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## ABSTRACT

Principles pertinent to the utilization of 1.55 cm wavelength radiation emanating from the surface of the Earth for studying the changing characteristics of polar sea ice are briefly reviewed. Recent data obtained at that wavelength with an imaging radiometer on-board the Nimbus 5 satellite are used to illustrate how the seasonal changes in extent of sea ice in both polar regions may be monitored free of atmospheric interference. Within a season, changes in the compactness of the sea ice are also observed from the satellite. Some substantial areas of the Arctic sea ice canopy identified as first-year ice in the past winter were observed not to melt this summer, a graphic illustration of the eventual formation of multiyear ice in the Arctic. Finally, the microwave emissivity of some of the multiyear ice areas near the North Pole was found to increase significantly in the summer, probably due to liquid water content in the firn layer.

## BACKGROUND

The imaging microwave radiometer utilized in these studies has been described elsewhere (Wilheit 1972, Gloersen et al. 1973). Briefly, The Electronically-Scanned Microwave Radiometer (ESMR) operates at a wavelength of 1.55 cm. In this wavelength region, the Raleigh-Jeans approximation applies to all targets of interest, and the microwave power received from a radiating target depends linearly on the brightness temperature of that target. This simplifies calibrating the output of the radiometer directly in terms of the brightness temperature of the target. In general, the observed brightness temperature depends on the physical temperature and emissivity of the viewed surface, and both direct and reflected components from the intervening atmosphere. The atmospheric components at a wavelength of 1.55 cm result principally from the liquid water and water vapor present. Since these quantities are small in the Arctic and Antarctic atmospheres, they have been neglected in determinations of surface brightness temperatures reported here. The stratus clouds usually obscuring the polar regions consist mostly of ice crystals, which are transparent to 1.55 cm radiation.

The observed variation of the brightness temperatures result from the combination of seasonal, diurnal, and climatic changes in the physical surface temperatures amounting to differences of about 40° K, and from significant variations in the emissivity of the surface, as illustrated in Figure 1, which translate into brightness temperature contrasts of 20 K and 120 K for multiyear sea ice and open water vs. first-year sea ice, respectively. The emissivity differences shown for first-year sea ice, multiyear sea ice, and open water result in microwave image patterns that are readily discernable in spite of variations in the physical temperature of the surface, since the latter vary sufficiently slowly in space and time compared to the emissivity differences. It should be noted that the emissivity of the central Arctic ice canopy, where most of the multiyear ice is located, has been observed to increase markedly over the values shown in Figure 1 in the summer months, probably due to a liquid water content in the firn layer. (Edgerton et al. 1971, Meier 1972) When the instantaneous field-of-view of the ESMR contains a mixture of the three polar sea components, intermediate brightness temperatures are observed. This may be used to infer compactness of sea ice, as illustrated in Figure 2.

The curve in Figure 2 is simply a linear interpolation between the cases of completely open water ($T_B = T_W = 131°K$) and completely consolidated first-year sea ice with a surface temperature, $T_s$, of 260°K, typical of areas near the edge of the ice pack, especially in Spring and Fall. The shading indicates the climatic variation of $T_s$ expected, in addition to the uncertainty of the brightness temperature measurement. This leads to an average uncertainty in the determination of the fraction of open water of about 4% from the observed brightness temperature. It has been observed that measurable open water usually occurs only in areas where little or no multiyear ice is present. Therefore, the curve fits most cases of interest; some downward adjustments to $T_s$ would be required for sea ice well-removed from its outer boundary in Antarctica during Austral Winter.

## SEA ICE COMPACTNESS

The curve of Figure 2 has been used to analyze the sea ice cover around Greenland and Antarctica, as shown in Figures 3 and 4, respectively. The distribution of compactness shown on these particular days has been observed to change significantly from one polar projection to another over time intervals as short as 10 days, the minimum time interval utilized so far in the data processing. It is evident that such determinations, combined with records of wind stress, would provide useful data for the study of ice dynamics. Such studies are currently in progress. In addition to the areas discussed so far here, other areas of considerable ice dynamic activity, as evidenced by the data on hand, are the Hudson Bay and the Bering, Chuckchi, East Siberian, Laptev, and Beaufort Seas.

## SEA ICE BOUNDARIES

Nimbus 5 ESMR data are now available for determining the near minimum and maximum sea ice boundaries for both polar regions in 1973. Such data are illustrated in Figures 5 and 6, illustrating quantitatively what is already known in a qualitative way, i.e. that the amount of ice cover changes by about a factor two in both polar regions during a given year.

In Antarctica (Figure 6), the observations might seem to indicate the formation of multiyear ice in some regions, since not all of the ice formed in 1972 melted during Austral Summer. On the other hand, these same areas had a distinct first-year signature in Austral Spring 1972 and Austral Winter 1973 indicating, at least, that it was not ice formed in previous years. This, coupled with the knowledge obtained by observers in these areas indicating high ice dynamic activity and the absence of multiyear sea ice leads to the conclusion that the sequential images are representative of a steady-state phenomenon, i.e. the areas of persistent sea ice cover are accumulation regions in a system of steady depletion and replenishment.

In the Arctic region (Figure 5), there are a number of noteworthy points to be made. First, the near-minimum boundary of the sea ice illustrated will be the basis for following the changing distribution of multiyear ice in the winter of 1973-4, giving valuable insight into the macroscale ice dynamics in the north polar region. It was also observed that not all of the sea ice identified as first-year in Winter 1972-3, particularly in the Kara, northern Chukchi, and Beaufort Seas, melted in Summer 1973. Thus, observing the changes in brightness temperature of these areas during Winter 1973-4 may result in new knowledge of the emissivity of sea ice vs. age at some intermediate points. In addition, such observations will give insight into the sources of multiyear ice in the Arctic. Finally, there is clear evidence that the sea ice northwest of Svalbard is strongly affected by ocean currents, since the boundaries are observed to change well out-of-phase with expectations based on seasonal variations alone.

## APPLICATIONS

Since the amount of open water in the polar regions has a profound impact on global circulation patterns of the atmosphere (Fletcher 1972), the detailed information of extent and location of open water in the polar regions is a valuable input for computer models of the atmosphere and climate.

In terms of shipping, the Fleet Weather Facility of the U.S. Navy at Suitland, Maryland is utilizing Nimbus 5 ESMR data obtained in near real-time to produce weekly ice limit reports for military, commercial, and international use. Plans for substituting an automated system for the present hand-analysis from quick-look ESMR records are under consideration.

The nature of the persistent radiometric patterns that have been observed in the continental ice sheets on Greenland and Antarctica have been described elsewhere (Gloersen et al. 1973). These patterns may be related to snow accumulation rates on these continents, but the correlation in Greenland is not high, based on the available contours drawn through relatively few measured points on the basis of a climatic model (Mock 1967). If subsequent surface measurements give more substantial support to a correlation with accumulation rates, it may be possible to monitor long-term changes in such rates with this instrument.

Although no such occurrances have been observed to date, it may be possible to monitor the calving of shelf ice of sufficient size from sources such as the Ross Ice Shelf. Similar studies of such enormous glaciers as the Lambert Glacier in Antarctica may also be possible, but the spatial resolution capability of the instrument would be stressed.

## REFERENCES


Edgerton, A. T., A. Stogryn, and G. Poe, 1971. Microwave radiometric investigations of snowpack. Final Report No. 1285 R-4 for U.S.G.S. contract No. 14-08-001-11828, Aerojet-General Corp., Microwave Division, El Monte, California.

Gloersen, P., T. T. Wilheit, T. C. Chang, W. Nordberg, and W. J. Campbell, 1973. Microwave maps of the polar ice of the earth. NASA/GSFC Report No. X-652-73-269.

Meier, M. F., 1972. Measurement of snow cover using passive microwave radiation. Proc. Intl. Symposia on the Role of Snow and Ice in Hydrology, Banff, Canada.

Mock, S. J., 1967. Accumulation patterns on the Greenland ice sheet. USA/CRREL Report No. 233. Also, 1973. Priv. Comm.

Wilheit, T. T., 1972. The electronically scanning microwave radiometer (ESMR). The Nimbus 5 User's Guide, pp. 59-104, U.S. Government Printing Office 1972-735-963/259.

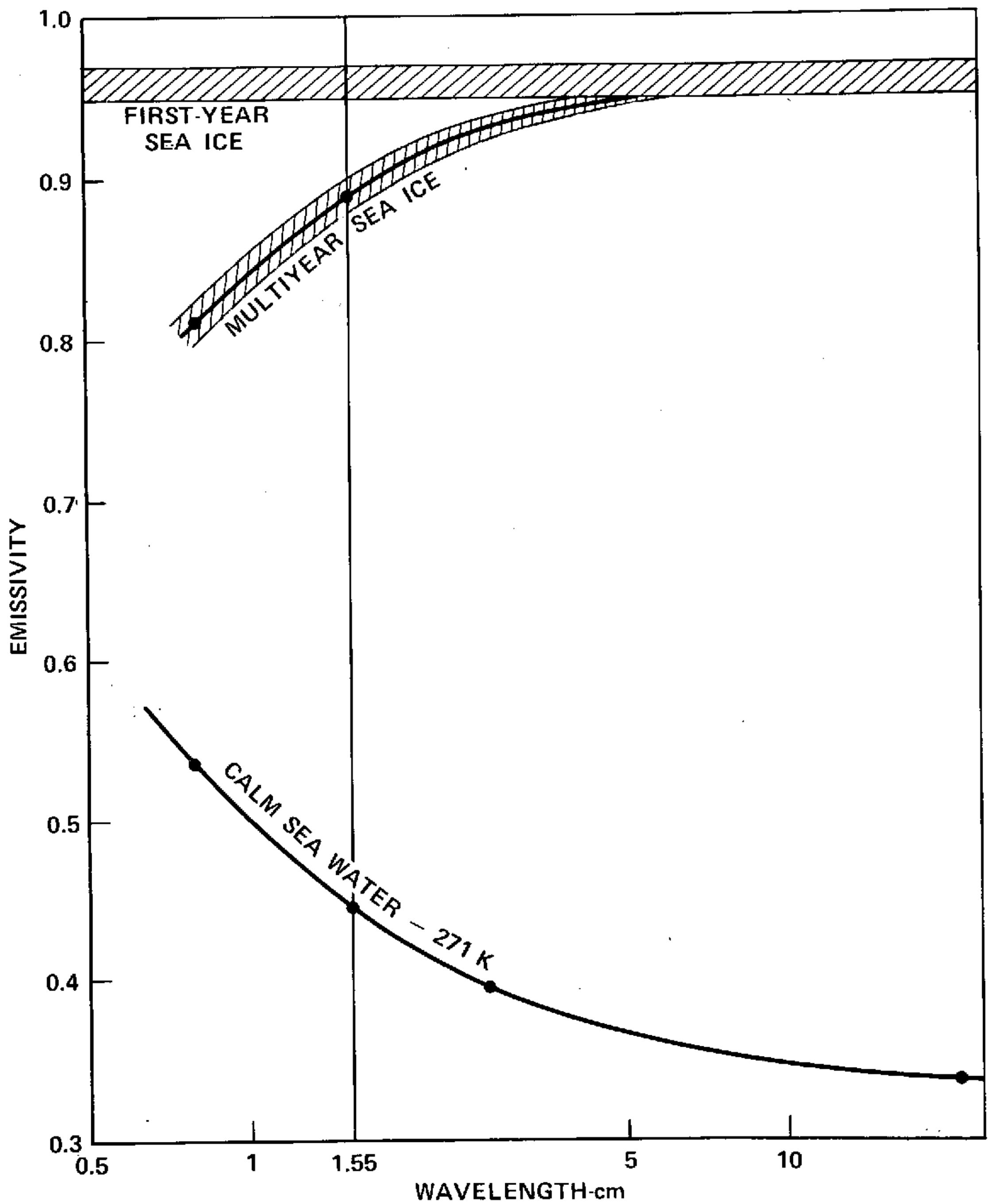


Figure 1. Microwave Emissivities of the Polar Seas

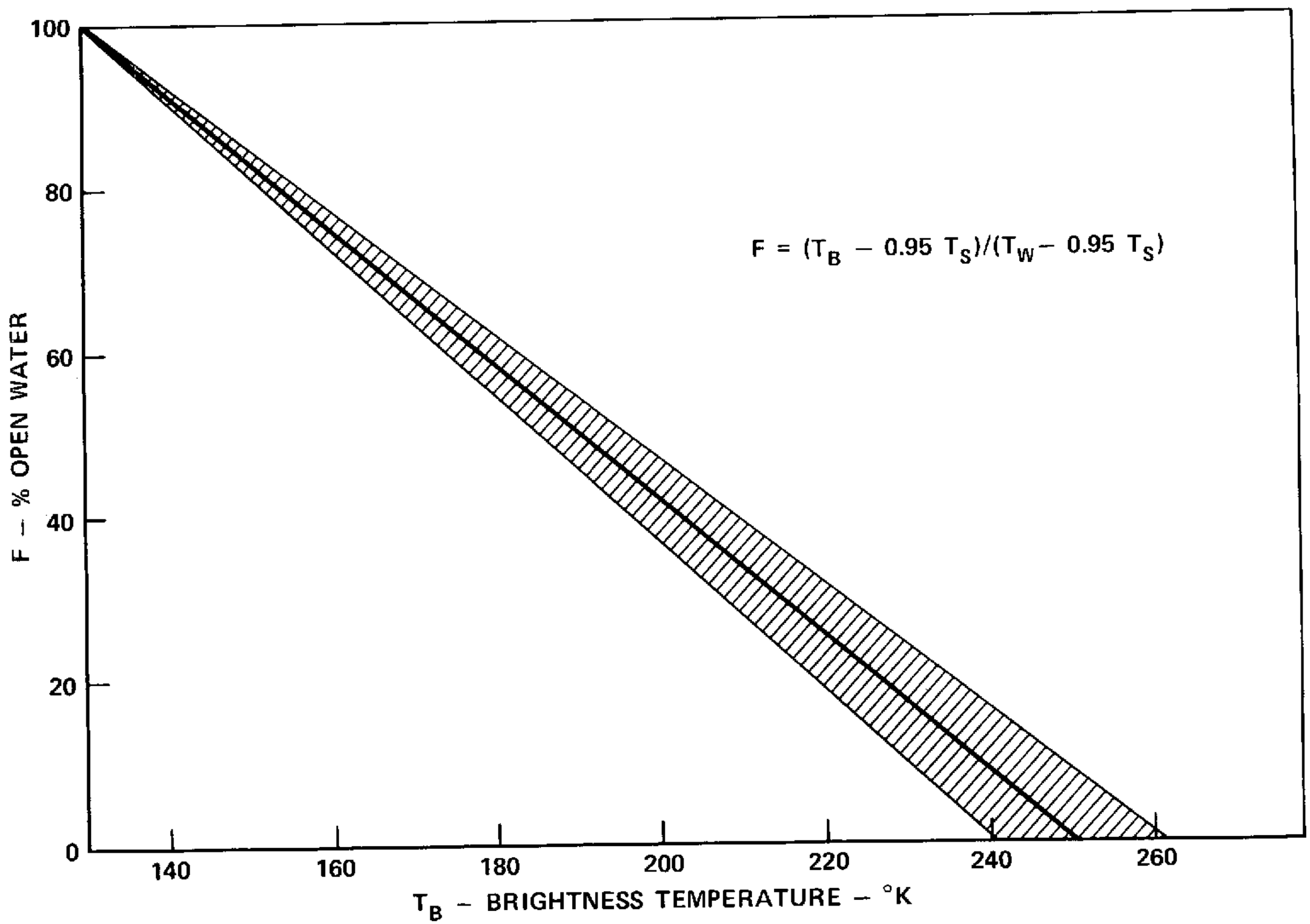


Figure 2. Determination of Unresolved Open Water in Areas Containing Sea Ice from the Microwave Brightness Temperature at $\lambda = 1.55$ cm

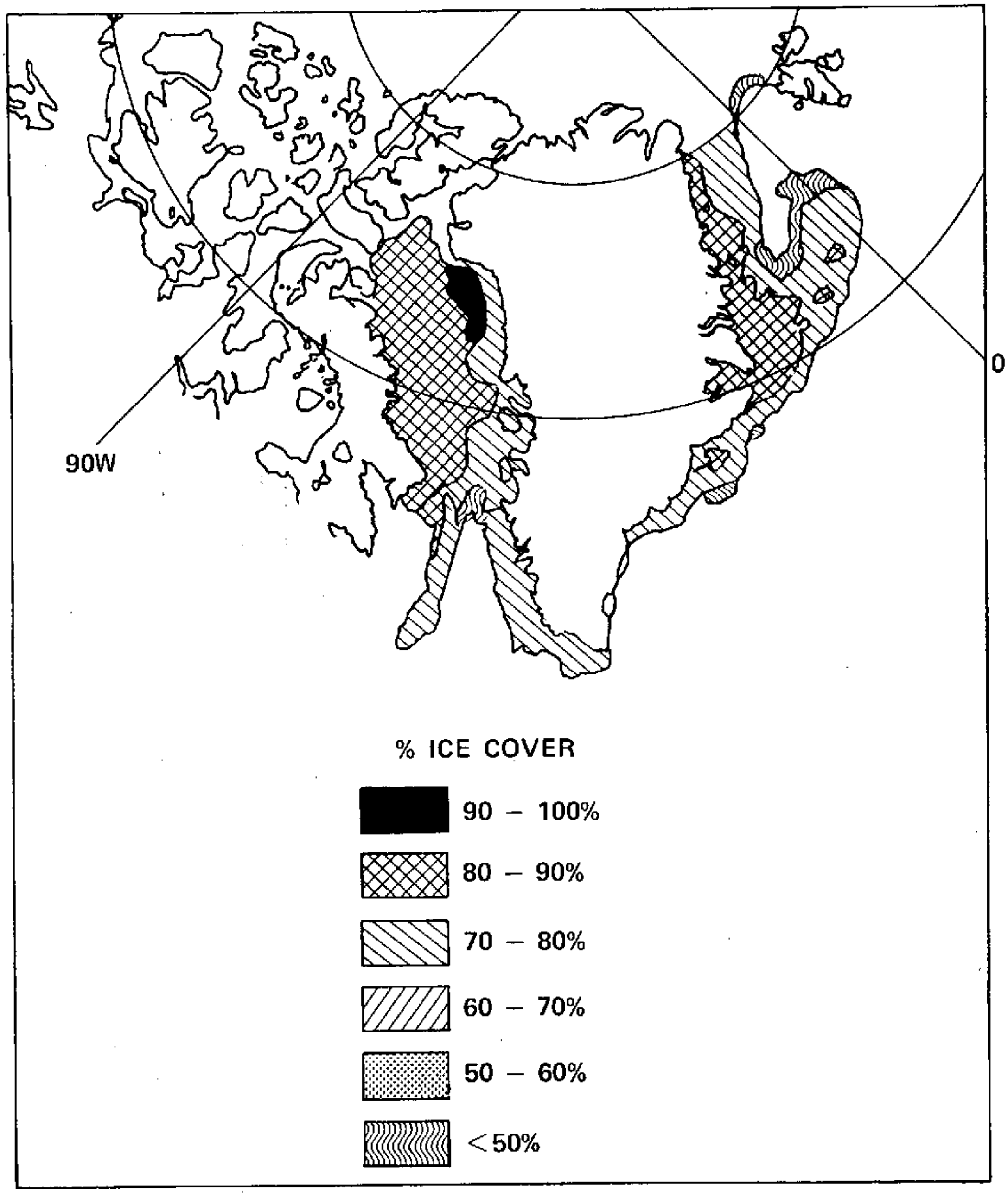


Figure 3. Compactness of Sea Ice Around Greenland on February 26, 1973.

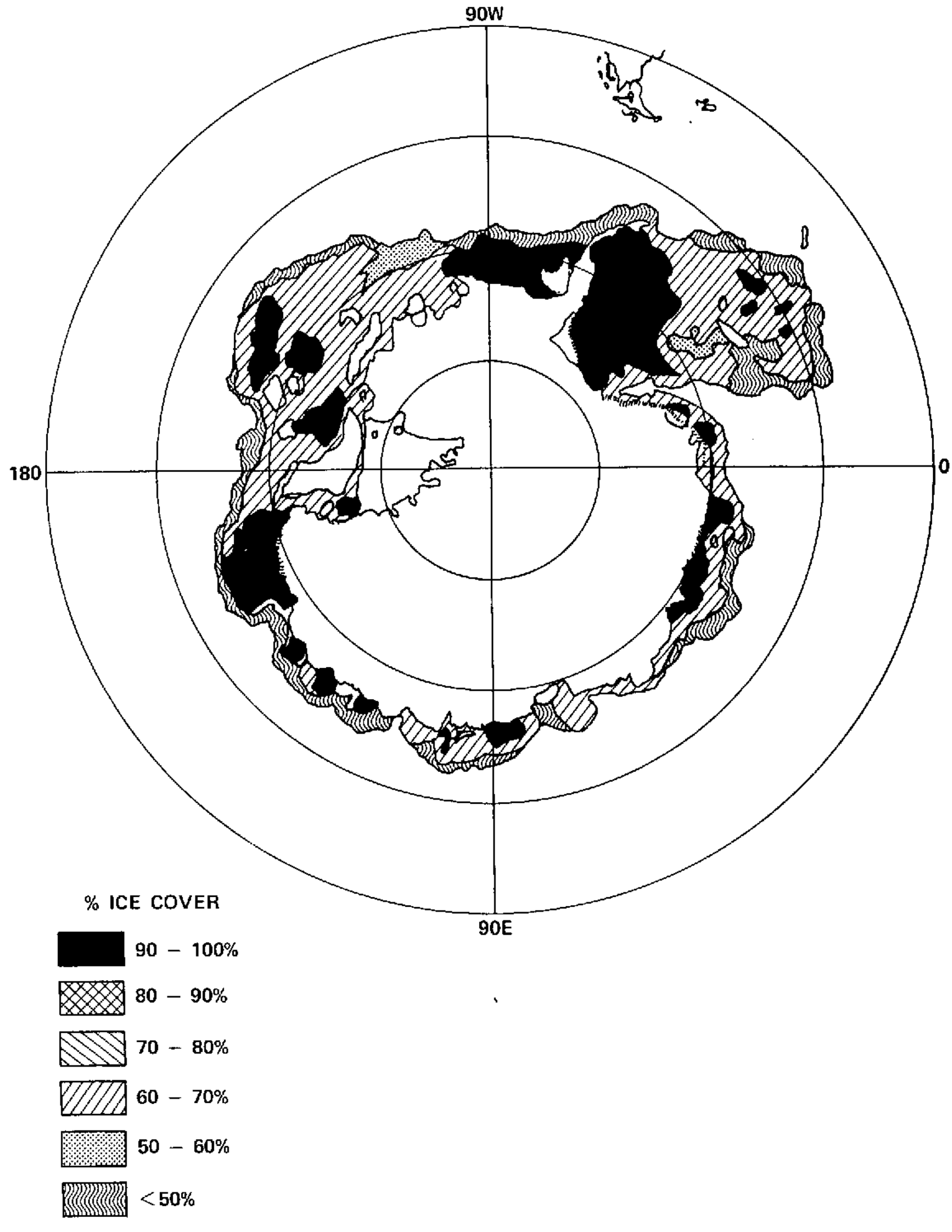


Figure 4. Compactness of Sea Ice Around Antarctica on December 26, 1972.

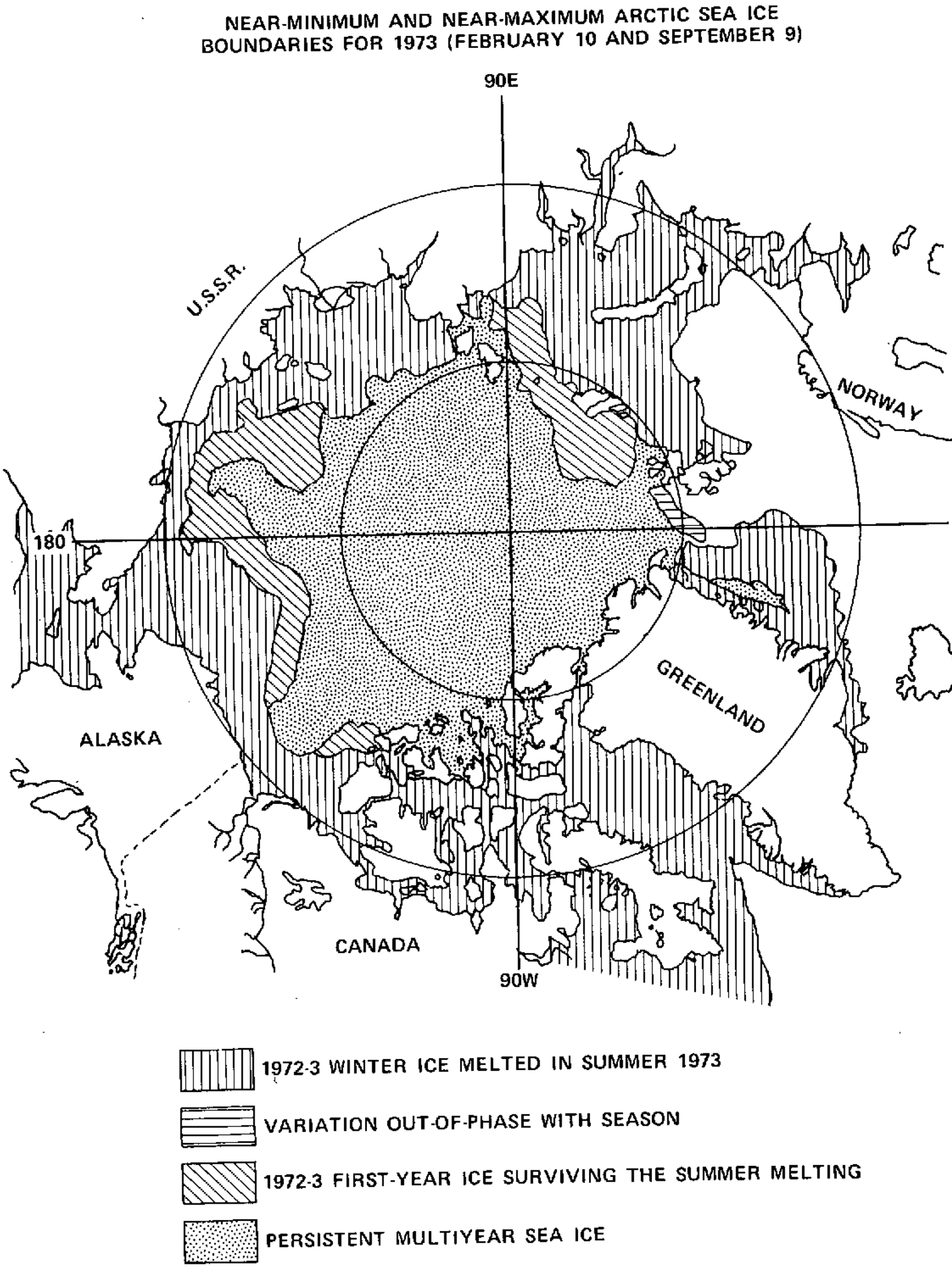


Figure 5. Seasonal Variation of Sea Ice in the Northern Hemisphere

NEAR-MINIMUM AND NEAR-MAXIMUM ANTARCTIC SEA ICE
BOUNDARIES FOR 1973 (FEBRUARY 10 AND JULY 16)

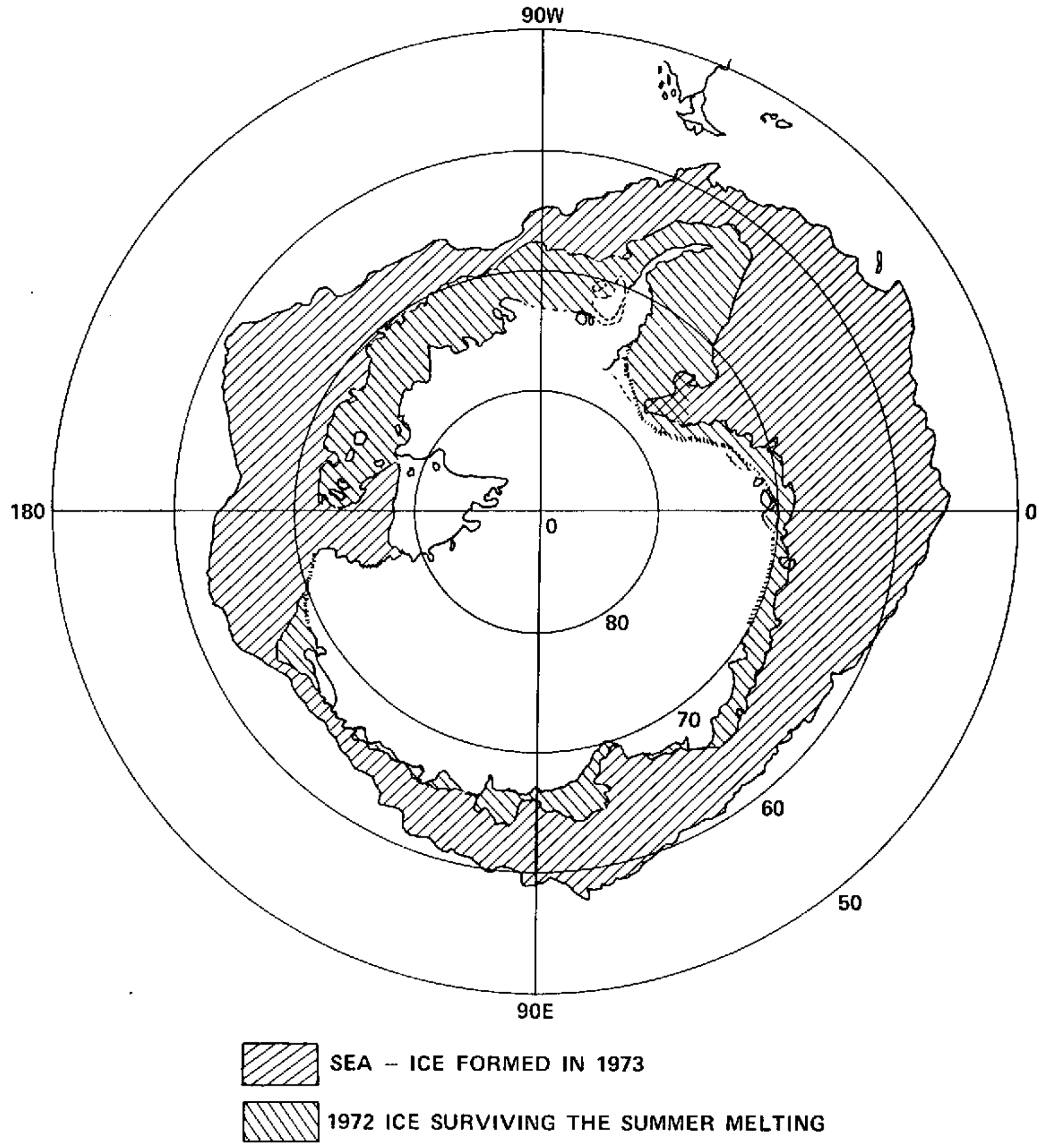


Figure 6. Seasonal Variation of Sea Ice in the Southern Hemisphere