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INVESTIGATIONS OF ALBEDO
OVER SNOW

INVESTIGATIONS OF ALBEDO OVER SNOW

by

LESLIE GREEN

A 4C6 Research Paper
Submitted to the Department of Geography
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Arts

McMaster University
April 1980

BACHELOR OF ARTS (1980)
(Geography)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: Investigations of Albedo Over Snow

AUTHOR: Leslie J. Green

SUPERVISOR: Dr. W.R. Rouse

NUMBER OF PAGES: vi 41

ABSTACT:

The importance of snow surface albedo has been recorded by many authors. Techniques have been attempted with less than favorable results by D.E. Petzold (1977). This paper investigates the methods proposed by Petzold and offers alternative methods of albedo estimations using polar, sub-polar and continental stations as data sources.

ACKNOWLEDGEMENTS

I wish to thank Dr. W.R. Rouse, Kim White and Paul Smith for their help and encouragement during this study.

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CHAPTER I

INTRODUCTION

I.I Review of Literature

Albedo (α) is a dimensionless ratio expressed in the form :

$$\alpha = \frac{K\uparrow}{K\downarrow} \qquad (I)$$

where $K\uparrow$ and $K\downarrow$ are the reflected and global solar irradiances respectively.

The radiation balance :

$$Q^* = (I-\alpha)K\downarrow + L^* \qquad (2)$$

where Q^* is net radiation, and L^* is the longwave radiation balance, shows the importance of albedo. Snow surface albedo is one of the most important items which controls the net radiation balance over a snowpack, the heat exchange processes and the melt rates of a snowpack (Arai, I966, Petzold, I977, Grey, I970, Giddings and La Chapelle, I96I). Because albedo is the most important meteorological property of the net radiative transfer at the surface of the snowpack, it is also important for calculating the radiative transfer within the snow.

Albedos range from .75 to .95 for fresh fallen snow to .40 to .70 for snow which is several days old (Sellers, I965). Arai (I966) found the albedo of old grain snow to be as low as .5I to .56 at the Takimami River Basin, Japan.

With the importance of albedo of snowcover being obvious, estimation techniques have been attempted. Giddings and La Chapelle (I96I) estimated the albedo of a semi-infinite and isotropic snowcover:

$$\alpha = \frac{I-w/2}{I+w/2} \qquad (3)$$

where w is a dimensionless parameter depending on the density of the snow and grain size of the snow particles. Also estimated by Giddings and La Chapelle (I96I) was the albedo of snow with an internal absorbing surface at a depth:

$$\alpha = \frac{I-w(I-y)/2}{I+w(I-y)/2} \qquad (4)$$

where y depends on the absorption rate of snow, the depth of snow and a diffusion coefficent, D. Giddings and La Chapelle (I96I) feel these equations are accurate until the albedo drops below about .60. Effects such as particulate fallout on the snow, influences of different snowtypes and zenith angles are not taken into account but the authors (Giddings and La Chapelle) feel that appropriate modification of their equations are possible.

The United States Army Corps of Engineers (U.S.A.C.E.) have developed widely used albedo estimators which rely only on the age of the snow (U.S.A.C.E., I960). The U.S.A.C.E. method estimates the albedo for the accumulation season and the melt season. Fig. I shows these relationships. This U.S.A.C.E. method assumes a percent decrease in the albedo per day, with no other influences on the snowpack except time.

Petzold (I977) incorporates into the U.S.A.C.E. method daily maximum temperature, cloud amount and cloud type. Utilizing this information, plus the U.S.A.C.E. method of number of days since last snowfall. Petzold (I977) attempts greater accuracy in the U.S.A.C.E. equations by adding his own correction factor.

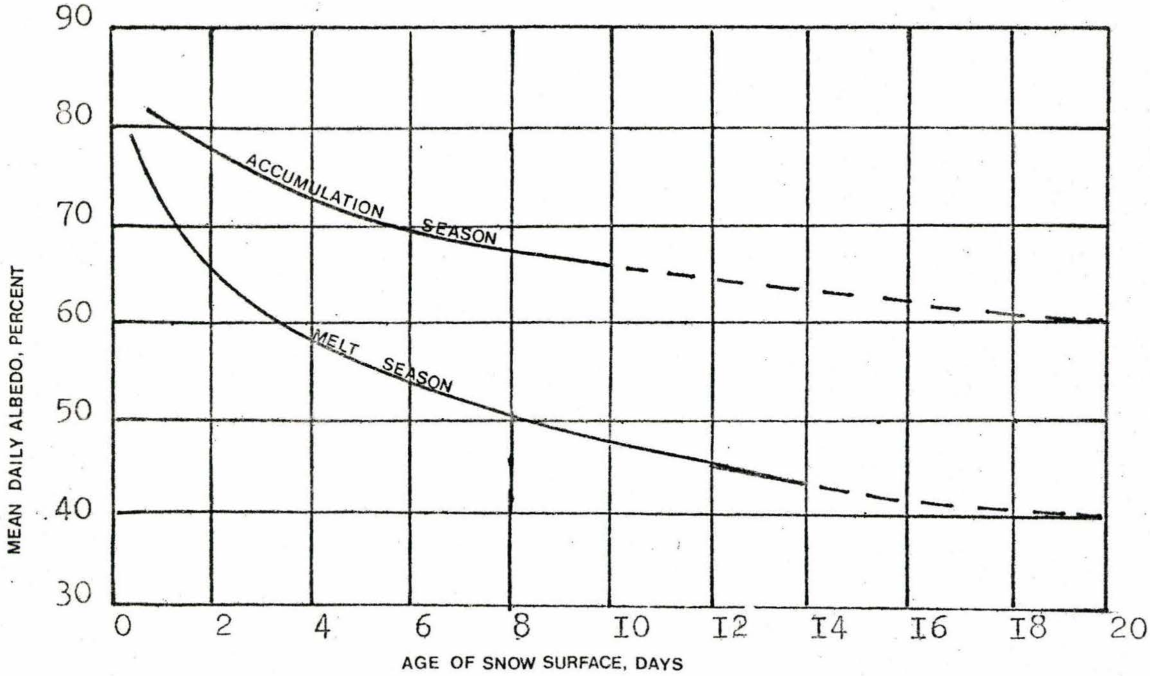


Fig. I. Variation in snow surface albedo with time (from U.S.A.C.E. I960).

I.2 Objective

The objective of this paper is to study the feasibility of the parameters used by Petzold (1977) in estimating albedo over snow and to determine if his correction factor enhances the U.S.A.C.E. method. In addition, an examination of other possible improvements is undertaken.

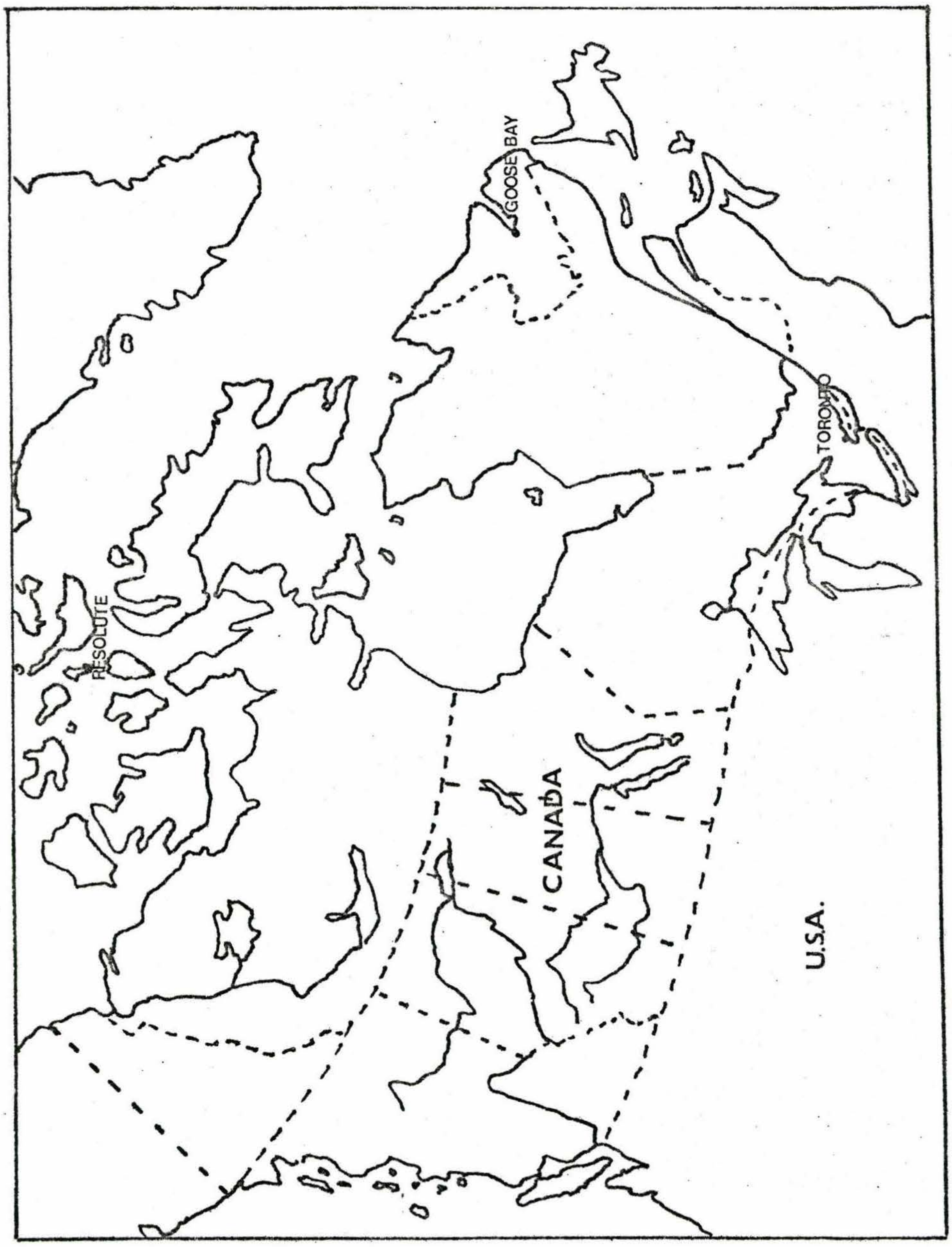


Fig. 2. Geographic locations of stations used in the analysis.

CHAPTER 2

STUDY AREAS AND DATA

2.1 Study Areas

Data were used for the three stations shown in Fig. 2.: Toronto Scarbourough Station, Ontario (43° 43'N, 79°14'W); Goose Bay Rawinsonde Station, Labrador (53° 18'N, 60° 33'W); and Resolute, North West Territories (79° 43'N, 94° 27'W).

According to the Genetic Classification of World Climates, E. Neef (from Barry and Chorley, 1968) classifies these areas climatically as cool continental, sub-polar and polar respectively. At all three stations instruments are run and maintained by the Atmospheric Environment Service (A.E.S.).

From the years 1966 - 1976 snow fall data were examined for all three stations and the year with the longest number of months with measurable snow on the ground at the end of the month was chosen as the data study period. For Resolute the time period studied was August 1967 to June 1968 with useable albedo data taken between September and October 1967, and February and April 1968. For Goose Bay the time period studied was November 1971 to April 1972, with useable albedo data found between the middle of December 1971 and the middle of April, 1972, and for Toronto the time period was between November 1965 and April 1966 with useable data found between early January to early February 1966, as well as a few days at the end of March, 1966. Appendix Three gives the data for the three stations.

The polar night in Resolute began on November I, I967 and continued until February 6, I968. Because of the smallness of the solar radiation during the solstice, useable measurements were not available until Feruary I6, I968. Data are missing for most of May and could not be used in this study.

The climate of Toronto is characterized by "spring thaw" conditions throughout the winter which creates patchy snow conditions (Petzold, I974), therefore only a small data sample is available.

2.2 Meteorological and Hydrological Data

All data were taken from the Monthly Radiation Summary and the Monthly Record: Meteorological Observations in Canada, both published by the Atmospheric Environment Service,(A.E.S.) Environment Canada.

Global solar radiation (K↓) and reflected solar radiation (K↑) were measured using Eppley or Kipp pyranometers and an inversley mounted Eppley or Kipp pyranometer respectively. The units of K↓ and K↑ are langleys (Ily. = I cal / $cm.^2$)

Albedo was calculated using eq. (I). Cloud type and amount were taken from micro - film files of the A.E.S. Times used were: 0600h, 1200h and 1800h at Toronto (Downsview Station); 0800h, 1600h and 2300h at Goose Bay; and 0600h, 1200h, 1800h, and 2100h at Resolute. The cloud amount and type were averaged each day to obtain a daily value.

Daily temperatures and precipitaion were obtained from the Monthly Record. Temperatures were measured at screen height, and maximum temperature of a given day is the highest temperature of a 24 hour period beginning at the morning observation of the day in question. Temperatures were converted to celsius degrees.

Rainfall was measured by a standard rain guage while snowfall is taken as a depth of freshly fallen snow, measured with a ruler in a area free from drifting. The depth of snow on the ground is the accumulation of snow on the ground measured on the morning of the last day of the month.

Daily precipitation at each station was recorded and checked with the average temperature and albedo of the day to determine snow fall events.

2.3 Data Accuracy

The accuracy of data supplied by the Atmospheric Environment Service must be questioned. The measured albedo at Resolute may not always represent the true regional albedo. The snow depth at Resolute is measured at the airport while the radiation is measured about three-quarters of a mile away over a small built up gravel area. Due to blowing snow and location, there may be no snow under the radiometers while there is snow being measured at the airport. This will especially effect the values of K↑ and Q*, thus affecting albedo values. Information on the location of instruments and special problems at Goose Bay were unavailable.

The Toronto location had to be split between Scarbourough and Downsview. Measurements of daily precipitation, maximum daily temperature, K↑ and K↓ were taken at Scarbourough but hourly cloud cover and cloud type data was not available and therefore were obtained from the Downsview station. No one station in Toronto measures daily temperature, precipitation, K↑, K↓, Q*, L* as well as hourly cloud cover and type.

In some instances albedo values had to be discarded. In cases where the impossible situation of daily K↑ being greater than daily K↓ occured, the data was rejected.

The U.S.A.C.E. (I960) have generally determined that a fresh snow cover has an albedo of .84, while Petzold (I974) places it between .84 and .89. On days with a fresh snow cover and missing albedo data, instead of using the above assumptions, the data was rejected.

CHAPTER 3
EFFECTS UPON ALBEDO

3.1 Cloud Cover

One of the most important effects of cloud on albedo results from the process of multiple reflection between the snow surface and cloud bases. Catchpole and Moodie (1971) express this multiple reflection in the form of a series:

$$\alpha c \alpha g \, K\downarrow = \alpha c \alpha g t + \alpha c^2 \alpha g^2 t + \ldots = \alpha c^n \alpha g^n t \qquad (5)$$

where αg and αc are albedos of ground and cloud, and t is the transmitted quantity which equals $K\downarrow(1-\alpha c \alpha g)$. The albedo of the cloud base is taken as .60. Fig. 3 shows this multiple reflection model.

Eq. (5) incorporates an infinite number of cycles. As the number of cycles increases the intensity of the reflected radiation approaches zero. For practical purposes one needs to include only the first cycle of multiple reflection. Eq. (5) approaches its maximum when there is frech snow and an overcast sky. Under these curcumstances the contribution of multiple reflection can approach, in magnitude, the downward flux of diffuse radiation resulting from the first pass of the primary beam through the cloud.

Albedo variarions under different cloud covers and conditions have been reported (Hubley, 1955, Nkemdirim, 1972, Petzold, 1974). Generally, the total albedo over any surface increases with cloudiness, the main contribution

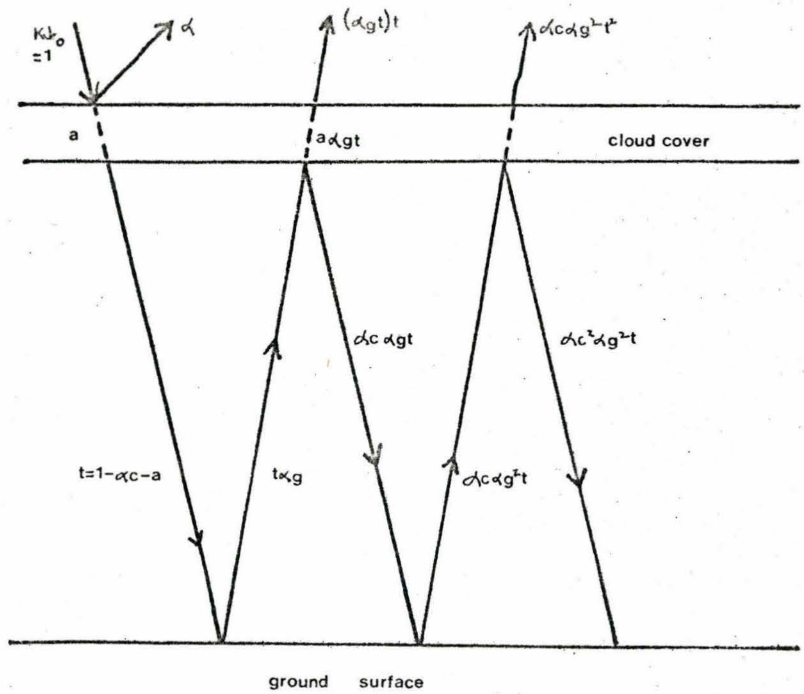


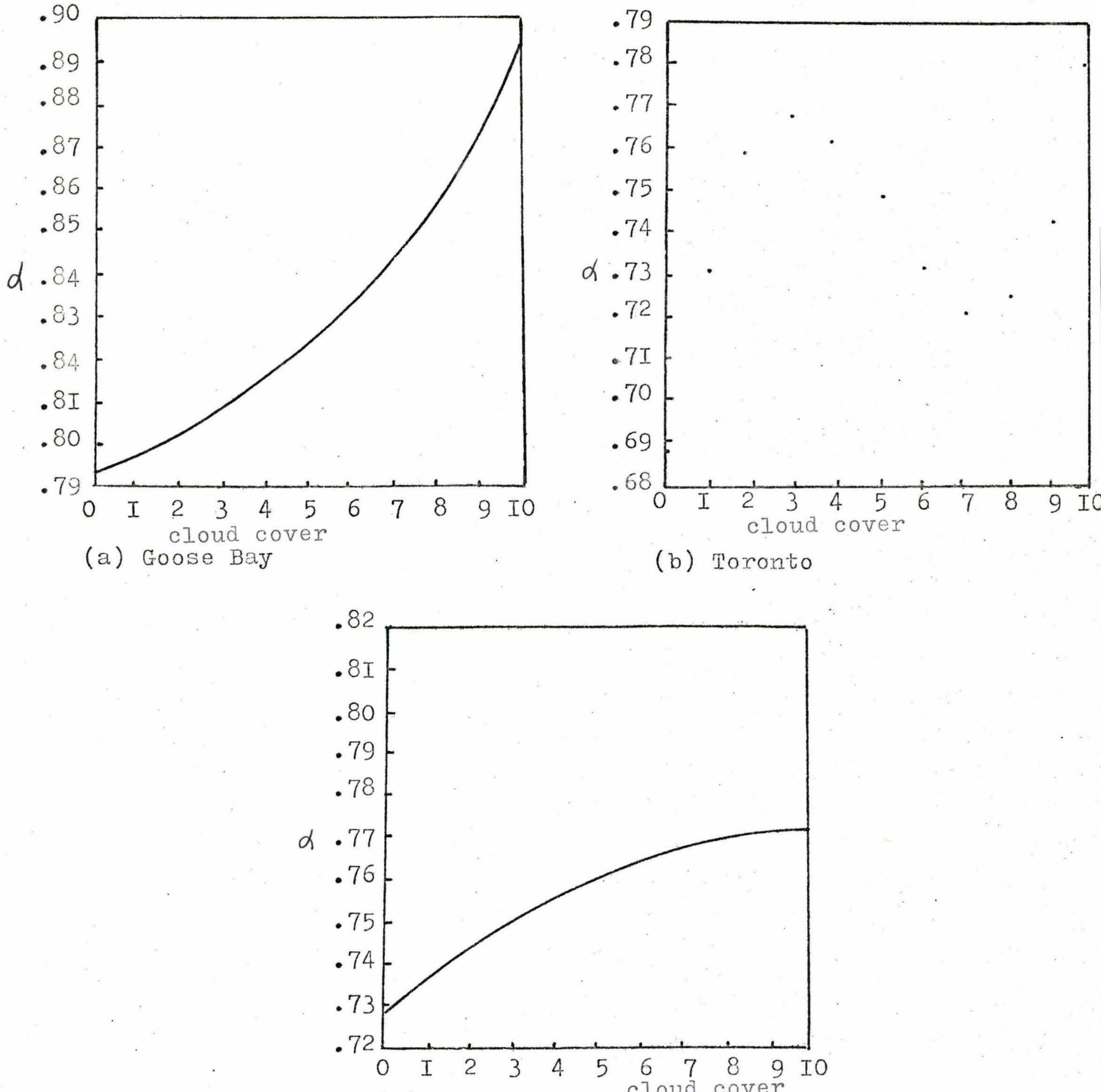
Fig. 3. Model of multiple reflection of solar radiation between the ground and atmosphere with a layer of clouds. $K{\downarrow}_o$ = incident solar radiation, αc = albedo of cloud, αg = albedo of ground, a = amount absorbed in cloud, t = transmitted quantity (from Catchpole and Moodie, I97I).

Coming from the diffuse component. Explanations have been given by Bergen (1975) and Petzold (1977).

A number of physical factors affect albedo. Albedo values for the near infra-red (>.75μm) portion of the solar spectrum are smaller than for visible light. With clouds, due to multiple reflections between cloud bases and snow surface, the predominately diffuse radiation will be high in visible light. With clear sky conditions, solar radiation is mainly direct, thus shadows are cast by surface roughness elements. Separate snow grains are reached by direct radiation on one side only, whereas with primarily diffuse radiation, the radiation reaches all sides of the grains. Thus, the snow albedo under clear skies can be expected to be smaller than those under cloudy skies.

Fig. 4, which plots selected data from the entire winter season, shows the general increase in albedo from clear sky conditions to cloudy sky conditions in Toronto, Goose Bay and Resolute, The plots of data from Goose Bay and Resolute follow the expected pattern of generally increasing albedo with increasing cloud cover. When a line is drawn through the Toronto points, a very definite sinusoidal pattern emerges. The albedo variation lies between .72 - .77. Increasing the data base would probably produce a band of points along this variation spread. The small data base in this study probably gives rise to the sinusoidal pattern.

Petzold (1977) relates cloud cover amounts, C, (measured in tens from 0 to 10), to the average percent change in albedo from the clear sky value ($\Delta\%\alpha$) in a linear regression where:



(a) Goose Bay

(b) Toronto

(c) Resolute

Fig. 4. Changes in albedo as a function of cloud cover. Equations of lines in Appendix One.

$$\Delta\%\alpha = 0.449 + 0.0097\ (C)^3 \qquad (6)$$

Eq. (6) is derived through regression analysis from data obtained at McGill Ice Cap, N.W.T.,(80N, 90W), Mirny, Antarctica, (67S, 92E), and Meighan Ice Cap, N.W.T., (80N, 100W). According to data from these stations Eq. (6) has a correlation coefficient of 0.999 and a standard error of regression of 0.2 percent.

Table 1 shows daily values for $\Delta\%\alpha$ for eleven different cloud covers calculated from Eq. (6). The percent change is relative to the previous days albedo. These percentages shown in Table 1 would be added to the previous days albedo and an estimated albedo would be obtained purely on the basis of the amount of cloud cover.

3.2 Snow Surface Decay

Natural decay of the snow surface alters albedo. Pack deterioration is altered by air temperature, aerosols in the atmosphere, original nature of fallen snow, age of the snow and its density.

A high inverse correlation has been found by Arai (1966) between snow surface density and albedo. Fig. 5 shows this relationship from measurements taken at the Takinami River Basin, Japan (36N, 144 W) during ablation season.

Dirmhirn and Eaton (1975) have found that re-crystalization within the snowpack results in a decrease of snowpack albedo. A strong radiative cooling at night

Cloud Amount	Percent Change From Clear Sky Albedo
0	.00449
1	.00459
2	.00527
3	.00711
4	.01070
5	.01662
6	.02544
7	.03776
8	.05410
9	.07520
10	.14900

Table 1: Percent change in albedo from clear sky to cloudy sky conditions using Eq. (6).

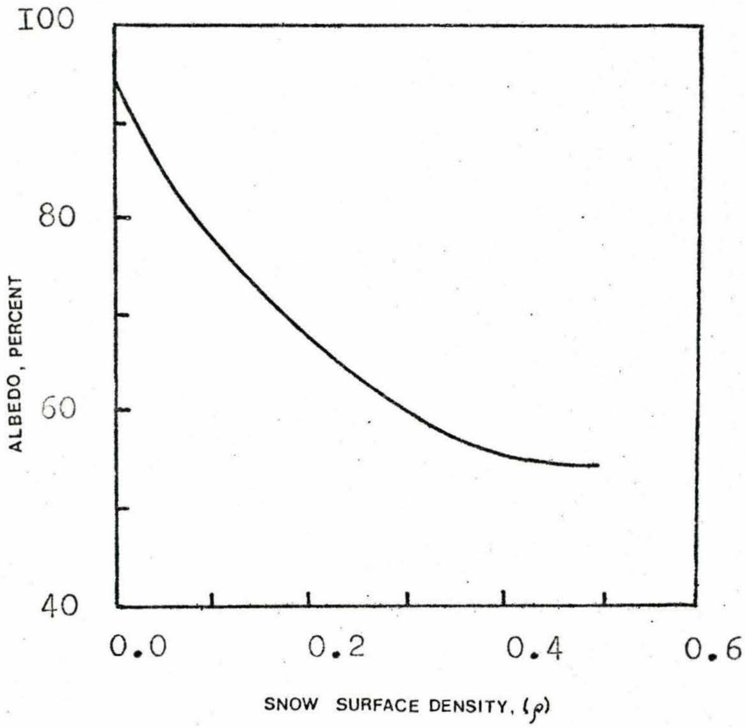


Fig. 5. The relationship between albedo and snow surface density at the Takinami River Basin, Japan (from Arai, 1966).

and heat applied during the day causes the recrystalization process and decreases the number of facets of the crystals of snow. Radiative scattering in the upper layers of the snow is decreased, and the radiation can penetrate deeper thus an overall increased absorption in a maturing snow pack takes place. This is an irreversable process. Petzold (1977), has found that at least 1 cm. of new snow is needed to obliterate the influences of the underlying surface. The albedo of a melting snowpack will change more rapidly than that of an accumulating snowpack. Fig. 1 shows the typical variation of snow surface albedo with time for both the accumulation and melt seasons, as does Fig. 6, which shows the variation of albedo with time for both seasons at Toronto, Goose Bay and Resolute. Again, because of the lack of data, the spread of the x axis is not very large. All three graphs show what would be expected. The accumulation season begins with a higher albedo value, and the rate of decrease is less pronounced than during the melt season. The melt season's day zero albedo begins lower than the accumulation season, and with increasing days since last snow, rapidly decays.

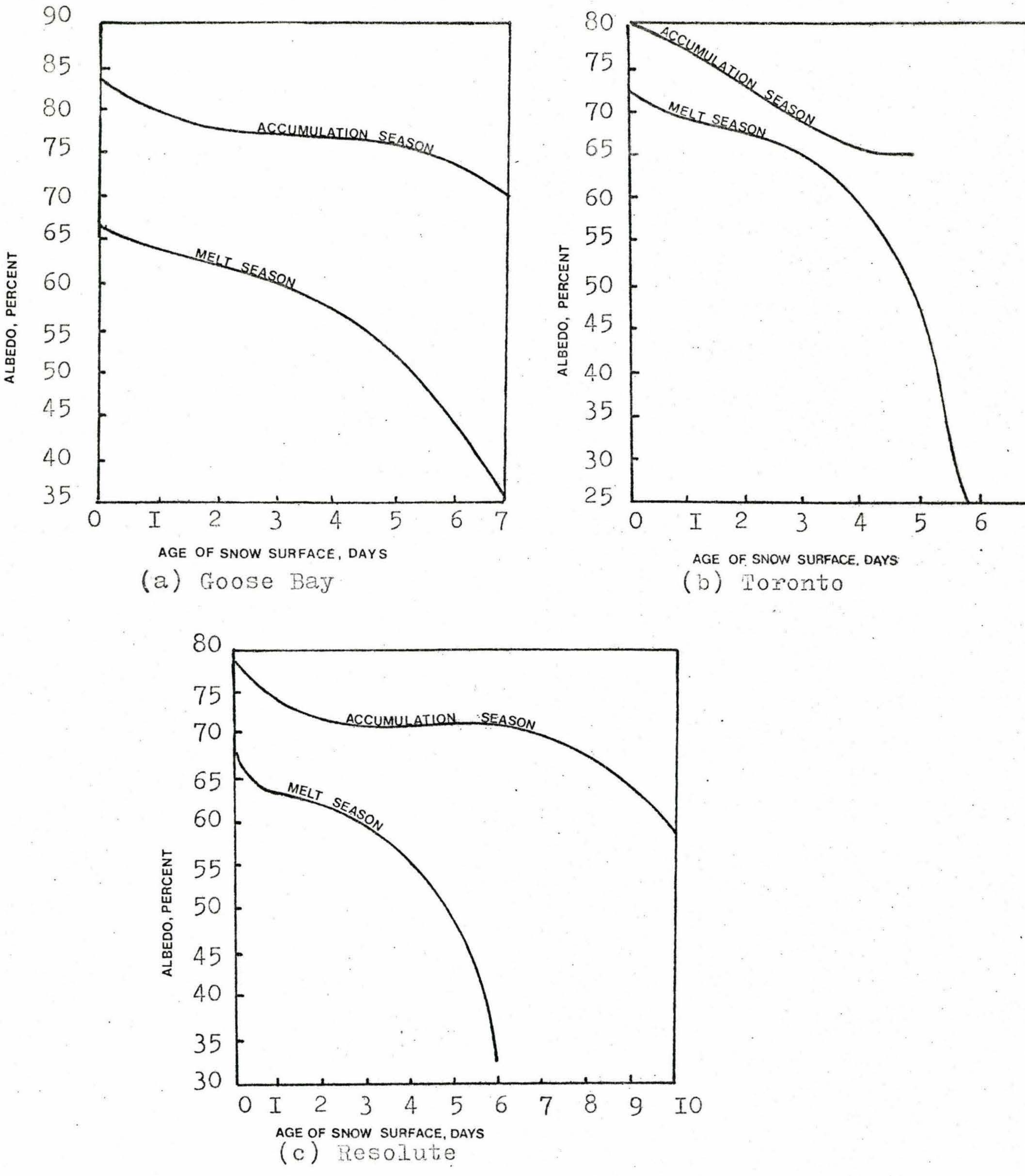


Fig. 6. Variation in snow surface albedo with time for the three stations. Equations of lines in Appendix Two.

Fig. 1 expresses natural albedo deterioration as a simple exponential decay function, one for accumultion season and one for melt season. Petzold (1977) uses the information from these graphs to obtain a relationship between percent daily change in albedo and age of the snow since last snow fall. Eq.(7)expresses the effects of metamorphosis on a accumulating snowpack (maximum daily temperature 0 C), and Eq.(8)expresses the same effects for a melting snowpack (maximum daily temperature 0 C):

$$\Delta\%\alpha = -10^{(0.78 - 0.069D)} \qquad (7)$$

$$\Delta\%\alpha = -10^{(1.05 - 0.07D)} \qquad (8)$$

where D is the number of days since last snowfall. As with Eq. (6) these percentage changes are applied relative to the previous days albedo.

Table 2 shows the average decrease per day in albedo by the U.S.A.C.E. method and the U.S.A.C.E. method modified by Petzold. The two models, by looking at their average percent differences, compare well.

Petzold uses this information and puts it into

Day	Equation 7 U.S.A.C.E.	Equation 7 Petzold	Equation 8 U.S.A.C.E.	Equation 8 Petzold
0-1	.0123	.0630	.1125	.0630
1-2	.0375	.0514	.0845	.0955
2-3	.0260	.0438	.0615	.0812
3-4	.0400	.0374	.0492	.0692
4-5	.0278	.0319	.0345	.0588
5-6	.0143	.0272	.0357	.0501
6-7	.0290	.0232	.0370	.0407
7-8	.0149	.0198	.0385	.0363
8-9	.0000	.0169	.0200	.0309
9-10	.0115	.0114	.0408	.0263
10-11	.0000	.0123	.0213	.0224
11-12	.0154	.0105	.0217	.0190
12-13	.0000	.0089	.0222	.0116
13-14	.0156	.0076	.0227	.0138
14-15	.0000	.0015	.0000	.0117
15-16	.0159	.0056	.0232	.0100
16-17	.0161	.0047	.0238	.0000
17-18	.0000	.0040	.0000	.0072
18-19	.0164	.0034	.0243	.0061
19-20	.0000	.0029	.0000	.0050

Table 2: Average decrease per day in albedo, comparing the U.S.A.C.E. method and eqs. 7 and 8. Percent difference between eq. 7 and U.S.A.C.E. method for days 0-7 is .0117% and for days 8-20 is .0005%. Percent difference between eq. 8 and U.S.A.C.E. method for days 0-7 is .0114% and for days 8-20 is .0039%.

a computer prediction model. Fig. 7 is a copy of the flow chart used for the albedo estimating programme.

3.3 Correction Factor

Running the programme, Petzold (1977) found the model to consistently underpredict the actual albedo. To compensate for this he found a relationship between this error and the age of the snow, and applied it to the data. The correction factor is as follows:

$$\% \text{ correction} = 3.86 + 0.380 + 0.123D^2 \qquad (9)$$

$$r = .95$$

where D is the age of the snow greater than zero days. This correction factor was developed on an 11 day period of no new snow, where the surface decayed at a constant rate. The correction factor was tested on a 42 day period in the summer of 1969 at the Meighan Ice Cap, N.W.T. The accuracy range was found to be $\pm$ 5.00%.

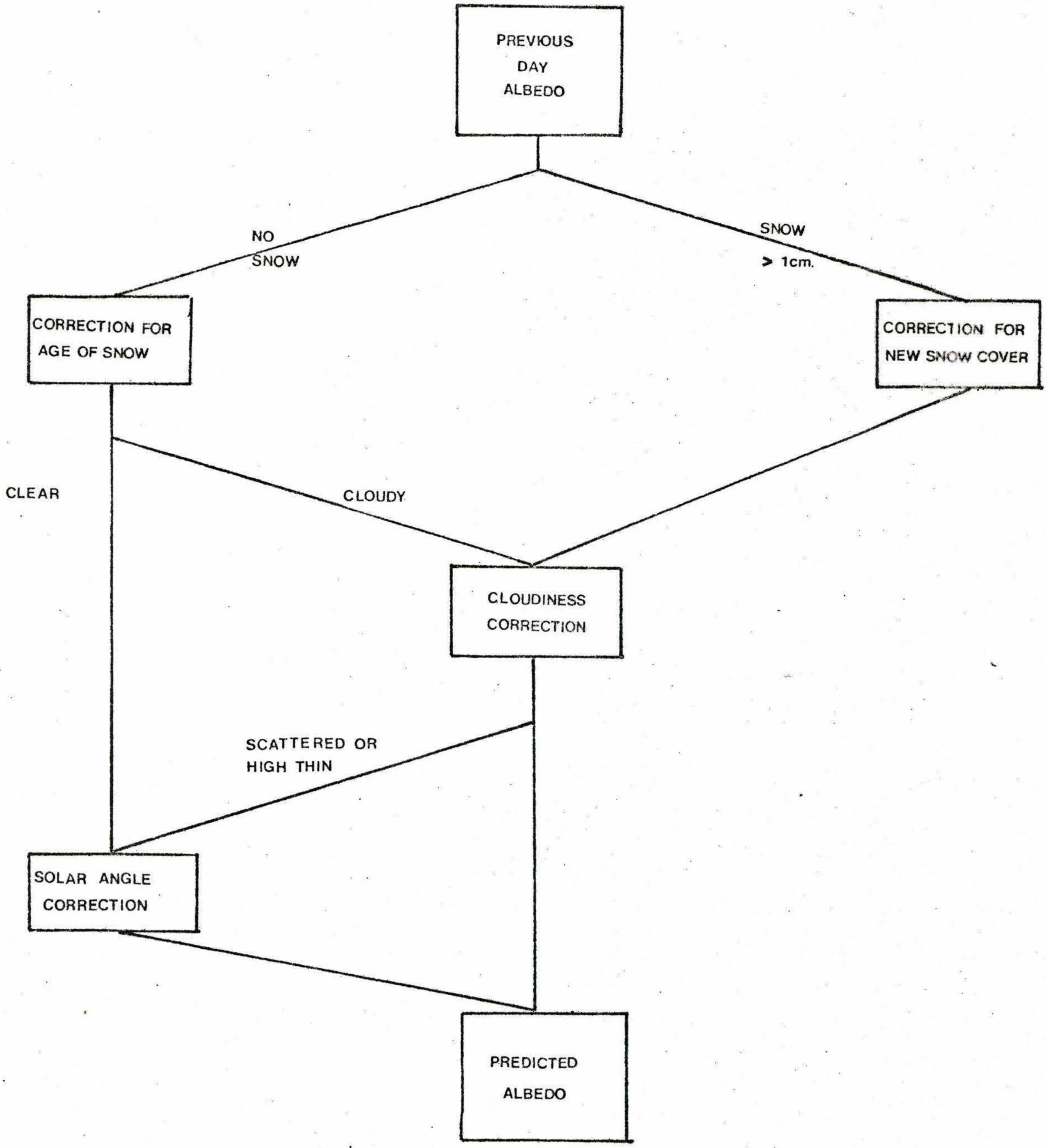


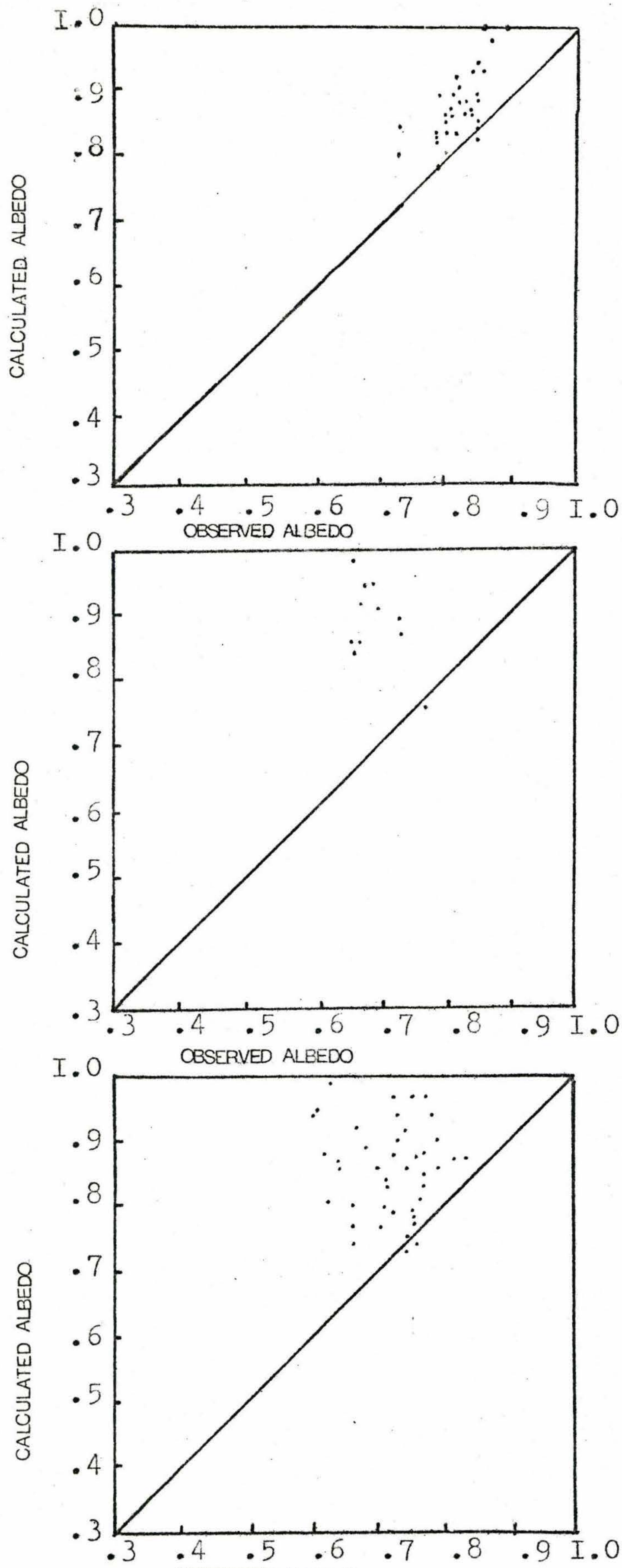
Fig. 7. Albedo Prediction Flow Chart
(from Petzold, 1977).

CHAPTER 4

TEST RESULTS

Following Petzold's (1977) method using cloud amount, daily maximum temperature and number of days since last snowfall, plus his correction factor, the model does not work for two of the three stations. The percent errors are as follows: Goose Bay ± 6.00%, Resolute ± 19.45%, and Toronto ± 27.60%. Goose Bay is the only station with an acceptable error and the only station that comes close to Petzold's estimated error of ± 5.00%. Fig. 8 plots Petzold's calculated albedo against the observed. In all cases the model overestimates albedo. It was generally found at the three stations that the percent error per day increased with the number of days since the last snowfall, possibly indicating an error at the beginning which is compounded when predicted upon. (Appendix 3 gives tables of actual albedo values and predicted values).

To correct for the large error occuring when using Petzold's method, regressions were run seperately for each station on (i) cloud amount and albedo, (ii) cloud amount and percent change in albedo, (iii) accum-



(a) Goose Bay
Percent Error= 6.00%

(b) Toronto
Percent Error = 27.60%

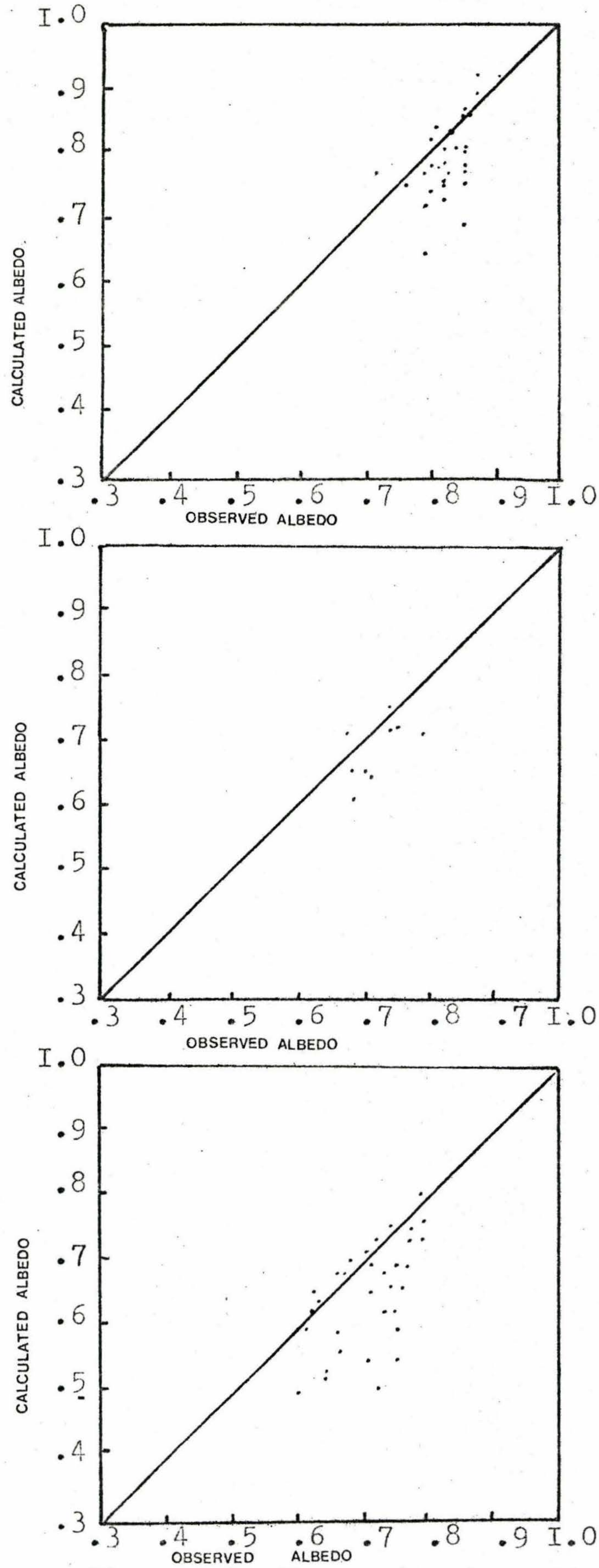
(c) Resolute
Percent Error = I9.45%

Fig. 8. Observed and predicted albedo for the three stations.

ulation season: days since last snowfall and albedo, (iv) accumulation season: days since last snowfall and the percent change in albedo from day zero, (v) melt season: days since last snowfall and albedo, and (vi) melt season: days since last snowfall and the percent change in albedo from day zero. The albedo was then estimated using the percent changes.

When using the effects of cloud amount while predicting albedo, the first prediction was corrected to the previous days cloud amount and subsequent days were estimated upon their corrected figure. Fig. 9 plots the new predicted albedo against the actual albedo. A marked reduction in the percent error experienced at each station is evident. Goose Bay's error reduced to ± 5.94%, Toronto's to ± 6.18% and Resolute's to ± 9.44%.

In Fig. 9 it can be seen that the range of the actual albedos for each station is fairly small. Goose Bay's albedos tend to "cluster" about .85, and Toronto's and Resolute's around .75. These values would tend to be a mode rather than a mean value. Taking the model one step further, Fig. 10 shows the results of using the above "cluster" values to predict upon each time instead, as previously used, predicting

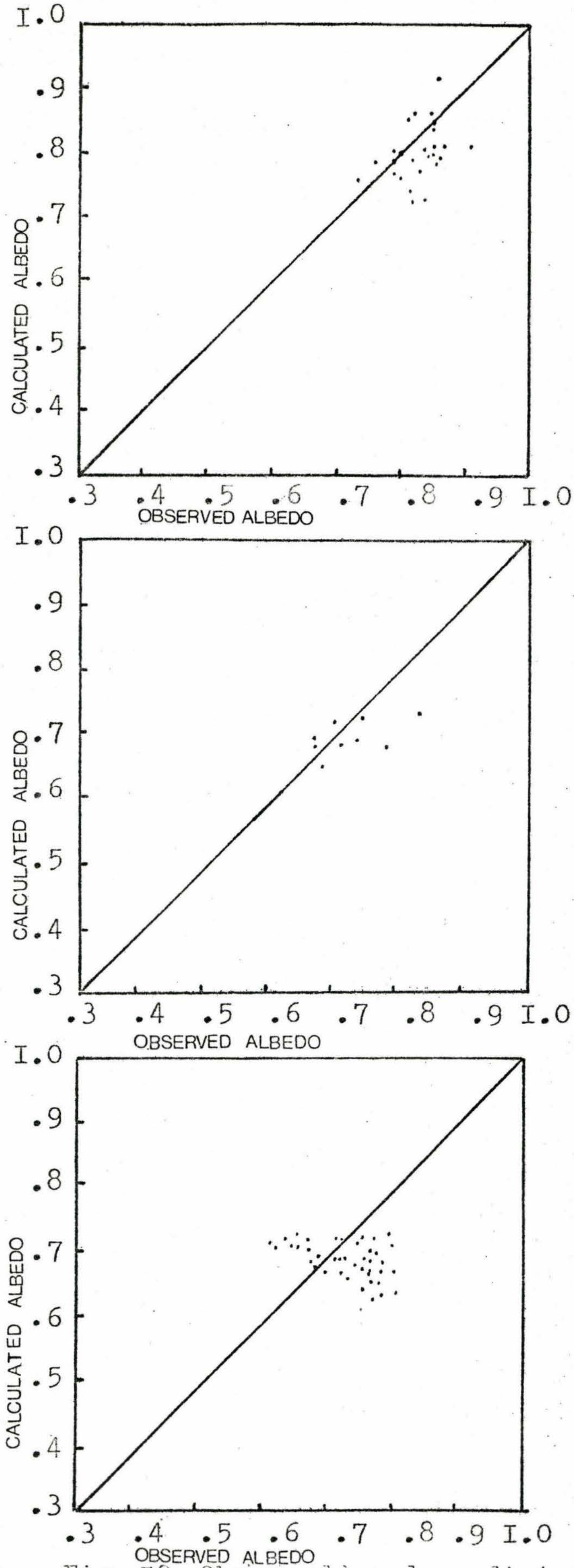


(a) Goose Bay
Percent Error =
5.94%

(b) Toronto
Percent Error =
6.I8%

(c) Resolute
Percent Error =
9.44%

Figure. 9. Observed and predicted albedo at the three stations.



(a) Goose Bay
Percent Error =
4.45%

(b) Toronto
Percent Error =
5.08%

(c) Resolute
Percent Error =
9.33%

Fig. IO. Observed and predicted albedo for the three stations.

using this third method further reduces the percent error, Goose Bay's becoming 4.45%, Toronto's becoming 5.08%, and Resolute's error becoming 9.22%.

CHAPTER 5

DISCUSSION OF RESULTS

Petzold's (1977) model of albedo estimation has proven not to be reliable in estimating albedo. Using this method Goose Bay was the only station to have an acceptable percent error. This may be due to the frequency of snowfall events because as was previously stated, the error gets larger with an increase of days since last snowfall. In the case of Toronto the sinusoidal relationship between cloud cover and albedo as shown in Fig. 3 gives reason for the original estimation model not working. The model assumes an increasing relationship between cloud cover and albedo, which does not occur in the Toronto data. Eq. (6) has been developed for this relationship.

Toronto, due to its climatic conditions has very little useable data over a full year period, and increasing the data base may improve the model. At all stations the location of snow measuring instruments at airports creates a problem. Because of this location, the melt period seems to be very short.

In Fig. 6 Petzold includes the effects of solar zenith angle on albedo but does not incorporate this effect into the working model. It has been recorded (Hubley, 1955, Salomonson and Marlatt, 1968, Bergen, 1975, Dirmhirn and Eaton, 1975) that changes in solar zenith angle significantly affect the albedo of snow, especially for clear days and solar angles under 40°-45°. Over snow, the albedo varies inversely with solar angle and is roughly symmetrical about noon. Unfortunaltely for this study, specific information for snow was unavailable. Petzold stated the U.S.A.C.E. model consistantly underestimated the albedo, thus he added his correction factor. Possibly the inclusion of the effects of zenith angle on albedo would increase the estimated albedo and decrease the percent error. This may also be the case in the last two methods of estimation presented in this study.

Hubley(1955) stated there is very little albedo dependence on the angle of incident radiation over fresh snow, but as snowpack metamorphism takes place, specular reflection appears and is manifest as a variation in albedo with zenith angle. This again may be the reason for the increasing error as the age of the snow increases.

The third method of estimation gives interesting results and poses important qusetions. Because the range of actual albedo is so small, using a standard albedo for each station to predict upon gives better results in all cases. It would be useful to increase the data base to at least 10 years and determine if the results still prove to be satisfactory.

CHAPTER 6

CONCLUSION

The model which Petzold(1977) presents does not adequately estimate albedo over snow. More information such as the effect of zenith angle on snow surface is important and has been omitted from this study.

The most interesting find shows better agreement between calculated and observed albedos using a mode or "cluster" albedo than with any other method investigated. If, as is suggested, the albedo values stay within a certain range, it is possible that the modelling method need not include the actual albedo. Better results are obtained by using the "cluster" method.

Increasing the data base would prove this correct or incorrect. Using a larger data base and breaking the data into accumulation and melt seasons, and obtaining a "cluster" value for each season is another possible way of improving the model. A more thorough study is needed to determine this.

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APPENDIX ONE

Curve Equations for Fig. 4

Albedo Variation with Cloud Cover

Toronto: $y = .66837 + .06386x - .01546x^2 + .00100x^3$

Goose Bay: $y = .79233 + .00509x - .00029x^2 + .00008x^3$

Resolute: $y = .73825 + .00692x - .00027x^2 + .00000x^3$

APPENDIX TWO

Curve Equations for Fig. 6

Accumulation: Albedo Variation with Days Since Last Snow

Toronto: $y = .79889 - .00878x - .01813x^2 + .00287x^3$

Goose Bay: $y = .87773 - .04087x + .00975x^2 - .00093x^3$

Resolute: $y = .78450 - .06722x + .01633x^2 - .00119x^3$

Melt: Albedo Variation with Days Since Last Snow

Toronto: $y = .69524 - .03750x + .02369x^2 - .00500x^3$

Goose Bay: $y = .70778 - .04185x + .01194x^2 - .00176x^3$

Resolute: $y = .64833 - .02663x + .01226x^2 - .00278x^3$

APPENDIX THREE

Actual and Predicted Albedos for Toronto, Goose Bay and Resolute

(i) Toronto

Date	Actual Albedo	Predicted Albedo I	Predicted Albedo II	Predicted Albedo III
Jan.				
8	.78			
9	.78	.76	.79	.71
29	.77			
31	.67	.86	.81	.71
Feb.				
1	.71	.91	.73	.64
2	.68	.92	.60	.61
Mar.				
24	.78			
25	.74	.87	.85	.72
26	.74	.89	.83	.75
27	.68	.86	.74	.65
28	.67	.84	.64	.63

(ii) Goose Bay

Date	Actual Albedo	Predicted Albedo I	Predicted Albedo II	Predicted Albedo III
Dec.				
17	.87			
18	.80	.86	.83	.78
19	.80	.83	.77	.74
20	.80	.80	.71	.68
25	.93			
26	.82	.92	.89	.81
27	.79	.89	.84	.77
28	.93			
29	M	.88	.89	.87
30	.80	.85	.86	.82
31	.82	.83	.80	.76
Jan.				
1	.79	.83	.74	.72
2	.79	.82	.76	.65
14	.81			
15	.73	.80	.77	.71
20	.82			
21	.76	.81	.78	.75
Feb.				
8	.85			
9	.84	.93	.81	.81
10	.82	.90	.75	.76
11	.85	.88	.68	.69
12	.88			
13	.86	.94	.93	.86

Date	Actual Albedo	Predicted Albedo I	Predicted Albedo II	Predicted Albedo III
Feb.				
17	.87			
18	.83	.86	.83	.83
19	.85	.85	.81	.78
29	.88			
Mar.				
1	.81	.84	.84	.84
3	.87			
4	.85	.86	.88	.79
5	.86	.93	.88	.79
9	.86			
10	.85	.84	.83	.81
11	.85	.82	.87	.77
12	.88			
13	.84	.84	.85	.75
15	.88			
16	.85	.88	.91	.87
17	.93			
18	.87	.97	.99	.89
20	.87			
21	.84	.86	.83	.81
22	.82	.83	.77	.73
23	.85	.84	.76	.84
28	.89			
29	.82	.88	.85	.77
30	.82	.86	.87	.78
31	.81	.89	.87	.78
April				
1	.85	.89	.84	.74

(iii) Resolute

Date	Actual Albedo	Predicted Albedo I	Predicted Albedo II	Predicted Albedo III
Sept.				
2	.79			
3	.72	.88	.79	.73
6	.77			
7	.70	.86	.77	.71
8	.67	.92	.75	.68
9	.63	.99	.70	.64
10	.65			
11	.66	.74	.65	.59
12	.66	.80	.63	.56
13	.64	.87	.59	.52
15	.76			
16	.77	.85	.76	.69
17	.76	.83	.73	.66
18	.75	.79	.68	.63
20	.71	.83	.61	.55
21	.64	.86	.58	.53
22	.60	.92	.55	.50
23	.73			
24	.66	.77	.73	.68
25	.62	.81	.70	.65
26	.62	.88	.66	.62
27	.61	.95	.62	.59
Oct.				
5	.77			
6	.68	.79	.77	.70
9	.78			
10	.83	.87	.78	.72
12	.81	.93	.71	.64

Date	Actual Albedo	Predicted Albedo I	Predicted Albedo II	Predicted Albedo III
20	.85			
21	.77	.88	.84	.75
Feb.				
14	.86			
15	.78	.94	.82	.76
16	.73	.94	.74	.68
18	.72	.97	.56	.50
24	.90			
26	.79	.86	.77	.73
27	.76	.87	.72	.68
28	.74			
Mar.				
1	.84			
2	.77	.83	.79	.73
3	.71	.80	.71	.65
4	.75	.77	.64	.55
5	.74	.75	.56	.47
6	.70	.77	.53	.44
8	.75			
9	.75	.74	.70	.69
26	.87			
27	.79	.86	.81	.76
28	.77	.83	.72	.68
29	.76	.81	.63	.59
April				
7	.84			
8	.79	.90	.84	.80
9	.74	.86	.78	.75
10	.71	.84	.72	.69
11	.74	.92	.69	.60
12	.73	.90	.65	.63