ALBEDO MEASUREMENTS OVER SUB-ARCTIC SURFACES

by

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ABSTRACT

During the summer months of 1961, measurements of the albedo of sub-Arctic surfaces in the Labrador-Ungava peninsula were undertaken. From chartered aircraft the parameter was measured over the major vegetarian cover-types previously studied and classified by a group of McGill workers. Ground measurements of albedo were also undertaken.

A description of the instrumentation and its problems is presented in Chapter II. In Chapter III the flight coverage of the peninsula in relation to the vegetation cover-types is discussed. Chapter IV discusses the representative values of albedo together with the phenomenon of different albedo values under direct or diffuse solar radiation.

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CHAPTER I

INTRODUCTION

(1) Background to the Study

In 1956, a group of workers at McGill University completed a task, begun in 1949, concerned with mapping the sub-Arctic physiography and vegetation cover-types of Labrador-Ungava. The inception of this project coincided with the confederation of Newfoundland with Canada and the recognition of the economic significance of the Labrador section of this province.

In order to meet the need so created for immediate fundamental knowledge of the terrain, the Defence Research Board sponsored the project of mapping the peninsula's physiography and vegetation. This was accomplished by air photograph interpretation based on the classification of the two environmental elements by ground checks.

During the course of mapping, it was observed that the significant differences in ground covers would be responsible for differences in ground-atmosphere energy and moisture exchanges. Further grants from the Defence Research Board permitted the initiation of a programme of micrometeorological studies in 1956, which aimed at providing quantitative data concerning the energy and moisture budgets of the different vegetation zones.

Particular emphasis was to be placed on the meteorological radiation characteristics fundamentally important to both budgets.

In 1956 and 1957, studies of evapotranspiration (16, 17) over lichen surfaces were undertaken at Knob Lake and, since 1957, data have been collected on albedo (9, 10), and net radiation (18) in the same area. *By using this information in conjunction with the completed ground cover maps, it is hoped to form regional estimates of the radiation and evapotranspiration terms within the Peninsula.

(2) "Albedo", and its Importance and Application

During the summer of 1961, the writer undertook a field programme to measure the albedo of the previously mapped cover types.

The term albedo is employed to denote surface reflectivity for all wavelengths in the range 0.3 to 2.0 microns. According to Kuhn and Suomi (12): "The albedo, A, of a surface may be defined as the ratio of solar energy which the surface reflects, Ir, to the solar energy incident upon such a surface, Io, or:

$$A = I_r/I_o$$

The ratio is commonly expressed as a percentage.

Monteith (15), has pointed out that the term "albedo" should be reserved for reflection in the visible range of the spectrum. "Albedo", he says, "is reflection related to the human eye." For this particular study a somewhat different application of the term will be employed, which includes some measurement of the infra-red portion of the spectrum.

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*The writer's work concerning albedo is a continuation of the programme.

The instruments used were designed as sensors to short wave radiation between the wavelengths of 0.3 and 2.0 microns. As the visible portion of the spectrum lies between 0.3 and 0.7 microns, the albedo will not be entirely "related to the human eye". Further reference will be made to this point later, in the discussion of results.

Albedo studies are of a special nature, seldom recorded on a regular basis as part of a weather station's observation routine. Yet, the application of albedo data is of vital importance to the study of the heat and moisture balances of the earth, both on a world-wide and on a local scale. A knowledge of incoming solar radiation and of its depletion by ground surface reflection enables the actual amount absorbed at the ground surface to be calculated.*

Indirectly, albedo is again important in moisture studies through its association (although not constant) with net radiation. The latter forms the most vital variable in formulae for water balance computations.**

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*Albedo is of fundamental importance in equations for the determination of the net radiation. Budyko's (4) equation for net radiation ("radiation balance"), is expressed as -

$$R = (Q + q)\ (1 - a) - I$$

where Q = total direct radiation, q = total diffuse radiation, a = albedo, I = the effective outgoing radiation.

**Hare (7) has stated: "Both Penman & Thornthwaite make explicit or implicit use of the radiation balance -

$$R = LE + A + Q$$

where R = net radiation (solar plus net infrared fluxes, after reflection) at surface,
E = evaporation, L = latent heat of vaporization,
Q = convective heat flux to air, and
A = heat flux to or from soil below surface."

Differences of albedo between cover types imply associated differences of absorption of incoming radiation, which is the basic mechanism for variations in convection currents. Thus, albedo studies are of value in the consideration of low level thermally induced turbulence. Over uniform land surfaces, differences of albedo are slight when compared with an area, such as the Labrador-Ungava Peninsula, where a chaotic mixture of bare tundra ridges, wooded lowlands and extensive lakelands is conducive to marked differences in convection, particularly between land and water surfaces.

Finally, albedo is relevant to studies of air mass modification. Modification of an air mass is primarily dependent upon the nature of the surfaces constituting the path over which it passes, for it tends to acquire, in its lowest layers, the heat and moisture characteristics of the surface beneath. In winter the Labrador-Ungava Peninsula absorbs insolation with a greater uniformity than in summer, for the general snow cover masks the differences inherent in the vegetation cover; consequently, there will be very little variation in the surface over which air masses travel. In summer, the variety of surface and the increase in absorptivity may cause instability and minor modifications from one surface to another.

(3) Methods of Measuring Albedo

The 1961 summer field programme included both albedo measurements from the air and on the ground, although the former study was by far the most extensive and intensive. Both methods have been used in the past.

Data on natural surfaces have been assembled from ground studies, such as those of Ångström (1). The development of agricultural research stations has led to the establishment of heat and moisture balance studies and hence to albedo measurements in association with crop growth and yield. Monteith discussed the "reflection coefficient" of certain crops in a temperate climate. In tropical regions the albedo of sugar cane has been studied, while in polar areas, studies on many glaciers and on floating research stations have provided data on snow and ice albedo. Thus, ground measurements of albedo have been conducted over many surfaces, natural and cultivated, over a wide range of latitude.

Airborne measurements of albedo are not novel, although they are fewer than ground measurements. Early work was undertaken in England by Richardson (19), in 1930; in more recent years this type of survey has been more common in North America and in Russia. In North America, Fritz (6), Kuhn and Suomi (12), Bauer and Dutton (3) and Jackson (9, 10), are representative. Fritz was concerned with data to be applied to a study of the albedo of the earth, thus flying was at a high level above cloud layers. Kuhn and Suomi, and Bauer and Dutton, operated projects at lower flying heights more akin to the one presently to be outlined. Jackson worked in the same area as the writer and also from the same base, Knob Lake, and his results are the only ones representative of sub-Arctic surfaces. Later in the study, the results obtained in 1961 are compared with Jackson's.

From Russia, airborne albedo measurements of Zubenok are reported by Kondrat'ev (11), as well as albedo values obtained by Faraponova from balloon flights. Other workers are mentioned by Budyko (4). Russian studies in the radiation balance have been particularly extensive, and Budyko refers to the availability of "ample data from observations on the mean values of the albedo for various underlying surfaces". He selects his references from "among the numerous works of determining the albedo".

(4) The Purpose of the Study.

The purpose of this study is twofold. First, there is an attempt to provide quantitative data on the albedo of the different cover-types of the Labrador-Ungava Peninsula, which may be applicable to future work on the heat and moisture balances, turbulence and air mass modification of that region. Secondly, some indication of the problems associated with the airborne measurement of albedo will be discussed. Although it has been for over 30 years a recognized technique for measuring albedo, the use of an aircraft has given rise to many problems peculiar to airborne studies and not to those on the ground. Several are of an instrumental nature, but the transference of the radiation-measuring station from ground level to above ground level necessitates some consideration of radiation scattering, cloud shadowing of the ground, and the actual correlation of a given reading with the particular surface being flown over.

Hitherto, workers in this field have not been content to present results alone, for the results themselves are coloured by instrumentation techniques and problems. This work will be no exception, for the writer recognized several limitations in the technique employed and is of the opinion that these should be fully described before presenting the actual field results.

CHAPTER II

INSTRUMENTATION

(1) Aircraft

It is important to discuss the two aircraft used and the role they played in the summer's fieldwork, for each in turn provided a mobile stand for the instruments.

An instrumented aircraft possesses distinct advantages over a ground station in the areal measurement of albedo. It permits the application of a reconnaissance method whereby a variety of ground cover types can be traversed in a short space of time and is thus readily applicable to determining differences between types. In such a region as the Labrador-Ungava Peninsula, the aircraft provides the only method for areal coverage, as overland communications are virtually non-existent except in the immediate vicinity of human habitation. In addition, a higher level of instrumentation site permits albedo measurement over lakes, woodland and areas of bogland.

Against these advantages one must consider the disadvantages. A certain amount of vibration inhibits an accuracy of reading such as that obtainable from a stable ground station. Also, as an aircraft is a constantly moving base for the instruments, one can never be absolutely sure that the radiation reflected from the surface immediately beneath is being read instantaneously by the observer.

The selection of an aircraft was governed mainly by availability. However, it had been decided previously to obtain a light aircraft equipped with floats to fly in bush country below the lowest cloud layers. The services of a suitable aircraft were engaged during the months of June, July and August from Clark Air Services Limited of Mont Joli, Quebec.

A "Cessna 180" floatplane (shown in Photograph A) was chartered in June and August, while during July it was replaced by a Piper "Apache" (shown in Photograph B), a twin-engined aircraft with a retractable undercarriage.

With two engines, the Piper aircraft possessed, theoretically, a higher safety factor than the Cessna, but the float landing gear of the latter more than compensated in this respect, as most lakes in the region are potential floatplane strips. The main advantages of the twin-engined aircraft were:

(i) Two-engined power, which made exceptionally low flying safer and more practical.

(ii) Retractable landing gear, which eliminated interference with any instrumental attachment. The housing of an instrument beneath and between the floats of the Cessna may have influenced the amount of measured reflected radiation.

Speeds of between 90 and 110 m. p. h. were maintained in order to minimize the effect of the time lag between the aircraft passing over a point on the ground and the moment of reading. Although only wide expanses of uniform cover type were studied, slow speeds ensured a more representative

Photograph A: The Cessna "180" floatplane used during June and August.

Photograph B: The Piper "Apache" aircraft used during July.

series of readings than higher speeds, for a greater number of readings per unit of distance could be performed. A flying height of approximately 200 feet above ground level was maintained, except over rugged terrain in conditions of turbulence, but the aircraft-to-ground distance never exceeded 500 feet. In the opinion of Kondrat'ev, an aircraft is a means of obtaining the average albedo of large areas. However, it is the opinion of the writer that very low flying, of the order of 200 feet or even less, will give good representation of the reflectivity of a particular cover type, provided it is extensive enough.

(2) Instruments for the Measurement of Albedo.

Incoming solar and sky radiation, and short wave radiation reflected from the ground surface, were each measured by a Kipp and Zonen Solarimeter, mounted on the aircraft as close to the horizontal as possible in upfacing and downfacing positions. This type of solarimetric thermopile measures in the short wave portion of the spectrum. The radiation, transmitted through two concentric hemispherical glass domes, is received within the inner dome on a blackened thermopile, which transforms the energy into an electric potential. Pre-fieldwork calibration indicated that electromotive forces of 7.03 mV and 7.60 mV were generated in response to a radiation of 1 gr. cal. cm^{-2} min.$^{-1}$ by the upfacing and downfacing instruments respectively.

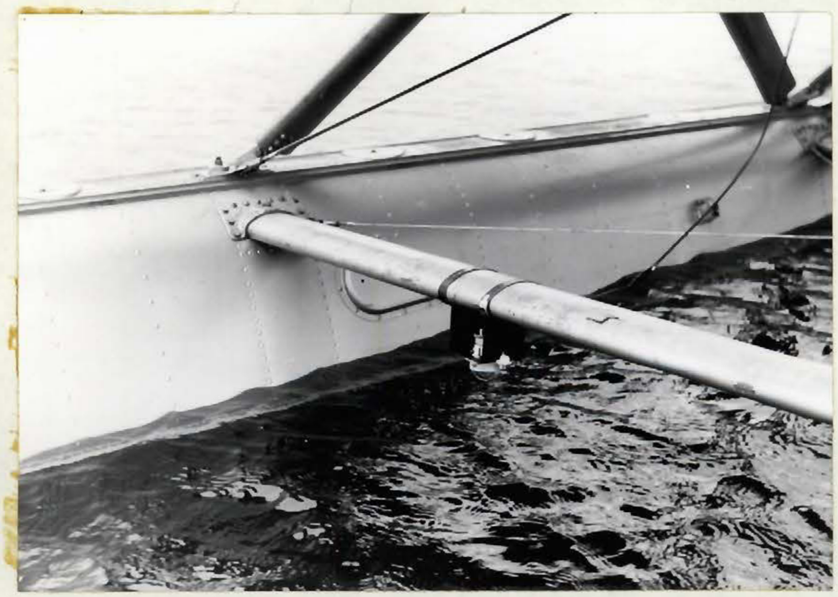
The Kipp and Zonen Solarimeter presents the problem of measuring radiation with an approximately hemispherical field of vision. Such a field of vision is ideal for recording incoming radiation from the whole sky but raises several problems in the measurement of reflected radiation:

(i) A wide expanse of cover type will be included in the field of vision, although presumably with greater weight being given to reflection from the surface directly beneath the instrument. However, instead of a uniformity of albedo readings for different cover types, as one would expect from such a "generalized" view, the change from one cover type to another was matched by a corresponding change in albedo, and it is the writer's opinion that low flying heights compensated to some degree for the wide-angle "vision" of the solarimeter.

(ii) With horizon to horizon instrumental sensitivity, skylight on the horizon might be recorded by the downfacing instrument. This applies particularly at times of low solar elevation when the sun might be positioned below the horizontal plane of the instrument. As flights were not made close to times of sunrise or sunset this problem was not encountered. Again, low flying height would tend to raise the horizon relative to the horizontal plane of the instrument.

(iii) Such a field of vision could include portions of the aircraft. Photographs C, D and E, which show the mounting positions of the instruments on the two aircraft, illustrate this. The mounting of the downfacing instrument on the

Photograph C: The mounting of the upfacing solarimeter. The same method was used on both aircraft.



Photograph D: The mounting of the downfacing solarimeter on the Cessna "180".

Photograph E: The mounting of the downfacing solarimeter on the Piper "Apache".

underside of the front spreader bar between the Cessna's floats cannot be considered satisfactory; however, this was the only practical location for installation. Readings were probably subject to the influence of the floats, which extended below the horizontal plane of the instrument by $15\frac{1}{2}$ inches. Fig. (1) demonstrates the effect of the floats in restricting the instrument's view to left and right. In these two directions the approximate 180° angle of vision is reduced to 135°. Along the line of flight, however, there is no obstruction. In contrast, the downfacing mounting in the fuselage of the Piper aircraft was completely unshaded from all angles. A comparison of the data collected on flights of the two aircraft shows a series of slightly lower albedo values from the former. This difference is interpreted largely in terms of shading of the downfacing instrument.

Kuhn and Suomi (12), and Bauer and Dutton have given some consideration to this problem of wide instrumental vision. To counteract it, they have developed the use of a "beam reflector", whereby the solarimeter (an Eppley in their case) is mounted in an upright position to measure reflected radiation from a parabolic reflector above it. Figs. (2) and (3) illustrate the difference between the two installations. The "beam reflector" has a narrow angle of vision of 4°, whereby at a flying height of 500 feet the recorded value of albedo refers to a circle of 35 feet diameter on the ground. Such an arrangement gives "point" sampling and is extremely valuable for small areas and for reducing the three problems

Fig. 1. Front view of the mounting of the downfacing solarimeter on the Cessna 180.

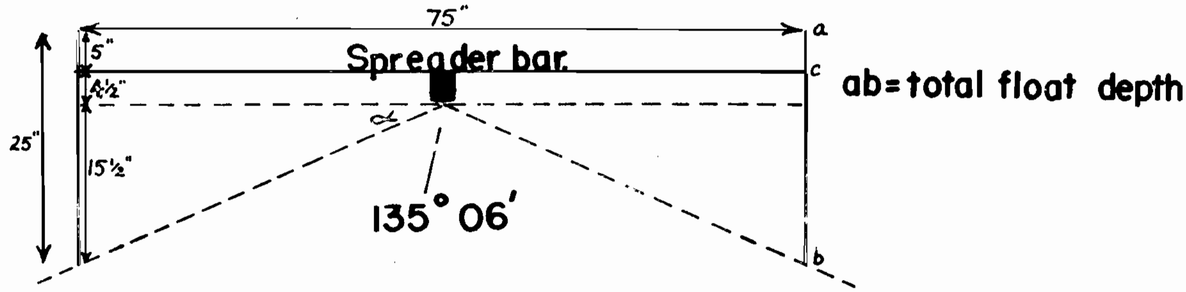


Fig. 2. Hemispherical albedo.

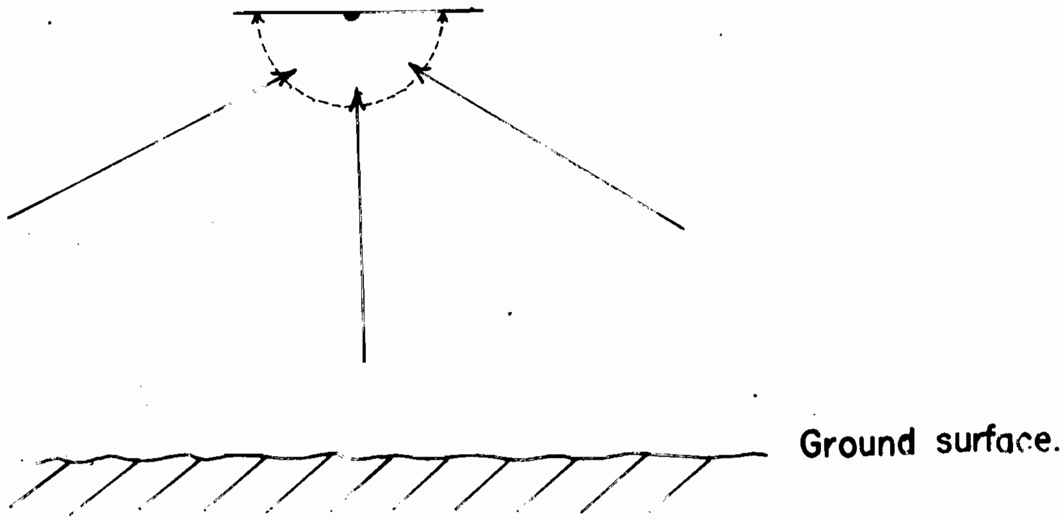
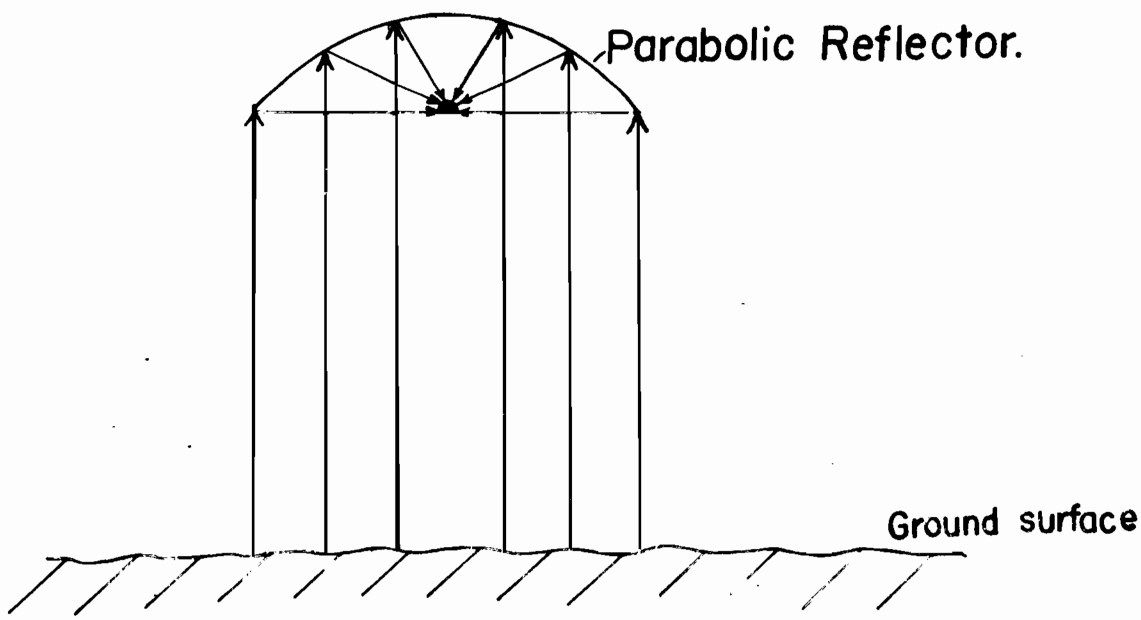


Fig. 3. Beam albedo.



just described. Bauer and Dutton have compared the readings of "beam" and "hemispherical" albedo (A_b and A_h) on the same flight, and have found significantly lower values for the former.

Over a uniform snow surface -	A_b	is	23%	lower	than	A_h
Over spring farmland -	"	"	22%	"	"	"
Over forest -	"	"	19%	"	"	"
Over rippled water -	"	"	60%	"	"	"

With regards to his own area of study the writer believes that the difference between A_b and A_h would not be great, for the sub-Arctic contains vast expanses of relatively uniform surface cover-types. Thus, the nature of the ground surface, combined with low flying would remove some of the error likely to arise from the use of an inverted solarimeter with no reflector shield.

In May 1961 the writer visited the workshops of the aircraft company at Mont Joli where suitable brackets for mounting the solarimeters on the aircraft were fabricated. Photographs C, D and E show the methods of bracketing. Brackets were bolted directly to the aluminum skin of the aircraft except in the case of the downfacing instrument on the floatplane, where attachment was to the front spreader bar. The brackets had the advantages of being inexpensive, easily installed and dismantled, and providing a firm horizontal base for the instruments in flight. The instruments were used without the standard base designed for outdoor installation at ground level.

The original cable connections between the solarimeters and the reading instrument were lenghthened to extend into the aircraft. Care was taken to make both cables of equal length, to ensure equal resistance, and to use a thick gauge wire to reduce resistance to a minimum. Any errors arising from the wiring installations should, therefore, be common to both instruments and insignificant in the calculation of albedos, where the ratio would remain the same. Care was also taken to see that the wire junctions were secure and bound with insulation tape.

On both aircraft the wires were passed through convenient gaps in windows and door frames to extend to the back seat from which the readings were noted by the writer and his assistant. A two-way switch system connected the cables to a portable Kipp Millivoltmeter scaled from -1.0 mV to 10.0 mV.

The millivoltmeter was practical as:

(i) It required no power supply.

(ii) It proved itself to be a very stable instrument under the strongest turbulence encountered.

(iii) It settled down quickly at a reading.

(iv) Its sharply defined scale and indicator facilitated rapid readings. With a little practice both the writer and his assistant could complete a pair of readings (i. e., one incoming and one reflected value) within a period of ten to fifteen seconds. Speed of reading was considered important in order to reduce errors due to the time lag between the instant the aircraft passed over a particular point on the ground and the instant of reading. Also, within a short period of time, sky conditions can alternate rapidly, especially with daytime cumulus, and thus it is essential to make one pair of readings quickly.

The main disadvantages and associated problems of the millivoltmeter were:

(i) Under extremely bright conditions, the instrument's range was insufficient. This occurred only on one flight on June 15th (close to the summer solstice), and as it lasted for no longer than 15 to 20 minutes, it cannot be considered a very serious problem.

(ii) Under dull conditions, which exist with low ceilings of thick stratocumulus, the low input was read very close to the end of the instrument's scale (1.0 - 1.5 mV) and the reflected radiation value was then invariably of the order of 0.1 mV, for all cover-types. Thus it appeared that the instrument was not sensitive enough to measure minor fluctuations in reflected values.

These disadvantages suggested that a more sensitive instrument would have been more practical, with an increased scale span to accommodate values in excess of 10.0 mV, and with a greater scale spread between whole millivolt units. This would give refinement of the measurements.

(iii) As the values of incoming and reflected radiation were read separately and not continually, the two readings could not be simultaneous and this could cause errors to arise. Table 1 below shows the distance on the ground that ten seconds and fifteen seconds (the time required to complete a set of readings) represent at the various speeds flown.

Table 1

The relation between airspeed and distance on the ground

Air speed (M. P. H.)	90	100	110
Reading time (secs.)			
10	1320'	1467'	1614'
15	1980'	2200'	2420'

These distances are large enough to cause errors unless measurements are only made over large expanses of cover-type. When flying over areas of mingled cover-types with very frequent boundary traversing, no readings were attempted.

The main problem regarding the ten to fifteen second lag concerned the alternation of direct solar radiation and diffuse radiation on days with heavy cumulus development, common in summer in Labrador-Ungava. Consequently, very shortly after a reading of incoming radiation a change in this value could occur, before it was possible to measure the reflected radiation. Also, under similar cloud conditions, cloud-cast shadows on the ground were common (see Photograph F). Thus direct solar radiation might be measured by the upfacing solarimeter, while the downfacing solarimeter measured reflected radiation from the shadowed area.

Knob Lake was used as a base for a similar study in the early summer of 1957, when albedo measurements were undertaken by Jackson along portions of the Mid-Canada Defence Line. The

Photograph F: The effect of cloud shadowing under moderate development of day-time cumulus.

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present work hopes to draw some comparisons with that of 1957, for the latter represents the only other work, known to the writer, that was conducted over sub-Arctic surfaces. Here, it is considered appropriate to outline some of the instrumental differences between the two programmes.

The 1957 project was limited to the use of a helicopter as no fixed-wing aircraft was available. Jackson mentions the problem of vibration, which made it difficult to read sensitive instruments accurately. Its low-flying qualities (at heights of 50 to 200 feet), and low airspeed of 90 m. p. h. are comparable with those of the 1961 project.

In 1957 only one solarimeter was available, and this was fixed permanently in flight in a downfacing position to measure reflected radiation alone. Measurement of incoming radiation was confined to before and after flights. Given completely clear or overcast skies, and a flight of short duration, this problem may have been minimized. However, under cumulus conditions, with rapidly alternating bright and cloudy intervals, the use of one solarimeter would have been impractical. Even under overcast conditions, it is seldom that a cloud cover of uniform thickness exists which transmits incoming radiation evenly. Under a ten-tenths cover of strato-cumulus, the occurrence of thinner and thicker layers, and their different effect on transmission of radiation is particularly noticeable. Table 2 shows the variation of incoming radiation under a complete sky cover of apparently uniform strato-cumulus cloud at an estimated height of 2,500 feet above ground level.

Table 2

Variation of incoming radiation under a complete sky cover

June 15

Civil Time	Incoming shortwave Radiation in Langleys/min.
16.37	0.338
16.42	0.324
16.45	0.506
16.52	0.310
17.02	0.380
17.07	0.324
17.12	0.252
17.17	0.310
17.22	0.366
17.27	0.238

The present instrumentation is less elaborate than that quoted by such workers as Bauer and Dutton and Kuhn and Suomi, particularly regarding the method of reading. Manual manipulation of a switch and the noting of every reading are tedious procedures compared with the use of an automatic recording device. However, the more laborious method has the tremendous advantage of being controlled entirely by the operator. Thus, under rapidly alternating bright and cloudy conditions, it was possible to take readings at an observed period of relative constancy of direct or diffuse radiation.

The measurement of albedo from aircraft is problematic instrumentally, which the present account has attempted to demonstrate. As a check on the instrumentation and instrumental behaviour, a number of ground readings of albedo over ground cover-types were undertaken under more stable conditions than those prevalent in an aircraft. The instruments were mounted in an upfacing and downfacing position, as in the case of the aerial measurements, with the difference that they were inter-changed. This served the additional purpose of checking the instrumental behaviour in normal and inverted positions. The instrumental mounting was of an improvised nature, being attached to a Suomi-Kuhn "Economical" Net Radiometer (13), as in Fig. (4). The upfacing instrument was mounted at the far end of the horizontal bar holding the net radiometer. An arm which was welded onto the vertical stand (at a height of 18 inches above ground level) served as a mounting for the down-facing instrument.

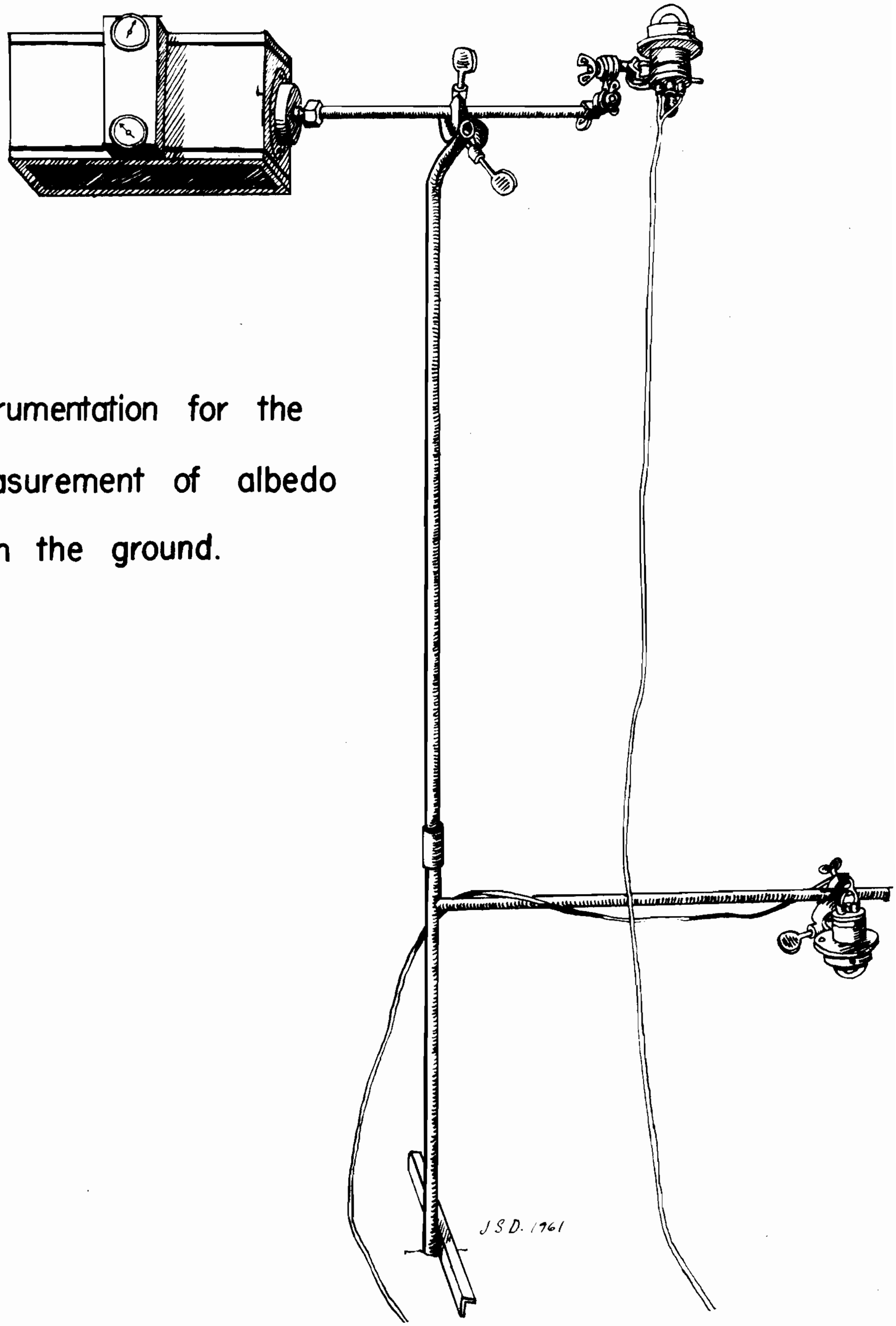


Fig. 4.

Instrumentation for the measurement of albedo from the ground.

CHAPTER III

COVER-TYPES AND THE FIELD PROGRAMME

This chapter describes the ground covers over which albedo measurements were made and outlines the flight coverage. The association of any cover-type with a particular flight or series of flights is indicated and also characteristics of the cover that might be most important in influencing the albedo.

(1) A Description of Cover-Types

The vegetation geography of the Labrador-Ungava peninsula has been discussed recently by Hare (8). His work is here used as the basis for cover-type description and his map of vegetational zonal subdivisions has been reproduced as Map 1.

The Boreal forest, with Arctic and Temperate formations flanking it to the north and south respectively, is the dominant formation of the peninsula. It consists of the woodland and forest sub-zones, merging via the forest tundra into the tundra of the Arctic. The actual cover-types, a map of which would be very intricate to reproduce, are superimposed upon these broader divisions. As the albedos of cover-types are to be determined, rather than the albedos of the zonal subdivisions, it follows that a brief outline should be given of the characteristics of each type as relevant to the measurement of albedo.

(i) Tundra, (bare rock and lichen-heath of Hare's classification), is found on thin or poor soils, a) north of the treeline in the Arctic tundra formation, b) within the forest-tundra zone, where tundra is represented on the higher, windswept ridges and crests, c) along the coast of the south-eastern corner of the peninsula, which extends westward beyond Anticosti Island in a narrow belt, and is a direct result of the rocky nature of the terrain.

Measurements were conducted over (a) and (b). Type (a) was encountered between Knob Lake and Indian House Lake where the tundra formation of the Torngat peninsula extends well southward to approximately latitude $55^{o}N$. Type (b) is well represented in many areas but particularly in the vicinity of Knob Lake in the ridge and valley topography of the forest-tundra.

Observation from aircraft, as opposed to a study of air photographs, satisfied the writer that extensive areas of "bare rock" do not exist (at least not along the routes flown). Except for free rock faces and associated talus piles, low level flying indicated a prominent lichen cover on all observable rock surfaces.

Dryness and the presence of the extremely light-coloured lichen, would suggest a relatively high albedo value for this cover-type.

(ii) Lichen woodland represents the most extensive and typical of the peninsula's cover-types. Ideally, it consists of fairly widely spaced spruce trees, rendered conspicuous by a lichen-covered floor. (See Photograph G.) However, considerable variations in tree spacing, and amount of green shrub layer (Photograph H), moss growth and bare rock outcrops

Photograph G: Open woodland with a pronounced lichen floor.

Photograph H: Open woodland with close tree spacing and greater development of a ground shrub layer than in Photograph G.

provide a variety of different reflecting surfaces. It was decided to group all these varieties under the heading of "lichen woodland" because the complex of divisions within this cover-type could not be differentiated readily by eye.

Shrub woodland and sedge shrub tundra of the McGill classification did not occur within the flight network.

(iii) Closed-crown forest was studied over the southern portions of the peninsula. The cover-type includes both deciduous and coniferous forest with interlocking crowns which conceal the forest floor. Thus a low albedo would be expected. Particularly noticeable were the light-green birch forests that have regenerated on recent burn areas in the vicinity of the Marguerite River, to the west and northwest of Seven Islands.

This cover-type has been mapped, by the McGill group, in the valley of the Koksoak River at approximately latitude $67^{o}N$. The writer was not convinced that this was "closed-crown forest", but rather close-crown woodland where the lichen floor is clearly visible from a low-flying aircraft. In fact, no outliers of the cover-type were witnessed outside the northern limit of the main zone just north of the North Shore.

(iv) Bog and muskeg (see Photograph I) do not follow the latitudinal pattern quite so clearly as do lichen woodland and closed-crown forest, for they are essentially lowland features. They are, in a sense, similar to the tundra outcrops south of the true tundra, in that they are topographical expressions.

Photograph I: String bogs and muskeg.

Characterized by the string bog and the spruce muskeg, they are well developed around large lakes, particularly Lake Kaniapiskau and Lake Michikamau. Otherwise, they are superimposed across the lichen woodland belt in areas of lowland. Large expanses do exist, but small areas which occur with a greater frequency are too small for their albedo to be measured by a solarimeter with a wide-angle vision.

The moist state of these areas would indicate a low albedo, although to the eye they present a comparatively light aspect.

(v) Burned areas are found independent of latitude or topography. They are very widespread in the peninsula in closed-crown forest and lichen woodland areas and were encountered frequently. Great differences of appearance were noticeable because of the great range of stages of regeneration attained in different localities. As with bog and muskeg, this cover-type often occurs in patches too small for their reflectivity to be measured.

(vi) Water surfaces are not discussed by Hare but they are of vital importance to any consideration of the meteorological characteristics of this region, because of the vast area of the Central Plateau area covered by lakes. Lakes Michikamau, Menihek, Ashuanipi and Manicouagan served as study areas of major interest, although many observations were made over others not so conspicuous on small scale maps.

(vii) Snow and ice were encountered on the earliest flights in June; in fact, ice delayed the beginning of the field project. Snow patches still existed on higher ground but no large continuous expanse was seen.

The two important characteristics of the cover-types relevant to the understanding of their reflectivity are ground moisture and the amount of lichen exposure. Albedo bears an inverse relationship to the former while it is directly proportional to the latter.

Boundaries are generally sharp and are of two types. The latitudinal boundaries, which delimit the major zonal subdivisions, are sharply defined on a map yet in reality, they are of a gradually merging nature. Local boundaries, as represented by lake shores, tree lines on hills and ridges, muskeg and bog areas superimposed upon lichen woodland, and burn areas, are sharply delimited and noticeable in terms of their difference in albedo.

(2) The Field Programme

Three groups of flights were made during June, July and August 1961, all within the peninsula of Labrador-Ungava. The following table indicates the routes flown during each month. It will be noticed that both Knob Lake and Lake Kepimits were used as bases of operation. During June and July the chartered aircraft operated from Knob Lake but during August, the base was changed to Lake Kepimits due to prior commitments of the aircraft company in the Ross Bay area.

Table 3

Routes and flights

Date	Base	Route Details
June 13	Knob Lake	A brief flight in the vicinity of the base to observe the response of the instruments, and to determine the best practical approach to albedo measurements
June 14	Knob Lake	To Griffiths Lake some 60 miles to the east
June 15	Knob Lake	To Fort Chimo on the south shore of Ungava Bay
June 16	Knob Lake	To Seven Islands via Lake Reed (near Gagnon), returning via Ashuanipi Lake (Ross Bay)
July 7	Knob Lake	A flight westward to the Kaniapiskau River and to Lake Kaniapiskau
July 8	Knob Lake	To Twin Falls via Wabush Lake
July 9	Knob Lake	A repeat of June 14, to Griffiths Lake
July 11	Knob Lake	To Indian House Lake, returning to base from the north after a detour to the west from Indian House
July 13	Knob Lake	A morning flight to Lake Michikamau followed by an afternoon flight to Fort Chimo similar to that of June 15
July 14	Knob Lake	To Seven Islands via Gagnon; a similar route to that of June 16
Aug. 12		From Ross Bay (approximately 110 miles due south of Knob Lake) to Kepimits Lake some 60 miles to the east
Aug. 17	Kepimits Lake	To Grand Falls and Twin Falls to the northeast of base, returning via Ross Bay
Aug. 18	Kepimits Lake	To Knob Lake

Map 2 shows a plot of the flight routes to indicate the actual extent of the coverage in relation to the area of the peninsula. The coverage is almost complete in a north-south direction from Fort Chimo to Seven Islands. The northwest, northeast, southwest and southeast extremities of the peninsula were not covered because of the problem of refuelling in those areas. The east-west coverage is meagre, as it was considered to be of greater advantage to span the latitudinal zoning of vegetation cover-types and their boundaries, than to traverse long distances along a zone where shorter journeys would accomplish the same. East-west air travel, in the region, also presents the problems of refuelling and safety, both important considerations in the operation of small aircraft.

The route map indicates the triangular pattern of the flight coverage plan; in this way it was hoped to avoid the duplication of routes, and to provide the most extensive coverage possible within the assigned number of flying hours. A total of fifty hours were flown and most of the major cover-types detailed in the McGill classification were observed and their reflectivity recorded.

In addition to airborne measurements, data on albedo were collected during August from certain sites over which measurements of net radiation were being conducted. An unthawed relict snow patch, a close green tundra cover, woodland lichen, bare ground, and grass growth on dry ground and on the wet fringe of a sedge meadow were the surfaces over which measurements were made. These covers provided data unattainable from aircraft measurement as they are essentially smaller features, components of the various cover-types that were studied from the air.

CHAPTER IV

RESULTS

(1) The Distribution of Readings

Out of a total of fifty flying hours, fifteen were flown in June, twenty-five in July and ten hours in August. In all, 1,967 albedo measurements were assembled; these are grouped in relation to each cover-type in Table 4.

Table 4

The Relation of numbers of measurements to months, flights and cover-types

Date	Tundra	Burn	Open woodland	Bog and muskeg	Closed-crown forest	Water	Ice	Snow
June								
13	-	-	30	-	-	1	4	5
14	9	6	35	3	-	7	9	-
15	15	13	90	2	-	5	10	-
16	14	44	125	22	53	14	-	-
Total	38	63	280	27	53	27	23	5
July								
7	13	9	100	15	-	18		
8	14	17	173	22	-	66		
9	1	2	38	24	-	41		
11	43	7	32	10	-	18		
13	9	4	47	69	-	51		
13	9	5	68	57	-	26		
14	18	15	82	58	109	76		
Total	107	59	540	255	109	296		
August								
12	-	-	2	-	-	-		
17	-	3	16	22	-	6		
18	-	2	12	11	-	10		
Total	-	5	30	33	-	16		
Total for all months:	145	127	850	315	162	339	23	5

Of the total number, 95.7% were recorded during June (26.3%) and July (69.4%), while only 4.3% were recorded in August. As explained previously, the small percentage during August was due to poor weather causing a sluggish response of the millivoltmeter. Thus, the results of the earlier part of the summer will constitute the main basis of the following discussion.

The number of measurements for each cover-type as a percentage of all readings is outlined in Table 5. The larger percentages for open woodland, bog and muskeg and water are functions of the degree of representation of these surfaces over the flight routes. In particular, open woodland covers a wide zonal belt (see Map 1). As closed-crown forest was encountered only on flights in the southern portion of the peninsula, and tundra and burn were often of very restricted extent, the representation of these cover-types is smaller. Snow and ice lasted only through the first few flights and thus constituted very small percentages of the total measurements.

Table 5

Measurements for each cover-type as a percentage of the total number of readings (1,967)

Cover-Type	Percentage Representation
Tundra	7.6
Burn	6.7
Open Woodland	44.4
Bog and muskeg	16.4
Closed-crown forest	5.6
Water	15.4
Ice	1.2
Snow	0.3

(2) The Arrangement of Data

After the conversion of the raw field data from millivolts into langleys and the subsequent calculation of albedo, average values representative of each cover-type were produced. Three representative averages were utilized, the arithmetic mean, the median and the mode. The median and the mode were used with the mean to check that the latter was not being affected too greatly by extreme values. Where sufficient items are present in a smooth distribution the mode is the most frequent value and is the most representative of the three being entirely independent of extremes (2). As the median was employed by Jackson, it is included here to permit comparisons between the two studies. The mean alone is used when groups of items are too small to form adequate arrays or modal classes. The values for the three representative averages (calculated from data for June, July and August) are listed in Table 6 along with the median values obtained by Jackson.

Table 6

Mean, median and mode values for the various cover-types

Cover-type	Mean	Median	Mode	Jackson's Median Value
Tundra	14.9	14.9	14.4	8.0
Burn	12.4	12.0	11.7	9.3
Open woodland	12.2	11.5	10.5	11.7
Bog and muskeg	11.0	10.5	9.7	8.2
Closed-crown forest	9.6	8.9	8.5	10.0
Ice	20.9	-	-	-
Snow	34.0	-	-	-
Water	7.6	7.0	4.8	-

Median and mode values were not calculated for ice and snow as readings were too few. Table 7 shows mean albedo for different cover-types for the three months, and Table 8, the values for individual flights. The cover-types are arranged in order of decreasing albedo.

Table 7

Mean albedo values for each month for each cover-type

Cover-type	June	July	August
Tundra	13.3	15.8	-
Burn	11.6	13.8	7.4
Open woodland	11.8	12.3	9.0
Bog and muskeg	9.0	11.3	6.7
Closed-crown forest	8.7	10.1	-
Water	9.3	7.7	4.3
Ice	20.9	-	-
Snow	34.0	-	-

Table 8

Mean albedo values for each cover-type for each flight

Date	Tundra	Burn	Open woodland	Bog and muskeg	Closed-crown forest	Water	Ice	Snow
June								
13	-	-	12.1	-	-	3.2	-	34.0
14	12.3	11.3	11.3	7.5	-	7.6	19.9	-
15	13.4	10.9	11.9	7.7	-	8.5	21.9	-
16	13.8	11.8	11.8	11.9	8.7	9.0	-	-
Range	1.5	0.9	0.8	4.4	-	5.8	2.0	-
July								
7	15.3	15.0	13.1	15.1	-	11.0	-	-
8	16.2	13.9	11.4	12.1	-	8.4	-	-
9	-	11.2	12.0	9.7	-	5.2	-	-
11	16.9	12.4	12.9	12.2	-	5.7	-	-
13	15.4	12.6	12.3	10.3	-	6.0	-	-
13	13.7	13.6	13.2	13.3	-	8.9	-	-
14	14.4	14.0	12.3	11.3	10. 1	8.7	-	-
Range	3.2	3.8	1.8	5.4	-	5.8	-	-

There is no considerable variance of albedo between cover-types, (ice and snow are exceptions). The following factors are significant in the explanation of this:

(i) The measurement of a generalized albedo by the solarimeter due to its almost full hemispherical vision.

(ii) The prevailing drabness of the landscape brightened only by lichen in open woodland and tundra expanses.

The lower albedo values for August are indicative of the poor instrumental response under very heavy overcast. This month is omitted from Table 8 for this reason.

To amplify the data of Tables 6, 7 and 8, histograms with associated frequency curves drawn by eye have been included. In this way the nature of the distribution of measurements for individual cover-types can be examined, as well as the three representative averages.

(3) The Albedo of Tundra

With median and mean values of 14.9% and a mode of 14.4%, tundra is the best reflecting surface in Labrador-Ungava other than snow and ice. Its relatively high albedo is a numerical expression of its smooth surface (free from darkening tree and extensive shrub growth); its dryness (runoff being aided by thin soils and relatively high elevations); and its unconcealed growth of lichen. Monteith has indicated that the human eye cannot gauge albedo correctly as short-wave radiation is not confined entirely to the visible portion of the spectrum. Nevertheless, tundra appears as the brightest of all cover-types when viewed from the air.

Approximately 30% of all measurements may be allocated to the flight from Knob Lake to Indian House Lake on July 11 and, thus, it seems justified to weigh one's estimate of the cover-type's albedo somewhat in favour of this flight. Also, on this flight alone was the tundra surface of sufficient extent to preclude influences from other cover-types. The 16.9% albedo of this flight, which is a mean value of a series of measurements ranging only from 12% to 21%, will be considered here as the most representative of tundra. The assumption is that moisture conditions were not anomalous on this flight.

Jackson's median of 8% would appear low for this relatively high reflecting surface. Although his field of operation was confined, and thus he may never have measured over such a wide expanse of tundra as in the vicinity of Indian House Lake, all of the 1961 measurements of tundra, within the woodland and forest-tundra vegetation zones, were grouped between the mean values of 12.3% and 16.9%. The frequency distribution of albedo values for tundra is shown in Fig.(5). From the fairly smooth distribution it is apparent that a figure as low as 8% forms only a minute frequency (below 1%).

The nature of the distribution and the frequency curve is anomalous when compared with histograms for the other cover-types except for burn. The anomaly is explained by the greater uniformity of this particular cover-type, for it lacks extensive vegetation growth other than lichens.

(4) The Albedo of Burn

This cover-type is characterized by a relatively high albedo; a mode of 11.7%, a median of 12.0% and a mean of 12.4%. That it should be such a good reflecting surface, might seem a little surprising, for, with an absence of lichen and with a notably rough surface and an overall grey appearance, one might expect the converse to be true. However, the spruce trees, stripped of their bark, reflect strongly and are particularly noticeable under direct

FREQUENCY DISTRIBUTION OF ALBEDO VALUES FOR TUNDRA.

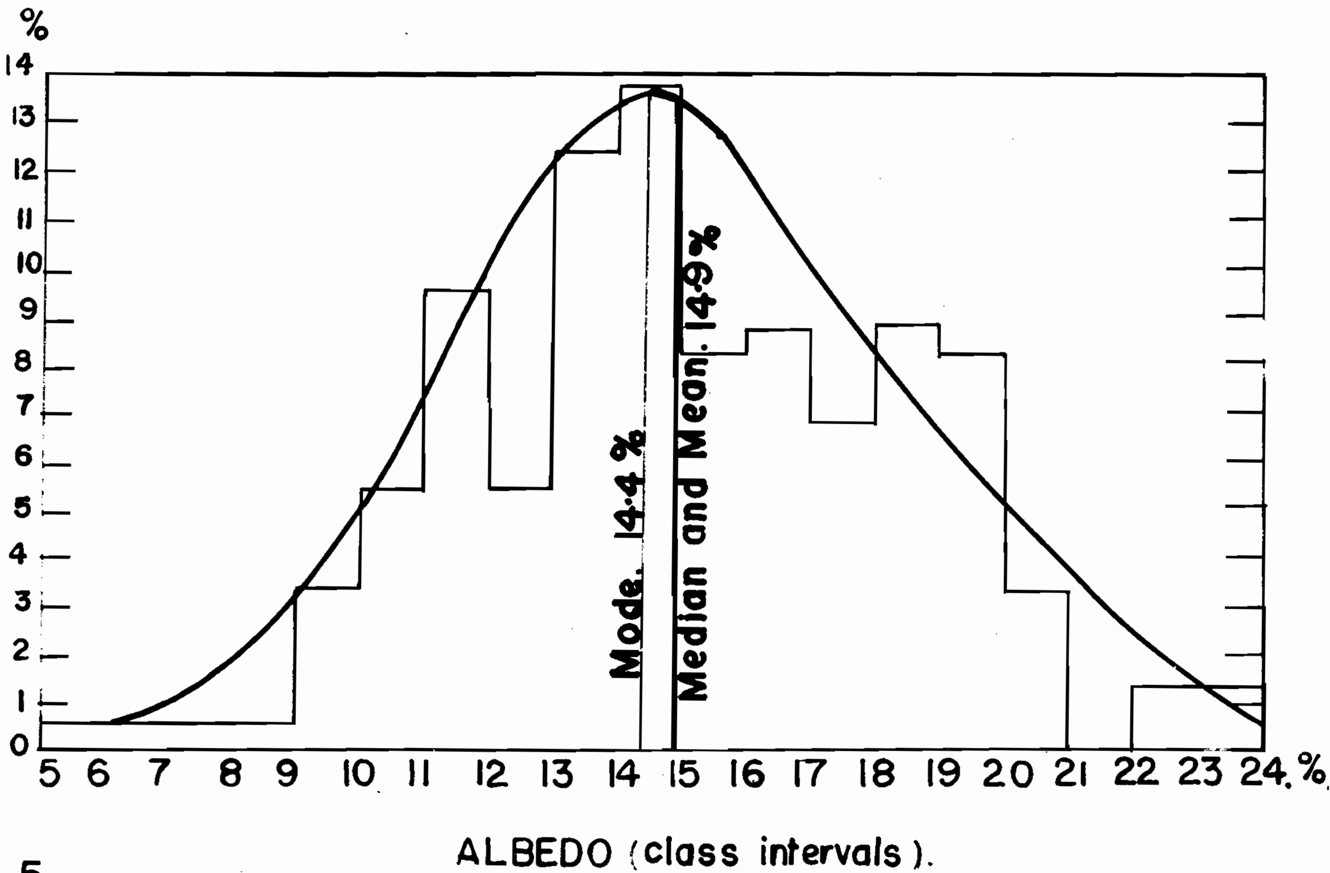


Fig. 5.

42

sunlight. Also, many dead trees litter the ground providing good reflecting surfaces for radiation perpendicular upon them. Even the existence of a dense green shrub layer appears to influence the reflectivity very little. Seldom is the regenerated shrub growth complete in its coverage, thus fallen trees are almost fully exposed.

Although the flight on June 16 totalled over 30% of all measurements over this cover-type, the mean value of 11.8% for June is considered as too low in view of the possibility of shielding by the airplane floats. On the other hand, burn areas that were traversed in July were not of adequate extent to accept implicitly the mean of 13.8%. Thus, on an arbitrary basis, 12.4% is advocated as the most representative value, it being the mean of 11.8% and 13.8%.

An examination of the July data in Table 8 shows that the average albedos for all flights have a considerable similarity, ranging between 11.2% and 14.0% only, if one removes the 15% figure of July 7 from consideration. The latter figure was a mean of flight measurements during early evening conditions, and is thus a function of a lower solar height. All other July flights were made closer to solar noon.

Jackson's median of 9.3% is somewhat lower but more in keeping with the 1961 measurements than his median for tundra.

The histogram for burn (Fig. 6) is similar to that for tundra in that it approaches a normal distribution with only a slight positive skewness. Variations within the

FREQUENCY DISTRIBUTION OF ALBEDO VALUES FOR BURNED AREAS.

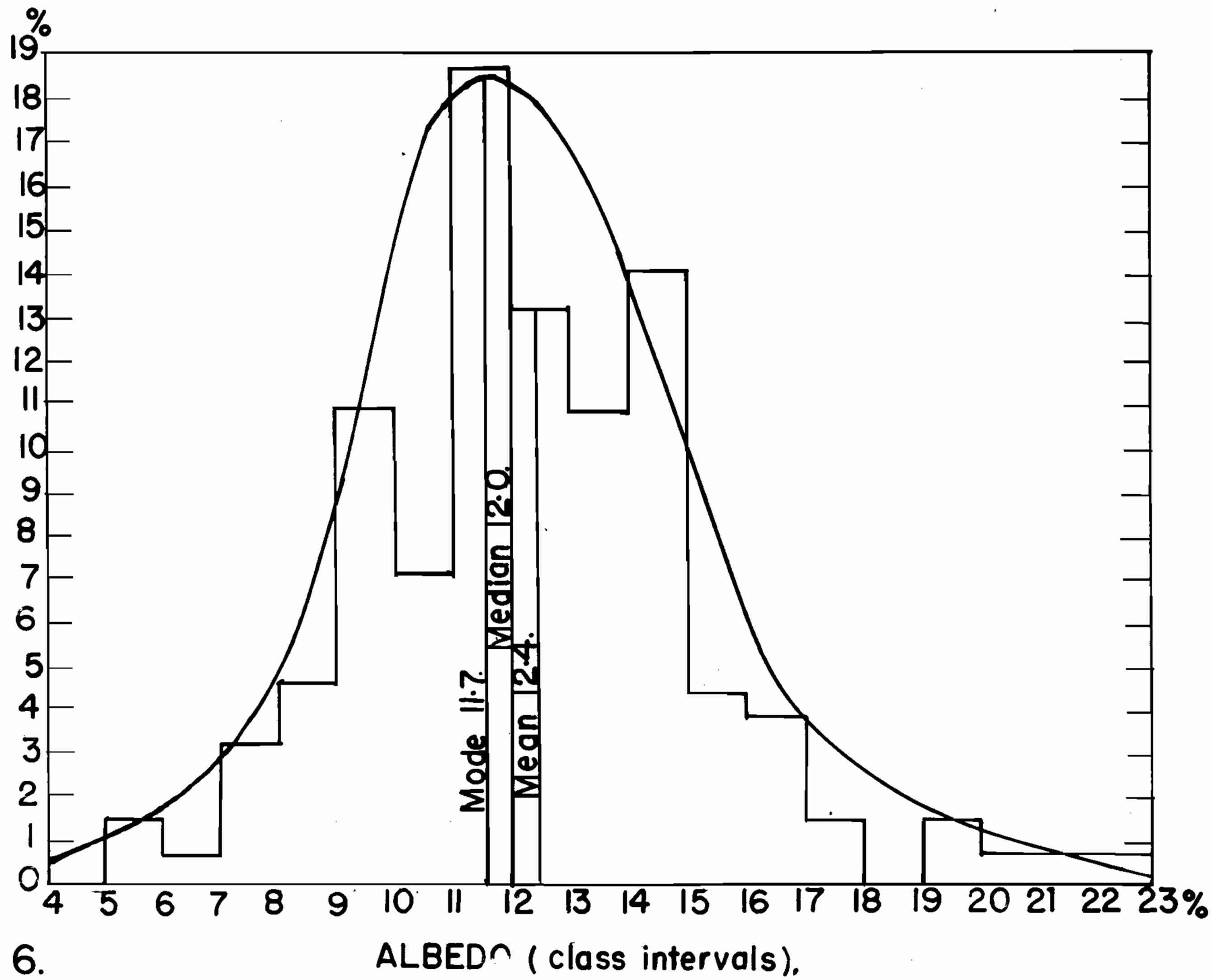


Fig. 6.

cover-type and in the time of observations may explain this. Unfortunately, the lack of measurements over a fuller time-scale prevents the adequate portrayal of the relationship of albedo to time. The importance of time in causing skewness of the distribution might be debatable when it is considered that a similar skewness is not evident in the case of tundra at all. However, the skewness of Fig. (6) is so slight that valid deductions concerning its relationship to time are impossible.

(5) The Albedo of Open Woodland

Constituting 44.4% of all airborne measurements, it is the best represented albedo of all cover-types. From the air and from air photographs it stands out prominently as a cover-type of strong contrast between lichen and spruce trees. Hare commented upon its open tree crown, "which allows full sunlight to play upon the ground layers. Brilliant illumination, bright colors and good visibility characterize the series, moreover the albedo is high, and from the air the ground looks snow-covered." It is the opinion of the present writer that the brightness of the floor is overemphasized. Ground measurements of albedo over broad expanses of homogeneous woodland lichen by Jackson produced a figure of 14.5%, and in 1961 it was measured as 20.4%. Accepting the latter value, as it is the writer's own measurement, a mode of 10.5%, a median of 11.5% and a mean of 12.2% for open woodland show a 40-50% reduction on 20.4%. Thus, it appears that there is a marked difference between albedos measured on the ground and from the air. A vertical variation of measured albedo might be expected, in terms of the depletion of radiation through scattering and absorption, for with increasing height above the ground surface there is less depletion of incoming radiation and greater depletion of reflected radiation, due to the greater concentration of scattering and absorbing particles in the lowest air layers. Bauer and Dutton have measured albedo at various heights to study this question, and they concluded that albedo measurements up to 1000 feet may be assumed to approximate the surface albedo within the error of the instruments. The percentage change of the hemispherical albedo from 50 to 1,150 feet was only -2.7. The difference between the albedos of lichen as measured on the ground and open woodland as measured from an aircraft can be explained with reference to the physiognomic difference between the two covers. The presence of dark spruce trees and a relatively dark shrub layer limit the albedo of lichen itself for they form a considerable area within the field of vision of the downfacing instrument.

A great range of sub-types of lichen woodland occurs due to the presence of areas of bare rock, varying densities of green shrubs and a wide range of tree spacing. Thus a wide range of albedo readings were to be expected and this is reflected in the frequency distribution of Fig. (7). It shows a very smooth distribution ranging from 5 to 25% with a marked positive skewness. With such a smooth distribution

FREQUENCY DISTRIBUTION OF ALBEDO VALUES FOR OPEN WOODLAND.

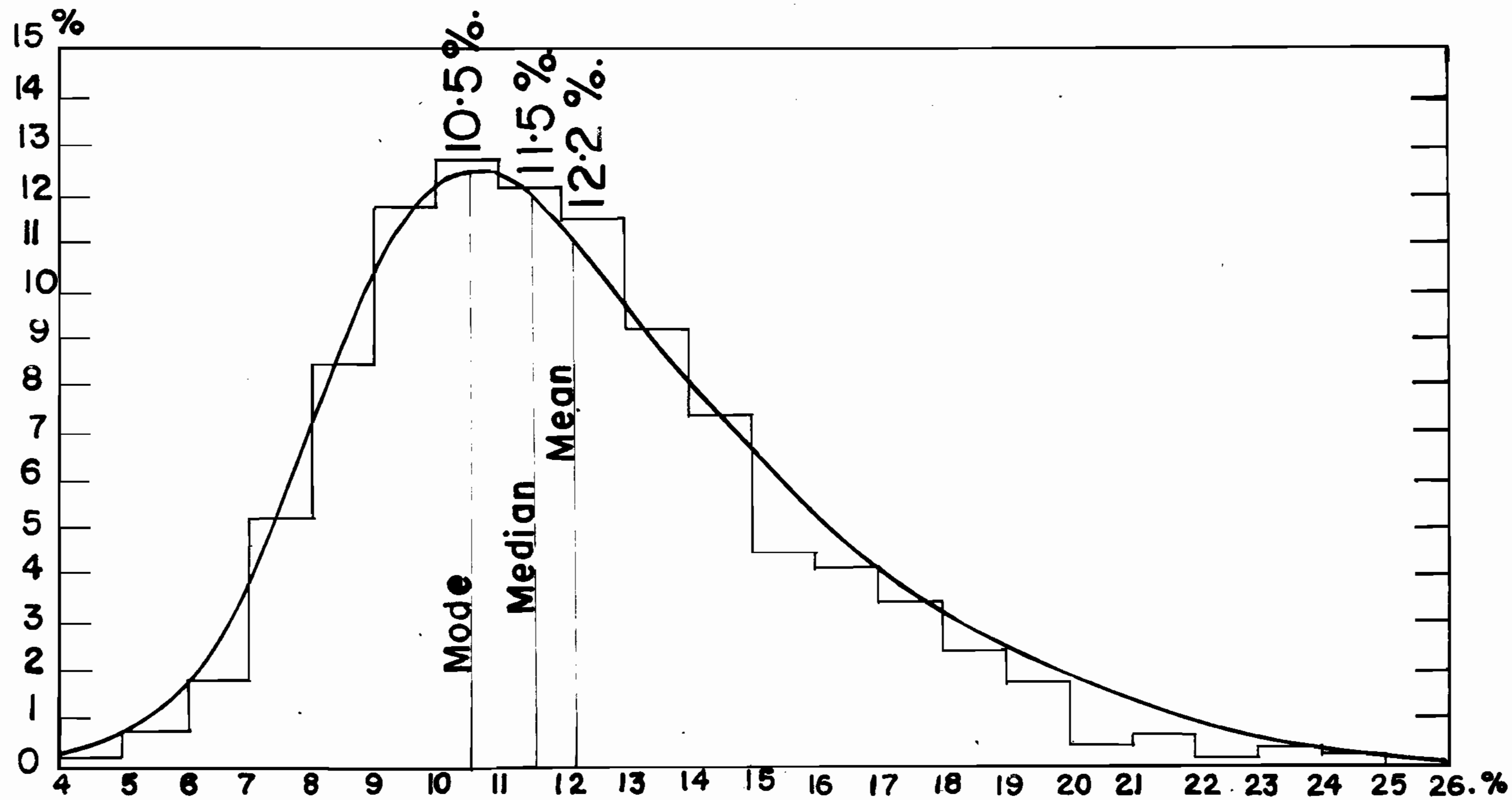


Fig. 7. ALBEDO (class intervals).

the mode value is the most representative as it is the most frequent value. Thus 10.5% will be accepted as the most representative average for open woodland.

However, such a great range of surfaces are included under the category of open woodland that one figure cannot be considered representative except in a purely statistical sense. As it was not possible to clearly group the lichen woodland cover-types into the categories of the McGill classification, a range of values must be accepted. A range of 7% to 20% is proposed, the lower value referring to a vegetation condition where all lichen is obscured by a shrub layer, and the upper value refers to the sparsest of open woodland where the ideal value of 20.4% for lichen alone will be approached.

Jackson's median of 11.7% compares favourably with 11.5% for 1961. This is the one cover-type over which the greatest agreement would be expected for it is so extensive over the peninsula. Jackson reported a range of 10 to 15% for group values which also compares favourably with the range of 11.3% to 13.2% shown in Table 8.

(6) The Albedo of Bog and Muskeg

Ideally, the two component parts of this cover-type should be considered separately, but it was found that their occurrence as allied types, often merging into each other, precluded their separation in the measurement of albedo. In most cases, spruce or tamarack muskeg border the true bog formations, which are essentially treeless but rich in moss, sedge and shrub growth. However, Jackson separated the two during his field measurements but grouped them together to obtain a mean albedo value.

The positively skewed distribution of Fig. (8) illustrates the range in the albedo of this combined cover-type. The lower values are probably an expression of the reflecting properties of bog areas with water lying above the ground surface, water having a low albedo except with low solar height. An examination of Table 8 reveals the greater range of mean values for flights for this cover-type than for other cover-types. For example, the July range is 5.4%, from 9.7% to 15.1%. The higher value is the mean for the flight to Lake Kaniapiskau on July 7, during the early evening. Although the range of individual albedos is great (Fig. 8) the distribution is fairly smooth and the mode of 9.7% is preferred to the mean (11.0%) and the median (10.5%).

Jackson's mean of 8.2% is somewhat lower than that of 10.5% but his group values ranging from 6.4% to 13.5% are very similar to the 7.5% to 15.1% range for June and July. An albedo between 9.7% and 11.0% is not considered too high for a cover-type characterized by its saturated condition. Seldom is water present above the vegetation surface and is thus not visible from the air. It is contained largely beneath the ground surface and will have little influence on albedo. Pools of water do occur in string bogs (see Photograph I), but they are seldom large enough to constitute a reflecting surface likely to affect the albedo greatly. Bog and muskeg are essentially vegetation surfaces.

FREQUENCY DISTRIBUTION OF ALBEDO VALUES FOR

BOG AND MUSKEG.

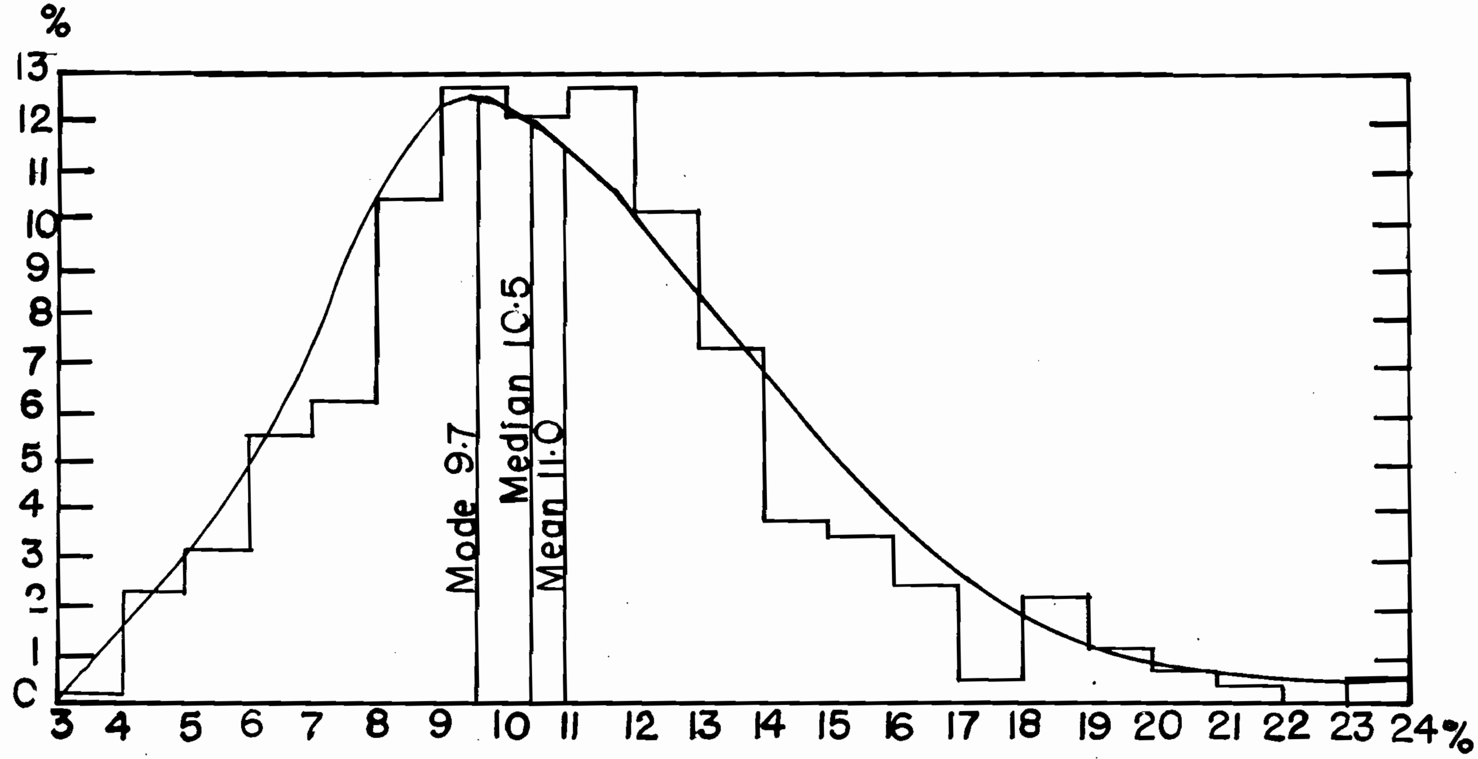


Fig. 8. ALBEDO (class intervals).

The seasonal variation within the cover-type is such as to limit further the influence of the water content on albedo. Early in the summer little surface moisture is present as it is yet contained in ground ice. As the summer progresses the growth of vegetation, particularly sedges, changes the nature of the surface and, although water is present, the growth of vegetation has been such as to have partly concealed it from aerial inspection. At no time is the high water content of muskeg visible from the air and thus it has little effect on albedo.

Ground measurements over the fringe of a sedge meadow in the vicinity of Knob Lake indicated that a very shallow layer of surface water, amidst a growth of sedge, had little effect on the albedo. A mean of 16.2% was obtained.

(7) The Albedo of Closed-Crown Forest

Two flights, one in June and one in July, traversed this cover-type in the southern portion of the Peninsula. The total number of albedo measurements over forest amounted to only 5.6% of measurements for all surfaces.

The difference between the two means of 8.7% and 10.1% for June and July respectively may be attributed to the possible shading of the downfacing solarimeter in the former month, when the float plane was used. However, it should be pointed out that the deciduous birch forests were not in full leaf in June and the relatively darker ground space was noticeable from the air. In July the crowns were completely closed. Thus a higher albedo would be expected, for a more uniform reflecting surface would be presented to the incident radiation.

No albedo difference was recognized between coniferous and deciduous closed-crown forests, although, to the eye, the light green birch contrasted strongly to the dark green spruce. This is an indication that albedo is not confined entirely to the visible portion of the spectrum, and consequently the human eye can serve only as a rough guide to differences in actual albedo values.

Also, it should be noted that closed-crown forest is coincident with the rugged southern rim of the central plateau, dominated in its topography by large river gorges. The irregularity of relief incurred turbulence, which necessitated a higher flying height, in turn making for less differentiation in albedo between surfaces as the albedo recorded would be more generalized than at lower levels.

The frequency distribution in Fig.(9) is not smooth enough to merit the acceptance of the mode as the most truly representative average. Likewise, the mean is not acceptable for there is a marked skewness of the curve. Thus the median of 9.2% is accepted as the average.

Zubenok (quoted by Kondrat'ev) obtained measurements from a low-flying aircraft between heights of 50 and 400 meters. Range values of albedo between 10 and 14% for coniferous forest and between 13 and 17% for deciduous forest resulted from this work. Kondrat'ev considers these

FREQUENCY DISTRIBUTION OF ALBEDO VALUES FOR CLOSED-CROWN FOREST.

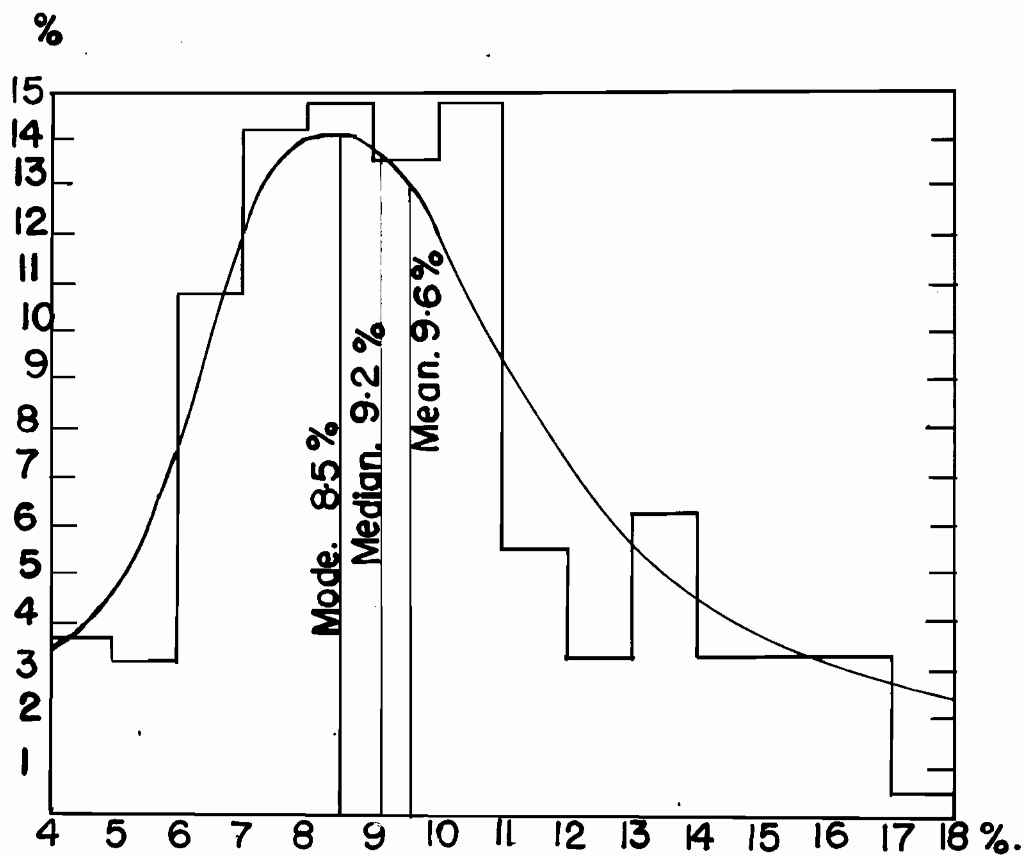


Fig. 9. ALBEDO: (class intervals).

measurements to be similar to those obtained from ground surface installations (presumably towers). Jackson quotes 11.1% from a range of group values of 7.5% to 12.7%. The Smithsonian Meteorological Tables (14) quote various workers whose results range between 3 and 10%. Thus a range of 3% to 17% can be admitted from the workers cited. A range of albedo usually implies a series of observations over a certain period of time, during which the height of the sun above the horizon changed perceptibly with an associated change in spectral composition and albedo. However, the measurements of both June and July were carried out around solar noon and just a little later, thus the skewed distribution of Fig. 9 cannot be attributed to this factor. Similarly, it has already been mentioned that there was found to be no difference in albedo between coniferous and deciduous forests, although this was found to exist by Zubenok. The interpretation of this skewness will remain unexplained at present for it is based on a hypothesis that will be presented later in this chapter.

(8) The Albedo of Vegetation Cover-Types

The various frequency curves (Figs. 5 to 9) for each cover-type have been plotted on one graph, Fig. (10), to show visually the difference between types. The only averages shown are those accepted for each of the cover-types.

There is a marked concentration of values between 9.2% and 12.4% with tundra (16.9%) remaining separate. Again it should be emphasized that open woodland cannot be adequately

FREQUENCY DISTRIBUTION OF ALBEDO VALUES FOR ALL COVER TYPES.

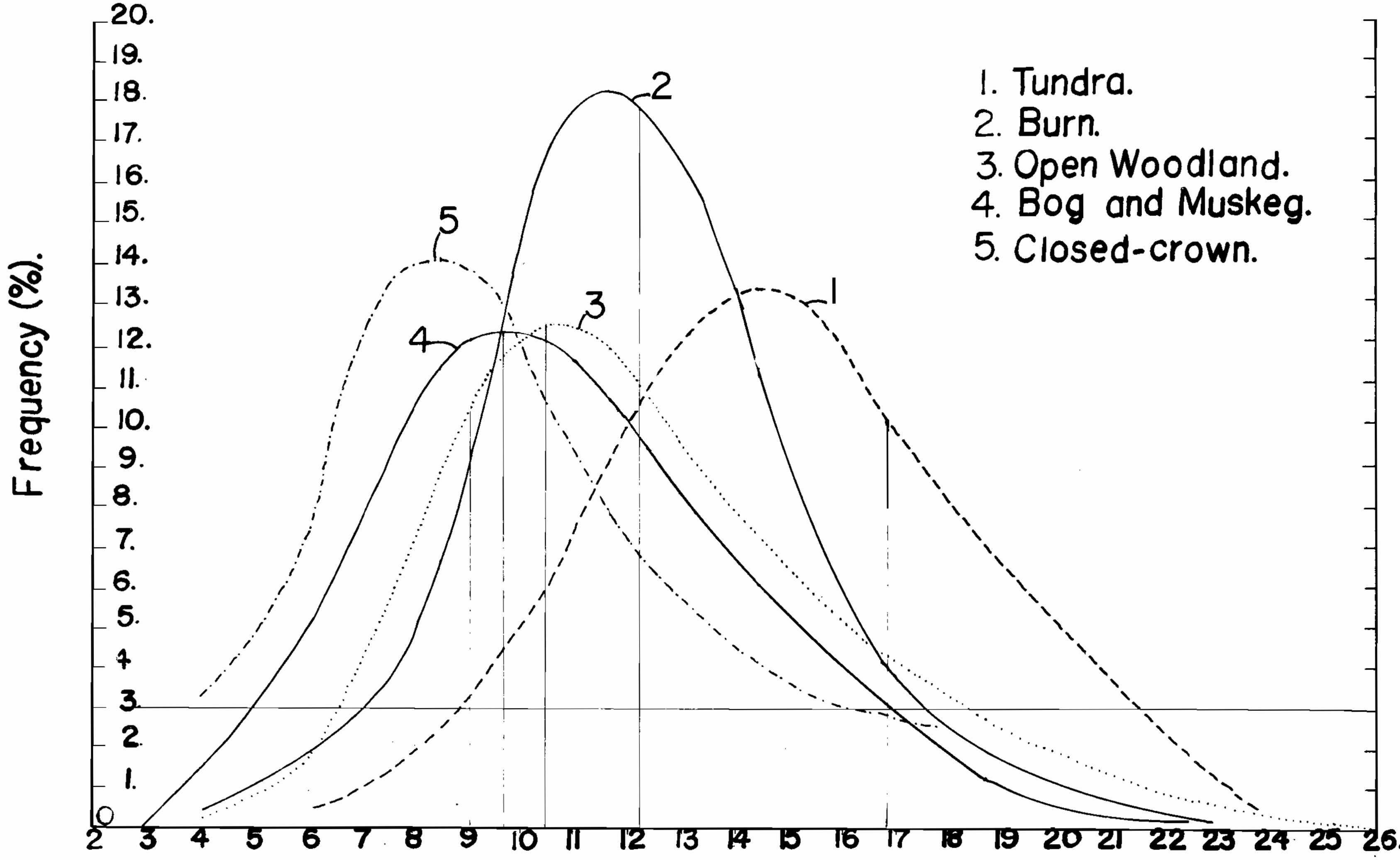


Fig. 10.

represented by a single albedo. The relative uniformity of albedo values is in keeping with the overall drabness of the landscape and with the almost complete hemispherical field of vision of the downfacing solarimeter.

Except for burn and tundra, the curves show a positive skewness. Such a trend in distribution is common and in the case of albedo measurements it is indicative of various controlling factors such as differences within each cover-type, or differences in time.

All of the curves have a wide base and it was considered that the actual range of values for any one cover-type included extreme values completely irrelevant to the main body of observations. By using a "cut-off" at a certain level of representation it was hoped to show the "effective range" for each cover-type. A level of frequency of 3% was selected arbitrarily as the "cut-off". The "effective range" of albedo values is shown in Table 9.

Table 9

The "effective range" of albedo values for vegetation cover-types

Cover-type	From (%)	To (%)	Range (%)
Tundra	9	21.5	12.5
Burn	7	17.5	10.5
Open woodland	6.5	18.5	12
Bog and muskeg	5	17	12
Closed-crown forest	4	17	13

(9) The Albedo of Ice

A late start of the field work in June prevented extensive albedo measurements from being conducted over ice surfaces. In all, the measurements of the albedo of ice constituted 1.2% of the summer's total readings. The measurements are related to the early June flights towards the end of the break-up period when the ice was decaying rapidly. Its grey and white mottled appearance was indicative of its waterlogged condition. A mean albedo figure of 20.9% emphasizes its wet condition. Bauer and Dutton's measurements over Lake Mendota showed a remarkable reduction in albedo once the snow cover had been removed.

Solar radiation is the main source of energy available for ice melting but the arrival of warmer air masses and rainfall as well as strong winds serve to disperse the ice rapidly. Wind-drifting of ice posed a problem in the measurement of albedo. Under strong winds ice accumulates on the downwind side of the lake. With ice and land so closely juxtaposed, measurements would include a certain amount of reflection from both surfaces. The most representative albedo of ice was measured over Lake Attikamagan on June 14, northeast of Knob Lake. The effect of albedo readings from ice and land at the same time was also observed. Table 10 illustrates this point. The values 24.6%, 20.3% and 24.8% are the only ones truly representative of ice albedo, while 15.4% and 17.1% are of interest for they show the transition from land to ice and vice-versa.

Table 10

The measurement of albedo over an ice-covered bay (Iron Arm) of Lake Attikamagan, June 14, 1961

Civil Time	Sky Condition	Surface	Incoming Radiation, Langleys	Reflected Radiation, Langleys	Albedo, %
14:22	Overcast	OW*	0.280	0.052	11.4
	Overcast	OW/ice	0.422	0.065	15.4
	Overcast	Ice	0.422	0.104	24.6
	Overcast	Ice	0.576	0.117	20.3
14:27	Overcast	Ice	0.576	0.143	24.8
	Overcast	Ice/OW	0.758	0.130	17.1
	Overcast	OW	0.758	0.078	10.2

On June 15, on a northerly flight from Knob Lake to Fort Chimo, data was assembled over lakes with whiter ice. An example appears in Table 11 from measurements over an unidentified lake.

Table 11

Measurements of the albedo of ice over an unidentified lake between Knob Lake and Fort Chimo, June 15, 1961

Civil Time	Sky Condition	Surface	Incoming Radiation, Langleys	Reflected Radiation, Langleys	Albedo %
14:40	Clear	Ice	0.828	0.234	28.3
	Cloudy	Ice	0.540	0.169	32.5
	Cloudy	Ice	0.492	0.130	26.4

The relatively high albedo of ice was associated with considerable turbulence over lake-land boundaries. The

*Open woodland.

higher albedo implies less absorption of incoming radiation by the ice than by the land surface. This, in turn, implies a lesser convective exchange between the surface and the atmosphere. Hence, the junction between ice and land is also a boundary between two convective regimes, between a relatively weak convection over ice and a stronger one over land. This convective turbulence was the most severe encountered throughout the summer except for that associated with strong headwinds.

(10) The Albedo of Snow

Measurements of snow albedo were fewer than those of ice and consisted only of five readings, forming but 0.3% of all the summer's measurements. No complete snow cover was traversed and the albedo values represent values mainly for vegetation cover-types modified by the presence of snow of varying extent.

The first flight on June 13th, in the vicinity of Knob Lake, included a traverse across the Geren Massif and Sunny Mountain, where the rapidly melting snow cover was best preserved. No readings over a complete snow cover are available but Table 12 lists a value of 51.8% for the highest portion of the Massif, where an extensive snow covering persisted.

Table 12

Measurements of snow albedo over the Geren Massif and Sunny Mountain on June 13, 1961

Civil Time	Sky Condition	Surface	Incoming Radiation, Langleys	Reflected Radiation, Langleys	Albedo %
12:37	Clear	Snow	1.404	0.325	23.2
	Cloudy	Snow	0.898	0.325	36.2
	Cloudy	Snow	0.702	0.364	51.8
	Overcast	Snow	0.604	0.234	38.7

The effect of a patchy snow cover on the albedo of open woodland was noticeable. This is shown in Table 13. The snow cover was confined to hollows and stream channels, forming only a small percentage of the total area.

A mean figure of 34% for all values is considered representative in view of the small number of readings available. It is in accordance with figures quoted by other workers. For example, for dirty wet snow, Kondrat'ev indicates a range of 20-39%.

Table 13

Measurement of the effect of snow patches on the albedo of open woodland on June 15, 1961

Civil Time	Sky Condition	Surface	Incoming Radiation, Langleys	Reflected Radiation, Langleys	Albedo %
12:27	Overcast	Open Woodland	0.534	0.039	7.3
	Overcast	Open Woodland and Snow	0.618	0.065	22.2

(11) The Albedo of Water Surfaces

Although 15.4% of all albedo readings were made over water surfaces, not all were employed in the data analysis. Data from all but the largest lake expanses have been discarded, emphasis having been placed upon the following:

Lake Attikamagen	Lat. 54°55'N.
Lake Ashuanipi	52°40'N.
Koksoak River	58°00'N.
St. Lawrence River	50°20'N.
Lake Manicouagan	57°30'N.
Menihek Lake	54°30'N.
Lake Michikamau	54°00'N.

Also, readings over large unidentified lakes have been included.

It is of little significance to represent the albedo of water surfaces by an average figure, for water has the characteristic of considerable variation of albedo throughout the day. A treatment of data, as has been undertaken for other cover-types in terms of a frequency distribution, produces a very strongly skewed curve as seen in Fig. (11). Such a distribution is incomplete in that higher values of albedo have been omitted on account of their extremely low frequency of occurrence. The heavy concentration of values towards lower albedos is a reflection of the time of day at which measurements were made, mainly between 0900 and 1500 hours, when solar height changes relatively little.

FREQUENCY DISTRIBUTION OF ALBEDO VALUES FOR WATER SURFACES.

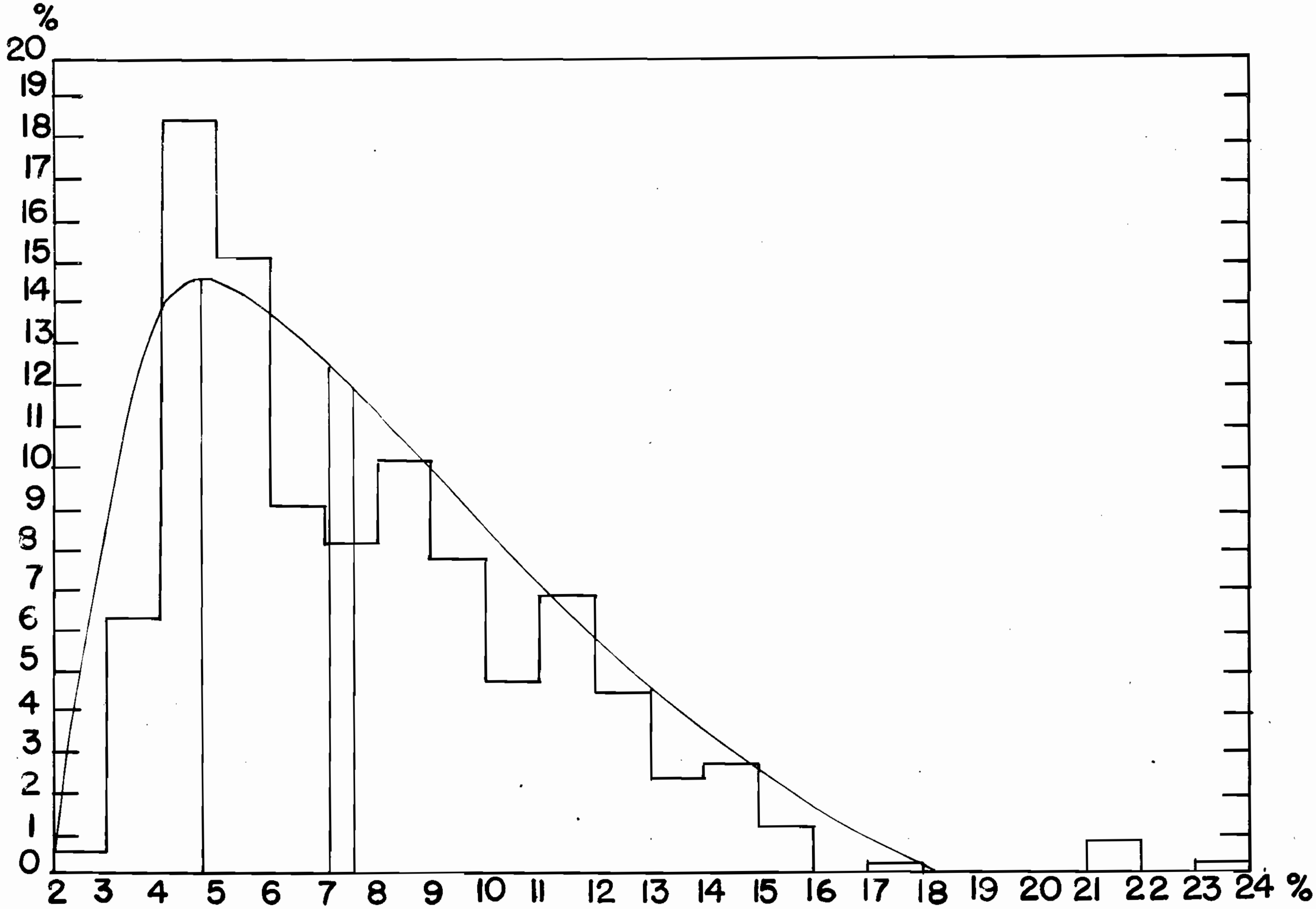


Fig. 11. ALBEDO (class intervals).

The albedo of a water surface is mainly a function of the solar height (h). Thus solar height had to be computed for each albedo value. Using Civil Time for all observations, values of solar height were calculated from the formula:

$$h = (90 - \alpha) + \delta$$

where α = the latitude of the observation,

and δ = the solar declination at noon,

obtained from The American Ephemeris and Nautical Almanac. The value of "h" derived from this formula is for solar noon but, knowing the civil time of observation (Atlantic Standard Time based on the longitude of 60°W) and the time of sunrise and sunset, the appropriate value of "h" could be computed. Solar noon has a height equivalence "h" as do sunrise and sunset (0°). Knowing the differences between noon, sunrise and sunset in terms of both time and solar height, the solar height for any intermediate position in time can be calculated.

Various workers have tabulated their results in relation to solar height. In Table 14, the writer's results are compared with those of Ångström, Fresnel and Kuzmin (quoted by Kondrat'ev). It can be seen that the data of 1961 are in fairly close accordance with the other workers cited.

Table 14

The albedo of water surfaces in relation to solar height

	Solar height, (°)										
	90	80	70	60	50	40	30	20	10	5	0
Ångström	-	-	-	-	-	-	8	15	49.0	70	-
Fresnel	2.0	2.0	2.1	2.1	2.5	3.4	6.0	13.4	34.8	58.4	100
Kuzmin	-	-	-	-	-	-	6.0	12.0	32.0	54.0	-
1961	-	-	-	3.0	6.0	7.0	8.0	10.0	31.0	51.0	-

Fresnel's values are theoretical, produced from his reflectivity formula:

$$R = \frac{1}{2}\left[\frac{\sin^2(i-r)}{\sin^2(i+r)} + \frac{\tan^2(i-r)}{\tan^2(i+r)}\right]$$

where R = reflectivity,

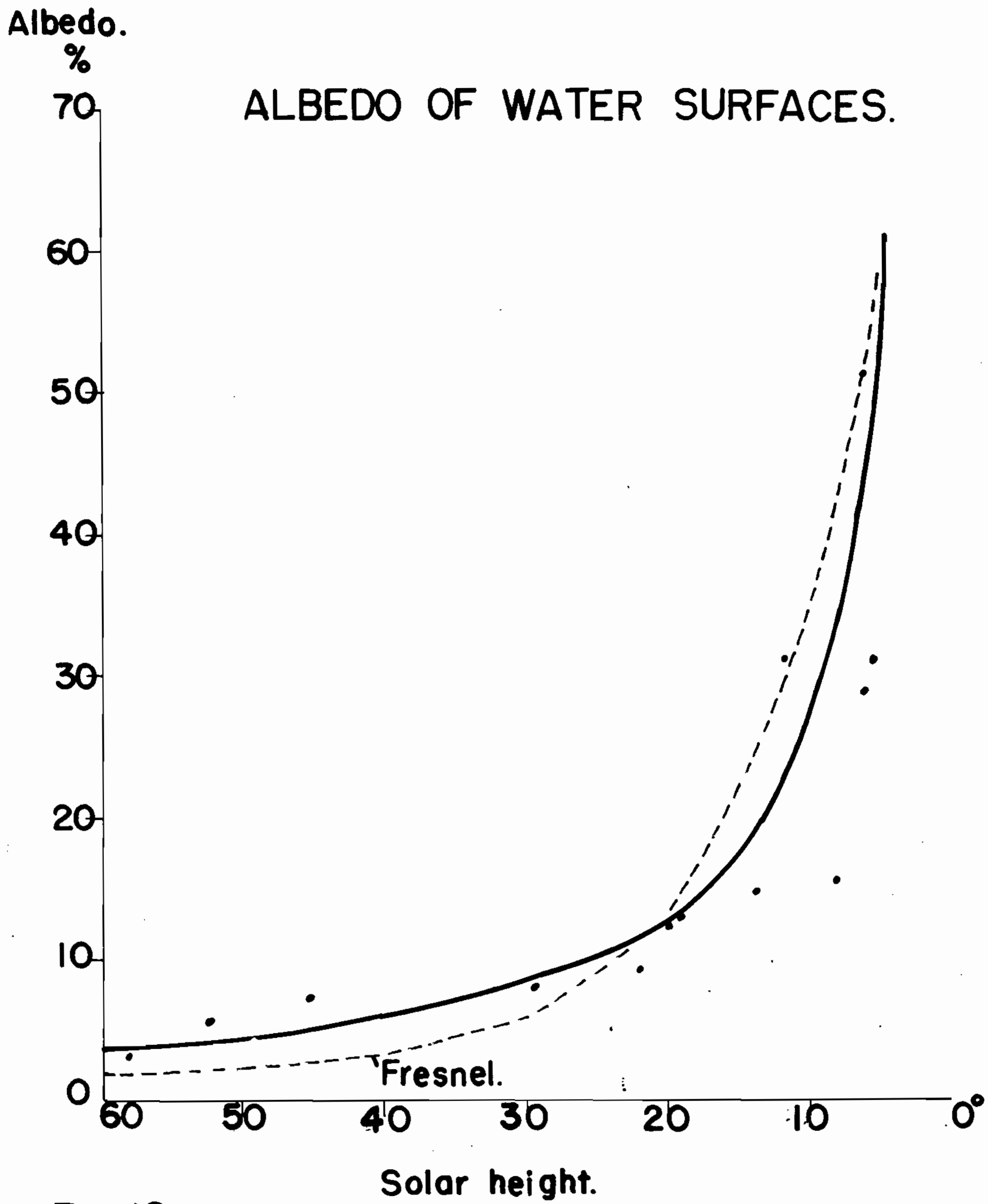
i = angle of incidence, (90 - h)

r = angle of refraction. "r" is determined from the formula

$$\sin r = \frac{\sin i}{n},$$

where n = the index of refraction (1.3333 for pure water, and 1.3398 for sea water).

Fresnel's formula is essentially concerned with unrippled surfaces. Ångström was of the opinion that there was little difference between the albedo of a calm and a disturbed water surface. Kondrat'ev's work indicated that, under conditions of rippling, albedo increases near solar zenith and decreases with decreasing solar height due to shadows cast by waves. Fig. (12) illustrates the difference between the Fresnel curve and a similar curve plotted from the writer's



ALBEDO OF WATER SURFACES.
Albedo.
%
70
60
50
40
30
20
10
0
Fresnel.
60
50
40
30
20
10
0°
Solar height.

Fig. 12.

1961 data. Fresnel's curve is based on his formula, and is thus theoretical, but the writer's was fitted to measured observations. The method of least squares was applied to thirteen points (representing a total of seventy-two readings) and an exponential curve:

$$y = ax^{-b} \quad \text{or}$$

$$\log y = \log a - b \log x$$

produced the following equation:

$$\log y = 2.4624 - 1.039 \log x,$$

where y is the albedo and x is the solar height. It is here stressed that readings were discarded in the process of curve fitting and thus the actual readings used may be considered selected. The selection, however, was based on the writer's faith in what was considered true representative measurement as opposed to measurement where other surfaces might have influenced the measurements. The majority of the discarded readings were located towards the lower portion of the curve during times near to solar noon.

Flights were mainly concentrated around solar noon and few readings at low solar heights were recorded. Hence the higher portion of the curve has a less firm foundation than the lower portion.

Some values represent means of groups of readings made over some duration of time over one lake, while others such as that of 57% are single values. Although the latter represents only one reading, it was a constant one, recorded under a perfectly clear sky, while traversing the very wide estuary of the Koksoak River at Fort Chimo.

Calm water surfaces are rarely encountered in the Labrador-Ungava Peninsula and, except for the readings over Lake Manicouagan, all were over lake and estuary surfaces with varying degrees of rippling or waves. A comparison appears in Table 15 between Lake Michikamau (July 13) and Lake Manicouagan (July 14). Conditions were fairly similar except for date and wind. The table indicates a somewhat higher albedo for a waved water surface with white foam. This may be compared with work by Kondrat'ev who measured albedos of 3.8% and 2.2% for waved and smooth sea surfaces respectively for a solar altitude of 60°. At low solar height the albedo of a waved surface would be lower than for a flat surface due to the effect of shadows cast by waves.

As the majority of measurements in 1961 were related to wave and ripple surfaces, there is not enough evidence to comment generally on albedo differences between calm and disturbed water surfaces. However, it may be tentatively pointed out that the deepening of the curve in Fig. (12), in relation to the Fresnel curve, may indicate higher albedos at higher solar altitude and lower albedos between a solar altitude of 22° and 5° due to the influence of waves.

Table 15

A comparison between the albedo of a calm and a rippled surface

Date	Time	Lake	Sky Condition	Solar Height	Lake Surface	Albedo
July						
13	10:45	Michikamau	Clear	$57^{\circ}21'$	Large waves and foam	4.4
14	12:30	Manicouagan	Clear	$60^{\circ}13$	Calm	3.4

(12) The Relationship between Albedo and Direct and Diffuse Incoming Radiation

A visual appraisal of readings indicated that albedo varied with different sky conditions, namely, between periods of direct solar radiation and periods of diffuse radiation. Two approaches were adopted to study the differences:

Method 1.

Table 16 summarizes mean monthly values of albedo for each cover-type, for conditions of direct radiation and diffuse radiation separately and the differences between them.

Table 16

Differences in albedo under conditions of direct and diffuse incoming radiation

Cover-type	Month	Direct Radiation Albedo (%)	Diffuse Radiation Albedo (%)	Difference
Open woodland	June	9.4	11.1	+1.7
	July	11.4	13.6	+2.2
	For both months	11.1	12.7	+1.6
Closed-crown forest	June	6.0	9.1	+3.1
	July	8.5	14.0	+5.5
	For both months	8.1	11.7	+3.6
Burn	June	9.3	11.1	+1.8
	July	12.9	14.7	+1.8
	For both months	12.3	12.9	+0.6
Tundra	June	6.8	14.2	+7.4
	July	13.8	17.3	+3.5
	For both months	13.4	16.1	+2.7
Bog and muskeg	June	11.6	12.0	+0.4
	July	13.2	12.9	-0.3
	For both months	10.9	11.1	+0.2
Water	June	8.1	10.7	+2.6
	July	8.4	10.3	+1.9
	For both months	8.4	10.3	+1.9

Snow and ice are not included as they comprise only a minute portion of all readings, and were not recorded extensively enough under the two different incoming radiation conditions to merit their inclusion. The plus sign, in the "Difference" column of the table, indicates the higher albedo under diffuse radiation conditions. When both months are taken as a whole the difference is of the order of 0.2% to 3.6% higher. There is only one anomaly but variations in the magnitude of differences occur, notably the 7.4% for tundra in June.

Method 1 gives quantitative expression to the differences but there is no indication of the nature of the difference. Method 2 was used to illustrate this.

Method 2

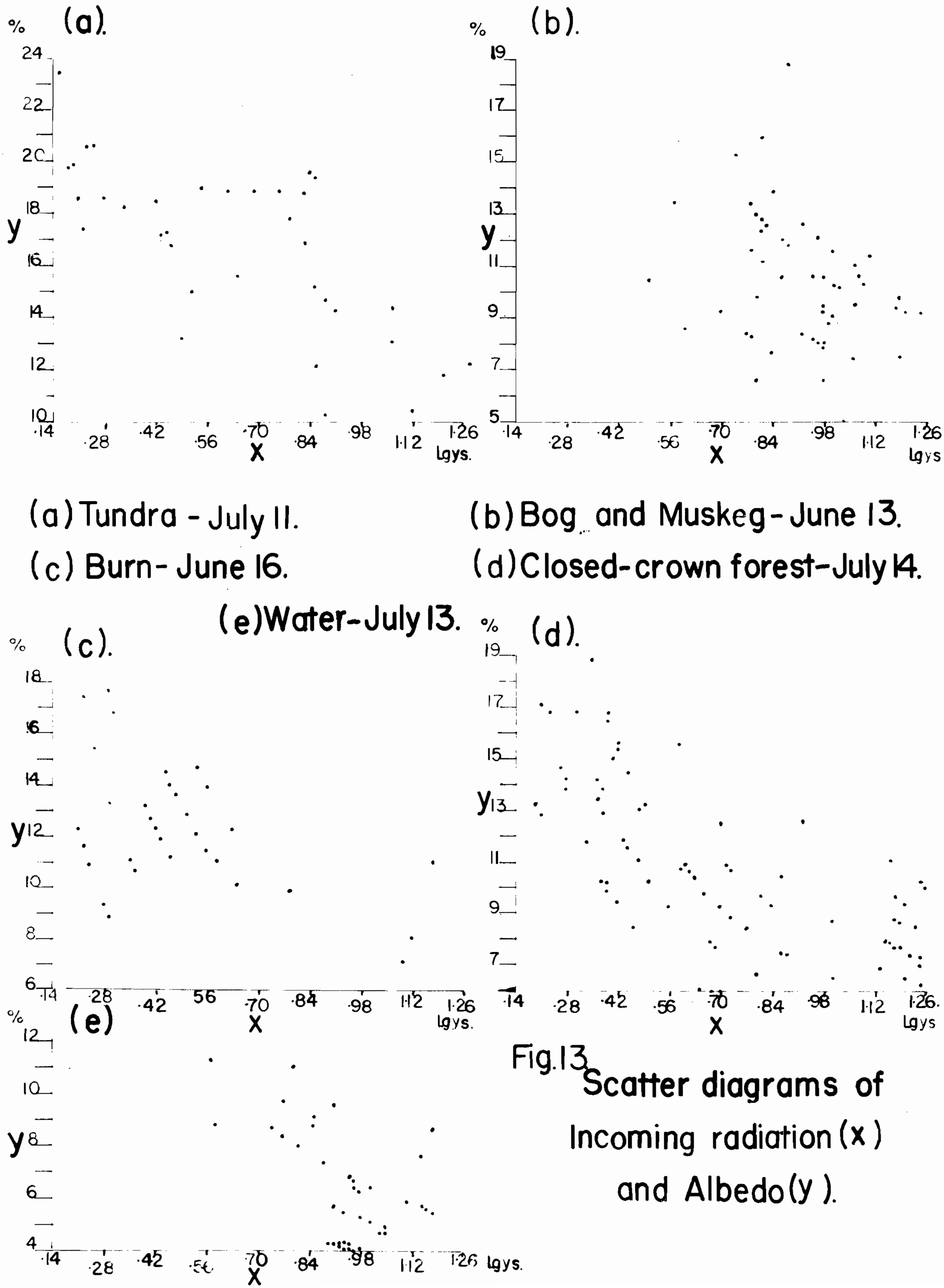
Scattergrams for all cover-types were constructed by plotting albedo as a function of incoming radiation (see Fig. 13). With the exception of tundra the scatters are grouped into a series of curves. This phenomenon is best demonstrated in Fig. (14), a scattergram for open woodland for the flight to Twin Falls (July 8). This graph illustrates the wide scatter that is common to all the others, the curves of decay, and the relatively uniform intervals between members of the curve family. For curve B, the relation of albedo (y) to incoming radiation (x) is:

$$\log y = 1.449 - 1.0103 \log x,$$

and for curve F it is:

$$\log y = 1.8042 - 0.9970 \log x.$$

The explanation of the uniform curve spacing was discovered when it was found that each curve was related to one particular value of reflection and that this value



(a) Tundra - July 11.

(b) Bog and Muskeg - June 13.

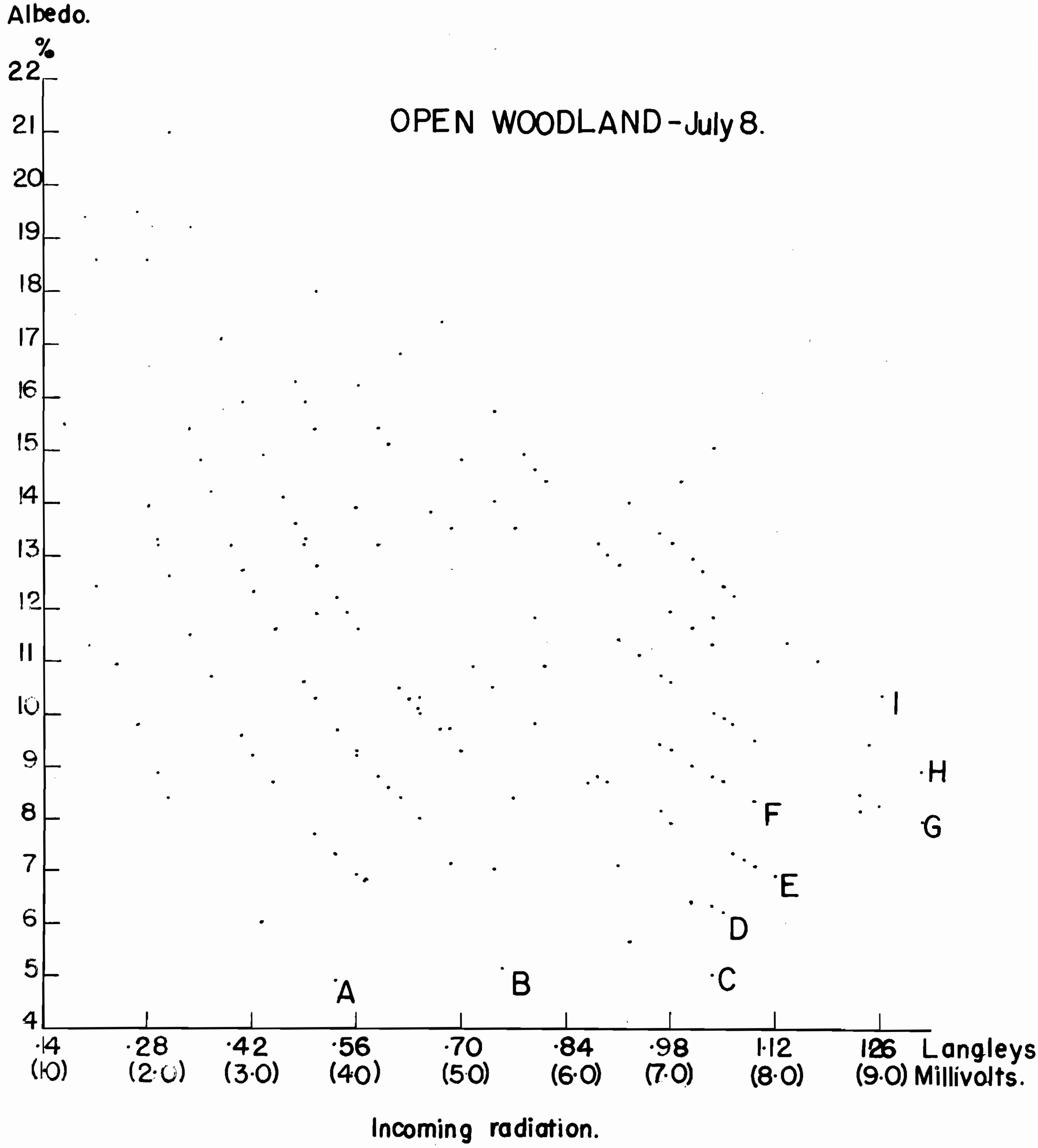
(c) Burn - June 16.

(d) Closed-crown forest - July 14.

(e) Water - July 13.

Fig. 13 Scatter diagrams of Incoming radiation (x) and Albedo (y).

Fig. 14.


Albedo.
%
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
OPEN WOODLAND - July 8.
A
B
C
D
E
F
G
H
I
·14 (1·0)
·28 (2·0)
·42 (3·0)
·56 (4·0)
·70 (5·0)
·84 (6·0)
·98 (7·0)
1·12 (8·0)
1·26 (9·0)
Langleys.
Millivolts.
Incoming radiation.

increased from curve A to curve I, being 0.2 mV at A and 0.9 mV at I. The progression of these values is arithmetical, of intervals of 0.1 mV. Thus curves B, C, D, E, F, G and H are characterized by the values 0.3, 0.4, 0.5, 0.6, 0.7 and 0.8 mV respectively. Thus, the explanation for the family of curves lies in the coarseness of the reading and rounding-off procedure adopted. It was impossible to read the millivoltmeter closer than to 0.1 mV, thus gaps in the conversion scale from millivolts to langleys would follow.

A detailed examination of each curve in turn showed that a curve/time-period relationship existed. Table 17 is a plot of each point within its time zone. The points of each curve were numbered beginning at their topmost point. From the table, the basic pattern that emerges is that of a diagonal band across the table, with marked time associations for the two extreme curves, A and I. Between these two the association does not appear to be so well marked. As sunrise and sunset on the 8th July were at 03.38 and 20.31 hours, respectively, the greater portion of the day that is represented in the table occupies the latter part of the period of incoming radiation from approximately two hours before solar noon to two hours before sunset. Thus, a total of 6 hours 37 minutes from dawn until 10:15 is unrepresented. If measurements were available for the earlier part of the day, it is expected that they would fall into line with curves representative of the later part of the day. The

TABLE 17

Albedo values for each curve related to time

CURVE \ TIME	10·15 - 10·25	10·25 - 10·40	10·40 - 10·55	10·55 - 11·10	11·10 - 11·25	11·25 - 11·35	STOP AT WABUSH LAKE	14·15 - 14·30	14·30 - 14·45	14·45 - 15·00	15·00 - 15·15	15·15 - 15·30	STOP AT TWIN FALLS	17·15 - 17·30	17·30 - 17·45	17·45 - 18·00	18·00 - 18·15	18·15 - 18·30
A														1, 4,	3,6,8,	2,5,7,		
B	7,9,									9, 10,	8,12,	13,14,		11,12,	1,	3, 15,	2,4,5,	6,
C	12,		16,		17,18, 19,			13,	1,5,	15, 16,	2,14, 20,			6,8,18,	3,	4,7,	9, 10, 11,	
D	4,10,15,	2,20,	21,		7,9,17, 18, 19,	14,			5,	3,6,	1,			8,11,13,			12,	
E	2,				14,16, 10,	5, 13,			1,4,7,	8, 11, 12,	3,6,			9,			15,	
F	1,4,	2,	12,	7,	5, 6, 8, 11,	9, 10,			3,									
G	13,		2,3,4,	5,17,		14,16,		1,	7,	11, 15,	6,9,10,	12,						
H	3, 5,	4, 8,	12,	6,11,		13,		1,2,10,	9,	7,								
I		6,8,9,	2, 5,	4,7,	10,				1,3,									

expected plot on a table similar to Table 17, therefore, would be in a form of a concave parabola. The presence of several points from curves B and C at the beginning of the time scale might indicate this.

Although the significance of the curve spacings and their time associations have been discussed, the curve trends are yet unexplained. The problem is resolved into a search for the factor (or factors) that prevents the ratio of reflected to incoming radiation from remaining fairly constant, changing only with changes in solar altitude and not depending on whether the radiation is direct or diffuse.

The hypothesis forwarded is based on the effect of shadowing. Two situations may be visualized:

(i) During periods of direct solar radiation, shadowing would result depending upon the nature of the cover-type and surface topography. Kondrat'ev measured lower albedos over a wave surface than over a smooth water surface at low sun angles, a difference attributed to shadowing. In the case of open woodland, this effect is particularly noticeable when one examines the differences in albedo between direct solar radiation and diffuse solar radiation. Here the shadowing effect obscures the bright lichen floor.

(ii) At times of low sun angles the shadowing effect would be emphasized and long shadows would be cast. Longer shadows would increase the area of shading and lower albedos would ensue. Fig. (14) illustrates this effect, for curves

A and B are related to lower solar angles than the other curves (see also Table 17). Thus it is suggested that the effect of shadowing operates contrary to the expected increase of albedo with low solar angles.

Tundra appears to be an exception to this curve pattern (see Fig. 13a). Being relatively free from vegetation, tundra would be smoother than other surfaces and thus the effect of shadowing would not be expected to such a degree. The surfaces of open woodland, burn and muskeg are shadow-producing surfaces because of their associated tree growth, while water surfaces are shadowed by waves as indicated by Kondrat'ev. Closed-crown forest is no exception for even a closed crown is an exceedingly rough surface.

Most flying days were characterized by conditions of rapidly alternating cloudiness and brightness under daytime cumulus with pronounced cloud shadowing of the ground surface (see Photograph F). Thus, there are two shadowing processes at work. It is from airborne measurements that the full effect of shadowing is apparent, thus different results are to be expected in the study of ground measurements of albedo.

(13) Ground Measurements of Albedo

The measurements were undertaken in connection with studies of net radiation during July and August. The instrumentation has been outlined in Chapter II and illustrated in Fig. (4). The purposes of this section of the albedo work were to acquire quantitative data for ground surfaces that could not be acquired by aerial methods, and to provide some form of comparison with the aerial method of measurement regarding instrumental behaviour.

The results of the observations are shown in Tables 18 and 19. As the range of values was not great the mean was employed in the calculation of representative averages. All values tend to be higher than the airborne values. This could be explained by the absence of dark reflecting surfaces such as spruce to tone down the albedo to low ground vegetation. It was possible to measure the albedo of woodland lichen without the interference of the tree component of open woodland, and also the albedo of a wide expanse of snow-cover.

The value of 16.2% for a waterlogged sedge-meadow surface supports the hypothesis forwarded in Section 6, namely, that although a relatively continuous water layer covered the peat and grass root surface layer of a bog, the strong grass growth shaded it, thus the effect of water content on albedo is not great.

To examine the relation between albedo and incoming radiation scatter diagrams (Fig. 15) were constructed as in Fig. (13). Measurements over snow and tundra cover were not considered as the number of associated measurements was few. Of the four remaining covers the measurements over the sedge meadow Fig. (15) and dry ground with sparse brown grass cover Fig. (15) do not follow the same trend as shown in Fig. (13), quite as definitely. The albedo values for the sedge meadow are narrowly confined to a range of 3%,

Table 18

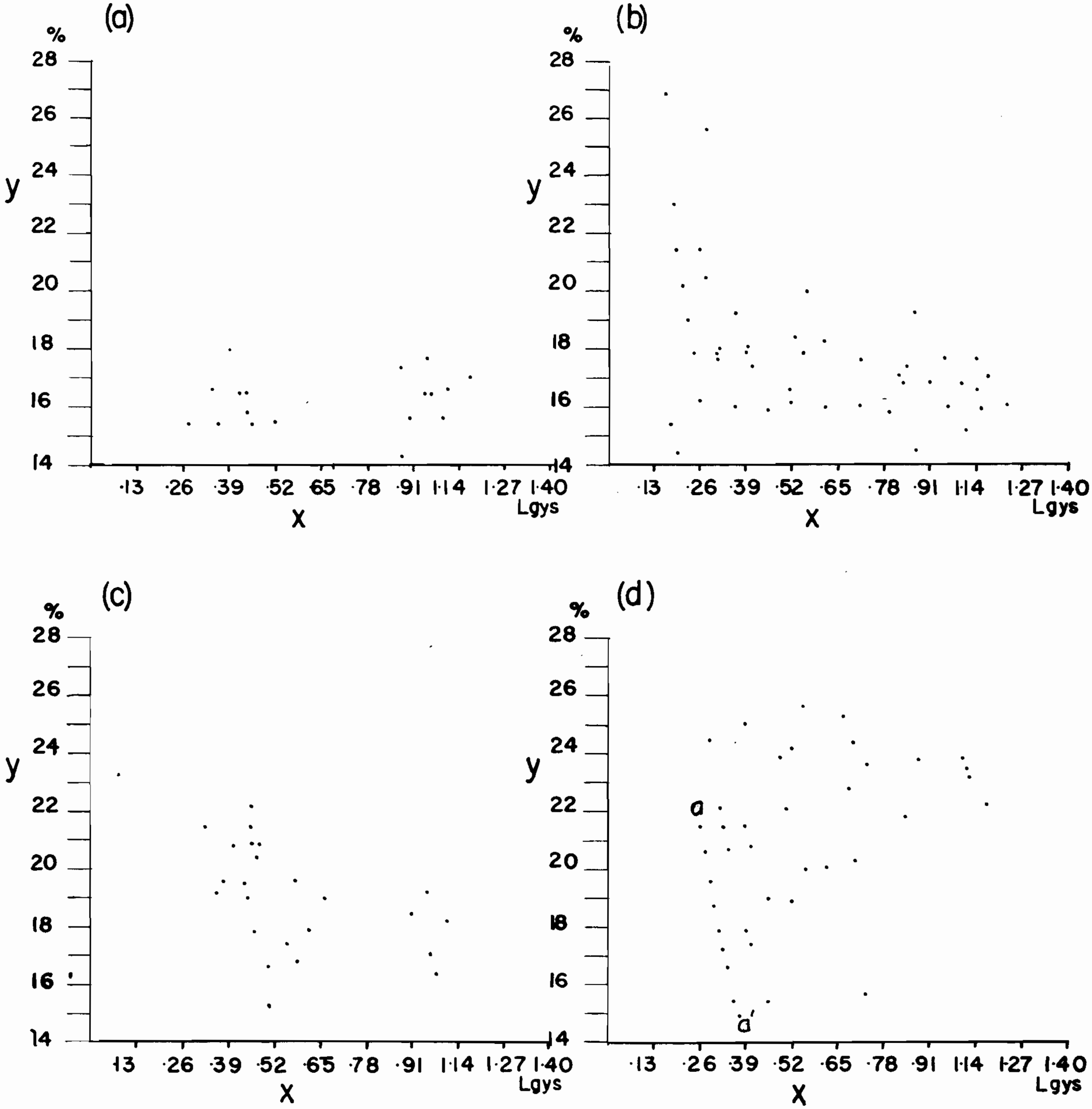
Hourly mean values of albedo for various surfaces

Date	Surface-cover	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19
July 21	Close green tundra cover				15.4						
" 21	Snow patch						42.6				
Aug. 4	Bare ground					18.6	17.7	17.1	20.0	19.6	25.0
" 5	Bare ground	18.2	18.1	16.3	16.3	16.6	17.1				
" 7	Dry ground and sparse brown grass		18.7	19.7	20.1						
" 7	Dry lichen						20.1	20.5	19.0		
" 8	Fringe of sedge meadow						16.9	16.1	16.3		
" 9	Dry lichen						18.7	20.1	20.2	23.3	

Table 19

Mean values of albedo for various surfaces

Snow patch	42.6%
Dry ground and sparse brown grass cover	21.1
Dry lichen	20.3
Bare ground	17.8
Fringe of sedge meadow	16.2
Close green tundra cover	15.4



(a)Sedge meadow - August 8·

(b)Bare ground - August 5·

(c)Dry ground & Brown grass - August 7

(d)Lichen - August 7 & 8·

Fig· 15- Scatter diagrams of Incoming radiation (x) and Albedo (y)·

between 15% and 18% for both high and low values of incoming radiation. Fig. (15) shows a more marked tendency towards increased albedo with decreased incoming radiation but it is not really marked enough to be definite. Fig. (15b) is clearly very similar to the trend shown in Fig. (13) but Fig. (15) shows a paradoxical condition where the overall shape of the distribution indicates an increased albedo with increased incoming radiation, while minor parts of the distribution show the reverse. The latter phenomenon is designated by the line of values aa'. Where lines within the scatter occur, they are straighter and more nearly vertical than those in Fig. (13) and do not show any tendency towards greater horizontality at lower values of albedo. However, this latter characteristic also occurs in Fig. (13), for at albedo values greater than 14% (all of the ground measurements lie above this threshold) the airborne albedo measurements form lines just as straight. Thus it is probable that lower albedo values from ground measurements would tend to curve towards increasing horizontality.

Very little can be concluded from these measurements regarding patterns of scattering especially in relation to the effect of shadowing. On a micro-scale shadowing would exist under direct radiation but its effect would be expected to be greater over the grass surfaces (sedge meadow and dry ground with grass cover) than over surfaces with no shading obstacles. Yet, the scanty evidence of the effect of shadowing might be indicative of its relative unimportance in these ground measurements. In terms of the results obtained from the air, it must be concluded that the results from ground measurements show a tendency to conform with airborne measurements in one case (Fig. 15b) and a tendency towards an opposite trend in one case (Fig. 15d).

CHAPTER V

CONCLUSIONS

The measurement of albedo from low-flying aircraft involves problems of instrumentation unique to the method and demands a meticulous approach to observation of ground cover-types beneath, cloud above, and shadowing by clouds. A change in any one of these three variables has repercussions in the measurements. While it is the variation in the first, with regards to changes in its albedo, that formed the primary purpose of this study, it was found that albedo altered with the nature of incoming radiation (whether direct or diffuse), and with the occurrence of cloud shadowing.

The existence of variables presents a strong case for recording albedo automatically and continually, in order that the variables themselves can be noted in greater detail. In view of the coarseness of reading (to one decimal place) as indicated in Fig. (14) and Fig. (15), more precise recording of incoming and reflected radiation would be desirable. As a check on "hemispherical albedo" measurements (i. e., their adequate representation of the albedo directly beneath the aircraft), it is suggested that the beam albedo method be operated simultaneously to give "point" albedo.

The effect of shadowing (Section 12) requires further field-work, along similar lines, to establish its validity as an element in the measurements of albedo (particularly from aircraft). The work of Kondrat'ev indicates a similar effect regarding waved water surfaces, also found by the present writer. It is logical that the same phenomenon applies also to land surfaces especially where tree growth exists. Relatively bare land surfaces, such as sub-Arctic tundra, appear to be different because of their lack of tree growth, here considered as a shading element. It follows that calm water surfaces would be different but on one occasion only was such a water condition encountered, and that under relatively uniform direct radiation.

The results obtained in the summer of 1961 have been treated statistically but weighted subjectively in certain cases in favour of the more representative areas of those cover-types traversed by the flight lines. Table 20 lists representative values for each cover-type as obtained by this method.

Table 20

Representative values of albedo for all cover-types

Cover-type	Albedo, %
Tundra	16.9
Burn	12.4
Open woodland	7 - 20
Bog and muskeg	9.7
Closed-crown forest	9.2
Ice	20.9
Snow	34.0

But it must be stressed that albedo is a parameter of considerable range, due to the effect of solar height and shadowing, and consequently, it is suggested that these figures must be considered in relation to the "Effective Range" (Table 9) and distribution of values as shown in the histograms (Figs. 5 to 10).

Ground measurements of albedo indicated that: 1) bare lichen is a less effective reflector of shortwave radiation than a visual interpretation might indicate, and that 2) vegetation growth on a sedge meadow (and bogs in general) will shade surface water.

Because of the difference between albedo measured from the ground and from the air as shown in Figs. (14) and (15) it is concluded that a different factor (or set of factors) such as the shadowing effect is operative once the instrumental base is raised above ground level. It might be rewarding to measure albedo from the two intrumental levels with a view to determining differences in the factors that need to be considered.

Albedo (i. e. $A = \frac{Ir}{Io}$) is a simple concept, yet it is difficult to measure and to evaluate for various reflecting surfaces. Important as it is to studies of the heat balance, its theory is incomplete and its mode of measurement experimental.

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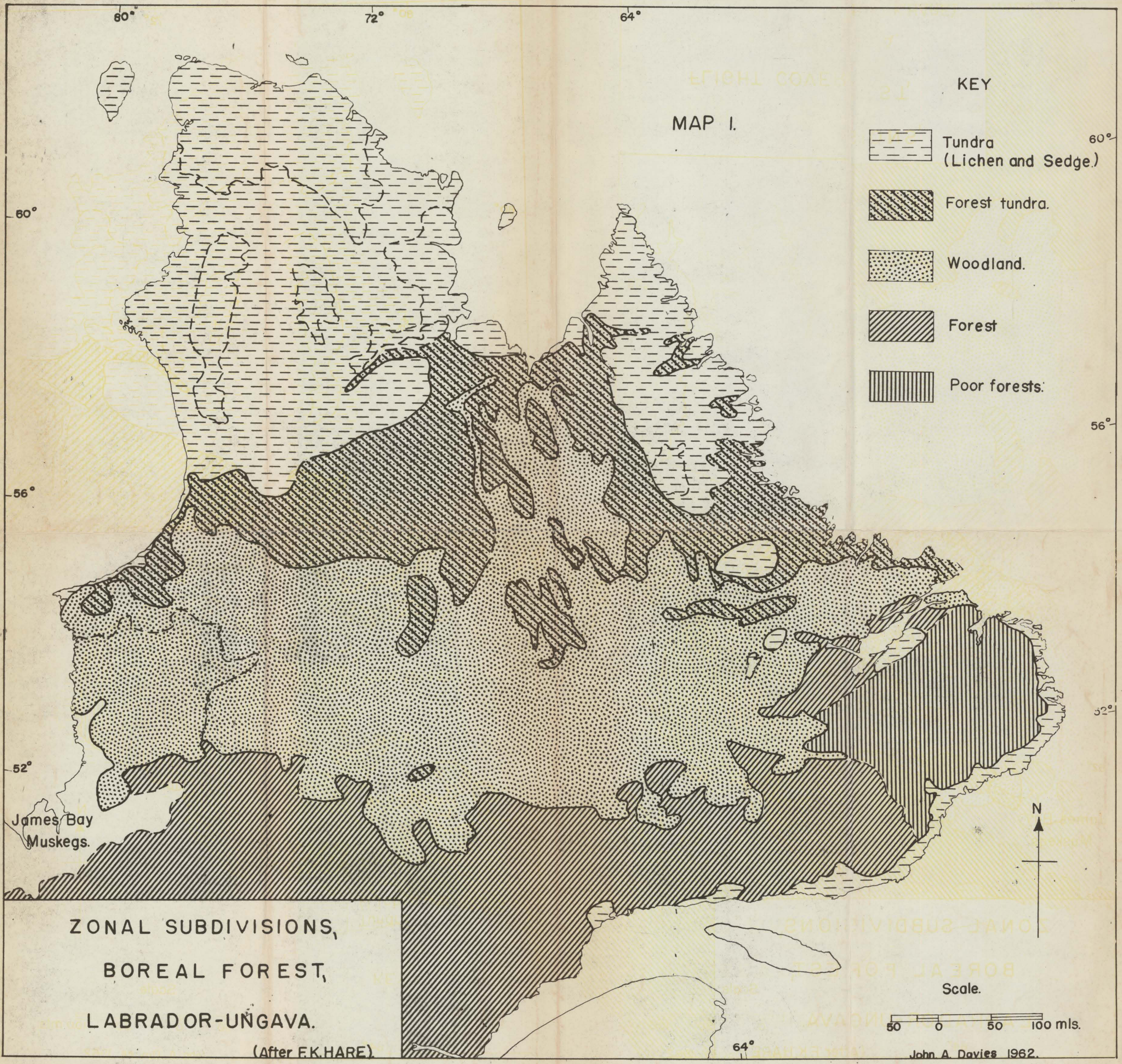
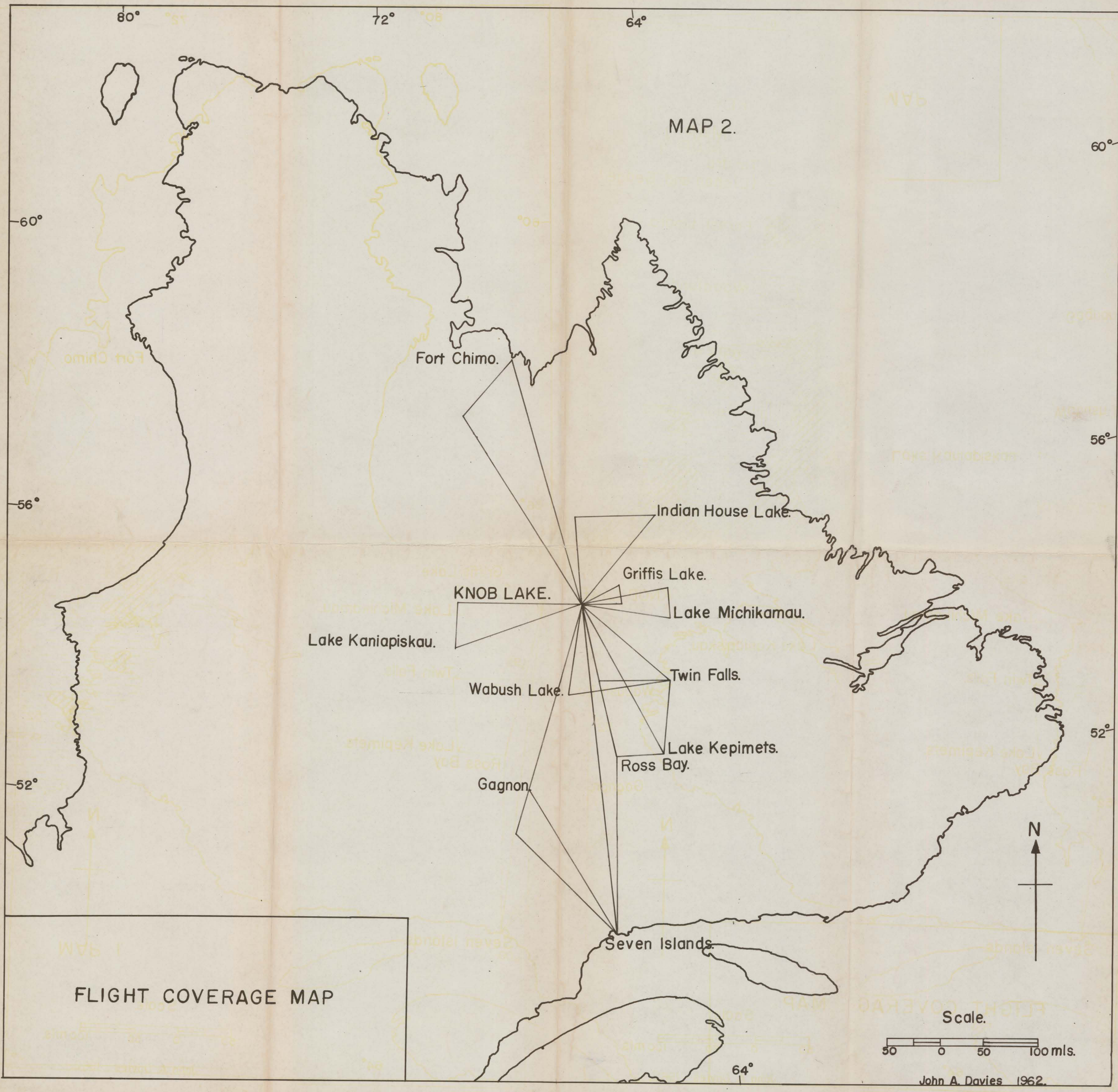

MAP I.
KEY
Tundra (Lichen and Sedge.)
Forest tundra.
Woodland.
Forest
Poor forests.
80°
72°
64°
60°
56°
52°
James Bay Muskegs.
N
Scale.
50 0 50 100 mls.
ZONAL SUBDIVISIONS,
BOREAL FOREST,
LABRADOR-UNGAVA.
(After F.K.HARE).
John A. Davies 1962.



MAP 2.
FLIGHT COVERAGE MAP