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DIRECTIONAL LUMINOUS REFLECTANCES OF OBJECTS  
AND BACKGROUNDS UNDER OVERCAST SKIES

by

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## FOREWORD

The first and second reports under Assignment 9 of Contract NObs-84075, identified as SIO Ref. 64-3 and SIO Ref. 64-5, contained atmospheric optical data and terrain and background data suitable for use in visibility calculations under atmospheric and lighting conditions which prevailed at the time of (medium high sun) Visibility Laboratory research flight 74. This, the third report prepared under Assignment 9, presents the directional reflectances of objects and backgrounds under overcast skies.

DIRECTIONAL LUMINOUS REFLECTANCES OF OBJECTS  
AND BACKGROUNDS UNDER OVERCAST SKIES

1. INTRODUCTION

The directional luminous reflectance of horizontal natural terrains and man-made surfaces presented in this report were measured under overcast skies. Some of the data were measured under natural illumination and some in a natural lighting simulator.

Data are presented in the form of directional luminous reflectances. A directional reflectance is the ratio of inherent luminance in the direction of a specified path of sight to the total illuminance on a fully exposed horizontal plane at ground level.

All objects and backgrounds were oriented horizontally during the reflectance measurements. It should be noted that any orientations other than horizontal would show different reflectance characteristics. A comprehensive discussion of directional reflectance may be found in Gordon.<sup>1</sup> Directional reflectances for objects and backgrounds for clear weather with moderately high sun are to be found in the aforementioned paper<sup>2</sup> and in Gordon and Church.<sup>3</sup>

## 2. OVERCAST SKY LUMINANCE DISTRIBUTIONS

Some of the reflectance data were measured under natural lighting conditions by Krinov.<sup>4</sup> The sky condition is described by Krinov as "a continuous even cloud cover extending across the entire sky." The zenith angle of the sun is not given.

A typical luminance distribution of overcast skies as observed or measured from the ground was expressed analytically by Moon and Spencer.<sup>5</sup> Their equation is as follows:

$$B_{\infty}^*(0,\theta) = B_{\infty}^*(0,90) [1 + 2 \cos \theta] ,$$

where  $B_{\infty}^*(0,\theta)$  is the sky luminance at zenith angle  $\theta$ .  $B_{\infty}^*(0,90)$  is the horizon sky luminance. The Moon and Spencer distribution is not azimuth dependent.

Sky luminances for overcast skies in the arctic were measured by Hood.<sup>6</sup> Two typical distributions as measured by Hood were duplicated in the natural lighting simulator at the Visibility Laboratory and measurements of objects and backgrounds were made therein. These two overcast arctic skies showed a gradient of approximately 2 to 1 between the zenith sky and the horizon, whereas the Moon and Spencer sky has a gradient of 3 to 1. The lower gradient was also noticed by Kasten and Moller<sup>7</sup> in their data on overcast skies over snow.

The sky map in Fig. 1 shows the luminance distribution measured by Hood on 21 May 1957, at 12:15 PM at Point Barrow, Alaska. The maximum luminance occurs near the zenith, with little azimuth dependency in the distribution. The total illuminance on a fully exposed horizontal surface at ground level is 4350 lu/ft<sup>2</sup>

(46,800  $\text{lu}/\text{m}^2$ ); the sun zenith angle is  $51^\circ$ . The day is described as warm, with a thin overcast, rapidly melting snow, and tundra showing in small patches.

The iso-luminance map in Fig. 2 shows the sky luminances measured by Hood on 24 May 1957 at 10:17 AM at Point Barrow, Alaska. The maximum luminance is located slightly higher than the sun position, and the distribution is azimuth dependent. The total illuminance on the ground plane is  $4260 \text{ lu}/\text{ft}^2$  ( $45,800 \text{ lu}/\text{m}^2$ ); the sun zenith angle is  $52^\circ$ . The day is described as cold and windy, overcast with the sun barely visible at times, very light snow in the air, and the ground about 10% clear.

The natural lighting simulator is an internally luminous hemisphere constructed by the Visibility Laboratory. The luminance distribution of any sky (with an obscured or unobscured sun) can be simulated in this hemisphere and held constant for any desired length of time while photometry of test surfaces is done. The reflectances of the objects and backgrounds are measured with a telephotometer under these simulated lighting conditions, using a magnesium oxide plaque as the calibration standard.

### 3. TERRAIN BACKGROUND

Directional luminous reflectances are presented for terrains (numbered consecutively) in Table I. Those numbered 1 through 10 are computed from spectral reflectance data of Krinov.<sup>8</sup> For every terrain measured by Krinov, a number in parenthesis follows the description. These are the identification numbers used by Krinov in his table of spectral reflectance measurements.

The reflectances for calm deep water (terrains 11 and 15) were computed from the sky luminance distributions in Figs. 1 and 2 using the equations by Duntley.<sup>9</sup>

The reflectances for the terrains numbered 12 through 14 were measured in the sky simulator with the overcast sky luminance distribution measured by Hood on 21 May 1957, see Fig. 1. Reflectances for these same terrains under the overcast sky luminance distribution of 24 May 1957, see Fig. 2, are numbered 16 through 18.

Temperature problems and transportation difficulties have thus far precluded the study of snow surfaces in the natural lighting simulator but, fortunately, goniophotometric measurements of typical snow surfaces have been published by Middleton and Mungall,<sup>10</sup> and it has been found possible to produce artificial white surfaces having goniophotometric characteristics that very closely duplicate in all respects those of the snows measured by Middleton and Mungall. These surfaces are composed of fine glass beads sprayed with very thin coats of white paint. Three types of snow terrain simulations were measured in the natural lighting simulator; these were (a) snow with surface hoar (terrains 12 and 16), (b) snow, with rain

crust (terrains 13 and 17), and (c) snow, with a glazed rain crust (terrains 14 and 18). It is interesting to note that the reflectance (0.75) of the snow, covered with a film of ice as measured by Krinov, terrain No. 10, agrees very well with reflectance of the glazed rain crust simulation at the same path of sight as measured under both overcast skies (0.76 and 0.75 respectively).

#### 4. OBJECT SURFACES

The only directional luminous reflectance data obtained thus far on object surfaces under overcast lighting conditions are for two samples of ship paint. These are presented in Table II; the entries numbered 1 through 3 were measured in the natural lighting simulator under the overcast luminance distribution of 21 May 1957 (see Fig. 1), whereas entries numbered 4 through 6 were measured in the lighting simulator with the 24 May 1957 luminance distribution (see Fig. 2). The deck paint was measured dry (objects 1 and 4), but the hull paint was measured both dry and wet (objects 2, 3, 5 and 6).

It will be noted that the reflectance data under the overcast sky for 21 May 1957 show little azimuth dependency (objects 1, 2, and 3), as did the sky luminance distribution (see Fig. 1). The larger azimuth dependency of the luminance distribution on 24 May 1957 (see Fig. 2) produced a greater difference in the directional reflectance data by azimuth (objects 4, 5, and 6).

## 5. CONTRAST

When the contrast of an object against a given background is to be determined out-of-doors, both object and background must be measured simultaneously or before any change in the lighting has occurred. A major advantage of all reflectance data obtained through the use of the natural lighting simulator is that they may be considered to be "simultaneous" in the sense that the lighting was precisely identical for all measurements. Thus, it is appropriate to compute contrasts from any of the data from Tables I and II with equivalent lighting. For example, terrains 11-14 and objects 1-3 may be used together in various combinations. What has been termed an object may become a background in any given problem, or conversely, what has been termed a background may be an object in yet another problem. Thus a considerable number of contrasts are derivable from these reflectance data.

The data taken under less stringently comparable (or simultaneous) lighting conditions are also usable, however, because they have been put in the form of directional luminous reflectance, which form minimizes or eliminates the effect of the change in total illuminance. Thus the directional reflectance data from Krinov, terrains 1-10, can be utilized with either the data appropriate to 21 May 1957 or 24 May 1957.

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Table I. Directional Luminous Reflectance of Terrain Backgrounds under Overcast

Description	Sun Zenith Angle	Azimuth of Path of Sight Relative to Sun	Zenith Angle of Path of Sight								
			180	165	150	135	120	105	100	95	
1. Weeds, dense growth, drying and brownish (beginning of autumn). (K No. 50-52) <sup>a</sup>	90	90	0.0384		0.0952	0.0476					
2. Pasture meadow, at end of summer. (K No. 78-80) <sup>a</sup>	90	90	0.113		0.163		0.290				
3. Meadow (with clover and timothy), mowed, wet after rain. (K No. 86-88) <sup>a</sup>	90	90				0.101	0.137 <sup>b</sup>				0.228
4. Wormwood, dense growth, flowering, end of summer. (K No. 148-150) <sup>a</sup>	90	90	0.0763		0.162		0.284				
5. Virgin steppe, low grass burnt by sun, beginning of autumn. (K No. 155-157) <sup>a</sup>	90	90	0.0819		0.0668		0.100				
6. Virgin steppe, low grass burnt by sun, beginning of autumn, fresher and wetter after rain. (K No. 158-160) <sup>a</sup>	90	90	0.0396		0.0512		0.0672				
7. Oats, with spikes, lighter in color. (K No. 189-191) <sup>a</sup>	90	90				0.0648	0.101 <sup>b</sup>				0.107
8. Soil, sandy loam, ploughed, moist. (K No. 290-294) <sup>a</sup>	90	90	0.0562	0.0562	0.0630	0.0924	0.116				
9. Earth road, trampled, sand loam. (K No. 321) <sup>a</sup>	90	90			0.142						
10. Snow, covered with film of ice. (K No. 354) <sup>a</sup>	90	90				0.750					
11. Calm water, infinite optical depth. <sup>c</sup>	51	0	0.0439	0.0456	0.0477	0.0430	0.067	0.208	0.364	0.57	
	51	45		0.0444	0.0455	0.0430	0.072	0.239	0.384	0.56	
	51	90		0.0426	0.0415	0.0437	0.078	0.239	0.348	0.52	
	51	135		0.0416	0.0383	0.0408	0.070	0.193	0.268	0.430	
	51	180		0.0416	0.0398	0.0382	0.056	0.156	0.252	0.464	

<sup>a</sup>. Directional luminous reflectances of terrains 1 through 10 were computed from spectrophotometric data taken by Krinov using C. I. E. Illuminant B.

<sup>b</sup>. NOTE: The zenith angle of the path of sight is 115°.

<sup>c</sup>. Computed from equations by Duntley for the luminance distribution measured by Hood on 21 May 1957.

Table 1. Directional Luminous Reflectance of Terrain Backgrounds under Overcast

Description	Sun Zenith Angle	Azimuth of Path of Sight Relative to Sun	Zenith Angle of Path of Sight							
			180	165	150	135	120	105	100	95
12. Snow, with surface hoar. <sup>d</sup>	51	0	0.69	0.68	0.66	0.66	0.67	0.67	0.67	0.70
	51	45		0.66	0.65	0.65	0.66	0.66	0.67	0.68
	51	90		0.66	0.65	0.66	0.67	0.68	0.68	0.69
	51	135		0.67	0.65	0.66	0.67	0.69		
	51	180		0.68	0.64	0.65	0.66	0.68	0.68	0.69
13. Snow, with rain crust (a crust formed by falling rain which does not freeze upon falling). <sup>d</sup>	51	0	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
	51	45		0.67	0.66	0.66	0.67	0.67	0.67	0.67
	51	90		0.66	0.67	0.67	0.68	0.68	0.68	0.68
	51	135		0.65	0.66	0.67	0.68	0.68	0.67	0.69
	51	180		0.67	0.64	0.65	0.67	0.68	0.68	0.69
14. Snow, with glazed rain crust (rain crust completely covered by a slightly undulating sheet of ice formed by freezing rain, subsequent freezing temperatures but no further precipitation). <sup>d</sup>	51	0	0.74	0.76	0.76	0.76	0.77	0.77	0.77	
	51	45		0.76	0.76	0.76	0.76	0.77	0.77	0.78
	51	90		0.74	0.76	0.76	0.76	0.78	0.78	0.77
	51	135		0.74	0.76	0.77	0.77	0.79	0.78	
	51	180		0.74	0.74	0.75	0.75	0.76	0.77	
15. Calm water, infinite optical depth. <sup>e</sup>	52	0	0.0386	0.0427	0.052	0.064	0.108	0.297	0.445	0.69
	52	45		0.0398	0.0409	0.0478	0.082	0.257	0.413	0.66
	52	90		0.0389	0.0389	0.0448	0.075	0.222	0.351	0.58
	52	135		0.0367	0.0368	0.0422	0.068	0.205	0.323	0.467
	52	180		0.0367	0.0374	0.0429	0.070	0.212	0.339	0.419
16. Snow, with surface hoar. <sup>f</sup>	52	0	0.65	0.62	0.63	0.67	0.66	0.70	0.71	
	52	45		0.65	0.65	0.67	0.68	0.70	0.70	
	52	90		0.65	0.65	0.65	0.65	0.68	0.68	
	52	135		0.64	0.63	0.64	0.67	0.68		
	52	180		0.65	0.64	0.63	0.65	0.66	0.66	
17. Snow, with rain crust (a crust formed by falling rain which does not freeze upon falling). <sup>f</sup>	52	0	0.65	0.62	0.63	0.63	0.66	0.67	0.67	0.68
	52	45		0.66	0.66	0.67	0.68	0.66	0.68	0.68
	52	90		0.66	0.66	0.66	0.67	0.67	0.66	0.67
	52	135		0.66	0.66	0.67	0.69	0.70	0.70	0.73
	52	180		0.65	0.65	0.67	0.67	0.68	0.67	0.69
18. Snow, with glazed rain crust (rain crust completely covered by a slightly undulating sheet of ice formed by freezing rain, subsequent freezing temperatures but no further precipitation). <sup>f</sup>	52	0	0.75	0.72	0.72	0.74	0.77	0.81	0.81	
	52	45		0.75	0.76	0.77	0.79	0.79	0.80	
	52	90		0.75	0.75	0.75	0.75	0.76	0.76	
	52	135		0.74	0.73	0.74	0.77	0.78	0.78	
	52	180		0.74	0.74	0.73	0.74	0.76	0.76	

<sup>d</sup>. Data taken with a telephotometer (April 1960) of simulated snow having reflectance characteristics reported by Middleton and Mungall. The photometry was done in the natural lighting simulator, using the sky luminance distribution measured by Hood on 21 May 1957.

<sup>e</sup>. Computed from equations by Duntley for the luminance distribution measured by Hood on 24 May 1957.

<sup>f</sup>. Data taken with a telephotometer (April 1960) of simulated snow having reflectance characteristics reported by Middleton and Mungall. The photometry was done in the natural lighting simulator, using the sky luminance distribution measured by Hood on 24 May 1957.

Table II. Directional Luminous Reflectance of Objects under Overcast

	Sun Zenith Angle	Azimuth of Path of Sight Relative to Sun	Normal from Surface		Zenith Angle of Path of Sight							
			Zenith Angle	Azimuth	180	165	150	135	120	105	100	95
1. Glossy black deck paint. <sup>a</sup>	51	0	0	0	0.050	0.059	0.063	0.064	0.090	0.228	0.391	0.57
	51	45	0	0		0.058	0.058	0.062	0.090	0.242	0.420	0.61
	51	90	0	0		0.053	0.0485	0.053	0.084	0.200	0.279	0.51
	51	135	0	0		0.054	0.051	0.061	0.094	0.213	0.332	0.51
	51	180	0	0		0.050	0.0470	0.051	0.077	0.174	0.294	0.58
2. Dull black hull paint, dry <sup>a</sup>	51	0	0	0	0.0364	0.0413	0.0436	0.051	0.078	0.197	0.302	0.50
	51	45	0	0		0.0403	0.0411	0.0485	0.079	0.208	0.315	0.53
	51	90	0	0		0.0388	0.0338	0.0475	0.076	0.171	0.255	0.400
	51	135	0	0		0.0372	0.0431	0.052	0.086	0.193	0.272	0.421
	51	180	0	0		0.0362	0.0377	0.0440	0.071	0.164	0.242	0.438
3. Dull black hull paint, wet <sup>a</sup>	51	0	0	0	0.0246	0.0393	0.0361	0.0416	0.061	0.211	0.381	0.60
	51	45	0	0		0.0352	0.0327	0.0411	0.066	0.233	0.416	0.66
	51	90	0	0		0.0311	0.0255	0.0363	0.057		0.268	0.53
	51	135	0	0		0.0321	0.0302	0.0396	0.062		0.320	0.490
	51	180	0	0		0.0301	0.0289	0.0335	0.0485	0.136	0.128	0.59
4. Glossy black deck paint <sup>b</sup>	52	0	0	0	0.0417	0.050	0.063	0.093	0.151	0.341	0.52	0.74
	52	45	0	0		0.0495	0.052	0.072	0.115	0.310	0.467	0.66
	52	90	0	0		0.0459	0.0475	0.056	0.088	0.210	0.348	0.52
	52	135	0	0		0.0428	0.0432	0.054	0.087	0.240	0.371	0.50
	52	180	0	0		0.0412	0.0432	0.054	0.087	0.224	0.375	0.431
5. Dull black hull paint, dry <sup>b</sup>	52	0	0	0	0.0392	0.0441	0.052	0.072	0.133	0.314	0.438	0.67
	52	45	0	0		0.0451	0.050	0.064	0.112	0.270	0.395	0.57
	52	90	0	0		0.0422	0.0437	0.051	0.084	0.192	0.296	0.448
	52	135	0	0		0.0401	0.0411	0.051	0.083	0.214	0.302	0.437
	52	180	0	0		0.0388	0.0407	0.0495	0.082	0.207	0.303	0.402
6. Dull black hull paint, wet <sup>b</sup>	52	0	0	0	0.0222	0.0358	0.0392	0.067	0.103	0.294	0.460	0.76
	52	45	0	0		0.0300	0.0315	0.052	0.077	0.286	0.441	0.68
	52	90	0	0		0.0302	0.0293	0.0408	0.052	0.182	0.346	0.53
	52	135	0	0		0.0291	0.0273	0.0381	0.054	0.194	0.362	0.498
	52	180	0	0		0.0264	0.0257	0.0376	0.056	0.176	0.362	0.436

<sup>a</sup>. Data taken with a telephotometer April 1960. The photometry was done in the natural lighting simulator, using the sky luminance distribution measured by Hood on 24 May 1957.

<sup>b</sup>. Data taken with a telephotometer April 1960. The photometry was done in the natural lighting simulator, using the sky luminance distribution measured by Hood on 24 May 1957.

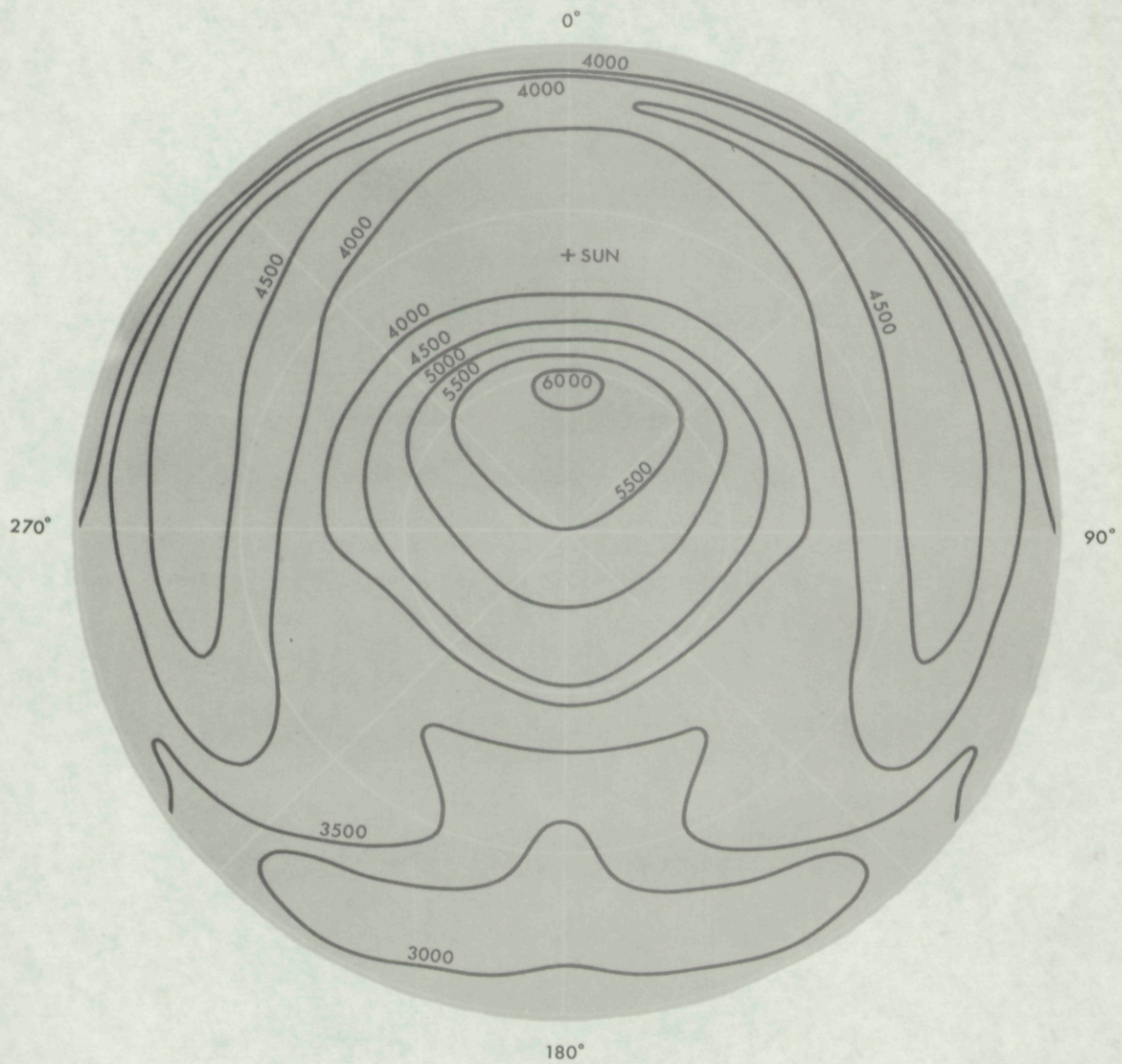


Fig. 1 Upper sky luminance in ft-L (luminance values multiplied by 10.76 give values in apostilbs) measured by Hood on 21 May 1957 at Point Barrow, Alaska.

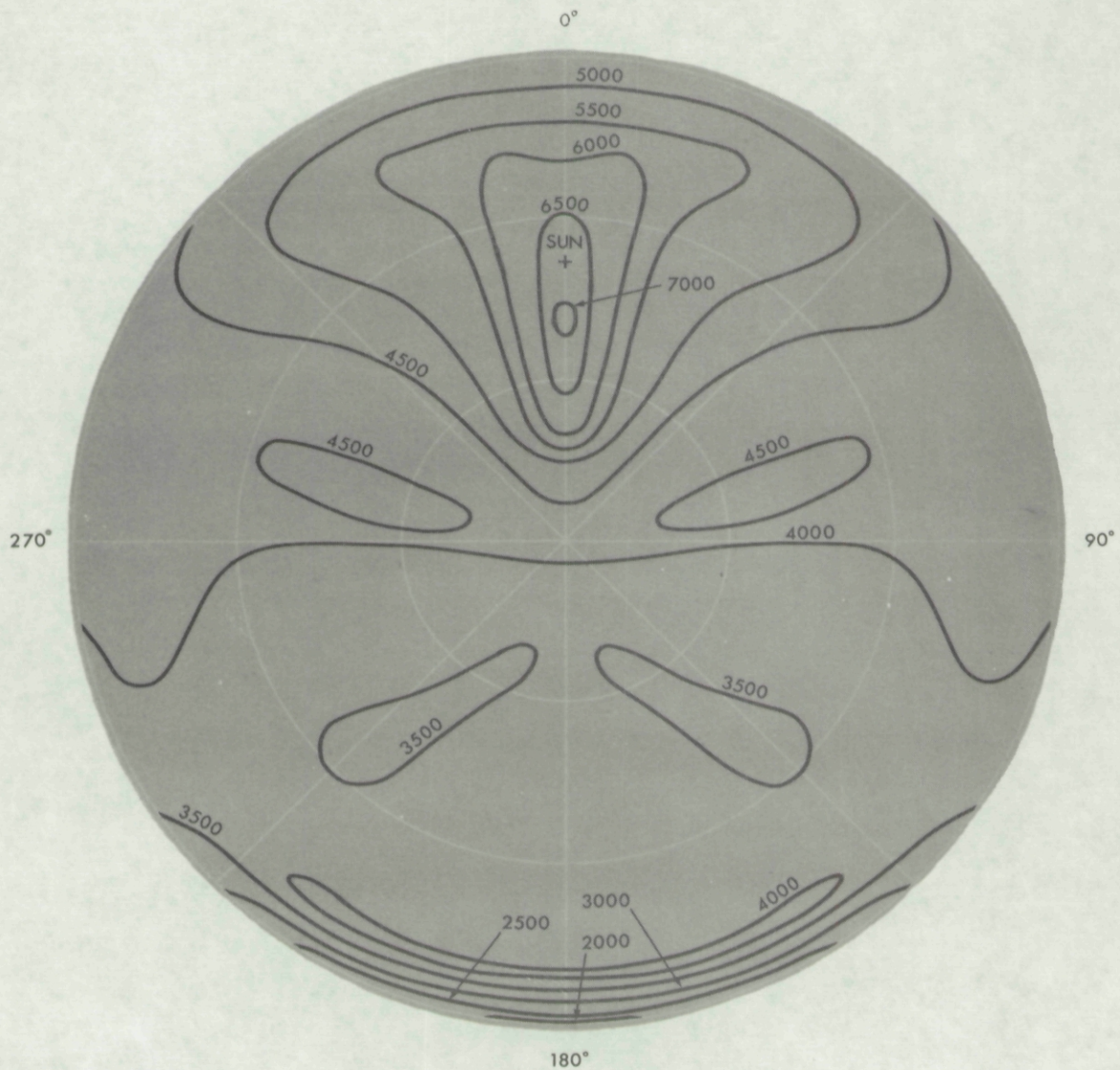


Fig. 2 Upper sky luminance in ft-L (luminance values multiplied by 10.76 give values in apostilbs) measured by Hood on 24 May 1957 at Point Barrow, Alaska.

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13. ABSTRACT  The directional luminous reflectance properties of a variety of natural terrains and man-made surfaces measured under overcast skies are presented. Two of the luminance distributions are for overcast sky above snow-covered terrain, and reflectance data obtained with these sky maps are included. Luminous reflectances computed from Krinov spectral reflectance data measured under overcast are also included. A considerable number of contrasts are derivable from these data.			

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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1 ORIGINATING ACTIVITY <i>(Corporate author)</i> Visibility Laboratory Scripps Institution of Oceanography University of California San Diego, California 92152		2a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		2b GROUP	
3 REPORT TITLE DIRECTIONAL LUMINOUS REFLECTANCES OF OBJECTS AND BACKGROUNDS UNDER OVERCAST SKIES			
4 DESCRIPTIVE NOTES <i>(Type of report and inclusive dates)</i>			
5 AUTHOR(S) <i>(Last name, first name, initial)</i> Jacqueline I. Gordon and Peggy V. Church			
6 REPORT DATE June 1965		7a TOTAL NO OF PAGES	7b NO OF REFS
8a CONTRACT OR GRANT NO NObs-84075		9a ORIGINATOR'S REPORT NUMBER(S) SIO Ref. 65-2	
b PROJECT NO Assignment No. 9		9b OTHER REPORT NO(S) <i>(Any other numbers that may be assigned this report)</i>	
c			
d			
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11 SUPPLEMENTARY NOTES		12 SPONSORING MILITARY ACTIVITY Bureau of Ships, Code 687C U. S. Navy Washington, D. C. 20360	
13 ABSTRACT  The directional luminous reflectance properties of a variety of natural terrains and man-made surfaces measured under overcast skies are presented. Two of the luminance distributions are for overcast sky above snow-covered terrain, and reflectance data obtained with these sky maps are included. Luminous reflectances computed from Krinov spectral reflectance data measured under overcast are also included. A considerable number of contrasts are derivable from these data.			