SECTION 88

APPLICATION OF SATELLITE INFRARED MEASUREMENTS TO MAPPING SEA ICE

by

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INTRODUCTION

This report summarizes work performed for the Environmental Sciences Group of the National Environmental Satellite Service of NOAA, under Contract No. 1-36025. The purpose of this contract is to study the application of ITOS-SR (Scanning Radiometer) Infrared measurements for mapping sea ice. The study has three principal objectives: (1) To determine whether ice distributions can be mapped from nighttime ITOS-SR data using the techniques and thresholds developed previously for Nimbus HRIR (High Resolution Infrared Radiometer) data; (2) to compare nighttime and daytime infrared measurements in the 10.5 to 12.5 μm spectral interval using ITOS and Nimbus 4 data; and (3) to perform quantitative analyses of the ITOS-SR photofacsimile data.

The work accomplished has included detailed mapping of ice features visible in the ITOS nighttime DRSR (Direct Readout SR) pictorial data and in Nimbus summertime film-strip data. Analyses of digital temperature values from computer printouts of ITOS stored data and from Nimbus data listings have also been undertaken, and densitometric measurements of both ITOS and Nimbus data have been initiated.

ANALYSIS OF PICTORIAL DATA

Detailed temperature patterns in the area of Northern Hudson Bay, Foxe Basin, and Hudson Strait were mapped from several ITOS DRSR passes during the 1971 winter season. The persistence of various areas of higher temperature indicates that these are most certainly associated with areas of lesser ice concentration near the islands and with leads and cracks in the narrow straits. The Nimbus film-strips mapped have been primarily for the purpose of comparing the film-strip patterns with digital temperature values. The techniques used to identify cloud-free areas and to map ice boundaries were those developed in earlier studies by the author and his associates using data from previous Nimbus satellites.

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ANALYSIS OF DIGITAL TEMPERATURE VALUES

Computer printouts for three passes of ITOS stored data over the western Canada/Alaska region during February, March, and April 1971 have been analyzed. Although cloud obscuration is evident in some areas, temperatures in the Beaufort Sea appear reasonable for ice-covered ocean. Warmer areas are evident along the northern coasts of Canada and Alaska.

Two of the ITOS passes were selected for more detailed analysis because of cloud-free conditions near Banks Island, an area previously well-documented in Nimbus 2 HRIR data. Although the values given in the ITOS data are in alphanumeric code and represent an average value of about three data spots, the orientation of the digital lines for these two passes corresponds closely to the orientation of the scan lines for a Nimbus 2 pass on 9 November 1966. A comparative analysis was performed, therefore, for these ITOS and Nimbus data.

The results of these analyses indicate that the ITOS data are not as noisy as the Nimbus 2 data, despite the fact that each of the alphanumerics used for the ITOS data represents not the actual T_{bb} value corresponding to the point, but the range of values in which the actual T_{bb} is to be found. Secondly, the ranges of temperatures corresponding to the ice ($250^{o}K$ to $260^{o}K$) and Banks Island ($240^{o}K$ to $250^{o}K$) are realistic. Thus, a tentative conclusion based on these analyses is that the ITOS digital data can depict significant ice features better than the Nimbus 2 because of the reduction in noise.

DENSITOMETRIC MEASUREMENTS

NIMBUS 4 DATA

Densitometric measurements have been made from Nimbus 4 positive transparencies for five passes over the Greenland-Baffin Bay area in April and May 1970. For these film strips, the following values were obtained for the calibration gray-scale step wedge:

Density	Gray-Scale Step Number									
	1	2	3	4	5	6	7	8	9	10
Mean	2.0	1.9	1.7	1.5	1.4	1.2	1.0	0.9	0.8	0.7
Minimum	1.9	1.6	1.4	1.3	1.1	0.9	0.8	0.7	0.6	0.6
Maximum	2.1	2.1	1.9	1.7	1.5	1.4	1.1	1.0	0.9	0.8

Using the mean densities obtained for the 10-step gray-scale wedge and the relationship between T_{bb} and the gray-scale steps given in the Nimbus 4 User's Guide, a Density-T_{bb} calibration was obtained. This "calibration" chart shows that the greatest temperature resolution, as defined by $\Delta D/\Delta T_{bb}$ is obtained at the two intervals between Steps 1 and 4,

and between Steps 5 and 7. The latter interval spans the range of temperatures significant for the identification and mapping of sea ice boundaries. In this regard, the Nimbus 4 data are similar to those of Nimbus 3 and much better than those of Nimbus 2.

A number of spot measurements were also made of representative ice features in the same passes. From the measured values and the above-mentioned Density-T_{bb} calibration chart, the following temperatures were obtained:

Feature	Mean Density	Mean T_{bb}	Maximum T_{bb}	Minimum T_{bb}
Ice Cap	0.91	234°K	256°K	196°K
Pack Ice	1.12	266°K	274°K	260°K
Water	1.26	278°K	283°K	273°K

The derived temperatures are reasonable when one considers that both Pack Ice and Open Water may contain some areas of "open pack."

ITOS-1 DRSR DATA

The ITOS data format does not include a calibration step wedge, nor is there a "nominal" gray scale calibration. Furthermore, due to the photographic processing involved, changes in the positive transparencies are to be expected from pass to pass even though the received signals may be identical. It is therefore necessary to devise some means of "normalizing" the density measurements if they are to be compared. The density of an ocean surface with temperatures at or near freezing was chosen for this "normalization."

Seven DRSR passes, each of which contained cloud-free areas in the region extending from Hudson Bay to Southern Greenland, were selected for analysis. In each pass, densities were measured at the same geographic locations. In comparing the measured values for the different passes it is evident that the density at any point can vary substantially from orbit to orbit. Since it may be assumed that for such points as those over "ice cap" areas, there should be no substantial changes in surface temperatures, the large variations in densities may be assumed to be artifact in the data processing. A second factor which substantiates this conclusion is the fact that the differences in the measurements between two passes are "systematic;" i.e., in general, the value $(D_a - D_b)$ has the same sign and approximately the same magnitude at all points, where a and b are two different passes. Furthermore, the mean values of $D_a - D_b$ for the sample points approximately equals the difference in the measured densities over the sea surface for the same orbit pairs.

Because of the systematic shift in densities between orbits, it was felt that a linear normalization technique, using the sea surface densities as reference, is justified. All measured densities were normalized by:

$$D_j^1 = D_j + kj$$

where

$$k_j = D^{sea}_{\text{orbit 4715}} - D_j^{sea}.$$

(Orbit 4715, 4 February 1971, had the smallest density value, so was selected as the base for the normalization.)

After normalization, the pass to pass differences at any point are significantly reduced, giving proof that the differences in photographic processing are linear at least through the range of densities in question. Furthermore, the results of the analysis of the ITOS densitometric measurements show that the features indicated to be "ice free," "pack ice" and "ice cap," fall into three almost unique classes of densities; that is,

$$D_{\text{ice free}} > .73$$

$$.73 \geq \overline{D}_{\text{pack ice}} \geq .61$$

$$\overline{D}_{\text{ice cap}} < .61$$

These are important findings if "objective" techniques are to be developed for field interpretation of the photographic densities.

ANALYSIS OF SUMMERTIME NIMBUS DATA

The high-resolution radiometer on the earlier Nimbus satellites measured in the 3.4 to 4.2 μm spectral interval. The resulting measurements were contaminated by reflected solar radiation during daytime hours. Thus, Nimbus 4 and ITOS-1, carrying radiometers that measure in the 10.5 to 12.5 μm interval, are the first satellites to provide infrared measurements over the arctic during the summer season.

Summertime data are in the process of being analyzed. In one instance (30 July 1970) a Nimbus 4 IDCS photograph shows an area of ice in central Baffin Bay. The ice cannot be detected in the concurrent IR film strip, in which Baffin Bay appears in a uniform gray tone.

To determine the temperature structure in more detail, digitized temperature values along several scan lines crossing the area were plotted for the same orbital pass. Two of these scan lines are shown in Figure 1,

with the temperatures plotted along the left axis and the corresponding film-strip gray levels along the right axis. These scan lines show that although the sea ice does have a lower measured IR temperature, the temperature values for both the ice and the open water fall into the same gray level. In the remainder of the study further analysis of daytime data will be undertaken to determine whether infrared measurements can provide useful ice information during the summer season.

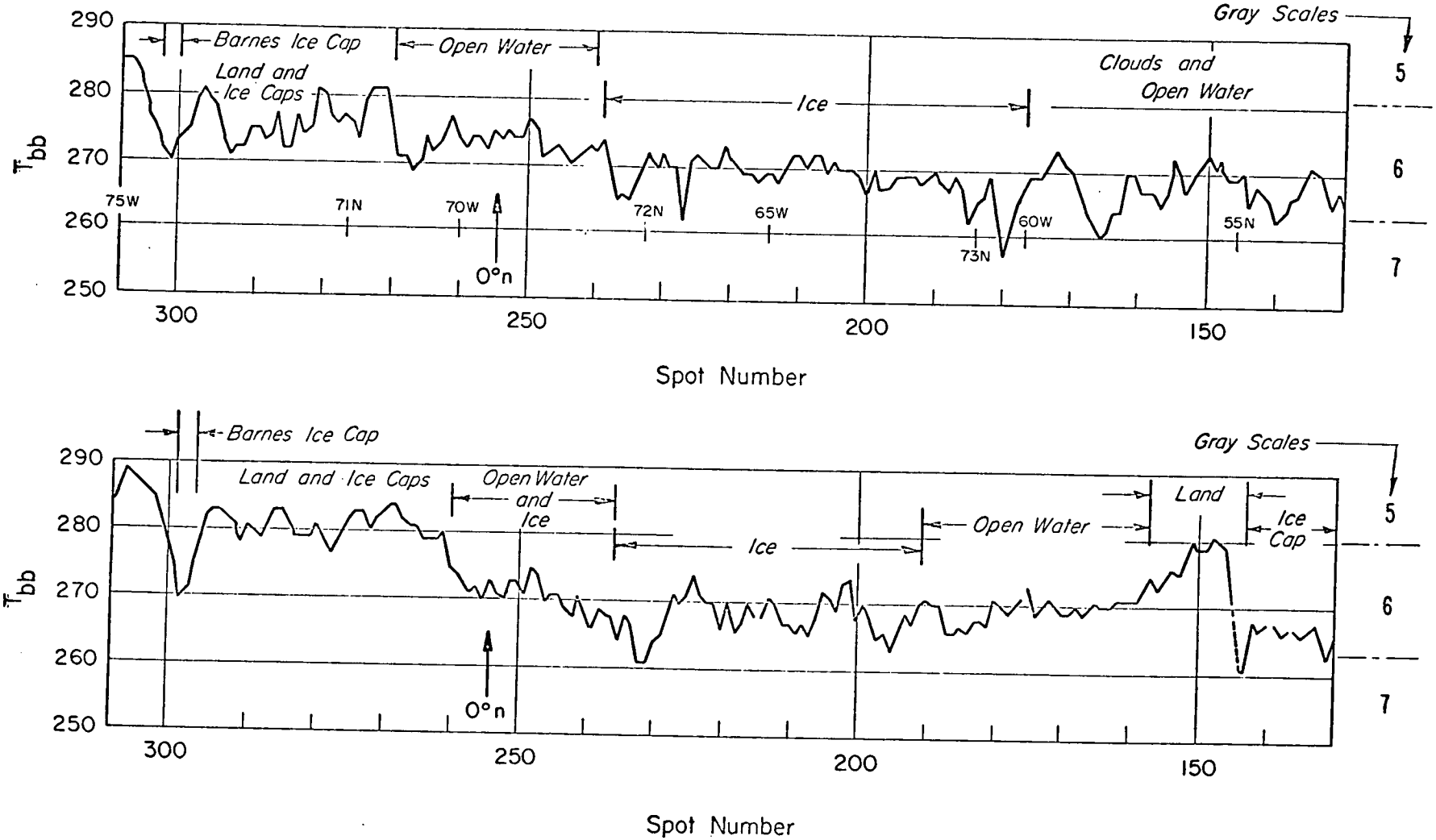

Figure 1 Analysis of digital temperature values along two scan lines crossing Baffin Bay; Nimbus 4 daytime thermal infrared, 30 July 1970.