NEW DEVELOPMENTS IN SNOW MAPPING BY SATELLITES

by

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ABSTRACT

In 1973, four new satellites, ERTS-1, NOAA-2, NOAA-3, Nimbus 5 furnished snow data to research hydrologist in unprecendented amounts. ERTS-1 was used to map snow in basins as small as 272 km^2. NOAA-2 Very High Resolution Radiometer (VHRR) data was used to map mesoscale flatland and mountain basins.

Accurate snowline mapping was also accomplished. The VHRR ground resolution is one kilometer, approximately 4 times better than that of visible band images on the previous NOAA satellites and 10 times better than infrared band images on previous satellites. NOAA-2 and NOAA-3 provide daily visible and IR data; ERTS-1 provides coverage once every 18 days but has near 100-meter ground resolution. Nimbus 5 has furnished microwave images of the Arctic and Antarctic through cloud cover.

INTRODUCTION

The year 1973 might well be called the "year of the hydrological satellite", because during that year the data collected by vastly improved satellite sensors aboard new satellites began to be applied to hydrological problems not only in research but also in limited operational tasks. The purpose of this paper is to document and demonstrate the high quality of the data currently available to anyone who desires it and to show the results of recent research and quasioperational snow mapping attempts.

Although not the first to speculate on the possibility of snow mapping from satellite data (cf. Fritz, 1963), Tarble, 1963, flatly predicted (p. 375) that, ". . . 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".

While an exhaustive literature review is not intended in this brief paper, the satellite snow studies of Barnes and Bowley 1968, 1968a, 1969, and 1972, represent some of the fundamental work done in this field. A few other papers that deal with some aspect of satellite snow studies include Ferguson, et al. 1969; Itten, 1970; McClain and Baker, 1967; Popham, 1968; Salomonson, 1971; Strong et al., 1971; Wiesnet, 1973; Wiesnet and McGinnis, 1973; Meier, 1973, 1973a. Many other fine papers are excluded simply because of space limitations.

For a more comprehensive (but pre-ERTS) overview of snow survey methods from earth satellites, McClain, 1973, is an excellent source with extensive international references. McClain points out that seven countries--Austria, Canada, Japan, New Zealand, Switzerland, the U.S.A., and the U. S. S. R.-have reported on satellite snow mapping in mountainous areas.

It is important for the members of the Eastern Snow Conference to know the currently active satellites, their sensors useful for gathering snow data and their limitations as well. Table 1 presents the NOAA-2 and -3 sensor specifications as well as the specifications for the Multispectral Scanner (MSS) aboard the ERTS-1 spacecraft.

Table 1.--Satellite Orbital Parameters

Parameters	NOAA-2 *	NOAA-3 **	ERTS-1 ***
Altitude (above Earth surface).................	1464 to 1510 km	1500 to 1509 km	908 to 929 km
Inclination................	101.7°	102.0°	99.1°
Nodal Period...............	115.14 min	116.19 min	103.28 min
Precession of Nodes........	0.9857° per day	0.9911° per day	1.43° per day
Equatorial crossing time (southbound)........	0851 local solar time	0830 local solar time	0942 local solar time
Coverage cycle duration....	12 hr for IR, 24 hr for VIS	12 hr for IR, 24 hr for VIS	18 days

* From Schwalb (1972)
** From A Butera, NESS personal communication
*** From General Electric (1972)

As can be seen from Table 1, the ERTS-1 MSS provides superb spatial resolution (80m) but it returns to view the same 185x185 km^2 area only once every 18 days. The NOAA-2 and -3 satellites have a 12-hour return for North America in the IR and a 24 hour cycle in the visible band with the Very High Resolution Radiometer (VHRR) sensor, but only a 900m spatial resolution.

SNOWLINE AND SNOWCOVER MAPPING

Figure 1 is a composite satellite (ESSA-9) view of the northeastern United States and southeastern part of Canada. It clearly shows the snow covered areas of the region. This image was prepared by having the computer examine five days of data (3/6/70) to (3/10/70)and select the minimum brightness value for each pixel. The resulting image is called a 5-day minimum composite brightness chart (McClain and Baker, 1967). In effect the method acts as a "cloud filter", and the resulting image portrays the brightness of the land surface not of cloud cover. Areas of persistent cloud cover, however, can and do occasionally affect the 5-day CBM's. A snowline map of North America results from these charts.

Results generated from ERTS-1 imagery over Alaska and Washington State show that snowline altitudes can be estimated to the nearest 60 meters under favorable conditions and that the areal extent of snow cover can be obtained to within 1% of drainage basins area (Meier, 1973). Early results from one season show that the areal extent of snowcover can be empirically related to runoff with accuracies that appear useful for runoff forecasting. Analysis of ERTS-1 imagery over the Salt and Verde River watersheds of Arizona show that more detail can be derived from imagery than is normally obtained from routine aircraft surveys (Barnes and Bowley, 1973)

Beginning in the winter of 1972-73, ERTS-1 MSS and the NOAA-2 VHRR were used experimentally for detailed mapping of snow cover extent in several selected river basins. Snow thickness and water equivalent cannot as yet be determined from satellite data.

For ungaged and (or) inaccessible and remote watersheds, or as ancillary data for conventional in situ snowpack monitoring networks, the early results indicate that ERTS-1 data can be used profitably for better management of snowpack water resources.

Because of its twice-daily revisit cycle, NOAA-3 excells in monitoring snowline and snow extent changes within mesoscale and macroscale basins. ERTS-1, because of its superior ground resolution and cartographic fidelity can be used to greater advantage for

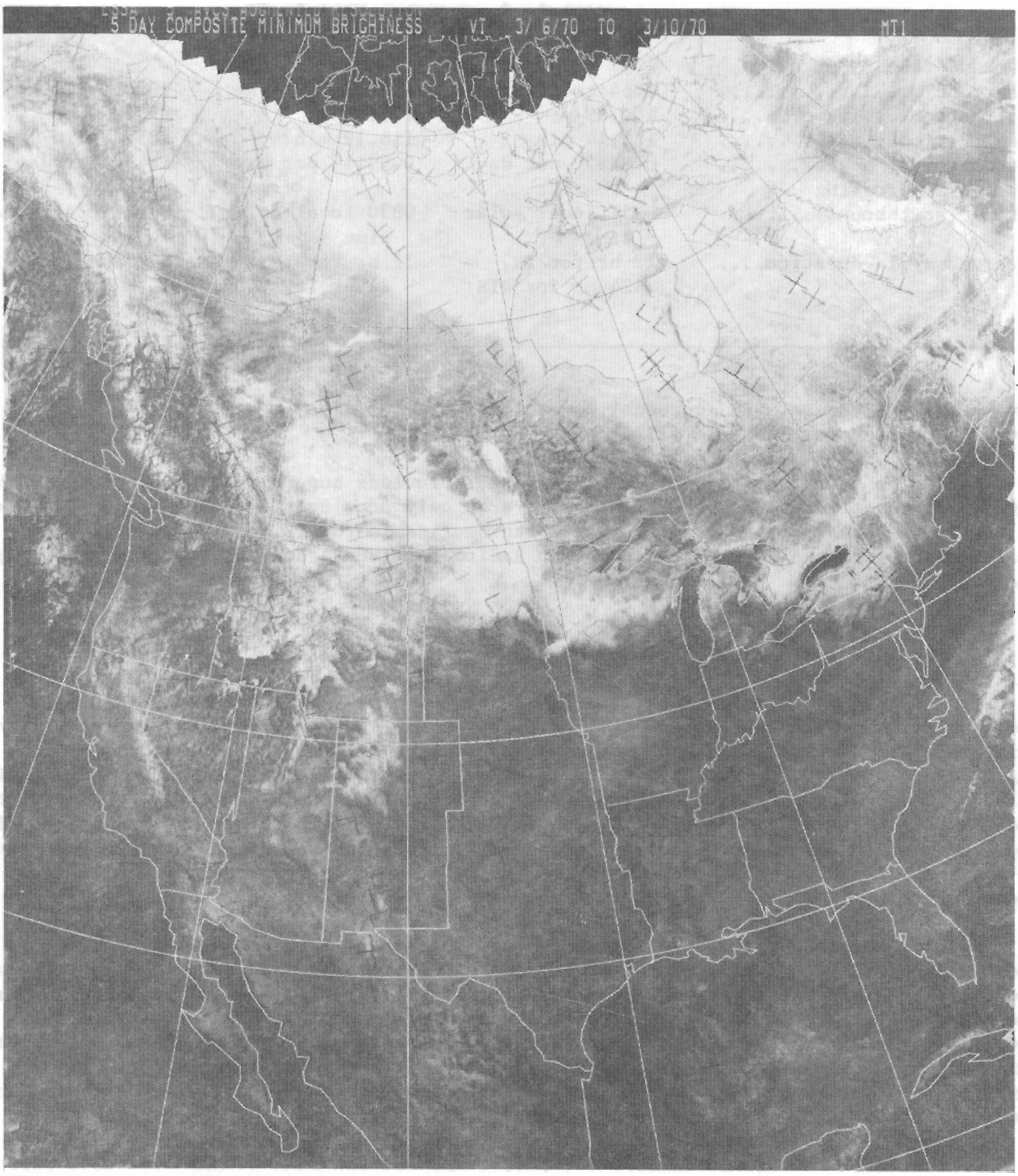

Figure 1. Computer-produced ESSA 9 5-day composite minimum brightness chart showing snow in North America during the period March 6-10, 1970.

snow extent and snowline mapping in small watersheds and for calibration of NOAA-3 VHRR observations.

QUASIOPERATIONAL SNOW EXTENT MAPPING

At the request of the National Weather Service/Office of Hydrology, snow extent mapping of several river basins for snow cover using VHRR data was begun in early 1973 by the Environmental Sciences Group of NESS. Cloud cover is a nagging problem in most areas but in the American River basin (5,600 km^2) in the Sierra Nevada, we were able to secure 14 VHRR measurements and we were also able to secure 6 ERTS measurements for comparison.

Within 36 hours after the satellite passed over the basin, the Sacramento River Forecast Center (RFC) received a measurement of percent of snow cover in the basin via teletype from NESS. In some cases, information was transmitted in less than 25 hours. At the present time, the new Satellite Field Station at Redwood City, California, has a real-time readout, and the RFC will be able to secure data the same day for its own use during the 1974-75 season.

The VHRR data received (Fig. 2) are converted to an image which is distorted and unrectified. By means of a Bausch & Lomb Zoom Transfer Scope, optical rectification of the image permits accurate registration with the base map (1:500,000 in this case). Areas of snow are then identified in the 0.6-0.7μm (visible) band imagery and are mapped directly on an overlay of the basin (Fig. 3). The snow area is subsequently measured using a planimeter. About two man hours is required to map the American River basin (2,163 mi^2) snow extent. The same amount of time was required to map the Red River of the North, a 40,200 sq. mi. basin in the Dakotas and Minnesota.

The ERTS-1 satellite provides superb, sharp (100 m ground resolution) multispectral images for snow extent mapping (Figure 4). With these ERTS-1 images of unsurpassed cartographic accuracy one can quickly and easily map snow extent in basins as small as 272 km^2 (Meier, 1973). Basins larger than 10,000 nmi^2 (34,000 km^2) would exceed the size of one ERTS frame and present some mapping problems. For example, on a cloudless day over a basin the first ERTS overpass would secure part of the desired imagery. The following day might be overcast resulting in no data on snow. Figure 5 shows the meltback in the American River Basin as mapped from ERTS-1 data for the 1973 melt season.

Other factors limiting the usefulness of ERTS imagery for snow studies are: 1) the 18-day revisit time; 2) the long wait (30-60 days) from collection of data to receipt by the investigator. A quicklook capability, such as developed by the Canadians at their ERTS data collection site, would ameliorate this second problem.

The 1000-meter resolution or "spot size" of the VHRR system, tends to eliminate the problem of distinguishing the "true" snowline from intermittent patches of snow interspered with bare ground (Figures 2 and 4). The VHRR tends also to integrate the snow areas near the line of continous snow cover and to eliminate the small snow patches which lie outside of the main body of continous snow cover. The shadow effect, in which a low sun angle can cause shadows that decrease the reflectivity of the snow in a steep-sided valley and the vastly better resolution of ERTS are probably the reasons for VHRR snow extent measurements being consistently lower than ERTS-1 measurements (Figure 6). This effect will be more severe at higher latitudes. A third problem, and probably the most vexing, is the difficulty of detecting snow in heavily wooded areas, particularly in the coniferous forests.

NEW RESEARCH ACTIVITY IN SATELLITE HYDROLOGY

Melting snow and ice have been detected by the Nimbus 3 satellite according to Strong et al. (1971), (Fig. 7) and from ERTS-1 (Wiesnet, 1972, Barnes and Bowley, 1972). The spectral reflectance of snow is not well known but recent measurements by O'Brien and Munis (in press) indicate that a significant drop in reflectance occurs at the instant water begins to form on the snow and ice (Fig. 8). This decrease in differential spec-

Figure 2. Portion of a NOAA-2 VHRR (visible) image showing snow cover in the Central Sierra Nevada, orbit 1728, 1727 GMT, March 2, 1973.

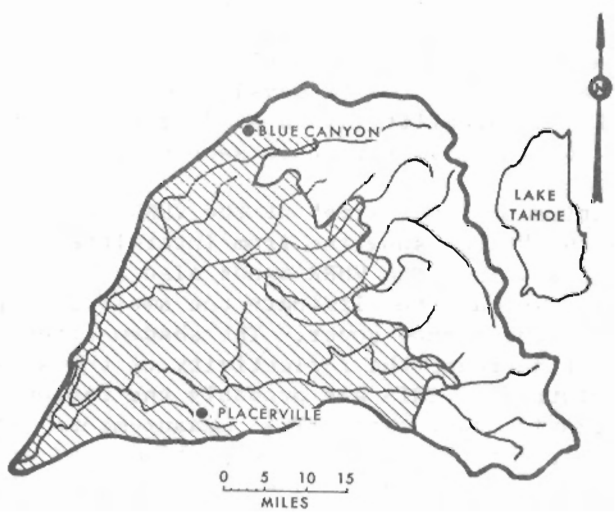

Figure 3. Map of the American River Basin showing extent of snow cover from VHRR-VIS data.

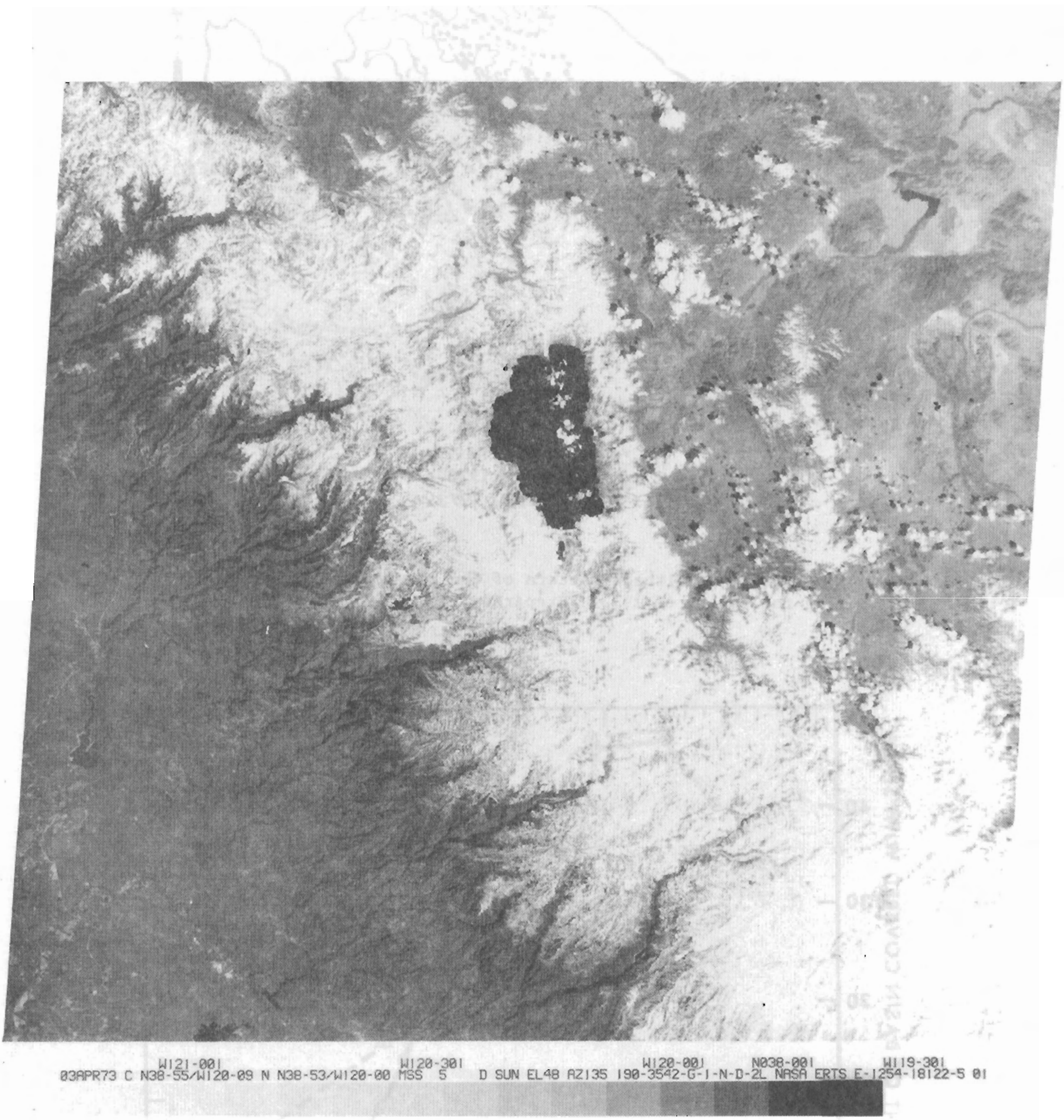

Figure 4. ERTS-1 (MSS Band 5) image of the American River Basin and vicinity, Central Sierra Nevada, April 3, 1973. Note the fine detail.

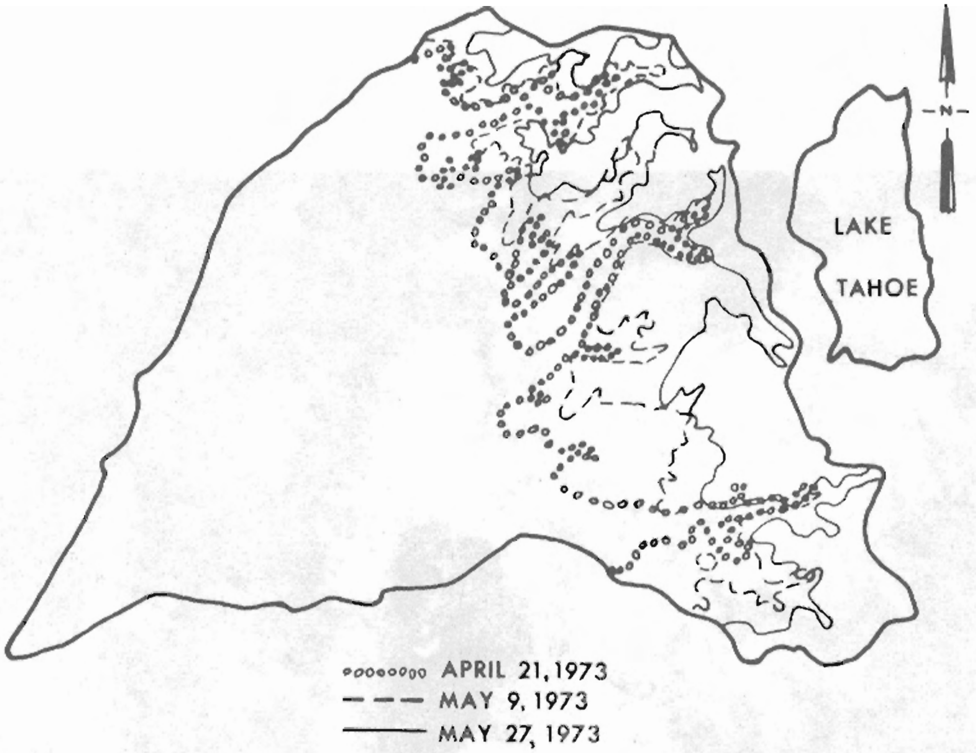

Figure 5. Map showing the meltback pattern of the snow in the American River Basin during the spring of 1973. Prepared from ERTS-1 images.

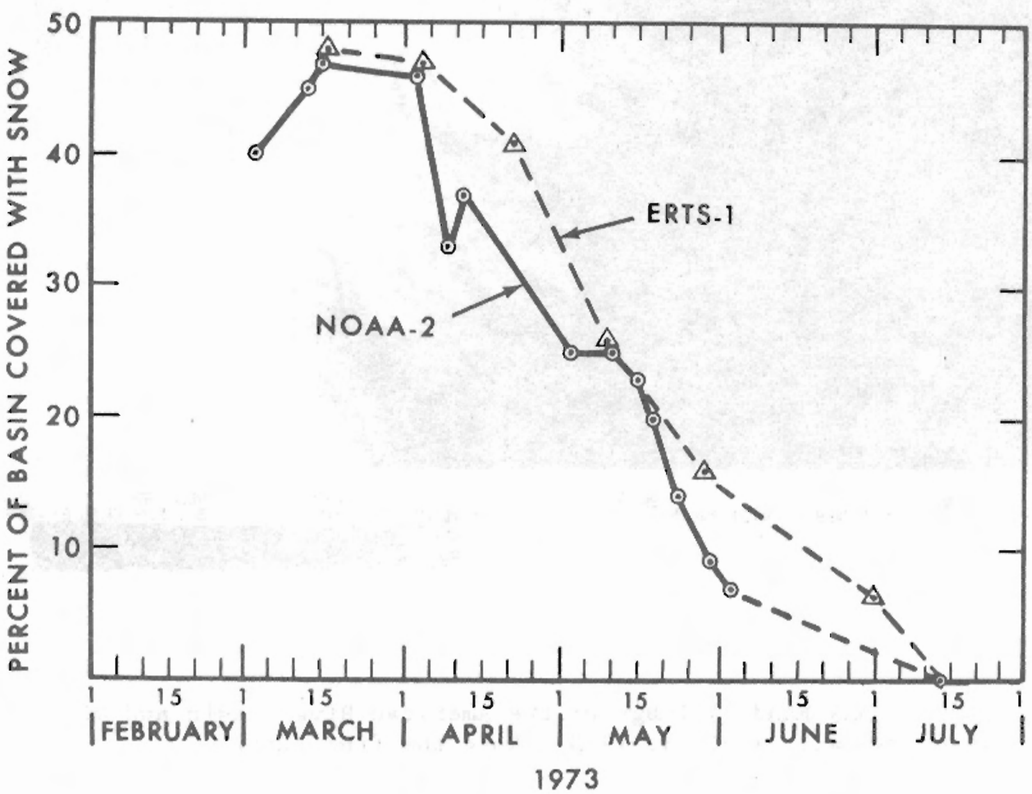

Figure 6. Comparison of ERTS-1 and NOAA-2 VHRR snow-extent data for the American River Basin, 1973.

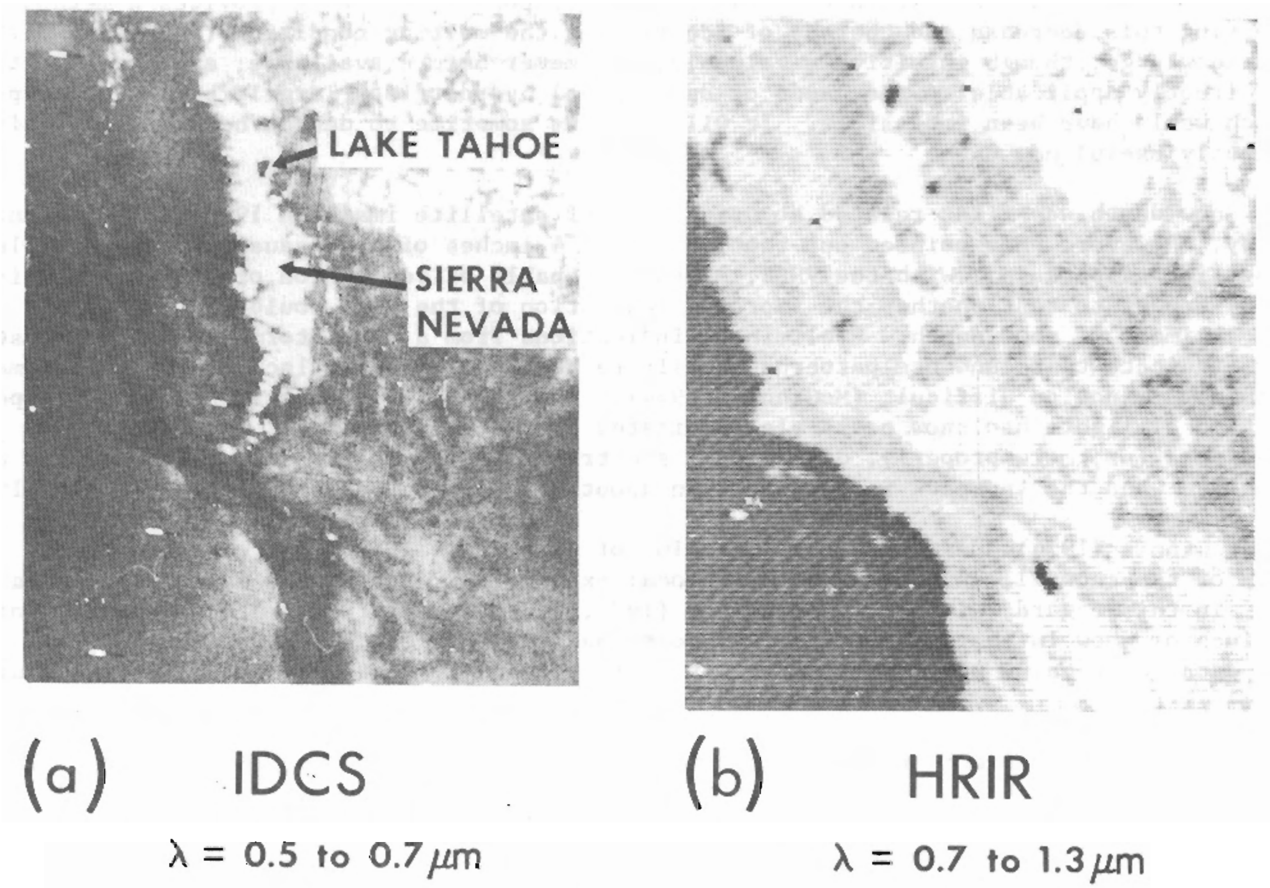

Figure 7. Visible (a) and near-infrared (b) images over the Sierra Nevada from Nimbus 3 on April 25, 1969 at 2000 GMT. (After Strong et. al., 1971).

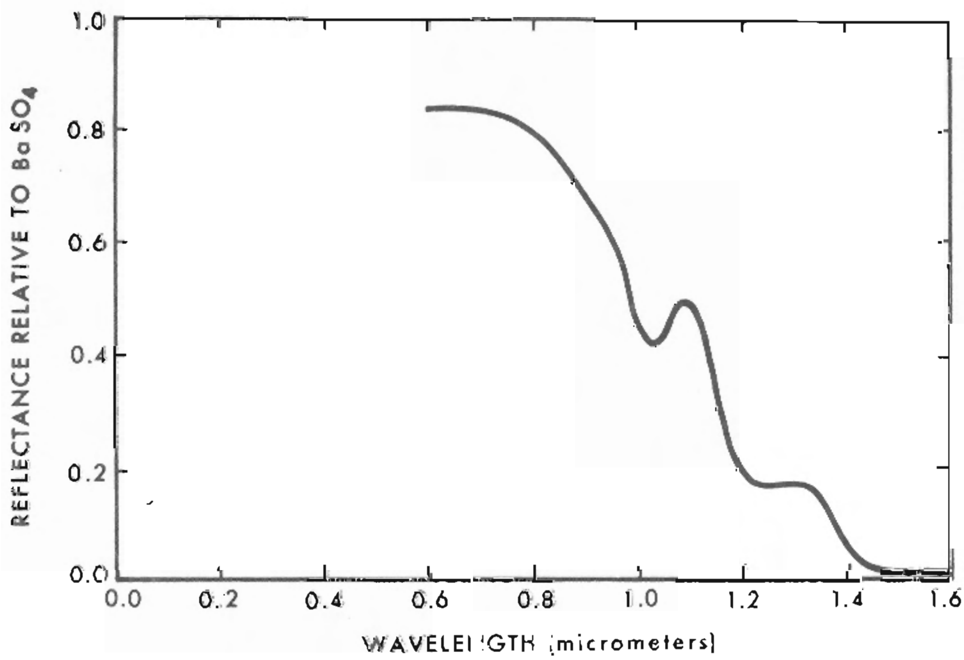

Figure 8. Spectral reflectance of melting snow. Note the rapid drop in reflectance in the near-infrared portion (after O'Brien and Munis).

tral reflectance is greatest in the near IR. Multispectral scanning provides a method of detecting this decrease and thereby of identifying the melting condition (Figs. 9 and 10). This knowledge, though intuitively valuable, was never before available; as a result it is not directly applicable to the needs of operational hydrologists largely because the approach would have been impossible. It will take us sometime to decide how to apply this obviously useful new data.

Snow depth was first related to brightness of satellite image in 1968 by Barnes and Bowley. However, they pointed out that more than 4 inches of snow caused no discernible change in reflectance. With the VHRR, a sensor capable of resolution of 900 m, McGinnis (1974) sought to test whether the improved resolution of the VHRR would in fact permit some estimate of snow depth. Preliminary indications from a snow storm in the Southeastern U. S. indicate that land use patterns complicate the integrated reflectance value and make depth determination difficult (McGinnis, 1974). Theoretical and experimental work on penetration of light into snow packs also indicates that this approach, i.e., relating brightness (or, more properly, directional spectral reflectance) to snow depth may not be effective when the snowpack is thicker than about 4-6 inches. (See Whiteley et al., 1973).

McGinnis (1974) does point out the value of using satellite data for defining the limit of the snowfall as contrasted with local extrapolations of point data (Figs. 11 and 12). In this regard, Wiesnet and McGinnis (1973, p. 183) have reported the detection of one inch of snow in the Red River of the North basin in Minnesota and the Dakotas from VHRR data. The value of such a capability in remote areas is obvious to the operational hydrologist.

Snow in heavy forest areas is a problem to detect from satellite and aircraft. The forest canopy obscures the forest floor. Typical satellite views of forested regions, such as the Adirondack Mountains, show no snow except on large clearings or on frozen lakes. At NOAA/NESS we have been experimenting with the use of special lookup table (gray scales) which in effect product computer enhanced images (Fig. 13). By accentuating the lighter portion of the dark forest areas in some cases, the snow is clearly brought out. Fig. 14 is such an image. It shows the distribution of snow in the Northeast in the thick coniferous forests of the Adirondack Mountains, the Canadian North Woods, and the White and Green Mountains of New England. This research is continuing.

NASA's Nimbus 5 satellite launched in December 1972, carries an Electrically Scanning Microwave Radiometer (ESMR) that is capable of measuring the Earth's brightness temperature--hence its snow cover--through almost any cloud cover. Ground resolution of the instrument ranges from 25 x 25 km to 45 x 160 km, thereby limiting the usefulness of this instrument--at least for snow mapping--to large area studies.

Soon to be launched is Synchronous Meteorological Satellite-1 (SMS-1) a geosynchronous satellite that will later be called GOES (Geostationary Operational Environmental Satellite) when two such satellites are positioned one near 70°W over the Atlantic and one near 130°W over the Pacific. These satellites are primarily designed for severe and tropical storm warnings but also have a high capacity for data collection and dissemination. As a data collection platform, this satellite has a great appeal. Any instrument remotely located can be interrogated in seconds and data can be received at the Data Acquisition Site in near-real time.

SUMMARY

A new generation of sensors on board operational and experimental satellites make snow mapping and the collection of snow data by satellite not only feasible but necessary for snow reconnaissance. The accomplishments of the ERTS-1, NOAA-2, NOAA-3, and Nimbus 5 satellites as cited by recent investigators includes:

(1) Under optimum conditions with ERTS-1 data, snowline elevation (or altitude) can be estimated to the nearest 60m (Meier, 1973).

(2) More detail can be obtained from the ERTS-1 images of snowline than is commonly

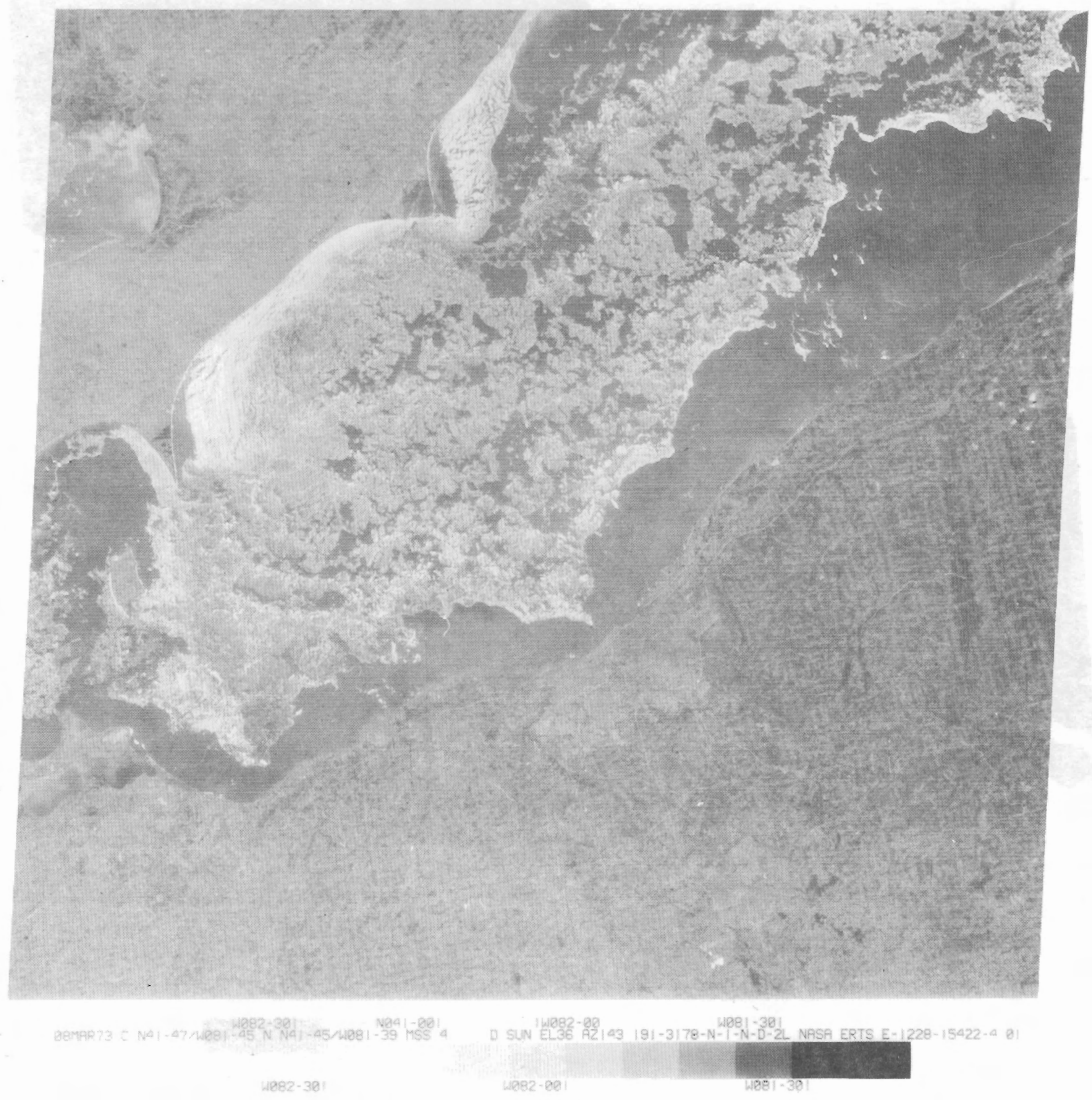

Figure 9. ERTS-1 image (MSS band 4) of central Lake Erie showing the melting lake ice pack on March 8, 1973.

Figure 10. ERTS-1 image (MSS band 7) of central Lake Erie showing the melting lake ice pack. Compare with figure 9 and note the lower reflectance in band 7.

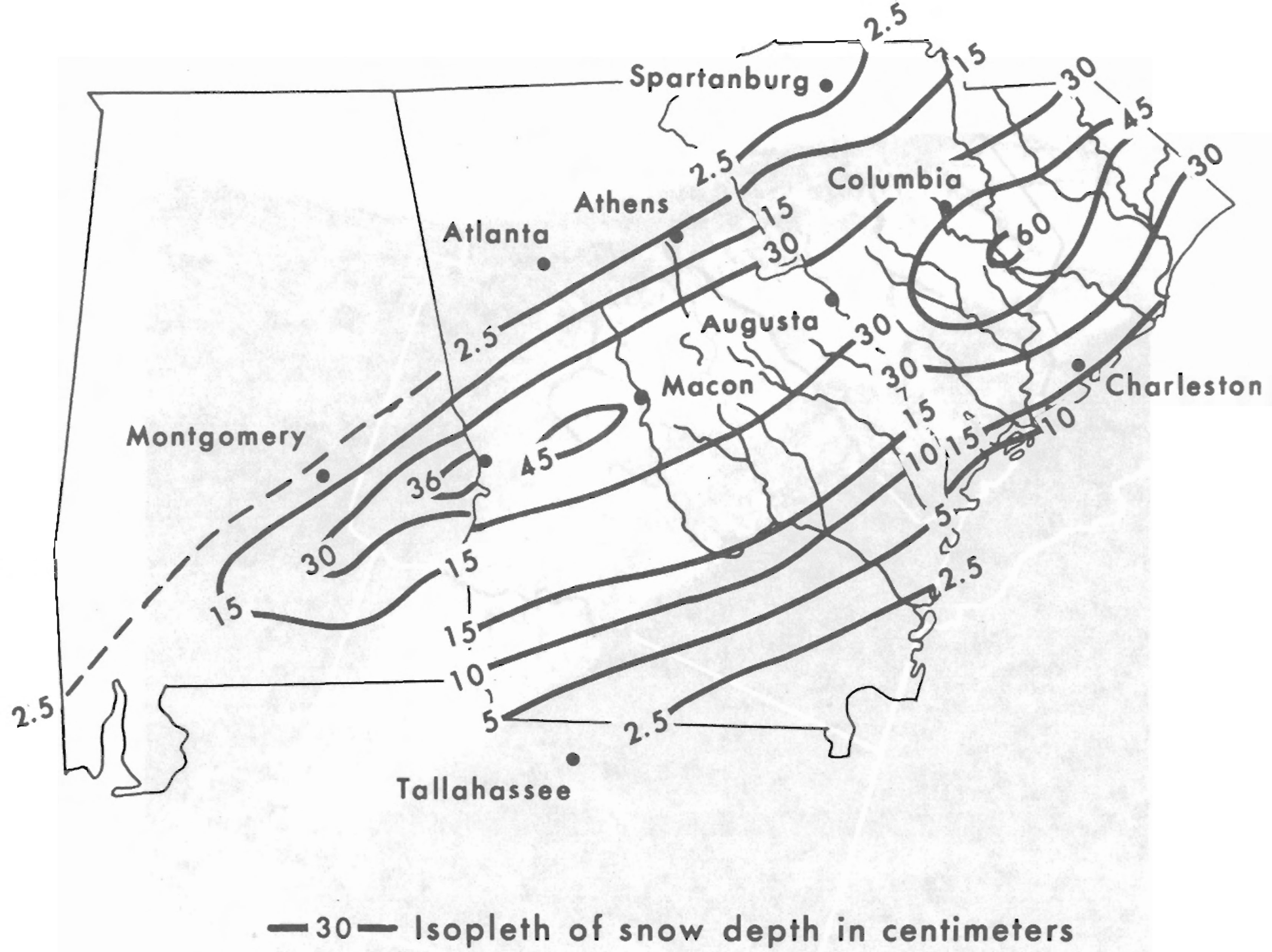

Figure 11. Map of the Southeastern U. S. showing isopleths of snow depth in centimeters February 11, 1973. Map was prepared for three states and was not adjusted at the state boundaries.

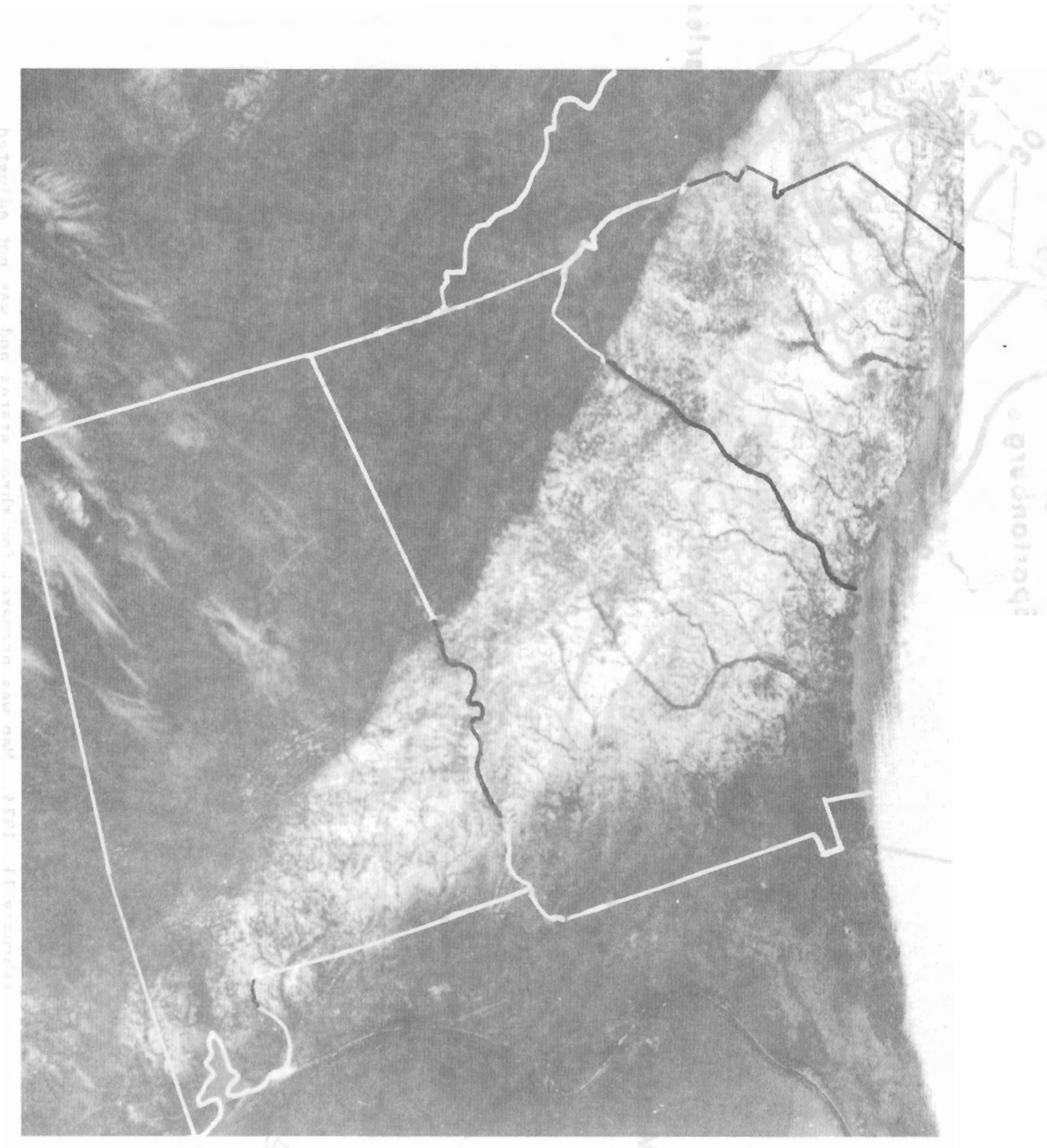

Figure 12. NOAA-2 VHRR-VIS image of the snow-covered Southeastern States on February 11, 1973. Note the very white central portion where the snow is deepest. Compare with figure 11.

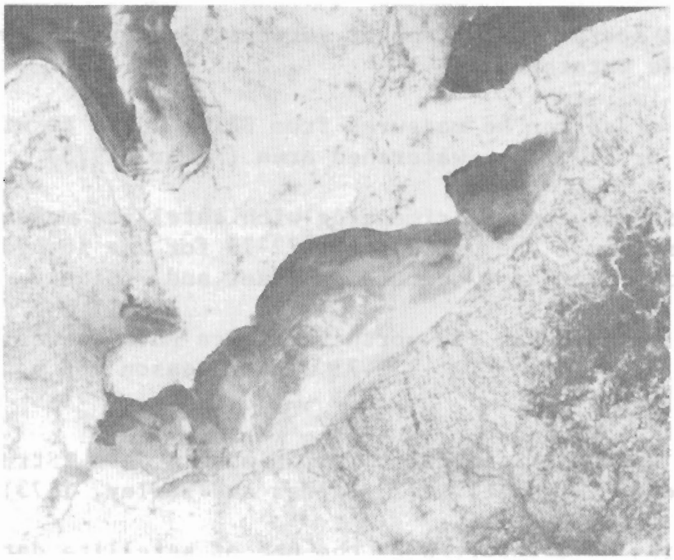

Figure 13. Nearly 100 percent ice cover in Lake Erie as viewed by computer-enhanced NOAA-2 VHRR at 1503 GMT on February 17, 1973, orbit 1564. Dark areas are covered by newly formed, transparent thin ice.

Figure 14. Computer-enhanced NOAA-2 VHRR-VIS image of the Northeastern U. S. and Southeastern Canada on March 28, 1973. Note the snow appearing in the Adirondack Mountains and in the Canadian North Woods as a result of the enhancement.

obtained from operational aircraft surveys (Barnes and Bowley, 1973) in the Salt and Verde watersheds.

(3) Snow-covered areas can be measured from ERTS-1 data to within 4% of the snow-covered area or 1% of the watershed area (Meier, 1973)

(4) The NOAA/NESS has been experimenting with satellite measurements of snow cover in four basins since the winter of 1972-73 for use in hydrologic forecasting by the NWS River Forecast Centers (Wiesnet and McGinnis, 1973).

(5) The American River Basin (in northern Sierra Nevada) was mapped by NOAA-2's VHRR a total of 14 times in 1972-73 winter season and 6 time by ERTS-1 (Wiesnet, in press).

(6) Melting snow has been identified from Nimbus 3 data (Strong et al., 1971) and from ERTS-1 data (Wiesnet, 1972; Barnes and Bowley, 1973).

(7) Seven countries have reported on the use of satellite data to map snow cover in mountainous areas: Austria, Canada, Japan, New Zealand, Switzerland, the U. S. A., and the U. S. S. R. (McClain, 1973).

In conclusion, today's operational and experimental satellites are capable of contributing greatly to operational snow studies and snow and ice research. As these technological advances in satellite remote sensing of hydrological data proliferate, so must the hydrologic community expand its awareness of and its training in satellite techniques.

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