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MONTHLY STATISTICS OF GLOBAL AVERAGE TEMPERATURE ANOMALIES

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Мартин Иванов. МЕСЕЧНА СТАТИСТИКА НА СРЕДНИТЕ ГЛОБАЛНИ ТЕМПЕРАТУРНИ АНОМАЛИИ

Статията представлява климатично изследване с глобален мащаб. Изучават се три времеви реда от глобални средномесечни температурни аномалии на приземния въздух – за южното и северното полукълбо и за цялото Земно кълбо. Целта е да се разкрие статистическата структура на редиците, като особено внимание се обърне на дисперсията и тренда, както и на спецификата на вътрешногодишното разпределение на тези характеристики по полукълба.

В северното полукълбо максимумът на стандартното отклонение е един и се постига през зимата. Тук температурните аномалиите за месеците от топлото полугодие са по-високо корелирани. В южното полукълбо стандартното отклонение има два максимума, като основният е през зимата, вторичният – през лятото. Тук корелациите са по-високи за аномалиите на месеците от студеното полугодие. И двете закономерности са физически обяснени. Заключенията на други изследвания относно устойчивия възходящ тренд и неговия годишен ход също са потвърдени. Важен извод за дисперсията е, че тя се състои от две компоненти – едната е свързана с тренда, а другата със случайните колебания около средното състояние. И двете са количествено оценени за отделните месеци. Бързата сходимост на разлагането по емпирични ортогонални функции може да се интерпретира като още едно доказателство за наличието на тренд, което не се основава но линейна регресия.

Martin Ivanov. MONTHLY STATISTICS OF GLOBAL AVERAGE TEMPERATURE ANOMALIES

The paper presents a global scale climatic study. Three time series of globally averaged monthly mean surface air temperature anomalies are analysed—for the Southern and Northern hemispheres and for the Globe. The goal is to reveal the statistical structure of the time series paying attention especially to variance and trends and the specifics of the intraannual distribution of these characteristics in the two hemispheres.

In the Northern Hemisphere the maximum of the standard deviation is single and is attained in winter. Here the warm half-year monthly anomalies are better correlated with one another. In the Southern Hemisphere the standard deviation has two maxima, the basic one in winter and a secondary one in summer. Here correlations are higher between the cold half-year monthly anomalies. Both regularities are physically explained. The conclusions of other studies concerning the persistent rising trend and its annual cycle are corroborated. An essential inference is that variance consists of two components—one caused by the trend and the other by random oscillations about the mean state. Both of them are quantified for the distinct months. The fast convergence of the singular value decomposition can be interpreted as another proof of the existence of trend which is not based on linear regression.

Keywords: climate change, global temperature anomalies, variance, trend, correlation, random oscillations

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1. INTRODUCTION

Statistical data analysis is a standard procedure for extraction of climatic information from experimental time series, supplied by the available network of meteorological stations. Among its basic objectives is diagnosing mean tendencies in the evolution of meteorological elements—trends and revealing the statistical properties of the oscillations that coexist with these trends.

Global mean surface air temperature is the most commonly used measure of the state of the climatic system. Its variations are especially indicative as they give us an idea of the susceptibility of the climatic system to external forcing factors such as changes in carbon dioxide concentration, solar output and frequency of volcanic eruptions. This is prerequisite for adequate prediction of future climatic changes. Diagnosing global temperature trends is an actual problem nowadays when the thesis of existence of global warming is highly speculated upon.

In this paper three time series of globally averaged monthly mean surface air temperature anomalies are analysed—for the Southern and Northern hemispheres and for the Globe. The goal is to conduct a global scale climatic study by means of appropriate statistical procedures. In particular the objective is to reveal the statistical structure of the time series paying attention especially to variance and trends and the specifics of the intraannual distribution of these characteristics in the two hemispheres. That is why, the current analysis is conducted monthly. The aim of the applied principal component analysis is to derive the dominant variability patterns of the time series and to give them an adequate physical interpretation.

2. HOW THE TIME SERIES ARE OBTAINED

Stations on land are at different elevations, and different countries estimate average monthly temperatures applying different methods. To avoid bi ases that could result from these problems, the monthly average temperatures are reduced to anomalies from the climatic monthly average values for the period with best coverage (1961–1990). These data are continuously analysed and updated by The Climate Research Unit in the United Kingdom and The Hadley Centre for Climate Prediction and Research, Meteorological office. They are available from the internet site [10]. The data consist of three time series for the period 1856–2002, each of them containing 1764 monthly values. It is considered to be the most precise data base of global surface air temperature anomalies [6].

Fig. 1 visualizes the time series of global temperature anomalies for the Southern and Northern hemispheres and for the Globe.

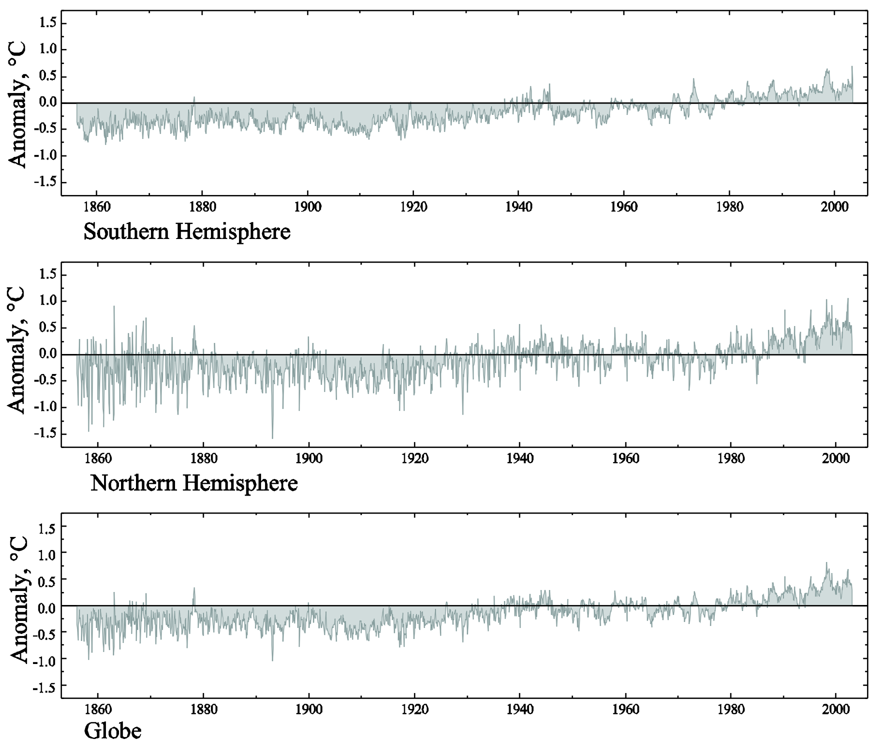

Fig. 1. The time series of global temperature anomalies for the Southern and Northern hemispheres and for the Globe. The months are on the horizontal axis and the anomalies in absolute temperature units are on the vertical. The anomalies are represented with grey lines. For better perspicuity the area between them and the zero has been filled with light grey

In all time, series the anomalies are negative in the beginning and then they grow to become positive after the mid seventies of the last century. Because of the fact that they have been calculated against the monthly mean values for the 1961–1990 period, before the mid seventies of the last century as a rule global temperatures are lower than the base period monthly means, and after that they are higher. So, there is evidence for a systematic global warming, going on synchronously in both hemispheres and the entire Earth. Linear estimates of the trend applied to the time series of annually averaged anomalies for the whole period give us grounds to affirm that in the course of the last 140 years global temperature has risen with about 0.7°C. This result coincides with the one in [2].

3. DESCRIPTIVE STATISTICS OF THE DATA

Fig. 2 presents the descriptive statistics of the data in the concise form of a box plot diagram. It contains the mean values, the standard deviations, the first and the ninety-ninth percentiles and the extreme monthly values of the anomalies. The monthly average value is calculated using all the 147 years.

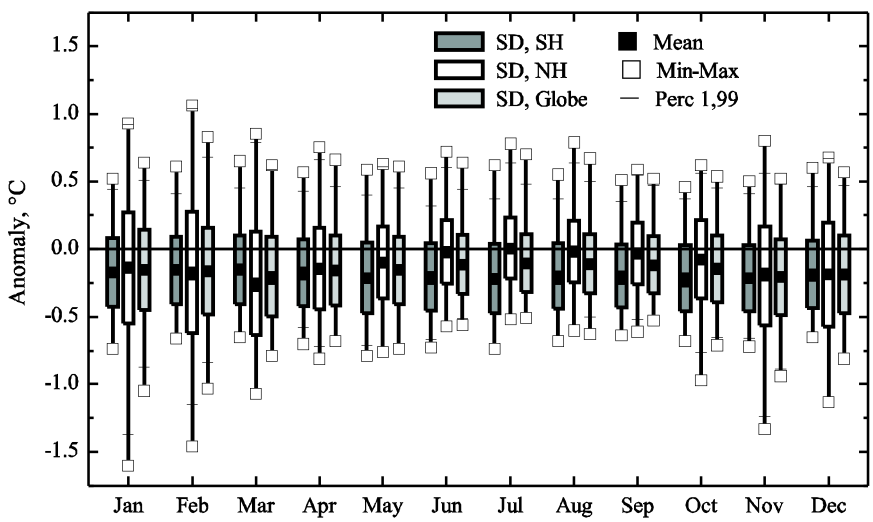

Fig. 2. Descriptive statistics of the mean monthly anomalies for the Southern and Northern hemispheres and for the Globe for the period 1856–2002. The x-axis represents months and the y-axis—the temperature anomalies in absolute degrees. The rectangles stand for the standard deviations and the small black filled squares in their centres represent the mean monthly values. The blank small squares stand for the extreme values and the small horizontal lines for the percentiles. Falling vertical lines visualize the range of monthly variation. Dark grey and white indicate the Southern Hemisphere and the Northern Hemisphere, respectively, and light grey—the Globe

Is the annual cycle of the mean monthly anomaly statistically significant? It is sufficient to estimate the statistical significance of the difference between a summer and a winter month—e.g., January and July. A nonparametric approach, called Wilcoxon Matched Pairs Test [4], has been applied. The result of the one-sided test shows that for all three time series the zero hypotheses can be rejected with a significance level less than 1.3%. So on the basis of the information contained in the data we have a good reason to assert that the absolute values of January anomalies are higher than the values of July anomalies for the Northern Hemisphere and the Globe. The opposite situation occurs in the Southern Hemisphere.

In both hemispheres the absolute values of the anomalies are larger in winter lower in summer. Concerning the Globe, the annual cycle of the anomalies follows that in the Northern Hemisphere, but with smaller amplitudes.

Concerning the extreme values of the anomalies, for all three time series the maxima are concentrated in the last 5–6 years, especially in 1997–1998. The absolute minima, with few exceptions, are observed in the 19th century. The concentration of positive anomalies about 1997–1998 ought to be assigned to the fact that exactly then the mightiest of all occurrences of the El Niño phenomenon for the last 50 years of precise instrumental observations was recorded [9].

Let us turn our attention to the second statistical moments. The standard deviation in the Northern Hemisphere is greater in winter with a maximum in February and a minimum in September. In the Southern Hemisphere it is comparatively uniformly distributed throughout the year with a relatively high maxima in May and January and minima in September and April. The yearly cycle of mean monthly anomalies for the Globe is well pronounced and follows that in the Northern Hemisphere. The standard deviation is greater in Northern Hemisphere winter months with a maximum again in February.

What is the explanation of the observed annual cycle of the standard deviation? Above all, we have to take into consideration the fact that a trend exists in all three time series. It certainly contributes a lot to the monthly variances. Random oscillations in turn partially contribute to the monthly variance. The component of monthly variance, explained by the trend, is greater during winter months which have a higher trend [5]. In the Northern Hemisphere the component of variance ascribed to random oscillations, comes to a maximum during the cold half-year as well. The reason lies in the greater baroclinic instability of the western flow in winter because of the greater thermal gradient between the equator and the North Pole. This leads to a more intense meridional exchange of air masses and consequently to more considerable interannual fluctuations. Thus, both components of the monthly variance are higher in winter months. That is, why in the Northern Hemisphere the monthly variance itself attains its maximum in winter.

In the Southern Hemisphere things are a bit different. Again the component of the monthly variance, attributable to the trend is higher in winter [5]. This explains the peak of the standard deviation in winter months. However, the component due to oscillations, associated with baroclinic instability comes to a maximum in the warm half-year. The reason is that, in contrast to the Northern Hemisphere,

here the strongest meridional temperature gradients in the middle latitudes are found in the summer months [7]. This explains the secondary peak of the standard deviation in winter. It is smaller than the first one because, as we shall see, the trend attributes a great deal more to the monthly variance than the oscillations do.

In the Northern Hemisphere the monthly standard deviations are higher than the Southern Hemisphere ones, pertaining to the same season. The reason for this is that while the component of monthly variance, formed by the trend is comparable in the two hemispheres, in the Northern Hemisphere the component, ascribed to random oscillations is much greater. This fact can be explained by the additional feeding of the Northern Hemisphere baroclinic instability by the zonal thermal contrast between land and ocean, as well as by the damping thermal effect of oceans in the Southern Hemi-sphere. For the Globe the annual cycle of the standard deviation follows that in the Northern Hemisphere. The reason is that the Northern Hemisphere random oscillations predominate because of their greater amplitudes.

The normalized mixed second central moments are elements of the correlation matrix. Let us consider its structure distinctly for the Southern and Northern hemispheres and for the Globe. All results of the following analysis comply with the conclusions in [1]. The three matrices are graphically represented in Fig. 3.

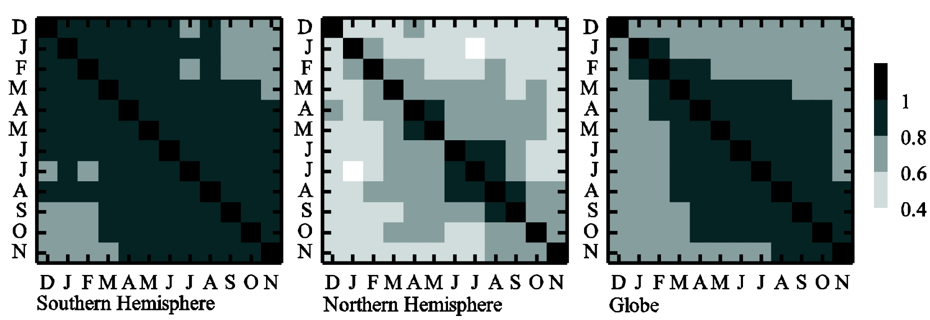

Fig. 3. Graphic representation of the correlation matrices for the Southern and Northern hemispheres and for the Globe. Higher correlations are given with darker shades and the lower with lighter

In the Northern Hemisphere cold half-year months are comparatively less correlated, both with one another and with warm half-year months. Warm half-year months are comparatively highly correlated with each other. A natural conclusion is that the statistical structure of summer months is more persistent. They are less variable. The reason for this again is the Northern Hemisphere baroclinic instability, whose warm half-year minimum is exceptionally well manifested.

In the Southern Hemisphere the correlation matrix is characterised with remarkably high correlations between separate months. Correlations between summer months are relatively lower. The higher correlation between the Southern Hemisphere monthly anomalies can again be explained by the high thermal inertia of the ocean. A specific peculiarity is that lower correlations are characteristic of warm half-year months. The reason is that here the maximum of baroclinic instability, giving rise to random oscillations, is attained in the warm half-year [7].

For the Globe the basic regularities follow the ones for the Northern Hemisphere, but are not so well evinced. This can be attributed to the higher amplitudes of temperature fluctuations in the Northern Hemisphere, whose patterns predominate globally.

4. TEMPORAL PRINCIPAL COMPONENT ANALYSIS

In order to study the structure of the correlation matrices, temporal principal component analysis [5] is conducted separately for the Southern and Northern hemispheres and the Globe. The time series of monthly anomalies are fixed as variables, starting with December and ending with November. If January was taken to be the first month of the year, then in the correlation matrices January would be correlated not with the neighbouring December, but with December of the same calendar year, i.e., 11 months ahead. This will lead to artificial separation of months belonging to the same season. Defining December to be the first month of the year helps to circumvent this problem. The consecutive years from 1856 to 2002 inclusive form the cases. For each hemisphere and for the Globe the correlation matrices, their eigenvalues, eigenvectors and the respective principal components are calculated.

Above all, the following fact must be emphasized. The original time series consist of temperature anomalies. The results we obtain refer to the very temperatures. This is due to the fact that after the standardization of the variables, the initial subtraction of the base period mean monthly temperatures has no effect.

The eigenvalues, arranged in a descending series, and some characteristics of the time series associated with them are systematized in Table 1. The total variance equals the sum of the individual monthly variances, that is, equals the sum of the eigenvalues of the correlation matrix.

The most impressive fact, obvious from Table 1, is that the first principal component alone bears a fairly high percentage of the total variance. From about 65% in the Northern Hemisphere and 82% for the Globe, its portion goes up to 86% in the Southern Hemisphere. On the more, for all three time series the contribution of the second empirical orthogonal function sharply decreases in comparison to that of the first one. For the Globe it is about sixteen times smaller, for the Northern Hemisphere about eight and about seventeen times for the Southern Hemisphere. The decrease of the contribution to the total variance at the third empirical orthogonal function is less pronounced than that at the second one. Eventually more than 90% of the total annual variance in the Southern Hemisphere is explained by the first two empirical orthogonal functions, in the Northern Hemisphere by the first six and by the first three for the Globe. Taking into account the rest of the eigenfunctions just slightly decreases the approximation error with an average value of about 1–2% for each one of them. So the convergence of the analysis procedure is very fast for all three time series, the first principal component bearing the greatest portion of the total variance.

Table 1. Convergence speed of the decomposition members for the Southern and Northern Hemisphere and for the Globe. Eigenvalues are written in the first basic column. The second, the third and the fourth basic column refer respectively to the Southern and Northern Hemisphere and to the Globe. They consecutively display the eigenvalues, the share of each mode in the total variance and the overall contribution of all eigenfunctions with numbers smaller or equal to the current one

№	Southern Hemisphere			Northern Hemisphere			Globe		
	Eigen-value	Total %	Cumul-ative %	Eigen-value	Total %	Cumul-ative %	Eigen-value	Total %	Cumul-ative %
1	10.344	86.20	86.20	7.798	64.98	64.98	9.815	81.79	81.79
2	0.594	4.95	91.16	0.925	7.71	72.70	0.633	5.27	87.07
3	0.198	1.65	92.81	0.801	6.67	79.37	0.360	3.00	90.07
4	0.182	1.52	94.33	0.576	4.80	84.17	0.273	2.27	92.34
5	0.140	1.17	95.51	0.483	4.03	88.20	0.213	1.77	94.12
6	0.123	1.02	96.53	0.416	3.47	91.68	0.196	1.63	95.76
7	0.095	0.79	97.33	0.261	2.18	93.86	0.127	1.06	96.82
8	0.090	0.75	98.09	0.214	1.78	95.65	0.115	0.95	97.78
9	0.069	0.57	98.66	0.187	1.56	97.21	0.084	0.70	98.48
10	0.062	0.52	99.18	0.146	1.21	98.43	0.076	0.63	99.12
11	0.049	0.40	99.59	0.113	0.94	99.38	0.055	0.46	99.58
12	0.048	0.40	100.00	0.074	0.61	100.00	0.049	0.41	100.00

At first glance one might deduce that the fast convergence could be due to the comparatively low order of the correlation matrix. Principally convergence is closely associated with peculiarities of the autocorrelation function that forms the correlation matrix. If it describes long-period atmospheric processes with large correlation radii, then the convergence speed of the temporal decomposition and the share in the first principal component are considerable [8]. Which is that long-period process of global scale, causing the fast convergence of the decomposition in all three cases? To answer this question, we can think in geometrical terms.

The goal of PCA is to find out a low dimensional hyperplane that optimally characterizes the data. More specifically a hyperplane minimizing the sums of the distances of the data points from itself [4]. Let $X_i(t_n)$ be the data set, where $i \in (1, 12)$ labels the distinct months and $n \in (1, 146)$ labels the years. The values for the different months do not evolve independently and for each year constitute a 12-dimensional vector $\boldsymbol{X(t_n)}$. Let us imagine the vectors $\boldsymbol{X(t_n)}$, $n \in (1, 146)$, in the 12-dimensional phase space. The ends of these vectors form a cloud of geometrical points. Data standardization makes the beginning of the coordinate system coincide with the geometrical centre of the cloud. The first base vector corresponds to the greatest eigenvalue of the correlation matrix. It defines the direction of most pronounced elongation of the cloud. The second base vector determines the next direction of greatest elongation, perpendicular to the first one, and so on. In this analysis, for all three time series, about and more than 80% of the total variance is borne by the first principal component. This means that the cloud of points is substantially elongated along the direction of the first base vector. That fact can only be accounted for by the existing rising trend in all three time series. The trend, as we saw, is a well pronounced and steady characteristic of the time series. Therefore, the exceptionally high convergence of the decomposition can be regarded as another proof of the presence of trend in the examined time series. In the Southern Hemisphere, where the trend is most persistent, the first principal component has the greatest contribution. In the Northern Hemisphere the trend coexists with large amplitude temperature variations whose behaviour varies a lot with the different seasons and years. This leads to a better manifested diversion of the vectors in the phase space from the direction of the first eigenvector, which is essentially determined by the trend. Consequently in the Northern Hemisphere the cloud of points is considerably elongated in directions, different from the one defined by the trend. As a result the rest of the principal components have much greater shares in the total variance there.

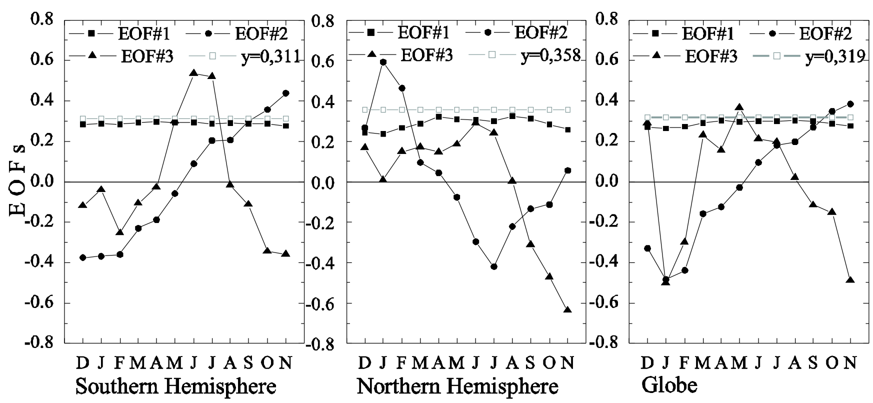

Fig. 4. The empirical orthogonal functions numbered one, two and three and the square root of the reciprocal value of the first eigenvalues for the Southern and Northern Hemisphere and for the Globe. The empirical orthogonal functions are represented by solid lines respectively with filled squares, circles and triangles, and the square root of the reciprocal value of the first eigenvalues—with hollow squares connected with dashed lines. The horizontal axis represents the months and the vertical has no dimension

So, the essential conclusion that imposes itself so far is that the variance of the time series of interest, both the monthly and the total one, consists of two components. The greater one of them, forming about and more 80 % of the variance, is due to the trend, and the other one owes its existence to random oscillations coexisting with the trend.

Fig. 4 represents the empirical orthogonal functions numbered one, two and three and the square root of the reciprocal value of the first eigenvalues for the Southern and Northern Hemisphere and for the Globe. The first three modes only are considered because they determine about 80% of the total variance in the Northern Hemisphere and more than 90% in the Southern Hemisphere and the Globe.

All in all the values of the first empirical orthogonal function are close to the square root of the reciprocal value of the first eigenvalues. It is easy to prove that this is due to the high contribution of the first empirical orthogonal function to the total variance. The approximation is best for the Southern Hemisphere and less precise for the Northern, which is quite natural, having in mind that in the Southern Hemisphere the first principal component bears about 21% greater portion of the total variance.

The squares of the values of an empirical orthogonal function reveal the distribution over the months of the relative contribution of the respective mode to the variance of the months. "Relative" means in comparison to the joint contribution of all other modes to the variances of the distinct months. Thus if the absolute value of an eigenfunction at a certain month is greater than its absolute value at another one, this means the relative contribution of that mode to the variance of the first month is greater in comparison to the relative contribution of the same mode to the variance of the second month. The sign of the value of the eigenfunction is informative of the bias induced by the respective mode. So if the values of an eigenfunction for a pair of months are opposite, this means that mode induces variations in opposite directions to these months. It is important to insist on the fact that the plot of the eigenfunctions does not allow us to compare the contributions of the different modes to a specific monthly variance. It only sheds light on the distribution of the contribution of a fixed mode over the months.

The most prominent feature in the behaviour of the first eigenfunction in the three cases is that it is strictly positive and almost constant when visualized in the same scale as the second and the third eigenfunctions. The constancy over the months is indicative of the stability of the manifestation of the trend throughout the year. The constancy of the sign comes to confirm that the global trend is strictly positive. Closer scrutiny of Fig. 4, however, lets us discern some slight annual cycle of the first eigenfunction, which is best pronounced in the Northern Hemisphere. Namely, in the Northern Hemisphere the maximum of first eigenfunction occurs in the months of the warm half-year, and in the Southern Hemisphere it takes place in the cold half-year. This regularity is easy to explain, having in mind the suggested interpretation of the modes of the decomposition. As it was mentioned above, the greatest meridional temperature gradient in the Northern Hemisphere is in the cold half-year. It is responsible for the greater share of the random temperature oscillations, induced by increased baroclinicity, in the monthly variances of the cold half-year months. Consequently the share of the trend is smaller for the winter months and greater for the summer ones. That is, why in the Northern Hemisphere the first eigenfunction comes to a maximum in the summer months. In the Southern Hemisphere, as we saw, the greatest meridional temperature gradient is in the warm half-year. Consequently the random temperature oscillations, induced by increased baroclinicity, have a greater share in the monthly variance in the warm half-year months. Hence, the share of the trend is smaller for the summer months and greater for the winter ones. Of course, because of the dampening influence of the ocean, the random oscillations here have much smaller amplitudes and their portion in the total monthly variance here is smaller than in the Northern Hemisphere. Therefore, the annual cycle of the first eigenfunction is less pronounced in the Southern Hemisphere.

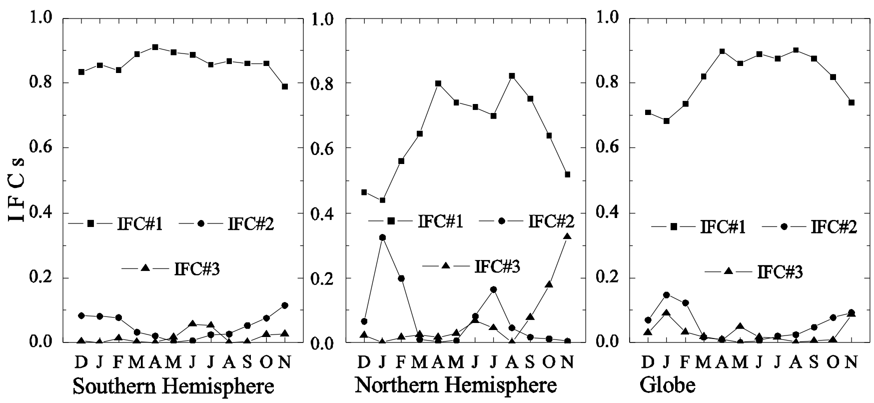

Fig. 5. The individual factor contributions numbered one, two and three for the Southern and Northern hemispheres and for the Globe. The empirical orthogonal functions are represented by solid lines respectively with filled squares, circles and triangles. The horizontal axis represents the months and the vertical has no dimension

The second and the third eigenfunctions describe random oscillations. In the Northern Hemisphere their absolute values are relatively higher for the cold half-year months. This should be attributed to oscillations incited by enhanced baroclinic instability. Relatively high absolute values are as well discernible in the typical summer months June, July and August. This is probably associated with the maximum of the summer monsoon, which takes place during these months and whose activity is subject to considerable random variations from year to year. The signs of the values of these eigenfunctions imply that these modes actually oppose the warm half-year to the cold one. In the Southern Hemisphere the maximal absolute values of the second eigenfunctions are during the warm half-year, which as it was already mentioned, is attributable to the maximum of baroclinic instability. The well pronounced maximum of the third eigenfunction for the typical winter months June and July should be associated with the relative increase of baroclinic instability in winter with respect to the neighbouring transitive seasons.

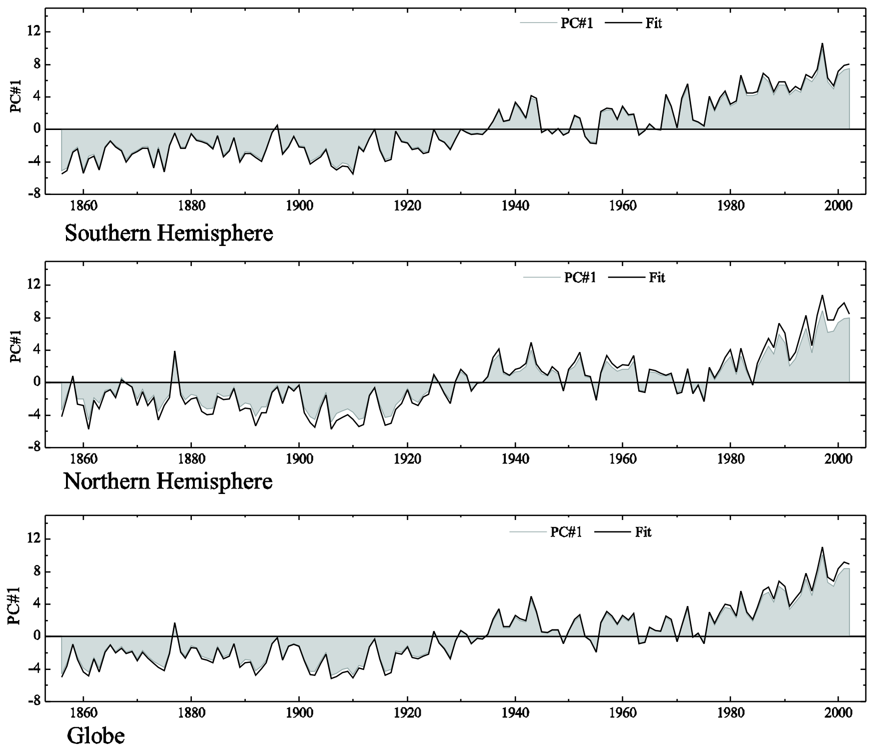

Fig. 6. Temporal evolution of the first principal component and the sum of the twelve standardized individual monthly anomalies, divided by $\sqrt{\lambda_1}$ for the Southern and Northern hemispheres and for the Globe. The principal component is represented by a light grey solid line. For perspicuity the area between it and the zero grid line has been filled with the same colour. The sum of the twelve standardized individual monthly anomalies, divided by $\sqrt{\lambda_1}$, is given with a black solid line. Months are displayed on the horizontal axis and the vertical is nondimensional

The product of the square of the value of the eigenfunction for a fixed month and the respective eigenvalue defines a quantity giving the portion of the variance of that month attributed to that very mode. Hence the distinct monthly variances equal the sum of these quantities over the twelve modes. Now it is clear why in this paper they are called individual factor contributions (IFC)—they represent the contributions of the individual factors (modes) to the distinct monthly variances. The IFCs are displayed in Fig. 5.

The IFCs, in contrast to the eigenfunctions, give us the opportunity to make comparisons between the relative contributions of the different modes. They do not provide any idea of the direction of the oscillations induced by a particular mode, but directly visualize the relative contributions of the modes to the monthly variances. All the basic features we already identified in Fig. 4 can be recognized, even more easily in Fig. 5. We can now quantify them. So in the light of the proposed interpretation, the effects of baroclinicity in the Northern Hemisphere winter account to about 20–30 % of the monthly variances, while the variable activity of the summer monsoon 10–20 % of the variances of the summer months. The effects of baroclinicity in the Southern Hemisphere summer and winter account to about 10–15 % of the monthly variances. In both cases the rest of the monthly variances are due to the trend.

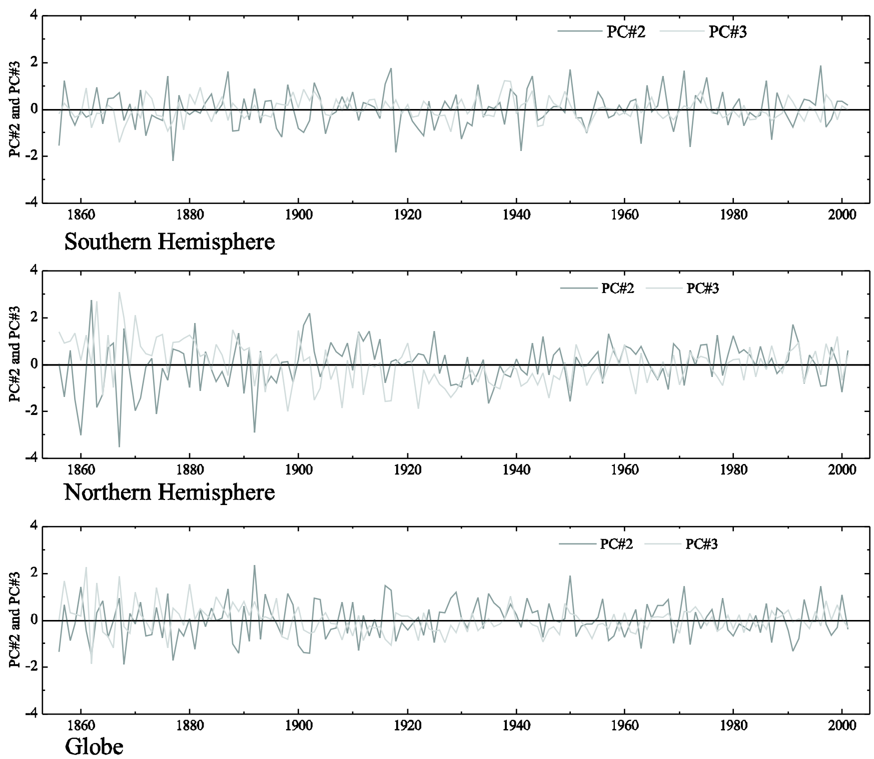

Fig. 7. The principal components numbered two and three for the Southern and Northern hemispheres and for the Globe. The principal components are represented respectively with grey and light grey solid lines. Months are on the horizontal axis and the vertical is nondimensional

For the Globe the basic regularities, characteristic of the Northern Hemisphere can be identified. Obviously, because of their greater amplitudes, the Northern Hemisphere random oscillations dominate the global patterns.

Fig. 6 shows the first principal component and the sum of the twelve standardized individual monthly anomalies, divided by $\sqrt{\lambda_1}$, for the Southern and Northern hemispheres and for the Globe.

It is obvious that the curve, representing the first empirical orthogonal function is very close to the one visualizing the sum of the twelve standardized individual monthly anomalies, divided by $\sqrt{\lambda_1}$. It is easy to prove that this is because of the large share of the first principal component in the total variance.

Fig. 7 depicts the principal components numbered two and three for the Southern and Northern hemispheres and for the Globe.

It is obvious that unlike the first principal component they have a zero trend. Therefore they only account for random oscillations about the mean state. So the trend in the data is wholly borne by the first principal component. The substantially larger variance, associated with each component in the Northern Hemisphere is easily discernible.

5. CONCLUSION

The basic results of this global scale climatic study can be summarized as follows.

It turns out that in the Southern and Northern hemispheres and the Globe the temperature anomalies and their variances have a significant annual cycle. In both hemispheres the mean monthly winter anomalies have larger absolute values. This can be ascribed to fact that they have warmed more significantly than the summer months [2]. In the Northern Hemisphere the maximum of the standard deviation is single and is attained in winter. In the Southern Hemisphere the standard deviation has two maxima, the basic one in winter and a secondary one in summer. In the Northern Hemisphere the warm half-year months are better correlated with one another, while in the Southern Hemisphere the correlations are higher between the cold-half-year months. For proper explanation of these phenomena the essential difference in the annual cycle of the baroclinic instability of the western flow in the two hemispheres has been emphasized. Namely the fact that while in the Northern Hemisphere the greatest meridional temperature gradient occurs in winter, in the Southern Hemisphere it occurs in summer [7]. An essential inference concerning the variance, both the monthly and the total one, is made. Namely, that it consists of two components—one caused by the trend and the other by oscillations about the mean state.

The study of the structure of the correlation matrices is logically ensued by the conducted temporal principal component analysis. The principal characteristic feature of this analysis is the remarkably fast convergence of the decomposition, which has been accounted for by the well pronounced trend in the time series. The first principal component wholly bears the trend, while the rest of the components describe random oscillations associated with intraannual and interannual variability. This variability is better pronounced in the Northern Hemisphere, so there the contribution of the modes with numbers greater than one is more significant. Consequently the high convergence of the decomposition can be regarded as the serial proof of existence of trend. The preciousness of that proof is that it is not based on linear regression. Both variance components are quantified for the distinct months (see Fig. 5).

What is the place of this work among the rest of the analyses dealing with the same or similar time series of global temperature anomalies? The conclusions of other studies concerning the persistent rising trend and its annual cycle are unambiguously corroborated. The results of previous analyses of the statistical structure of warm and cold half-year months, showing that the months corresponding to summer in the Northern Hemisphere, possess a more uniform statistical composition, are as well confirmed. The fast convergence of the singular value decomposition can be interpreted as another proof of existence of trend which is not based on linear regression. The annual cycle of the contributions of the trend and the random oscillations to the monthly variance has been studied in detail and quantified.

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