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DETECTION OF THAWING SNOW AND ICE PACKS THROUGH THE COMBINED USE OF VISIBLE AND NEAR-INFRARED MEASUREMENTS FROM EARTH SATELLITES

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ABSTRACT

A case is made for the detection of melting snow or ice using multispectral remote sensing from earth satellites. Snow and thick ice are highly reflective in both the visible and the near-infrared portions of the electromagnetic spectrum. During thaw conditions, however, near-infrared radiation is absorbed strongly, while reflection of visible radiation is only slightly affected. Simultaneous visible and near-infrared imagery from the Nimbus 3 satellite illustrates how these reflectance differences can be used to obtain information of hydrologic usefulness. Two examples of such use are presented.

1. INTRODUCTION

Hydrologic information from earth satellites has been increased by the addition to the Nimbus 3 meteorological satellite of instrumentation to obtain solar reflectance imagery from the near-infrared. Several studies (MacLeod 1971, MacLeod 1970, Barnes and Bowley 1970) have indicated potential hydrological uses of these data for obtaining information on drainage basins, snow cover, plant distribution, and flood extent. Use of the near-infrared (near-IR) data in combination with the visible spectrum imagery appears to permit the detection of thawing snow and ice packs. Two examples of such use, over the Lake Winnipeg region of Canada and the Sierra Nevada of California and Nevada, are presented in this report.

The experimental Nimbus 3 meteorological satellite, launched Apr. 14, 1969, provided for 24-hr mapping of the global cloud cover and for nighttime infrared measurements of earth surface and cloud top temperatures in the 3.6- to 4.2-μm portion of the spectrum. During the day, the High Resolution Infrared Radiometer (HRIR) complements the television coverage (0.5–0.7 μm) of the Image Dissector Camera System (IDCS), by measuring reflected shortwave radiation in the 0.7- to 1.3-μm spectral region. The area instantaneously viewed by the HRIR scanner at nadir is about 8.5 km in diameter, a resolution somewhat coarser than the 4.1-km resolution of the IDCS. Additional information on the Nimbus 3 satellite system may be obtained from the *Nimbus III User's Guide* (Goddard Space Flight Center 1968).

2. LAKE WINNIPEG AREA

The area of the United States and Canadian Plains viewed simultaneously by the Nimbus 3 IDCS and HRIR near 1800 GMT on Apr. 25, 1969, is shown in figure 1. In the IDCS photograph (fig. 2A), Lake Winnepeg is clearly visible in the area between two cloud masses. The brightness of the lake indicates the presence of ice, possibly covered by snow. Small details, such as an island in Lake Winnipeg, are easily seen. Also visible, though not as bright, are Lake Winnipegosis to the West of Lake Winnipeg, and Lake Nipigon on the edge of the photograph, southeast of Lake Winnipeg.

The corresponding daytime HRIR image (fig. 2B) shows almost identical cloud patterns. The Great Lakes and parts of the Mississippi River appear darker than the adjacent land, since vegetation is more reflective than water in the near-IR. One would have expected ice-covered Lake Winnipeg to be easily visible in the daytime HRIR imagery, especially since the lake was surrounded by terrain having no snow cover. However, the clear region between the cloud masses shows no indication of the frozen lake. Has it disappeared? Careful examination of the HRIR image reveals a slight darkening, suggestive of an open water surface, in the area of the "absent" Lake Winnipeg.

3. SIERRA NEVADA AREA

In the area of the western United States (fig. 1) covered by simultaneous IDCS and HRIR at 2000 GMT on Apr. 25, 1969, the snow-covered Sierra Nevada appear very bright in the IDCS visible imagery (fig. 3A). Though

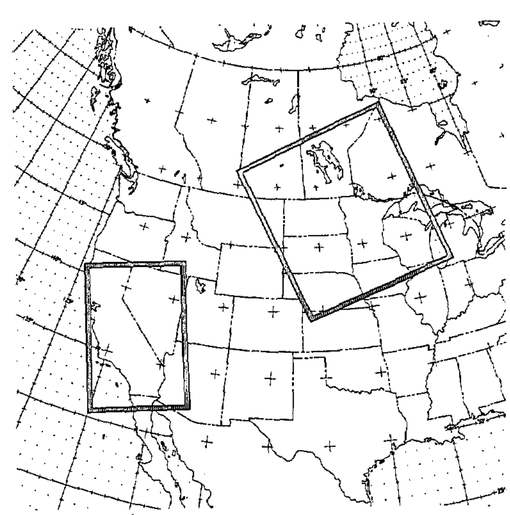

FIGURE 1.—Regions shown in the Nimbus 3 photographs, figures 2 and 3.

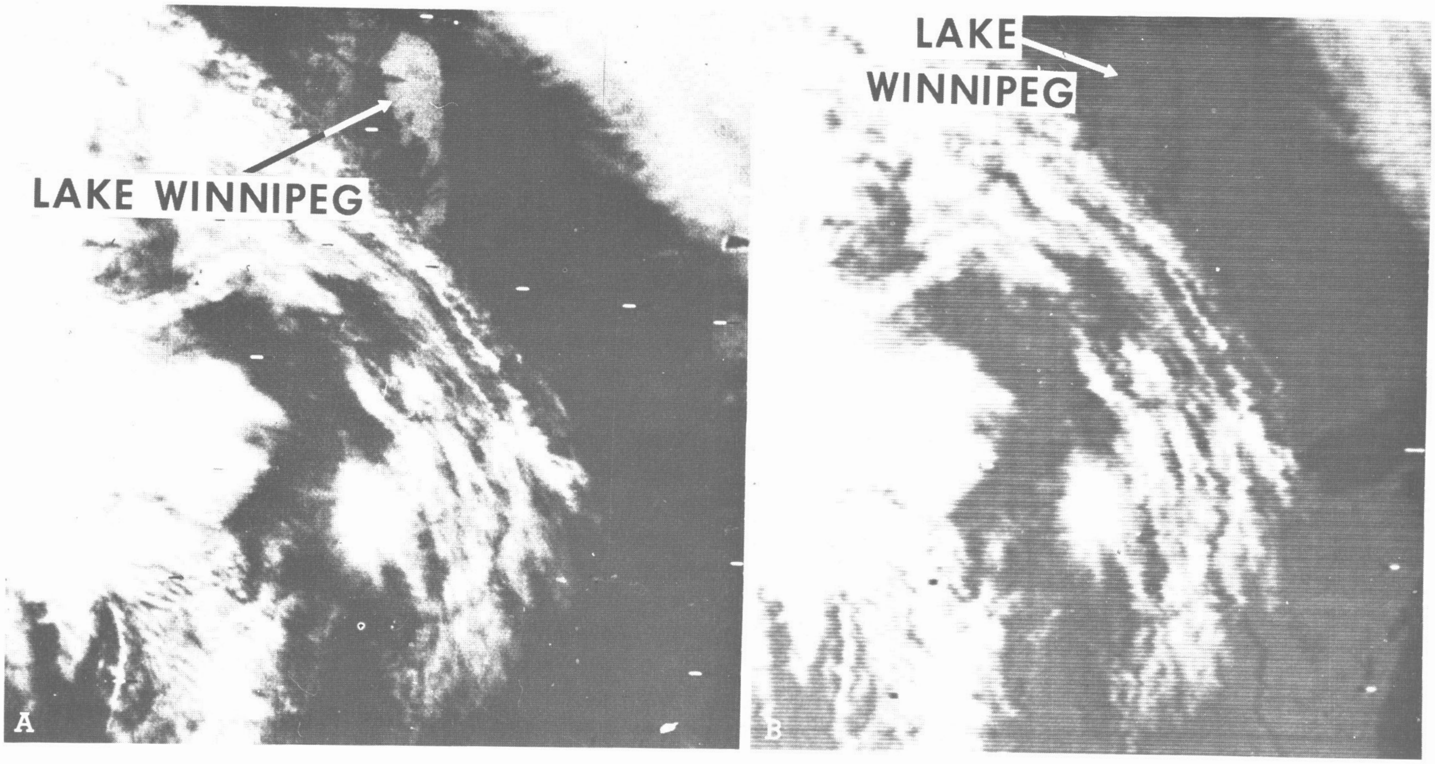

FIGURE 2.—(A) visible and (B) near-infrared images over Lake Winnipeg, Canada, from Nimbus 3 on Apr. 25, 1969, at 1800 GMT.

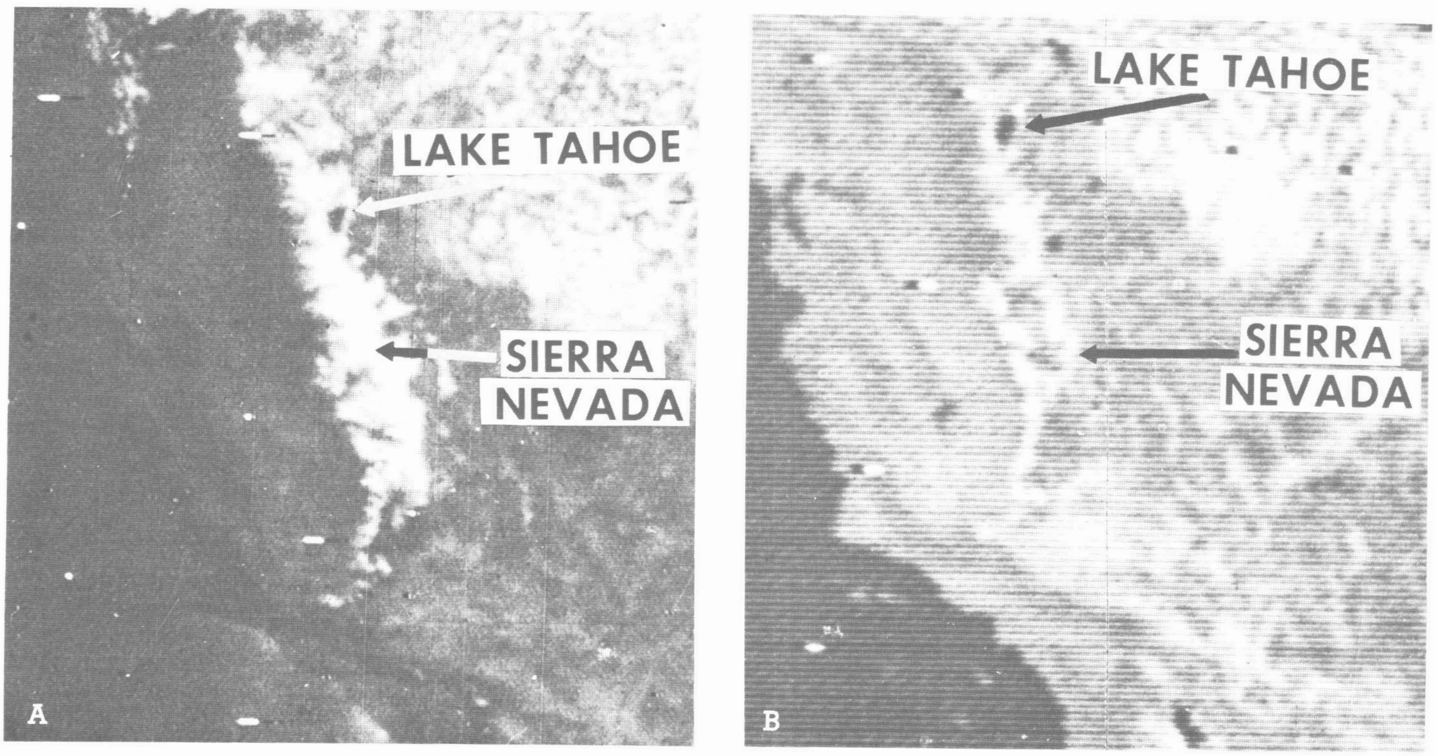

FIGURE 3.—(A) visible and (B) near-infrared images over the Sierra Nevada from Nimbus 3 on Apr. 25, 1969, at 2000 GMT.

not completely absent in the daytime HRIR (fig. 3B), the bright area over the Sierra Nevada is much smaller and corresponds to the higher elevations. Some questions exist as to why the secondary bright band to the south and west of the Sierras appears in the infrared imagery. Land elevations are not of sufficient height to be snow covered; it is suggested that clouds may be responsible for the observed brightness.

4. DISCUSSION

Although MacLeod (1971) states that fresh snow is light in tone but is darker than clouds in the near-IR, he

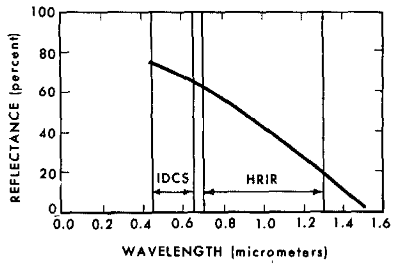

FIGURE 4.—Spectral reflectance of melting snow (Mantis 1951).

does not discuss old or melting snowpacks or ice. The most likely explanation of the near-IR brightness reversal of Lake Winnipeg and the Sierra Nevada is that surface melting of the lake or snowpack caused the surface to absorb in the infrared while still reflecting in the visible.

Meteorological data in the Lake Winnipeg area indicate near-surface temperatures under the noon sun ranging from 8° to 15°C; these temperatures substantiate melting conditions. In the Sierra Nevada, temperatures at the 1500-m level were near 8°C, while at elevations above 3000 m there were subfreezing temperatures. Below the 3000-m elevation, a thawing snowpack absorbed a sufficient amount of incident radiation to cause it to appear dark in the HRIR image. At higher elevations, the snow surface remained frozen and highly reflective in the near-IR.

The extinction coefficient of pure water for wavelengths near 1.2 μm, the maximum response of the Nimbus 3 daytime-HRIR, is approximately 1 (Neumann and Pierson 1966). This may be interpreted as an optical depth of 1 cm. For a beam of incoming radiation to penetrate a surface water film, reflect from an underlying ice or snow surface, and pass again through the water film, the water film must be considerably less than 1 cm thick; a 1-cm thickness represents nearly total absorption. Considerable absorption would be expected for even a 1-mm layer of water. Therefore, it appears that a visible layer of water would not necessarily be needed to cause an appreciable reflectance drop in the near-IR.

Investigations have been made into the spectral response of snow and ice under various conditions. A study of fresh snow under clear skies by Kondrat'ev et al. (1964) indicated almost constant reflectivity over the range of the visible spectrum, with reflectance values of the order of 90 percent. Reflectance of wet snow in the visible was again found invariant with wavelength but was slightly less than that for dry snow. Results by Mellor (1964) show a slight drop in reflectance for dry snow, with a more rapid drop for wet snow; the drop in reflectance over wet snow is more marked at the longer wavelengths (to 0.7 μm).

In the lower end of the near-IR spectrum (0.90 to 0.95 μm) Kondrat'ev et al. (1964) noted a lesser reflectance than in the visible of both dry and wet snow, with a larger change for wet snow. Their results indicated a 16 percent drop in reflectance for wet snow compared with an 8 percent drop for dry snow. Data presented by Mantis (1951), shown in figure 4, agree with Kondrat'ev's findings and provide additional reflectance measurements out to 1.5 μm. In the vicinity of 1.2 μm, where the HRIR response is a maximum, reflectances of melting snow are only 25 percent. Information is being sought to describe the reflectance of *dry snow* beyond 1.0 μm. Without this information, we are unable to demonstrate with certainty that dry snow remains bright in the near-IR.

5. CONCLUSIONS

Although the results of this study are preliminary in nature and the details of the explanation only tentative, a case is made for the detection of melting snow or ice by remote sensing from earth satellites. Additional information on the response of dry snow in the near-IR is necessary before final conclusions can be reached. Other cases showing minimal or reduced brightness of melting snow in the near-IR are being examined. The detection method takes advantage of the strong absorption of incident radiation in the near-IR by a covering film of water. Combined with visible channel data, in which this film of water becomes essentially transparent, the two-channel measurement provides information on snow and ice pack conditions beyond that of merely delineating the boundaries of ice and snow-covered areas (McClain and Baker 1969).

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