20-YEAR EXTRAORDINARY CLIMATIC PERIOD IN SLOVAKIA

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Slovakia has quite a reliable series of meteorological measurements of air temperature (3 stations since 1881) and precipitation (203 stations since 1901). Early instrumental meteorological observations have been provided by Dr. Adam Reimann at Prešov in 1717–1720. In 1991 the activity of Czecho-Slovak National Climate Program began (Slovak National Climate Program since 1993) and the first climate change scenarios were issued in the next year. Now is the right time to evaluate the 20-year extraordinary warm period from 1988–2007 and also the reliability of climate change scenarios issued in 1991–2000.

Slovensko má pomerne kvalitné rady meteorologických meraní teploty vzduchu (3 stanice od r. 1881) a úhrnov zrážok (203 staníc od r. 1901). Najstaršie prístrojové meteorologické merania robil Dr. Adam Reimann v Prešove v rokoch 1717–1720. V r. 1991 začal aktivity Česko-slovenský národný klimatický program (Slovenský národný klimatický program od r. 1993) a prvé scenáre klimatickej zmeny pre Slovensko boli vydané už v roku 1991. Teraz je ten správny čas na vyhodnotenie mimoriadne teplého 20-ročného obdobia 1988–2007 a tiež na zhodnotenie spoľahlivosti klimatických scenárov z r. 1991–2000.

Keywords: climatic anomaly, climate change, climate change scenarios, long-term series

INTRODUCTION

The Czecho-Slovak National Climate Program was established on January 1, 1991 (by the decision of the Federal Minister of Environment J. Vavroušek, the Slovak National Climate Program (NCP) was introduced by the Slovak Ministry of Environment in 1993). This was an important step prior to the design of climate change scenarios for Slovakia. Until 1991 no significant signal of mean temperature increase has been registered either in worldwide series or in Slovakia (CRU, Fig. 1). The first instrumental meteorological observations were made in Slovakia by Dr. Adam Reimann at Prešov in 1717–1720. Usable long temperature series are only available from meteorological observations in Bratislava (since 1851, Konček, 1979). Afterwards detailed evaluation of climatic series reliability three temperature series (Hurbanovo, 115 m a.s.l., SW Slovakia, Košice, 230 m a.s.l., SE Slovakia and Liptovský Hrádok, 640 m a.s.l., N Slovakia) since 1881, and 203 stations with monthly precipitation totals since 1901 have been selected for climate change analysis in the NCP studies. Precipitation totals from 203 stations are used also for the calculation of areal precipitation totals by the Double Weighted Average Method (DWAM) at the Slovak Hydrometeorological Institute in Bratislava (SHMI). DWAM areal precipitation totals have been calculated from a lower number of stations also for the period 1881–1900.

A temperature increase by 1.6 °C and annual precipitation decrease by 24 mm (3.1 %) was registered in Slovakia for the period 1881–2007. Details since 1901 can be seen in Fig. 1. On the other hand annual relative air humidity (based on Hurbanovo data only) decreased by 5 % and the April–September season means by 6 % since 1901 (Fig. 2). Water vapour pressure had an insignificant linear trend between 1901–2007 all year round with some lower values in 1976–1993, mainly in the April–September season (Lapin et al., 2008). A significant increase in air temperature and changes in precipitation have occurred in Slovakia also during the period 1951–2007, predominantly after 1985. The power trend of air temperature is significant also at $\alpha = 99$ % level, at annual precipitation totals only at $\alpha = 90$ % level (Fig. 1; Nosek, 1972).

RESULTS OF ANALYSIS

Detailed analysis of monthly temperature and monthly precipitation total changes is presented in Tabs. 1 and 2. It can be clearly seen that while temperature increase is nearly regular, precipitation changes vary significantly during the year. The recent 20-year period seems significantly warmer mainly in the months from January to August (by 0.9 to 1.5 °C compared to 1951–1980 long-term average). It is quite surprising that November and December temperatures

have been lower recently by 0.1 and 0.4 °C than in 1951–1980. The longer temperature series (1901–2000) at Hurbanovo has nearly the same means as the official normal calculated for the period 1951–1980 (November and December averages are warmer in the period 1951–1980). This supports the meaning that the 1951–1980 temperature normals are very suitable for the recent climate change deviation analysis. Annual and WHY precipitation totals in the recent 20-year period correspond very well with those calculated for the very long period 1901–1990, only in April and September were significantly higher (by 11.5 and 13.3 %) and in January significantly lower (by 7.2 %).

In Figs. 3 and 4 an analysis of the growing period (April–September) mean temperature and areal precipitation totals correlation in 1881–2007. As can be seen, a higher temperature average is usually connected with lower precipitation totals and vice versa. This correlation was very common in 1881–1987 (Fig. 4 left, coefficient of determination $r^2 = 0.242$, correlation coefficient $r = 0.492$). In the recent 20-year period a different regime of temperature/precipitation correlation has started. Some higher temperature means are connected with very high precipitation totals, which did not exist in the period 1881–1987. On the other hand some very warm growing periods had very low precipitation totals in Slovakia as a whole, with a very serious drought in the south. Generally it can be stated that also the warmer growing periods with relatively high precipitation totals were unusual. Besides several longer dry spells also shorter events with very intense precipitation occurred in the growing period, which finally ranked the whole growing period among the wet seasons. A changed regime of events with higher precipitation totals is surely connected with the existence of warmer synoptic situations with higher absolute air humidity. An increase of air temperature by 4 °C means also an increase of saturated air humidity by about 25 %. Higher absolute air humidity results in more intense precipitation events during cyclonic or convective (thunderstorm) synoptic situations (Lapin et al., 2003). On the other hand, if non-cyclonic and non-convective synoptic situations occur the potential evapotranspiration increases very rapidly with rising air temperature also at the same relative humidity (Lapin et al., 2008; Lapin, 2005).

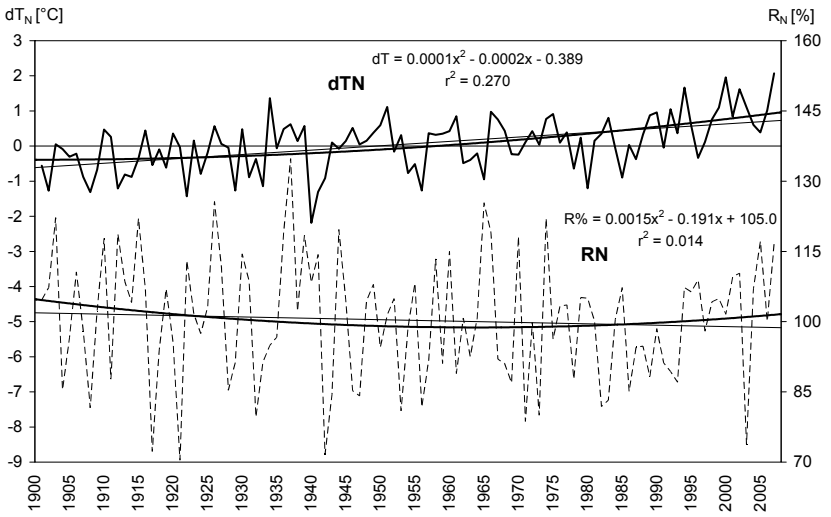


Figure 1.
Deviation of annual air temperature (dT_N) in Slovakia (means from 3 stations) from 1951–1980 long-term average and % of areal annual precipitation totals (R_N) in Slovakia from 1901–1990 long-term averages in 1901–2007 (linear and power trends are included, data by the SHMI).

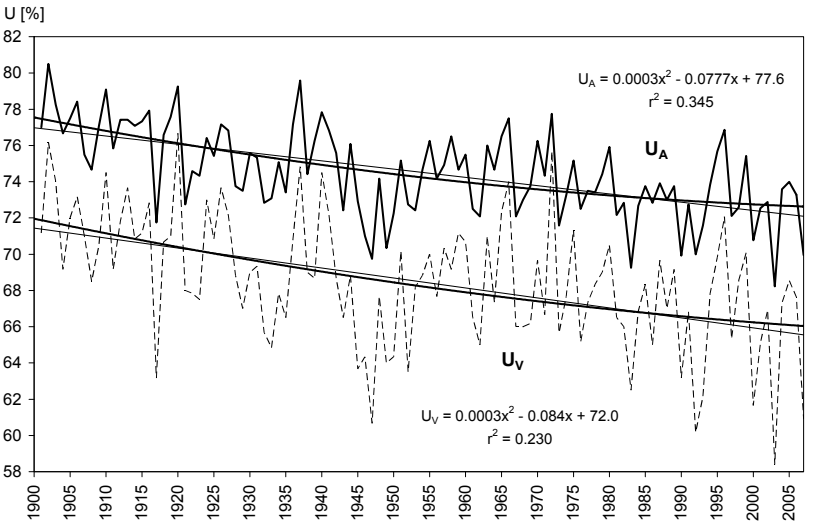


Figure 2.
Annual (U_A) and seasonal (April–September, U_V) relative air humidity means at Hurbanovo in 1901–2007 (linear and power trends are included, data by the SHMI).

Table 1.
Air temperature normals in 1951–1980 for Hurbanovo (HU), Košice (KO) and Liptovský Hrádok (LH), temperature long-term average at Hurbanovo in 1901–2000 and deviations of temperature averages in 1988–2007 from the normals 1951–1980 at 3 stations in Slovakia dT all in [°C].

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year	WHY
HU 1951–1980	–1.5	0.7	5.0	10.5	15.2	18.8	20.1	19.4	15.3	10.0	5.0	0.8	9.9	16.6
KO 1951–1980	–3.4	–1.1	3.1	9.1	13.9	17.5	18.9	18.3	14.2	8.7	3.6	–1.0	8.5	15.3
LH 1951–1980	–4.8	–3.0	0.8	6.2	11.2	14.7	15.9	15.1	11.3	6.6	2.0	–2.6	6.1	12.4
HU 1901–2000	–1.5	0.3	5.1	10.4	15.5	18.5	20.3	19.5	15.4	10.0	4.6	0.6	9.9	16.6
dT HU	1.6	1.2	0.9	0.9	1.5	0.9	1.4	1.5	0.4	0.6	–0.1	–0.4	0.9	1.1
dT KO	1.5	0.8	1.3	1.1	1.4	0.9	1.4	1.5	0.3	0.6	–0.1	–0.4	0.9	1.1
dT LH	1.5	0.8	1.3	1.1	1.4	0.9	1.4	1.5	0.3	0.6	–0.1	–0.4	0.9	1.0
Mean ***dT***	1.5	0.9	1.1	1.0	1.4	0.9	1.4	1.5	0.3	0.6	–0.1	–0.4	0.9	1.1

Table 2.
Areal precipitation total (R) in Slovakia based on the DWAM from 203 stations [mm], Max and Min are the highest and the lowest totals in 1901–2007, WHY is April to Sept. season.

R in period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year	WHY
1988–2007	41.3	44.6	46.9	59.1	75.6	87.3	93.6	77.4	67.8	55.5	58.5	49.5	756.9	460.7
% of R_N	92.8	106.1	105.0	111.5	98.1	95.7	106.6	98.3	113.3	98.0	94.9	90.9	100.7	102.9
R_N (1901–1990)	44.5	42.0	44.6	53.0	77.0	91.2	87.8	78.7	59.8	56.6	61.6	54.5	751.3	447.5
1901–1950	45.1	41.8	46.8	54.1	78.0	87.6	89.2	79.7	62.8	61.5	63.5	53.4	763.6	451.4
1951–1980	43.7	43.7	41.9	53.2	70.7	97.9	92.8	78.8	54.4	53.2	61.5	55.5	747.3	447.7
1961–1990	43.5	41.7	40.8	52.6	78.8	92.7	80.3	77.9	57.3	50.9	62.6	54.9	734.0	439.6
1971–2000	42.5	36.7	42.1	57.0	78.4	89.9	82.1	72.7	63.3	54.9	57.3	52.8	729.8	443.5
Max	111	94	137	118	165	187	192	176	152	198	148	122	1013.0	651.0
Year	1976	1977	1937	1994	1939	1926	1960	1913	1922	1974	1962	2005	1937.0	1965.0
Min	6	6	5	6	23	31	24	21	6	2	5	5	529.0	239.0
Year	1964	1976	1974	2007	1947	1917	1928	1992	1959	1951	1902	1972	1921.0	1917.0
1991–2007	44.5	43.1	47.4	57.2	74.8	87.9	98.2	78.6	67.6	58.1	58.9	49.6	766.0	464.3
2000–2007	58.1	50.3	54.9	49.1	75.9	83.1	105.5	85.4	66.4	48.6	58.8	49.3	785.3	465.4

Figure 3.
Deviation of April–September air temperature means (dT) at Hurbanovo (normalized mean temperature) from 1951–1980 long-term average and % of areal precipitation totals (R) in Slovakia (normalized precipitation totals) from 1901–1990 long-term averages in 1881–2007.

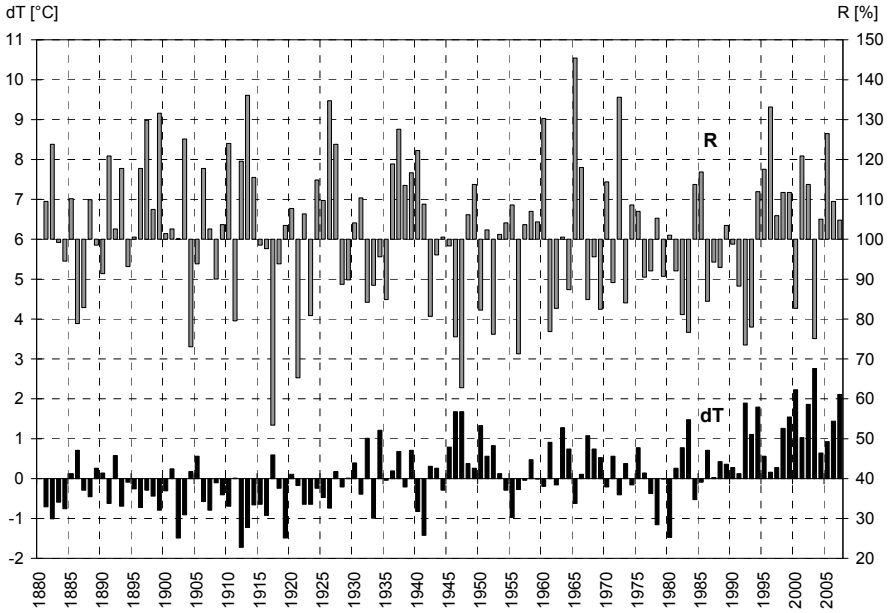
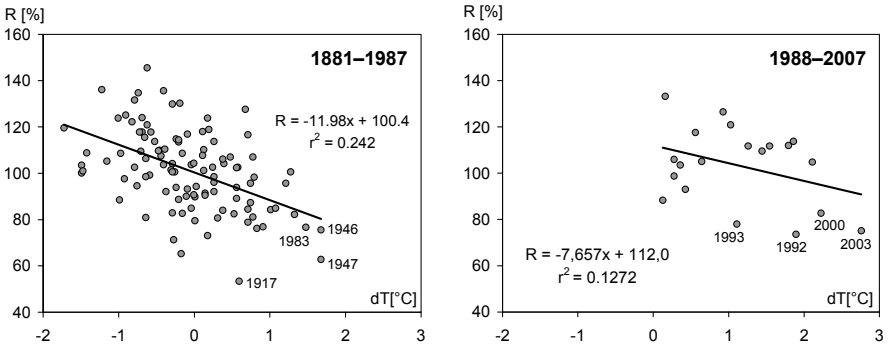


Figure 4.
Correlation of April–September normalized air temperature means (dT) at Hurbanovo and normalized areal precipitation totals (R) in Slovakia (see Fig. 3) in 1881–1987 (left) and 1988–2007 (right).



The mentioned change in air temperature averages and precipitation total regime between the periods 1988–2007 and the previous ones can be also analyzed using climatic maps. Figs. 5 and 7 show annual and seasonal air temperature means in Slovakia and Figs. 6 and 8 the deviations from the normal period 1961–1990. The maps have been designed by using GIS (ArgInfo and GRASS) techniques, as well as long-term averages from about 50 stations at air temperature and about 550 stations at precipitation totals also 102 values in mountainous areas were introduced. These 102 values have been calculated by regression methods taking into account altitude and orientation of slopes in topography. More about this method can be read in Pecho et al. (2006).

Fig. 6 demonstrates deviations in the annual air temperature from 0.0 to 1.2 °C between the periods 1988–2007 and 1961–1990 (more in the South) and Fig. 8 the same for April–September temperatures, from 0.0 to 1.6 °C (also more in the South). In spite of nearby periods the deviations in mean temperature are relatively high and represent a very rushed change in climatic conditions. The normal deviation of annual temperature between Hurbanovo and Trenčín is only 1.0 °C, so within about 30 years a shift of climatic borders represents about 200 m of altitude in southern Slovakia (less in the North). Such a great change in temperature means wasn't registered in Slovakia during modern history (since 1775) and probably also in the last Millennium (Faško et al., 2003; Konček, 1979).

Figs. 9 to 12 show the same comparisons as Figs. 5 to 8, but concerning precipitation totals in the whole of Slovakia. It can be seen that while annual precipitation totals decreased in southern Slovakia in 1988–2007 very significantly (up to 20 %), in northern Slovakia an increase in annual precipitation up to 10 % has been registered. On the other hand the seasonal (April to September) precipitation totals decreased in northwestern Slovakia (up to 20 %) and increased at many sites in southern and northeastern Slovakia (up to 20 %). In spite of this serious drought events occurred in southern Slovakia in nearly every year during the growing seasons 1988–2007. The reason is obvious – an increase of the growing season's air temperature by 1.0 °C represents also an increase of potential evapotranspiration needs by about 100 mm in the Slovak lowlands. This is sharply 20 % of the annual precipitation total there.

Finally it must be stressed that higher April–September precipitation totals in southern and mainly in eastern Slovakia have been created predominantly by the occurrence of several shorter episodes with very intense precipitation causing flash and regional flooding. These floods are counted among the most serious in this region since the beginning of regular hydrological observations (Majerčáková et al., 2004).

Figure 5. Annual air temperature means in Slovakia in 1988–2007.

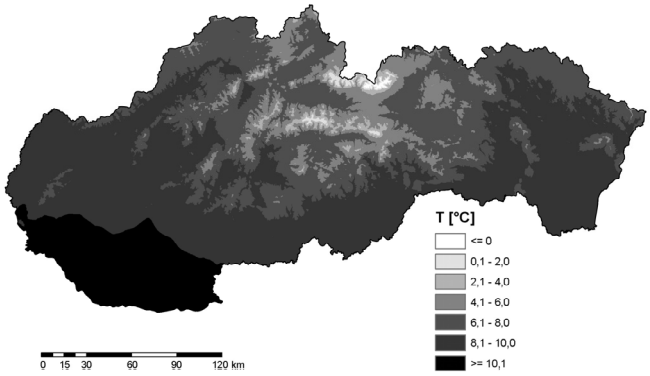


Figure 6. Deviations of annual air temperature means in Slovakia between the periods 1988–2007 and 1961–1990.

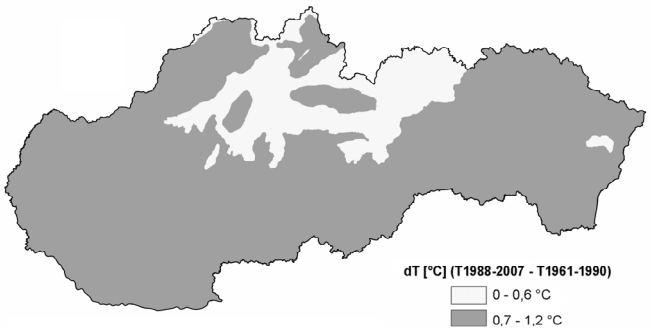


Figure 7. Seasonal (April–September) air temperature means in Slovakia in 1988–2007.

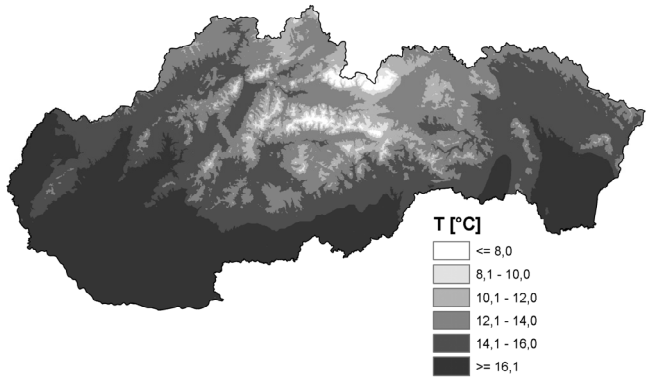


Figure 8. Deviations of seasonal (April–September) air temperature means in Slovakia between the periods 1988–2007 and 1961–1990.

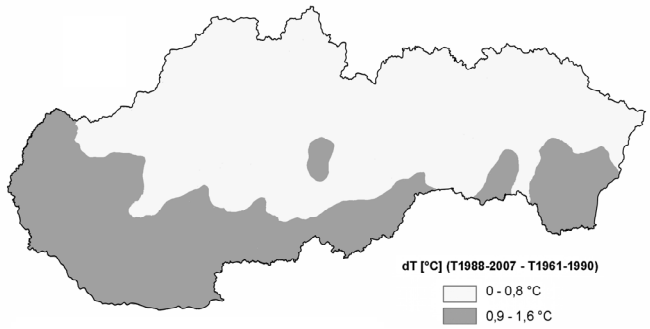


Figure 9. Mean annual precipitation totals in Slovakia in 1988–2007.

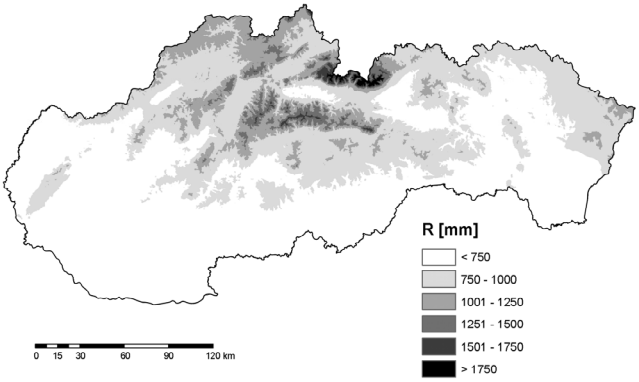


Figure 11. Seasonal (April–September) mean precipitation totals in Slovakia in 1988–2007.

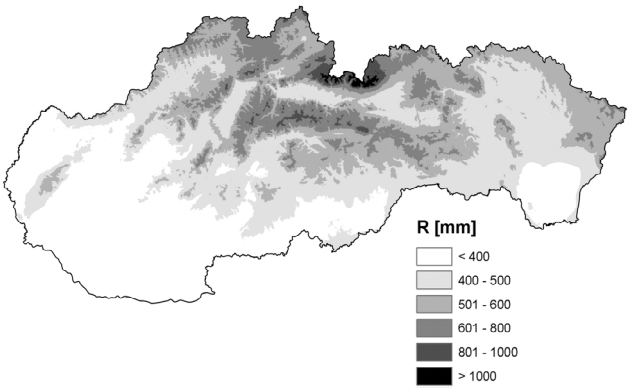


Figure 10. Deviations of annual precipitation means in Slovakia between the periods 1988–2007 and 1901–2000 expressed as % of 1988–2007 totals from 1901–2000 ones.

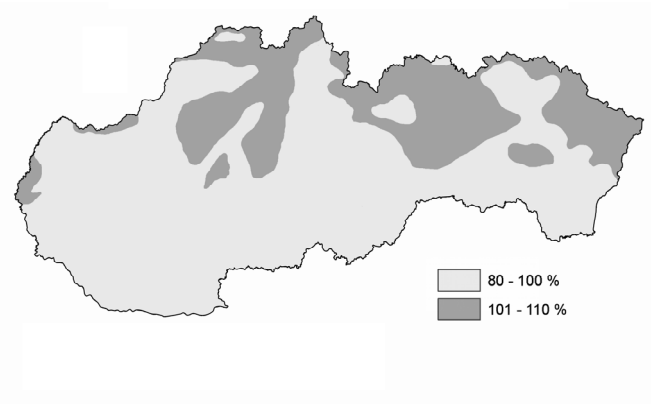
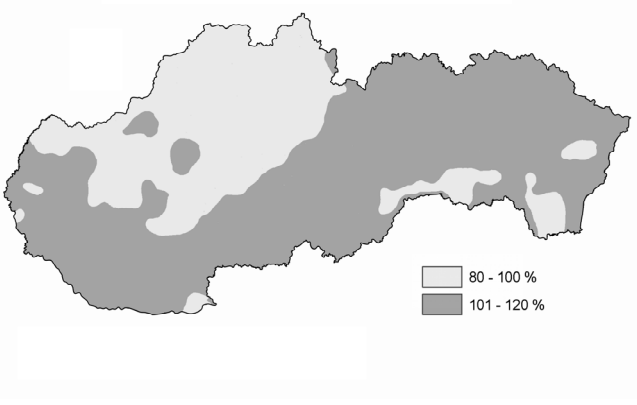


Figure 12. Deviations of seasonal (IV–IX) precipitation means in Slovakia between the periods 1988–2007 and 1901–2000 expressed as % of 1988–2007 totals from 1901–2000 ones.



CLIMATE CHANGE MONITORING

In 1991–2000 there were issued several scenarios of climate change in Slovakia for air temperature and precipitation totals (based on different methods). In Tab. 3 there are presented only the mostly applied ones by users and only for the 2010 time frame (Lapin et al., 1995; Lapin and Melo, 2004).

It can be seen that deviations for the period 1988–2007 (1998 time frame) roughly correspond, or at temperature also exceed, the scenarios projected for the time frame 2010, i.e. 12 years later. Details are presented in Figs. 13 and 14. Our conclusion is, that the climate change development in Slovakia is in the case of temperature rise more rapid than was supposed by any scenario designed in 1991–2000 for Slovakia. The 20-year time frame is too short for precipitation, so detailed evaluation of precipitation scenarios would be possible to issue in 10 years only.

CONCLUSIONS

Climate change monitoring is considered as one of the most important tasks among all climate change issues and studies. Slovakia has good conditions for the implementation of this task, because it was agreed a comprehensive NCP design of station network for climate change monitoring in Slovakia at the Slovak Hydrometeorological Institute in 1993. The presented analysis showed a good reliability of scenarios designed in 1991–2000, moreover up to the present development of climate change seems to be still more rapid than projected. The 20-year period is too short for an ultimate statement on projected scenarios, but on the other side it is clear that the impact studies in various sectors based on these scenarios can be considered also as quite reliable for preparing adapting measures (Balajka et al., 2005; Majerčáková et al., 2004; Pekárová and Szolgay, 2005; Hlavčová et al., 2004, 2005, 2006 etc.).

Climate change observed in 1988–2007 indicates also some new aspects in significant change of precipitation and evapotranspiration variability. The evaluation of such changes needs longer, at least a 30-year, monitoring period (IPCC 1998, 2007; Lapin and Tomlain, 2001; Lapin et al., 2005).

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Table 3.
Air temperature T [°C] and precipitation totals R [%] average scenarios for the 2010 time frame in Slovakia (period 1996–2025) compared to 1951–1980 period's normal (WHY - April–Sept., N, S – northern and southern half of Slovakia, WP – analogue scenario).

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year	WHY
T (CCCM1995)	1.2	1.4	1.4	1.0	0.9	0.9	1.1	1.0	1.1	1.1	0.9	0.9	1.1	1.0
T (GISS1995)	1.8	1.7	1.6	1.2	1.0	0.8	0.8	0.8	1.2	1.4	1.5	1.6	1.3	1.0
T (WP1995)	1.4	1.7	1.5	1.3	0.9	0.6	0.9	1.1	0.8	0.4	0.3	0.7	1.0	0.9
T (CCCM1997)	0.5	0.7	0.9	0.7	0.4	0.6	0.9	1.0	1.0	0.9	0.6	0.4	0.7	0.8
T (CCCM2000)	0.6	0.8	1.9	1.8	1.5	0.8	1.4	1.2	1.2	0.9	0.3	0.4	1.1	1.3
T (GISS1998)	0.3	0.3	0.5	0.7	0.7	0.6	0.6	0.4	0.3	0.5	0.6	0.5	0.5	0.6
R (CCCM1995N)	110	105	100	103	98	100	96	96	96	106	108	111	102	98
R (CCCM1995S)	109	101	105	101	95	95	93	101	97	103	105	107	100	96
R (GISS1995N)	105	110	109	111	106	102	103	102	95	108	110	101	105	103
R (GISS1995S)	105	108	108	109	106	102	106	106	94	109	109	102	105	103
R (WP1995N)	98	102	104	105	106	103	97	92	90	93	98	99	98	98
R (WP1995S)	97	98	89	84	92	97	96	95	92	95	100	097	94	92
R (CCCM1997)	103	97	108	100	109	95	93	94	104	108	107	103	101	99
R (CCCM2000)	105	98	106	98	106	91	90	92	106	113	111	104	101	97
R (GISS1998)	98	97	98	101	102	100	98	102	106	103	100	100	100	101

Figure 13.
Deviations of monthly and seasonal air temperature means from the normal 1951–1980 projected by several scenarios and observed in Slovakia in 1988–2007 (black, see Tabs. 1 and 3).

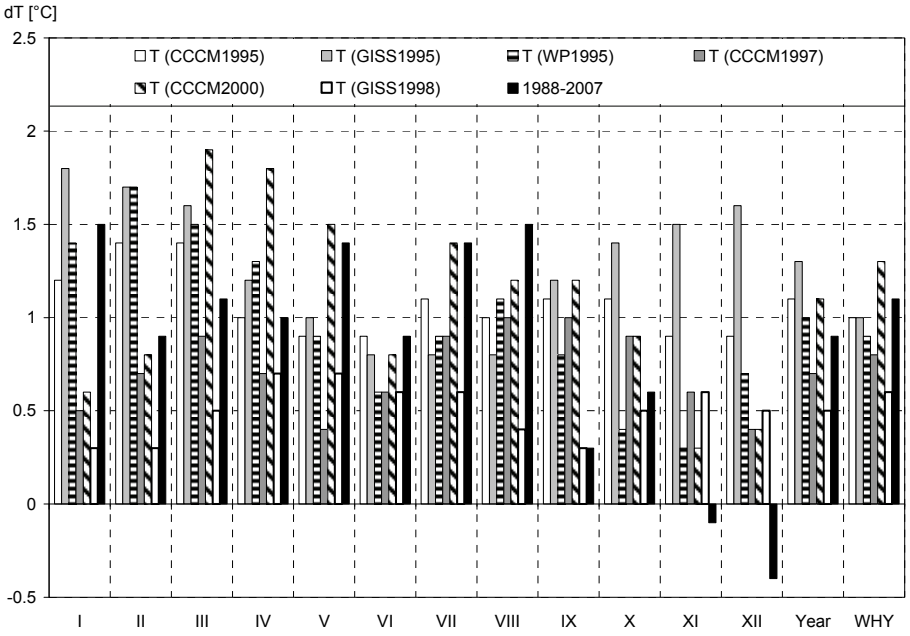
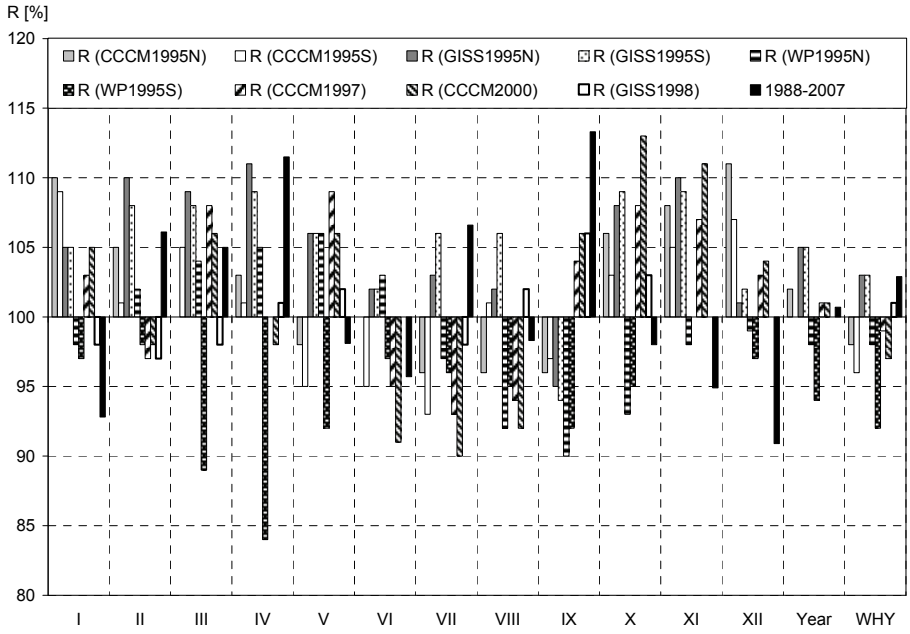


Figure 14.
Deviations of monthly and seasonal precipitation totals from the normal 1951–1980 projected by several scenarios and observed in Slovakia in 1988–2007 (black, see Tabs. 2 and 3).



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