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SYNOPSIS OF CURRENT SATELLITE SNOW MAPPING TECHNIQUES, WITH EMPHASIS ON THE APPLICATION OF NEAR-INFRARED DATA

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ABSTRACT

The Skylab EREP S192 Multispectral Scanner data have provided for the first time an opportunity to examine the reflectance characteristics of snowcover in several spectral bands extending from the visible into the near-infrared spectral region. The analysis of the S192 imagery and digital tape data indicates a sharp drop in reflectance of snow in the near-infrared, with snow becoming essentially non-reflective in Bands 11 (1.55-1.75 μm) and 12 (2.10-2.35 μm). Two potential applications to snow mapping of measurements in the near-infrared spectral region are possible: (1) the use of a near-infrared band in conjunction with a visible band to distinguish automatically between snow and water droplet clouds; and (2) the use of one or more near-infrared bands to detect areas of melting snow.

INTRODUCTION

More than 15 years ago, in April 1960, snow could be detected in eastern Canada in the initial pictures taken by the first weather satellite, TIROS-1. Since then, as improved satellite systems have been developed, an increasing use has been made of remote sensing from space to map snowcover. Recently, a handbook of techniques for satellite snow mapping has been prepared to assist in the planning of a practical demonstration project of the application of satellite data to snow hydrology (1). In the handbook, the emphasis is on the use of NOAA VHRR (Very High Resolution Radiometer) and LANDSAT (formerly, the Earth Resources Technology Satellite) visible imagery. These data have been shown to have practical application to snow hydrology.

In addition to satellite imagery in the visible portion of the spectrum, measurements in the near-infrared spectral region may also have considerable application to snow mapping. In this paper, the results of an investigation of snow reflectance characteristics using data from the Skylab EREP (Earth Resources Experiment Package) S192 Multispectral Scanner are presented (3). The S192 Multispectral Scanner provided for the first time an opportunity to examine the spectral characteristics of snow from spacecraft altitude over the spectral range extending from the

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visible to well-into the near-infrared.

S192 MULTISPECTRAL SCANNER DATA

Description of S192 Sensor

The S192 Multispectral Scanner is a 13-band radiometer with 12 of the bands being in the visible or near-infrared portion of the spectrum extending to about 2 μm (the thirteenth band is in the thermal infrared). The spectral range for each band is given in Table 1. The conical scan pattern of the S192 covers a swath of the earth's surface that is approximately 72.4 km wide; the instantaneous field-of-view (IFOV) is 79.25 meters (260 feet). A detailed description of the Multispectral Scanner is given in the Skylab Earth Resources Data Catalog (5). Both imagery and digital data from Computer Compatible Tapes were used in the data analysis.

TABLE 1.-S192 MULTISPECTRAL SCANNER SPECTRAL BANDS

Band Number	Description	Spectral Range (μm)
1	Violet	0.41-0.46
2	Violet-Blue	0.46-0.51
3	Blue-Green	0.52-0.56
4	Green-Yellow	0.56-0.61
5	Orange-Red	0.62-0.67
6	Red	0.68-0.76
7	Infrared	0.78-0.88
8	Infrared	0.98-1.08
9	Infrared	1.09-1.19
10	Infrared	1.20-1.30
11	Infrared	1.55-1.75
12	Infrared	2.10-2.35
13	Thermal Infrared	10.2-12.5

Data Sample

The S192 data used in this study were acquired for four test site areas: the Sierra Nevada-White Mountains are in California; the Wasatch Range in Utah; the central Arizona mountains; and a portion of the Upper Mississippi-Missouri River Basin in the north-central part of the country. Data from five EREP passes were analyzed, two from the SL-2 mission in June 1973 and three from the SL-4 mission in January-February 1974.

Meteorological data indicate the snowcover in the test site areas observed in June 1973 was quite probably in a melting condition, except perhaps at the highest elevations. In each of the test site areas observed in mid-winter, some melting could have been taking place at lower and middle elevations, or the snowpack could have been refrozen from melting that had occurred during the preceeding few days. However, the snow conditions were more stable than in the two springtime cases. No S192 data were collected over a test site area immediately following a fresh snowfall or during a very cold period.

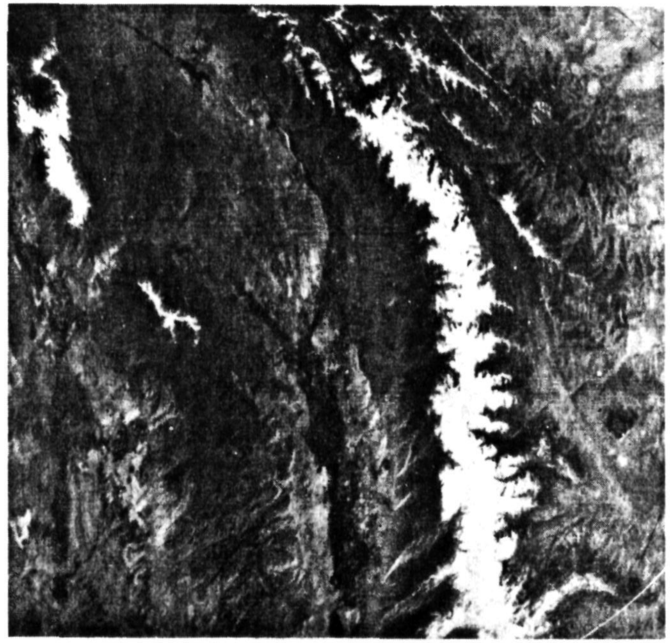
ANALYSIS OF S192 IMAGERY

The S192 imagery displays a marked drop in the reflectance of snow in the near-infrared bands. This effect is readily apparent in the imagery from the two SL-2 EREP passes, over the Sierra Nevada-White Mountain area and the Wasatch area. For the Wasatch area the S192 Band 2 and Band 11 imagery is shown in Figures 1a and 1b. Similarly, the S192 Band 3 and Band 11 imagery for the White Mountains is shown in Figures 2a and 2b. In both cases, snowcover has a high reflectance in the visible band, but appears essentially black in the near-infrared.

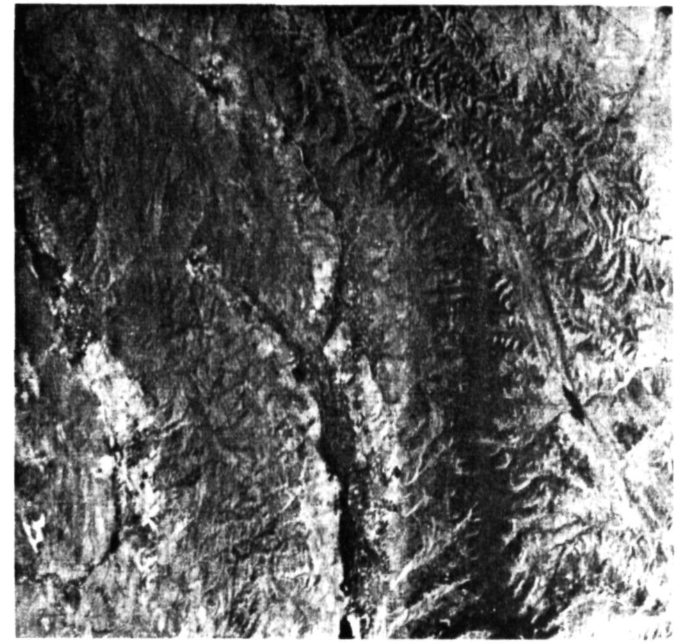
In Figures 2a and 2b, not only is the difference in the reflectance of the snow between the visible and near-infrared bands dramatic, but also the distinct nature of the clouds in the near-infrared spectral region. The concurrent S190A photograph indicates that cellular-type clouds, a pattern representative of cumulus (water clouds) cells, cover much of the area. Over the mountains, it is difficult to distinguish between the clouds and the snow in the visible band S192 imagery because both have essentially the same reflectance. In the Band 11 imagery, however, the clouds still appear white, whereas the snow appears essentially black; therefore, each cumulus cell is distinct, even those cells directly over the snowcovered mountains.

In the imagery from the June 1973 pass over the White Mountains, some snow can be detected in Band 9 but the extent of the snow appears less than in the visible band; the Band 9 imagery is shown in Figure 3. The apparent decrease in snow extent in the intermediate spectral bands is also observed in the data for the Utah test site area, which includes the Mt. Nebo Range and San Pitch Mountains (Figures 4a through 4f). In the visible band, the entire snowpack has a high reflectance. In Band 7, however, a slight decrease in the apparent snow extent in the Mt. Nebo Range is observed; in Bands 8, 9, and 10, the apparent snowcover successively decreases until in Band 10 the only bright area is along the highest ridge of the range; in Band 11, no snow can be detected. In the San Pitch Mountains, which are at a lower elevation, the less extensive snowcover can barely be detected in Band 7 and cannot be detected in Bands 8 through 11.

The results of the analysis of S192 imagery for the wintertime cases are essentially the same as those for the SL-2 data discussed above. In each case, snow has a high reflectance in the visible, except in areas that are forested, whereas in the Band 11 imagery, the entire snowcovered area is non-reflective. In the intermediate spectral bands, a gradual lowering of the reflectance is observed beginning with about Band 8 or 9; however, the decrease in reflectance is uniform across the snowcover, and no gradual decrease in the apparent snow extent is observed, as was the case in the data from each of the SL-2 passes.

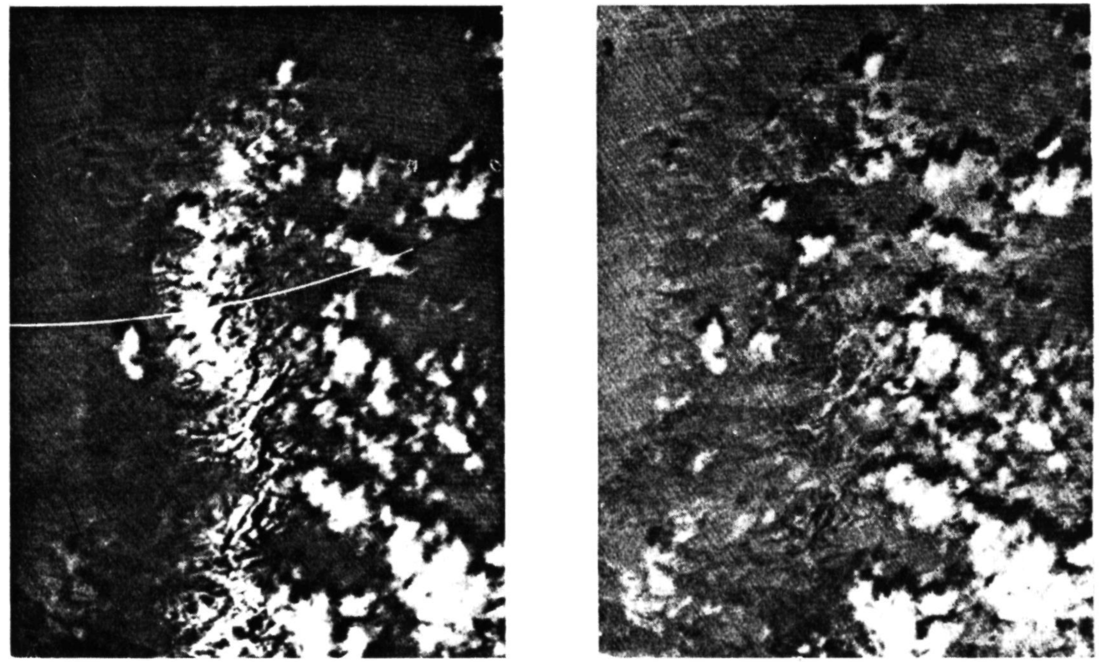


(a) Band 2



(b) Band 11

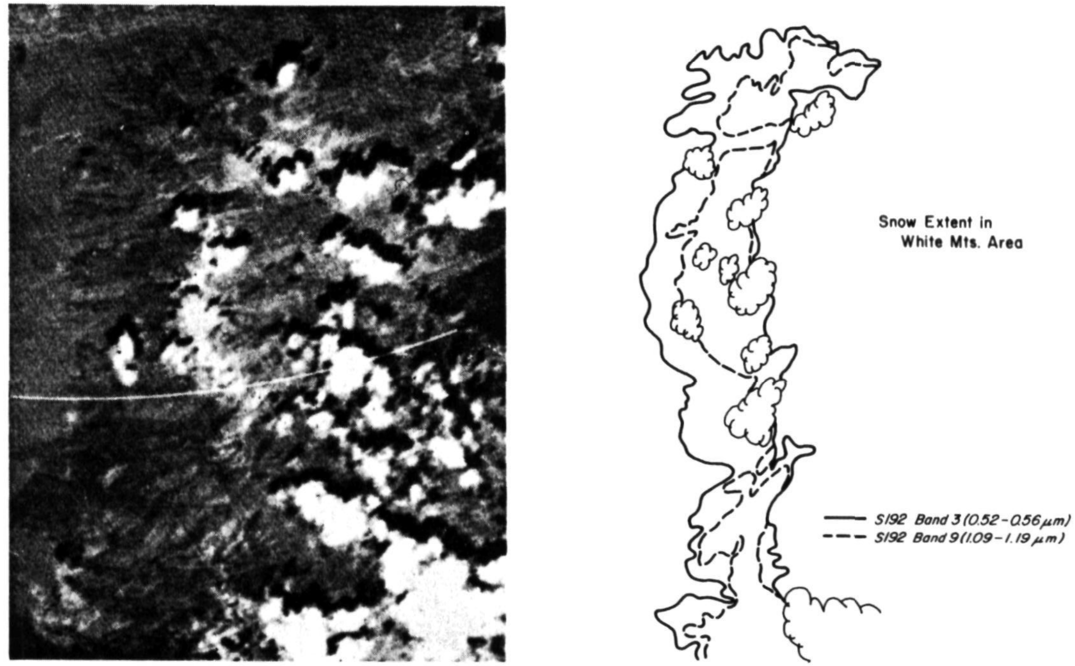
Figure 1 S192 imagery from EREP Pass 5, 5 June 1973; (a) Band 2 (0.46 - 0.51 μm), (b) Band 11 (1.55 - 1.75 μm). Area covered is the Wasatch Range in Utah. Note decreased reflectance of snow in Band 11 as compared to the Band 2 imagery.



(a) Band 3

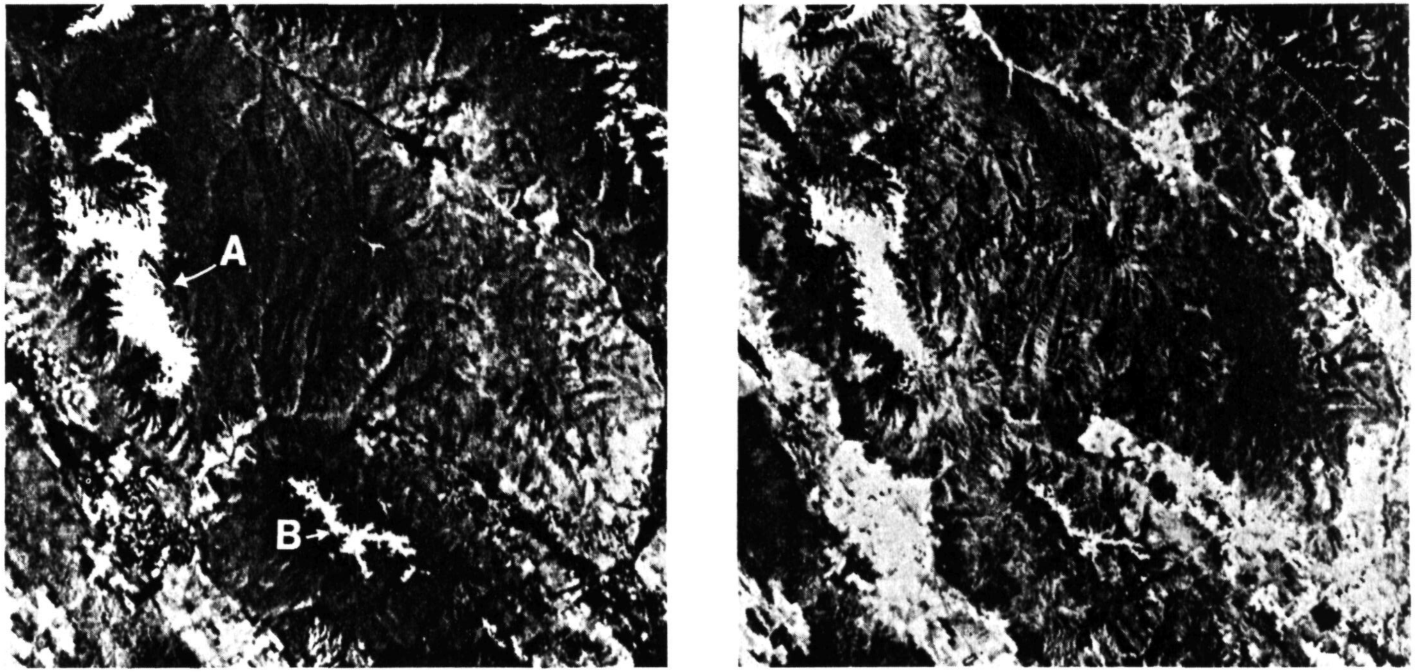
(b) Band 11

Figure 2 S192 imagery from EREP Pass 3, 3 June 1973; (a) Band 3 (0.52 - 0.56 μm), (b) Band 11 (1.55 - 1.75 μm). Area covered is the White Mountains. Because of the decreased reflectance of the snow, clouds that cannot be detected in Band 3 are distinct in Band 11.



(a) Band 9 (b)

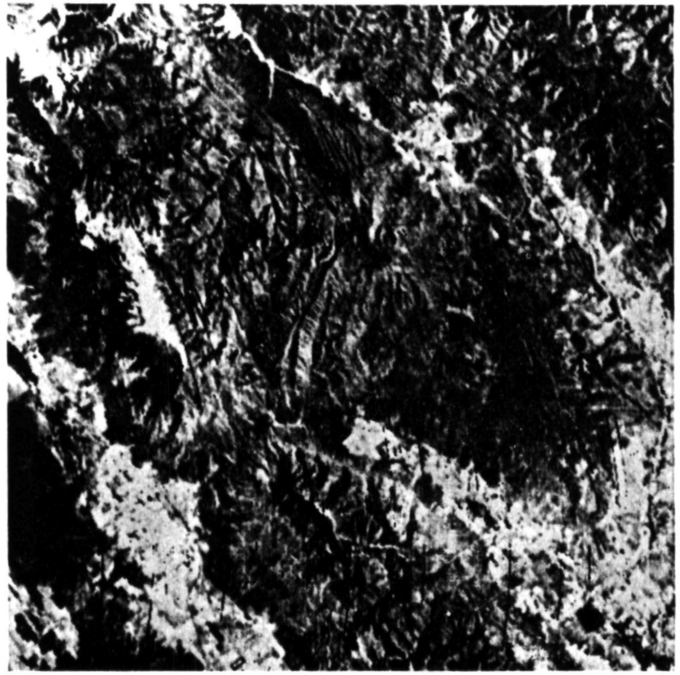
Figure 3 (a) S192 Band 9 imagery (1.09 - 1.19 μm) from EREP Pass 3, 3 June 1973; area covered is the White Mountains. Note the decrease in the apparent snow extent as compared to the visible band imagery (Figure 2a). (b) Comparative map showing relative extent of apparent snowcover mapped from S192 Band 3 (Figure 2a) and Band 9 (Figure 3a) imagery.



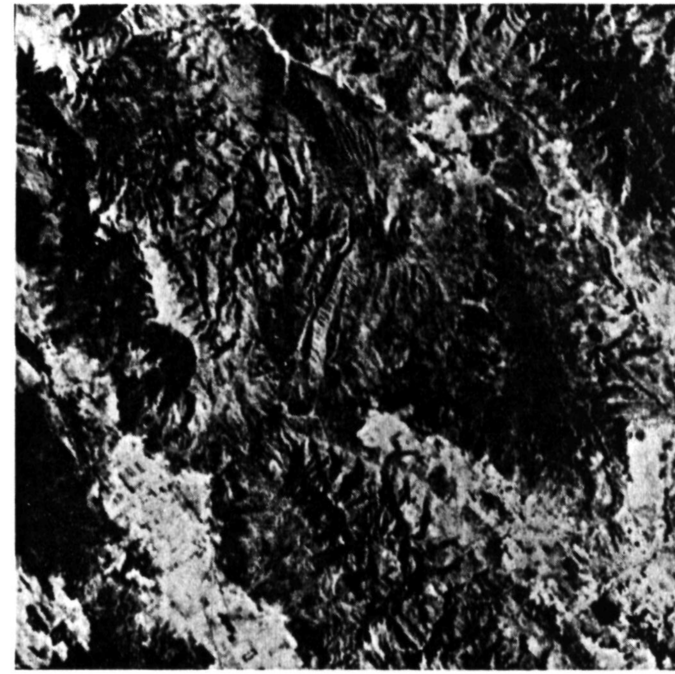
(a) Band 3

(b) Band 7

Figure 4 S192 imagery from EREP Pass 5, 5 June 1973; area covered includes the (A) Mt. Nebo Range and (B) San Pitch Mountains in Utah. (a) Band 3 (0.52 - 0.56 μm), (b) Band 7 (0.78 - 0.88 μm), (c) Band 8 (0.98 - 1.08 μm), (d) Band 9 (1.09 - 1.19 μm), (e) Band 10 (1.20 - 1.30 μm), and (f) Band 11 (1.55 - 1.75 μm). Note the gradual decrease in the extent of snowcover that maintains a high reflectance from Bands 3 through 11.

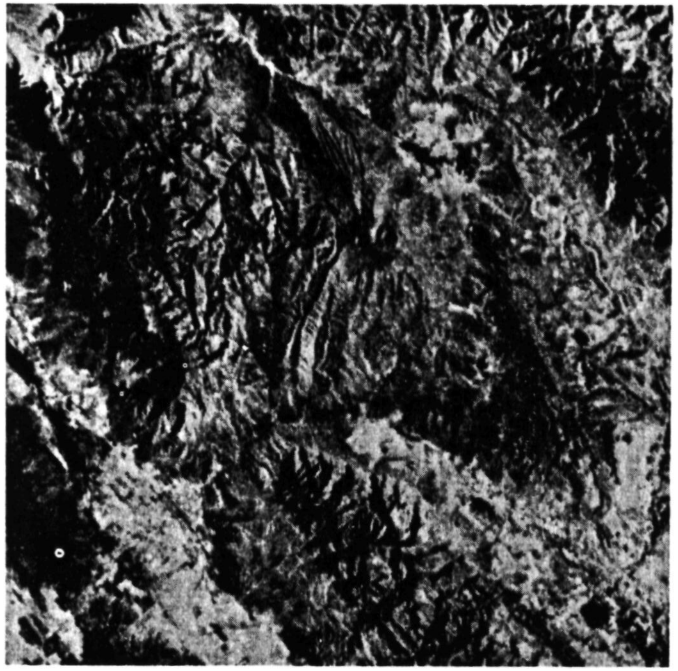


(c) Band 8

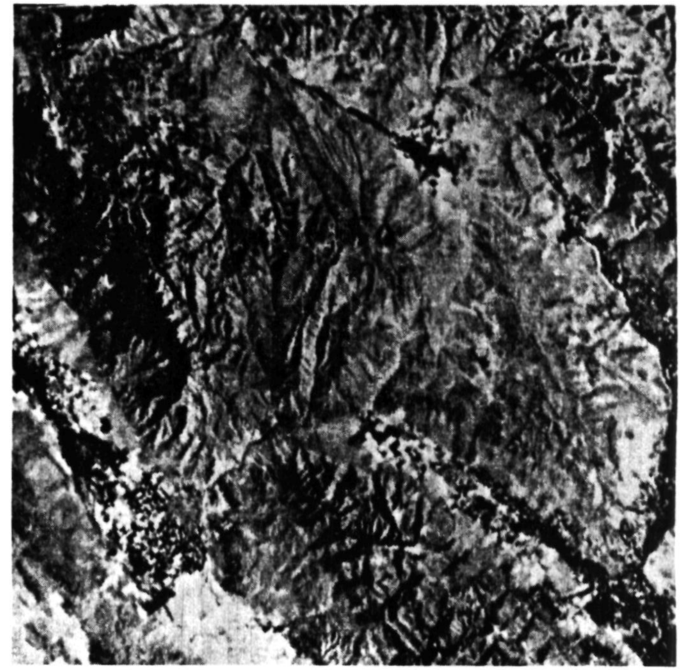


(d) Band 9

Figure 4 continued



(e) Band 10



(f) Band 11

Figure 4 continued

ANALYSIS OF S192 DIGITAL DATA

Data Processing Procedures

The high data rate of the S192 instrument presented some problems in working with the Computer Compatible Tapes (CCT's). Even for the rather limited time segments for which CCT's were provided, it was not feasible to perform digital count to radiance conversions for the entire data segment. The principal problem, therefore, was to devise a technique for the selection of specific data segments of only a few scanlines corresponding to the locations of known ground features.

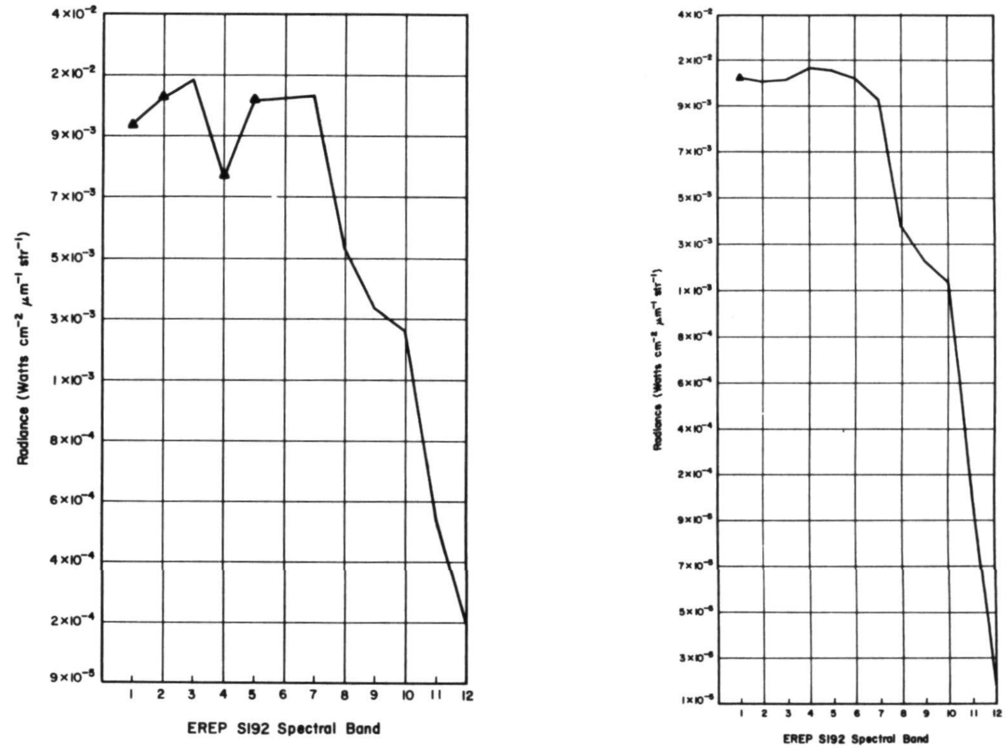
The technique devised to accomplish this task was a preselection procedure based on the analysis of raw channel counts. Knowing from the information on the S192 data supplied by NASA that snowcover would likely be saturated in the visible bands, a channel corresponding to one of the visible bands was selected. The CCT's were then manipulated such that each pixel in that channel that was saturated (raw data count = 255) would be printed out as a black dot and each pixel that was not saturated (raw data count < 255) would be left blank. The result produced an image-like printout where all snowcovered (non-forested) areas appear black, and, therefore, specific features could be located.

Following selection of the specific numbers of scanlines and pixels from the printout, the calibrated radiances for each required channel were computed using the appropriate conversion equation supplied with the tapes. This processing technique was found to be extremely efficient and greatly facilitated the handling of the S192 Computer Compatible Tapes.

Results of Analysis

The radiance values obtained from the processing of the digitized data were analyzed for each of the four cases (digital data were not available for the June 1973 pass over the California site area). A single pixel determined to be located within a uniform snowpack was selected for each of the four test site areas. The radiance value for the pixel was averaged with the five pixels before and after it to acquire a true representation of the snow response. This process was repeated for each band, and the averaged values were then graphed. The resulting graphs of the radiance values for each spectral band are shown in Figures 5a and 5b for two of the test sites, the Wasatch and the central Arizona Mountains.

For each of the test sites, the graphs indicate saturation or near saturation values (triangles indicate saturation levels) throughout the visible portion of the spectrum followed by a significant decrease in reflectance in the near-infrared. In the interpretation of the graphs it is necessary to consider not only the curve itself, but also the curve in relation to saturation levels; in this way, a saturated value is not misinterpreted as a decrease in reflectance (such as Band 4).



(a) (b)

Figure 5 Graph showing S192 measured radiance vs. spectral band for snowcover in (a) the Wasatch test site and (b) the central Arizona test site. Triangles indicate saturated values.

DISCUSSION OF RESULTS OF S192 DATA ANALYSIS

Comparison of SL-2 and SL-4 Data

For the five cases for which S192 data were analyzed, the overall results of the analysis of the imagery and the digital radiance values are consistent. In each case, snowcover exhibits a marked drop in reflectance in the near-infrared portion of the spectrum. Moreover, no significant difference in the reflectance characteristics of snow is apparent in the five cases examined, even though two of the cases were from the late spring and the other three from mid-winter. One difference that was observed, however, is that in both of the late spring cases the apparent extent of the snowcover gradually decreases from Band 7 through Band 11; in the winter cases, a uniform decrease in reflectance is observed with no apparent change in the detectable snow extent.

As was pointed out in the earlier discussion of the data sample, even in the winter cases no data were collected immediately following a fresh snowfall. Thus, the two spring cases were at times when the snowpack was in a general melting condition, whereas the three wintertime cases were at times when the snowpack was more stable but still consisting of somewhat aged snow that might be undergoing slight melting or had undergone melting and become refrozen.

It must also be remembered that the problem of measuring radiance values from a spacecraft platform is extremely complex. Many factors, such as the slope of the reflecting surface and especially the solar elevation angle, can influence the measurements. The solar elevation angle must be considered when attempting to compare measurements taken over different areas at different times of the year. Atmospheric attenuation must also be taken into account; however, the preliminary results of another Skylab investigation being conducted at ERT indicate that the error in determining surface reflectance for snow would be less than five percent for all spectral bands.

Comparison With Laboratory Experiments

The results of the analysis of the Skylab data are in general agreement with the results of laboratory experiments of the red and near-infrared spectral reflectance of snow (6). Since the laboratory results are in terms of the snow reflectance relative to a standard (white barium sulfate powder), it is difficult to compare these results directly with S192 measured radiances. However, graphs of the laboratory results show similar tendencies to the S192 radiances over snowcover. The S192 results indicate a decrease in snow reflectance beginning in Band 8 (0.98-1.08 μm); the laboratory experiments indicate a high reflectance in the red, with a marked decrease in reflectance from about 0.90 to 1.0 μm (a slight increase in reflectance occurs at 1.0 to 1.1 μm). Secondly, the S192 results show a slight leveling off of the drop in snow reflectance in Band 10 (1.20-1.30 μm); the laboratory experiments show that the reflectance decreases rapidly from 1.1 to 1.5 μm with the exception that at about 1.25-1.35 μm it levels off and even makes a slight recovery. Finally, the S192 results show the lowest reflectance values to be in Bands 11 (1.55-1.75 μm) and 12 (2.10-2.35); the laboratory experiments show low reflectance values at about 1.5-1.6 μm and an even stronger depression at 1.95-2.05 μm with a very slight rise at about 2.25 μm.

In the laboratory experiments, natural aging of the snow influences both the degree and rate of change of the reflectance. In general, melting lowers the reflectance, with some recovery if the snow is refrozen. A significant difference in the reflectance curves for dry and melting snow occurs at about 1.2 -1.4 μm. The snowcover observed in the Skylab experiment had in each case aged to a certain extent.

POTENTIAL APPLICATIONS TO SNOW MAPPING

Based on the results of the analysis of S192 data, two potential applications to snow mapping of measurements in the near-infrared spectral region are possible: (1) the use of a near-infrared band in conjunction with a visible band to distinguish automatically between snow and clouds; and (2) the use of one or more near-infrared bands to detect melting snow.

The nearly complete reversal in snow reflectance between the visible bands and Bands 11 and 12 observed in each case indicates that in this portion of the near-infrared, snow surfaces are essentially non-reflective regardless of the condition of the snow. In contrast, the reflectance of clouds (water droplet) is essentially the same in each of the S192 bands, displaying no drop in the near-infrared. As a result, a technique combining two spectral bands, one in the visible and one in the near-infrared at the position of Band 11 or 12 (1.55-1.75 μm or 2.10-2.35 μm), can be used to distinguish between snow, clouds, and non-snowcovered ground. A feature having a high reflectance in the visible and a low reflectance in the near-infrared would be classified as snow; a feature having a high reflectance in both bands would be classified as cloud; and a feature having a low reflectance in the visible and a medium reflectance in the near-infrared would be classified as non-snowcovered ground. An automatic technique for distinguishing snow from clouds is of particular significance, since this has been recognized as a serious problem with regard to the eventual machine processing of satellite data for snowcover mapping.

The second potential application, that of detecting melting snow, is based on the observed behavior of snow in the intermediate bands from about Band 7 (0.78-0.88 μm) through Band 10 (1.20-1.30 μm). In an early investigation using Nimbus-3 near-infrared data (8) the observed low reflectance of snow and ice was attributed to the existence of meltwater on the snow/ice surface. In studies using LANDSAT imagery (2, 4, and 7), the near-infrared band has consistently indicated less snowcover than has the visible band; the difference has been attributed to the reduced near-infrared reflectance associated with melting or refrozen snow.

Although the Skylab data sample was limited, the S192 film products for the spring cases (June) display snow reflectance characteristics not observed in the winter cases (January-February). In the two spring cases, the apparent snow extent decreases gradually from a maximum in the visible (Band 6) to a minimum in Band 11. This gradual decrease in the area of high reflectance is difficult to account for unless it is because the snow at the lower elevations is melting, and therefore exhibits a more rapid drop in reflectance, whereas the snow at the highest elevations is dryer or refrozen, and therefore does not exhibit a significant drop in reflectance until Band 11. In the winter cases, the snowpack is more uniform at all elevations, so does not display the gradual reduction in reflectance. It is concluded, therefore, that bands in the spectral range from about 0.8 μm to about 1.30 μm should provide the most information on the condition of the snow surface with regard to the snow being melting (wet surface) or being not melting or refrozen (dry surface).

Further study of snow reflectance characteristics is needed. The available data sample did not include a situation where snow and ice clouds are present, where the technique to distinguish between snow and water droplet clouds could be tested to determine its application to ice clouds. Also, measurements over fresh, dry snow as well as additional measurements over areas of known melting snow are needed before the relationships between reflectance and snow condition are completely understood. Nevertheless, the results of the analysis of Skylab EREP data are believed to be sufficiently conclusive to warrant careful consideration for including one or more near-infrared spectral bands on radiometers to be flown on future operational satellite systems. Measurements in the near-infrared spectral region, in combination with visible and thermal infrared measurements, have the potential for providing greatly improved information with regard to snow hydrology and thus have the potential for providing eventual significant cost savings to snow survey programs.

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