JANUARY 1968
T-R-566

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RESEARCH TRANSLATION

The Zonal Distribution of Radiation Reflected From Various Natural Surfaces

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United States Air Force

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AD 667 414

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American Meteorological Society
Boston, Massachusetts

January 1868

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Translation of

Zonal'noe raspredelenie radiatsii, otrazhennoĭ razlichnymi estestvennymi poverkhnostiami

by

N. I. Goĭsa and M. P. Fedorova

Kiev. Ukrainskiĭ Nauchno-Issledovatel'skiĭ Gidrometeorologicheskiĭ Institut, Trudy, No. 48: 113-120, 1965.

This translation was produced by the American Meteorological Society under Contract AF 19(628)-3880, through the support and sponsorship of the

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BEDFORD, MASSACHUSETTS
01731

T-R-566

1. The zonal distribution of radiation reflected from various natural surfaces

2. Goĭsa, N. I. and M. P. Fedorova. Zonal'noe raspredelenie radiatsii, otrazhennoĭ razlichnymi estestvennymi poverkhnostiami, Kiev. Ukrainskiĭ Nauchno-Issledovatel'skiĭ Gidrometeorologicheskiĭ Institut, Trudy, No. 48: 113-120, 1965 [in Russian].

3. 10 typewritten pages

4. Date of translation: August 1967

5. Translator: George E. Brady, Jr.

6. Produced for Air Force Cambridge Research Laboratories, Office of Aerospace Research, United States Air Force, L. G. Hanscom Field, Bedford, Massachusetts, by the American Meteorological Society, Contract number AF 19(628)-3880.

7. Unclassified and complete

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N. I. Goĭsa and M. P. Fedorova

Data are presented on the zonal distribution of radiation reflected by a field of barley in the ear formation stage, a field of barley in the stage of waxy maturity, barley stubble, Sudan grass, dry snow, snow covered with an ice crust, and stratus cloud cover.

Research on the angular distribution of the intensity of reflected short-wave radiation [1] showed that radiation reflected from natural underlying surfaces is essentially anisotropic. In this connection, data on the angular distribution of the intensity of reflected radiation are required to solve many practical problems in meteorology other than the albedo magnitude. These data permit one, for example, to determine the zonal distribution of reflected radiation. The zonal distribution must be known in order to determine the correction factor to the response of the instrument measuring the reflected radiation and also to work out other procedural problems of actinometric observations.

The purpose of the present paper is to determine the zonal distribution of radiation reflected by various natural surfaces based on the data of measurements of the angular distribution of its intensity.

The intensity of reflected radiation from various directions was measured with the vacuum thermocouple of Professor B. P. Kozyrev's system. The radiation thermoelement is a Chromel-Copel thermocouple whose "hot" junction is placed in the focus of a metallic aluminized mirror and whose "cold" junction is placed behind the mirror. The instrument's angle of vision is 10°. The thermoelement is placed in a glass bulb and, thus, it measures the same short-wave radiation as the Ianishevskiĭ pyranometer. The sensitivity of the radiation thermoelement is 1.25 v/w and the lag is 12 sec. The thermocouple with the galvanometer was not graduated. The intensity of the reflected radiation was determined in relative units, taking the intensity of reflected radiation at the nadir as a unit.

The thermoelement was attached to a theodolite and mounted on a level platform where the underlying surface was uniform in nature. Measurements were made in the direction of the nadir and at vertical angles of 25, 50, and 75° reckoned from the nadir, every 30° of azimuth from 0 to 360°. Thus, the reflected radiation was measured in 37 directions. The instrument was mounted at a height of 1.5 m. Here the required radius of the platform was 8.5 m. In all the measurements, the size of the platform was considerably larger than necessary.

The measurements were made using a barley field during ear formation and in waxy maturity, barley stubble, Sudan grass, dry snow, and snow covered with an ice crust. Measurements were mainly carried out when the sky was cloudless and when there was total overcast cloud cover at various elevations of the sun. A single series of measurements took 10-12 min. The results obtained are analyzed in [1].

From the data of measurements, a graph was plotted for each series showing the relative values of the intensity of reflected radiation

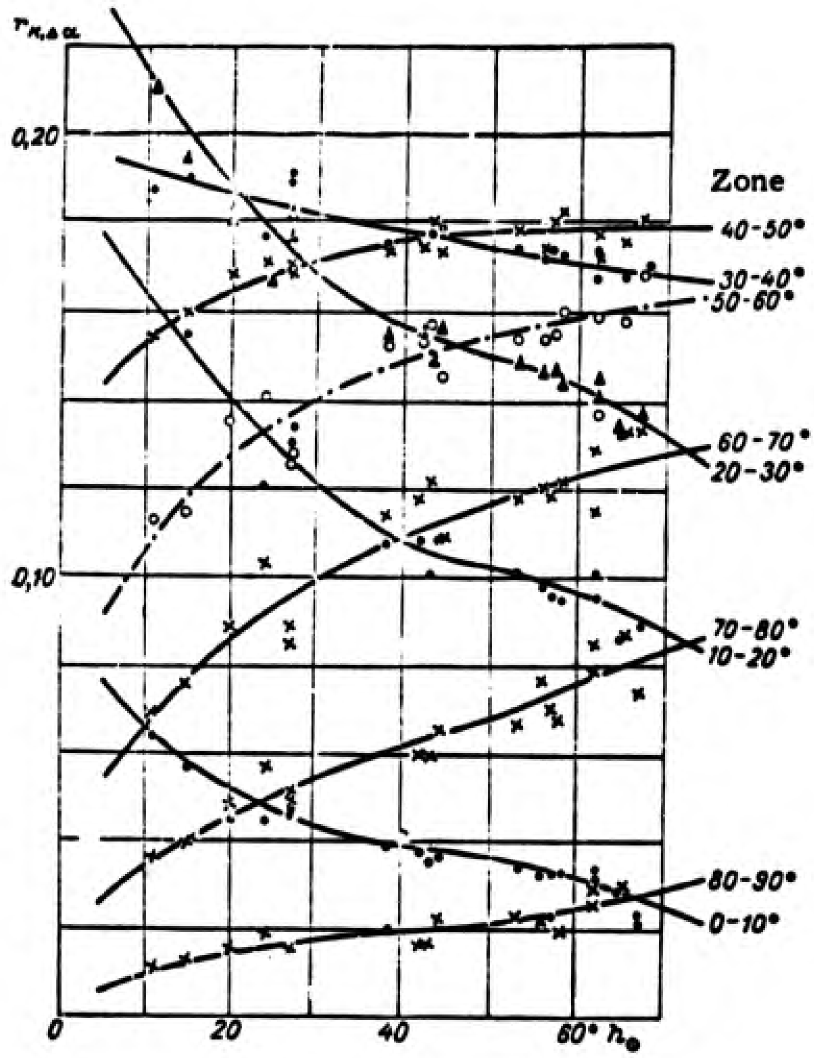

Figure 1. The relative intensity of radiation reflected in different zones by a barley field in the ear formation stage versus the elevation of the sun $h_{\odot}$ (clear sky).

versus the azimuth ψ and the sighting angle α. In this case, for the sake of convenience, the latter was reckoned from the horizontal plane rather than from the nadir, which is the usual practice.

On the basis of these graphs, the flux of the reflected radiation was integrated and its relative values were determined from the individual ring-shaped zones $r_{K,\Delta\alpha}$. The width of the zone of $\Delta\alpha$ was taken to be 10° (0-10, 10-20, 20-30°, etc.).

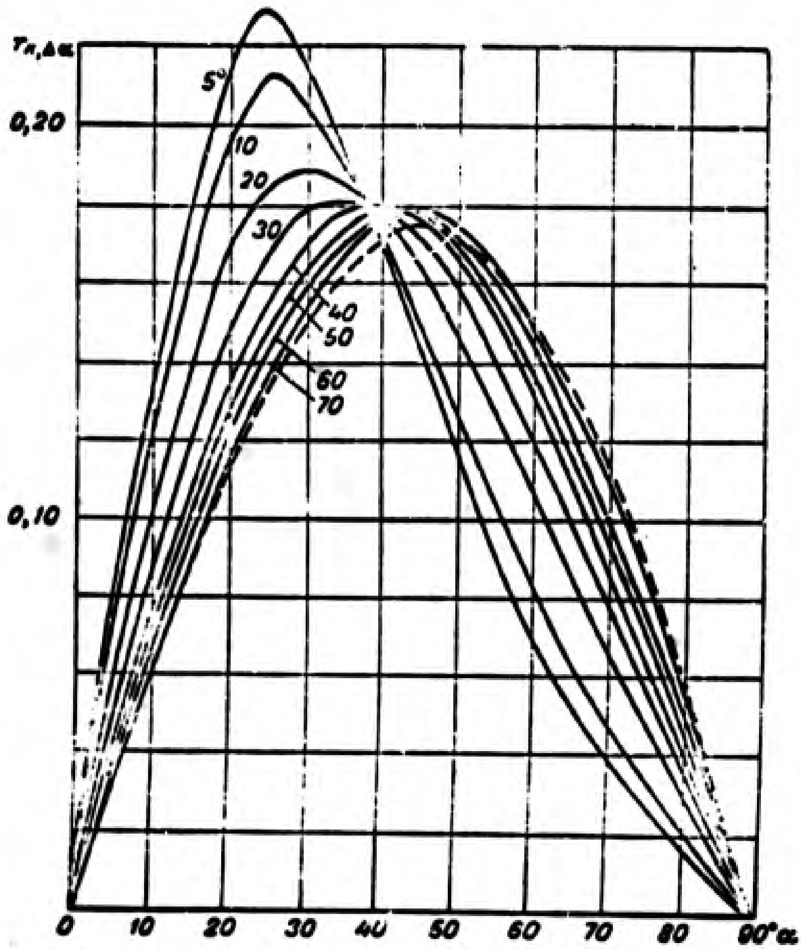

Figure 2. The zonal distribution of the relative intensity of radiation reflected by a barley field in the ear formation stage, measured at different elevations of the sun $h_{\odot}$. (Clear sky; the dashed line shows the isotropic distribution.)

Then, the values of $r_{K,\Delta\alpha}$ were plotted with respect to the elevation of the sun $h_{\odot}$ for each type of surface. When this plotting was done, the measurements were averaged and the effect of extraneous factors on the final results was eliminated. Figure 1 gives an example of $r_{K,\Delta\alpha}$ versus $h_{\odot}$ for a barley field when sky is clear. This figure shows that an increase in the elevation of the sun leads to a substantial redistribution of the values of $r_{K,\Delta\alpha}$ over the individual zones. For zones in the interval of 0-40°, the relative values of the reflected radiation fluxes decrease as $h_\odot$ increases, but for zones above 50° the reverse pattern is observed. The magnitude of $r_{K,\Delta\alpha}$ in the central zone of 40-50° is practically independent of the elevation of the sun.

The values of $r_{K,\Delta\alpha}$ for the individual zones of $\Delta\alpha$ and elevations of the sun $h_\odot$ were plotted from the graphs of the function $r_{K,\Delta\alpha} = f(h_\odot)$. Table 1 presents the corresponding data for various types of surfaces. Figure 2 also gives $r_{K,\Delta\alpha}$ versus α at various elevations of the sun for a barley field in the ear formation stage. Table 1 and Figure 2 show that the nature of the zonal distribution of reflected radiation is essentially dependent on the irradiation conditions (on the elevation of the sun and the presence of clouds). The greatest deviation from an isotropic distribution of $r_{K,\Delta\alpha}$ over the zones occurs at small elevations of the sun. When $h_\odot \geq 50°$, the zonal distribution of $r_{K,\Delta\alpha}$ becomes close to isotropic.

Figure 2 shows that the sighting angle at which the maximum values of $r_{K,\Delta\alpha}(\alpha_{max})$ are observed, is also determined by the elevation of the sun. Table 2 gives α_{max} versus $h_\odot$ for different types of natural surfaces. From Table 2, it follows that the values of α_{max} at the same elevation of the sun are close to each other for almost all the types of surfaces studied, except for dry snow. The structure of the irradiating flux (the presence or absence of direct solar radiation in this flux) has a substantial effect on the position of the zone with the maximum values of $r_{K,\Delta\alpha}$. Thus, the data on the zonal distribution of radiation reflected by dry snow when the sky is cloudy shows that even when $h_\odot = 5°$, the maximum values of $r_{K,\Delta\alpha}$ fit into the central zone. This fact indicates that when the underlying

Table 1

The Zonal Distribution of Radiation Reflected by Various Natural Surfaces

Karadag

Barley field in the ear formation stage, clear sky. June 1956

Elevation of the sun, degrees	Zone, degrees 0—10	10—20	20—30	30—40	40—50	50—60	60—70	70—80	80—90
5	0,077	0,178	0,229	0,191	0,144	0,092	0,052	0,027	0,007
10	067	164	213	190	152	105	065	034	010
15	059	151	198	187	159	118	075	041	012
20	052	140	186	185	164	127	085	046	015
25	046	130	176	183	169	135	093	051	017
30	043	121	167	181	172	140	101	056	019
35	041	114	161	179	175	145	107	059	019
40	039	108	156	178	176	150	111	062	020
45	038	105	152	176	178	152	114	065	020
50	037	101	149	174	178	155	117	068	021
55	035	100	146	172	178	156	120	071	022
60	032	097	143	170	178	159	123	075	024
65	029	093	138	169	178	161	126	080	026
70	026	089	133	168	177	163	130	085	029

Barley field in the stage of ear formation. Cloudy sky, 8/0-10/0 Ci. June 1956

Elevation of the sun, degrees	0—10	10—20	20—30	30—40	40—50	50—60	60—70	70—80	80—90
5	0,088	0,198	0,231	0,159	0,119	0,079	0,065	0,043	0,015
10	074	177	216	168	134	102	070	044	015
15	064	158	200	173	136	128	076	046	016
20	056	145	189	175	154	136	080	049	016
25	050	133	179	177	160	147	086	051	017
30	046	124	174	176	161	152	092	055	017
35	042	116	168	174	167	157	099	059	018
40	040	110	163	172	170	158	105	063	019
45	037	103	158	170	173	161	112	066	020
50	036	099	155	170	176	163	118	069	021
55	033	093	148	168	177	164	121	073	023
60	032	088	143	168	178	164	127	076	024
65	031	084	140	166	178	163	132	080	026
70	030	082	136	164	178	162	138	084	028

Barley field in the stage of waxy maturity. Sky clear. July 1956

Elevation of the sun, degrees	0—10	10—20	20—30	30—40	40—50	50—60	60—70	70—80	80—90
5	0,071	0,167	0,211	0,177	0,138	0,106	0,074	0,041	0,015
10	064	157	201	182	146	113	076	045	016
15	058	148	193	185	152	120	079	048	017
20	053	140	184	187	159	126	083	051	017
25	049	132	175	186	164	132	090	054	018
30	044	123	169	184	167	137	100	057	019
35	041	115	163	180	171	144	108	059	019
40	038	110	157	177	173	149	115	061	020
45	037	104	151	175	176	154	120	063	020
50	035	100	147	173	178	157	124	065	021
55	034	096	143	172	179	160	127	067	022
60	033	093	140	171	180	162	130	068	023
65	030	090	138	170	182	165	132	069	024
70	029	086	136	170	184	167	134	071	024

Table 1 (Continued)

Elevation of the sun, degrees	Zone, degrees 0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90
	Barley stubble. Clear sky. August 1956								
5	0,073	0,174	0,219	0,177	0,143	0,092	0,064	0,015	0,013
10	064	160	205	179	149	101	075	050	014
15	057	147	191	180	155	116	084	054	016
20	051	135	180	180	160	127	093	057	017
25	047	123	169	179	165	136	101	062	018
30	043	113	161	176	170	144	107	067	019
35	040	106	155	175	172	150	112	070	020
40	037	100	149	174	175	154	116	073	022
45	035	096	145	172	176	157	120	076	023
50	033	092	140	170	177	161	124	079	024
55	031	089	135	168	178	164	128	081	026
60	029	086	132	164	179	166	133	084	027
65	028	083	130	160	181	169	135	086	028
70	027	081	128	157	182	172	137	087	029
	Sudan grass. Clear sky. July-August 1956								
5	0,067	0,173	0,2[illegible]	0,181	0,138	0,095	0,068	0,018	0,016
10	059	156	193	180	150	115	080	050	017
15	052	141	181	180	157	127	090	054	018
20	048	131	172	179	162	133	098	057	020
25	044	123	165	179	166	138	104	060	021
30	041	117	160	178	169	142	109	062	022
35	039	110	156	176	171	145	114	066	023
40	037	106	152	174	173	148	119	069	024
45	036	102	147	171	174	151	121	073	025
50	034	099	143	169	175	154	124	076	026
55	033	097	140	166	175	156	127	079	027
60	032	095	139	163	176	158	128	081	028
65	031	094	137	162	176	159	130	082	029
70	030	093	135	161	176	160	132	083	030
	Voeikovo								
	Dry snow. Clear sky. December 1955, March 1956								
5	0,046	0,119	0,161	0,171	0,167	0,138	0,103	0,071	0,024
10	038	109	15[illegible]	170	170	146	111	076	027
15	035	103	149	170	171	150	115	078	029
20	035	099	145	169	172	153	117	080	030
25	034	096	143	168	175	155	117	081	031
	Dry snow. Cloudy sky. December 1955 - March 1956								
5	0,035	0,106	0,150	0,168	0,170	0,149	0,119	0,076	0,027
10	032	096	140	169	179	157	123	077	027
15	029	089	129	170	186	163	130	077	027
	Snow with ice crust. Clear sky. December 1955 - March 1956								
15	0,055	0,147	0,182	0,181	0,161	0,125	0,087	0,014	0,018
20	049	135	172	178	162	132	094	058	020
25	043	122	165	176	166	139	102	065	022
30	037	108	158	177	172	145	110	070	023
35	033	094	150	181	181	150	114	072	025

Table 2

The Values of α_{max} (in Degrees of Sighting Angle for Which Maximum Values of $r_{K,\Delta\alpha}$ are Observed) for Various Elevations of the Sun

Type of surface	Elevation of sun, degrees										
	5	10	15	20	25	30	35	40	50	60	70
Barley in the ear formation stage. Clear sky	23,5	25,0	27,0	29,0	31,0	33,5	35,5	38,0	42,0	44,5	46,0
Barley in the ear formation stage. Sky covered by Ci	21,5	24,0	25,0	26,5	28,5	31,0	34,0	37,0	43,0	45,5	48,0
Barley in the stage of waxy maturity. Clear sky	23,5	25,0	27,0	29,0	31,0	33,5	35,5	38,0	42,0	44,5	46,0
Barley stubble. Clear sky	23,5	25,0	27,5	30,0	34,0	37,0	40,0	42,0	44,0	46,0	46,5
Sudan grass. Clear sky	24,0	26,5	29,0	32,0	34,5	36,5	38,5	40,0	43,0	45,0	46,0
Dry snow. Clear sky	36,0	40,0	43,0	44,0	45,0	—	—	—	—	—	—
Dry snow. Cloudy sky	43,0	45,0	45,0	—	—	—	—	—	—	—	—
Snow with an ice crust. Clear sky	—	—	29,0	33,5	35,0	39,0	40,0	—	—	—	—
Top of St layer (sky clear above clouds)	—	—	—	28,0	—	—	—	—	—	—	—

surface is irradiated by diffuse radiation (direct solar radiation was absent when the sky was cloudy), the zonal distribution of reflected radiation is close to the isotropic distribution for any elevation of the sun.

On the basis of Figure 3, one can see how the zonal distribution of reflected radiation is dependent on the type of natural surface. Figure 3 gives the zonal distribution of $r_{K,\Delta\alpha}$ for different types of surfaces at an elevation of the sun of 20°.

The curve for St was computed from data obtained by V. P. Kozlov and E. O. Fedorova on measurements of the distribution of the luminance of clouds [2]. These measurements were made by a photoelectric recording

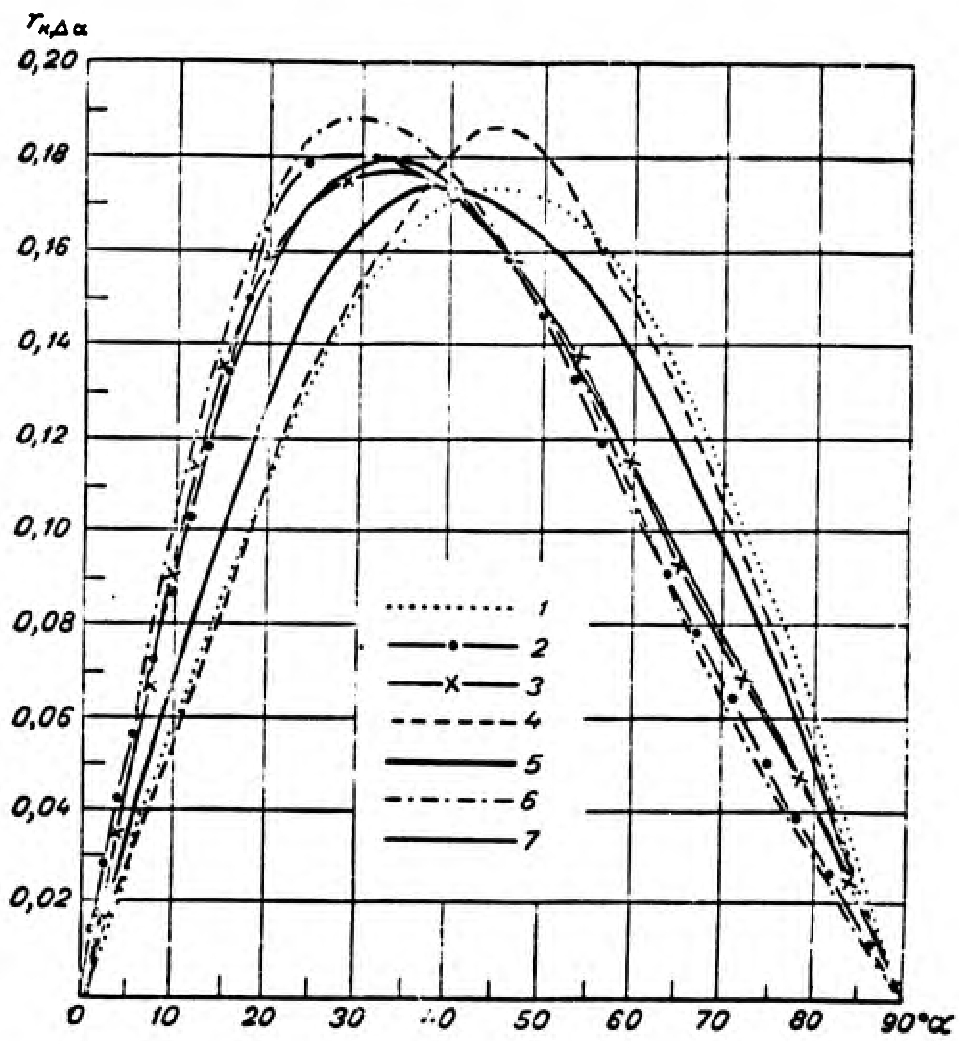

Figure 3. Zonal distribution of the relative intensity of radiation reflected by various natural surfaces.

1. Isotropic distribution; 2. St, $h_\odot = 20^\circ$, sky clear above clouds; 3. snow with ice crust, $h_\odot = 20^\circ$, clear sky; 4. pure, dry snow, $h_\odot = 15^\circ$, cloudy sky; 5. pure, dry snow, $h_\odot = 20^\circ$; 6. barley in the ear formation stage, $h_\odot = 20^\circ$, clear sky; 7. Sudan grass, $h_\odot = 20^\circ$, clear sky

photometer installed in an airplane. The airplane flew at an altitude of 100 m above the top of the cloud layer. The measurements were made in the spectral range $\Delta\alpha = 50$ millimicron with $\lambda_{max} = 800$ millimicron.

In this connection, the data are not completely comparable to the data obtained in ref. [1]. However, the practically complete absence of other data on the angular distribution of radiation reflected by clouds forces us to use the indicated measurement results so as to obtain at least an approximate pattern. The object measured was an St cloud that was 150-200 m thick and had its base at 600-700 m. The elevation of the sun was about 20°.

Of all the vegetation covers investigated, data are presented in Figure 3 only for barley in the ear formation stage and Sudan grass as the greatest divergence was observed for these. If Figure 3 is analyzed, the following conclusion can be drawn.

The zonal distributions of radiation reflected by plant covers of various structure, St clouds, and snow cover with an ice crust are close to each other under the same irradiation conditions. The zonal distribution $r_{K,\Delta\alpha}$ of snow cover is quite variable. Considerably less anisotropy is inherent in pure, dry snow than in snow covered with an ice crust (at the same elevation of the sun and with a clear sky). When the weather is cloudy (and, obviously, in all cases where there is no direct solar radiation), the zonal distribution $r_{K,\Delta\alpha}$ approaches an isotropic distribution.

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