SNOW EXTENT MEASUREMENTS FROM GEOSTATIONARY SATELLITES USING AN INTERACTIVE COMPUTER SYSTEM

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ABSTRACT

An interactive computer data access system (McIDAS) is used to measure the extent of snow fields in the Salt and the Verde River Basins in central Arizona from satellite images. This study was based on real-time visible image data of 1 Km resolution generated by the eastern GOES (Geostationary Operational Environmental Satellite) in orbit approximately 37,500 Km (20,000 nm) above the earth at 0^{o} latitude, 75^{o} longitude. This new method for preparing Snow Covered Areas (SCA) is compared to the current operational SCA techniques used by the National Environmental Satellite Service (NESS).

INTRODUCTION

Environmental satellite data provides much of the needed information concerning snow cover. Accurate snow interpretation and mapping from environmental satellites has been demonstrated by Barnes and Bowley (1966, 1974); in 1973, the National Environmental Service (NESS) established a quasi-operational snow cover program (Schneider, et. al., 1976). Satellite-derived snow covered area (SCA) measurements for specific river basins within the United States have been provided since then by NESS to selected National Weather Service Forecast Centers for use in various hydrological models. Two of these operational basins, the Salt and Verde in Arizona, were selected for this study (figure 1).

This study used real-time data from the Geostationary Operational Environmental Satellite (GOES), analyzed by an interactive computer system to calculate SCA. Full resolution (1 Km) visible data from the eastern GOES satellite (0^{o}N, 75^{o}W) was selected for this study; the GOES visible sensor detects radiation between 0.55-0.75 μm. A complete description of the GOES system is given by Bristor (1975). The University of Wisconsin's Man-computer Interactive Data Access System (McIDAS) used to make the SCA measurements is described by Smith (1975), and by Chatters and Suomi (1975).

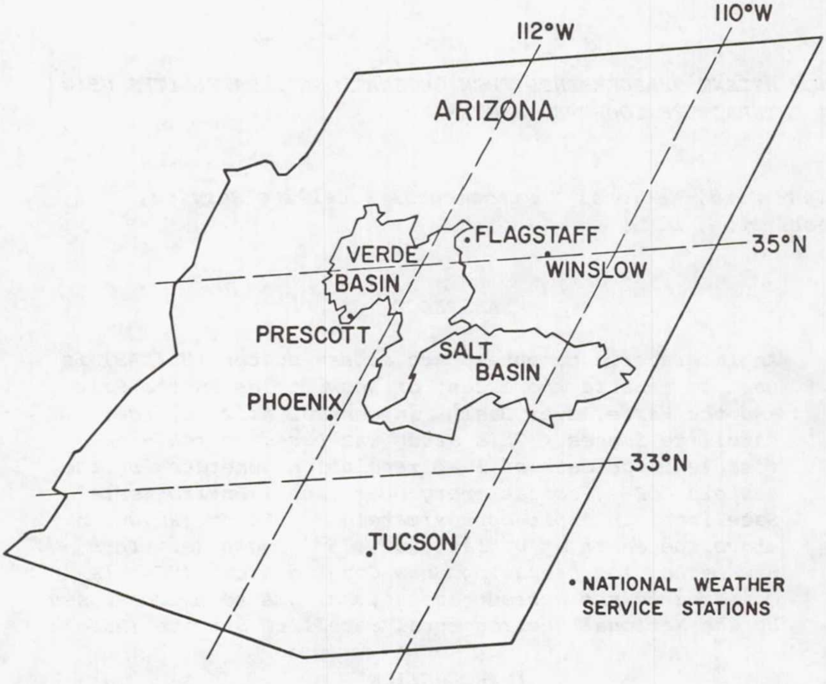

Figure 1. Salt and Verde river basins, viewed from the eastern GOES satellite position.

The GOES and McIDAS combination provided many opportunities to improve and increase the flexibility of SCA. The GOES satellite provides real-time data and generates more than one image per day, so it was possible to select an optimum image for each specific basin, taking into account such factors as solar zenith angle and cloud cover. A recent study by Breaker and McMillan (1975), indicated that daily and perhaps hourly snow-melting rates could be obtained from GOES data film loops. In related reports, Schumann (1975), and Warskow, et al. (1975) indicated the need for such hourly snow-melting rates during periods of high run-off and minimum available reservoir storage capacity--rate calculations that are extremely important for desert cities like Phoenix, Arizona.

Throughout this paper, reference will be made to a Registered Image Sequence (RIS). This is a time series of GOES full resolution visible image sectors viewed on the McIDAS video component in chronological order and registered (navigated) to within ± 1 image pixel. For a complete description of the McIDAS navigation *system see Phillips and Smith (1973). During a RIS, the land masses remain fixed, clouds may move, form and dissipate, while snow fields change shape and character in response to meteorological conditions. By studying a RIS that is compiled from real-time data, the McIDAS analyst can compute real-time hourly snow melting rates. The McIDAS software, under analyst control, can eliminate synoptic-scale clouds from a RIS to create a SCA from a composite image. The usefulness of cloud-free composite images for SCA has been established by McClain and Baker (1969), although they did not use real-time data. The cloud elimination technique used in this paper is described in a later section.*

Finally, it should be noted that all SCA measurements are performed by the McIDAS computer directly from the satellite data; this reduces errors by reducing the number of transformations in the SCA measurement process.

EXPERIMENTAL PROCEDURES

The Salt and Verde river basins used in this paper, were selected for the following reasons. The basins are routinely mapped by the NESS SCA program, so comparison of NESS versus GOES/McIDAS results would be straightforward. Second, these basins have many visible landmarks (Lake Roosevelt, Mormon Lake, and the Little Colorado River) which would be helpful in establishing the accuracy of the McIDAS navigation. (Navigation is required for any type of RIS analysis and can be used in the final SCA measurement.) Third, five National Weather Service Stations are located in or around the basins (figure 1), so conventional data (including weather radar reports) could be useful to examine closely the winter history of the basins. Finally, the basins are frequently cloud-free, even during the winter months, thereby making it possible to compile a long-term data set for SCA analysis.

This study was conducted in three phases: the set-up phase, the data collection phase, and the analysis phase. In the set-up phase, the basin perimeters were defined in terms of latitude and longitude points and stored within McIDAS. Second, a preliminary GOES image data set (early December) was collected in which both basins were free of cloud and snow cover. During the data collection phase, GOES image data was saved for those days on which a SCA measurement looked feasible. In the final analysis phase, SCA measurements were conducted using McIDAS.

Set-up Phase

The first step in defining the basin perimeters was to obtain a map of the basin areas from the United States Geological Survey in Phoenix, Arizona. The map was a Phoenix Sectional Aeronautical Chart, scale 1:500,000. A number of latitude and longitude points were selected from the perimeter outlines--56 and 89 points for the Salt and Verde basins, respectively. These grid points were then punched onto computer cards and read into McIDAS. Once stored in McIDAS, the perimeter outlines could be displayed on the McIDAS video at any time by typing in a single command line via the keyboard. A denser network of points could have been used, but for this study it was not deemed necessary.

The second part of the set-up phase was the collection of the preliminary data set. These images were used to familiarize the McIDAS analyst with the basin geography (landmark features). Numerous landmarks were clearly visible within the area of interest; the most prominant are Lake Roosevelt, Mormon Lake, Mount Baldy, and the Little Colorado River. The preliminary data set was collected from December 7, 1976 to December 24, 1976; a local noon image, 1900 GMT, was selected as the primary data collection time for this study. During this 17-day period, nine images were collected but only three images satisfied the cloud and snow free requirements and were of acceptable quality (i.e., had no missing data lines). The three images were then navigated via McIDAS and assembled to form the initial RIS--the start of the "winter history" for both basins.

In the final part of the set-up phase, the accuracy of the computer-generated basin perimeters was checked. First, the basin perimeters and GOES satellite data were viewed simultaneously on the McIDAS video display. This product was compared to the aeronautical chart and obvious mistakes in the perimeter points were corrected. Second, the total area of the two basins was computed using the GOES data and McIDAS. The basin perimeters were traced using the McIDAS video cursor, controlled by a manual joy-stick; the McIDAS software then automatically calculated the number of satellite pixels enclosed by the cursor derived outline. The area results, expressed in terms of square kilometers differed by less than 2% (33,235 Km^2 vs. 32,686 Km^2) from the ground truth numbers provided by Schumann (1975).

Data Collection Phase

The data collection phase of this project took place between January 4, 1977, and February 1, 1977. During this phase all possible 1900 GMT cloud-free GOES images of the basins were collected using McIDAS. Daily checks of the synoptic weather conditions were conducted at 1400 GMT and updated at 1800 GMT, using the National Weather Service products collected by the University of Wisconsin - Madison, Department of Meteorology. If all conditions at 1800 GMT looked favorable, McIDAS ingested the 1900 GMT GOES visible data centered on Phoenix, Arizona. After ingest, the data was archived onto magnetic tape so the SCA analysis could be carried out at any later time (depending on McIDAS availability). During this 28-day period, a total of 14 images were collected and saved. Only five of the 14 images were completely cloud-free and were used for SCA; the remaining nine had some degree of cloudiness, mostly thin cirrus, in the basins.

Analysis Phase

Prior to final SCA analysis, the image to be studied was incorporated into the already existing RIS in the following way. The first three images of the RIS were the three snow-free, cloud-free images from the preliminary data set. The fourth image of the RIS was the first image of the data-collection phase, and so on, until all five images from the data collection phase were incorporated into the RIS. It was quite easy to detect minor changes in the snow fields between two sequential images; this "historical" RIS was a valuable aid in maintaining a consistent SCA product throughout the project. A further discussion is presented in the Results section.

Once the specific image was incorporated chronologically into the RIS and compared to previous images and the trend of the snow field changes was established, the SCA analysis was conducted.

To make an accurate SCA, each GOES image had to be displayed as a four-fold expansion on the McIDAS video (16 CRT pixels for every satellite pixel). Because of this expansion, analysis of each basin had to be carried out in four sub-sectors. A second expanded image--"yesterday's" image relative to the five images of the data collection set--was displayed alternately on the McIDAS video to help detect very small changes in the snow fields. While these images alternated on the video, the cursor was used to outline the snow fields. Once a snow field within the sub-sector was outlined, a second tracing using the cursor was initiated. Completion of this second tracing automatically invoked the area calculation software of McIDAS, and the area calculation for the snow field within the sub-sector was displayed and printed out. The area calculation was expressed in terms of the number of satellite pixels and in km^2. Once the areas for all the snow fields were calculated for the sub-sector, another sub-sector was selected and appropriate steps repeated. After the analysis of all sub-sectors was completed, the snow field calculations for each basin were added together. Since the total area of the two basins was calculated from the preliminary data set, a SCA could be calculated for the two basins.

Cloud Subtraction Technique for SCA

A powerful feature of the McIDAS software is the Cloud Subtraction Routine (CSR). For a complete description of the Cloud Subtraction Routine see Mosher (1977). In order to produce meaningful results, the CSR must be performed on a RIS. Inside McIDAS, the CSR matches up to six images from the RIS, scanning the images and retaining only the darkest pixels at each location from the RIS images. The resulting composite image is thus composed of the darkest pixels from the RIS, in effect eliminating *the lighter clouds moving over the darker land.*

To demonstrate the usefulness of the CSR in doing SCA calculations, a RIS was compiled from 1830, 1900 and 1930 GMT images for February 6, 1977. In each of the three images, both basins were obscured by clouds and no SCA could have been prepared from any of the individual images. The CSR successfully eliminated the clouds from the three images and produced a composite image suitable for a SCA. The results of this technique will be discussed in the following section.

EVALUATION OF RESULTS

Comparison of Methods

The GOES/McIDAS SCA results show good agreement when compared with the NESS products (figure 2) during the first part of this study (January 10-15, 1977). The second part of this study (January 16-28, 1977) shows the GOES/McIDAS products to be approximately three to five percent less than the NESS polar-orbiting based products. A similar result has been previously observed by Schneider and McGinnis (1977). Another significant difference was noted. From January 13 to January 15, 1977, the NESS products showed an <u>increase</u> in the snow cover for the Verde basin, while the GOES/McIDAS product <u>implied</u> no change in the snow cover for approximately the same period. Additionally, a check of National Weather Service Radar Reports during this period indicated no precipitation had occurred within the Verde basin. Therefore, the increase in snow cover reported in the NESS analysis appears to be an error--the type of error that might be expected using the current manual techniques during periods of little or no change in the snow cover. The use of RIS could help eliminate this type of error, since small changes in the snow cover between any two days are easily detected when viewing the images within a RIS. The RIS thereby provides continuity for sequential SCA operations.

A comparison of SCA results for January 10, 1977 is shown in figure 3, indicating an apparent loss of detail in the snow cover outlines produced by GOES/McIDAS. This difference, however, is not real. It results from the transfer of the SCA analysis from the McIDAS video to the worksheet; the actual outlines generated by McIDAS and used for the SCA did contain more detail. The two products show good agreement with the minor exception of the snow-capped mountain peaks located in the southern part of the Verde basin. Old or new snow on mountain peaks shows up very clearly when the analysis image was compared to a snow-free image in the RIS.

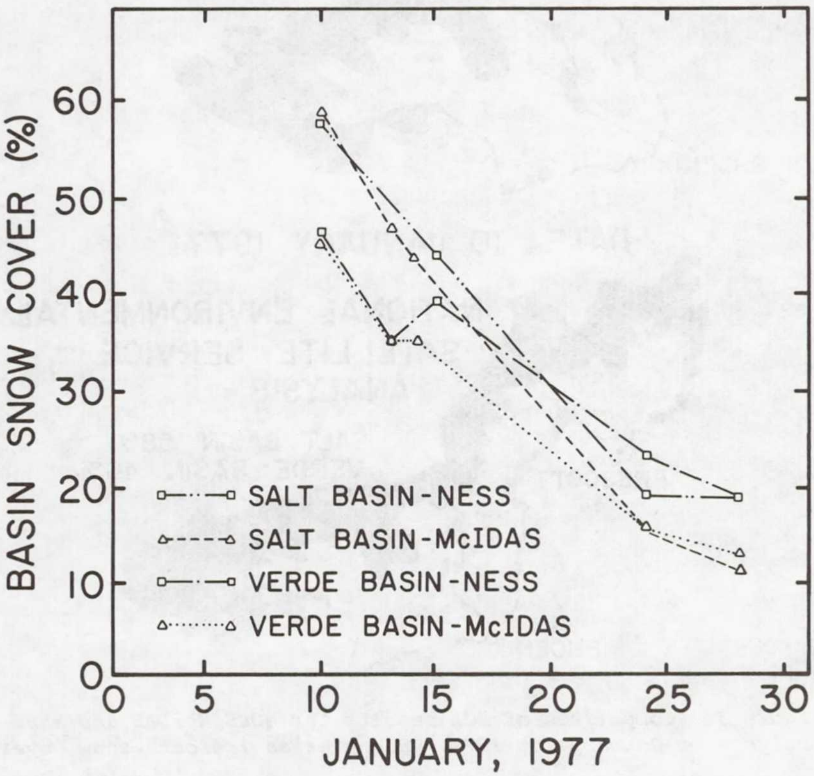

Figure 2. Comparison of Snow Cover Area (SCA) measurements for the Salt and Verde river basins.

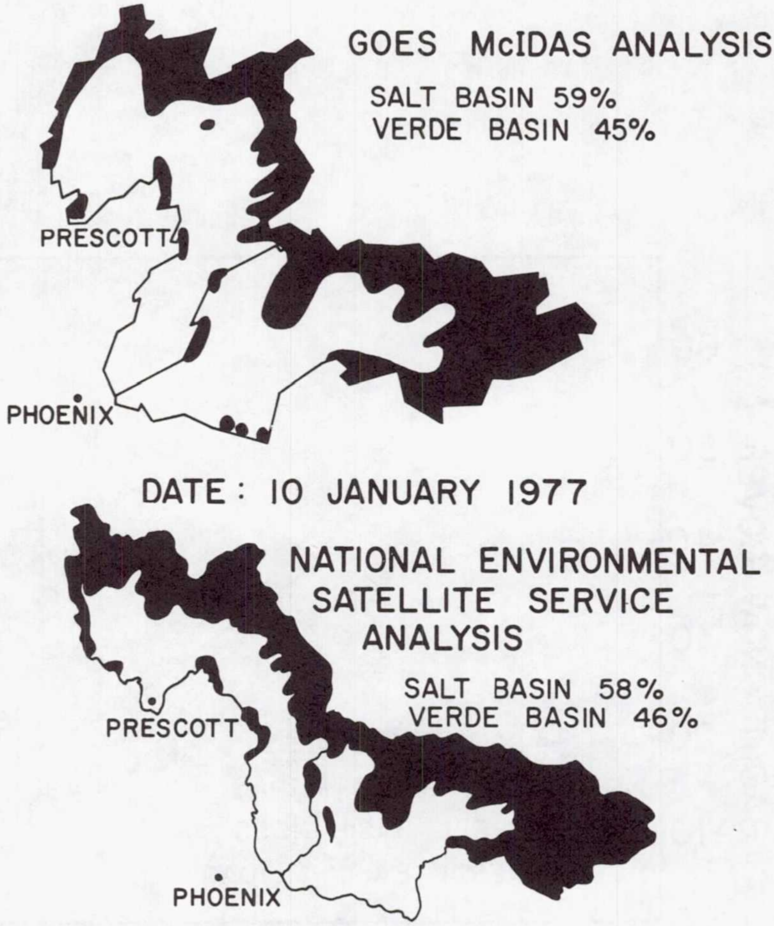

Figure 3. Comparison of SCA results for GOES/McIDAS and NESS analysis on January 10, 1977. Black areas indicate snow cover.

Satellite Pixel vs Km^2 Results

A comparison of GOES/McIDAS-generated SCA results using both satellite pixels and km^2 areas was conducted. The results indicate only second-order differences between the two methods. The shape of the satellite pixel is approximately square for this basin location, although the pixel distortion does get worse the further away an Earth pixel is located from the GOES satellite subpoint (0^{o}N, 75^{o}W). The navigation software in McIDAS calculated the approximate dimensions in the area of the basins as 0.59 nm wide and 0.68 nm long. Although the units of area used to calculate SCA (satellite pixel or km^2) did not matter for these two basins, other basins analyzed by GOES/McIDAS would have to be treated as individual cases when selecting the area units.

Cloud Subtraction Results

The SCA results generated by McIDAS from the cloud-free composite image agreed favorably with the NESS products. The GOES/McIDAS SCA for the Salt basin for February 6, 1977, indicated 11% snow cover; the NESS product for February 7, 1977, showed the Salt basin to be 17% snow covered. The clouds that were eliminated from the images were estimated to be of either the mid-level or high-level type, and they did produce significant shadows on the ground which were not eliminated from the composite image. Further investigation of the cloud elimination scheme is recommended.

Analysis Time

The time required to complete a SCA with the GOES/McIDAS system averaged 30 minutes per image throughout this study, but this time can fluctuate ± 15 minutes depending upon the complexity of the snow cover. New snow cover, which covers a larger, more uniform area, is easier to analyze than older, patchy snow cover. The GOES/McIDAS analysis time is approximately equal to the current manual NESS operation. The significant difference between methods is that a GOES/McIDAS analysis can be completed within an hour after image reception time, whereas the current manual NESS operation takes 24 hours or more to complete. It should be noted,however, that an improvement in analysis time was not an objective of this study.

Errors

The most significant source of error in the GOES/McIDAS scheme is the experience of the analyst in snow mapping, although experience and confidence increased rapidly (and errors declined) during this study. A second source of error was in the McIDAS tracing software routines. This software requires the storage of satellite pixels in order to define the snow cover outline. Because this storage array is limited, the McIDAS analyst had to rapidly trace the outlines in order to avoid overflowing the storage array. Faster tracing implies fewer satellite pixels to be stored. This limitation would be a serious problem when performing a SCA that required fine detail in the outlined basin. Since these tracing software routines are still considered developmental, corrections could be applied to the operational version. Another source of error (related to the tracing problem) was the extreme sensitivity to trace details as small as one or two pixels (isolated snow-capped mountain peaks); considerable practice was required.

CONCULSIONS AND RECOMMENDATIONS

This study indicates that the GOES/McIDAS SCA process can produce reliable, consistent snow mapping results. Further, interactive computer systems like McIDAS offer advantages over the present manual techniques. Improvements, however are needed in the McIDAS software. Additional software could be included to introduce semi-automatic tracing techniques; parts of the snow cover that extend up to the basin perimeters could be outlined automatically, since the basin perimeter is defined within the computer in terms of latitude and longitude. Total automation of SCA seems remote, however; accurate definition of snow cover still requires human interpretation.

On the basis of this study, it is recommended that snow cover mapping using the GOES/McIDAS method should be incorporated into the present snow mapping program of the National Environmental Satellite Service. Further investigations should examine the following topics: selection of a wider variety of snow basins for study; use of polar-orbiting satellite data with McIDAS for the mapping of northern basins; and the use of techniques such as elevation slicing and cloud elimination schemes to further improve SCA procedures.

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