CLIMATIC SCENARIOS AND THE ASSUMED IMPACTS OF CLIMATIC CHANGES IN THE REGION OF CZECHOSLOVAKIA FOR THE MODEL OF THE GLOBAL WARMING OF THE EARTH

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SUMMARY

Series of global air temperature anomalies of the two hemispheres and the Earth as a whole have exhibited a rising trend since the last century. It is explained by the intensification of the greenhouse effect due to the rise in CO_2 concentrations and those of further trace gases in the atmosphere, which is in connection with anthropogenic activity. For making a regional scenario of climatic changes for the region of the CSFR for the model of warm Earth one starts from the methods of analogy and employment of general circulation models. In the case of palaeoclimatic scenarios conditions of the climatic optimum of the Holocene (an analogy of about the year 2000), the Eemian interglacial (the year 2025) and the climatic optimum of the Pliocene (the year 2050) are given, in which there revailed higher temperatures and precipitation in our region than today. On the basis of the comparison of the warmest and the coldest 20-year periods changes in air temperature, precipitation, sunshine, air pressure and cloudiness in the CSFR are estimated for the case of global temperature rise of the Northern Hemisphere by 0.4 and/or 0.5 °C. A conspicuous warming in all seasons of the year starts for the region of the CSFR from the application of GISS and GFDL models for the doubling of CO_2 content, when there should also be a rise in precipitation. In connection with the assumed climatic changes also some impacts of the expected climatic changes on different spheres of human activity are discussed. The impacts on agriculture, forestry and water management are discussed in detail under the conditions of the CSFR.

1. OBSERVED GLOBAL CLIMATIC CHANGES AND THE GREENHOUSE EFFECT

The analysis of the present fluctuation of the climate is based on the series of land surface air temperature anomalies of the Northern and the Southern Hemispheres, calculated and analysed in the papers by Jones et al. (1986a, b), Jones (1988), Hansen and Lebedeff (1987, 1988) and Vinnikov et al. (1987, 1990). As 70.8 % of the total area of the Earth is constituted by oceans, the study of global temperature fluctuations must also include ocean temperatures. Series of sea surface temperatures (SST) were processed by Farmer et al. (1989) and Bottowley et al. (1990; quotations of the two papers in Houghton et al., eds., 1990). By combining those series with the data of Jones (1988) a series was obtained for the whole globe, represented in Fig. 1, which shows an overall rise in temperatures in the present century.

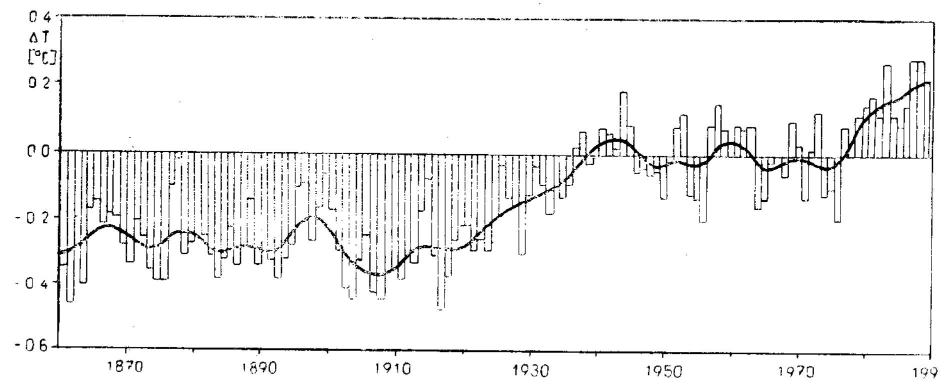


Fig. 1. Annual deviation (ΔT) of global mean combined land air (Jones, 1988) and sea surface temperatures (UK Meteorological Office and Farmer et al., 1989) for the period 1861—1989 (shown by bars), relative to the average for 1951—1980 (smoothed by a low pass binomial filter with 21 terms). According to Houghton et al., eds. (1990)

A linear trend fitted between 1890 and 1989 gives values of 0.50 °C/100 years (globe), 0.47 °C/100 years (Northern Hemisphere) and 0.53 °C/100 years (Southern Hemisphere), for the period of 1870—1989 successively the values of 0.41, 0.39 and 0.43 °C/100 years, respectively (Houghton et al., eds., 1990).

Air temperature fluctuations are affected above all by natural factors, among which there belong mainly solar processes, volcanism, ocean processes and by means of interactions ocean-atmosphere controlled stochastic fluctuations. On the whole, the solar influence (fluctuation of the solar constant) is assumed to be 0.2—0.3 °C in global temperature series. As for volcanism, it helps the warming of the stratosphere and the cooling of the troposphere. Hitherto analyses show that its cooling effect in the above series lies between 0.2—0.5 °C (Cress and Schönwiese, 1990).

Besides natural factors the existing temperature trend is linked up with the anthropogenically conditioned increase in trace elements (also greenhouse gases) in the Earth atmosphere which contribute to the intensification of the natural greenhouse effect. It is particularly carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O, ozone O_3 in the troposphere and chlorofluorocarbons (CFCs), above all CCl_3F (CFC-11) and CCl_2F_2 (CFC-12). Their contribution to the intensification of the greenhouse effect in the years 1980—1990, besides the effect of ozone difficult to quantify, was 55 % for CO_2, 15 % for CH_4, 6 % for N_2O, 17 % for CFC-11 and CFC-12, and 7 % for the other CFCs (Houghton et al., eds., 1990). According to the report of the Enquete-Commission of the West German Federal Parliament (1988) the shares were as follows: CO_2 50 %, CH_4 19 %, CFC-12 10 %, O_3 in the troposphere 8 %, CFC-11 5 %, N_2O 4 %, water vapour in the stratosphere 2 %, further CFCs 2 %. A conspicuous rise in concentrations of the above gases in the Earth atmosphere in comparison with the pre-industrial period is expressed in Table 1. Whereas in the years 1750—1800 their concentrations were practically stabilized, up to now the content of CO_2 increased by about 26 %, CH_4 by about 115 %, and N_2O by about 8 %. Chlorofluorocarbons were developed only in the 1930's and their most conspicuous increase falls to the 1960's and 1970's. In connection with carrying out the conclusions of the Montreal protocol their concentration should drop and/or the production of some CFCs should be stopped altogether. Many of the greenhouse gases exhibit long lifetime, so that the stabilization of their concentration at the present level would require a drastic immediate drop of their present anthropogenic emissions (see the last line in Table 1). Since the pre-industrial period the contribution to the intensification of the greenhouse effect was in CO_2 61 %, CH_4 17 % directly and 6 % by means of the concentration of water vapour increase in the stratosphere, N_2O 4 %, and CFCs 12 % (Houghton et al., eds., 1990).

Table 1. Selected characteristics of greenhouse gases (according to Houghton et al., eds., 1990)

Atmospheric concentration:	CO_2 [ppmv]	CH_4 [ppmv]	CFC−11 [pptv]	CFC−12 [pptv]	N_2O [ppbv]
– pre-industrial (1750−1800)	280	0.8	0	0	288
– present day (1990)	353	1.72	280	484	310
– current rate of change per year	1.8 (0.5%)	0.015 (0.9%)	9.5 (4%)	17 (4%)	0.8 (0.25%)
Atmospheric lifetime (years):	50−200	10	65	130	150
Reduction of human-made emissions for maintaining the present concentration (%):	>60	15−20	70−75	75−85	70−80

With respect to the importance of greenhouse gases for the changes in the climate, the Working Group III of the Intergovernmental Panel on Climatic Change (IPCC) prepared four emission scenarios based on the assumed emissions of CO_2, CH_4, N_2O, CFCs, carbon monoxide CO and nitrogen oxides NO_x from the present up to the year 2100. In making the scenarios the same assumptions were taken as the starting point as in the growth of population (9.5 thousand million in 2050 and 10.4 thousand million in 2100) and the economic growth (2−3 % per year in developed countries and 3−5 % in Eastern Europe and in the developing countries in the coming decade). The economic growth levels were assumed to decrease thereafter.

In the Business-as-Usual scenario (Scenario A) the dominating burning of fossil fuels (chiefly coal) is assumed for the production of power, the continuing felling of tropical forests, the uncontrolled agricultural emission of CH_4 and N_2O, and only partly keeping the Montreal protocol. As early as in 2020−2030 there should be a doubling of the equivalent CO_2 (to make it possible to render the effect of further greenhouse gases, their effect is expressed by a fictive additional concentrations of CO_2) and the concentrations should keep rising (Fig. 2). Scenario B is based on the control of emissions on the world-wide scale, a more intense utilization of earth gas, stopping of the deforestation and sticking fully to the Montreal protocol. At an overall growth in concentration CO_2 should not reach the double of its pre--industrial concentration by 2100, whereas the double of the equivalent CO_2 should

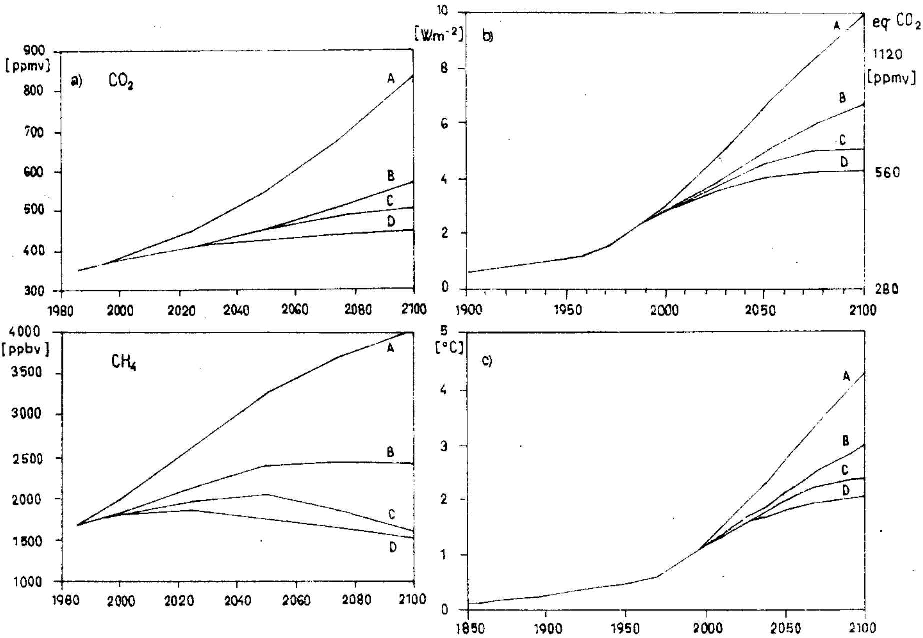


Fig. 2. Atmospheric concentration of CO_2 and CH_4 (a), increase in radiative forcing since the mid-18th century and predicted, expressed as equivalent CO_2 concentrations (b), simulations of the increase in global mean temperature from 1850—1990 due to observed increase in greenhouse gases and predictions of the best-estimate rise between 1990 and 2100 (c) resulting from IPCC Scenario A(Business-us-Usual), B, C, and D emissions (adapted according to Houghton et al., eds., 1990)

be reached about the year 2060. Scenarios C and D assume strict regulations resulting in the limitation of emissions, stopping the emissions of CFCs, limitation of agricultural emissions, introducing new technologies, utilization of nuclear energy and alternative sources of energy. CO_2 emissions should be reduced to one-half of the 1985 value in the mid-21st century, and in its latter half the increase in equivalent CO_2 concentrations should be stopped.

Linking up with the above emission scenarios, the paper by Houghton et al., eds. (1990) estimates the expected global temperatures. According to IPCC Business-as-Usual (Scenario A) emissions of greenhouse gases (Fig. 2), global mean temperature should increase during the next century by about 0.3 °C per decade (with an uncertainty range of 0.2 to 0.5 °C per decade), which corresponds e.g. to the older medium scenario according to Jäger (1988). This will result in a likely increase in global temperature about 1 °C above the present value by 2025 and 3 °C before the end of the next century. The rise will not be steady because of the influence of other factors. The other IPCC emission scenarios which will assume progressively increasing levels of controls, rates of increase in global mean temperature of about 0.2 °C per decade (Scenario B), just above 0.1 °C per decade (Scenario C) and about 0.1 °C per decade (Scenario D).

2. SCENARIOS OF THE FUTURE CLIMATE

As follows from Chapter 1, a conspicuous increase in the concentrations of greenhouse gases can, in the near future, evoke considerable climatic changes unparallelled for the period of the last 10,000 years, with many impacts on the environment and the human society. Despite the fact that the forecast of climate stands beyond the possibilities of climatology as a branch of science, it is possible to prepare qualified estimates of climatic conditions of the next period which are denoted as climatic scenarios. Each of them is, of course, biased with a different rate of uncertainty and it will be necessary to precision them currently in connection with new information. At the same time, it is necessary to understand them rather as material showing the possible trends of development than as a fully realistic picture of climatic conditions of the future. At present there are two fundamental approaches to making climatic scenarios. One starts from the method of analogy when in the history of the Earth's climate situations are looked for that might be models of the future climate, the other from modelling the climate (Fig. 3). The two approaches have their priorities and drawbacks which are below discussed in connection with making regional climatic scenarios for the region of the CSFR.

2.1 Analogue climatic scenarios

On the one hand they start from regional reconstructions of the palaeoclimate of past warm periods (palaeoclimatic scenarios), on the other hand from comparing instrumental observations in warm and cold periods (instrumental scenarios).

2.1.1 PALAEOCLIMATIC SCENARIOS

The following models of warm periods are chosen: the Medieval Warm Epoch (c. 800—1200 AD); early Holocene warmth (c. 5000—9000 BP, referred to variously as the Altithermal, the Hypsithermal or the postglacial climatic optimum); the last (Eemian) interglacial around 125,000 BP; the climatic optimum of the Pliocene (c. 3—4.5 million years).

The preceding warm periods are used as scenarios of the future climate up to the mid-21st century e.g. in the paper by Budyko and Izrael, eds. (1987) in the following way: for the year 2000 the climatic optimum of the Holocene (the assumed rise in global air temperature from the end of the 19th century by 1.4 °C); for the year 2025 the Eemian interglacial (2.5 °C) and for the year 2050 the climatic optimum of the Pliocene (3—4 °C).

The Medieval Warm Epoch is only seldom used as a possible model of the future climate. Its culmination falls to different periods in the individual regions (thus, in the region of the Alps and in the western part of central Europe probably to the period of 900—1100). Favourable iceless conditions in the northern part of the Atlantic Ocean made it possible for the Vikings to reach and populate Iceland and Greenland at that time. Grain was grown in Iceland and in Norway up to 65 °N, the limit of the forest in Canada moved at least 100 km more to the north as compared with the present and in European mountains 100—150 m higher. That was

Fig. 3. Development of climate scenarios (adapted and completed according to Meinl, Bach et al., 1984)

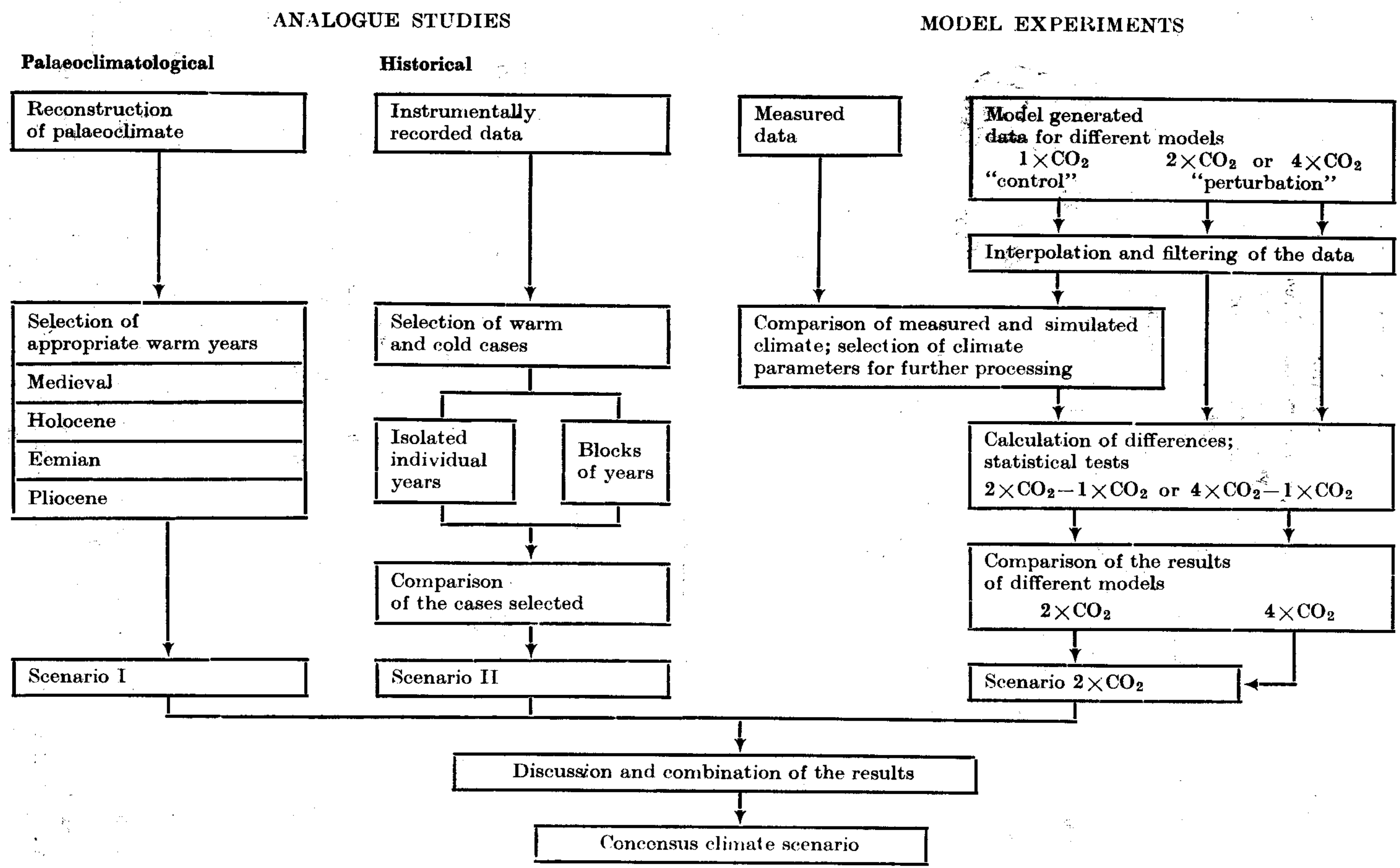


Table 2. The estimate of climatic parameters for England and Wales in different periods (simplified according to Lamb, 1977)

Period	Air temperature [°C]			Precipitation[1]	Evaporation[1]
	Year	Jul./Aug.	Winter	Year	Year
1916–1950	9.4	15.8	4.2	100	100
Medieval Warm Period[2] (1150–1300)	10.2	16.3	4.2	103	104
Climatic optimum of the Holocene (about 6,000 BP)	10.7	17.8	5.2	110–115	108–114

[1] percentage of the mean of the period of 1916–1950
[2] probably also valid for the years 900–1050

mainly due to the rise in summer temperatures, as shown by assumed temperatures for England and Wales (Table 2). In Eastern Prussia, Pomerania and southern Scotland vine growing is documented, impossible nowadays due to frequent late frosts. In Europe, south of the 60th parallel there were frequent summer droughts (Flohn, 1985). According to Lamb (1977) the above warm period was connected with the shift of the cyclone pathways by 3–5 degrees of latitude towards the north with a more frequent occurrences of anticyclonal weather in western and central Europe, conditioning warmer and drier summers. In winter there are similar situation with blocking highs characteristic of severe winters in central Europe and dry periods in Eastern Europe. From the region of today's territory of the CSFR the information relating to the Medieval Warm Epoch is very scarce. The first credible written record about the weather relating to our territory from the Czech Cosmas Chronicle comes from only 1092. Strnad's paper (1790) giving a chronological list of natural catastrophies in Bohemia since 633 and that by Augustin (1894) about droughts in Bohemia since 962 lack above all a critical evaluation of the data listed (Brázdil, 1990).

Substantially greater attention than to the Medieval Warm Epoch is paid to the conditions of the climatic optimum of the Holocene (e.g. Borzenkova and Zubakov, 1984; Ložek, 1980, 1983; Velitchko and Klimanov, 1990). The Holocene is from the point of view of the course of the Quaternary climatic cycle, equivalent to earlier warm periods, the interglacials. The diagram of the Quarternary climatic cycle in central Europe, characterized by the sequence of climatic phases repeating in a regular cycle, is shown in Fig. 4. According to Ložek (1983) it is possible to denote a certain formation as interglacial, if it is characterized by a set of sediments, soils, fauna and flora which correspond to the climate of equal temperature or warmer as is prevailing in the given locality at present. The present evidently falls into the latter half of the warm period which is generally characterized by a mild deterioration of the climate and a certain reduction of biocenoses by the most requiring species. Since, however, this evolution has so far not progressed conspicuously, we find ourselves somewhere at the turn of the middle and the last thirds of the warm period. According to Velitchko (1983) the conditions of the present interglacial are harsher than in the preceding one and the natural trend in the subsequent period should be aimed at cooling.

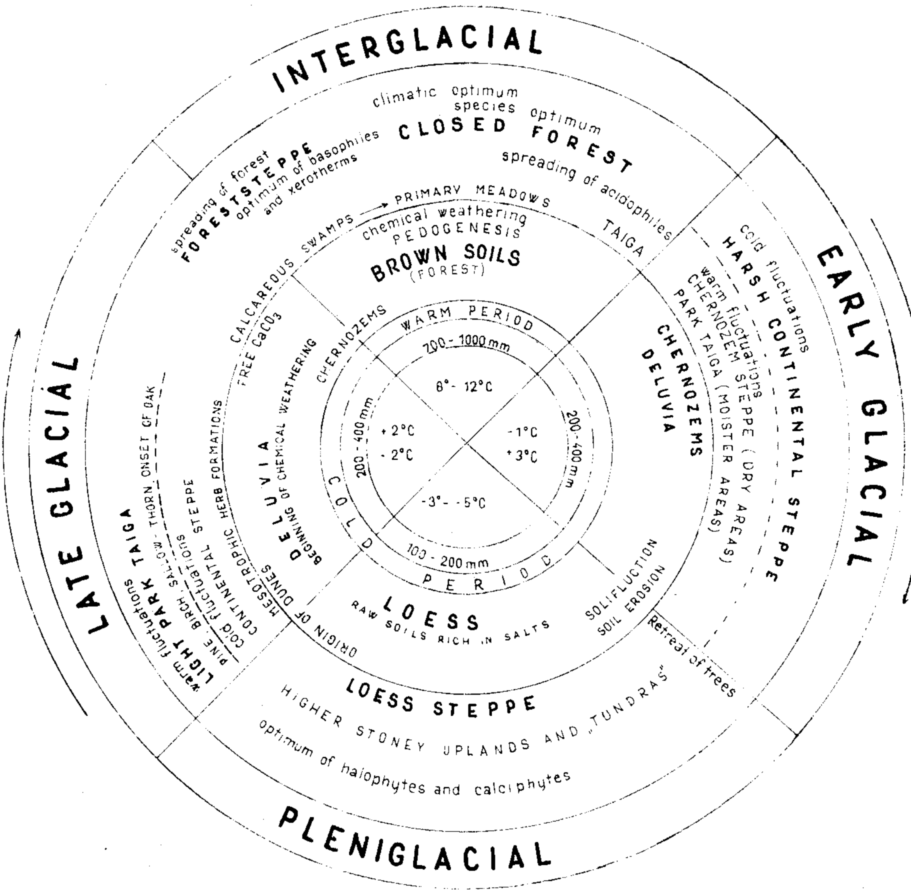


Fig. 4. Diagram of the Quarternary Climatic Cycle (according to Ložek, 1983)

In the paper by Borzenkova and Zubakov (1984) the curve of temperature changes for the belt delimited by 55 and 65 °N (Fig. 5) on the basis of the analysis of different palaeoclimatic data. It is evident from it that the fluctuation of the climate had a complex character, the most conspicuous being the following warm waves 8.9—8.8, 7.8—7.5, 6.9—6.5 and 6.2—5.3 thousand years ago. The object of the greatest interest is above all the last warm wave in the Atlantic. Temperatures in central Europe at that time were 1—2 °C higher than at present both in the annual mean, and in January and July—August (Borzenkova and Zubakov, 1984; Velitchko and Klimanov, 1990). According to the reconstruction of the July temperatures with respect to palynological data temperatures in central Europe should have been even more than 2 °C higher than at present (Huntley and Prentice, 1988), but, on the other hand, the lower localities of southern Europe should have been colder than now. Koperowa (1962) gives for the basin of Nowy Targ in Poland July temperatures higher by only 0.5 °C, January temperatures, however, by 0.8—1.5 °C higher.

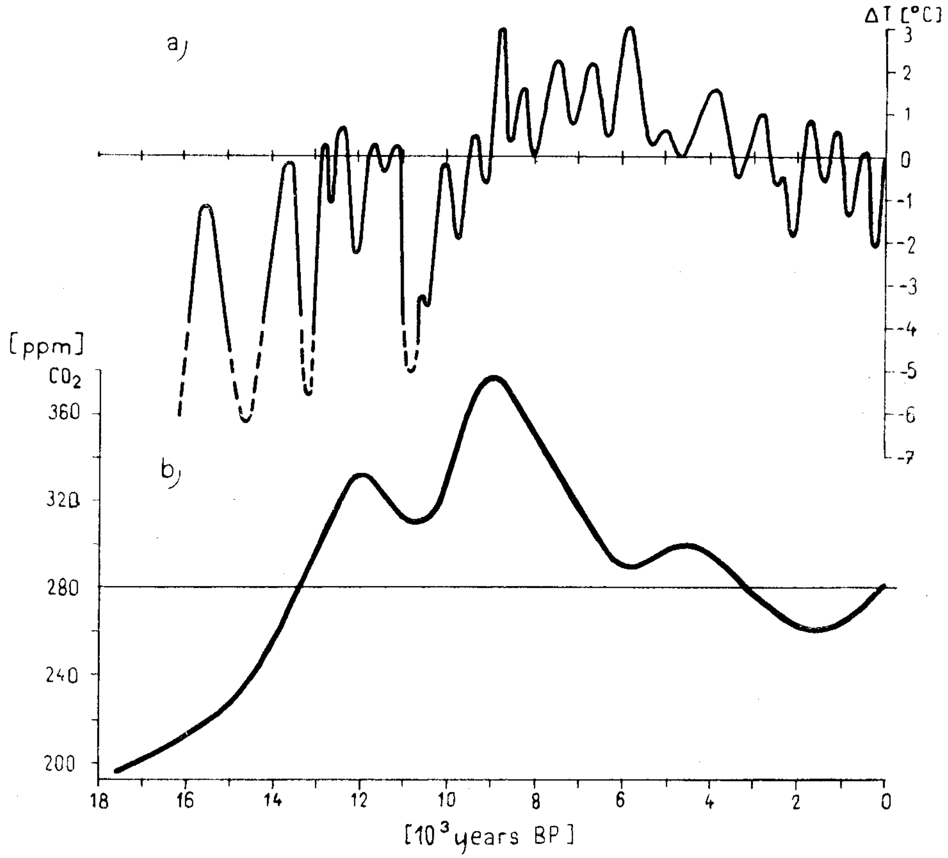


Fig. 5. The curve of changes in air temperature (a) in latitudes 55—65°N obtained by the generalization of different geological data (Borzenkova and Zubakov, 1984) and CO_2 concentration (b) averaged according to data by Berger (1978 — quotation in Budyko and Izrael, eds., 1987)

In the paper by Velitchko and Klimanov (1990) the weakening of the Greenland and the Siberian anticyclones are mentioned, as well as the intensification of the North Atlantic Current and the activation of cyclonal processes in the polar regions of the Northern Hemisphere. Although generally there were more favourable moisture conditions in the Holocene, in central parts of Europe there was as much precipitation as there is at present, or, perhaps, less (by as much as 50 mm). In the west of central Europe the precipitation should have been lower by about 5 %. The above warm period of the Holocene is put in connection with the change in the length of the perihelium, when the Northern Hemisphere accepted in summer 6—7 % more solar radiation than it does nowadays. Relatively higher — in comparison with the preceding interglacials — was also the content of CO_2 (Fig. 5) and of CH_4. These gases, according to Lorius (1991), play by their rise from the glacial to the interglacial by 40 and 100 %, respectively, an important role in the change of the climate, as follows from the analysis of ice from glacial bore holes at the Antarctic station Vostok (the radiative greenhouse forcing associated with glacial-interglacial changes is 2 W . m^{-2} which implies a temperature change of 0.7 °C without feedback).

The quoted papers and further ones point to varied changes in temperature and precipitation in the individual regions. It also follows from the analysis of the evolution of nature in central Bohemia in the Holocene carried out by Ložek (1980). After the rise in temperature in the Preboreal, a typical spread of pine and birch forests with the first requiring trees (oak, hazel, elm) the climate in the boreal (−7,700 to −6,000) has an outspoken warm character (as much as 2 °C above the present mean), and at the same time it is temporarily drier. There is a marked forestation with the onset of mixed oak forests, in many places with open enclaves of the steppe character, in drier regions typical czernozem steppes appear. In the Atlanticum (−6,000 to −4,000) the climatic optimum sets in with high temperatures (temporarily as much as 3 °C above the present average) and precipitation (in places probably by as much as 50 % higher than today). At a quick rate the spreading of forests continues; they have the character of closed mixed stands with the prevalence of oaks and other deciduous trees. It is a period of an intentional remodelling of environment with the beginning of agricultural settlement. Under the pressure of the settlement in the subsequent period of Epiatlanticum (−4,000 to −1,250) there is a general retreat of the forest in lower positions and the former forest-steppe is converted to a permanently deforested cultural steppe. From the climatic viewpoint it was a period of alternation of drier continental and more humid oceanic phases. In the unsettled regions the evolution of the forest continued by the onset of beech woods and the retreat of mixed oak forests into warm and dry positions with the onset of the hornbeam. In the Epiatlanticum closed forests are formed of a similar composition as today. The above climatic conditions correspond to those described e.g. by Jankovská (1980, 1986) for the Třeboň Basin or for the Krušné hory Mts. region.

In the climatic optimum of the Eemian interglacial the Northern Hemisphere was about 2 °C warmer than it is today on the annual average; in summer it was 1.6 °C and in winter 2.4 °C. The climate was less continental and the temperature gradient between the pole and the equator dropped, which was reflected in the change in circulation conditions in different parts of the Earth (Zubakov and Borzenkova, 1990). The rise of the sea level is documented by 5−7 m, which resulted e.g. in the isolation of Scandinavia and Finland from the continent and the flooding of a considerable part of western Siberia. A document of generally higher temperatures by 2−3 °C than today and of mild winters without long periods of frosts are finds of remains of lions, hippopotamuses and an extinct species of forest elephants from southern England and the Rhine Valley near Worms (Flohn, 1983, 1985). According to Budyko and Izrael, eds. (1987) the winter temperatures in the Eemian should have been in our region about 4 °C higher and the summer ones by more than 2 °C, the precipitation exceeding the present sums by 300−500 mm. That corresponds with the paper by Ložek (1980) according to which at that time a warm and humid climate prevailed in central Bohemia with warm winters and mean annual temperatures of 9−12 °C and precipitation of 800−1000 mm. A consequence thereof was an absolute prevalence of mixed deciduous forests of the warm character, resulting in an almost total supression of open areas that could only persist on sunny rocky slopes. The presence of some southern species contributes to a more varied species pattern of forest ecosystems.

As for the cause of the climatic optimum of the Eemian interglacial, they are analogical to the effects given for the climatic optimum of the Holocene. As stated

Table 3. The differences of values of meteorological elements in the warmest (1934—1953) and the coldest (1901—1920) 20-year periods of the 20th century on the Northern Hemisphere for selected stations and regions on the territory of the CSFR (in sunshine and precipitation the period of 1901—1920 represents 100 %, * — the compared periods of 1934—1953 and 1879—1898)

Station, region	Year	Winter	Spring	Summer	Autumn
			Sunshine duration [%]		
Sněžka Mt.	11.1	−1.2	17.1	16.1	5.4
Hurbanovo	17.9	15.8	20.4	17.1	17.1
			Air temperature [°C]		
Prague-Klementinum	0.6	−0.5	0.6	1.1	1.1
Bratislava	0.6	−0.5	0.6	1.0	1.1
Hurbanovo	0.5	−0.5	0.4	0.8	1.1
Oravský Podzámok	0.6	−0.1	0.4	0.8	1.1
			Air pressure [hPa]		
Prague-Klementinum*	0.0	−1.4	1.1	0.5	0.0
Prague-Klementinum	0.1	−0.6	0.7	0.2	−0.2
			Atmospheric precipitation [%]		
Bohemia	−1.1	−4.1	−1.5	0.6	−1.3
Moravia	−5.7	−2.5	−3.7	−7.8	−6.0
Slovakia	−0.5	−5.2	−1.0	0.9	2.5
Bohemia*	−3.6	17.1	−8.2	−8.4	−5.1

In the case of annual procipitation sums (series of areal precipitation) there should be a drop up to 6 % with an increase in the variability of precipitation (thus, the variation coefficient for Bohemia in the years 1901—1920 was 12.4 %, but in the period of 1934—1953 17.0 %). On the other hand, in the case of sunshine the annual variability drops (thus, at Hurbanovo 8.9 and 7.8 %, respectively, Sněžka Mt. 12.2. % and 11.6 %, respectively) and the number of hours with sunshine increases conspicuously (e.g. Hurbanovo as a typical lowland station exhibited an annual increase by 18 %, a typically mountainous station Sněžka by 11 %, the most conspicuous being the rise in spring by 20 and 17 %, respectively).

A problematic element in instrumental scenarios is the cloudiness which, unlike the preceding elements, is to a greater extent biased by the subjectivism of the observer. Henderson-Sellers (1986) used the same method as Lough et al. (1983) for estimating the changes in cloudiness in Europe. According to his paper the global rise in temperature on the Northern Hemisphere by 0.4 °C results in a drop of cloudiness in the region of the CSFR. To quantify the scope of this drop is, of course, problematic, because the observations used by Henderson-Sellers concerning the cloudiness of Prague are not homogeneous. It is above all the period of 1895—1918, when the observed values are very high (Coufal and Stuchlík, 1962). As a certain analogy it is possible to use observations from the station of Vienna-Hohe Warte (Auer et al., 1989), where the above warming was reflected by a drop by 0.6 tenths of cloudiness in the year and in autumn, by 0.7 tenths in spring and summer, and by 0.3 tenths in winter. That, of course, corresponds with the extension of the time of duration of sunshine in the central European region, as mentioned above.

As for air pressure, during the warming its drop in winter and its rise in summer can be observed.

The surprising drop in winter temperatures following from the above analysis is evidently a consequence of the fact that in the model warm period of 1934—1953 there were extremely cold winters of 1939/40, 1941/42 and 1946/47, because the number of temperature above average winters in the two periods of twenty years was the same in Prague. The winter cooling explained probably as due to increasing blocking appears in the whole context rather as accidental and little credible. This is, by the way, confirmed by a new analysis for the warmest (1934—1953) and the coldest (1879—1898) periods from the series of Jones et al. (1986a) in the period of 1851—1989, when the global temperature increase on the Northern Hemisphere by 0.5 °C corresponds to the increase in winter temperatures by 0.7 °C in Prague and by 0.8 °C in Bratislava. In the further periods there were following changes: Prague — year 0.9 °C, spring 1.0 °C, summer 1.1 °C, autumn 0.8 °C; Bratislava — year 0.8 °C, spring 0.9 °C, summer and autumn 0.6 °C. Compared with the preceding analysis surprising is above all the increase in differences between the two stations and the decrease in the assumed temperature increase in summer and in autumn. In the case of the precipitation series of Bohemia precipitation should drop by about 4 % (in spring and summer by 8 %, in autumn by 5 %), but in winter it should increase by 17 %.

The information about the fluctuation of the above meteorological elements are in accordance with the statement by Šebek (1990a), viz. that about the year 2030 in the summer season our territory should be prevailingly under the influence of higher air pressure, when the belt of Azores high should be extended by about 600 km more to the north. On the other hand, the winter seasons should be rather more oceanic, when numerous frontal disturbances would pass across our territory from the west or southwest.

The above information corresponds also to the paper by Mika (1988) when in the increase in global temperature on the Northern Hemisphere by 1 °C summer temperatures in Hungary should increase by 1.5 °C and winter temperatures by 1 °C, precipitation in the vegetation period should be by more than 10 % lower, the duration of sunshine and the probability of drought should exceed 60 %. In another paper Mika (1990) gives for temperature increase by 0.5 °C precipitation drop by 7—14 % and the extension of sunshine duration by 20 %.

With the aim of including the whole observation series into the estimate of temperature changes regression dependences and correlation coefficients for 5, 10, 15 and 20-year periods were calculated starting with the year 1851 and then for all periods together for the series of Jones et al. (1986a) and the series of Prague and Bratislava, respectively. As can be expected, the closeness of the correlation increases with the extension of the length of averaging from 5 to 20 years, it being lower

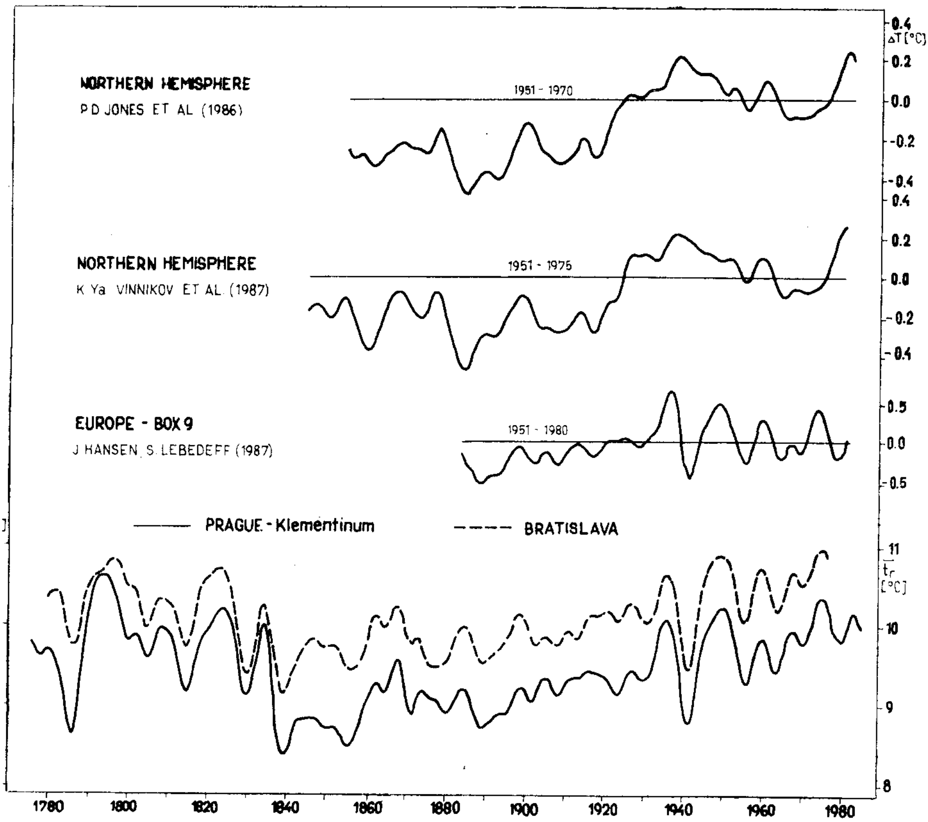


Fig. 6. Long-term changes in global anomalies of annual air temperatures ΔT of the Northern Hemisphere and "Box 9" and mean annual temperatures $\bar{t}_r$ of Prague-Klementinum and Bratislava smoothed by the 10-term Gauss filter (Brázdil, 1991)

for the Bratislava series. The rise in air temperature on the Northern Hemisphere by 0.3 °C (IPCC Scenario A) corresponds to the increase in annual temperatures in Prague by 0.5—0.6 °C, in Bratislava by 0.4—0.5 °C. Higher increase corresponding to the Prague series can be explained by including warm years 1981—1989 into the procession (the Bratislava series ends with the year 1980) and probably by a stronger manifestation of the urban heat island. That is why the estimate derived from the Bratislava series can be considered to be more realistic. Under a credible estimate of the global increase in air temperature of the Northern Hemisphere by 0.3 °C per decade (Scenario A) it would mean by the end of the century for the ter-

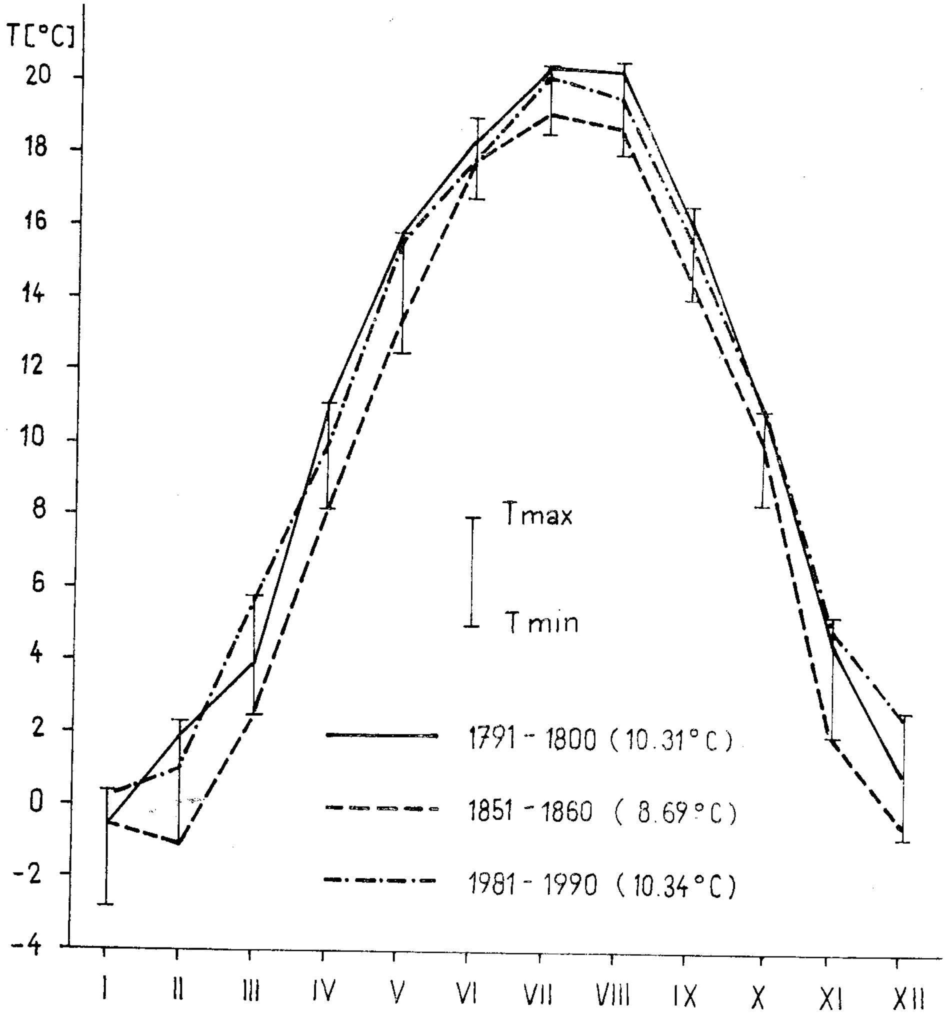


Fig. 7. The comparison of the annual variation of air temperature at Prague-Klementinum in the hitherto warmest (1791—1800, 1981—1990) and coldest (1851—1860) decades in the period of 1771—1990. Tmax indicates the highest and Tmin the lowest temperature of the given month for the decades 1771—1780, 1781—1790, . . ., 1981—1990

by Houghton et al., eds. (1990), atmospheric CO_2 reached about 300 ppm during the Eemian optimum but a more important cause of the warmth may have been that the eccentricity of the Earth's orbit around the Sun was about twice the modern value, giving markedly more radiation in the Northern Hemisphere summer. Pittock (1991), on the basis of the parallel behaviour of the two Hemispheres in the Holocene optimum (about 6,000 BP northern Australia was wetter, which is similar to the trend in the Indian sub-continent) admits the employment of that period as a partial analogy to the increase in greenhouse gases, since the direct forming mechanism seems to have been mediated through some globally symmetric process, rendering the exact cause of the warming irrelevant to the resulting spatial pattern. Some papers (e.g. Budyko, 1989; Budyko et al., 1989) stress the intensification of the effect of the changes in the parameters of the Earth's orbit by two feedbacks, one of which resulted in the decrease of the albedo and the other provided the increase in CO_2 concentration in the atmosphere.

For the climatic optimum of the Pliocene Zubakov and Borzenkova (1990) give for the Nothern Hemisphere (0—80 °N) the mean air temperature 3.6 °C higher than that at present. A relatively warm climate of the Pliocene was connected with high CO_2 concentration which was on the average twice as high as in the 19th century. The warming was also intensified by a conspicuously lower albedo of the system Earth-atmosphere which was to a considerable extent the result of warmer climate (Budyko, 1989; Budyko et al., 1989). In the climatic optimum of the Pliocene summer temperatures in our region should have been higher by 2—4 °C, in winter by only about 2 °C, and the rise in annual precipitation sums with respect to the present should not have exceeded 200 mm (Budyko and Izrael, eds., 1987).

The criticism of using palaeoclimatic scenarios (Flohn, 1990; Houghton et al., eds., 1990) is based on the fact that the past climatic situations as an analogue of possible future situations should not differ from them in the forcing factors (e.g. greenhouse gases, orbital variations) and in boundary conditions (e.g. ice coverage, topography). But both in the mid-Holocene and in the Eemian CO_2 concentrations corresponded to the pre-industrial level. The orbital perturbations increase the annual mean radiative heating in high latitudes and reduce it in the tropics (for the mid-Holocene up to 5 W . m^{-2} and -1 W . m^{-2}, respectively). The radiative forcing due to the doubling CO_2 increases everywhere, from about 2.5 W . m^{-2} in high latitudes to 5 W . m^{-2} in the tropics. The changes in orbital perturbations produce seasonal anomalies of up to 40 W . m^{-2} at certain latitudes whereas the CO_2 forcing is relatively constant throughout the year. Thus the mid-Holocene and Eemian cannot be considered as reliable analogues for a climate with increased concentrations of greenhouse gases. In the case of Pliocene the carbon dioxide levels may have been higher than present, but whether or not they were as high as double present concentration is disputed. Further the following problems are pointed out: imprecise dating of the records, especially those from the continents (uncertainties of 100,000 years or more); differences from the present day surface geography, including changes in topography (thus Tibet was at least 1000 m lower than now, the Greenland ice sheet may have been much smaller, an open Isthmus of Panama, which would have profoundly affected the circulation of the North Atlantic); the ecology of life on Earth from which many of the proxy data are derived was significantly different.

2.1.2 INSTRUMENTAL SCENARIOS

Sets of warm and cold years are selected and by comparing their characteristics a spatial picture of differences is obtained. Scenarios based on adding individual isolated warm and/or cold years do not agree with the slow evolution of the anthropogenic climatic change. A better way of simulating a gradual increase in greenhouse gas concentrations is the employment of blocks of subsequent warm and cold years. A drawback of scenarios starting from instrumental observations is the fact that they are based on a relatively small temperature change as compared with the warming conditioned by the increase in CO_2 amount and those of further greenhouse gases in the atmosphere. Therefore it is possible to use as analogons the initial phases of the warming, and one must not forget the conformity of the result of the selection of warm and cold years (for detail see e.g. Pittock and Salinger, 1982; Bolin et al., eds., 1986).

Lough et al. (1983) made a scenario of warm Europe on the basis of the comparison of the warmest (1934—1953) and the coldest (1901—1920) periods of 20 years in the present century on the Northern Hemisphere (for the series of temperature deviations according to Jones et al., 1986a, the corresponding difference is 0.4 °C). According to this scenario, at the global warming of the Northern Hemisphere by 0.4 °C, temperature rise in our region in the year and in the spring should be 0.0 to 0.5 °C, in the summer and in the autumn as much as 0.5 to 1.0 °C (read from the respective published maps). Surprising is the decrease in winter temperatures within the limits of 0.0 to —0.5 °C, accompanied by the growth of interannual variability. As for precipitation, there should be an increase within the limits of 0.0 to 0.5s in autumn (s is the standard deviation). In the other seasons of the year and in the year as a whole the picture of changes in the space of our territory is more complicated within the limits of —0.5s to 0.5s.

As essential assumption for making instrumental scenarios are sufficiently long and homogeneous series of observation including periods that are the object of comparison. In the case of urban stations it is necessary to take into account the effect of intensification of the urban heat island. This holds above all for our longest temperature series in Prague-Klementinum where the warming effect was estimated in the case of the mean annual air temperature to be 0.1 °C for a decade in the period of 1941—1980 (Němec, 1989). For comparison, Jones et al. (1989) estimate a maximum overall warming bias in all three global temperature land data sets (Jones et al., Hansen and Lebedeff, Vinnikov et al.) due to urbanisation on 0.1 °C/100 year, or less.

Table 3 shows the results of the comparison of values of different meteorological elements for the warmest (1934—1953) and the coldest (1901—1920) 20-year periods of the present century on the Northern Hemisphere for selected stations and regions from the territory of the CSFR. Thus, at the increase in global temperature of the Northern Hemisphere by 0.4 °C the mean annual air temperatures should rise by about 0.6 °C according to data from Prague and Bratislava, with the most marked increase in temperatures in summer and in autumn (1.0—1.1 °C), but a drop of winter temperatures by 0.5 °C. In comparison with the Slovak stations of Hurbanovo (Petrovič, ed., 1960) and Oravský Podzámok (Petrovič, ed., 1972) which are unaffected by the town effect, Prague and Bratislava exhibit a more marked temperature rise in spring and in summer. Surprising is only a slight cooling in winter for Oravský Podzámok. The differences established would seem to require a more detailed temporal and spatial analysis.

ritory of the CSFR an increase by 0.4–0.5 °C, by the year 2030, however, as much as 1.6–2.0 °C (Brázdil, 1991).

A relatively considerable heterogeneity of the results obtained is due to a small representativity of the global series of the Northern Hemisphere for temperature changes in central Europe, as was indicated e.g. in the papers by Brázdil (1988, 1991). This is also documented by Fig. 6 in which changes in air temperature for global series of the Northern Hemisphere of Jones et al. (1986a) are represented as well as those of Vinnikov et al. (1987) in comparison with the series of Prague and Bratislava and the temperature anomalies for Box 9 from the paper by Hansen and Lebedeff (1987) which also includes central Europe. In the case of the last three series the good agreement is well perceptible.

Whereas in global temperature series the 1980's have so far been the warmest and they included — within the temperature rise since the mid-1970's — the six so far warmest years (in the sequence 1988, 1987, 1983, 1989, 1981, 1986 — Kelly, 1990), in the case of the series of Prague-Klementinum only in the period 1981–1990 the temperature of the decade 1791–1800 was reached, that decade being so far the warmest for the whole period of the Prague instrumental observations since 1771. In Fig. 7 there are represented changes in the annual variation of air temperature in the above warmest decades and in the hitherto coldest decade, 1851–1860, when above all the months February–April and November were extremely cold. On the

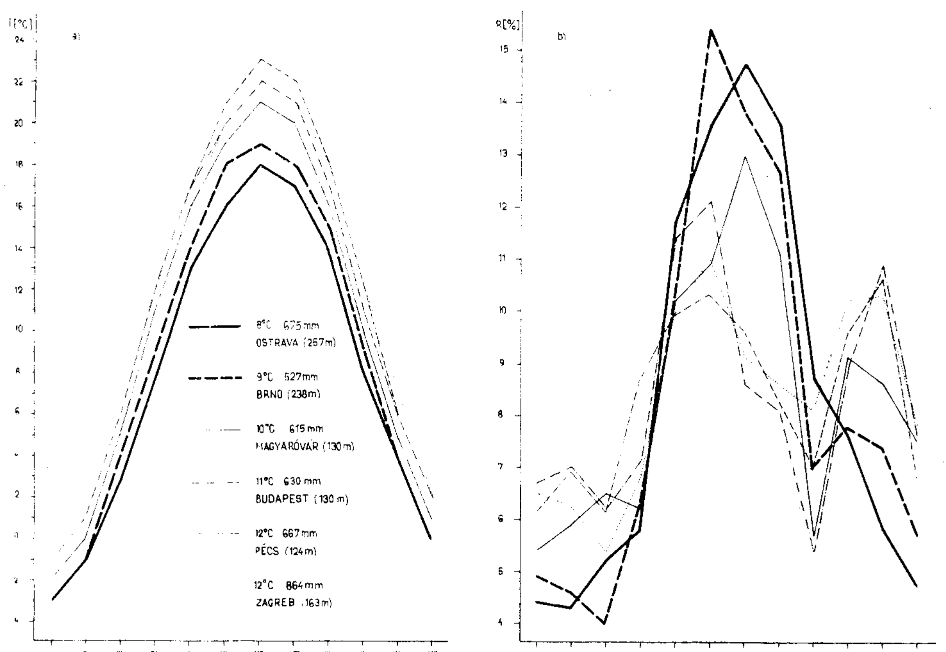


Fig. 8. Comparison of the annual air temperature variation T (a) and precipitation variation R (b), expressed in % of the annual sum, for selected stations in the CSFR, Hungary and Yugoslavia. In each station in graph (a) there is the mean annual air temperature, the mean annual precipitation sum and the height above sea level of the station. Compiled according to data by Rudloff (1981) — in Brázdil (1991)

other hand, in the decade 1791—1800 extremely warm were the months of April, May, July and October, in the decade 1981—1990 March and October, but also December and January. The former of the last two decades was warmer particularly in summer (by 0.5 °C), whereas the latter in winter (by 0.5 °C) and mildly also in spring (by 0.2 °C).

A certain analogue of the expected climatic and natural changes in the near future based on the instrumental observations can for our territory be the conditions in that part of central Europe situated to the south of our territory. If we take into consideration the fact that our warmest lowland regions have mean annual air temperatures within the limits of 8—10 °C, then about the year 2030 it could be between 10—12 °C, which at present are temperatures corresponding to the territory of Hungary or the northern lowland part of Yugoslavia. The comparison of the annual variation of air temperature and precipitation with potential stations-analogues is represented in Fig. 8. Whereas the character of the annual variation of air temperature remains practically constant with the increase in temperatures in all seasons of the year, in the precipitation its distribution in the course of the year is changed more conspicuously. The most marked is the relative weakening of summer precipitation and the intensification of autumn and winter precipitation, i.e. a change in the typical simple annual precipitation continental wave to a more balanced variation with two marked maxima.

2.2 Scenarios based on the climate modelling

Climatic models make it possible to describe not only the past and the present climates, but also the possible climatic changes linked up with the changes of certain external factors (such as greenhouse gases), by which they are well utilizable for making scenarios based on modelling the climate. The corresponding method is schematically represented in Fig. 3. According to Meinl, Bach et al. (1984) it is started with space and time filtering of the model results. The data which were originally calculated for a grid system specific to each model are then transferred to a reference grid with uniform spacing both in latitude and longitude. The data of the control experiments are compared with measured data to estimate the reliability of the model performance. The changes in climate parameters between the perturbed ($2 \times CO_2$ or $4 \times CO_2$) and the control experiments ($1 \times CO_2$) are calculated for each individual model. A comparison of the different model results ($2 \times CO_2$, $4 \times CO_2$) leads to construction of a scenario for a $2 \times CO_2$ perturbation. The sensitivity of the model climate can be studied for the time-dependent continual increase of CO_2 (equivalent CO_2) in the atmosphere (transient response studies) and/or for time-independent doubling of CO_2 (equivalent CO_2) (equilibrium response studies).

According to Bach (1988), for regional climatic scenarios models having transient response and a high spatial/temporal resolution would be ideal, but they are not available. Among the available hierarchy of climate models it is only the three-dimensional general circulation models (GCMs) that are capable of generating data of high spatial and temporal resolutions. Unfortunately, their disadvantage is their employment in time-dependent equilibrium response experiments, whereas in realistic conditions the concentrations of greenhouse gases increase rather continually.

The present models, according to Houghton et al., eds. (1990) give for the doubling of CO_2 concentration in comparison with the pre-industrial period a significant equilibrium rise in the global mean surface temperature within the limits of 1.9—5.2 °C. Most results are situated between 3.5 to 4.5 °C, which, of course, does not mean that the correct value must necessarily lie within these limits. Thus, in the quoted paper the value of 2.5 °C is considered to be the "best guess". The employed models agree in different large-scale features of the simulated changes at the doubling of CO_2 concentration. Thus, from the viewpoint of air temperature all exhibit the warming of the Earth surface and of the troposphere and the cooling of the stratosphere, increased warming in higher latitudes in late autumn and winter and higher summer warming of northern mid-latitude continents than the global mean. In the case of precipitation all models give their increase in high latitudes and the tropics throughout the year and in the mid-latitudes in winter. The application of three high-resolution models (CCC — Canadian Climate Center, Canada; GFDL — Geophysical Fluid Dynamics Laboratory, USA; UKMO — Meteorological Office, United Kingdom) was used in the paper by Houghton et al., eds. (1990) to make an estimate of regional changes since the pre-industrial period up to the year 2030 for the IPCC scenario A for southern Europe (35—50°N, 10°W—45°E). The warming should reach about 2 °C in winter and 2—3 °C in summer. The precipitation should increase in winter, but in summer it should drop by 5—15 %. As stated in the above paper, it is necessary to bear in mind the limited ability of current climate models to simulate regional climatic change and assumptions made in deriving the regional estimates.

According to Bach (1988), the general circulation models utilizable for making regional climate scenarios should be based on a realistic geography and topography, should have a high spatial and adequate temporal resolutions, should incorporate a coupled model of the atmosphere-ocean circulation and should simulate realistically the patterns of the observed climate, none of the present models fulfilling all requirements. In the quoted paper the use of the GISS-1984 model (Goddard Institute for Space Studies, USA) is discussed in detail and evaluated for the forecast of regional changes of air temperature and precipitation in the European region. From Fig. 9 it follows that in the region of the CSFR, under the doubling of CO_2 content in the atmosphere winter temperatures should increase by more than 5 °C, summer temperatures by 2—3 °C and the temperatures of the transition seasons by about 4 °C. The average precipitation rate should change from 0.2—0.4 mm/day in summer to 0.6—0.8 mm/day in spring (Fig. 10). This situation would correspond to climatic conditions which were in our region probably at the time of the Eemian interglacial or in the climatic optimum of the Pliocene (see Chapter 2.1.1).

Analogous conclusions can also be arrived at on the basis of using the GFDL model (Kaczmarek, 1991). Starting from the values of node points near the territory of the CSFR, under the doubling of CO_2 content the warming in winter and in the transition seasons of the year should reach values between 4.5—5.0 °C, which to some extent corresponds with the GISS model. In summer, of course, the assumed warming, unlike the GISS model, should be almost twice as high (between 5.2—5.5 °C). Whereas the GISS model gives for the double content of CO_2 for the central European region an increase in precipitation in all seasons of the year, the GFDL model gives for the summer season negative average precipitation rate (in the GISS model the region of the drop of precipitation is bound to western Europe — see Fig. 10). On the other hand, the two models agree in the most conspicuous rise in precipitation in spring. These facts confirm the conclusions about the utility of the models for estimating regional climatic changes presented in the paper by Houghton et al., eds. (1990).

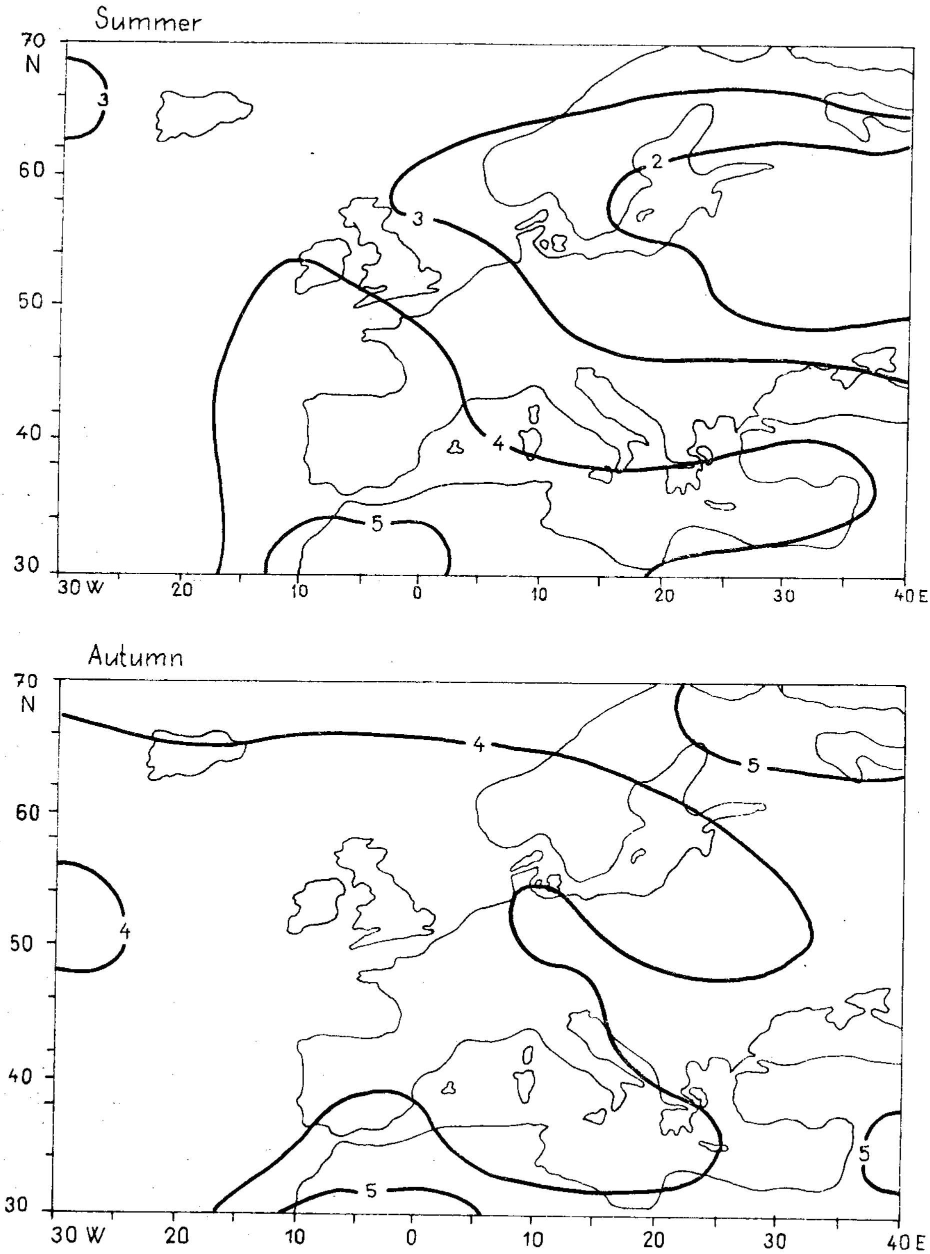
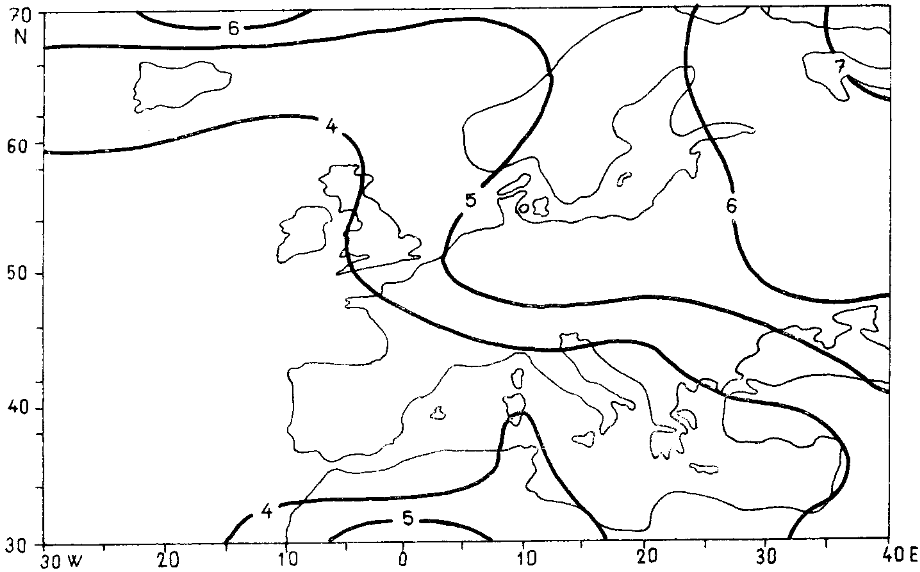
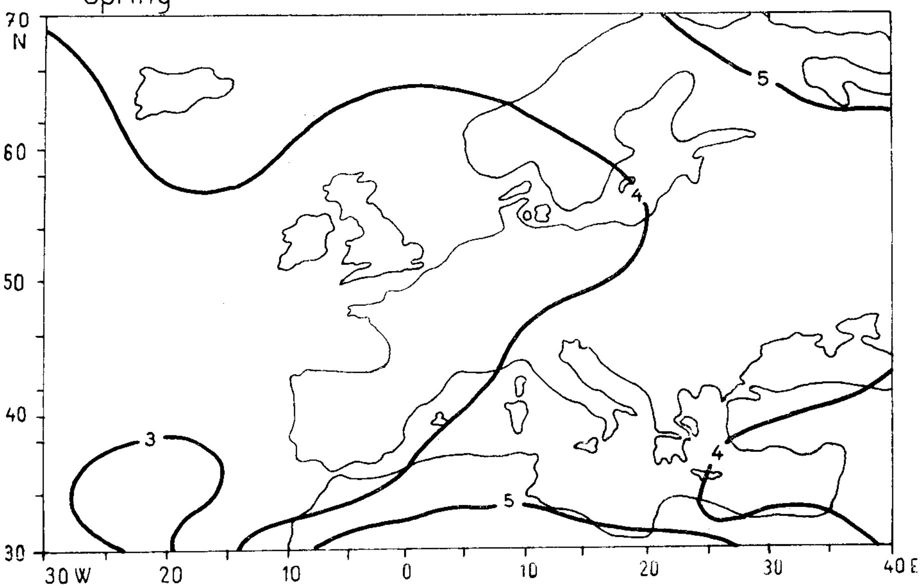


Fig. 9. Regional distribution of the average surface temperature change (°C) between the GISS model $2\times CO_2$ and $1\times CO_2$ experiments in the European region by seasons of the year. All values are statistically significant at the 5 % level (according to Bach, 1988)

Winter



Spring



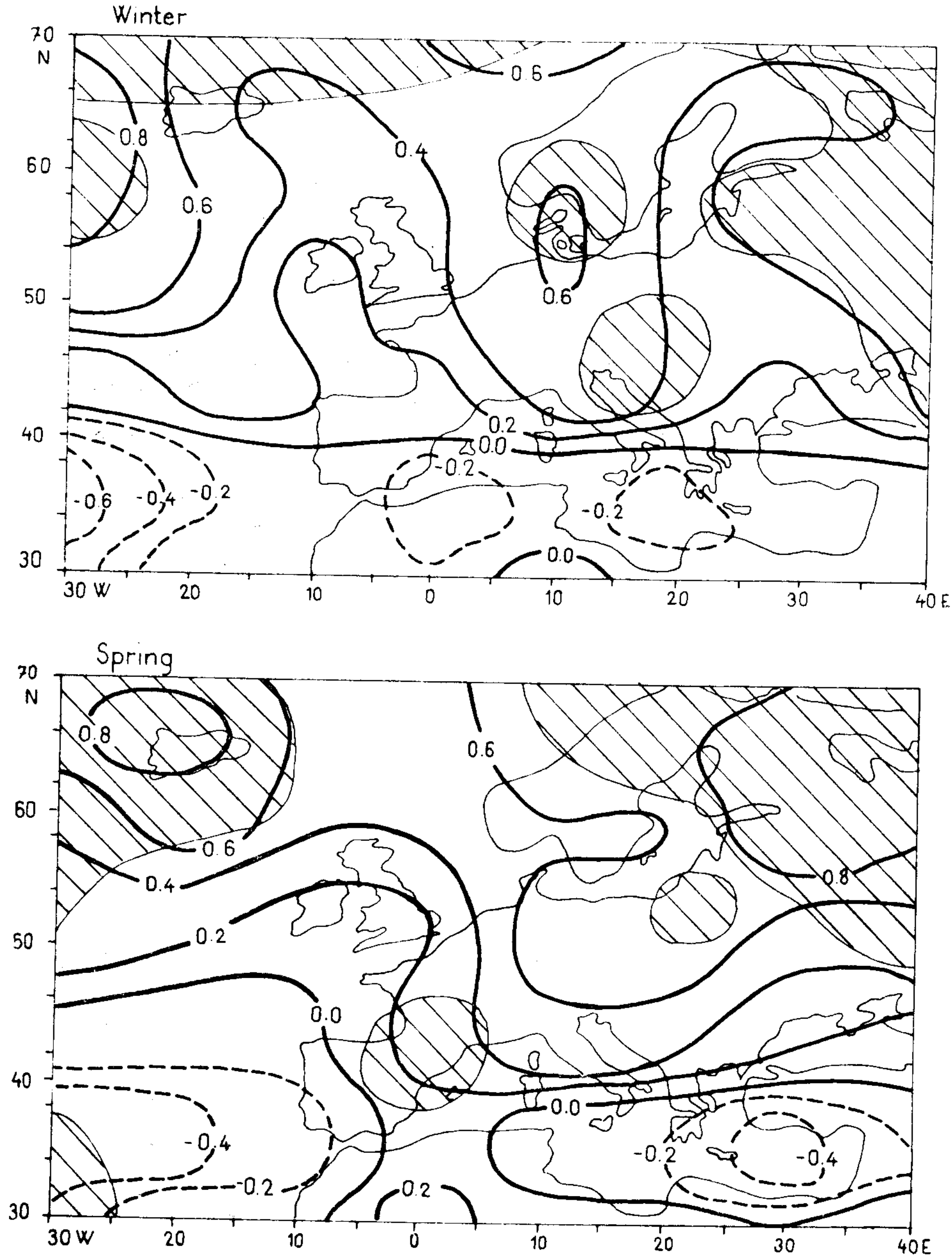
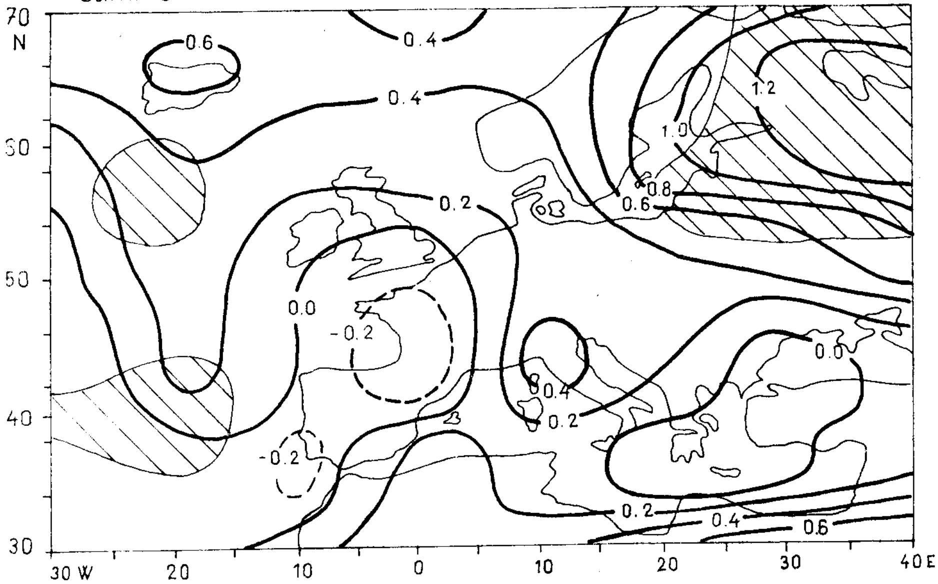
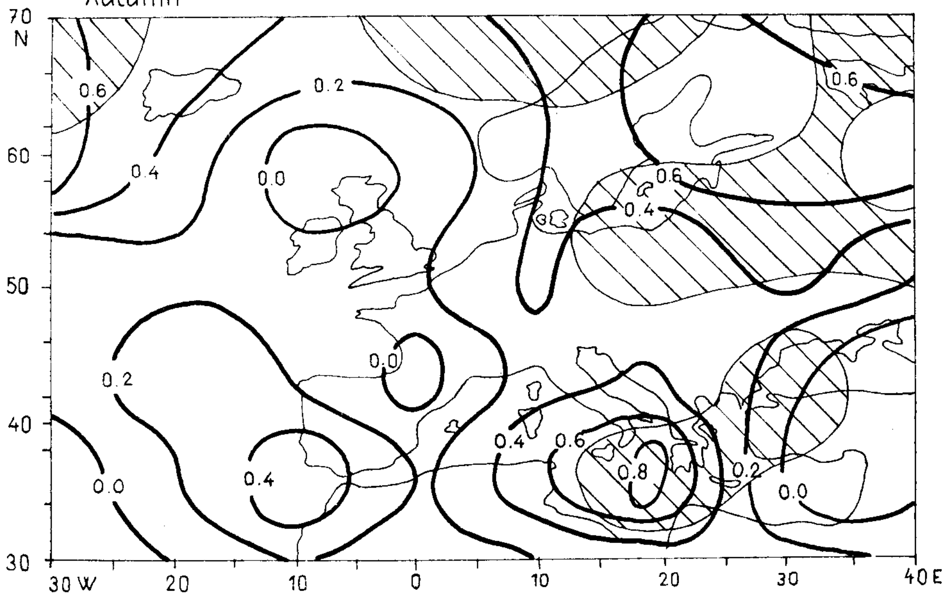


Fig. 10. Regional distribution of the change in average precipitation rate (mm/day) between the GISS model 2×CO_2 and 1×CO_2 experiments in the European region by seasons of the year. Shading indicates changes that are statistically significant at the 5 % level (according to Bach, 1988)

Summer



Autumn



3. CLIMATIC IMPACTS IN THE CSFR

The estimate of climatic changes on the environment and the society in the near future must be based on regional climatic scenarios which, as has been stated in the preceding part, have rather the character of qualified estimates of the assumed development. Despite a considerable rate of uncertainty given both by the scenarios themselves and the respective response of the environment or the society to changed climatic conditions on the Earth, the importance of the studies oriented at the estimate of climatic changes is indisputable. A complex infrastructure of modern society, requiring technical systems and large agglomeration with considerable concentration of the population are namely much more sensitive to possible impulses conditioned by the variability of the climate than was the society in the past periods. The adaptations to new climatic conditions could probably require great capital investments and the provision of a number of different measures. Thus, according to Hosokawa et al. (1991) for a 20 cm and a 110 cm sea level rise (as a result of global warming), the extra construction cost by Japanese conventional coastal works is estimated as 10,000 million and 30,000 million US dollars, respectively. This includes no construction cost for the coastal protection at the present sea level, but expresses minimal required cost due to the sea level rise.

Whereas in the CSFR with the exception of two studies by Šebek (1990a, b) practically no papers from the sphere of climatic impacts have been published, much attention is being paid to these topics abroad. Thus, a comprehensive view of the impacts on the ecosystems of the land, including agriculture and forestry is presented in the paper by Bolin et al., eds. (1986), on agriculture by Parry et al., eds. (1988) and by Parry (1990). Parry (1991) considers the potentially most important climatic changes for agriculture to be changes in climatic extremes, warming in the high latitudes, poleward advance of monsoon rainfall and reduced soil water availability. Global circulation models are used for the study of crop response in the southern Great Plains (USA) in the paper by Rosenzweig (1990), from which for the doubling of the CO_2 content wheat and corn yields will drop. On the other hand, in the European part of the USSR the expected global warming should contribute to the increase in productivity of agroecosystems (Sirotenko et al., 1990). From among further regional studies one can metion e.g. the paper by Yoshino (1990), dealing with the impacts of climate on agriculture and forestry in east Asia. In the impacts on forestry, special attention is paid to changes in boreal forests for the model of the warm Earth (e.g. Kauppi and Posch, 1985; Sargent, 1988; Kojima, 1991). A summarising view on the ecology of the forest and forest economy under the influence of the greenhouse effect is given by Thomasius (1990). Analogously to the preceding papers the potentially most important changes in vegetation are mentioned during the warming in high latitudes on the basis of the Holdridge Life-Zone Classification in the paper by Emanuel et al. (1985). Thus, Boreal Forest Zones are replaced by either Cool Temperate Forest or Cool Temperate Steppe, depending on average precipitation.

Considerable attention is also paid to climatic impacts on hydrology and water management (e.g. Gleick, 1989; Lockwood, 1989; Takahasi, 1991), when for the esti-

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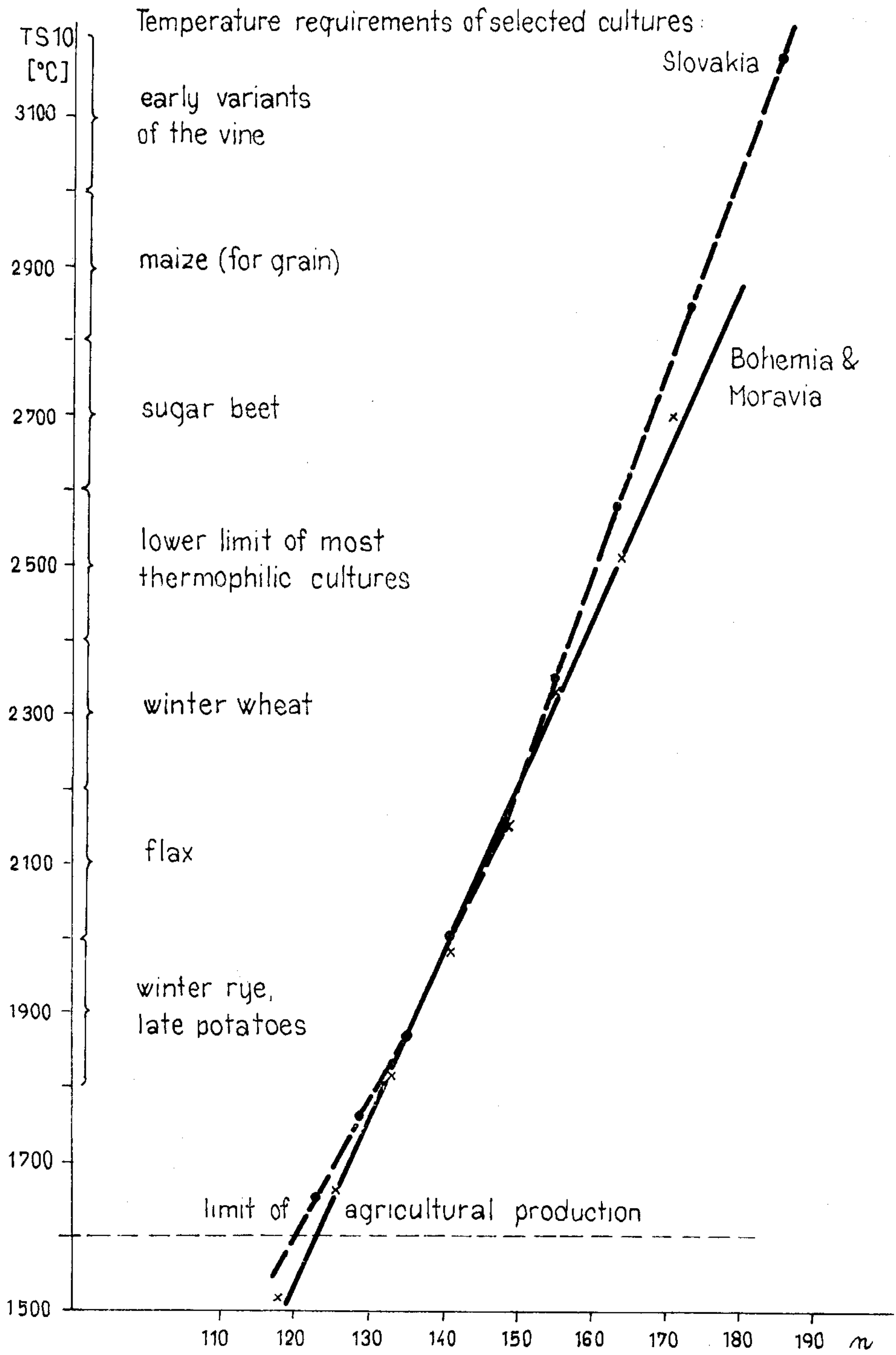
Fig. 11. A schematic representation of requirements of selected agricultural cultures for the temperature sums of the main vegetation period (TS 10) and the relation between temperature sums TS 10 and the number of days with the mean daily temperature of $\geqq$ 10 °C (n) in the period of 1931–1960 for Bohemia, Moravia and Slovakia (data according to Kurpelová et al., 1975)


Temperature requirements of selected cultures:
TS10 [°C]
early variants of the vine
maize (for grain)
sugar beet
lower limit of most thermophilic cultures
winter wheat
flax
winter rye, late potatoes
limit of agricultural production
Slovakia
Bohemia & Moravia
3100
2900
2700
2500
2300
2100
1900
1700
1500
110
120
130
140
150
160
170
180
190
n

mate of regional hydrologic impacts for the expected global climatic changes general circulation models are used (Thomas, 1990; Croley II, 1990). A specimen of an actual comprehensive study of potential impacts for CO_2-induced climatic change on the example of Ontario (Canada) can be the paper by Cohen and Allsopp (1989). A number of contributions to the set of topics of climatic impacts on the environment and the human society were also presented at the international conference in the Japanese Tsukuba in January 1991 (Abstracts, 1991).

The threat of global warming with an unsually broad scale of serious impacts call for a new paradigm of resource planning, which should incorporate at least four elements (Riebsame, 1990): resource sensitivity analysis that explicitly recognizes the potential for fundamental environmental change; stepwise adjustment tied to the increasing certainty of greenhouse effect; an enlarged range of alternative adjustments; planning in a global context and recognizing links between the causes and impacts of anthropogenic climate change.

Under the conditions of the CSFR there should be particularly important impacts on agriculture. The rise in CO_2 itself should positively affect the rate of yields. As stated by Bolin et al., eds. (1986), the doubling of CO_2 concentration should increase the harvest of corn and sugar beet by 0—10 %, wheat, soybean and rice by 10—50 %. The assumed rise in temperatures should permit growing of temperature requiring crops whose shift to a higher height above sea level (under other favourable conditions) and in some crops even two harvests per year. Negatively should operate the increase in evapotranspiration and a drop of precipitation in spring and summer seasons with the necessity of irrigation. Higher winter temperatures would be favourable for the survival of a higher amount of pests — insects and rodents. For the estimate of potential impacts on growing different agricultural plants under changed climatic conditions it is possible to use the sums of temperatures of days with mean daily temperatures $\geqq$ 10 °C (TS 10), delimiting the main vegetation period. Individual agricultural cultures require in it temperature sums of a certain size which are necessary for their ripening. In Fig. 11 the above temperatures of selected crops are marked and the dependence of temperature sums on the number of days with temperatures $\geqq$ 10 °C is presented for the period of 1931—1960 on the territory of the CSFR according to Kurpelová et al. (1975). From the relations between mean temperatures, the number of days with the mean daily temperature of $\geqq$ 10 °C and temperature sums TS 10 it is possible to estimate that the increase in temperature sums TS 10 reaches about 250 °C under warming by 1 °C. Fig. 12 shows the corresponding changes in temperature sums TS 10 depending on the elevation for the warming by 1 and/or 2 °C in comparison with the period of 1931—1960. From it the shift of temperature sums and thus also of certain crops to higher elevations is evident when the essential moisture conditions are fulfilled. Thus, for early variants of vine the warming by 1 °C in the case of Slovakia means a potential shift 100 m higher, by another degree then another 130 m higher. While in the period of 1931—1960 the warmest region of Czechoslovakia with the sum higher than 3000 °C took up only southwest Slovakia and a small area in the East Slovakian lowland, with the warming by 1 °C this area should also extend to south Moravia and with the warming by 2 °C even to central Moravia and central Bohemia (Fig. 13). It is, of course, evident that the potential impacts of the assumed warming on agriculture must be judged in the context of changes of further meteorological elements (such as radiation, evaporation, precipitation), of soil conditions, agrotechnology, etc.

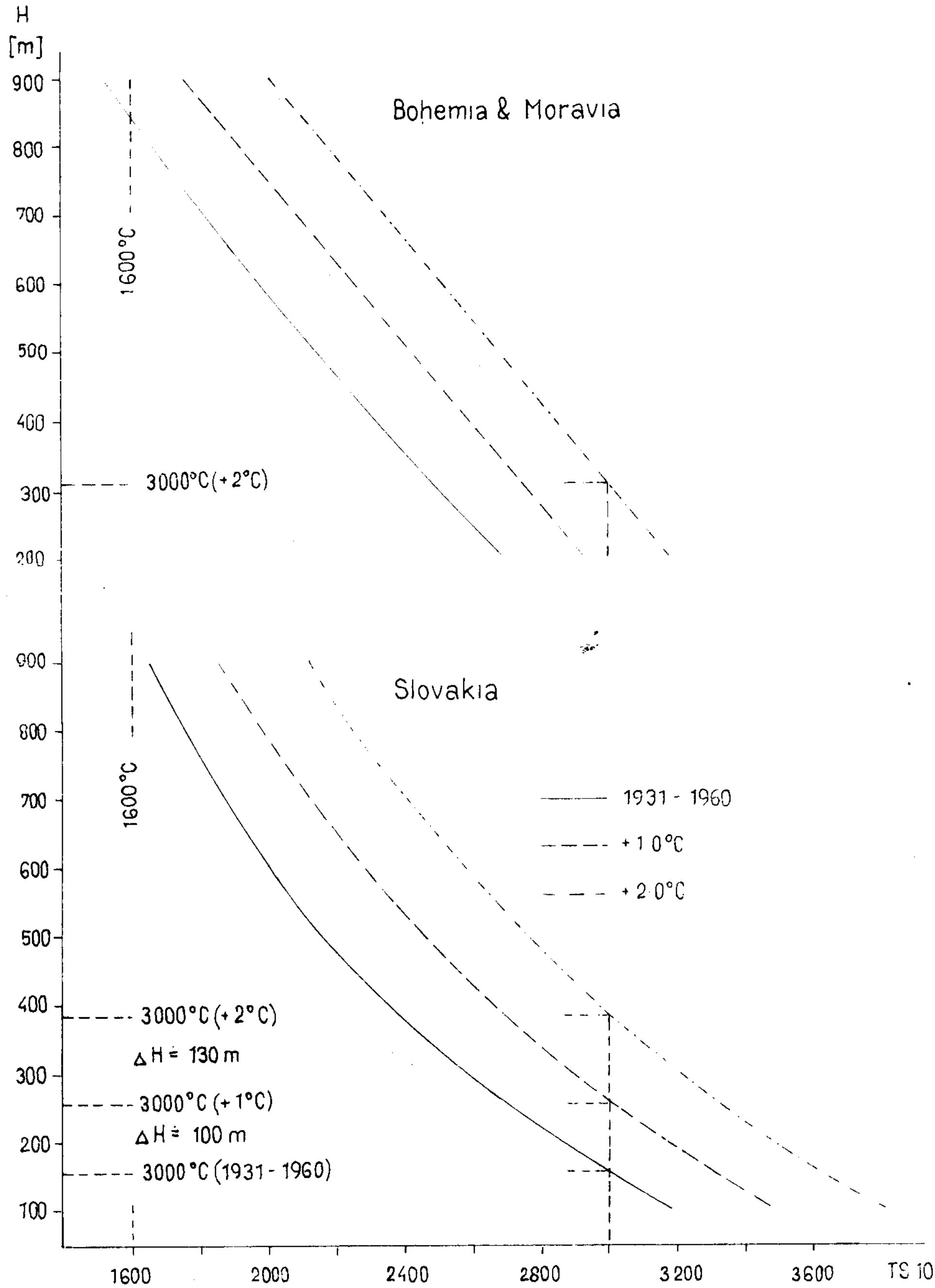


Fig. 12. Change in temperature sums of the main vegetation period (TS 10) depending on elevation in the period of 1931—1960 (data according to Kurpelová et al., 1975) and at the potential warming by 1 and/or 2 °C. In the figure are marked the corresponding changes in the height position for TS 10 = 3,000 °C and the upper limit of agricultural production (TS 10 = 1,600 °C)

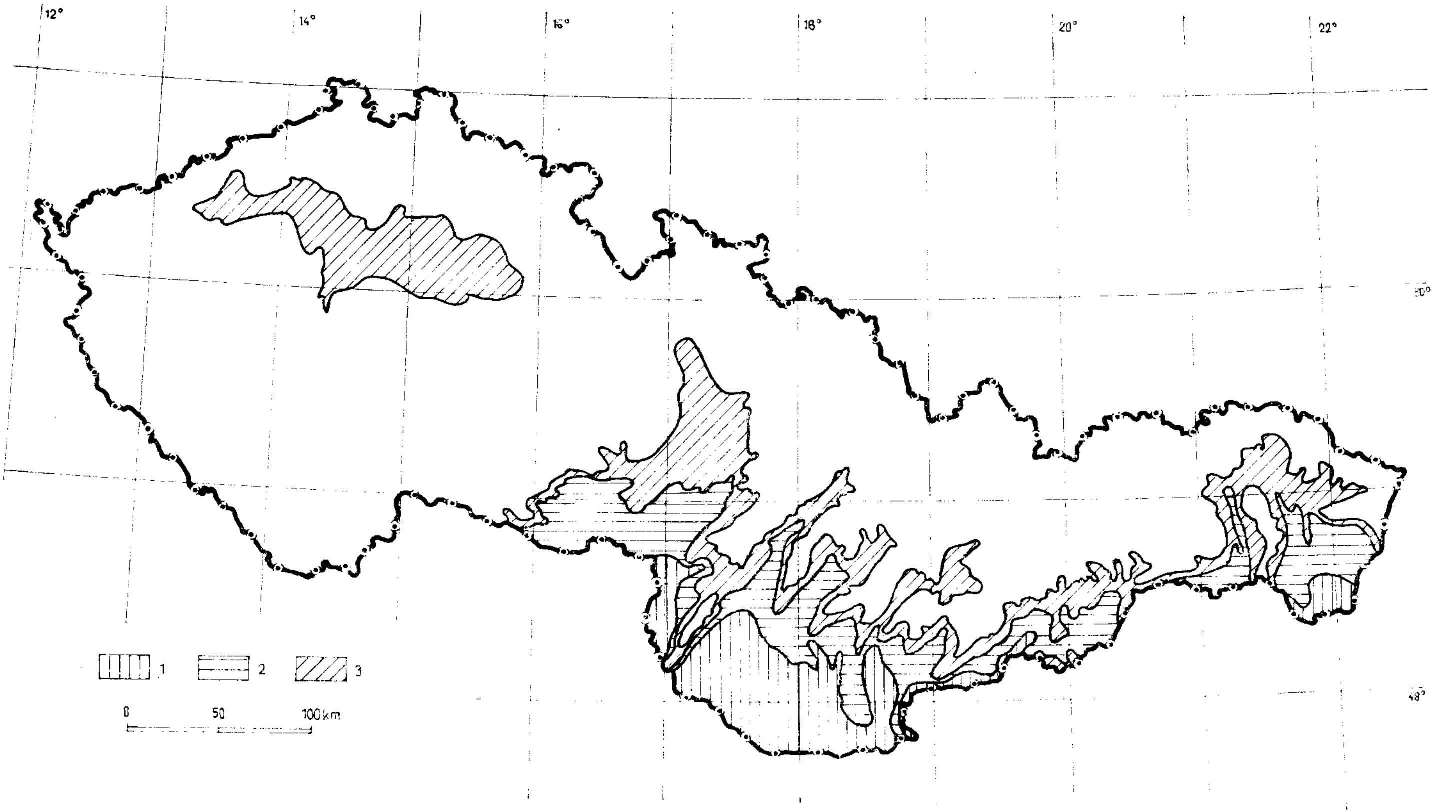


Fig. 13. A schematic representation of regions with the temperature sum of the main vegetation period TS 10 ≧ 3,000 °C in the period of 1931—1960 (data according to Kurpelová et al., 1975) and a potential extension of those regions at the warming by 1 and 2 °C, respectively, on the territory of the CSFR

Not less complicated is the complex of impacts of expected climatic changes in forestry. For about 20—30 years it has been possible to demonstrate a higher increment of annual rings (Thomasius, 1990) in sound forests of central Europe in dependence on the growing content of CO_2, the same as in the annual rings of sub-alpine conifers in the western United States (La Marche et al., 1984). The assumed warming could potentially condition the shift of forest communities to higher positions, species changes with the penetration of Mediterranean vegetation, the retreat of conifers at the cost of deciduous forests (also under the influence of exhalations), on the other hand, however, an easier survival of forest pests in warmer winters and due to more frequent dry periods in summer as well as an increased danger of forest fires. In Fig. 14 there is a dependence of forest communities on temperature sums of the main vegetation periods and annual precipitation sums. The potential warming at problematic changes in moisture conditions should be reflected both by changes in the species pattern (a shift along the x-axis), when the retreat of spruces should be replaced by the onset of oaks, greenwood beeches and lime-trees, and the communities constituted by them into higher elevations. The corresponding estimates of this type are presented in Table 4.

Despite controversial estimates of changes in atmospheric precipitation it is possible to expect significant impacts of assumed climatic changes in the water economy. In part 2.1.2 signalised drop in precipitation on the territory of the CSFR in the case of warming of the Northern Hemisphere by 0.4 and/or 0.5 °C is also reflected in

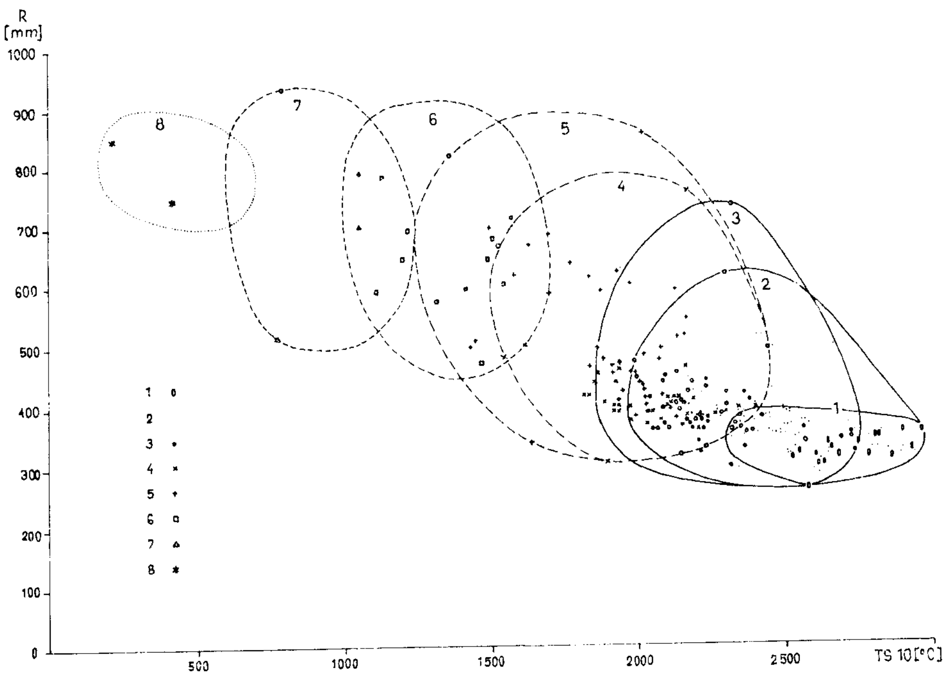


Fig. 14. The occurrence and requirements of forest communities for temperature sums of the main vegetation period TS 10 and annual precipitation sums R in Bohemia and Moravia (Matějka, 1976). The numbers of figure correspond to forest communities in Table 4

Table 4. Average vertical distribution of forest communities in Bohemia and Moravia — present situation according to Matějka (1976) (a), with warming by 1 °C (b) and by 2 °C (c) and requirements for the sum of temperatures ≧ 10 °C (TS10)

Forest communities	(a) [m]	(b) [m]	(c) [m]	TS10 [°C]
1 Subxerophilous oak forests	to 400	to 570	to 730	≧2290
2 Hornbeam-oakwoods (groves)	to 450	to 620	to 780	≧2210
3 Acidophilous oak forests, pine-oak forests	to 550	to 730	to 880	≧2030
4 Acidophilous beech forests	500— 800	680— 990	830—1140	2120—1600
5 Rich beech forests	500— 900	680—1090	830—1250	2120—1430
6 Mountain acidophilous beech forests	850—1050	1040—1240	1200—1400	1510—1170
7 Mountain spruce (climax) forests	1050—1350	1240—1540	>1400	1170— 650
8 Stands of mountain pine	1350—1500	>1540	—	650— 380

the discharge rates. Thus, the Elbe River in Děčín exhibits — in comparison of the warmest period of 1934—1953 and the coldest one of 1879—1898 — a drop by 2.3 % and even a more conspicuous drop of evaporation by 4.2 %, which is in contradiction to theoretical assumptions about the increase in evaporation in the period of warming. An analogous value of discharge rates to that of the Elbe is also exhibited by the Odra River at Gozdowice by 1.9 % (the comparison of the periods of 1934—1953 and 1901—1920); the Morava River at Moravský Ján gives for the same period an essentially greater drop by as much as 10 %. Also the annual regime of the rivers should be changed, because with the assumed warming it is possible to expect the increase in the share of the liquid precipitation and thus also of the winter runoff, and the spring inflows should be reduced due to the increase in the upper limit of the winter snow cover. This can be documented by comparing the annual runoff regime in selected years with extremely warm and cold winters at the Elbe and the Morava with their long-term means (Fig. 15). On the two rivers the highest discharge rates occur on the average in the period from February to May, with a conspicuous peak in March and April, which points to a considerable share of the runoff from the thawing snow cover as an important source of filling our rivers (Brázdil and Netopil, 1985). Irrespective of the complexity of the formation of the runoff process entered by a whole complex of factors influencing one another, after severe winters with ample snow (such as those of 1946/47, 1962/63) the maximum runoff comes in March and April, whereas after extremely warm winters with lack of snow (e.g. 1974/75, 1988/89) the share of the spring runoff is below average. Since the main source of the water of our rivers is atmospheric precipitation, its possible drop in the region of the CSFR at the beginning phase of global warming can negatively affect the water management at the assumed increase in evaporation and its growing consumption for necessary irrigation. A more conspicuous fluctuation of the water levels of ponds, rivers and reservoirs is expected as well as the decrease in the supply of ground water. More important than the mean values constituting

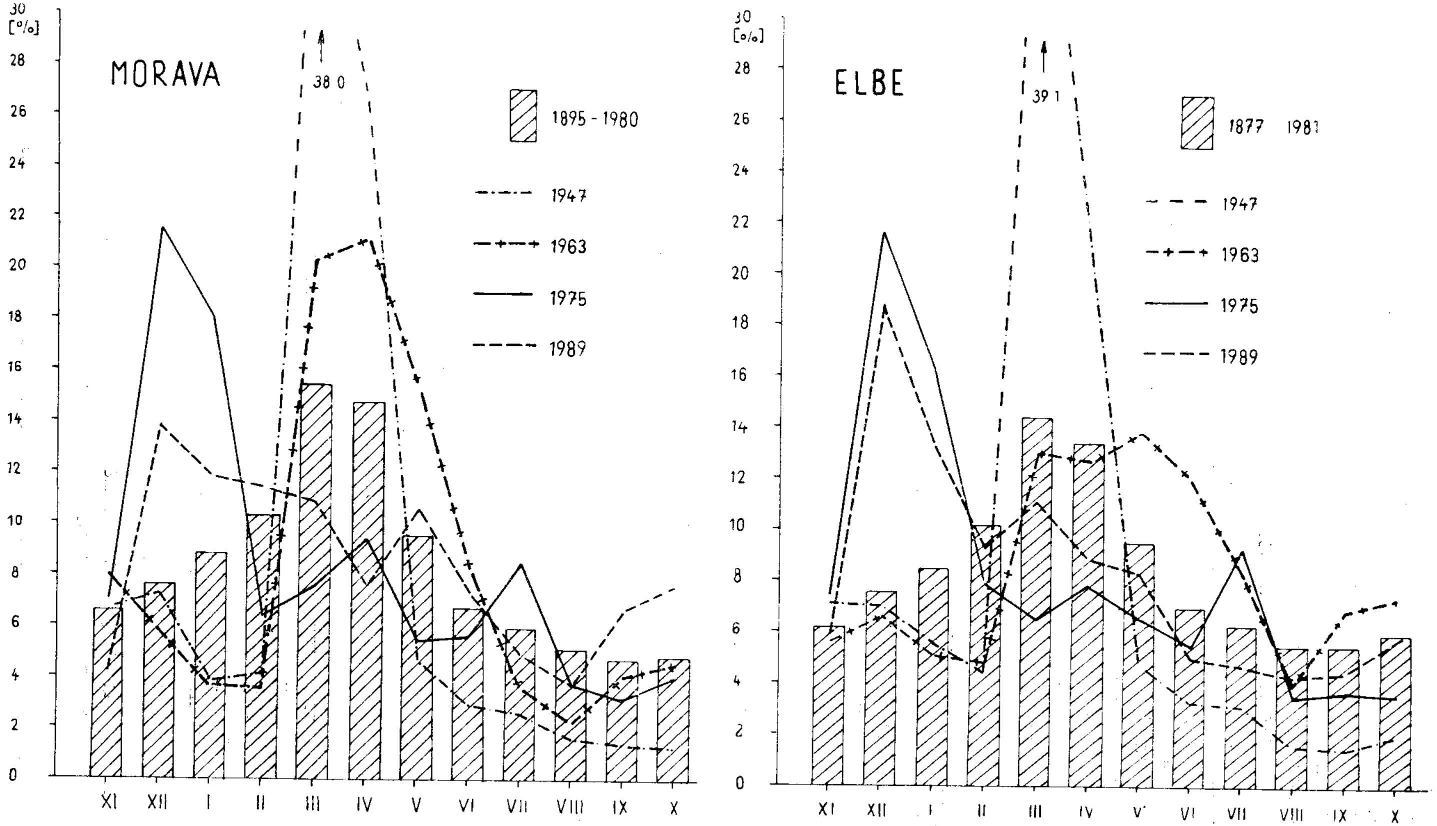


Fig. 15. Relative long-term variation of discharge rates (%) of the Elbe at Děčín and the Morava at Moravský Ján in comparison with the relative annual variation in the years with extremely cold (1947, 1963) and extremely warm (1975, 1989) winters (the year is taken as hydrological, i.e. November—October)

the basis of the estimates of the assumed changes can, of course, be extreme characteristics. As described by Benetin et al. (1990), in the past a certain amount of damage was due to floods or droughts with a low frequency of occurrence, whereas nowadays the same damage is due to hydrological phenomena with much more frequent occurrence and smaller extremity. One of the main causes of higher vulnerability by natural catastrophies is the increasing density of built-up areas and increase in population. Whereas all the available water projects are based on the stationary climatic situation, in the future water management systems should be as flexible for effective operation in future variable climatic conditions (Shiklomanov, 1991).

In a more general form than in the case of agriculture, forestry and water management the assumed climatic impacts in the CSFR can be estimated for further regions. Despite the assumed warming in all seasons, its impacts in summer and in winter can be quite controversial (Šebek, 1990a). Thus, the rise of winter temperatures can contribute to the reduction of electric power consumption, improvement of conditions for the maintenance of roads, a smaller danger of damaging delicate foodstuffs in transport during frosts, but a deterioration of conditions for the winter skiing conditions, as, after all, already signalled by very warm and poor in snow winters of 1987/88, 1988/89 and 1989/90 which, according to the observation at Prague-Klementinum, come close to the hitherto warmest winters of 1795/96, 1793/94 and 1974/75. On the other hand, warmer summers will enforce a higher consumption of electricity by introducing the necessary air-conditioning both in dwelling houses and in passenger and cargo transport, and probably improvement of conditions for summer recreation at the water bodies. The summer increase in sunshine will create potentially better conditions for utilising solar energy as an alternative energetic source; in winter, during stronger streaming potentially favourable conditions should be formed for the utilization of wind power stations. It seems that it will be necessary to count on a certain flexibility of the existing standards for the loading of structures by wind and snow. In winter there should be a drop of the sensitivity to deaths, but in summer to its increase, since, as was stated at the 1st World Climate Conference (in Šebek, 1990a), the lowest mortality rate at mean daily temperatures in our geographical latitudes is between 15.6 and 26.6 °C, and it grows to either side from this interval. From the point of view of pisciculture there should be a negative reflection of the summer lowering of the level of streams and the reduction of the oxygen content in quickly warming shallow waters.

4. CONCLUSION

The present state of the environment on the Earth and the spatial pattern of a number of activities of human society are to a certain extent a reflection of the existing climate of the Earth and in its individual parts. Conspicuous changes in the climate in the geological past of the Earth have conditioned long-term oscillations of the character of the environment whose extreme limits were given probably on the one hand by extremely warm periods of the Paleozoic and, on the other hand, by cold Quarternary glacials with extensive glaciation of the Earth. There is no doubt about the fact that climatic changes have been reflected in the evolution of man and human society when, together with other factors, they played many a time an important role. With gradual acquisition and remodelling of nature man, however, starts affecting the climate by its activities, these activities acquiring today a global extent. The global warming conditioned by the production of greenhouse gases represents a serious threat for the further development of mankind, because it can essentially affect the evolution of the environment on our planet. In this phase a thorough knowledge of the climatic system and the bonds within it, the estimate of scenarios of the future climate and their impacts on the environment and the society becomes the basis of global climatic management which must aim at the protection of the Earth's climate, as it was worded in the resolution of the Plenary Session of the UN 43/53 of 6 Dec., 1988 and in the materials of the Second World Climate Conference in November, 1990 in Geneva (Conference Statement and Ministerial Declaration). The possible future climatic changes concern all nations and inhabitants of our Earth. The complexity of the present world fosters the idea that, despite the possible improvement or deterioration of the climate within the individual countries or their parts, in the assumed change of climate there cannot be any national "winners" or "losers". Therefore, as Maunder (1991) states, it is not necessary to understand the climatic change as a threat, but as an appeal to all scientists, economists, engineers, entrepreneurs and politicians to produce a better environment for all people of all nations.

While the knowledge of the development of global climate and its impacts is relatively satisfactory, insufficient is the information concerning the change of climate on the regional scale. This is also evident from this contribution in which different approaches for making regional climatic scenarios for the region of the CSFR have been presented for the model of the warm Earth. Both analog palaeoclimatic and instrumental scenarios and scenarios based on calculations by means of general circulation models have their advantages and drawbacks, which brings in a different extent of uncertainty into the formulated knowledge about the possible evolution of the climate in the region of the CSFR. This is also projected into the estimate of the possible climatic impacts, particularly into agriculture, forestry, water management, but also into further spheres. Although at this stage the expected impacts of climatic changes in the case of the CSFR do not seem to be so serious as e.g. the expected rise of the sea level in the case of coastal countries or the possible effects on the provision of sufficient food production in a number of thickly populated countries of Asia, qualified estimates of climatic impacts can become valuable information for the managements in the near future. The comprehensiveness of the problems solved requires that it be joined, besides climatologists, also by specialists from other spheres who should evaluate the expected changes in the management of the society in the sphere of land-use, power production, water management, agriculture, etc. That would no doubt contribute considerably to improving the estimate of the expected climatic impacts. It is, however, also necessary to take into consideration the fact that the society of the 21st century may in different ways differ from the present one.

The submitted contribution represents one of the uptake materials to the topic of climatic scenarios and climatic impacts linked up with them under the conditions of the CSFR. These topics should become the object of serious research within the National Climatic Programme that is being established.

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