PROGRESS IN MEASURING SNOW COVER FROM ERTS IMAGERY

579-74

By

Wm. E. Evans 1/

Introduction

The problem of snow area measurement appears deceptively simple at first. It is certainly true that snow provides one of the most easily recognized features in any satellite imagery. Its relatively high brightness, near-white color, characteristic spatial pattern, and normally high contrast with surrounding background greatly facilitate identification even in single spectral band reproductions. And since the basic spatial resolution element, or Pixel, for the ERTS sensor is on the order of one acre in size, there would appear to be adequate detail for any practical snow inventory need.

While all of the foregoing statements are true, an assortment of knotty problems lies hidden behind other statements which were left unsaid. A particularly significant omission from the list is that nothing was said about errors of omission--snow covered areas which escape detection because of a variety of reasons. These reasons may be categorized as follows:

- Poor illumination (including effects of terrain relief and complete shadowing)
- Tree cover
- Patchiness
- Surface conditions
- Instrumental deficiencies (poor detail contrast)

The relative importance of these various effects will of course vary greatly with terrain, location, scale size, and application, but our experience indicates that for many scenes of practical interest in mountain areas a surprisingly great amount of care must be taken to prevent absolute errors from these more fundamental, optically-related sources from pyramiding to as much as 50 percent or more of the true snow area. That order of accuracy may be scarcely more useful than an educated guess for some applications. At SRI, we have been studying these error sources and this paper will suggest means for circumventing some of them.

Measurement Procedures

Several options are available to measure the snow covered area in an ERTS image. Undoubtedly the simplest procedure is the eyeball and planimeter technique. All that is required is a photographic enlargement, a planimeter, a good eye and much patience. The work can be done either in black and white or in color and the analyst bases his classification decisions on a complex combination of brightness, pattern shape, detail contrast, and color, if that is available. For delineating snow in monochrome, the usual preference is for the MSS-5 (visible red) image. Manual results come slowly and are subject to enough subjective interpretation that there is strong urge to develop automated, objective procedures. Nevertheless, manual photo interpretation does provide a baseline method, and remains a powerful competitor for more elaborate machine-based techniques. To be success' fill, machine methods obviously must excell in speed, accuracy, or cost--preferably in all three.

One of the simplest and most obvious first steps toward an objective procedure is to operate on the brightness, or radiance, data contained in the single-band records. Several conceptually equivalent procedures are available. One can use high-contrast photography to expose only the highlights of the image, or he can use a micro-densitometer or any of the several commercially-available "density slicing" equipments based on television scanning. For most precise work, a computer can be used to extract the highlight values from the digital tape record. Any of these objective devices can perform the amplitude

---

1/ Staff Scientist, Electronics and Radio Sciences Division, Stanford Research Institute, Menlo Park, California.

thresholding task much better than the human eye, which is notoriously poor in making absolute brightness estimates. An objective classifier, however, must be given very explicit rules about where the threshold should be set, and that is where the real trouble begins with radiance thresholding and where the mechanics of exactly how the job is done become important.

ESIAC

Most of our work at SRI has been done with the aid of an electronic viewing/measuring system of our own design which we call the ESIAC, for Electronic Satellite Image Analysis Console. This equipment combines manual, analog, and digital techniques to permit one to rapidly test many different processing procedures.

While ESIAC can be loaded from digital tape, its normal data sources is 70 mm positive film transparencies which provide the second best data record and are much more rapidly available and less expensive. We scan all or selected portions of the images with a high quality television camera, and have provision for storing several hundred TV frames along with their calibration grey scales in precise register on an analog video disc memory. Then by using relatively standard television editing and animation techniques *we* can merge, superimpose, or flicker selected image combinations on a black and white monitor, or we can combine the various band records into an additive color composite on a color TV monitor. At the same time that the scenes are being viewed as images, the scene radiance data is continuously available in electrical form, ready to be measured or operated upon either in single-band or multi-spectral analysis. For example, Figure 1 illustrates the procedure used for making a classification based on signal amplitude ("radiance thresholding").

One capability which currently *is* unique to our system is the ability to present a time-lapse sequence of registered multi-date ERTS imagery, with the timing, contrast, and color balance under the viewer's immediate and complete control. In snow measurement, we find the time-lapse capability useful in differentiating clouds from snow, and in following the seasonal progression of snowlines. We have used this equipment to perform many hundreds of thematic extractions of snow by the single band radiance-above-threshold technique. While the general principle is similar to that used by others who employ electronic or photographic "density slicing", a key difference is that the superposition feature of the ESIAC provides a convenient means for the operator to continuously and critically compare the thresholded snow mask with the original scene image, in full tonal range and sometimes in color, while he is adjusting the threshold.

This permits us to combine the better features of conventional human photo interpretation with the quantitative precision of electronic thresholding and area measuring.

> During the oral presentation, a short movie sequence of Mount Ranier, Washington, was shown at this point to illustrate the process of adjusting a radiance threshold to achieve the best visual match between a binary thematic mask and a color image.

While the radiance thresholding procedure works beautifully for dome scenes, there are’ many others where it is annoyingly difficult to obtain agreement among operators regarding the "best" threshold setting.

The uncertainty rapidly becomes worse as the operator lowers the threshold, trying to include the low-radiance snow--regions where the response is low because of tree cover, shadowing or any of the other effects that were mentioned earlier. Other factors being equal, the radiance of snow as seen by a satellite overhead will be proportional to the cosine of the solar incidence angle. Snow on south-facing slopes may be nearly perpendicular to the sun and thus generate a full-scale response even in the middle of winter, while identical snow on nearby north-facing slopes may exhibit radiance of only a few percent of full scale and thus almost certainly will be missed by any threshold set to exclude reasonably bright non-snow scene elements.

Figure 2 is an array of small reproductions of the binary snow masks showing the distribution of snow during the year for a relatively small (397 km^2) basin in the North Cascades. The measured areas are shown by each mask, and the gaps in the coverage due to

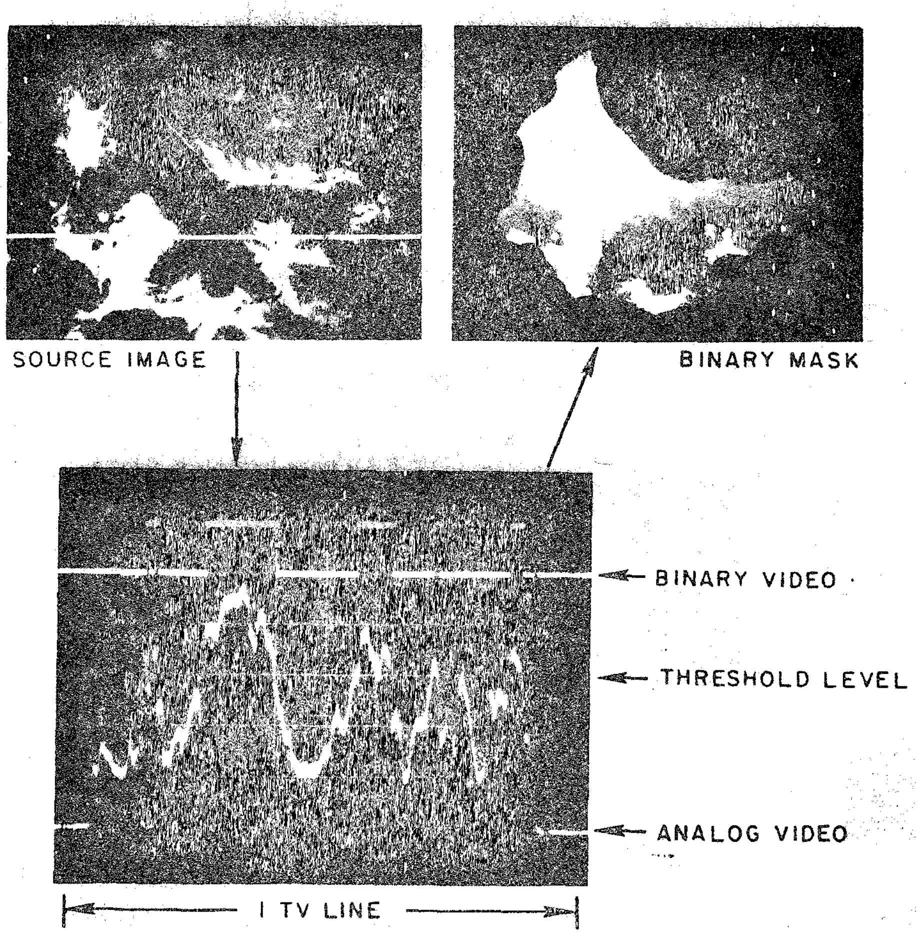

Figure 1

EXAMPLE OF CREATION OF BINARY SNOW MASK BY AMPLITUDE THRESHOLDING OF THE ESIAC TV WAVEFORM. Display shown is a small section of the MSS-5 record of ERTS Image 1041-18253 of 2 September 1972. The Thunder Creek Drainage Basin outline has been electronically superimposed. The analog video waveform is for the single horizontal scan line shown intensified in the upper left figure. Note that when the video waveform is above the threshold level (bright portions of image) the binary signal is "high". The binary video is logically combined with a stored binary basin outline map, then used to generate a binary map (mask) and to control a digital counter which totals the areas-above-threshold within the basin.

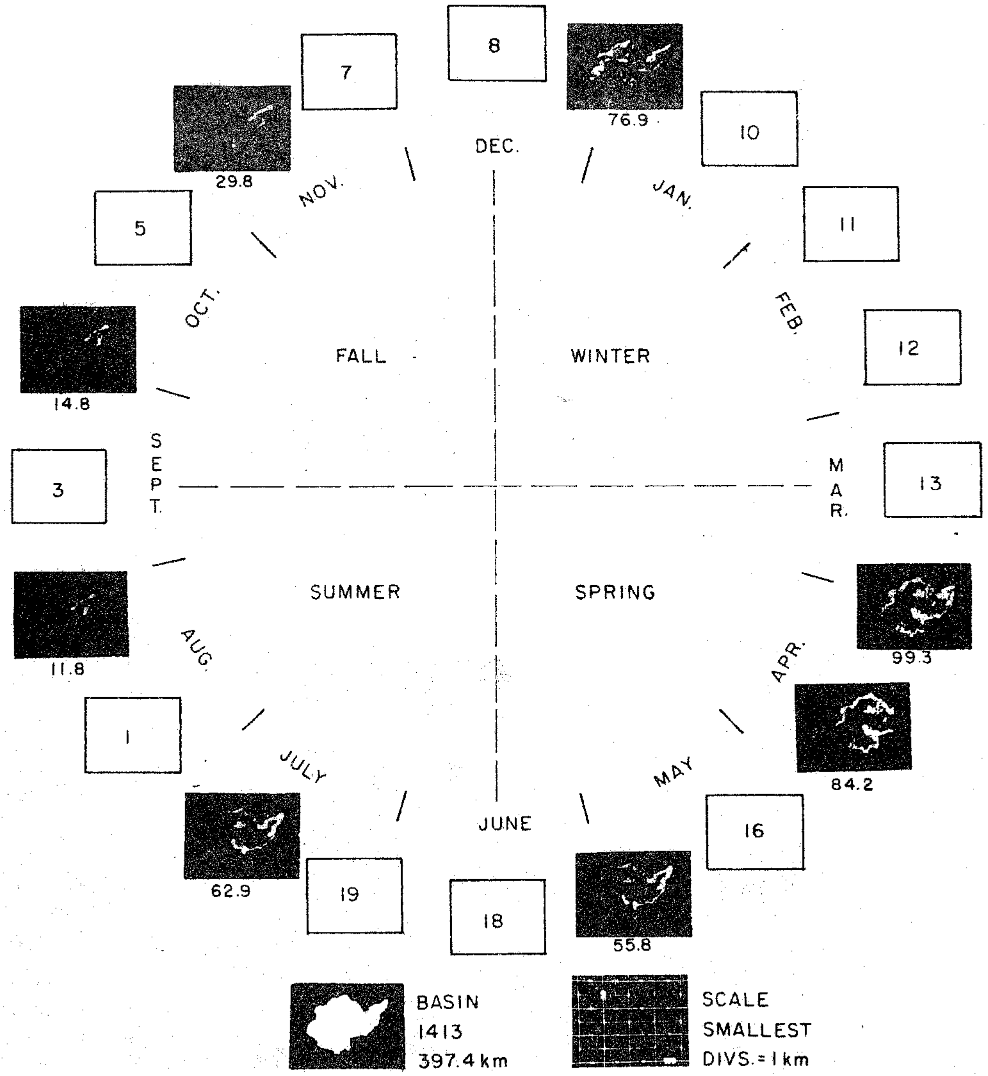

Figure 2

BINARY MASKS OF MEASURED SNOW WITHIN BASIN 1413, NORTH CASCADES, WASHINGTON.

Data shown for all available cloud-free images within the period 29 July 1972 through 30 May 1973. Radiance threshold for MSS-5 set for Best Visual Estimate (BVE). Numbers below masks give snow area in km^2.

cloud cover are obvious by the omissions. Figure 3 shows the area results in graph form and includes the operator's estimates of possible variance from ground truth (Estimation Spread). Note that even on a percentage basis, the spread bars are significantly larger for the larger snow areas. This observation we find to be quite generally true. When the coverage is small, the patches tend to be grouped in small areas, reducing the effect of spatial differences and reducing the number of compromises which must be made. When the coverage is greater, the spatial patterns are more likely to be dendritic, and very small changes in the threshold can rapidly change the fatness of the branches. Also at times when the coverage is large, the sun angle tends to be low so that illumination and therefore radiance is very non-uniform.

We have tried numerous refinements in attempts to reduce the subjective spread among operators, and--more difficult--the possible spread between our readings and what we believe to be ground truth. Among these refinements are use of color for the reference scene, and the use of map overlays to show where to expect shadows, and trees. Presentation of well registered multi-date sequences in time lapse is also a definite help. The ESIAC also provides an editing feature, which permits the operator to electronically "touch up" the binary snow mask before it is measured--erasing obvious artifacts and filling in obvious voids. We had hoped that most of the extraneous areas would be sufficiently well isolated that manual editing would be practical but unfortunately that has not proven to be the case. Much of the problem occurs in precisely defining an average snowline over a relatively long perimeter, and the error is so well distributed that it easily passes unnoticed.

Unfortunately, we do not yet have coincident ground truth data against which to check the absolute accuracy of our measurements, but the relatively poor precision--that is the inability to repeat measurements, or to obtain the same answers from different operators, is sufficient cause for concern. It is our conclusion after many series of measurements, that measurements in mountain regions by the single band thresholding technique provide at best, a reliable figure for the minimum amount of snow that might be present, but that attempts to specify the "true" coverage always will be only approximate, and subject to considerable subjective interpretation.

Measuring Area Change

The possibility still remains that useful data about the operationally important date-to-date change in the snow area can be obtained by radiance thresholding on single-band imagery, even though the absolute amount may be in doubt.

When an operator is provided with a capability for flickering between two registered scenes taken on different dates, and sufficient care has been taken to minimize spurious picture processing differences, our results indicate that he can usually detect snow area changes of only a few percent. This exploits the powerful principle of substitution measurement, the "A-B test". A quantitative measure of the change can be obtained by differencing two binary masks made by radiance thresholding, and the reliability is greatly enhanced by the fact that masks were created by the same operator within a short period of time, while using the same identification criteria on near-identical imagery.

Establishing Snowline Altitude

Another approach is to attempt to establish the average snowline elevation. Then since cumulative area versus elevation data are known for most basins of practical interest, the probable snow area can be inferred and the problems of shadowing are largely eliminated.

In its simplest embodiment, one merely adds a contour overlay to the satellite picture and estimates the snowline elevation. With the ESIAC *we* can simplify some of the scaling, registration, and contrast problems by accomplishing the same thing electronically. The estimating task is made very much easier, if we arrange to apply the contours one at a time rather than all at once. Here the multi-frame storage capacity of the ESIAC again provides help. It permits us to store a registered sequence of masks enclosing all regions above the elevation shown on a label. When we overlay such a sequence on the satellite image, the operator can turn the knob back and forth until he arrives at the best overall visual match to the snowline, and then read the elevation label. This procedure is very fast, and is one that might be implemented completely optically, with an overhead projector and a film strip. A movie sequence illustrating these two procedures was shown at this point.

First, a contour map was faded on and off over the Mt. Rainier image. Then a series of specially-prepared area-above-elevation masks were cycled over the image in register. These were changed until the best match to the observed snow-line was obtained. The film concluded with a 10-scene sequence of basin 1413 covering a 14 month period during 1972-73.

The contour masks used in the movie were prepared by hand from topographic sheets, but with the digitized maps now available, it would be a straightforward task to prepare them completely by machine.

For Mt. Rainier imagery, during the first full year of ERTS we find very little disagreement among operators in locating the average snowline elevation to within 250 feet, which for that region amounts to a projected area variance of + 13.4%. This is comparable to the best that we have been able to do on Mt. Rainier with single band radiance thresholding, and appreciably better than we can do by radiance thresholding in winter, when coverage is great and shadows are long.

Multi-Spectral Analysis

To achieve a completely objective snow classification system, there seems little question but that the multi-spectral information inherent in the ERTS images will need to be exploited more fully than has been done in any of the schemes which I have described thus far. Not to do so implies a great waste of one of the most important capabilities of the satellite.

One of the very real obstacles in this route thus far has been the matter of cost, particularly if the processing is done entirely by conventional digital computers. There appears to be considerable room for maneuvering toward a more cost-effective system in the vast middle ground between the eyeball and planimeter and the all-digital approach. The eventual solution probably will involve a man-machine combination.

The bar graph of Figure 4 gives predicted, generalized responses in the four ERTS bands for snow, trees, rocks, and ice and shows some of the basis for optimism about the potential of multi-spectral analysis for snow area surveys. It can be seen, for example, that the maximum responses to be expected from mountain snow can exceed the full scale range of the system in all four bands--that is, the system will saturate--and numerous observations have verified that this is indeed so. Since very few other surfaces found in mountain areas are capable of such response, such saturation signals can be classified as snow with a very high degree of certainty. It should be kept in mind, however, that these are maximum responses, for surface optimally illuminated. While all of the bars will become shorter with poor illumination and rougher texture, the relative lengths, that is the bandto-band ratios, should not change substantially.

Consider, for example, how readily snow radiances in the two visible bands (4 and 5 at the left of each group) can fall to less than half or a third of its maximum value (remember the cosine incidence law) and thus be impossible to separate from nearby sunlit rocks and soil by single-band radiance thresholding.

A particularly attractive characteristic of the target groups shown here is that if the band 7 response is less than about 0.6 of the band 5 response, the sample can be classified unambiguously as snow regardless of the absolute radiance level. This rule will of course be modified whenever individual scanner resolution cells must average over two or more scene constituents. Also the list of competing categories shown in Figure 4 is far from complete. Nevertheless, our initial experiments using both the digital tapes and the photographic transparencies indicate that the band 7/band 5 ratio alone is a very powerful snow classifier. Used in combination with one or more other criteria, it gives promise of being completely adequate for objective snow surveys. Note that when the snow is wet, it is even easier to distinguish from competing spectral signatures.

Our transparency-based ESIAC console provides capabilities which go a long way into the realm normally thought of as reserved for fully digital processing and it permits rapid visualization of the effectiveness of various classification algorithms.

For example, it is possible to perform analog ratioing of two registered single-band signals before employing the level-detection and pixel-counting circuitry. Using this

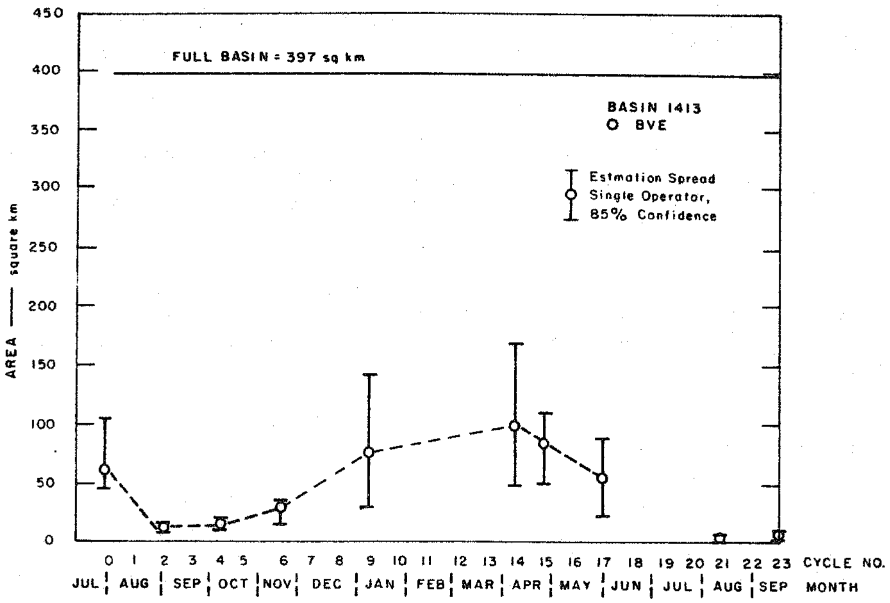

Figure 3

REPRESENTATIVE SNOW AREA MEASUREMENTS IN A 397 km^2 BASIN. Circled points represent preferred or Best Visual Estimate (BVE) values. Bars indicate operator estimates of possible departures from ground truth.

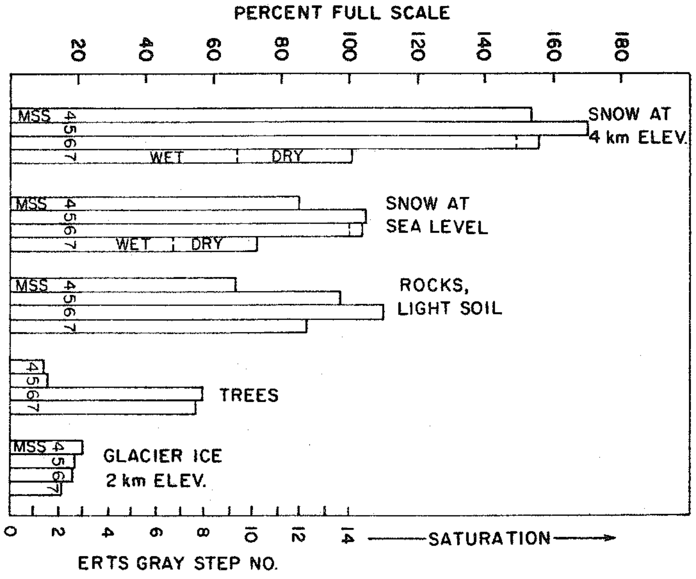

Figure 4

MAXIMUM EXPECTED RESPONSE FOR VARIOUS TARGETS. Derived from numerous sources of reflectance data, combined with solar irradiance and atmospheric transmission from Geophysics Handbook. Surface elevations are sea level unless otherwise specified and all are assumed normal to the sun direction, i.e., radiances shown are assumed maxima. Sun elevation assumed 45°.

procedure, the binary mask can be made to represent all picture points for which the spectral ratio exceeds some specified value, is less than the specified value, or falls between two specified values. We are actively pursuing this approach and hope soon to be able to report accuracy and precision figures for it.

Conclusions

1) Attempts to obtain absolute measurements of snow extent by simple radiance thresholding in a single spectral band appear doomed to an annlying amount of subjective variation, particularly in mountain areas in winter where local illumination levels vary widely.

2) Date-to-date differencing techniques appear useful in cancelling some of the systematic errors in the absolute measurements when the important parameter is the change in snow cover, but firm figures on this differential accuracy must await more complete ground truth data.

3) Establishing the transient snowline altitude is a simple, rapid technique which appears to be reasonably accurate.

4) The most promising approach to reducing the subjectivity of snow area measurements is to exploit the multi-spectral data contained in the ERTS imagery. While all-digital processing undoubtedly is the most powerful means of accomplishing this multi-spectral analysis, analog or hybrid procedures may prove adequate and perhaps preferable from the standpoint of overall cost and convenience.

ACKNOWLEDGMENTS

Much of the work reported here was performed under Contract NAS5-21841 issued by Goddard Space Flight Center, Greenbelt, Maryland, and was in support of projects in dynamic hydrology headed by Dr. Mark F. Meier USGS (WRD), Tacoma, Washington. The ESIAC was an in-house development of the SRI Atmospheric Sciences Laboratory.

BIBLIOGRAPHY

1. Wiesnet, D. R., and D. F. McGinnis, Hydrologic Applications of the NOAA-2 Very High Resolution Radiometer; Proceedings American Water Resources Association Symposium on Remote Sensing and Water Management (June 1973), Burlington, Ontario, Canada.
2. Wiesnet, D. R., "The Role of Satellites in Snow and Ice Measurements." International Hydrologic Decade Symposium on Advanced Concept and Techniques in the Study of Snow and Ice Resources. Monterey, California, December 2-6, 1973.
3. Barnes, J. D. and J. Bowley, 1968: Snow Cover Distribution as Mapped from Satellite Photography, Water Research, 4:257-272.
4. Barnes, J. C., C. J. Bowley, and D. A. Simmes, "Use of Satellite Data Mapping Snow Cover in the Western United States," The American Society of Photogrammetry, Symposium Proceedings, Management and Utilization of Remote Sensing Data, Sioux Falls, South Dakota, October 29 - November 1, 1973, pp 166-176.
5. Haefner, H., R. Gfeller, and K. Seidel, "Mapping of Snow Cover in the Swiss Alps from ERTS-1 Imagery." Contributed Paper for Symposium A - Session 6 COSPAR XVIth Plenary Meeting and Related Symposia, Konatans 23 May - 6 June 1973.
6. Evans, W. E., "Time-Lapse Analysis of ERTS Imagery Using Special Electronic Viewing/ Measuring Equipment," Proceedings of Second Annual Remote Sensing of Earth Resources Conference, University of Tennessee Space Institute, Tullahoma, Tennessee 37388 March 26-28, 1973.
7. ERTS Data User's Handbook, NASA Document No. 71SD4249, Goddard Space Flight Center, Revised to Feburary 15, 1972.
8. Hoffer, R., September 1973, "Interdisciplinary Evaluation of ERTS for Colorado Mountain Environments Using ADP" LARS Type II Report to GFSC.
9. Handbook of Geophysics, McGraw Hill.1965.