ON THE TRANSFER OF VISIBLE RADIATION THROUGH SEA ICE AND SNOW

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ABSTRACT. Coefficients of absorption of visible radiation are determined for sea ice and snow as a function of porosity of the medium and wave-length of energy refracted into it. A comparison is made between the values derived and those obtained by other investigators under similar snow conditions. A difference in results suggests a significant rôle of crystal size and orientation in the absorption properties of sea ice and snow.

RÉSUMÉ. Les coefficients d'absorption du rayonnement visible sont déterminés pour la glace de mer et la neige en fonction de la porosité du milieu et de la longueur d'onde du rayonnement réfracté. Les valeurs obtenues sont comparées avec celles données par d'autres chercheurs pour des conditions de neige similaires. La différence des résultats conduit a suggérer que la grosseur des cristaux et leur orientation jouent un rôle important dans les propriétés d'absorption de la glace de mer et de la neige.

ZUSAMMENFASSUNG. Absorptionskoeffizienten der sichtbaren Strahlung werden für Meer-Eis und Schnee als Funktion der Porosität des Mediums und der Wellenlänge der in ihm refrangierten Energie dargestellt. Hieraus abgeleitete Werte werden mit solchen verglichen, die von anderen Forschern bei ähnlichen Schnee-verhältnissen erhalten wurden. Die Verschiedenheit der Ergebnisse lässt einen beträchtlichen Einfluss der Grösse und der Orientierung der Kristalle auf die Absorptionseigenschaften von Meer-Eis und Schnee vermuten.

INTRODUCTION

Experiments leading to the collection of data herein were conducted in 1959 and 1960 on the sea ice of Drifting Station "Charley" in the Arctic Ocean; at the Arctic Research Laboratory, Point Barrow, Alaska and in the Cascade Mountains of Washington State.

Weston photoelectric cells, horizontally embedded, were used at all locations. On ice floe station "Charley" they were installed at the following depths: (1) ice surface, (2) 70 cm. and (3) 350 cm. The latter was just beneath the ice–water interface. Three cells were unfiltered and three (each) provided with red and yellow special-work filters. It was planned to use three blue filters in addition, but these were not available in special-work quality before the experiment began. To keep millivoltage within recorder-scale limits resistors were hooked in parallel in each circuit.

On the shore-fast ice at Point Barrow the cells were planted at the following places: (1) snow surface; (2) snow–ice interface; (3) 100 cm. in the ice and (4) immediately above the ice–water interface, 180 cm. beneath the ice surface. Because the study was carried out during a period of the year (May and June) when ice was deteriorating, intensity of light was measured manually to avoid risking the loss of a recorder.

For investigating the properties of snow as a medium of visible energy exchange, densities were measured and grain-size was estimated with a magnifying glass, as microscopic equipment was not available. In general, the technique of Liljequist (1956) was used in the collection of data from snow. Blue, green and red special-work filters were used and in some cases the polychromatic band was measured. Care was taken at each station to insure the homogeneous composition of the snow and that the incident intensity did not vary appreciably during the readings. Resistors were used on a switch to keep the millivoltmeter from "pegging".

DISCUSSION

In computing the absorption of radiation in homogeneous ice and snow it is assumed that the Lambert law is valid. This may be written

$$I_z = I_0 e^{-kz}, \tag{1}$$

where I_z is the intensity of radiation at depth z, I_0 is the non-reflected radiation available for transfer into the medium, and k is the coefficient of absorption.

To compute coefficients of absorption in a downward flux, the equation is solved for $-k$ and written

$$-k = (1/z)\ln(I_z/I_o). \tag{2}$$

At Point Barrow albedo values were available, but at other places they were computed by determining I_o from (1) and (2) and deducing the albedo A from the equation

$$A = 1-(I_o/I_s), \tag{3}$$

where I_s is the incident intensity.

Porosity of snow and its permeability to air was investigated by Bader (1939) who related porosity n to density by the equation

$$n = (\Upsilon_e - \Upsilon_s)/\Upsilon_e, \tag{4}$$

where Υ_e is the density of ice (0·917 g. cm.$^{-3}$), and Υ_s is the density of snow.

TABLE I. COEFFICIENTS OF ABSORPTION AND ALBEDO OF SEA ICE AND SNOW AS A FUNCTION OF DENSITY AND POROSITY

Medium	Density	Porosity	Wave-length	Coefficient of absorption, k	Albedo	Solar altitude	Snow condition
	g.cm.$^{-3}$		mμ	cm.$^{-1}$	per cent		
Sea ice* (shore-fast)	0·870	0·051	polychromatic	0·0219	65	24° 09′	
Sea ice* (pack)	0·900	0·018	polychromatic	0·0111	66	09° 27′	
			590	0·0084	71		
			660	0·0093	94		
Snow*	0·285	0·689	polychromatic	0·275	81	30° 48′	wet
Snow*	0·316	0·655	polychromatic	0·243	75	21° 26′	wet, corn
Snow	0·087	0·905	polychromatic	0·401	73	22° 30′	fresh
			420	0·133	87		
			540	0·230	88		
			660	0·305	93		
Snow	0·348	0·620	polychromatic	0·246	60	34° 18′	wet, corn
			420	0·185	71		
			540	0·198	80		
			660	0·231	83		
Snow	0·396	0·586	polychromatic	0·233	67	28° 48′	wet, fine
Snow	0·428	0·532	420	0·163	65	24° 18′	moderate grain-size
			540	0·205	72		
			660	0·231	80		
Snow	0·439	0·531	420	0·193	75	27° 06′	moderate grain-size
			540	0·200	81		
			660	0·231	84		
Snow	0·500	0·471	420	0·095	68	43° 06′	moderate grain-size
			540	0·136	86		
			660	0·145	90		
Snow	0·620	0·348	polychromatic	0·196	70	38° 46′	corn
			420	0·096	74		
			540	0·117	79		
			660	0·144	83		
Snow	0·640	0·302	polychromatic	0·155	75	33° 12′	wet, moderate grain-size
			420	0·065	78		
			540	0·089	78		
			660	0·115	84		
Snow	0·720	0·215	polychromatic	0·085	70	25° 42′	corn
			420	0·056	72		
			540	0·066	83		
			660	0·078	90		
Snow	0·810	0·117	420	0·025	70	46° 16′	corn, large grain-size
			540	0·036	80		
			660	0·064	84		

* Values averaged over a period of time.

The results of the investigation of the transfer of visible radiation in sea ice and snow are shown in Table I. Because concentration of sediments in shore-fast ice at Point Barrow is high, the coefficient of absorption is nearly double that of pack ice in the central Arctic Ocean.

Table II compares some data in Table I with representative observations of other authors, among whom it shows a lack of accord. Moreover, Liljequist (1956) observed a marked selective extinction of light while Sauberer (1938) remarked that the extinction of different colors within the band from $0 \cdot 38\mu$ to $0 \cdot 78\mu$ is, in the main, the same. Some minor variation in results of measurements in common media is to be expected due to multiple light reflection at depth and instrumentation factors. However, the magnitude of disagreement in Table II makes it apparent that absorption of light cannot be solely a function of wave-length and the porosity, density, grain-size or humidity of the medium. Discounting such foreign elements as brine pockets, interstices and inclusions, orientation of the c-axes of ice crystals (which are ordinarily uniaxial) must significantly affect transparency of a medium for refracted light. This may well account for incongruities in the value of $-k$ for common media. In fresh snow the shape of the crystals, and in old snow that of the grains, surely also influences transparency.

TABLE II. VALUES OF COEFFICIENTS OF ABSORPTION AS DETERMINED BY VARIOUS AUTHORS FOR VISIBLE RADIATION IN CERTAIN TYPES OF SNOW

Authors	Wave-length	Type of snow	Coefficient of absorption, k
	mμ		cm.$^{-1}$
Kalitin (1931)	polychromatic	wet	$0 \cdot 450$
Eckel and Thams (1939)	polychromatic	wet	$0 \cdot 446$
Liljequist (1956)	polychromatic	wet	$0 \cdot 280$
Kudō (1941)	polychromatic	wet	$0 \cdot 350$
Table I	polychromatic	wet	$0 \cdot 275$
Devaux (1933)	polychromatic	fresh	$0 \cdot 230$
Thams (1938)	polychromatic	fresh	$0 \cdot 083$
Sauberer (1938)	polychromatic	fresh	$0 \cdot 150$
Table I	polychromatic	fresh	$0 \cdot 401$
Liljequist (1956)	420	standard*	$0 \cdot 066$
Liljequist (1956)	520	standard*	$0 \cdot 083$
Liljequist (1956)	590	standard*	$0 \cdot 114$
Liljequist (1956)	650	standard*	$0 \cdot 172$
Table I	420	standard*	$0 \cdot 163$
Table I	540	standard*	$0 \cdot 205$
Table I	660	standard*	$0 \cdot 231$

* Standard snow, according to Liljequist (1956), has a density of $0 \cdot 42$ to $0 \cdot 43$ g.cm.$^{-3}$ and a grain-size of $0 \cdot 3$ mm.

For example, dendritic, plate, cup and needle crystal types should have different optical properties even though the density and porosity be identical. Furthermore, in fresh snow, crystals—particularly dendritic ones—may become unevenly rimed. In old snow, the formation of depth-hoar layers can also vary the absorption of energy.

CONCLUSIONS

The above hypothesis suggests a need for investigation of absorption properties of ice and snow as a function of crystal size and orientation.

Notwithstanding the incongruity of results shown in Table II, the conclusions of other investigators support the data presented in Table I in making apparent the following fact: *Absorption coefficients and albedos vary inversely with density of the medium and frequency of the energy.*

When sufficient data are collected and tabulated it will be possible to determine by inspection, any one of the several variables governing the transfer of visible radiation. For example, with space as a variable, the size and shape of a medium may be delimited. In areas of pack ice where surface observations are available, thickness and perhaps other characteristics may be inferred by a submarine on a traverse beneath the ice–water interface. Or

the ice seaman (who is concerned with crystal orientation) may improve his breaking and navigating techniques.

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