in: Presentations at the Fifth Tri-Service Clouds Modeling Workshop. U.S. Naval Academy, Annapolis, MD, 23-24 June 1987

SATELLITE ANALYSIS OF CLOUDS OVER ARCTIC SEA ICE

David A. Robinson and George Kukla
Lamont-Doherty Geological Observatory of Columbia University
Palisades, New York 10964

Abstract:

The extent and thickness of late-spring and summer cloudiness in the Arctic Basin was found to vary considerably in space and time during the 1977-1979 period. Clouds were manually charted from Defense Meteorological Satellite Program (DMSP) imagery. While, on the average, clouds covered two thirds or more of the Basin at any one time, cloud-free episodes, particularly common from mid June to late July, persisted locally for several days up to a few weeks. Most of the clouds were semi-transparent, with optically thick clouds most often associated with low pressure systems. Cloud-free skies were most frequent in high pressure cells. The central Arctic was found to be less cloudy than the coastal zones in spring, but more cloudy in summer. Results were compared with those of another manual analysis technique and with those from the Air Force 3-D nephanalysis algorithm, with general agreement seen in the distribution of cloudiness. However, the automated 3-D nephanalysis reported less extensive cover and local to regional differences in the distribution of cover were noted between each product.

Introduction:

The large-scale distribution and dynamics of arctic clouds are not well understood due to the spatially limited number of off-coast stations and to difficulties in the automated identification of clouds from satellite imagery in the presence of snow and ice. Earlier reports of summer cloudiness in the Arctic Basin present conflicting results, ranging from upwards of 90% cloud cover with little variation (Huschke, 1969; Vowinckel and Orvig, 1970; Marshunova and Chernigovskii, 1971) to highly variable mean-monthly cloudiness as low as 50% (Chukanin, 1954; Jayaweera, 1977; Gorshkov, 1980). Recently, Barry et al. (1987) found considerable geographic and interannual variability of arctic cloudiness during the springs of 1979 and 1980.

Improved knowledge of arctic cloudiness is required for a number of reasons, including: 1) a better understanding of the earth/atmosphere radiative environment in this climatically sensitive region, 2) potential use as an indicator of climate change and 3) aircraft operations. Here, we present an arctic-wide analysis of cloudiness from mid May to mid August based on a manual interpretation of satellite data. Cloud cover was charted in three thickness classes at approximately three-day intervals in 1977 and 1979 and at selected intervals in 1978.

Data:

Clouds were charted using shortwave (0.4-1.1 micrometers) and infrared (8.0-13.0 micrometers) imagery from the Defense Meteorological Satellite Program (DMSP). Daily images were available in Transverse Mercator projection on positive film transparencies with a resolution of 2.7 km (supplemented by some 0.6 km imagery).

Procedure:

Clouds were visually differentiated from snow and ice, primarily by the characteristic large-scale features of the pack ice identified in shortwave imagery. In addition, certain cloud fields, particularly those associated with cyclonic systems, were recognized by their characteristic shapes and patterns in both the shortwave and infrared. Clouds were assigned one of three classes of optical thickness based on the degree to which surface features were able to be recognized under them, if at all. Along with a category for clear skies, these included: 1) cloud free (surface features seen with high contrast); 2) thin clouds or subresolution patchy clouds (surface features clearly recognizable but with reduced contrast as compared to cloud-free skies); 3) moderately-thick clouds or fog (surface features marginally recognizable through the cloud). 4) thick or multilayer clouds (no surface features recognizable). Multiple images for a given date were combined to cover as much of the Arctic Basin as possible. Several adjacent passes, separated by as short a time interval as possible, were used to minimize inaccuracies due to moving clouds.

Estimates of absolute values of optical thickness for each class ranged from less than 5 to about 25. These values are based on comparisons with published flight data (Tsay and Jayaweera, 1984; Herman and Curry, 1984) and by employing image processor measurements of the contrast in DMSP satellite-observed brightness between ice and open-water surfaces for clear and cloudy conditions in a detailed radiative-transfer model (Robinson et al., 1983).

All cloud charts and National Meteorological Center (NMC) 00Z charts of surface pressure used in the study were digitized using the NMC standard data grid (fig. 1). For analysis purposes, the Arctic Basin was divided into five regions based on geographic criteria (fig. 2). Regions contained from 35 to 146 NMC grid cells. They include the: 1) Central Arctic Ocean, 2) Outer Arctic Ocean, 3) Arctic Coastal Waters 4) Canadian Archipelago and 5) Coastal Land. Data coverage approached 100% in the Central Arctic, where there is the greatest overlap of satellite passes. A similar high percentage was found for regions 2-3 in most 1978 and 1979 charts. Missing imagery resulted in region 5 in 1978 and 1979 and regions 2-4 in 1977 having between 60% and 80% cell coverage and region 5 in 1977 averaging less than 50% coverage.

Tests were conducted with two interpreters to assess the subjectivity of the charting and counting methodology. Six mid-month charts were independently constructed by each analyst, with a reasonable agreement found for all charts. Individually, cloud-free regions agreed best, differing by only 2%. The largest differences were found when distinguishing between moderate and thick clouds. This is the most subjective distinction to make, particularly when distinctive surface features are absent, therefore the two classes are frequently combined in the reported results. Further information on all charting procedures may be found in Kukla (1984) and Robinson et al. 1985).

A determination of precise monthly means is not possible when sampling approximately every three days. However, our error margin is not expected to be large, given the sluggish movement of summer weather systems in the Arctic and the relatively suppressed diurnal variation of cloud cover because of the small diurnal variability of solar zenith angle. Also, since only three years were analysed, our results should not be taken as representing longterm average conditions of late-spring and summer cloudiness in the Arctic.

Results:

Significant variability in the type and spatial distribution of clouds throughout the Arctic Basin was exhibited in each of the cloud charts constructed in the 1977-1979 study interval. As an example, on July 15, 1979 thick and moderately thick clouds covered 65% of the Basin and were most abundant in the Outer Arctic Ocean and Canadian Archipelago (fig. 3). Skies were clear or had thin clouds north of Greenland and in much of the Barents and Kara Seas. Considerable temporal variability in the extent of cloudiness across the Arctic Basin was also noted, as seen in the Outer Ocean (fig. 4). Cloud cover was most extensive in early June of 1977 and 1979. Clear skies and thin clouds peaked in the second half of June and the first half of July in 1977 in all regions. In 1979, moderate and thick cloudiness also decreased between early and late June, but less so than in 1977.

Regional estimates of cloudiness for the last half of May and for all of July in 1979, based on six and ten charts respectively, are shown in figure 5. The zone of heavy cloudiness progressed polewards during the late spring. In May skies were less cloudy in the Central Arctic than in either of the ocean regions closer to the coast. The opposite case was observed in July 1979 when the Central Arctic was cloudiest, with clear skies present approximately 10% of the time. Cloudiness decreased towards the coast where coastal regions and the Archipelago had approximately 50% moderate and thick cloud cover. The July 1979 results are representative of estimates for July 1977 and June 1977 and 1979 (fig. 6). Means for the four months ranged from 14% coverage for class 2 to 38% for class 3. These two classes showed the smallest and largest ranges between the four months, 6% and 16%, respectively.

The distribution of cloudiness in the Basin was compared with coincident surface pressure data and an association between increased cloudiness and lower pressure was found. Several vigorous lows penetrating into the Basin in the first half of June 1979 (eg. fig. 7) resulted in extensive cloud cover. Overall clouds, particularly the moderate and thick varieties, were closely associated with the position of surface lows (fig. 8). Likewise, cloud-free skies were most frequently associated with high pressure cells. The optically thick clouds were also found to be associated with atmospheric flow from lower latitudes at the surface and aloft. These relationships are apparent when examining estimated monthly means of cloudiness and surface pressure. Figure 9 shows the heaviest cloud cover in June 1979 between a high in the Beaufort-East Siberian Sea portion of the Basin and a zone of lower pressure extending from north of Greenland into the Kara Sea. Here, winds, also verified at the 700mb level, tended flow from the south during the month. Figure 10 shows an abundance of clouds over a low in the Beaufort-East Siberian Sea region and relatively cloud-free skies over a Kara and Barents Sea high in July 1979.

Several June 1979 charts from this study were compared with ones derived from DMSP imagery using another manual analysis technique (Barry et al., 1987) and with those from the Air Force 3-D Nephanalysis algorithm, which primarily uses an automated threshold technique on DMSP infrared imagery to determine cloud cover in the Arctic (Hughes and Henderson-Sellers, 1985; McGuffie, 1985). General agreement was seen in the distribution of cloudiness in the Basin, however the automated analysis reported less extensive cover and local to regional differences in the distribution of cover were noted between each product (fig. 11).

Discussion and Conclusions:

Cloudiness over the Arctic Basin was found to be heterogeneous in space and time during the late springs and summers between 1977 and 1979. This is in agreement with the basin-wide results of Barry et al. (1987) for the springs of 1979 and 1980 and those of Jayaweera (1977) for the Beaufort Sea in June and July 1975. The late-spring cloud maximum in 1977 and 1979, which occurred over all but the central portion of the Basin, and the later retreat of the maximum to the Central Arctic provides further support to the suggestion that extensive spring cloudiness is associated with the advection of moisture from lower latitudes by synoptic disturbances (Barry et al., 1987).

The initiation of snow melt on the pack ice appears to accompany the regional cloud maximum (Robinson et al., 1986 and 1987). Melt does not appear to preceed the increase in cloudiness, thus ruling out a local moisture source as a major contributor towards the early cloud development. Warm air accompanying the clouds into the Basin may initiate the melt; however, once there the clouds may serve as the major factor enhancing the melt. As the majority of clouds over the basin appear to be relatively transparent, they should allow a high amount of incoming solar radiation to penetrate to the surface. Once through the clouds, this solar radiation and any terrestrial radiation tend to remain trapped near the surface, promoting further melt.

If the behavior of cloudiness in the late springs and summers of 1977-1979 is common in most years, climate models must be able to reproduce this in order to correctly address the present earth/atmosphere energy budget in the Arctic and its association with the underlying sea ice and open ocean, as well as to adequately assess the climate response of the region to atmospheric perturbations.

Continued monitoring of arctic cloudiness would be useful, however it is a tedious and time-consuming task when done manually and, at present, automated satellite analyses are insufficient for adequate cloud mapping in this region. The latter suffers from difficulties in distinguishing between cloud tops and the sea-ice surface in the shortwave and problems distinguishing between the surface and the tops of low-level stratus in the infrared. Present efforts should be directed towards improving automated satellite analyses, with manual analyses being of use in the improvement and validation of these products.

Acknowledgements:

DMSP imagery was supplied by the National Snow and Ice Data Center, University of Colorado, Boulder. This work was funded by the U.S. Department of Energy, Carbon Dioxide Research Division agreement number DE-AC02-81EV10665 and the Air Force Office of Scientific Research, Air Force Systems Command, USAF, under grant AFOSR 86-0053. The U.S. Government is authorized to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright notation thereon.

References:

Barry, R.G., Crane, R.G., Schweiger, A., Newell, J. (1987) Arctic cloudiness in spring from satellite imagery. J. Climatol. (in press).

Chukanin, K. (1954) Meteorological observations. Materialy nabluidenii

nauchno-issledovatel'skoi dreifususchchei stantsii 1950/51 (translated from Russian)
Gorshkov, S.G. (ed.) (1980) Military Sea Fleet Atlas of Oceans: Northern Ice Ocean. Ministry of Defense, USSR: 184 pp (in Russian).
Herman, G.F., Curry, J.A. (1984) Observational and theoretical studies of solar radiation in arctic stratus clouds. J. Cli. Appl. Met. 23: 5-24.
Hughes, N.A., and Henderson-Sellers, A. (1985) Global 3-D nephanalysis of total cloud amount - climatology for 1979. J. Cli. Appl. Met., 24, 669-686.
Huschke, R. (1969) Arctic cloud statistics from "air-calibrated" surface weather observations. Rand Corp. Memorandum RM-6173-PR, 79pp.
Jayaweera, K. (1977) Characteristics of arctic stratus clouds over the Beaufort Sea during AIDJEX. AIDJEX Bulletin No. 37: 135-151.
Kukla, G.J. (1984) Variation of Arctic Cloud Cover During Summer 1979. L-DGO Technical Report LDGO-84-2: 65pp.
Marshunova, M., Chernigovskii, N. (1971) Radiation regime of the foreign Arctic. Gidrometeorologicheskoe Izdatel'stvo (translated from Russian): 189pp.
McGuffie, K., 1985: Cloud over radiation over cryospheric surfaces: Climatology and climate sensitivity. Ph.D. thesis, University of Liverpool, Liverpool, England, 363pp.
Robinson, D.A., Henderson-Sellers, A., Shine, K.P., Kukla, G.J. (1983) (abstract): A new method of determining arctic cloud properties from remotely sensed data. International Association for Hydrological Sciences Programme and Abstracts, Hamburg, F.R. Germany, Aug. 1983: 46.
Robinson, D.A., Kukla, G.J., Serreze, C. (1985) Arctic cloud cover during the summers of 1977-1979. L-DGO Technical Report LDGO-85-5: 175pp.
Robinson, D.A., Scharfen, G., Serreze, M.C., Kukla, G., Barry, R.G. (1986) Snow melt and surface albedo in the Arctic Basin. Geophys. Res. Lett. 13: 945-948.
Robinson, D.A., Scharfen, G., Barry, R.G., Kukla, G. (1987) Analysis of interannual variations of snow melt on arctic sea ice mapped from meteorological satellite imagery. in: Proceedings of the IAHS/IUGG Symposium on Large-Scale Effects of Seasonal Snow Cover. Aug. 1987, Vancouver, Canada (in press).
Thorndike, A.S., Colony, R. (1980) Arctic Ocean Buoy Program Data Report, 19 January 1979 - 31 December 1979. Polar Science Center, U. Washington, Seattle, WA, 131pp.
Tsay, S., Jayaweera, K. (1984) Physical characteristics of arctic stratus clouds. J. Clim. Appl. Res. 23: 584-596.
Vowinckel, E., Orvig, S. (1970) The climate of the North Polar Basin. in: Climates of the Polar Regions (ed. S. Orvig), Elsevier Pub. Co.: 129-252.

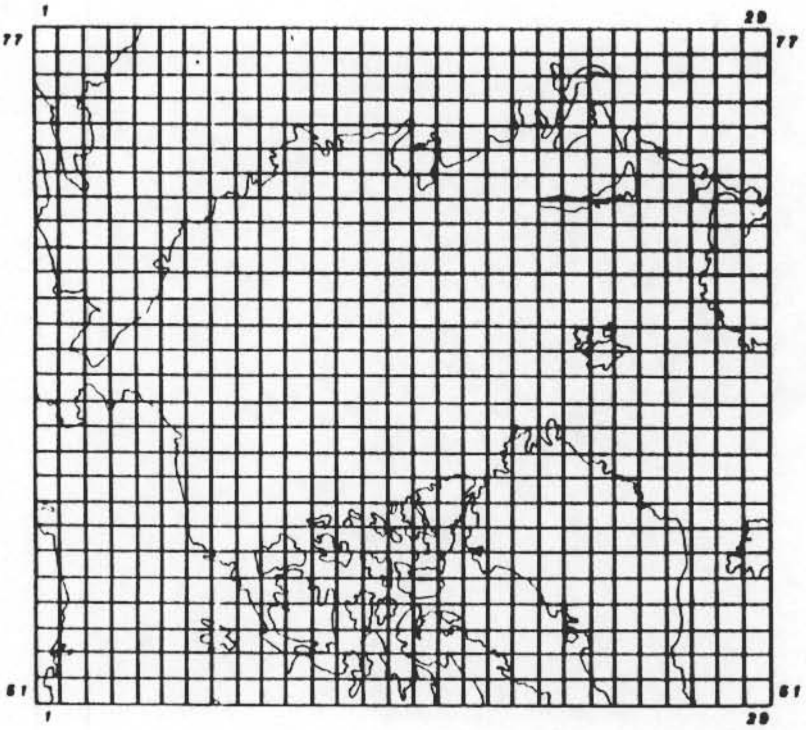


Fig. 1. National Meteorological Center standard data grid used in chart digitization.

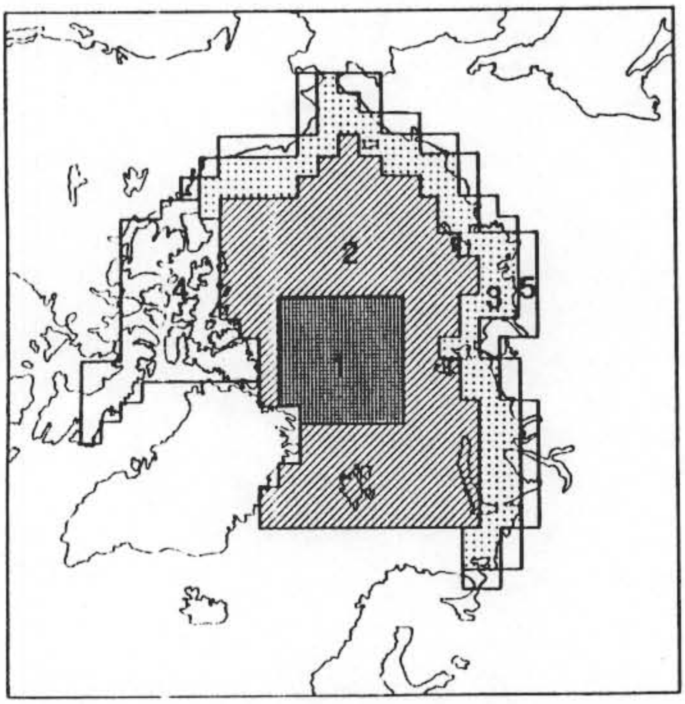


Fig. 2. Regions in the Arctic Basin used in this study. Region 1) Central Arctic Ocean 2) Outer Arctic Ocean 3) Arctic Coastal Waters 4) Canadian Archipelago and 5) Arctic Coastal Land.

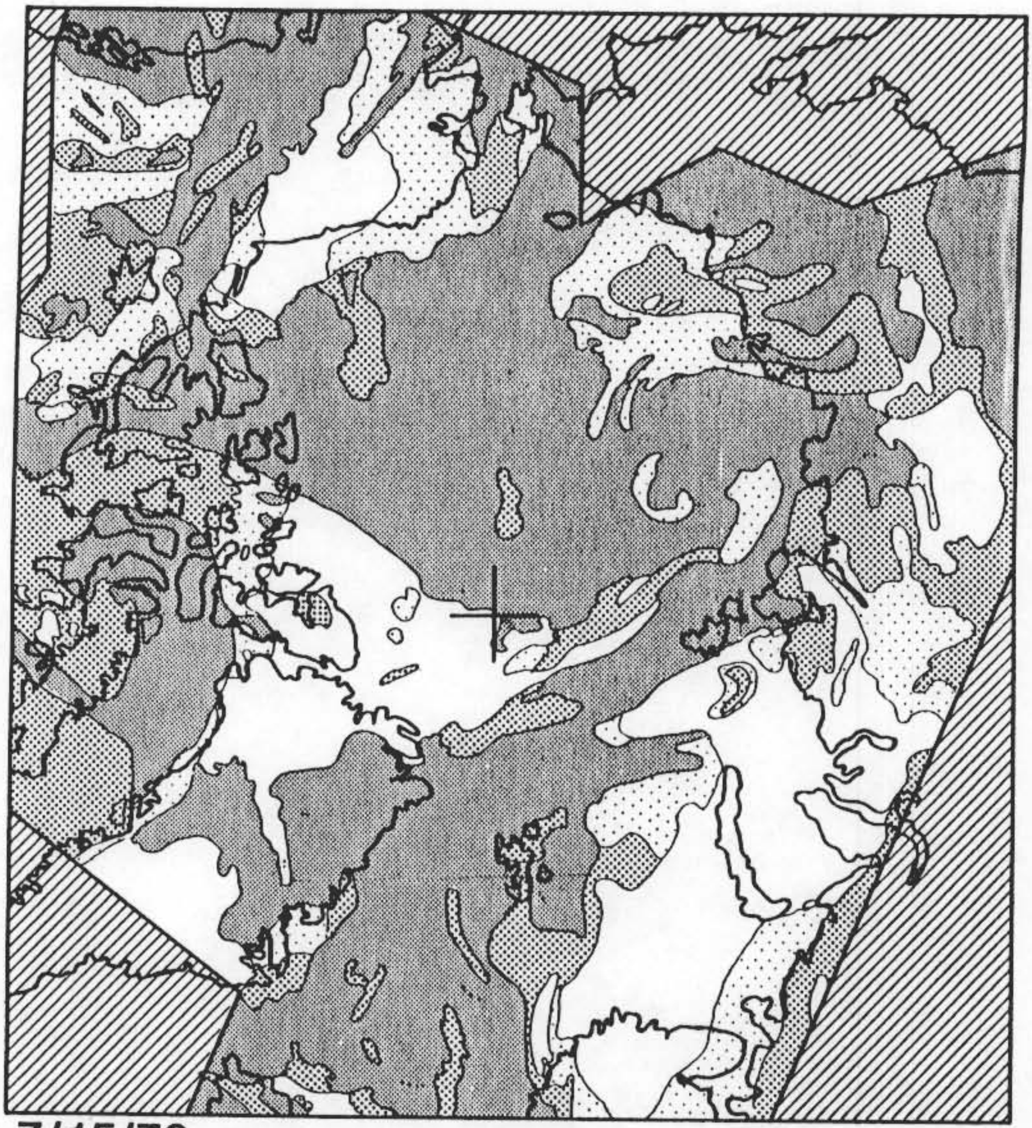


FIG. 3. Cloud-cover field for July 15, 1979. Classes include: 1) Cloud free (open), 2) thin clouds (light stippling), 3) moderately-thick clouds (moderate stippling and 4) thick clouds (dense stippling. Hatched where data were unavailable. The North Pole is marked with a cross.

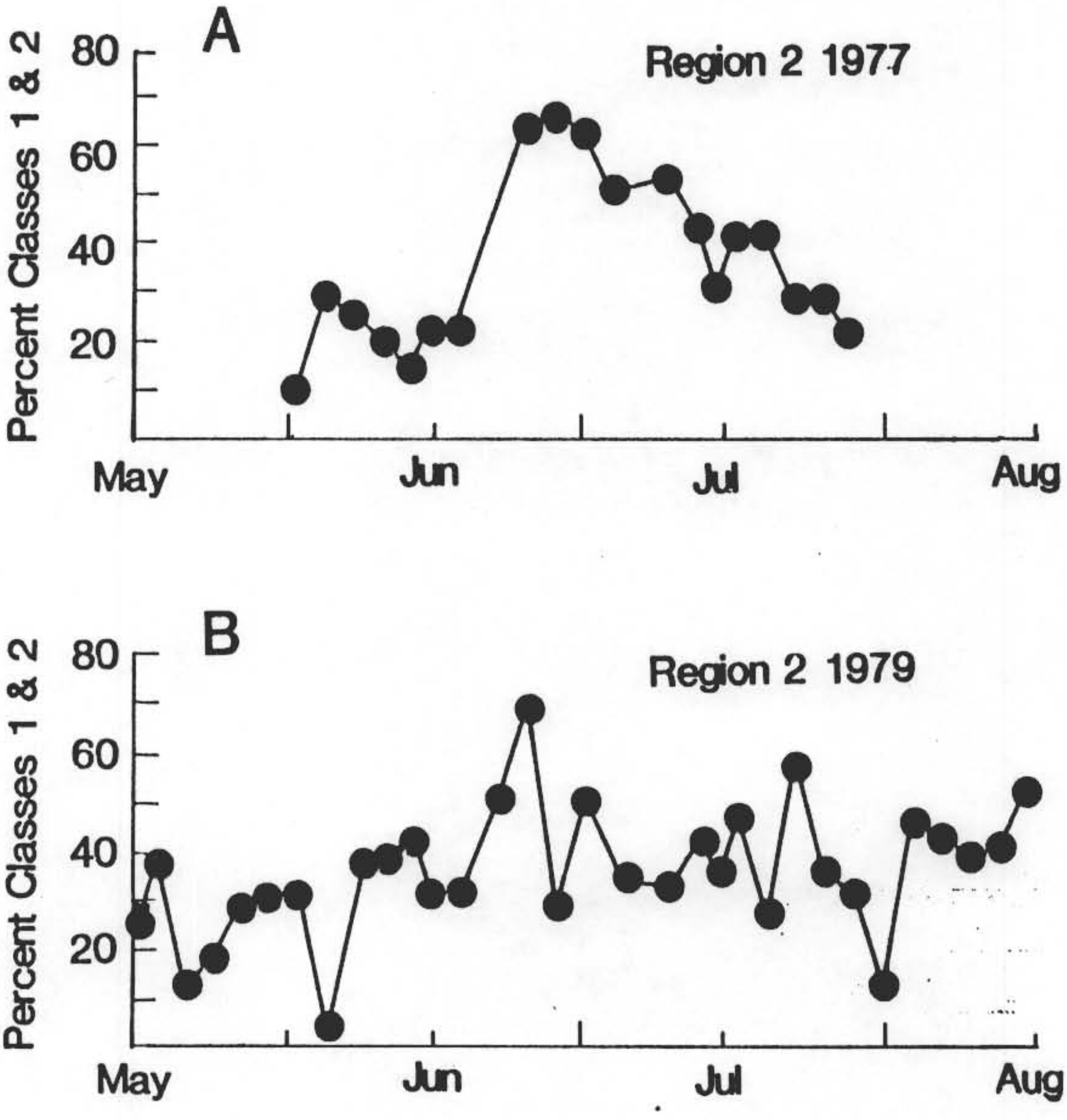


FIG. 4a. Coverage of cloud-free skies plus thin clouds (classes 1 and 2) over the Outer Arctic Ocean (region 2) for approximately every 3 days in June and July 1977.

4b. Same as a, except for May 15 to August 15, 1979.

A

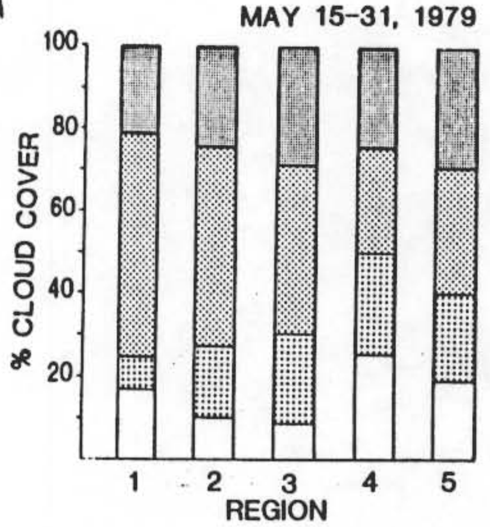


FIG. 5a. Estimates of the mean area covered by the three cloud classes and the cloud-free class in the five study regions for the second half of May 1979. Symbols same as in Fig. 3.

B

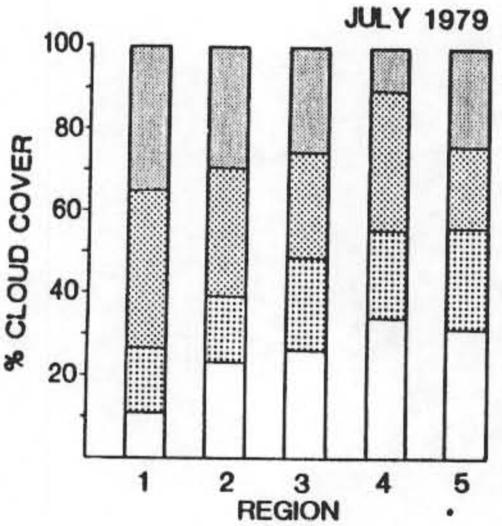


FIG. 5b. Same as a, except for all of July 1979.

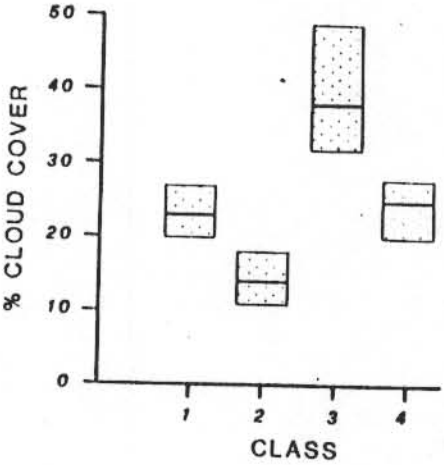


Fig. 6. Mean cloud cover in the Outer Arctic Ocean by individual classes averaged from June and July 1977 and 1979 data (thick bar). Stippling denotes the range between the lowest and highest mean values of the four months.

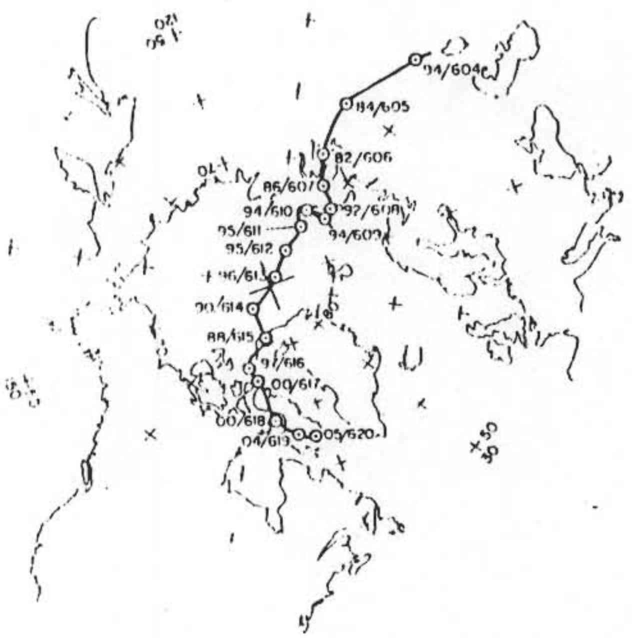
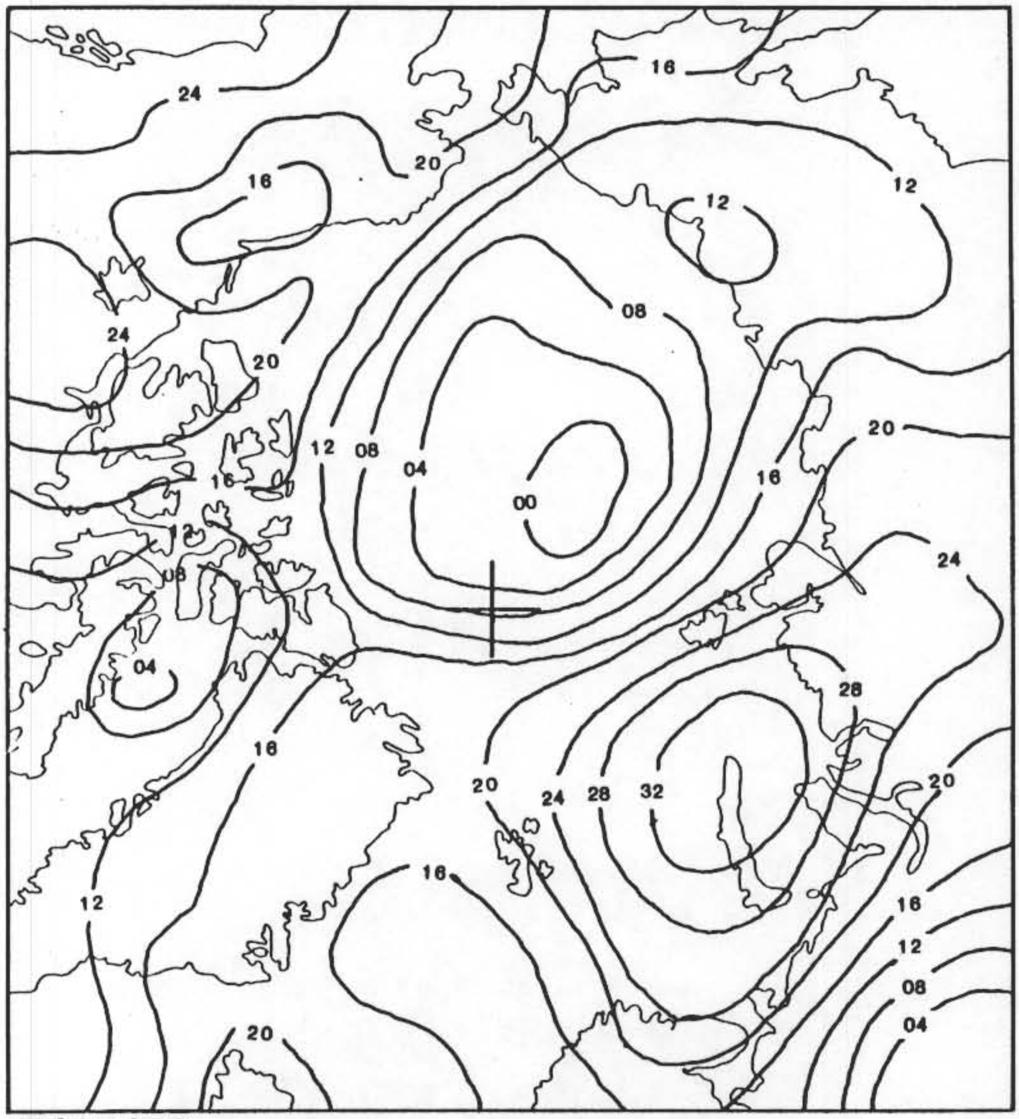


Fig. 7. Progression of a surface low pressure system across the Arctic Basin from June 4 to June 20, 1979, as taken from NMC 00Z Northern Hemisphere charts (June 4-6 and 17-20) and 1200Z buoy and station data (June 7-16) from Thorndike and Colony (1980). Pressure in millibars (add 900mb to values >50 and add 1000mb to values <50). Month and day given in the denominator.



7/15/79

FIG. 8. Surface atmospheric pressure field for July 15, 1979 from NMC 00Z Northern Hemisphere chart. Add 1000mb to all values.

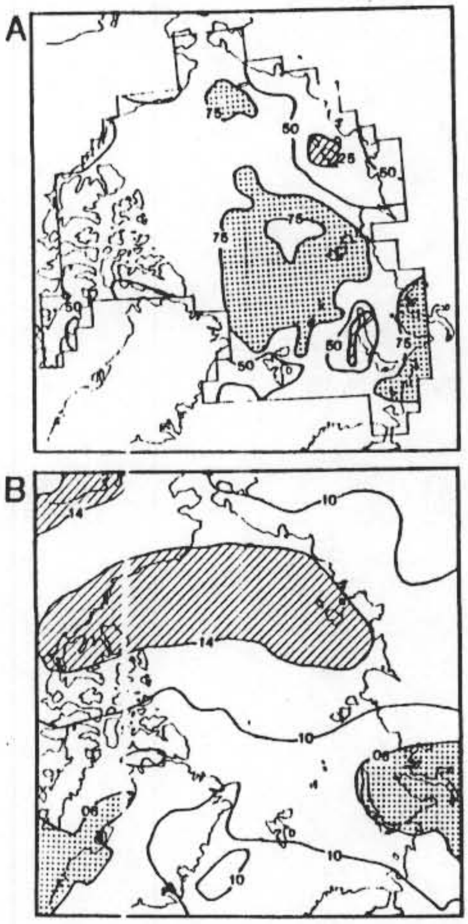


FIG. 9

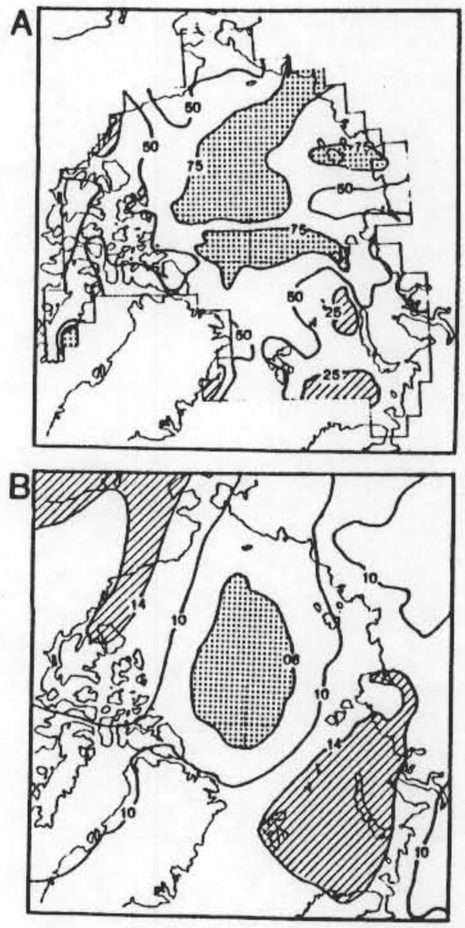
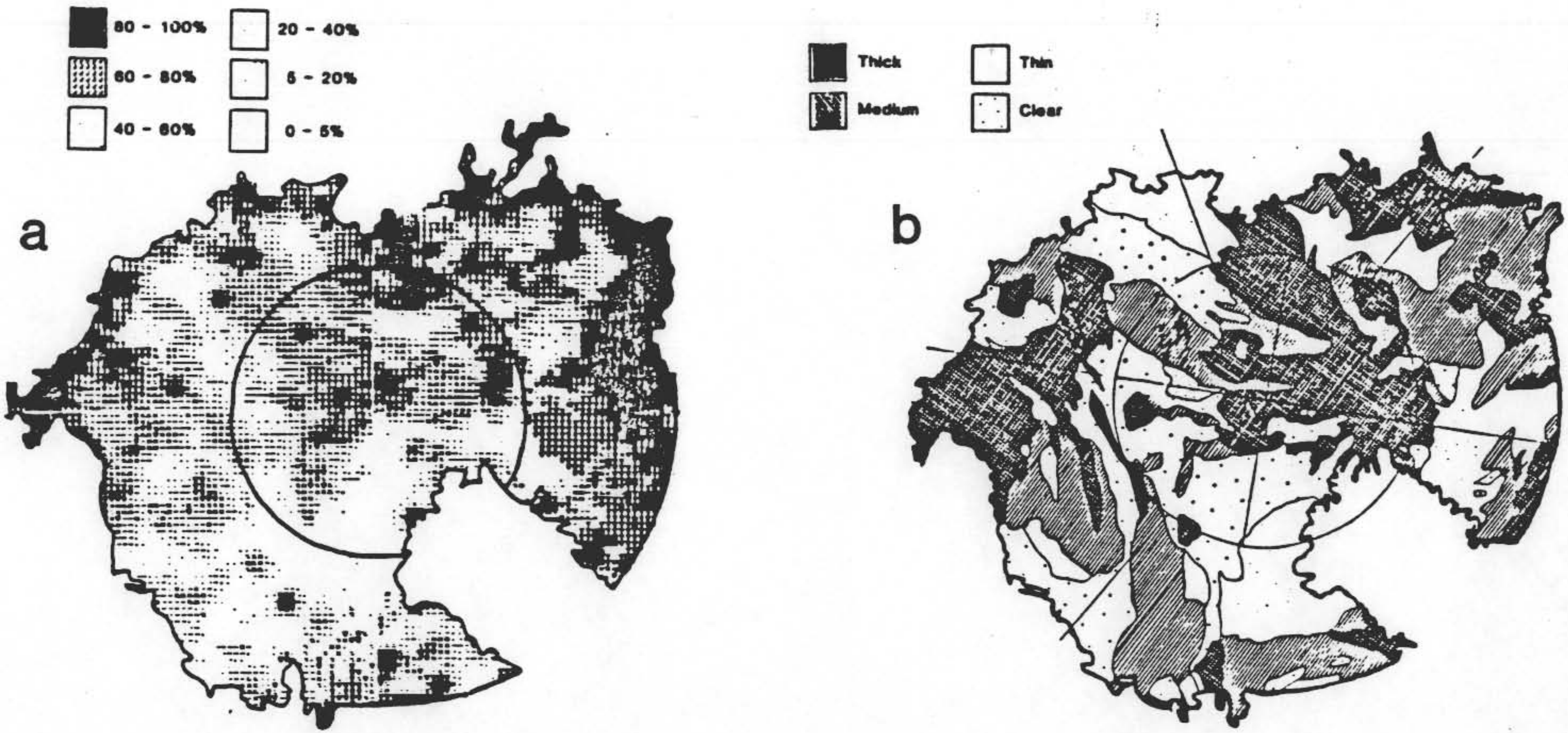


FIG. 10

FIG. 9a. Percent frequency of moderate and thick cloud cover for June 1979 within the study regions. Areas with >75% cover shown with stippling, <25% cover with hatching.

9b. Mean-monthly surface pressure field for June 1979. Derived from NMC charts on dates when clouds were charted. Add 1000mb to all values.

FIG. 10. Same as Fig. 9 except for July 1979.

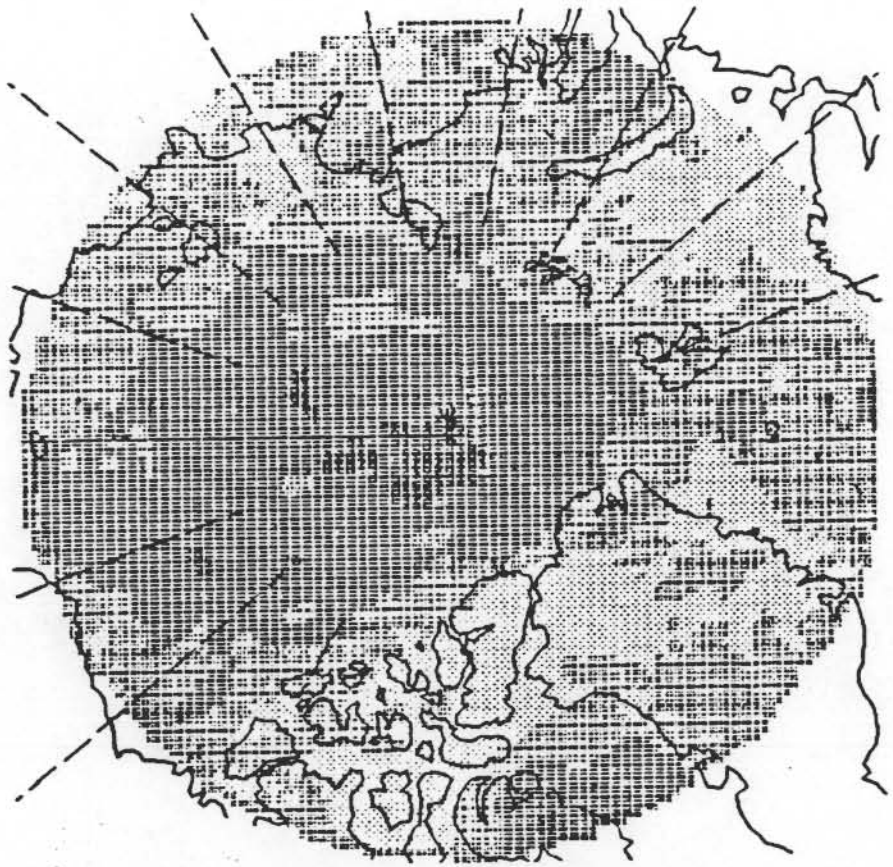


10th June 1979

FIG. 11. Total cloud amount for June 10, 1979:
a) from 3-D nephanalysis, in percent (from McGuffie, 1985)
b) from DMSP imagery analysis (from Robinson et al., 1985)
c) average for synoptic type 4 (Kara Sea low, Beaufort Sea high)
(log scale with five classes divided at 4.7, 6.9, 8.5 and 9.5 tenths)
(from Barry et al., 1987)

FIG. 11

C



Tenths

>9.5

8.5–9.5

6.9–8.5

4.7–6.9

<4.7