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## Arctic Ocean Snow Melt Onset Dates Derived From Passive Microwave, A New Data Set

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### Abstract

Snow melt onset is defined as the point in time when the appearance of liquid water in the snow pack changes the crystalline structure within the pack. Owing to the associated increase in surface albedo during melt, surface energy absorption increases rapidly after the onset of snow melt. Monitoring interannual variations in snow melt onset is therefore useful for accurately modeling surface conditions, and it is also valuable for validating climate models and detecting climate change. Since microwave emission changes rapidly when liquid water appears in the snow pack, passive microwave remote sensing techniques can monitor melt onset. Passive microwave satellite data from the Scanning Multichannel Microwave Radiometer (SMMR) and the Special Sensor Microwave/Imager (SSM/I) are indispensable for this task because they represent an all-season, all-weather, diurnally consistent, and reasonably continuous data set for more than 20 years in length (1979-1998). The microwave data time series is created from a blended brightness temperature record generated from different satellite platforms through linear regression analysis to ensure consistency in the data set. The melt onset date is calculated by monitoring the difference between the 18-GHz (SMMR) or 19-GHz (SSM/I) horizontal brightness temperatures and 37-GHz horizontal brightness temperatures. Results indicate both regional and annual variations exist in the melt onset dates. The melt onset dates are generated annually and are available via ftp from the National Snow and Ice Data Center (NSIDC). This new data set provides a valuable addition to researchers for seasonal-to-interannual and long-term climate studies, and it is hoped that others will find the data set useful.

### Introduction

The discussion of global warming in recent decades has caused increased interest in year-to-year climate variations in the polar regions. The sensitivity of the polar regions to climate variations and change is believed to result from the complex exchange mechanisms operating between the oceans, ice, and atmospheric systems. The significance of sea ice in the polar regions is particularly emphasized during the spring transition period from winter conditions to summer conditions. For example, during the melt period, the surface albedo can vary from values greater than 0.9 for fresh dry snow to values less than 0.3 for wet-snow covered sea ice. With lower albedos, more shortwave energy is absorbed, further warming the air and ice surfaces. Therefore, determination of the melt onset is an important event in the polar region and this new data set produces a 21-year time series of individual melt onset dates. Understanding the energy variations that take place during the spring transition through the determination of melt onset can help determine the effects of climate variations, and therefore climate change in the polar region.

Microwave emissivity of snow increases dramatically as the snow melts and liquid water appears. Surface scattering dominates over volume scattering, resulting in a sharp increase in the brightness temperature signature. Lower microwave frequencies (19.3 GHz for the SSM/I instrument, and 18.0 GHz for the SMMR instrument) are more responsive to melt onset in the firn than are higher frequencies (37.0 GHz for both SSM/I and SMMR), due primarily to the change in emission depth associated with melt. The difference between 19.3 (or 18.0) GHz and 37.0 GHz brightness temperatures changes from positive to near-zero or negative. The increase in brightness temperatures associated with melt is frequency- and polarization-dependent; horizontal channels reflect a stronger dependence on snow conditions during melt.

## Data

25 km<sup>2</sup> daily-averaged brightness temperature data from the Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave/Imagers (SSM/I) were obtained from the National Snow and Ice Data Center (NSIDC) archive. Since the passive microwave data originated from four different radiometers, all data were converted to be consistent with the SSM/I F8 data using regression analysis during overlap periods. Brightness temperature from SMMR were converted to F8 using the slope and intercept values provided by Jezek et al. (1991), and the F11 to F8 with values from Abdalati et al. (1995). The brightness values from F13 were first converted to F11 values using the slope and intercept from Stroeve et al. (1998), and then converted to F8 with the values from Abdalati et al. (1995). These conversions are essential in determining variability in the melt onset, and not changes in the radiometers.

### Mean Melt Onset Pattern

The 20-year mean melt onset map indicates the spatial melt pattern is roughly radial in nature, beginning along the southern ice edges and progressing northward (Anderson Figure 1, page 115). Melt onset typically starts prior to Julian Day 70 in the Bering Sea, the Sea of Okhotsk, and along the Labrador coast. From Julian Days 70-90, melt onset usually occurs in most of the Bering Sea and the Sea of Okhotsk, and some melt onset is noticeable in Hudson Bay, the South Greenland coastline, and the eastern Arctic Islands. Through Julian Days 90-110, the melt onset area expands to include the Hudson Bay coastline, and southern portions of Davis Strait. Melt onset also appears in the East Siberian Sea and along the Russian coastline. From Julian Days 110-130, melt is typically detectable in most regions of the Arctic Basin, and throughout all of Hudson Bay. The next 20 days (Julian Days 130-150) are marked by melt onset covering the Davis Strait and most of the southern Canadian Arctic Archipelago Islands. At this point, the melt onset pattern begins to rapidly expand northward, and from Julian Days 150-170 the total melt onset area nearly doubles. The latest melt onset dates are located in the Lincoln Sea north of Greenland, consistent with the fact that the minimum summer temperatures are located on the Greenland ice sheet. Superimposed upon the roughly radial melt onset pattern are significant regional patterns. For instance, it is evident that melt onset begins near coastal regions and islands. The former can clearly be seen in Hudson Bay, while the latter is noticeable along the larger islands of the central Arctic region.

There also appears to be regional differences in the variability of melt onset over the 20-year study period. The range in melt onset (Anderson Figure 1, page 115) at a given location, defined as the latest melt date minus the earliest melt date, shows a definite geographic pattern. The vast majority of points in the Arctic basin have a range of one to two months, while the range in the more southerly latitudes, such as Hudson Bay and along the continental coastlines, often exceeds two months. The smaller variability in the central Arctic suggests the annual melt onset date is influenced mainly by the spring transition in incoming solar radiation. In contrast, the larger variability along the ice edges hints that synoptic atmospheric conditions play a more significant role in influencing the melt onset date in these areas. The one-standard deviation map (Anderson Figure 1, page 115) displays a similar pattern to the range map. Variations of 7-14 days are found mainly in the central Arctic, while areas with a standard deviation of 14-21 days are found in the western Arctic, the Bering Sea, and the Sea of Okhotsk. Most of the regions with standard deviations of 21-28 days are located either in Hudson Bay, or along the coastal regions. Variations larger than 28 days are visible along the eastern Arctic ice edge.

### Annual Melt Onset Pattern

In order to better understand interannual variations in the melt onset dates, the distribution of the annual melt pattern (Anderson Figure 2, page 115) are displayed. It is clear that the distribution of melt in any given year rarely follows the mean melt distribution (Anderson Figure 1, page 115). 1981 best resembles the mean melt distribution, but it still exhibits areas where the melt occurs either earlier or later than average. For instance,

earlier melt is seen in the Siberian and Chukchi Seas, and the west-central Arctic Ocean. In contrast, later than average melt is observable in the Kara and Barents Sea regions.

In two of the years, 1979 and 1987, the melt distribution is greater than average in March and April, but then melt is delayed, and from May through July the spatial area of melt is less than average. In 1979 earlier melt occurs in the Bering Sea, along the Alaskan coast, and in portions of Hudson Bay, explaining the enhanced melting noted in March and April. Similarly, melt onset is delayed in much of the central Arctic, explaining why the melt distribution is below average from May through July. In 1987, earlier melt is seen in Hudson Bay and the Sea of Okhotsk, while later melt is observed from the Siberian Sea northward in to the Arctic Ocean.

Several years, including 1988, 1993, 1994, and 1998, show an opposite pattern to 1979 and 1987. In these cases, the spatial melt area is below normal in March and April, but quickly increases such that from May through July the spatial area of melt onset is greater than average. In 1988, the vast majority of area that melts on average in March and April is delayed several weeks, with the exception of southern Hudson Bay. The enhanced melting seen from Julian Days 160-190 is due to earlier melt in the Arctic Ocean north of the Laptev Sea. In comparison, during 1993, delayed melt is observable throughout all of Hudson Bay, and most of the other southern ice regions, with the exception of a small band of earlier melt along the southern edge of the East Siberian Sea and the Laptev Sea. The enhanced melt later in the season is due to earlier melt in the Arctic Ocean north of the Chukchi Sea. It is also clear that deviations from the average are stronger in 1993 than 1988, and that even though the melt is enhanced from Julian Days 150-180, there are sections of later than average melt noticeable in the central Arctic during this time. In 1994, the spatial melt pattern is similar to 1988, with earlier than average melt seen in southern Hudson Bay, set against delayed melt in much of the remaining southern ice regions. Enhanced melt from Julian Days 160-190 is caused by earlier melt in the Arctic Ocean north of the Canadian Arctic Archipelago. In comparison with the other three years that have a similar melt distribution, 1998 displays a much more hemispherically- based melt pattern. For instance, very early melt is seen over vast portions of the Western Hemisphere, especially in the Arctic Ocean. In contrast, later than average melt is noticeable in the Kara and Barents Seas, as well as the Arctic Ocean directly north of these seas. Enhanced melting towards the latter stages of the melt period are also noted for 1989, 1991, and 1995. In 1989, large sections of Hudson Bay experience later than average melt, while parts of the Sea of Okhotsk, the Laptev Sea, the Kara Sea, and the central Arctic Ocean experience earlier than average melt. Similarly, in 1991, Hudson Bay experiences later melt, while the Beaufort Sea, the East Siberian Sea, the Chukchi Sea, and the Laptev Sea all experience early melt. In 1995, an average melt pattern is seen for most of Hudson Bay, but earlier than average melt is observable in the Beaufort, Kara, and Barents Seas. The melt pattern in 1990 stands out as a very abnormal melt season.

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## Summary

This study presented an improved snow melt onset-date detection algorithm for Arctic sea ice surfaces. The new Advanced Horizontal Range Algorithm (AHRA) utilizes temporal information in the brightness temperature difference between 19 GHz (18 GHz for SMMR) and 37 GHz to determine melt onset over sea ice locations in the Arctic. From 1979 through 1998, snow melt onset began in the Bering Sea and Sea of Okhotsk in the first week of March, and progressed northward towards the central Arctic by the middle of July. The latest melt onset dates were observed in the Lincoln Sea, north of Greenland, in accordance with the minimum in air temperatures located over Greenland. In comparison with the roughly radial northward melt progression of the annually averaged melt onset map, specific years showed a high degree of spatial variability. Most years typically have some regions of earlier than average melt, and other regions with later than average melt. However, 1990 appeared to be an extraordinarily early melt onset year, with later than average snow melt onset predominately occurring in the Beaufort Sea.

There is considerable opportunity to use this new melt onset data set for climate studies, including the development and validation of general circulation model outputs, and for the detection of climate change. Currently, work is underway to examine the interannual trends in melt onset at the regional level. In addition, the large interannual variability in melt onset data, especially in the southern regions, suggests an atmospheric influence.

## Data Availability

The Arctic snow melt product is titled Snow Melt Onset Over Arctic Sea Ice from SMMR and SSM/I Brightness Temperatures, and the data and documentation are available from the National Snow and Ice Data Center on their Web page at <http://nsidc.org/data/nsidc-0105.html>.

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