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SPECTRAL ANALYSIS OF CANADA BASIN UNDER-ICE DRAFT DISTRIBUTION AS RECORDED BY THE USS QUEENFISH, AUGUST 1970

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Abstract. Spectral analysis has been applied to 940 kilometers of under-ice thickness data recorded by the USS QUEENFISH in the Canada Basin, August 1970. Periodicities of 50-150 m most commonly occurred throughout the track, with longer wavelengths common in areas of thicker, more variable ice. While some regional variations could be discerned, unique regional patterns were not apparent, supporting the hypothesis that ice characteristics in this region are relatively homogeneous.

Introduction

During early August 1970, the USS QUEENFISH (SSN-651), continuously recorded the under-ice topography of the Canada Basin along the 155 West meridian between latitudes 74-00.0 and 83-30 degrees North. Subsequent statistical analysis of the acoustically recorded under-ice draft distribution confirmed ship's observations that the under-ice topography in this region was relatively uniform and quite moderate in draft [McLaren, 1986]. The uniformity of ice in the Beaufort Sea was also noted by Wadhams [1980]. McLaren [1986, 1987 and 1988] further determined that the sea ice of this area, within the central part of the Beaufort Gyre, may be thinner and more open than elsewhere within the central Arctic Basin.

The above analyses provided the impetus to examine further the under-ice profiles recorded by QUEENFISH through the Canada Basin [McLaren, 1986] to determine what other indications of environmental forcings might be found. Visual examinations of the profile data indicated possible spatial periodicities. Accordingly, spectral analysis was used to describe the shape and apparent non-randomness of the under-ice draft profiles which QUEENFISH recorded within this particular area.

The morphology of sea ice has been previously analyzed statistically by Rothrock [1979, 1986], Hibler [1980], Thorndike et al. [1975], Wadhams and Horne [1980], Wadhams [1981], McLaren [1986] and others. Hibler and LeSchack [1972] applied spectral analysis to the undersea ice profile in the central Arctic. They found periodicities of 56 and 82.5 m to be significant. Kozo and Tucker [1974] applied Fourier analysis to sonar data in the Denmark Strait, from the ice edge to the the Greenland coast. They found an increase in ice thickness variability with increasing distance from the ice edge and a corresponding increase in the importance of the longer wavelengths in the Fourier analysis.

This paper reports the results of a spectral analysis of approximately 940 kilometers of under-ice profile along longitude 155°-00.0′ W, between latitudes 74°-22.5′ and 82°-55.0′ N (Figure 1). Our objectives were to identify the dominant periodicities in the draft distribution and to further test the hypothesis that ice conditions in the Canada Basin are relatively homogeneous.

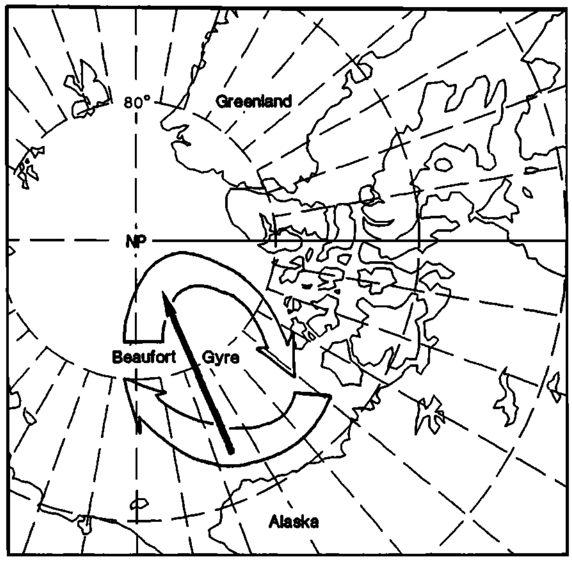

Figure 1. Track of the USS QUEENFISH in early August, 1970 across the Canada Basin.

Data and Methods

QUEENFISH continuous analog under-ice draft recordings and supporting navigational logs were obtained from the Arctic Submarine Laboratory, U.S. Naval Ocean Systems Center, San Diego. To record the under-ice topography, QUEENFISH used a narrow-beam, 205 kHz, upward-beamed acoustic profiler of an AN/BQS-8 sonar system with a footprint diameter of 2.68 m. Over three million data points were obtained from the manually digitized analog recordings for subsequent statistical analysis. The data were then interpolated to 145 cm intervals in order to ensure a more balanced representation of under-ice thickness. The accuracy of the submarine's acoustic profiler is ±15 cm at best.

The 940 km track was divided into 5 km subsections with data points averaged over 10 m. This point spacing and subsection length combination were found to provide an adequate balance between resolution within the range of wavelengths under study (20-2000 m), the relative homogeneity of subsections, and computational

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efficiency. Gaps varying in length from 4-90 km occur within the track but amount to less than 10% of the total data. These areas were not used in subsequent analyses.

The spectral analysis method applied here follows Mitchell et al. [1966], where all serial covariances for lags of 0 to m units are computed from a series of length n (m<n). The cosine transform of the m+1 lags are then computed, which are the raw estimates of the power spectrum. Each estimate is a measure of the total variance in the original series that is contributed by wavelengths near that harmonic of the fundamental wavelength. The population null continuum is that of a "red noise" spectrum and the confidence intervals are computed as the ratio of the spectral estimate to the population continuum value for each harmonic. To inhibit aliasing in the analysis, frequencies above the Nyquist frequency were removed with a low-pass, 1-2-1 filter.

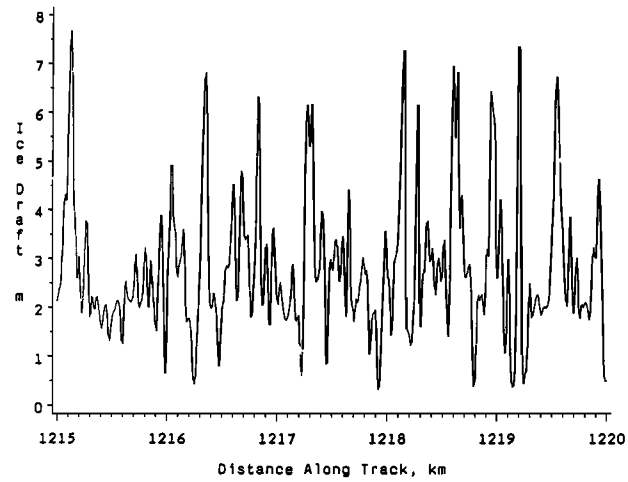

Figure 2. Under-ice profile of a 5 km section from the study area. The horizontal axis indicates the distance from the beginning of the Queenfish track.

Periodicities in the Under-ice Profiles

Spectral analysis was applied to each 5 km subsection of the 940 km track. Figure 2 shows a 5 km under-ice profile based on point spacings of 10 m. The horizontal axis marks the distance from the beginning of QUEENFISH's overall 1970 track (the beginning of the study area is km 340). The importance of periodicities is illustrated in the corresponding power spectrum shown in Figure 3, where the hypothetical population continuum and the 90% and 95% upper confidence levels are shown as broken lines. The peaks in the spectrum represent periodicities of 307, 175, 160, 117, 80, and 75 m; the broad peaks at 160-175 and 75-80 m are perhaps better described as a "quasi-periodicities".

Figure 4 summarizes the periodicites identified through spectral analysis for the entire track. Periodicities representing significant peaks (90% confidence level) in the spectra were grouped into 20 m bins and the frequency within each bin was determined. (For the point spacing and subsection length employed in this analysis, harmonics

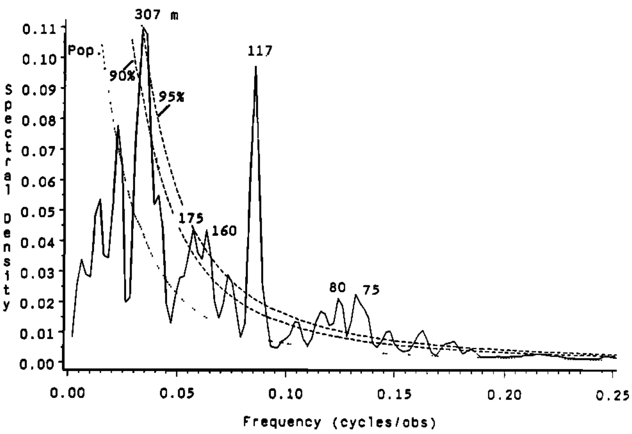

Figure 3. Power spectrum corresponding to the profile in Figure 2, with the population contiuum (lower dashed line), and the 90% and 95% upper confidence levels (upper two dashed lines). Wavelengths (meters) are noted above significant peaks.

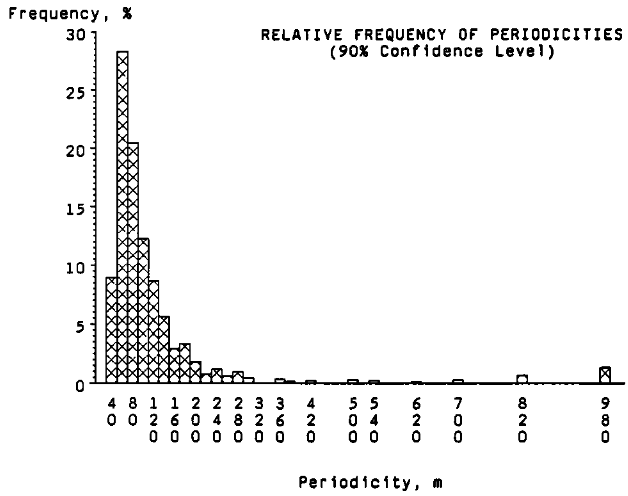

Figure 4. Frequency histogram of significant periodicities grouped in 20 m bins. Each bin is represented by its midpoint on the abscissa.

represent periodicities of 4920, 2460, 1640, ..., 20 m; therefore gaps occur in the figure). Periodicities in the range of 30-130 m are most frequent. The shorter of these may correspond to "blisters" observed by Wadhams [1988] in sidescan sonar data which had wavelengths of 28-63 m.

Histograms constructed for other areas (not shown) demonstrated an increase in the relative frequency of longer wavelengths, 1000 m and longer, in those areas with greater mean thickness and variability, generally beyond kilometer 1000 (80°-20.0′ N, 155°-00.0′ W) of the QUEENFISH track. Similarly, less variable, thinner ice areas (south of 75°-00.0′ N, 155°-00.0′ W) showed an increase in shorter wavelengths with few keel-to-keel distances greater than 1000 m. Hibler and LeSchack [1972], in a spectral analysis study of ice surface laser data, also observed that young ice has greater high frequency roughness while multi-year ice is more undulating. In general, the thinner ice in the first 700 km of the track showed little variability in the periodicities which describe it, while the thicker, more variable ice in the northern 200 km demonstrated an increase in the importance of the longer wavelengths.

Application of the frequency cutoff measure of the spectrum (the number of Fourier components required to account for 95% of the data variance) employed by Kozo and Tucker [1974] also indicates generally homogeneous ice conditions within this region. In that study, the frequency cutoff ranged from 90 to 180 components, a higher number required in areas of lower standard deviation in ice thickness. The frequency cutoff in the current study averages 102 components thoughout the Canada Basin with a range of 90-220, and no trend was observed in either standard deviation or frequency cutoff. We also note that the spectra follow a power law of -1.33 (mean over the study area), exhibiting only a weak linear relationship with ice thickness mean and standard deviation, and the frequency cutoff.

Concluding Remarks

Spectral analysis has been applied to approximately 940 km of under-ice thickness data as recorded by the narrow-beam sonar of USS QUEENFISH in the Canada Basin during early August 1970. The overall track was divided into 5 km subsections based on points spaced every 10 m. These subsections were then examined separately. The analysis revealed common periodicities in the under-ice thickness distribution in the range of 30-130 m. This distribution of periodicities is in general agreement with spacing distributions of ridges and independent keels as described by Wadhams [1980], Lowry and Wadhams [1979], Hibler et al. [1972], Mock et al. [1972] and others, where the highest frequency of spacings occurs at approximately 50-150 m. These distributions have been theorized to follow negative exponential [Hibler et al., 1972] or lognormal [Wadhams and Davy, 1986] models. Results presented here suggest that models of keel/lead spacings should include a parameter describing their periodic nature.

Sections of the track with larger mean ice drafts and variability show an increase in the relative frequency of longer wavelengths compared to the less variable, thin ice areas, which show an increase in shorter wavelengths with few keel-to-keel distances greater than 1000 m. In general, however, the dominant wavelengths and their distributions show little variability over the study area. The results of this study further demonstrate the homogeneity of ice in this region and time. The absence of detailed buoy and satellite data for 1970 and requisite oceanographic and ice mechanics information precludes detailed analysis of these data for possible environmental forcings which produced the observed results. Accordingly, assistance is required from the oceanographic and ice dynamics community.

Future research includes the application of this procedure to other regions and times, as well as a two-dimensional spectral analysis data from side-scan sonar and intersecting transects (when available). Comparison of the results from this analysis with the theoretical distributions of ridge and keel spacings will be presented subsequently.

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