EMPIRICAL MODEL OF THE MONTHLY SUM OF PRECIPITATION AND THE NUMBER OF DAYS WITH PRECIPITATION IN WINTER BASED ON SPACEBORNE DATA FROM "METEORB SATELLITE

A.A. Isaev and N.V. Zukert

M.V. Lomonosov State University, Moscow

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The model proposed earlier for assessment of monthly sums of precipitation has been tested in winter period in the square areas of 5 to 10 degrees in the center of European territory of Russian Federation. Computed magnitudes of R_p and the number of days with precipitation D_p are determined by the linear correlation equations $R_p = f(K)$ and $D_p = f(\omega_1)$, where K and ω_1 are the indices of the above characteristics R_p and D_p, calculated by means of empirical relationships between the repetition of quantity and forms of cloudiness with weighting factors of precipitation. Quite good correlation $r = 0.7–0.9$ between the measured and computed data makes the research in this field promising.

The problems of interpreting the results of satellite observations for indirect assessment of the fields of hydrometeorological elements remain urgent in the satellite climatology. In this connection the authors[1–5] have developed methods for reconstruction of the most important characteristics of precipitation on the basis of satellite observations of cloudiness (Table I, left part) above the territory of European part of Russian Federation.

The assessment of monthly characteristics of precipitation in summer and fall is usually implemented by the above methods.

The aim of the present paper is to study the potentialities of the methods[1,4,5] of reconstruction of the fall time precipitation in application to winter conditions. Assumptions on the applicability of the above methods to winter period are caused by the quasihomogeneity of the repetition of similar forms of cloudiness and the precipitation regardless of the date. The empirical model is based on the known functional dependence of the actual amount of precipitation R_a on the intensity J and the precipitation duration τ over certain period:

$$R_a = \sum_1^D J\,\tau. \tag{1}$$

Since spaceborne measurements of J and τ are unavailable, the problem is reduced to selection of an indirect analog of the total precipitation, namely, the precipitation index K, statistically connected with the actual precipitation R_a by the empirical relation

$$R_a = f(K) = f((\omega\Sigma Q/\Sigma D)\,\tau^*), \tag{2}$$

where $\omega\Sigma Q/\Sigma D$ is the daily mean cloudiness for the period ΣD, determining the potential daily precipitation intensity with the account for the cloud index of precipitation formation ω, τ^* is the index of duration of potentially "rainy situations" (as will be shown below), statistically connected with the number of precipitation days (the precipitation is more than 1 mm). It is known that the precipitation of more than 1 mm forms the basic portion in total values for definite periods of observations ΣD (decade, season, year).

The cloud index of precipitation ω is the dimensionless parameter and it is directly determined from satellite observations of cloudiness over the area 5°×10°:

$$\omega = \frac{(0.3D_{3-6} + 0.6D_{7-8} + 0.8D_{9-10} + 0.9D^*_{7-10} + D^*_{9-10})\mathrm{Cu, Cb} + 0.7D^*_{7-10\ \mathrm{Cu, Cb-St, Sc}} + (0.2D^*_{7-10} + 0.5D^*_{9-10})\mathrm{St, Sc}}{(0.7D_{3-6} + 0.4D_{7-8} + 0.2D_{9-10} + 0.1D^*_{7-10} + 0.5D_{0-2})\mathrm{Cu, Cb} + 0.3D^*_{7-10\ \mathrm{Cu, Cb-St, Sc}} + (0.8D^*_{7-10} + 0.5D^*_{9-10} + D_{\le 6})\mathrm{St, Sc}}, \tag{3}$$

where D is the number of days with minimum daily cloudiness with the cloud amount of 0–2, 3–6,...,9–10 being mostly: cumuliform clouds Cu, cumulus congestus Cb, stratus St, stratocumulus Sc or their combinations Cu–Cb, St–Sc, Cu, Cb–St, Sc; D^* is the number of situations when certain forms of cloudiness or their combinations are observed permanently (2 or 3 times during separate or sequential days).

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TABLE I. Characteristics of clouds derived from the data of spaceborne observations from "MeteorB satellite (the square 0636 conditionally centered at Orel city, December 1973).

Initial data				Results of computations	
Date	Time, h	Cloud form*	Cloud amount index	Dominating cloud form*	Cloud amount index of dominating cloudiness form
1	03	1	06	1	06
2	16	4	06	4	06
3	02	–	00	0	00
4	15	2	08	2	08
5	15	2	10	2	10
6	02/15	1/–	07/00	1	07
7	02/15	2/1	06/05	2	06
8	02/15	1/–	07/–	1	07
9	02	1	04	1	04
10	02	1	08	1	08
11	15	1	06	1	06
12	02	1	04	1	04
15	15	1	04	1	04
18	15	1	07	1	07
20	14	1	07	1	07
21	01/10	1/2	05/09	2	09
22	08/23	1/1	07/07	1	07
23	14/21	1/1	03/04	1	04
24	23	1	07	1	07
25	14	1	03	1	03
26	12/23	1/1	07/10	1	10
27	21	2	07	2	07
28	14/21	1/1	03/04	1	04
29	21	1	07	1	07
30	14/21	2/2	06/07	2	07
31	14	2	10	2	10

*Designations of cloud forms: q u (1), St (2), Sc (3), Cb (4) (for more details of the data processing see Ref. 2).

TABLE II. Probability of precipitation depending on combination of forms and amount of clouds based on the "Meteor" satellite observations under conditions of European territory of Russia.

Months	Cu–Cb						St–Sc			Cu, Cb–St, Sc
	D_{0-2}	D_{3-6}	D_{7-8}	D_{9-10}	D^*_{7-10}	D^*_{9-10}	$D_{\le 6}$	D_{7-10}	D^*_{9-10}	D^*_{7-10}
October	0	0.3	0.6	0.8	0.9	1.0	0.2	0.2	0.5	0.7
December–February	0	0.3	0.7	0.8	0.7	0.8	0	0.2	0.5	0.7

TABLE III. Repetition (days) of various cloud situations, forming the precipitation index K in the ratios (2), (3) (the square 0636, Orel, December, 1973).

q u–Cb						St–Sc			Cu, Cb–St, Sc	ΣQ	ΣD
D_{0-2}	D_{3-6}	D_{7-8}	D_{9-10}	D^*_{7-10}	D^*_{9-10}	$D_{\le 6}$	D_{7-10}	D^*_{9-10}	D^*_{7-10}		
1	9	6	0	3	0	1	4	4	1	165	26

The constants 0.3–0.9 in formula (3) are derived by the empirical method based on a conjugate analysis of daily cloud amount and daily precipitation R with the cloudiness forms Cu, Cb, St, Sc separately for the situations with $R \ge 1.0$ mm and $R \le 1.0$ mm, including the situations with the lack of precipitation.

Thus, quantitatively the value of w indirectly characterizes the relationship of the duration of potentially rainy periods and periods without the rain for the observation time ΣD.

Table II shows the estimates of probabilities for D (Cu, Cb–St, Sc, and so on) for winter conditions.

Table II clearly shows the identity of probability of precipitation from identical forms at the same cloud amount regardless of season that in fact demonstrates good prospects for implementation of the methods developed in Refs. 1–5.

The empirical model (2) was tested using data of standard satellite observations of the cloudiness for the areas of 5°×10° size with the agreed centers in the town of Valdai (square 0679) and in Orel (square 0636) in the period from 1970 to 1977. The monthly precipitation within the square was determined by summarizing the daily values averaged over 10 or 12 stations located evenly over the square. Subsequently, to continue searching for best connections $R_a = f(K)$, the annual area values of precipitation were normalized to their average many-year values within the limits of the square.

An example of processing the cloudiness data for estimating precipitation amount successively for every month of a year is presented in the right-hand side of Table I. Table III presents an example of calculation of the cloud precipitation index by the ratio (3). The dimensionless precipitation index, calculated based on the data of Tables I and III and relations (2) and (3), in particular, for December 1973, equals 1.72 (Table IV*b*, 1973).

The precipitation indices for the entire observation period (Table IV*b*, lines K and R_c) represent reasonably well the dynamics of annual variability of the precipitation R_a for some months. The value of correlation coefficients r_{R_1K} turned out to be sufficiently high and significant for the sampling volumes processed. The correlation coefficient equalled 0.85 for the square 0679, and for the square 0636 it was 0.70.

The operating regression equations for estimating the precipitation layer R_c are of the following form for evaluating the absolute area-averaged values of precipitation:

for the square 0679 (Valdai)

$$R_c\text{ ,mm} = 24.90K + 5.9; \tag{4}$$

for the square 0636 (Orel)

$$R_c\text{ ,mm} = 18.73K + 5.6; \tag{5}$$

and for estimating the area-averaged normalized precipitation the operating regression equations are of the form:

for the square 0679 (Valdai)

$$R_c,\text{ mm} = 0.83K + 0.15; \tag{6}$$

for the square 0636 (Orel)

$$R_c,\text{ mm} = 0.68K - 0.03 \tag{7}$$

Comparative analysis of the retrospective estimates of the measured R_a and calculated R_c precipitation for 1973 to 1977 period for the area-averaged absolute and normalized to many-year total values is given in Tables IV and V. When interpreting the results of comparison we started from the existing accuracy of measurements of winter precipitation, which is approximately 30% or ±10 mm of monthly precipitation. As follows from Tables IV and V, the differences between the absolute values in most cases are within the limits of ±10 mm, the differences between the relative values are within 30%. From the comparison of Tables IV and V it follows that the normalized values of precipitation are reconstructed better than the absolute values since in all cases these values do not exceed the limits of admissible accuracy ±30 per cent.

TABLE IV. Index of precipitation (K), actual, R_a, and calculated, R_c, monthly total precipitation in the regions of Valdai and Orel.

Characteristics	December			January				February			
	1973	1974	1975	1970	1971	1972	1977	1973	1975	1976	1977
	=) square 0679 (Valdai)										
K, arb. units	1.30	1.98	1.49	0.20	–	–	1.21	2.15	0.98	0.45	1.84
R_a, mm	47	56	57	8	–	–	29	47	31	14	53
R_c, mm	38	55	43	11	–	–	36	59	30	17	52
Δ, mm	9	1	14	−3	–	–	−7	−12	1	−3	1
	b) square 0636 (Orel)										
K, arb. units	1.72	2.13	1.29	1.27	2.09	0.35	1.62	2.17	0.77	0.76	1.99
R_a, mm	44	50	40	52	37	4	37	46	21	2	53
R_c, mm	38	40	52	30	45	12	36	46	20	12	43
Δ, mm	6	10	14	−12	22	8	−8	1	0	−10	10

TABLE V. Index of precipitation (K), normalized actual, R_a, and calculated, R_c, monthly total precipitation in the regions of Valdai and Orel.

Characteristics	December			January				February			
	1973	1974	1975	1970	1971	1972	1977	1973	1975	1976	1977
	=) square 0679 (Valdai)										
K, arb. units	1.30	1.98	1.49	0.20	–	–	1.21	2.15	0.98	0.45	1.84
R_a, mm	130	187	149	30	–	–	132	160	97	47	174
R_c, mm	123	175	139	32	–	–	115	193	96	52	168
Δ, mm	7	8	10	−2	–	–	17	−33	1	5	6
	b) square 0636 (Orel)										
K, arb. units	1.72	2.13	1.29	1.27	2.09	0.35	1.62	2.17	0.77	0.76	1.99
R_a, mm	118	115	111	96	115	7	116	137	62	16	140
R_c, mm	114	142	85	83	139	21	107	144	45	28	132
Δ, mm	4	−27	26	13	−24	−14	9	−7	17	−12	8

TABLE VI. The number of days with precipitation of more than 0.1 mm ω_1, *actual,* N_a, *and calculated,* N_c, *number of days with precipitation of more than* 0.1 mm *(the 0636 square, Orel, 1970–1977).*

Characteristics	December				January			February			
	1972	1973	1974	1975	1970	1972	1977	1973	1975	1976	1977
ω_1, arb. units	12.0	10.8	12.2	8.1	6.3	3.7	8.9	13.5	3.7	2.7	10.5
N_a, mm	9	12	10	10	8	4	8	13	7	5	9
N_c, mm	10	9	10	8	7	6	8	10	6	6	9
Δ, mm	−1	3	0	2	1	−2	0	3	1	−1	0

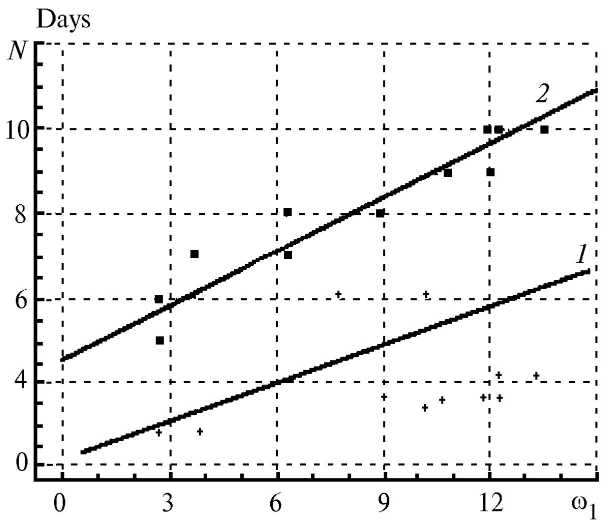

FIG. 1. Connection of the parameter w_1 *with the number of days with precipitation N: the number of days with precipitation exceeding* 1 mm *(1), the number of days with precipitation exceeding* 0.1 mm *(2).*

In addition to the precipitation an important characteristic feature of moisture is the number of days with precipitation. During the investigation a serious efforts were attracted to reveal the connection between the numerator of the relation (3), which is arbitrarily called ω_1 (this numerator is called as the index of the number of days with precipitation ≥0.1 mm) and the number of days with precipitation ≥1 mm (N). In Fig. 1 (curve *1*) an essential scatter of points of the correlation field is observed. However, we can see the tendency to a linear dependence. The essential scatter of points can be due to a small fraction of days with precipitation more than 1 mm as compared to the total number of days with precipitation less than 0.1 mm in winter. Therefore, we determined the connection between ω_1 and the number of days with precipitation more than 0.1 mm (straight line *2* in the figure). The correlation coefficient for this connection in the 0636 square turned out to be equal to 0.90, and the regression equation is of the form:

$$N_c = 0.43\ \omega_1 + 4.5. \tag{8}$$

Table VI gives the calculated values of N_c according to Eq. (8). The comparison of these with the observed data shows a good agreement, namely, in 64% of cases it does not exceed one day, and in 82% of cases it does not exceed two days.

Thus, the obtained good agreement of the calculated total precipitation and the number of days with precipitation with the actual data points to the fact that for indirect calculations of precipitation in winter under conditions of European territory of Russia based on the data of cloudiness, obtained from the "Meteor" satellite, we can use the empirical relations (2) and (3) proposed previously for the summer–fall period.

In the near future it is appropriate to test the above conclusions on the basis of more extensive and independent studies.

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