Preliminary Analysis of Water Equivalent/Snow Characteristics Using LANDSAT Digital Processing Techniques

Carolyn J. Merry[1], Harlan L. McKim[2], Saul Cooper[3] and Stephen G. Ungar[4]

ABSTRACT

The primary emphases of this analysis was to evaluate the accuracy of mapping the areal extent of snow and to determine the relationship between the water equivalent of the snowpack and the radiance obtained from the LANDSAT digital data. The test area selected for this task was the Dickey-Lincoln School Lakes Project located above the confluence of the St. John and Allagash Rivers in northern Maine.

The computer algorithm utilized in this study uses two features--"color" and "albedo"--of the LANDSAT digital data to classify the multispectral data into land and water categories. The "color" of each pixel refers to the relative energy distribution among the four spectral bands (0.5-0.6μ, 0.6-0.7μ, 0.7-0.8μ and 0.8-1.1μ), whereas, the "albedo" refers to the total radiant energy for the entire wavelength region of the four bands (0.5-1.1μ).

Three snow courses (Allagash B, Beech Ridge and Ninemile B) yielding snow depth and water equivalent data were located on the 11 February 1973 computer compatible tape (CCT). This task was accomplished using computer-generated gray scale printouts (scale 1:24,000) and topographic maps. The preliminary results indicated that the snow radiance values remained approximately the same for a similar water equivalent value of 9.5 inches. Extrapolation of these radiance values for the entire watershed can be used to map the areal extent of snow cover/vegetation with a water equivalent value of 9.5 inches which enables computation of potential water runoff.

Future work will include refinement of extrapolation techniques to map classes of snow cover related to water equivalent for a known vegetative cover, slope and aspect for sites located within and outside the Dickey-Lincoln School Lakes Project area. The sites used in the 11 February scene will be studied on the 26 November, 19 April and 23 July CCTs. The change in snow radiance with time will be related to the accumulation and ablation of the snowpack at individual sites. Establishing this relationship will provide techniques that will be useful in subsequent years for predicting spring runoff from snowmelt as long as the site characteristics do not change significantly.

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[1]Research Geologist, Earth Sciences Branch, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

[2]Research Soil Scientist, Earth Sciences Branch, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

[3]Chief, Water Control Branch, New England Division, Corps of Engineers, Waltham, Massachusetts

[4]Director, Earth Resources Program, NASA Goddard Institute for Space Studies, New York, New York

INTRODUCTION

Objective

The primary objective of this analysis is 1) to evaluate LANDSAT digital data as a rapid and effective means of providing snow cover maps and 2) to determine a relationship between the water equivalent of the snowpack and the radiance obtained from LANDSAT digital data. Once a general relationship is found, the correlation of water equivalent in a snowpack to spectral signatures developed from the computer compatible tapes (CCTs) could be used to estimate the spring water runoff. The test area selected for this task is the Dickey-Lincoln School Lakes Project located above the confluence of the St. John and Allagash Rivers in northern Maine (Fig. 1). Discussed in this paper are preliminary results from an analysis of an 11 February 1973 LANDSAT scene.

Description of the LANDSAT CCTs

The LANDSAT satellite circles the earth in a 572 mi (920 km) near-polar orbit once every 103 minutes, completing approximately 14 orbits per day. A black and white photographic data product can be processed from the multispectral scanner (MSS) imaging system of an area approximately 115 mi (185 km) on a side for the following spectral regions: band 4 (0.5-0.6μ), band 5 (0.6-0.7μ), band 6 (0.7-0.8μ) and band 7 (0.8-1.1μ). This information can also be obtained in digital form on a CCT (NASA 1972).

The standard LANDSAT CCT was computer processed to produce a geometrically corrected tape with observations transformed to a UTM (Universal Transverse Mercator) grid. This geometrically corrected CCT is comprised of 2432 scan lines with each scan line covering 3200 pixels.* Differing levels of radiant energy within the scene are registered on a scale from 0 to 127 (minimum to maximum) for bands 4, 5 and 6 and 0 to 63 for band 7 (Thomas 1975).

Description of the computer algorithm

The geometric correction and the computer classifications used in this analysis were performed at the NASA Goddard Institute for Space Studies (GISS) via a remote entry terminal at USACRREL. The classification algorithms used in the study were developed at GISS (Ungar 1977).

The LANDSAT MSS observation may be thought of as a point in a four-dimensional "color" space, where the values along each axis represent the radiant energy received by the satellite in one of the four bands (this is illustrated for three bands in Fig. 2a). Observations lying in a similar direction from the origin in this four-dimensional color space

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* picture element, whose dimensions are 61 x 76 meters.

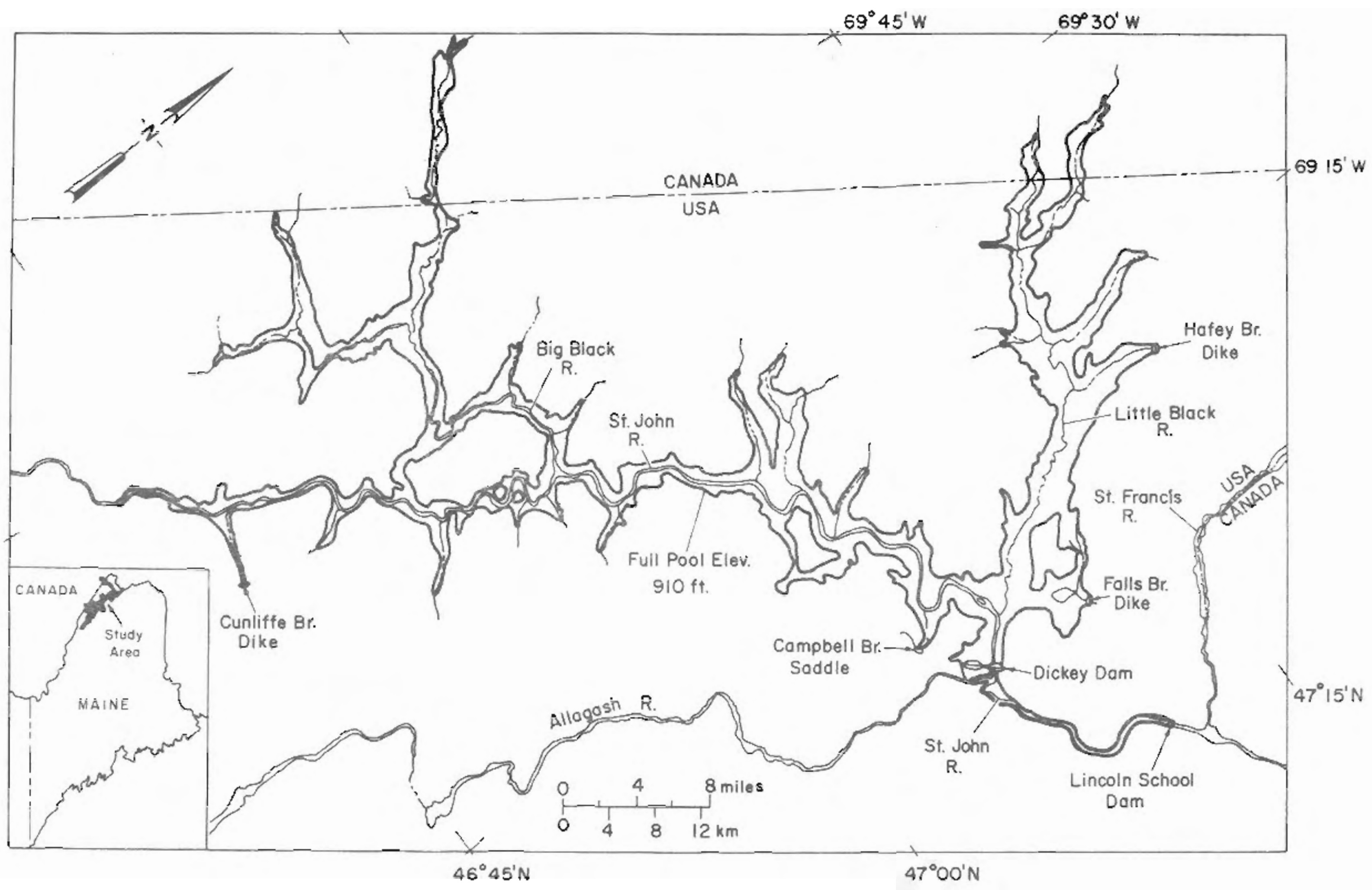
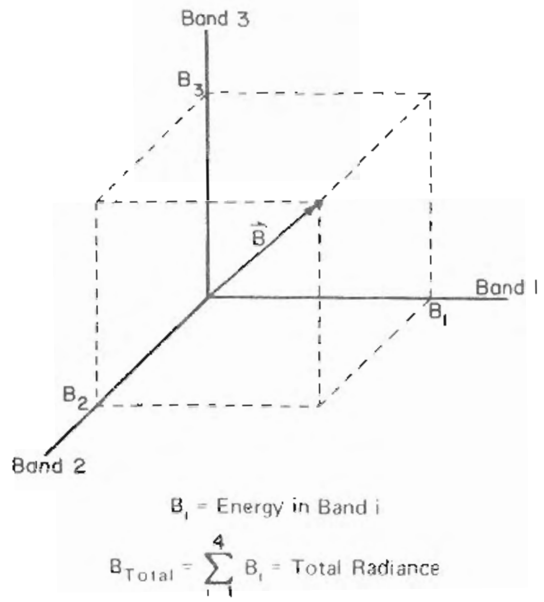
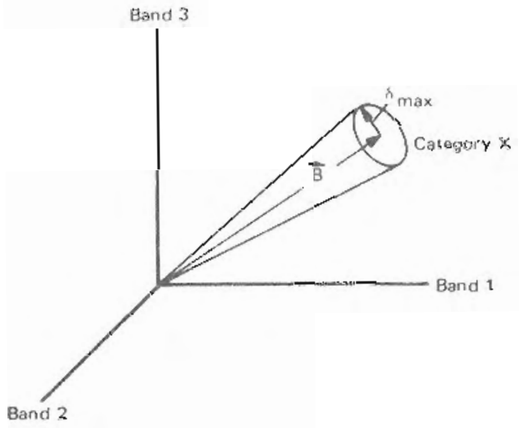


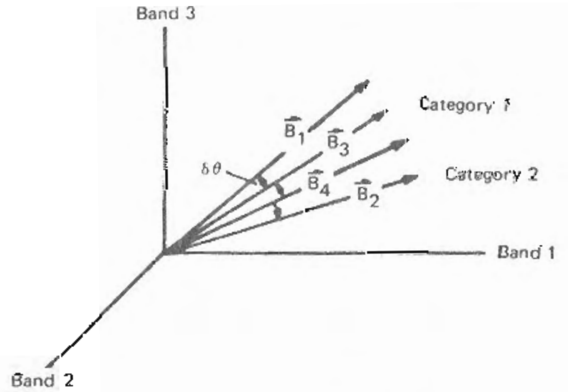
Figure 1. Site location map of Dickey-Lincoln School Lakes Project, Maine.



a. A color vector which is illustrated for three bands.



b. Supervised mode. The user-defined criterion, δ_{max}, defines category X about the specified signature, $\vec{B}$. Any color vector that lies within this cone belongs to category X.



c. Unsupervised mode. $\vec{B}_3$ is similar in direction to $\vec{B}_1$ ($\delta\theta \leq \delta_{max}$) and placed in category 1. $\vec{B}_4$ is similar in direction to $\vec{B}_2$ and placed in category 2. However, $\vec{B}_4$ is also similar in direction to $\vec{B}_3$ (category 1). Therefore, category 1 is merged with category 2.

Figure 2. Concept of the four-dimensional "color" space, represented in three bands.

are said to be similar in color regardless of their total radiant energy. The distance of an observation from the origin is a measure of the total radiance associated with that data point. The algorithm is primarily designed to combine observations similar in color into the same classification category. There is provision for evaluating brightness differences and for weighting these differences in with the color discrimination when constructing the classification categories.

Discrimination based solely on color is obtained when one examines the difference in direction between the color vectors (observations). If the angle between the observations is smaller than some user-defined *criterion* the vectors are considered to be lying in the same direction and, therefore, the observations are placed in the same category.

There are two modes in which this classification scheme may be employed, supervised and unsupervised. In the supervised mode the user specifies a *signature* (the energy distribution in the four LANDSAT bands). If an observation lies within an angle smaller than the user-defined criterion, δ_{max}, it is said to belong to the category represented by the signature (Fig. 2b). Therefore, all vectors lying within a cone of angle, δ_{max}, about the signature representing category X belong to category X.

In the unsupervised mode the color vector corresponding to the first observation is compared with all subsequent observations. If color vector 1 is similar in direction to color vector 2 (i.e. $\delta\theta \leq \delta_{max}$), observation 2 is placed in the same category as the first observation (Fig. 2c). In a similar fashion observations subsequent to observation 2 are compared to the second observation and so on right up to the last observation. If in the process of constructing categories, a member is found which belongs to a previous category, the new category is *chained* to the original classification category forming one joint category. In effect the unsupervised classification will form several categories based on a criterion specifying maximum color difference permissible between members of the same category.

In addition to discrimination based solely on color, the GISS algorithm provides the capability of weighting total radiance (*albedo*) differences into the discriminant. The percent albedo difference between two observations is computed. This normalized albedo difference is then combined with the color difference angle (expressed in radians) by performing a weighted average in the RMS (root mean square) sense. This albedo-weighted quantity is now compared with the user-defined criterion. A relatively small albedo weighting allows very large albedo differences to disqualify observations that are similar in color from membership in the same category, thereby adding a second level of discrimination. Discrimination of the classification categories based partially on overall brightness differences plays an important role for the work discussed in this paper.

Literature review

Manual methods have been used to delineate the areal extent of snow and the mean altitude of the snowline from LANDSAT photographic data products (Barnes and Bowley 1974, Meier 1975a, Meier 1975b). However, a quantitative measure of the water equivalent of the snowpack has not been obtained from LANDSAT photographic data products. Usually the areal extent of snow has been related indirectly to subsequent watershed runoff occurring during the springtime (Meier 1975c). Another LANDSAT manual interpretation method has used a coded snow cover classification scheme to account for vegetation cover, density, aspect, elevation and slope to map the areal extent of snow (Katibah 1975).

A snow mapping experiment comparing the identification of six snow cover types was accomplished using three image processing systems--LARSYS Version 3, STANSORT-2 and General Electric Image-100 (Itten 1975). In addition, other studies have focused on digital analyses of LANDSAT data in defining various snow cover types (Bartolucci et al. 1975, Dallam 1975, Luther et al. 1975). In these studies a quantitative estimate of water equivalent content associated with snow cover types was not accomplished. In one case it was suggested that spectral variations within the snowpack area could not be reliably determined because of detector saturation problems (Bartolucci 1975).

Another study used simulated infrared LANDSAT color composites and snow course data to estimate water equivalent related to the snowpack (Sharp 1975). In this study sampling units on the LANDSAT image were mapped to determine the areal extent of snow. An estimation of a snow water content index was calculated using a linear regression equation relating the imagery to ground truth data.

It has been stated that remote sensing might be used to detect subtle differences within the snowpack since the magnitude and wavelength of reflectance vary with snow type (Mellor 1965). Also, the albedo is high for a layer of new snow and as the new snow coalesces and coarsens in texture the albedo falls steadily (Bergen 1975). In addition, a reduction in the spectral reflectance occurs from the combination of densification and increased particle size associated with aging (McGinnis et al. 1975). Therefore, it is believed that the LANDSAT CCTs may contain useful information that can be used to estimate water equivalent in a snowpack. If so, then LANDSAT digital data can be used for estimating spring runoff from a large watershed more accurately than is now available.

APPROACH

Site description

The Dickey-Lincoln School Lakes Project, Maine, is presently being evaluated by the NEDCE for the generation of hydroelectric power, flood control and recreational purposes and was an ideal site for an analysis of snow cover utilizing the LANDSAT CCTs. Due to the remoteness and inaccessibility of the area there is no adequate data collection system for evaluating the water equivalent of the snowpack each year.

The climate of this region is characterized by short, cool summers and long, cold windy winters. Average annual temperature is 39°F (3.9°C) with extremes of -40°F (-40°C) in the winter to 99°F (37°C) in the summer (New England Division, Corps of Engineers 1967). The average annual precipitation is approximately 36 in (91 cm) and occurs uniformly throughout the year with about 30% in the form of snow. The average annual snowfall is about 100 in (254 cm) which occurs during 8 months of the year (New England Division, Corps of Engineers 1967). Average winter snow depth ranges between 20 to 40 in (51 to 102 cm) with the upper limit exceeding 50 in (127 cm). Water equivalent of the snowpack reaches a maximum in late March and usually exceeds 10 in (25 cm). The geology and vegetation of the Dickey-Lincoln School Lakes Project area was previously mapped and served as a data base of site characteristics in this study (McKim and Merry 1975, McKim 1975).

Snow course description

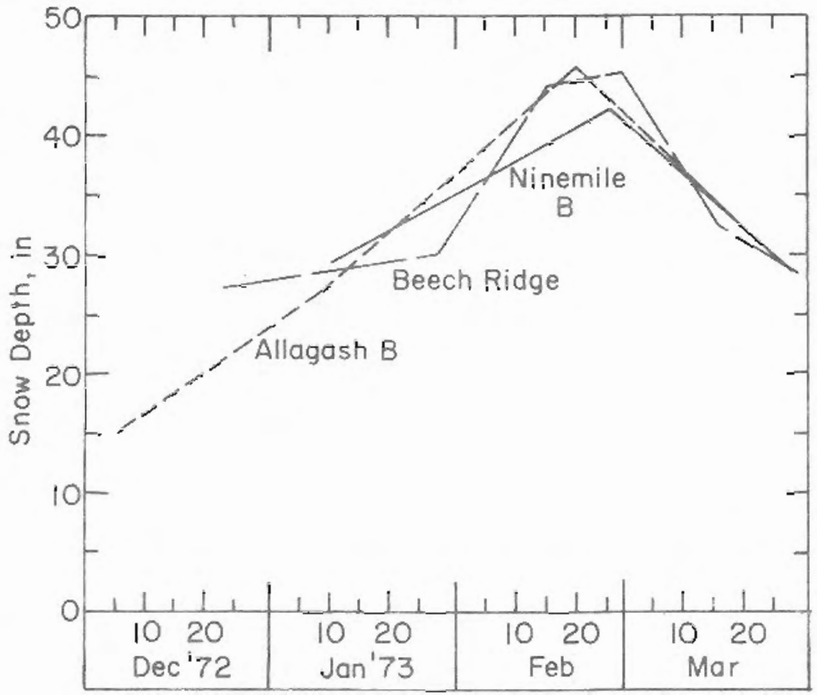
The ground truth consisted of snow course data obtained in the upper St. John River Basin by the U. S. Geological Survey and the Allagash Wilderness Waterway (Fig. 3). The snow depth and water equivalent for each snow course shown in Table I was obtained from Figure 3 for the date of 11 February 1973 (U.S. Department of Commerce 1973, Li and Davar 1975).

Table I. Snow course data (11 February 1973).

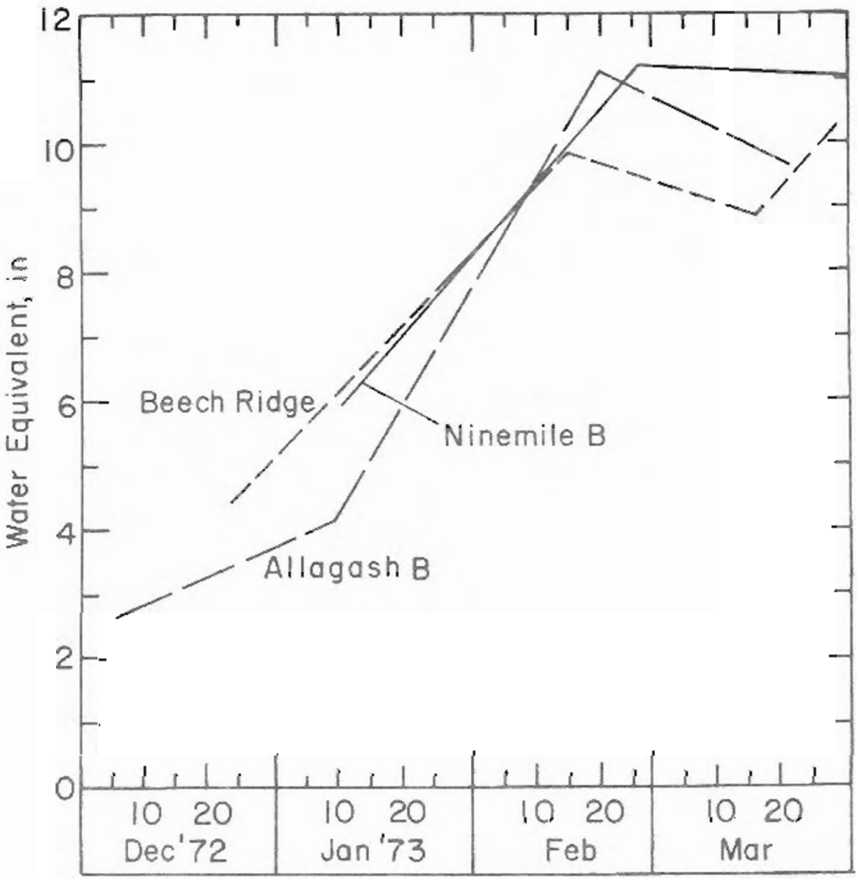
Snow course	Latitude/ Longitude	Snow course length	Sampling points	Snow depth (in)*	Water equivalent (in)*
Allagash B	47°05'N/69°04'W	1000	10	42	9.6
Beech Ridge	46°36'N/69°28'W	-	-	41	9.4
Ninemile B	46°42'N/69°43'W	1000	10	38	9.5

*1 in = 2.54 cm

The Allagash B snow course is located within a mixed forest near the confluence of the Allagash and St. John Rivers at an elevation of about 640 ft. It is characterized by a southeast exposure with gently sloping terrain. The Beech Ridge snow course is located within a mixed forest near the Frontier-Churchill Road near Umsaskis Lake at an elevation of about 1300 ft. It is characterized by a western exposure on gently sloping terrain. The Ninemile B snow course is located within a coniferous



a. Snow depth



b. Water equivalent

Figure 3. Snow depth and water equivalent data for selected snow courses in the Dickey-Lincoln School Lakes Project, Maine, during the 1972-73 winter season (1 in = 2.54 cm).

forest on the floodplain near the USGS gaging station on the St. John River at an elevation of about 950 ft and is characterized by a northwest exposure.

The snow courses were located on the 11 February 1973 CCT by generating a geometrically corrected, 16-level grayscale computer printout of a 320 by 256 pixel area (146.9 mi^2 or 380.6 km^2) on a scale of 1:24,000. The observations were assigned into 16 levels or shades of gray depending on their radiance values in MSS band 7. The snow course sites were located on the gray scale printouts using available topographic maps as reference.

The test site containing each snow course is 40 by 32 pixels for a total area of 2.3 mi^2 (6.0 km^2). The snow course was located in the center of each computer test site. The computer algorithm described previously was applied to extract information concerning the spectral characteristics of the snow cover/vegetation within the snow course computer test sites.

Computer classification

Unsupervised classifications were performed on the three snow course sites for a range of δ_{max} (delmax) values between 0.02 and 0.04 with several albedo weightings (for example, 0.1, 0.2, 0.3). Computer runs which produced large numbers of categories were selected so that several signatures could be extracted for the pixels contained within the snow course areas. This allowed for an evaluation of signature variation within each snow course. The sun elevation angle (23°) of the scene was corrected to zenith to account for seasonal variations in irradiance.

RESULTS AND DISCUSSION

The snow course computer classification maps are shown in Figures 4, 5 and 6. The location of the snow course is shown outlined on the computer test site. The snow radiance values associated with each pixel within the snow course are indicated by the arrows within the *categorization summary*. In this summary the two left hand columns are the category symbol and the number of pixels (*num*) within each classification category, respectively. The *tol* column is a measure of the variation between the signatures within a category, with the smaller numbers indicating little variation. The *normalized radiances* in each band *(B1', B2', B3' and B4')* are listed for each category; these four values always total 1. Also, the *true radiances* are listed for each band *(B1, B2, B3 and B4)*; these values sum to the total radiance (units in $mw/cm^2/sr$*) listed in the *albedo* column. The *delmax* and the *albedo weighting* used in the unsupervised classification are indicated toward the bottom of the summary.

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* milliwatts/centimeter squared/steradian

ALLAGASH B SNOW COURSE
640' ELEVATION   ASPECT: SOUTHEAST

WATER EQUIV. 9.6"
SNOW DEPTH 42"

DIGITIZED OUTPUT OF SUBSEGMENT(S) 726,
SHOWING 45 CATEGORIES

CATEGORIZATION SUMMARY

	NUM.	TOL.	B1' B1	B2' B2	B3' B3	B4' B4	ALBEDO
/	157	2.	0.26 1.38	0.16 0.87	0.16 0.89	0.42 2.24	5.38
*	126	2.	0.27 1.33	0.16 0.81	0.16 0.82	0.41 2.06	5.01
.	120	2.	0.27 1.25	0.16 0.74	0.16 0.75	0.41 1.87	4.62
+	118	1.	0.25 5.12	0.21 4.15	0.17 3.39	0.37 7.57	20.23
Q	101	2.	0.25 1.47	0.16 0.95	0.17 0.96	0.42 2.43	5.81
W	75	2.	0.25 1.51	0.16 1.00	0.17 1.02	0.43 2.62	6.15
)	57	2.	0.25 1.62	0.16 1.08	0.16 1.09	0.43 2.80	6.59
E	49	2.	0.24 1.70	0.16 1.15	0.17 1.16	0.43 2.99	7.00
R	47	2.	0.28 1.17	0.16 0.68	0.17 0.71	0.40 1.68	4.24
T	19	1.	0.24 1.75	0.16 1.20	0.17 1.23	0.43 3.18	7.36
Y	13	1.	0.24 1.95	0.17 1.37	0.17 1.37	0.42 3.36	8.06
U	12	1.	0.30 1.20	0.16 0.65	0.16 0.66	0.37 1.50	4.00
I	10	1.	0.23 1.99	0.16 1.41	0.17 1.43	0.44 3.74	8.57
O	9	1.	0.23 1.95	0.17 1.41	0.17 1.41	0.43 3.55	8.32
&	8	1.	0.25 1.95	0.17 1.35	0.16 1.27	0.41 3.18	7.74
P	8	1.	0.26 1.96	0.18 1.34	0.16 1.24	0.40 2.99	7.53
A	8	1.	0.23 2.57	0.18 2.02	0.17 1.90	0.41 4.53	11.02
_	7	.	0.28 1.09	0.17 0.64	0.16 0.63	0.39 1.50	3.87
D	6	1.	0.26 1.71	0.17 1.11	0.17 1.12	0.40 2.62	6.56
F	5	1.	0.24 2.80	0.19 2.13	0.17 1.94	0.40 4.60	11.47
G	5	1.	0.25 3.94	0.19 3.10	0.17 2.67	0.39 6.28	15.99
H	5	0.	0.25 1.09	0.15 0.69	0.18 0.78	0.42 1.87	4.42
J	4	0.	0.25 1.20	0.17 0.79	0.19 0.69	0.39 1.87	4.74

CATEGORIZATION SUMMARY

	NUM.	TOL.	B1' B1	B2' B2	B3' B3	B4' B4	ALBEDO
K	4	1.	0.23 3.30	0.19 2.69	0.16 2.31	0.42 5.93	14.24
L	4	1.	0.23 1.77	0.17 1.30	0.17 1.28	0.44 3.36	7.71
Z	4	1.	0.24 2.41	0.19 1.87	0.17 1.68	0.41 4.11	10.08
X	4	1.	0.24 2.51	0.18 1.89	0.17 1.78	0.41 4.30	10.49
C	4	1.	0.28 2.21	0.18 1.45	0.16 1.26	0.38 2.99	7.91
=	4	1.	0.27 1.06	0.15 0.60	0.15 0.59	0.43 1.68	3.94
V	4	1.	0.27 1.74	0.17 1.09	0.18 1.12	0.38 2.43	6.37
B	3	1.	0.23 3.56	0.19 2.97	0.17 2.53	0.40 6.17	15.23
(	3	1.	0.30 3.23	0.21 2.34	0.16 1.79	0.33 3.55	10.91
N	3	1.	0.25 2.40	0.18 1.77	0.16 1.56	0.41 3.92	9.66
M	3	1.	0.24 1.20	0.16 0.79	0.18 0.90	0.42 2.06	4.95
,	3	0.	0.27 1.10	0.17 0.69	0.19 0.74	0.37 1.49	4.02
1	3	1.	0.25 1.17	0.15 0.73	0.17 0.79	0.43 2.06	4.74
2	3	0.	0.24 1.72	0.17 1.26	0.18 1.29	0.41 2.99	7.26
3	3	0.	0.28 1.80	0.19 1.21	0.16 1.04	0.38 2.43	6.46
4	3	1.	0.24 3.40	0.19 2.65	0.17 2.38	0.40 5.61	14.03
5	3	0.	0.30 1.10	0.17 0.60	0.17 0.60	0.36 1.31	3.62
6	3	0.	0.22 1.55	0.16 1.13	0.16 1.08	0.46 3.18	6.93
7	3	1.	0.25 2.12	0.17 1.45	0.17 1.37	0.41 3.36	8.30
8	3	1.	0.31 1.00	0.18 0.56	0.16 0.52	0.35 1.12	3.21
9	3	0.	0.31 1.05	0.17 0.56	0.18 0.60	0.34 1.12	3.34
0	3	0.	0.23 1.75	0.16 1.17	0.16 1.22	0.45 3.36	7.50

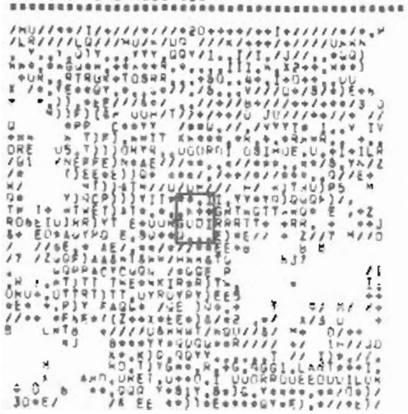
NO. POINTS CLASSIFIED = 1048 NO. POINTS UNCLASSIFIED = 232

DELMAX = 0.0200   ALBEDO WEIGHTING = 0.500

100.00 PERCENT OF BAND 1 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 2 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 3 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 4 USED IN ALBEDO CALC.

Figure 4. Computer classification map of the Allagash B snow course.

DIGITIZED OUTPUT OF SUBSEGMENT(S) 600, SHOWING 48 CATEGORIES



BEECH RIDGE SNOW COURSE
1300' ELEVATION ASPECT: WEST

WATER EQUIV. 9.4" SNOW DEPTH 41"

CATEGORIZATION SUMMARY

NORMALIZED RADIANCES / TRUE RADIANCES

	NUM.	TOL.	B1' B1	B2' B2	B3' B3	B4' B4	ALBEDO
/	160	1.3	0.13 0.76	0.14 0.63	0.06 0.37	0.68 4.11	6.06
▶ *	120	0.5	0.12 0.70	0.14 0.78	0.06 0.34	0.68 3.92	5.74
▶ .	117	0.4	0.13 0.75	0.14 0.80	0.06 0.37	0.67 3.42	5.84
▶ +	78	1.2	0.12 0.80	0.13 0.84	0.06 0.39	0.69 4.49	6.56
▶ 3	54	0.9	0.14 0.70	0.14 0.75	0.06 0.34	0.66 3.55	5.34
▶ (	50	0.6	0.13 0.70	0.14 0.75	0.06 0.35	0.67 3.74	5.54
)	49	0.4	0.13 0.65	0.13 0.69	0.06 0.30	0.69 3.55	5.16
E	43	0.4	0.12 0.65	0.13 0.72	0.05 0.31	0.70 3.42	5.60
R	40	0.7	0.13 0.75	0.13 0.75	0.06 0.36	0.67 3.74	5.60
T	38	0.6	0.12 0.65	0.13 0.70	0.06 0.32	0.68 3.74	5.41
Y	37	0.9	0.14 0.75	0.14 0.78	0.06 0.35	0.65 3.55	5.44
▶ U	38	0.6	0.14 0.80	0.14 0.78	0.07 0.37	0.66 3.74	5.69
▶ I	31	0.7	0.14 0.85	0.14 0.65	0.07 0.40	0.65 3.92	6.02
▶ O	23	0.5	0.14 0.80	0.13 0.78	0.06 0.37	0.67 3.92	5.87
$	12	0.5	0.11 0.65	0.13 0.75	0.06 0.32	0.70 4.11	5.83
P	10	0.6	0.13 0.65	0.14 0.67	0.06 0.28	0.68 3.36	4.96
A	10	0.4	0.12 0.60	0.13 0.68	0.06 0.29	0.69 3.55	5.11
S	9	0.4	0.13 0.80	0.15 0.91	0.06 0.39	0.65 3.42	6.02
D	9	0.7	0.15 0.96	0.16 1.04	0.07 0.47	0.62 4.11	6.56
F	8	0.5	0.12 0.60	0.12 0.59	0.05 0.25	0.71 3.55	4.96
▶ G	8	0.3	0.13 0.75	0.15 0.89	0.07 0.40	0.65 3.74	5.76

NORMALIZED RADIANCES / TRUE RADIANCES

	NUM.	TOL.	B1' B1	B2' B2	B3' B3	B4' B4	ALBEDO
H	7	0.4	0.14 0.80	0.15 0.90	0.07 0.41	0.64 3.74	5.84
J	6	0.5	0.13 0.87	0.13 0.93	0.06 0.43	0.58 4.67	6.89
K	5	0.5	0.14 0.85	0.15 0.91	0.07 0.41	0.63 3.74	5.91
L	5	0.3	0.15 0.85	0.14 0.80	0.07 0.38	0.65 3.74	5.76
Z	5	0.6	0.11 0.70	0.11 0.71	0.08 0.32	0.72 4.48	6.21
X	4	0.5	0.14 0.96	0.15 1.00	0.06 0.43	0.55 4.48	5.87
C	4	0.4	0.14 0.70	0.14 0.74	0.06 0.30	0.66 3.36	5.10
#	4	0.4	0.14 0.65	0.15 0.84	0.07 0.41	0.63 3.55	5.64
V	4	0.2	0.15 0.90	0.15 0.93	0.07 0.43	0.63 3.92	6.19
B	4	0.4	0.12 0.84	0.12 0.83	0.05 0.34	0.71 4.06	6.86
(	4	0.2	0.11 0.65	0.12 0.69	0.08 0.27	0.72 4.11	5.72
N	4	0.4	0.15 0.60	0.14 0.79	0.06 0.35	0.65 3.55	5.46
M	4	0.4	0.15 1.02	0.15 1.02	0.07 0.48	0.64 4.48	7.01
,	4	0.4	0.15 1.04	0.14 0.99	0.06 0.44	0.65 4.67	7.14
1	3	0.3	0.14 0.80	0.16 0.89	0.07 0.38	0.63 3.55	5.62
2	3	0.4	0.15 0.95	0.16 1.01	0.07 0.43	0.62 3.92	6.31
3	3	0.3	0.12 0.85	0.14 1.03	0.08 0.44	0.68 4.84	7.16
4	3	0.2	0.13 0.85	0.12 0.81	0.06 0.40	0.69 4.67	6.73
5	3	0.2	0.13 0.60	0.11 0.70	0.05 0.32	0.71 4.48	6.30
6	3	0.3	0.16 1.37	0.15 1.26	0.07 0.57	0.62 5.23	8.43
7	3	0.3	0.12 0.90	0.12 0.90	0.05 0.37	0.72 5.61	7.77
8	3	0.3	0.11 0.70	0.11 0.75	0.05 0.34	0.73 4.66	6.65

NO. POINTS CLASSIFIED = 1030 NO. POINTS UNCLASSIFIED = 257

DELMAX = 0.0110 ALBEDO WEIGHTING = 0.200

100.00 PERCENT OF BAND 1 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 2 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 3 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 4 USED IN ALBEDO CALC.

Figure 5. Computer classification map of the Beech Ridge snow course.

NINE-MILE BRIDGE SNOW COURSE
950' ELEVATION ASPECT: NORTHWEST

WATER EQUIV. 9.5"
SNOW DEPTH 38"

DIGITIZED OUTPUT OF SUBSEGMENT(S) 770,
SHOWING 40 CATEGORIES

CATEGORIZATION SUMMARY

NORMALIZED RADIANCES / TRUE RADIANCES

	NUM.	TOL.	B1' B1	B2' B2	B3' B3	B4' B4	ALBEDO
/	225	3.	0.17 1.17	0.06 0.44	0.15 1.02	0.62 4.29	6.87
*	163	2.	0.19 1.09	0.07 0.39	0.15 0.84	0.58 3.18	5.45
.	151	3.	0.17 2.81	0.06 0.99	0.13 2.19	0.64 10.71	16.70
+	93	2.	0.20 0.98	0.08 0.38	0.16 0.79	0.57 2.80	4.95
Q	93	3.	0.15 4.46	0.05 1.52	0.13 3.71	0.67 19.54	29.22
*	89	2.	0.18 1.05	0.07 0.39	0.16 0.88	0.59 3.36	5.69
)	65	2.	0.19 0.98	0.07 0.37	0.16 0.83	0.58 2.99	5.16
E	28	2.	0.14 1.75	0.05 0.63	0.14 1.79	0.67 8.52	12.68
R	19	2.	0.15 3.20	0.05 1.12	0.13 2.80	0.67 14.31	21.42
T	17	2.	0.20 0.95	0.08 0.36	0.16 0.74	0.56 2.62	4.67
Y	17	1.	0.10 1.44	0.04 0.54	0.15 2.06	0.71 9.81	13.85
U	16	1.	0.14 1.51	0.05 0.54	0.15 1.59	0.66 7.00	10.63
I	13	1.	0.08 1.28	0.03 0.47	0.15 2.47	0.74 12.11	16.34
O	10	1.	0.18 1.98	0.06 0.70	0.14 1.51	0.62 6.93	11.11
&	10	1.	0.19 2.37	0.06 0.81	0.13 1.65	0.62 7.76	12.59
P	10	1.	0.21 2.20	0.07 0.78	0.13 1.36	0.59 6.32	10.65
A	9	1.	0.15 3.59	0.05 1.30	0.13 3.00	0.67 15.71	23.60
S	8	1.	0.21 4.84	0.07 1.62	0.12 2.68	0.60 13.71	22.84
D	6	1.	0.11 1.02	0.04 0.38	0.16 1.54	0.70 6.69	9.63
F	6	1.	0.23 2.72	0.08 0.99	0.12 1.48	0.57 6.79	11.99

CATEGORIZATION SUMMARY

NORMALIZED RADIANCES / TRUE RADIANCES

	NUM.	TOL.	B1' B1	B2' B2	B3' B3	B4' B4	ALBEDO
G	5	1.	0.19 2.24	0.07 0.78	0.14 1.58	0.61 7.06	11.66
H	4	1.	0.21 1.37	0.07 0.48	0.14 0.92	0.57 3.74	6.52
J	4	1.	0.09 2.26	0.03 0.85	0.14 3.31	0.74 17.00	24.21
K	4	0.	0.24 4.86	0.08 1.61	0.11 2.23	0.57 11.40	20.10
L	4	0.	0.23 2.20	0.08 0.80	0.13 1.24	0.56 5.37	9.61
Z	4	1.	0.12 2.35	0.04 0.82	0.14 2.68	0.70 13.64	19.48
X	4	1.	0.29 2.70	0.11 1.00	0.12 1.10	0.49 4.67	9.47
C	3	1.	0.24 1.58	0.10 0.64	0.14 0.87	0.52 3.36	6.47
=	3	1.	0.14 1.68	0.06 0.64	0.14 1.68	0.66 7.66	11.67
V	3	0.	0.24 2.47	0.09 0.87	0.13 1.27	0.54 5.48	10.09
B	3	1.	0.25 3.05	0.08 1.02	0.12 1.49	0.55 6.79	12.35
(	3	1.	0.24 1.37	0.09 0.48	0.15 0.84	0.53 2.99	5.68
N	3	1.	0.21 1.35	0.08 0.52	0.14 0.87	0.56 3.55	6.30
M	3	1.	0.24 3.30	0.08 1.12	0.12 1.70	0.56 7.85	13.96
,	3	1.	0.20 2.80	0.07 0.95	0.13 1.71	0.60 8.22	13.69
1	3	1.	0.08 1.62	0.03 0.59	0.14 2.92	0.75 15.38	20.51
2	3	1.	0.26 1.65	0.09 0.56	0.14 0.91	0.50 3.18	6.30
3	3	1.	0.26 4.45	0.09 1.45	0.11 1.82	0.54 9.09	16.81
4	3	1.	0.14 1.27	0.05 0.48	0.15 1.40	0.66 6.17	9.31
5	3	1.	0.23 1.53	0.09 0.60	0.13 0.87	0.55 3.74	6.75

NO. POINTS CLASSIFIED = 1116 NO. POINTS UNCLASSIFIED = 164

DELMAX = 0.0225 ALBEDO WEIGHTING = 0.300

100.00 PERCENT OF BAND 1 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 2 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 3 USED IN ALBEDO CALC.
100.00 PERCENT OF BAND 4 USED IN ALBEDO CALC.

Figure 6. Computer classification map of the Ninemile B snow course.

The Allagash B snow course computer classification map is shown in Figure 4. The total radiance (albedo) of pixels contained in the snow course area varied from 6.93 to 7.74 $mw/cm^2/sr$ (categories: E T & P 2 6) corresponding to a water equivalent value of 9.6 inches. An important observation was that the radiance for MSS band 7 was consistently 2.99 or 3.18 $mw/cm^2/sr$, a difference of only one energy level.

The Beech Ridge snow course computer classification map is shown in Figure 5. The total radiance of pixels contained in this snow course varied from 5.34 to 6.54 $mw/cm^2/sr$ (categories: * . + Q W U I O G) corresponding to a water equivalent value of 9.4 inches. The Ninemile B snow course computer classification map is shown in Figure 6. The total radiance for the pixels contained in the site varied from 5.45 to 6.87 $mw/cm^2/sr$ (categories: / * W C) corresponding to a water equivalent value of 9.5 inches.

The total radiance varied from 5.34 to 7.74 $mw/cm^2/sr$ over the snow course areas which corresponded to water equivalent values of approximately 9.5 inches. It must be kept in mind that variations in vegetative cover, slope and aspect occurred between these snow course areas.

The greatest total radiance occurred in cleared areas such as fields and river channels. As an example, the snow cover on the St. John River (Figs. 4 and 6) showed the highest total radiance ranging from 20.23 to as high as 29.21 $mw/cm^2/sr$. These high radiance values can be attributed to the highly reflective character of the snow when not affected by vegetative cover. It is believed that the important factors to be considered in the snow cover mapping and water equivalent analysis in the Dickey-Lincoln School Lakes area is the vegetative cover, slope, aspect, geomorphic position, and to a lesser degree, elevation. Patterns of snow radiance values can be observed on the computer maps which suggests the interrelationship of vegetation, slope and aspect.

CONCLUSIONS

Preliminary analysis of the LANDSAT CCTs using the GISS computer algorithm shows that the total radiance of the snow and vegetative cover vary from approximately 20 $mw/cm^2/sr$ in non-vegetated areas to less than 4 $mw/cm^2/sr$ for densely covered forested areas. Comparison of the digital data from three snow courses in the Dickey-Lincoln School Lakes area to the total radiance value of the snowpack at these sites indicate that the total radiance varies from 5.34 to 7.74 $mw/cm^2/sr$ with the majority of the radiance values being 7.0 ± 0.4 $mw/cm^2/sr$. The water equivalent of the snowpack for this range of radiance values was 9.5 ± 0.1 inch of water. Therefore, it is anticipated that extrapolation of these radiance values for the entire watershed can be used to map the areal extent of snow cover/vegetation with a water equivalent value of 9.5 inches. This would result in the computation of potential water runoff for the 11 February 1973 LANDSAT scene.

Further refinement of the multispectral signatures used in the preliminary analysis will be done to test the significance of the 5.34 to 7.74 mw/cm^2/sr total radiance range in relationship to the water equivalent of the snowpack. In this preliminary analysis the most significant radiance values occur in MSS band 7. Due to the spectral characteristics of MSS band 7, the radiance should decrease significantly in MSS band 7 as the snowpack ripens because of the increased moisture content in the snowpack.

FUTURE PLANS

Future work will include refinement of extrapolation techniques to map classes of snow cover related to water equivalent for a known vegetative cover, slope and aspect for sites located within and outside the Dickey-Lincoln School Lakes Project area. The snow cover/vegetation radiance values developed from the 11 February 1973 scene will be compared to digital data on other selected CCTs (26 November 1973, 19 April 1974 and 23 July 1973) for the same sites. The change in snow radiance with time will be related to the accumulation and ablation of the snowpack at individual sites. On the basis of these studies the use of the LANDSAT digital data in obtaining information on water equivalent of the snowpack will be evaluated for operational Corps of Engineers use for predicting snowmelt runoff from a watershed.

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