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PAR transmittance through thick, clear freshwater ice

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Abstract

Measurements of photosynthetically active radiation through clear freshwater ice 154–158 cm thick varied from 14.8 to 24.8% depending, in this case, primarily on the amount of flocullent material trapped within the ice. Transmittance in one area dropped to less than 1% with the presence of a 3 cm thick snow cover. Extinction coefficients varied from 0.014 to 0.010 cm^{-1}.

Introduction

The transmittance of photosynthetically active radiation (400–700 nm) through clear freshwater ice, 154–158 cm thick, was measured on Great Slave Lake in the Canadian Northwest Territories as a portion of a joint under-ice ecology program between the Environmental Sciences Division of the National Hydrology Research Institute of Environment Canada and the Great Lakes Environmental Research Laboratory of the National Oceanic and Atmospheric Administration (NOAA). The data are of interest since measurements through freshwater ice of such great thickness are not readily available, and since the ice was clear throughout its entire thickness. Bulk and spectral extinction coefficients and transmittances for sea ice have been reported by Gilbert & Buntzen (1986), Grenfell & Perovich (1986), Perovich et al. (1986), and Weller (1969). Their values are similar to those given here, but are not strictly comparable due to differences in conditions found on the surface of both natural freshwater and sea ice and due to differences in the physical/chemical properties of sea and freshwater ice such as the presence or absence of brine inclusions. Relatively recent measurements of the transmittance of photosynthetically active radiation (PAR) through clear and combinations of clear and opaque freshwater ice have been reported by Bolsenga et al. (1991), Bolsenga (1981, 1978), Stewart & Brockett (1984), and Maguire (1975a & b). In earlier papers, Schindler et al. (1974), Anderson (1970), Schindler & Nighswander (1970), Halsey (1968), Goldman et al. (1967), Saijo & Sakamoto (1964), Wright (1964), Greenbank (1945), and Croxton et al. (1937) reported on radiation transmittance through freshwater ice, but most of those studies used relatively outdated instrumentation.

Instrumentation

Lambda Instruments Corporation quantum sensors were used to measure radiation integrated over the 400–700 nm band. Detectors for both sensors are silicon photodiodes with enhanced response in the visible spectrum. Interference filters combined with detector characteristics produce sharp cutoff at approximately 400 and 700 nm. Sensor output was measured by a battery operated, portable Lambda Instruments Quantum Radiometer-Photometer. A folding arm (Figure 1) was used to position the underwater unit below the ice/water interface. The level of the sensor at the end of the arm was adjustable with respect to an above-ice spirit level.

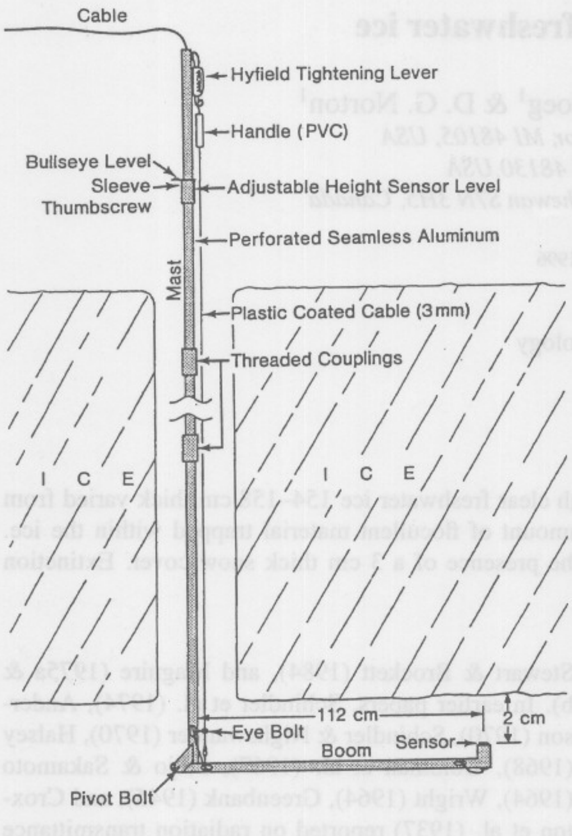

Figure 1.

Table 1a. Yellowknife Bay Ice Transmittance (T) and Extinction Coefficient (k).

Ice Type	Location from Borehole	T(%)	k(cm^{-1})
Clear	North	21.5	
	East	24.8	
	South	23.3	
	Avg (3)		0.010

Table 1b. Hay River Area Ice Transmittance (T) and Exitinction Coefficients (k).

Ice Type	T (%)	k (cm^{-1})
Clear ice with sediment floc	14.8	0.014
Snow covered (3 cm)		
clear ice	0.5	
	0.7	
	0.5	
Avg (3)		0.033

Results

A set of three transmittance measurements were collected on an ice road through 154 cm of clear ice near the north shore of the west arm of Great Slave Lake on Yellowknife Bay about 3 km from the city of Yellowknife (62°25.5′ N, 114°20′ W). The ice road was periodically cleared of snow, and vehicular traffic was frequent. Snow accumulation to the side of the road was about 45 cm. Scattered patches of compacted snow, less than 1 cm thick, covered approximately 50% of the area adjacent to the measurement site, but none were positioned directly over the under-ice sensor. The ice displayed a moderate number of cracks in vertical planes extending from the surface to the ice/water interface. Solar altitude at the time of measurements was 21°53′ (1053 LST, March 5, 1991), and skies were clear. Three measurements were collected from the same borehole in different locations under the ice in order to obtain an assessment of the effects of the crack structure and snow patches. The transmittances (Table 1) were nearly the same indicating that those effects were small. Measurements at different solar altitudes might have yielded more widely varying transmittances. The extinction coefficient in Table 1 is an average of the three measurements and was computed by:

$$k = \frac{\ln E_0 - \ln E}{z}$$

where

E_0 = irradiance at surface,
E = irradiance at depth,
z = depth (cm).

It is lower than values published by Maguire (1975a & b) (0.02 ± 0.003 cm^{-1}), but compared favorable with values published by Bolsenga (1978) (0.006–0.011 cm^{-1}).

Measurements were also collected near the south shore of Great Slave Lake approximately 32 km offshore from the city of Hay River, NWT (61°00′ N, 115°50′ W). The ice at this location was 158 cm thick and, for the most part, covered with snow. Patches of snow-free clear ice or opaque/clear ice combinations were scattered over approximately 5% of the surface.

Measurements were made through two boreholes, one in the center of a snow-free clear ice area and another, approximately 10 m away, in ice completely covered by approximately 3 cm of snow. Solar altitude during the period of the measurements varied from 23°28′ to 17°14′ (1221–1505 LST, March 7, 1991), and skies were overcast. Each pair of under-ice and above-ice measurements were made under what appeared to the eye as uniform sky cover. Measurements of incident PAR both before and after an under-ice measurement were nearly the same, or the set of readings was discarded. A set of measurements took from 3 to 5 minutes to complete.

The water in the Hay River area was extremely turbid due to the influence of the Hay River plume. The transmittance of the ice (Table 1) shows the influence of flocullent material frozen into the ice. The ice at the Hay River location was 4 cm thinner and with a similar crack structure to the ice measured at Yellowknife Bay, but the transmittance differed by nearly 7% or more. The extinction coefficient was, as one would expect due to the presence of the flocullent material, higher than for the Yellowknife Bay clear ice. The flocullent material was similar to that observed on Lake Erie (North American Great Lakes) by Bolsenga et al. (1989) with the exception that, in this case, the flocullent material was firmly frozen into the ice near the surface, whereas in Lake Erie the flocullent material often occurred at the ice/water interface and was not always frozen into the ice surface.

The low transmittance of the snow-covered ice at Hay River (Table 1) was not surprising. Both Maguire (1975a & b) and Bolsenga (1981) reported on the attenuation of PAR by snow. In the latter study, transmittance varied from 77 to 85% through a snow-free portion of 28 cm of clear ice and dropped to 8 to 10% through the same ice cover with a layer of 3 cm of hardpacked snow. The fact that any radiation at all was transmitted through a combination snow/ice cover of this thickness is surprising. Bolsenga et al. (1991) measured transmittances of 2.5% or less on Lake Erie through 21 cm of clear ice covered by 7–8 cm of snow. Transmittances were about 85% through the same Lake Erie ice without the snow cover.

Summary and comments

Measurements of PAR transmittance through clear freshwater ice indicate that a significant amount of radiation is likely to penetrate to the water column in the absence of a snow cover even though the ice is thick. Agreement with previously published extinction coefficients is reasonable. Measurements of the spectral distribution of under-ice radiation would be of value and will possibly be collected in the Canadian NWT under similar conditions in the future.

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