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E7.4-10582

CR-138687

A STUDY TO DEVELOP IMPROVED SPACECRAFT SNOW SURVEY METHODS USING SKYLAB/EREP DATA: DEMONSTRATION OF THE UTILITY OF THE S190 AND S192 DATA

ERT Document 0412-7

Interim Report

JUNE 1974

(E74-10582) A STUDY TO DEVELOP IMPROVED
SPACECRAFT SNOW SURVEY METHODS USING
SKYLAB/EREP DATA: DEMONSTRATION OF THE
(Environmental Research and Technology,
Inc.) 55 p HC \$5.75 CSCL 05B

Contract No. NAS 9-13305

N74-28825

Unclas
G3/13 00582

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prepared for
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STUDY TO DEVELOP IMPROVED SPACECRAFT SNOW
SURVEY METHODS USING SKYLAB/EREP DATA:
DEMONSTRATION OF THE UTILITY OF
THE S190 AND S192 DATA

(EREP Investigation No. 420)

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Interim Report

June 1974

Contract No. NAS 9-13305

Prepared for:

Principal Investigations Management Office
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77958

Technical Monitor: Larry B. York - Code TF6

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Study to Develop Improved Spacecraft Snow Survey Methods Using Skylab/EREP Data: Demonstration of the Utility of The S190 and S192 Data		5. Report Date June 1974	6. Performing Organization Code
		8. Performing Organization Report No. P-412-7	10. Work Unit No.
7. Author(s) James C. Barnes Clinton J. Bowley Michael D. Smallwood		11. Contract or Grant No. NAS 9-13305	
		13. Type of Report and Period Covered Interim Report	
9. Performing Organization Name and Address Environmental Research & Technology, Inc. 429 Marrett Road Lexington, Massachusetts 02173		14. Sponsoring Agency Code	
		12. Sponsoring Agency Name and Address Principal Investigations Management Office National Aeronautics and Space Administration Lyndon B. Johnson Space Center Houston, Texas 77958	
15. Supplementary Notes Technical Monitor: Larry B. York, Code TF6 EREP Investigation EPN No. 420			
16. Abstract This interim report provides a demonstration of the utility of spacecraft acquired Skylab S190A and S190B photography and S192 imagery for mapping areal extent of snow cover in western United States test site areas. The data sample is from the SL-2 mission flown in June 1973. The results of the investigation indicate that areal snow cover extent can be mapped more accurately from the S190A and S190B photography than from any other spacecraft system, including ERTS. The results of a qualitative analysis of the S192 imagery indicate considerable potential for the utility of multispectral snow cover analysis; the potential for distinguishing snow from clouds automatically is particularly significant.			
17. Key Words (Suggested by Author(s)) Skylab S190A and S190B Data Skylab S192 Data Snow Cover Mapping Snow Hydrology		18. Distribution Statement	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 52	22. Price*

ABSTRACT

This interim report provides a demonstration of the utility of spacecraft acquired Skylab S190A and S190B photography and S192 imagery for mapping areal extent of snow cover in western United States test site areas. The data sample is from the SL-2 mission flown in June 1973. Examples of the data collected over three test site areas are presented, and the snow extent mapped from the Skylab photography is compared with the snow extent mapped from ERTS imagery.

The results of the investigation indicate that areal snow cover extent can be mapped more accurately from the S190A and S190B photography than from any other spacecraft system, including ERTS. Further investigation is needed, however, to determine more precisely the mapping accuracy attainable using the S190A and S190B photography and to examine more thoroughly certain of the observed data characteristics.

The Skylab S192 Multispectral Scanner provides for the first time an opportunity to examine the spectral reflectance characteristics of snow from space over a spectral range extending from the visible to well into the near-IR (to 2 μm). The results of a qualitative analysis of the S192 imagery indicate considerable potential for the utility of multispectral snow cover analysis; the potential for using two spectral bands, one in the visible and one in the near-IR, to distinguish snow from clouds automatically is of particular significance.

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1. INTRODUCTION

1.1 Overall Purpose of Investigation

The overall purpose of this investigation is to compare and evaluate Skylab data for mapping of snow cover. Visual interpretation of the S190 photographs is being performed to map areas that are snow-covered. The S192 imagery and digital printouts, S193 data, and S194 data will then be compared to the S190 photographs to determine how much additional information on areal extent of snow can be obtained from various spectral bands, thermal data, and microwave data. Snow-depth and area measurements taken routinely by various Government agencies in the Sierra Nevada, Cascades, and Great Plains shall provide ground truth. The relatively high-resolution EREP data are being compared with television and radiometric measurements from other satellites and available aircraft imagery, to determine the optimum future system for mapping the areal extent of snow. The results of this investigation will enable a more accurate assessment of the extent of snow cover in the United States and aid in prediction of run-off and better management of the country's water resources.

1.2 Purpose of Interim Report

The purpose of this interim report is to provide a demonstration of the utility of spacecraft acquired Skylab S190A and S190B data for mapping areal extent of snow cover in the western United States test site areas. The data sample used in the preparation of the report is from the SL-2 mission flown in June 1973. Examples of the photography collected over three test site areas are presented, and the snow extent mapped from the Skylab photography is compared with the snow extent mapped from ERTS (Earth Resources Technology Satellite) imagery. Although the emphasis in the report is on the S190A and S190B data analyses, the results of the analysis of a sample of S192 screening film are also discussed.

2. TEST SITE AREAS

2.1 Locations of Test Site Areas

Five test site areas were originally specified for the investigation; four of the sites are in mountainous areas of the western United States and one in the area of relatively flat terrain in the north-central part of the country. The sites in the western mountains were selected because each has characteristically different terrain, forest cover, and snowfall climatologies. The western United States test site areas, which are shown in the map in Figure 2-1 are as follows: No. 318107, southern Sierra Nevada in California; No. 318108, Cascades in Washington and Oregon; No. 318191, Upper Columbia Basin in Idaho and western Montana; and No. 318208, Salt-Verde Watershed in Arizona. In each of these areas snowmelt runoff is an important hydrologic consideration.

Because of the late spring launch of the SL-2 mission, acceptable snow cover existed in only three of the specified test site areas (Sites 318107, 318108, and 318192). The Army Corps of Engineers, who conduct aerial snow surveys in parts of the Sierras and the Columbia River Basin, reported that in the southern Sierras substantial snow cover existed in early June, especially in the more sheltered terrain above the 3000 m level. It was also reported that snow cover existed in the higher terrain of the Cascades and Columbia River Basin, although the snow amounts were considerably below normal as the result of an exceptionally dry winter-spring season (the snow drought in the Northwest produced a power generation crises later in the summer).

In addition to the test site areas specified for this investigation, one test site of another Skylab/EREP investigation being conducted at Environmental Research & Technology, Inc. (EPN No. 439) also included mountainous terrain that was snow covered in early June. This additional test site, which covers the central Utah area near Great Salt Lake, is indicated in Figure 2-1 (Site 547220).

2.2 Characteristics of Test Site Areas

In the southern Sierra Nevada, the annual streamflow in the areas adjacent to the southern San Joaquin Valley is the most variable of any

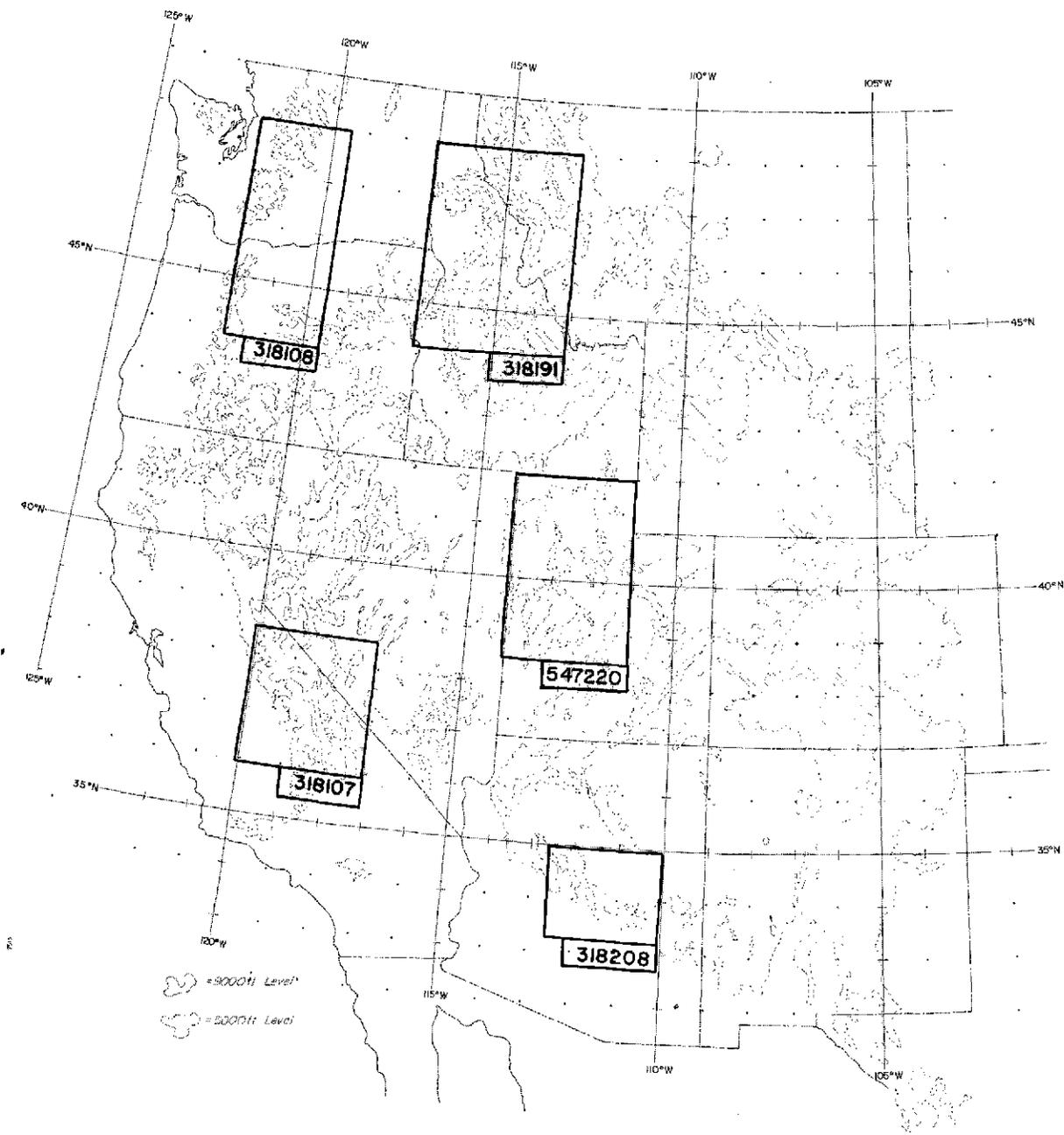


Figure 2-1 Map showing originally specified test site areas.

California watershed, due mainly to a large variability in the number and intensity of the winter storms crossing the region (Anderson, 1963). Moreover, the results of an earlier study (Barnes and Bowley, 1970) indicated the Sierra Nevada to be a mountainous region for which satellite snow surveillance is particularly promising. Since much of the southern Sierras is not heavily forested, the mountain snowpack can be readily identified in satellite photographs. Cloud-free observations are also plentiful during the spring snowmelt season, generally considered to be from early April through June.

The highest peaks in the Sierras range from 3000 to more than 4000 m. Land usage charts depict the Southern Sierras as consisting primarily of "forest and woodland, mostly ungrazed," with some "forest and woodland, grazed." In a slightly different classification scheme, Anderson (1963) designates the higher elevation as "Alpine" and "Commercial Forest." In this scheme, a narrow band of "Lower Conifer Zone" borders the commercial forest zone along the western slope of the Sierras, with the lower elevation designated as "Woodland-Brush-Grass Zone." Despite the apparent abundance of forest-covered land, Court (1963) points out that in total area the Kings River Basin is only 28% forested; furthermore, trees are so sparse in the forested area that only about 17% of the basin is covered by the tree canopy. For the Sierras as a whole, Court reports that 76% of the area is exposed to the sky.

The Cascades and the Upper Columbia Basin area are more densely forested than is the southern Sierras region. Except for some lower elevation grassland and farmland, land-usage charts indicate most of the region to consist of "forest and woodland, mostly ungrazed." This region consists of mountain ranges intersected by numerous river valleys. In areal extent the individual ranges are considerably smaller than the Sierras, and only isolated areas exceed 10,000 feet in elevation. The terrain in the region more closely resembles the Canadian Rockies just to the north than it does the Sierras.

The snowfall climatology of the Upper Columbia Basin region is also different from that of the southern Sierras. In general, snowfall is more consistent and distributed over a longer season. Although maximum depths may exceed 100 inches, total water content is usually less than that

contained in the maximum snowpack areas of the Sierras; the period of maximum hydrologic interest is usually from late April into the early summer.

The major mountain area within the Utah test site is the Wasatch Plateau, where the highest terrain is about 3000 m. The higher elevation terrain is indicated to be "forest and woodland grazed"; the tree density, therefore, is similar to that of a large part of the southern Sierra Nevada.

3. DATA SAMPLE

3.1 Skylab SL-2 Data

3.1.1 Test Site 318107 (EREP Pass 3)

Post mission information indicates that the "desired" data requirement was satisfied for Site 318107 and the "mandatory" requirement for Site 318108. On EREP Pass 3 (3 June) data were collected for Site 318107 on Rev. 290/291, Track 6; the time of the pass was about 1130 LST (1930 GMT). Although Track 6 was not considered the optimum for the southern Sierra Nevada test site, the revised track (about 1° west of that originally planned) did cross the northern part of the site in the Lake Tahoe area. The ground track is plotted on the map shown in Figure 3-1.

Data from the S190A Multispectral Photographic Camera and the S192 Multispectral Scanner were collected for this test site. The S190B Earth Terrain Camera had not yet been placed into operation at this stage of the mission. Excellent quality S190A 70mm photography for all six spectral bands were received for analysis; a considerable amount of cumulus cloud does, however, cover the mountains, particularly the area near Lake Tahoe. S192 screening film (3/4 inch) containing three spectral bands was also received; later, interim film (3.5 inch) containing several bands was received for a small, mostly cloud-free segment of the pass in the area of the White Mountains (on the California-Nevada border east of the Sierras). Although neither the screening film nor the interim film appear to be of optimum quality, the film has been found useful for qualitative analysis.

3.1.2 Test Site 318108 (EREP Pass 8)

On EREP Pass 8 (11 June) data were collected on Rev. 403/404, Track 48 for Site 318108; the time of the data-take was about 0712 LST (1512 GMT). Because of a 4-7 tenths cloud cover, however, this data-take satisfied the "mandatory" but not the "desired requirement." Extensive cloud cover limited the data-take to a rather small part of the overall test site, the partially cloud-free segment being in the area of Mt. Adams, Mount St. Helens, and Mt. Hood (the Washington-Oregon border). The ground track is plotted on the map in Figure 3-2.

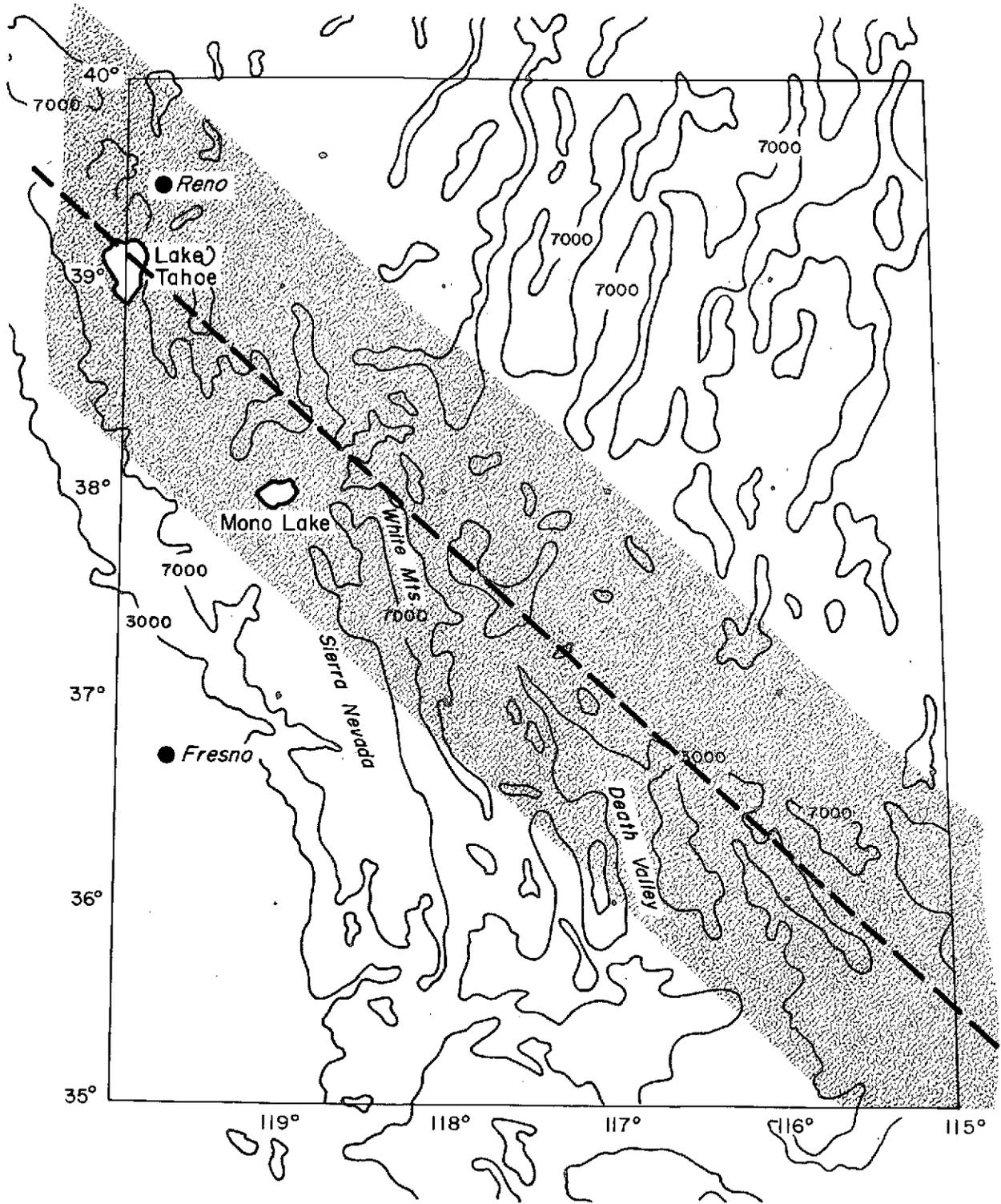


Figure 3-1 Diagram showing ground track of EREP Pass 3 over the Sierra Nevada on 3 June 1973 (Test Site 318107). Shaded portion indicates area of coverage for the S190A photography.

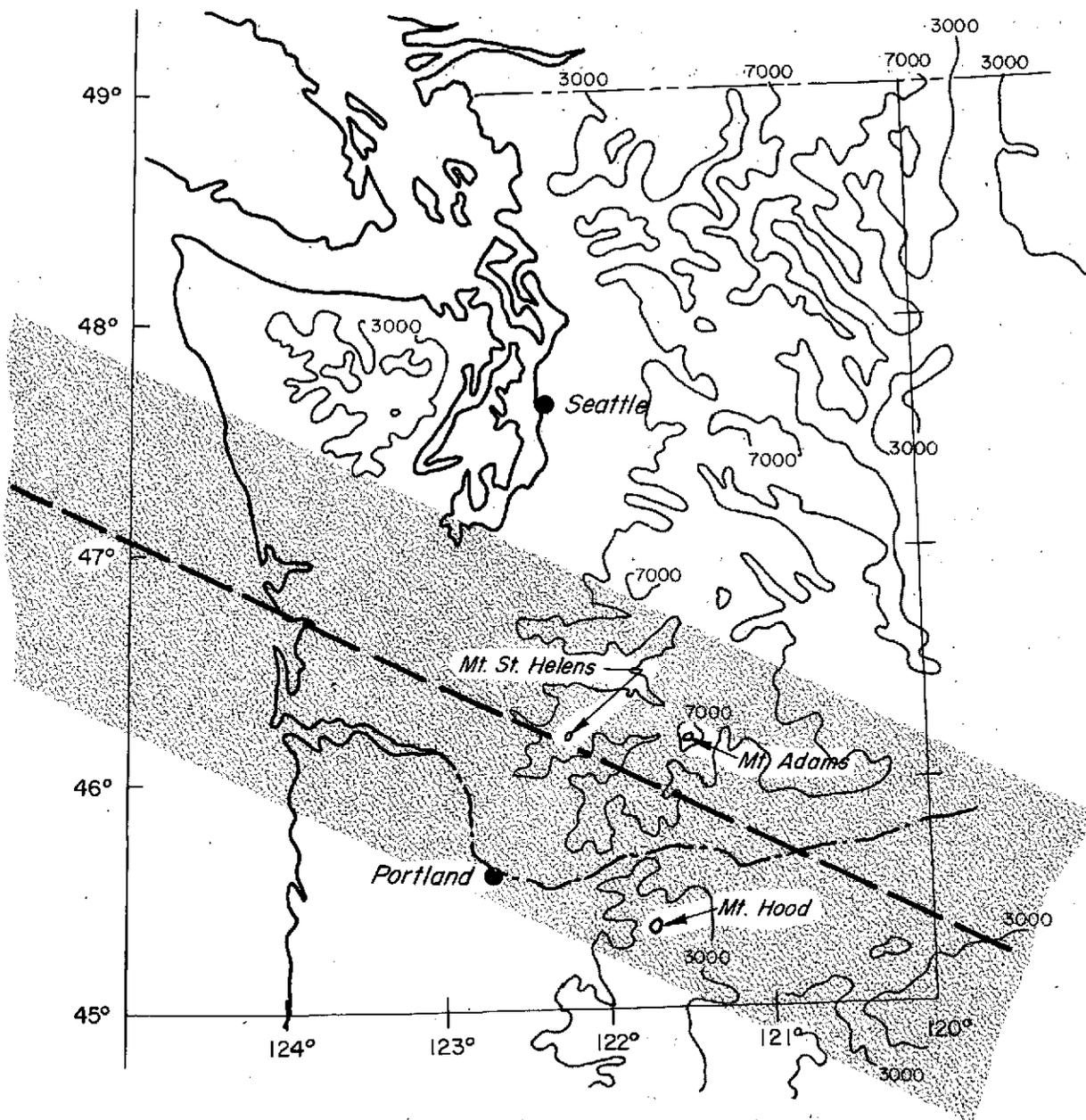


Figure 3-2 Diagram showing ground track of EREP Pass 11 over the Cascades on 8 June 1973 (Test Site 318108). Shaded portion indicates area of coverage for the S190A photography.

Excellent quality S190A photography was received, and despite the cloud cover, snow on the three peaks mentioned above could be identified. On this particular pass, the S190B camera was apparently not turned on in time, so that no S190B photography was collected. S192 screening film from this pass was examined, but terrain features were difficult to identify because of the cloud obscurations.

EREP passes on 9 and 10 June (Tracks 19 and 5, respectively) crossed Site 318191. Although acceptable snow cover was reported in certain of the mountain ranges within the site, cloud obscuration prevented a successful data-take on either day.

3.1.3 Test Site 547220 (EREP Pass 5)

Data over central Utah collected on EREP Pass 5 (5 June), Track 34, were received at ERT for analysis in Investigation EPN No. 439. The time of this pass was about 1058 LST (1758 GMT). The ground-track is plotted on the map in Figure 3-3.

Both S190A and S190B (aerial color) photography were received from Pass 5, as well as S192 screening film. In the photography and in the rather good quality screening film, the snow covered Wasatch Plateau south-east of the Great Salt Lake can be identified. At the time of the data take the region was completely cloud-free.

3.2 Correlative Data

During the period of the SL-2 mission, few correlative snow observations were available. In the southern Sierras, the final aerial snow survey was made on 11 June, but the area flown was well to the south of the ground track of EREP Pass 3. Measurements were made at snow survey courses by the California Department of Water Resources only through early May. In the upper Columbia Basin, only a limited number of aerial survey flights were made in the 1973 spring season because of the much below normal snow cover.

Although neither ground nor aerial snow measurements were available during the SL-2 mission, imagery from ERTS-1 was used as a source of correlative snow data. ERTS imagery for Test Site Areas 318107 and 318108 was on file, having been acquired previously for use in an ERTS-1 investigation

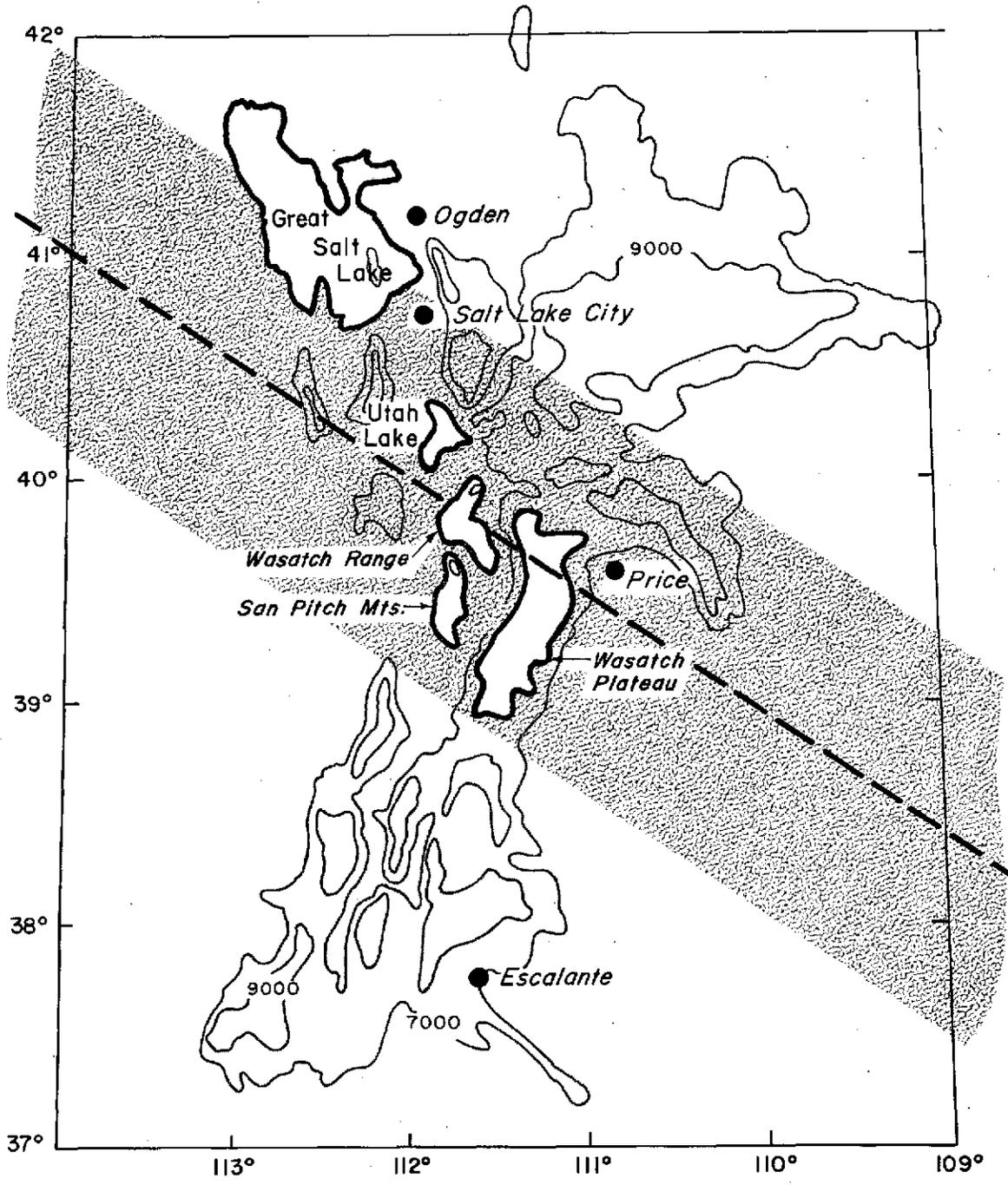


Figure 3-3 Diagram showing ground track of EREP Pass 5 over the Central Utah area on 5 June 1973 (Test Site 547220). Shaded portion indicates area of coverage for the S190A photography.

conducted for NASA Goddard Space Flight Center. The closest cloud-free ERTS images to the date of EREP Pass 3 (3 June) were on 12 June (Mono Lake-Lake Tahoe area) and on 26 May (White Mountains area). For the Cascades, the closest cloud-free ERTS image was on 30 May, some 13 days prior to EREP Pass 8 (11 June). ERTS imagery covering central Utah near the date of EREP Pass 5 (5 June) was requested through ERTS User Services, but was not received in sufficient time to be of use in the preparation of this interim report.

The application of ERTS imagery to mapping snow cover in the western United States has been reported in papers at the Second and Third ERTS Symposia (Barnes and Bowley, 1973; Barnes, Bowley, and Simmes, 1973) and in a final report (Barnes, Bowley, and Simmes, 1974). The results of the investigation indicate that for test sites in the southern Sierra Nevada and in the central Arizona Mountains, the extent of the mountain snow-packs can be mapped from ERTS data in more detail than is depicted in aerial survey snow charts. In nearly all cases in which significant discrepancies occur, the differences can be explained by changes in snow cover during the interval between the ERTS observation and the aerial survey. In addition to comparative analysis with aerial snow charts, the ERTS data have also been compared with high-altitude aircraft photography. The results of the comparative analysis indicate that although small details in the snow line that cannot be detected in the ERTS data can be mapped from the higher resolution aircraft data, the boundaries of the areas of significant snow cover can be mapped as accurately from the ERTS imagery as from the aircraft photography.

4. DATA ANALYSIS PROCEDURES

4.1 Processing of Imagery

The S190A 70 mm film was first examined to determine the precise areas covered by each pass. For selected frames enlarged prints were then processed from the 70 mm negatives at ERT's photographic laboratory. The enlargements were made to a scale of slightly larger than 1:500,000; this was found to be a useful scale with regard to the mapping of detailed snow cover patterns. Prints were made for each of the S190A black and white spectral bands. For the two S190A color products, black and white enlargements were also made; subsequently color prints were processed for selected frames.

Enlarged black and white prints of similar scale were processed from the S190B aerial color film. As with the S190A color film, color prints were then processed for selected frames. Corresponding segments of the S192 screening film were also processed in print format; to facilitate the data analysis, prints from the S192 interim film were processed to a scale compatible with that of the S190A prints.

4.2 Procedures for Identifying and Mapping Snow

4.2.1 Distinguishing Snow from Clouds

The procedure used to identify snow and to distinguish snow from clouds are based to a large part on the experience in working with ERTS data. The procedures developed using ERTS data are briefly described in the two ERTS Symposia papers (Barnes and Bowley, 1973; Barnes, Bowley, and Simmes, 1974), and are discussed in detail in the report by Barnes, Bowley, and Simmes (1974).

The areal extent of the snowpack is in itself a significant hydrologic parameter. Studies such as those by Leaf (1969) and Leaf and Haeffner (1971) have shown that in mountain snowpacks, a functional characteristic exists between extent of snow cover during the melt season and accumulated runoff; these snow-cover depletion relationships are useful for determining both the approximate timing and the magnitude of seasonal snowmelt peaks. The two most convenient ways to express areal snow extent in mountain drainage areas are in terms of the snowline elevation on the percentage of a river

basin that is snow covered.

In the studies using ERTS imagery, it was found that the latter was the most appropriate parameter to measure from space. Because of the limited nature of the Skylab data, however, an entire river basin is generally not covered by a data swath; therefore, rather than attempt to measure the percentage of an area snow covered, the areal snow extent was measured from the S190A photographs in terms of the snowline elevation.

Snow can be identified in all of the S190A spectral bands because of its high reflectance in comparison to that of areas not snow covered. The differences in reflectance from band to band are discussed in Section 5. The methods to distinguish snow from clouds in the S190A photographs are essentially those that were found useful with ERTS imagery. A discussion of the potential application of the S192 data for automatically distinguishing snow from clouds is presented in Section 7. The interpretive keys used with the S190A data are as follows:

- **Pattern Recognition.** Mountain snowpacks cover the higher elevation terrain and, thus, are directly related to the geologic structure. Since the configuration of the geologic structure of typical mountain ranges is quite different from the patterns of clouds as viewed from space, the snow cover can be instantly recognized. Additionally, in an area of relatively steep terrain, the snow line is usually well-defined and forms a sharper boundary than is characteristic of most cloud edges.

- **Recognition of Terrestrial Features.** Terrestrial features can be recognized in cloud-free areas. Because of the high-resolution of the S190A and B photography, numerous terrestrial features that are not visible in lower resolution satellite photographs can be recognized. In addition to natural features, such man-made features as roads, power line swaths, and cultivated fields are detectable; in the heavily forested areas of the Cascades, timber cuts are clearly visible.

- **Uniformity of Reflectance.** Snow cover in areas that are not forested, typically has a more uniform reflectance than do clouds. Furthermore, the distinct changes in reflectance that are associated

with forested and nonforested areas are not found in cloud patterns. In the color products, particularly the S190A color-IR, the snow surfaces also appear "whiter" than do most clouds, which tend to have a "bluish" tone.

- Shadows. Cloud shadows can often be detected, particularly with cumuliform clouds. At times of low sun angle, north slopes of mountain ridges may also be in shadow; these shadows, however, can be distinguished from cloud shadows because they fit the configuration of the geological structure.

4.2.2 Mapping Techniques

In the analysis procedure the snow line was mapped at the edge of the brighter tone without regard to changes in brightness within the overall area deduced to be snow covered. In the S190A data the snow-covered areas appear to have a rather uniform reflectance; this may be due to the limited data sample and to the season of the observation, the snow being confined in late spring to the higher elevations above the areas of dense forest cover.

The method used to measure the snow line elevation was to overlay the snow pattern mapped from the S190A photograph directly onto an elevation contour chart. In this method, reference was made to charts from the National Topographic Map Series (scale: 1:250,000). Although the scale of these charts is larger than that of the S190A prints, charts of this scale were found to be the most useful for matching the amount of detail that could be mapped from the photographs. In the procedure used, an accurate half-degree latitude longitude grid overlay was prepared on a transparent overlay using landmark references. Then through use of a variable scale, a fine mesh grid was drawn within each half degree square on the transparent overlay. The snow boundaries were traced onto the gridded overlay, and transferred to an identical (fine mesh grid) transparent overlay on the corresponding topographic chart, which had an elevation contour interval of 60 m (200 ft.). The mean snowline elevation was determined through measurements at many points along the snow boundary.

5. ANALYSIS OF S190A DATA

5.1 Multispectral Data Characteristics

5.1.1 Black and White Spectral Bands

S190A photography over snow covered mountains in the western United States was collected on the three SL-2 EREP passes listed in Section 3.1. For EREP Pass 3 (3 June) the S190A film covers an area extending southeastward from Lake Tahoe across Mono Lake to about Las Vegas. Snow can be identified in the Sierra Nevada to the south of Lake Tahoe and to the west of Mono Lake. In the area near Lake Tahoe, however, considerable cumuli-form cloudiness exists obscuring some of the snow. To the east of the Sierras, snow can also be identified in the White Mountains; although some clouds also exist in that area, the mountains are less obscured than are the Sierras. Individual frames for Camera Station 6 (0.6 - 0.7 μm) and Station 2 (0.8 - 0.9 μm) are shown in Figures 5-1 and 5-2, respectively. The area covered in these frames extends from the Sierra Nevada near Mono Lake eastward to include the White Mountains (see map, Figure 3-1).

For EREP Pass 8 (11 June) the S190A film extends from the Washington-Oregon border near Portland southeastward across eastern Oregon. A large part of this swath is cloud obscured, especially in the eastern part. Near the western end of the swath, Mount Adams and Mount St. Helens in Washington and Mt. Hood in Oregon can be identified in spite of the clouds. The reflectance of these snow-covered peaks is considerably higher than that of the thin clouds covering the region. A portion of the Station 6 frame (0.6 - 0.7 μm), in which Mt. Adams and Mt. St. Helens can be identified, is shown in Figure 5-3; the Station 2 frame (0.8 - 0.9 μm) of the same area is shown in Figure 5-4.

For EREP Pass 5 (5 June) the S190A film extended from the salt flats west of the Great Salt Lake southeastward across the Wasatch Plateau. In these photographs, taken when the area was completely cloud-free, the snow covered Wasatch Plateau is particularly distinct; smaller areas of snow can also be identified on the Wasatch Range and the San Pitch Mountains. The frame covering these mountain areas for the same two Camera Stations as shown for the other two test sites are shown in Figures 5-5 and 5-6.

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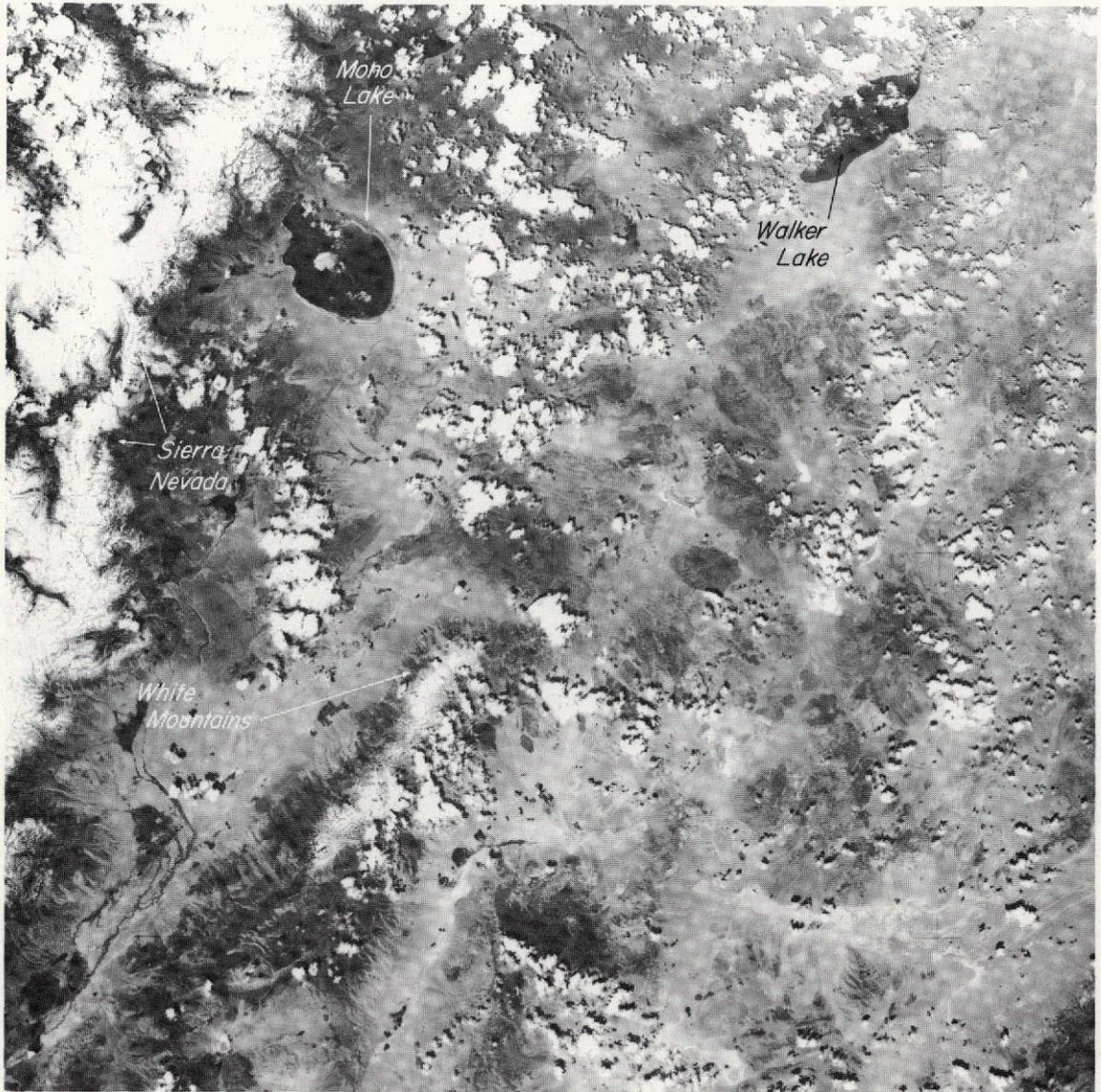


Figure 5-1 S190A Camera Station 6 (0.6 - 0.7 μm) photograph from EREP Pass 3, 3 June 1973; - area covered includes part of the Sierra Nevada and the White Mountains.



Figure 5-2 S190A Camera Station 2 (0.8 - 0.9 μm) photograph from EREP Pass 3, 3 June 1973; - same area as shown in Figure 5-1.

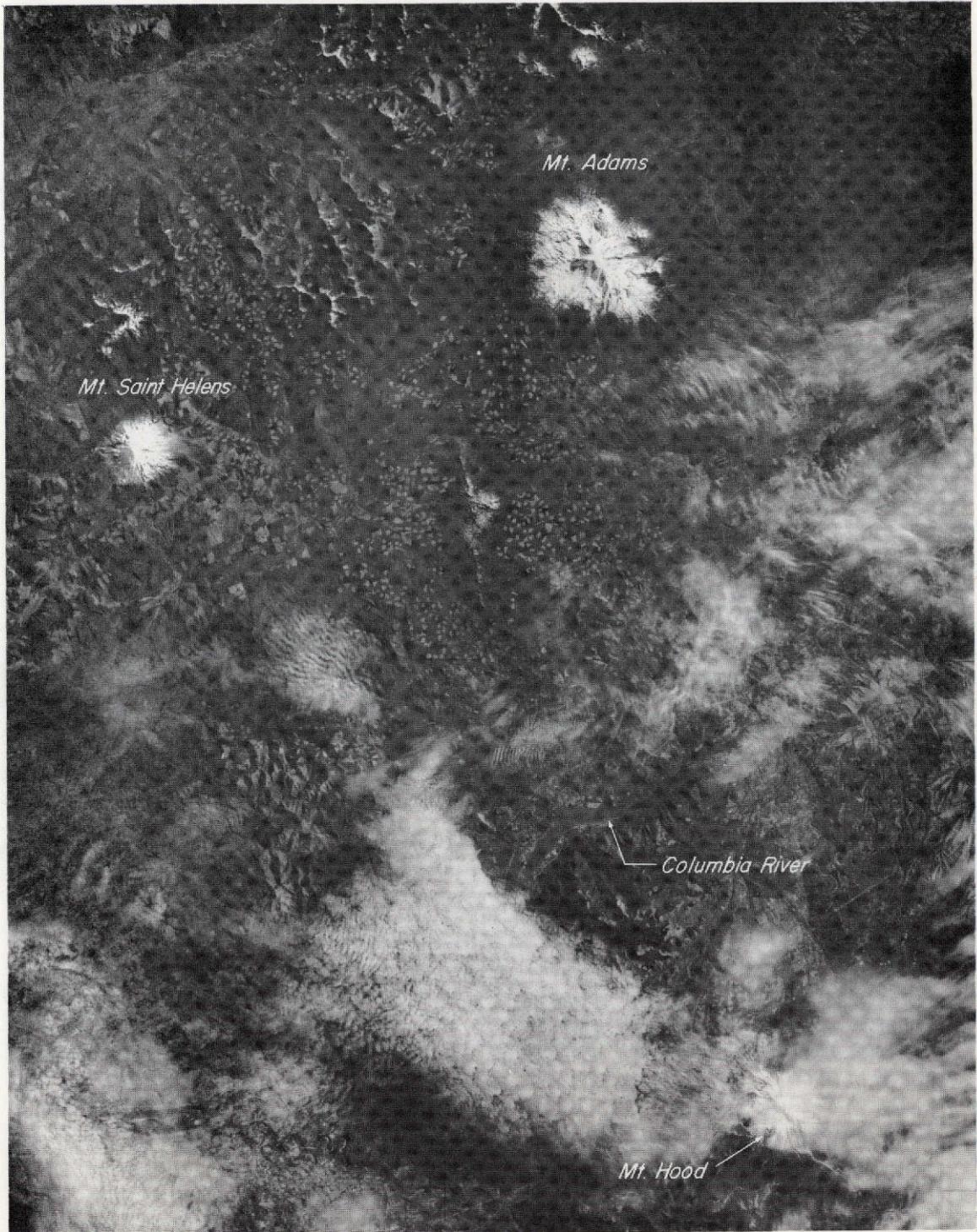


Figure 5-3 S190A Camera Station 6 (0.6 - 0.7 μm) photograph from EREP Pass 8, 11 June 1973; - area covered includes Mt. Adams, Mt. St. Helens and Mt. Hood in the Cascades.



Figure 5-4 S190A Camera Station 2 (0.8 - 0.9 μm) photograph from EREP Pass 8, 11 June 1973; - same area as shown in Figure 5-3.

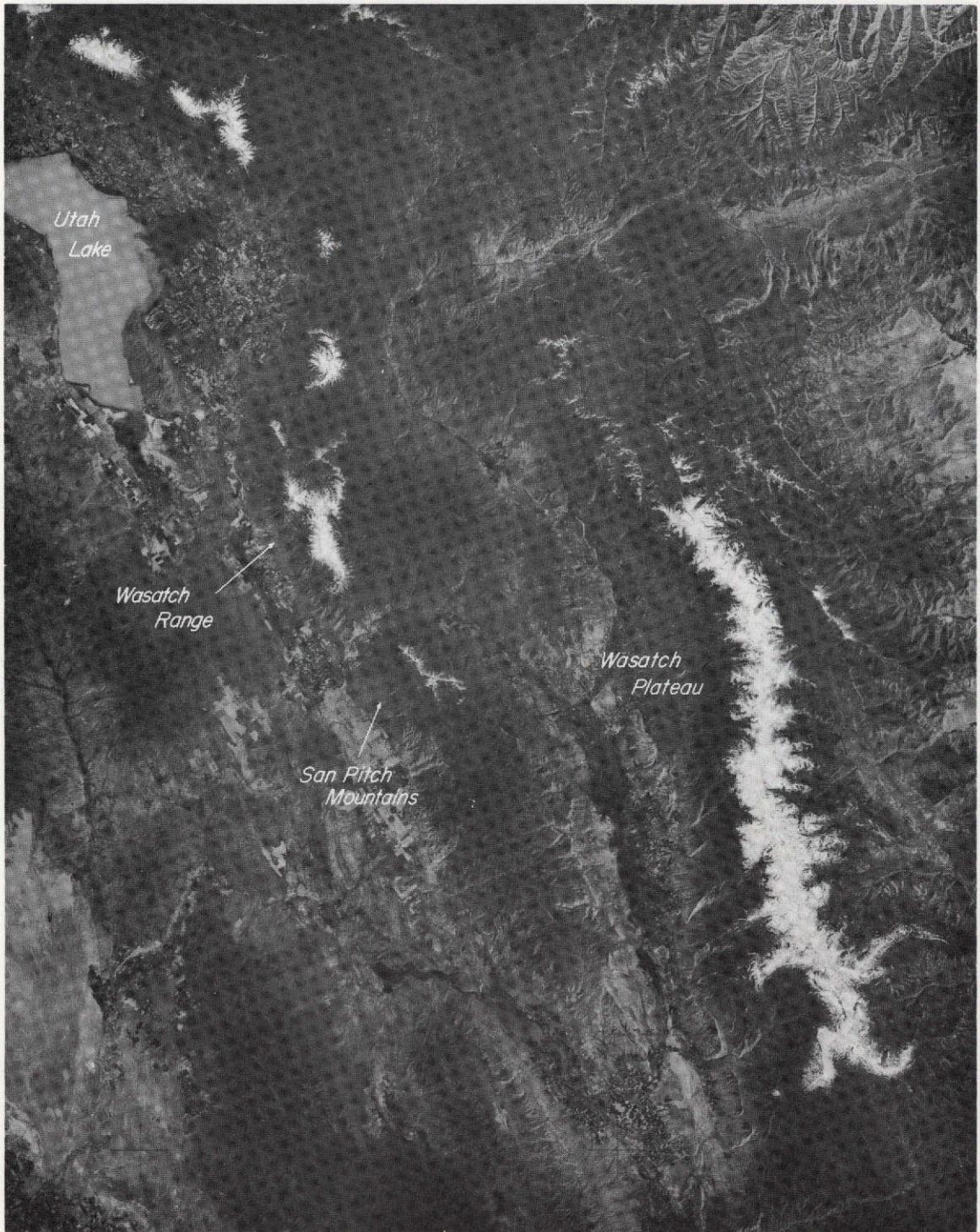


Figure 5-5 S190A Camera Station 6 (0.6 - 0.7 μm) photograph from EREP Pass 5, 5 June 1973; area covered includes the Wasatch Plateau in Utah.



Figure 5-6 S190A Camera Station 2 (0.8 - 0.9 μm) photograph from EREP Pass 5, 5 June 1973; - same area as shown in Figure 5-5.

Comparison of the four black and white spectral bands of the S190A photography for the three regions listed above has revealed many significant differences. The two visible bands, Station 5 (0.5 - 0.6 μm) and Station 6 (0.6 - 0.7 μm), appear best for mapping the actual snow limit. These bands display considerably more detail along the outer limit of the mountain snowpacks due to the higher contrast between the highly reflective snow cover and the darker, non-snow covered terrain. In addition, areas of mountain shadows, observed on the western slopes of Mt. Adams and Mt. St. Helens (Figure 5-3) remain bright enough to permit the distinction between snow and bare rock within the shadow.

In the two near-IR bands, Station 1 (0.7 - 0.8 μm) and Station 2 (0.8 - 0.9 μm), the mountain snow cover displays a much lower reflectance (compare, for example, the White Mountains in Figures 5-1 and 5-2). In these near-IR photographs, existing tongues or fingers observed at the outer limits of the snowpacks in the visible spectral bands are not discernible. Also, the mountain shadow areas appear too dark to distinguish snow cover from the bare rock (compare Figures 5-3 and 5-4). One possibly significant feature was observed within the snowpacks in each of these near-IR photographs, particularly in the 0.8 - 0.9 μm spectral band, whereas the snowpacks appear highly reflective and, in places, saturated in the visible spectral bands, distinct variations in reflectance exist within the snow covered areas in the near-IR. The variations in reflectance may relate to variations in forest density or possibly even to snow depth.

Further comparison of the four bands has shown that cumulus cloud cells observed over the Sierras region (Figures 5-1 and 5-2) appear as bright as the highly reflective snow cover in the visible band imagery making them rather difficult to detect; however, the cloud cells appear somewhat better defined in the corresponding near-IR image. Also, water bodies (lakes, reservoirs, rivers) which are barely discernible in the visible bands, appear extremely dark and well defined in the near-IR imagery.

5.1.2 Color Data Products

The detection of snow in the S190A color data products was examined using both the original 70 mm transparencies and color prints enlarged to approximately an 8 x 10 inch size. A print of a portion of an aerial

color frame (Camera Station 4; 0.4 - 0.7 μm) showing the Wasatch Plateau is given in Figure 5-7; the color-IR data product (Camera Station 3; 0.5 - 0.88 μm) covering the same area is shown in Figure 5-8. In the aerial color product the snowpack appears bright white against a brown background; because of the resulting contrast in color as well as in reflectance, a greater amount of detail in the edges of the snowpack can be mapped. The actual snow limit can, therefore, be mapped more accurately than in any of the black and white bands, in which areas of brighter snow-free terrain (such as highly-reflecting rock surfaces) can be misinterpreted as being snow covered. In the photographs of the Cascades, (not shown), distinct color variations that appear to be associated with snow-free terrain can be detected within the mountain shadow areas.

In most instances, the mountain snowpacks also appear well defined in the color-IR 70 mm transparencies; however, in the color-IR, the areas along the immediate limit of the snow tend to reflect the overall blue background tone observed in snow free terrain; as a result, areas of patchy snow observed within forested areas or along narrow ridges appear to become absorbed into the blue background, and are difficult to map precisely. This effect can be seen by comparing Figure 5-8 with Figure 5-7, noticing particularly the smaller areas of snow near the lake. In the photographs of the Cascades the effect is also pronounced.

Although some vegetated areas appear in a red tone in the color-IR film, the areas along the Wasatch Plateau that are indicated on charts to be forested appear in a dark blue-green tone. These areas are equally well defined in the aerial color film in which they appear dark brown.

5.2 Measurement of Snowline Elevation

The discussion in the preceding section indicates that the snow cover extent is best defined in the two black and white spectral bands and in the aerial color product. As a result of the improved contrast, greater detail in the snowline can be mapped from the color photography. It was not possible, however, to map the snow extent from the 70 mm transparencies because of the small scale. Furthermore, because of the photographic processing involved, enlarged prints could be prepared from the black and white film more easily and at less cost. Therefore, measurements of the



Figure 5-7 S190A Camera Station 4 (aerial color; 0.4 - 0.7 μm) photograph from EREP Pass 5, 5 June 1973; area covered includes the Wasatch Plateau in Utah.

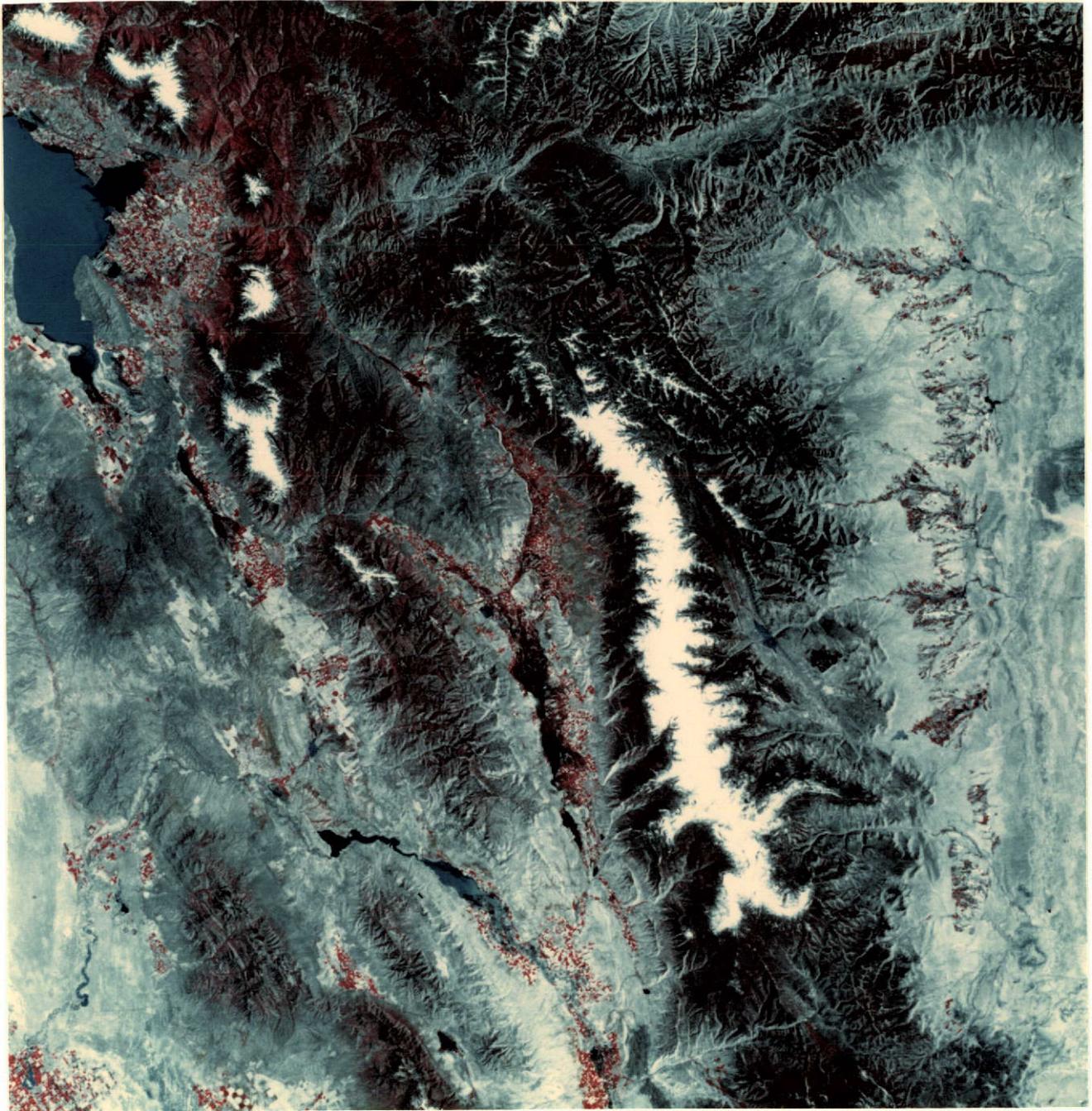


Figure 5-8 S190A Camera Station 3 (color-IR 0.5 - 0.88 μm) photograph from EREP Pass 5, 5 June 1973; same area as shown in Figure 5-7.

snowline altitude were made from the black and white (0.6 - 0.7 μm) prints rather than from the aerial color film.

Using the analysis procedure described in Section 4.2, the snowline elevation was determined for each of the three test site areas. The mean snowline elevation along the west slope of the White Mountains was determined to be at the 3600 m level, while along the partially cloud obscured eastern slope, the average elevation was 3150 m. Although little correlative snow data exist, reports from two stations located in the White Mountains (June 1973 Climatological Data Summary for State of California) substantiate the measured snowline elevation. One station, at an elevation of 3741 m. reported 5 inches of snow on the ground on 3 June, with snow having fallen on the first two days of the month; the other Station, located at 3,045 m, reported no snow on the ground at the time of the EREP pass.

Analysis of the frame viewing the eastern slope of the Sierras near Mono Lake revealed a mean snowline elevation of 3000 m which is in good agreement with the snow line elevation measured along the east slope of the White Mountains and with the snowline elevation estimated by Corps of Engineers personnel.

In the area of the Cascades, the mean snowline elevation for Mt. Adams was found to be at the 1680 m level along the west slope and near the 1890 m level along the east slope. Analysis of the Mt. St. Helens snowpack revealed a nearly uniform snow line elevation of 1380 m. Though thin cirrus clouds were present over the Mt. Hood region, the higher reflectivity of the snowpack provided good definition of the actual snow limit, which fell along the 1800 meter level. The mean snowline elevation measured for the Wasatch Plateau was 2750 m along the west slope and 2910 m along the east slope.

5.3 Comparison Between S190A and ERTS Data

For the White Mountains the eastern slope of the Sierras, and the Cascades, the areal snow extent mapped from the S190A photography was compared with the snow extent mapped from ERTS imagery taken as near as possible to the date of the EREP pass. The resolution of ERTS is considered to be 70 - 100 m, whereas the resolution of the S190A data has been reported by several investigators to be 30 - 70 m. In the comparative analysis, the ERTS MSS-5 spectral band, which has the same spectral range as the S190A Camera Station 6, was used.

The results of the analysis indicates that greater detail in the snow line can be mapped from the Skylab photography. For the White Mountains area, the corresponding ERTS image (12 June) is shown in Figure 5-9, and a comparative map of the snow lines mapped from the two types of data is shown in Figure 5-10. It appears that relatively little snowmelt had occurred over the White Mountains region during the 9-day period between the respective observations. The mean snow line elevation mapped from the ERTS imagery along the west slope was determined to be 3670 m and along the east slope 3240 m; this compares with 3600 m and 3150 m respectively for the S190A measurements. However, despite a possible change in snow amount, it is evident in Figure 5-10 that more detail in the snow line can be mapped from the Skylab data.

An ERTS image covering the eastern slope of the Sierras was available for 26 May (Figure 5-11). The comparative analysis for this area is shown in Figure 5-12. The snowline measurement from the ERTS data revealed a somewhat lower elevation of 2775 m along the east slope of the Sierras, some 225 m lower than the S190A measurement eight days later. As was true for the White Mountains, the detail that can be mapped from the S190A photography is greater.

Analysis of an ERTS image from 30 May 1973 (not shown) indicates a close correlation with the 8 June S190A analysis of snow line elevations for the Cascades region. Because of a lack of overall contrast and detail in the ERTS visible spectral bands (MSS 4 and 5) for this case, the MSS-7 near-IR band (0.8 - 1.1 μm), which displayed greater contrast, was used for the comparison. The mean snow line elevation along the west slope of Mt. Adams was found to be 1560 m and along the east slope 1860 m. Analysis of the snow line elevation for Mt. St. Helens showed a mean snow line elevation of 1290 m, whereas the Mt. Hood snow line elevation fell along the 1740 m level. These values are generally within 100 m of the values determined from the Skylab data.

5.4 Stereo-Viewing of S190A Photographs

The overlap from frame to frame along the flight path permits stereo viewing of the S190A Data. Steroscopic analysis was performed using the aerial color 70 mm transparencies. Black and white prints of two frames from the EREP Pass 3, which can be viewed stereoscopically, are shown in Figure 5-13.



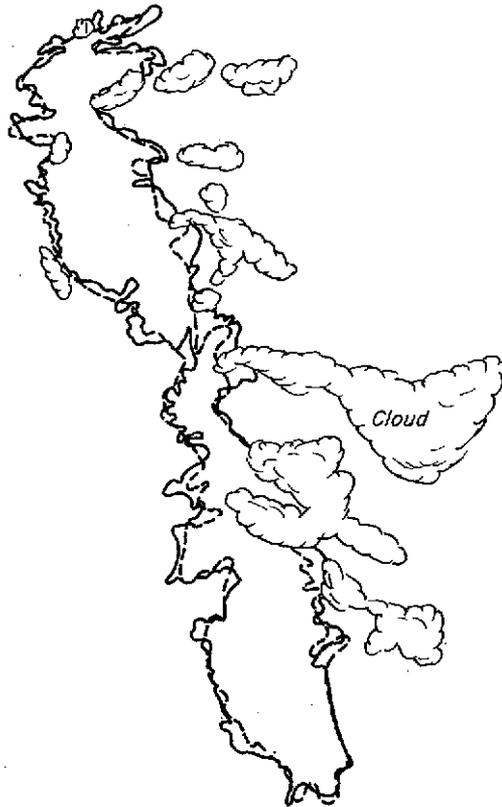
Figure 5-9 Enlarged portion of ERTS-1, MSS-6 image (0.7 - 0.8 μm), I.D. No. 1324-18005, 12 June 1973, area covered is the White Mountains in California.

118°30' W
38° N

118° W
38° N

———— SL2 S-190A, Band 6, (0.6-0.7 μ m) - 6 June 1973

----- ERTS-1 Snowline, 12 June 1973, MSS-5



37°30' N
118°30' W

37°30' N
118° W

Figure 5-10 Comparative map for White Mountains showing snow lines mapped from S190A Camera Station 6 imagery on 3 June 1973 and from ERTS-1, MSS-5 (0.6 - 0.7 μ m) image (I.D. No. 1324-18005) on 12 June 1973.

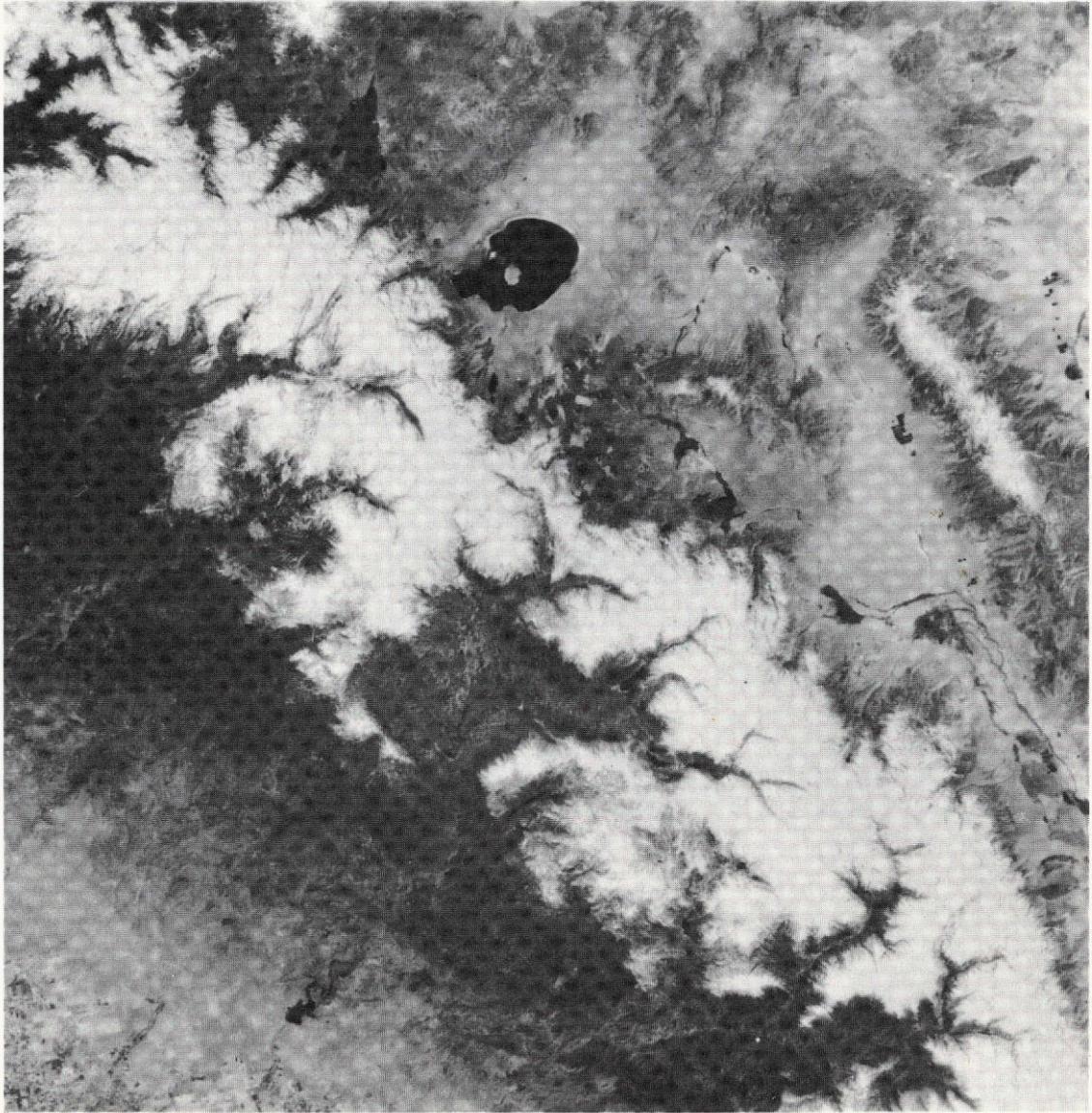


Figure 5-11 ERTS-1, MSS-5 image (0.6 - 0.7 μm), I.D. No. 1307-18064, 26 May 1973; area covered is the Sierra Nevada.

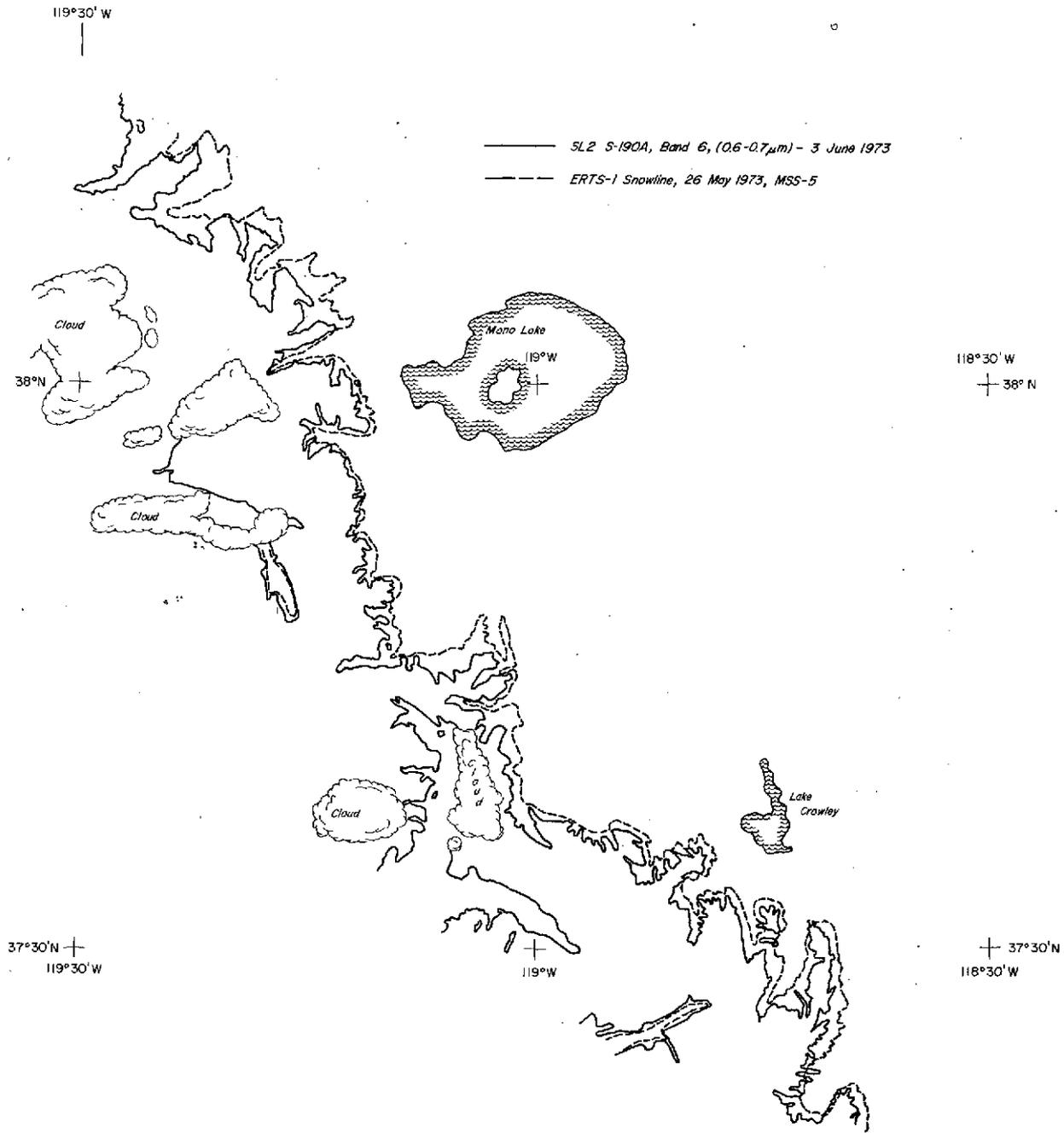


Figure 5-12 Comparative map for east slope of Sierras near Mono Lake showing snow lines mapped from S190A, Camera Station 6 imagery on 3 June 1973 and from ERTS-1, MSS-5 (0.6 - 0.7 μm) image (I.D. No. 1307-18064) 26 May 1973.

The stereo effect is pronounced in this stereo pair, with the definition of the cloud heights above the terrain very evident. Along the slopes of the mountains, the constant height of the cumulus cells in contrast to the lowering elevation of the terrain aids in the interpretation of the clouds over the snow. Over the highest terrain, however, the clouds are not as distinct because the elevation difference between the mountain peaks and the cumulus cells is small. Even with stereo viewing, therefore, clouds over the highest mountains are difficult to distinguish from snow.

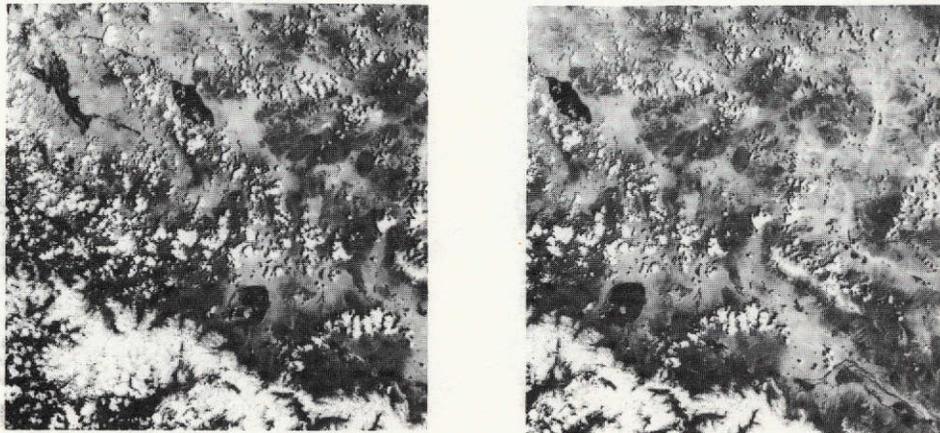


Figure 5-13 Stereo Pair, S190A, Camera Station 5 (0.5 - 0.6 μ m) photographs from EREP Pass 3, 3 June 1973; - area covered includes the eastern slopes of the Sierras.

6. COMPARISON BETWEEN S190A AND S190B DATA

Photography from the S190B Earth Terrain Camera was available for only one of the test site areas, the one in central Utah on EREP Pass 5. An enlarged color print processed from the original aerial color transparency is shown in Figure 6-1. A comparison between this print and the S190A camera station 4 aerial color print (shown in Figure 5-7) indicates significant differences in the amount of visible snow covering the Wasatch Plateau. The better resolution of the S190B imagery (reported to be 10 - 30 m) allows observation of relatively small scale snow packs along narrow isolated ridges or peaks, which are either barely discernible or not observed in the lower resolution (30 - 70 m) S190A imagery. Also, areas of patchy snow cover extending into heavily forested areas appear well defined in the S190B imagery, whereas the S190A imagery suggests a much sharper snow boundary.

In the process of mapping the snow limit along the Wasatch Plateau on an 8 x 10 inch black and white print of the S190B aerial color image, an overall comparison with the original 4 1/2 inch sq. aerial color transparency was made. This comparison revealed that some regions of high reflectance along ridges in the black and white print, which normally would have been interpreted as nearly solid snow pack, are actually regions of higher reflecting barren terrain, which are generally free of significant snow cover. Therefore, it appears that black and white imagery alone does not accurately define the actual limit of the snow; because of the color contrast between the white snow and the brown tone of the snow-free terrain, therefore, the S190B aerial color photography is considered to be the better product for detailed mapping accuracy.

Using the same procedure as with the S190A data, the snow line elevation in the Wasatch Plateau was measured from the S190B black and white print. The resulting snow line is at the 2700 m level along the west slope and 2880 m along the east slope. The corresponding S190A measurements are 2760 m and 2910 m, respectively. The slightly lower snow line elevation measured from the S190B data is attributed to the fact that more detail is detectable in the higher-resolution photographs; thus, areas of patchy snow which are not detectable in the S190A photographs can be mapped.

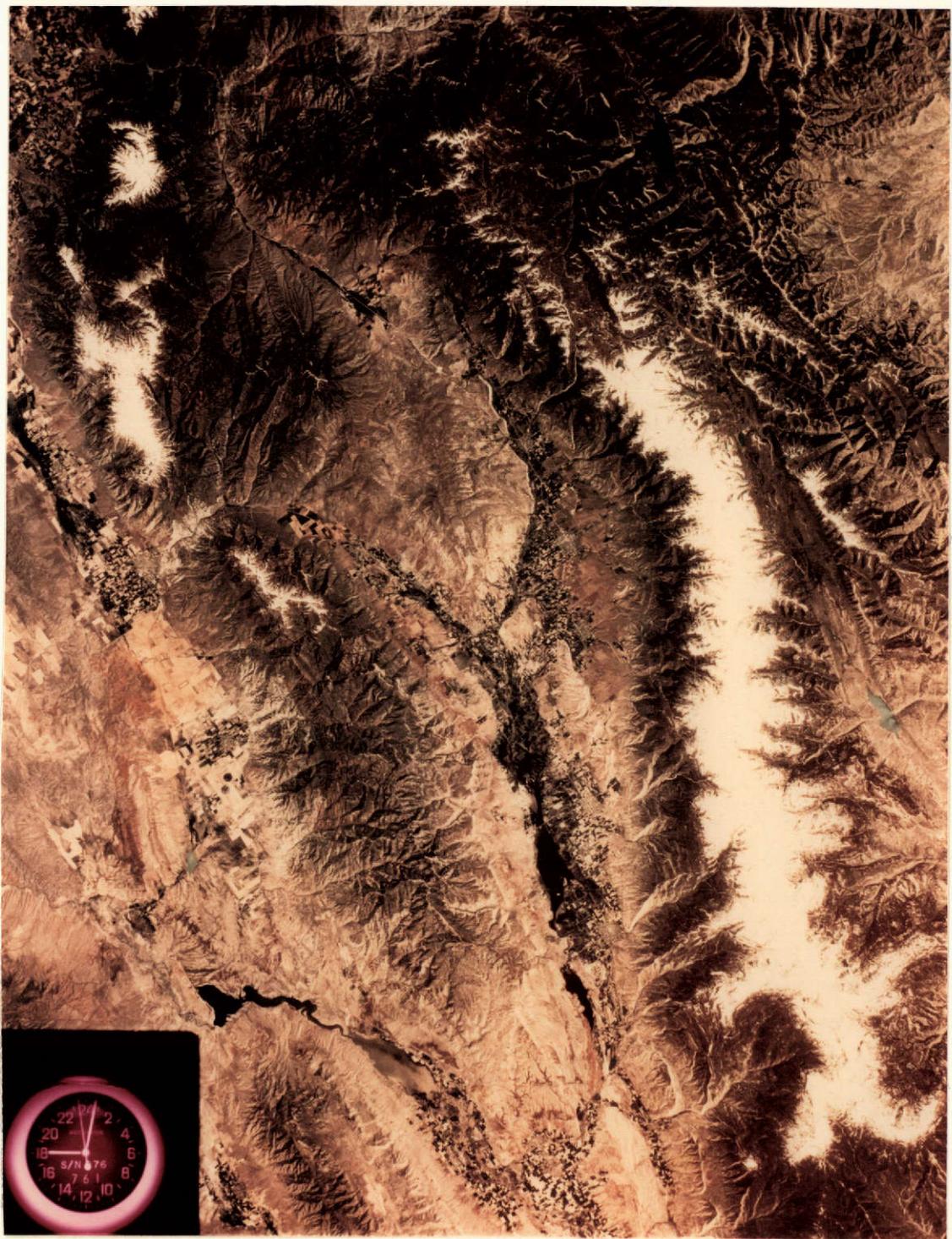


Figure 6-1 S190B aerial color (0.4 - 0.7 μm) photograph from EREP Pass 5, 5 June 1973; - area covered includes the Wasatch Plateau in Utah.

7. ANALYSIS OF S192 DATA

7.1 Spectral Reflectance of Snow Cover

The spectral reflectance of snow has not been well understood. Prior to the ERTS-1 and now the Skylab multispectral data, the only near-IR measurements available from a spacecraft were from the Nimbus-3 HRIR (High Resolution Infrared Radiometer). A drop in the reflectance of snow in the HRIR near-IR channel (0.7 - 1.3 μm) was first noticed in a study by Barnes and Bowley (1970). In a subsequent, more thorough investigation of the Nimbus-3 data, Strong et al (1971) attributed the drop in the reflectance of snow and ice surfaces to the existence of melt water, pointing out that with even a thin layer of melt water the snow or ice surface would be highly -reflective in the visible and essentially non-reflective in the near-IR.

In the ERTS-1 investigations (Barnes, Bowley, and Simmes, 1974), the contrast between snow and bare ground was found to be considerably lower in the MSS-7 near-IR band (0.8 - 1.1 μm) than in the MSS-5 visible band. Despite the lower contrast, however, the snow line in the winter time images can be mapped from the MSS-7, and the snow extent appears to be about the same as determined from the MSS-5 data.

In some late spring cases, however, the areas appearing very bright in MSS-7 are significantly smaller than those appearing bright in MSS-5. For example, in the Kern Basin (in the Sierra Nevada) on 30 June, the brightest tones in MSS-7 are limited to the highest ridges, whereas in MSS-5 a distinctly larger area appears to be snow-covered. It was concluded that the snow visible in the near-IR image may be the high-elevation dry snow, whereas both the dry and lower elevation wet snow surfaces are detectable in the visible image.

Recent laboratory experiments reported by O'Brien and Munis (1973) have been conducted to determine the effects of various natural conditions, especially melting and refreezing, on the spectral reflectance of a snow cover in the red and near-IR regions. The results of these experiments indicate that toward the red end of the visible spectrum, the reflectance declines somewhat and falls off rapidly in the near-infrared region. As fresh snow ages without melting, there is a small decrease in reflection, but temperatures near-melting (but not melting) do not produce a great

reduction in reflectance; melting to the point of producing wet snow on the surface, on the other hand, produces a significant reduction in reflectance.

7.2 Reflectance Variations of Snow Cover in S192 Data

The Skylab S192 Multispectral Scanner provides for the first time an opportunity to examine the spectral reflectance characteristics of snow from space over a spectral range extending from the visible to well into the near-IR (to 2 μm). Although only the S192 screening film and a limited amount of the larger scale interim film have been available, it has been possible to use these data to analyze qualitatively the variations in reflectance of snow cover in certain of the spectral bands. Because of the narrower swath scanned by the Multispectral Scanner, the coverage is less than that of the S190A data.

S192 imagery from EREP Pass 5 is shown in Figure 7-1; in this figure, a segment of the screening film for Band 2 (0.46 - 0.51 μm) is shown in (a) and for Band 11 (1.55 - 1.75 μm) in (b). In the visible band, snow cover in the Wasatch Plateau and in the nearby Wasatch Range and San Pitch Mountains appears with a very high reflectance. In the near-IR band, however, a dramatic reversal in the snow reflectance is observed; in Band 11, the snow appears almost black, having even a lower reflectance than the surrounding terrain. On this date, the maximum air temperature at Salt Lake City was about 70°F; it is probable, therefore, that much of the snow cover in even the higher elevations was in a melting state (wet snow surface) at the time of the EREP pass.

In Figure 7-2 (a and b) imagery for the same two S192 spectral bands is shown from EREP Pass 3, extending from Lake Tahoe to beyond the White Mountains. In Band 2, clouds cover much of the area, but snow can be detected in the Sierra Nevada and the White Mountains. In Band 11, on the other hand, the clouds are still visible but the snow can no longer be detected.

To investigate further the spectral response of the snow, interim S192 film for a segment of this pass covering the White Mountains was examined more carefully.

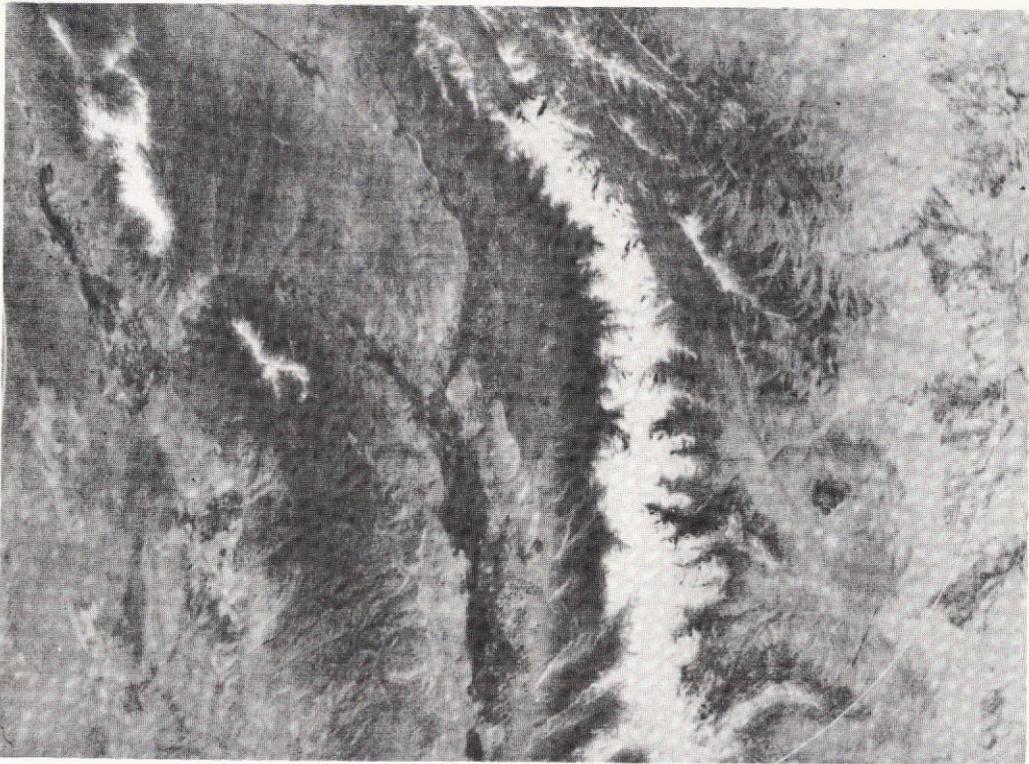


Figure 7-1a S192 Band 2 imagery (0.46 - 0.51 μm) from EREP Pass 5, 5 June 1973; area covered includes the Wasatch Plateau in Utah.

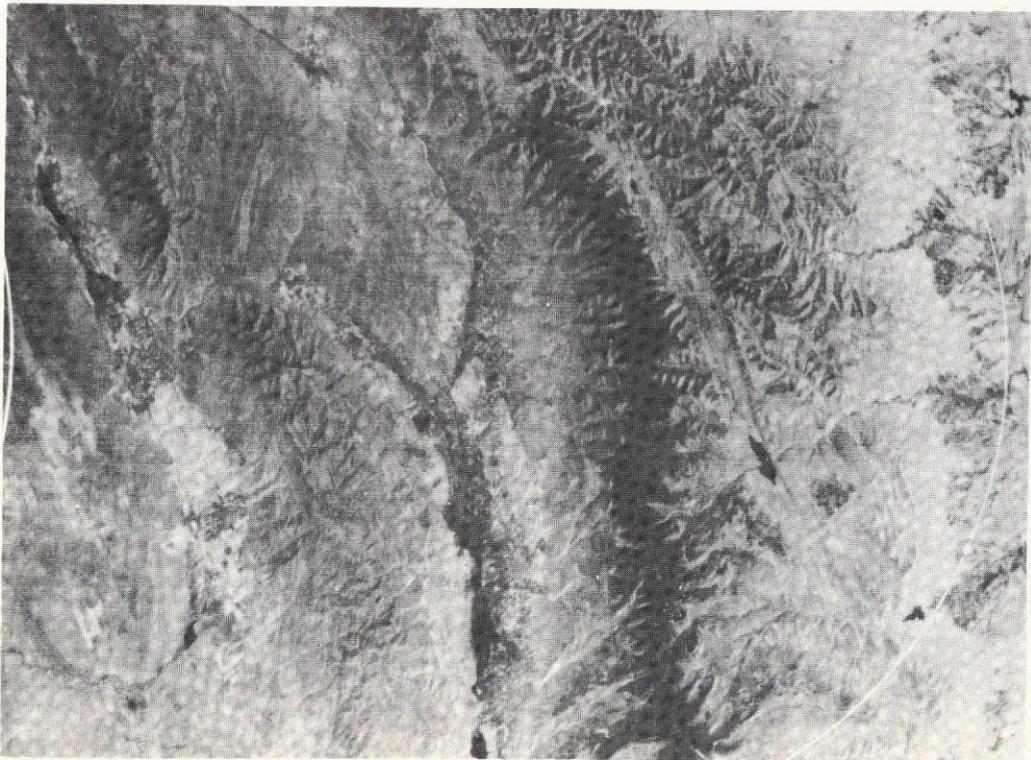


Figure 7-1b S192 Band 11 imagery (1.55 - 1.75 μm) from EREP Pass 5; same area shown in Figure 7-1a. Note decreased reflectance of snow as compared to the visible band imagery.



(a)



(b)

Figure 7-2 S192 imagery from EREP Pass 3, 3 June 1973; (a) Band 2 (0.46 - 0.51 μm), (b) Band 11 (1.55 - 1.75 μm). Area covered extends from Lake Tahoe to White Mountains; note decreased reflectance of snow in near-IR (b) as compared with visible (a).

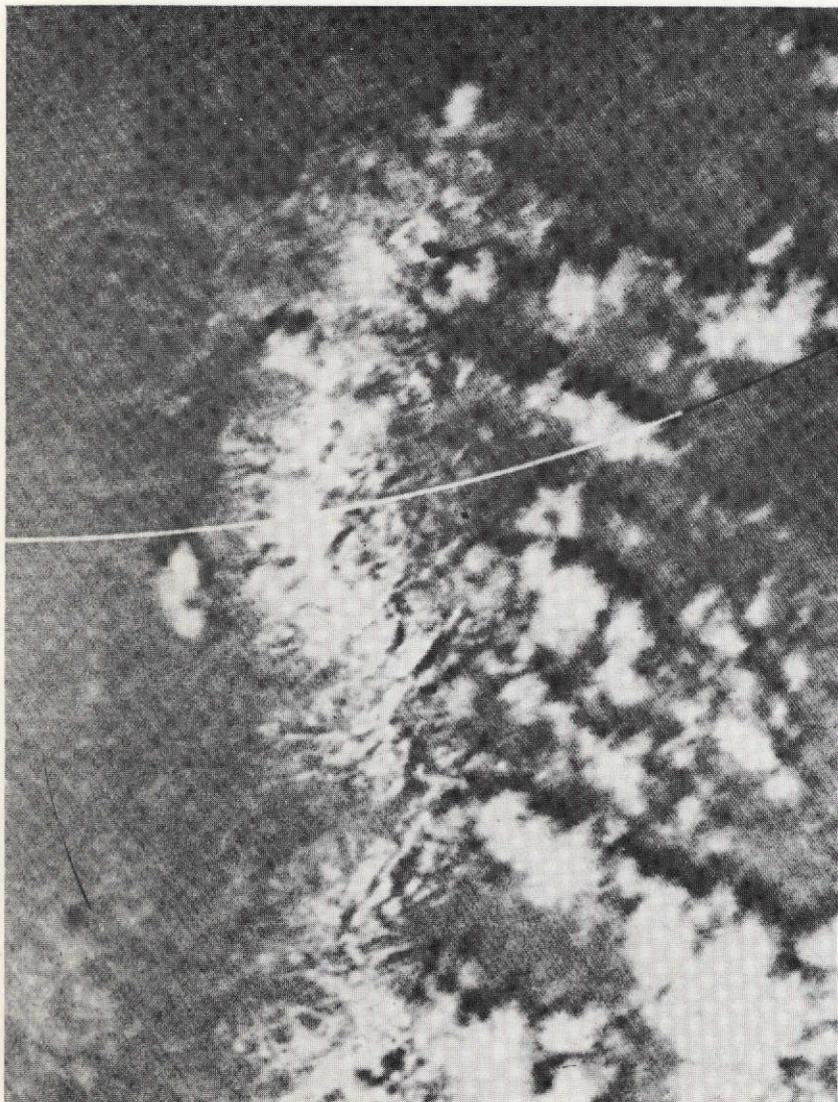
The interim film for Band 3 (0.52 - 0.56 μm) and Band 11 (1.55 - 1.75 μm) is shown in Figure 7-3 (a and b). The same area in Band 9 (1.01 - 1.19 μm) is shown in Figure 7-4a; a comparative map of the snow extent as mapped from the visible band and from Band 9 is given in Figure 7-4b.

These figures reveal variations in the reflectance of the snow surface that are in accordance with those observed in the initial S192 screening film. In Band 3 the snow appears very bright. In the Band 9 imagery, however, the extent of the snow-covered area that has a high reflectance is considerably less than in the visible imagery. In fact, it appears that only the snow at the highest elevations of the White Mountains has a high reflectance; the snow at lower elevations cannot be detected in this band. In Band 11, a complete reversal in reflectance is seen, with the entire snow-covered area actually appearing darker in tone than the surrounding terrain.

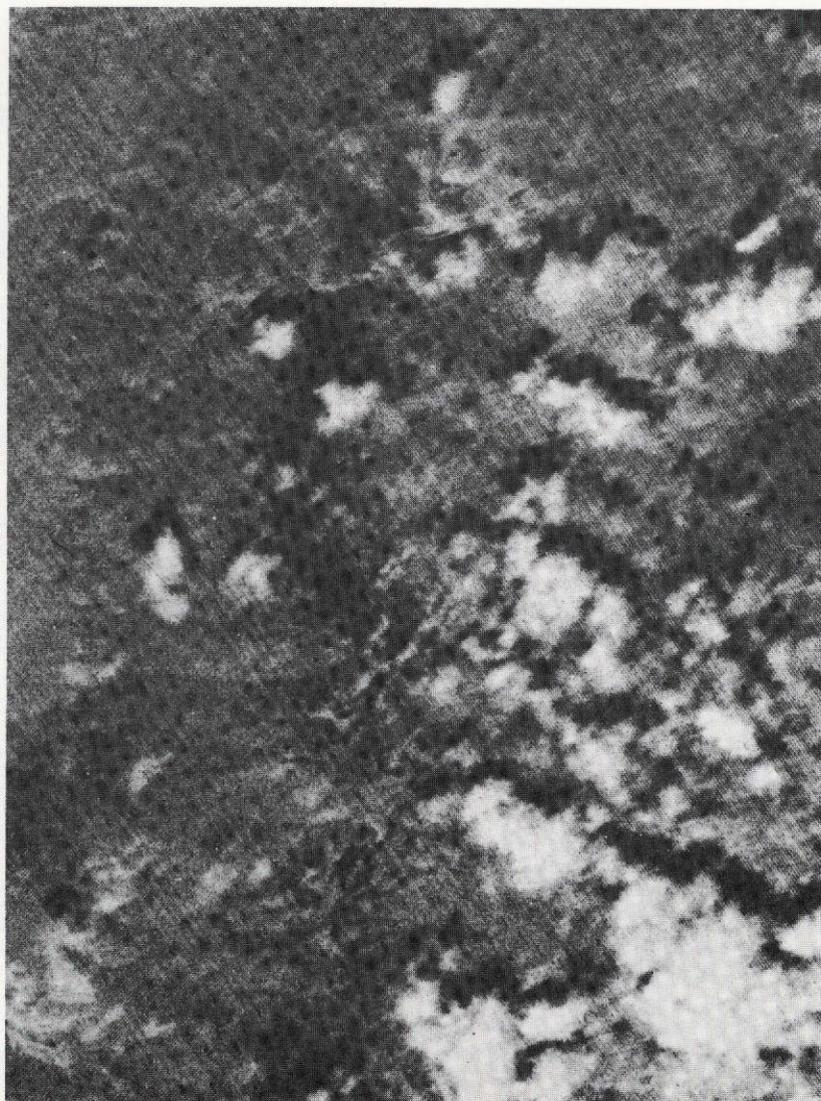
On 3 June, the maximum temperature at a station at the 3700 m level, which reported a 5 inch snow cover, was 41°F; at a station at the 3700 m level, which reported no snow cover, the maximum temperature was 53°F. It is possible, therefore, that at the time of the EREP pass (1130 LST), melting had begun at the lower part of the snow pack but not at the highest elevations (both of these stations had minimum temperatures below freezing that morning). As a result, the reflectance of the wet snow surface has decreased more than the reflectance of the frozen snow surface in the Band 9 imagery. In the Band 11 imagery, which is further into the near IR spectral range, the snow reflectance has decreased for both the wet and the frozen snow surfaces. These results would be in agreement with the laboratory experiments reported by O'Brien and Munis (1973); they report that wet snow has a somewhat lower reflectance than refrozen snow at about 1.1 μm , but both types have an equally low reflectance at 1.5 - 1.75 μm .

7.3 Use of S192 Multispectral Data to Distinguish Snow and Clouds

In the EREP Pass 3 S192 imagery, not only is the difference in the reflectance of the snow between the visible and near-IR bands dramatic, but also the distinct nature of the clouds in the near-IR spectral region. Whereas the snow surface exhibits wide variations in reflectance, no significant change in the reflectance of the clouds occurs over the spectral

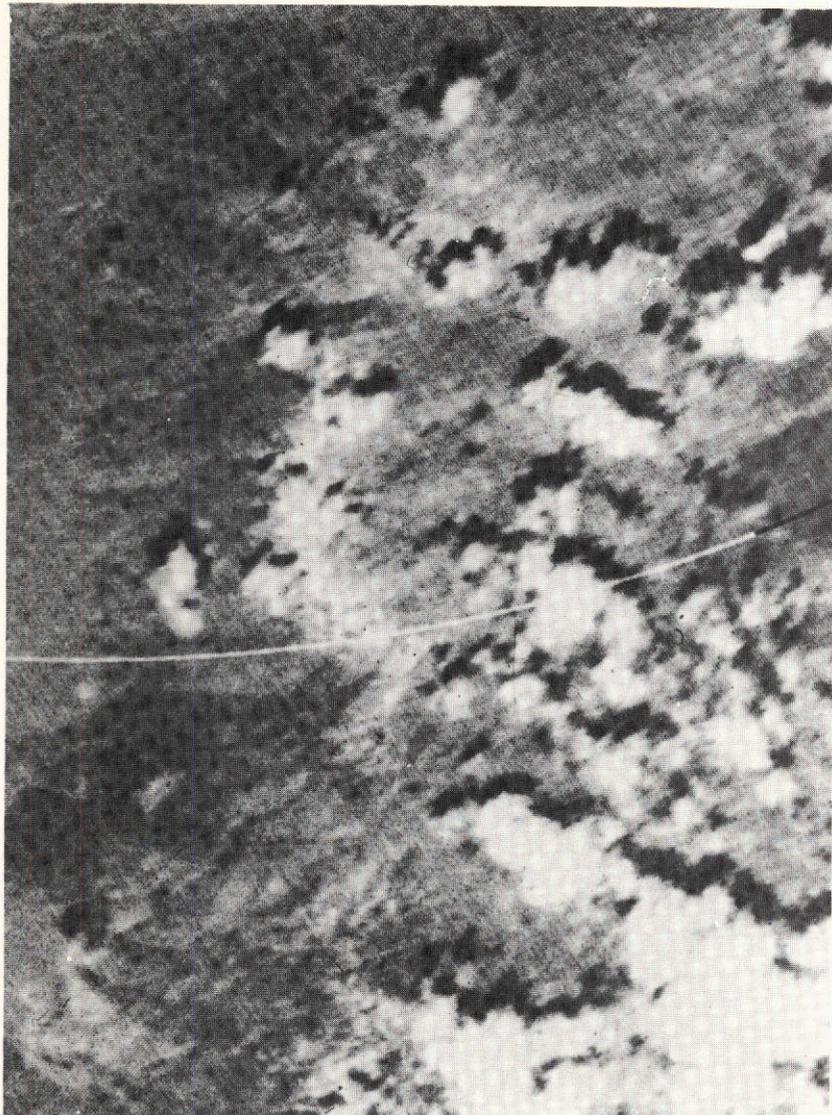


(a)

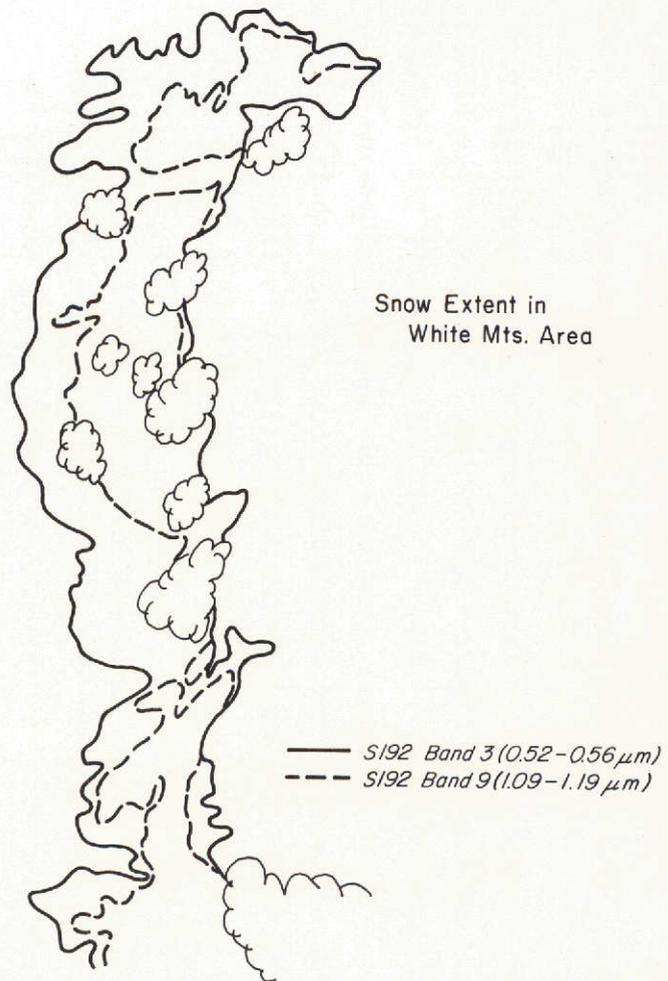


(b)

Figure 7-3 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; note the reversal in the reflectance of the snow in these two spectral bands.



(a)



(b)

Figure 7-4

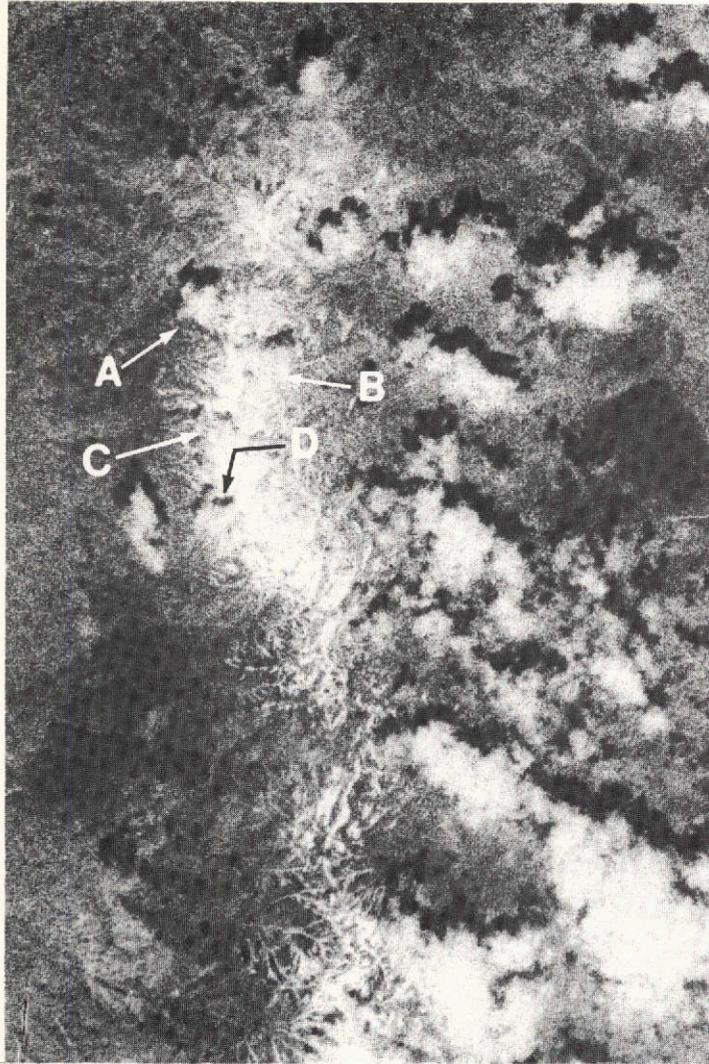
(a) S192 Band 9 imagery (1.09 - 1.19 μm) from EREP Pass 3, 3 June 1973; area covered is the same as shown in Figure 7-3. Note the decrease in the apparent snow extent as compared to the visible band imagery (Figure 7-3a).

(b) Comparative map showing relative extent of apparent snow cover mapped from S192 Band 3 (Figure 7-3a) and Band 9 (Figure 7-4a).

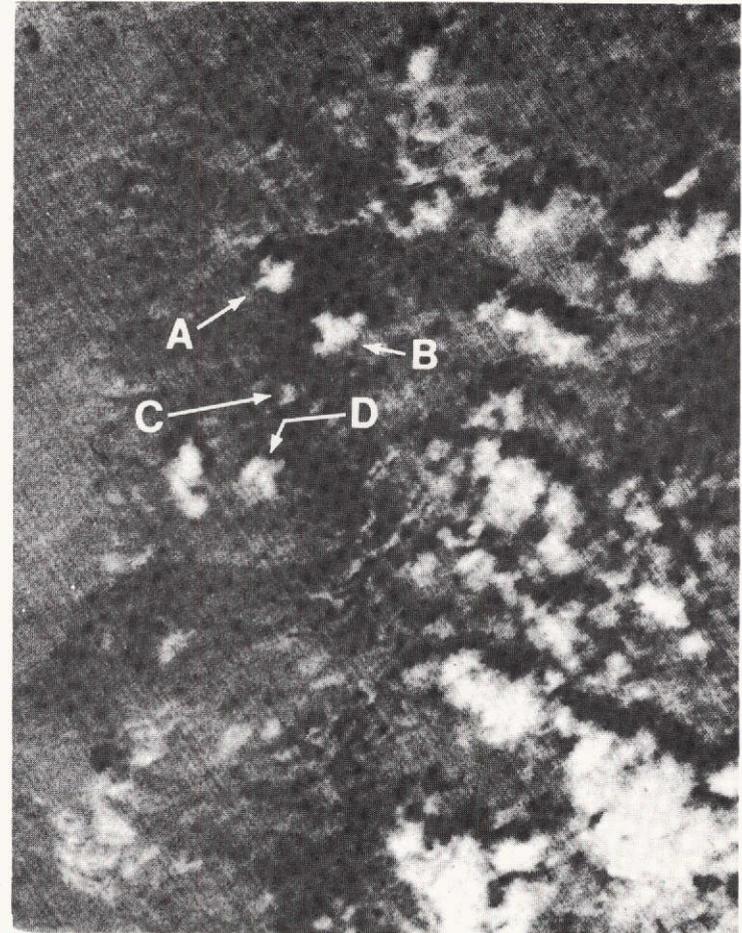
range examined. In the Band 11 data, therefore, the clouds appear white and snow appears black; in the Band 3 data, both the clouds and the snow appear white.

A further example of the relative differences in the reflectance of snow and clouds is shown in Figure 7-5; in (a), a portion of the S190A Camera 2 photograph (0.8 - 0.9 μm) is shown, whereas in (b) the S192 Band 11 image (1.55 - 1.75) is shown. Cumulus cells over the mountains are difficult to detect even in the near-IR S190A band because their reflectance and that of the underlying snow is almost identical. In the S192 imagery, however, each cumulus cell is distinct, even those cells directly over the snow-covered mountains.

These results indicate a potential technique to use S192 data to distinguish automatically between snow and clouds. Because of the relative differences in reflectance, a visible band and a near-IR band (in the 1.5 - 2.0 region) could be used. In such a scheme, using, say, Band 3 (visible) and Band 11 (near-IR), features that have a high reflectance in both bands would be clouds, features that have a high reflectance in the visible but a low reflectance in the near-IR would be snow, and features that have a low reflectance in both bands would be cloud-free terrain that is not snow covered.



(a)



(b)

Figure 7-5

(a) S190A Camera Station 2 ($0.8 - 0.9 \mu\text{m}$) photography and (b) S192 Band 11 ($1.55 - 1.75 \mu\text{m}$) imagery for EREP Pass 3, 3 June 1973, White Mountains area. Clouds at A, B, C and D that are difficult to detect in the S190A photo are distinct in the S192 near-IR spectral band.

8. CONCLUSIONS

EREP data were collected on the SL-2 mission over three test site areas in the western United States in which mountain snow cover existed. Because of the late spring season, the snow was confined to the higher elevation terrain. Despite the rather limited data sample, and the meager correlative snow data available in early June, an investigation has been conducted to determine the utility of the S190A and S190B photography and the S192 imagery for mapping areal snow extent. The conclusions based on this investigation are presented in the following sections.

8.1 Utility of S190A and S190B Photography

The results of the analysis of the S190A photography indicate that of the four black and white camera stations, snow cover is best defined in the two visible spectral bands. The overall extent of the snow can be mapped more precisely and the snow within shadow areas is better defined in the visible bands. In some instances, however, variations in reflectance within snow covered areas are observed in the near-IR bands but not the visible; these variations may be associated with forest effects or even snow depth, but improved ground-truth data are needed before a definite conclusion can be drawn.

Of the two S190A color products, the aerial color photography is the better. In fact, because of the contrast in color as well as the contrast in reflectance between snow and snow-free terrain, this product is concluded to be the best overall of the six camera stations for detecting and mapping snow. Excellent definition between snow and bare rock within shadow areas is observed in the aerial color photographs. In the color-IR product, the edges of the snowpack tend to have a bluish tone similar to that of the adjacent terrain, and, thus, are not precisely defined; the bluish tone may be the result of patchy snow cover mixed with forest, but better ground-truth data are needed before this can be verified.

The overlapping S190A frames permit stereo viewing, which aids in distinguishing clouds from the underlying snow. Over the highest terrain, however, the distinction is more difficult because of the smaller difference in the elevation of the clouds and the terrain. Therefore, subjective interpretive keys, such as those developed for analysis of ERTS data, must generally be used to distinguish snow from clouds.

Because of the improved spatial resolution of the S190B Earth Terrain Camera (reported to be 10-30 m as compared to 30-70 m for the S190A), areal snow extent can be mapped in greater detail than from the S190A photographs. In the one test site area for which S190B photography was available, small areas of snow lying along narrow ridges that were not observed in even the S190A aerial color film could be detected. As was true with the S190A data, the S190B aerial color product was better than a black and white print (processed from the color transparency) because of the contrast in color tone as well as the contrast in reflectance.

The snow line elevation measured from the S190A and S190B photographs is reasonable compared to the meager ground truth data available. Comparisons between the areal snow extent mapped from the S190A black and white visible band photographs and that mapped from ERTS imagery indicate that the snowline can be defined in greater detail from the Skylab product. Moreover, the definition of snow in the S190A aerial color photographs is considerably better than the definition in the ERTS imagery.

Previous investigations have shown that snow can be mapped in more detail from ERTS than from aerial surveys and that the snowline elevation can be measured from ERTS to an accuracy of about 60 m. Thus, although it was not possible to determine the aerial snow extent in a complete river basin, the greater detail in the S190A photographs gives every indication that the snow line elevation can be mapped to an accuracy of better than 60 m.

Based on the results of the analysis of the SL-2 data sample, the overall conclusion is that areal snow cover extent can be mapped more accurately from the S190A and S190B photography than from any other spacecraft system, including ERTS. Further investigation is needed, however, to determine more precisely the mapping accuracy attainable using the S190A and S190B photography and to examine more thoroughly certain of the observed data characteristics. The further investigations can be performed using data from the SL-4 mission collected when snow cover is more extensive and when a greater amount of correlative snow measurements are available. Analysis of the SL-4 data sample will enable a more conclusive evaluation of the operational utility of data with the S190A and S190B characteristics; it may be that a more readily processed black and white data product from a system that provides somewhat poorer resolution, say, of the order of that of the ERTS imagery, will be sufficient for most operational snow mapping purposes.

8.2 Utility of S192 Imagery

The Skylab S192 Multispectral Scanner provides for the first time an opportunity to examine the spectral reflectance characteristics of snow from space over a spectral range extending from the visible to well into the near-IR (to 2 μm). Although only the S192 screening film and a limited amount of the larger scale interim film have been available, it has been possible to use these data to analyze qualitatively the variations in reflectance of snow cover in certain of the spectral bands. The results of the investigation indicate a dramatic decrease in the reflectance of the snow surface in the near-IR portion of the spectrum. These results are in general agreement with the results of laboratory experiments.

In the S192 data, a complete reversal in the snow reflectance occurs in the Band 11 (1.55 - 1.75 μm) imagery, with the entire snow-covered area actually appearing darker in tone than the surrounding terrain. In contrast, whereas the snow surface exhibits wide variations in reflectance, no significant change in the reflectance of the clouds occurs over the spectral range examined.

Two potential applications are possible, based on these results. First, because the reflectance of the snow surface in an intermediate band (Band 9; 1.01 - 1.19 μm) is much lower at the lower elevation terrain, it appears that the drop in reflectance in the near-IR portion of the spectrum may be related to the wetness of the snow surface. In early June, the snow would be expected to be melting at the lower elevations, but might still be dry at the highest elevations. Thus, measurements at this spectral band (1.09 - 1.19 μm) may have application for distinguishing between dry and melting snow surfaces.

Secondly, the complete reversal in reflectance that is observed in the Band 11 data (1.55 - 1.75 μm) indicates that in this portion of the spectrum snow surfaces have a low reflectance regardless of the condition of the snow. Because clouds do not exhibit a similar drop in reflectance, measurements in this spectral band have potential use for automatically distinguishing snow from clouds. In a scene using two spectral bands, say Band 3 (visible range) and Band 11, features that have a high reflectance in both bands would be clouds, features that have a high reflectance

in the visible but a low reflectance in the near-IR would be snow, and features that have a low reflectance in both bands would be cloud-free terrain that is not snow covered.

As with the S190A and S190B photographic data products, further investigation using improved S192 film products and the digitized data are needed to evaluate fully the utility of multispectral measurements for snow mapping. Analysis of data from the SL-4 mission, which were collected during the mid-winter when snow conditions are quite different from those existing in the late spring, is essential before final conclusions can be drawn. The results of the initial investigation; however, do indicate considerable potential for the utility of multispectral snow cover analysis; the potential for distinguishing snow from clouds automatically is particularly significant, since this has been recognized as a serious problem with regard to the eventual machine processing of satellite data for snow survey.

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