NOAA Technical Memorandum NESS 83

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

RIVER BASIN SNOW MAPPING AT THE NATIONAL ENVIRONMENTAL SATELLITE SERVICE

Washington, D.C.
November 1976

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NESS 58 The Role of Satellites in Snow and Ice Measurements. Donald R. Wiesnet, August 1974, 12 pp. (COM-74-11747/AS)

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RIVER BASIN SNOW MAPPING AT THE NATIONAL ENVIRONMENTAL SATELLITE SERVICE

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Elliot L. Richardson, Secretary

NATIONAL OCEANIC AND
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Robert M. White, Administrator

National Environmental
Satellite Service
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Stanley R. Schneider, Donald R. Wiesnet, and Michael C. McMillan
National Environmental Satellite Service, NOAA, Washington, D. C.

ABSTRACT. This report describes the development of the operational river basin snow mapping program at NESS. Satellite derived areal snow cover measurements are now being provided for over 20 river basins to Federal and State agencies around the United States. The snow maps are made, and results are disseminated within 24 hours of a satellite pass over a study basin. The satellite sensors used in snow mapping, the methodology, possible sources of error, and quality control techniques are also described in this report.

INTRODUCTION

Attempts to identify and quantify the amount and distribution of snow from satellite images have been underway since the first United States weather satellite TIROS-1 (Television InfraRed Observational Satellite) began to tape and transmit television images in 1960. This report, written 16 years later, does not attempt to chronicle all the early efforts to improve snow mapping. Instead, our purpose is to document briefly some of the early work and to concentrate on the current photo-interpretative techniques used in operational snow mapping of river basins and the steps that led to the adoption of the technique.

We fully anticipate that the photo-interpretative technique described herein will be modified, improved, and ultimately replaced--presumably by an automatic data-processing technique. For the moment, however, the NESS program is the only operational, river basin snow extent mapping program in the United States that can furnish usable data to the National Weather Service River Forecast Centers and to other interested local authorities within 24 hours of the satellite overpass.

The data on snow cover in selected river basins are used as input to river forecasting models. Some of the Federal, State, and local agencies in the program as of April 1976 are: National Weather Service, Soil Conservation Service, Bureau of Reclamation, United States Army Corps of Engineers, United States Geological Survey, and Salt River Project (Arizona).

THE VHRR SYSTEM

The primary sensor used to obtain data for the NESS snow mapping program is the Very High Resolution Radiometer (VHRR) on board the NOAA series of polar orbiting satellites. The VHRR is sensitive to two portions of the spectrum, a 0.6- to 0.7-μm (visible) and a 10.5- to 12.5-μm (thermal infrared) channel. Energy is gathered by an elliptical scan mirror (100.4 cm^2) rotating at 400 rpm. A Dall Kirkham optical system focuses the incoming radiation at a point behind the primary mirror. Visible energy is detected by a silicon photo diode detector; IR radiation is sensed by a mercury-cadmium-telluride detector. Bandpass filters in both channels define the spectral characteristics.

The VHRR achieves lateral coverage through continuous horizon-to-horizon scanning by a mirror oriented perpendicular to the forward motion of the spacecraft. Since the mirror rotates at a constant angular rate, the geometric resolution on the ground changes as the distance from the satellite subpoint increases. The resulting image produced from these signals will appear foreshortened in the area of the horizons. The instantaneous field of view is designed to be 0.6 milliradians for both channels; this provides a spatial resolution of approximately 0.9 km at the subpoint. Schwalb (1972) and Fortuna and Hambrick (1974) provide a detailed description of the satellite and its sensors.

Data are received through the High Resolution Picture Transmission (HRPT) system at three NESS receiving facilities: Wallops Island, Va.; Redwood City, Calif.; and Gilmore Creek, Alaska. The essentially raw, ungridded, unmapped image signals are displayed through a film recorder which produces a 25- by 25-cm film negative. Each negative covers an area approximately 2100 km square with 3 frames usually available per pass. Prints from the image negatives, at a normal scale of about 1:10,000,000, are used in the snow-mapping program.

DEVELOPMENT OF A SNOW MAPPING SYSTEM

Although Fritz (1962) was the first to speculate on the possibility of snow mapping from satellite data, Tarble (1963, P. 375) rather prophetically stated, ". . . satellites of the not too distant future will provide the coverage which can allow us to make a more definitive estimate of the areal coverage of the snow." Singer and Popham (1963) stated that the first and simplest application of spacecraft to snow hydrology would be to map the areal extent of the snow pack. Barnes and Bowley (1966), using TIROS photography, determined that these photos could be used to map snow boundaries in the relatively flat upper Mississippi and Missouri River basins in subbasins 400 square miles or larger in area.

According to Popham (1968), the first experiment designed to test operational applications of satellite imagery for snow surveillance purposes was conducted in April 1963. TIROS-V photographs of mountainous areas in Colorado and New Mexico were mailed to the United States Weather Bureau in Albuquerque, N.M., within hours after picture acquisition. J.C. Barnes and C. J. Bowley, under contracts let by NESS, produced several papers evaluating the sensors aboard the TIROS and ESSA satellites as potential tools for snow studies (Barnes and Bowley, 1966; 1968, 1969; 1970). Snow-extent mapping in several Sierra Nevada basins was shown to be feasible by comparing the satellite results with aircraft flight data.

The Environmental Sciences Group

In 1972 through 1973, the Environmental Sciences Group (ESG) of the Office of Research (NESS) began mapping the American River basin above Fair Oaks, Calif., and transmitted these snow areal extent measurements to the RFC at Sacramento (Wiesnet, 1973). Shortly thereafter, the Portland RFC requested snow mapping of the Willamette River basin in Oregon, the Kansas City RFC requested mapping of the Red River of the North, and the Hartford RFC requested snow maps of the Upper and Lower Genesee River in New York State. These basins are diverse hydrologically, climatologically, and topographically.

Measurements, expressed in terms of percent of basin covered by snow, were derived by using NOAA-2 VHRR imagery corrected by use of a Zoom Transfer Scope. The areas were then planimetered manually, and the figures were sent to the RFC's within 30 hours after the satellite pass.

The RFC personnel evaluated the data and generally were favorably impressed and so encouraged the collection of satellite snow mapping by river basin. As interest grew, and as requests for additional basins mounted, the project was judged suitable for development and was transferred to the Environmental Products Group (EPG) of the NESS Office of Operations.

The Environmental Products Group

In January 1974, a number of river basins were assigned to the Environmental Products Group (EPG) for quasioperational snow extent mapping and development. This project was consistent with the EPG mission to assume, modify, and perform newly demonstrated techniques to provide an operational satellite-derived product. The EPG has since demonstrated that reliable measurements of snow extent in 20 selected river basins can be obtained and transmitted to users within 24 hours of a satellite pass.

The primary users of these snow data are the National Weather Service's River Forecast Centers (RFC). Eleven RFCs provide river forecast and flood warnings for most of the contiguous United States (fig. 1). Each RFC is served by one or more River District Offices (RDO). It is the responsibility of the RDO to maintain the hydrologic network and collect data for the RFC. The RDO also disseminates to the public river forecasts and warnings provided by the RFC.

Areal snow percentages determined by EPG are being provided to six RFCs (and the Phoenix RDO) for use as input parameters to computer run-off models. River basins have generally been added to the satellite snow analysis program upon request of the NWS Office of Hydrology. Table 1 contains a list of river basins currently being snow mapped by the EPG. In addition to these, a number of basins located in remote, densely forested areas are being mapped in a joint effort with the Canadian Government as part of the World Meteorological Organization World Weather Watch and WMO Snow Studies by Satellite program. These include four subbasins of the Winnipeg River, the St. John River basin, and several tributaries of the Upper Columbia River.

Approximately 440 basin snow cover measurements were determined during the 1974-75 snow season. Basins are generally mapped whenever cloud-free. Owing to favorable weather conditions, the greatest amount of data are obtained for the Salt, Verde, and San Juan basins in the southeastern United States and the American River basin in California (table 1). Adverse weather conditions combined with brevity of snow melt season reduces the number of opportunities available for mapping basins in the Northeast and the Midwest.

As previously stated, areal snow percentages are teletyped to the user within 24 hours of a satellite pass over a subject area. Telecopiers can be used to transmit snow maps as well as areal percentages within this same time frame. The EPG and the New Brunswick Department of Environment used such telecopiers to exchange snow data for the St. John River basin in near real-time during the 1975 and 1976 melt season.

The use of an electronic planimeter has reduced the number of man-hours required in determining basin snow cover and has also enabled the EPG to augment the number of basins being mapped on an operational basis from five basins during the 1974 melt season to 20 for 1975, and finally to 26 for 1976. As many as 16 basins have been mapped by the EPG in one day, at a rate of less than 1/2 hour per basin.

Synoptic Analysis Section

The Environmental Products Group staff works a standard five-day week. Consequently, snow measurements derived from weekend imagery are transmitted late. This problem will be eliminated through the transfer of river basin snow mapping duties to the NESS Synoptic Analysis Section (SAS) for real-time analysis. Four teams of meteorologists, working on rotating shifts, will be available for snow mapping around the clock. Snow cover data will be routinely transmitted over teletype within 12 hours of a satellite pass.

SAS meteorologists began monitoring the American River basin snow pack during the 1975 snow melt season. Approximately 50 snow cover measurements were determined between January 11 and June 30, 1975. Basins tentatively scheduled for such real-time analysis in the future include the Salt, Verde, and San Juan in southwestern United States and several tributaries of the Snake River in Idaho. These areas have snow during much of the year, and cloud conditions usually allow at least one snow measurement per week.

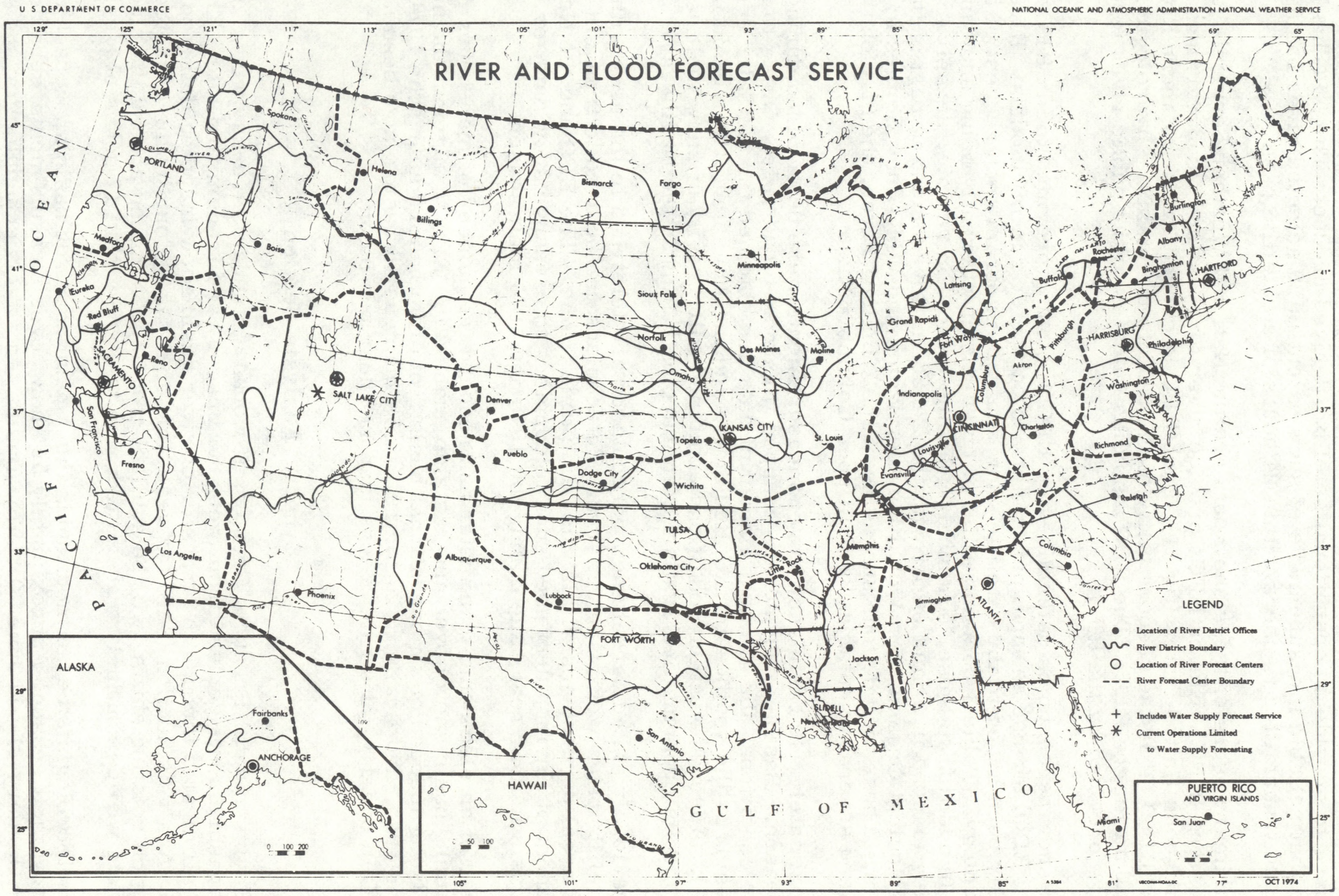

Figure 1.--Map of the United States showing areas covered by the National Weather Service River and the Flood Forecast Network. The dashed lines are the River Forecast Center Boundaries, and the solid lines are River District Boundaries.

Table 1. --Basins for operational snow mapping.

River basin	Number of snowcover determinations (74-75)	Drainage area in KM	RFC
Red River of the North (above Emerson, Manitoba)	11	104,120	Kansas City
Souris River (above Westhope, N. Dak)	3	43,771	Kansa City
Willamette, Ore.	27	26,159	Portland
Deschutes, Ore.	22	27,195	Portland
John Day, Ore.	29	19,632	Portland
Umatilla, Ore.	18	5,931	Portland
Salmon (above Whitebird, Ida.)	18	35,095	Portland
Clearwater (above Peck, Ida.)	13	20,824	Portland
Weiser, Ida.	23	3,781	Portland
Payette (above Emmett, Ida.)	26	6,941	Portland
Boise (above Lucky Peak, Ida.)	27	6,941	Portland
American (above Folsom, Calif.)	65	5,601	Sacramento
Genesee (above Portageville, N.Y.)	10	2,541	Hartford
Genesee (below Portageville, N.Y.)	8	3,812	Hartford
Chemung (N.Y.-Pa.)	10	6,721	Harrisburg
Salt, Ariz.	43	16,141	Salt Lake City
Verde, Ariz.	40	17,094	Salt Lake City
San Juan (Colo.-Utah-Ariz.-N.M.)	48	65,273	Salt Lake City

Some basins are not amenable to real-time analysis by the SAS either because of excess cloudiness (Oregon and Great Lakes region) or brevity of snow melt season (flat basins in the Midwest and the Northeast). The Environmental Products Group will continue to map these areas for the time being.

METHODOLOGY

Imagery

VHRR visible-band imagery is first examined for cloud cover. A complete snow map can be made only if the river basin is free of obstructing clouds. The VHRR thermal-infrared imagery can be used to distinguish snow from cloud cover, especially when there is a significant difference between atmospheric and surface temperatures. An experienced analyst can also discern rivers, lakes, and forests in a snow landscape. Such ground detail may be either partly or totally hidden by clouds.

A certain amount of panoramic distortion is present in VHRR imagery. Optical rectification is possible by use of a Zoom Transfer Scope. The distortion, however, becomes acute close to the edges of the imagery, and a snow cover analysis should not be attempted if the river basin is located outside the synchronization ("sync") lines of the image.

Maps

The VHRR image is used with a basin map of the drainage area. Basin maps are available from the United States Geological Survey as well as from some State water resource agencies. Elevation contours should be indicated to assist in mapping. This is especially important in mountainous basins where snow tends to conform to a certain elevation. In fact, some hydrological models in mountainous terrain use "snowline elevation" as an input parameter.

To make an accurate snow cover analysis, the entire river basin map should fit under the Zoom Transfer Scope field of view and on the Color Densitometer Screen. The scale of maps used, therefore, varies inversely with the basin size. For instance, the Environmental Products Group uses a 1:500,000 map for the American River basin (5000 km^2) and a smaller scale map, approximately 1:3,000,000, for the Red River of the North basin (100,000 km^2).

Image-Map Alignment

The distorted, 1:10,000,000-scale VHRR frame must be enlarged and "stretched" to fit over the larger scale basin map before a snow analysis can be done. This can be accomplished by optical means through use of the Zoom Transfer Scope (ZTS). The procedure is as follows:

1. The VHRR image is mounted on the ZTS and the basin map placed on the desk below (fig. 2).

2. The operator manipulates both image magnification and stretch controls to obtain an alignment. The image can be magnified up to 14 times and stretched linearly in any direction up to 2 times. The magnification is a constant for each basin, since the scales of image and map are fixed. The amount of stretch applied depends on proximity of the subject area to the synchronization lines.

3. Physiographic landmarks are overlaid on the image and basin map. Lakes, reservoirs, rivers, and shorelines are useful features for this purpose. In mountainous areas, basin boundaries are usually located on ridge lines. Rivers on the drainage map must be aligned with their respective valleys on the VHRR image.

Drawing the Snow Line

After the image has been aligned, the base map is taped down with tracing paper over it. The analyst traces the basin boundary and then draws in the snow line.

Several problems confront the analyst:

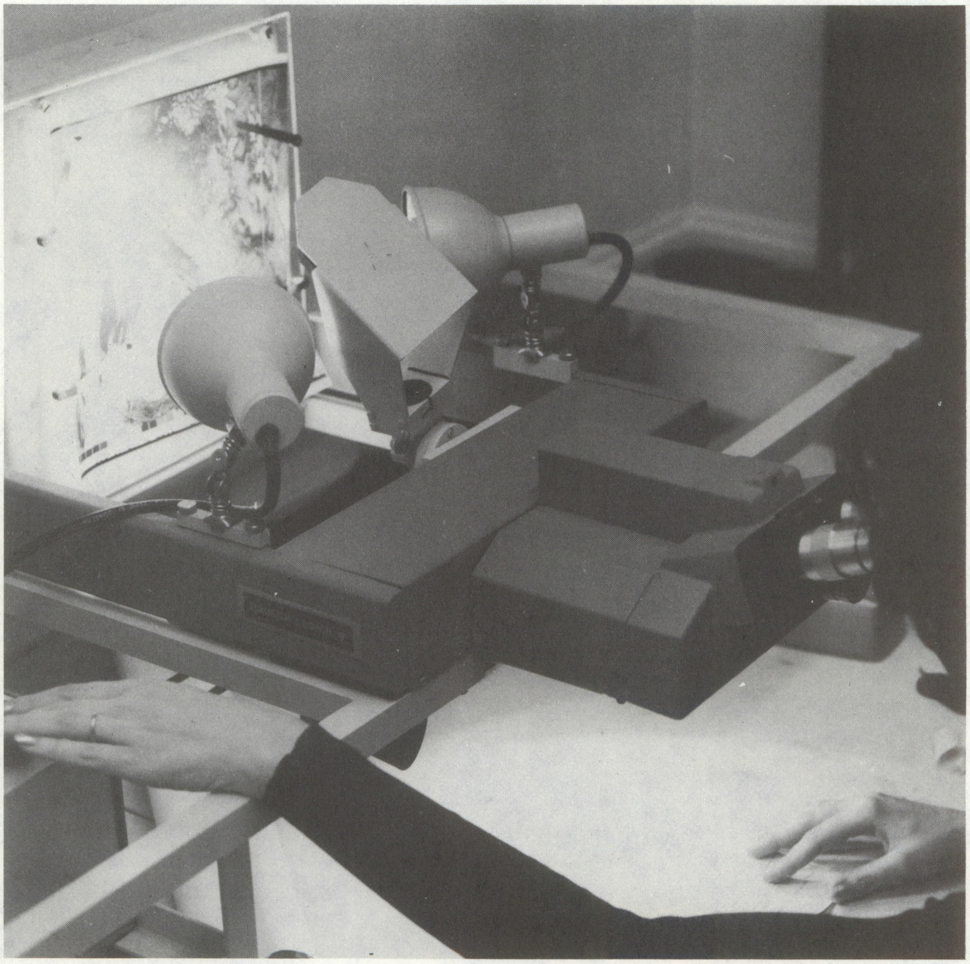

Figure 2.--The Zoom Transfer Scope in operation. The satellite image on the easel is being registered to the basin map on the desk.

1. It is difficult to detect snow in heavily wooded regions, a fact which complicates snow mapping in New England and much of Canada.

2. In the western United States, the line to be drawn usually must separate forest with snow from forest without snow. This snow line is often hard to discern.

3. In the latter part of the melt season, the snow may retreat above the timber line; such snow is hard to distinguish from bare rock which may have a similar high reflectance, e.g., the light-colored granodiorities of the Sierra Nevada.

4. It is difficult to distinguish between a steep walled valley that is snow-free and one that is snow covered but cloaked in shadows caused by the sun angle.

These problems diminish as the analyst gains experience and develops a "feel" for the basin.

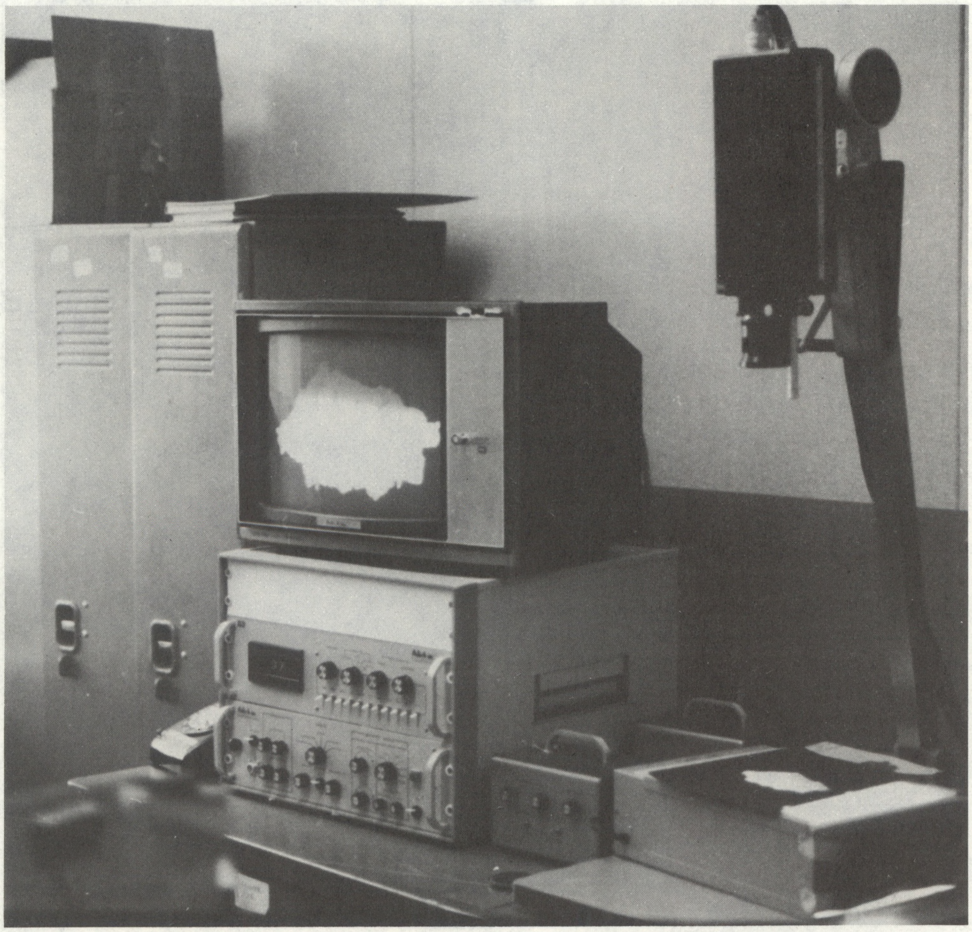

Figure 3.--A color densitometer in use. The silhouette appearing on the screen is that of the Willamette River basin. The densitometer is used to electronically measure the percentage of snow cover for the basin.

Measurement of Areal Extent

Percentage snow cover for the basin can be calculated after the snow line has been drawn. This calculation can be done with either a manual or an electronic planimeter.

Manual Planimeter

A compensating polar planimeter can be used to measure plane areas of any shape. By measuring the part of the basin covered with snow and then dividing by the total area of the basin, the percentage of snow cover can be determined. This method works best in areas where there is one continuous snow line. In drainage basins dominated by volcanic mountains, each "patch" of snow has to be separately measured and then combined to obtain total snow cover. This compounds the operator error inherent in the process.

Electronic Planimeter

An electronic densitometer/planimeter can also be used to measure percentage of snow cover. Figure 3 shows an electronic planimeter in use. The densitometer is used to selectively color-illuminate gray shades in the image. The colors are projected spatially on a display screen; the percentage values are represented on a digital meter. The procedure used is as follows:

1. Areas within the snow line are shaded with a felt tip marker.

2. The snow map is placed on the densitometer with a previously prepared opaque mask outlining the basin. The sensitivity (density) control is manipulated until only three discrete colors appear on the screen, one for the mask, and the others for the basin. The two colors assigned to the basin represent the shaded (snow) areas and the unshaded (bare) areas.

3. The two basin colors are calibrated to 100.00 (percent) on the digital meter by using a planimeter control. The percentage of snow cover can then be directly determined by subtracting an individual color. Although use of the densitometer speeds up the determination of areal extent, especially when several basins must be measured quickly, there are certain drawbacks. These include the added step of shading the snow area and the necessity of having pre-cut basin masks. The relatively high cost of the densitometer compared with that of the manual planimeter must also be taken into account.

SOURCES OF ERROR

The major source of error in the NESS method of snow mapping is in the photointerpretation of what is and what is not snow on the satellite imagery. Minor errors, such as the standard error present when doing any kind of measurement, are not discussed. Errors due to misinterpretation of the imagery can arise from a variety of sources. They fall into two main categories: Misinterpretation because of ground features, and misinterpretation because of satellite or film features.

Ground Features

Several features on the ground, when scanned by the satellite, may hinder correct interpretation of snow line location in the resulting imagery. Variations in solar illumination of the snowpack can be caused by basin topography and solar elevation. Solar radiation is not transmitted vertically to most snowpack surfaces in mountainous areas. The snowpack slope and aspect may either decrease or increase the amount of incident radiation, affecting the radiance level available to the satellite scanner. Variations in topography also may produce shadows on the snow surface, which can cause misinterpretation especially in steep, mountainous terrain. This problem is accentuated in VHRR imagery since nominal scanning time is 9:30 in the morning local time, at which time there is a low sun angle.

Heavy vegetative cover, such as coniferous forests, can also significantly alter the amount of reflected solar radiation reaching a spacecraft from snowfields. The VHRR integrates over an area of about 1 km^2, an area often containing considerable forest cover. This cover masks the snowpack directly through its mass and indirectly through its shadows. Although snow can be detected in clearings, the presence of forest cover can lead to errors in snow line determination.

Satellite and Film Features

VHRR data are displayed in a unique cartographic projection. The viewing geometry causes a decrease in resolution as the scanner moves from nadir. Both effects tend to decrease the positional accuracy of image registration. This, in turn, can lead to errors in determining snow line position.

Determination of snow on satellite imagery depends on the selection of photographic gray shades for corresponding satellite detected radiance levels. Various look-up tables are employed in the imagery display. Some of these tables may enhance the snow line, others may obliterate it.

QUALITY CONTROL

Quality control is an integral part of the snow mapping program at NESS. Snow maps derived from VHRR imagery are compared with those produced from alternate satellite sensors and to data obtained from aerial surveys and ground observations. Basins may be remeasured using digitally enhanced VHRR imagery to check the veracity of the original results.

Comparison to Ground Observations

VHRR snow maps are compared to ground measurements whenever such data are available. Snow surveys are performed in many regions by agencies of Federal and State governments. Climatological data are published monthly for each State by NOAA's Environmental Data Service (EDS).

The two satellite snow maps in figure 4 show snow cover conditions in the Red River of the North basin for April 9 and April 16, 1975. Note the change in snow cover that took place in just one week. The point measurements obtained from the Environmental Data Service verify the snow line locations determined from the VHRR imagery.

Comparison with Aerial Surveys

Satellite snow maps compare favorably with those produced by areal survey (Barnes and Bowley 1970, 1974). The Environmental Products Group (EPG) has been provided aerial survey data for the Salt-Verde basin and for several basins in Canada (Upper Columbia and St. John) by the Salt River Project and Environment Canada, respectively. To some extent, aerial surveys are plagued by the same variables that affect satellite imagery analysis--i.e., judgment and skill of the image interpreter.

In general, aerial surveys can be used to delineate small snow patches that are not discernible on the VHRR imagery (fig. 5). This is a result of the small scale of the satellite imagery, the shadow effect on northern slopes, the lack of reflectance in a shallow, "mottled" snow area, or a combination of all three factors.

Comparison of Satellite Data

Snow analysis has also been done using data from sensor systems on both Landsat (formerly ERTS) and Geostationary Operational Environmental Satellite (GOES, formerly SMS). The additional spatial, temporal, and spectral coverage provided by these satellites has been of great use in the operational snow mapping program at NESS.

Highly detailed imagery (80-meter ground resolution) can be obtained in four spectral bands from the Multispectral Scanner (MSS) on board the Landsat. Snow maps of the American River basin made using both VHRR visible and MSS-5 (0.6 to 0.7μm) data from Landsat have been shown to compare favorably by NESS investigators (Wiesnet and McGinnis 1973).

Unfortunately, the Landsat imagery has limited value in an operational program. This is because of the satellite's once-in-18-days coverage (now reduced to 9 days with the addition of Landsat-2) as contrasted with the daily coverage provided by NOAA-4. Furthermore, the limited geographic area covered in a Landsat image frame 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 coverage. Using the data in this way complicates a snow analysis, especially when there is a dynamic change in weather conditions or areal snow cover in the intervening 24-hour period.

Geostationary satellites have proved to be an effective platform for viewing the Earth's surface. This type of satellite occupies a position in space that is fixed relative to the ground. The NESS currently monitors two such satellites: GOES-1 and SMS-2. They are currently stationed over the equator at 75°W and 135°W, respectively. Imaging capability is provided by the Visible and Infrared Spin Scan Radiometer (VISSR), which can sense in both the visible (0.55 to 0.75μm) and the thermal infrared (10.5 to 12.5μm) portions of the spectrum. VISSR visible imagery resolution is roughly equivalent to that of VHRR,

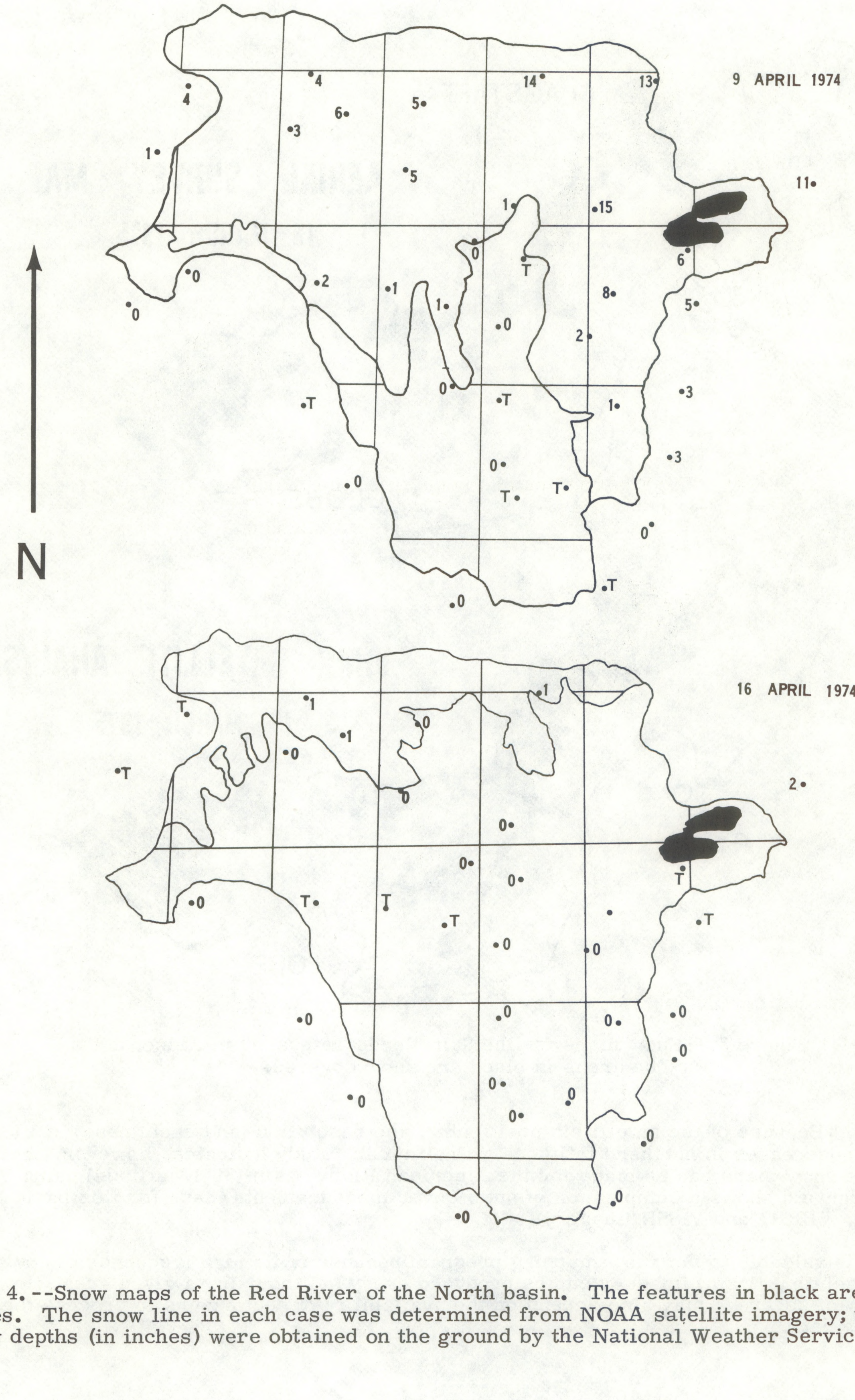

Figure 4. --Snow maps of the Red River of the North basin. The features in black are the Red Lakes. The snow line in each case was determined from NOAA satellite imagery; the point snow depths (in inches) were obtained on the ground by the National Weather Service.

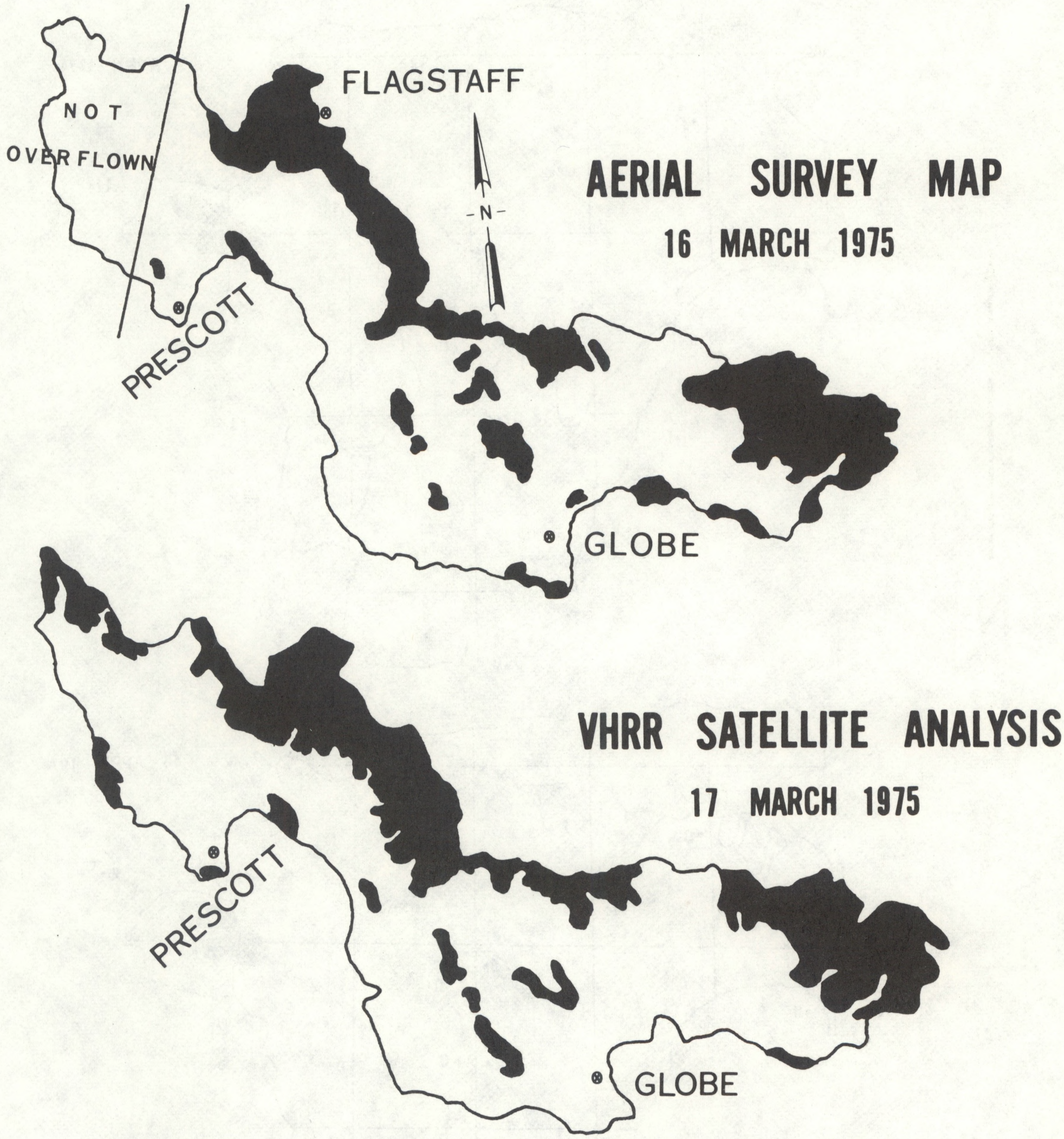

Figure 5.--Snow maps for the Salt-Verde watershed in Arizona. The areas in black are snow covered.

or 1 km. Because of the satellite's positioning, the resolution (and usefulness) of VISSR imagery decreases in northern latitudes. Preliminary study indicates, however, that accurate snow maps can be made for the American River basin (39°N latitude) using VISSR data. Figure 6 shows a comparison of snow cover measurements made for this basin from Landsat, VHRR, and VISSR imagery.

GOES is valuable to the snow mapping program because of its high frequency of coverage. High resolution (1 km) imagery can be produced every half hour for a given area. However, intensity of coverage may also depend on the availability of sectorizers to process the incoming data.

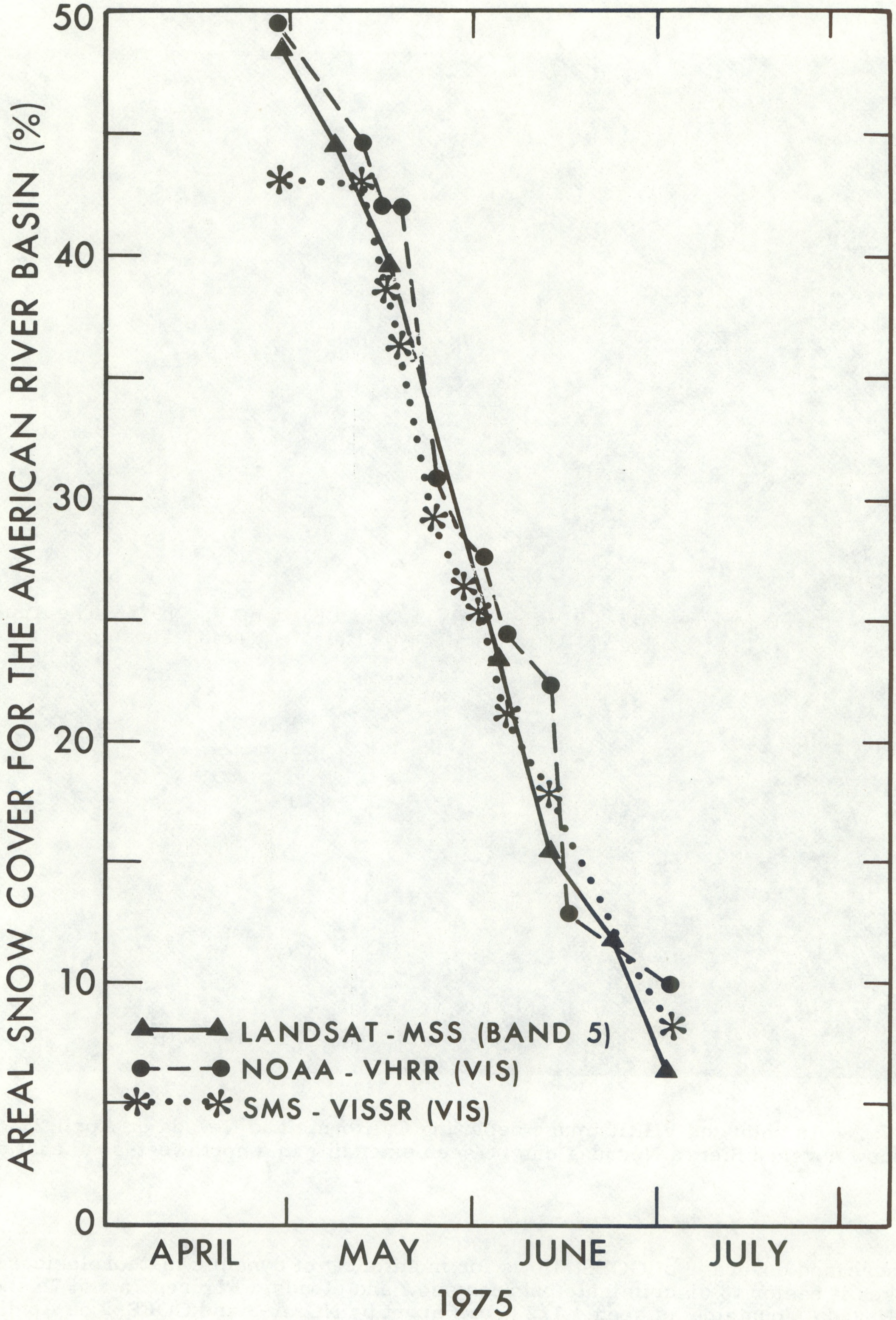

Figure 6. --Comparison of Landsat, VHRR, and VISSR derived snow cover measurements for the American River basin in California. Results are generally close for all three sensors.

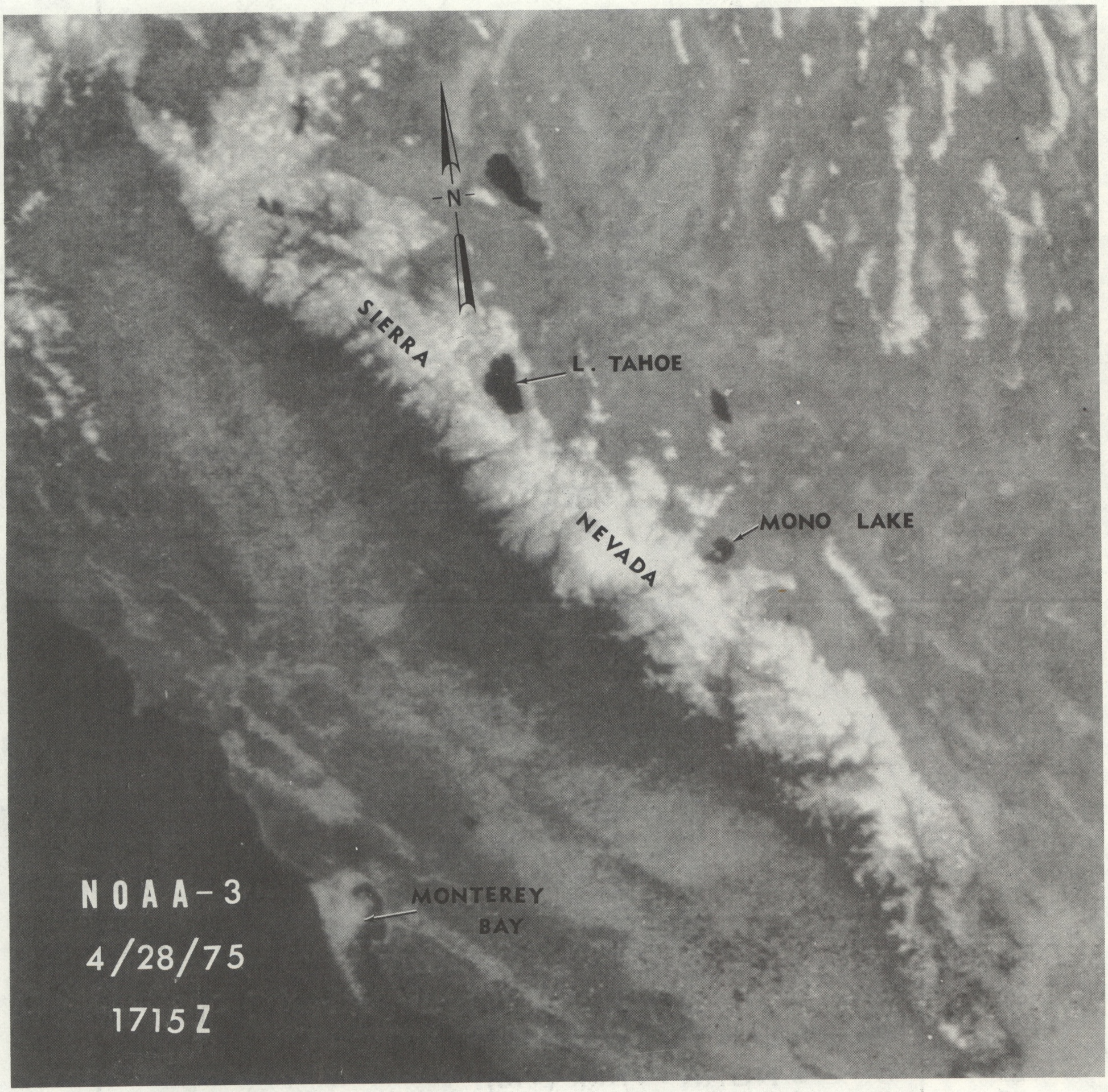

Figure 7a. --An enlarged VHRR image depicting California and Nevada on April 28, 1975. The snow covered Sierra Nevadas can be seen extending in a northwest-southeast direction.

The increased coverage of GOES allows for monitoring of dynamic meteorological events and makes it easier to discriminate between snow and clouds. Figures 7a and 7b show the Sierra Nevada Mountains as seen 4 1/2 hours apart by NOAA-3 and GOES-2 on April 28, 1975. In the later image, the fog in Monterey Bay has burned off, and there has been a buildup of cumulus clouds along the western slopes of the Sierras. Note that the features on the VISSR image appear to be compressed in relation to those on the VHRR image. This distortion is caused by the oblique viewing angle of GOES-2. The image can be rectified by using the Zoom Transfer Scope to "stretch" the VISSR image optically along an axis in the direction of the basin from the subpoint--in this case, north-south.

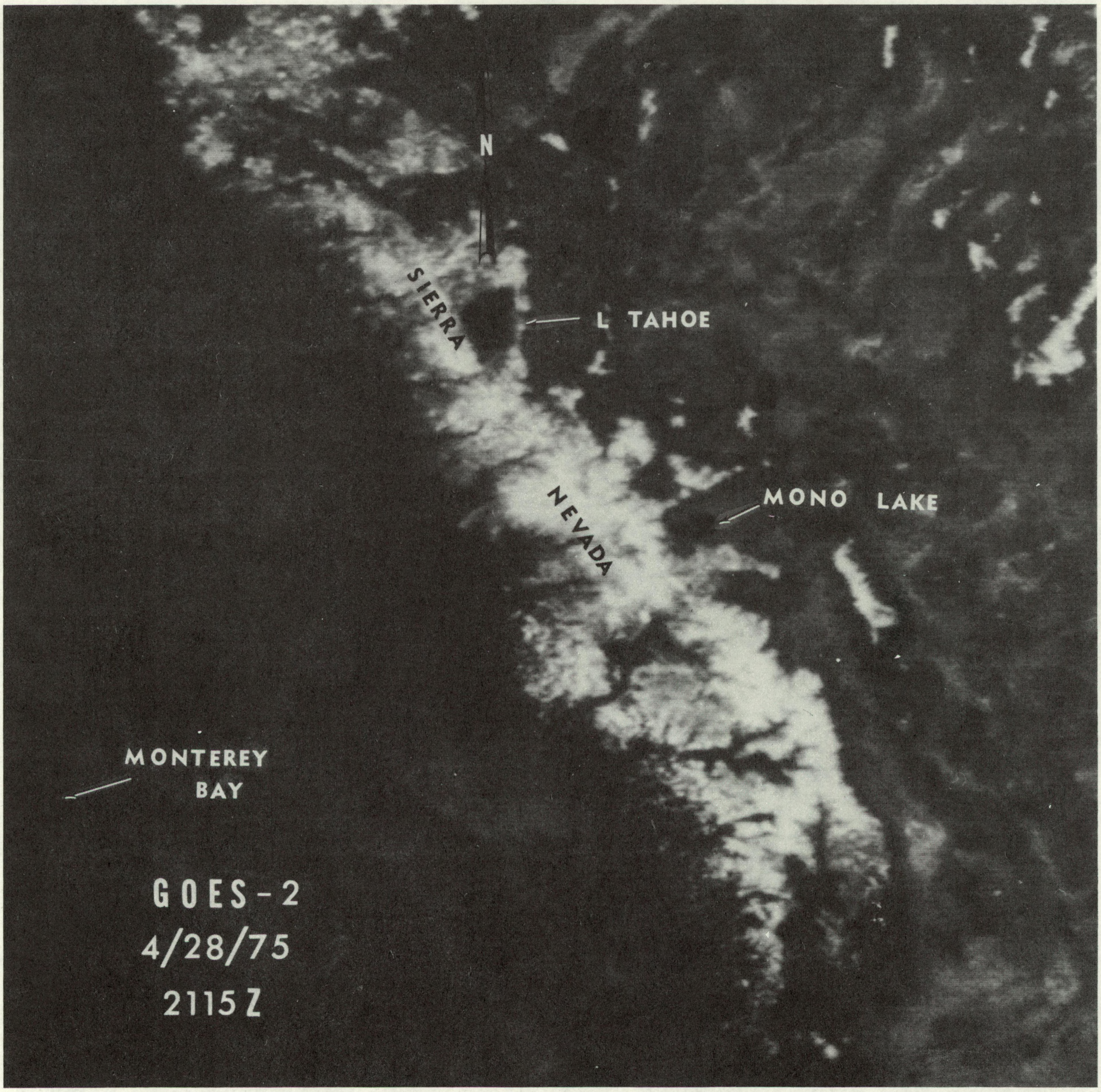

Figure 7b. --A VISSR image depicting the Sierra Nevadas four hours after the VHRR picture was taken.

Comparison with Computer Enhancements

With the aid of computers, VHRR tape data can be redisplayed to show certain desired ground features in more detail. Figure 8a is an enlargement of an operational image received and transmitted over landline by the National Environmental Satellite Service (NESS) Command and Data Acquisition (CDA) Center in Wallops Island, Virginia. Figure 8b was produced directly from the VHRR digital tape data using a specially designed table of gray shades shifted towards the black end of the scale. The geographic area shown in both images is the Northeastern United States as it appeared on April 14, 1975. The enhanced

Figure 8a. --The Northeast United States as viewed by NOAA satellite on April 14, 1975. This picture is an enlargement of an operationally acquired VHRR image.

image (fig. 8b) is preferable for depicting frozen lakes within the snow covered areas. However, enhancement of the snow covered area in this case also resulted in a degraded appearance for land-sea boundary. This decrease in contrast makes it difficult to discern the banks of Lake Ontario and the New England coastline in figure 8b. Other look-up tables of gray shades can be used to enhance the snow line, to make it easier to discern snow cover in wooded terrain, and to increase the clarity and sharpness of the VHRR data.

Figure 8b. --This picture shows how the data depicted in figure 8a can be redisplayed with an alternate look-up table to enhance certain ground features within the snow covered area.

APPLICATIONS

Knowledge of new techniques or scientific discoveries has seldom led to a rapid adoption of those techniques or discoveries. The time between discovery and widespread application is usually measurable in decades. Satellite snow mapping is a new and wholly different way of measuring snow distribution. Fortunately, in the National Environmental Satellite Service, a new group--the Environmental Products Group--was formed at about the time the snow mapping research was nearing fruition in the Environmental Sciences Group. This circumstance speeded the transition from research to operational status. The NWS RFC at Portland, under Vail Schermerhorn, was helpful, enthusiastic, and cooperative during both the research and the quasioperational phases of snow mapping.

The key element in the application of snow mapping to hydrological forecasting was the decision to map snow distribution basin by basin. This decision made the data applicable to modeling. The SSARR, Sacramento, and the modified Stanford models can use percent-of-basin snow covered as model input data either directly or indirectly.

Basin snow cover mapping has also proved useful in studying snowmelt runoff relations (Rango and Solomonson 1976). It can complement or supplement aircraft observations (Schuman 1975). It aids in runoff forecasting and watershed management in Arizona (Warskow et al. 1975). Brown (1975) pointed out the usefulness of satellite snow mapping to update water-supply forecasts as the melt season progresses in California. In fact, Breaker and McMillan (1975, p. 195) maintain that daily snow melt rate may be computed from SMS data, and that a daily record of cloud-seeding effects can also be obtained from the SMS data.

Perhaps the most important application of basin snow-cover mapping will be the buildup of data sets of climatic significance. Reliable snow cover data have never before been available to the climatologists and hydrologists. The statistical analysis of such data sets should be a powerful new tool that can be applied to river forecasting in local basins as well as to continental climatic studies (Wiesnet and Matson 1975).

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