NOAA's OCEANOGRAPHY STUDIES UNDER THE EARTH RESOURCES SURVEY PROGRAM

by

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INTRODUCTION

The long-range objective of NOAA's program of oceanography studies is to develop, in-house and through contracts, techniques for comprehensive, repeated, and timely satellite mapping of the following oceanic variables on a local, regional, or global basis: (1) sea surface temperature; (2) sea surface roughness and near-surface winds; and (3) ice concentration and condition. An integral part of this objective is to assist in the development of applications of these remotely-acquired data to operational and research problems in oceanography and closely related efforts in meteorology. Most of this research is being carried out or technically monitored by personnel of the Environmental Sciences Group (ESG) of NOAA's National Environmental Satellite Service (NESS). A portion is being performed by researchers in NOAA's Atlantic Oceanographic and Meteorological Laboratories (AOML).

Among the short-range objectives of these studies supported under NASA's Earth Resources Survey Program are:

(1) Continue studies to define and develop methods of suppressing system noise and cloud contamination in satellite measurements of infrared window radiation emitted from Earth's surface. Refine techniques for sea surface temperature mapping over cloudfree and partly cloudy areas and use to generate multi-day composite thermal charts for large areas, including global.

(2) Relate sea surface temperature patterns in the vicinity of the Gulf Stream and in the Gulf of Mexico to associated thermal front structure at greater depth, or to the presence of associated phenomena such as currents or upwelling, with the aid of infrared data from Nimbus or the Improved TIROS Operational Satellite (ITOS).

(3) Test the feasibility of mapping sea surface roughness and low-level wind speed over the tropical oceans by means of sequential imagery from the Application's Technology Satellites (ATS) in the sun glitter zones.

(4) Continue limited study of microwave radiometer measurements from aircraft and theory for determination of optimum wavelength(s), polarization, etc. for future applications to oceanography, with particular emphasis on their usefulness and limitations for all-weather mapping of surface roughness, sea ice conditions, and possibly surface temperature.

(5) Evaluate the newly-available scanning radiometer (SR) data (visible and infrared channels) from ITOS for purposes of mapping snow and ice conditions.

A few recent results from some of the aforementioned studies are discussed briefly in the following sections.

SEA SURFACE TEMPERATURE STUDIES

Nimbus II and Nimbus III (nighttime) HRIR data have been examined by NESS over selected areas to study the problem of noise in the data and to develop a technique to derive sea surface temperatures over various size grid intervals (Smith et al, 1970). The method infers surface temperatures from histograms of generally cloud contaminated brightness temperatures within areas 100 km or more on a side. The brightness temperature associated with the clear atmosphere model, peak radiance is the statistically most probable surface temperature within the area. Comparison of temperatures inferred from Nimbus II HRIR data over the North Atlantic and Pacific, and from Nimbus III data over the BOMEX area, with ship observations showed good agreement. This technique is now being used to generate, by computer, global sea surface temperature maps using ITOS-1 SR measurements (see Fig. 1). Relative and absolute differences (RMS) of approximately 1°C and 2°C, respectively, have been attained with respect to ship observations in spite of noise (attributed to the ITOS on-board tape recorder) in the data.

A technique which reduced the effect of noise and cloud interference in the NIMBUS HRIR data, and which yields sea-surface temperatures with a spatial resolution of about 37 km was developed under contract with the Research Triangle Institute (Vukovich, 1970).

Ground truth data were gathered by the Cape Fear Technical Institute's Research Vessel (R/V) ADVANCE II in the Phase III BOMEX grid, and by the Duke University Marine Laboratory's R/V EASTWARD, off the North Carolina coast. The compa ison between the processed HRIR data and the ground truth data revealed a high degree of correlation. The best agreement was attained in the Gulf Stream studies off the North Carolina coast.

Recent infrared imagery (Fig. 2) and quantitative temperature mapping (Fig. 3) derived from direct readout of data from ITOS-1 appears to be virtually noisefree and demonstrate that full-resolution (i.e. 8 km scan spot) sea surface temperature mapping is possible during cloudfree conditions. The image in Fig. 2 was displayed to bring out the thermal contrast between the warm Gulf Stream (darkest tone) and the cooler water farther inshore. Note what appears to be a secondary thermal front west and north of the primary Gulf Stream front. In Fig. 3 the Gulf Stream front is defined by the gradient from 22C to 26C on the northwest side of the 26C water. Lower temperatures in the southeast and northeast corners are associated with cold clouds. The thermal gradient from ocean to the cooler land grossly defines the major features of the coastline.

Since infrared sensors on aircraft and satellites are capable only of detecting the surface thermal gradient associated with such phenomena as the Gulf Stream front, AOML researchers used bathythermograph data from 100 crossings of the Gulf Stream to investigate the relationship between the surface temperature front and the deeper thermal front identified with the core of the stream (Hansen & Maul, 1970). It was found that the mean separation between the surface front and the maximum horizontal temperature gradient at 200 meters depth was 14.5 km. An AOML study of ART and other data acquired by NASA Houston and Navy ASWEPS aircraft in conjunction with Nimbus II overflights of the C&GS vessel EXPLORER was completed. A strong linear correlation was found between sea surface temperature as measured by ART and the water vapor content of the atmosphere beneath the aircraft. There was good agreement among the ship, aircraft, and satellite observations with respect to the position of the surface thermal front and the magnitude of the thermal gradient.

SEA SURFACE ROUGHNESS STUDIES

Earlier ESG research relating sun glitter patterns in ESSA satellite pictures to ocean roughness and near-surface wind speeds, (Strong & Ruff, 1970), has been extended to include digitized brightness distributions from sequences of ATS imagery taken over a period of a few hours on given days. Glint is detectible over a broad area that sweeps westward across the tropics with Earth's rotation. Local time variations of the brightness are a function of distance from the specular point track (known) and the roughness of the sea surface (inferred). Preliminary results based on a limited data sample indicate the feasibility of mapping the distribution of wind speeds, at least at the lower end of the speed range, from geosynchronous altitude. Further experimentation in this area was precluded by lack of computer time to process additional samples of ATS data.

An ESG study of the microwave data (1.6 cm) from the Salton Sea 1967 flights by NASA confirmed Stogryn's prediction of a cosine function fall-off of brightness temperature with increasing nadir angle out to about 30° (Stogryn, 1967), and a general increase of brightness temperature with increasing roughness of the sea surface. The slight dip in temperature at and very near zero nadir predicted by theory is inconclusive due to extreme scatter in the data at these angles. The uniform brightness temperatures across the Salton Sea prove the success of the radiometer in measuring small-scale roughness effects (small ripples and/or capillaries)--no upwind shore fetch-limited effects are seen.

SEA ICE STUDIES

Computer produced 5-day Composite Minimum Brightness (CMB) charts (McClain & Baker, 1969) have been used by ESG to study large-scale changes in snow and ice conditions in the Arctic. The CMB technique has proven effective in removing or suppressing the effects of cloudiness on the brightness of the scene. A method of using these data quantitatively to delimit sea ice conditions was developed (McClain, 1970). In this method the brightness data taken over the central Greenland ice cap and cloudfree ocean areas are used as a means of external calibration in order to adjust to observations to yield an internally consistent data set (Fig. 4). The adjusted relative brightness have been used to study sea ice conditions in the North American Arctic during the late Spring and Summer of 1969. Characteristic brightness levels have been found corresponding to the various ice concentrations and conditions summarized in Table 1.

Under a contract with Allied Research Associates, High Resolution Infrared Radiometer (HRIR) data from the Nimbus II and III satellites were used to develop improved techniques for ice mapping (Barnes et al., 1970). Sea-ice distributions in the autumn of 1969 mapped from Nimbus III HRIR film strips are compared with distributions previously mapped from Nimbus II for the similar period of 1966. Ice is also mapped for two winter months, a season for which data had not previously been available. In order to obtain a more objective interpretation of the gray-scale variations in the HRIR film strips, densitometric measurements were also carried out.

The results of the film-strip analyses indicate that principal sea-ice boundaries in the Arctic can be reliably mapped using the techniques developed in an earlier study. Of particular interest is that ice mapping from infrared data appears most reliable during winter, the season of maximum polar darkness during which other data sources are severely limited. Despite the success in identifying ice boundaries through relative temperature differences, the densitometric analyses show that it is impossible to obtain quantitative interpretation of the film strips, even when the gray-scale wedges are used as reference. Through an improved scheme, however, the data can be presented in a format from which accurate quantitative information can be visually derived and in which features of importance to sea-ice mapping are more clearly defined.

Microwave radiometer data (19.3 GHz or 1.6 cm) taken from a 1967 NASA aircraft mission over the Arctic Ocean near Point Barrow, Alaska, were examined (Strong and Fleming, 1970). The microwave brightness temperatures corresponding to varying ice pack conditions were correlated with simultaneous photography and infrared radiation data. Microwave measurements of the surface taken both through and from beneath a stratus cloudcover were investigated for atmospheric attenuation and emission effects. It was found that the influence of clouds was greatest when the radiometer was viewing surfaces such as water, which appears cold at microwave frequencies because of its low emissivity. In general, cloudiness diminished the capability of the 19.3-GHz radiometer to discriminate between ice and water. Polynya and other openings displayed a characteristic brightness temperature nearly 100K° below that for pack ice when viewed through a cloud-free atmosphere, whereas this differential decreased by as much as 20-40°K when clouds intervened between the surface and the radiometer.

CONCLUDING REMARKS

Knowledge of winds and waves is important to safer and more expeditious commercial ship routing, to naval operations, and to rescue and recovery at sea. Knowledge of the sea surface temperature distribution is important in the understanding of certain oceanic and atmospheric processes, and in the detection and monitoring of ocean currents, upwelling zones, and other thermal or motion systems. Knowledge of sea ice distribution and condition is vital to commercial and military ship movements in the Arctic and Antarctic. Ice cover is also important in the heat balance of polar regions, and this in turn influences the general circulation. Thus an economic and scientific requirement exists for large-scale mapping of oceanic conditions. Comprehensive and repetitive survey by means of surface-based observation systems or by means of sensors carried in aircraft or similar vehicles would be hazardous, time-consuming, and very costly because of the vast areas to be covered. A polar-orbiting Earth satellite, however, could provide a practical means of obtaining oceanographic information for research and operational purposes.

The work briefly described above contributes to the Earth Resources Survey Program because the experience and knowledge gained in validation, interpretation, handling, and applications of available satellite and/or aircraft data can be brought to bear directly on refining requirements and specifications for analogous data acquisition and usage from the future Earth resources survey satellites. This research relates to stated NOAA requirements for data from ERTS A and B in the area of oceanography and meteorology, although part is more applicable to later satellites or manned spacecraft (e.g. SKYLAB) carrying microwave sensors.

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CATEGORY	ADJUSTED CMB AVERAGE	ICE CONCENTRATION	ICE CONDITION
1	9-10	COMPACT OR VERY CLOSE PACK (10/10-9/10)	SNOW COVERED (>7/10)
2	7-8	COMPACT OR VERY CLOSE PACK (10/10-9/10)	SNOW FREE (< 3/10); LITTLE OR NO PUDDLING (< 1/10)
3	5-6	VERY CLOSE OR CLOSE PACK (9/10-7/10)	SOME PUDDLES AND THAW HOLES (1/10-3/10)
4	2-4	OPEN PACK (6/10-4/10)	MUCH PUDDLING (>3/10) AND ROTTEN ICE
5	0-1	VERY OPEN PACK (3/10-1/10) OR ICE FREE WATERS	—

TABLE I.- COMPOSITE MINIMUM BRIGHTNESS (CMB) VALUES FOR VARIOUS ICE CONCENTRATIONS AND CONDITIONS

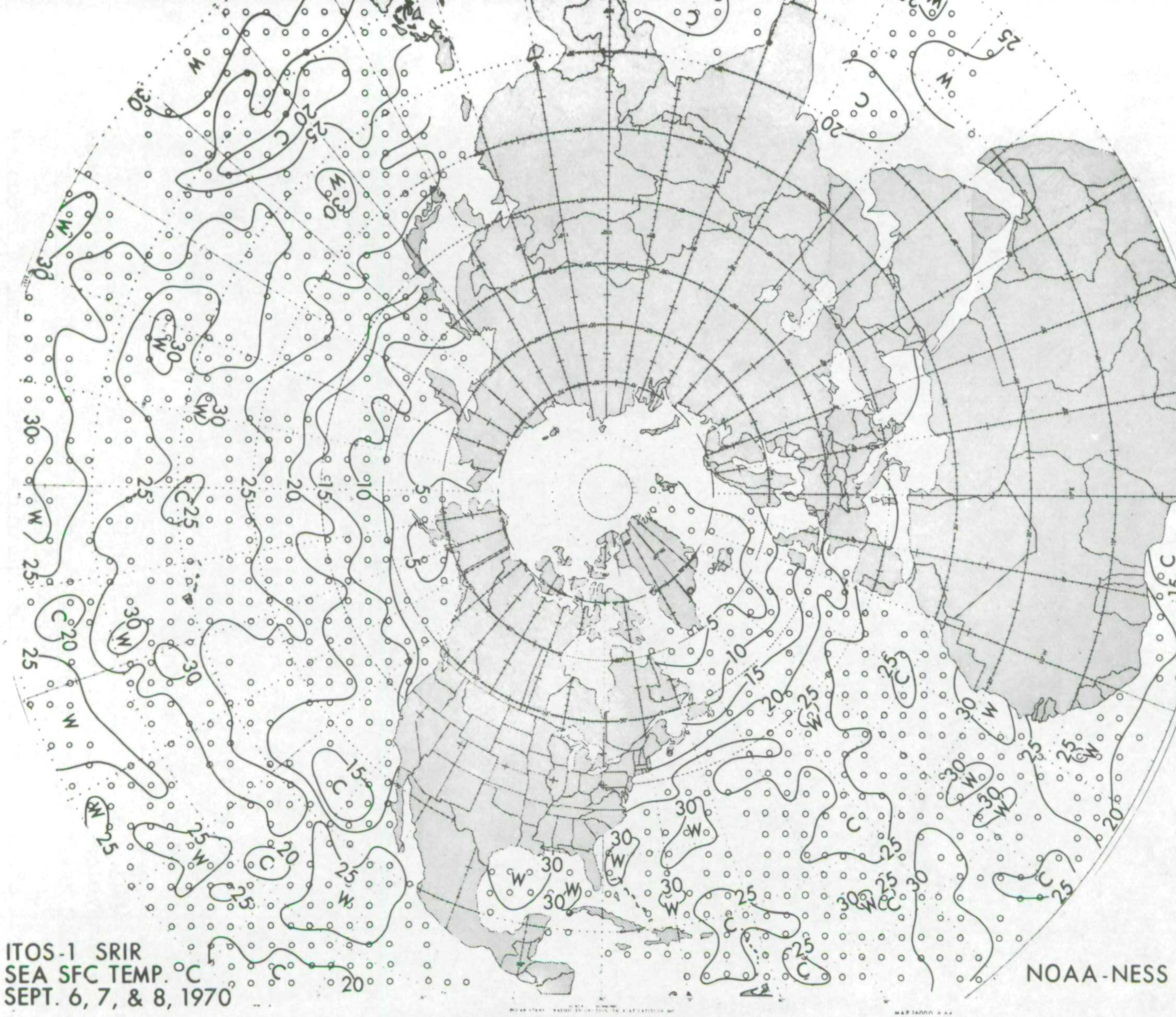

Figure 1.- Three-day composite chart of sea surface temperature derived statistically from all satellite infrared measurements falling within 280 km grid areas. An open circle is shown at the center of each grid where a temperature could be derived. Persistent cloudiness or noisy data prevented temperature derivation in the remaining grid areas.

Figure 2.- Image derived from satellite infrared measurements (10.5-12.5 m wavelength) on October 19, 1970 at 0900 GMT. The warmer the radiating surface (Earth or cloud tops), the darker the tone in the image. Thus the east coast of the United States and the Great Lakes stand out clearly because of the thermal contrast between the cooler land and the warmer water. The coldest (lightest) areas are clouds.

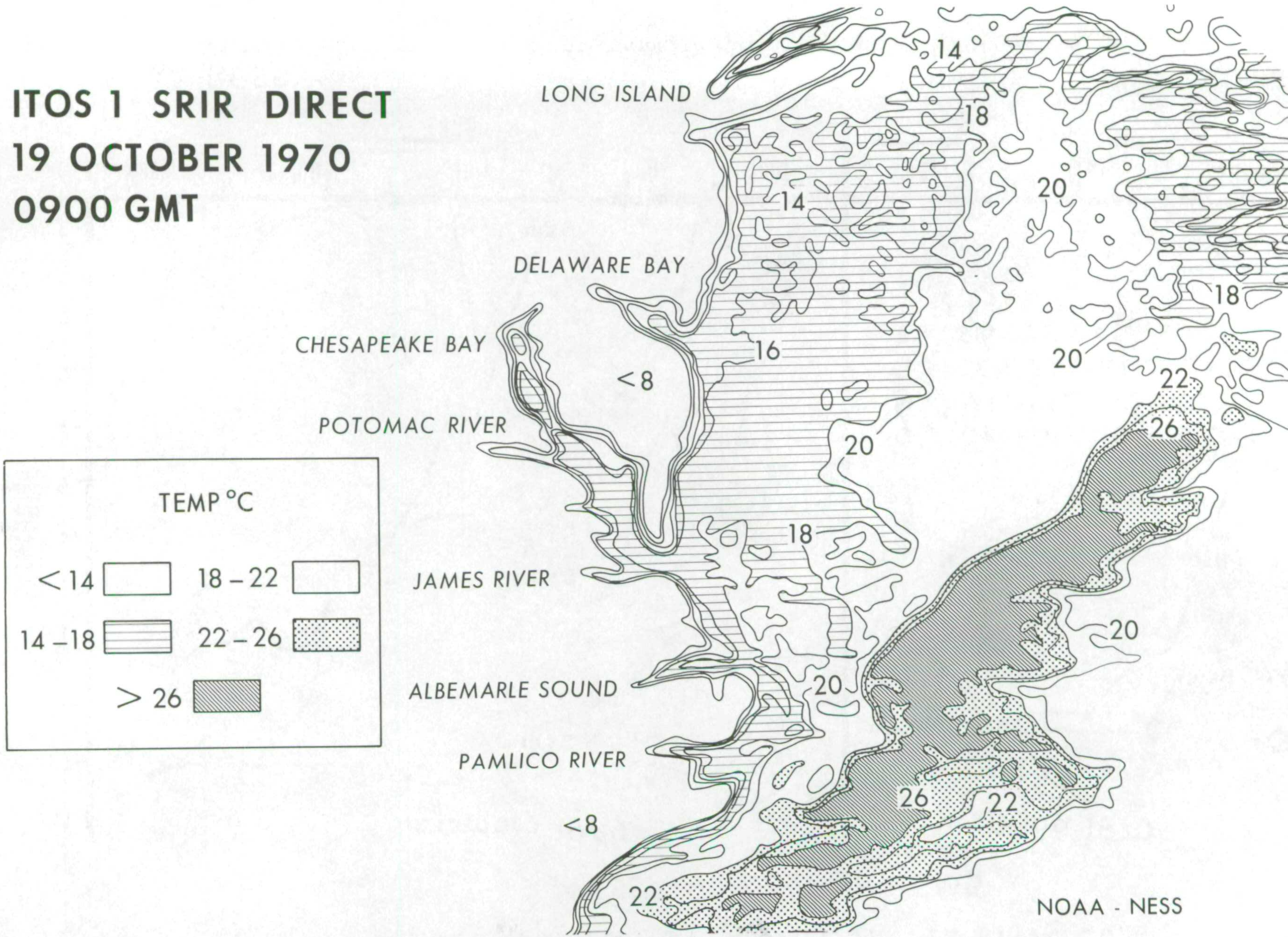

Figure 3.- Sea surface isotherms analyzed from scan-spot listings of satellite infrared measurements for the same time and for a portion of the same area as in Figure 2.

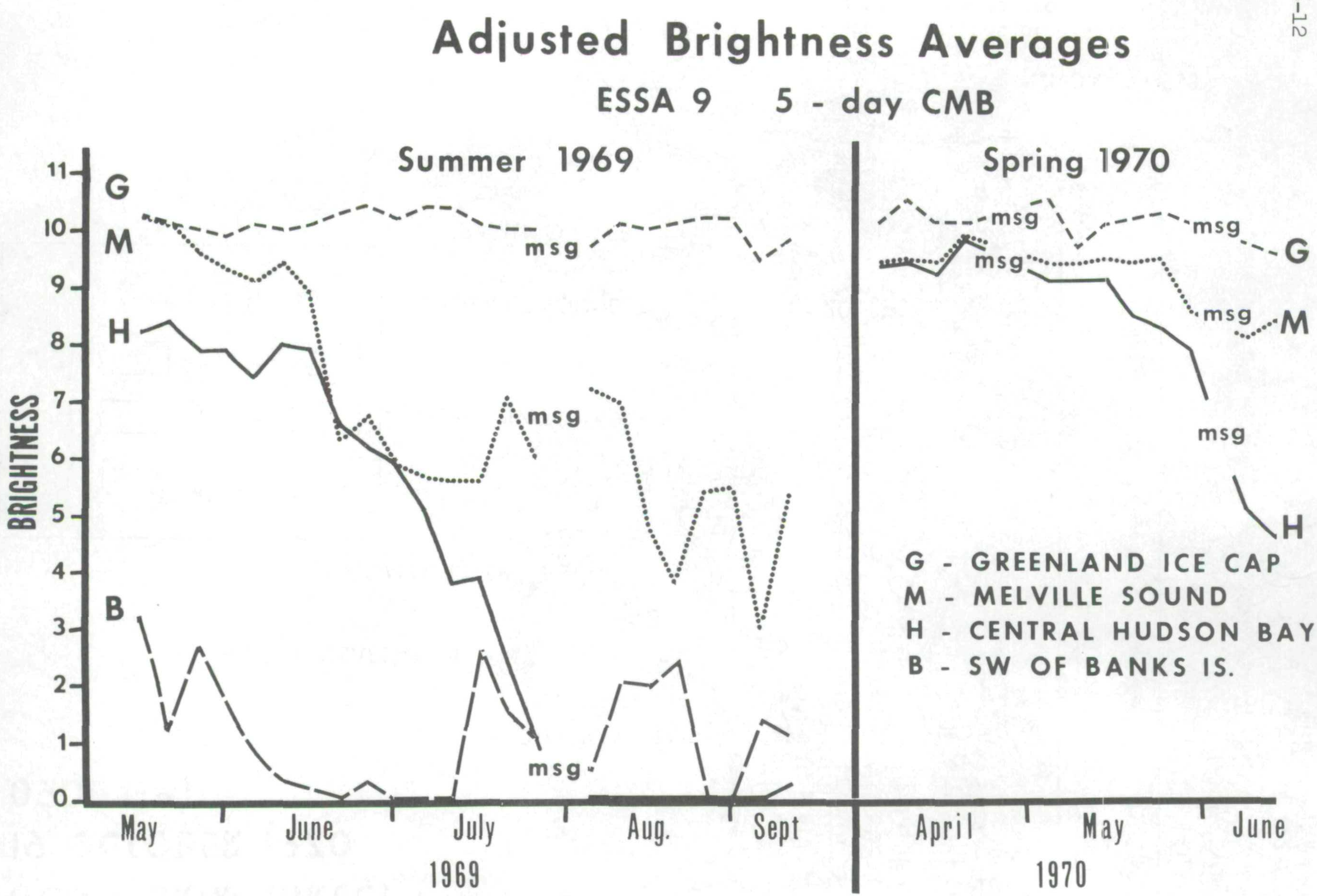

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Figure 4.- Seasonal variation of Composite Minimum Brightness (CMB) values for several sea ice areas in the North American Arctic. CMB values are routinely derived for 5-day periods from digitized and mapped vidicon data obtained by ESSA operational satellites. The notation "msg" means