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COMPUTER-AIDED ANALYSIS OF SKYLAB SCANNER DATA FOR LAND USE MAPPING, FORESTRY, AND WATER RESOURCE APPLICATIONS

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Computer-Aided Analysis of Skylab Scanner Data for Land Use Mapping, Forestry and Water Resource Applications*

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Abstract

SKYLAB data were obtained over a mountainous test site containing a complex association of cover types and rugged topography. The application of computer-aided analysis techniques (CAAT) to the multispectral scanner (MSS) data produced a number of significant results. Techniques were developed to digitally overlay topographic data (elevation, slope, and aspect) onto the S-192 MSS data to provide a method for increasing the effectiveness and accuracy of computer-aided analysis techniques for cover type mapping. The S-192 MSS data were analyzed using computer techniques developed at LARS, Purdue University. Land use maps, forest cover type maps, snow cover maps, and area tabulations were obtained and evaluated. These results compared very well with information obtained by conventional techniques. Analysis of the spectral characteristics of SKYLAB data has conclusively proven the value of the middle infrared portion of the spectrum (~1.3-3.0μm), a wavelength region not previously available in multispectral satellite data.

1. Introduction

The ability to collect data from satellite altitudes far surpasses existing capabilities to interpret and analyze even a small portion of the data in a timely manner. This becomes particularly evident when working with multispectral scanner data, such as that collected from SKYLAB, where data from the same area on the earth's surface is collected in each of 13 discrete wavelength bands. Thus, there exists a distinct need to develop effective, efficient techniques to convert such multispectral scanner data into useful information in a timely manner.

This study involved an interdisciplinary effort to test the value and applicability of digital computer-aided analysis techniques for identifying, mapping, and tabulating areas of the major cover types in a portion of the Colorado Rocky Mountains, using SKYLAB multispectral scanner data. Emphasis was given to the analysis of this data for purposes of (1) general land use mapping, (2) forest cover type mapping, and (3) evaluation of water resources. Two additional phases of this research of importance involved (a) the development of techniques to combine topographic data (elevation, aspect, and slope) with the spectral data obtained from SKYLAB, and (b) a study to determine the importance of the various spectral regions and wavelength bands for accurate resource mapping.

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2. Test Site and Data Characteristics

The SKYLAB test site was located in the rugged San Juan Mountains of southwestern Colorado, containing a complex association of forest types, rangeland, alpine tundra, agricultural areas, water bodies, and various man-made features. This area is fairly typical of the Rocky Mountain Region in terms of its forest, water, and recreational resources. The timberline in this region is at approximately 3600 meters. Extensive areas of tundra are found above this elevation, and a variety of forest species are found in different elevation zones. These species are grouped into forest cover types which include the Spruce-Fir, Douglas and White Fir, Ponderosa Pine, Aspen, and Oak-Mahogany.

The specific area over which data were obtained and analyzed for this study was designated the Granite Peaks Test Site. This study area contains 77,350 hectares, with elevations ranging from 2000 to 3700 meters.

An unusual and particularly valuable set of remote sensor data was obtained over this test site during the SKYLAB SL-2 mission. On June 5, both SKYLAB and LANDSAT-1 satellite data were obtained over the test site within an hour of the same time. The following day, color-infrared photography was obtained from 18,288 meters (60,000 feet) by NASA's WB57, and both photographic and multispectral scanner data were obtained from 11,186 meters (30,000 feet) by NASA's NC130 aircraft. In addition, ground observation data were gathered throughout the week to complete the data set.

The SKYLAB (MSS) data utilized were digitally processed by NASA to correct for the conical scanner configuration of the S-192 scanner, but were not put through NASA's digital filtering procedure, which was developed to correct for at least some of the noise in the data. Qualitative examination of the individual wavelength bands of the data indicated that some wavelength bands appeared to have better data quality than other wavelength bands. This situation indicated a need to quantitatively assess the data quality of each wavelength band and to take such differences into account in evaluating the relative importance of the various wavelength bands for accurately classifying the data.

3. Geometric Correction, Scaling, and Overlaying

One aspect of particular significance in working with the SKYLAB data involved a geometric correction, scaling, and overlaying procedure. The first portion of this program rotates, deskews, and rescales the data to produce a geometrically corrected data tape, which if every resolution element is displayed on a standard computer line printer, will result in a 1:24,000 logogrammatic printout, oriented with north at the top (Ref. 2). The use of this geometric correction and scaling program allowed for correction of the orbital path of the SKYLAB satellite, thereby allowing the data to be utilized in a format that was much easier to work with since the printouts could be directly related to the existing 1:24,000 scale topographic maps of the area (Ref. 5).

A procedure to digitally overlay multiple data sets had also been developed at LARS. This overlay procedure was applied to the LANDSAT-1 data that had been obtained over the test site approximately one hour before the SKYLAB data were collected. It is significant that there was approximately a 90° difference in orbital paths between the LANDSAT-1 and SKYLAB satellites which was successfully accounted for in the development of this overlaid data tape. Next, a digital tape containing elevation data was obtained and rescaled to match the 1:24,000 scale SKYLAB and LANDSAT data tape. In addition to the elevation data, channels containing slope and aspect data were developed and overlaid onto the SKYLAB and LANDSAT data tape.

The final result of this data processing procedure, therefore, was a single digital data tape containing 13 channels of multispectral SKYLAB data, 4 channels of LANDSAT MSS data, and 3 channels of topographic data (one channel each for elevation, slope, and aspect), all at a 1:24,000 geometrically correct scale. This data tape was subsequently utilized in all of the analysis sequences of this study.

4. Land Use Mapping Results

The first phase in the analysis of this SKYLAB data involved a land use classification. The Level II land use categories described by U.S.G.S. Circular 671 were used as a basis for this analysis (Ref. 1). The Level II categories that are present in the study area included Snow, Water (Reservoirs), Tundra, Exposed Rock, Grassland, Coniferous Forest, and Deciduous Forest. The modified clustering technique (Ref. 4) was used to develop training statistics, and the LARSYS divergence algorithm was utilized in defining the "best 4" wavelength bands to use in the classification (Ref. 6). For this analysis of SKYLAB data, the 0.46-0.51, 0.78-0.88, 1.09-1.19, and 1.55-1.75μm wavelength bands were designated as best. The maximum likelihood algorithm (Ref. 6) was then utilized to classify each resolution element within the test site. The resultant cover type or land use map is shown in Figure 1. This map was analyzed in detail and compared to existing land use maps that had been developed using standard photo-interpretation techniques. The two types of land use maps compared very well, indicating that a reasonable classification had been achieved.

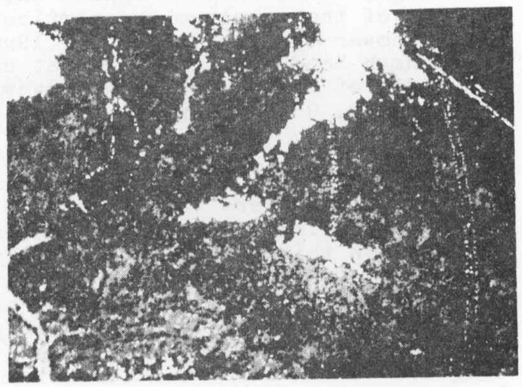

Figure 1. Land use map (Level II) obtained by computer classification of SKYLAB MSS data. Cover types represented are (from lightest to darkest): Snow, Grassland, Deciduous Forest, Coniferous Forest, and Water.

To obtain a more quantitative evaluation of this computer derived land use map, a statistically defined grid of test plots, each 4 x 4 resolution elements in size, was established. The computer classification of land use for each resolution element within these test areas could then be compared to the land use of that area indicated on the existing land use maps. In this analysis of the SKYLAB data, 2,400 test resolution elements were utilized in this quantitative evaluation. The results indicated an overall classification accuracy of 85%, which is believed to be very good, considering the spectral complexity of the test site area. In an area of flat terrain, the accuracy would probably be somewhat higher.

5. Forest Cover Type Mapping Results

The major emphasis of this study was on the analysis of the SKYLAB S-192 data for purposes of forest cover type mapping. The ten different cover types present in the study area that were involved in this phase of the analysis were spruce-fir, Douglas and white fir, ponderosa pine, aspen, oak-mahogany, grassland, tundra, exposed rock, water, and snow (Ref. 1 & 7). The classification procedure followed was similar to that described above for the land use mapping. The analysis required 32 spectral classes to be defined in order to statistically characterize the various cover types present. Differences in density of forest stands, as well as variations in slope and aspect, cause differences in spectral response of individual forest cover types. Therefore, it is usually necessary to utilize a larger number of spectral classes than the number of cover types present in order to achieve accurate classifications. The alpine tundra was all under snow cover on June 5, 1973, so tundra was not mapped using this data set.

A map of forest types (similar to the land use map shown in Figure 1, but with more detail) was generated by the computer. To evaluate the results, this map was qualitatively compared to the existing forest cover type maps and also to the aerial photos of the test site area. These comparisons indicated that the computer classification results were reasonably accurate. The quantitative evaluation of 2400 resolution elements (using the same procedure described above, except for the more detailed definition of classes) resulted in a 71% classification accuracy, which was lower than the result for the general land use classification. However, it was found that many of the apparent misclassifications could be explained by interactions between various classes of conifer forest cover types and variations in stand density (such as stand of low density ponderosa pine with an understory of gambel oak that were classified as oak rather than pine). A quantitative evaluation of the thirteen wavelength bands in this SKYLAB data indicated that the near infrared portion of the spectrum was particularly useful in this analysis of forest cover types. The 1.09-1.19μm band was the single most useful wavelength band, and the six most useful wavelength bands included (in order of selection by the divergence algorithm): 1.09-1.19μm, 0.46-0.51μm, 0.78-0.88μm, 1.55-1.75μm, 0.56-0.61μm, and 10.2-12.5μm wavelengths.

Next, the number of scanner resolution elements classified into each cover type were tabulated, and the area of each cover type was calculated using a conversion factor of 0.46 hectares per resolution element for this SKYLAB data. To enable a statistical evaluation of the accuracy of such area estimates, the tabulation was carried out on a quadrangle by quadrangle basis for the entire test site. The area estimates of each cover type for each quadrangle, based upon the computer classification of the satellite data, were then compared to similar estimates obtained through manual aerial photo-interpretation (from which cover type maps were produced) and standard planimeter techniques. The result of this comparison is shown in Figure 2. The resultant correlation coefficient was 0.929, indicating a very strong relationship between the two methods of estimating the area of the various cover types.

6. Snow Cover Mapping

The third major analysis task for which the SKYLAB data was utilized involved mapping of the snow cover in the test site. The water supply for much of the southwestern United States comes from runoff in the upper mountain watersheds of the Colorado Rocky Mountains. Accurate information concerning the extent and condition of the snowpack is necessary for making accurate predictions of the quantity of water in the runoff each spring.

Previous studies had shown that LANDSAT-1 data had some distinct limitations for mapping snow cover. The limited spectral range of the LANDSAT scanner, as well as a detector saturation problem, resulted in an inability to spectrally discriminate between snow and clouds.

SKYLAB SL-2 data clearly showed the advantages of obtaining multispectral scanner data in the middle infrared (1.3-3.0μm) and longer near infrared (0.7-1.3μm) portions of the spectrum.

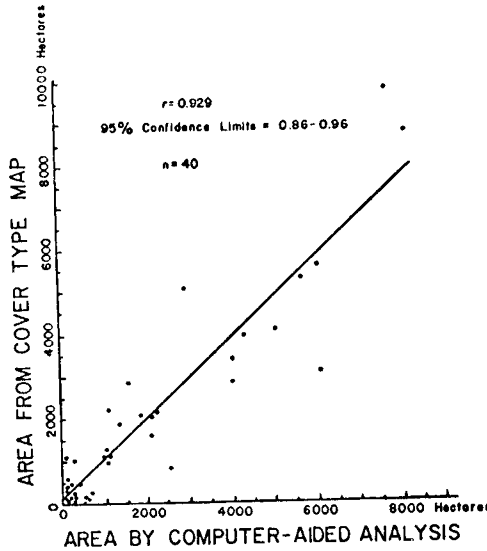

Figure 2.
Area estimates by computer analysis of SKYLAB data compared to aerial photo-interpretation results.

As shown in Table 1, clouds have a very high reflectance throughout the visible, near infrared, and middle infrared wavelength portions of the spectrum (due to non-selective scattering by the water droplets within the cloud. Snow has an equally high reflectance in the visible portion of the spectrum (0.4-0.7μm), but a somewhat decreasing reflectance in the near infrared wavelengths (0.7-1.3μm), and a very low reflectance in the middle infrared wavelengths (1.3-3μm). Clouds and snow both have relatively low emittance in the thermal infrared wavelength band. Although there is a distinct difference in reflectance in the 1.20-1.30μm band, both the clouds and portions of the snowpack are white on the imagery.

Table I -- Comparison of Reflectance Measurements From Clouds and Snow, Using SKYLAB S-192 Data[1]

	Wavelength Region and Band (in micrometers)												
	Visible					Near Infrared					Middle IR		Thermal IR
	.41-.46	.46-.51	.52-.56	.56-.61	.62-.67	.68-.76	.78-.88	0.98-1.08	1.09-1.19	1.20-1.30	1.55-1.75	2.10-2.35	10.2-12.5
Clouds	127	124	114	126	127	123	115	111	114	105	81	80	31
Snow	128	125	115	128	127	123	115	91	82	53	17	20	34

[1] Data obtained over the La Sal Mountains, Utah, on June 5, 1973. The values indicate the mean relative reflectance for several hundred resolution elements.

It is only in the middle infrared wavelengths that the snow becomes black in tone while the clouds remain white (1.55-1.75μm and 2.10-2.35μm). These and similar results obtained by other investigators (Ref. 3), clearly indicate that the middle infrared wavelength bands will be essential for a reliable, operational snow cover mapping program.

The next step in the analysis of the SKYLAB data involved computer analysis of the S-192 data to differentiate and map different categories of snow cover. Figure 3 shows the results of this analysis. Five distinctly different classes of snow were mapped. Differences in the liquid water content of the snowpack at different elevations and differences in density of the forest cover at different elevations were the dominant factors that caused the variations in spectral reflectance of snow.

To obtain an indication of the value of the topographic overlay data, the elevation data were combined with the results of the snow cover map. The area of each of the five spectral classes of snow cover was quickly determined as a function of elevation (using 100 meter elevation increments). These results are shown in Table 2 below.

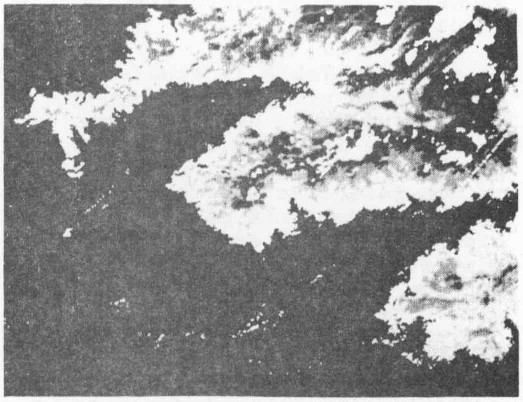

Figure 3.
Snow cover map showing five spectral classes of snow. (Black represents other cover types.)

The capability to rapidly obtain this type of information through computer analysis of satellite data, in combination with other data sources, has tremendous potential for assessing various natural resource situations.

Table 2 -- Snowpack Area Within 100 Meter Elevation Increments

Elevation (Meters)	1	2	3	4	5	Total Area (hectares)
	----------Spectral Class of Snow--------					
Above 3700	1179	2464	308	108	7	4066
3600-3700	400	1914	694	135	37	3180
3500-3600	129	1868	1858	517	61	4433
3400-3500	45	904	1858	1266	280	4353
3300-3400	13	378	1305	1417	812	3925
3200-3300	7	94	922	1258	1298	3579
3100-3200	6	22	529	793	1540	2890
3000-3100		6	213	433	1041	1693
2900-3000		1	38	188	535	762
2800-2900			4	54	289	347
2700-2800			1	13	147	161
2600-2700				1	95	96
Below 2600					79	79
Totals	1779	7651	7730	6183	6221	29564

7. Summary and Conclusions

SKYLAB MSS data were geometrically corrected and overlaid with LANDSAT-1 and topographic data to produce a 20-channel digital tape, from which 1:24,000 scale map outputs could be obtained. Computer classification of the SKYLAB data resulted in Level II land use map with an 85% classification accuracy (based upon 2400 test resolution elements). Thirty-two spectral classes were required to classify and map detailed forest cover types, resulting in a ten category map having an overall accuracy of 71%. Acreage estimates based on the computer classification results were compared to the results obtained by standard photo-interpretation techniques. This comparison resulted in a correlation coefficient of 0.929, indicating a reasonably close relationship between these two methods of determining acreage. Study of the various wavelength bands indicated the value of each of the major wavelength regions, but particularly the near infrared for purposes of forest cover mapping. Five spectral classes of snow were spectrally defined and mapped, and the value of the middle infrared wavelengths was clearly shown for purposes of spectrally separating snow from clouds. Analysis of the overlaid topographic data in conjunction with the multispectral scanner data allowed area estimates of various classes of snow cover to be tabulated according to elevation zones.

In addition to these specific results, the following general conclusions can be drawn:

1) The value of the increased spectral range obtained by the SKYLAB multispectral scanner has been proven.

2) The capability and value of overlaying multispectral satellite data with topographic data has been clearly demonstrated.

3) Computer-aided analysis of satellite multispectral scanner and supplemental data offers a powerful tool for mapping and assessing a variety of natural resource situations.

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