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USE OF ERTS DATA FOR MAPPING SNOW COVER IN THE WESTERN UNITED STATES

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16. Abstract

The purpose of this investigation is to evaluate the application of ERTS data for mapping snow cover, primarily in the mountainous areas of the western United States.

The results of the analysis of the initial sample of ERTS data indicate that the MSS-5 spectral band (0.6 to 0.7 μm) is the most useful for detecting and mapping mountain snow cover. At the ERTS resolution, snow cover can be readily detected in the MSS-5 band and can be distinguished from clouds. Snow line elevations have been mapped for five mountain areas. In one case for the Salt-Verde Watershed in Arizona good agreement is observed between the location of the snow line as mapped from the ERTS data and as depicted on an aerial snow survey chart compiled a week earlier. Examination of data from the Arctic has revealed that multispectral data can provide information on glacial conditions that cannot be ascertained from observations in a single spectral band.

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PREFACE

The purpose of this investigation is to evaluate the application of ERTS data for mapping snow cover, primarily in the mountainous areas of the western United States. The specific objectives are to determine the spectral interval most suitable for snow detection, to determine the accuracy with which snow lines can be mapped in comparison with the accuracies attainable from other types of measurements, and to develop techniques to differentiate reliably between snow and clouds and to understand the effects of terrain and forest cover on snow detection.

The results of the analysis of the initial sample of ERTS data covering the specified test sites in the western United States indicate that the MSS-5 spectral band (0.6 to 0.7 μm) is the most useful for detecting and mapping mountain snow cover. At the ERTS resolution, snow cover can be readily detected in the MSS-5 band and can be distinguished from clouds. In four mountain areas for which data have been analyzed on at least two different dates, changes in snow line elevation ranging from 200 to as much as 4000 ft have been mapped. In once case analyzed for the Salt-Verde Watershed in Arizona, good agreement is observed between the location of the snow line as mapped from the ERTS data and as depicted on an aerial snow survey chart compiled a week earlier. Although a thorough investigation of the multispectral characteristics of snow has not yet been undertaken, examination of data from the Arctic has revealed that the multispectral approach can provide information on glacial conditions that cannot be ascertained from observations in a single spectral band.

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1. INTRODUCTION

1.1 Purpose and Objectives

The purpose of this investigation is to evaluate the application of ERTS data for mapping snow cover, primarily in the mountainous areas of the western United States. The specific objectives are to determine the spectral interval most suitable for snow detection, to determine the accuracy with which snow lines can be mapped in comparison with the accuracies attainable from other types of measurements, and to develop techniques to differentiate reliably between snow and clouds and to understand the effects of terrain and forest cover on snow detection.

The snow extent mapped from the ERTS imagery is being correlated with standard snow measurements, aerial-survey snow charts, and aerial photography for both mountainous and flat terrain within the United States. The three primary geographic areas of interest are the southern Sierra Nevada in California, the Upper Columbia Basin in northern Idaho and northwestern Montana, and the Salt River Project Area in Arizona; in each of these areas mountain snow cover is of significant hydrologic importance. Measurements for flat terrain are in the Upper Mississippi-Missouri River Basins region.

Snow cover is a water resource for which spacecraft observation holds great promise. The results of this study will provide the hydrologist with interpretive techniques that will enable data from future operational satellite systems to be used to map snow on a more cost-effective basis.

1.2 Summary of Work Performed During Reporting Period

During this reporting period a considerable amount of ERTS data from the fall and early winter seasons has been received. For each of the geographic areas of interest usable ERTS coverage has been obtained on at least two separate dates, permitting changes in the snow line to be mapped. The total data sample received to date is summarized in Section 2.1.

As the data are received, they are being catalogued and examined to determine whether the areas of primary interest are essentially cloud-free. For the cloud-free cases the snow extent is being mapped from the 9.5 inch positive prints using transparent overlays. The MSS-5 (0.6 to 0.7 μm) band is being used for the analyses because snow cover can be readily identified in this spectral interval and yet the snow-covered areas are not saturated as is sometimes the case in the MSS-4 (0.5 to 0.6 μm) spectral band. Following the mapping of the snow extent the snow line elevation is determined for each case through comparison with contour maps. In the analyses completed during the reporting period the mean snow line elevation has been determined for the White Mountains in California (three dates), the Olympic Mountains and Mt. Rainier area in Washington (two dates), the Three Sisters Mountains in Oregon (two dates), and the Salt River Area in Arizona (one date).

Because of the amount of detail contained in the ERTS imagery, the snow extent is being mapped for limited areas rather than for entire mountain ranges. Also, very little correlative snow data have yet been obtained, except for the Salt River Project area in Arizona. For that area, aerial snow survey charts are being received on a regular basis, and thus can be correlated with the ERTS data. For the one date in November for which ERTS coverage has been received, the agreement between the snow line mapped from the ERTS picture and the aerial-survey snow line is good. It is anticipated that correlative data for the other areas will be obtained during the next reporting period.

2. MAIN TEXT

2.1 Data Sample

Data from some 135 ERTS-1 passes have been received. For approximately half of these passes the data are in the form of 70 mm positive transparencies and corresponding negatives, whereas the other half of the sample consists of 70 mm negatives and corresponding 9.5 inch paper prints. Most of the 70 mm negatives received earlier in the contract period, however, were of a too high density to permit their use with the standard photographic equipment available at ERT. Therefore, paper prints have been requested for all subsequent data. The number of passes for each geographic area in which essentially cloud-free conditions exist and snow can be identified is given in Table 1.

2.2 Correlative Data

For most of the geographic areas of interest little correlative snow data have yet been acquired. Most of the ERTS data examined for the mountainous areas in the western United States have been from the summer to early winter seasons, the period when few snow measurements are available. As the winter season progresses, however, correlative snow data will become more plentiful.

For the Salt-Verde Watershed area in Arizona aerial snow survey charts have been acquired for several dates, beginning 14 November (through the courtesy of the Salt River Project Office). The aerial survey procedures are described in a paper by Warskow (1971, "Remote Sensing as a Watershed Management Tool on the Salt-Verde Watershed," paper presented at ARETS Seminar on Applied Remote Sensing of Earth Resources in Arizona). An

TABLE 1

SUMMARY OF DATA SAMPLE

Geographic Area	No. of Passes	Period of Coverage
Olympic Mountains (Washington)	8	25 July - 14 December 1972
Lower Columbia Basin (Washington, Oregon)	6	28 July - 02 December 1972
Canadian Rockies (British Columbia)	1	27 July 1972
Upper Columbia Basin (Southern Montana-Wyoming)	3	12 September - 23 November 1972
Upper Columbia Basin (Montana, Idaho, Nevada)	12	27 August - 14 December 1972
Sierra Nevada (California, western Nevada)	8	25 July - 14 December 1972
Salt-Verde Watershed (Arizona)	3	21 November - 26 December 1972
Upper Mississippi-Missouri River Basin Area	19	24 November - 02 January 1972
(Total number of useful passes: 55) .		

ocular estimate is made of the snow depth using the logs left from timber operations in the mountain areas, ground and vegetation textural characteristics and cultural features (such as fences, road cuts) as indicators of the snow depth. Both the aerial outline of the snowpack and the observed depths are recorded on a map overlay. The initial chart has been used in the analysis of ERTS data from a week later (21 November); as more ERTS data covering central Arizona are received, the later charts will provide a valuable source of ground truth.

2.3 Analysis Procedures

Examination of the multispectral characteristics of snow cover definition has shown that the contrast between snow-covered and snow-free terrain is greatest in the MSS-5 (0.6 to 0.7 μm) spectral band. Although the MSS-4 (0.5 to 0.6 μm) data also appear useful, the contrast between snow and no snow overall is less than in the MSS-5 data. Moreover, at higher sun angles some snow-covered areas are near saturation in the MSS-4 band, causing a loss of some detail in the snow patterns. Therefore, the MSS-5 data have been used in the initial analyses.

In the longer wavelengths, especially the MSS-7 near-IR band (0.8 to 1.1 μm), snow cover is more difficult to detect. However, the near-IR band may provide useful information for certain purposes such as detecting melting conditions. As discussed later in this report, MSS-7 data have been found extremely useful for studies of glaciers in the Arctic. Further investigations of the multispectral characteristics of snow will be conducted later in the study period.

Snow cover can be identified in the MSS-5 data because of its greater reflectance than the surrounding snow-free terrain. Although snow and clouds have similar reflectances, mountain snow cover can be differentiated from cloud primarily because the configuration of the snow patterns is very different from cloud fields and can be instantly recognized. The snow boundaries are also sharper than typical cloud edges, and snow fields usually appear with a more uniform reflectance than do clouds, which have considerable variation in texture. Furthermore, cloud shadows are usually visible, especially with cumuliform clouds, and various terrestrial features can be recognized in cloud-free areas. In fact, in the images from the flatter terrain of the Midwest that are completely snow covered, recognition of terrestrial features is the principal means to establish cloud-free areas. Because of the high resolution of the ERTS data, numerous terrestrial features that are not visible in lower resolution meteorological satellite photographs can be recognized. In addition to natural features, such man-made features as roads, electric power lines, and cultivated fields are detectable. In the heavily forested areas of the Cascades, timber cuts are clearly visible.

For each case analyzed, the snow limit was mapped from the 9.5 inch prints using a transparent acetate overlay. The snow line was located at the edge of the brighter area without regard to changes in brightness within the overall area deduced to be snow covered. Although the snow-covered areas in most of the cases analyzed exhibited fairly uniform brightness, some variations in tone were observed. The relationships between these variations and factors such as terrain and forest cover will be examined. Also, the accuracy of the snow line locations will be evaluated when correlative snow data are acquired. As the snow line elevation lowers into the more heavily forested areas as the winter progresses (in areas such as the Cascades), the snow line may not be as clearly defined as it is in the late summer and fall cases analyzed so far.

To determine the snow line elevation, 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 9.5 inch ERTS prints, charts of this scale were found to be the most useful for matching the amount of detail in the ERTS data. In the procedure used, grid lines, corrected where necessary, were first drawn on each overlay at 15-minute latitude-longitude intervals. Similarly, elevation contours at 1000 ft intervals were drawn on overlays at the scale of the topographic charts. The snow limit mapped from the ERTS data was then transferred to the contour overlay using the configuration of the pattern as a guide in adjusting the scale. The final adjustment was made using a variable-scale rule to check the corresponding distances of selected features at the two scales.

2.4 Results of Analyses

Using the analysis procedures described in the previous section, mean snow line elevations have been determined for a part of the Olympic Mountains in Washington (for 29 July and 4 September), the Mt. Rainier area in Washington (28 July and 2 September), the Three Sisters Mountains in Oregon (28 July and 2 September), the White Mountains in California (16 September, 21 October, and 27 November), and the Salt-Verde Watershed area in Arizona (21 November). For each area, significant changes in snow line elevation occur during the time intervals between the ERTS observations. The analyses for each area are discussed in the following sections.

2.4.1 Olympic Mountains (Washington)

Analysis of ERTS-1 data for 29 July and 4 September 1972 reveals a 500 ft snow line retreat over the eastern two-thirds of the Olympic

Mountains in northwestern Washington near 47°45'N and 123°15'W. The RBV-1 (0.475 to 0.574 μm) data for 29 July (Pass 84, Image ID 1006 - 18313) indicates that significant snow is still present in the eastern two-thirds of the Olympic Mountains on this date (the western third was not visible in the imagery). The snow limit mapped from the ERTS data, after being transferred to the corresponding topographic map, fits extremely well with the shape of the 5000 ft contour throughout the several narrow ridges comprising this region of the mountain range. Maximum elevation of these ridges ranges from 6000 and 7800 ft.

Analysis of MSS-5 data for 4 September (Pass 600, Image ID 1043 - 18372) shows that a considerable retreat of the snow line has occurred during the preceding five weeks. The mean snow line elevation measured from a considerable number of points on the contoured topographic map is at the 5900 ft level, a retreat of 900 ft from the previous observation. Actually, because the slopes in this area are not as steep as in some other areas, the 900 ft change is associated with a significant change in snow extent.

2.4.2 Mount Rainier (Washington)

An RBV-1 image for 28 July (Pass 70, Image ID 1005 - 18260) was analyzed to determine the mean snow line elevation for the Mt. Rainer area (maximum elevation 14,410 ft). The mean elevation of 65 points along the snow limit for this date is 5200 ft. Analysis of MSS-5 data for 2 September (Pass 572, Image ID 1041 - 18260) shows a considerable retreat in snow line elevation. The mean of 45 elevation points taken from the topographic map overlay is 6100 ft, a change of 900 ft since 28 July. This snow line retreat of 900 ft corresponds exactly to that measured for the same period over the Olympic Mountains located 100 miles to the northwest.

2.4.3 Three Sisters Mountains (Oregon)

ERTS observations on 28 July and 2 September indicate a 1000 ft snow line retreat on the western slope and a significantly smaller retreat of 200 ft on the eastern slope of the Three Sisters Mountains (near 44°N, 121° 45'W). On 28 July the snow line elevation mapped from the RBV-1 image (Pass 70, Image ID 1005 - 18265) is at 6000 ft on the western slope and at 7000 ft on the eastern slope. Five weeks later, however, the snow line mapped from the MSS-5 image (Pass 572, Image ID 1041 - 18265) along the western slope is 7000 ft, a change of 1000 ft from the earlier observation, whereas the mean snow line elevation on the eastern slope is 7200 ft, a change of only 200 ft.

2.4.4 White Mountains (California)

Analysis of three ERTS-1 passes during the period from mid-September through late November 1972 reveals broad changes in snow line elevation for the White Mountains of eastern California. This range, with peaks from 12,000 to 14,200 ft is oriented north-south just east of the Sierras between 37° and 38°N at 118°15'W. On 16 September (MSS-5, Pass 767, Image ID 1055 - 18055) snow cover is restricted to the higher terrain at a mean elevation of 12,800 ft. Five weeks later on 21 October 1972 (MSS-5, Pass 1255, Image ID 1090 - 18003), a dramatic lowering of the snow line elevation has occurred, particularly along the western slopes. The snow line elevation is 7000 ft (mean of 25 points) along the western slope, and 10,500 ft (mean of 30 points) along the eastern slope.

The ERTS data on 27 November (MSS-5, Pass 1771, Image ID 1127 - 18064) shows, however, that significant snow melt has apparently occurred during the preceding five-week period. The snow line elevation along the western slope has receded some 4000 ft to 11,000 ft (mean of 33 points), whereas measurements of the eastern slope show a retreat of only 500 ft to 11,000 ft (mean of 36 points). Of interest also is that the ERTS data show that during the period from 16 September to 27 November, the Tinemaha Reservoir, located west and just south of the White Mountains in the Owens Valley, increases significantly in size. On the earlier date, the reservoir measures 1-1/2 n.mi. north to south, whereas in late November, the length of the reservoir has increased to about 2 n.mi. Meteorological data will be acquired to determine the weather conditions during this period.

2.4.5 Salt-Verde Watershed (Arizona)

Analysis of MSS-5 data from 21 November (Pass 1687, Image ID 1121 - 17330) shows a well-defined snow boundary in the Salt-Verde Watershed, a narrow mountainous area extending from 35°30'N, 113°W southeastward to 33°45'N, 109°15'W. In this analysis the ERTS snow limit was outlined on a transparent overlay which was gridded for every 30' of latitude and longitude. This snow boundary was then transferred to the Salt River Project Aerial Snow Survey map of 14 November. Although this aerial survey snow line was charted a week earlier than the satellite observation, there is reasonably good agreement between the two, especially in the region from about 35°N, 112°W to 34°15'N - 111°W. Differences showing the aerial survey snow line some 2 to 5 n.mi. broader in extent are, however, observed in the region near 34°N and 110°20'W to 111°W. As only light snow amounts (1 to 4 inches) were reported for 50% to 60% of this region on 14 November, it seems reasonable to assume that this 2 to 5 mile difference could well be the result of snow melt over the one-week period between the aerial and satellite observations. The same is undoubtedly true for differences observed along an isolated, narrow ridge just south of 34°N near 111°W, where the aerial survey indicated a T to 1 inch above the 6200 ft level and 12 inches to 16 inches above 7000 ft. The ERTS snow line is observed close to the small area above 7000 ft in the region of significantly greater snow depth.

Several aerial survey maps for the period from mid-November through early February 1973 have been received from the Salt River Project and it is anticipated that additional comparisons with the ERTS imagery will be possible. These charts contain snow depth estimates as well as the location of the snow line, so will be very useful for investigating the variations in the snow brightness observed in the ERTS data.

2.5 Analysis of Arctic Data

A considerable amount of ERTS data over the Arctic has been received for use in a separate study (SR126: Evaluate the Application of ERTS-A Data for Detecting and Mapping Sea Ice). These data show the seasonal increase in snow cover in several areas such as the islands of the Canadian Archipelago and northern Alaska. For example, in late July, Banks Island in the Canadian Archipelago is completely snow-free (26 July, Identifier 1003-19504-123); in early September, however, snow covers the higher elevations of the central portion of the island, and in late September the entire island is snow-covered (4 September, Identifier 1043-20122-4567; 21 September, Identifier 1060-20063-4567). With snow cover, relatively small-scale terrain features, such as isolated hills, stream valleys, gullies, and ridges, are greatly enhanced. This is particularly evident in the MSS-7 band (0.8 to 1.1 μm) where large differences in brightness exist between sunlit features and shadows in the low-sun angle imagery.

In other Arctic data, considerable detail is evident in glaciers located along the east and west coasts of Greenland (for example, 23 September, Identifier 1062-16504-4567). Detectable features include imbedded sediment trails (medial moraines), crevassed areas, and apparent limits of new snow cover over older glacial ice. Furthermore, significant differences are apparent in the various spectral bands. Several glaciers exhibit a uniform reflectance in the MSS-4 band (0.5 to 0.6 μm), whereas in the MSS-7 band (0.8 to 1.1 μm) the lower elevation portions appear much darker than the higher elevation portions. This difference in reflectance is believed to be due to the existence of melt-water on the surface of the glacier at the lower elevations. It is hoped that appropriate meteorological data can be obtained to determine the temperatures in the vicinity of the glaciers at the times of the ERTS observations.

3. NEW TECHNOLOGY

No new technology has been developed during the first six-month period of the subject contract.

4. PROGRAM FOR NEXT REPORTING PERIOD

During the next reporting period analysis of data for the specified mountainous areas of the western United States will be continued. It is anticipated that ERTS coverage of these areas will continue to be received through the winter season, providing the opportunity to map changes in snow line elevations. Because of the amount of detail in the snow patterns observable at the ERTS resolution, the analyses will be restricted to selected areas and river basins, rather than attempting to map all the snow visible in the ERTS data. For example, in the southern Sierra Nevada, where analyses have not yet been undertaken, the effort will be restricted to the area of the Kern, Kaweah, Tule, and Kings River Basins.

Correlative snow data will become more plentiful as the winter season progresses. Measurements from snow survey courses usually are initiated during the midwinter period, and in areas such as the southern Sierras aerial surveys begin in late March or early April. The aerial survey of the Salt-Verde Watershed will continue through the snowmelt period. When correlative data are acquired for the various areas, investigations will be conducted to determine the accuracy of the snow limits as mapped from ERTS and to evaluate the influence of forest cover on the mapping accuracy.

In addition to the correlative snow measurements, we have been informed that U-2 flights in support of the ERTS mission will be flown over two test sites specified in this study in late February or early March. The two sites are the southern Sierras and the Salt-Verde Watershed. Data from the onboard RBV sensor will be collected as the plane crosses each of the snow-covered mountain ranges. These aircraft data will then be analyzed in conjunction with the corresponding ERTS imagery, hopefully collected within a few days of the U-2 flight.

Analysis of data covering the relatively flatter terrain of the Upper Mississippi-Missouri River Basins region will also be undertaken during the next reporting period. The data from this region will present an opportunity to investigate the differences in snow reflectance in forested and non-forested areas and the differences in reflectance as snow amounts increase from a no-snow situation to depths of several inches or more.

5. CONCLUSIONS

The results of the analysis of the initial sample of ERTS data covering the specified test sites in the western United States indicate that the MSS-5 spectral band (0.6 to 0.7 μm) is the most useful for detecting and mapping mountain snow cover. At the ERTS resolution, snow cover can be readily detected in the MSS-5 band and can be distinguished from clouds because the configuration of mountain snow patterns is very different from that of clouds, snow boundaries are sharper than typical cloud edges, snow fields usually appear with a more uniform reflectance than do clouds which often have considerable variation in texture, cloud shadows are often visible, and terrestrial features can be recognized in cloud-free areas. At the ERTS resolution numerous terrestrial features not visible in lower resolution meteorological satellite data can be detected. In addition to various natural features, man-made features such as roads, electric power lines, cultivated fields, and timber cuts are visible.

In the four mountain areas for which data have been analyzed on at least two different dates, changes in snow line elevation ranging from 200 to as much as 4000 ft have been mapped. In these analyses topographic charts of a scale of 1:250,000 have been found to be useful for measuring snow line elevation. In one case analyzed for the Salt-Verde Watershed in Arizona good agreement is observed between the location of the snow line as mapped from the ERTS data and as depicted on an aerial snow survey chart compiled a week earlier. Evaluation of the snow line accuracy in the other areas must await the acquisition of correlative snow data.

Although a thorough investigation of the multispectral characteristics of snow has not yet been undertaken, examination of data from the Arctic has revealed that the multispectral approach can provide information on glacial conditions that cannot be ascertained from observations in a single spectral band. Several glaciers along the coasts of Greenland exhibit a uniform reflectance in the MSS-4 (0.5 to 0.6 μm) band, whereas in the MSS-7 (0.8 to 1.1 μm) band the lower elevation parts appear much darker than the higher elevations. This difference in reflectance is believed to be due to the existance of melt-water on the surface of the lower parts of the glaciers as opposed to snow cover on the upper parts.

6. RECOMMENDATIONS

Specific recommendations will await further data analyses to be conducted during the next reporting period.