MULTISTAGE REMOTE SENSING OF SNOWCOVER IN THE ADIRONDACKS - A PROGRESS REPORT

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Introduction

In the Northeast, much of the water stored as snow accumulates in the least accessible mountainous areas, swampy drainages, and forested slopes. Under these conditions, conventional snow surveys are not as frequent as required nor are the most important areas sampled. Furthermore, conventional sampling is laborious, time consuming, and occassionally dangerous.

Remote sensors aboard satellites and high altitude aircraft have greatly increased our ability to gain information rapidly about snow and ice resources (Tarble, 1963; McClain and Baker, 1969; McGinnis, Pritchard, and Wiesnet, 1973; Evans, 1974). Barnes and Bowley (1968) mapped snow distribution in the Upper Mississippi and Missouri plains using TIROS and ESSA sensors. Changes in image tonal patterns have been attributed to melting and/or storm passage. These changes in brightness matched areas of differing snow depths. Gradations in image density from black to white were used to delineate four different levels of snow accumulation. In another study, Strong (1973) noted pronounced daily variations on NOAA-2 VHRR images of Great Lakes ice distribution and movement by winds and currents.

The Adirondack Study

Most of the earlier studies have been conducted over relatively flat topography or in areas of low uniform vegetation. But one of the more vexing problems concerns the detection of snow in heavily forested, mountainous regions. Consequently, three cover types typical of the mountainous Northeast have been located on lands managed by the SUNY College of Environmental Science and Forestry Ranger School at Wanakena, New York, near Cranberry Lake. A lowland wetland larch-balsam-spruce bog, an upland pine-spruce site, and a mature beech-birch-maple hilltop are being studied. Topography in this region consists of well-rounded hills with an average available relief of 150 feet and a maximum of about 400 feet. Observations being made include filtered 70mm photographs from Cessna aircraft, LANDSAT 1 and 2 (formerly ERTS) imagery and NOAA-4 satellite very high resolution radiometer (VHRR) visible and thermal infrared imagery. Our overflights have been scheduled for every 9 days. However, since sunny days are the exception rather than the norm, we will soon be watching for high pressure systems moving across the country and flying on expected clear days. We can then utilize the daily NOAA coverage and hopefully enlarge our sample size.

Near-Surface Measurements

Our efforts seek to relate spectroradiometric measurements taken above the forest canopy to the aerial and satellite image densities. This relationship should reflect interactions of forest stand characteristics with optical and physical properties of the snowpack. It is well known that albedo decreases as the snow ages. But, to what extent does the condition of the stand influence albedo as sensed remotely? Satellite imagery generally depicts forested areas in dark tones, but what level of information is relayed in this variable and what is the "Noise" consideration?

Albedo from a completely snow covered conifer canopy does not exceed 20% due to the irregular structure of the tree crowns (Leonard and Eschner, 1968 and Berglund and Mace, 1972). As expected, much incident energy is retained in coniferous stands; but Federer and Leonard (1971) have shown that bare hardwood stems may also absorb as much as 65 percent of the solar radiation incident upon them. Hence, considerable energy is available for melt processes but relatively little brightness change is apparent when snow is on the ground. Satellites are expected to monitor changes in albedo, and inversely the variation in snowpack melt.

Our intention is to determine what forest factors control the reflection from the snowpack, and how satellite image analysis can separate out confusing information while accentuating masked information. The diagram in Figure 1 describes some of the considerations.

Application of Satellite Data

Satellite imagery is particularly well suited to quantitative analysis since it is originally sensed as a set of discrete, numerical spots, generally referred to as pixels. In the photographic copy of the image, these spots are packed so closely that they produce a continuous tone rendition of the image. Quantitative measurements of image brightness could be determined from the photographic copy using a microdensitometer, but far more precise values may be obtained from computer compatible tapes which digitally describe the intensity of each of the discrete pixels which comprise the image.

As part of our study, computer programs are being written to read, manipulate, and display the digital image data from both LANDSAT and NOAA satellites. Small portions of the image are displayed at a large scale using overstruck characters on a line printer. The tape data contain several geometric distortions which can be removed with a geometric transformation matrix derived from satellite information and ground control prints (Bernstein and Ferneyhough, 1975). Using the transformation matrix, the precise pixel which overlays the sampling site may be found, and the exact value of intensity determined. Figure 2 shows a computer printout of a LANDSAT image (band 6, near infrared) of the Wanakena-Cranberry Lake area and a corresponding high altitude (60,000 ft.) aerial photograph.

Applying the Model

In this research effort, we are using many point observations to model snow characteristics as a function of image intensity and ground factors. Given such a model, imagery data which were referenced to a geographic data base describing the significant ground factors could be analyzed, pixel by pixel, to provide a map of snow characteristics.

A manual-interpretation analogue of this approach is the "Image Sample Unit" technique developed at University of California, Berkeley (Katibah, 1975), in which the ground factor of vegetation is considered. Reference grids (1 cm.) are placed on corresponding summer and winter images, which are then superimposed in a stereoscope or Zoom Transfer Scope. The interpreter "blinks" from one image to the other, evaluating a cell in the summer image for vegetation cover before interpreting snow condition in the winter image. The logical extension of this technique is a digital interpretation using individual pixels as the sample cells and making comparisons to a digital data bases describing vegetation, topography, and other masking characteristics (Dallum and Foster, 1975, and Bartolucci, Hoffer and Luther, 1975).

We hope to generate a data base for an area in the Adirondacks to which satellite data may be compared for evaluation of our model in a quasi-operational system. Vegetation data will be available in a digital format from a LANDSAT scene analysis performed for the College by Bendix Aerospace Systems as part of another research project. Equipment is available to digitize contour maps for hypsometric, slope, and microclimatologic variability.

Removal of masking effects is an expensive task. Whether it will be economically competitive with manual interpretation of satellite imagery by interpreters familiar with the region remains to be seen, but the continued decline in computing costs and increase in use of digital geographic data systems suggest the potential of quantified techniques.

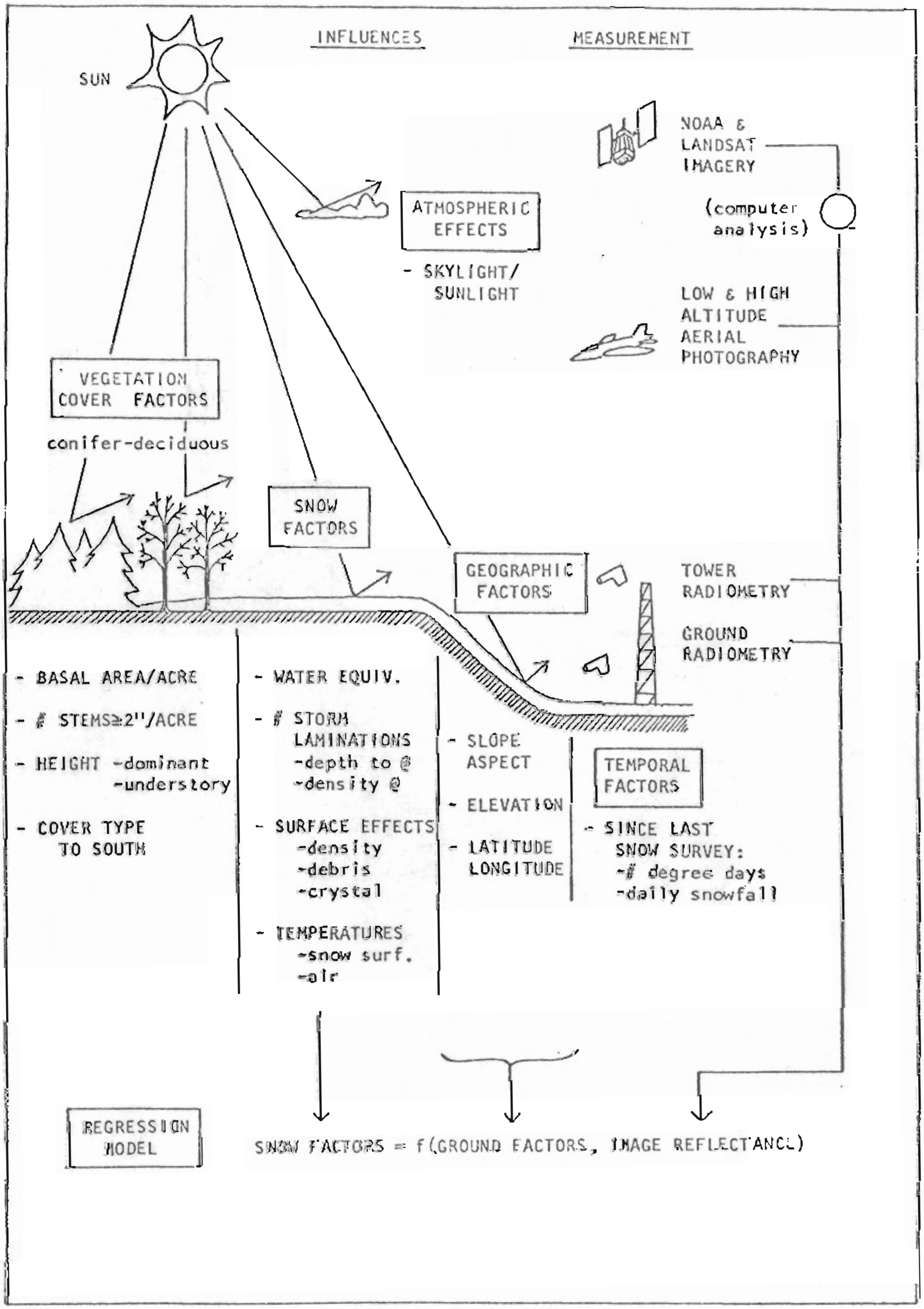

Figure 1. Schematic diagram of the relationships among extraterrestrial, aerial, vegetational and ground level influences on a model for predicting snow depth.

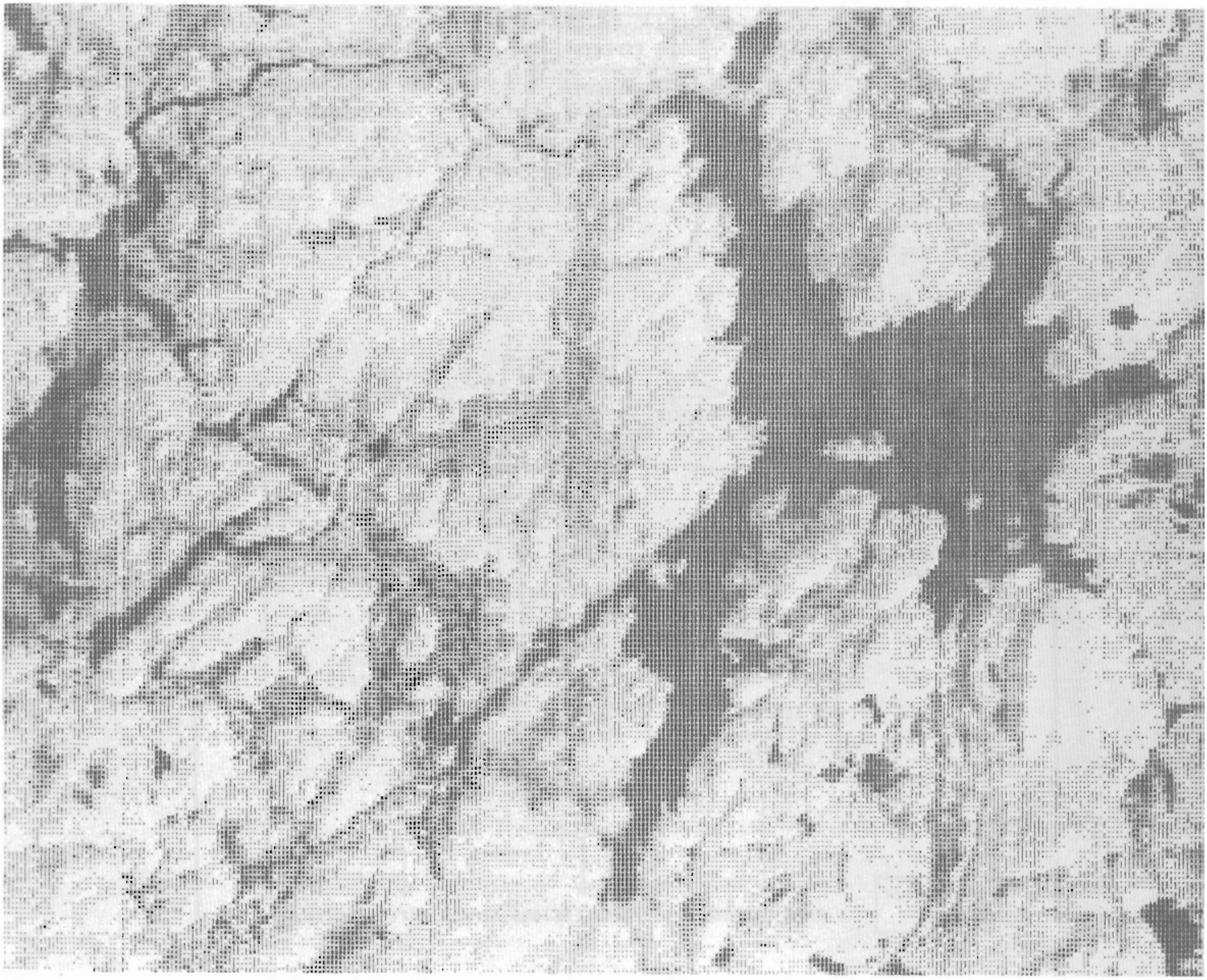

Figure 2a. Computer printout of a LANDSAT image (Band 6, near infrared) of the Cranberry Lake area.

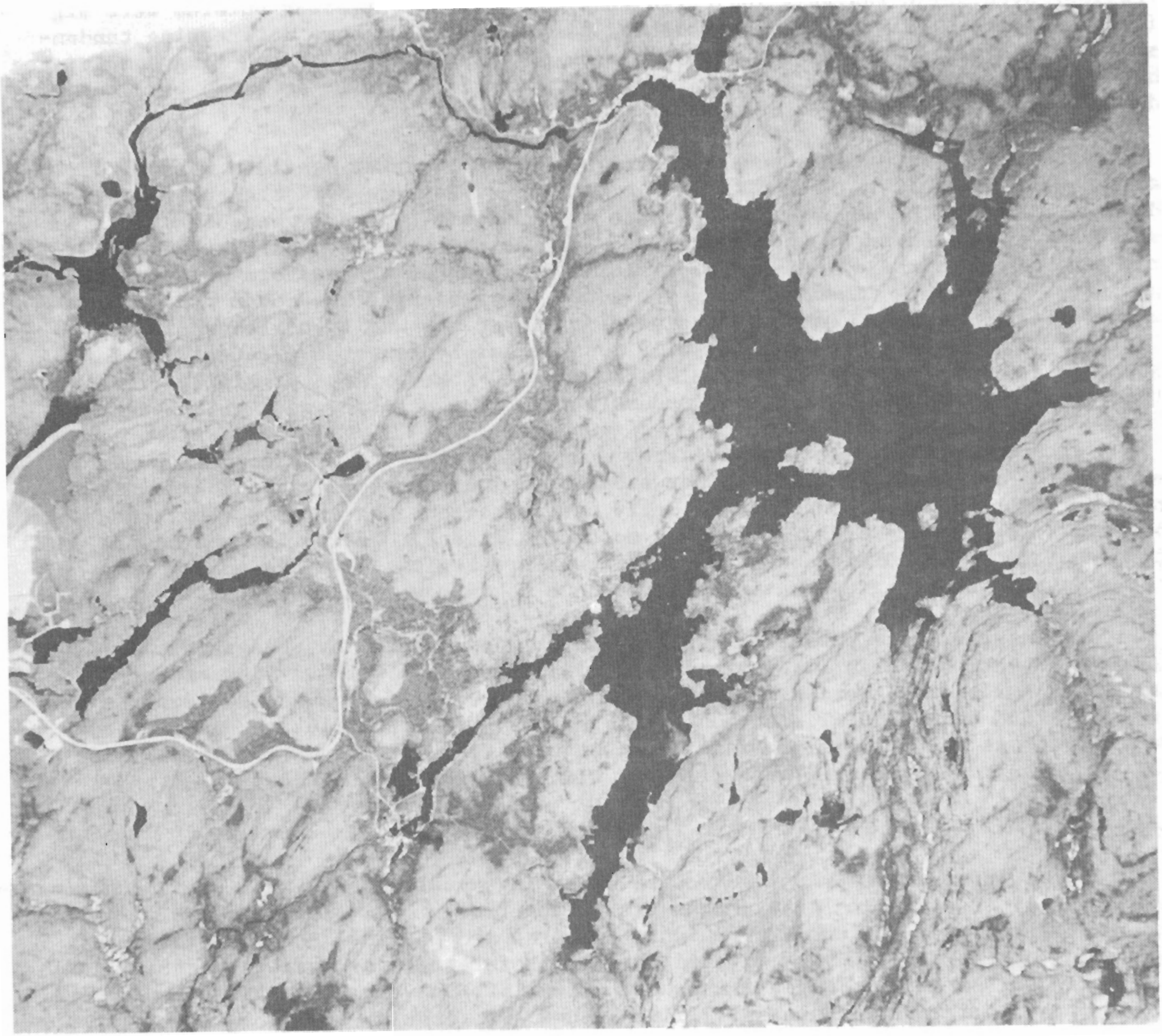

Figure 2b. High altitude (60,000 feet) aerial photograph of the Cranberry Lake area.

Preliminary Results

During the summer of 1975, 18 snow survey sites across the northern Adirondacks were evaluated in terms of the site factors and location factors of Figure 1. As a first approximation to determine the most influential factors, snow depths reported at these stations for the last date in each of the first three months of 1972 and 1973 were tallied. The number of degree days above freezing between any two successive snow measurements were recorded at the closest weather station. The resulting multiple regression/correlation analysis indicated that 5 of the 13 variables entered were significant at the 0.01 level. The correlation matrix indicated some interesting tendancies, but the coefficients were too small to be of value. For a season-long sample, the number of degree days, latitude, longitude, elevation, and number of stems per acre of hardwoods apparently influence changes in snow depth.

Bias may be introduced by several factors. First, weather stations were often 20 miles from the snow site. Second, only 5 of the 18 sites were more than half softwood. Hardwood stands will be expected to dominate the analysis, not only because of the number of sites but also because of the greater snow depths which occur under hardwoods. Third, five of the sites either had major local differences in the form of a recently logged site, a clearing immediately to the south, or a significant cover type change immediately to the south. Lastly, precipitation input was wholly neglected in this analysis. The amount of snow falling will most certainly have the greatest single impact on a function predicting accumulation. Again, however, the proximity of the few weather stations recording daily snow accumulation limits accuracy with this measure.

The second approximation predicts snow water equivalent to within an inch of that measured at 12 stations since 1971. For successive increments in water equivalent from January through mid-March, accumulated daily precipitation, degree days, latitude, and number of stems per acre of hardwoods are most significant. During late March and April melting appears to be solely dominated by temperature regimes. We are adding this winter's data to this regression formula and hope to improve the model.

Figure 3 reveals the potential for Adirondack snow mapping by NOAA satellite. Brightness gradations on an image are indeed closely matched with varying amounts of snowcover in a forest situation. The daily coverage provided by NOAA should prove more informative than LANDSAT. Although LANDSAT has greater resolution and a broader sensor range, its coverage is too infrequent to be a functional snow monitoring tool alone, especially in this area with frequent winter overcast conditions.

Conclusion

Ongoing spectroradiometric research is combining knowledge of three typical Adirondack forest cover types with satellite image data in an effort to develop near-real time turnaround of snow reflection information. Spectral and physical characteristics of accumulating and aging snow vary significantly with forest cover type, elevation, latitude, longitude, and date. Digital computer images of NOAA and LANDSAT lend credence to the hypothesis that scene analysis will produce quantitative estimates of extent and possibly depth of snowcover in mountainous forests.

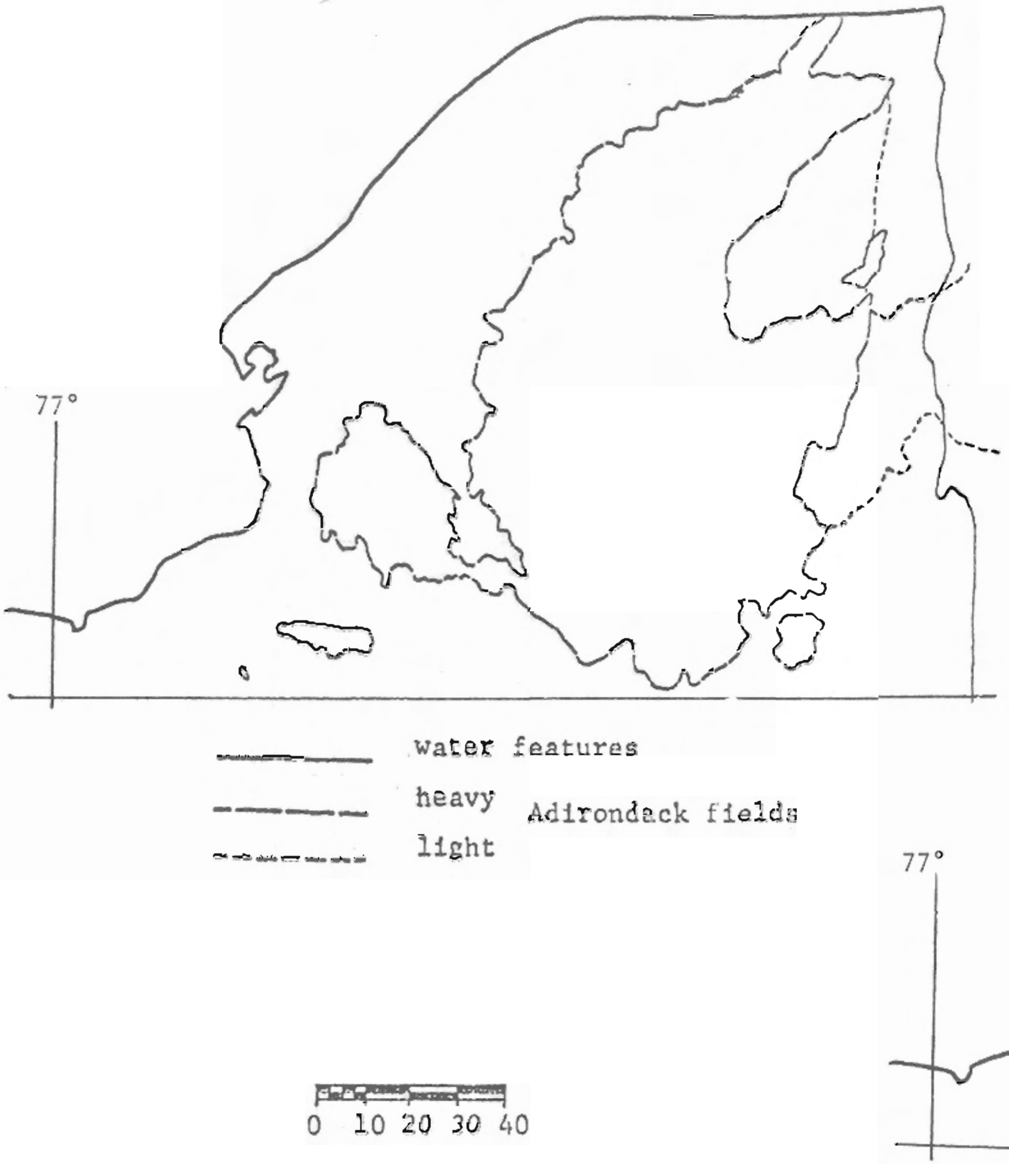

Figure 3a. Snow extent in northern New York 22 April 1975. NOAA/NESS Satellite Visible Band.

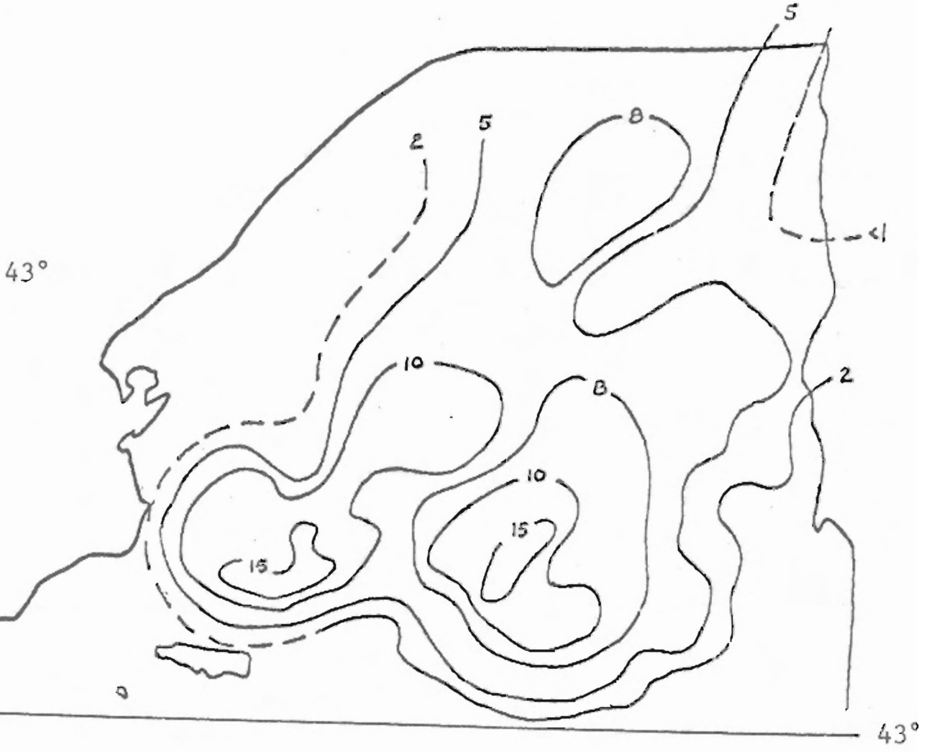

Figure 3b. Water Equivalent of snow (inches) in northern New York, 14-16 April 1975 from Cooperative Snow Survey.

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