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Summer Cryospheric and Atmospheric Variability in the Arctic Basin

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1. INTRODUCTION

In order to better understand the climate of the Arctic, studies of air-sea-ice interactions are needed (U.S. Arctic Research Plan, 1987). This requires the generation of multi-dimensional data sets for diagnostic studies and for the parameterization and verification of climate models (eg. Ross and Walsh, 1987). Such data sets are also useful in the recognition and assessment of natural or human-induced climatic change in the region.

Results are reported here from a continuing effort to collect and analyze cryospheric and atmospheric data in the Basin (fig. 1). Among the variables studied are the extent of ice, the melt of snow cover on the pack ice, surface albedo, cloudiness, atmospheric pressure and surface air temperatures. Concentration is on the summer, where significant variability of each component during the season as well as between summers is found and several apparent relationships amongst the variables are identified.

2. DATA AND METHODS

The primary years of study include 1977, 1979, 1984 and 1985, with preliminary data from 1978 and 1986. Snow melt and cloud data were derived from visual analyses of Defense Meteorological Satellite Program (DMSP) shortwave (0.4-1.1μ) and infrared (8.0-13.0μ) imagery. DMSP imagery are in the form of hard-copy film transparencies with resolutions of 2.7 km and 0.6 km (for the Chukchi, Beaufort and Bering Seas).

Snow melt atop the sea ice was charted in three-day increments by a manual analysis of tonal contrasts and textural patterns on DMSP shortwave imagery. The near polar-orbiting satellites provide highly repetitive coverage under nearly constant solar illumination during the arctic summer. A three day interval is sufficiently long so that in general 80% or more of the Basin surface may be charted, yet details on the behavior of the snow cover are not lost.

Four ice-surface classes were identified. These classes represent: class 1) fresh snow cover over 95% of the ice; class 2) snow covers between 50-95% of the surface, with the remainder being bare or ponded ice; in spring this is considered the initial stage of active snow melt; class 3) the final stage of active snow melt, with between 10-50% of the ice surface snow covered and with numerous melt ponds; or, following pond drainage, predominantly bare ice, with snow patches and scattered ponds; and class 4) heavily-ponded or flooded ice with less than 10% snow cover or exposed bare ice.

Large-scale surface albedo for each charted class is considered to be: class 1) 0.80; class 2) 0.64; class 3) 0.49; and class 4) 0.29, with standard deviations between 0.08 (class 3) and 0.05 (class 4). These values are adjusted for average summer cloudiness and albedo is decreased to account for the presence of open water within the pack.

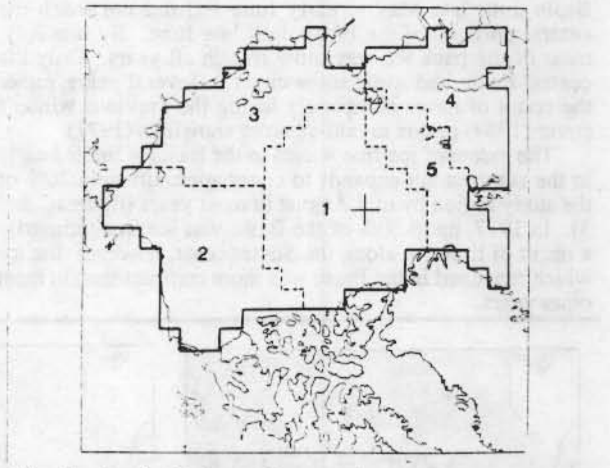


Fig. 1. Arctic Basin study zone (heavy line) divided into five regions (dashed lines): 1) Central Arctic, 2) Beaufort/Chukchi Seas, 3) East Siberian/Laptev Seas, 4) Kara/Barents Seas and 5) Northwest North Atlantic.

Class albedos were calculated by measuring the brightness of selected clear-sky scenes on a digital image processor and linearly interpolating between homogeneous targets of bright snow on multi-year ice and dark open-water. Target albedos were estimated from measured ground and aerial data (eg. Langleben, 1971; Bryazgin and Koptev, 1970; Payne, 1972; Grenfell and Maykut, 1977; Cogley, 1979). Further information on snow melt charting procedures is found in Robinson et al. (1986) and Scharfen et al. (1987).

Areas which remained uncharted following a basin-wide snow melt analysis are categorized as regions of persistent cloudiness. In addition, in 1977 and 1979, daily cloud cover was charted over the basin every three days from DMSP shortwave and infrared imagery. Clouds are differentiated visually from snow and ice, primarily by the characteristic large-scale features of the pack ice identified in shortwave imagery. Depending on the cloud optical depth and solar angle, these features are either completely or partly obscured. In addition, certain cloud fields, particularly those in cyclonic regions, are recognized by their characteristic shapes and patterns in both wave bands.

Three cloud-thickness classes and a cloud-free class were recognized: class 1) cloud free (surface features seen with high contrast); class 2) thin clouds or sub-resolution patchy clouds (surface features clearly recognizable but with reduced contrast as compared to cloud-free skies); class 3) moderately thick clouds or fog (surface features marginally recognizable through the cloud); and class 4) thick or multi-layer clouds (no surface features recognizable). Further information on cloud charting procedures is found in

Robinson et al.(1985) and Kukla and Robinson (1988).

Sea ice extent and concentration, in eighths for 1977-1979 and tenths for 1984-1986, were taken from Navy/NOAA weekly ice charts, monthly temperature anomalies, as derived from coastal station reports, are from *Climate Monitor* and surface pressure data are from daily NMC and Arctic Ocean Buoy Program charts.

3. RESULTS

Inter-annual variations in the onset of extensive snow melt are on the order of several weeks. In figure 2, maps show the progression of snow melt over the Basin and peripheral seas during two summers. In 1977, the onset of melt was earliest, by mid June most of the Basin had active snow melt in progress or was already snow free. In 1979, when the early season melt progression was more like 1978 and 1984-86, active melt did not begin over much of the Basin until late May to early June and did not reach the central portions of the Basin until late June. By late July, most of the pack ice was snow free in all years. Only the central Basin had some snow cover in several years, either the result of never completely losing the previous winter's cover (1984) or due to mid-summer snowfalls (1977).

The extent of ice-free waters in the Basin is limited early in the summer but expands to cover approximately 20% of the study region by mid August in most years (figures 2 and 3). In 1977, up to 30% of the Basin was ice free, primarily a result of little ice along the Soviet coast, however the ice which remained in the Basin was more compact than in most other years.

The timing and extent of snow melt early in the season and the extent of melt and ice cover later in the season determine the regional surface albedo. Therefore, albedo was at its lowest in the summer of 1977, when monthly means ranged upwards of 0.08 lower than other years (table 1). Early season values were highest in 1979. July and August albedos in both 1984 and 1985 averaged 0.48 and 0.42, respectively, some 0.02 to 0.06 higher than in 1977 and 1979.

TABLE 1 Average surface albedo over the Arctic Basin (as outlined in fig. 1) for each month in the four study years.

	1977	1979	1984	1985
May	0.73	0.77	0.73	0.76
June	0.58	0.66	0.61	0.65
July	0.43	0.44	0.48	0.48
August*	0.36	0.40	0.42	0.42

*for the period August 1-17

The distribution of ice in 1977 appears to be related to the persistent high pressure at the surface and aloft over the Beaufort Sea to northern Greenland and the low pressure

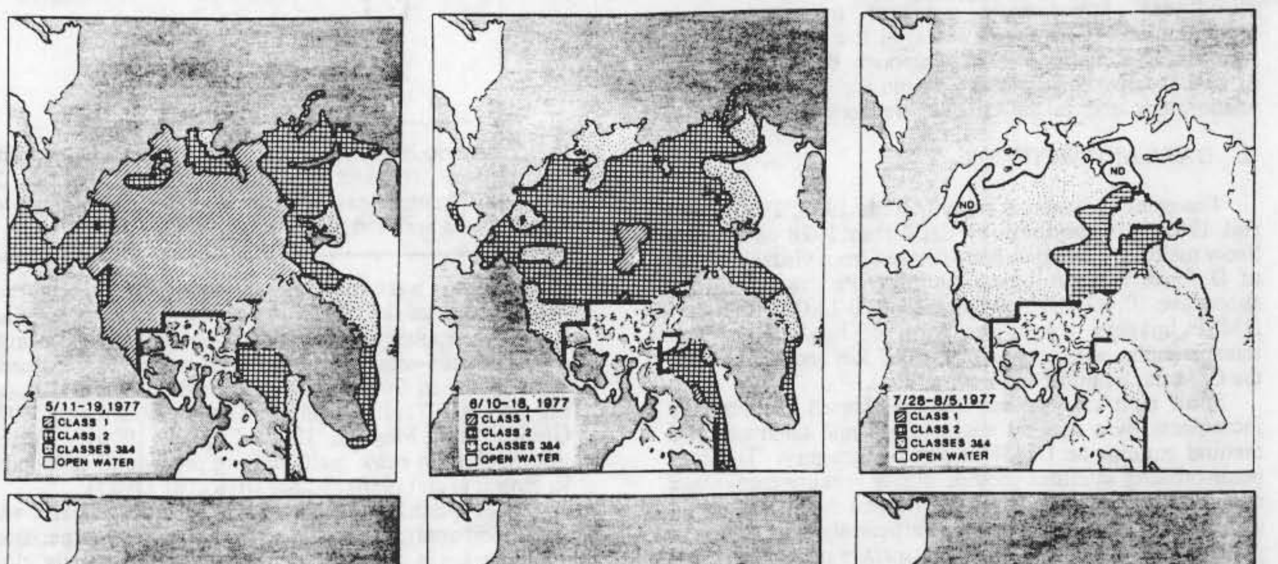


Fig. 2. Charts showing the progression of snow melt atop arctic sea ice in the summers of 1977 and 1979. Melt classes are defined in the text. ND=not determined. Charts are based primarily on data from the middle three days of the interval noted. Data from the adjacent periods were used to fill in gaps resulting from persistent clouds during the middle period.

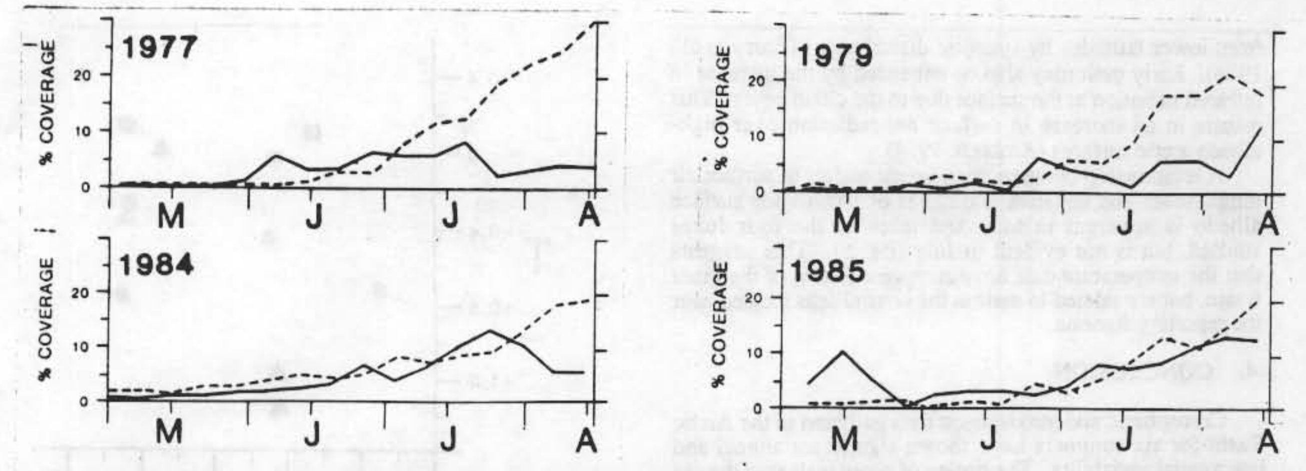


Fig. 3. Percentage of the Basin with open water or with less than a 12% (1977, 1979) or 10% (1984-85) concentration of ice (dashed line) and percentage of the basin with 12%-75% ('77,'79) or 80% ('84,'85) ice concentration (solid), according to weekly Navy/NOAA ice charts.

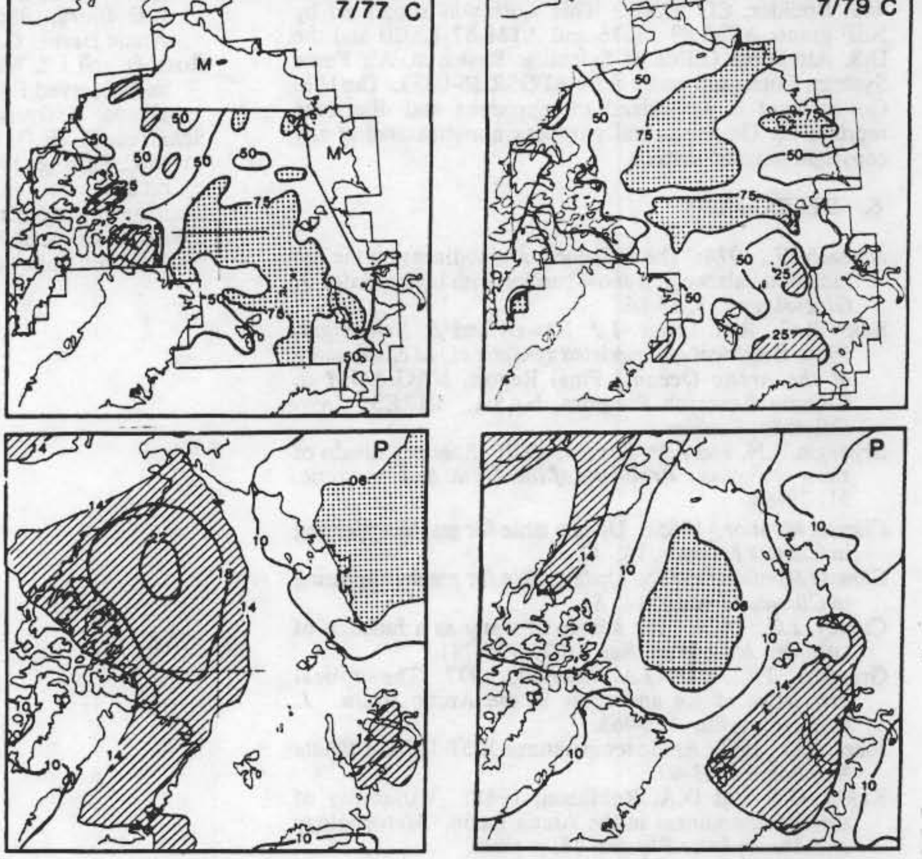
found over Siberia (fig. 4). This pattern would seemingly help rid the Laptev and East Siberian Seas of ice more so than in a year such as 1979, when pressures were high over the Beaufort to Laptev regions in June and pressure over much of the Basin was low during July (fig. 4). It may also be that there is a relationship between the lack of ice along the coast and the early onset of snow melt in 1977.

Cloud cover shows a late May - early June maximum in extent (averaging approximately 90%) and thickness over the Basin in the six study years. This is followed by a period of less extensive (ranging downwards to 50%) and somewhat thinner cover extending into early August, when cloudiness begins to increase. Cloud cover persisted for three-day snow charting intervals over some 5 to 40% of the region during summer. The years 1977 and 1984 on average had upwards of 15% more persistent clouds than 1979 and 1985.

A relationship between increased cloudiness and lower surface pressure is noted. On both daily and monthly bases, moderate and thick clouds are associated with the position of surface lows (fig. 4). Likewise, cloud-free skies are most frequently associated with surface highs. Optically thick clouds are also found to be associated with atmospheric flow from lower latitudes at the surface and aloft, as seen in July 1977.

The early-summer cloud maximum appears to be related to the onset of snow melt in the Basin. Both may be due to the poleward retreat of the Arctic Front and advection of air

Fig. 4. Top chart for each July shows the percent frequency of moderate and thick cloud cover for the month based on a three-day sampling interval. Bottom chart shows the surface pressure field for the month derived from days when clouds were charted. Add 1000mb to all values.



from lower latitudes by synoptic disturbances (Barry et al., 1986). Early melt may also be enhanced by the increase in infrared radiation at the surface due to the cloud cover. This results in an increase in surface net radiation over high-albedo arctic surfaces (Ambach, 1974).

A relationship between positive anomalies of surface air temperature and negative anomalies of basin-wide surface albedo is apparent in May and three of the four Junes studied, but is not evident in July (fig. 5). This suggests that the temperature data are not representative of the inner Basin, but are related to melt in the coastal seas located near the reporting stations.

4. CONCLUSION

Cryospheric and atmospheric data gathered in the Arctic Basin for six summers have shown significant annual and interannual variability. The timing of snow melt atop the sea ice may vary by several weeks. Along with the variable extent of summer sea ice, the extent and timing of snow melt result in monthly variations in regional surface albedo of up to 0.08. The distribution and amount of cloudiness and the distribution and strength of atmospheric pressure also vary. Relationships between clouds and pressure, pressure and ice distribution, clouds and snow melt, snow melt timing and late-season ice extent and early-season snow melt and coastal surface air temperature are seen. However, these relationships must be considered tentative until data for additional years are available. Presently, the data base is being expanded to ten years. When it is completed, further diagnostic and modeling studies will be undertaken.

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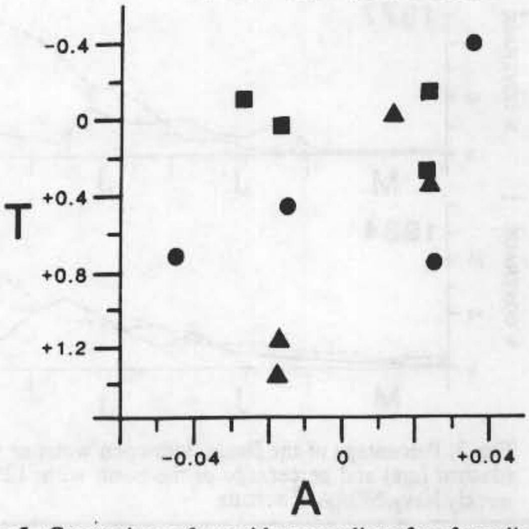

Fig. 5. Comparison of monthly anomalies of surface albedo over the Arctic Basin and surface air temperature from 65-85oN, for May (triangles), June (circles) and July (squares) of the four study years. Albedo anomalies are based on an average of the four years. Temperature anomalies are based on 1951-1970 means (Jones, 1985; Climate Monitor, 1985a & 1985b).

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