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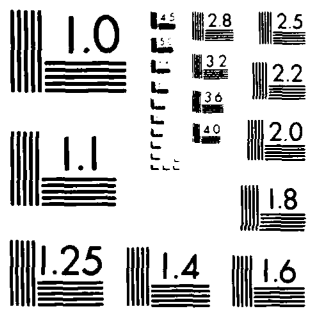
1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

NORDA Technical Note 209

Naval Ocean Research and
Development Activity
NSTL Station, Mississippi 39529

Open Water and Thin Ice Detection in the Arctic Marginal Ice Zone Using Reflectometer Signal Analysis

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March 1983

ABSTRACT

Approximately 2000 kilometers (~1250 statute miles) of reflectometer data collected within 160 kilometers (100 statute miles) of the ice edge in the North American Arctic were analyzed. The reflectometer signal, which shows a sharp decrease in areas of open water/thin ice, was used to initiate and develop a method to begin an evaluation of the frequency of occurrence and percentage of open water from the ice edge to approximately 160 kilometers (100 statute miles). Comparisons were made within and among regional data sets. Individual regions were not unambiguously identifiable by lead width and frequency characteristics. Distance into the pack from the ice edge did not have a direct relationship to the frequency or percentage of open water. The result of no apparent relationship between the frequency of occurrence and percent of area of open water may be due to the restricted samples--restricted in season and total area covered.

A-1

ACKNOWLEDGMENTS

This work was funded by NAVELEX SYSCOM under Program Element 980101, C. R. Rollins, Program Manager.

OPEN WATER AND THIN ICE DETECTION IN THE ARCTIC MARGINAL ICE ZONE USING REFLECTOMETER SIGNAL ANALYSIS

INTRODUCTION

The extent of Arctic ice coverage ranges from a summer average minimum of 5.2 million km^2 to a winter average maximum of 11.7 million km^2 (Wittman, 1959). The precise extent of the ice edge at any time is a result of previous meteorological and oceanographic conditions. In the course of its southward growth and drift during winter months the outer margin of the Arctic pack eventually merges with sheets of new fast ice growing seaward from the coastlines, ending surface navigation for all ships except icebreaker assisted operation. These operations are primarily along the fringe of the pack with limitation of mobility increasing with pack penetration. From October to June the Arctic Ocean remains virtually ice-locked; however, tides, winds, and currents can produce areas of open water within the pack and along the marginal ice zone at any time.

The purpose of this investigation is to develop a method and to begin an evaluation of the frequency and percentage of open water from the ice edge to approximately 100 miles into the pack.

Open water associated with the ice edge can be placed in one of five categories. A crack is a small unnavigable break caused by tides, temperature change, current, or wind. A lead is a long narrow navigable water passage in pack ice and a polynya is any sizable sea water area, other than a lead, encompassed by sea ice. A bay is a minor, with a bight a major inward bend of the ice edge or ice limit formed either by wind or current. Because of the fine resolution obtainable in this study (15 meters), a crack, lead, and polynya will be contained in one category with a bay or bight being regarded as the ice edge. Average ice limits were plotted relating to the year and season of data collection and areas of open water were analyzed from the ice edge to approximately 100 miles into the pack. Seasonal ice limits have been estimated but for increased precision the reader is directed to the Eastern-Western Arctic Sea Ice Analysis annually prepared by the Naval Polar Oceanography Center (NPOC), Suitland, Md., which was used in this study.

Satellite data interpretation over the Arctic regions shows major areas of open water, but the low resolution limits spatial detection. Thus, precise percentages of water within the pack are difficult to obtain by this method.

The two types of data combined for this study are aerial photography and reflectometer signal analysis in conjunction with a laser profilometer. The data has been collected over the Arctic pack ice on an opportunity basis since 1970 using RC-8 and RC-10 aerial cameras and a Spectra Physics Geodolite 3A laser terrain profiling system, which uses a modulated continuous wave laser technique to obtain a precise measurement of instrument height above the surface. Details of laser analysis and a description of the system can be found in Ketchum (1971) and Welsh and Tucker (1971).

The laser signal is stored on magnetic tapes and is used to classify dynamic ice parameters such as surface roughness, ridge height distribution and frequency, and power spectral density, as well as for input to and refinement of various ice prediction models of the Arctic.

Three other signals are recorded on coincident channels to compliment laser data, which are time code, phase lock fail, and reflectometer. When the time code record is correlated with the aircraft navigation logs, accurate track lines are reconstructed. The reflectometer channel records the measured millivolt change in light intensity, which is the total of the laser light and the sunlight reflection passing through a 3 angstrom optical filter centered on 6328 angstroms. Open water is seen as a sharp decrease in the reflected laser light intensity (Fig. 1) (Wilheit, Nordberg, and others, 1972). This figure will be discussed in detail in the later section on data analysis. The reflectometer signal is "noncalibrated;" therefore, all measurements are relative to surrounding values. The phase lock fail channel indicates loss of laser signal caused by environmental conditions, i.e., clouds. This signal can be used as a check to insure that the laser record has not been geographically distorted by environmental conditions. A detailed description of the laser data reduction process written and utilized at NORDA (Naval Ocean Research and Development Activity) can be found in Lohanick (1981).

DATA ANALYSIS

The selected magnetic analog tape containing the chosen data track is played on an Ampex FY-1300 tape recorder through an HP2240A (analog/digital converter). The analog voltages are then digitized to make them compatible for reading by the HP9845B (tabletop computer). The data is stored on flexible discs driven by an HP9885M (flexible disc drive) for manipulation, and a plot of the data is generated for analysis.

The preliminary stage of this investigation involved matching aerial photography with the plots of the reflectometer signal to determine the relative change of signal intensity with ice thickness. A distinctive drop in signal strength occurred in areas of open water and thin ice. Thin ice, for the purpose of this study is defined as <30 cm. As shown in Figure 1, the change and variation in signal intensity is a direct measurement of surface albedo. In newly forming ice, the surface albedo will generally have a direct correlation with thickness. In Figure 1, the reflectometer transition at point A from a homogeneous lower return to a higher response with increased variation is shown on the photograph as a newly ridged zone from A to B. The signal change at point C is not as great or distinctive as at point D because the newly forming ice evident in the photograph increases the albedo and is starting to blend the signal to surrounding features. The distinction at the lead boundaries (points C and D) allow for the fine resolution of this procedure. Point E shows the signal response across a ridge; the great variation in surface reflectivity due to roughness may lead to another future method of discerning ice types with an optical system. These data plots are scaled according to the aircraft navigation logs, and the width and frequency of these areas are cataloged for analysis (Appendix B). Computer programs were written at NORDA for this investigation to automatically identify areas of open water/thin ice in the reflectometer signal but the methods proved inadequate or unworkable. Holyer et al. (1977) discusses some problems of automatic data analysis with the laser signal. These, along with a "relative" rather than "calibrated" signal, complicates the procedure; therefore, more effort will be required in the future to generate a reliable, totally automated procedure.

STATISTICAL PROCEDURE

The raw data from the reflectometer signal yields the frequency and width of areas of open water/thin ice along the aircraft track. A Wilcoxson's Sum of Ranks Test was then used to determine the level of significance between and within the data sets. This statistical test was used because it allows nonparametric comparison of two populations based on independent random samples and is insensitive to the dispersion of measurements in the sample. It is also free of the invalid assumptions of normality. Testing for a null hypothesis (H_O) of no difference between the samples with the alternative (H_1) realizing a difference to a measurable level, a probability (P) > 5% is interpreted as no significant difference being proven by this test, P = 5% or less is regarded probably significant, and P = 1% or less statistically significant. Original data rather than the "class interval" data shown in Appendix B was used to eliminate tied ranks that tend to weaken the power of this test. A detailed description of the test can be found in Langley (1970). The statistical test was run on the data sets using a HP9845B (tabletop computer). A listing of the program written at NORDA for this investigation can be found in Appendix A. Appendix D shows a sample printout from this program.

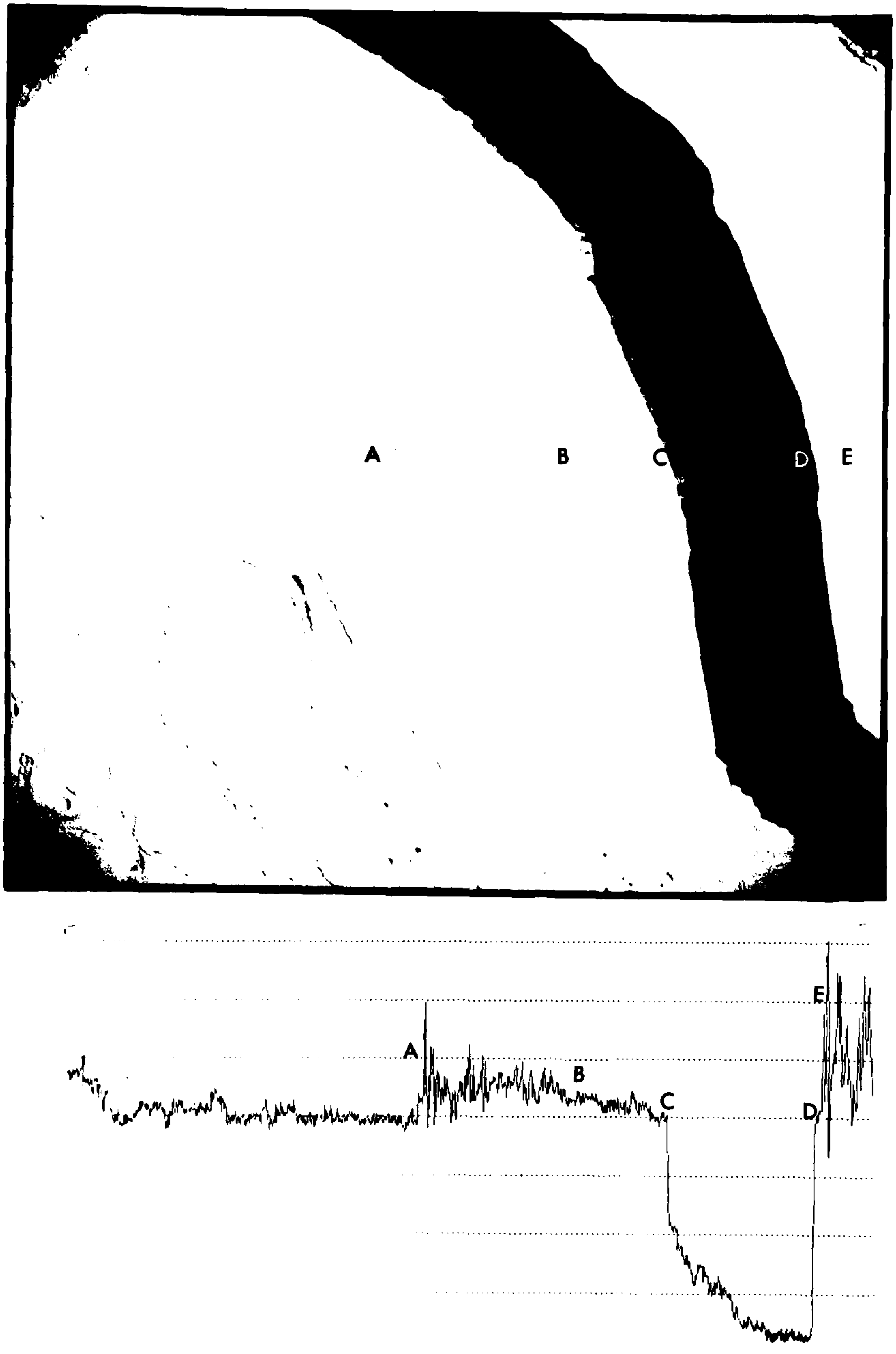

Figure 1. Relative change in response of reflectometer signal as a lead is crossed showing the direct relation of signal intensity to surface albedo

The data sets were separated into consecutive 5 minute segments to determine levels of significance within regions and were combined geographically to test significance between regions.

RESULTS

The ice conditions described in the following regional summaries are sometimes referred to as "minimum" or "maximum", which designates the extent of southern growth and accumulation with no regard to ice type distribution. Therefore, at maximum conditions the ice is generally thinner in the first 100 miles from the ice edge due to its recent formation and thicker during minimum extent due to the higher percentage of multi-year ice contained in the boundary zone. The following summaries are related to the divisions shown in Figure 2. The laser/reflectometer data was collected on an opportunity basis; therefore, seasonal comparisons are limited. The dates of data collection are included with the histograms in Appendix C and will be seasonally correlated with future data.

LINCOLN SEA

Approximately 380 km of reflectometer data was collected in the Lincoln Sea on 6 November 1970 (Fig. 2, track line 5). The data was analyzed in 14 consecutive 5-minute segments (approximately 27 km per segment) originating 160 km from the ice edge. Ninety-one 2-digit combinations exist with 14 data sets but only 86 combinations were tested because five combinations did not combine to form at least 10 elements, which is required for the test.

The first segment analyzed (segment farthest from ice edge) was one of two segments found to be significantly different from others in this region. The probabilities that the data from this segment came from the same population as the other segments in this regions were: <0.2% for two segments, 0.2-1% for two segments, 1-5% for 4 segments, 5-10% for two segments, and >10% for two segments. This shows that for this data set a change in lead frequency and width characteristics occur about 100 miles from the ice edge. Four of the five segments of no significant difference (P > 5%) for this segment occur 50-90 km from the ice edge, which identifies a within-region variation separate from the total population. Segment 10, approximately 40 km from the ice edge showed a probable significant difference from two segments (P = 1-5%) and statistically significant difference (P < 1%) for two other segments with no apparent relationship to pack penetration.

In summary, 74 of the 86 pairs of data sets compared showed no significant difference with respect to lead width and frequency. The first 100 miles from the ice edge is a relatively homogeneous zone with a significant boundary

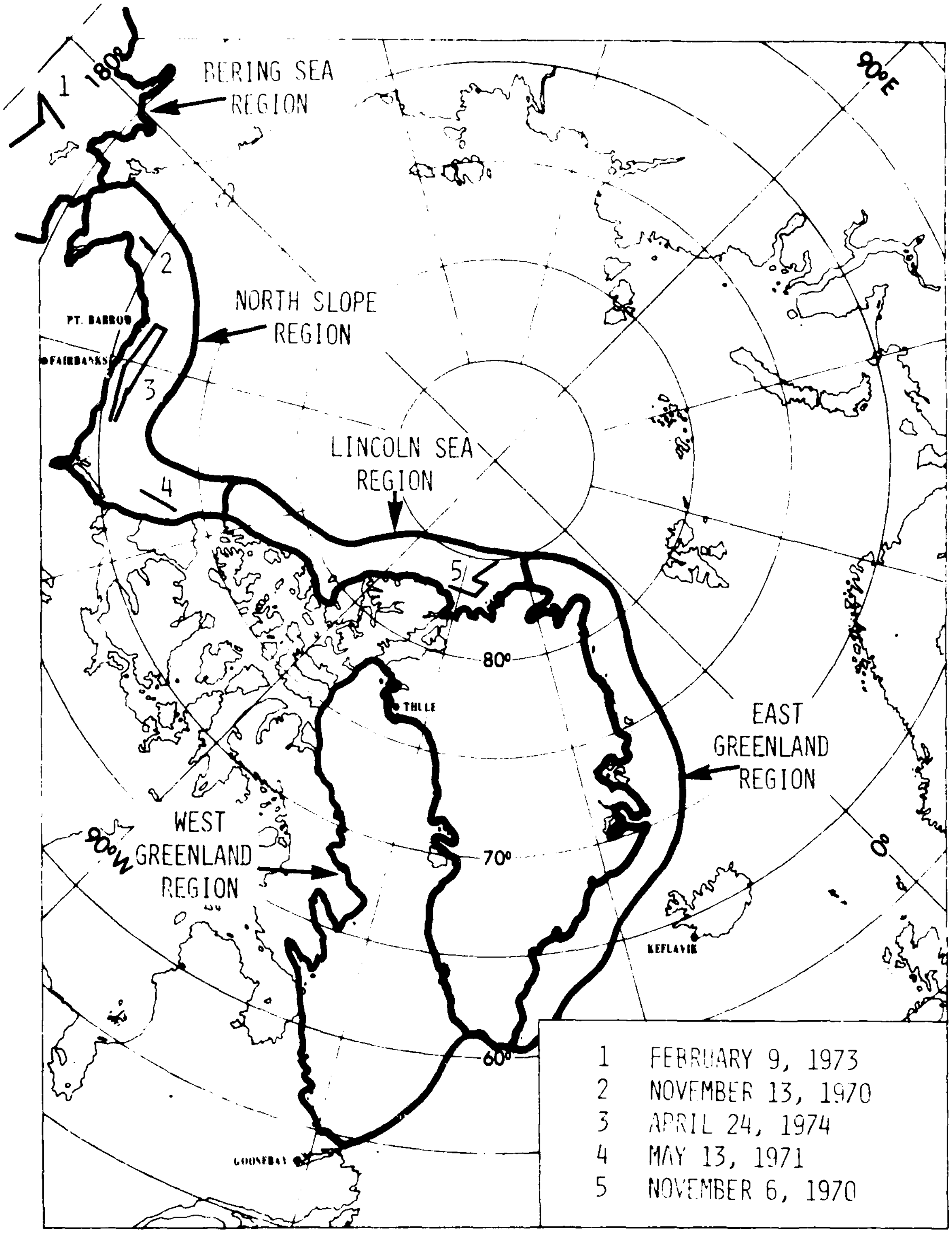

Figure 2. Display of regions and track lines of reflectometer data

occurring beyond this distance. There is also no apparent relationship between the percentage of open water with distance from the ice edge as shown in Appendix B. The region had an overall open water coverage of 3.78%.

NORTH SLOPE REGION

The North Slope region contains the Beaufort and Chukchi Seas and is one of the most studied as well as most strategic areas in the Arctic. Three track lines of reflectometer data were analyzed as shown in Figure 2. Track 2 was flown 13 November 1970, perpendicular to the ice edge 150 km. Each of the five data segments were compared with each of the other segments (total of 10 comparisons), and only one pair showed statistical difference. This pair was the first and last segment of the track. Possibly a subtle change is occurring with each segment as the pack is penetrated, and it requires 100 miles of separation before the difference can be statistically observed. This track line crossed the ice edge (first segment), which is an unstable area and had 10.99% open water compared to the lowest segment of 1.11% water. The first segment beyond the 160 km limit of this investigation was also statistically different from the segment containing the ice edge and had 5.32% open water. Therefore, a general statement that percentage of open water decreases with distance from ice edge is not valid in this population.

The second track line was flown 13 May 1971, parallel to the coast of Banks Island 130 km from shore for a distance of 86 km (Fig. 2, Track 4). This area is one of the roughest areas in the Arctic due to ice movement in the Beaufort Gyre. The area had mostly small fractures (15-90 m), and the data segments averaged only 2.74% open water with no significant difference found between any segment comparisons.

The third track line collected data off the North Slope of Alaska during maximum ice conditions (24 April 1974). This track line paralleled the Coast from 145° to 156°N longitude at both 65 and 93 km (Fig. 2, Track 3). The individual data segments are not contained in Appendix B because no water openings >15 m were found. A few small cracks (5-10 m) appeared occasionally in the data with no apparent pattern. The lack of open water in this data set is a result of a general southward drift of sea ice under the influence of the prevailing northerly winds present in the Beaufort Sea during this time of year. The only persistent open water in this region during maximum ice conditions determined from satellite imagery is off the south-facing coast east of Point Hope.

Wadhams and Horne (1980) analyzed submarine sonar data collected in April 1976 in the same area as track 3. In their study, a lead was defined as a continuous sequence of depth points in which no point exceeds 1 m in draft. Their results showed that 98% of the leads were <50 m cross-track and, if a submarine requires a 200 m lead for a safe surfacing, it would have to travel 68 km to find one.

BERING SEA

Reflectometer data in this region was collected on 9 February 1976 (Fig. 2, Track 1). Beginning 160 km from the ice edge, six 5-minute consecutive segments were obtained perpendicular to the ice edge followed by seven parallel segments 70 km from the ice edge. There were great variations in lead distributions between segments ranging from 0.35 to 5.34% open water (Appendix B) with no obvious relationship to distance from the ice edge. With 13 data sets, 78 comparisons are possible, but five segment pairs contained less than the required 10 elements; therefore, only 73 significance determinations were made. Sixty-seven of these comparisons showed no significant difference ($P > 10\%$). There was a probable significance level ($P = 1\text{-}5\%$) between segment pairs (1 and 12, 3 and 4, 3 and 12, 4 and 6, 4 and 13) and a statistically significant difference ($P < 1$) between segments 1 and 4.

This region is composed of mostly first-season ice, and due to ocean swell, great fluctuations in percentages of open water can occur rapidly. Wind from the pack will scatter the floes as an opposite wind will compact the area.

EAST GREENLAND REGION

The East Greenland region includes the Greenland Sea and Denmark Strait. The East Greenland drift stream represents the major efflux zone of water, ice and heat outward from the central polar pack ice regions. This region is often termed a dynamic "Ice Factory" because it is subject to nearly instantaneous response to wide variations in wind speed and direction. Great quantities of new, first-year, and sometimes multi-year ice are advected into the warm waters. In mid-winter months (December-March, inclusive) thousands of square miles of new ice are continually forming.

The reflectometer data collected in this region was gathered during adverse weather conditions with respect to the system potential. Therefore, a direct count of open water areas could not be obtained with confidence. Figure 3 shows the percentage of ice concentration along the marginal ice zone with respect to latitude for average minimum and maximum conditions. The figure was constructed from data available from the Navy-NOAA Joint Ice Center, Navy Polar Oceanography Center, Suitland, Md., in their "Analysis of Eastern Ice Limit," 1973 through 1980.

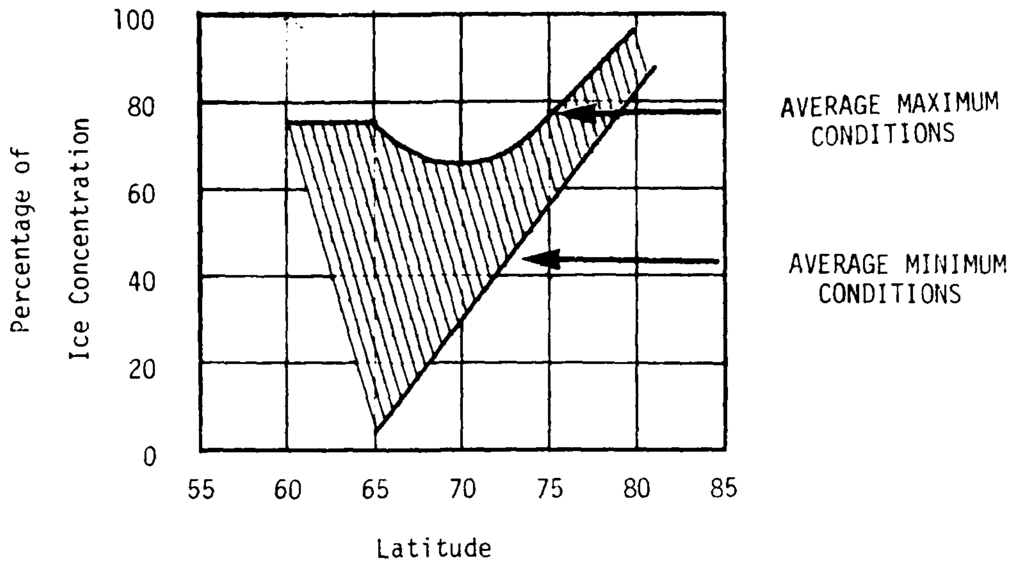

Figure 3. Change in percentage of ice concentration with latitude in the East Greenland Region during average minimum and average maximum conditions

Minimum conditions occur in the second/third week in September. During this time the ice limit has retreated to approximately 71°N latitude, during which severe conditions can leave a narrow band of very low ice concentration along the coast to 64°. From the southernmost edge of the ice limit in the Greenland Sea to North Spitzbergen (approximately 80°N), the data showed a linear decrease in the percentage of open water with latitude (Fig. 3).

At maximum ice extent in late April/early May, the ice limit along the east coast of Greenland extends beyond the southern tip due to the cold east Greenland current. Data analysis shows a high concentration of thin first year ice (approximately 70-80%) from 59°N to 64°. The concentration in this area can change dramatically over a short period of time, particularly if the sea swell breaks the ice and prevailing southerly winds and currents transport it away from the coast. A lower ice concentration (60-70%) is encountered from 64°N to 72°N due in part to the physical changes along the Greenland coast and the geographic position of Iceland. From 75° to 80°N a linear increase of ice concentration is displayed with a similar rate of change for that area during minimum conditions but with an average 15% higher concentration.

WEST GREENLAND REGION

The West Greenland Region includes Baffin Bay, Davis Strait, and the Labrador Sea. This region parallels the East Greenland Region in that it is virtually ice free in the late summer months with high concentrations of thin ice after freeze-up.

Analysis of ice edge movement in Baffin Bay from 1973 through 1980 shows that minimum conditions occur, on the average, during the first two weeks in September. Davis Strait and Baffin Bay become ice free with occasional bergs entering via Kennedy Channel or Lancaster Sound. Following exceptionally cold winters or during exceptionally cool summers low ice concentrations will remain along the coast of South Ellesmere, Devon, and North Baffin Island.

Maximum ice extent occurs during the last two weeks in April. Due to coriolis, wind, and the cold Labrador current, ice growth proceeds along the western coastline of this region to a southern extent of 45°N latitude. The ice near the southern limit (approximately 45°-50°N) is generally less than 30 cm thick with a rapid increase in concentration with latitude as shown in Fig. 4.

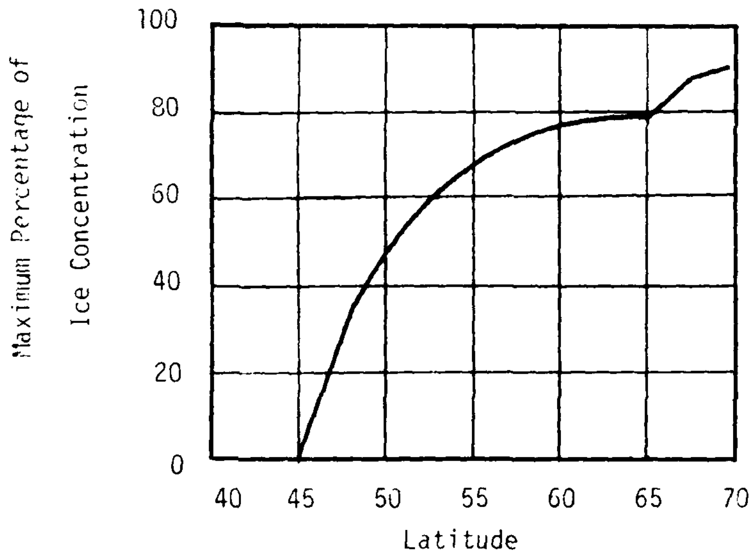

Figure 4. Change in percentage of ice concentration with latitude in the West Greenland Region during maximum conditions

From 50° to the northern extent of the ice limit at maximum conditions (approximately 67°) the rate of increase of the ice concentration from the edge to 100 miles into the pack decreases as the average thickness increases ranging from 30 to 120 cm.

CONCLUSION

The use of reflectometer signal analysis for open water identification in Arctic sea ice has proven successful. Its future use regarding ice type identification with respect to roughness shows great potential as shown in Figure 1.

The frequency and percentage of open water and thin ice areas of individual data sets and geographic regions are listed in Appendix B. The instability of the Arctic pack, particularly in late summer months, can lead to great variations of ice conditions over short time periods and distances as shown in the data. The thinner first-year ice of the Bering Sea showed no obvious relation between distance from the ice edge and lead characteristics with an overall first-year ice concentration greater than 98%.

Within the limits of this study (ice edge to 160 km), the Lincoln Sea and North Slope regions also displayed no apparent relation of open water percentages to distance from ice edge with ice concentrations greater than 95%. However, both regions statistically yielded significantly different lead characteristics in data sets just beyond the 160 km limit. This may indicate a transition from the marginal ice zone to central pack ice with respect to open water/thin ice and required further investigation.

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Appendix A. Listing of Wilcoxson Sum of Ranks program

written by A. W. Lohanick, NORDA Code 332

APPENDIX A

```
10    ! THIS PROGRAM PERFORMS A " WILCOXON S SUM OF RANKS TEST " AS DESCRIBED IN
      " PRACTICAL STATISTICS " BY RUSSELL LANGLEY pp.168,169,DOVER PUB.
20    REAL X1(1:500),X2(1:500),Xc(1:1000),Flag1(1:500),Flag2(1:500),Rank(1:1000)
30    INTEGER P,Comb_file_size,Incdec,Na,Nb,Nr,R
40    DIM T$(1:1000)[1],Tag1$(1:500)[1],Tag2$(1:500)[1],S$[30]
50    PRINTER IS 0
60 ! ................. DATA STATEMENTS .........................................
70              ! ( MARK END OF EACH DATA SET WITH 9999 )
80              !  EXAMPLE:  DATA "01",3,5,2,6,1,9999
90              !
100 ! ............. INPUT DATA FROM DATA STATEMENTS ............................
110             !
120     FOR Time=1 TO 2
130         IF Time=1 THEN READ Region1$
140         IF Time=2 THEN READ Region2$
150                FOR A=1 TO 500
160                     IF Time=2 THEN Second_time
170                              READ X1(A)
180                              Tag1$(A)="A"
190                              GOTO 220
200 Second_time:                 READ X2(A)
210                              Tag2$(A)="B"
220           IF (Time=1) AND (X1(A)=9999) OR (Time=2) AND (X2(A)=9999) THEN Off
230                NEXT A
240 Off:!
250        IF Time=1 THEN File_size_1=A-1
260        IF Time=2 THEN File_size_2=A-1
270   NEXT Time
280           Comb_file_size=File_size_1+File_size_2
290 ! .............. COMBINE FILES ...............................................
300           FOR N=1 TO Comb_file_size
310                IF N<=File_size_1 THEN Xc(N)=X1(N)
320                IF N<=File_size_1 THEN T$(N)=Tag1$(N)
330                IF N>File_size_1 THEN Xc(N)=X2(N-File_size_1)
340                IF N>File_size_1 THEN T$(N)=Tag2$(N-File_size_1)
350           NEXT N
360 ! .............. SORT COMBINED FILE ..........................................
370        IF O$="A" THEN Incdec=1
380        IF O$="D" THEN Incdec=0
390   CALL Vectorsort_q(Xc(*),T$(*),1,Comb_file_size,Incdec)
400 ! ................. BEGIN RANKING ............................................
410     Rank_value=1
420           FOR P=2 TO Comb_file_size
430                IF Xc(P)<>Xc(P-1) THEN No_tie
440 Tie:!
450                    T=1
460                    FOR O=P TO Comb_file_size
470                          IF Xc(O)=Xc(O-1) THEN T=T+1   ! i.e. T=2 is a tie
480                          IF Xc(O)<>Xc(O-1) THEN Out
490                    NEXT O
500 Out:!
510                    Sum=0
520                    FOR R=1 TO T
530                         Sum=Sum+Rank_value
540                         Rank_value=Rank_value+1
550                    NEXT R
560                    FOR S=P-1 TO P+T-2
570                         Rank(S)=Sum/T
580                    NEXT S
590                P=P+T-1
600                GOTO Check_for_end
610 No_tie:!
620                Rank(P-1)=Rank_value
630                Rank_value=Rank_value+1
640 Check_for_end:!
650                IF P<Comb_file_size THEN Next_p
660                Rank(P)=Rank_value
670                GOTO Results
680 Next_p:  NEXT P
690 ! ................. OUTPUT RESULTS ...........................................
700 Results:!
710     !      PRINT Region1$,Region2$
720            PRINT "A = ";Region1$,"B = ";Region2$
730      FOR A=1 TO 69
740        IF A=1 THEN PRINT CHR$(132)
```

```
750         PRINT USING "#,A";" "
760          IF A=69 THEN PRINT CHR$(128)
770        NEXT A
780        PRINT "| Data values  |  Tally  |        Rank values        | A ranks | B r
anks  |"
790        FOR A=1 TO Comb_file_size
800              IF T$(A)="B" THEN B
810         IF FRACT(Rank(A))=0 THEN PRINT USING "4X,DDDD,12X,A,11X,DDDD,13X,DDDD"
;Xc(A),T$(A),Rank(A),Rank(A)
820         IF FRACT(Rank(A))<>0 THEN PRINT USING "4X,DDDD,12X,A,11X,DDDD.D,11X,DD
DD.D";Xc(A),T$(A),Rank(A),Rank(A)
830         Total_a=Total_a+Rank(A)
840           GOTO Next_a
850 B:!
860         IF FRACT(Rank(A))=0 THEN PRINT USING "4X,DDDD,12X,A,11X,DDDD,24X,DDDD"
;Xc(A),T$(A),Rank(A),Rank(A)
870         IF FRACT(Rank(A))<>0 THEN PRINT USING "4X,DDDD,12X,A,11X,DDDD.D,22X,DD
DD.D";Xc(A),T$(A),Rank(A),Rank(A)
880         Total_b=Total_b+Rank(A)
890 Next_a:      NEXT A
900           PRINT CHR$(132)
910        FOR A=1 TO 80
920          PRINT USING "#,A";" "
930        NEXT A
940           PRINT CHR$(128)
950        PRINT USING "7X,DDDD,8A,X,DDDD,7A,9X,7A,X,DDDDD.DD,3X,DDDDD.DD";File_s
ize_1," from A,",File_size_2," from B","Totals:",Total_a,Total_b
960 Z_value: !
970                 Na=File_size_1
980                 Nb=File_size_2
990                 R=MIN(Total_a,Total_b)
1000       IF NOT ((Na>20) OR (Nb>20)) THEN Table_lookup
1010                IF Total_a<=Total_b THEN Nr=Na
1020                IF Total_b<=Total_a THEN Nr=Nb
1030             Z=(Nr*(Na+Nb+1)-2*R)/SQR(Na*Nb*(Na+Nb+1)/3)
1040                IF ABS(Z)>3.09 THEN S$="<0.2%"
1050                IF (ABS(Z)<=3.09) AND (ABS(Z)>2.58) THEN S$="between .2% and 1%"
1060                IF (ABS(Z)<=2.58) AND (ABS(Z)>1.96) THEN S$="between 1% and 5%"
1070                IF (ABS(Z)<=1.96) AND (ABS(Z)>1.64) THEN S$=">5% but <10%"
1080                IF ABS(Z)<=1.64 THEN S$=">10%"
1090    PRINT USING "4A,2X,DDD.DDD";"Z = ",Z
1100       GOTO Print_s
1110 Table_lookup:!
1120          CALL Table(Na,Nb,R,S$)
1130 Print_s:!
1140             PRINT LIN(1),"       Probability that both samples came from same pop
ulation is "&S$
1150             PRINT LIN(3)
1160 END
1170  SUB Table(INTEGER Na,Nb,R,S$)
1180           DATA 2,8,4,3,0,0
1190           DATA 2,9,4,3,0,0
1200           DATA 2,10,4,3,0,0
1210           DATA 2,11,4,3,0,0
1220           DATA 2,12,5,4,0,0
1230           DATA 2,13,5,4,0,0
1240           DATA 2,14,6,4,0,0
1250           DATA 2,15,6,4,0,0
1260           DATA 2,16,6,4,0,0
1270           DATA 2,17,6,5,0,0
1280           DATA 2,18,7,5,0,0
1290           DATA 2,19,7,5,3,0
1300           DATA 2,20,7,5,3,0
1310           DATA 3,5,7,6,0,0
1320           DATA 3,6,8,7,0,0
1330           DATA 3,7,8,7,0,0
1340           DATA 3,8,9,8,0,0
1350           DATA 3,9,10,8,6,0
1360           DATA 3,10,10,9,6,0
1370           DATA 3,11,11,9,6,0
1380           DATA 3,12,11,10,7,0
1390           DATA 3,13,12,10,7,0
1400           DATA 3,14,13,11,7,0
1410           DATA 3,15,13,11,8,0
1420           DATA 3,16,14,12,8,0
1430           DATA 3,17,15,12,8,6
1440           DATA 3,18,15,13,8,6
1450           DATA 3,19,16,13,9,6
```

```
1460        DATA 3,20,17,14,9,6
1470        DATA 4,5,12,11,0,0
1480        DATA 4,6,13,12,10,0
1490        DATA 4,7,14,13,10,0
1500        DATA 4,8,15,14,11,0
1510        DATA 4,9,16,14,11,0
1520        DATA 4,10,17,15,12,10
1530        DATA 4,11,18,16,12,10
1540        DATA 4,12,19,17,13,10
1550        DATA 4,13,20,18,13,11
1560        DATA 4,14,21,19,14,11
1570        DATA 4,15,22,20,15,11
1580        DATA 4,16,24,21,15,12
1590        DATA 4,17,25,21,16,12
1600        DATA 4,18,26,22,16,13
1610        DATA 4,19,27,23,17,13
1620        DATA 4,20,28,24,18,13
1630        DATA 5,5,19,17,15,0
1640        DATA 5,6,20,18,16,0
1650        DATA 5,7,21,20,16,0
1660        DATA 5,8,23,21,17,15
1670        DATA 5,9,24,22,18,16
1680        DATA 5,10,26,23,19,16
1690        DATA 5,11,27,24,20,17
1700        DATA 5,12,28,26,21,17
1710        DATA 5,13,30,27,22,18
1720        DATA 5,14,31,28,22,18
1730        DATA 5,15,33,29,23,19
1740        DATA 5,16,34,30,24,20
1750        DATA 5,17,35,32,25,20
1760        DATA 5,18,37,33,26,21
1770        DATA 5,19,38,34,27,22
1780        DATA 5,20,40,35,28,22
1790        DATA 6,6,28,26,23,0
1800        DATA 6,7,29,27,24,21
1810        DATA 6,8,31,29,25,22
1820        DATA 6,9,33,31,26,23
1830        DATA 6,10,35,32,27,24
1840        DATA 6,11,37,34,28,25
1850        DATA 6,12,38,35,30,25
1860        DATA 6,13,40,37,31,26
1870        DATA 6,14,42,38,32,27
1880        DATA 6,15,44,40,33,28
1890        DATA 6,16,46,42,34,29
1900        DATA 6,17,47,43,36,30
1910        DATA 6,18,49,45,37,31
1920        DATA 6,19,51,46,38,32
1930        DATA 6,20,53,48,39,33
1940        DATA 7,7,39,36,32,29
1950        DATA 7,8,41,39,34,30
1960        DATA 7,9,43,40,35,31
1970        DATA 7,10,45,42,37,33
1980        DATA 7,11,47,44,38,34
1990        DATA 7,12,49,46,40,35
2000        DATA 7,13,52,48,41,36
2010        DATA 7,14,54,50,43,37
2020        DATA 7,15,56,52,44,38
2030        DATA 7,16,58,54,46,39
2040        DATA 7,17,61,56,47,41
2050        DATA 7,18,63,58,49,42
2060        DATA 7,19,65,60,50,43
2070        DATA 7,20,67,62,52,44
2080        DATA 8,8,51,49,43,40
2090        DATA 8,9,54,51,45,41
2100        DATA 8,10,56,53,47,42
2110        DATA 8,11,59,55,49,44
2120        DATA 8,12,62,58,51,45
2130        DATA 8,13,64,60,53,47
2140        DATA 8,14,67,62,54,48
2150        DATA 8,15,69,65,56,50
2160        DATA 8,16,72,67,58,51
2170        DATA 8,17,75,70,60,53
2180        DATA 8,18,77,72,62,54
2190        DATA 8,19,80,74,64,56
2200        DATA 8,20,83,77,66,57
2210        DATA 9,9,66,62,56,52
2220        DATA 9,10,69,65,58,53
2230        DATA 9,11,72,68,61,55
```

```
2240          DATA 9,12,75,71,63,57
2250          DATA 9,13,78,73,65,59
2260          DATA 9,14,81,76,67,60
2270          DATA 9,15,84,79,69,62
2280          DATA 9,16,87,92,72,64
2290          DATA 9,17,90,84,74,66
2300          DATA 9,18,93,87,76,68
2310          DATA 9,19,96,90,78,70
2320          DATA 9,20,99,93,81,71
2330          DATA 10,10,82.78,71.65
2340          DATA 10,11,86,81,73,67
2350          DATA 10,12,89,84,76.69
2360          DATA 10,13,92,88,79.72
2370          DATA 10,14,96,91,81,74
2380          DATA 10,15,99.94,84,76
2390          DATA 10,16,103,97,86,78
2400          DATA 10,17,106,100.89,80
2410          DATA 10,18,110,103,92.82
2420          DATA 10,19,113,107.94,84
2430          DATA 10,20,117,110.97,87
2440          DATA 11,11,100,96,87,81
2450          DATA 11,12,104,99.90,83
2460          DATA 11,13,108,103,93,86
2470          DATA 11,14,112,106,96,88
2480          DATA 11,15,116,110,99.90
2490          DATA 11,16,120.113,102,93
2500          DATA 11.17,123,117,105,95
2510          DATA 11,18,127,121.108,98
2520          DATA 11,19,131,124.111.100
2530          DATA 11,20,135,128,114,103
2540          DATA 12,12,120,115.105,98
2550          DATA 12,13,125,119,109,101
2560          DATA 12.14,129.123,112,103
2570          DATA 12,15,133,127.115,106
2580          DATA 12,16,138,131,119,109
2590          DATA 12,17,142,135,122,112
2600          DATA 12,18,146.139,125,115
2610          DATA 12,19,150,143,129,118
2620          DATA 12,20,155,147,132,120
2630          DATA 13,13,142,136,125,117
2640          DATA 13,14,147,141,129,120
2650          DATA 13,15,152.145,133,123
2660          DATA 13,16,156,150,136,126
2670          DATA 13,17,161,154,140,129
2680          DATA 13,13,166,158.144,133
2690          DATA 13,19,171,163,148,136
2700          DATA 13,20,175,167.151,139
2710          DATA 14,14,166,160,147.137
2720          DATA 14,15,171.164,151,141
2730          DATA 14,16,176,169,155,144
2740          DATA 14,17,182,174,159,148
2750          DATA 14,18,187,179.163,151
2760          DATA 14,19,192,183.168,155
2770          DATA 14,20,197,188,172,159
2780          DATA 15,15,192,184,171.160
2790          DATA 15,16,197.190,175,163
2800          DATA 15,17,203,195.180,167
2810          DATA 15,18,208.200.184,171
2820          DATA 15,19,214.205.189,175
2830          DATA 15,20.220.210,193.179
2840          DATA 16.16,219,211,196.184
2850          DATA 16,17,225,217.201.188
2860          DATA 16.18,231,222.206,192
2870          DATA 16.19,237,228.210,196
2880          DATA 16,20,243.234.215,201
2890          DATA 17,17,249,240,223.210
2900          DATA 17,18,255,246.228.214
2910          DATA 17,19,262,252.234.219
2920          DATA 17,20,268,258.239.223
2930          DATA 18,18,280.270,252,237
2940          DATA 18,19,287,277.258,242
2950          DATA 18,20,294,283,263.247
2960          DATA 19.19,313,303,283,267
2970          DATA 19,20,320,309,289,272
2980          DATA 20,20,348.337,315,298
2990            FOR A=1 TO 182
3000                 READ N1,N2,P1,P2,P3,P4
3010                   IF NOT ((Na=N1) AND (Nb=N2) OR (Na=N2) AND (Nb=N1)) THEN Ne
```

```
t_a
3020                    IF R<P4 THEN S$="< 0.2%"
3030                    IF (R>=P4) AND (R<P3) THEN S$="between .2% and 1%"
3040                    IF (R>=P3) AND (R<P2) THEN S$="between 1% and 5%"
3050                    IF (R>=P2) AND (R<P1) THEN S$=">5% but < 10%"
3060                    IF R>=P1 THEN S$=">10%"
3070                    SUBEXIT
3080 Next_a:  NEXT A
3090          S$="Not in table"
3100  SUBEND
3110  SUB Vectorsort_q(A(*),A$(*),INTEGER I1,J1,Incdec)
3120  INTEGER Logtwo
3130     N=J1+1-I1
3140     Logtwo=INT(LGT(N)/LGT(2))+1
3150     CALL Qsort(A(*),A$(*),Logtwo,I1,J1,Incdec)
3160 SUBEXIT
3170 SUB Qsort(A(*),A$(*),INTEGER Log,I1,J1,Incdec)
3180 OPTION BASE 1
3190 DIM L(Log),U(Log)
3200     M=1                              ! Set stack pointer.
3210     I=I1                             ! Set lower endpoint.
3220     J=J1                             ! Set upper endpoint.
3230 Start1:IF I>=J THEN Nextgroup
3240 Start2:K=I
3250         I2=INT((J+I)/2)              ! Determine the midpoint of a segment.
3260         T=A(I2)
3270         T$=A$(I2) !
3280         IF Incdec=0 THEN D1
3290 I1:     IF A(I)<=T THEN Lowmiddle1
3300         GOTO 3320
3310 D1:     IF A(I)>=T THEN Lowmiddle1   ! Check to see if lower endpoint and
3320         A(I2)=A(I)                   !  midpoint are in order.  If not,
3330         A(I)=T                       !  switch them.
3340         T=A(I2)                      ! Reset midpoint.
3350         A$(I2)=A$(I)     !
3360         A$(I)=T$         !
3370         T$=A$(I2)        !
3380 Lowmiddle1: L=J                              ! Set upper endpoint.
3390                IF Incdec=0 THEN D2
3400 I2:            IF A(J)>=T THEN Middlehigh
3410                GOTO 3430
3420 D2:            IF A(J)<=T THEN Middlehigh  ! Check to see if the midpoint and
3430                A(I2)=A(J)                  !  the upper endpoint are in order.
3440                A(J)=T                      ! If not, switch them.
3450                T=A(I2)
3460                A$(I2)=A$(J)   !
3470                A$(J)=T$       !
3480                T$=A$(I2)      !
3490                IF Incdec=0 THEN D3
3500 I3:            IF A(I)<=T THEN Middlehigh
3510                GOTO 3530
3520 D3:            IF A(I)>=T THEN Middlehigh  ! Check to see if the switch left
3530                A(I2)=A(I)                  !  the lower endpoint and the mid-
3540                A(I)=T                      !  point in order.
3550                T=A(I2)                     ! If not, switch them.
3560                A$(I2)=A$(I)    !
3570                A$(I)=T$        !
3580                T$=A$(I2)       !
3590 Middlehigh: L=L-1                          ! Decrement the upper endpoint.
3600                IF Incdec=0 THEN D4
3610 I4:            IF A(L)>T THEN Middlehigh
3620                GOTO 3640
3630 D4:            IF A(L)<T THEN Middlehigh   ! Check to see if the new upper
3640                T1=A(L)                     !  endpoint is in order.
3650                T1$=A$(L)  !
3660 Stepup: K=K+1                    ! If not, save the upper endpoint and
3670          IF Incdec=0 THEN D5
3680 I5:      IF A(K)<T THEN Stepup   !  increment the lower endpoint.  Now
3690          GOTO 3710
3700 D5:      IF A(K)>T THEN Stepup
3710          IF K>L THEN Passed      !  check if the lower endpoint is less
3720          A(L)=A(K)               !  than the midpoint.  If not, then switch
3730          A(K)=T1                 !  the upper and lower endpoints.
3740          A$(L)=A$(K)  !
3750          A$(K)=T1$    !
3760          GOTO Middlehigh
3770 Passed:  IF L-I<=J-K THEN Storehigh   ! Sort the shortest segment first.
3780          L(M)=I                       ! Store the lower
```

```
3790          U(M)=L                             !  endpoints.
3800          I=K                                ! Set the new lower endpoint.
3810          M=M+1                              ! Push the stack
3820          GOTO 3870
3830 Storehigh: L(M)=K                           ! Store the upper
3840             U(M)=J                          !  endpoints
3850             J=L                             ! Set the new upper endpoint.
3860             M=M+1                           ! Push the stack
3870             IF J-I<=11 THEN Start2
3880             IF I=I1 THEN Start1
3890             I=I-1
3900 Inc:  I=I+1                           ! Increment lower endpoint.
3910       IF I=J THEN Nextgroup           ! If the current segment is sorted, then
3920       T=A(I+1)                        !  sort the next segment.
3930       T$=A$(I+1)    !
3940       IF Incdec=0 THEN D6
3950 I6:   IF A(I)<=T THEN Inc
3960       GOTO 3980
3970 D6:   IF A(I)>=T THEN Inc             ! Check to see if next element is in order.
3980       K=I                             ! Insert element in otherwise sorted list.
3990 Copy: A(K+1)=A(K)                     ! This section bumps the array up.
4000        A$(K+1)=A$(K)  !
4010        K=K-1                          ! Prepare to bump next element.
4020        IF Incdec=0 THEN D7
4030 I7:    IF T<A(K) THEN Copy
4040        GOTO 4060
4050 D7:    IF T>A(K) THEN Copy            ! Check to see if insertion is here.
4060        A(K+1)=T                       ! If so, then insert.
4070        A$(K+1)=T$     !
4080        GOTO Inc
4090 Nextgroup: M=M-1                      ! Pop the stack.
4100            IF M=0 THEN Out            ! Check for end conditions.
4110            I=L(M)                     ! Restore the
4120            J=U(M)                     !  previous endpoints.
4130            GOTO 3870
4140 Out: SUBEXIT
```

Appendix B. Data tables arranged in class intervals

APPENDIX B. Class interval in meters

REGION: BERING SEA
DATE: FEBRUARY 9, 1973
TRACK #: 1

Samp#	15-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-600	actual width (m) >600	Track Coverage (m)	Water Coverage (m)	% Water Coverage
01	3	6		1	1	1							30,907	726	2.35
02	1			1									30,907	109	.35
03	3	4	3									1035	31,364	1451	4.63
04	8	1											31,638	188	.59
05	2	3				1							32,004	339	1.06
06	3	2	2	1									23,957	404	1.69
07	1	1											24,689	76	.31
08	9	2	2	1								802	24,689	1319	5.34
09	11	4	2										24,689	549	2.22
10	7			2									25,512	346	1.36
11	3	1											25,512	104	.41
12	11	2		1									29,078	398	1.37
13	6	3	2										29,078	378	1.30
Tot.	68	29	11	7	1	2						2	364,024	6387	MEAN = 1.75

APPENDIX B. Class interval in meters

REGION: NORTH SLOPE
DATE: NOVEMBER 13, 1970
TRACK #: 2

Samp#	15-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-600	actual width (m) >600	Track Coverage (m)	Water Coverage (m)	% Water Coverage
01	2		1		1	1	1	1	1		2	1244	29,261	3216	10.99
02	3	1									1		29,261	641	2.19
03	6	2					1					922	29,261	1407	4.81
04	2	2	2									1522	29,261	1798	6.15
05	7	2		1									29,261	325	1.11
Tot.	20	7	3	1	1	1	2	1	1		3	3	146,305	7387	MEAN = 5.05

APPENDIX B

REGION: NORTH SLOPE
DATE: APRIL 24, 1974
TRACK #: 3

Class Interval in Meters

Samp#	15-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-600	actual width (m) >600	Track Coverage (m)	Water Coverage (m)	% Water Coverage

THIS TRACK LINE COVERED 1,020 KM WITH NO WATER OPENINGS >15 M

APPENDIX B

REGION: NORTH SLOPE
DATE: MAY 13-14, 1971
TRACK #: 4

Class Interval in Meters

Samp#	15-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-600	actual width (m) >600	Track Coverage (m)	Water Coverage (m)	% Water Coverage
01	5	6	2										26,417	501	1.90
02	15	8	3	1									29,361	962	3.28
03	9	8	4			1							30,084	912	3.03
Tot.	29	22	9	1		1							85,862	2375	MEAN = 2.74

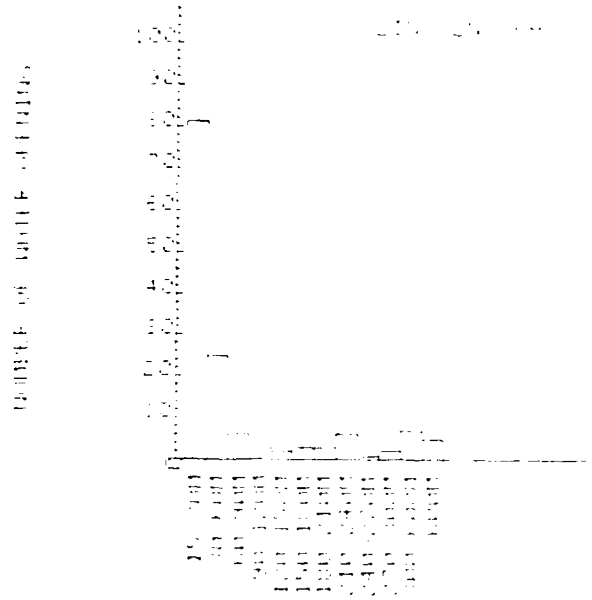
APPENDIX B. Class interval in meters

REGION: LINCOLN SEA
DATE: NOVEMBER 6, 1970
TRACK #: 5

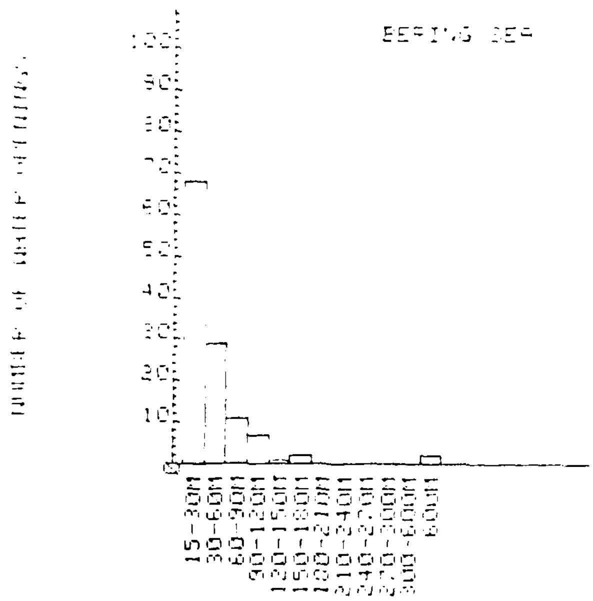
Samp#	15-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-600	actual width (m) >600	Track Coverage (m)	Water Coverage (m)	% Open Water
01	1	4						2	1		3	848	27,798	2830	10.18
02	9	1									1		27,798	773	2.78
03	14	4	1								1		29,352	941	3.20
04	10	2			2					1	2	653 807	29,352	3251	11.08
05	3		1				1						29,352	335	1.14
06	2												29,352	45	.15
07	2			1									29,352	164	.56
08	3	2											29,352	150	.51
09	6	2				1		3					14,676	1132	7.71
10	5	4	2	1		1	1	1		1	1	676 1034	31,821	3325	10.45
11	7	2	1	1		1							29,352	602	2.05
12	8	1					1						29,352	405	1.38
13	8	2											29,352	236	.80
14	3	1	1										13,899	178	1.28
Tot.	81	25	6	3	2	3	3	6	1	2	8	5	380,160	14,367	MEAN = 3.78

Appendix C. Regional and overall histograms showing lead width and frequency distributions

APPENDIX C

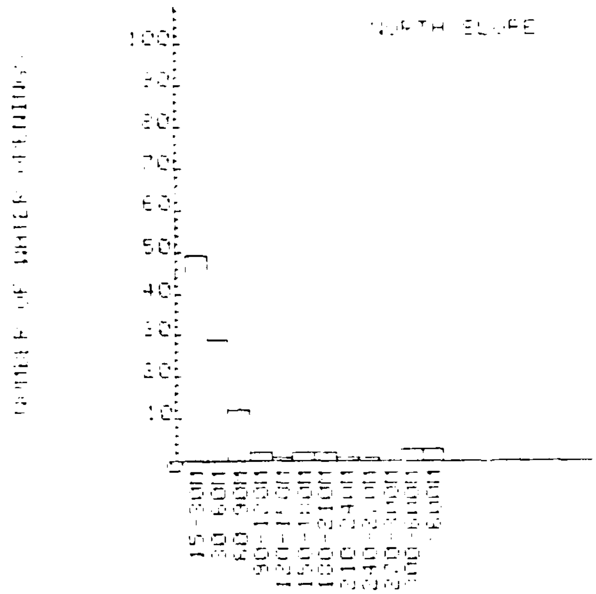


Lead width and frequency distribution from figure 2 track 5

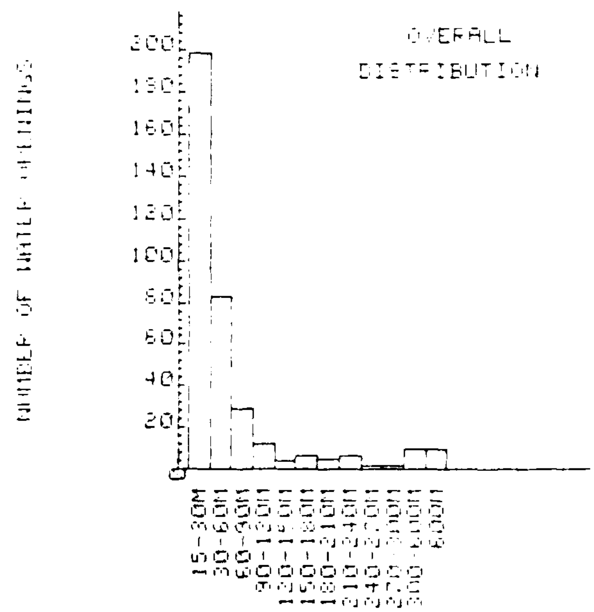


Lead width and frequency distribution from figure 2 track 1

APPENDIX C



Lead width and frequency distribution from figure 2 track 2, 3, 4



Lead width and frequency distribution from figure 2, all track lines combined

Appendix D. Example of HP-9845B printout from Wilcoxson

Sum of Ranks program listed in Appendix A

APPENDIX D

A = Nor Slo 0a   B = Nor Slo 0b

Data values	Tally	Rank values	A ranks	B ranks
63	A	1	1	
72	B	2		2
86	B	3		3
96	B	4.5		4.5
96	A	4.5	4.5	
120	B	6		6
216	A	7	7	
480	A	8	8	
528	A	9	9	
624	A	10	10	
768	A	11	11	
864	A	12	12	
1392	A	13	13	
1440	A	14	14	
1728	B	15		15
4080	A	16	16	

11 from A,   5 from B   Totals: 105.50   30.50

Probability that both samples came from same population is >10%

A = Nor Slo 0a   B = Nor Slo 0b

Data values	Tally	Rank values	A ranks	B ranks
4080	A	1	1	
1728	B	2		2
1440	A	3	3	
1392	A	4	4	
864	A	5	5	
768	A	6	6	
624	A	7	7	
528	A	8	8	
480	A	9	9	
216	A	10	10	
120	B	11		11
96	A	12.5	12.5	
96	B	12.5		12.5
86	B	14		14
72	B	15		15
63	A	16	16	

11 from A,   5 from B   Totals: 81.50   54.50

Probability that both samples came from same population is >10%

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REPORT DOCUMENTATION PAGE

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4. TITLE (and Subtitle) Open Water and Thin Ice Detection in the Arctic Marginal Ice Zone Using Reflectometer Signal Analysis		5. TYPE OF REPORT & PERIOD COVERED FINAL
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Charles J. Radl James P. Welsh		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ocean Research & Development Activity Ocean Science & Technology Laboratory, Code 330 NSTL Station, Mississippi 39529		10. PROGRAM ELEMENT PROJECT TASK AREA & WORK UNIT NUMBERS 980101
11. CONTROLLING OFFICE NAME AND ADDRESS Same		12. REPORT DATE March 1983
		13. NUMBER OF PAGES 32
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Arctic	Lead
Laser	Reflectometer
Sea Ice	Polynya

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Approximately 2000 kilometers (~1250 statute miles) of reflectometer data collected within 160 kilometers (100 statute miles) of the ice edge in the North American Arctic were analyzed. The reflectometer signal, which shows a sharp decrease in areas of open water/thin ice, was used to initiate and develop a method to begin an evaluation of the frequency of occurrence and percentage of open water from the ice edge to approximately 160 kilometers. Comparisons were made within and among regional data sets. Individual regions were not unambiguously

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Block 20 (continued)

identifiable by lead width and frequency characteristics. Distance into the pack from the ice edge did not have a direct relationship to the frequency or percentage of open water. The result of no apparent relationship between the frequency of occurrence and percent of area of open water may be due to the restricted samples--restricted in season and total area covered.