LONG–PERIOD VARIATIONS OF THE SPECTRAL TRANSMITTANCE OF THE ATMOSPHERE

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Methods of selecting the long–period components from the series of monthly average values of the atmospheric spectral transmittance are discussed in the paper. The polynomials of first and second degree are shown to be the best approximations of the trend.

As is known[1,2] it is necessary to possess the information on the atmospheric spectral transmittance over the selected area for taking into account the effect of the atmosphere on optical radiation propagating through it, for selecting the regions with the most optimum conditions for operation of optical systems, and for development of the techniques for forecasting the optical weather.

Investigations into the spectral transmittance over USSR were carried out by Berezkin, Beletskii, Kalitin and other authors[3–5] from measurements of the direct solar radiation using the glass Shott filters. The method of investigating the atmospheric spectral transmittance from measurements of solar aureoles with Fesenkov's aureole photometer was applied by Pyaskovskaya–Fesenkova, Toropova, Livshits, and Panova.[6–8]

The data on the spectral transmittance were obtained in Ref. 9 with photometers based on telescopes. Further investigations into the spectral transmittance were carried out using the interference filter proposed by Nikitskaya.[9] The observations of the spectral transmittance of the atmosphere were carried out using this technique in different sites.[10,11]

Creation of the ozonometric stations network[12] have given new feasibilities for investigation into the atmospheric spectral transmittance. Measurements carried out over the whole of the USSR territory by unified technique with uniformly adjusted devices simultaneously make it possible to investigate the spatial and temporal structure of the spectral transmittance and its components.

By now the results of measurements of the atmospheric spectral transmittance are published for 17 years (1972–1988) for 46 ozonometric stations situated in Russia and neighbour countries[13] in the form of daily average values of the spectral transmittance related to the wavelengths from 326 to 638 nm. Time series of the spectral transmittance are not continuous. Missing the values in the series is caused by different reasons, but the objective ones are the covering of the Sun by clouds and the low Sun elevation. According to Ref. 12 measurements should be carried out only when the elevation of the Sun is greater than 10°. Due to this reason, measurements are not carried out during winter at the stations situated in high latitudes.

The results of measurements obtained in the ozonometric network have been generalized in Refs. 14 and 15. However, these investigations were devoted mainly to the problem of spatial distribution of the atmospheric spectral transmittance characteristics over territory of the USSR. The problems concerning the temporal structure of the atmospheric spectral transmittance series almost are not touched on. Exception is Ref. 15, where temporal variations of the spectral transmittance are explained by aerosol extinction on the base of comparison of the energy spectra of the variance of aerosol depth and atmospheric spectral transmittance.

It should be noted that this conclusion is related to the high–frequency region of the spectrum (periods vary in the range from 2 to 60 days). The long–term and low–frequency variations of the spectral transmittance are not investigated yet. In this connection our problem is the development and substantiation of the techniques for separating out the long–period component of atmospheric spectral transmittance for the wavelengths of 334, 369, 530, 572, and 627 nm.

The time series of the spectral transmittance having obtained at the Omsk station during 17 years (1972–1988) were used for investigation. Missing in these series are caused by presence of clouds and the station location latitude (55°N). So the data on the spectral transmittance in January, February, November, and December are absent. Such an observation structure is characteristic of the midlatitudes of Russia. Therefore, one can consider the temporal series of spectral transmittance obtained at the Omsk station as representative ones for the whole of midlatitudes of Russia.

The principal part of the time series theory is devoted to the expansion of them into components and isolated study of each of them. Typical time series are composed from four components: trend, variations near the trend with more or less regularity, season effect, and the random component.[16,17] The sum of these components is the initial time series.

It is the most difficult to define trend. Generally trend is some stable variation during a long period. However, the term "long" is quite relative. Never one can be sure that the trend is not a part of the slow oscillation process, no matter how great the time series may be. Thus, as about the trend, it is necessary to mind the series length.

A number of authors[16–19] consider the trend as the variations that can be described by polynomial. One can divide the majority of investigations of this problem into three groups depending on the polynomial degree and the technique of its application.

The first group of authors describes the trends of time series by polynomial of high degree (third degree and more), using all terms of the series to calculate the polynomial coefficients. The analysis of the investigations

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of this group is given in Ref. 19. As a result of applying the high degree polynomial the nonperiodic function that reflects the hidden long–period variations of the time series is obtained. However, such an approach has disadvantages. Firstly, the weight of initial and final points of the series is overestimated. Therefore, the trend value in the initial and final portions of the series is greater then in the inner ones. The application of the obtained polynomial for trend extrapolation can be unreasonable for such an approach. Secondly, adding the new points to the series or changing the polynomial degree require the recalculation of the polynomial coefficients and, therefore, changing of the analysis. Thirdly, no polynomial has the horizontal asymptote, so the possible situation of the trend absence in a future is unreproducible.

The second group of authors[16,17] suggests to use the sliding polynomial approximation of a part of the series in contrast with calculation the polynomial. Such an approximation of the time series has the advantage that one can arbitrary set the period, for which the trend is calculated, and also select the degree of the approximation polynomial. In addition, when adding the new terms of the series, it is not necessary to reestimate the last values of the trend. Sometimes the sliding polynomial approximation is called as the filter of low frequencies. The sliding polynomials smooth the high–frequency periodic components (small periods of variation) and keep the low frequencies untouched. However, the main condition for such an approach is the absence of missing series terms; besides, the extrapolation of the further trend value is not a simple problem.

The third, most numerous group of authors, suggests to approximate the time series by the polynomial of first degree, or the linear function.[20,21] Authors of this group determine the parameters of the linear trend for the whole of time series[20] or its part.[21] Then the authors[21] suggest the algorithm of separating out the parts with linear trend within the time series. On their opinion, the proposed algorithm makes it possible to optimize the process of finding new empirical facts about the change of system functioning regime.

In this connection the goal of research was to separate out the trends from the spectral–transmittance time series at Omsk station using different techniques for their obtaining.

To reveal the long–term trends it is advisable to pass from the time series of daily average values to the time series of monthly average spectral transmittance. However, the statistical structure of the series changes in passing, and one should take into account this change. Moreover, the monthly average values were calculated over different quantity of observations. As it took place, the number of observations varied from 2 to 24 from month to month (Omsk station).

To establish the correspondence between daily average and monthly average series of the atmospheric spectral transmittance we calculated the standard statistical characteristics presented in Tables I and II.

TABLE I. Characteristics of the statistical structure of series of the daily average spectral transmittance for different wavelengths.

Wavelength, nm	Mean value, %	Variance, %	95% confidence interval	Minimum	Maximum
334	39.4	52.9	(39.0; 39.8)	12	66
369	43.2	61.0	(42.8; 43.7)	14	65
530	68.8	91.9	(68.3; 69.3)	31	92
572	69.8	82.4	(69.3; 70.3)	33	88
627	73.5	111.5	(73.0; 74.1)	36	98

TABLE II. Comparative characteristics of the statistical structure of series of the monthly and daily average spectral transmittance for different wavelengths.

Wavelength, nm	Mean value, %	Variance, %	Variances ratio, %	Minimum	Maximum
334	40.2	19.39	2.73	29.7	52.6
369	44.3	25.02	2.44	32.1	58.8
530	70.3	46.73	1.97	54.3	86.0
572	71.2	41.44	1.99	55.1	84.6
627	75.2	68.64	1.62	55.8	92.0

It follows from the analysis of Tables I and II that the average transmittance values calculated from the series of daily and monthly average values are not practically different. At the same time the variances of the monthly average transmittance values for different wavelengths are 1.62–2.73 times less than the variances of daily average transmittance. The variances ratio decreases with increasing the wavelength. It is evidence of the fact that the short–period variations of transmittance, caused by the change of air mass, are more pronounced for the short waves. In general, 40–60% of the variance of daily average transmittance values, depending on the wavelength, is determined by the processes with duration less than a month. The rest of the variance is determined by variations with the period greater than a month. When passing from daily average to monthly average transmittance series the amplitude of oscillation of the series terms also decreases.

To separate out the long–term trends from the monthly average transmittance series the linear or polynomial approximation was applied. It was impossible to use the sliding approximation in view of missing in observations.

When dividing the time series into trend and the deviations (rests) using the polynomial approximation, the components obtained do not correlate with each other. Hence, the variance of the initial series is equal to the sum of variances of the trend and the rests. This proposition allows us to estimate the contribution of the trend to the total variance of the series.

We have obtained the polynomial coefficients by means of the least–squares method

$$Y_t = Y_0 + a_1 t + a_2 t^2 + ... \quad (1)$$

As it took place the polynomial degree varied from 1 to 4. The variance characteristic of the trend is given in Table III. It follows from its analysis that, depending on the wavelength and polynomial degree, the long–term trend determines from 7.1 to 25.7% of the variance. As would be expected, the portion of described variance increases with increasing the polynomial degree, but the increase behavior is different, depending on the wavelength. The noticeable decrease of growth of the variance portion in increasing the polynomial degree occurs as wavelength increases. Thus, for the wavelength of 344 nm the variation of the polynomial degree from 1 to 4 increases the trend portion of the variance by 2.7 times, and for λ = 627 nm the variance increases only by 1.1 times. It seems likely that the more variable spectral transmittance for short wavelength is determined by the significant contribution of long–period variations.

TABLE III. Portion of variance (%) caused by long–term trends described by polynomials of different degree for different wavelengths.

Wavelength, nm	Polynomial degree			
	1	2	3	4
344	7.1	11.1	11.1	19.6
369	11.9	15.2	15.6	25.7
530	15.4	18.9	20.4	23.4
572	16.9	21.7	23.1	23.2
627	13.8	15.7	16.2	16.4

The approximation of the trend with high–degree polynomials makes it possible, in contrast to the linear trend, to separate out the parts with the same tendency inside time series, because the transmittance variation rate can increase, decrease, and be constant in different time intervals. The polynomials with higher degree, starting from the second one, make it possible to determine the time intervals of different behavior of the transmittance.

Figures 1 and 2 show the temporal behavior of the atmospheric transmittance at the wavelength of 530 nm and the trends approximated by polynomials of first (Fig. 1, dashed curve), second (solid curve), third (Fig. 2, dashed curve), and fourth (Fig. 2, solid curve) degrees.

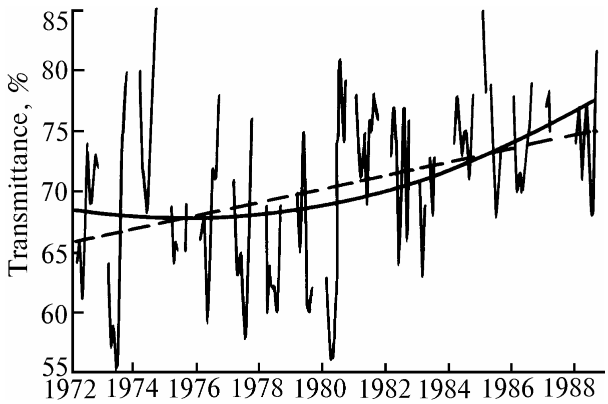

FIG. 1.

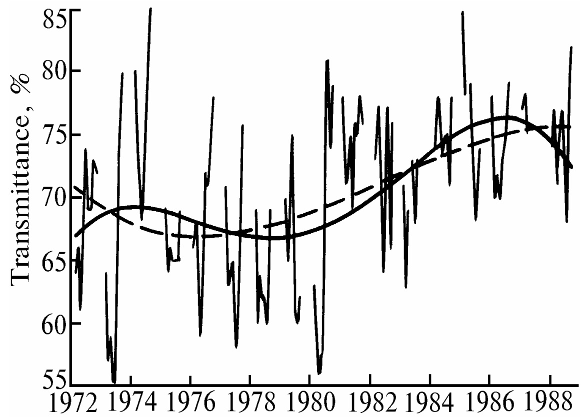

FIG. 2.

The visual analysis of the plots shows that the transmittance trends represented by polynomials of second and higher degrees have the parts of increase and decrease in the transmittance value. The transmittance trends obtained using the third– and higher– degree polynomials are of wavy nature.

On the hypothesis that the transmittance variations are the sum of the trend, variations near the trend of more or less regularity, effect of seasonal prevalence, and the random component, it becomes clear that the trend can not have the wavy behavior. Therefore, one should restrict the polynomial degree by first or second ones for selecting out the trend of monthly average spectral–transmittance series.

The approximation of the trend by the linear function has the advantages and disadvantages in comparison with the approximation by higher–degree polynomials. The main disadvantage is the monotone character of the linear function. At the same time the linear trends can be easily extrapolated, that allows one to forecast the tendency of the transmittance variation.

The values of the relative linear trend of the spectral transmittance are given in Table IV for five considered wavelengths as well as the limits of 95% confidence intervals.

TABLE IV. Comparison of estimates of the relative linear trend for different wavelengths.

Parameter	Wavelength, nm				
	334	369	530	572	627
Relative trend	0.23	0.35	0.55	0.54	0.66
Lower limit	0.08	0.18	0.32	0.33	0.38
Upper limit	0.39	0.52	0.77	0.75	0.93

It follows from the analysis of Table IV that during 17 years (from 1972 till 1988) the increase in the atmospheric transmittance was observed for all considered wavelengths. The value of the relative trend is statistically significant at the 5% level. The increase in the relative trend is also noted with increasing the wavelength.

The research makes it possible to revealed that the variations with the period more than 30 days give the significant contribution to the spectral transmittance variations. The atmospheric transmittance at the Omsk station has tendency toward the increase for all considered wavelengths. It is shown that polynomials of first or second degree are more appropriate for approximation of the trend.

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