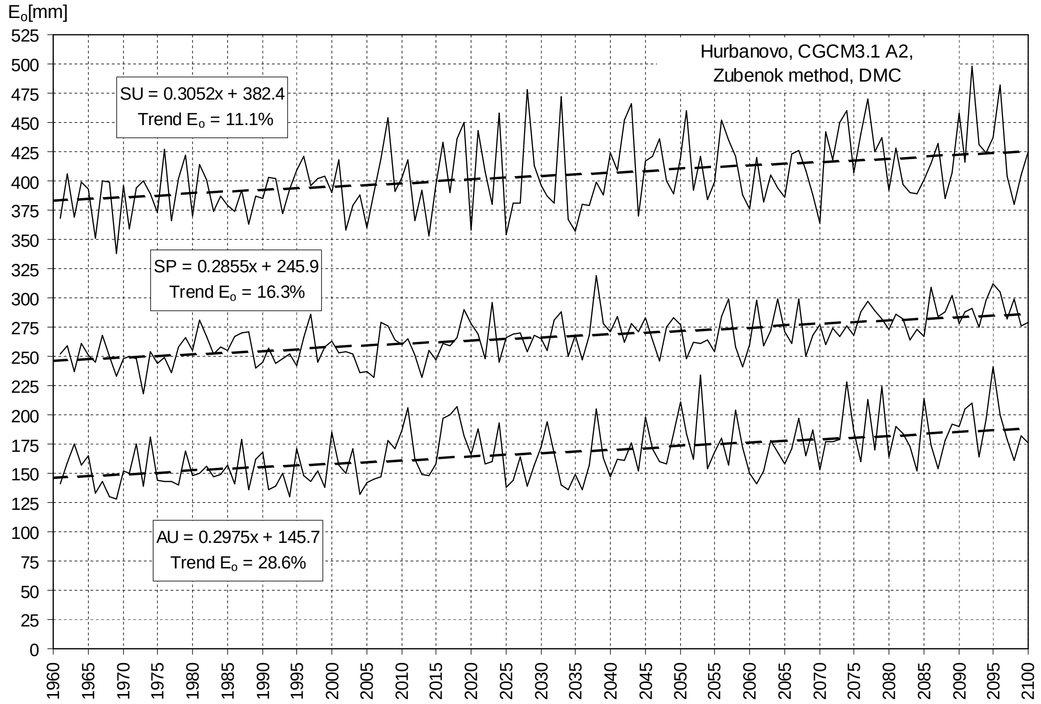

Figure. 16: Seasonal sums of potential evapotranspiration at Hurbanovo calculated by the Zubenok method from modified CGCM3.1 model outputs (SRES A2) in 1961-2100, SU – Summer (June-Aug.), SP – Spring (March-May), AU – Autumn (Sept.-Nov.), the trend in % represent increase of linear trend-line from 1961 to 2100.

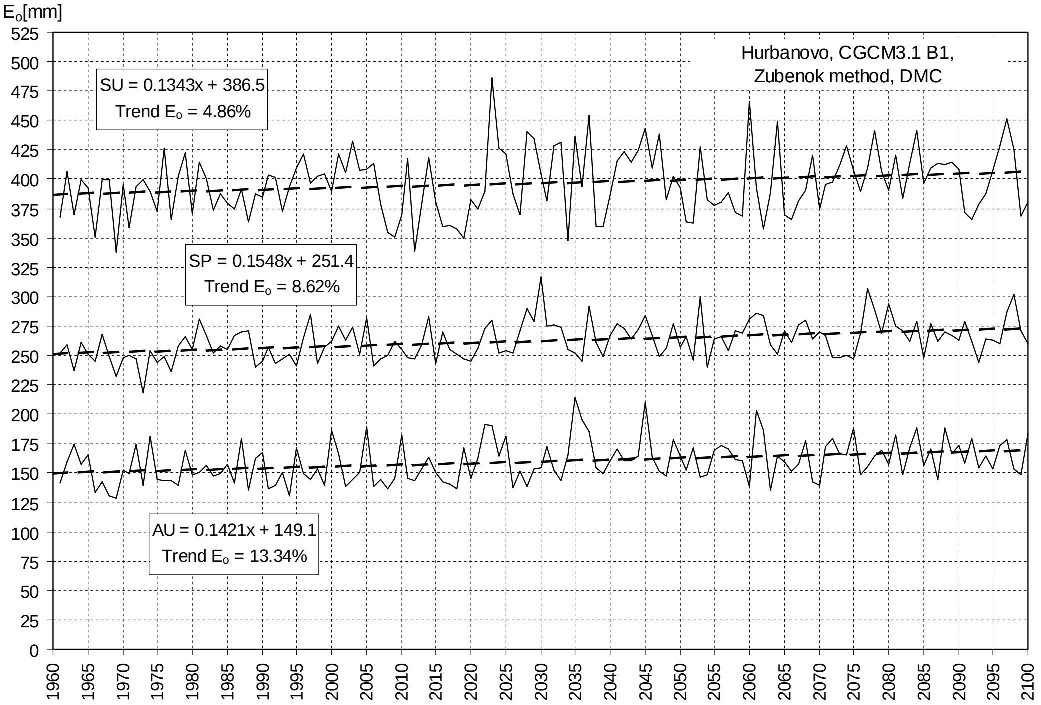

Figure. 17: Seasonal sums of potential evapotranspiration at Hurbanovo calculated by the Zubenok method from modified CGCM3.1 model outputs (SRES B1) in 1961-2100, SU – Summer (June-Aug.), SP – Spring (March-May), AU – Autumn (Sept.-Nov.), the trend in % represent increase of linear trend-line from 1961 to 2100.

5. Conclusions

The presented paper demonstrates a series of possible difficulties related to the reliable design of air humidity and potential evapotranspiration scenarios. The Slovak Hydrometeorological Institute (SHMI) Observatory at Hurbanovo (115 m a.s.l., since 1871) was the main source of observed data series for this paper. The Canadian CGCM3.1 model outputs seem suitable for detail air humidity based scenarios calculation, potential evapotranspiration sums assessed by simple Zubenok method are very close to those based on more complex Budyko method (mainly in the April-September season). After evaluation of more stations data the all Slovakia evaporation scenarios will be designed.

This paper also outlined the importance of climate change impacts on the frequency distribution and temporal trends of selected climatic elements. Climate change may cause that the design values calculated from the historical observations to be invalid even at present and likely in the next decades. Therefore, the methods of design value estimation should be modified. From this point of view of more detailed reliability testing of input data, it is recommended to re-process also the design values of climatic means and extremes published in the past decades. It is clear that the authors of the aforementioned studies have sometimes not kept the basic principles of selection, testing and statistical elaboration. The scientific interpretation and practical applications of these results could therefore be problematic.

Other climatic and hydrologic elements, from the aspect of climatic means, trends and extreme events, have been studied by further authors, e.g. Gaál 2006, Majerčáková et al. 2004, Pekárová and Szolgay 2005 etc. In some other papers, the difficulties in scenarios of complex variables like evapotranspiration, water balance and extreme events design under climate change impacts have been emphasized (IPCC 1998, Lapin et al. 2001, 2003, Lapin and Hlavčová 2003, Hlavčová et al. 2006, Lapin et al. 2004, Pekárová and Szolgay 2005 etc.).

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