Journal of Glaciology, Vol. 18, No. 80, 1977

SHORT NOTE

PRELIMINARY OBSERVATIONS ON THE DAILY VARIATION OF ICE ALBEDO*

By S. J. Bolsenga

(Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Ann Arbor, Michigan 48104, U.S.A.)

Abstract. A preliminary assessment of the daily variation of ice albedo in the 285–2 800 nm range was made using field data collected over snow ice and refrozen slush. Significant diurnal variations could be attributed to changing low solar altitude under clear skies or to decay of the ice surface. Changes in albedo due to changes in cloud cover were observed for the most part to be slight. The measurements provide a base for a program of wider scope which would consider other types of ice under a variety of natural conditions.

Résumé. *Observations préliminaires sur les variations journalières de l'albédo de la glace.* Une approche préliminaire de la variation journalière de l'albédo de la glace dans la plage des 285–2 800 nm a été faite en utilisant des données recueillies à la fois sur de la glace de neige, et de la neige fondue et regelée. On n'a pas observé en toutes occasions des variations journalières significatives mais quand elles se produisent, on peut les attribuer soit à un changement dans les faibles incidences du soleil en cas de ciel clair, soit au pourrissement de la surface de la glace. Les changements de l'albédo dues aux variations dans le couvert nuageux ont dans la plupart des cas été minimes. Ces mesures donnent une base pour un programme de plus larges investigations qui prend en compte d'autres types de glace sous un grand nombre de conditions naturelles.

Zusammenfassung. *Vorläufige Beobachtungen zur täglichen Schwankung der Eis-Albedo.* Anhand von Feldbeobachtungen, angestellt über Schneeeis und wiedergefrorenem Matsch, wurde eine vorläufige Schätzung der täglichen Schwankung der Eis-Albedo im Bereich von 285–2 800 nm vorgenommen. Merkliche Tagesschwankungen traten als Folge von niederen Sonnenhöhen unter klarem Himmel oder des Zerfalls der Eisoberfläche ein. Hingegen erwiesen sich die Albedoschwankungen infolge wechselnder Wolkenbedeckung meist ale geringfügig. Die Messungen bilden die Grundlage für ein weitergespanntes Programm, bei dem andere Eistypen unter einer Vielfalt natürlicher Bedingungen zu untersuchen wären.

Introduction

Studies on the albedo of ice have received considerably less attention than those on snow. It is known that snow albedo varies with time, according to surface roughness change, impurity content, melting or refreezing, and atmospheric state (Eckel and Thams (in Bader and others, 1939, English translation, p. 245–304); Hubley, 1955; Diamond and Gerdel, 1956, p. 5–6). Although similar processes occur in ice, they have not yet been quantified. A preliminary study conducted in 1967 (Bolsenga, 1969) to obtain the total albedo (285–2 800 nm) of various types of ice common to the Great Lakes indicated that albedo values ranged from 10% for clear ice to 46% for snow ice. However, that study cannot be considered complete because albedo readings were taken at only one solar altitude under cloud conditions prevailing at the time.

In this study, information was compiled during the 1975–76 winter season on two ice types common to inland lakes. Tests were performed near Ann Arbor, Michigan, U.S.A. (lat. 42° 18′ N., long. 83° 43′ W.). Data were gathered on the variation of albedo according to changes in the solar altitude, cloud types and cloud amounts. Only snow-free ice surfaces were studied since snow-albedo characteristics are well known, whereas ice-albedo characteristics are relatively little known. If ice albedo is better understood, then in natural surfaces where ice and snow are combined, both snow-free ice-albedo values and snow-albedo values can be artificially integrated to obtain a good approximation of the natural albedo of a large area. Some investigators (Langleben, 1968) have measured the albedo of surfaces which are a combination of ice and snow. It is felt that such observations are site specific and that a better understanding of the albedo of ice–snow combinations can be gained by initially studyir g each surface separately.

* Great Lakes Environmental Research Laboratory Contribution No. 84.

Instruments and procedure

Incident and reflected total global radiation were measured by factory-calibrated Eppley high-precision spectral pyranometers. The Schott WG7 clear-glass hemisphere is transparent from a wavelength of about 285 (center of lower sharp cut-off) to 2 800 nm. A Schott RG8 hemispherical filter with a lower sharp cut-off of about 700 nm was interchanged with the outer WG7 for some measurements to provide readings in the near infra-red range. Pyranometer output was measured with a highly accurate precision portable potentiometer. Sensors were mounted on a 1 m high tripod equipped with a horizontal cross arm extending about 1.5 m outward from the tripod for reflected-bulb suspension. At the lake, an appropriate snow-free site was selected. If all areas were snow-covered, the ice was shoveled and swept with a broom until the surface was snow-free.

Results

The ice surfaces studied were snow ice and refrozen slush. Snow ice is milky-white in color and contains various sizes and concentrations of air bubbles. The snow ice at the measurement site was formed by snow loading an existing ice cover with upward seepage of water through stress cracks in the old ice cover into the snow layer, which subsequently refroze. The refrozen slush is similar in appearance to snow ice but the method of formation is different. First, mild temperatures and rainfall reduced the snow cover on the lake to slush and then subsequently lower temperatures completely froze this slush into the snow-ice-like substance here called refrozen slush.

Average albedo for all days of measurement was 43%. Averages for individual days and associated ice types are given in Table I. Bolsenga (1969) observed the albedo of Lake Superior snow ice was 46% and that of refrozen slush was 41%. The differences between those values and the values given here are due to differences in the ice surfaces and to the fact that measurements in this study were taken under a wider range of solar altitudes.

Table I. Average albedo for the ice types involved in this study

Date	*Ice type*	*Average albedo* %
8 January 1976	Snow ice	41
15 January 1976	Snow ice	39
22 January 1976	Snow ice	46
27 January 1976	Refrozen slush	46
3 February 1976	Refrozen slush	58*
24 February 1976	Refrozen slush	35

* High albedo due to significant amount of granular snow adhering to ice surface.

Above-freezing temperatures prevailed for several days before the measurements shown in Figure 1 (smooth curves in Figures 1 and 2 fitted by eye). A layer of water formed on the ice during the day but low night-time temperatures had solidly frozen this layer by the morning of the measurements. Temperatures were mild during the day of the measurements, causing the ice surface to melt partially. The albedo decreased rapidly from 48% at 08.47 h TST ($\gamma = 22° 01'$) to 21% at 12.39 h TST ($\gamma = 36° 52'$). At the lowest albedo, water was observed to occupy the interstitial spaces between small protruding grains of the ice surface. The albedo was thus a combination of water and ice reflectivity. It should be emphasized that the ice appeared as ice, not water, to the casual observer. The visual appearance of the ice varied from white in the early morning to a medium gray tone at 12.00 h TST. A thin but relatively even layer of clouds prevailed during the measurements.

Differences in albedo due to changes in cloud cover were small. Measurements made under cumulus clouds of varying amounts and within clear-sky "windows" between the clouds showed albedo differences of only 1–2%. On one of the days of measurement the cloud cover varied from 8/10 to 10/10 cirrostratus and stratocumulus to 3/10 stratocumulus (lower layer) plus 7/10 cirrostratus (upper layer) and finally back to 10/10 stratocumulus. The largest variation of the average albedo between the different cloud regimes was only 1.6%.

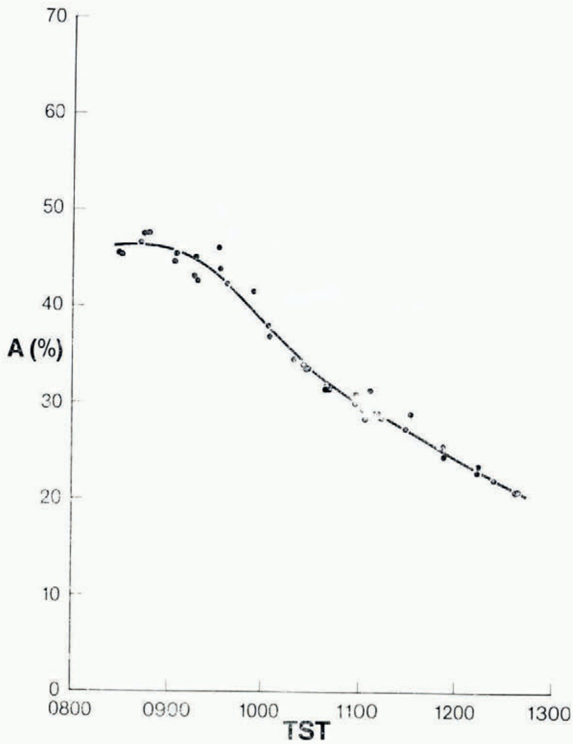

Fig. 1. Albedo under decaying ice conditions. 24 February 1976.

A larger change in albedo was measured when a variable cloudy pattern changed to nearly clear skies (Fig. 2). The albedo had fluctuated in a fairly narrow range with gradually increasing values during the period 13.22–15.11 h TST ($\gamma = 25° 57'–14° 39'$). At a point when the skies were nearly clear (15.29 h TST) the albedo abruptly increased about 6%. The albedo then continued to increase an additional 7% from 15.29 h to 16.11 h TST as the solar altitude decreased from 11° 54′ to 5° 46′. The increase in albedo near the end of the day with decreasing solar altitude is likely due to the effects of increasing diffuse-sky radiation which is relatively rich in visible light (i.e. incident flux component due to direct solar radiation becomes progressively smaller and the diffuse component relatively larger). If the ice albedo is high in the visible spectrum, as with snow, the albedo of the ice could be expected to increase at increasingly lower solar altitudes under clear skies (Liljequist, 1956, p. 88). The limited information available indicates that the albedo of ice similar to slush ice and snow ice in the visual spectral range is high but that this would not be the case for clear ice (Sauberer, 1938). Investigations are planned to quantify both the effects of the diffuse component and the spectral albedo.

Near-infra-red albedo readings were taken on two separate days, both for periods lasting less than 1 h. Readings were made near mid-day when variations in the solar altitude were minimal and also when cloud conditions had not varied and were not expected to vary for a considerable period of time. Near-infra-red albedo of snow ice on 15 January 1976 averaged 34.2% ($\gamma \approx 25°$) within a 0.9% range. On 24 February 1976, when the refrozen slush ice surface was melting, albedo averaged 13.4% ($\gamma \approx 35°$) within a 1.5% range. On both occasions the near-infra-red albedo was about 7% lower than the total albedo observed just before or just after the near-infra-red measurements.

Conclusions

Significant diurnal variations in albedo were observed during some of the measurement days. The largest variations can be attributed to either changes in solar altitude under clear skies or changes in the ice surface. Changes due to atmospheric conditions were considerably less than those due to other

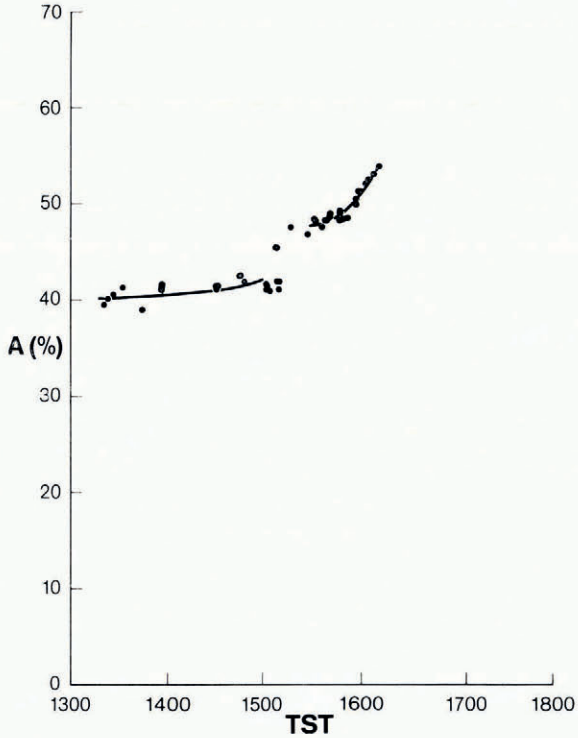

Fig. 2. Effect of cloud cover on albedo and changes in albedo due to changes in solar altitude. 27 January 1976.

causes. Larger changes than observed here might be expected when sky conditions change at low solar altitudes from cloudy, where most of the incident radiation remains diffuse at increasingly lower solar altitudes, to clear where the contribution of the direct and diffuse components changes with lower solar altitudes. The average albedo of snow ice was less than that observed in a previous study, while the average albedo of refrozen slush was about the same. Differences are attributed to the wider range of solar altitudes accounted for here and also to differences in the ice surfaces.

In the context of energy-budget studies, the diurnal variations are small. It appears that the use of an average mid-day albedo under average sky conditions would suffice for the reflected radiation term in most energy-balance studies. In remote sensing, the implications are not as clear. Slight changes in albedo are sometimes critical to target recognition as in some bands of multispectral scanning systems.

Acknowledgements

The helpful suggestions of Professor William Farrand of the University of Michigan and Dr Frank H. Quinn of the Great Lakes Environmental Research Laboratory are gratefully acknowledged.

MS. received 6 September 1976 and in revised form 29 January 1977

REFERENCES

Bader, H., *and others*. 1939. Der Schnee und seine Metamorphose, von H. Bader, R. Haefeli, E. Bucher, J. Neher, O. Eckel, C. Thams, P. Niggli. *Beiträge zur Geologie der Schweiz. Geotechnische Serie. Hydrologie*, Lief. 3. [English translation: *U.S. Snow, Ice and Permafrost Research Establishment. Translation* 14, 1954.]

Bolsenga, S. J. 1969. Total albedo of Great Lakes ice. *Water Resources Research*, Vol. 5, No. 5, p. 1132–33.

Diamond, M., *and* Gerdel, R. W. 1956. Radiation measurements on the Greenland icecap. *U.S. Snow, Ice and Permafrost Research Establishment. Research Report* 19.

Hubley, R. C. 1955. Measurements of diurnal variations in snow albedo on Lemon Creek Glacier, Alaska. *Journal of Glaciology*, Vol. 2, No. 18, p. 560–63.

Langleben, M. P. 1968. Albedo measurements of an Arctic ice cover from high towers. *Journal of Glaciology*, Vol. 7, No. 50, p. 289–97.

Liljequist, G. H. 1956. Energy exchange of an Antarctic snowfield. Short-wave radiation (Maudheim, 71° 03′ S., 10° 56′ W.). *Norwegian–British–Swedish Antarctic Expedition, 1949–52. Scientific Results*, Vol. 2, Pt. 1A.

Sauberer, F. 1938. Versuche über spektrale Messungen der Strahlungseigenschaften von Schnee und Eis mit Photoelementen. *Meteorologische Zeitschrift*, Bd. 55, Ht. 7, p. 250–55.