ON VARIATIONS OF SPECTRAL DENSITY OF LANDSCAPE RADIANCE IN SPECTRAL RANGE FROM 0.4 TO 1.2 μm

M.I. Allenov, A.I. Gusev, N.P. Ivanova, and V.V. Sulimov

Institute for Experimental Meteorology at the Scientific and Production Association "Taifun," Russian State Committee on Hydrology and Meteorology, Obninsk, Kaluga Region

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Statistical characteristics of the spectral density of radiance of such landscape elements, as grass, soil, and forest are presented. Time correlation between the reference (initial) observations and the later ones (shifted in time by several days or weeks) is determined.

Spectral density of landscape radiance was studied experimentally on the evidence derived at the Obninsk testing ground from a 313-m high meteorological mast. Some experimental results obtained for different landscape elements, meteorological conditions, and wavelengths are presented in Table I.

The spectral density of radiance was measured at the following wavelengths: 0.43, 0.482, 0.544, 0.66, 0.711, 0.772, 0.801, 0.864, 0.93, 1.020, 1.125, and 1.210 μm. The measurements were performed with a spectroradiometer set on a scanning table. The space scanning was performed in different directions with the nadir angle from 90 to 40°. The results presented in Table I are averaged over several hundreds of cases.

The observed data were divided, as a rule, into groups of 100 to 150 values with intervals corresponding to the spatial resolution of the device.

TABLE I. Average values of the spectral density of radiance $\mu\cdot10^6$, *in* W/(cm^2·sr·nm), *its variance* $\sigma^2\cdot10^{14}$, *in* W/(cm^2·sr·nm), *and the variation coefficients* $\sqrt{\sigma^2}/\mu$.

Sky	Measured parameter	λ, nm 437	481	544	660	772	801	864	930	1020	1125	1210
		Soil, spring, observation angle of 42°										
Clear	μ	0.65	0.82	1.12	1.1	0.83	0.75	0.68	0.3	0.36	0.13	0.2
Overcast	μ	0.04	0.06	0.07	0.07	0.06	0.06	0.04	0.02	0.03	0.01	0.02
		Grass, spring, observation angle of 42°										
Clear	μ	0.19	0.36	0.6	0.48	1.67	1.65	1.16	0.73	0.8	0.22	0.26
	σ^2	0.6	0.5	1.2	3.1	20.7	25.4	24.1	7.1	15.2	2.27	4.5
	$\sqrt{\sigma^2}/\mu$	0.41	0.20	0.18	0.37	0.27	0.31	0.42	0.37	0.49	0.68	0.82
		Grass, fall, observation angle of 42°										
Clear	μ	0.31	0.49	0.59	0.59	1.4	1.37	1.06	0.7	0.87	0.29	0.36
	σ^2	0.8	0.7	1.9	4.2	36.5	47.3	31.2	9.4	20.1	3.33	5.78
	$\sqrt{\sigma^2}/\mu$	0.29	0.17	0.23	0.35	0.43	0.50	0.53	0.44	0.52	0.63	0.67
		Forest, spring, observation angle of 60°										
Clear	μ	0.49	0.46	0.6	0.37	2.50	2.0	1.8	1.04	1.5	0.54	0.7
	σ^2	1.9	1.4	1.7	3.40	45.9	51.7	47.2	20.4	27.5	16.0	21.9
	$\sqrt{\sigma^2}/\mu$	0.28	0.26	0.22	0.50	0.27	0.36	0.38	0.43	0.35	0.74	0.67
		Forest, fall, observation angle of 60°										
Clear	μ	0.36	0.39	0.75	0.71	2.1	1.8	2.1	1.05	1.8	0.47	0.9
	σ^2	0.9	1.3	1.6	4.9	60.4	59.1	53.6	21.2	29.7	20.5	24.3
	$\sqrt{\sigma^2}/\mu$	0.26	0.29	0.17	0.31	0.37	0.43	0.35	0.44	0.30	0.97	0.54

The measurements were conducted when the path was uniformly irradiated by the sunlight, that is, it was free of cloud shadows.

The results were obtained at noon from 11:00 to 14:00 of the local (Moscow) time in spring and fall seasons of 1984 to 1986. As seen from Table I, the spectral density of radiance at the wavelength of 0.66 μm decreases, and the minimum values differ in different seasons. As a rule, they are more pronounced in spring. This is due to chlorophyll increase in biomass of plants. In the fall, when chlorophyll drops, the minima are somewhat smoothed out.

Table II gives the meteorological conditions and the correlation coefficients obtained using the technique from Ref. 1.

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TABLE II. Correlation coefficients for grass and forest (June of 1987).

Measurement days	Meteorological conditions (cloud type, cloud amount index)							Wavelength, μm
	Cu	*Ci*	*CiAcCu*	*Ac*	*CbAcCi*	*AcCuCi*	*CuCi*	
	2/2	3/0	10/1	10/0	8/4	8/3	9/7	
	01	03	06	08	16	20	23	
1	2	3	4	5	6	7	8	9
				Grass				
01	1.0	0.91	0.7	0.55	–	–	–	
03		1.0	0.82	0.70	–	–	–	
06			1.0	0.9	0.42	–	–	
08				1.0	0.52	–	–	0.43
16					1.0	0.75	0.58	
20						1.0	0.8	
23							1.0	
01	1.0	0.9	0.72	0.6	–	–	–	
03		1.0	0.84	0.65	–	–	–	
06			1.0	0.9	0.45	–	–	
08				1.0	0.59	–	–	0.482
16					1.0	0.78	0.62	
20						1.0	0.83	
23							1.0	
01	1.0	0.94	0.82	0.65	–	–	–	
03		1.0	0.9	0.76	0.4	–	–	
06			1.0	0.93	0.53	0.45	–	
08				1.0	0.65	0.4	–	0.544
16					1.0	0.84	0.69	
20						1.0	0.82	
23							1.0	
01	1.0	0.96	0.90	0.82	0.4	–	–	
03		1.0	0.94	0.89	0.52	–	–	
06			1.0	0.95	0.70	0.6	–	
08				1.0	0.79	0.58	0.42	0.66
16					1.0	0.92	0.83	
20						1.0	0.85	
23							1.0	
01	1.0	0.95	0.85	0.78	–	–	–	
03		1.0	0.93	0.87	0.47	–	–	
06			1.0	0.94	0.63	0.4	–	0.772
08				1.0	0.73	0.51	–	
16					1.0	0.37	0.7	
20						1.0	0.82	
23							1.0	
01	1.0	0.95	0.86	0.78	–	–	–	
03		1.0	0.94	0.89	0.50	–	–	
06			1.0	0.95	0.66	0.42	–	0.864
08				1.0	0.76	0.54	–	
16					1.0	0.89	0.71	
20						1.0	0.82	
23							1.0	
01	1.0	0.92	0.81	0.72	–	–	–	
03		1.0	0.9	0.81	0.45	–	–	
06			1.0	0.91	0.64	0.40	–	1.210
08				1.0	0.72	0.5	–	
16					1.0	0.84	0.67	
20						1.0	0.81	
23							1.0	

Table II (continued).

1	2	3	4	5	6	7	8	9
				Forest				
01	1.0	0.94	0.79	0.62	0.4	–	–	
03		1.0	0.9	0.72	0.42	–	–	
06			1.0	0.93	0.52	–	–	0.43
08				1.0	0.56	–	–	
16					1.0	0.82	0.61	
20						1.0	0.86	
23							1.0	
01	1.0	0.94	0.74	0.63	0.42	–	–	
03		1.0	0.92	0.8	0.46	–	–	
06			1.0	0.93	0.56	–	–	0.482
08				1.0	0.61	0.42	–	
16					1.0	0.8	0.66	
20						1.0	0.84	
23							1.0	
01	1.0	0.95	0.87	0.79	0.5	–	–	
03		1.0	0.9	0.85	0.6	0.42	–	
06			1.0	0.95	0.7	0.56	0.41	0.544
08				1.0	0.75	0.62	0.5	
16					1.0	0.87	0.76	
20						1.0	0.89	
23							1.0	
01	1.0	0.96	0.92	0.9	0.63	0.51	0.4	
03		1.0	0.95	0.92	0.72	0.59	0.5	
06			1.0	0.96	0.80	0.70	0.59	0.66
08				1.0	0.85	0.75	0.64	
16					1.0	0.94	0.83	
20						1.0	0.91	
23							1.0	
01	1.0	0.95	0.9	0.85	0.6	0.45	–	
03		1.0	0.93	0.90	0.64	0.5	0.4	
06			1.0	0.95	0.75	0.62	0.5	0.772
08				1.0	0.81	0.69	0.6	
16					1.0	0.92	0.84	
20						1.0	0.9	
23							1.0	
01	1.0	0.95	0.91	0.87	0.63	0.45	–	
03		1.0	0.93	0.91	0.67	0.51	0.4	
06			1.0	0.95	0.76	0.62	0.53	0.864
08				1.0	0.82	0.71	0.63	
16					1.0	0.92	0.81	
20						1.0	0.9	
23							1.0	
01	1.0	0.94	0.88	0.86	0.58	0.41	–	
03		1.0	0.91	0.86	0.62	0.49	–	
06			1.0	0.94	0.73	0.60	0.47	1.210
08				1.0	0.80	0.67	0.6	
16					1.0	0.91	0.81	
20						1.0	0.86	
23							1.0	

N o t e . Cloud types: cumulus (*Cu*), cirrus (*Ci*), altocumulus (*Ac*), and cumulonimbus (*Cb*). The bar (–) means that the corresponding correlation coefficient is less than 0.4.

Radiance characteristics of the landscape elements were first measured under clear sky conditions, and just these measurements were then considered as reference ones. Then the same characteristics were measured in other days under similar meteorological conditions. The correlation coefficients were then obtained using the reference and measured results for different wavelengths and time shifts (intervals between the reference and further measurements). The correlation coefficients were calculated by the following expression:

$$r_{k,k_0,\lambda_n} = \frac{\sum_{i=1}^{N} B_i^{k,\lambda_n} B_i^{k_0,\lambda_n} - N\,\overline{B^{k,\lambda_n}}\;\overline{B^{k_0,\lambda_n}}}{\left\{\left[\sum_{i=1}^{N} (B_i^{k,\lambda_n})^2 - N(\overline{B^{k,\lambda_n}})^2\right]\left[\sum_{i=1}^{N} (B_i^{k_0,\lambda_n})^2 - N(\overline{B^{k_0,\lambda_n}})^2\right]\right\}^{1/2}},$$

where λ_n is the nth wavelength; k is the running number of a case; k_0 is the number of a reference case at the nth wavelength λ_n; B_i^{k,λ_n} and $B_i^{k_0,\lambda_n}$ are the radiance values at the ith point of the kth and reference case, respectively, at the wavelength λ_n; $\overline{B^{k,\lambda_n}}$ is the average value of radiance for the kth case and the wavelength λ_n; $\overline{B^{k_0,\lambda_n}}$ is the average value of radiance for the k_0th reference case at the wavelength λ_n.

The correlation coefficients were estimated for different time shifts from 2 to 22 days. They were averaged over 10 to 17 values for similar measurement conditions. As seen from Table II, the values of the correlation coefficients decrease rapidly with increase of time shift. The effect is especially pronounced at the wavelengths of 0.43, 0.482, and 0.544 μm. This decrease is due to stronger scattering of sunlight at these wavelengths.[2] It should be noted that the measurement path changed during the measurements. First it was light-green; then some its parts became yellowish because of florescence. By the end of the measurement cycle, some blades of grass along the path withered, and grass was mown down in some places.

At longer wavelengths the coefficients are significantly higher. They are the highest within the chlorophyll absorption band (about 0.66 μm). The correlation is somewhat stronger for forest than for grass at the same intervals. The correlation coefficients for forest are higher in both short-wave and long-wave spectral ranges. The forest measurement path almost did not change visually during the measurement cycle.

The higher values of the correlation coefficients should be attributed to the fact that the nadir angle was on average 72° in our measurements. Additional illumination coming from near-horizon clouds might manifest itself at such large angle. This dependence has also been noted earlier.[1]

REFERENCES

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