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OPERATIONAL APPLICATIONS OF NOAA-VHRR IMAGERY IN ALASKA

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ABSTRACT

A discussion of near-real time operational applications of NOAA satellite enhanced thermal infrared imagery to snow monitoring for river flood forecasts, and a photographic overlay technique of imagery to enhance snowcover are presented. Ground truth comparisons show a thermal accuracy of ∿±1°C for detection of surface radiative temperatures. The application of NOAA imagery to flood mapping is also presented.

INTRODUCTION

In Alaska, snow is a fact of life for most of the state for at least 6 months of the year and, in the Arctic, it is present for 8 to 9 months. It is surprising, therefore, that more is not known about the snowcover at this stage of development. The facts are, however, that observation stations and snowcourses are sparse; the population is small; and what ground based data is present tends to be clustered around the larger population centers: Anchorage, Fairbanks, and Juneau. For this reason, the availability of daily synoptic NOAA - Very High Resolution Radiometer (VHRR) imagery was a welcome addition to the sparse data network of snowcover observations.

The NOAA series satellites are polar orbiting and sun-synchronous. The VHRR is only one of many sensors which are carried on board the satellite, but is the only one of interest for snow observations. Imagery is produced in the visible portion of the spectrum (0.6 - 0.7 μm) and in the thermal infrared (10.5 - 12.5 μm), hereinafter referred to as IR. Standard imagery is ∿1:8.5x10^6 scale and a single orbital pass can scan an area 1700 km wide and about 6000 km long. Consequently the entire state of Alaska can be monitored easily in two successive passes. No other satellite provides this frequency of coverage at Alaska's latitude. Resolution is 900 meters at nadir. The IR imagery can also be calibrated to display radiative surface temperatures to an accuracy of ±1°C (Barnes, *et al.*, 1974), and has been applied successfully to synoptic snowmelt monitoring.

Previous work on applications of NOAA-VHRR has centered mainly on snowmapping for water resource information or for scientific interest (Wiesnet, 1974; McGinnis, *et al.*, 1975; Rango, 1975; and Barnes, *et al.*, 1974; Barnes, *et al.*, 1974). Water contained in the snowpack is important as a source of summer water supplies for communities and irrigation and for aquifer recharge. Information obtained for these purposes can be integrated into timely resource allocation plans. In Alaska, however, applications of VHRR imagery are of a more expedient nature. Since few communities in Alaska rely on snowmelt information for water or irrigation, snowmapping is not usually necessary. Instead, snowmelt itself is the important factor because of the frequent flooding it causes. What is needed in Alaska is synoptic, near real-time imagery which clearly delineates the physical (thermal) state of the snowpack, allowing hydrologists to analyze the progress of snowmelt and the possibilities of flooding caused by rapid snowmelt and ice jams.

Since a data-link communication system exists between the U.S.W.S. Offices in Fairbanks, Anchorage, Juneau, and the data acquisition facility at Gilmore Creek (near Fairbanks), the ability to transmit imagery in near-real time is limited only by the necessity to calibrate an IR display. Calibration is necessary because of variability in the VHRR sensor on board the satellite. This problem was solved by programming the calibration functions on a small HP-65 calculator on site at Gilmore tracking station so that the necessary calibration time was only about twenty minutes. Consequently, calibrated IR displays could be sent to the Regional Hydrologist's Office in Anchorage and Fairbanks about two hours after they were acquired.

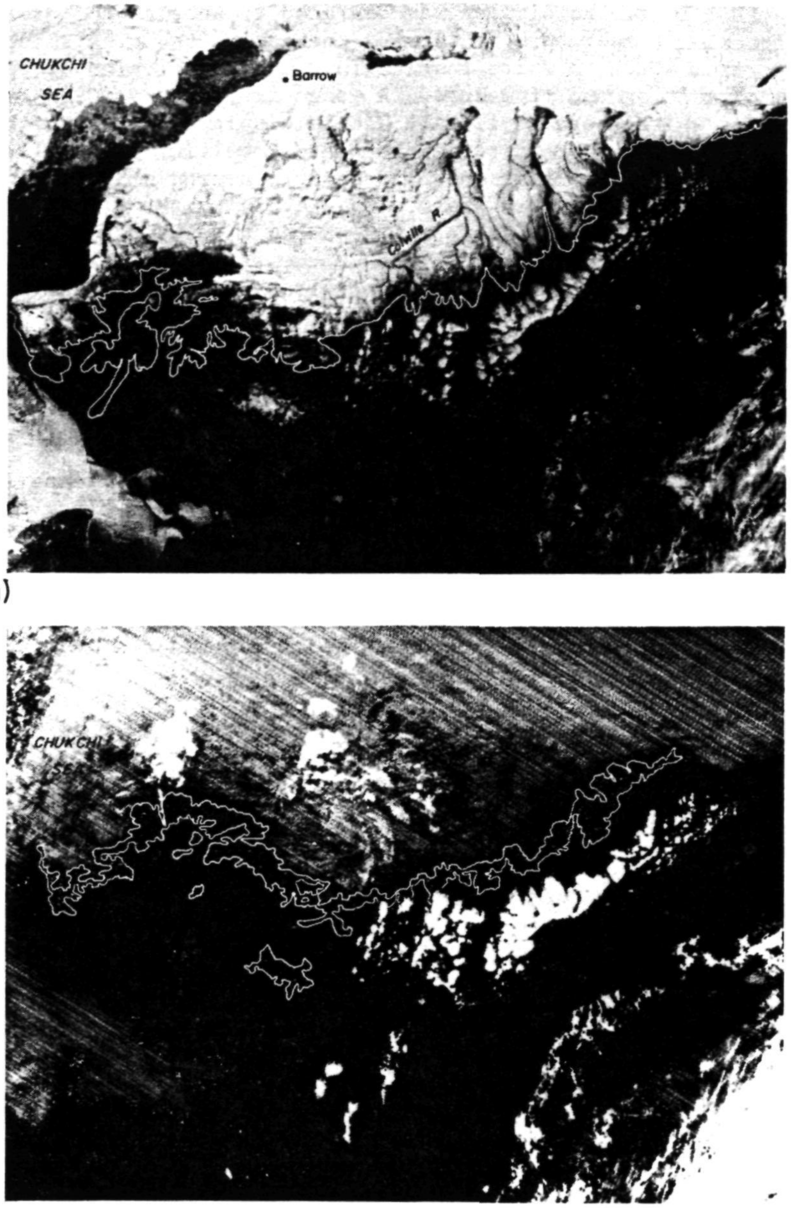
With snowmelt information as a first priority, an enhanced thermal IR display was felt to have the most value as an operational tool. The enhanced IR display was specially developed for hydrologic applications. Since the 0°C isotherm is the most significant feature during the spring snowmelt, this temperature was singled out for enhancement. After tests of a few display schemes, the following scheme was put into daily operational use:

I. Radiative temperatures from -20°C to just below freezing (-0.5°C) are displayed in an ascending gray scale. This means that any temperatures which are detected to be -20°C or colder are displayed as white, and temperatures intermediate between -20°C and -0.5°C are displayed in a shade of gray. The darker the grays, the warmer the temperatures, until at -0.5°C the display is black. This is essentially the same type of display used in a standard IR image, but the display has been adjusted to cover a much narrower band than usual (usually 185-315°K).

II. Next, the display was designed to enhance the areas at the freezing temperature by showing them as white. The abrupt change from black to white results in a clear depiction of the areas of melting and ripe snow. A range from 0 to +1°C is displayed as white, because if only 0°C is displayed as white the resolution of the satellite may not detect melting areas clearly, since the zone of melting snow may be very narrow or patchy, especially in mountainous areas. By displaying the 0°C to 1°C range as white, the display clearly shows the melting regions without adding much error. This is because surface temperatures rise rapidly once an area becomes snowfree, and the actual area which is snowfree and at 1°C is rather small. Essentially what results is a compromised, but very useful and informative snowmap. Melting snow can be seen in the imagery as a stippled white and black area instead of the expected continuous white region (Figure 1).

III. Finally, any areas with detected radiative temperatures equal to or greater than 2°C were displayed as black. This has two advantages; first it produces the same logical display as a visible image, since snowfree areas are always the darker areas in the visible band imagery. Secondly, it results in another abrupt change, this time from white to black to delineate those areas which are snowfree from those which are still at or just above the freezing temperature.

An example of this display scheme on June 4, 1975 is shown in Figure 1, along with the visible band image of the same general area, the Brooks Range and North Slope regions of Alaska. It should be pointed out that both images are always more useful and have more information content when used together. In the thermal IR, the sensor is essentially viewing a field of "glowing" objects and, since normal visual images are not analogous, orientation is extremely difficult using just the IR imagery. By comparing the visible with the IR, considerable additional information is gained. In the example for June 4 (Figure 1) the stippled white area (0 to +1°C) in the enhanced IR image clearly shows the area of melting snow lying in a band across the entire region with still frozen snow to the north and snowfree conditions to the south. A unique situation exists here also, since the snowfree areas are generally at a higher elevation than most of the remaining snowcover. Snowmelt on Alaska's North Slope initiates in the middle elevations (600-900 m) and proceeds in both directions, with the highest peaks and the lowest coastal areas the last to melt. When comparing this "band" of ripe and melting snow with the visible image, it is evident that it corresponds closely to the edge of the snowcover. A limitation of the IR imagery is also shown because the presence of low stratus cloud cover on the coastal plain obscures the snow cover in the IR. The visible imagery shows that a large, open, sea-ice lead is present off the northwest coast and the IR imagery shows that



a)

b)

JUNE 4, 1975, ORBIT No.2519, NOAA-4-VHRR

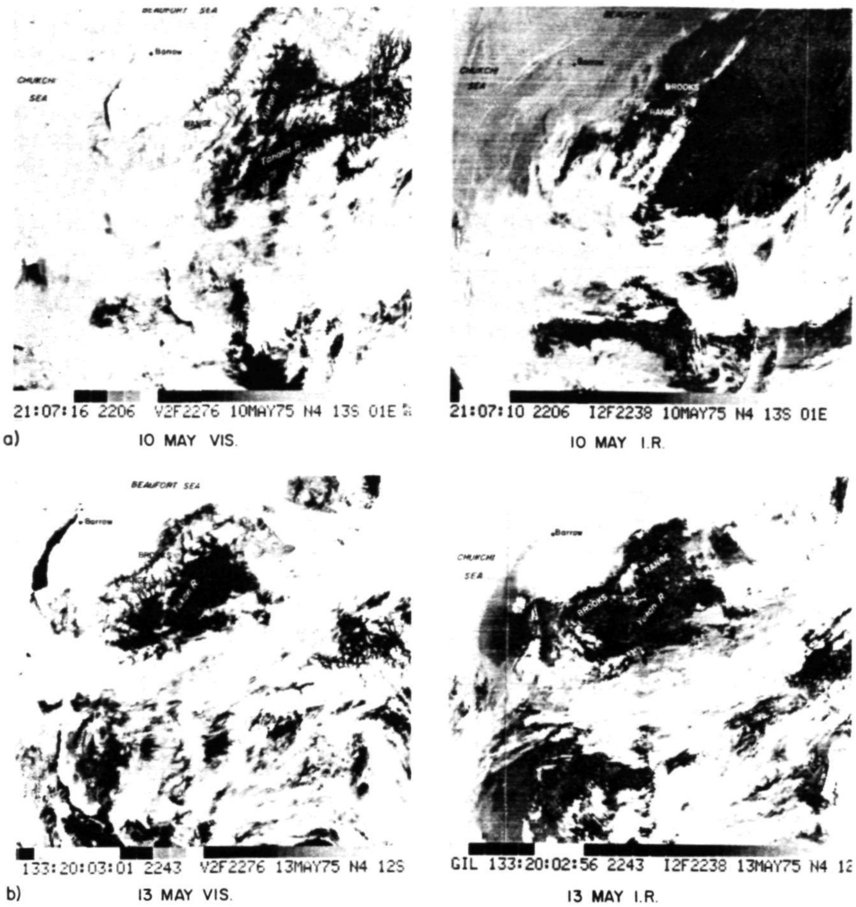
a) Vis. Enlargement
b) Enhanced I.R. Enlargement

Figure 1

it is isothermal with the stratus cloud cover. Water can be seen flowing out over the shorefast sea ice (ice frozen to the shore) at the mouths of the Colville, Sagavanirktok, and Kuparuk Rivers. This is also a unique feature of Arctic rivers. It is due to the pattern of snowmelt and the presence of shorefast ice. Because the coastal plain and shorefast ice are still frozen and snow-covered when runoff begins to flow down the river channels, some of the water simply continues out over the channel ice and shorefast ice at the mouths, flooding large areas of the sea ice.

Fortunately, there were some extreme weather conditions this spring which permitted tests of the response of the enhanced imagery. On May 10 and 11, 1975, record high temperatures of 27°C (80°F) and 26°C (79°F) respectively, were recorded at the Fairbanks WSO and record high temperatures were experienced generally throughout the Tanana and Yukon Valleys. This was also the mid-point of the snowmelt period and consequently snowmelt was rapidly accelerated. Figure 2 shows a series of images, the visible and IR images from May 10, and the same images for May 13. A comparison of the enhanced IR images of both days shows some striking changes and discrepancies. In fact, the first impression is that the snow cover has increased, even though no precipitation fell during the four-day period. The weather on May 13 was generally cooler (10 - 15°C) and moderately strong winds (16 - 20 km/hr) were recorded at most of the interior Alaska weather stations. Interpretation is further confused in that comparisons of both days' visible images with the enhanced IR images shows discrepancies both days between indicated snow cover in each type of imagery.

The worst 1975 case of discrepancy of the imagery is presented here in order to show the dependence of interpretation on surface weather conditions. Under conditions of very high surface temperatures the imagery will indicate greater snowmelt than is actually present. This is probably the result of advection of warm air over the melting snow areas and the integrated thermal effect of warm air and emergent vegetation warmed by the air and sun over the remaining snow cover, causing it to appear "thermally snowfree." The opposite effect occurs on windy, lightly cloudy days, as air movement obliterates any surface heating and low light cloud cover lowers the radiative temperature. There may be other, subtler effects as well, but a theoretical analysis will not be attempted in this paper. The important point is that interpretation of the enhanced IR imagery must be tempered with the synoptic context of surface weather conditions and use of visible, standard IR, and enhanced IR imagery. This will enable an operational river forecaster to give his forecast with more confidence in lieu of the limitations inherent in the enhanced IR imagery.



A COMPARISON OF THERMAL I.R. ENHANCEMENTS UNDER DIFFERENT SURFACE CONDITIONS:

a) May 10, 1975, Record High Temperatures Which Induced Flood Warnings

b) May 13, 1975, Strong Winds

Figure 2 - These examples show the possibility for errors in interpreting enhanced IR imagery if it is not used with the visible and standard IR images. Measurements of the snowfree areas centered around the Yukon River on the two days shown indicated 27% less snowfree area on 13 May than had been measured three days earlier.

GROUND TRUTH TEST

A test of the imagery was made with ground truth water temperature measurements made in the Yukon River at various villages in the interior of Alaska. These measurements are taken by village residents with U.S.W.S. equipment. The comparisons are tabulated in Table 1.

TABLE 1

COMPARISONS OF SATELLITE VHRR-IR MEASUREMENTS
WITH YUKON RIVER WATER TEMPERATURE MEASUREMENTS

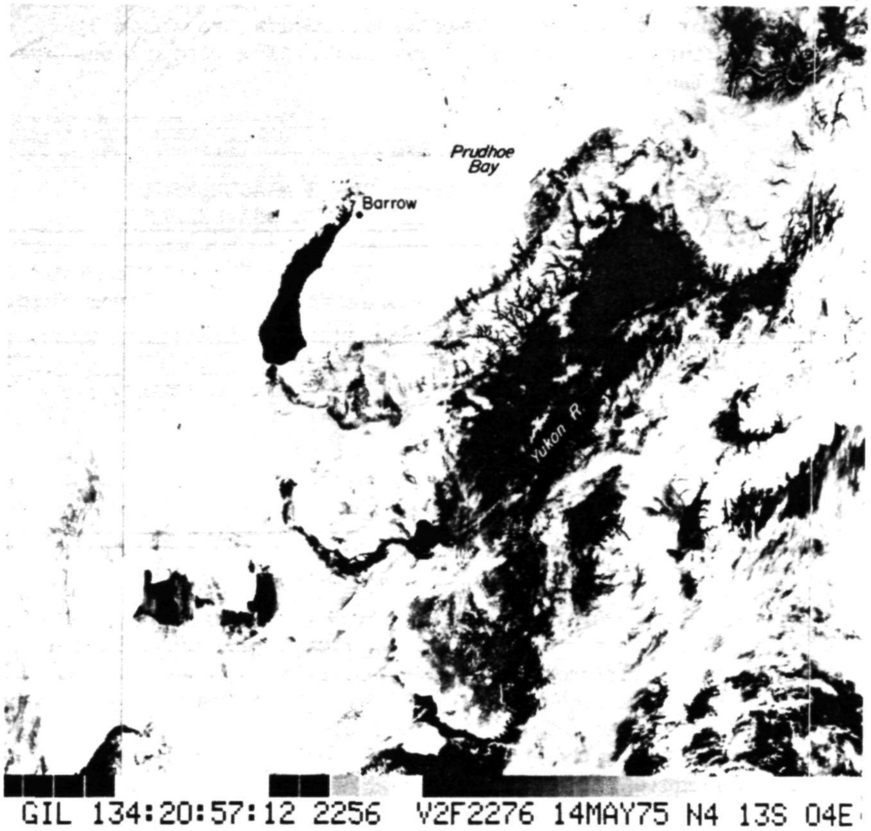
Location of River Temp. Meas.	Date	Thermal IR "Temp." Measured From Enhanced VHRR Imagery	*Measured River Temp.
Beaver, Alaska	14 May	0-1°C	1.7°C
Eagle, Alaska	16 May	>2°C	2.2°C
Circle, Alaska	16 May	0-1°C	1.7°C
Beaver, Alaska	16 May	0-1°C	1.1°C
Beaver, Alaska	19 May	0-2°C (Stippled & Black)	1.7°C

*Courtesy of U.S.W.S. Regional Hydrologist's Office.

The temperatures compare closely with a maximum difference of 0.7°C. This confirms the stated accuracy of NOAA thermal IR imagery of ±1°C (Barnes, *et al.*, 1974b). When temperatures rose above 2°C (36°F), the calibrated IR could no longer differentiate temperatures because the display scheme was designed to show all temperatures above 2°C as black.

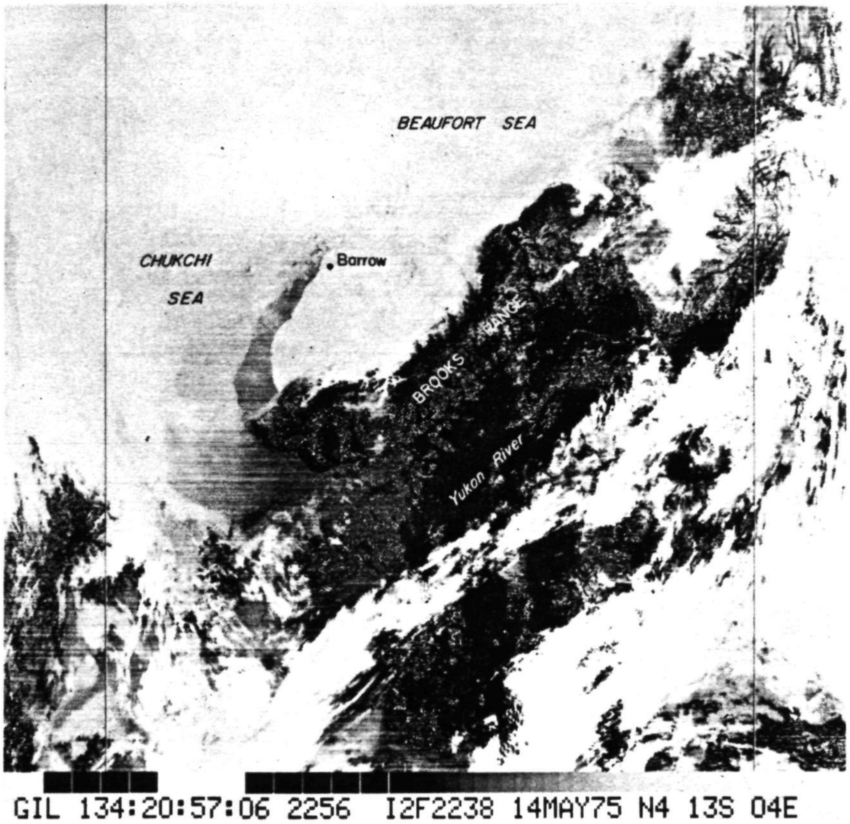
ADDITIONAL APPLICATIONS

Another opportunity to provide snowcover information in a synoptic form is available through the technique of photographic combination of the visible and enhanced IR images. By overlaying one image negative on top of the other and aligning them, a print can be made of an entire frame of the imagery which enhances snow cover (Figures 3, 4, and 5). Since an IR enhancement is used, areas which are "thermally snowfree" will be displayed as black, similar to the visible imagery. Terrain shadowing effects can be somewhat eliminated by this technique because the IR temperatures will cause them to be displayed as white, i.e. snowcovered, when they might be displayed dark in the visible imagery. Because this process uses negatives, snow cover is always retained and enhanced in the image, because its image density in the enhanced IR will be greater than, for instance, the density of a corresponding shadowed area. This also means



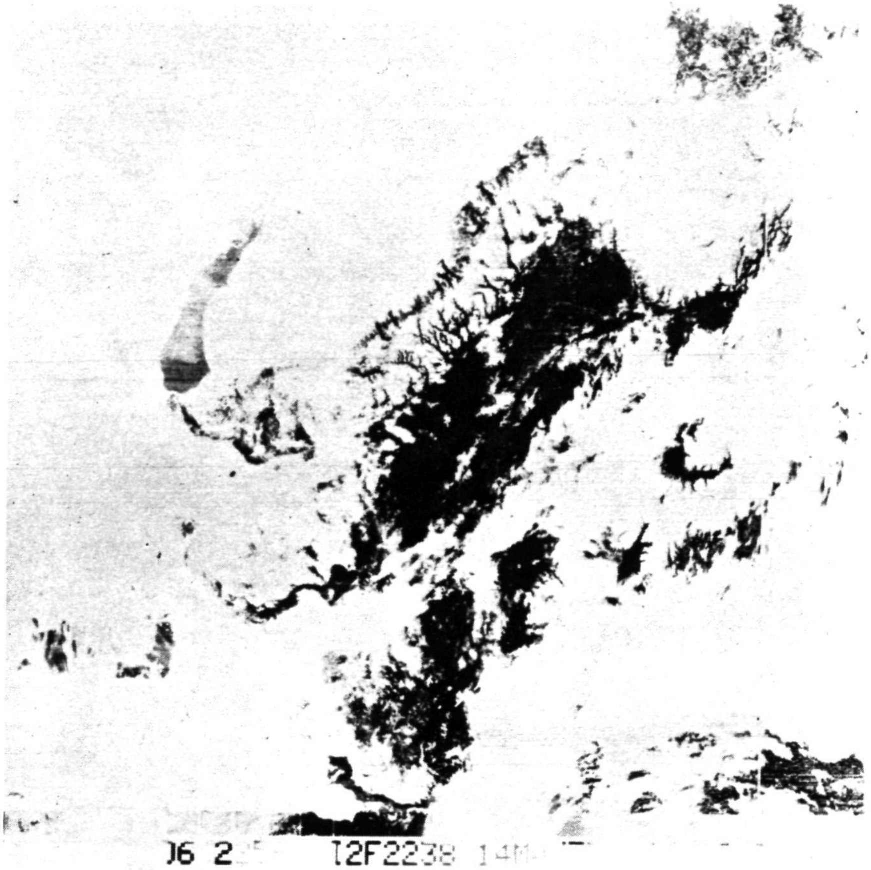
MAY 14, 1975

Figure 3 - An exceptionally clear day during the snow melt period, and nearly the entire state is visible. The negative of this standard visible band image was overlain on the negative of the enhanced IR image (Figure 4) to produce the print shown in Figure 5.



MAY 14, 1975

Figure 4 - This enhanced IR image was used in producing the overlay print shown in Figure 5. Note the stippled white areas indicating melting or ripe snow. Nearly the entire Brooks Range is in this condition. The Yukon River is also visible because it is at or near the 0-1°C temperature range. A water temperature measurement at the village of Beaver was made this same day, and the measured temperature was 1.7°C.



MAY 14, 1975, ORBIT No. 2256
AN OVERLAY PRINT USING BOTH THE VISIBLE IMAGE NEGATIVE & THE ENHANCED I.R. NEGATIVE

Figure 5 - This overlay technique enhances marginally snow covered areas, and may eliminate some problems of shadowing that often effects visible imagery.

that marginally snowcovered (patchy) areas are enhanced, because they are more likely to be at the freezing temperature and thus displayed as white. Some shadowed areas may be displayed as dark in the enhanced IR as well because they are just below the freezing temperature. This problem could be remedied by expanding the enhanced IR display scheme to display a wider temperature range in white. This was not attempted in Alaska, however, because it would eliminate detection of "ripe" snow, which, in Alaska, is a more important factor. In snow surveys where detection of melting snow is not critical, this technique could prove very useful.

The overlay technique is not operational in real time because the images can only be produced photographically at present. This is not a limitation for water resource inventories however, and the possibility exists for daily or weekly snow cover overlay images which could be made available a day or two after initial acquisition.

Snowmelt runoff is responsible for many floods in Alaska and, during the river break-up, ice jams can cause rapid and unpredictable rises in water levels both when they form and again when they break. Two floods caused by ice jams were observed in the standard IR imagery and in the enhanced IR during the river breakup. Both were on the Yukon River and both flooded areas were greater than 2500 km^2. The first flood occurred near Holy Cross, Alaska, a Yukon River village, on May 24, 1975. It is depicted best on the regular IR imagery, and an enlargement showing the flooded area is shown in Figure 6. The flooded area was measured with a polar compensating planimeter and found to be 2590 km^2 ±5%. Just as a comparison, this is more than 5 times the surface area of Lake Tahoe. NOAA imagery provided the only areal measurement available for this flood.

A second flood caused by ice jams occurred May 29, 1975, in the Yukon Delta. The flooded area was also measured with a planimeter and found to be 2710 km^2 ±5%. A comparison of the mapping accuracy is pending in lieu of receipt of a LANDSAT image made of this area on the same date.

CONCLUDING REMARKS

NOAA VHRR imagery has demonstrated its utility for daily synoptic, near-real time snowmelt information. By using all the available VHRR imagery (visible, IR, and enhanced IR), reliable and timely supplemental river forecast information is available by 3 p.m. each day. Ground truth comparisons are very encouraging and more will be sought. A NOAA satellite field service station is to become operational in November of this year and tests and developments will continue as new data needs and uses evolve.

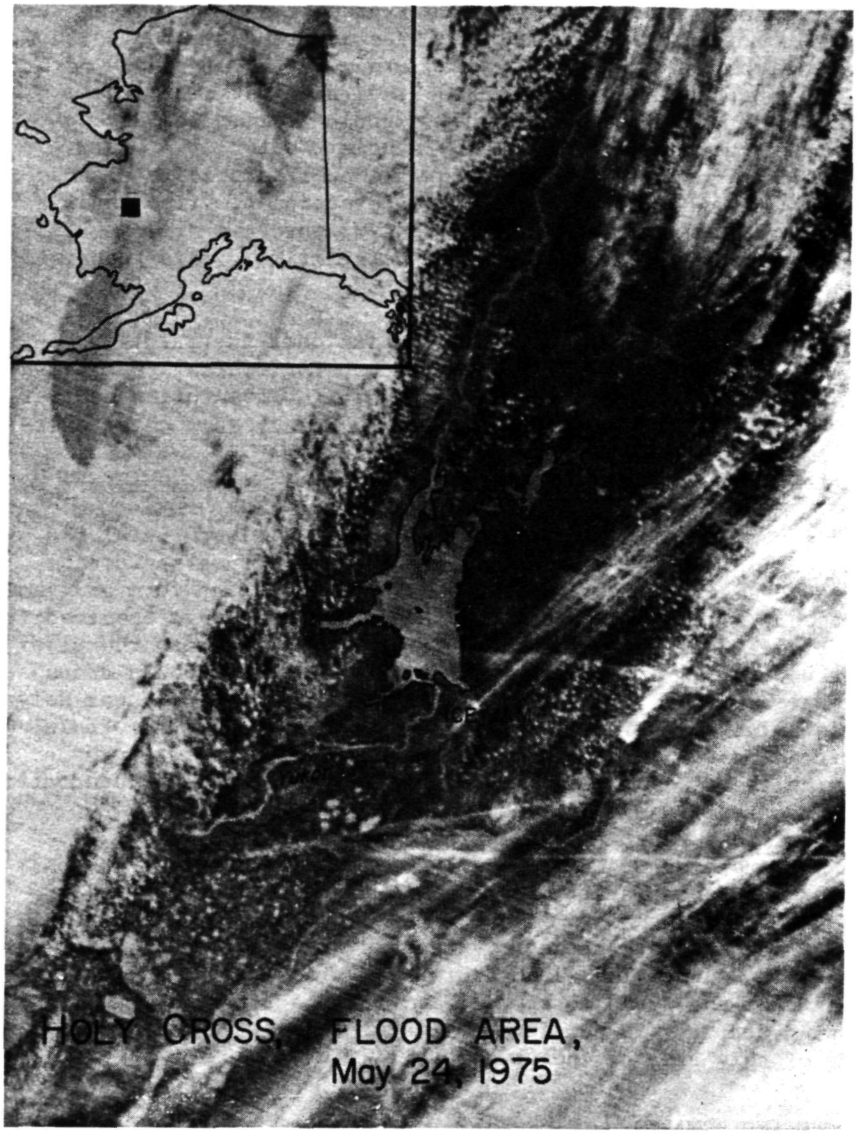


Figure 6 - An enlargement of a standard IR image demonstrating the ability of the VHRR to detect flooded areas. This flood was measured using a polar compensating planimeter and found to be 2590 km^2 in area. This is more than five times the surface area of Lake Tahoe (499 km^2).

ACKNOWLEDGEMENT

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