SPECIAL DISPLAYS OF SATELLITE INFRARED DATA FOR SEA ICE MONITORING

by

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INTRODUCTION

The Arctic Ocean and the fringes of the Antarctic are rather remote and inaccessible parts of the world. Furthermore, being subject to incursions of polar ice and strong storms, they are harsh environments, too. Comprehensive and repetitive oceanographic or meteorological survey by surface vessels, or even by aircraft, would be costly, difficult, and even rather hazardous. The polar-orbiting environmental Earth satellite is thus, in many ways, a suitable sensor platform for such areas.

Knowledge of sea ice distribution and condition is important to commercial and military ship movements in the Arctic and Antarctic. Much physical data on both ice buildup, movement, and decay are needed for understanding of the processes and to develop forecasting methods. Ice cover also plays an important role in the heat balance of polar regions, and this in turn influences the circulation within the atmosphere and oceans.

NOAA OPERATIONAL ENVIRONMENTAL SATELLITES

The second generation of Improved TIROS Operational Satellites was inaugerated in 1970 (Albert, 1968). Environmental satellites of this ITOS series, which are designated NOAA-1, NOAA-2, etc., carry vidicon camera systems (0.5-0.7μm), two-channel scanning radiometers (0.5-0.7μm and 10.5-12.5μm), and solar proton monitors. These satellites are put in near-polar, circular, sun-synchronous orbits at a nominal altitude of 1450 km. Equator-crossing times are 0300 and 1500 local time.

Data are received from these satellites in two modes. Global coverage on a daily basis is provided by temporary storage of information on board the spacecraft by means of tape recorders. The stored data are read out on command to complex command and data acquisition stations in Alaska and Virginia, whence they are relayed by land-line to a central facility and computer complex near Washington, D. C.

Local coverage is provided by means of a direct-readout capability known as APT (Automatic Picture Transmission), which requires only simple receiving and display equipment.

Thermal infrared imagery (9-km resolution at nadir) is used on Earth's night side to supplement the visual imagery (4-km resolution) on the day side to produce global cloud maps at 12-hour intervals. Furthermore, the IR measurements can be used to infer additional information such as cloud-top temperatures/heights (Rao, 1970) and temperatures at the surface of the sea, water or ice, day or night (Smith et al, 1970; Rao et al, 1971). Extensive computer processing of these satellite data is necessary in order to rectify them, normalize them for variable solar illumination and camera distortions or radiometer calibrations, and redisplay them on standard map projections on a regional or global basis (Bristor et al, 1966). Further manipulations of the digitized brightness or thermal values are employed to derive products such as average or composite maximum or minimum charts for selected periods (Booth & Taylor, 1969).

SEA ICE SURVEILLANCE BY SATELLITE

A major problem in the use of either visual or infrared imagery for sea ice surveys is the differentiation between sea ice and clouds, whose reflectances (or temperatures) can often be comparable. Photo-interpretation methods have proved effective, but only when applied by skilled analysts who are familiar with the meteorology/oceanography and geography of the area. Characteristic differences in form, tone, texture, and particularly of persistence and movement, are the principal interpretive tools. Changes in cloudiness from day to day are much greater than changes in the ice pack. Also clouds tend to obscure landmarks otherwise discernible.

Figure 1 is a single vidicon camera frame of the Bering Sea area taken on 14 March 1971 when the polar ice pack was near its maximum seasonal extent. The nominal grid of latitude, longitude, and coastlines is superimposed by computer during display. The boundary of the first-year ice covering the northern and eastern parts of the Bering Sea is clearly evident over most of its length. Although cloudiness is present nearby, confusion with the ice is unlikely except perhaps near the Siberian coast. There is little contrast between the ice pack and the adjacent snow-covered land. Some less reflective areas, usually indicative of the presence of some open water (i.e., less than ten/tenths concentration of ice), are discernible south of such islands as St. Lawrence, St. Matthew, and Nunivak, as well as elsewhere.

The transient nature of clouds in comparison with major ice and snow fields has enabled the development of an automated procedure for suppressing the cloudiness by compositing satellite visual data over periods of time ranging from five days upward to a month (McClain & Baker, 1969). Digitized brightness values, after rectification and normalization, are composited by saving and displaying only the minimum brightness at each grid point in the array during the period. By calibrating the composite minimum brightness (CMB) values externally with respect to the brightness of the Greenland ice cap (high reflectance) and cloudfree ocean areas (low reflectance), it has been found that distinct changes in brightness with time can be related to the concentration and physical condition of the ice, such as the presence or absence of a snow cover or melt water pools (McClain, 1972).

Lack of sufficient solar illumination, however, greatly limits the use of vidicon camera systems or scanning radiometers operating in the visible part of the spectrum for ice monitoring during much of the cold half of the year. This limitation has been overcome largely by the use of thermal infrared imagery (Barnes et al, 1970). Figure 2 is an example of thermal IR imagery obtained by direct-readout in Alaska some 12 hours after the visual image in Figure 1 was obtained. The IR image is unrectified and ungridded, and some "noise" from electrical interference is evident, but major geographic features are easily recognized. The gray-scale display employed for this image has some 32 steps corresponding to temperature intervals of about 4K and proceeding from less than 180K (white) to more than 310K (black). The coasts of Alaska and Siberia are readily seen because of the temperature contrast between the cold land and the relatively warmer ice pack covering the northern portion of the Bering Sea. This contrast is greater than the difference in reflectivity between the snow-covered land and the ice pack as seen in most vidicon pictures, when there is sufficient daylight for usuable television pictures.

SPECIAL DISPLAYS OF INFRARED DATA

Figure 2 is a standard infrared image produced for meteorological purposes. The maximum of 32 gray steps has been expended over a very large temperature range, and thus each step represents a fairly large temperature interval. In an attempt to tailor the IR display for ice analysis, several ice enhancement experiments were run. Figure 3 shows the results of using only 10 gray steps and proceeding from $\geq$ 273.5K (black) to $\leq$ 221.0K (white) with relatively large temperature intervals (see Table I). Figure 4 is the result of using 22 gray steps to cover the same temperature range with a temperature interval of about 2K (see Table II).

In both Figures 3 and 4 the southernmost boundary of the ice pack is clearly delineated by a band of relatively warm, ice-free ocean. Shallow (cool) clouds are present over much of the Bering Sea to the south of the ice pack, and deep (cold) clouds are found to the southeast and over the Aleutians, as well as to the west near northern Kamchatka. Of particular interest are the distinctly warmer areas showing up, for instance, south of the islands St. Lawrence, St. Matthew, and Nunivak, and in the eastern Gulf of Anadyr. These evidently represent areas of significantly thinner or less-concentrated ice (i.e., some open water). The enhanced ice displays facilitate the delineation of features such as these, as well as temperature contrasts associated with coastlines and cloud areas.

CONCLUDING REMARKS

Infrared measurements from Earth satellites now enable sea ice surveys and monitoring to be accomplished during the polar night, which is not possible with visual sensors. Furthermore, the use of thermal data enables additional information, such as the thickness or physical state of the ice, to be obtained or inferred. Enhancement of the IR imagery promotes the detection of significant ice boundaries, openings, thin areas, and can assist in cloud discrimination. Computer printouts of the calibrated temperature values for more quantitative studies are readily produced from the same magnetic tapes used to obtain the imagery. Experiments are being conducted to develop a multiday compositing technique for the filtering of clouds from the scene, although this is proving more difficult than it was with visual range data. The problem stems from the fact that deep temperature inversions are common at high latitudes over land in winter, resulting in some cloud tops being actually warmer than the Earth's surface in nearby cloud-free areas.

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TABLE I.- IR ICE DISPLAY TABLE 5

Radiation Temperature Range	Gray Scale Step	Display Level
≥273.5K	1	0 (black)
268.0 - 273.0	2	10
261.5 - 267.5	3	20
255.5 - 261.5	4	27
249.5 - 255.5	5	32
243.5 - 249.0	6	37
238.0 - 243.0	7	42
231.0 - 237.0	8	47
222.0 - 230.0	9	54
≤221.0	10	63 (white)

TABLE II.- IR ICE DISPLAY TABLE 6

Radiation Temperature Range	Gray Scale Step	Display Level
≥273.5	1	0 (black)
271.0 - 273.0	2	10
268.5 - 270.5	3	14
266.0 - 268.0	4	18
263.5 - 265.5	5	22
261.0 - 263.0	6	25
↓ - ↓	↓	↓
-		
-		
234.0 - 236.0	17	47
231.0 - 233.0	18	49
228.0 - 230.0	19	51
225.0 - 227.0	20	54
222.0 - 224.0	21	58
≤221.0	22	63 (white)

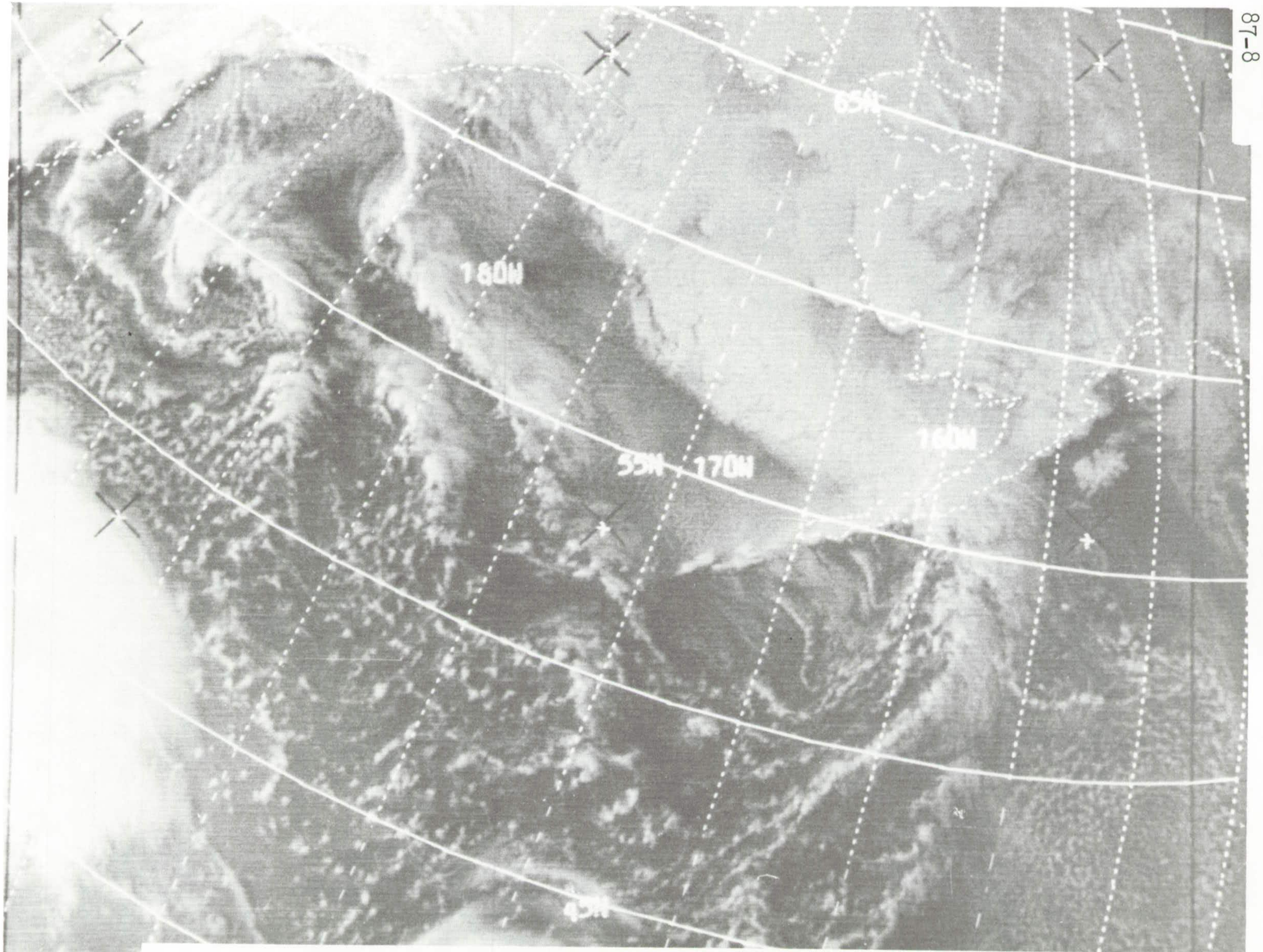

Figure 1. Pass 5186, Frame 2, taken by the Advanced Vidicon Camera System on the ITOS-1 satellite, 14 March 1971, in Bering Sea Area.

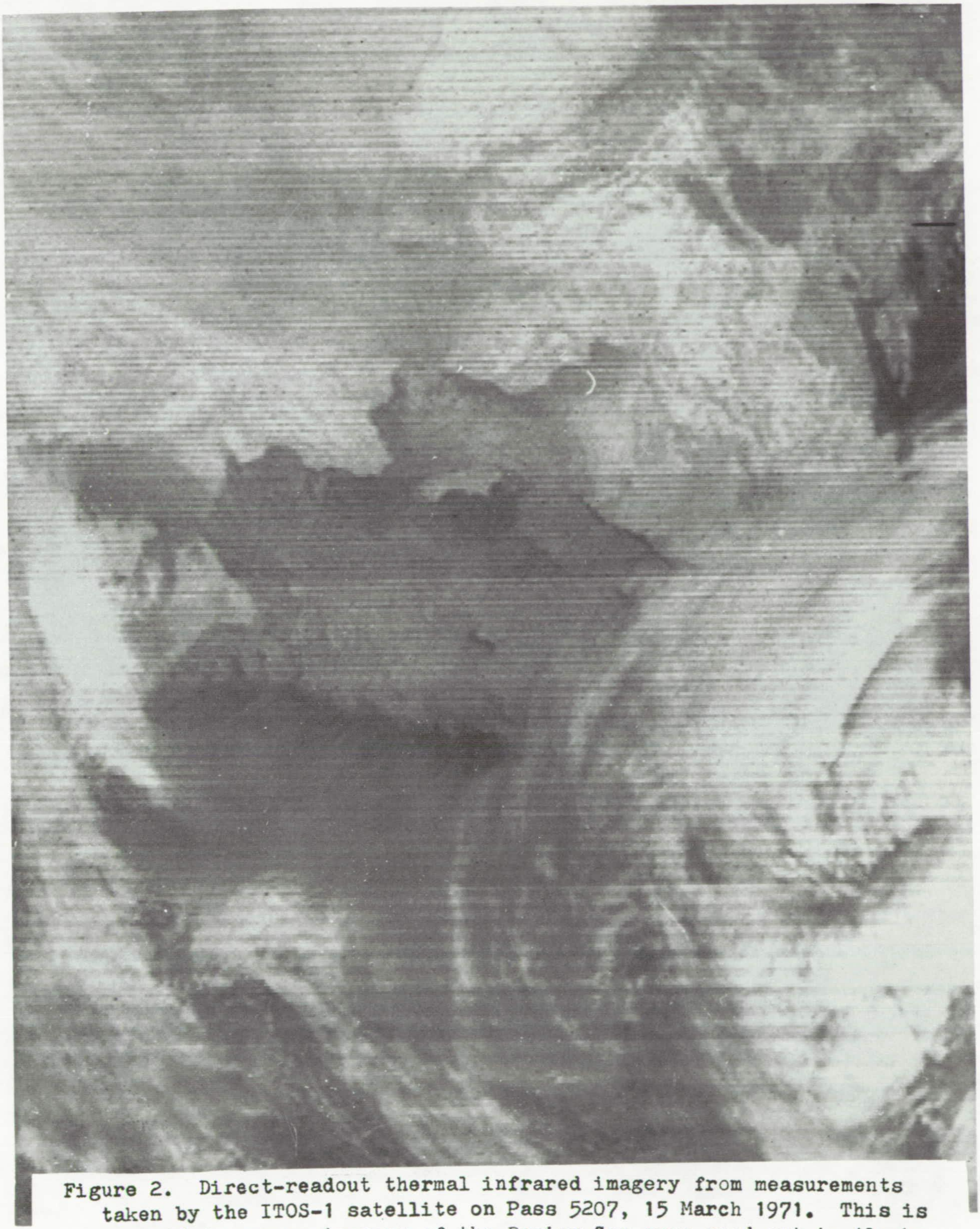

Figure 2. Direct-readout thermal infrared imagery from measurements taken by the ITOS-1 satellite on Pass 5207, 15 March 1971. This is ungridded scanner imagery of the Bering Sea area read out in Alaska.

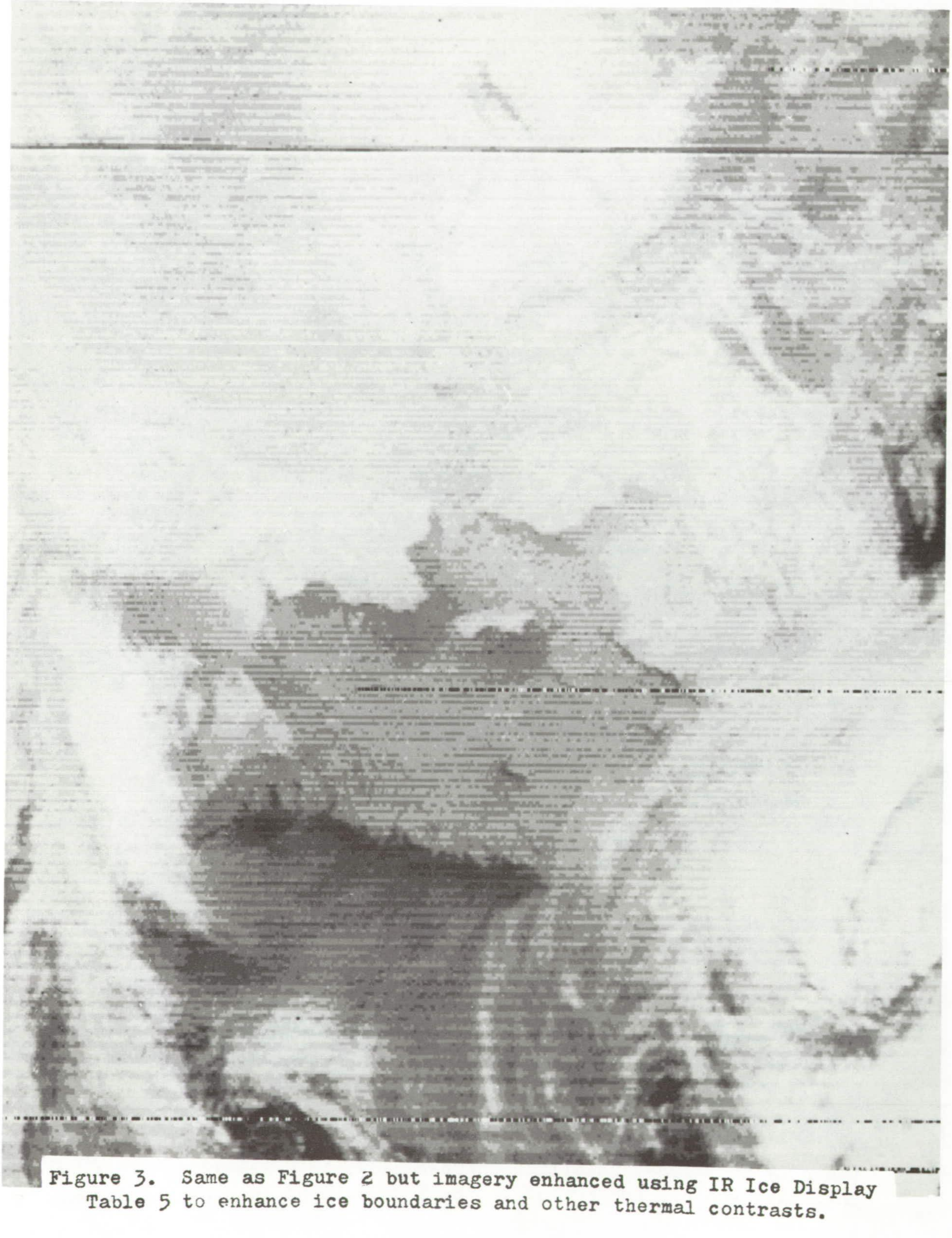

Figure 3. Same as Figure 2 but imagery enhanced using IR Ice Display Table 5 to enhance ice boundaries and other thermal contrasts.

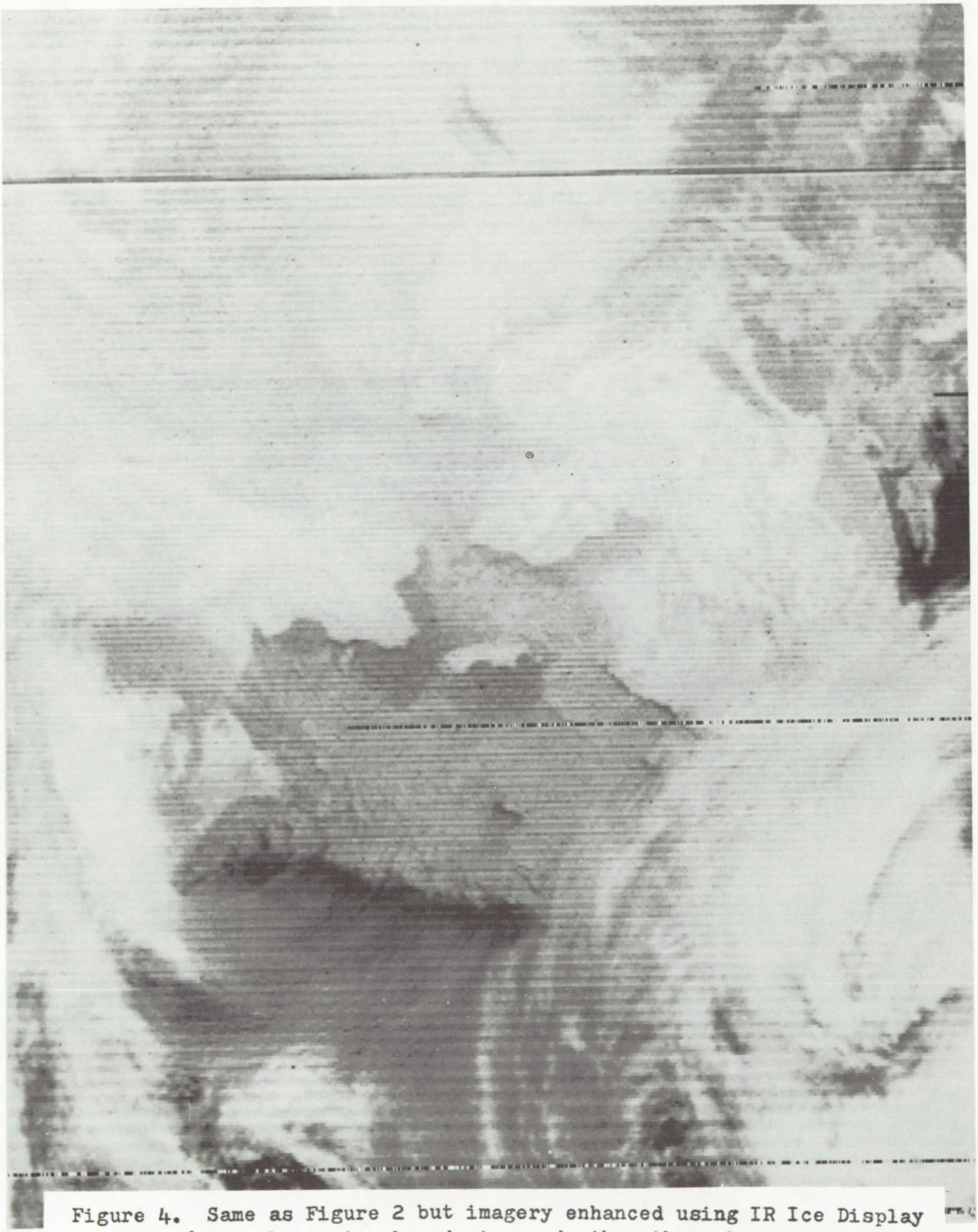

Figure 4. Same as Figure 2 but imagery enhanced using IR Ice Display Table 6 to enhance ice boundaries and other thermal contrasts.