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AIR TEMPERATURE VARIATIONS IN THE CSSR WITH RESPECT TO AIR TEMPERATURE CHANGES ON THE NORTHERN HEMISPHERE

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On the basis of data from stations Prague-Klementinum and Bratislava variations and cyclicity of series of mean annual and monthly air temperatures on the territory of the CSSR for more than 200 years of instrumental observation is studied. In series of annual values the quasi-biennial oscillation (i. e. a period of 2.2 year) appears as a statistically significant trend, in the series of monthly values it is the annual wave. The obtained information from the territory of the CSSR is compared with analogously processed series of mean annual and monthly temperature anomalies for the Northern Hemisphere according to Jones et al. (1986) and Vinnikov et al. (1987). The procession indicates regional differences in relation to the global changes in temperature on the Northern Hemisphere.

INTRODUCTION

In recent years considerable attention has been paid in the world's climatological literature to the analysis of air temperature variations based on the series of mean temperature anomalies for the whole of the Northern Hemisphere or its part (e. g. 4, 18, 19, 21, 34, 35, 36). According to (34) the following generalizing conclusions can be drawn from the above and also from other papers:

1. In the 1940's intense warming of the Northern Hemisphere, setting on at the end of the 19th century, finished.
2. This warming was interrupted by the process of cooling which lasted from the 1940's to the 1960's.
3. In the mid-1960's the process of warming of the Northern Hemisphere is renewed and has been lasting up to the present.
4. In passing from high and middle latitudes to low latitudes there is a marked reduction in the amplitude of air temperature changes.

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5. The amplitude of temperature changes in winter markedly exceeds the corresponding amplitudes in the other seasons of the year.

These conclusions have general validity for the Northern Hemisphere as a whole; in the individual regions and/or periods and seasons smaller or greater deviations can occur. They are due to the temporal and spatial variability of circulation characteristics. The recognition of regional differences from the global climatic trend is thus important for understanding the spatial structure of these changes also with respect to creating a scenario of regional climatic changes in the future.

This holds above all also for the region of Central Europe and the CSSR, where climatic conditions are formed above all under the influence of the Atlantic Ocean, the Mediterranean Sea, and the extensive Eurasian continent. The objective of the present contribution is to judge air temperature variations in the CSSR since the 1770's up to the present, also with respect to global temperature changes on the Northern Hemisphere.

THE EMPLOYED TEMPERATURE SERIES

For characterizing temperature changes in the CSSR, series of mean monthly and annual air temperatures were used — stations Prague-Klementinum (period 1771—1985, scope of the set n = 215) and Bratislava (period 1775—1980, n = 206). Observations in Prague started by the year 1775, and they were extended to the year 1771 in (16). The location of the station has not changed so far, so that this temperature series can be considered homogeneous and representative for Bohemia. Observations in Bratislava, starting by the year 1851, were extended as far back as to 1775 in (22) by means of temperature differences with respect to Vienna. In this series no changes can be observed, either, that would impair its homogeneity.

For the analysis of temperature changes for the Northern Hemisphere two series were used. Jones et al. (18) calculated a series of annual and monthly temperature anomalies for the period of 1851—1984 ($n = 134$) with respect to the reference period of 1951—1970 for a network of points 5° latitude by 5° longitude from 1584 reliable and corrected stations. In the period of the best data coverage, 58 % of the area of the Northern Hemisphere is covered by the available data network. Vinnikov et al. (35), on the basis of the method of optimum averaging, determined a series of annual temperature anomalies for the period of 1841—1985 ($n = 145$) on the basis of 167 stations, tested for homogeneity and random errors, and of monthly anomalies for the years 1881—1985 from the data of 301 stations (reference period 1951—1975). The correlation coefficient between the two series is 0.94 for the annual values and for the monthly values it varies from 0.79 in January up to 0.89 in October.

AIR TEMPERATURE VARIATIONS IN THE CSSR

As follows from the graph of mean annual temperatures of the stations Prague and Bratislava, smoothed by five-year running averages (Fig. 1), the highest five-year running averages occurred from the beginning of the period

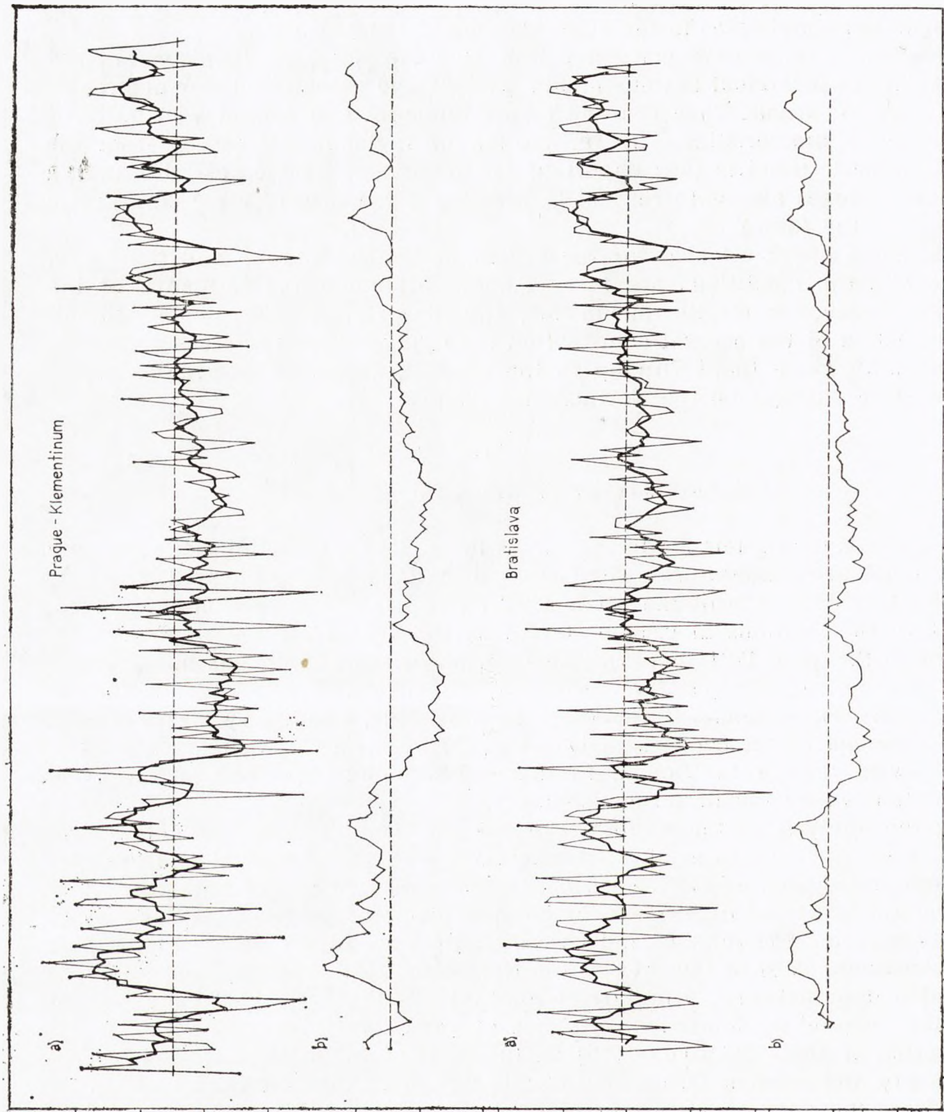

Fig. 1. The variation of annual air temperatures T of stations Prague-Klementinum and Bratislava, smoothed by five-year (*a*) and eleven-year (*b*) running averages. The horizontal line denotes the respective long-term mean.

processed up to about 1825 (particularly increase in temperature in the 1790's and about the year 1820), and further after 1930, when more pronounced increases in air temperature fell on the period about the year 1950 and the beginning of the 1970's. The period between the years 1825 and 1930 was characterized by more or less below-average five-year running values. The indicated trend is also well visible in the graph of eleven-year running averages when a

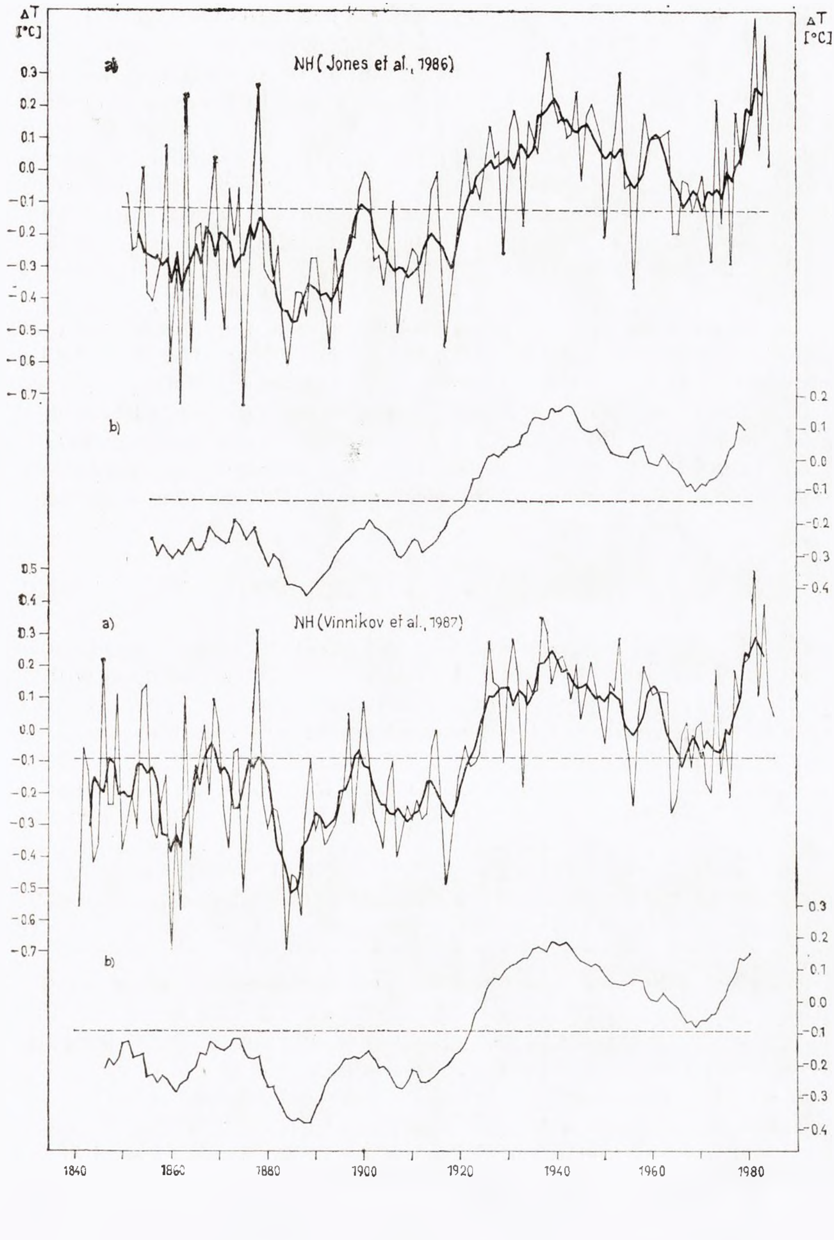

Fig. 2. The variation of mean annual anomalies of air temperature $\triangle T$ of the Northern Hemisphere (HN) according to Jones et al. (18) and Vinnikov et al. (35), smoothed by five-year (*a*) and eleven-year (*b*) running averages. The horizontal line denotes the respective long-term mean.

more or less continuous rising trend (warming) is reflected starting with about the year 1890 in Prague, and in Bratislava practically since the end of the 1870's. Despite this long-term rise in temperature the highest values of the end of the 18th century have not yet been exceeded in Prague, whereas in Bratislava the five-year running averages have equalled the above maximum and the eleven-year running averages are already slightly higher. A question remains of to what extent the heat island of the town participates in the rise mentioned, as was shown on the example of Berlin by Helbig (in 3). Analogous features in the course of the mean annual temperatures to those at the above stations can also be found e. g. in the temperature series of Cracow, Vienna and Budapest (6).

Analogously expressed course of annual temperature anomalies for the whole of the Northern Hemisphere differs conspicuously from the described course of temperatures in the CSSR (Fig. 2). The fundamental difference consists above all in the break in the increase in temperature in the 1940's and in their fall up to the 1960's, followed by another marked increase in temperatures. In the period when the warming on the Northern Hemisphere culminated there appeared a considerable drop in temperatures at the stations analyzed.

THE CYCLICITY OF AIR TEMPERATURE SERIES IN THE CSSR

Hitherto analyses of temporal changes in temperature series have shown that it is practically impossible to find in them a periodicity (perhaps with the exception of the one-year period) in the mathematical sense, i. e. for $x(t_i) = x(t_i + T)$ to hold, where $x(t_i)$ is the time series and T is the period. The periods contained in the temperature series can change their phase and amplitude, one periodic change being able to pass into another or change into an aperiodic one. The variation of temperatures has thus a quasi-periodic character that can be expressed by the term rhytmicity (25) or cyclicity (13). Schönwiese and Malcher (31) understand cyclical variations (with variable amplitude and period) as covering the whole domain between periodicity and randomness according to the pattern: $\{\text{exact period T}\} \leftarrow \{\text{cyclus T}\} \rightarrow \{\text{random variation}\}$.

The cyclicity of the processed temperature series is evaluated on the basis of methods of autocorrelation analysis, spectral analysis according to Blackman and Tukey (further B&T), and maximum entropy spectral analysis (further MESA). All these methods in the form employed in the present paper are described in (5) with references to the respective original literature.

The results of the autocorrelation analysis are shown in Fig. 3. The courses of the autocorrelation coefficients of annual temperature series of Prague and Bratislava are similar, but they do not point to the occurrence of marked periodicity and the coefficient values mostly do not start from the interval (0.20, —0.10). The confidence level of 99 % is exceeded only by the autocorrelation coefficients $r(\tau)$ for the lag $\tau = 9a$ ($r(9)$ are 0.244 for Prague and 0.187 for Bratislava), $15a$ (Prague) and $16a$ (Bratislava) (a = year). In the case of temperature series of the Northern Hemisphere there is a remarkable conspicuous persistence of the temperature series according to (18), when up to $\tau = 28a$ the respective autocorrelation coefficients exceed the confidence level of 99 % and high value are reached by autocorrelation coefficients particularly for the lag 2*a* (0.488), 4*a* (0.528) and 9*a* (0.438). This is evidently in connection with the character of the averaged series (with its lower variability) in which the noise component is rather supressed at the cost of the climatic signal proper. The second average series (35) has autocorrelation coefficients higher than the respective 99 % confidence level up to $\tau = 16a$, the highest values being reached for the lag 1*a* (0.533) and 4*a* (0.486) (Fig. 3).

The existence of a more pronounced noise component of the annual temperature series is also evident in the calculated power spectra, which is reflected by the occurrence of a series of maxima of power value for different fre-

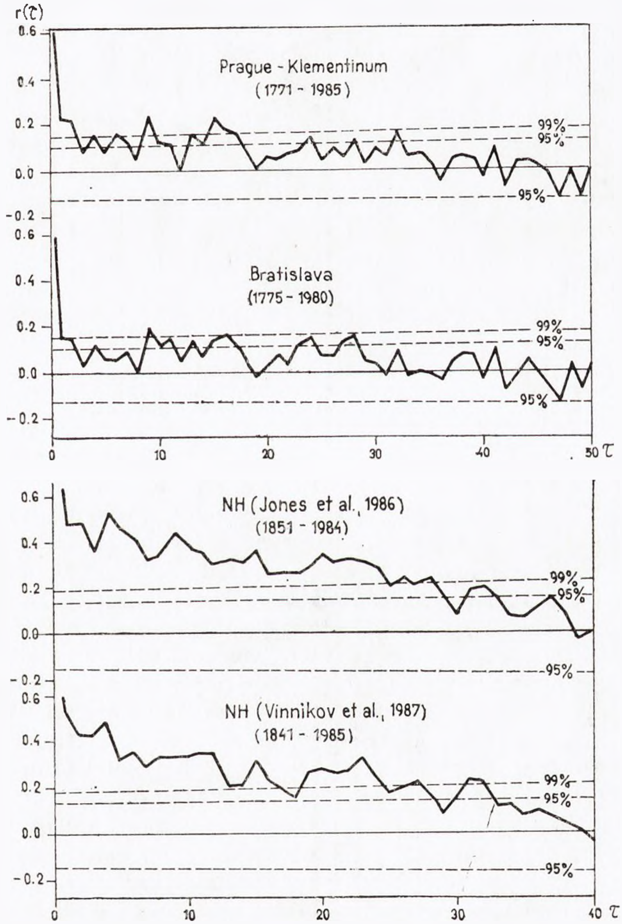

Fig. 3. The course of autocorrelation coefficients $r(\tau)$ of series of annual air temperatures of stations Prague-Klementinum and Bratislava and series of mean annual anomalies of air temperature of the Northern Hemisphere (NH) according to (18) and (35). The dashed line denotes confidence levels according to Anderson, τ — time lag.

quencies, the above power values not exceeding mostly at least 90 % confidence level, i. e., they can be considered insignificant. In the power spectra according to B&T of the temperature series of Prague and Bratislava (Fig. 4) a statistically significant trend is evident (for the confidence level of 99 %) and a significant period of the length of about 2.2*a* (for Prague for 99 %, for Bratislava for 90 %), i. e. the so-called quasi-biennial oscillation. As is known, the increase in the value of the maximum lag *m* in calculating autocovariances in the method according to B&T results in a greater resolution of the spectrum, which is reflected by the occurrence of further peaks in the spectrum. Thus, in the case of Bratislava, besides the significant period of 2.2*a*, there also appears a significant period of 2.3*a* (90 %) at $m = 50$. In general features, the B&T-spectra for the two series are practically analogous, which (also with respect to the results of the analysis in the previous part) points to the same trend of temperature changes on a large spatial scale, whereas, say, for the variation of precipitation on the territory of the CSSR (5) it holds to a substantially more limited extent. Besides the spectral analysis according to B&T also ME-spectra were calculated for the two series by the application of MESA. These spectra, as compared with the preceding ones, are characterized by a better resolution, but, on the other hand, by more or less limited possibilities for testing the results (the possible testing of the significance of the results is given in 23). Their comparison with the B&T-spectra can be seen from Fig. 4.

The significance of the quasi-biennial oscillation and the significant trend were also shown by the spectral analysis of the series of annual temperature anomalies of the Northern Hemisphere according to (18), where in the B&T-spectra there appear as significant at $m = 30$ periods of the length of 2.1*a* (95 %) and 2.0*a* (90 %), and at $m = 40$ the period of 2.2*a* (95 %). In the series according to (35) in B&T-spectra at $m = 30$ significant periods are practically of the same length as in the preceding series (2.1 or 2.0*a* for 90 %); at $m = 40$, there is, however, besides the period 2.1*a* (90 %), also a significant period of 3.8*a* (90 %). In the case of the two series the trend component is so marked that the power values falling to the other frequencies are relatively very small.

The explanation of the described differences of the two global series is evidently to be looked for not only in the unequal lengths of the series processed, but particularly in the different number and geographical distribution of the stations whose temperature series were employed for calculating the mean temperature anomalies. From the point of view of the application of the methods alone of spectral analysis an important requirement of their applicability is the fulfilment of the condition of stationarity and ergodicity of the series analyzed, which in meteorological series is very problematic. The stationarity is reflected in the fact that the mean value and the variance of the time series are constant. The ergodicity means that the average of the values of the series in the found moments converges towards the mean value of the series (for detail see 1) with the length of the interval in which the series is studied. Not keeping to this requirement of stationarity causes the results of spectral analysis to have the informing ability mainly for the period studied and it is necessary to interpret them carefully, particularly as the forecasts are concerned. Discussion of the problems of stationarity and non-stationarity of climatic series can be found in e. g. (31).

As followed from the previous analysis, besides a marked trend the most im-

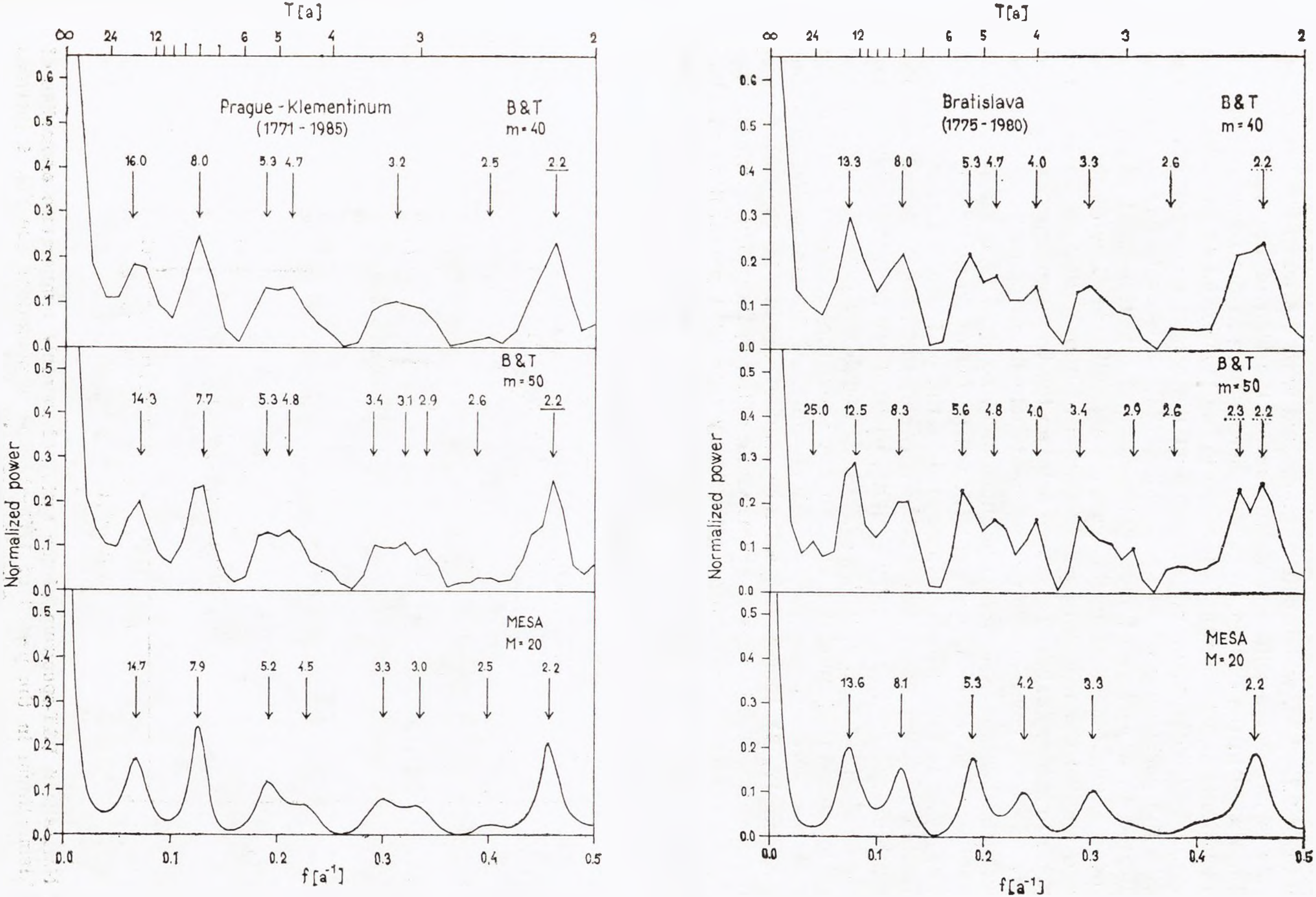

Fig. 4. Normalized power spectra of series of mean annual air temperatures of stations Prague-Klementinum and Bratislava. The standardization of the spectrum was carried out by co-ordinating value 1 to the highest power value and value 0 to the lowest one. Explanation: T — period, f — frequency, a — year; B&T-spectra: m — see text, significant periods are underlined: 90 % dotted line, 95 % dashed line, 99 % full line; ME-spectra: M — filter lenght; period — see Fig. 3.

portant components of the variation of temperature series are oscillations in the length of 2.1—2.3*a*, which can be connected with the quasi-biennial cycle. This cycle is connected with the alternation of the sign of the zonal component of the wind in the equatorial stratosphere, where in the zone between 10° northern latitude and 10° southern latitude in the layer from 18 to 35 km there is a repeated alternation of the eastern and the western components of the wind with the periodicity of 20 to 31 moths [32]. This cycle has so far been demonstrated in a variety of meteorological and climatological papers. The origin of the quasi-biennial cycle was theoretically dealt with by Pechala [24], who applied the theory of compensation of nonequilibrium states in the atmosphere to subtropical high-pressure belts on the two hemispheres. He found that they produced compensation components which are more conspicuous on the Southern Hemisphere where the subtropical zone of high air pressure is more stable and continuous, varying with the period of 26 months [i. e. about 2.2*a*]. The cysle is intensified or weakened in the period of 18 years.

Connection is often being looked for between the periods found and the cycles with characteristics of solar activity, particularly with the relative number of sunspots [see e. g. 7, 8, 17, 26, 27]. Although the periods found in the previous procession of annual series do not show the apparent conditioning [series of the Northern Hemisphere exhibit an insignificant period of about 11.4*a*], Bucha [7, 8] found that warmer winter seasons in Central Europe correspond to increased value of geomagnetic activity; the warmer winters are due to prevailing zonal streaming affected by increased penetration of electrons into lower atmosphere, and on the other hand, low values of geomagnetic

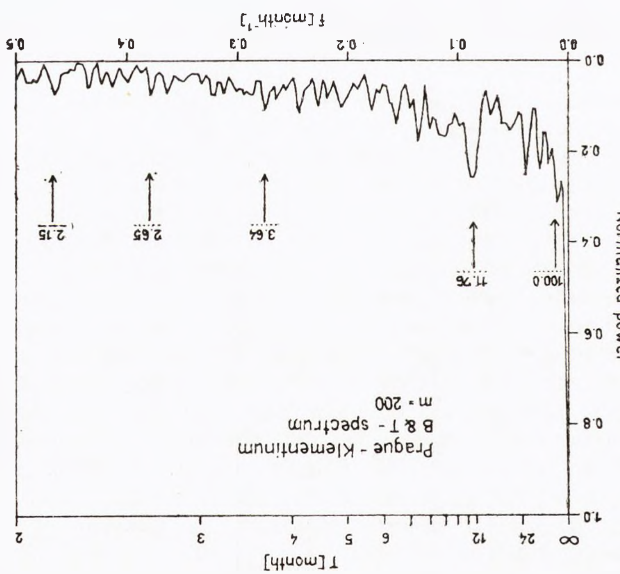

Fig. 5. Normalized B&T-spectrum of the series of monthly temperature anomalies of Prague-Klementinum in the period of 1771—1985 — explanations see Fig. 4 [periods given in months].

activity correspond to colder winter periods with prevailing meridional streaming.

As for the temperature trend for longer time and/or long-term oscillations, they are most frequently connected with changes in the chemical composition of the atmosphere, above all with the increase in CO_2 content as a result of anthropogenic activity and volcanic eruptions. The literature devoted to these problems is nowadays so extensive that only some papers can be quoted here with references to the literature in them (such as 2, 9, 10, 14, 15, 27, 28, 29, 30). Schönwiese (28) showed that 84—91 % of the long-term (but only 38—65 % of the annual data's) variance of the temperature series of the Northern Hemisphere can be explained by volcanic/solar parameters and the observed anthropogenic CO_2 increase, where the solar influence, however, is very problematic to realize.

The analysis of the series of mean annual air temperatures on the territory of the CSSR can be completed by the analysis carried out on the basis of the series of mean monthly temperatures for the above period of observation ($n = 2580$ for Prague and $n = 2472$ for Bratislava). From the results of the autocorrelation and spectral analyses it follows that in these series significant appears only the annual wave, conditioned by the seasonal rhythm of the Earth's revolution around the Sun with a corresponding more or less stable annual course of temperature. Further periods exceeding by their power values at least 90 % confidence levels appear only in the series of monthly anomalies whose spectrum, as shown on the example of Prague (Fig. 5), is conspicuously similar to the red spectrum. A considerable trend and the significant annual period are preserved here. From among periods longer than 1*a* are conspicuous oscillations of the lengths of about 8.3*a* for Prague and 3.3*a* for Bratislava in the B&T-spectrum ($m = 200$). They are also included, as practically insignificant, in the spectrum of annual series. More numerously are represented periods shorter than 1*a* (Prague gradually 3.64, 2.65 and 2.15 months, Bratislava 7.41, 3.67, 2.76, 2.65 and 2.30 months). Their causative explanation is more problematic and can evidently be attributed to circulation changes and autovariations in the climatic system itself. In the series of monthly anomalies of the Northern Hemisphere (18) the period longer than 1*a* with the power value exceeding the respective confidence levels is not represented at all, from among shorter ones than 1*a* this condition is fulfilled by periods of the length of 6.06 (the half-year wave), 4.65, 3.36, 2.38, 2.21, 2.14 and 2.04 months.

CONCLUSION

The objective of the present paper was to express some series of air temperature variations on the territory of the CSSR, also with respect to global changes in air temperature on the Northern Hemisphere. In comparing the results obtained it is necessary to take into consideration also the different lengths and the character of the series processed, as well as the possibility of the application of statistical methods. Several studies have hitherto appeared in the CSSR trying to give — from different views — at least a qualitative and, as a rule, seasonal forecast of the temperature trend of the 1980's (7, 11, 12, 33]. So far climatic models have not been used with this objective. These models, according to [20] yield, of course, only realistic estimates of global and zonal changes which can, on the regional scale, be quite different, as is, after all, shown by the present contribution. Therefore it will be necessary to orient further studies of the variations of the climate in the CSSR on the so-called diagnostic methods, starting from the analysis of climate behaviour in the period of instrumental observations and seeking for suitable analogies. For those very studies the Prague and Bratislava temperature series create the best assumptions, and the present contribution is to be understood at the same time as one of the introductory studies towards this set of problems.

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KOLÍSÁNÍ TEPLOTY VZDUCHU V ČSSR SE ZŘETELEM NA ZMĚNY TEPLOTY VZDUCHU NA SEVERNÍ POLOKOULI

Na základě údajů stanic Praha—Klementinum (období 1771—1985) a Bratislava (období 1775—1980) je metodami klouzavých průměrů, autokorelační analýzy, spektrální analýzy podle Blackmana a Tukey a spektrální analýzy maximální entropie (MESA) studováno kolísání a cykličnost průměrných ročních teplot vzduchu v ČSSR. Získané výsledky jsou porovnávány se souběžně prováděnou analýzou řad průměrných ročních teplotních anomálií severní polokoule, vypočítaných jednak Jonesem et al. (18) (období 1851—1984), jednak Vinnikovem et al. (35) (období 1841—1985). Z chodu pětiletých a jedenáctiletých klouzavých průměrů ročních teplot vyplynulo, že nejvyšší hodnoty se vyskytovaly od začátku pozorovacího období asi do r. 1825 a dále po r. 1930 s výraznějšími vzestupy teploty kolem r. 1950 a začátkem 70 let, kdy v případě Bratislavy byly dosaženy i mírně překročeny nejvyšší hodnoty z počátku zpracovávaného období. V období 1825—1930 byly hodnoty převážně podprůměrné. Víceméně souvislý vzestupný teplotní trend (oteplování) se projevuje v Praze asi od r. 1890, v Bratislavě již od konce 70. let 19. století. V obou teplotních řadách je statisticky významný trend a vystupuje v nich signifikantní perioda délky kolem 2,2 roku (tzv. kvazidvouletá oscilace). Značná podobnost charakteristik obou teplotních řad naznačuje stejnou tendenci teplot-

ních změn ve větším prostorovém měřítku. Porovnání s řadami teplotních anomálií pro severní polokouli však ukazuje na regionální odlišnosti od globálního klimatického trendu, které se projevují jak v dlouhodobém chodu teploty, tak i v charakteru variančních spekter.

Obr. 1. Chod průměrných ročních teplot vzduchu T stanic Praha—Klementinum a Bratislava, zhlazený pětiletými (a) a jedenáctiletými (b) klouzavými průměry. Vodorovná čára značí příslušný dlouhodobý průměr.

Obr. 2. Chod průměrných ročních anomálií teploty vzduchu $\triangle T$ severní polokoule (NH) podle Ionese et al. (18) a Vinnikova et al. (35), zhlazený pětiletými (a) a jedenáctiletými (b) klouzavými průměry. Vodorovná čára značí příslušný dlouhodobý průměr.

Obr. 3. Chod autokorelačních koeficientů $r(\tau)$ řad průměrných ročních teplot vzduchu stanic Praha—Klementinum a Bratislava a řad průměrných ročních anomálií teploty vzduchu severní polokoule (NH) podle (18) a podle (35). Čárkovaně jsou vyznačeny konfidenční meze podle Andersona, τ — časový posun.

Obr. 4. Normovaná varianční spektra řad průměrných ročních teplot stanic Praha—Klementinum a Bratislava. Normování spektra bylo provedeno tak, že nejvyšší spektrální hustotě byla přiřazena hodnota 1 a nejnižší hodnota 0. Označení: T — perioda, f — frekvence, a — rok; B&T-spektra: m — viz text, signifikantní periody jsou podtrženy: 90 % tečkovaně, 95 % čárkovaně, 99 % plně; ME-spektra: M — délka filtru; období — viz obr. 3.

Obr. 5. Normované B&T-spektrum řady průměrných měsíčních teplotních anomálií Prahy—Klementina v období 1771—1985 — vysvětlivky viz obr. 4 (periody jsou uváděny v měsících).

Рудольф Браздил

ИЗМЕНЕНИЯ ТЕМПЕРАТУРЫ ВОЗДУХА В ЧССР В ОТНОШЕНИИ К ИЗМЕНЕНИЯМ ТЕМПЕРАТУРЫ ВОЗДУХА СЕВЕРНОГО ПОЛУШАРИЯ

На основе данных станций Прага—Клементинум (период 1771—1985 гг.) и Братислава (период 1775—1980 гг.) методами скользящих средних, автокорреляционного анализа, спектрального анализа по Блекману и Тьюки и спектрального анализа максимальной энтропии (MESA) изучаются изменения и цикличность средних годовых температур воздуха в ЧССР. Полученные результаты сравниваются с параллельно анализированными рядами средних годовых аномалий температуры воздуха северного полушария, исчисленных с одной стороны Джонсоном и др. (18) (период 1851—1984 гг.), с другой стороны Винниковом и др. (35) (период 1841— —1985 гг.). Из графиков пятилетних и одиннадцатилетних скользящих средних годовых температур вытекает, что самые высокие величины появлялись с начала периода наблюдений приблизительно до 1825 г. и дальше после 1930 г. с более выразительными максимумами температуры около 1950 г. и в начале 1970-х годов, когда в случае станции Братислава были достигнуты и немножко превысены самые высокие величины с начала периода измерений. В период 1825—1930 были величины преимущественно больше среднего. Приблизительно связная восходящая тенденция температуры (потепление) появляется в Праге приблизительно с 1890 г., в Братиславе уже с конца 1870-х годов. В обоих рядах температуры оказывается статистически значимая тенденция, и появляется в них статистически значимый

период около 2,2 года (т. н. квазидвухлетняя осцилляция). Большое сходство характеристик обоих рядов температуры намечает на одинаковую тенденцию изменений температуры в большем пространственном масштабе. Однако сравнение с рядами аномалий температуры воздуха северного полушария показывает на региональные отличия от глобального климатического тренда, которые проявляются как в долгосрочном ходе температуры, так и в характере спектров дисперсии.

Рис. 1. Ход средних годовых температур воздуха T станций Прага—Клементинум и Братислава, сглаженный пятилетними (*a*) и одиннадцатилетними (*b*) скользящими средними. Горизонтальная линия обозначает соответствующую долгосрочную среднюю.

Рис. 2. Ход средних годовых аномалий температуры воздуха $\triangle T$ северного полушария (NH) по Джонсону и др. (18) и Винникову и др. (35), сглаженный пятилетними (*a*) и одиннадцатилетними (*b*) скользящими средними. Горизонтальная линия обозначает соответствующую среднюю.

Рис. 3. Ход коэффициентов корреляции $r(\tau)$ рядов средних годовых температур воздуха станций Прага—Клементинум и Братислава и рядов средних годовых аномалий температуры воздуха северного полушария по (18) и по (35). Штриховкой обозначены уровни значимости по Андерсону, τ — временный сдвиг.

Рис. 4. Нормированные спектральные плотности рядов средних годовых температур воздуха станций Прага—Клементинум и Братислава. Нормирование проводилось таким образом, что самая большая спектральная плотность получила величину 1 и самая небольшая величину 0. Обозначение: T период, f — фреквенция, a — год; B&T-спектр: m — см. текст, статистически значимые периоды подчеркнуты: 90 % точки, 95 % черточки, 99 % полная линия; ME-спектр: M — длина фильтра; период исчислений — см. рис. 3.

Рис. 5. Нормированные спектральные плотности ряда средних месячных аномалий температуры воздуха станции Прага—Клементинум в период 1771—1985 гг. — объяснение см. рис. 4 (продолжительность периодов в месяцах).