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SIERRA NEVADA SNOW MELT FROM SMS-2

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ABSTRACT

A film loop from SMS-2 imagery shows snow melt over the Sierra Nevadas from May 10 to July 8, 1975. The sequence indicates a successful application of geostationary satellite data for monitoring dynamic hydrologic conditions.

INTRODUCTION

The National Environmental Satellite Service (NESS) has established five Satellite Field Services Stations (SFSS) to interface with field users of NESS satellite data. One of the functions of the SFSS is to provide environmental satellite data and related analyses, interpretations, and services. The support provided varies by station depending on the interests of its regional users. Since January 1975, the SFSS in Redwood City, California has participated in the NASA sponsored Snow Application Systems Verification Test (ASVT) by providing satellite imagery from the NOAA and SMS environmental satellites.

It seemed a reasonable progression, based on the effectiveness of meteorological film loops from SMS, to construct a similar registered sequence showing the time-space variations of snowfields. A film "loop" consists of a short piece of film spliced into one continuous movie, thereby allowing the same set of imagery to be seen over and over. A meteorological loop may show imagery spanning several hours but a hydrological loop showing snow melt would have to cover a period of several months.

The idea of applying time-lapse techniques to hydrological phenomena is not new. Serebreny et al, 1974, summarizes past applications of LANDSAT imagery to temporal studies.[1] For example the idea of monitoring snowline recession via sequential satellite imagery is presented. Unique in the hydrologic time-lapse sequence presented here however is the source of data from which it has been constructed.

There are two reasons for constructing the loop. The first is to document and display the capabilities of the SMS satellites for hydrologic applications. The second reason is to show the character and rate of snowline recession in the Sierra Nevadas during this most recent snow melt season.

SATELLITE AND SATELLITE DATA

The Synchronous Meteorological Satellites (SMS) now in orbit are NASA-sponsored prototypes. Future satellites in this series will be entirely NOAA-funded and will be designated Geostationary Operational Environmental Satellites (GOES).

The SMS satellites are geostationary, their position with respect to the earth remains fixed. This occurs because the angular velocity of the satellites in their orbit is identical to that of the earth. The SMS-2 subpoint resides at the equator with a longitude of 115°W; SMS-1 is at 75°W. Both spacecraft are at an altitude of about 35,000 km.

Visible and infrared data from SMS are provided by a Visible and Infrared Spin Scan Radiometer (VISSR). Images are created through the horizontal spinning motion (100 rpm) of the satellite and by vertical internal stepping of the scan mirror after each spin. Eight identical visible sensors (0.55-0.75 μm) are aligned in a linear array so that they generate 8 scan lines per satellite rotation. This results in 1 km resolution at the satellite subpoint. In order to reduce the data volume, the visible sensor output can also be combined in sets of 2, 4, or all 8 sensors. Visible channel imagery can then be selected with 1, 2, 4, or 8 km resolution, respectively. Two identical and redundant infrared sensors (10.5-12.6 μm) provide 8 km resolution at nadir. More information on the VISSR can be found in references 2 and 3.

Although SMS-2 produces an image of almost an entire hemisphere during each scanning cycle, geographical "sectors" of limited extend are normally extracted for local use. The data stream from the satellite is sectorized by computer and the appropriate images distributed to the SFSS's. Sectors with 1 km resolution cover an area at nadir of approximately 22 x 10^5 km^2 and were chosen for this study because they contain maximum spatial resolution. A sample sector is shown in Figure 1.

SMS viewing geometry produces imagery displayed in an unfamiliar cartographic projection. The display, somewhat similar to a standard orthographic meridional

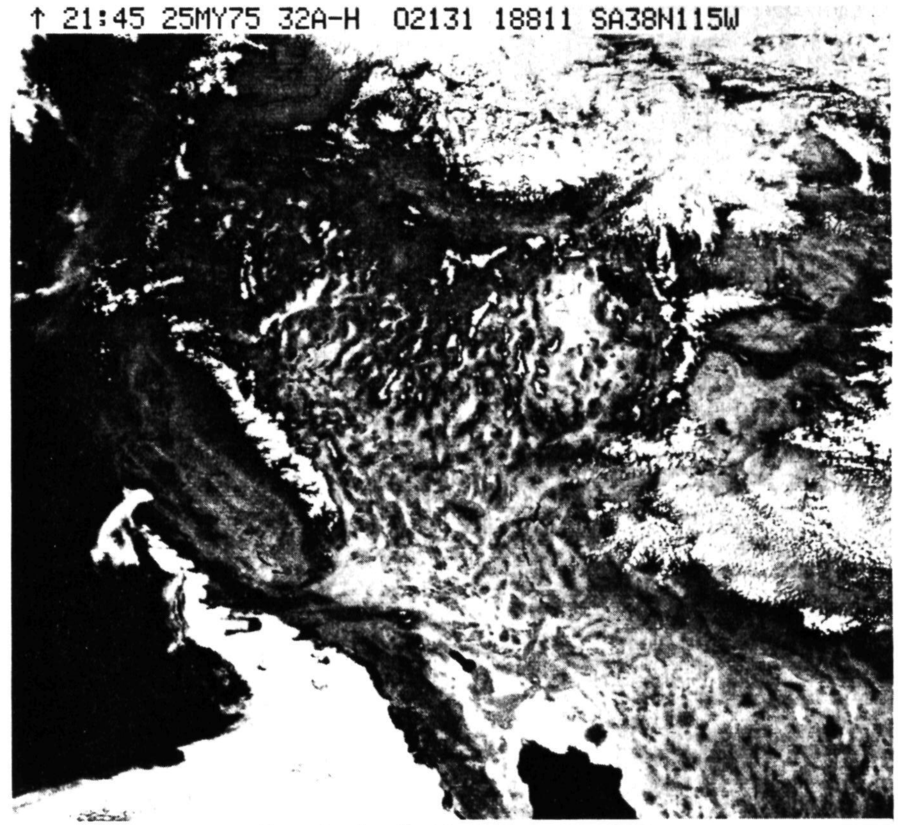

FIGURE 1 - HALF MILE VISUAL SECTOR FROM SMS-2

projection, is identical to that produced by photographing a world globe. In this case, the camera has been replaced by the spacecraft. Related to this type of projection is a radial decrease in resolution. As the distance from the satellite subpoint increases, the earth is viewed more obliquely, such that the instantaneous field of view covers a larger area. This predictable decrease in resolution results in a value between 1 and 1.5 km for the center of the sector used in the film loop.

The quality of SMS imagery is affected by the method of transmission. The data is received from the satellite at the NESS headquarters in Suitland, Maryland. There it is sectorized and transmitted to the various SFSS's over a conditioned C-5 telephone line. There, the data are recorded photographically on 25 x 25 cm high quality negatives, from which the imagery is produced. A qualitative comparison of SMS-2 images produced at Suitland and Redwood City has indicated that a slight loss in sharpness occurs over the line. However, areal snow cover measurements from these images showed little difference.

METHOD

Area Selection

Several items were considered immediately before the data collection period. First, sector location had to be specified and was subsequently chosen to include three of the four westernmost study areas in the ASVT project, namely, the Pacific Northwest, the Sierra Nevadas, and the Salt and Verde River watersheds in Arizona. The sector chosen is centered at 38°N, 115°W as shown in Figure 1. Based on other operational requirements, it was decided that one sector per day could be allocated to the effort thus establishing the sampling frequency. Also, it was decided to request the sector at about the same time each day, 2200 GMT (Table 1). This was done to minimize day-to-day sun angle variations and to reduce sector subpoint changes due to diurnal extra-orbital motion.

It became apparent that an entire sector would provide too much information when constructing the final loop. Consequently, one of the three ASVT study areas included in the daily sector was selected for constructing the final sequence. Cloud cover during the data collection period made the choice simple. The Sierra Nevadas were completely or partially cloudfree at least 65% of the time (Table 1). Other factors also influenced our decision. First, the large areal extent of snow in this region made its selection appealing. Second, snow can be viewed directly over much of this range because of the high percentage of unforested areas.

Loop Construction

In constructing the loop, images were pin-registered using prepunched plastic strips taped to each negative. Each negative was overlaid on a reference negative (May 11) throughout the sequence; Mono Lake was the primary geographic reference point.

A number of problems were encountered during the construction of the loop. Initially two questions arose. First, should days when clouds obscured the Sierras be included? Second, what should be done about dates during the sequence when negatives were not obtained? The first question was easily answered--yes. If cloud-cover statistics during the data collection period were to be of interest, and it was felt they would, then days with and without clouds should be included. The second problem was not serious inasmuch as only three days out of 60 were missing. It was decided to assemble the loop without the missing dates and not to fill the gaps with adjacent negatives.

The major problem in loop construction related to image-to-image brightness variations. An attempt has been made to minimize these brightness variations by first measuring individual negative densities, and then compensating photographically while explosing the negatives. This was partially successful, but could not correct for differences in contrast.

A minor problem in loop construction dealt with proper animation. Initially each image was exposed on four frames as is customarily done with meteorological loops. At a nominal film speed of 16 frames per second, each day was presented on the screen for 1/4 second. This motion, however, was too rapid and 10 frames per day were selected for the final construction.

The final product is a 16mm film loop containing 57 images over a period of 60 days. The first and last images are repeated 20 times with the intervening images repeated 10 times each. The entire loop is thus 590 frames in length, compressing two months of Sierra Nevada snow melt into about 37 seconds.

DISCUSSION

The film loop starts on May 10 and terminates on July 8, 1975. The dates are included in the upper righthand corner of each frame. In viewing the loop, it is recommended that subareas or basins within the Sierras be selected for scrutiny. Considerable concentration is required. Cloud motion is very distracting and changes in snow cover are often not obvious.

Figure 2 illustrates major river basins of the Sierras covering the same area and in the same cartographic projection as the satellite imagery. A film loop cannot of course, be included in the text. Figure 3, however contains a selected sequence of eight images taken from the loop and illustrates the pattern of snow melt.

Over the 60 day period of the loop, a gradual recession of the dendritic snow envelope is apparent. However, during the period of the loop, significant snow accumulation occurred on at least three separate occasions, May 21-22, June 17, and June 24. New snow may be detectable following the June 17 snowfall. Unfortunately, the radiances of snow and cloud tops in the visible band are often almost identical making a distinction between the two nearly impossible. Cloud contamination was especially troublesome following the June 17 snowfall when trying to detect the presence of new snow.

The original idea for generating a snow melt film loop did not occur until the first week in May. It was indeed fortunate that snow melt was delayed this year by cooler than normal weather throughout April and into early May. Field data confirmed that maximum snow accumulation was delayed this year and occurred around the first week in May. This date for maximum accumulation was at least a month later than usual.[4] Thus, more by good fortune than planning, we were able to capture that period when maximum snow melt occurred.

CONCLUDING REMARKS

The purpose for constructing a film loop of snow melt over the Sierra Nevadas has been to demonstrate the applicability of SMS-2 one kilometer visual-band imagery to the study of snow cover dynamics. With this time lapse sequence, the character and rate of snow line recession in the Sierra Nevadas during the 1975 snow melt season has been shown.

The Sierra Nevadas, during spring, are a subject well suited to satellite surveillance. Statistics from Table 1 indicate that the Sierra Nevadas were totally obscured by clouds only seven percent of the time and partially cloud covered one-third of the time. Cloud cover climatology indicates that this area is generally favorable for viewing from space during the spring season.[5]

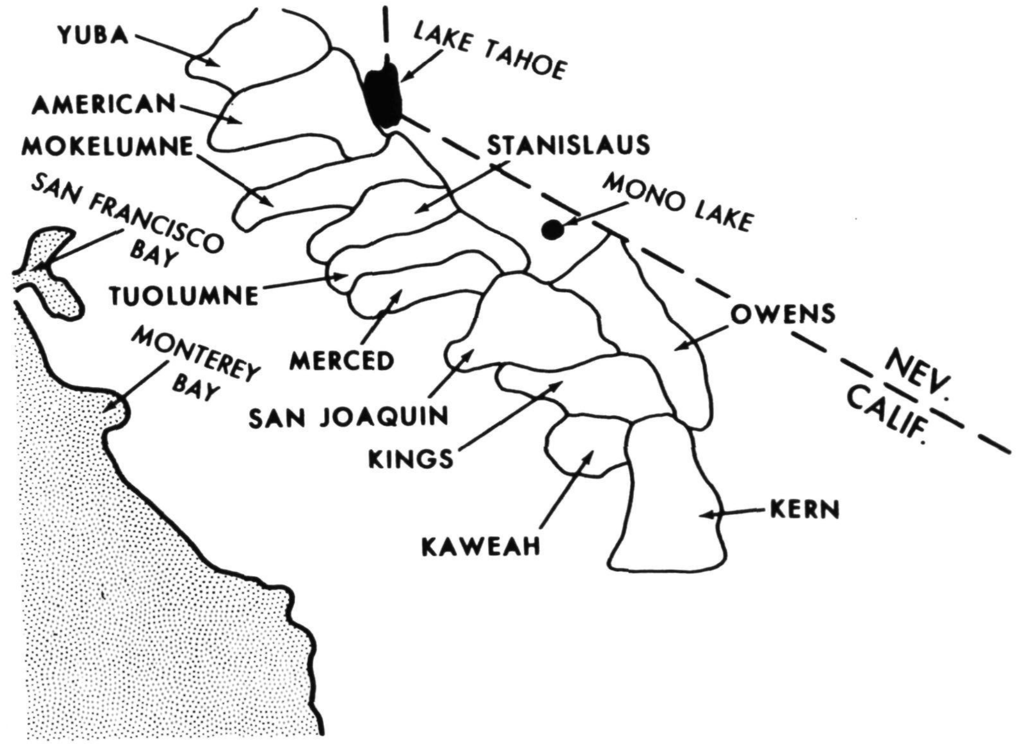

FIGURE 2 - MAJOR SIERRA NEVADA RIVER BASINS

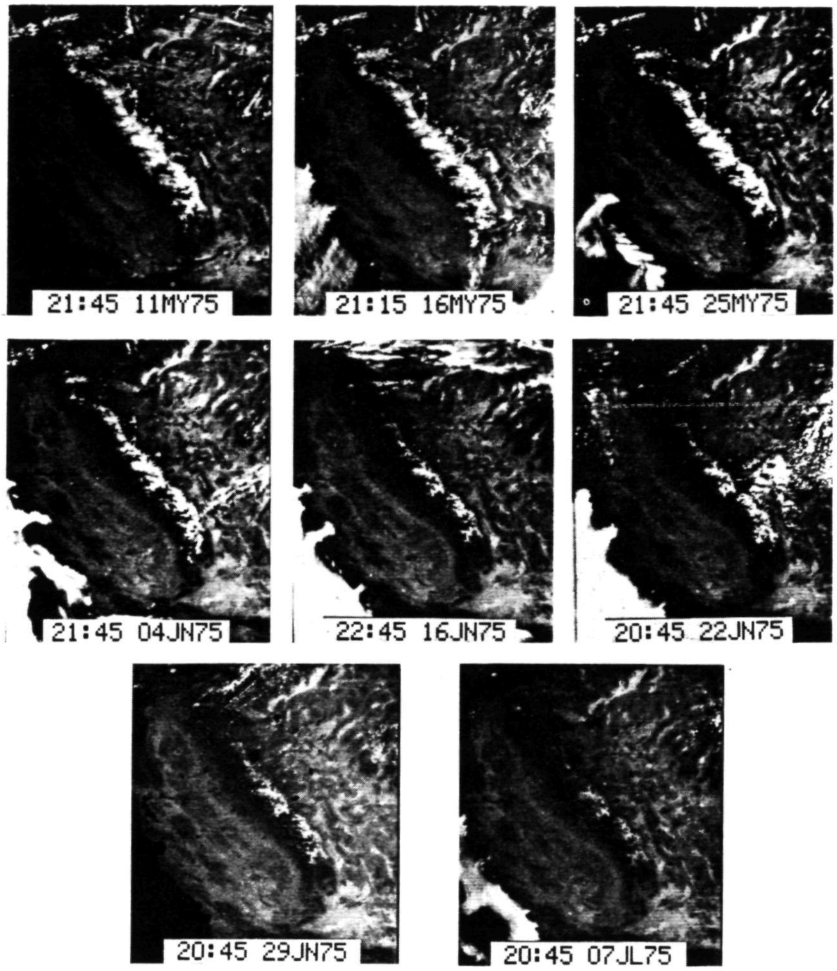

FIGURE 3 - SEQUENCE OF SMS-2 IMAGES OVER THE SIERRA NEVADAS

The SMS satellites, 1 and 2, have the ability to view the earth from a fixed vantage point as well as provide imagery every one-half hour. This combination at 1 km resolution provides the hydrologist with a unique surveillance capability. Useful applications of this capability are far more numerous than merely constructing a film loop. Several examples follow.

1. Areas having an early morning fog or mist, such as the Pacific Northwest, are difficult to snowmap with current NOAA or LANDSAT data. Cloudfree SMS imagery, however, can often be obtained in the afternoon (Schneider, 1975).[6] In fact, imagery of a particular basin can be obtained if the area is cloudfree for only half an hour per day.

2. The daily snow melt rate may be computed. In areas of rapid snow melt, such as the Southwest, hourly snow melt rates can be determined.

3. An immediate, daily record of cloud seeding effects on both cloud shape and snowfall can be obtained.

4. Time-lapse analysis on an hourly scale can assist in snow/cloud discrimination.

5. Selection of optimum solar zenith angle for individual watersheds is possible. Basins facing west should be imaged after solar noon, for example, to minimize valley wall shadows. Similarly, the solar angle could be selected which would minimize forest shadows to assist in detecting snow in forested areas. Halverson and Smith (1974) have published tables of shadow lengths as a function of time which would be helpful.[7]

6. Middleton et al (1952) have studied snowpack reflection at various zenith angles.[8] Their results indicate it may be possible to differentiate among snowpack surface conditions in early morning or late afternoon imagery.

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Table 1

FILM LOOP STATISTICS

1. Number of Images

   (1) Total = 57
   (2) 3 missing over 60 day period

2. Daily Time Spread (GMT)

   (1) Total: 19:15 - 00:45 - 5-1/2 hours
   (2) Over 90% fall between 20:45 and 22:45
   (3) Mean image time ≈ 2200

3. Cloud Cover

   (1) Partial Cloud Cover = 33%
   (2) Totally Obscured = 7%