SECTION 94

DETERMINATION OF THAWING SNOW AND ICE SURFACES USING EARTH SATELLITE DATA

by

Donald R. Wiesnet and David F. McGinnis
National Oceanic and Atmospheric Administration
Washington, D. C. 20331

INTRODUCTION

One of the earliest proposed and perhaps least imaginative uses of environmental earth satellite systems was to map snow on continental land masses of the world. Once weather satellites, such as TIROS, Nimbus, ESSA and NOAA (as well as Gemini and Apollo missions) were up and sending back imagery of the earth to meteorologists, it became clear that snow and ice were indeed readily apparent. However, cloud cover and other problems presented obstacles to accurate snow mapping. As NOAA's satellite hydrology program developed, improved snow detection and mapping has continued to be one of its fundamental goals. Ultimately, the goal of NOAA's Satellite Hydrology Program is to provide timely, comprehensive, and repeated satellite and aircraft information on the areal distribution of hydrologic factors on a local and regional basis, and to assist in the development of applications of these data to operational and research problems in hydrology and meteorology.

The purpose of this paper is to report on the apparent differential spectral reflectance as sensed by the Imaging Dissector Camera System (IDCS) in the visible portion of the electromagnetic spectrum and by the High-Resolution-Infrared Radiometer (HRIR) in the near-IR portion of the electromagnetic spectrum . Both instruments were aboard the Nimbus 3 satellite. A paper on this phenomenon was published in November in the Monthly Weather Review (Strong, McClain, and McGinnis, 1971). Research on this differential spectral reflectance and possible applications is continuing in NOAA/NESS.

SENSORS

The experimental Nimbus 3 meteorological satellite provided for 24-hour mapping of the global cloud cover and for nighttime infrared measurements of both earth-surface and cloud-top temperatures in the 3.6 to 4.2 micron portion of the spectrum. However, during the day the HRIR was programmed to measure near infrared radiation (0.7 to 1.3

micrometers) radiation to complement the Image Dissector Camera System (0.5-0.7 micrometers). The field of view of the HRIR at nadir (8.5 km diameter) is about twice that of the IDCS (4.1 km diameter). For additional information consult the Nimbus III Users Guide (GSFC, 1969).

LAKE WINNIPEG

Figure 1 is an index map showing the location of the Nimbus 3 satellite IDCS and HRIR imagery taken simultaneously at about 1800 hours GMT (1200 hours local) on April 25, 1969. In the IDCS photograph (Figure 2A) Lake Winnipeg is clearly visible in the area between two cloud masses. The brightness of the Lake indicates the presence of ice, possibly snow-covered ice.

Compare the corresponding daytime HRIR image (Figure 2B) taken at the same time (1800 hours GMT, 1200 hours local). Cloud patterns are almost identical. The Great Lakes and parts of the Mississippi River appear darker than the adjacent land, whose vegetation is more reflective than water in the 0.7 -1.3 micron range. One would expect ice-covered Lake Winnipeg to be easily visible on the HRIR imagery, especially as the surrounding land was free of snow cover. Yet, as seen in Figure 2B, there is no trace of Lake Winnipeg on the HRIR imagery, although careful examination of the original imagery does reveal a slight darkening, suggestive of an open water surface where Lake Winnipeg ought to be.

SIERRA NEVADA SNOW COVER

Figure 1 shows the area included in Nimbus 3, simultaneous visible and near infrared imagery of California and Nevada (Figure 3) taken at 2000 GMT (1200 local) on April 25, 1969. On the visible, (Figure 3A) the snow-covered Sierra Nevada appears very bright. In the near IR (Figure 3B), the bright area is much smaller and correlates well with the high elevations. The bright band south and west of the Sierra is believed to be a band of clouds and is not snow. Why can we not see the snow that we know is the Sierra?

GROUND TRUTH

At 1200 local time the air temperature at Lake Winnipeg on April 25, 1969, ranged from 8° to 15°C. No snow was reported on the ground. In the Sierra Nevada, the air temperatures at the 1500-meter level were about 8°C. Above the 3000-m contour, subfreezing temperatures prevailed.

DISCUSSIONS

It is postulated by Strong, McClain, and McGinnis (1971) that the melting conditions at Lake Winnipeg (8° - 15°C) caused water films to be predominant at the snow (ice) surface, thereby causing the absorption of incident solar radiation. Enough radiation was absorbed to cause the surface to appear dark on the near IR imagery. In fact, they point out that even a 1 mm layer of water would result in very high absorption of the solar radiation. In other words, the layer of water at the surface might be so thin as to be unobservable even by an experienced snow hydrologist.

The melting and breakup of lake ice has been well studied and we will repeat here the accurate description of the final stages by G. P. Williams (1966).

"The ice first starts to melt on the shore because it is thinner there and because more heat comes from the adjoining ground surface. A free water surface appears along the shoreline leaving the main body of ice floating free. At the time the ice cover still has considerable strength."

Williams (1966) also stated: "During the second stage of melting there is melt of the snow and of the snow ice on the floating ice. The melt water flows along drainage patterns on the surface andit drains to the open water at the shore line or to holes that appear to develop preferentially along old thermal cracks. When the melt water drains away, the surface has a porous, white and crumbly structure which reflects solar radiation and retards internal melting. As the melt season progresses some melt water accumulates beneath the ice surface. A typical ice-cover profile will then consist of a shallow, porous surface layer 2 to 3 inches thick, a layer of water-logged ice several inches thick and then solid unmelted ice extending to the water.

"In the final stages, the underlying entrapped water layers result in darkened surface ice and most of the incoming solar radiation is absorbed."

Despite a lengthy but not exhaustive literature search, only a few meager bits of data on spectral reflectance of snow were found: Kondrat'ev et al. (1964) found a fairly steady 90% reflectance for dry snow as wave length increased in the visible region and somewhat less -- but fairly steady -- percentage for wet snow. Mellor (1964) indicated a fairly rapid drop off for wet snow, which is more marked at the longer wave lengths. In the near IR, Montis (1951) showed a reflectance of only 25% at 1.2 micrometers, the maximum response point of the HRIR.

NOAA/NESS is currently arranging for additional field and laboratory measurements with Goddard SFC and CRREL. Additional examples of differential spectral response have been secured and are under study.

Although the results of this study must be called preliminary, it should be pointed out that this potential 2-channel method of detecting thawing snow is of great interest to hydrologists for snowpack-runoff prediction, flood forecasting, lake navigation, and commercial shipping.

REFERENCES

1. Strong, A.E., McClain, E.P., and McGinnis, D.F., 1971, Detection of Thawing Snow and Ice Packs through the Combined Use of Visible and Near-Infrared Measurements from Earth Satellites, Monthly Weather Review, V. 99, No. 11, p. 828-830.

2. Goddard Space Flight Center, NASA, 1969, Nimbus III Users Guide, NASA, Greenbelt, Md. 238 p.

3. Williams, G.P., 1966, Freeze-up and Break-up of Fresh Water Lakes, Proc. Nat. Research Council Conf. on Ice Pressures Against Structures. Tech. Man. 92, p. 203-215.

4. Mellor, Malcom, 1964, Properties of Snow, Cold Regions Science and Engineering, Pt. III, Sec. A., U.S. Cold Regions Res. and Eng. Lab., Hanover, N. H., 105 p.

5. Mantis, H.T., 1951, Review of the properties of Snow and Ice, vs. Cold Regions Res. and Eng. Lab., Hanover, N. H.

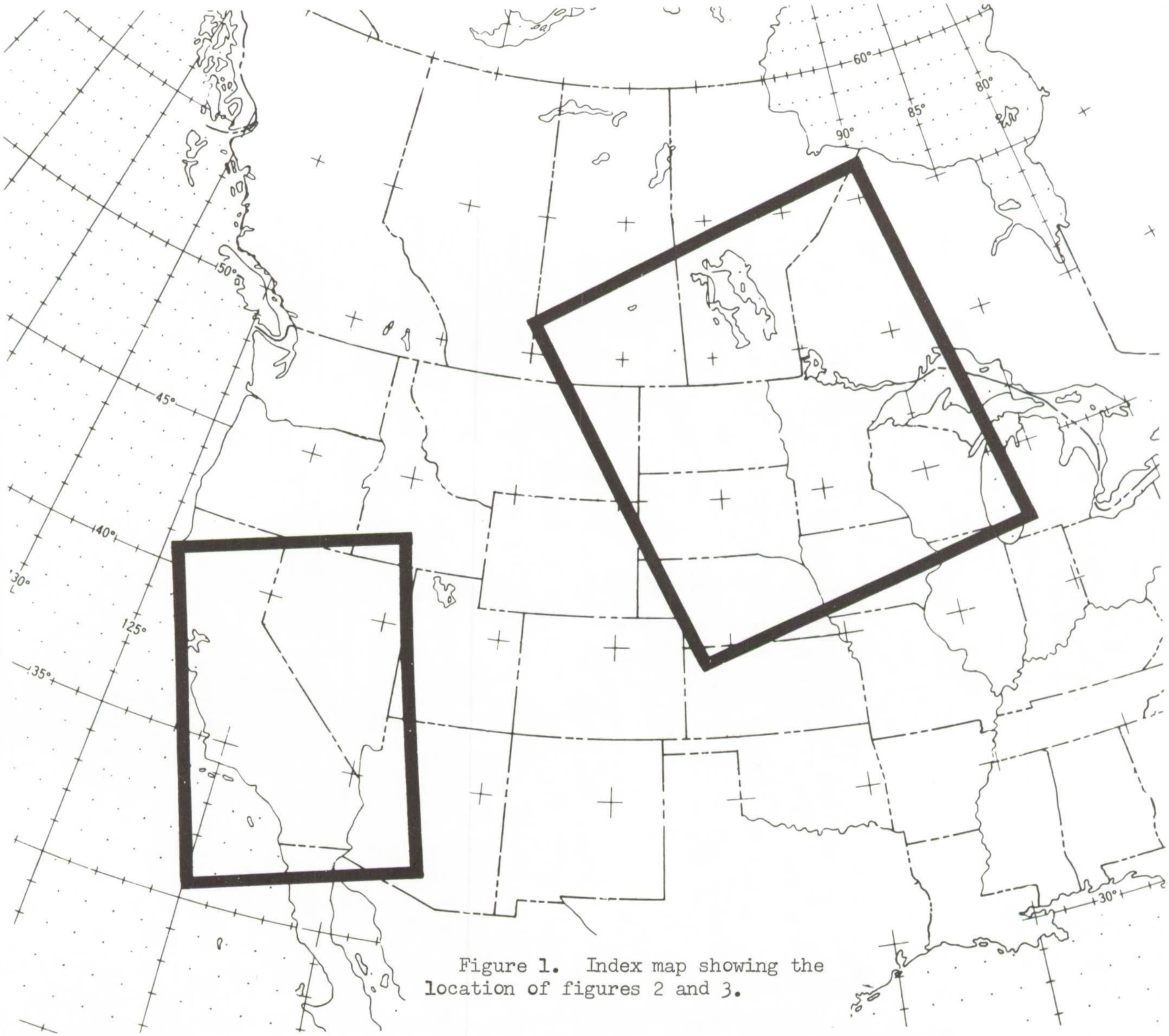


Figure 1. Index map showing the location of figures 2 and 3.

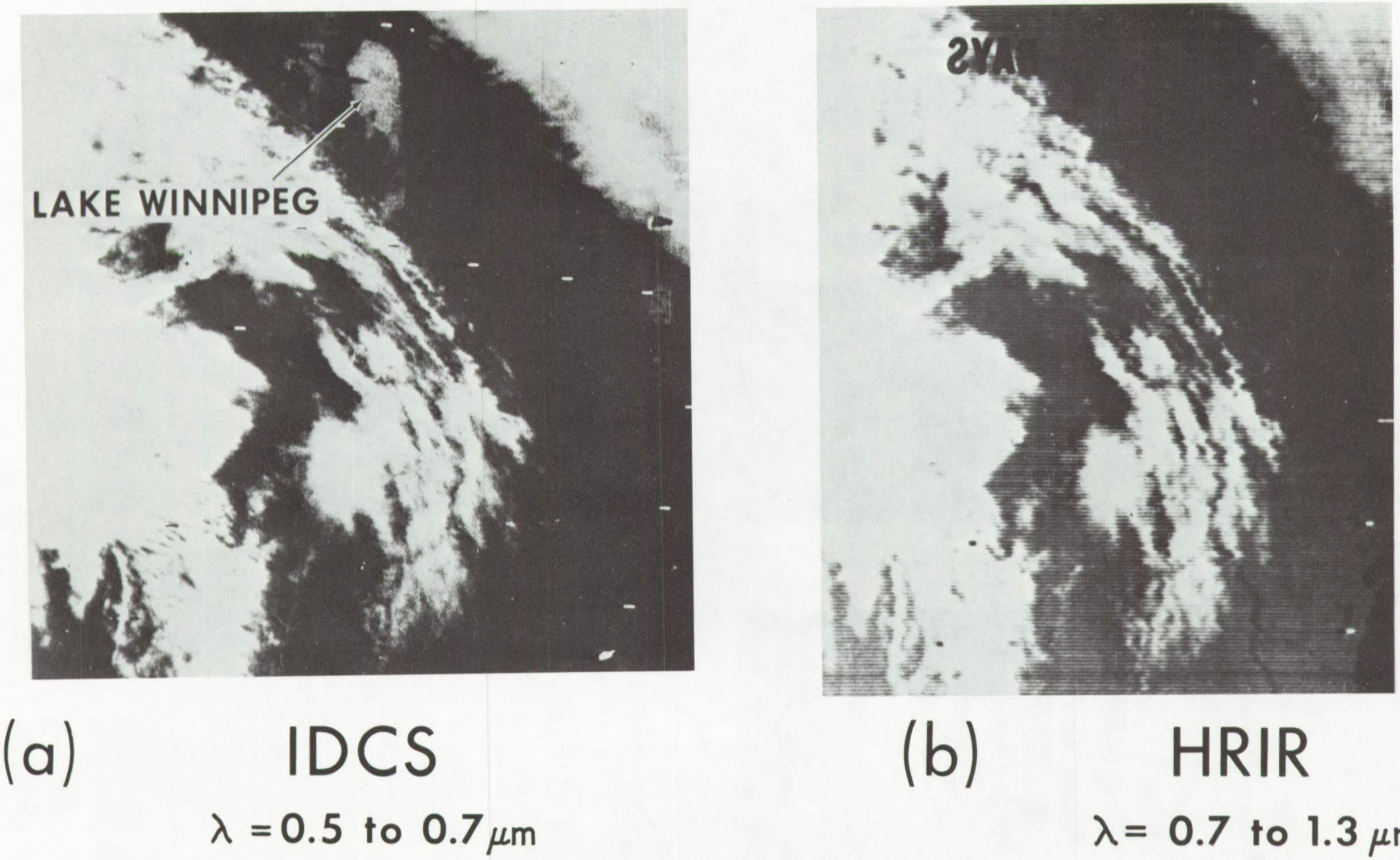
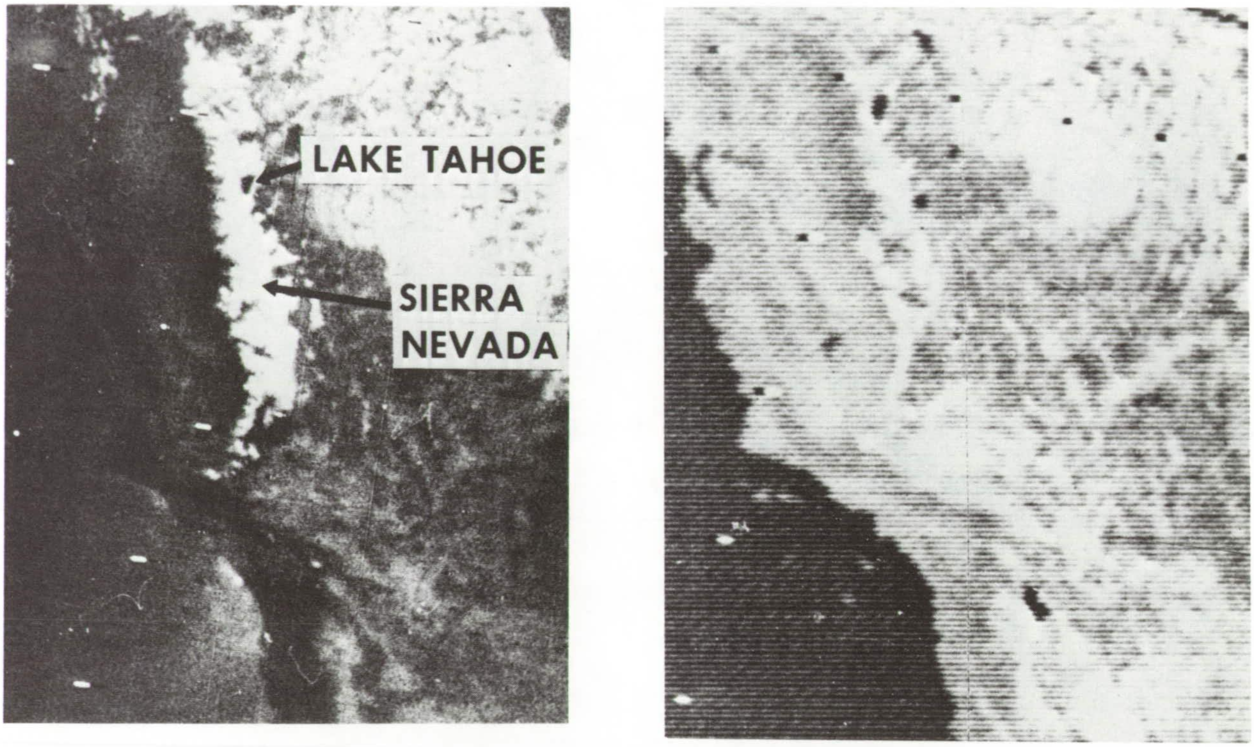


Figure 2. Simultaneous daytime visible (a) and near IR (b) images of the Lake Winnipeg area, showing detection of melting lake ice in the visible but no reflectance of the melting ice in the IR. Air temperature, 8°C; 1800 hours GMT.



(a) IDCS

λ = 0.5 to 0.7 μm

(b) HRIR

λ = 0.7 to 1.3 μm

Figure 3. Simultaneous daytime visible (a) and near IR (b) images over the Sierra Nevada showing non-reflectance in the near IR of melting snow in the lower areas of the Sierra Nevada. April 25, 1969 at 2000 GMT.

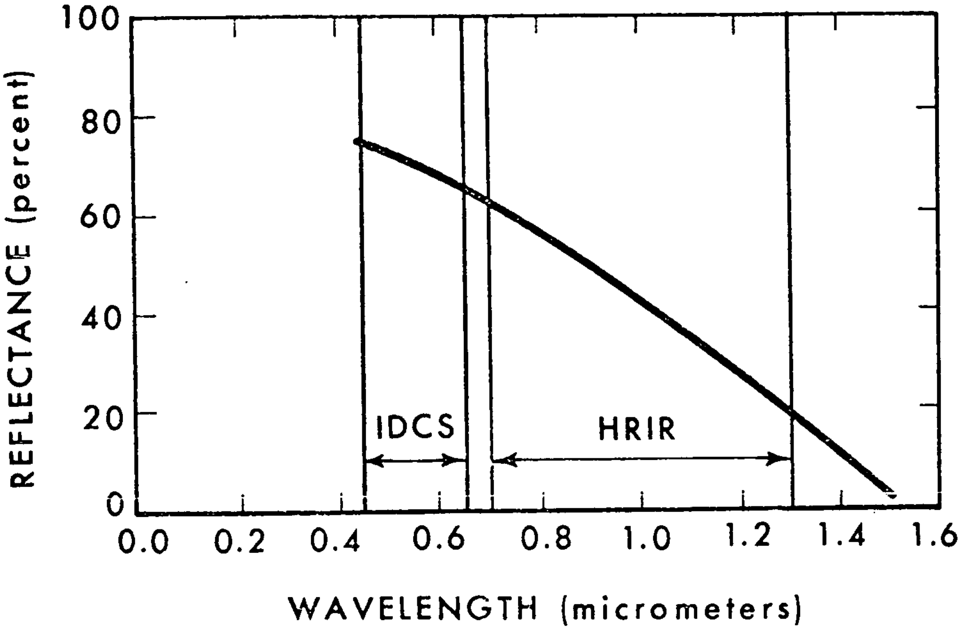


Figure 4. Spectral Reflectance of melting snow (Mantis, 1951).