METHODOLOGY FOR FORECASTING THE CITY MESOCLIMATE AS APPLIED TO CRITERIAL ESTIMATES OF THE COLD PERIOD

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In this paper we consider the methodology for modeling and forecasting the temporal run of the climatic characteristics (beginning, end, duration, and mean temperature) of the cold period with a year-term forecast. The spectral analysis and the method of multiple cyclicity form the basis of this methodology. The performance of this technique being evaluated showed that forecasts are borne out in 70% of cases.

Among the important problems of modern mesoclimatology, the problem on evaluating and forecasting the evolution of a mesoclimate in big cities becomes increasingly urgent. This is due to the steadily growing impact of man's activities upon the local climate, especially, in big cities. This impact manifests itself as changes in the radiation regime of the city's atmosphere (thus, due to dust and smog that markedly reduce the atmospheric transmittance, lost are up to 20% of solar radiation[1]), a decrease (due to pollution of air) of the effective emission and, as a consequence, the night cooling, an increase (as a result of fuel burning and a small amount of heat coming to evaporation) of the temperature inside a city as compared to environs vicinities, i.e. the formation of the so-called island of heat over a city.[2]

All factors listed influence the formation and the evolution of the city mesoclimate thus hindering its correct evaluation and forecasting. Just this problem is considered in our paper.

1. TECHNIQUE FOR CALCULATING THE CLIMATIC CHARACTERISTICS AND SOME RESULTS

To study changes in the city mesoclimate and to develop the technique for its forecasting, we used the statistical approach based on the analysis of climatic characteristics of cold period, which allow for the whole complex of factors influencing the climate and most accurately reflect the nature of local climate changes.

Among these characteristics are the following: the date of the cold season beginning (D_b) in fall and the date of its end (D_e) in spring, its duration (L) from the beginning till the end, and the mean temperature T°C over the whole period L.

Usually, the beginning of cold period is counted out from the day in fall when the average daily temperature reduces down to +8°C or lower and during four days does not rise above +8°C, whereas its end coincides with such a day in spring when the average daily temperature rises up to +8°C or upper and during four days does not reduce below +8°C. The chosen boundaries of the beginning and the end of the cold season correspond to the beginning and the end of the heating season. The choice of a four day period is conditioned by the mean duration of natural synoptic periods.[3]

In practice (see, for example, Ref. 4), the estimates for D_b, D_e, L, an T are usually obtained by indirect formulas taking into account relations between the dates D_b and D_e and mean temperature of the month immediately before (or after) the transition toward $t < 8$°C or $t > 8$°C. As preliminary calculations showed, such an approach ignores real annual behavior of temperature during a particular year and can only be used to obtain approximate estimates of D_b, D_e, and L from the many-year monthly-mean air temperatures. In particular, this approach was used when preparing corresponding data in the reference book.[5]

In this paper, to obtain these estimates, we used the every-year monthly-mean air temperatures in the cold period interpolated by the method of linear interpolation for every day of this period. The choice of the optimal interval N (in days), during which the temperature reduces (rises) most steadily lower (above) 8°C according to measurement data on the daily-mean temperatures in cold months in Moscow, was justified beforehand. We have analyzed 10 variants of the criterion for the period of stable transition $t < 8$°C or $t > 8$°C from one to nineteen days with a two-day step over the period 1950–1994. In each variant and for every year we have calculated the parameters D_b, D_e, L, and T.

Analysis of the data obtained has shown that as the number of days N of the stable transition of the air temperature through +8°C point increases from 1 to 19, the date of the beginning D_b shifts toward later dates, reaching "saturation" approximately after two weeks. The date of the end D_e behaves similarly. In contrast to D_b and D_e, the duration L and the mean temperature T of the cold season are practically independent of N and their values are practically constant.

In addition, the analysis has shown that the optimal interval, from which the dates of the end and the beginning of the cold period should be counted out, for Moscow conditions is the interval of the stable reduction (rise) of the temperature below (above) +8°C during no less than five consecutive days. Therefore, all the results presented below have been derived using this criterion. In this case the results obtained from the annual monthly-mean values of temperature correspond to the results obtained with this criterion but from actual data.

Table I presents statistical characteristics: the mean, the rms deviation, the minimum and maximum values of D_b, D_e, L, T taken for different periods of averaging (1880–1995, 1950–1995, and 1980–1995) that allows one to evaluate the character of climate change in Moscow in time.

As follows from the table, the parameters L and T are subject to change to a greatest extent for the last century. So, for the last 15 years (1980–1995) L shortened from 209 to 201 days as compared to the beginning of this century, whereas the mean temperature changed from −3 to −1.7°C. The duration shortens at the expense of the earlier end of the cold period D_e.

TABLE I. Estimates of the average dates of the beginning D_b and the end D_e, the duration L and the mean temperature T°q of the cold period in Moscow for different periods of observation

		Characteristics			rms	Average over trend for
Years	Parameter	Mean	Minimum	Maximum	deviation	1901/2000
1880–1995	D_b	30.09	11.09	20.10	8	27.09/27.09
1950–1995		30.09	10.09	19.10	8	
1980–1995		30.09	10.09	15.10	8	
1880–1995	D_e	27.04	08.04	21.05	8	30.05/17.04
1950–1995		22.04	08.04	07.05	7	
1980–1995		19.04	10.04	29.04	6	
1880–1995	L	209	171	242	13	215/202
1950–1995		204	171	235	12	
1980–1995		201	185	222	10	
1880–1995	T	−3.0	−6.8	0	1.4	−3.6/−1.1
1950–1995		−2.4	−6.1	0	1.4	
1980–1995		−1.7	−4.6	0	1.2	

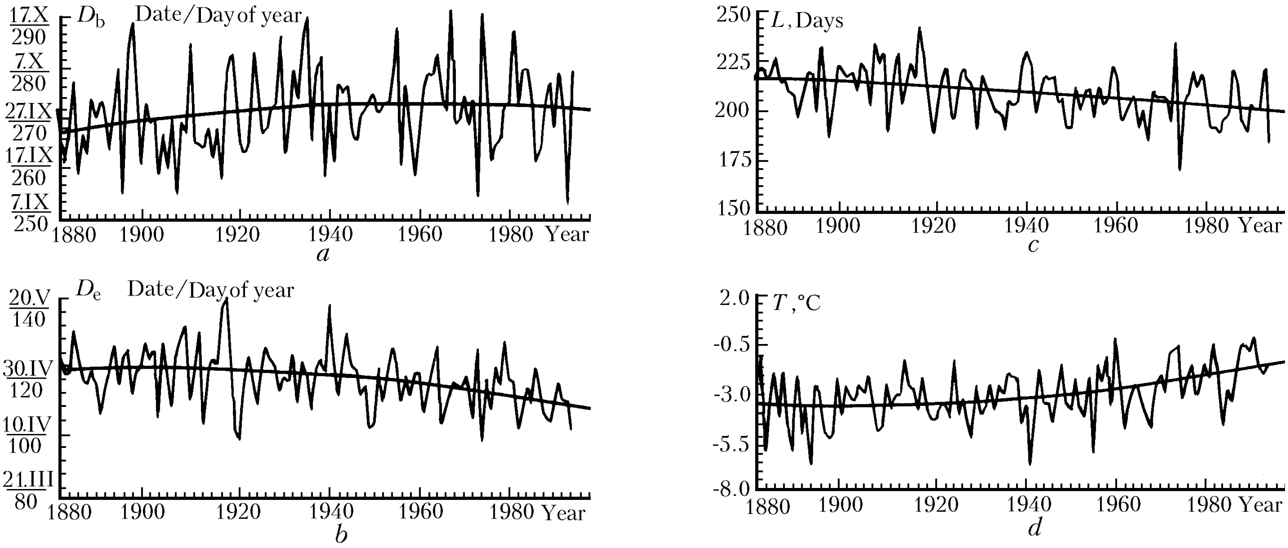

FIG. 1. Dates of the cold period beginning (D_b) and the end (D_e), its duration (L), mean temperature, and their trends.

If the extrapolation estimates by the trend curves (Fig. 1) are used, it turns out that to 2000 the mean date of the end D_e may shift to the middle of April (April 17). Then, at a relatively constant L to 2000 the mean temperature of the cold period in Moscow may rise by approximately 0.5°C to the beginning of the next century as compared with the present days, that is rather significant.

2. SERIES SIMULATION AND FORECAST

The visual (Figs. 1–3) and spectral analyses (Table II) show the presence of quasicyclic components in the series of the characteristics D_b, D_e, L, and T and the presence of a trend component, especially in the series of D_e and T (Figs. 1 and 3).

TABLE II. Significant cycles (in years) of variations of the characteristics of the cold period within 95%-*confidence for Moscow in 1950–1995.*

Characteristics	Cycles					
D_b	16.0	8.9	4.2	3.4	2.8	2.4
D_e	–	8.0	5.4	3.2	2.7	2.2
L	18.2	7.8	4.5	3.3	2.8	2.2
T	15.3	8.5	4.1	3.1	–	2.2

The spectral analysis reveals the presence of quasimultiple cycles, such as 16/8/4/2. More close visual analysis of the plots of the characteristics of the cold period studied over the whole history of observations (the plot is not presented) has shown that the 16–18-year cycle consists of two unequal cycles of about 8–9 years, whereas the 8–9-year cycles consist of two unequal cycles of 4–5 years or three cycles of about 3 years, the 4–5-year cycles, in their turn, comprise the cycles of 2 or 3 years. Pair-wise alternation of close, but unequal cycles makes more difficult the application of classical methods to cyclicity analysis, that is why the further analysis and simulation were carried out using the method of so-called multiple cyclicity. The behavior of a characteristics containing the trend was described by the model of linear trend and the model of multiple cyclicity. The method of multiple cyclicity includes the method of epoch superposition in a chosen regular dates with the period τ. The period τ is chosen in such a way that it covers several unequal cycles. In our case, for alternating 4- and 5-year cycles $\tau = 9$ is suitable, whereas for alternating 8- and 9-year cycles $\tau = 17$ is suitable. The entire series is divided into sections of τ years. For every point at the interval τ the average value is calculated from similar points at all sections. Thus some averaged sample of the set of irregular cycles is obtained.

It is important in such an approach that the model describes well all outliers and cyclicities that have periods multiple of τ. Intensity and duration of perturbations of the parameter under study within τ may be different. An important point is only that the processes at the same subsequent sections should follow the same regularity. From the physical point of view, this method allows the system of complex alternating perturbations to be described, if some periodic force with a known period is a common source of such perturbations.

At the stage of the analysis in our case the model of multiple cyclicity describes two periodical compositions of τ_1 and τ_2 cycles inscribed into the intervals τ_1 and τ_2. Periods of 9 and 16–17 years, as a rule, were first set according to the results of spectral analysis and analysis of the autocorrelation function of the temporal series. Then they were refined by numerous numerical experiments on reconstructing the initial series with different deviations from the present periods.

The quality of the model of multiple cyclicity was estimated for each characteristic under study by the method of variance analysis. In so doing the fraction of perturbations described by the model was estimated with respect to the total variance of a series.

Before we proceed to the description of the models for the characteristics of the cold period, let us describe some designations used below. Thus, R denotes the unbiased estimate of the fraction of the total variance of a series described by the model; F is used for the Fisher criterion; t is the Student criterion; the term "probability" is used for the probability of a randomness of the model. The probability value less than 0.05 means that the model randomness is less than 5% or the model significance is more than 95%.

It should be added to the above that when constructing the models we used temporal series of year estimates of D_b and D_e for the period from 1950 to 1995.

As a result of numerical experiments, the first period of cyclicity was chosen to be equal to 9 years for each characteristic. The values of second period are close for all characteristics. It equals 17 years for D_b and 16 years for others. We are coming now to the description of statistical properties of the models.

3. MODEL OF DATES OF THE COLD PERIOD BEGINNING

There is no trend in the dates D_b for last decades. Year-to-year changes in the D_b date are quasicyclic in nature (Fig. 1*a*).

Based on the results of numerical experiments, we have chosen the model of multiple cyclicity without regard for a trend. The model parameters are presented below.

Time interval	
Starting time	1950
Finish time	1994
Length of the time period	45 years
First period of cyclicity	9 years
Second period of cyclicity	17 years

Analysis of variance

	Degree of freedom	Sum of squares	Rms deviation	F criterion	Probability
Model	24	2700.4	112.52	4.2109	0.0030
Remainders	20	534.4	26.72	–	–
Total	44	3234.8	–	–	–

R=0.6366

Remainder analysis

Remainder average	0
Remainder rms error	3.4461
Maximum absolute error	8.8596
Time of the maximum error	1955
Darbin-Watson statistics	1.733

The variance analysis of the model shows that the model describes 64% of the total variance of the initial series (R = 0.6366). The model randomness probability is less than 1%. The model standard error is about 4 days. Figure 2 shows actual and model data on D_b as well as the forecast for the beginning of the cold season as it follows from the model. In 1995 the forecast of the cold season beginning is approximately 267th day of the year, i.e. on September 24. With allowance for the spread, the cold season is forecasted to begin between September 17 and October 1.

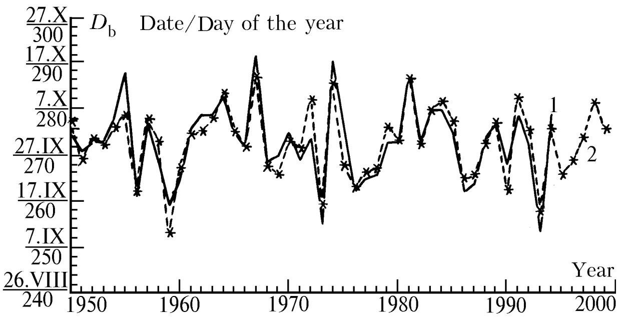

FIG. 2. Actual (1) and model (2) dates of the beginning of the cold period.

4. MODEL OF DATES OF THE COLD PERIOD END

In the D_e dates a stable linear trend is observed in the last decades (Fig. 1*b*), on the background of which quasicyclic variations take place. Therefore, the model for D_e was constructed in two stages. At the first stage the model of linear trend was constructed, whose parameters are presented below.

Model of D_e trend
Time interval

Starting time	1930
Finish time	1994
Length of the time period	65 years
The value t=1 corresponds to the time moment	1930

Trend: $Y(t) = -0.15219 \cdot t + 120.07 + e$

Estimates of the parameters

Parameter	Value	Standard error	t	Probability
A	−0.15219	0.048028	3.1687	0.0024
b	120.07	1.8232	65.857	0.0000

R=0.1096.

Remainder analysis

Remainder average	0
Remainder rms error	7.2648
Maximum absolute error	20.606
Time of the maximum error	1940
Darbin-Watson statistics	2.001

The trend describes 10% of the total variance.

At the second stage the trend was subtracted from the initial series and the remainder analysis was carried out. As a result of experiments performed, the model of the multiple cyclicity was chosen, whose parameters are presented below.

Model of multiple cyclicity of D_e remainders.
Time interval

Starting time	1950
Finish time	1994
Length of the time period	45 years
First period of cyclicity	9 years
Second period of cyclicity	16 years

Analysis of variance

	Degree of freedom	Sum of squares	Rms deviation	F criterion	Probability
Model	23	1672.7	72.726	3.4244	0.0054
Remainders	21	446	21.238	–	–
Total	44	2118.7	–	–	–

R=0.5589.

Remainder analysis

Remainder average	0
Remainder rms error	3.1482
Maximum absolute error	6.4815
Time of the maximum error	1973
Darbin-Watson statistics	2.540

The variance analysis shows that the model of remainders describes 56% of the total variance of the initial remainder series (R = 0.5589). The model randomness probability is less than 1%. The model standard error is about three days. We do not present here actual and model data on D_e as well as the forecast for the dates of the cold period end. In addition, we have constructed the model of remainders for the period 1960–1995.

Model of multiple cyclicity of D_e remainders.
Time interval

Starting time	1960
Finish time	1994
Length of the time period	35 years
First period of cyclicity	9 years
Second period of cyclicity	16 years

Analysis of variance

	Degree of freedom	Sum of squares	Rms deviation	F criterion	Probability
Model	23	1519.5	66.065	3.8895	0.1425
Remainders	11	186.84	16.985	–	–
Total	34	1706.3	–	–	–

R=0.6616

Remainder analysis

Remainder average	0
Remainder rms error	2.3105
Maximum absolute error	4.4286
Time of the maximum error	1977
Darbin-Watson statistics	1.584

The variance analysis of the model shows that since 1960 the model describes 66% of the total variance of the initial series. The model randomness probability is less than 1%. The model standard error is about two days. Figure 3 demonstrates the D_e remainders. The forecast for the date of the cold period end results from the sum of forecasts given by the trend and cyclic components. The heating season in 1995–1996 will finish approximately in (110+15) = 125th day of the year, i.e. April 25. With the allowance for the spread, the end of the cold season is forecasted to occur between April 17 and May 2.

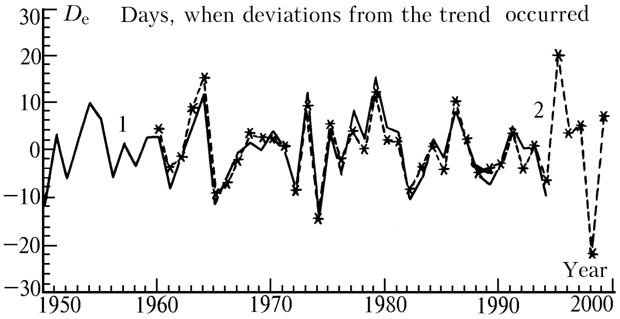

FIG. 3. Actual (1) and model (2) deviations from the trend of the dates of the cold period end.

5. ESTIMATES OF RELIABILITY OF THE D_b AND D_e FORECASTS

Reliability of the D_b and D_e forecasts was estimated from independent observations for 1985–1995. The forecasts were constructed using the model of multiple cyclicity based on the data obtained in early years. The forecast error (see Table III), in so doing, was estimated as the difference ε between the forecasted, D_b and D_e, and actual, D_b^a and D_e^a, dates

$$\varepsilon_b = D_b - D_b^a, \quad \varepsilon_e = D_e - D_e^a.$$

TABLE III. Estimates of the forecast reliability from independent data.

Period of the data used	Year of forecast	ε_b	ε_e
1950–1984(85)	1985–86	4	−1
1950–1985(86)	1986–87	10	0
1950–1986(87)	1987–88	4	8
1950–1987(88)	1988–89	−6	10
1950–1988(89)	1989–90	−8	0
1950–1989(90)	1990–91	5	5
1950–1990(91)	1991–92	3	0
1950–1991(92)	1992–93	0	−6
1950–1992(93)	1993–94	1	−0
1950–1993(94)	1994–95	−10	8

All errors of one-year forecasts for the dates of the beginning and the end of the heating season are within 10 days. If one week is taken as an acceptable error, then the reliability of forecasts for the dates of the beginning and the end of the heating season in Moscow is 70%. The estimate of reliability of 2–3-year-term forecasts is analogous. It is indicative of the stability of the chosen model parameters. Therefore, it is worthwhile to continue the researches in this direction.

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