

## SECTION 95

SNOW STUDIES USING THERMAL INFRARED  
OBSERVATIONS FROM EARTH SATELLITES

by

James C. Barnes\*  
Allied Research Associates, Inc.  
Concord, MassachusettsINTRODUCTION

This report summarizes work performed for the Environmental Sciences Group of the National Environmental Satellite Service of NOAA, under Contract No. 1-35350. The purpose of this contract is to study the application of satellite high resolution infrared data for mapping snow cover. The study has two objectives: (1) to determine whether existing radiometers onboard the Nimbus and ITOS satellites can provide hydrologically useful snow information, and (2) to develop analysis techniques applicable to future IR sensor systems on earth satellites. The IR measurements are being analyzed in conjunction with concurrent satellite photographs and conventional snow cover data.

DATA SAMPLE

Infrared measurements from the Nimbus 4 and ITOS-1 satellites are being analyzed in this study. The Nimbus 4 THIR (Temperature Humidity Infrared Radiometer) system was in operation from early April 1970 until 8 April 1971, except for a brief period during January. ITOS-1 was launched in February 1970 and operated until June 1971. The most usable data from the ITOS SR (Scanning Radiometer) system were during the period from December 1970 through April 1971.

The infrared channels of the THIR and SR sensors measure in the same spectral interval (10.5 to 12.5  $\mu\text{m}$ ) and are similar in spatial resolution (approximately 8 km). Thus, measurements from the two sensors can be considered compatible. Since these were the first high-resolution radiometers to measure in the 10.5 to 12.5  $\mu\text{m}$  channel, the Nimbus 4 and ITOS-1 satellites have provided for the first time both nighttime and daytime thermal infrared data.

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\*The author's current affiliation is with Environmental Research & Technology, Inc., Lexington, Massachusetts 02173. The work reported in this paper is being continued at ERT, Inc.

Data have been analyzed for three primary geographic areas: (1) the Northeastern United States, including New England and New York; (2) the Upper Mississippi-Missouri River Basin region; and (3) the Sierra Nevada in California. Infrared measurements during periods of snow cover and snow cover change are available for all three of these areas, each of which has different terrain and vegetation characteristics. A few analyses have been extended into the south-central part of the country and into other mountain areas, principally the Colorado Rockies and the Pacific Northwest.

#### ANALYSIS OF FILM STRIP DATA

For the geographic areas described above, the temperature patterns evident in Nimbus THIR and ITOS SR film strip data have been mapped onto base maps and have been correlated with snow distributions mapped from satellite photographs, snow reports obtained from climatological data summaries, and other information derived from elevation and forest cover charts. These analyses are described in the following paragraphs.

#### NORTHEASTERN UNITED STATES

##### Nimbus 4 THIR

Very good quality data were available over the Northeast during April and May 1970, early in the operation of Nimbus 4. Primarily through identification of land features, the region was determined to be cloud-free in passes on six dates during this period. Snow distributions evident on concurrent Nimbus IDCS (Image Dissector Camera System) photographs were also mapped for these dates and overlaid on the mapped IR temperature patterns.

The period from 14 April to 5 May 1970 was a period of rapid snow melt in New England and New York. Snow reports indicate that most of the higher terrain was snow covered in early April, whereas by the end of the month little snow cover remained. The decrease in snow extent is clearly evident in the IDCS photographs. On 14 April, the IR film strip displays an area of distinctly lower temperature that correlates very closely with the area of snow cover mapped from the photograph. On the other dates analyzed the agreement is also good; on 5 May, when the photograph shows little or no snow cover, the IR temperatures are uniformly higher over the entire area. In these film strips, no variation in gray tone can be detected within the snow-covered areas; these areas simply appear uniformly colder than the lower elevation, non-snow covered terrain such as the Hudson, Mohawk, and St. Lawrence Valleys.

## ITOS-1 DRSR

Temperature patterns were also mapped from a sample of ITOS-1 nighttime DRSR film strips from February and March 1971. In each case sufficient identification of land features, such as coastlines, lakes and river valleys, was evident in the IR imagery to determine the cloud-free regions. These data also show good agreement in most instances between areas of lower DRSR temperatures and snow cover. In one February case distinct variations in gray tone are evident within areas such as the Adirondack Mountains of New York; more detailed analysis is currently being carried out to determine whether these variations can be related to differences in elevation and vegetation, since the area is thought to be uniformly snow-covered at that time.

A DRSR pass on 9 February shows particularly distinct gray-tone patterns over the eastern and central United States. Three bright bands of significantly lower temperature exist: one across Southern Missouri and northern Arkansas into Oklahoma; another from Ohio and western Pennsylvania, southward across Kentucky and Tennessee to northern Mississippi; and the other along the Appalachians. The colder bands correlate very well with areas of recent snowfall (on 7 and 8 February, snow fell as far south as Mississippi). Snow reports indicate from 1 to 6 inches of snow within the areas of lower temperature; no snow was reported outside these areas.

## UPPER MISSISSIPPI-MISSOURI RIVER BASIN REGION

Nimbus 4 daytime THIR film strips over the Upper Mississippi and Missouri River Basins region have been analyzed for several dates during December 1970. For the data analyzed areas of lower temperature are generally in good agreement with the actual limit of the snow cover as mapped from concurrent IDCS photographs. In most cases, in fact, a narrow band of less than one inch of snow cover through central Minnesota and the Dakotas appears as an area of slightly higher temperature than does the surrounding snow-covered terrain.

## SIERRA NEVADA

Similar analyses have also been performed for some 15 Nimbus 4 daytime passes over the Sierras during the runoff period of April, May, and June 1970. In many of the film strips, two distinct gray levels are evident in the area of the southern Sierras. The maximum brightness (lowest temperatures) varies considerably from day to day, however, indicating that quantitative evaluation of IR film strips on a day to day basis is difficult. In comparative analyses with the snow extent mapped

from concurrent photographs, the area of brighter tone appears to be associated with the higher terrain in general rather than with the snow-covered areas. The brightest tone occurs within the snow-covered area, but even the extent of this tone does not correlate exactly with the extent of snow cover. The area of lowest temperatures in one nighttime pass analyzed (24 April) is more limited in extent than the corresponding brightest tone in the daytime pass on the same date. Since this is an isolated case, however, it is difficult to draw any conclusions from it regarding differences in daytime and nighttime IR measurements.

### ANALYSIS OF DIGITIZED DATA

In order to obtain a more quantitative evaluation of relationships between measured IR temperatures and snow cover, digitized data are being analyzed. Digitized data are available from Nimbus in the form of 1:1 million scale Mercator maps with nearly full-resolution temperatures printed; ITOS computer printouts also provide close to full resolution data, although ranges of temperature, in approximately  $2^{\circ}$  intervals, are given rather than actual values.

### COMPLETED ANALYSES

The initial analysis of the digitized data has consisted of mapping the temperature distribution (at approximately  $10^{\circ}\text{K}$  intervals) and correlating these distributions with geographic features and with the snow extent mapped from the IR film strips and the Nimbus IDCS photographs.

### NORTHEASTERN USA

The results of the initial analysis for the Northeast indicate the IR temperatures over snow-covered terrain to be several degrees higher than would be anticipated. For three representative passes, the IR temperature values that provide the best fit with the snow line mapped from the IDCS photographs (and with the snow line mapped from the IR film strips, which as stated earlier was found to be in close agreement with the IDCS snow line) are as follows: (14 April)  $T = 285^{\circ}\text{K}$ , (16 April)  $T = 290^{\circ}\text{K}$ , (26 April)  $T = 289^{\circ}\text{K}$ . For these same dates, the average temperatures for the nonsnow-covered areas of southern New England are about 292, 296, and  $296^{\circ}\text{K}$ , respectively. The temperatures for representative ocean areas just east of New England remain about 274 to  $276^{\circ}\text{K}$  throughout the period. Thus, the sensor system seems to be relatively stable and the snow-covered areas are consistently 6 to  $7^{\circ}\text{K}$  colder than the nonsnow-covered areas. However, even with a melting snow surface, one would expect the sensor to measure a temperature of near  $273^{\circ}\text{K}$  over the snow; the actual measured temperatures are some 10 to  $15^{\circ}\text{K}$  higher than the expected value.

## FAR WEST

Nimbus daytime passes over the Sierras on 5 and 31 May 1970 also display temperatures somewhat higher than anticipated. On 5 May the temperature that appears to be associated with the boundary of the brightest tone in the film strip is  $290^{\circ}\text{K}$ ; on this date, the lowest temperatures measured over the Sierras are about  $276^{\circ}\text{K}$ . On 31 May, the temperatures are some  $10^{\circ}$  higher than on 5 May.

Analysis of the daytime and nighttime maps on 24 April 1970 indicates that the nighttime temperatures over the snow-covered Sierras region are some 10 to  $15^{\circ}$  lower than the daytime values. The nighttime minimum values are between  $260^{\circ}$  and  $265^{\circ}\text{K}$  and the maximum values near  $275^{\circ}$ ; these are closer to the temperatures anticipated for snow surfaces.

The ITOS computer printouts also show temperatures closer to those anticipated, especially during nighttime. For the three dates for which data were available, the mean temperatures over the Sierras are as follows: (7 February)  $T(\text{day}) = 276^{\circ}\text{K}$ ,  $T(\text{night}) = 264^{\circ}\text{K}$ ; (18 March)  $T(\text{day}) = 272^{\circ}\text{K}$ ,  $T(\text{night}) = 260^{\circ}\text{K}$ ; (15 April)  $T(\text{day}) = 276^{\circ}\text{K}$ ,  $T(\text{night}) = 264^{\circ}\text{K}$ . It is seen, therefore, that despite the advance in season the overall temperatures remain similar.

The nighttime IR temperatures are also seen to be some 10 to  $15^{\circ}\text{K}$  lower than the daytime. However, it has been noted that despite the lower temperatures, the definition of the higher mountains is obscured in the nighttime measurements. This is apparently due to the fact that the lower terrain, particularly over the Great Basin, cools considerably at night. The result is a uniformly low temperature over the entire area, regardless of elevation.

## UPPER MISSISSIPPI-MISSOURI RIVER BASIN REGION

Three Nimbus passes over the Midwest have been analyzed. In two daytime passes, on 17 and 29 December 1970, the snow line as mapped from IDCS photographs is associated with IR temperatures of  $270$  to  $275^{\circ}\text{K}$ . In nighttime data on 29 December, the corresponding temperature is about  $260^{\circ}\text{K}$ . Thus, in this geographic area also, the difference between daytime and nighttime IR measurements over snow cover is 10 to  $15^{\circ}\text{K}$ . Overall, the temperatures are considerably lower than those measured in the spring over the Northeast, but are in the same range as those measured by ITOS over the Sierras.

## ANALYSES IN PROGRESS

Further investigations are currently in progress to determine in more detail the structure of the IR temperature measurements across snow fields. For each of the above geographic areas, analyses using both the data on hand and additional data will include: (1) Determination of the temperatures that best fit the apparent snow line mapped from the IR film strips and from satellite photographs, and the average temperatures over snow-covered and nonsnow-covered areas; (2) for selected climatological stations representative of both lower and higher elevations in the regions of interest, determination of the mean value and the range of measured IR temperatures for that immediate area; and (3) for each observation date, plotting of snow depth and the maximum and minimum surface temperatures for each climatological station, along with station elevations and profiles of the general elevation of each area. The results of these analyses will be evaluated with regard to the satellite system (Nimbus or ITOS), the season of observation (some passes are midwinter whereas others are in spring during snow melt periods), snow amount, terrain elevation, and vegetation characteristics.

In addition to the above analyses, investigations are underway to determine the effects of variations in emissivity and surface temperature that might result from partially snow-covered ground. Preliminary calculations have indicated that during daytime, even a relatively small amount of bare rock (say, 2/10 rock and 8/10 snow within the field of view of the radiometer) might have a significant effect on the measured temperature.

SUMMARY OF PRELIMINARY RESULTS

## ANALYSIS OF FILM STRIP DATA

1. The ITOS-1 direct readout data (DRSR) are less noisy than the Nimbus 4 THIR film strips. Small temperature variations are, therefore, more clearly depicted in the ITOS data.
2. In the Northeast (New England and New York) during April 1970, areas of distinctly lower temperature (brighter tone) are displayed in several Nimbus film strips. The limits of these areas are in close agreement with the limits of snow cover mapped from Nimbus photographic data and from snow reports.
3. Although the snow-covered areas appear in a uniform gray tone in the above-mentioned Nimbus data, considerable variation in the temperatures measured over snow cover is detectable in an ITOS nighttime DRSR

pass across the Northeast in February 1971. Later in the same month, new snowfall of from 1 to 6 inches across parts of the south-central USA is clearly depicted in ITOS nighttime DRSR data.

4. In the Upper Mississippi-Missouri River Basins region, snow-covered areas during December 1970 appear colder than nonsnow-covered areas in Nimbus film strips. In fact, an area in the Missouri Basin, in which an inch or less of snow depth is reported, appears noticeably warmer than the surrounding areas of several inches snow depth. The forested area near Lake Superior, which in photographic data always appears in a darker tone than the adjacent nonforested areas when snow covered, cannot be detected in the IR film strips.

5. In Nimbus daytime film strips over the West, the Sierra Nevada and other mountain ranges appear distinctly colder than the lower elevations. However, the extent of the coldest patterns appears to be associated with the higher elevation terrain rather than with snow extent.

#### ANALYSIS OF DIGITIZED DATA

1. In the Nimbus daytime data over the Northeast during April 1970, the snow-covered areas are at least 6 to 7°K colder than the nonsnow-covered areas. However, temperatures within snow-covered areas are as high as 285 to 290°K, some 10 to 15° higher than would be anticipated. These measurements were made on relatively warm days, with the reported maximum air temperatures at stations within the snow-covered areas being as high as 290°K.

2. In Nimbus daytime data over the Sierras during May 1970, the measured temperatures are also as high as 290-300°K, considerably higher than would be anticipated even over a melting snow surface.

3. ITOS data during February, March, and April 1970 depict daytime temperatures over the Sierras of 272 to 276°K and nighttime temperatures of 260 to 264°K. During nighttime, however, definition of the mountain ranges is greatly reduced because of the cooling of the lower elevation terrain.

4. In a limited sample of Nimbus data over the Midwest during December 1970, the snow line mapped from photographic and film strip data is associated with an IR temperature of 270 to 275°K in the daytime measurements and about 260°K in the nighttime measurements.