HIGH FREQUENCY DYNAMIC RESPONSE OF THE CANADIAN EAST COAST SEASONAL SEA ICE ZONE

Dennis M. Nazarenko[1]

Department of Geography
McGill University
805 Sherbrooke Street West
Montreal, Quebec H3A 2K6

ABSTRACT

The seasonal sea ice zone extending from Baffin Bay to the Grand Banks exhibits considerable within-season variability in terms of concentration and areal extent. Short term dynamics are significant, especially near the ice margin where the ice pack may vary spatially on time scales of a few days to weeks in response to passing atmospheric disturbances. An investigation of intra-annual variation was made using time series of gridded total ice concentrations derived from Nimbus 7 Scanning Multichannel Microwave Radiometer data available at two day intervals. Two distinct seasons are compared - 1980/81 and 1984/85 - seasons representing both heavy and light ice conditions. Time series analyses were performed to evaluate the frequency characteristics of ice cover variation through the ice season.

I INTRODUCTION

The interaction between atmosphere and ocean is complex, made even more so by the presence of sea ice. On a global scale, sea ice plays a significant role in the climate system as both agent and product of atmospheric and oceanic variation. Annual Arctic sea ice extent varies from approximately $8*10^6$ km^2 in summer to $14*10^6$ km^2 in winter (Walsh and Johnson, 1979) at which time the ice cover extent is equivalent to approximately half the area of North America. This virtual twofold variation in the Northern Hemisphere sea ice cover represents a sizeable change in the amount of ocean surface directly exposed to the atmosphere. As an interface between the ocean and the atmosphere, the zone of seasonal ice at the polar ice cap periphery has a major impact on numerous interactive processes which take place between the two media. In addition to the obvious seasonal fluctuations in the ice margin, within-season variations are considerable with pack ice near the ice margins influenced by synoptic scale atmospheric activity.

The purpose of this study was to evaluate the time dependent variation in sea ice cover with special attention paid to the high frequency variability. An area including most of the Canadian east coast seasonal sea ice zone was selected for consideration. Ice concentrations were obtained for two seasons, 1980/81 and 1984/85 using passive satellite imagery. The utility of this data set as a tool in the evaluation of high frequency ice extent variation is also considered.

Figure 1 shows the east coast study area and provides an indication of typical mid-season ice extent along the east coast. The February 15 and February 17 3/10 ice concentration contours also show the variability in ice conditions over short time scales.

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[1] Present address: Norland Science and Engineering Ltd., 902-280 Albert Street, Ottawa Ontario K1P 5G8

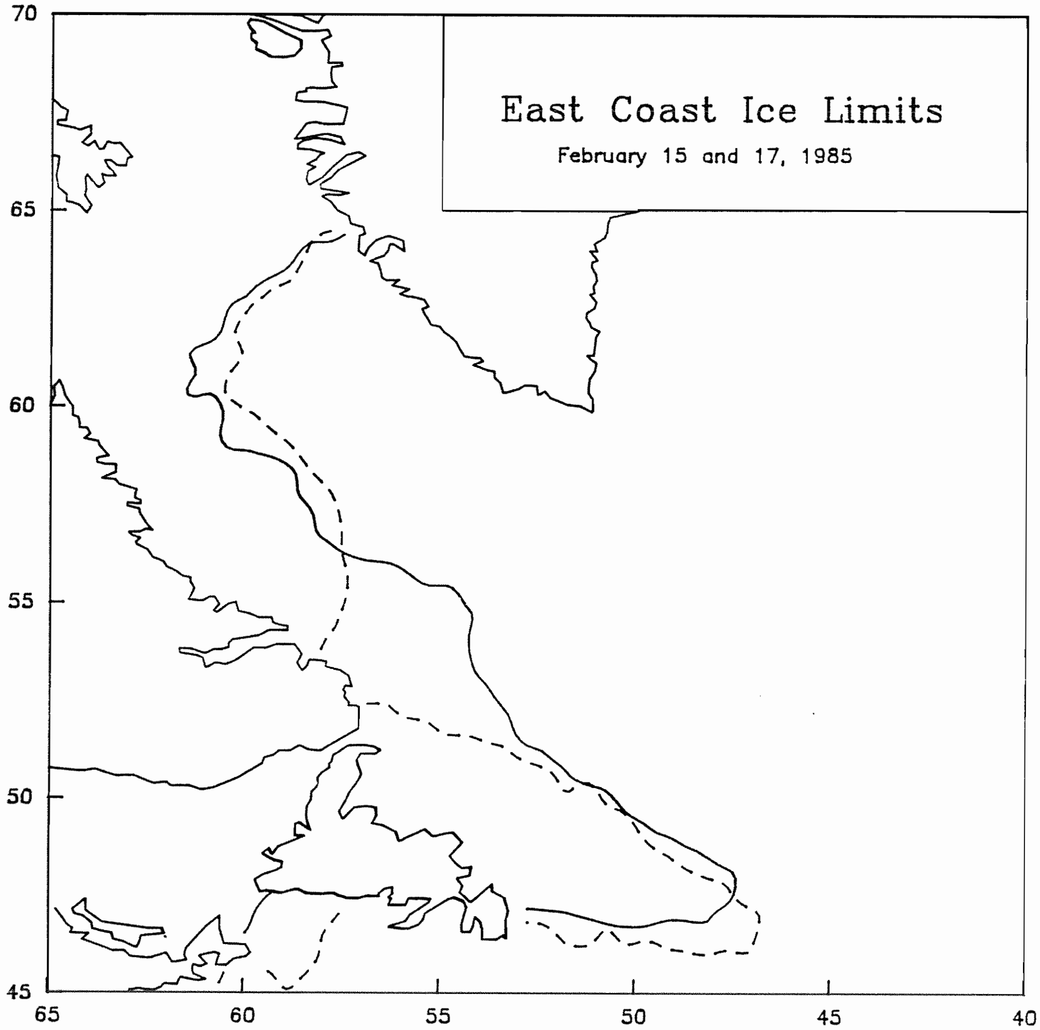

Figure 1 Map of the study area showing variation in the 3/10 ice limit between February 15 and 17, 1985

II SEASONAL SEA ICE ZONE DYNAMICS

The seasonal sea ice zone is recognized as the most dynamic portion of the sea ice regime in either hemisphere, affected by forcing from a variety of meteorological and oceanographic factors. Along the Canadian east coast, seasonal ice coverage extending from the northern portion of Baffin Bay to the Grand Banks of Newfoundland, within the Gulf of St. Lawrence and occasionally onto the Scotian Shelf. In many ways this seasonal ice zone is typical of ice margins in general, however, ice coverage in this region is unique in that it represents the most extreme southern penetration of sea ice in the northern hemisphere.

The Canadian east coast offshore region, in addition to being an area of considerable seasonal ice development, is strongly influenced by synoptic atmospheric activity during the period when ice is present. The influence of both cyclonic and anticyclonic activity contributes, at least in part, to the extremely dynamic nature of the sea ice cover in this region. As an example, passing synoptic conditions in early 1985 were responsible for both the rapid growth of new ice and the advection of older ice as far south as the Grand Banks much earlier in the season than normal. Ensuing atmospheric conditions enabled the ice to persist in the region despite the opposing effects of the warm Gulf Stream waters.

While much of the research concerned with sea ice temporal variability has focused on time scales on the order of months and years, some work has been directed at higher frequency variability. Notable among this work are studies of Antarctic ice cover fluctuations including the findings of Cahalan and Chiu (1986) which indicate strong matching between the spatial pattern and advection of sea ice anomalies and atmospheric sea level pressure. Crane (1983) has shown that in the Beaufort and Chukchi Sea areas, sea ice cover variability can be related to sea level atmospheric pressure and temperature at synoptic scales.

Previous work in the Labrador Sea/Baffin Bay region during the late 1970's has focused on the development of a synoptic climatology (Barry *et al.* 1975) as well as efforts to classify synoptic regimes associated with different ice patterns or to focus on variations at seasonal scales (Crane, 1978; Jacobs and Newell, 1979).

III SATELLITE MAPPING OF SEA ICE

A major limitation in evaluating synoptic scale activity rests in the problem of monitoring ice dynamics at this scale. Satellite remote sensing offers an attractive method of accomplishing this.

In particular, remote sensing at microwave frequencies has several attractions, stemming primarily from the fact that it offers an all-weather, day/night means of sensing the character of the earth's surface. Equally important, coverage of polar regions is frequent. The resolution of passive microwave systems is coarse at approximately 30km but still within reason for synoptic-scale studies.

The application of passive microwave data to an evaluation of surface conditions is based on the characteristic variation in emissive properties of different physical objects. The importance of emissive properties in interpreting sea ice conditions arises from the strong emissive contrast between open water and ice. This difference translates into an ice/water brightness temperature difference of approximately 80-100 degrees Kelvin (K), making it possible to distinguish between open water and sea ice from a single frequency microwave signal such as that achieved with initial passive microwave systems. More recent systems such as the Scanning Multichannel Microwave Radiometer (SMMR) permit enhanced ice/water delineation through the incorporation of multiple frequencies in the ice algorithms. Data obtained through this system provided the basis for evaluation of ice extent variation in this study.

IV ICE CONCENTRATION DATA

Ice concentrations derived from Nimbus 7 SMMR brightness temperature readings provided the basis for regular evaluation of ice conditions through the study area for the 1980/81 and 1984/85 ice seasons. Regional ice maps were prepared every second day from November 1 to July 31, providing virtually complete coverage of the ice season within the study area.

The Canadian Atmospheric Environment Service (AES) databases include a large ice data set derived form SMMR brightness temperatures using an algorithm developed by AES in conjunction with Phd. Associates Ltd. The ice concentration data have been archived by AES and were retrieved from their databases using CRISP (Sea Ice Climate Information System), an AES data analysis and retrieval package. For each orbit date, a series of point concentration values corresponding to SMMR footprints were obtained.

To produce a time series of ice cover variation, the study region was divided into half degree sub-units. This yielded 2500 grid cells within the study area, with 2039 free of land. Ice concentrations from the irregularly spaced SMMR were remapped onto the standard half degree grid. The remapping provided a concentration value ranging from 0/10 to 10/10 for each cell and permitted direct comparison from one satellite orbit to the next. Rather than consider individual cells, the number of cells showing a concentration change exceeding some value were summed. This yielded a count of cells experiencing some level of concentration change ranging from zero to a possible maximum of 2039 cells. Since the SMMR data were available every second day, the time series sample interval was 2 days and the record length 136 and 137 orbits for the 1980/81 and 1984/85 seasons respectively.

V ICE CONCENTRATION VARIATION

The temporal variation in ice concentration for the two ice seasons can be seen in Figure 2. The two curves indicate the number of grid cells within the study area having concentrations greater than or equal to 3/10 cover. In both series the seasonal pattern is clearly evident, with seasonal maxima at approximately orbit 50 (corresponding to mid-February) in 1980/81 and orbit 60-65 (late February to mid-March) in 1984/85. For a given orbit cell counts are generally higher in 1984/85, a reflection of the heavier east coast ice conditions during that season.

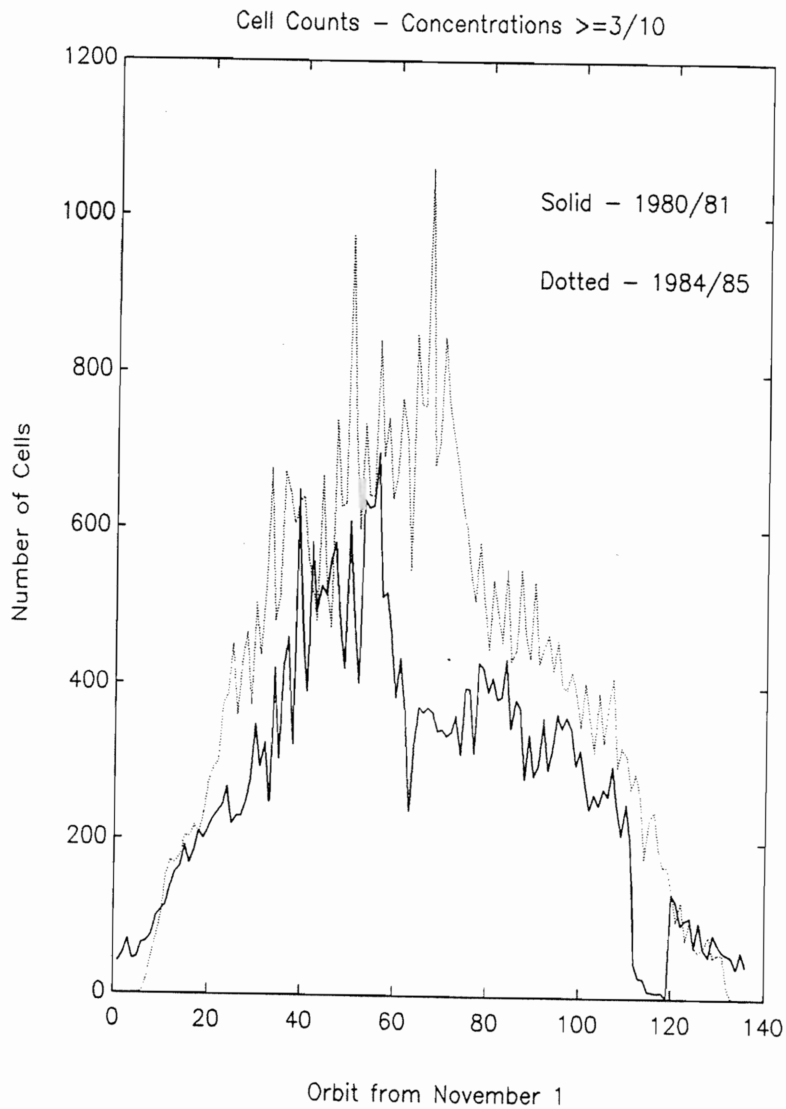

Figure 2 Comparison of the grid cell counts for the 1980/81 and 1984/85 ice seasons

In addition to the seasonal trend, considerable high frequency variability is evident in both series. To investigate this further, the change in ice concentration was considered. The difference in concentration between successive orbit dates was calculated, yielding two new time series for each ice season, one showing concentration changes where the increase in concentration was ≥3/10 and a second recording the cell count for concentration decreases ≥3/10.

One of the difficulties encountered with the SMMR data was that at the latitudes of interest to this study, complete satellite coverage was not available for each orbit date. As a result, the number of SMMR footprints varied substantially, affecting the interpolation of a regular ice concentration surface. This had the potential of introducing bias to the time series of concentration change variability. To alleviate this problem, an attempt was made to determine the periodicity of this variation and to filter the data with an appropriate band rejection filter. By analyzing the record of footprint counts for the two seasons it was apparent that a periodicity of approximately 5.5 days was evident in the footprint variability. A band frequency filter was constructed to minimize the influence of this variability and applied to the ice concentration change data.

Table 1 provides a statistical summary of the four band filtered series. The results confirm that the seasonal differences seen in the previous figure remain in the filtered series.

The mean cell counts in 1984/85 at 61.7 and 67.4 for concentration increases and decreases respectively, are almost double those for the 1980/81 season (32.1 and 33.2). Additionally, the 1984/85 series are noticeably more variable as shown in their standard deviations. Comparing the series for concentration increases ≥3/10, the standard deviation for 1984/85 is 32% greater than for 1980/81 and 39% greater for decreases ≥3/10.

Table 1 Ice Season Cell Counts for Concentration Changes ≥ 3/10 Cover

Season	Change Direction	Mean	Standard Deviation
1980/81	Increase	32.1	44.7
	Decrease	33.2	41.5
1984/85	Increase	61.7	59.4
	Decrease	62.4	57.8

In Figure 3, time histories of cell counts for concentration increases and decreases ≥3/10 are plotted for the two ice seasons. Here, in each case the seasonal variation has been removed leaving the residual high frequency variability. A comparison of the two curves for each season indicates a consistent trend with cell count variability at or near zero in early November, gradually increasing and reaching a maximum between orbits 35 and 70 (mid-January and mid-March). Variability declines once more towards the end of July as would be expected with greater amounts of the area becoming free of ice. The period of high variability tends to be wider in the 1984/85 series. As a check, subtracting the decrease cell counts from the increase cell counts (Figure 4) indicates that one does not cancel the other, confirming that considerable high frequency variation is present within the ice pack.

Considering the nature of this high frequency variability further, an investigation of spectral characteristics was undertaken. Subjecting the four time series to Fourier transformations, power spectra were calculated to identify frequency characteristics within each time series.

The results of this analysis are shown in Figure 5 where the two power spectra for 1980/81 concentration increases and decreases are superimposed in Figure 5a and for 1984/85 in Figure 5b. The small record length limits spectral resolution and dictate wide confidence limits but once again, a general pattern emerges which is consistent among the spectra. Two amplitude peaks appear consistently at 0.03 cycles/day and at 0.13 to 0.14 cycles/day, the latter significant at 5% confidence levels. At 0.13-0.14 c/d, the corresponding period is approximately 7-8 days.

Other investigations have shown that, in the Bering Sea, periodicities in the seasonal ice cover variation could be related to synoptic atmospheric events of 3-5 days (Pease, 1980) while along the Antarctic ice

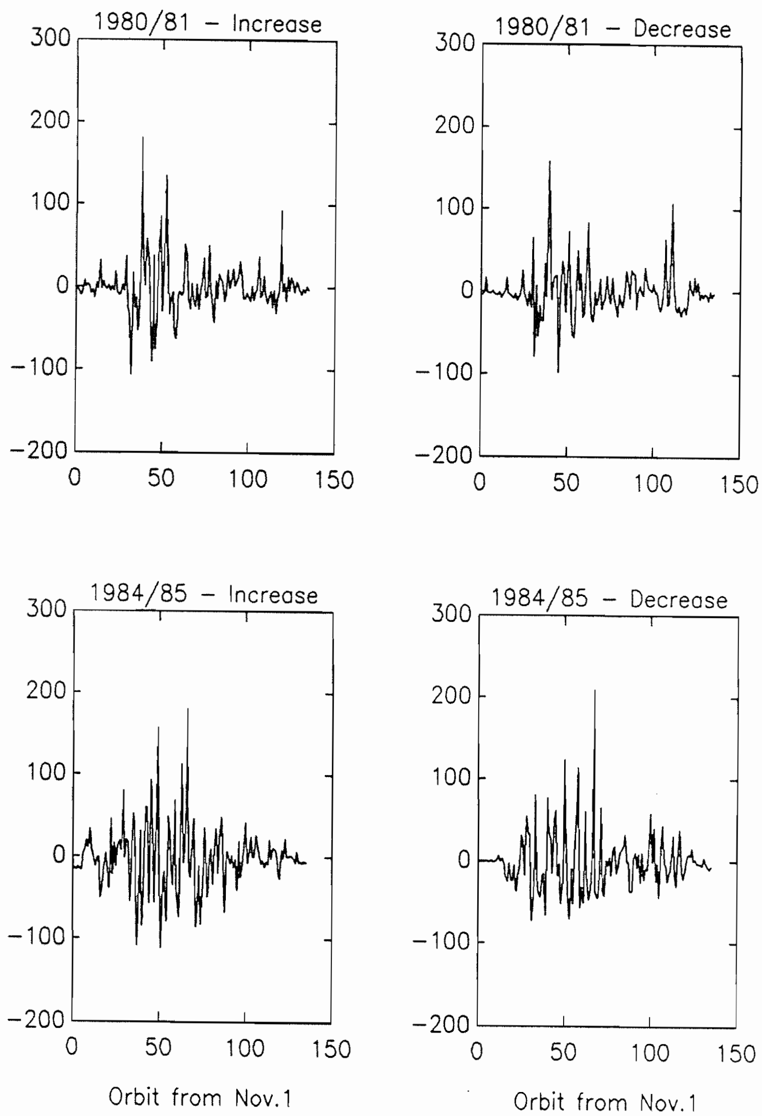

Figure 3 Time series of cell counts for concentrations variations ≥3/10 ice cover

margin interactions at time scales of a week were observed (Carleton, 1984). The results of this study would suggest that similar periodicities in ice cover variation are seen off Canada's east coast.

V SUMMARY AND CONCLUSIONS

Passive microwave imagery has been utilized successfully to monitor sea ice variability along Canada's east coast. The use of microwave data from the latest satellite system, the U.S. Defense Meteorological Satellite Program, Special Sensor Microwave/Imager (SSM/I) would provide more frequent and more complete coverage of the study area. The data presented here demonstrate the short-term variability in ice cover along the east coast of Canada. Significant differences are evident between the two seasons with 1984/85, the heavier ice season, showing greater high frequency variability as well. The short record length is a major limitation in evaluating confidence in the frequency information, however the 7-8 day periodicity is consistent with results observed elsewhere. Further work will focus on the correlation between ice cover dynamics and atmospheric activity.

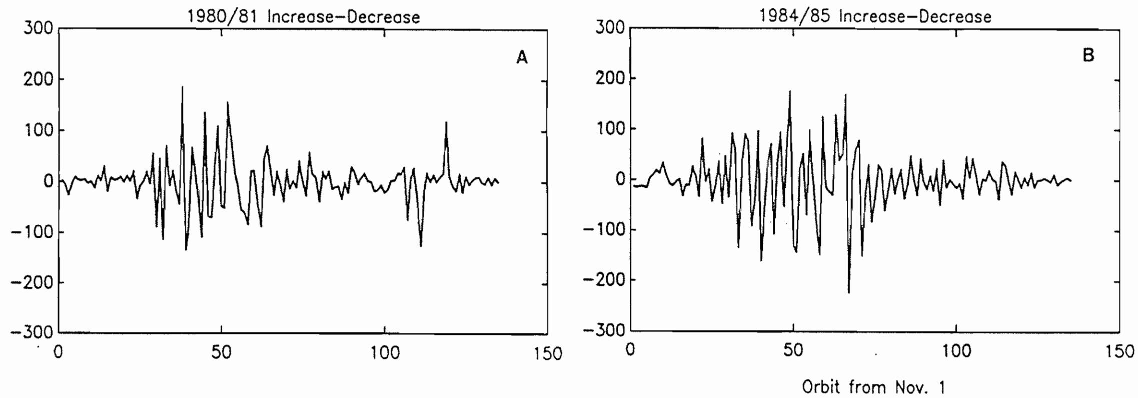

Figure 4 Time series of cell counts where the daily decrease count has been subtracted from the daily increase count

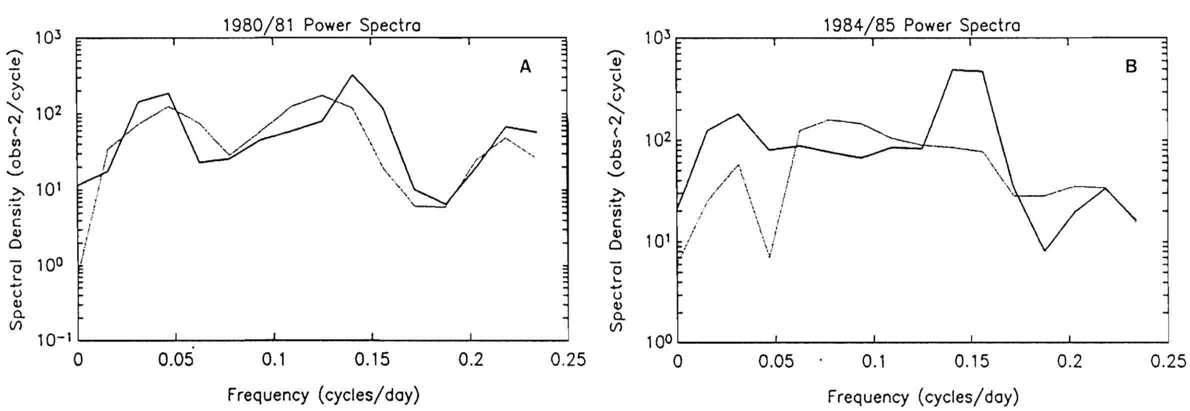

Figure 5 Power spectra for the two ice seasons with the solid line representing concentration increases ≥3/10 and the dotted line concentration decreases ≥3/10

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