STATISTICAL PROPERTIES OF THE SPATIAL STRUCTURE OF THE CLOUDINESS FIELD

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We discuss here some results of correlation analysis of spatial structure of the cloudiness field based on the data of long-term observations from the U.S.A. meteorological stations for homogeneous cloudy regions. The probability of stably favorable and unfavorable cloudy conditions is considered in connection with the operation of the observation optical systems.

In recent years considerable attention has been focused on the correlation analysis of a global cloudiness field based on the data of ground-based and spaceborne measurements.[1–3] However, up to now, we have considered mainly the spatial correlation of monthly mean values of cloudiness or the averaged (over longitude and latitude) correlation coefficients of decade, five-day, or daily mean values of cloudiness. The spatial correlation functions of the data of actual observations of cloudiness are not practically investigated. Therefore, it is interesting to estimate spatial correlation functions based on the data of actual values of cloudiness.

The present paper describes the results of correlation analysis of spatial structure of the cloudiness field, performed for January and July and based on the data of many-year (1964–1978) four-time a day observations at 141 meteorological stations of the USA for homogeneous cloudy regions (HCR)[4] (a fragment of such division into districts for the USA is shown in Fig. 1). About 20 stations fell within every HCR. The bulk of samples for every station was about 600 observations.

We describe here the normalized correlation and structure functions of deviations of the total cloud cover from standards. As the field of standards turned out to be inhomogeneous, these deviations were determined, based on the initial sample for every meteorological station individually.

Table I shows the smoothed values of normalized correlation functions of the total cloud cover and their confidence, half-open, intervals $\varepsilon_{\beta,n} < r_{\hat{x}}(\rho)>$ at $\beta = 0.95$ and $n = 1500$, calculated for some HCR.

Analysis of correlation functions, obtained using the data from 141 stations has shown that the character of spatial variability of the cloudiness is different in different seasons. A general feature for both seasons is a rapid decrease of the correlation between the values of cloudiness in a direction from the west-northwest to the east-southeast and those along the direction from south-southwest to the north-northeast. The field of isocorrelate is of the form of ellipse, whose large axis is oriented in the direction of predominant air-mass transport. In the direction of small axis of the ellipse the correlation function passes through zero at the distance about 1000–1200 km and in the area 7 (July) at the distance of 3000 km. In the direction of large axis of the ellipse the transition of the correlation function through zero was not revealed.

Analysis of the isocorrelate field of the cloudiness for the stations located in central parts of the HCR has shown that they are close to circular ones up to the distance of 700–800 km in January and 500–600 km in July what confirms the independence of the correlation of the direction. Thus, the field of cloudiness in the first approximation can be considered homogeneous and isotropic relative to the correlation function. At large distances the isotropy is violated.

The largest spatial variability of the total cloud cover was determined in the regions 9 (January) and 14 (July) (see Table I). Thus, the correlation coefficient values in regions 9 and 14 are statistically insignificant ($r(\rho)$ is less than 0.1) already at a distance of 500 km.

Spatial correlation functions of cloudiness can be approximated by the dependences of the type:

$$r_{\hat{x}}(\rho) = \exp(-\alpha\ \rho)\ , \quad (1)$$

$$r_{\hat{x}}(\rho) = \exp(-\rho/\rho_0)^{\gamma}. \quad (2)$$

As is seen from Table II, the parameters of the approximation of spatial functions of the total cloud cover are the following: $\alpha(\text{km}^{-1})$, ρ_0 (thousand km), ($\alpha = 1/\rho_0$), characterizing the rate (degree) of the correlation function fall off with increasing distance and it is the dimensionless parameter. Table II shows that the spatial correlation radius ρ_0 (the distance at which the correlation function of cloudiness decreases by e times) takes the values from 200 to 500 km. The parameters of the spatial correlation function approximation were determined by the iteration method.

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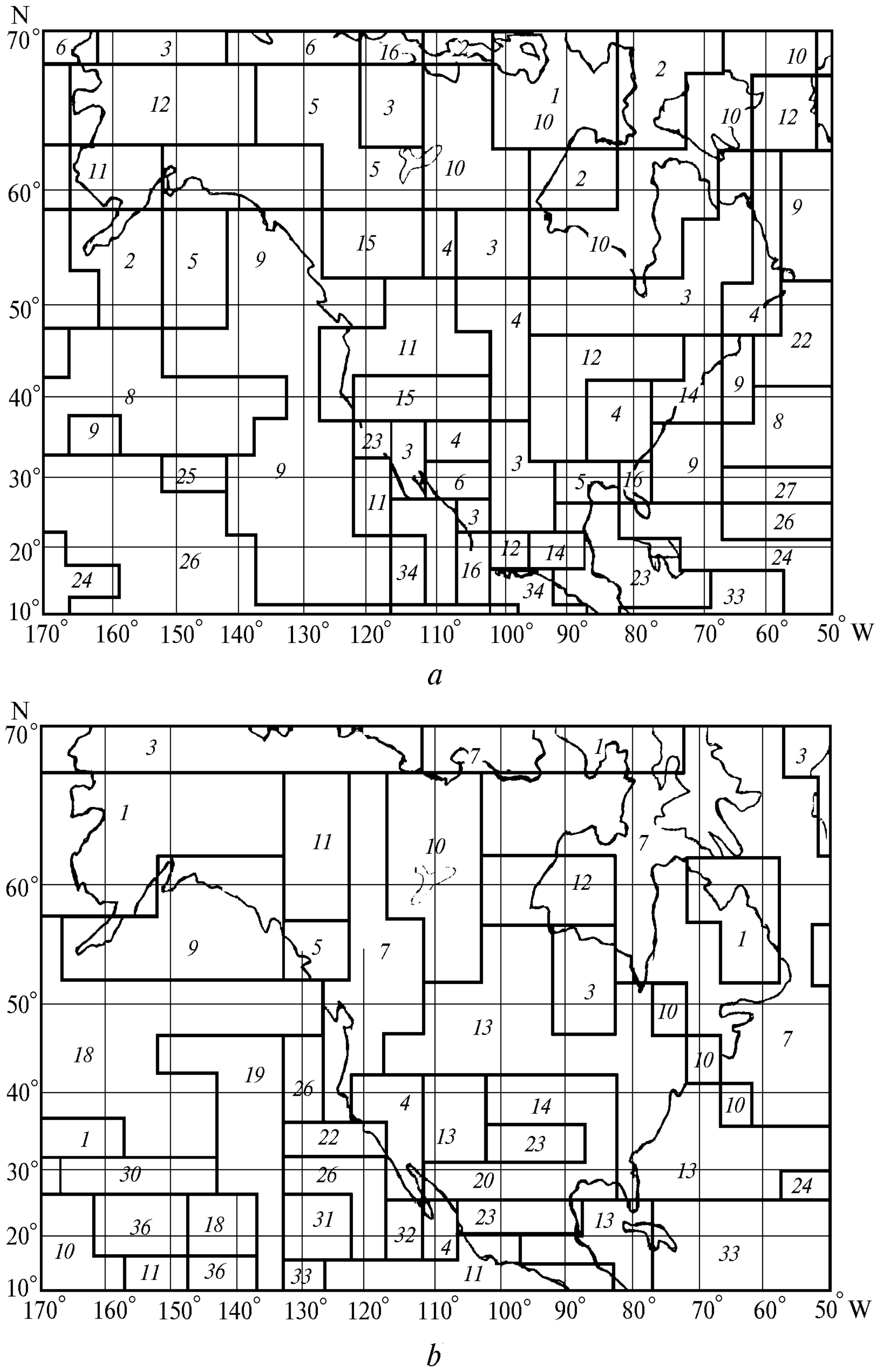

FIG. 1. The map of homogeneous cloud regions of the North-American continent (a – winter, b – summer).

We have checked the validity of these dependences, (1) and (2), approximating correlation functions of the cloudiness using the Pearson and Kolmogorov goodness-of-fit tests at 5 percent level of significance.

The correlation function of cloudiness is described by the dependences (1) and (2) at $\rho_0 = 400–500$ km (the parameter γ is close to 1). Up to this distance the field of cloudiness is practically isotropic at large distances the condition of isotropy is violated since the correlation along the direction from southwest to northeast is higher than along the direction from northwest to southeast. In the general case the dependence of the form (2) enables one to describe more exactly the spatial correlation function of cloudiness and preference is given to the above dependence.

TABLE. I. Space correlation functions of the total cloud cover (numerator) and their confidence half-intervals (denominator) at $\beta = 0.95$, $n = 1500$.

The region number	Distance (thousand km)														
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.4	1.8	2.2	2.6	3.0
January															
14	0.76/0.05	0.61/0.07	0.48/0.09	0.37/0.10	0.28/0.10	0.23/0.11	0.18/0.11	–	–	–	–	–	–	–	–
9	0.62/0.07	0.38/0.10	0.24/0.11	0.15/0.11	0.09/0.12	0.06/0.11	0.04/0.11	0.02/0.11	0.01/0.11	0.01/0.11	–	–	–	–	–
15	0.80/0.04	0.63/0.08	0.50/0.08	0.38/0.10	0.29/0.10	0.25/0.11	–	–	–	–	–	–	–	–	–
11	0.82/0.04	0.68/0.06	0.55/0.08	0.45/0.09	0.37/0.10	0.30/0.10	0.25/0.11	0.20/0.11	0.16/0.11	0.13/0.11	–	–	–	–	–
3	0.47/0.09	0.39/0.10	0.37/0.10	0.35/0.10	0.34/0.10	0.31/0.10	0.29/0.10	–	–	–	–	–	–	–	–
23	0.77/0.05	0.58/0.08	0.44/0.09	0.35/0.10	0.26/0.11	0.18/0.11	0.13/0.11	–	–	–	–	–	–	–	–
July															
7				0.37/0.10		0.25/0.11		0.16/0.11		0.12/0.11	0.06/0.11	0.04/0.11	0.02/0.1	0.01/0.11	0.00/0.11
13	0.78/0.04	0.56/0.08	0.48/0.09	0.38/0.11	0.28/0.10	–	–	–	–	–	–	–	–	–	–
23	0.70/0.06	0.52/0.08	0.39/0.10	0.30/0.10	0.25/0.11	0.20/0.11	–	–	–	–	–	–	–	–	–
20	0.76/0.05	0.57/0.08	0.44/0.09	0.38/0.10	0.26/0.11	0.20/0.11	0.14/0.11	0.10/0.11	0.08/0.11	–	–	–	–	–	–
10	0.80/0.04	0.58/0.08	0.46/0.09	0.42/0.09	0.33/0.10	0.25/0.11	0.21/0.11	0.17/0.11	0.13/0.11	–	–	–	–	–	–
14	0.66/0.05	0.45/0.08	0.30/0.09	0.19/0.10	0.12/0.11	0.07/0.11	–	–	–	–	–	–	–	–	–

TABLE II. Parameters of approximation of space correlation functions of the total cloud cover by the dependences of the form: $r_{\hat{x}}(\rho) = \exp(-\alpha\rho)$ and $r_{\hat{x}}(\rho) = \exp(-\rho/\rho_0)^{\gamma}$.

The region number	14	9	15	11	3	23
January						
α	2.714	4.780	2.406	2.020	–	2.740
ρ_0	0.370	0.209	0.416	0.495	0.333	0.356
γ	0.838	1.001	1.052	1.011	0.234	1.036
The region number	7	13	23	20	10	14
July						
α	2.500	2.445	3.034	2.697	2.299	4.100
ρ_0	0.400	0.410	0.330	0.370	0.435	0.240
γ	0.806	0.987	0.863	0.988	1.012	0.969

TABLE III. Probability (%) of conservation of unfavorable (numerator) and favorable for optical systems operation (denominator) cloudy conditions.

The region number	Distance (thousand km)														
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.4	1.8	2.2	2.6	3.0
January															
14	92/88	87/78	84/68	80/61	76/55	72/48	69/44	–	–	–	–	–	–	–	–
9	90/88	80/78	74/70	66/62	58/56	54/50	48/44	44/38	40/34	36/28					
15	94/88	88/76	84/68	80/58	76/51	70/44								–	–
11	96/86	92/76	88/68	84/60	80/52	78/45	75/40	72/35	69/31	65/27				–	–
3	92/86	74/56	68/48	63/41	58/35									–	–
23	90/90	64/70	58/65	51/58	44/55									–	–
July															
7				86/50		82/35		78/24		72/17	64/9	56/5	50/3	44/2	40/1
13	82/89	68/82	57/78	48/74	40/68									–	–
23	80/88	67/78	58/70	50/64	44/58									–	–
20	86/80	78/70	71/64	65/60	60/54	56/50	52/48	48/45	45/42	43/40				–	–
10	86/84	78/75	72/78	69/63	64/58	60/54	57/50	54/46	50/43					–	–
14	54/97	37/96	25/95	18/94	13/93	9/92								–	–

The paper describes also the probability of conservation in space of favorable (0–6 cloud amounts) and unfavorable (7–10 cloud amounts) conditions of cloudiness as applied to functioning of optical observation systems.

As the space function the probability of conservation of favorable and unfavorable cloud conditions, for the use of optical systems, is determined based on the same initial data as the correlation functions of cloudiness.

According to the observational data, the maximum spatial stability as well as the temporal one, is typical of the overcast and clear sky. Therefore, within the limits of gradation of cloudiness and 0–6 and 7–10 cloud amounts the overcast (10 cloud amounts) and clear sky (0 cloud amount), respectively.

Table III shows the probabilities of conservation of unfavorable cloudiness situation (UCS) and favorable cloudiness situation (FCS) as a function of the distance from an observation point. Table III shows that in all the homogeneous cloudiness region (HCR) in January the gradation of cloudiness of 7 to 10 cloud amounts is more stable, except for the region 23, where at the distance of 700 km the probability of conservation of unfavorable cloudiness situation creases to 44 percent, and the probability of its change for the favorable cloudiness condition increases up to 56 percent. In the above-mentioned region the favorable cloudiness condition (FCC) is more stable. In July in the regions 13, 14 and 23 FCC is more stable (the probability of its conservation here is 58–93 percent at a distance of 600 km), and in the regions 7, 10 and 20 the cloudiness of 7–10 cloud amounts dominates.

Thus, the results obtained have shown that the cloudiness field in the first approximation can be considered homogeneous and isotropic relative to the space correlation function at distances of 700–800 km in January and 500–600 km in July. Moreover, from these results it follows that the maximum conservation probability is typical for the unfavorable cloudiness situation (7–10 cloud amounts) observed at a distance of 500–700 km.

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