SNOW SURFACE ALBEDO VARIATION IN THE ST. ELIAS MOUNTAINS

by

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Abstract

Two Eppley pyrheliometers were used to measure incoming and reflected sun and sky radiation on a high altitude snow field during the summer season. Mean values of snow surface albedo, calculated from the radiation data, showed an inverse variation with age of snow, grain type, and snow wetness; and a direct variation with solar elevation. The effect of cloud cover was inconclusive. The upward facing instrument may have been in appreciable error at low solar elevations. A diurnal variation in albedo; thought to be largely due to diurnal changes in the snow free water content, was found.

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Introduction

During the summer of 1963, essentially continuous observations of incoming and reflected solar radiation over a snow surface were made as a part of a continuing investigation of the sub-arctic environment that is being conducted by the Icefield Ranges Research Project, (I. R. R. P.).

The I. R. R. P. is an annual expedition to the Icefield Ranges of the St. Elias mountains in the Yukon Territory, Canada. It is jointly sponsored by the Arctic Institute of North American and the American Geographical Society. The project affords an opportunity for field research in the earth sciences of glaciology, geology, geophysics, and glacial-meteorology. In 1963 the meteorological work was supported by the Earth Sciences Division, U.S. Army Natick Laboratories, Natick, Massachusetts. A more detailed description of the I. R. R. P. is given by Wood (1963).

The 1963 radiation observations were made at the main meteorological station on the ice field. This station was situated near the topographic divide between the Hubbard and Kaskawulsh glaciers. Surveys placed the station at 139.6° West, 60.8° North and at an elevation of 2640 m. (8660 ft.). Thus, the station was situated in high altitude, sub-arctic environment. (Fig. 1).

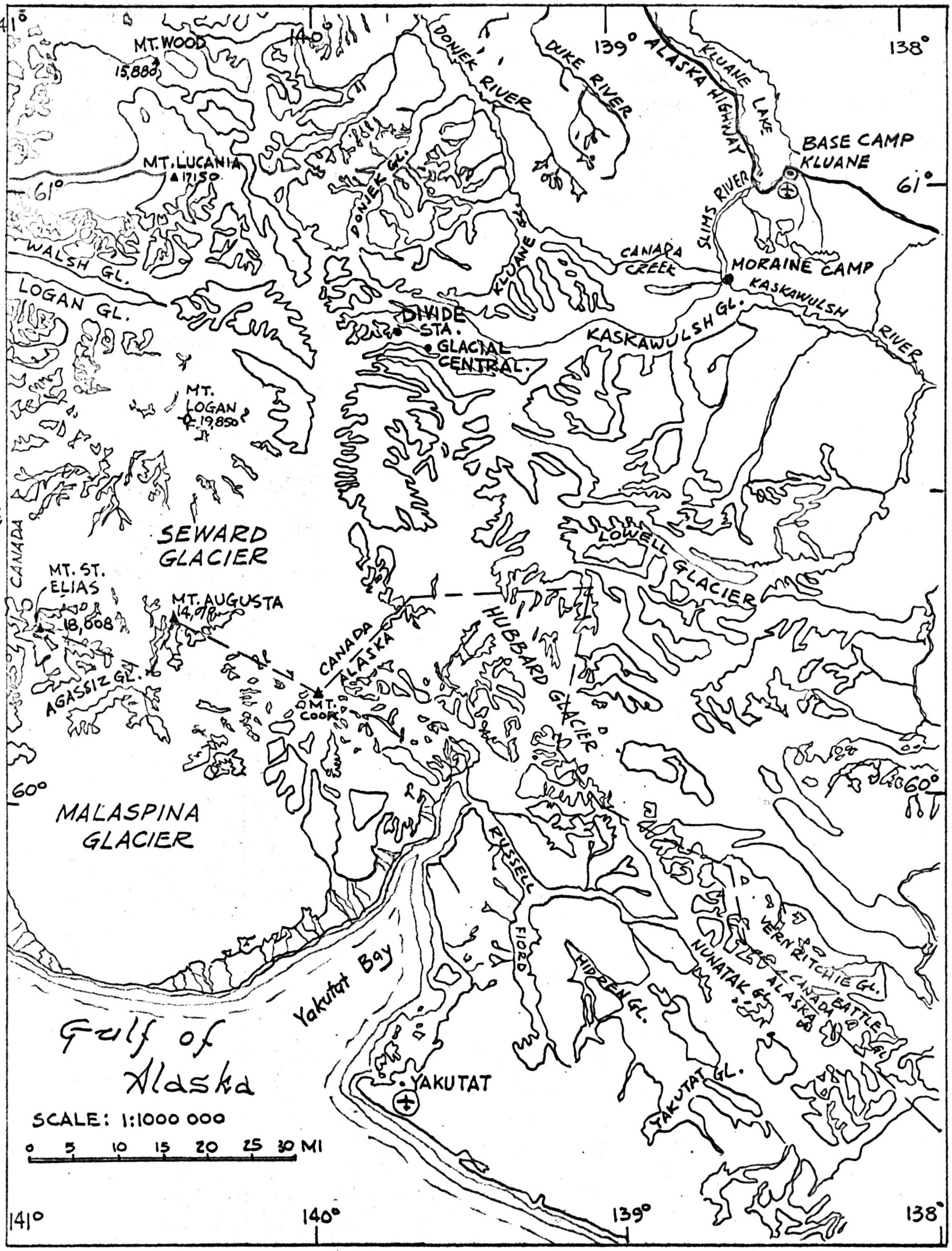

Figure 1: Location Map of Icefield Ranges Research Project Area

The area in the vicinity of the meteorological station was a gently rolling snow field. The nearest obstacles were at least three-fourths of a mile away and none of the surrounding nunatacks[1] protruded more than six degrees above the horizon.

Two epply pyrheliometers were mounted back to back about one meter above a flat horizontal snow surface.

The weather during the observation period can be characterized as being warmer than normal. This was particularly true of August when nearby weather stations recorded record high temperatures. As a consequence the melt season on the snow field was longer than usual. Precipitation principally occurred when cyclonic systems from the Gulf of Alaska crossed the Icefield Ranges. The cold snow surface inhibits local convective activity. More complete descriptions of the weather during the season can be found in Havens (1964) and by Havens and Saarela (1964).

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[1]Nunatack - The top of a mountain or peak which protrudes above the surrounding relatively flat snow or ice field. It may or may not be snow covered depending on elevation and season.

I Collection and Reduction of Data

Incoming and reflected solar radiation were measured during the sixty day period, 23 June 1963 to 21 August 1963.

The instruments used were two Eppley 50-junction pyrheliometers, #3678 (upward facing) and #5028 (downward facing). They were mounted back-to-back and bolted on a stand made of Dexion slotted angle steel. The pyrheliometers were initially placed so that the bases of each were approximately 100 cm. above the snow surface. Subsequent settling of the stand and accumulation of snow lowered the height of the instruments so that at times the bases were approximately 50 cm. above the snow surface. The snow surface in the immediate vicinity of the instruments was flat and nearly horizontal. The surface was smooth initially and after snowfalls, but, during periods of melt, it developed small undulations and depressions, one or two cm. in depth.

The pyrheliometers and a Beckman and Whitley net radiometer were connected to a four channel Honeywell-Brown potentiometric recorder. Power was supplied by a Kohler four kilowatt portable generating plant. The recorder was set to a -5 to +20 millivolt scale with the unused channel printing a constant zero point. The scale was chosen to give the instrument readings a maximum spead across the paper. All three instrument constants were about eight millivolts/langley per minute. (1 langley = 1 calorie/cm^2 per minute).

The recorder printed the output of each instrument at approximately two minute intervals. The time interval between readings was not constant because it was found impossible to keep the generator output voltage constant. Becuase of this variation, the correct time was marked on the chart at hourly intervals during the observation period.

Upon completion of the observation period, the data were transferred from the strip chart rolls to punch cards by employees of U. S. Army Laboratories, Natick, Massachusetts. Following this conversion, hourly mean values, hourly radiation totals, hourly mean albedos, and hourly long wave balance were computed for the entire period. Primarily, the hourly mean albedos, combined with other meteorological data, were used in the analysis which follows in section II, III, and IV.

The data originally received as computer output consisted of hourly mean values over the whole period of record. The values used for further analysis were selected from this group. First, all the values during which the sun was less than five degrees above the level horizon for any part of the hour were rejected. Then, from the remaining group, all hours containing less than 25 individual measurements were rejected. Such occasions were usually due to the equipment being shut down for part of the hour. Normal maintenance requirements caused most of these minor gaps in the record.

It was noted that the bulbs of the pyrheliometers accumulated frost and liquid condensation at times. The observer cleaned the instrument frequently when this occurred. According to MacDonald (1951), liquid condensation has no noticeable effect. When periods of very heavy rime formation were excluded, the rest of the frost present hours could not be distinguished from the frost-free hours.

After the process of selection was completed, there was left a sample consisting of 833 hourly mean values of albedo. The albedo values which make up this sample are given in Appendix A.

In observations of this sort, there were several possible sources of systematic error which are considered in Appendix C.

A detailed description of the instrumentation used is presented in Appendix B.

II. Values of Snow Surface Albedo

As a first step the mean value of albedo over the entire period was calculated. This overall mean was greater than 80% and seemed somewhat high when compared with representative values of about 65% found by others. Since the albedo showed a marked variation from hour to hour, a new mean was calculated using only values within two hours of local noon. Other investigators seem to have favored midday for their observations. A comparison of these two values with those found by others is in Table 1 below.

Snow Surface Albedo Comparisons

Albedo	Location and Remarks	Author
.81	0500 - 2000 Local Time	Saarela
.77	1000 - 1400 (277 obs.)	Saarela
.603	Karsä Blacier Sweden	Wallen (1948)
.816 - .724	14 Days of measurements Austrian Alps	Dirmhirn and Trojor(1955)
.73 - .61	United States	Gerdel (1948)
.75	Ward Hunt Island	Sagar (1962)
.77	4 obs., Baffin Island	Orvig (1954)
.81 - .59	Spitzbergen	Olsson (1936)
.88 - .45	Dovos, Switzerland	Eckel and Thams(in Bader et al)
.88 - .65	Alaska	Hubley (1955)
.95 - .70	U.S.S.R.	Rikhter (In Jen - Hu - Chang, 1958)

Table 1

Where two values are given for albedo in Table 1, the first refers to new snow and the latter to old wet snow. In looking at Table 1, it is seen that other values of albedo greater than 80% are only found with a fresh snow surface. The difference between the mean of the midday hourly albedo and the total mean leads to the conclusion that there was an appreciable diurnal variation with higher albedos in the morning and evening hours.

This diurnal variation, depicted in figure 2, ranged from just over 98% in the hour beginning at 1900 Y. S. T. (Yukon Standard Time) to a flat minimum of about 75-77% in the period 0900-1500 Y. S. T. The albedo is about 80-82% before 0900 and climbs to the 98% after 1500. Now, values of snow albedo of 98% are highly unreasonable. Snow is a good reflector of solar energy but it is not a mirror. Upon looking into the individual hourly means for hours late in the day, the author could find no simple relation between meteorological variables and these unreasonably high values of albedo. The high values seem to be independent of cloud cover, temperature, visibility, and pressure. The high albedos nearly always occurred at solar elevations of from 5° - 10°.

The apparent relation between solar elevation and albedo leads one to a consideration of relevant instrumental errors. The downward facing instrument views a largely diffuse reflector while, for clear conditions, much of the radiation reaching the upward facing instrument is in a parallel beam. Thus, if the instrument does not accept radiation from all directions equally, it will give false readings at some incidence angles.

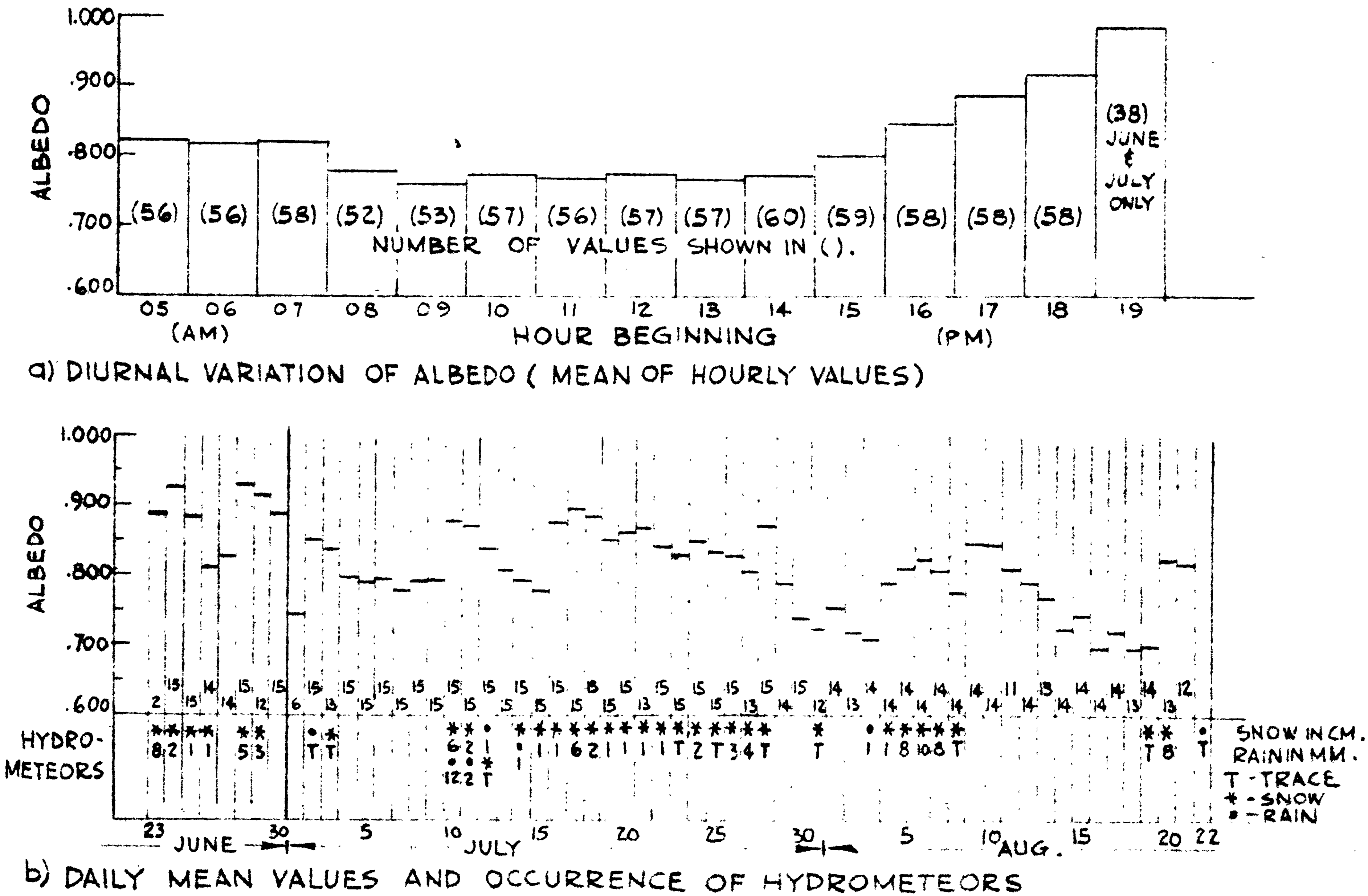

Figure 2: Systematic Albedo Variations

The equal acceptance of radiation from all incidence angles is necessary in a pyrheliometer, such as the ones used, which measures the radiation incident upon a level surface. The instrument itself incorporates the cosine correction for translating incident radiation from a beam to a level surface. If the instrument does not follow this consine response curve closely, large errors are possible.

In fact, some, but not all, Eppley pyrheliometers read about 15 to 20% too low when the incoming radiation reaches the receiving surface of the instrument at angles of incidence greater than 75°. Unfortunately, the instrument was not tested for any errors of this nature. The most that can be said is that instrumental error may have caused the albedo at low solar elevation angles to be some 15 to 20 per cent too high. Appendix C treats this question in greater length.

Figure 2 also contains the day to day variation of the daily mean albedo for the observation period. Below the daily values is a symbolic representation of the twenty-four hour precipitation observed at the station. The albedo shows a general downward trend through the observation period. This reflects the aging and contamination of the surface. Superimposed upon this gradual lowering are sudden jumps in the daily albedo at some, but not all, times of appreciable snowfall. Reference to the concurrent general meteorological observations shows that during periods when an appreciable amount of snow fell and the albedo did not rise sharply, the temperature was above freezing for much of the period.

III Albedo Variation with Snow Surface and Precipitation

Part of the observational program consisted of observations of the nature of the snow surface. The snow surface was inspected every six hours throughout the observational period and classified according to its grain nature and wetness. The classification system used was a slightly modified form of the "Simplified Field Classification of Natural Snow Type of Engineering Purposes", (SIPRE (1952).

The grain nature was classified as follows:

Symbol	Description
Fa	New snow (original crystal forms are recognizable).
Db	Old snow, granular, fine grained (mean diameter less than 2mm.).
Dd	Old snow, granular, coarse grained (mean diameter greater than 2mm.).
Sh	Surface hoar (any type of frozen condensation, e.g. hoarfrost rime).

The category, Sh, was added to the basic classification scheme.

The snow wetness was classified as follows:

Symbol	Description
Wa	Dry (snowball cannot be made using gloved hands).
Wc	Moist (snowball can be made, but liquid water not obviously present).
Wd	Wet (obviously contains liquid water).

The albedo values were separated into seven groups according to the seven characteristics given in the preceding page. In general, each group formed of values for a particular wetness contained values from all four snow types and each group formed of a particular snow type contained values from all three wetnesses. Hours for which the snow surface parameters were uncertain or for which combinations of the characteristics applied were excluded.

The mean of each of the seven groups was then calculated. This mean is depicted in Figure 3a and listed in Table 2.

There exists a possibility that one or more of the characteristics may have tended to predominate at certain times of the day. To see if this was the case, the original data were normalized to remove the mean diurnal variation. In doing this, each individual value was corrected by the amount that the mean for that hour of the day differed from the overall mean. The mean of the normalized values was calculated for each snow surface type. A large difference between the actual and normalized means indicated that the values comprising the group were biased toward some part of the day. The normalized means of the albedo for different snow surface characteristics are depicted in Figure 3a and listed in Table 2.

As mentioned above, there exists a possibility that, for low solar elevations, the upward facing instrument was reading some 80% of the true value.

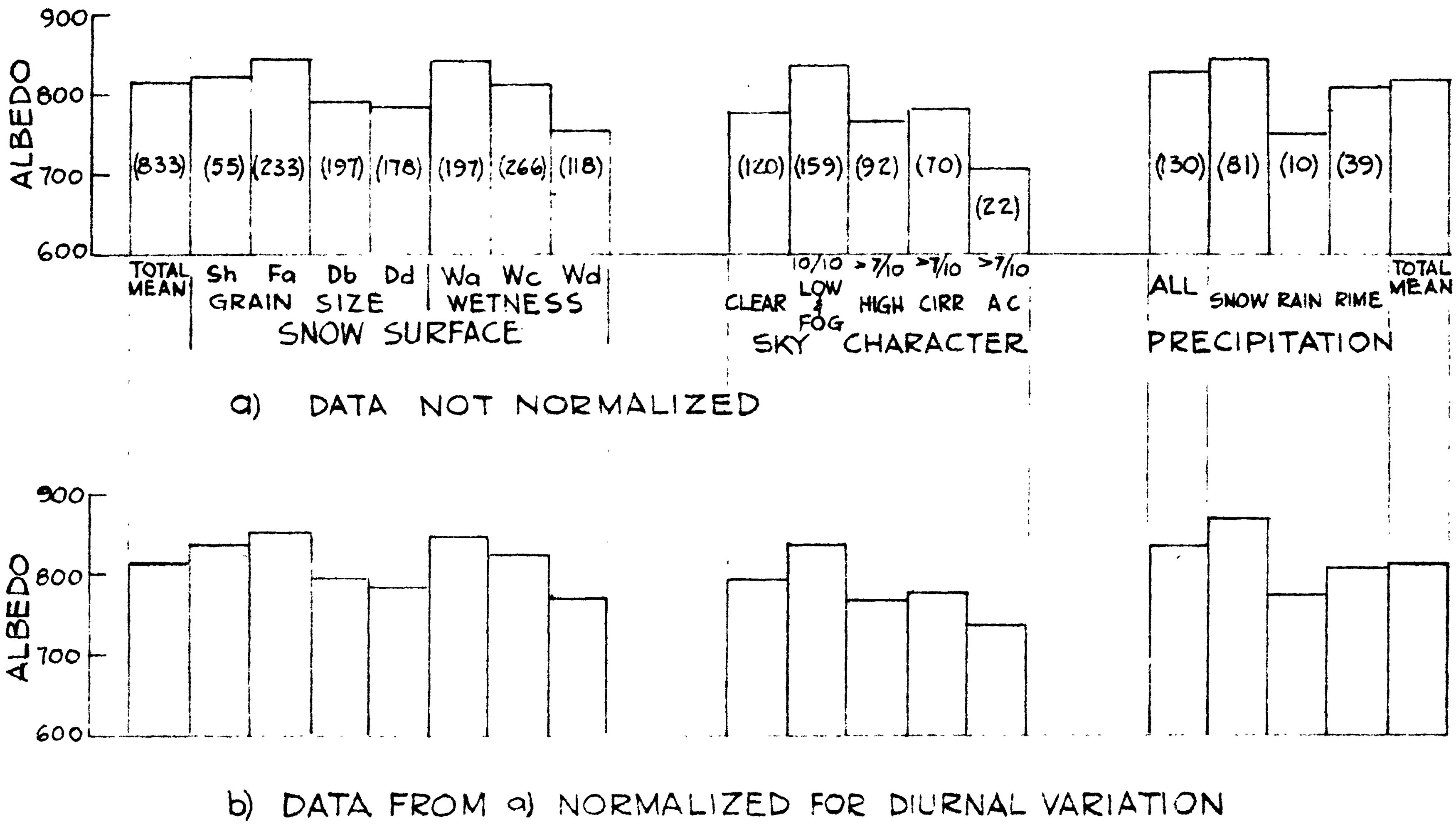

Figure 3: Variation of Albedo with Certain Snow Surface and Meteorological Conditions (Mean Values)

Table 2 also lists a corrected mean value for each of the snow surface types. This corrected mean was calculated by modifying the actual mean as:

$$\bar{A}\ (\text{corrected}) = \frac{[\ \bar{A} \times (N - K)\ ] + [\ \bar{A} \times 0.8 \times K\ ]}{N}$$

where $\bar{A}$ = uncorrected mean

N = number of values in group

K = number of values with low solar elevation (less than 15°)

0.8 = assumed error in the K values

Uncorrected, Normalized and Corrected Mean Albedos For Various Snow Surface Parameters

Parameter	Uncorrected	Corrected (K)	Norm	No. of Values
Grain Nature				
Fa	.85	.83 (18)	.85	233
Db	.79	.77 (25)	.79	197
Dd	.78	.77 (20)	.79	178
Sh	.82	.82 (1)	.83	155
Wetness				
Wa	.84	.82 (25)	.85	197
Wc	.81	.80 (18)	.83	266
Wd	.75	.75 (4)	.77	118

Table 2

There is very little difference between the corrected, and normalized of albedo. At the most, it amounts to three per cent. The difference between the different snow surfaces is about twice this at the maximum. In general, new snow and frost have albedos from 5 to 8% higher than old snow. The grain size of old snow has little effect on the albedo. Dry snow has a higher albedo than wet snow, again by about 8%.

Since grain nature and wetness are not mutually exclusive categories, an analysis of variance or the like would be necessary to find out the relative influence on the albedo of snow type and wetness.

The periods of snow, rain and light or moderate rime formation were also separated and means calculated as shown on the preceding page. The figures are presented in Table 3.

Mean Values of Albedo
With Different Types of Precipitation

Type Precip.	Uncorrected	Corrected (K)	Norm.	No. of Obs.
Snow	.85	.83 (7)	.86	81
Rain	.75	.73 (1)	.77	10
Rime	.81	.77 (2)	.81	39
All precip.	.83	.81 (10)	.84	130

Table 3

Here the difference between the uncorrected, corrected and normalized means are greater than before. This larger variability is primarily due to the smaller size of the samples and the possibly greater effect of precipitation on instrumental accuracy. The differences between snow and rain are, not surprisingly, seen to be about the same as those between Wa and Wd wetnesses.

IV The Influence of Clouds

In general, the radiation incident upon the upward facing instrument consists of two parts; the direct solar beam and the diffuse skylight. The diffuse skylight is the down scattered portion of the part of the direct solar beam that is scattered by the atmosphere.

Clouds have an important effect on the relative proportions of direct and diffuse radiation incident on the earths surface. In an attempt to find an empirical relation between the snow surface albedo and cloud cover, mean albedos were calculated for the seven snow surface parameters and two categories of cloud amount; total overcast with thick stratiform clouds and clear or less than 1/10 cloud cover.

During periods of overcast, the radiation reaching the ground will be more or less diffuse, depending on the extent that the sun is totally obscured. Ideally, none of the direct solar beam will reach the surface. With no cloud, the portion of incoming radiation from the direct solar beam is at a maximum. The results of the computations are in Table 4.

The presence or absence of clouds did not show a consistent effect on the snow surface albedo during the present observations. This negative result is in contrast to the finding of Olsson (1936) and Wallén (1948). Olsson found increase in snow surface albedo with clear conditions while Wallén found that the albedo of wet, old snow increased with increasing cloudiness. These contradictory results were found using only a few observations and are not definitive.

Snow Surface Mean Albedo
With Overcast and Clear Conditions
(Hours of less than 10° solar elevation excluded.)

	Cloud Cover 10/10 low		Cloud Cover 1/10 or less	
Type Surface Grain	Albedo	No. of Obs.	Albedo	No. of Obs.
Sh	0.80	7	0.81	3
Fa	0.86	81	0.91	4
Db	0.81	12	0.78	49
Dd	0.70	29	0.76	34
Wetness				
Wa	0.89	32	0.76	8
Wc	0.83	66	0.76	24
Wd	0.74	27	0.76	25

Table 4

Conclusions

The most important conclusions to be drawn are the dependence of the snow surface albedo on the grain nature and free water content of the snow. The variations between mean albedos of 84% for dry snow and 75% for wet snow; and between mean albedos of 85% for new crystals and 78% for old coarse grains, are most striking. The overall mean albedo of 81% is probably about 5% too high due to the probable error in the readings of the upward facings pyrheliometer at low solar elevations. The 77% mean of the 1000-1400 period is probably more representative of the 1963 season. The diurnal variation in the albedo may be due in part to the error in the instrument at low solar elevations. Most important, in total effect, is the daily variation in free water content of the snow. Dirnhirn and Trojor (1955) have stressed this effect.

Any effect of cloud cover on albedo was not demonstrated by the present observations.

It is estimated that all the mean values calculated involving more than thirty hourly periods are accurate within about 3%. This estimate is based upon the fact that, in Section III, the uncorrected, corrected, and normalized means all are within 3% of each other in any particular category. The random instrumental error, except at low solar elevations, is estimated to be 2% or less.

During the analysis several deficiencies came to ligh which, if rectified in future studies, would add much to the end results. If at all possible, the instruments used should be tested for their response to radiation at all incidence angles up to 85°. If the instruments are not checked in this manner, reasonably accurate readings can be expected only when the sun is higher than 25° above the horizon. At high latitudes the sun is above 25° for only a short period, if at all. This calibration is essential if a maximum of meaningful data is to be attained in the high arctic.

In the present study, the downward facing pyrheliometer was between 50 cm and 100 cm from the snow surface. Since the greater part of the radiation it receives comes from a small circular area below the instrument, the variability of the individual albedo readings should be less if the instrument is mounted as high as practicable , say 3 to 5 meters above the snow surface. A higher instrument mounting will sample a larger and hopefully more representative area of snow.

It would also be desirable to reverse the positions of the upward and downward facing instruments from time to time so as to detect any changes in the instrument characteristics.

In the present study, the snow surface observations were part of a general meteorological program and were rather widely spaced. As a result there were many periods in which the nature of the snow surface was not definately known so that the albedo data could not be used. More frequent observations would provide more useful data.

The variation of albedo is controlled by many factors, all interrelated in complex ways. This paper has only looked, very superficially, at a few of them. The accuracte prediction of snow albedo from other parameters requires a more detailed knowledge of the relative influence of each.

Appendix A

The data presented on the following chart comprise a relatively homogenous sample. Each value is the mean of from 25-29 individual measurements taken during the hourly period.

Brackets indicate that frost formed on the instrument bulbs during part or all of the hour.

Blanks indicate equipment not in operation or value discarded.

HOURLY ALBEDOS X 10^{-3}

Month	Day	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	No. Of Values	Daily Mean
		Hour Beginning																
JUNE	23								851		919						2	885
		888	875	888	872	847	902	855	880	947	1021	842	875	971	1055	1096	15	921
	25	879	874	835	797	799	813	797	858	857	814	833	867	963	1048	1161	15	880
		886	862	851	853	754	757	762	—	793	797	830	906	1004	1031	1084	14	811
		900	902	879	848	855	895	891	891	873	897	889	898	888	—	906	14	823
		867	869	907	908	914	916	942	945	939	938	937	941	957	954	947	15	925
		983	1004	930	—	—	850	—	819	806	818	851	928	908	939	1074	12	909
	30	836	928	867	813	819	835	795	819	866	896	895	937	922	931	1029	15	886
		Number of Observations																
		7	7	7	6	6	7	6	7	7	8	7	7	7	6	7		
JULY	1										749	786	859	928	991	1135	6	743
		840	822	806	732	766	756	790	832	840	845	842	852	924	1018	1081	15	850
		840	819	824	816	—	—	831	828	822	828	842	870	827	865	869	13	837
		840	814	838	737	717	716	696	704	695	701	736	807	886	977	1100	15	748
	5	832	839	792	700	681	679	669	688	682	684	730	810	890	981	1095	15	783
		753	783	752	674	674	680	669	699	704	721	776	858	951	1053	1137	15	792
		757	790	800	783	718	831	731	698	699	734	791	798	808	830	853	15	774
		698	745	724	651	643	864	682	697	690	703	770	864	953	1060	1165	15	781
		743	789	694	677	647	664	661	679	720	708	766	852	953	1069	1121	15	783
	10	744	720	771	813	876	902	872	915	887	850	851	858	897	1063	1077	15	872
		828	853	854	847	873	869	853	842	847	849	843	905	879	881	885	15	860
		825	825	801	796	815	836	861	870	839	810	830	815	847	845	910	15	835
		764	761	748	693	686	740	753	773	711	717	780	861	945	1060	1110	15	807
		784	785	755	711	651	723	728	734	743	714	746	852	927	1051	957	15	791
	15	782	767	772	768	776	800	753	750	750	780	770	783	781	812	801	15	776
		876	886	889	884	874	861	883	886	847	843	859	866	869	875	901	15	873
		866	856	869	882	886	895	888	850	906	883	898	912	894	992	902	15	892
		892	876	933	874	854	874	890	844	872	877	888	898	894	898	916	15	885
		882	934	898	790	753	780	761	793	838	843	852	875	930	916	906	15	850
	20	793	858	877	828	822	870	832	845	849	886	857	886	890	876	928	15	860
		875	852	869	—	—	770	765	797	761	746	809	878	1084	1095	958	13	866
		791	915	830	804	819	757	744	743	729	738	793	868	947	1039	1109	15	842
		820	834	873	790	796	773	810	785	816	827	854	859	866	857	879	15	829
		866	776	848	857	812	855	791	834	794	776	842	915	942	907	715	15	849
	25	811	822	813	814	812	781	790	819	774	822	891	784	900	982	915	15	835
		883	836	854	849	808	822	801	754	710	718	793	880	946	921	875	15	830
		769	756	775	—	—	756	750	795	794	809	826	831	838	870	902	13	805
		951	887	983	775	723	778	739	759	740	754	828	921	999	1083	1104	15	866
		804	839	849	—	724	711	701	704	685	690	757	831	892	938	838	14	783
		750	734	729	727	750	739	715	674	668	649	733	792	770	792	838	15	737
	31	749	745	768	691	633	622	—	—	—	674	737	722	735	767	800	12	724
		Number of Observations																
		30	30	30	27	27	29	29	29	29	31	31	31	31	31	31		
AUG.	1	796	753	712	752	726	739	757	739	751	760	748	722	815	759		14	752
		675	—	694	689	633	645	666	709	683	683	727	800	861	903		13	721
		681	635	636	669	691	724	743	730	626	657	680	775	818	864		14	709
		700	720	709	716	714	709	722	756	732	754	785	953	1063	962		14	785
	5	802	792	788	735	802	822	779	809	821	824	834	825	839	837		14	808
		710	850	851	802	828	812	848	795	847	821	841	827	832	838		14	822
		811	808	816	810	809	812	739	767	775	790	815	857	810	824		14	803
		762	736	784	753	770	788	766	764	739	725	764	802	813	880		14	775
		816	822	868	818	757	784	790	802	781	801	871	936	956	1056		14	847
	10	934	932	917	823	764	777	759	761	733	752	827	903	974	988		14	846
		971	834	884	—	—	725	728	725	741	728	789	853	—	921		11	809
		1074	845	848	776	699	713	708	708	689	706	768	826	854	840		14	785
		998	819	830	—	675	693	685	676	663	678	742	798	833	820		13	762
		736	736	810	748	658	677	666	664	648	696	722	782	824	774		14	722
	15	983	809	808	735	648	665	649	648	631	636	710	778	845	824		14	741
		702	712	707	687	700	664	730	668	631	662	702	736	717	738		14	697
		913	840	821	732	642	655	644	631	608	622	692	758	808	732		14	721
		690	752	721	676	686	685	688	679	640	630	713	—	796	705		13	697
		612	676	702	716	694	701	698	679	701	695	706	734	757	713		14	699
	20	—	784	836	853	841	837	811	799	839	777	788	842	816	837		13	820
		—	—	908	798	712	743	755	748	728	745	819	917	967	936		12	815
		Number of Observations																
		19	19	21	19	20	21	21	21	21	21	21	20	20	21			
		Three Months Number of Observations																
		56	56	58	52	53	57	56	57	57	50	59	58	58	58	31		
		Three Months Mean																
		820	816	817	776	755	770	764	770	763	768	800	847	886	913	981		

Appendix B

Instrumentation

The instruments with asterisks are the property of Arctic Institute of North America; all others are the property of the U. S. Army, Natick Laboratories, Natick, Massachusetts

Radiation measurements:

Eppley 50-junction pyrheliometer, serial # 3678
Resistance - 102 Ohms
Constant before observation season - 8.70 millivolts/langley/min.
Constant after observation season - 8.65 mv/langley/min.
Temperature correction - -0.15%/°C

Eppley 50-junction pyrheliometer, serial #5028
Resistance - 98 Ohms.
Constant, before 1963 season - 8.00 mv/ly/min.
Constant, after 1963 season - 7.80 mv/ly/min
Temperature correction - -0.12%/°C

(Standardization based on International Pyrheliometric Scale 1956)

The Eppley pyrheliometer (pyronometer) consists of a thermopile mounted under thin flat concentric silver ring receivers. A center disk and outer ring are coated with magnesium oxide while the inner ring is coated with Parsons optical black laquer. The white magnesium oxide coated ring has a cooler equilibrium temperature than the black ring. This temperature difference is used by the thermopile junctions to generate a potential which is roughly proportional to the incident solar radiation. The whole assembly is hermetically sealed in a glass bulb. MacDonald (1951) and instruction manuals available from the Epply Company contain more detailed descriptions of the instruments.

Minneapolis Honeywell - Brown four channel, multi-point
potentiometric recorder, Model 153X64p12-X-7A1,
Instrument #877558, serial # 5239-N.

Beckman and Whitley thermal radiometer (net), model
N188-01, serial # 243
Constant - 0.118 ly/min/mvv

General Meteorology

H. J. Green instrument shelter, type 176, containing:
Weksler maximum thermometer (general), 1°F divisions
Weksler minimum thermometer (arctic 1°F divisions
Bendix-Friez hygrothermograph, model 594, serial 4250 (daily charts)
Bendix 'Psychron', model 566-2

Wallace and Tiernan barometer, type ML-316/TM, serial 200
** H. J. Green 3-cup anemometer, type 323F, serial A998
H. J. Green 3-inch rain gauge, type 331

Snow Observations

** 5 500cc snow density tubes and beam balance
** 5 10-ft aluminum poles with wood casings (snow stakes)
Pocket lens and millimeter grid card

Other Equipment

** Kohler 4-Kw electric plant, model 4MM21, serial 247637
** Bruno-New York Industries Corp. multimeter ME-70A/PSM-6, serial 33705
Thermo-Electric "MiniMite" portable pyrometer indicator, model 70200
6-power Bausch and Lomb Optical Co. binoculars
Keuffel & Esser Co. magnetic compass
2-m. meter tape; 100-ft. metal tape
17 3-ft. lengths 'Dexion' slotted angle steel
Tool box with assorted tools, electrical tape, etc.
6 Keuffel & Esser Co. level books, No 373

Appendix C

Possible Systematic Errors

As mentioned in the text, the Eppley pyrheliometer is subject to several possible errors. The instrument is somewhat sensitive to ambient temperature. According to MacDonald (1951) and others, this variation is about 8% over the range -40 to +120°F. Since the range of air temperature during the field season was only about 40°F, and the variation of output has roughly the same gradient for all Eppley pyrheliometers, this source of error is negligible for albedo purposes. A sample computation using the extreme low albedo value (.608) and the extreme high temperature change (reducing the temperature from -40°F to +4°F) did not change the albedo value more than two-tenths of one per cent.

The glass envelope of the instrument absorbs about ten per cent of the incident radiation at (1 to 2 μ) wave lengths. However, again all instruments have approximately the same envelope absorption, so the albedo value is not changed.

An important source of error is found when one considers the incident angle of radiation reaching the instrument. The downward facing instrument looks at a surface that can usually be considered an approximately diffuse reflector. Thus it receives radiation from all directions in the hemisphere that it faces. The upward facing instrument receives, at least on clear days, a substantial part of its radiation from the parallel solar beam. The instrument is designed to register a voltage proportional to the radiation per unit area parallel to the flat receiving surface. The response to a parallel beam of constant flux density should be proportional to the cosine of the angle of incidence. MacDonald (1951) has shown that 5 instruments of 6 tested did not follow the cosine law at high angles of incidence. The error amounts to 20% at angles of incidence of about 80°. Since this error would normally apply only to the upward facing instrument, it follows that the albedo value will be about 1.1 times the true value when the sun is 10 degrees above the level horizon. Applying this correction to, for example, the unreasonably high 1900-2000 mean albedo of 98% reduces it to a more reasonable 82%. Unfortunately the particular instrument used was not checked for its cosine response characteristics. It is likely that the instrument was indeed in error and that the albedo values for low solar elevations are too high.

If the assumption that the snow surface is a diffuse reflector was not true, the high values could have been caused, at least in part, by the snow surface acting as a focussing reflector. This is very unlikely.

An overcast sky which blocks off the direct solar beam should then eliminate this specular reflection of the solar beam. Middleton and Mungall (1952) state that the specular reflective qualities of snow increase for high angles of incidence. However, specular reflection is very large only for frozen ice surfaces, which did not occur during the 1963 season. It is unlikely that the snow surface acted as a specular reflector to any important extent. Of 80 hourly values of albedo greater than 95% selected for further study, 16 or 20% occurred during periods of overcast. In the total of 833 hourly albedos, 159 or 19% had overcast conditions. The high albedos were not biassed with respect to overcast conditions.

In Appendix B, it may be noted that the constants of the pyrheliometers changed between calibrations. The first calibrations were used in the computations. If the later calibrations were used, each albedo value would be lowered approximately 2%. This is negligible compared to other instrumental errors. At any rate, one is unable to determine just when and how the constants varied.

Both instruments are similar electrically, both had connecting leads the same length (about 200 feet) and were connected to the same recorder. The type of circuit used in a potentimetric recorder minimizes the effect of losses in the connecting leads.

The varying voltage output of the generator did not effect the calibration of the recorder, but only the chart speed. Field tests of the recorder calibration showed that it was not strictly linear. However the error is estimated to be on the order of 1%, or less, of the full scale.

In general, the only error in the instruments that seems important is the one due to the probability that upward facing instrument did not follow the cosine response curve at high angles of incidence.

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