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# SNOW MELT AND SURFACE ALBEDO IN THE ARCTIC BASIN

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Abstract. Meteorological satellite imagery has been used to map the changes of surface brightness and texture associated with the seasonal progression of snow melt on the arctic pack ice in 1977 and 1979, and, using an image processor, surface albedo has been estimated. This is the first basin-wide information on the temporal and spatial change of the ice surface and its albedo. In both years studied, melt progressed poleward from the Barents and Kara Seas and from the southern Beaufort and Chukchi Seas. Average surface albedo of the Arctic Basin fell to 0.40, and in the central Arctic to about 0.50, in late July of each year, but the melt occurred approximately 3 weeks later in 1979 than in 1977. Results suggest a significant year-to-year variability in the arctic energy and mass balances.

## Introduction

The extent, timing and degree of snow melt on the pack ice has long been recognized as a critical variable influencing the summer climatic regime in the Arctic Basin, with potential impacts on other parts of the Northern Hemisphere (Fletcher, 1966). The snow melt has implications for the long-term mass balance and stability of the sea ice and may serve as an indicator of $CO_2$-induced climatic change (Barry, 1985). Up to now, direct observations of melt and the resultant changes in albedo in the basin have been collected at drifting stations, on fast ice and by a few aircraft missions. Others have used these data and microwave data to estimate the average summer albedo of the region.

## Data Generation

Imagery from the polar orbiting Defense Meteorological satellite (DMSP) served as the primary data source. Shortwave (0.4-1.1 um) images with resolutions of 0.6 km in direct read-out format and 2.7 km in orbital swath format were used.

Snow melt on the ice is recognized in the imagery by a characteristic decrease in brightness and a change in surface texture. As the snow dissipates, melt ponds form and bare ice is exposed (Barry, 1983) (Fig. 1 A). Landfast ice and first-year pack ice brighten again when melt ponds drain. Comparisons of DMSP imagery with synchronous 80m resolution Landsat imagery confirm the recognition of surface features in the lower resolution products. The comparisons also show that brightness and textural changes due to melt processes on the ice may, in most cases, be successfully distinguished from variations in ice concentration.



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Basin-wide (Fig. 2) maps of surface brightness and texture were constructed manually in three day increments from May through August 1977 and 1979. Repetitive coverage and characteristic textures permitted the differentiation of moving clouds from the surface (Robinson et al., 1985). Interactive image processor analyses of selected scenes showed good agreement with visual classifications of surface brightness. Maps were digitized using the National Meteorological Center standard grid, which divides the basin into 212 cells. At least one cloud-free scene per 3-day interval was available over more than 80% of the basin from May to mid-August. Missing cells were either: 1) assigned observed brightness values from an immediately preceding or subsequent chart, 2) considered open water, if shown as such on the Navy/NOAA weekly ice chart closest to the analysed interval, or 3) handled as missing data (less than 10%, on average).

Four ice-surface classes are identified (cf. Fig. 1 B). Ground and aerial observations made earlier (eg. Laktionov, 1953; Untersteiner, 1961; Zubov, 1963; Pautzke and Hornof, 1978; Hanson, 1980; Lapp, 1982; Holt and Digby, 1985) suggest that these classes represent: class 1) fresh snow cover over approximately 95% or more of the ice, class 2) the initial stage of active snow melt, with between 50-95% of the surface snow covered and the remainder being bare or ponded ice, 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 about 10% snow or bare ice.

Large-scale surface albedo for the charted classes is taken as: 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). Albedo is a property of the surface, defined as the ratio of incident to reflected global solar radiation. It is not radiationally weighted. Variations in illumination at the time of satellite overpass are minimal during the study interval, as the noon solar zenith angle at the Pole varies by less than $10^{\circ}$.

Class albedos were calculated as follows; a) brightness measurements of selected clear-sky DMSP scenes were made on an image processor, b) brightnesses of homogeneous bright snow on multiyear ice and dark open water targets found in each scene were assigned clear-sky albedos derived from published ground truth (eg. Hanson, 1961; Langleben, 1971; Payne, 1972; Kuznetsov and Timerev, 1973; Cogley, 1979), c) measured class

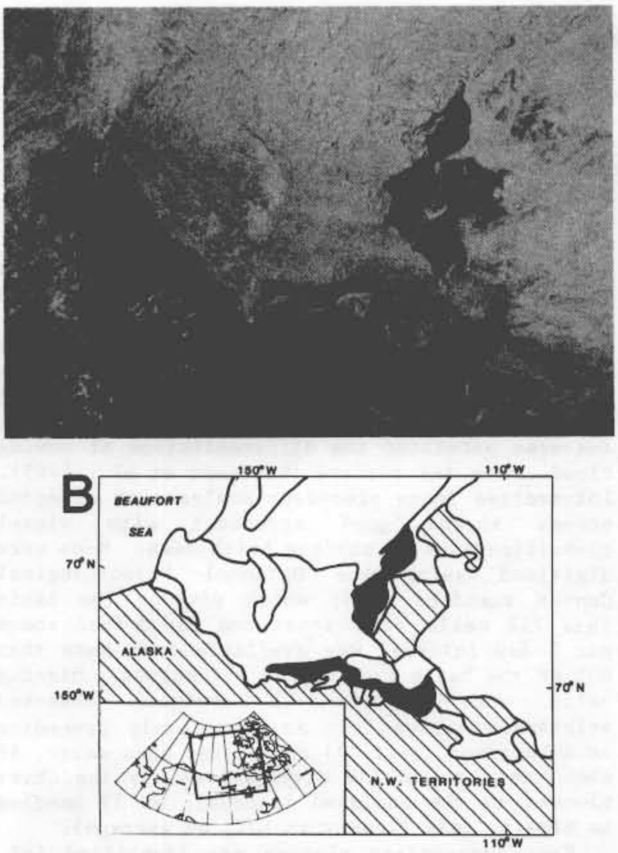


Fig. 1. A. High resolution (0.6 km) DMSP shortwave image of the Beaufort Sea on June 11, 1977, showing stages of snow melt on the sea ice. B. Manually constructed surface brightness chart with classes (cf. text) marked with light grey shading (class 1) to dark grey shading (class 4). Open water is black, cloud cover white and land areas hatched.

brightnesses were converted to clear-sky albedos using a linear interpolation between the bright and dark targets, and d) these values were adjusted for average summer cloudiness (Robinson et al., 1985) by +0.05 for brightness classes 1-3 and +0.02 for class 4 (Grenfell and Perovich, 1984). When calculating regional albedos, class albedos were decreased to account for the presence of open water within the pack. For class 1, the correction ranges from -0.17 when the ice concentration is 75% to -0.01 when the ice concentration is 99%.

## Results and Discussion

Our maps show that, in its seasonal progression, the melt moved northward and eastward from the Barents and Kara Seas and northward from the southern Beaufort and Chukchi Seas. The melt fronts meet on the American side of the North Pole. Some earlier maps also showed the snow melt progressing towards the Pole (Marshunova and Chernigovskiy, 1978; Campbell et al., 1980). In 1977, active melt (classes 2 and 3) covered over 75% of the basin by mid May (Fig. 3 A), while over half of the basin was categorized as class 3 or 4 by the end of June.

Melt began almost 3 weeks later in 1979 (Fig. 3 B), yet classes 3 and 4 covered half of the basin by the end of June, as in 1977. Due to the earlier melt in 1977, basin albedo averaged 0.73 in May compared to 0.77 in 1979 and in June it was 0.58 in 1977 and 0.66 in 1979. Mean July albedo was the same (0.43) in both years. The first half of August averaged 0.36 in 1977, compared with 0.40 in 1979, primarily due to the presence of more open water in 1977.

The albedo of the ice surface (sea water excluded) in those parts of the basin where ice concentration exceeded 75% was approximately 0.45 to 0.50 in July and early August (Fig. 3). Near the Pole it was 0.50-0.55, due to less extensive ponding. Albedo rose slightly in the second week of August, as some of the meltwater along the ice margins drained and fresh snow was deposited in the Central Arctic. Our satellite derived albedo is lower than that reported earlier from drifting stations (Nazintsev, 1964; Pautzke and Hornof, 1978). This may be the result of our averaging albedo over all surfaces in a region, as opposed to the observations made mostly on thick multi-year ice at drifting stations. Alternatively, the August snowfalls may have come relatively late in 1977 and 1979. Available cloud-free scenes show extensive areas of fresh snow in late August of both years.

A regional breakdown of albedo (Fig. 4) shows the earlier snow melt in 1977 compared with 1979 to be most pronounced in the seas adjacent to Eurasia and in the Central Arctic (regions 1, 3 and 4). In the coastal seas, the difference is a result of a continued loss of ice into the late summer of 1977, whereas in 1979 the ice covered area remained relatively constant and melt ponds drained in August, thus regional surface albedo increased slightly.

The albedo of 0.53 calculated for the Central Arctic in July is close to the midpoint of published estimates (eg. Larsson and Orvig, 1962; Posey and Clapp, 1964; Hummel and Reck, 1979; Robock, 1980; Kukla and Robinson, 1980; Carsey, 1985), which range from 0.40 to 0.65, reflecting the high year-to-year variability in the extent of snow melt, degree of ponding and frequency of

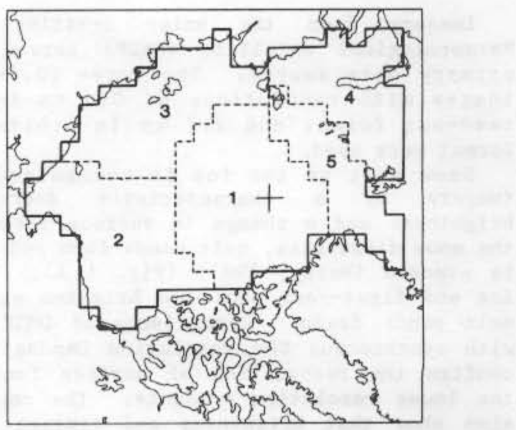


Fig. 2. Arctic Basin study zone (heavy line) divided into five regions (dashed lines): 1) Central Arctic, 2) Beaufort/Chukchi Seas, 3) East Siberian/Laptev Seas, 4) Kara/Barents Seas and 5) Northwest North Atlantic.

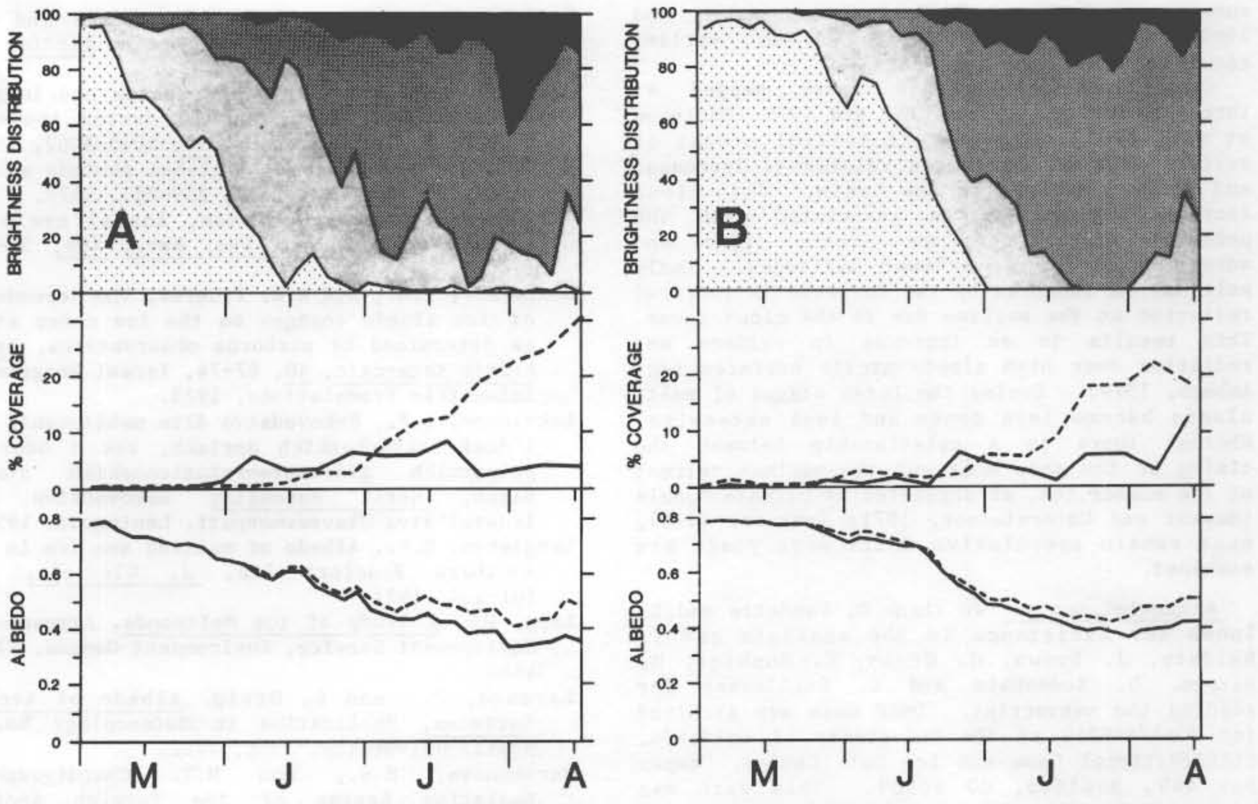


Fig. 3 A. Top: progression of snow melt and subsequent ponding and drainage on arctic sea ice from May to mid-August 1977 as shown by the changing distribution of brightness classes, shaded as in Fig. 1. Areas with less than 12% ice concentration or open water omitted. Middle: percentage of the basin with open water or with less than a 12% (1/8) concentration of ice (dashed line) and percentage of the basin with 12%-75% (1-6/8) ice concentration (solid), according to 1977 weekly Navy/NOAA ice charts. Bottom: basin-wide albedo (including sea ice and open water) from May-August 1977 (solid line). Albedo of ice (sea water excluded) in areas with at least 75% ice concentration (dashed). B. Same as 3 A, except for 1979.

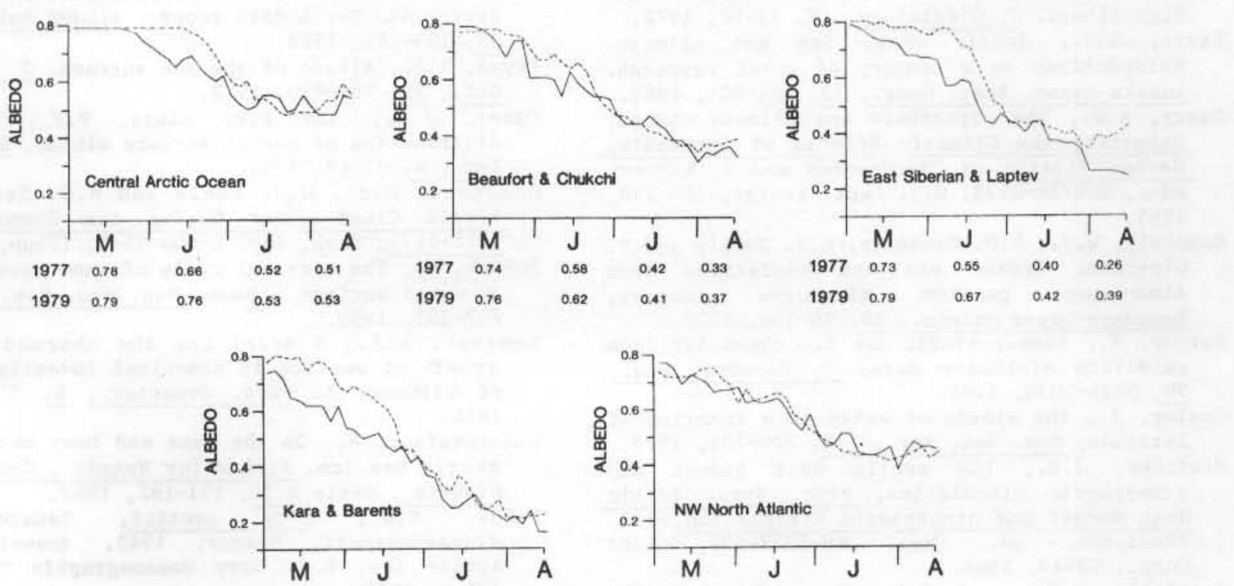


Fig. 4. Albedo of regions within the Arctic Basin at three day intervals in 1977 (solid line) and 1979 (dashed) and monthly means (below month).

summer snowfalls. Differing approaches and limited data bases available to earlier researchers may also be a factor.

Comparisons with cloud cover mapped at three-day intervals for 1977 and 1979 (Robinson et al., 1985) suggest that initial stages of surface melt may have been related to increased and thicker clouds in the basin. This cloud increase appears to be associated with the poleward retreat of the Arctic front and advection of air from lower latitudes. Early melt may 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 (eg. Ambach, 1974). During the later stages of melt, clouds become less dense and less extensive. Whether there is a relationship between the timing of the snow melt and the maximum retreat of the summer ice, as suggested by climate models (Maykut and Untersteiner, 1971; Semtner, 1976), must remain speculative until more years are examined.

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