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TENDENCIES OF CLIMATIC EXTREMES OCCURRENCE IN DIFFERENT MORAVIAN REGIONS AND LANDSCAPE TYPES

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Abstract

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In this study present frequency of several characteristic days as tropical, summer, arctic, frost and ice days and also length of heat waves was compared with modelled future occurrence of these climate extreme indices. Climate-diagrams were used for drought hazard assessment. The main objective of our research was to detect possible changes of frequency of the extreme events toward future. Data from four localities in the Czech Republic (Moravia) were chosen for the evaluation. Each locality represents different climatic, landscape and settlement conditions. Localities are represented by the closest grid points. Future trend was modelled for scenario data (scenario A1B) by regional model ALADIN-Climate/CZ in the Czech Hydrometeorological Institute. The results showed obvious rising tendency of tropical and summer days frequency on all localities, especially in lowland regions. Very strong decreasing trend seemed to be in occurrence of arctic days, which might be very scarce in the future. Frost days and ice days should also decrease. Increase in number of days in heat wave was considerable. Climate-diagrams showed possible rising drought hazard for all localities towards future periods.

characteristic days, climatic extremes, ALADIN

Extreme climatic events can have serious impact on environment and society. Analyses of observed temperature in many regions of the world have already shown some important changes in the extremes occurrence. The extreme climatic events are mainly associated with precipitation and temperature.

Global air temperature has increased by an average of 0.74 °C (IPCC 4th Assessment Report 2007) in last hundred years. Generally, the global daily minimum and maximum air temperature values (Tmin and Tmax) increase, though the minima increase three times faster (Kejna *et al.*, 2009). The negative consequences of possible climate change are rather connected with changes in variability and occurrence of extreme events than with changes in average temperature characteristics.

The research of tendencies of several climatic extreme indices has been realized in many countries all over the world. A study of the long-term changes of various climatic extremes was made jointly by a number of European countries. It was found that the changes in maximum and minimum temperatures follow the corresponding well-documented mean temperature changes. Minimum temperatures, however, have increased slightly more than maximum temperatures, although both have increased. As a result, the study confirmed that the diurnal temperature range has mostly decreased during the present century in Northern and Central Europe. Frost has become less frequent (Heino *et al.*, 1999).

Not only changes in average or minimum and maximum air temperature are suitable to study changes of climatic conditions. Characteristic days (tropical, summer, ice, frost and arctic days) are also very useful indices.

A research focused on such temperature characteristics was also done in Canada. Vincent and Mekis (2006) studied trends and variations in several indices of daily and extreme temperature (frost days, cold days, cold nights, summer days, warm days, warm nights) and precipitation in Canada for the periods 1950–2003 and 1900–2003, respectively.

Trends temperature extremes for South America during 1960–2000 are presented by Vincent et al. (2005). The results showed changes in temperature extremes in South America. Significant trends were observed in the indices based on daily minimum temperatures. The percentage of cold nights is decreasing while the percentage of warm nights is increasing, and these changes are more pronounced during the summer (DJF) and fall (MAM). The night time warming corresponds to a significant decrease in the diurnal temperature range over the continent. The results generally agree with what has been observed in many other parts of the world. The near global analysis by Frich *et al.* (2002) has indicated an increase in the frequency of warm nights, a decrease in the extreme temperature range, and also a decrease in the number of frost days. Frost days is not a representative index for South America since the temperature remains above 0°C almost everywhere with the exception of the stations located in the high mountains of Ecuador, Peru, and Bolivia, and for those stations located in the southern part of Argentina and Chile. The results from the Caribbean region have indicated that the frequency of warm nights and warm days has significantly increased since the late 1950s while it seems that in South America only the warm nights have increased.

Temperature and precipitation extremes were studied also in many Asian countries. Changes in indices of climate extremes in central and south Asia were studied by Klein Tank *et al.* (2006). At 70 per cent of the stations, statistically significant increases in the percentage of warm nights/days and decreases in the percentage of cold nights/days were observed for the period 1961–2000.

In the conditions of Czech Republic temperature extremity was evaluated by Pokladníková *et al.* (2008). Three stations in south Moravia in elevation about 200 m a.s.l. Every month of the period 1961–2007 was included to defined category of extremity (extraordinary above normal, very above normal, above normal, normal, below normal, very below normal and extraordinary below normal). As extraordinary above normal 79 months, as very above normal 115 moths, as above normal 175 were classified. As extraordinary below normal 32 months, as very below normal 86 and as below normal 129 were classified. Periods of 1961–1970 and 1971–1980 contains more cold months than last two periods (with prevails warm month).

Hot weather and changes in precipitation already express themselves in various sectors and regions, for example in agriculture. Very undesirable effect of climate extremes is drought. Drought events may occur in case of long-term lack of precipitation coinciding with hot weather. Analysis of several temperature and precipitation indices and their changes in the second half of the 20th century in Hungary with emphasis on agriculture was done by Pongrácz *et al.* (2006). Their results showed that regional intensity and frequency of extreme precipitation increased, while the total precipitation decreased in the region and the mean climate became drier.

Recently a few episodes of heat waves have been observed in European countries, especially in Mediterranean region. Some of them were connected with hundreds of human death cases (from hyperthermia and heart failure). Severe heat waves have caused catastrophic crop failures. Anyway they mean stress for humans, animals and plants.

The research of heat waves duration has been done mainly in urban areas, especially in big agglomeration. In Czech Republic occurrence of heat waves and tropical days was evaluated by Středová *et al.* (2010) and Kyselý (2003).

Most of the research has been done for the present and past. Modelling the tendencies of climatic extremes is quite rare, but definitely not uninteresting and unimportant because of the management planning in various economy sectors.

The uncertainty of future climate change trends arises from the ignorance of future development of emissions and greenhouse gases concentration (and also aerosols that have cooling effect). That is why the models work with emission scenarios with a wide range – from low to high emissions. Four main groups of emission scenarios of possible development of society and climate till the end of 21st century were established within the frame of the Intergovernmental Panel on Climate Change.

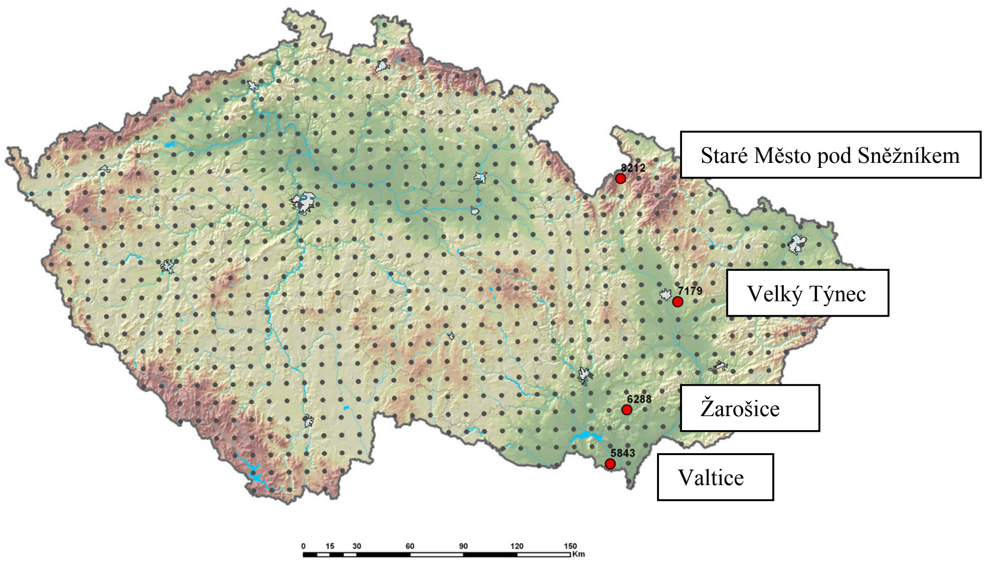
A1 Scenario is a group of scenarios that describes the world with a very fast economy growth and new technologies development. A1B is a subgroup which was used in this paper. This scenario represents a state with balance in use of all fuels (fossil and other fuels).

MATERIALS AND METHODS

Chosen localities

For the evaluation four localities were chosen. Each locality represents different type of landscape or settlement and is located in different climatic conditions. Every locality is also represented by one grid point (see map – Fig. 1), that is closest to the chosen municipality. The point Velký Týnec represents suburban climate, it is a suburb of Olomouc. The point in Žarošice cadastre represents agricultural type of landscape. Next point Staré Město pod Sněžníkem is a representative of mountain region. The last point Valtice represents fluvial landscape and the area of interest is called Lednice-Valtice.

According to Agroclimatic regionalization (Kurpelová *et al.*, 1975) **Žarošice** belongs to warm macroregion, sufficiently warm region,



1: *Map with marked chosen localities (source: ČHMÚ)*

predominantly xeric subregion and district of relatively mild winter. It is situated in elevation 193 m above see level.

Staré Město pod Sněžníkem belongs to cold macroregion, slightly cold region, wet subregion and district of cold winter. Elevation of the point is 650 m above see level.

Lednice-Valtice belongs to warm macroregion, predominantly warm region, predominantly xeric subregion and district of relatively mild winter. The elevation of the point is 197 m a. s. l.

Velký Týnec belongs to warm macroregion, predominantly warm region, slightly xeric subregion and district of relatively mild winter. The point is located in elevation 258 m a. s. l.

Applied emission scenarios

CHMI scenarios outputs (by Štěpánek *et al.*, 2008) were evaluated for future trend analyzes. The data were created by regional climatic model ALADIN-Climate/CZ integration in frame of CECILIA (7th FP) international project. The project was aimed to central Europe climatic conditions simulation by ALADIN-Climate/CZ regional climatic model with 10 km spatial resolution. Two thirty years' period (2021–2050 and 2071–2100) were simulated under emission scenarios A1B (according to IPPC). The regional model was driven by a global circulation model GCM ARPEGE-Climate.

Used data

The Czech Republic area contains 789 grid points. Model data correction based on validation, it means technical data series of 10 km grid and model results comparison, was realized before analysis itself. The validation period was 1961–1990. Scenarios data for the periods 2021–2050 and 2071–2100 were corrected by Déqué method. The method is based on meteorological element correction by individual percentiles of two databases comparison. The model results are fully compatible with observed (directly measured) data after this correction. The grid data creation and all data processing including further climate analyses were worked up by ProClimDB software (Štěpánek, 2007).

Analysed characteristics

Climate-diagrams provide very object conception of monthly average air temperature and precipitation of a locality. They picture a course of these climatic characteristics for future normal periods 2021–2050 and 2071–2100 in comparison with the normal 1961–1990. They can refer to danger of drought in a locality. If the curve of temperature falls below the curve of precipitation, it poses a risk of drought.

Number of **tropical days**, **summer days**, **ice days**, **frost days** and **arctic days** are also important climatic indicators. Tropical day is a day when maximum air temperature is 30 °C or higher. Summer day is a day when maximum air temperature is 25 °C or higher. Ice day is a day when maximal air temperature is lower than 0 °C. Frost day is a day when minimal air temperature is lower than 0 °C. Arctic day is a day, when maximal air temperature is –10 °C or lower.

Very actual mainly for urban and suburban areas is the heat waves occurrence. Heat wave is defined as a different long episode of extremely hot weather. Meteorological dictionary (Sobíšek *et al.*, 1992) defines the heat wave as more days lasting period of summer heat during which the daily maximum air temperatures reaching 30 °C or more.

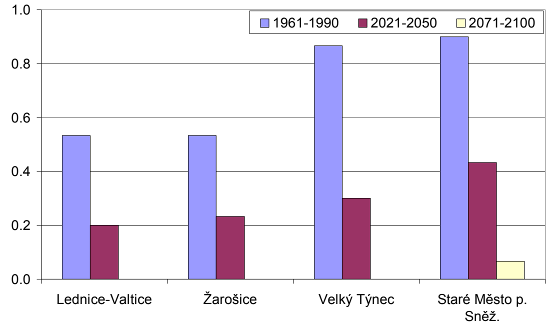
In Central Europe an existence of a heat wave is conditioned by advection of tropical air above the land or intensive radiological heating of polar air continuing above overheating land in the anticyclone area.

RESULTS AND DISCUSSION

Characteristic days

Arctic days

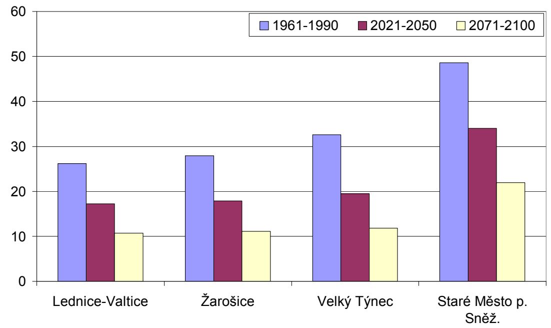
In the first evaluated period 1961–1990 the annual average number of arctic days varies from 0.5 in Lednice-Valtice to 0.9 in Staré Město pod Sněžníkem. In the second period average number of arctic days varies from 0.2 (Lednice-Valtice) to 0.4 (Staré Město pod Sněžníkem). Further decline up to value 0 days occurred in the third evaluated normal 2071–2100. Arctic days were registered at no locality except Staré Město pod Sněžníkem (0.1 days) – see Fig. 2.



2: *Number of arctic days on all localities in chosen periods*

Ice days

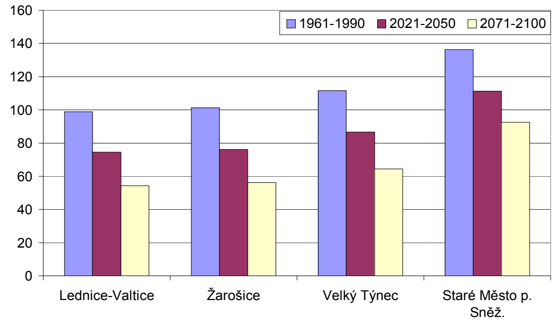
Annual average number of ice days for all localities was 33.8 days in the first evaluated normal. On single localities it varies from 26.2 days in Lednice-Valtice to 48.6 days in Staré Město pod Sněžníkem. In the second period 2021–2050 the average values decrease up to 17.2 days (difference 9 days compared to the previous period) in Lednice-Valtice or 34 days in Staré Město pod Sněžníkem (difference 14.6 days). Average decrease 8 days more was registred in the third normal (6.5 days fewer in Lednice-Valtice and 12.1 days fewer in Staré Město pod Sněžníkem compared with the previous period) – see Fig. 3.



3: *Number of ice days an all localities in chosen periods*

Frost days

Annual average number of frost days in the first period on all chosen localities varied from 98.9 days in Lednice-Valtice to 136.4 days in Staré Město pod Sněžníkem. There is a decrease to 74.5 days in Lednice-Valtice and 111.3 days in Staré Město pod Sněžníkem in the second period (2021–2050). Average number of these days is 87.1 days for all localities (decrease 25 days compared with the previous period). Further decrease occurs in the third period (2071–2100); average value for all localities is 66.9 days (20.2 days fewer than in previous period). In Staré Město pod Sněžníkem the average value is 18.8 days lower and in Velký Týnec 22.1 days lower compared with the second period – see Fig. 4.



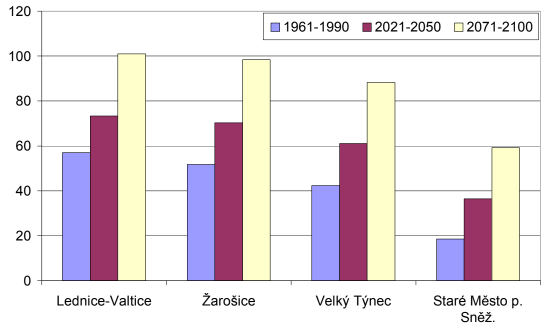
4: *Number of frost days on all localities in chosen periods*

Summer days

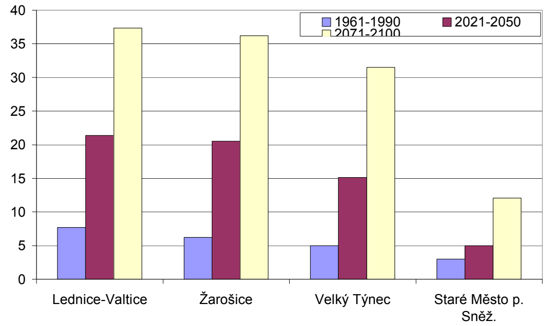
Annual average number of summer days in the first period (1961–1990) varies from 18.5 days in Staré Město pod Sněžníkem to 57 in Lednice-Valtice. Average value for all localities is 42.4 summer days per year in that period. The number of these days increases in the second evaluated period (2021–2050); in Lednice-Valtice 73.3 days and in Staré Město pod Sněžníkem 36.4 summer days occur. In this period the average number of summer days is 60.3 for all chosen localities. Average value further increases and in the third period (2071–2100) the average number is 86.7 days (26.4 days more than in the previous period). The smallest increase is in locality Staré Město pod Sněžníkem, compared with the second period there is increase 22.8 days (average value 59.2 days per year). Highest values are registred in Žarošice (98.4 days, 28.4 more than in the second period) and especially in Lednice-Valtice (101 days, almost 30 days more compared with the previous period) – see Fig. 5.

Tropical days

Annual average number of tropical days varies from 0.8 day in Staré Město pod Sněžníkem to 11 days in Lednice-Valtice in the first evaluated period. Average number of these days for all localities is 6.7 days in the period 1961–1990. In the second normal period (2021–2050) the average value increases, the

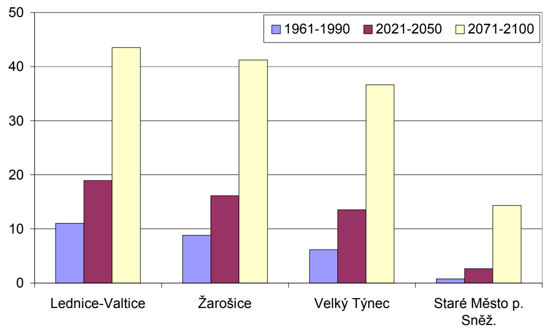


5: *Number of summer days on all localities in chosen periods*



7: *Number of days in heat wave on all localities in chosen periods*

least in Staré Město pod Sněžníkem (2 days more) and the most in Lednice-Valtice (7.9 days more), where the average number of these days is 18.9. The increase was determined in the third period (2071–2100) as well, even more marked. On locality Žarošice the increase is the most obvious – 25.1 days more compared to previous period. The average value of these days in the third period is 11.7 days more in Staré Město pod Sněžníkem and in Lednice-Valtice 24.5 days more than in previous modelled period – see Fig. 6.



6: *Number of tropical days on all localities in chosen periods*

Heat wave duration

In the first period the number of days of an average heat wave is 5.5 days for all localities (it varies from 3 days in Staré Město to 7.7 days in Lednice-Valtice). The average value increases in the second period (2021–2050) and it amounts to values from 5 days in Staré Město pod Sněžníkem to 21.4 days in Lednice-Valtice (13.7 days more than in previous period). The average duration of heat wave days in this period is 10 days longer than in the first one. In the third period (2071–2100) the increase of average value continues and it varies from 12 days in Staré Město pod Sněžníkem to 37.3 days in Lednice-Valtice that means 7 and almost 16 days more than in previous period. The most intensive increase was determined on locality Velký Týnec – 16.4 days. Compared with the period 1961–1990 the increase on chosen localities is quadruple or even almost sextuple – see Fig. 7.

Climate-diagrams

Diagrams present climatic conditions on chosen localities. They picture course of average monthly air temperature and precipitation for future normal periods 2021–2050 and 2071–2100 in comparison with the normal 1961–1990.

Locality **Lednice-Valtice** is relatively endangered by drought already in the present, but the number of months, when the curve of temperature falls below the other curve, increases (especially in the future period 2071–2100) or the danger appears also in spring not only in summer. There is also obvious increase of average monthly temperatures and precipitation sums in some months in the future.

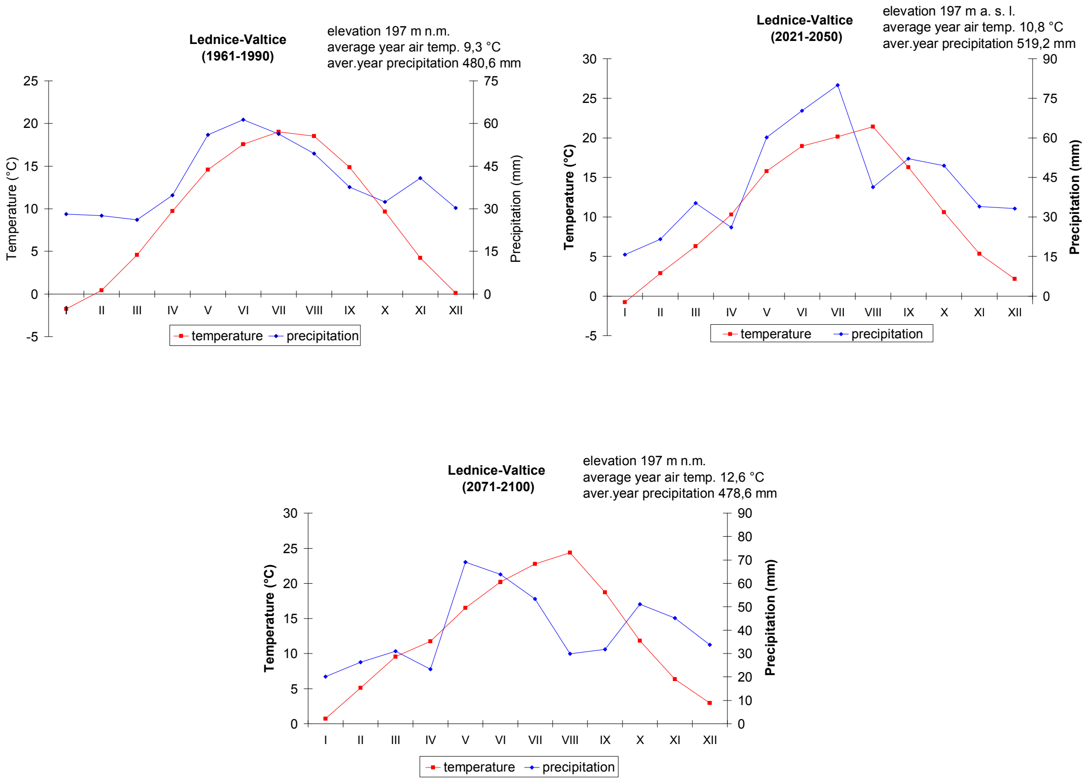
Locality **Žarošice** is situated almost in the same elevation as the locality Lednice-Valtice but it is not so endangered by drought in the present (see Fig. 11). In the future tendency to drought appears in spring (April) and the difference between the curve of temperature and precipitation increases. The most months liable to drought are pictured in the third period and the temperature curve does not fall below zero value in any month in that period.

Velký Týnec does not seem to be endangered by drought in any part of the year in the present it. Modelled future periods show another situation. First in August the temperature curve falls below precipitation curve (period 2021–2050, see Fig. 15) and then in the third period drought endangers this region three months in vegetation period (see Fig. 16).

Staré Město pod Sněžníkem represents mountain region where drought is rare because of sufficiency of rainfall and lower temperatures. The amount of precipitation and slightly also average temperatures increases in the future period and the two curves become closer than in the present time. Shape of the precipitation curve changes and the maximum value is reached in May in the third period in contrast to other previous periods (see Fig. 17–19). This tendency appears on all localities.

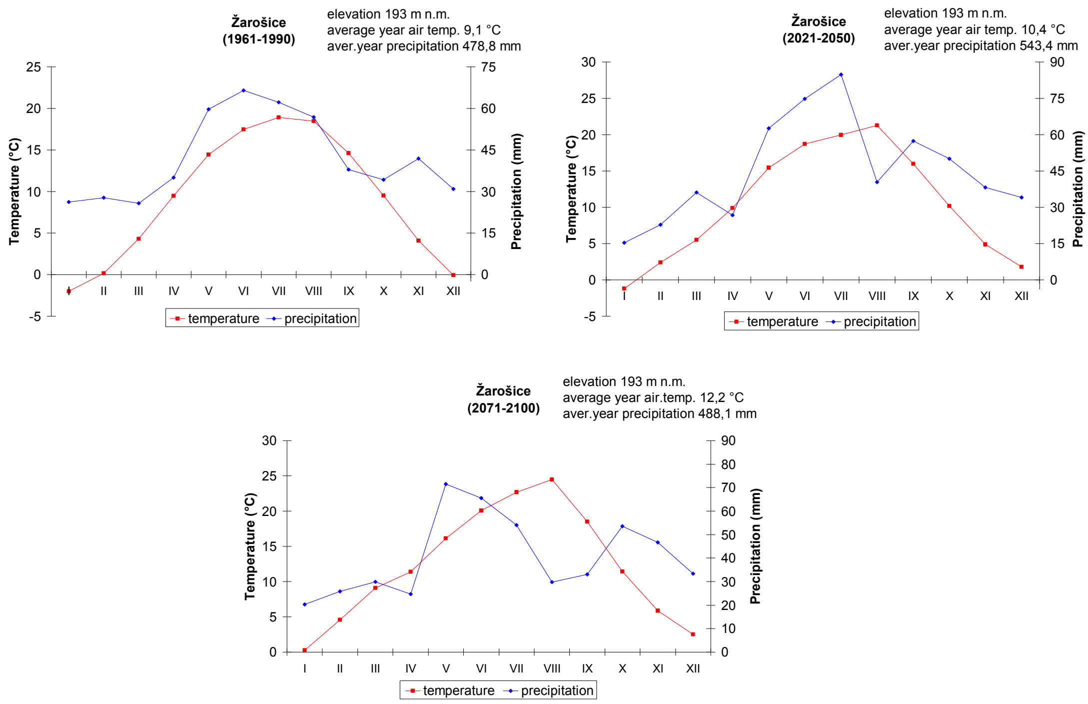
Trends toward fewer days with low extremes have been observed in many countries and confirmed by several studies (Karl *et al.*, 1996; Jones *et al.*, 1999; Heino *et al.*, 1999; Zhai *et al.*, 1999; Plummer *et al.*, 1999). Overall, the findings have suggested a significant decrease in the number of days with

Lednice-Valtice



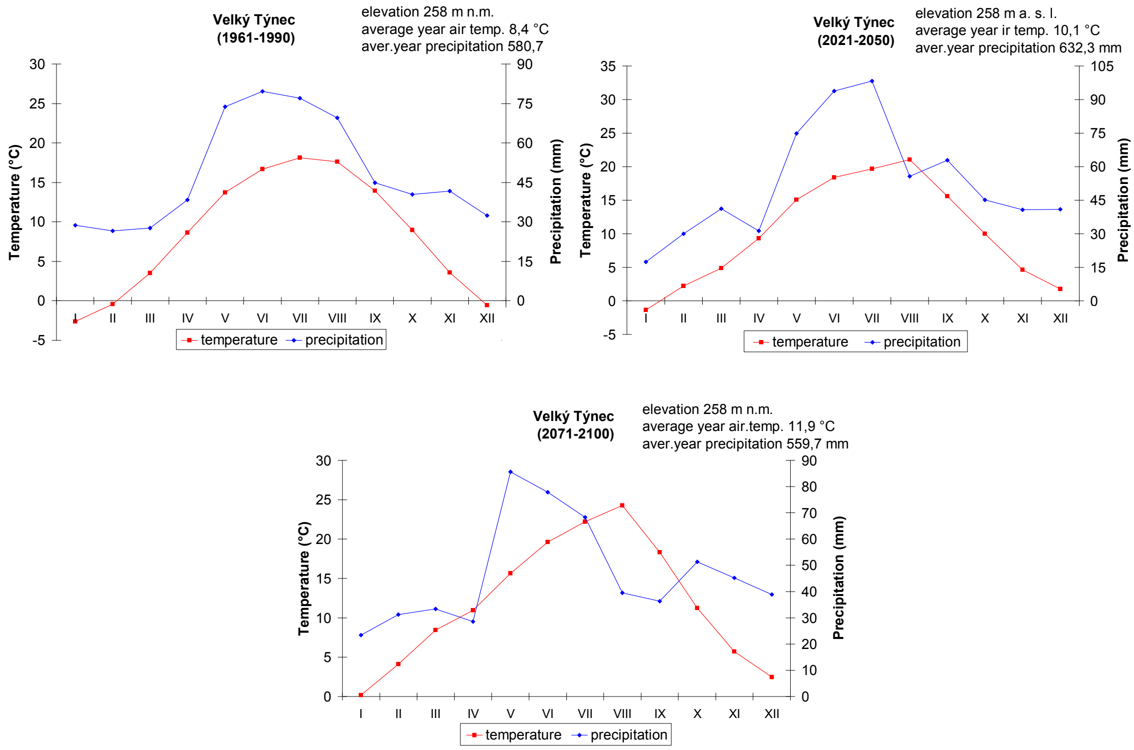
8–10: *Climate-diagrams – Lednice-Valtice for chosen periods*

Žarošice



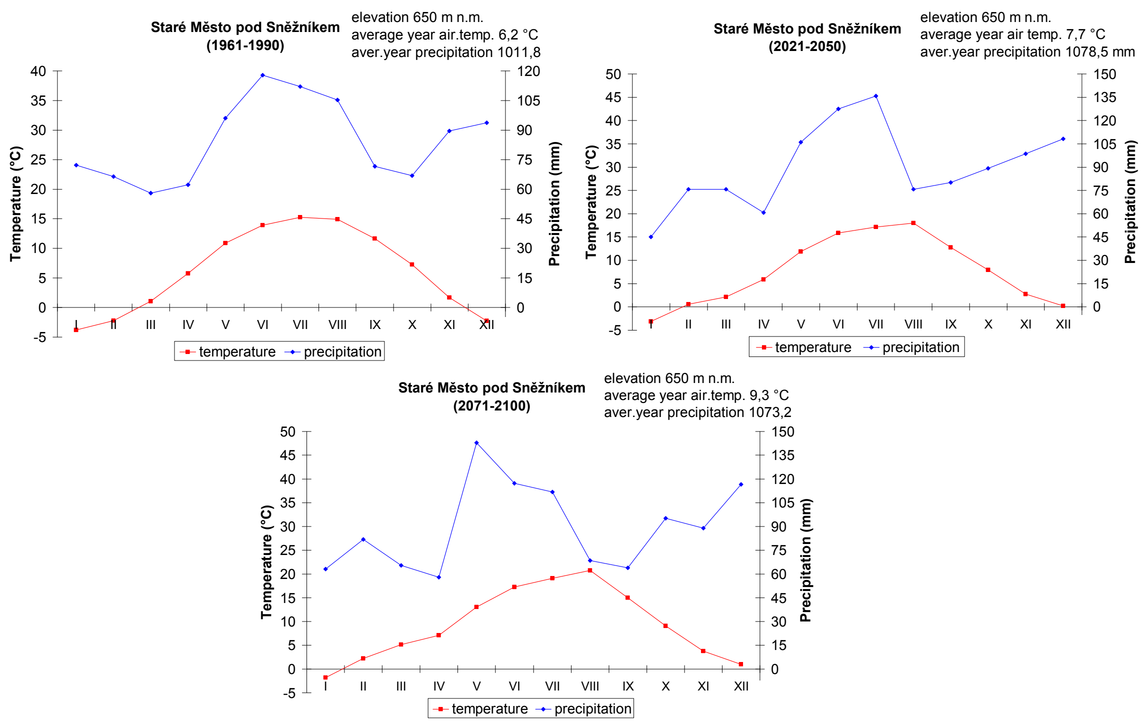
11–13: *Climate-diagrams – Žarošice for chosen periods*

Velký Týnec



14–16: *Climate-diagrams – Velký Týnec for chosen periods*

Staré Město pod Sněžníkem



17–19: *Climate-diagrams - Staré Město p. Sněžníkem for chosen periods* extreme cold temperatures, an increase in the number of days with extreme warm temperatures. Decrease in the number of frost days was registered over Australia, China, northern and central Europe, New Zealand, and the United States (Easterling *et al.*, 2000). Vincent and Mekis (2006) confirmed the occurrence of fewer cold nights, cold days and frost days, and conversely more warm nights, warm days and summer days across Canada for 1950–2003. The trends in Canada indicated 8.0 fewer frost days and 6.0 more summer days during the past 54 years.

CONCLUSIONS

Climate-diagrams picture a course of average monthly air temperature and precipitation for future normal periods 2021–2050 and 2071–2100 in comparison with the normal 1961–1990. They can refer to danger of drought in a locality. Locality Lednice-Valtice is relatively endangered by drought already in the present, but the number of months, when the curve of temperature falls below the other curve, increases (especially in the future period 2071–2100) or the danger appears also in spring not only in summer. There is also obvious increase of average monthly temperatures and precipitation sums in some months in the future.

Locality Žarošice is situated almost in the same elevation as Lednice-Valtice but it is not so endangered by drought in the present. In the future tendency to drought appears in spring (April) and the difference between the curve of temperature and precipitation increases. The most months liable to drought are pictured in the third period and the temperature curve does not fall below zero value in any month in that period.

Velký Týnec is located in the central Moravia in elevation 258 m above see level. In the present it does not seem to be endandered by drought in any part of the year. Modelled future periods show another situation. First in August (period 2021–2050) the temperature curve falls below precipitation curve and then in the third period drought endangeres this region three months in vegetation period.

Staré Město pod Sněžníkem represents mountain region where drought is rare because of sufficiency of rainfall and lower temperatures. The amount of precipitation and slightly also average temperatures increases in the future period and the two curves become closer than in the present time. Shape of the precipitation curve changes and the maximum value is reached in May in the third period in contrast to other previous periods. This tendency appears on all localities.

The analysis of typical days occurrence showed decrease of number of arctic days (by up to 0.8), ice days (by up to 27) and frost days (by up to 45) in the second and third evaluated period for all localities. Number of summer and tropical days and days in heat wave has increasing tendency by up to 43, 33 and 30 days.

This study confirmed decrease of “colder days” and increase of “warmer days” toward future. Climate-diagrams show increasing drought hazard in the Czech Republic in the perspective, mainly in the lowland regions.

The modelling of trends toward future decades enables to think about possible preventive measurement in economy sectors to make the human society less vulnerable and to face the extremes more prepared.

SUMMARY

The main objective of our research was to detect possible changes of the extreme events (tropical, summer, arctic, frost and ice days and heat waves) frequency toward future. Climate-diagrams were used for drought hazard assessment. Data from four localities in the Czech Republic (Moravia) were chosen for the evaluation. Each locality represents different climatic, landscape and settlement conditions. Localities are represented by the closest grid points. Future trend was modelled for scenario data (scenario A1B) by regional model ALADIN-Climate/CZ in the Czech Hydrometeorological Institute. Locality Lednice-Valtice is relatively endangered by drought in the present and the danger might increase in the future and not only in summer. There is an increase of average monthly temperatures and precipitation sums in some months in the future. Locality Žarošice is situated almost in the same elevation as Lednice-Valtice but it is not so threatened by drought. In the modelled future tendency to drought appears in spring and in summer. Velký Týnec is located in elevation 258 m. In the present it does not seem to be endangered by drought in any part of the year. In the period 2071–2100 drought might endanger this region three months in vegetation period. Staré Město pod Sněžníkem represents mountain region where drought is rare. The amount of precipitation and slightly also average temperatures increases in the future period and the two curves become closer than in the present time. Shape of the precipitation curve changes and the maximum value is reached in May in the third period in contrast to other previous periods. This tendency appears on all localities. According to modelled data the average number of arctic days might decrease toward future. For the third evaluated normal 2071–2100 arctic days were registered only on mountain locality. Average number of ice days should also decrease but not so dramatically. There is also a decrease of frost days frequency toward future. Number of summer days should increase. Average number of tropical days

should increase very significantly. Compared with the period 1961–1990 the length of an average heat wave on chosen localities in period 2071–2100 is quadruple or even almost sextuple.
This study confirmed decrease of "colder days" and increase of "warmer days" toward future. Climate-diagrams show increasing drought hazard in the Czech Republic in the perspective, mainly in the lowland regions.
The average number of arctic days varies from 0.5 to 0.9 days in the first period and from 0.2 to 0.4 in the second period. Average number of ice days on single localities varies from 26.2 to 48.6. In the second period the average values decrease up to 17.2 and 34 days respectively. Average decrease 8 days more was registered in the third period.
Average annual number of frost days in the first period on all chosen localities varied from 98.9 to 136.4 days and decreases to 74.5 and 111.3 days respectively in the second period. Further decrease occurs in the third period; average value for all localities is 66.9 days (20.2 days fewer than in previous period). Number of summer days in the first period varies from 18.5 to 57 days. The number of these days increases in the second period; varies from 73.3 to 36.4 summer days. Average value further increases and in the third period the average number is 86.7 days (26.4 days more than in the previous period). Highest values were registered in Žarošice (98.4 days, 28.4 more than in the second period) and especially in Lednice-Valtice (101 days, almost 30 days more compared with the previous period).
Average number of tropical days varies from 0.8 to 11 days in the first evaluated period and increases in the second period and the average number of these days is 18.9. The increase was determined in the third period as well, even more marked. Heat wave duration varies from 3 to 7.7 days in the first period. It increases in the second period and it amounts to values from 5 to 21.4 days. In the third period the increase of average value continues and it varies from 12 days to 37.3.

Acknowledgement

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