Paper No. 7

THE OPERATIONAL PROGRAM OF SATELLITE SNOWCOVER OBSERVATIONS AT NOAA/NESS

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ABSTRACT

The operational river basin snow mapping program at NESS is described with emphasis on quality control techniques and results for the 1974-1975 snow season.

INTRODUCTION

NOAA's National Environmental Satellite Service (NESS) has been producing satellite derived areal snow cover maps for selected river basins during the past three snow seasons. This project began in the Spring of 1973 with four basins originally targeted for study. The basins were selected so as to provide a variety of topographic, spatial and climatological characteristics (Wiesnet and McGinnis, 1973). The subject areas included the American River basin in California, the Willamette River basin in Oregon, the Red River of the North basin in North Dakota and Minnesota, and two sub-basins of the Genesee River in New York. An increase in manpower resources and the procurement of an electronic planimeter has enabled NESS to expand this successful program. Operational coverage is now being provided for 18 basins in the United States as well as several in Canada.

SATELLITE IMAGERY

The satellite imagery currently being used for snow mapping at NESS is from NOAA-4, a polar orbiting satellite that is the third in a series of improved TIROS operational satellites; the first, NOAA-2, was launched on October 15, 1972. The imaging system relevent to snow mapping on board NOAA-4 is the Very High Resolution Radiometer (VHRR). It provides daily coverage over the United States in the visible portion of the spectrum (0.6 - 0.7μm) and twice daily coverage in the thermal infrared (10.5 - 12.5μm). Spatial resolution for both the visible and the infrared data is one kilometer at nadir.

METHODOLOGY

Snow maps are produced by first registering a VHRR image to a hydrologic basin map. A Bausch and Lomb Zoom Transfer Scope is

utilized for this purpose. The snow line seen on the image is then traced onto the basin map.

The percentage of snow cover for the basin is determined through use of either a manual or an electronic planimeter. To use the manual planimeter, the area covered by snow is first measured and then divided by the total basin area. The manual planimeter works best for basins in which there is a single continuous snow line. In basins where there are isolated peaks and valleys, such as the Cascade Range, each snow area must be measured separately and then added together, thus compounding operator error.

Measurements can be made with great speed using an electronic planimeter. However, the operator is obligated to shade in the snow map and prepare a basin silhouette or "mask" before using the electronic planimeter.

THE CURRENT SNOW MAPPING PROGRAM

Snow cover measurements are taken whenever the subject area is cloud free and are generally transmitted within 30 hours of a satellite pass to serve as input to computer run-off models. Measurements are being made for eighteen river basins in the United States, ranging in size from 2541 km^2 for the Genesee River above Portageville, New York to 104,120 km^2 for the Red River of the North above Emerson, Manitoba (see Table I).

The primary users of these areal snow extent data are the National Weather Service River Forecast Centers (RFC). Twelve River Forecast Centers provide river stage forecasts and flood warnings for most of the United States. Each RFC is served by one or more River District Offices (RDO). These River District Offices maintain stream gauges in their geographic areas of responsibility, relaying data to the RFC. Areal snow cover percentages determined by NESS are being sent to the Hartford, Harrisburg, Kansas City, Salt Lake City, Sacramento and Portland RFC, as well as the Phoenix RDO.

River basins have been added to the snow mapping program upon request of the NWS, Office of Hydrology. As can be seen from Table I, half the basins being analyzed for snow cover are located within the states of Oregon and Idaho. These basins are all a part of the Columbia River drainage system and have proved to be areas in which snowmelt is a critical factor in regard to water supply forecasting and flooding. In fact, rapid snowmelt in the Salmon, Clearwater and Payette basins caused extreme flooding in Idaho during June, 1974.

In addition to those listed in Table 1, a number of basins located in densely wooded areas are being mapped by NESS in a joint effort with agencies of the Canadian Government as part of

TABLE 1

BASINS FOR 1974-1975 OPERATIONAL MAPPING

RIVER BASIN	LOCATION	DRAINAGE AREA IN km^2	RFC
Red River of the North (Above Emerson, Manitoba)	Dakotas-Minnesota Manitoba	104,120	Kansas City
Souris River (Above Westhope, N.D.)	North Dakota Saskatchewan	43,771	Kansas City
Willamette	Oregon	26,159	Portland
Deschutes	Oregon	27,195	Portland
John Day	Oregon	19,632	Portland
Umatilla	Oregon	5,931	Portland
Salmon (Above Whitebird, Idaho)	Idaho	35,095	Portland
Clearwater (Above Peck, Idaho)	Idaho	20,824	Portland
Weiser	Idaho	3,781	Portland
Payette (Above Emmett, Idaho)	Idaho	6,941	Portland
Boise (Above Lucky Peak, Idaho)	Idaho	6,941	Portland
American (Above Folsom)	California	5,601	Sacramento
Genesee (Above Portageville, N.Y.)	New York	2,541	Hartford
Genesee (Below Portageville, N.Y.)	New York	3,812	Hartford
Chemung	New York-Pennsylvania	6,721	Harrisburg
Salt	Arizona	16,141	Salt Lake City
Verde	Arizona	17,094	Salt Lake City
San Juan	Colorado-Utah-Arizona-New Mexico	65,273	Salt Lake City

a World Meteorological Organization program of snow studies by satellite. These include four sub-basins of the Winnepeg River, the upper Columbia River and the St. John River basin in Maine and New Brunswick.

RESULTS FOR THE 1974-1975 SNOW SEASON

Approximately 440 snow cover measurements were transmitted by NESS to RFCs between November 1, 1974 and June 30, 1975. A monthly breakdown is provided in Table II. All maps and measurements were determined by the NESS/Environmental Products Group (EPG) except for the American River basin which was turned over to meteorologists of the NESS/Synoptic Analysis Section (SAS) on January 11, 1975. As many as 16 basins were mapped on a single day, at a rate of less than one half man-hour per basin. Since basins were mapped whenever cloud free, the number of measurements for an area depended mainly on weather conditions. Other factors that affected the quantity of data were basin latitude, elevation and drainage area.

Northeast

The amount of data retrieved for the Genesee and Chemung Rivers was limited due to poor weather conditions in the Lake Ontario region and the long periods during which the basins were 100 percent snow covered (no snow maps were made in such cases). None the less, a combined total of 28 snow cover measurements were determined for the three basins during the 1974-1975 snow season.

Snow maps for the St. John River basin were made at a 1:2,500,000 scale, segregated into about 50 sub-basins through use of a transparent plastic overlay, and then transmitted to the New Brunswick Department of the Environment over XEROX 400 Telecopier. The following data were determined:

St. John River Basin
(Areal Snowcover Percentages)

22 April 1975	100 Percent Snow Covered
1 May 1975	71 Percent Snow Covered
10 May 1975	35 Percent Snow Covered
14 May 1975	21 Percent Snow Covered
17 May 1975	15 Percent Snow Covered
25 May 1975	Snow Free

TABLE II

NUMBER OF SNOW COVER MEASUREMENTS
November 1, 1974 - June 30, 1975

River Basin	November	December	January	February	March	April	May	June	TOTALS
Red River of the North	2	1	2	0	4	2	Snow Free	Snow Free	11
Souris River	0	0	0	1	2	0	Snow Free	Snow Free	3
Willamette	0	4	3	2	6	4	6	2	27
Deschutes	0	4	2	2	2	3	6	3	22
John Day	0	3	2	5	7	3	6	3	29
Umatilla	0	2	3	5	3	2	3	0	18
Salmon	2	1	0	0	2	3	4	6	18
Clearwater	0	3	0	0	1	2	3	4	13
Weiser	1	2	0	1	4	3	7	5	23
Payette	1	3	0	1	4	3	7	7	26
Boise	1	2	1	1	4	3	7	8	27
American	4	6	11	8	6	8	12	10	65
Lower Genesee	2	0	1	2	2	3	Snow Free	Snow Free	10
Upper Genesee	2	0	0	0	2	4	Snow Free	Snow Free	8
Chemung	2	0	0	2	2	4	Snow Free	Snow Free	10
Salt	3	4	8	9	6	9	4		43
Verde	3	5	8	10	8	6	Snow Free	Snow Free	40
San Juan	6	7	5	10	4	8	5	3	48
TOTALS	29	47	46	59	69	70	70	51	441

Midwest

As in the Northeast, the paucity of data for the Souris, Red River of the North and Winnipeg basins was largely due to inclement weather and long periods of total snow cover. In fact, the Souris basin was 100 percent snow covered from the last week of December 1974 until the third week in February 1975. A substantial decrease in snow cover was then recorded for the Souris; from 89 percent on February 27 to 42 percent on March 18. However, heavy snow storms in late March completely blanketed the area again; the basin was observed as being 100 percent snow covered as late as April 10. Unfortunately, poor weather conditions prevented any opportunity of monitoring the subsequent melt from satellite imagery. By the time the Souris could next be seen, which was on April 21, the area was almost completely snow free. The drastic decrease in snow cover during this 10 day period was closely paralleled in the Red River of the North basin. Results for the four sub-basins of the Winnipeg River were particularly disappointing. Due to excess cloud cover and rapid melt, only one snow map could be made.

Southwest

Weather conditions in the Southwest were ideal for snow mapping. A large quantity of data for the Salt, Verde and San Juan rivers were worked up; a total of 131 snow maps for the three basins combined. Maximum (1975) areal snow cover for the Salt-Verde basins was observed on February 18 with a reading of 70 percent for the Salt basin and 57 percent for the Verde basin. The San Juan River basin was totally blanketed on several occasions during the winter but this was a temporary phenomenon owing to rapid melt at lower elevations in the basin. In one case, 19000 km^2 of snowcover were observed to melt off within 24 hours. Snow in the Verde River basin was almost totally gone by the end of April 1975 but remained in the headwater region of the Salt for another few weeks. Snow in the San Juan Mountains persisted into July 1975.

Sierra Nevadas-California

Generally clear California weather and the relatively small size of the drainage area being studied (5601 km^2) allowed for 65 measurements to be made of the American River basin during this past snow season. The snow pack in the Sierras built up very slowly between November 1974 and January 1975. However, heavy snow storms commencing early in February caused a steep increase in areal snow cover. The American River basin was determined to be 59 percent snow covered on February 11; the highest figure obtained for the basin in three seasons of monitoring by NESS (the previous high had been 49 percent). In fact, basin snow cover remained over 50 percent during much of March and April, reflecting a heavy snow year in the Sierras.

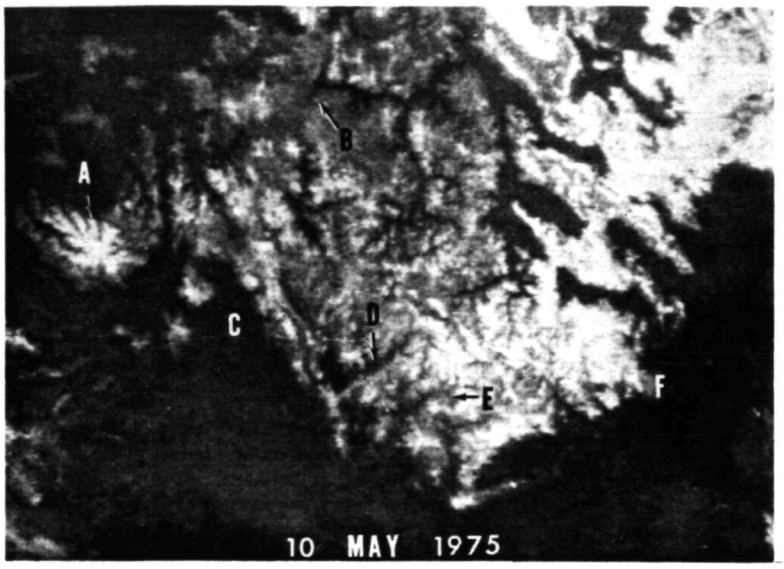

Figure 1a. VHRR image of Idaho on May 10, 1975. Wallowa Mts. are at (A), Salmon R. at (B), Weiser R. basin at (C), Payette R. (D), Boise R. at (E) and Craters of the Moon at (F).

Figure 1b. VHRR image of Idaho on May 5, 1974.

Pacific Northwest-Idaho

The Weiser, Payette, Boise, Salmon and Clearwater River basins were totally snow covered during much of the past winter. Snowmelt in these basins began later in March and ended in July. The 1974-1975 snow season was particularly heavy. Figures 1a and 1b clearly show more extensive snow cover in Idaho on May 10,1975 than there was on May 5, 1974. Areal snow cover percentages for these dates are given below:

	Weiser	Payette	Boise	Salmon
May 5, 1974	16%	49%	35%	50%
May 10, 1975	26%	73%	68%	82%

Pacific Northwest-Oregon

The number of snow cover measurements for the Willamette, Deschutes, John Day and the Umatilla basins (96) was surprisingly high considering the generally wet weather in Oregon. The maximum snow cover in the Willamette was 47 percent as determined on December 23, 1974 while the Deschutes, John Day and the Umatilla basins were observed as being totally snow covered for a short time in January 1975. Snow in these basins was mostly gone by the second week in June, with the exception of several glacial peaks in the Cascades.

Rapid winter snowmelt in the Oregon basins has been observed on VHRR imagery. Figures 2a and 2b show the Willamette, Deschutes and the John Day River basins on February 7 and February 10, 1974. The snow maps derived from these images are depicted in Figures 2c and 2d. The fog that is labeled on the VHRR image for February 10 is a common feature in the Willamette River valley and makes snow mapping in that basin difficult.

QUALITY CONTROL

Quality Control is an important part of the NESS snow mapping program. Snow maps derived from the VHRR imagery are compared to those produced from alternate satellite sensors (LANDSAT MSS and GOES VISSR) as well as to data obtained from aerial surveys and ground observations. Computer enhanced VHRR imagery have been useful in locating basin snow lines.

Ground Observations

Data from ground observations is regularly obtained for many of the study basins. The two satellite maps in Figure 3 depict snowcover conditions in the Red River of the North basin for April 9 and April 16, 1974. Note the decrease in snowcover during

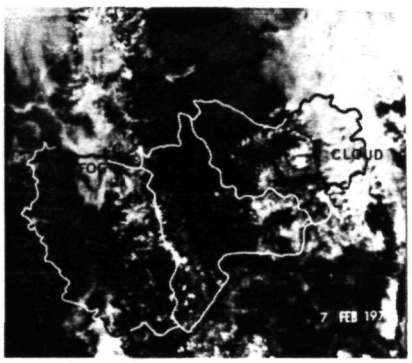

Figure 2a. VHRR image showing Oregon on February 7, 1974. Willamette River basin is on the left, Deschutes in the middle and John Day on the right.

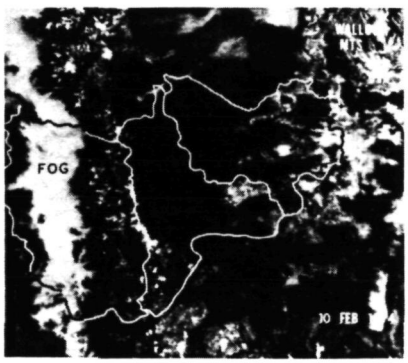

Figure 2b. VHRR image showing Oregon on February 10, 1974.

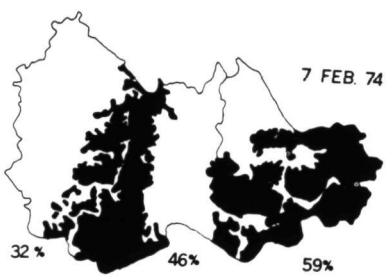

Figure 2c. Snow maps derived from the February 7th imagery (black areas are snow covered).

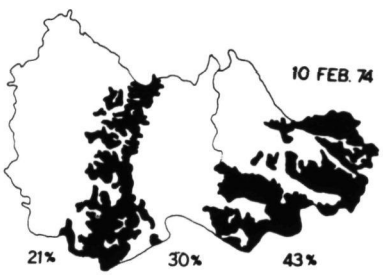

Figure 2d. Snow maps derived from the February 10th imagery.

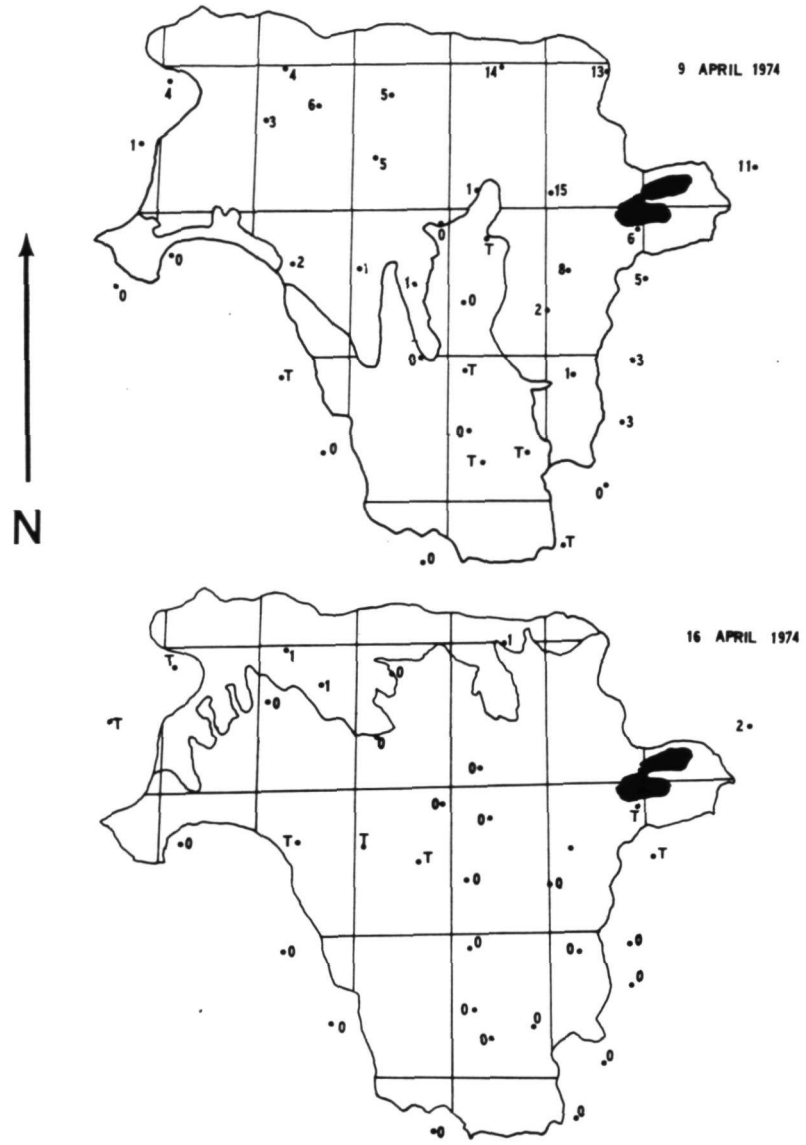

Figure 3. Snowcover maps for the Red River of the North above Emerson, Manitoba. The features in black are the Upper and Lower Red Lakes.

this one week period. The point measurements obtained from NOAA's Environmental Data Service (EDS) match well with the snow line location determined from the VHRR imagery.

Aerial Surveys

Satellite snow maps have been favorably compared with aerial survey data in the past (Barnes and Bowley, 1970; Barnes and Bowley, 1974). Aerial survey data for this past season have been provided to NESS by the Salt River project and the British Columbia Hydro and Power Authority. Figure 4 shows an aerial survey map of the Salt-Verde River basin together with a VHRR derived snow map. The two maps are in general agreement but there are differences as to location, extent and presence of several snow covered areas. These differences may have been caused by the 24 hour gap between data collection, the small scale of the VHRR imagery, snow on the northern slopes being obscured in the imagery by a low sun angle, the lack of reflectance of shallow "mottled" snow areas and finally, the differing judgements of aerial surveyor and satellite image interpreter.

LANDSAT and GOES

The additional spatial, temporal and spectral coverage provided by the sensor systems on board LANDSAT and GOES (Geostationary Operational Environmental Satellite) has been a boon to the NESS snow mapping program.

Highly detailed (80-meter ground resolution) can be obtained in four spectral bands from the Multispectral Scanner (MSS) on board the LANDSAT satellite. Owing to this high resolution, snow maps derived from the MSS-5 (0.6 - 0.7μm) data have been used at NESS as a "calibration standard" for those derived from VHRR data (Wiesnet and McGinnis, 1973).

Unfortunately, the LANDSAT imagery has certain limitations when used operationally. These limitations include the satellite's 18 day revisit period (reduced to nine days with the addition of LANDSAT-2) and the limited geographic area covered in a LANDSAT image frame. The latter makes snow mapping difficult in basins larger than 34,000 km^2 (Wiesnet and McGinnis, 1973). For such large basins frames from more than one satellite pass (taken one day apart) would have to be used together to assure complete geographic coverage. However, dynamic changes in weather conditions and areal snow cover can preclude the use of LANDSAT data in this manner.

Geostationary satellites occupy a position in space that is fixed relative to the ground. The NESS operates two such satellites, GOES-1 and GOES-2. They are currently stationed over the equator at 75^{0}W and 115^{0}W longitude respectively. Imaging capability is provided by the Visible and Infrared Spin Scan Radio-

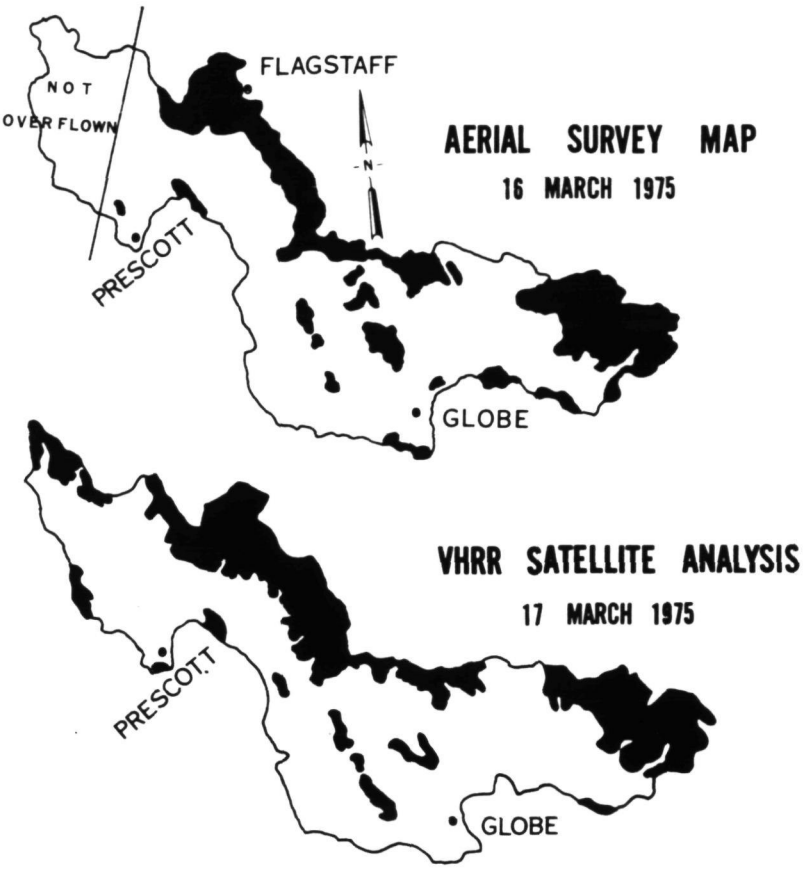

Figure 4. Comparison of Aerial Survey Map and VHRR Satellite Analysis for the Salt-Verde River basins. Areas in black are snow covered.

Figure 5a. VHRR image of the Sierra Nevadas.

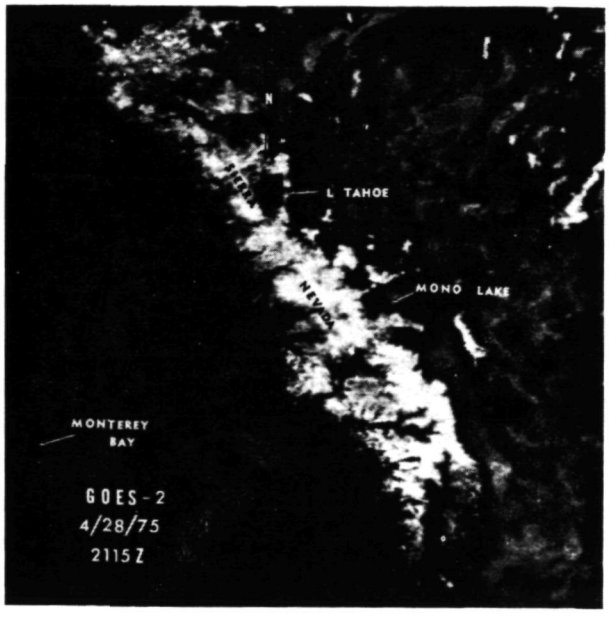

Figure 5b. VISSR image of the Sierra Nevadas.

meter (VISSR) which can sense in both the visible (0.55 - 0.75μm) and thermal infrared (10.5 to 12.6μm) portions of the spectrum. The imagery is available at several resolutions (Bristor, 1975), with the optimum resolution for the visible data being 1 kilometer. Coverage may be as frequent as every half hour.

Figures 5a and 5b depict the Sierra Nevada Mountains as viewed by NOAA-3 and GOES-2 on April 28, 1975. As can be seen, the fog in Monterey Bay has dissipated and there has been a build-up of cumulus clouds in the intervening 4 hours. The "squashed" appearance of features on the VISSR image is due to the oblique receiving angle afforded by GOES-2.

The usefulness of GOES data for snow mapping is currently being evaluated at NESS. Preliminary results show that snow maps of the American River basin (39^0N) prepared using VISSR imagery, differ from those derived from VHRR data by an average of 3.25 percent of basin snow cover (ten cases have been studied thus far). The Salmon River basin in Idaho will also be studied to determine the amount of degradation in VISSR imagery for basins in more northern latitudes.

Computer Enhancements

With the aid of computers, VHRR digital tape data can be enhanced to bring out desired ground features, (i.e. snow lines). However, the time involved in computer handling precludes the use of such data for real-time analysis.

FINAL COMMENTS

Several additional basins are scheduled to be added to the mapping program during the 1975 through 1976 snow season. A number of basins are also being consigned to the NESS/Synoptic Analysis Section where four teams of meteorologists, working on rotating shift, will be able to transmit areal snow cover data to users within 8 hours of a satellite pass, instead of the present 30.

Complete sets of snow maps for this past season are available for the basins listed in Table 1 from the NESS/Environmental Products Group (EPG). Members of the hydrologic community are invited to contact EPG to arrange for possible transmission of areal snow cover percentages and/or maps on a continuing basis.

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REFERENCES

Barnes, J. C., and Bowley, C. J., The Use of Environmental Satellite Data for Mapping Snow-Extent Decrease in the Western United States, Final Report, Contract No. E-252-69(N), Allied Associates, Inc., Concord, Mass., 1970, 105 pp.

Barnes, J. C., and Bowley C. J., Handbook of Techniques for Satellite Snow Mapping, ERT Document No. 0407-A Environmental Research and Technology, Inc., Concord, Mass., 1974, 95 pp.

Bristor, C. L., Central Processing and Analysis of Geostationary Satellite Data, NOAA Technical Memorandum NESS 64, U.S. Department of Commerce, Washington, D. C., March 1975, 155 pp.

Environmental Data Service, Climatological Data Minnesota, Climatological Data North Dakota, Vol. 80, No. 4 and Vol. 83 No.4, National Climatic Center, NOAA, U. S. Department of Commerce, Asheville, N. C., April, 1974.

National Weather Service, River Forecasts Provided by the National Weather Service, Vol. 1, U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Rockville, Md., 1972, 62 pp.

Schwalb, A., Modified Version of the Improved TIROS Operational Satellite (ITOS D-G) NOAA Technical Memorandum NESS 35, U. S. Department of Commerce, Washington, D. C., April 1972, 48 pp.

Wiesnet, D. R., The Role of Satellites in Snow and Ice Measurements, NOAA Technical Memorandum NESS 58, U. S. Department of Commerce, Washington, D. C., August 1974, 12 pp.

Wiesnet, D. R. and McGinnis, D. F., Snow-Extent Mapping and Lake Ice Studies using ERTS-1 MSS together with NOAA-2 VHRR, Third Earth Resources Technology Satellite-1 Symposium, December 10-14, 1973, Goddard Space Flight Center, Washington, D. C., pp. 995-1009

U. S. Department of the Interior, Geological Survey, Water Resources Review for June 1974, Water Resources Review, U. S. Geological Survey, Reston, Va., July 1974, 14 pp.