

Environmental Studies Research Funds

Report No. 114

March, 1992

BEAUFORT SEA EXTREME WAVES STUDY

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The correct citation for this report is:

Eid, B.M. and V.J. Cardone. 1992. Beaufort Sea extreme waves study. Environmental Studies Research Funds, Report Series No. 114. Calgary, Alberta, 143 p. + Appendices.

March 4, 1992

Atmospheric Environment Service
Environment Canada
4905 Dufferin Street
Downsview, Ontario
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Attention: Mr. Val Swail
Head, Hydrometeorology

Dear Val:

RE: ESRF Beaufort Sea Extreme Waves Hindcast Study
Final Report – ESRF Study #4860

We are pleased to submit our final report for the above referenced study. The report includes your review comments.

We look forward to the final review by ESRF. A camera-ready version of the final report will be submitted to ESRF shortly after receiving their review.

Yours very truly,

MacLAREN PLANSEARCH (1991) LIMITED

Bassem M. Eid, P.Eng., Ph.D.
Project Manager

Enclosure

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ACKNOWLEDGEMENT

This study was carried out by MacLaren Plansearch (1991) Limited (MPL), Halifax, Nova Scotia, in association with Oceanweather Inc., (OWI), Cos Cob, Connecticut and D. F. Dickins and Associates, Vancouver, British Columbia. MPL provided the literature review, data base assembly, storm classification and storm selection, review of methodologies, model hindcast verifications, extremal analysis and report preparation. OWI was responsible for wave model development and storms hindcast; Dickins and Associates provided ice edge for the storm events considered in this study.

The study was initiated and funded by Environmental Studies Research Funds (ESRF). Additional funding was provided by COGLA under DSS contract #KM169-0-8160 for hindcasting additional 15 storms. The Scientific Authority for this study was Mr. Val Swail, Atmospheric Environment Services (AES), Environment Canada. The Study Review Committee consisted of Mr. Val Swail, Dr. Ken Sato, National Energy Board, Mr. Brian Wright, Gulf Canada Resources Limited, and Mr. Tom Agnew, AES.

EXECUTIVE SUMMARY

The objective of this study was to develop new and definitive estimates of the extreme wave climate in the Canadian Beaufort Sea, with emphasis on offshore exploration areas in deep and shallow water. A hindcast approach was adopted, which includes: (1) assembly of comprehensive data base of archived historical meteorological, waves, and ice cover data; (2) identification and ranking of historical storm occurrences during the potential open-water season, over as long an historical period as allowed by the data, and selection of a top-ranked severe wave generating storm population (30 storms) for hindcasting; (3) adaptation and validation of accurate numerical hindcasting procedures to specify time histories of surface wind fields, wave fields and directional spectra in each hindcast storm; (4) hindcast production of the selected storms; and (5) statistical analysis of hindcast extremes at a selected number of model grid points. The ODGP spectral ocean wave model, as adapted recently to shallow water and a variable ice edge, was used for the wave hindcasts. Wind fields were calculated from the sea surface pressure fields using proven marine planetary boundary layer model.

The Beaufort Sea presents a number of special problems: (1) the relative scarcity of historical meteorological and seastate data; and (2) the highly variable and complex nature of sea-ice cover, which exert a significant control over the wave field. The presence of sea ice also complicates the storm selection process, hindcast processes, and extremal analysis methods. In order to account for the variability and uncertainty of extremes associated with ice edge effects, four different ice edges were used for each storm: actual ice edge and climatological ice edges for three probability levels (98%, 50% and 30% occurrences). The results are presented for individual and combined ice edge scenarios.

Comparison of the present results with other previous studies indicated that this study produced extreme values which are at the lower end of the wide range of extremes provided by previous studies.

RÉSUMÉ

L'objectif de la présente étude consistait à mettre au point de nouvelles et définitives estimations du régime extrême des vagues dans la partie canadienne de la mer de Beaufort avec emphase sur les régions d'exploration au large en eau profonde et peu profonde. Une approche de prévision à postériori englobant les composantes suivantes a été adoptée : 1) assemblage d'une base de données exhaustive de données historiques archivées sur la météorologie, les vagues et la couverture glacielle; 2) l'identification et le classement des tempêtes historiques survenues pendant la saison possible d'eau libre pour une période d'aussi longue durée que le permettaient les données et la sélection d'une population (30 tempêtes) de tempêtes de premier rang ayant soulevé les plus grosses vagues pour la prévision à postériori; 3) la modification et la validation de procédures précises de prévision à postériori permettant de spécifier des historiques temporels de champs de vent en surface; 4) la production à postériori des tempêtes choisies; et 5) l'analyse statistique des conditions extrêmes prévues à postériori en un certain nombre de points choisis du quadrillage du modèle. Le modèle spectral de vagues océaniques ODGP, tel que récemment modifié pour l'application à des eaux peu profondes et à une lisière des glaces variable a été utilisé pour la prévision à postériori des vagues. Les champs de vent ont été calculés d'après les champs de pression à la surface de la mer au moyen de l'éprouvé modèle marin de la couche limite planétaire.

La mer de Beaufort pose un certain nombre de problèmes spéciaux : 1) les données historiques sur la météorologie et l'état de la mer y sont relativement rares; 2) la couverture de glace de mer y est de nature très variable et complexe, ce qui y détermine de manière importante le champ de vagues. La présence de glace de mer complique également le processus de sélection des tempêtes, les processus de prévision à postériori et les méthodes d'analyse des conditions extrêmes. Afin de tenir compte de la variabilité et de l'incertitude associées aux effets de la lisière des glaces, quatre lisières des glaces différentes ont été utilisées pour chaque tempête; la lisière réelle des glaces et des lisières des glaces climatologiques associées à trois niveaux de probabilité (98 %, 50 % et 30 %). Les résultats sont présentés pour des scénarios individuels et combinés de lisières des glaces.

La comparaison des présents résultats à ceux d'études antérieures indique que les valeurs extrêmes obtenues dans le cadre de la présente étude se situent à la partie inférieure de la plage étendue de valeurs extrêmes obtenues lors d'autres études.

1.0 INTRODUCTION

The objective of this study was to produce, via hindcasting, a climatology for extreme storm waves in the Beaufort Sea, to be used as a reference for design considerations of offshore structures. Phase I, of this study was aimed at reviewing previous environmental studies for the Beaufort region, and establishing an appropriate procedure to provide the design reference information, selecting an appropriate spectral wave model, selecting severe storms affecting the Canadian Beaufort Sea region, and evaluation of model hindcasts. Phase II of the study consisted of the final selection of the top severe storm population, hindcast production, extremal analysis, treatment of ice edge and presentation of final results.

Already at the outset, it was realized that considerable effort would be required in order to provide adequate overwater wind fields and specification of the effects of sea ice and shallow water. Compared to previous studies with similar objectives for other areas such as the Canadian East and West Coasts or the Gulf of St. Lawrence, the number of available marine observations of weather and sea state from ships and rigs in the Beaufort is relatively small. The selection and hindcast of the potential severe storms is further complicated by the existence of sea ice. Extra care must therefore be taken when determining the wind and ice fields.

Due to the special operating conditions in the Beaufort Sea, where drilling is mostly carried out on structures which differ from those used elsewhere, different considerations must be taken for establishing design criteria and critical conditions, and when selecting severe storm events for hindcasting. Some effort was therefore put into estimating which storms were likely to generate extreme currents for example, as these would likely increase the potential for erosion of artificial islands.

In the following sections, the results of a major literature review covering previous environmental and design studies for the Beaufort Sea are discussed, followed by a description of the data sources utilized, event selection methods and the resulting lists of storm events. A description of the wave hindcast model selected for this application is also given in this report with hindcast verification results provided. The production hindcast of the top 30 storms is described and hindcast results presented. Finally extremal analysis techniques are described and final results are presented for different statistical ice edge conditions (eg. 30%, 50%, 98% and actual ice edge are considered).

1.1 **STUDY AREA**

The study area covers the Canadian Beaufort Sea region bounded by longitudes 162°W and 120°W, latitude 76°N and the shoreline to the south (Figure 1.1). This covers the maximum extent of open water expected to occur during a summer season. Figure 1.1 also shows the selected model domain and the wind hindcast model grid.

1.2 **HISTORICAL PERIOD COVERED**

Experience from studies in other areas shows that a 30 year data base provides a sufficient number of storm events for establishing design criteria for offshore structures. The period covered in this study was the summer seasons (15 June –15 November) of 1957–1988 (32 years). The quality and quantity of data from earlier periods is often insufficient, and much harder to verify.

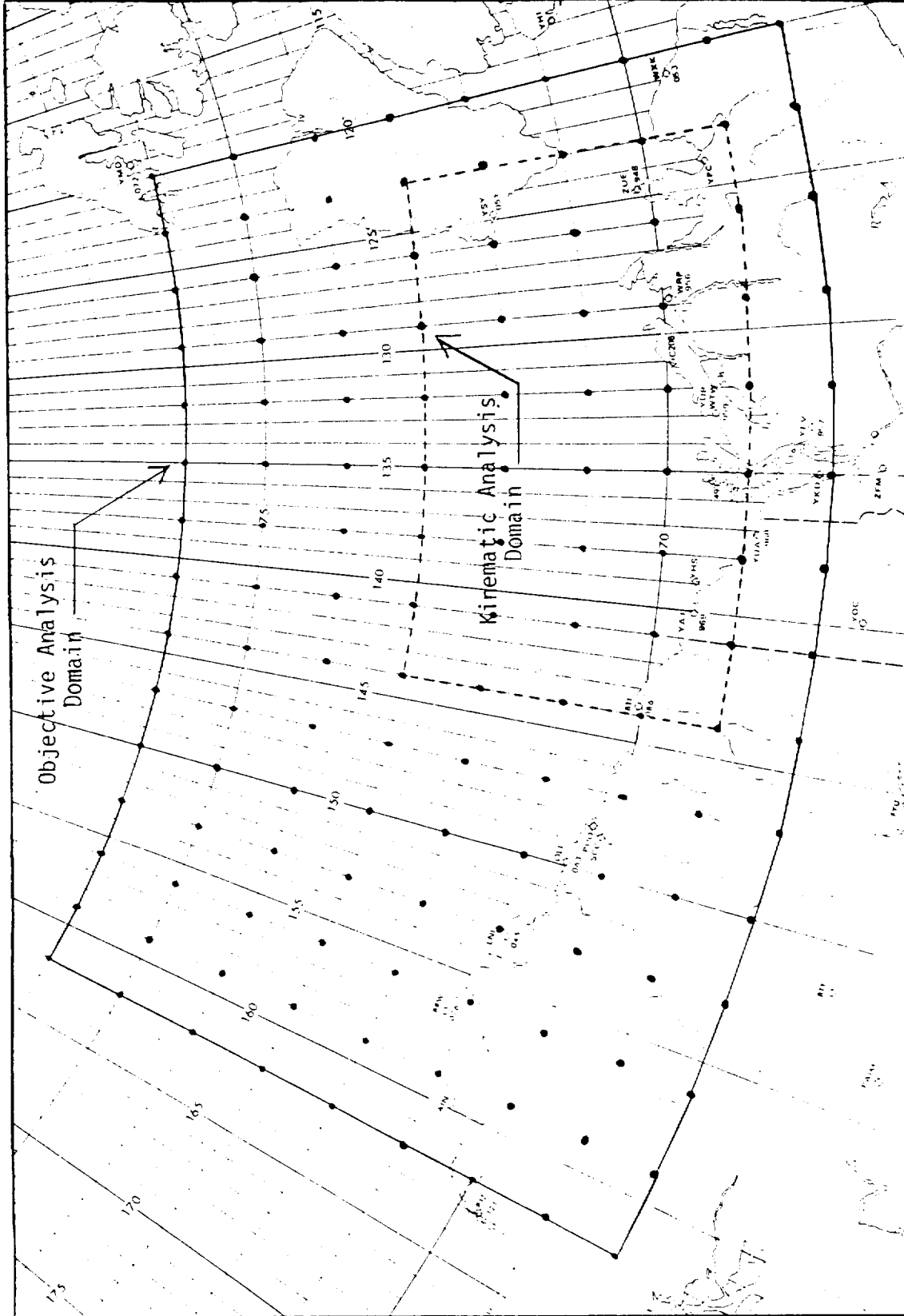


Figure 1.1 Study Area

2.0 LITERATURE REVIEW AND METHODOLOGY

2.1 REVIEW OF PREVIOUS STUDIES

It must be emphasized that the main objective of this study is to produce a climatology for extreme storm waves in the Beaufort Sea, to be used as a common reference guide for design consideration of offshore structures, artificial islands, and facilities. This is to be done by hindcasting the highest wave generating storms in the past several years (e.g. 30 years) with considerable attention paid to the specification of over water wind fields, the effect of the marginal ice zone (MIZ), and shallow water effect.

In addition, the study is to identify and select parameters that encompass the definition of "design storms", including wave height, period and direction, storm duration, and associated storm currents and erosion potential (i.e. the storm parameters which are critical for the design and operation of various offshore structures, artificial islands, pipelines, etc.). The hindcasting of the storm currents and erosion potential is beyond the scope of this study and should be considered in future investigation.

The approach we adopted here is based on a comprehensive hindcasting technique which is based on an extensive review of all marine data bases, careful selection of potential severe storms and the use of a well calibrated spectral ocean wave model. This approach is similar to that used in a recent East Coast Extreme Wind and Wave Hindcast Study by MacLaren Plansearch Limited and Oceanweather Inc., 1991 (see also Swail et al. 1989). However, additional complexity due to sparse data and ice effect must be addressed in the Beaufort Sea application.

A comprehensive literature review was carried out with the following objectives:

1. Provide an overview of previous environmental studies related to the Beaufort Sea, and review the state-of-the-art in estimating extreme values for offshore structure design parameters.
2. Extract and compile a list of all Beaufort Sea storm events previously identified and studied.
3. Identify limitations of previous studies and devise a strategy to overcome them if possible.
4. Establish an appropriate methodology for conducting the present extreme waves study.

Several extreme wave studies have previously been carried out for the Beaufort Sea. As pointed out by Murray and Maes (1986), the studies provided a wide spread in the resulting estimates of extreme waves, for example the estimated 100 year return period extreme wave height varied from 4 m to 16 m. This may be attributed to the different approaches and data bases used in these various studies. Murray and Maes (1986) reviewed several studies of which two were given most attention, Hydrotechnology (1980) and Seaconsult (1981). Murray and Maes recommended several improvements to the methods they reviewed. These include using synoptic weather charts in combination with a kinematic analysis to specify wind fields varying in space and time, and using a hindcast model with improved resolution, both temporally and spatially. They pointed out that an

improvement of the specified wind fields would provide the single most important contribution towards improving the extreme wave estimates. The Baird & Associates (1987) study to estimate the wave climate at Minuk-I-52, is an example. They used wind data from a few land stations, converted to over-water values through a transfer function, to derive wind-fields for the Beaufort. This did not account for spatial variations in the wind field, which in turn affects the spectral shape and directional distribution of the hindcast waves. Also, it is questionable whether or not land observations from one or a few selected points are representative of offshore conditions, as considerable variability in coastal wind fields is found due to the orographic effect of Brook Mountain (Kozo and Robe, 1986).

Another common feature of the previous studies is the relatively limited consideration which was given to ice cover in deriving the wave climate. Although ice cover was included in model runs in recent hindcast studies, e.g. Baird & Associates (1987), sea ice cover variability was generally not included in the ensuing statistical analyses used to estimate extreme values, e.g. the 100 year extreme wave height. This could possibly have lead to substantial over- or underestimation of the extreme values which were determined.

As the emphasis for several of the previous studies has been on establishing design criteria for Sacrificial Beach Islands (SBI's), erosion has been of concern. Storm event duration, waves and currents as well as extreme currents were therefore also studied. The recent Seaconsult (1989) design storm study addressed these concerns. This study utilized more measured data than hindcast results. Storms were classified according to the shape of their normalized time history of significant wave height, peak period and current speed, which could help to determine what "type" of storm is likely to produce the most severe overall conditions. The Seaconsult study, however, did not proceed to examine if different storm types were related to different generating situations, such as wind field characteristics, ice cover, storm propagation direction and season. Such relationships might however, help to understand how extreme conditions occur.

The estimation of extreme current speeds, and the correlation between extreme winds, waves and currents has so far been somewhat limited by the relatively scarce amount of current data available. For the existing measurements, data quality is of concern, as pointed out by Buckley and Budgell (1988). Buckley and Budgell (1988) carried out hindcast studies of currents using a storm surge model. However, the results are more representative for low frequency type wind-related current events, rather than extreme storm values. We therefore find that both existing hindcast and measured current data are mostly of limited value for extreme value estimations, and for use in combination with other parameters for determining design conditions for certain structures such as SBI's.

2.2 STORM PARAMETERS IDENTIFICATION

In order to identify events where environmental parameters are considered extreme and pose danger to a structure, the essential design parameters must be identified. These depend strongly on the type of structure under consideration. In the Beaufort Sea, SBI's have been widely used. In a number of the studies we reviewed, SBI's were used for determining design criteria.

Our review identified the following parameters to be most important:

- wind speed and direction
- waves (significant wave height, peak periods, and directionality);
- current speed and direction;
- duration of high values of the above parameters;
- measures of erosion, based on the above parameters;
- water level;
- ice cover; and
- joint probability distributions for the above mentioned quantities.

For an SBI, erosion is of primary concern. In this case, it seems that water level and current conditions are of significant importance, in addition to wave action. These factors may not have been considered sufficiently in the reviewed studies. The selection of storms which may produce serious erosion will be quite a different problem than selecting storms which produce the highest waves.

The derivation of extreme, or return period, values of design parameters depends on a reliable method for identification of storm events, and on which events are selected as the most severe. It would be desirable to determine a reduced number of parameters for ranking the storms according to severity. It therefore seems that the definition of an erosion index, as was done by Baird & Associates (1987), is a useful approach. This could be modified to account for other variables such as currents. The severity measure should be based on the energy available in a storm for carrying out erosion work, and the duration for which it is capable of carrying out this work.

However, in order to identify the most extreme storms in the above mentioned manner, the storms would all have to be hindcast, so that necessary wave information would be available. This would be time consuming and expensive.

Alternatively, an initial index for selecting potential severe storms can be estimated as:

$$S_w = \frac{1}{N} \sum_{j=1}^N U_j^2 \cdot F \cdot D$$

where N is the number of samples during the storm, U is the wind speed, F is the fetch for the wind direction corresponding to U_j , and D is the event duration. The inclusion of fetch and duration in this expression will indirectly give a measure of the expected wave and wind-driven current energy present in each storm. Having used this index to select a sufficient number of the most severe storms, a more detailed analysis can then be carried out, using the above mentioned (modified) erosion (or wave power) index to rank the storms according to severity.

The selection of the most severe wave-generating storms (combined with large currents and high erosion potential) is a very important and perhaps the most crucial step in such a process. Large effort, must therefore be spent in review all relevant data bases (e.g. marine observations, land station data, weather charts, buoy measurements) and previous studies.

In two previous studies, carried out by MPL and OWI for AES (MacLaren Plansearch Limited, 1987 and 1989), wind fields for a total of 24 summer storms in the Beaufort Sea were Hindcast. The selection criteria of these storms and hindcast methods were given by Agnew et al (1989). Two selection criteria were used:

- 1) Fourteen high wind producing storms were selected with highest severity index (which is defined by multiplying the maximum wind speed times storm duration above 30 knots).
- 2) Independently the 10 "high" wave producing storms were selected where wave measurements were available.

In the above selection no consideration was given to storm type, wind direction, ice conditions, or to a certain extent, storm duration.

The above storm selection procedure needs to be reexamined since the existing wind fields span a limited historical period, during which not all storm types have been sufficiently sampled, with the most severe storms possibly missed. At least 20 and possibly 30 years are needed to properly capture a sample of storm population in the entire potentially open water season. One of the approaches to the derivation of extremes assumes that the storm climatology and the ice-cover climatology are independent. Therefore, we are interested not only in storms which occurred in large open water conditions but those storms which might have occurred in maximum ice conditions, but within the calendar period in which open water conditions are possible (i.e. June – October).

If the storm climate and ice-cover climate are independent, the storm population needs to be selected irrespective of the actual ice-cover, but within the potential open-water season. The above hindcast storm set (which is referred to as AES set) is biased toward larger open ice years, since the selection criteria depended mainly upon MEDS buoy measured wave records. An unbiased storm selection should develop a production of several hindcast storms in 20–30 years, stratified into monthly or perhaps biweekly periods between late June and late October, and refined to a target population of say 30 storms. There should be some overlap between this set and the AES set, but probably new wind fields need to be developed for about half of the storms to be hindcast. In addition, in the selection of the top severe events, considerations may be given to their potential extreme current generation, direction and storm duration.

2.3 SEA ICE COVER

Historical ice cover information for the Beaufort Sea is needed in this study in several forms. The approaches to the extremal analysis discussed below (Section 2.6) require not only ice cover actually associated with particular historical storms to be hindcast, but also a climatological description of the ice edge as a function of time in a potentially open season. The following sea-ice data sources were considered:

- 1) Records of composite sea-ice data for the Beaufort Sea which are held by the Ice Branch of AES, Ottawa. The period of data coverage is from 1959 to present in a form of hard copy of daily and weekly composite charts or digitized charts on 55 km grid.

- 2) The Canadian Climate Centre, AES, Downsview has compiled a digital ice data base (1959 – 1986). This data set contains weekly information on ice concentration, extent, age/type, etc. This data base can be accessed through the CRISP System (Climate Research in Ice Statistics Program) at AES. It can provide various summaries and analysis of ice data , e.g. concentration frequencies, ice edge for given concentration, etc., and presents results in either tabulated or graphical form.
- 3) Digitized data set compiled by Walsh and Johnson (1979) where sea ice concentrations are available on a one degree grid. The data are available from the National Centre for Atmospheric Research (NCAR).
- 4) U.S. Navy and NOAA Joint Ice Centre (JIC), Suitland, MD, has archived maps of weekly synoptic analysis of sea ice cover. These maps have been digitized and made available on tape by the NOAA NCDC at a 1/4° latitude–longitude resolution for period 1972–1984.
- 5) Climatological Atlas of Brower et al (1977) which summarized about 20 years of ice data in terms of charts of mean, maximum and minimum sea ice extent and concentration in biweekly periods.
- 6) Marine climatological Atlas–Canadian Beaufort Sea, Agnew et al. (1987). It provides ice cover concentration summary, percent occurrences of any ice maps in a semi–monthly period and mean concentration where ice is present (98%, 90%, 70%, 50%, 30% and 10%).

2.4 STORM HINDCASTING

A spatially and temporally varying wind field is necessary to account for gradients and storm propagation across the Beaufort Sea. The best method of deriving acceptable wind fields is proven to be the application of objective analysis of weather charts in combination with a kinematic wind analysis. The method developed by Cardone et al (1980) and described by MacLaren Plansearch Ltd. (1987 and 1989) is proposed for this study.

A fully discrete spectral model of proven capability in shallow water as well as deep water is required for hindcasts. A spectral model also provides special advantages in the treatment of ice cover, since the effects of an irregular ice–edge as it affects the fetch lengths and widths, are automatically accounted for in such models. For this study, a special version of the ODGP (Ocean Data Gathering Program) spectral ocean wave model is used. The model incorporates a shallow water algorithm and a variable ice edge. The model is an extension of the deep water ODGP algorithm, which has provided skilful deep water hindcasts in a wide range of regimes, including the Beaufort, Chukchi and Bering Seas, and in the North Atlantic and Pacific Oceans (Canadian Climate Centre, 1991; Eid and Cardone, 1987).

2.5 EXTREME VALUE ANALYSIS

Having selected and hindcast a given number of storms (e.g. 30 or more), an extreme value analysis may be carried out on either the wind and wave data, or on computed severity indices.

From the literature review, it seems that the most practical approach is to use a Peak Over Threshold (POT) model as described by Baird et al. (1987). Included in the analysis should be a test of goodness

of fit of the selected distributions to the data. If a Gumbel distribution is found to be appropriate, the fitting method which according to theory should give the least bias is the Maximum Likelihood Estimate (MLE). The Method Of Moments (MOM) fitting method may also be used, as it is easier to implement, and gives reliable results. Different methods were examined in this study and the Gumbel distribution fitted to the Method of Moment is recommended.

2.6 JOINT PROBABILITIES OF ICE AND STORMS

None of the studies which were reviewed addressed the problem of joint occurrence of extreme winds, waves and ice coverage. In order to reliably assess 100 year return period waves, the variability of the ice cover should be included.

The difficulty in estimating extreme wave conditions, e.g. 100 year return values, in the Beaufort Sea is enhanced by the effects of the sea ice cover. The ice conditions affect the wave conditions, and to some extent, vice versa. When estimating extreme conditions are it therefore does not seem correct to assume that the ice and wave conditions are completely independent. Joint probability distributions are therefore not easy to determine, as these methods usually require the assumption that the processes under study are independent. Moreover, a possible larger scale (in time and space) dependence of storm occurrence/genesis on other climate factors, which may also affect ice conditions, has not been determined. It is possible, for example, that higher temperatures in the region (due to global warming) would result in less ice, a higher frequency of storm occurrences, and that storms would generally be more severe. The combination of less ice and more severe storms would likely result in significantly higher waves. This has by no means been established though.

A commonly used method of estimating extreme wave conditions, is to extract a given number of the most severe storms (30–50) from a historical data base of weather conditions, generally covering a 30 year period. This procedure was carried out for the Beaufort Sea, where several hundred storms were identified, and ranked according to severity, in order to determine the most severe cases. As the available wave observations are very limited in this region, extreme wave conditions are estimated on the basis of hindcasts from a numerical model. In order to reduce costs, only the top 30 storms were hindcast. This procedure would, however, not provide a large enough sample to estimate the "true" extreme wave values, when taking reasonable variations in ice cover into consideration.

One method which has been proposed, is to hindcast storms several times, with different ice edges varied according to ice coverage statistics. For example 30 storms hindcast with 4 different ice edges, would then give wave fields for 120 storms, which could be analyzed for extreme values and return periods. However, it is difficult to assess how reliable these results are. The extreme value analysis procedures generally assume that the samples are independent. These storms will clearly not be, as groups of 4 will have the exact same driving forces, i.e. the wind fields.

An alternative approach is to use an empirical orthogonal functions technique as described below.

Two-dimensional fields, such as ice coverage, may be characterized by Empirical Orthogonal Functions (EOF's). A number of studies involving analysis of atmospheric pressure fields have been

carried out in meteorology, using this technique. Similarly, vector processes, such as ocean current, have been analyzed using EOF's.

Decomposing time series into EOF's is essentially a coordinate transformation, resulting in a set of functions with zero covariance. Each of the functions' amplitude time series will contain some fraction of the total variance of the original process. Usually, just a few of the largest functions will account for the major part of the variance (70–90%) of the parent process. Also, in many cases, each EOF can be related to a given underlying physical process. If this were the case for EOF's derived for the ice fields, we could likely relate one EOF to wind-driven ice coverage variability, and maybe a second function to ocean circulation controlled ice variability.

Joint probabilities of each EOF and wave heights could then be calculated, using multivariate normal and log-normal distributions. This method would necessarily be quite involved and requires greater level of efforts which is beyond the scope of this study. This should be addressed in future investigations.

In this study, the first approach is used, i.e. by hindcasting the selected severe storms with different ice edges, which includes actual ice edge, 30%, 50% and 98% occurrence of any ice. Extremal analysis is then applied to each group separately and for the entire population with different climatological ice edges. The results are then analyzed to study the sensitivity of the estimated values to different ice edges. This in turn provides the range of extreme values which may be expected.

3.0 DATA BASE ASSEMBLY

A comprehensive file of historical meteorological and sea state data was assembled for the selection of severe storms in the study area.

The data fall into the following categories:

- 1) archived surface weather charts;
- 2) weather observations from ships in transit;
- 3) weather observations from stationary offshore platforms and land stations; and
- 4) wave data from instruments, visual observations and numerical models.

The following sections describe the various source data bases which were used.

3.1 ATMOSPHERIC ENVIRONMENT SERVICE

The Hydrometeorology and Marine Division (CAAH) of the Canadian Climate Centre (CCC), AES, has collected and compiled a large number of marine data sets. In addition, several software packages are also available to access these data bases and analyze the data (e.g., MAST, LAST, DUST).

The following AES digital data bases were accessed using MAST/LAST systems:

- a) COADS ship observations (1957–1988);
- b) Drilling rigs (1974–1985);
- c) Geostrophic Wind Climatology GWC (1957–1987);
- d) Land stations data (1957–1988);
- e) Digital pressure data (SPASM) (1958–1987); and
- f) Ice data bases.

3.2 MARINE ENVIRONMENTAL DATA SERVICE

The Marine Environmental Data Services Branch (MEDS) of the Department of Fisheries and Oceans has been largely responsible for collection, retrieval, and analysis of data from the majority of wave measurement programs in Canadian waters since 1970. The bulk of MEDS wave data are from non-directional waverider buoys. A typical waverider observing program has a buoy located close to a nearby vessel, drilling platform, or land station where the signal is radioed and recorded on tape. The digital wave data base archived at MEDS can be accessed from remote terminals or data can be obtained on magnetic tapes.

3.3 THE BEAUFORT WEATHER OFFICE

During the 10 year period 1976–1985, the Atmospheric Environment Service operated the Beaufort Weather and Ice Office (BWIO or BWO) on contract to the offshore oil industry operating in the area. The office was operational in the summer seasons, lasting from June to November.

The BWO received weather and other available environmental observations (e.g. wave height, period) on a regular basis from drilling rigs and ships in the area, from ARGOS buoys when available

and from aircraft, in addition to regular weather information through data links to other agencies (mainly AES–Edmonton). The office issued a variety of ice and weather reports. The reports used in this study were the annual reports providing seasonal summaries of time series and statistics for key parameters, lists of storm events, as well as a discussion of some of the major storm events in a given year. This information was used to identify storms for the Master Candidate List (MCL) and rank them according to severity.

3.4 LITERATURE

As described in Section 2 , a number of storms were identified and documented in previous studies. Lists of storms were extracted from the following reports and entered in the storm Master Candidate List (MCL):

- Murray & Maes (1986): Beaufort Sea Extreme Wave Studies Assessment –ESRF Study #023;
- Seaconsult (1986): An Extreme Value Analysis of Storm Wave Power at Minuk;
- Seaconsult (1989): Amauligak Development Studies 1988/89 – Design Storm Characteristics; Amauligak Region, Beaufort Sea;
- Baird & Associates (1986): Estimation of the Wave Climate at Minuk I–53 1960–1985;
- Buckley and Budgell (1988): Meteorologically Induced Currents in the Beaufort Sea;
- MacLaren Plansearch previous hindcast studies for AES (1988, 1989); and
- Manak, D.K. (1988) Climatic Study of Arctic Sea Ice Extent and Anomalies. CRG Rep. # 88–10.
- AES, Canadian Climate Centre report #87–2 (1987). Severe storms over the Canadian Western High Arctic, 1957–1983.

The Murray and Maes report provided an extensive review of two reports:

- Hydrotechnology (1980): Wave Hindcast Study, Beaufort Sea. Report for Gulf Canada; and
- Seaconsult (1981) A hindcast study of extreme water levels in the Beaufort Sea. Report for Esso Resources Canada Ltd.

Several other reports and publications were studied for further documentation of the storm of September 15–18, 1985.

3.5 ICE DATA

The Canadian Climate Centre of AES, Downsview, Ontario, has compiled digital ice data bases for the Canadian Arctic for the period 1959–86. This data set contains weekly information on ice concentration and ice age/type on irregularly spaced grid points. This data base can be accessed through the CRISP (Climate Research in Ice Statistics Program) system at AES. CRISP can provide various summaries and analyses of ice data, such as ice concentration statistics, frequencies of each ice concentration by date, ice concentration for each year by date, different areas, etc. The results can be displayed in a form of contour maps using the CONAN and DUST packages.

Weekly Canadian ice charts for the study are from 1975 to 1989, June to October are also available to the project from Ice Central, Ottawa.

3.6 MICROFILM ARCHIVED WEATHER CHARTS

The National Climatic Data Centre (USA) archives a vast amount of world-wide weather data, records, and charts. The microfilm charts used in this study were the Northern Hemisphere Surface Charts covering the period May 1954 to October 1989.

These 6-hourly charts (00z, 06z, 12z, and 18z) are plotted and analyzed by The National Meteorological Centre (USA). The Final Analysis Charts are derived from all available land stations, buoys, ship reports, and rigs.

3.7 BWO ARCHIVED SURFACE ANALYSIS CHARTS

The Beaufort Weather Office archived surface analysis weather charts were used in the previous wind hindcast studies carried out by MPL/OWI for AES. The relevant charts for selected storms were obtained from BWO for use in the present study.

4.0 STORM CLASSIFICATION AND STORM SELECTION

4.1 INTRODUCTION

The single most important property of candidate storms in this study is the potential for generation of severe sea states somewhere within the study area. The process of identifying candidate storms is greatly complicated by the large size of the study area involved, unlike previous extreme wave climate studies, which generally considered specific sites. This is greatly complicated by the existence of the sea ice. Therefore, it was necessary to explore in this study many different possible indicators of storm occurrences and their severity.

Previous experience has shown that the most effective screening parameter is simply the maximum integrated wind speed (integration time 12 to 24 hours) in the fetch zone of wave generation directed toward the target site or area. Unfortunately, this parameter is not usually directly available as a screening parameter in archived meteorological data, except where continuous measured series are available from Ocean Station Vessels, e.g. in the North Atlantic. Therefore indirect estimates of storm wave generation potential derived from ship, coastal, or island wind observations, and surface pressure patterns must be used. Ultimately, some subjective assessments by meteorologists with specific experience in correlation of meteorological storm properties with wave generation must also be used in the ranking process, especially in the selection of the final most severe storms.

In a previous study, carried out for the Canadian East Coast, Canadian Climate Centre (1991) indirect estimates of storm wave generation potential were used to identify potentially severe storms. These included maximum sea-level pressure gradients, storm central pressure, and deepening rate. Szabo et al. (1989) were able to demonstrate objectively that the indirect procedures using parameters gleaned from operational Northern Hemisphere 6-hourly surface analysis correctly selected all storms which exceeded the effective wave height threshold of the extremal analysis at a given target point. That study also showed that the spatial structure of storms was very important in the selection of extreme events for an area as opposed to a point location.

In the present study, sea-level pressure gradients and storm duration were found to be the two most important parameters. This was mainly due to the fact that severe conditions were not always linked to specific storm centres, which meant that storm centre pressures and deepening rates could not be quantified.

Storm frequency is relatively high for the study area. A target of 50 storms was set for a final list. During the process of storm list compilation, several hundred storms were identified. The task of reducing the list was carried out in several steps.

First, all assembled data sources and previous studies were utilized to develop a comprehensive list of candidate storms in the study area. This list was then reduced in several stages to a refined storm list, with the aid of both objective storm intensity ranking parameters and subjective ranking and intensity assessments.

In summary, the storm selection is accomplished in three main steps:

- 1) selection of candidate population of severe storms;
- 2) storm verification and cross-checking between data sources; and
- 3) storm ranking and final selection.

4.2 IDENTIFICATION OF POTENTIAL SEVERE STORMS

In addition to the storms compiled during the literature survey, the development of the initial coarse list of potentially severe wave-producing storms consisted of examining the data bases listed in Table 4.1 . For each storm identified, the starting and ending dates/times, available maximum values of wind speed and wave height, maximum significant wave height, and duration of wind speed and wave heights above given thresholds, were extracted from the data records.

Data and storms were, for selection purposes, restricted to the ice free season – June 15th to November 15th. Following a major cross-referencing and consolidation task, an initial coarse list of storms was established, consisting of 1,058 storms or storm events. Through further cross-checking between data sources, data quality, combination of events, review of synoptic conditions, etc., this list was reduced to 511 events to provide the Master Candidate List (MCL) as shown in Appendix A (Table A.1). The MCL shows storm duration, peak wind and wave parameters and data sources utilized.

Table 4.1
Initial Storm Selection Criteria

| <u>Data Source</u> | <u>Coverage</u> | <u>Threshold</u> | <u>Number of Events</u> |
|--------------------|-----------------|------------------------|-------------------------|
| LAST Wind | 1957–1988 | Wind \geq 25 kts | 647 |
| COADS Waves | 1957–1988 | Waves \geq 1.5 m | 245 |
| COADS Wind | 1957–1988 | Wind \geq 25 kts | 346 |
| RIG Waves | 1976–1985 | Waves \geq 1.5 m | 152 |
| RIG Wind | 1974–1985 | Wind \geq 25 kts | 245 |
| SPASM | 1958–1987 | Pressure \leq 970 mb | 73 |
| MEDS | 1975–1987 | Waves \geq 1.5 m | 92 |
| GWC | 1957–1987 | Wind \geq 40 kts | 143 |
| Literature | – | As given in literature | 220 |

4.3 REDUCTION OF THE MASTER CANDIDATE LIST

From the MCL (Master Candidate List), a subjective analysis using microfilm scan and examination of wind/wave peak values was made to eliminate some of the weaker storms and isolated events. In general, storms with a significant wave height less than 2.0 m were eliminated. As well, if there was only one wind or wave observation and a wind speed less than 30 knots, the storm was not included in the MCL. This cut-down also took into account wind and wave scenarios that would be producing strong currents; that is, significant durations (24 hours or greater) of wind with an easterly or westerly component. Storms that contained high wind or wave values but short durations remained on the list,

especially if they were quoted by numerous data sources. The latter were evaluated for storm duration, observed wind speed and wave height. Measured or observed values were also "weighted" higher than derived computations. Numerous events were also "lumped" together into single storm events. A "Semi-Final" storm list was then made up of 160 storms as shown in Appendix A , Table A.2 . This selection process identified possible severe storms where wave generation may have been restricted due to ice conditions.

4.4 THRESHOLD ANALYSIS RANKING (TAR)

In recent hindcast studies carried out by Oceanweather, increased emphasis has been given to a method of objective ranking of historical storms based upon readily available properties of the surface pressure pattern of extratropical storms. In a study by Szabo et al.(1989), it was shown that there is a high correlation between certain storm properties and maximum H_S in a storm at a site, (see also Canadian Climate Centre, 1991).

These properties were:

- 1) minimum central pressure;
- 2) deepening rate;
- 3) maximum pressure gradient in the fetch zone of wave generation oriented such that waves generated therein affect the site of interest;
- 4) duration of maximum pressure gradient and a storm intensity parameter or a severity index made up of the product of the strength of the gradient and its duration; and
- 5) total pressure drop across the storm.

Given sufficient measured wave height data in storms, the correlations between measured wave height and the above parameters may be used to calibrate a ranking system in terms of parameter thresholds. This is simply done by defining for each parameter a threshold value for which H_S exceeds a specified value in all observed or hindcast storms. The established thresholds then provide a basis for a scoring system which can be used for identifying and ranking storms. For example, if the properties of a candidate storm are such that the given thresholds for all the above 5 listed parameters are exceeded, then the storm is assigned a threshold analysis ranking (TAR) score of 5, on a scale of 0 to 5.

For the Beaufort, the above typical TAR scores could not be used in the same manner as for storms in the mid-latitudes. Minimum central pressure usually had no bearing on the gradient in the study area. At times, there were no individual central low pressure over the study area in storms analyzed. Strong gradients could be generated by a trough of low pressure over Alaska and high pressure north of the Beaufort. In other instances, with the study region being relatively small, gradients from storms as far away as the Gulf of Alaska which cover a vast area would spread their effects into the Beaufort Sea. Since there were no storm centres to pin-point, maximum deepening rate had no meaning. The storm gradient (difference in mb of the high pressure centre and low pressure centre affecting the study area) was not always uniform. A packing of isobars along the coastline existed independent of the storm gradient and also independent of any individual low or high pressure extremes. A storm "pattern"

rather than the above individual parameters then became the deciding factor for extreme wave height and current generation. These patterns were comparable to those described by the Beaufort Weather Office. Patterns 1, 3 and 5 (see Figure 4.1) likely to produce the highest waves and strongest current with a westerly wind. Patterns 2 and 7 most likely to generate the highest wave and current with an easterly wind.

With these storm patterns in mind, a final storm list made up of 50 storms was selected out of the 160 semi-final storms with the following general thresholds:

| <u>Westerly Winds:</u> | <u>Pressure Gradient/2° Lat</u> | with <u>Duration of</u> |
|------------------------|---------------------------------|-------------------------|
| | 8 mb | ≥ 48 hrs |
| | 9 | 36 |
| | 10 | 24 |
| | 11 | 21 |
| | ≥ 12 | 18 |

| <u>Easterly Winds:</u> | <u>Pressure Gradient/2° Lat</u> | with <u>Duration of</u> |
|------------------------|---------------------------------|-------------------------|
| | 8 mb | ≥ 60 hrs |
| | 9 | 54 |
| | 10 | 48 |
| | 11 | 42 |
| | ≥ 12 | 36 |

The storms selected met these thresholds. When there were any storms that could not follow these guidelines, as in one storm with a strong north wind and high wave height, actual measured parameters from either MEDS or BWO reports were used in the selection or elimination process.

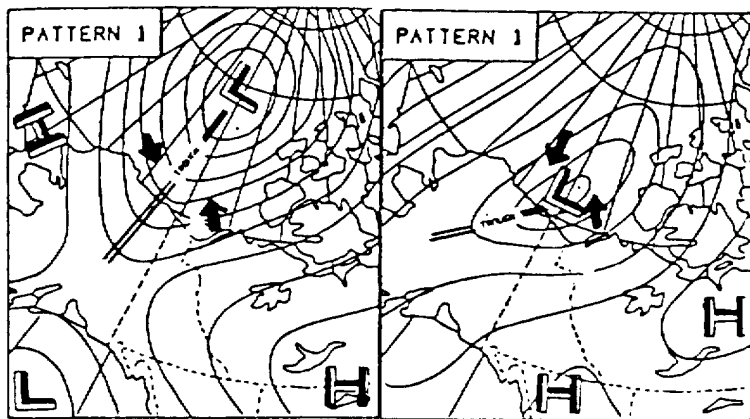
The final top 50 severe storms are listed in Table 4.2 .

For further reduction of storms to the target population of about 30 events, additional careful analysis is required. This analysis may include among other things, the currents, erosion index, severity index, and sea ice conditions. In order to obtain sufficient population to present storm directionality, 30 storms may not be sufficient. In this case it is recommended to hindcast the entire 50 storms.

The final selection will also depend on the results of the model verification (Section 6.0) and review model response to different types of storms.

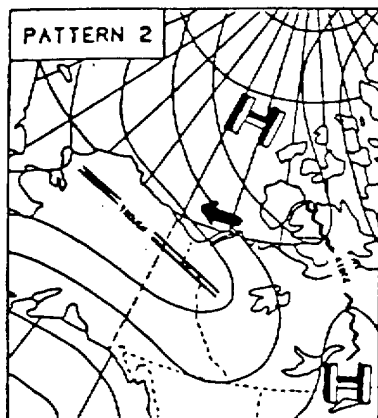
Again it must be mentioned here that the main objective of this study was to select the storm population which produce the highest waves to define the "design" wave parameters. Separately, we need to identify some number of current/erosion storms, which may or may not have large waves. This should be a subject of future investigations. No doubt the selected storm population in the semi-final list of 160 storms would have captured those potential severe erosion storms.

Seventeen storms out of the above 50 were previously hindcast in MPL (1987) and (1989). Some of these storms required additional hindcast efforts to extend the storm duration to allow sufficient model spin-up, covering storm peak and allow the wave field to decay.



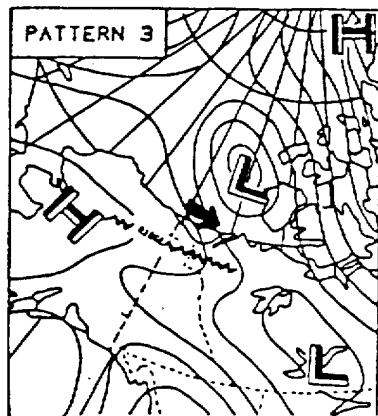
Pattern 1

Low or trough moves eastward across the Beaufort with or without a front(s) associated.



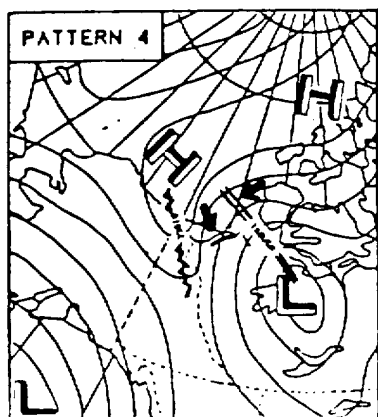
Pattern 2

Trough NW to ESE across central or northern Alaska extending across the Yukon into the Mackenzie valley. Ridge NW to SE across the eastern Beaufort, Amundsen Gulf or Banks Island. Often evolves into a pattern 3 or 4.



Pattern 3

Starts off as a pattern 2 or 7 (trough over Alaska). Trough moves offshore into the southern Beaufort. One or more low centres may develop in the trough. Trough and low(s) move northeastward as a ridge develops over Alaska.

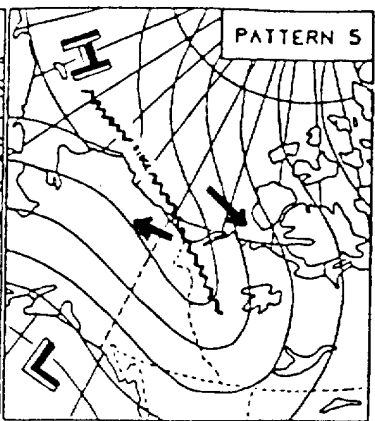
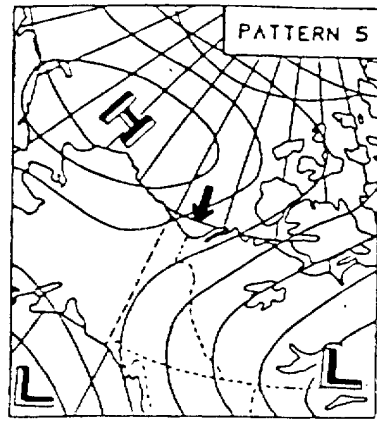


Pattern 4

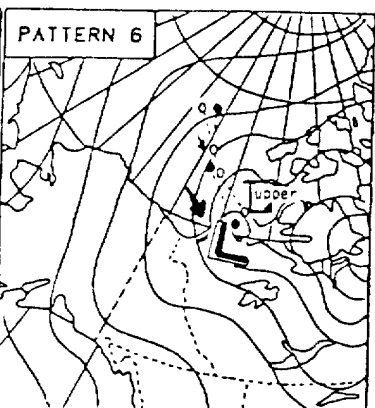
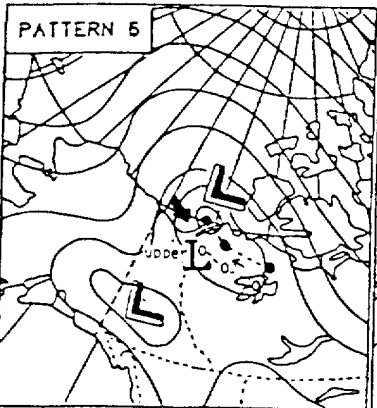
Initially a deepening low over the Mackenzie Valley or the Great Arctic lakes. As the low develops and moves off, a trough extends into the Beaufort. A ridge develops across the north Alaska and north Yukon coasts and builds into the Mackenzie Valley.

Beaufort storm patterns.

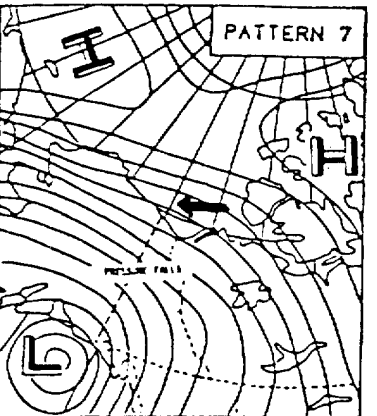
Figure 4.1 Beaufort Weather Office Weather Patterns



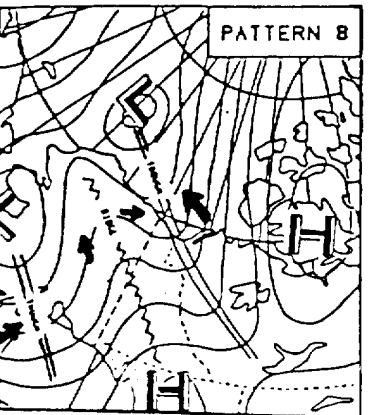
Pattern 5
Area of high pressure over the Beaufort or northern Mackenzie Valley.



Pattern 6
Surface lows moving with upper cold lows.



Pattern 7
A major Pacific storm moves toward southern Alaska. Overrunning warm air causes pressures to fall over Alaska and the Yukon. A strong cyclonic gradient eventually covers Alaska, Yukon, Mackenzie Valley and the southern Beaufort. Often evolves into a pattern 3.



Pattern 8
Pacific disturbances migrate into the Bering Sea or Chukchi Sea. Associated troughs and ridges move northeastward across Alaska. Concurrently, a high pressure area usually lies over the western or central Arctic islands.

Figure 4.1 (cont'd)

Table 4.2 List of Top 50 Storms

FINAL-"50" Storm list for the Beaufort Sea

SOURCES:

A Severe storms over the Canadian Western High Arctic 1957-1983 Report #87-2
 B Beaufort Weather Office Annual Summaries (1976-1985)
 C Arctic Petroleum Operator's Association, 1983: Beaufort Sea Hindcast Study 1970-1982. APOA Study 203
 D Seaconsult, 1986: An extreme value analysis of Storm Wave Power at Minuk.
 E Baird & Associates, 1987: Estimation of the Wave Climate of Minuk I-53 1960-1985
 F Buckley and Budgell, 1988: Meteorologically Induced Currents in the Beaufort Sea
 G Sea Consult, 1989: Design Storm Characteristic, Amuligak Region, Beaufort Sea
 H Maclaren Plansearch Database
 I Seaconsult 1987: Wind and wave Hindcast for the storm of September 15 to 19, 1985
 J Seaconsult 1986: Analysis of the ADGO Wave Measurements for the storm of September 15 to 18, 1985
 K Baird & Associates, 1987: Estimation of the Wave Climate at Minuk I-53 during the storm of September 15 to 19, 1985
 L COADS.wave waves >= 1.5 m
 M COADS.wind winds >= 25 kts
 N LAST.wind winds >= 25 kts
 P RIG.wave waves >= 1.5 m
 R RIG.wind winds >= 25 kts
 S SPASM central pressure <= 970 mb
 T MPL HINDCAST
 V MEDS

| | START | END | Dur | Obs | Wind | Combined Sea | | | SEVERETY | Min Cent | Waverider | Sources |
|-------|-------------------|----------|------|-------|---------|--------------|---------|-------|----------|----------|-------------------------|---------|
| | YYMMDDHH | YYMMDDHH | (hr) | (kts) | Spd Dir | Hs Tp Dir | (m) (s) | INDEX | Pressure | Hs Tp | | |
| | | | | | | | | | (mb) | (m) (s) | | |
| * 86. | 62072115-62072506 | | 88 | 21 | 50. 290 | 4.0 5.0 080 | | 4400 | | | L,M | |
| 95. | 62090311-62090715 | | 100 | 34 | 56. 310 | 9.5 16.0 310 | | 5600 | | | L,M | |
| 97. | 62090903-62091106 | | 51 | 14 | 48. 250 | 8.0 6.0 230 | | 2448 | | | L,M | |
| 196. | 70090218-70090716 | | 118 | 37 | 45. 110 | 4.5 12.0 330 | | 5310 | | 3.6 8 | C,L,M,N,V | |
| 198. | 70091218-70091512 | | 47 | 28 | 63. 240 | 5.6 7.0 284 | | 2961 | 968. | 2.5 6 | A,C,L,N,N,T,V | |
| *213. | 71082112-71082412 | | 72 | 5 | 26. 360 | 2.9 7.1 | | 1872 | | 2.9 7 | C,N,V | |
| 270. | 75080815-75081118 | | 75 | 29 | 40. 280 | 4.7 10.0 310 | | 3000 | | 2.4 6 | L,M,V | |
| 274. | 75082606-75082814 | | 56 | 29 | 45. 230 | 5.0 0.0 270 | | 2520 | | 2.2 6 | D,L,M,N,V | |
| 282. | 76081121-76081423 | | 72 | 61 | 35. 050 | 4.3 6.2 | | 2520 | | 2.8 6 | B,C,D,L,M,N,P,R,V | |
| 293. | 76092814-76100208 | | 90 | 166 | 32. 070 | 4.0 6.0 070 | | 2880 | | 1.9 7 | L,M,P,R,V | |
| 302. | 77082512-77090118 | | 102 | 59 | 41. 320 | 3.4 6.9 290 | | 4182 | | 3.2 8 | B,C,D,E,F,L,M,N,P,R,T,V | |
| 310. | 77092100-77092214 | | 38 | 60 | 42. 270 | 3.0 6.0 290 | | 1596 | | 2.9 7 | D,N,P,R,V | |
| 313. | 77100515-77101300 | | 166 | 179 | 45. 130 | 3.5 5.0 120 | | 7470 | | 2.2 8 | B,D,F,N,P,R,T,V | |
| 320. | 78082218-78082618 | | 104 | 54 | 40. 300 | 3.1 6.7 | | 4160 | | | C,E,N,R | |
| 321. | 78090100-78090900 | | 240 | 211 | 40. 090 | 2.7 6.0 037 | | 9600 | | 2.7 8 | B,C,D,F,L,M,N,P,R,T,V | |
| 322. | 78090906-78091412 | | 126 | 54 | 38. 030 | 6.3 8.0 062 | | 4788 | 969.0 | 1.9 7 | L,M,R,S,V | |
| 325. | 78091900-78092206 | | 91 | 99 | 40. 070 | 7.5 12.0 098 | | 3640 | | 3.6 10 | B,C,D,L,M,N,R,V | |
| 326. | 78092800-78100303 | | 99 | 98 | 45. 280 | 3.5 5.0 | | 4455 | | 2.4 9 | M,N,R,T,V | |
| 327. | 78100600-78101004 | | 100 | 162 | 50 050 | 3.5 7.0 | | 5000 | | | B,F,M,N,R,T | |
| 333. | 79091110-79091923 | | 205 | 448 | 36. 070 | 4.0 6.0 090 | | 7830 | | 2.5 8 | D,L,M,N,P,R,V | |

Table 4.2 (cont'd)

| START YYMMDDHH | END YYMMDDHH | Dur (hr) | Obs (kts) | Wind Spd Dir | Combined Hs Tp | Sea Dir | SEVERETY INDEX | Min Cent Pressure (mb) | Waverider Hs Tp (m) (s) | Sources |
|-------------------------|-----------------|-------------|--------------|-----------------|-------------------|------------|-------------------|------------------------------|-------------------------------|---------------------------|
| 334a.79092900-79100806 | | 246 | 339 | 42. 080 | 3.5 6.0 | | 10332 | 965.2 | 2.4 7 | B,C,D,E,F,L,M,N,P,R,S,T,V |
| 335. 79100800-79101720 | | 236 | 441 | 40. 110 | 4.5 6.0 | 080 | 9440 | | 2.0 6 | B,D,L,M,N,P,R,V |
| 337. 79102112-79102606 | | 114 | 122 | 45. 060 | 0.5 5.0 | 070 | 5130 | 953.9 | | M,N,R,S,T |
| 350. 80082800-80090412 | | 120 | 12 | 22. 280 | 3.3 8.0 | 240 | 2640 | | 3.3 8 | G,P,T,V |
| 351. 80082900-80090503 | | 171 | 117 | 40. 130 | 3.7 6.0 | 100 | 3960 | | 1.9 6 | B,N,P,R |
| 366. 81080100-81081021 | | 70 | 201 | 40 310 | 4.0 5.0 | 310 | 2800 | | 2.7 7 | B,D,E,F,L,M,N,P,R,T,V |
| 369. 81081500-81081812 | | 60 | 125 | 45. 290 | 6.0 5.0 | 290 | 2700 | | 3.4 8 | B,D,E,F,L,M,N,P,R,T,V |
| 370. 81081900-81082700 | | 167 | 212 | 35. 310 | 3.5 6.0 | 080 | 5845 | 967.3 | 2.3 7 | C,D,E,L,M,N,P,R,S,V |
| 371. 81082818-81090212 | | 124 | 299 | 45. 240 | 4.0 8.0 | 270 | 5580 | | 2.4 7 | B,C,D,F,L,M,N,P,R,T,V |
| 376. 81092700-81092912 | | 275 | 710 | 36. 040 | 5.0 8.0 | 020 | 9900 | | 2.8 8 | B,C,D,E,F,M,N,P,R,T,V |
| 378. 82071901-82072218 | | 88 | 67 | 35. 350 | 3.0 6.3 | | 3080 | | 2.5 6 | B,C,E,N,R |
| 380. 82072614-82072912 | | 70 | 111 | 50. 315 | 5.0 6.4 | | 3500 | 1008 | 3.4 8 | A,B,N,P,R,T,V |
| 386. 82081912-82082318 | | 93 | 121 | 38. 280 | 3.5 6.0 | | 3534 | | 2.8 | B,D,E,M,N,P,R,V |
| 391. 82091600-82091806 | | 52 | 53 | 41. 230 | 3.0 5.0 | | 2132 | | 2.4 7 | B,D,N,P,R,V |
| 392. 82091900-82092321 | | 117 | 268 | 41. 110 | 4.0 6.0 | 110 | 4797 | | 3.3 8 | B,D,F,L,M,N,P,R,T,V |
| 395. 82100200-82100600 | | 192 | 151 | 34. 290 | 3.0 3.0 | | 6528 | 965.3 | | B,E,N,P,R,S |
| 397. 82101717-82102312 | | 253 | 147 | 54. 270 | 4.0 5.0 | | 13662 | 967.3 | | B,F,N,P,R,S,T |
| 415. 83082917-83091200 | | 295 | 179 | 45. 280 | 5.4 6.0 | 262 | 13275 | | | B,D,L,M,N,P |
| 436. 84071709-84072200 | | 72 | 55 | 35. 250 | 2.0 5.0 | | 2520 | | 2.0 5 | B,N,P,R |
| 444. 84081006-84081418 | | 99 | 88 | 36. 180 | 2.5 6.0 | 270 | 3564 | | 2.2 6 | D,H,N,P,R,V |
| 446. 84082400-84082912 | | 96 | 122 | 38. 360 | 2.5 5.0 | 280 | 3648 | | 2.5 5 | E,B,N,P,R |
| 454. 84091800-84092412 | | 110 | 143 | 38. 090 | 2.5 5.0 | 100 | 4180 | | 2.5 5 | B,L,M,N,P,R |
| 456. 84092803-84100120 | | 89 | 131 | 34. 110 | 4.0 5.0 | 350 | 3026 | | 2.5 5 | B,N,P,R |
| 466. 85080506-85080917 | | 77 | 66 | 32. 130 | 2.0 5.0 | | 2464 | | 2.0 5 | B,R |
| 473. 85090103-85090318 | | 63 | 40 | 34. 110 | 3.5 5.0 | | 2520 | | 3.5 5 | B,L,P,R |
| 475. 85091221-85091906 | | 153 | 312 | 50. 280 | 6.0 6.0 | 280 | 7650 | | | B,E,F,I,J,K,L,M,N,P,R,T |
| 483. 86082118-86082512 | | 90 | 26 | 36. 320 | 5.1 9.0 | 331 | 3240 | | 3.2 5 | H,M,N |
| 487. 86090706-86091712 | | 246 | 32 | 32. 120 | 4.0 8.0 | 110 | 7872 | | 3.0 9 | H,L,M,N |
| *492. 87082400-87090106 | | 102 | 68 | 46. 270 | 6.5 6.0 | 260 | 4692 | | 3.5 9 | L,M,N,V |
| 507. 88080103-88080500 | | 93 | 61 | 38. 310 | 4.3 8.0 | 288 | 3534 | | 2.7 | L,M,N |

* COMBINES TWO EVENTS FROM THE MASTER CANDIDATE LIST (TOP160 STORMS)

4.5 ROLE OF THE ICE EDGE IN STORM EVENTS

A simple comparison was conducted to determine if a relationship exists between storms and ice edges. The actual storm ice edge was compared to the median ice edge to determine if it was offshore or inshore of the median edge position. Canadian ice charts prepared by Ice Forecasting Central, Atmospheric Environment Service, were used to determine the storm ice edge position. Ice charts were available for 45 of the 50 storms listed in Table 4.2 . The median ice edge location was obtained from Markham's ice atlas (1980 and 1984) which summarizes ice charts from 1959 – 1980. Webster's ice atlas (1982) was used to double check and verify Markham's maps. The ice edges were surveyed along the whole length of the study area, from 130° to 160°. The ice edge was defined as 5/10 concentration as this concentration was presented by both Markham (1981) and Webster (1982).

The results of the comparison confirmed that a correlation exists between ice edge location and storm events. In general, the ice edge location during storms was offshore of the median position as shown in Table 4.3 . 58% of the storm ice edges were offshore, 20% were not significantly different from the median position, and only 22% were classified as inshore of the median ice edge position. One potential explanation is that if wave heights were used as an initial criterion to select storms, then offshore ice edges will provide greater fetch than an inshore ice edge. A possible conclusion from the comparison is that an extreme storm would occur with an extreme offshore ice edge.

Several methods could be used to bring the ice edge location into the analysis of extreme storms. First, the actual ice edge during the storm could be used. For this purpose, the weekly ice charts from Ice Central Branch, AES can be used for 45 of the top 50 storms selected. The ice edge for the other 5 storms (earlier dates) can be obtained from other sources.

Table 4.3 Position of Ice Edges for the Top 50 Storms

| Storm Number | Position | Storm Number | Position |
|--------------|----------|--------------|----------|
| 213 | M | 371 | O |
| 270 | M | 376 | O |
| 274 | I | 378 | O |
| 282 | M | 380 | O |
| 293 | O | 386 | O |
| 302 | O | 391 | O |
| 310 | O | 392 | O |
| 313 | O | 395 | O |
| 320 | I | 397 | M |
| 321 | O | 415 | I |
| 322 | O | 436 | I |
| 323 | O | 444 | M |
| 326 | O | 446 | I |
| 327 | O | 454 | M |
| 333 | O | 456 | M |
| 334 | O | 466 | I |
| 335 | O | 473 | I |
| 337 | M | 475 | M |
| 350 | I | 483 | O |
| 351 | I | 487 | M |
| 366 | O | 492 | O |
| 369 | O | 507 | O |
| 370 | O | | |

O Offshore The Median Ice Edge
 M Median Ice Edge
 I Inshore The Median Ice Edge

A second alternative would be to construct a set of storm ice edges to use as part of the probabilistic approach. Since the storm ice edges tend to be further offshore than the set of all ice edges, a set of storm ice edges would possess different characteristics. Ice edges for the top 160 storms could be used to provide a large enough set. Ice edges could then be selected at random and matched to various storms. It is felt that the ice edges should not be amalgamated and used to produce contours of percentage occurrence. This process smooths the gross irregularities of the ice edges.

What ice concentration should define the ice edge for storm purposes? The 7/10 concentration is defined as close pack ice composed of floes which are mostly in contact with each other. The 5/10 concentration falls in the category of open pack ice where the floes are just beginning to come in contact with each other, but generally are not in contact. Studies of the marginal ice zone and its effect on wave damping have found that 5/10 ice concentration will damp out all wave periods less than 10 seconds (Squire, 1983). This is for waves generated in open water moving into the pack ice. The 5/10 ice concentration is probably the best definition of the ice edge for the purposes of wave generation. At this concentration the ice cover is sufficient to prevent wave generation and to damp out short period waves. Nevertheless, this subject requires further research work to establish, not only the representative ice edge for modelling purposes, but also the wave generation inside the marginal ice

zone (MIZ) and Wave propagation into the MIZ. This has recently been one of the objectives of the LIMEX (Labrador Ice Margin Experiments) projects.

4.6 STORM POPULATION CHARACTERISTICS

In an attempt to analyze the characteristics of the selected top severe storms (e.g. climatology, storm types, direction characteristics, and trends). The top 160 storms and the final top 50 events were distributed by year of occurrence (Figure 4.2 and 4.3) in order to examine the bias in selection, if any, trends, and any correlations with climate variabilities and anomalies. As shown in Figures 4.2. and 4.3 most of the storms were selected from the period 1970 to 1988 (e.g. 140 out of 160 were found in period 1970 to 1988 and 47 storms out of 50 are from the period 1970 to 1988). Earlier storms are not represented in proportion to their frequency of occurrence and therefore may not be included in the final selection for hindcast. The extremal analysis therefore may be based upon 20 years rather than 30 years as initially suggested.

As shown, the storm selection is bias towards more recent years. This is mainly due to the marine data coverage and data quality. The earlier storms are not detectable due to the poor meteorological charts, sparse observations, and poor quality data for early years.

BEAUFORT SEA STORMS
Histogram of Top 160 Storms

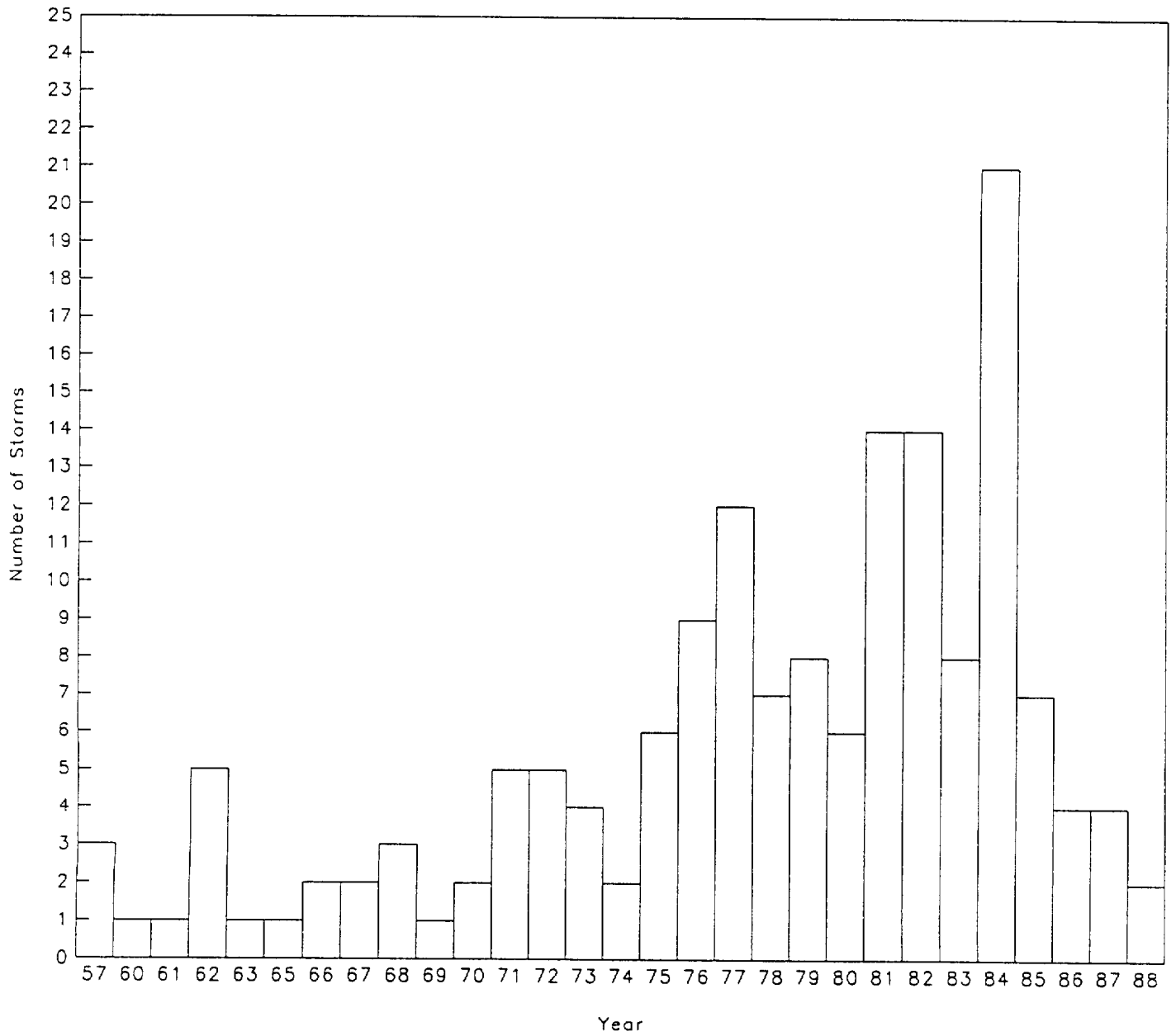


FIGURE 4.2

BEAUFORT SEA STORMS
Histogram of Top 50 Storms

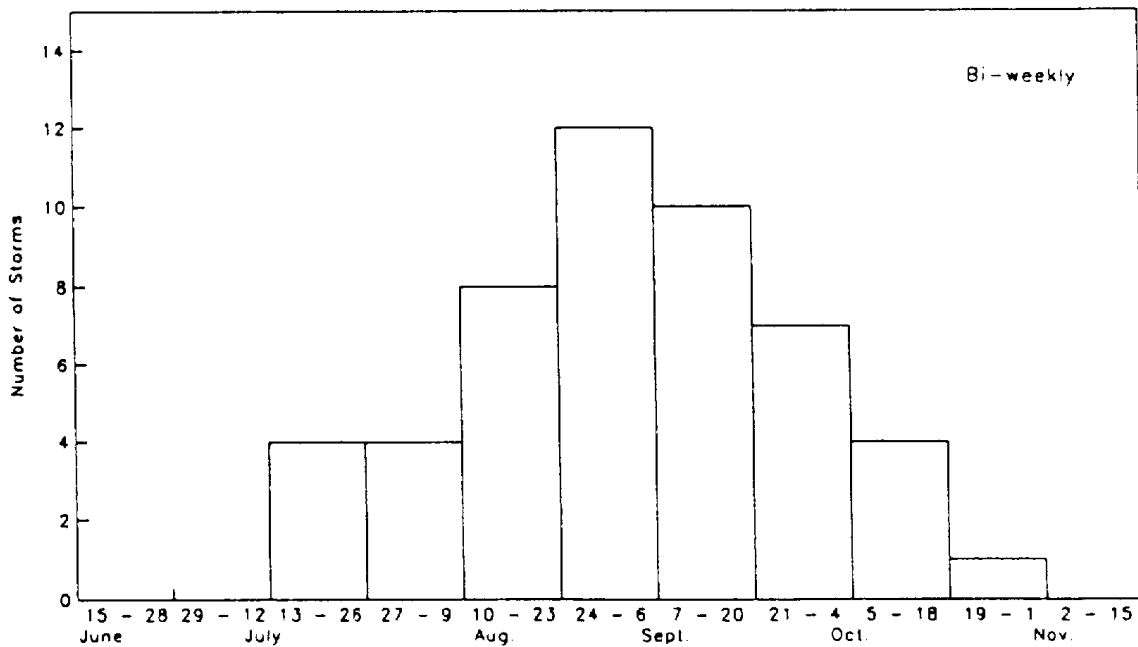
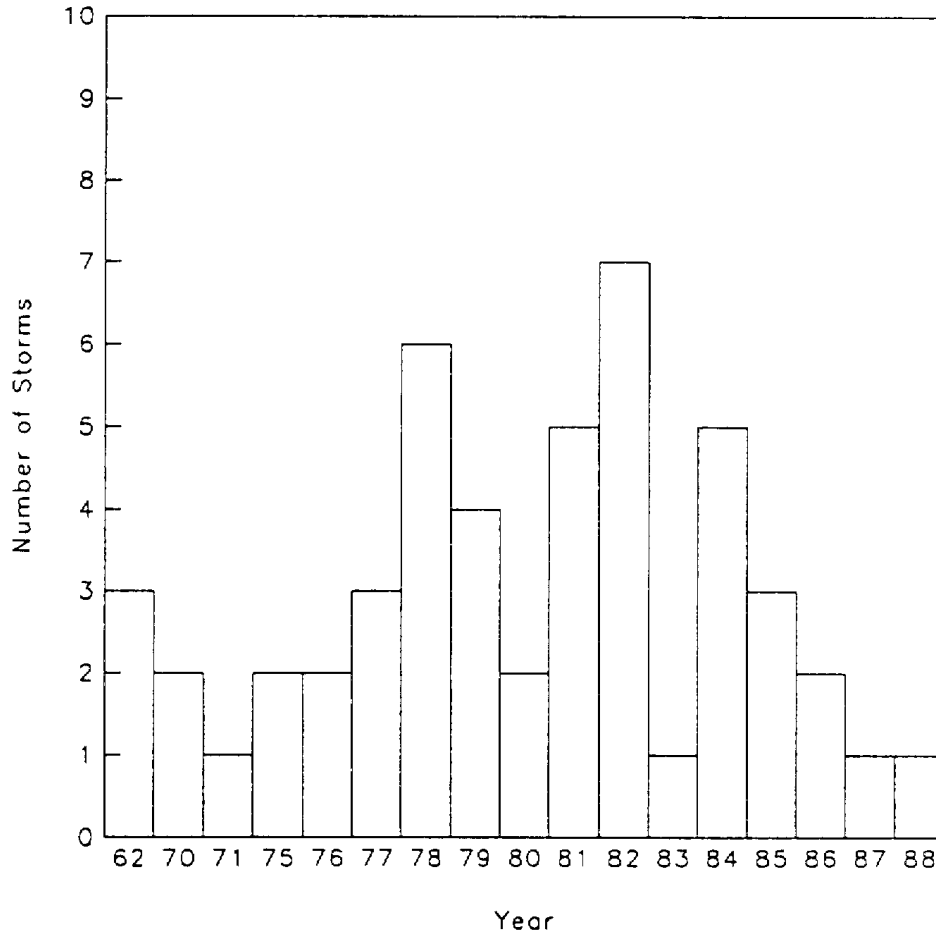


FIGURE 4.3

The variability in the distribution of storm population may be related to climate variability and sea ice anomalies. Manak (1988) studied the Arctic sea ice extent and anomalies for the period 1953 – 1984 and its correlation with climate variabilities. It was found that there is a 4 – 6 year cycle which he related to El-Nino, Southern Oscillation (ENSO) phenomenon or to natural interannual variability in Northern Pacific sea level pressure which may or may not be related to ENSO. A close look at Figures 4.2 and 4.3 shows a cycle of high number of storms in years with periodicity of about 4 – 6 years which may correspond to the above finding of Manak (1988), i.e. the variation in the ice edge. These speculations should be studied further in future work.

Of the storms to be hindcast from Table 4.2, wind fields are available (from previous AES study) only for 17 storms (smaller numbers of this may reach the final target population). The expansion of this population to say 30 storms should consider the directional distribution of storm types. As shown in Figure 4.4, the top 50 storms are distributed evenly over the three main directional sectors (i.e. W, N, and E) where as the 17 AES hindcast storms are more or less evenly divided between the westerly and easterly sectors. In the selection of the final storms, it is recommended that at least 10 storms are to be chosen from each directional sector (which also represent three different storm types).

Finally, a correlation between the storm severity index (SI) and the corresponding "observed peak significant wave height (H_s) is presented in Figure 4.5 (for the 160 and 50 top storm lists). As shown, a weak correlation between SI and H_s was found. The severity index would be a good indicator for current strength and erosion potential (as it includes both prime parameters, wind strength and storm duration). This weak correlation between SI and H_s indicates that the storms with large wave generation potential may not be a severe "erosion storms".

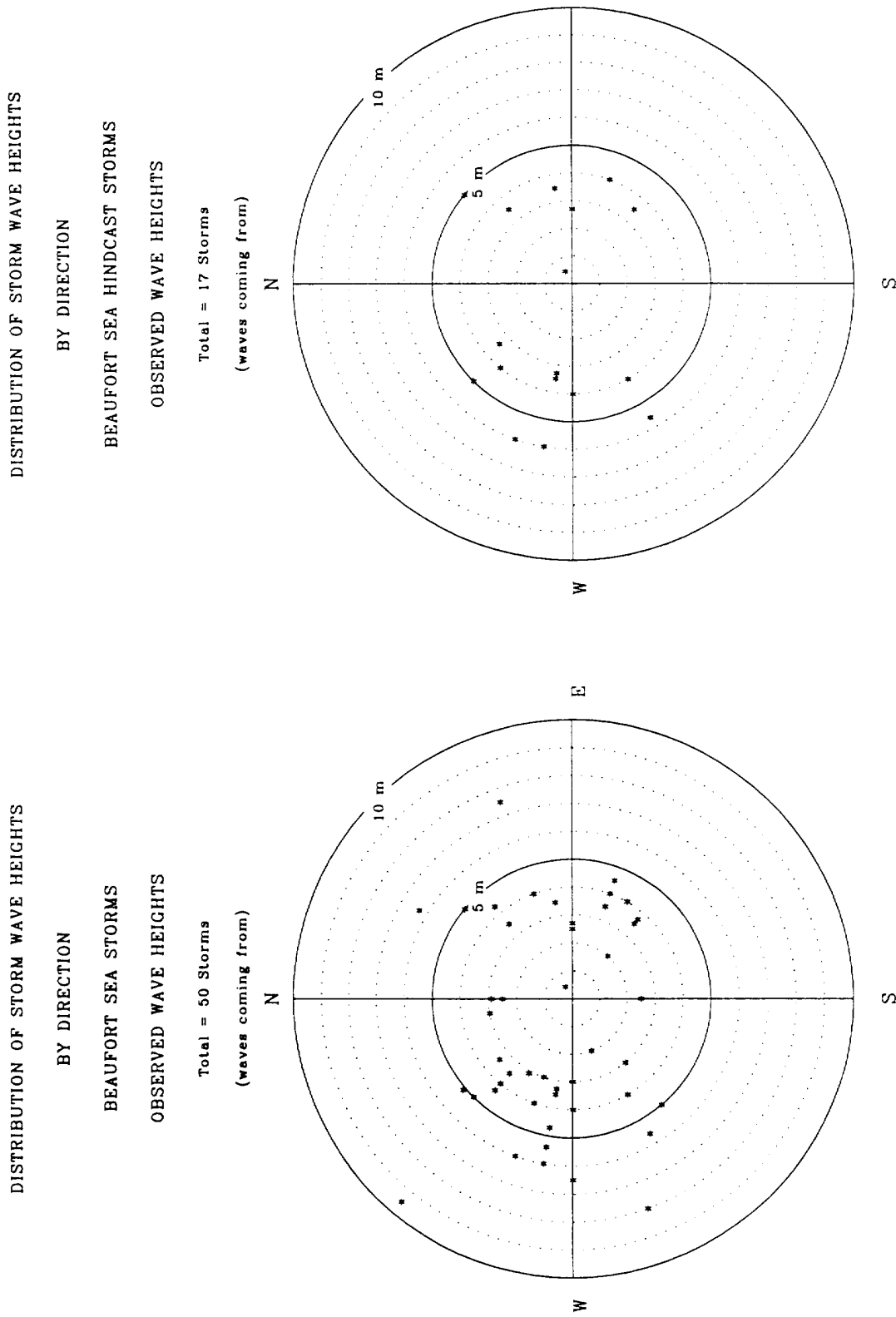
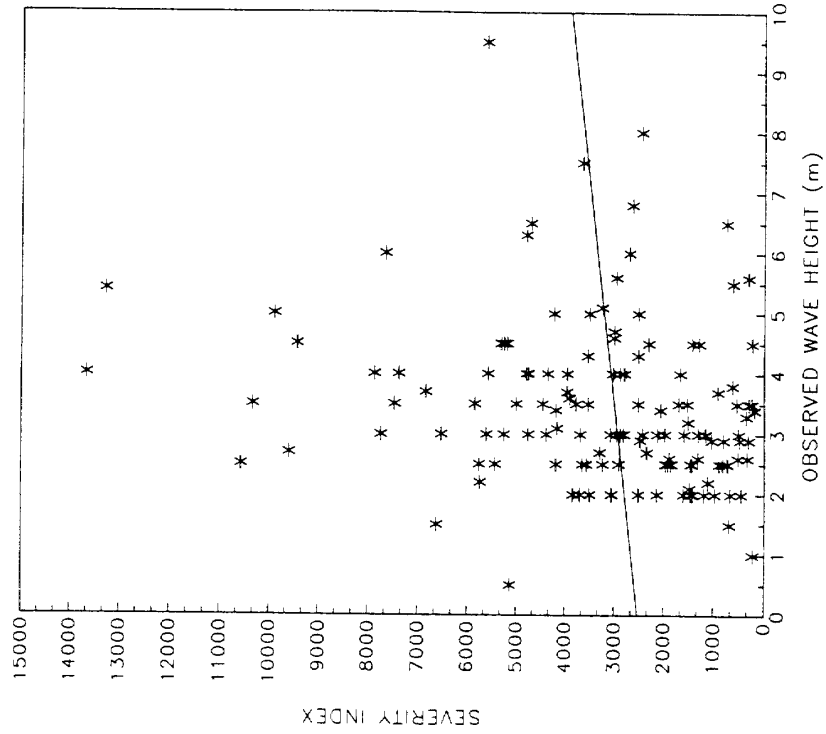


Figure 4.4 Distribution of Storm Wave Height by Direction

BEAUFORT SEA STORMS
TOP 160 STORMS

Correlation : 0.077



BEAUFORT SEA STORMS
TOP 50 STORMS

Correlation : 0.075

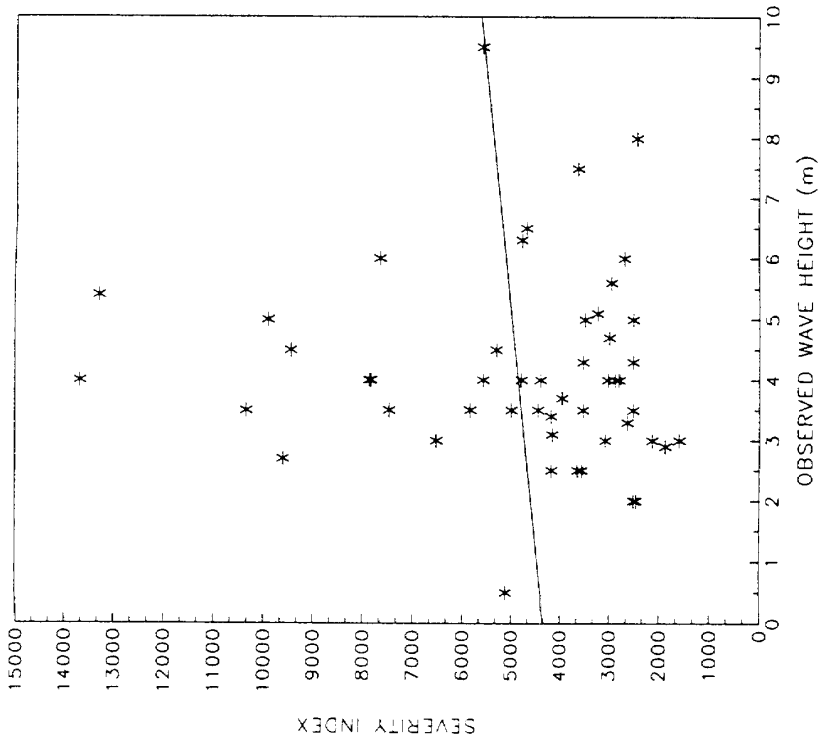


Figure 4.5 Correlation Between Storm Scatter Index and Wave Height

4.7 FINAL STORMS LIST

It is recommended that at least 30 storms be hindcast, drawn from the list of the 50–top events listed in Table 4.2 . Of those event, 47 are from the period 1970–1989. Earlier storms are not represented in proportion to their frequency of occurrence and therefore should not be included. The extremal analysis therefore will be based upon 20–years. The reason that a longer historical period is not recommended is that earlier storms are not detectable owing to the poor meteorological charts for earlier years. In addition, even if such storms could be reliably detected, the attendant ice conditions would be poorly known.

Of the storms to be hindcast from Table 4.2 , wind fields are available only for 17 storms from previous studies. The expansion to 30 storms must consider the rather broad directional distribution of storm types. Basically, the top–50 storms are distributed almost evenly over the three main sectors of considerations, i.e. northerly, easterly and westerly as shown in Figure 4.4. It is recommended that the final population should include at least 10 storms in each sector, therefore even more than 30 storms should be hindcast if possible.

The consideration of direction is believed to be important in this study since each class does not merely represent variability in direction of wave approach from storm to storm, but rather result from fundamentally different storm types, as classified for example by the BWO. The ultimate intensity to be attained by each class may be controlled by rather different meteorological processes and therefore the extreme distribution of say central pressure or maximum wind speed may vary from class to class, in turn providing rather different extreme wave distributions. It is well established by now that different storm classes should not be mixed in the extremal analysis. For example along the east coast of North America hurricanes and winter storms are treated separately. In the Beaufort, it should be at least considered that the different storm types may possess different extremal distributions.

Three further considerations support a larger storm population. First, since design is affected not only by peak wave heights but by storm duration effects on erosion and currents, a wider range of storm types within each directional class is required to sample all relevant storm extremes. Second, the storm selection process is imperfect, and in view of the scarcity of historical meteorological data in the area, it is even more imperfect than is typical of studies of this type in other areas. Therefore it is necessary to hindcast more storms just to ensure that the true top–ranked historical storms of each class are included in the selected population. Finally, ice coverage affects each storm class differently. Easterly storms are the least affected by variability of ice cover from year to year, westerly storms somewhat more affected than easterly types, and northerly storms most affected as the fetch limitation in northerly storms is almost always limited directly by the ice field.

The list of final 30 storms was subjectively selected from the top 50 storms. The selection was based on a review of all available information i.e., microfilm of weather charts, observed/measured data, storm characteristics, wind conditions and storm intensity and direction, ice conditions, etc.

The top 30 storms are shown in Table 4.4 . As shown, the top 30 storms consist of 15 previously hindcast storms and 15 new storms. The surface pressure analysis charts were obtained from AES for

the new storms, from Beaufort weather office for the period 1976–1985, and from Arctic Weather Centre (AWC) for periods outside this period.

Since the extremes are to be derived following a hindcast approach, each part of that approach must be specified, including the specification of the storm population as described previously, the selection of reliable hindcast method, and the treatment of the ice effect both within the hindcast process and the extremal analysis. As part of the hindcast process it is important to provide the best possible specification of the ice cover and to explore the sensitivity to errors in the location and concentration of the ice field upwind the main fetch zone of wave generation in each particular storm. In the specification of the effective fetch limit imposed by ice cover, the 5/10th isoline was considered although there are indications that this may lead to somewhat conservative sea state specification in fetch (ice) limited conditions. It would also be desirable to investigate the possible effect of relatively low concentrations of ice (less than 5/10th) on the definition of the effective upwind fetch, although such a research program appears to be beyond the scope of the present study.

Table 4.4 Final Top 30 Storms

| Storm Periods (YY MM DD HR) | | | |
|-----------------------------|------------------------|-------------------|-----------------|
| <u>Number</u> | <u>MCL I.D. Number</u> | <u>Start Date</u> | <u>End Date</u> |
| 1 | 198 | 70 09 13 00 | 70 09 16 12 |
| 2 | 270 | 75 08 09 00 | 75 08 11 12 |
| 3 | 274 | 75 08 25 12 | 75 08 29 00 |
| 4 | 282 | 76 08 11 12 | 76 08 14 00 |
| 5 | 293 | 76 09 28 00 | 76 10 02 00 |
| 6 | 302 | 77 08 25 12 | 77 08 28 00 |
| 7 | 310 | 77 09 23 12 | 77 09 26 00 |
| 8 | 325 | 78 09 19 00 | 78 09 22 12 |
| 9 | 326 | 78 09 28 00 | 78 10 01 00 |
| 10 | 327 | 78 10 06 00 | 78 10 10 12 |
| 11 | 333 | 79 09 14 00 | 79 09 17 12 |
| 12 | 334a | 79 09 29 12 | 79 10 06 18 |
| 13 | 335 | 79 10 08 12 | 79 10 11 12 |
| 14 | 350 | 80 08 28 12 | 80 09 04 00 |
| 15 | 366 | 81 08 01 00 | 81 08 04 12 |
| 16 | 369 | 81 08 16 00 | 81 08 19 00 |
| 17 | 371 | 81 08 30 00 | 81 09 03 00 |
| 18 | 376 | 81 09 27 00 | 81 09 29 00 |
| 19 | 380 | 82 07 26 00 | 82 08 02 00 |
| 20 | 386 | 82 08 19 12 | 82 08 22 12 |
| 21 | 391 | 82 09 16 00 | 82 09 18 00 |
| 22 | 392 | 82 09 20 00 | 82 09 23 00 |
| 23 | 405 | 82 10 19 00 | 82 10 27 00 |
| 24 | 446 | 84 08 25 00 | 84 08 28 00 |
| 25 | 456 | 84 09 29 00 | 84 10 02 12 |
| 26 | 475 | 85 09 16 00 | 85 09 19 00 |
| 27 | 483 | 86 08 22 00 | 86 08 24 00 |
| 28 | 487 | 86 09 08 00 | 86 09 10 00 |
| 29 | 492 | 87 08 28 00 | 87 09 02 12 |
| 30 | 507 | 88 08 02 00 | 88 08 05 06 |

5.0 THE WAVE HINDCAST MODEL

5.1 BACKGROUND

The wave hindcast model adapted for this study is a special version of the ODGP which includes shallow water formulation. This model is a so-called fully-discrete spectral wave model. That is, the wave spectrum is resolved in discrete frequency-direction bins, a grid of points is laid out to represent the basin of interest, and a solution is obtained based upon integration of the spectral energy balance equation, a process which successively simulates, at each model grid point, and for each time step, the physical processes of wave growth and dissipation (through the source terms of the energy balance) and wave propagation.

Three classes of spectral models are generally recognized. First-generation models (1G), such as the ODGP model (Cardone, Pierson, and Ward, 1976), are part of the family of fully-discrete spectral models originally proposed by Pierson, Tick, and Baer (1966). This type of model is characterized by a source-term formulation which does not include an explicit representation of conservative transfers of energy between spectral components, believed to be associated with resonant non-linear wave-wave interactions. Second-generation models (2G) were introduced to include at least a parametric representation of a wave-wave interaction source term, while third-generation (3G) models, only recently introduced, attempt to model the wave-wave interaction source term rigorously.

The formulation of the ODGP model has been described in detail in past studies, most recently in MacLaren Plansearch Limited (1985) and ESRF (Eid and Cardone 1987). The skill of the model has also been documented in numerous studies, including Reece and Cardone (1982), and more recently by Cardone and Greenwood (1987), wherein the characteristics of the model are compared to those of recent 2G and 3G models.

While a number of 2G models and the so-called 3G-WAM model (WAMDI Group, 1988) have been demonstrated in some applications to achieve hindcast skill comparable to the ODGP 1G model, no clear superiority of these later formulations has been established. For example, the 2G model developed at Oceanweather for an international wave model comparison program (SWAMP, 1985), and known as the SAIL model (Greenwood, Cardone, and Lawson, 1985), has been calibrated against the same data used for the ODGP model, and validated against wave measurements in some of the same validation storms used in this study with good skill, but only in a deep water mode. The 3G-WAM was not considered for this study. It has been tested against three Gulf of Mexico hurricanes (WAMDI Group, 1988) and provides no greater skill in specification of peak wave height and period than provided by ODGP when driven by identical wind fields, yet 3G-WAM requires a factor of 5 or more computer time than ODGP. The 3G-WAM model was also applied in a deep water mode for those tests. The shallow water version of 3G-WAM has not been tested against tropical cyclone data.

5.2 GRID SYSTEM

Basically, the ODGP wave model was adapted in this problem on a very high resolution grid system covering the domain shown in Figure 5.1 . The model has basically the following attributes:

| | |
|--------------------------------|---|
| grid domain: | 69°–76° North latitude 120°–162° West longitude |
| grid spacing: | 37.3 km nominal, 614 grid points |
| projection: | transverse mercator, assumed meridian at 141 degrees West |
| time step: | 60 minutes (30 minutes grow, 60 minutes propagation, 30 minutes grow) |
| angular spectral resolution: | 24 directions, 15 degree bandwidth |
| frequency spectral resolution: | 15 frequencies, binned as given in Table 5.1 |
| spectral growth algorithms: | ODGP2 (deep water); ODGPS (shallow water) |
| propagation: | interpolatory, deep water and shallow water, great circle effects and refraction and shoaling included. |

Table 5.1

| Band | Nominal Frequency | Bandwidth |
|-------------|--------------------------|------------------|
| 1 | 14/360 Hz = .03889 Hz | 1/180 Hz |
| 2 | 16/360 = .04444 | 1/180 |
| 3 | 18/360 = .05000 | 1/180 |
| 4 | 20/360 = .05556 | 1/180 |
| 5 | 22/360 = .06111 | 1/180 |
| 6 | 24/360 = .06667 | 1/180 |
| 7 | 26/360 = .07222 | 1/180 |
| 8 | 29/360 = .08056 | 1/ 90 |
| 9 | 33/360 = .09167 | 1/ 90 |
| 10 | 37/360 = .10278 | 1/ 90 |
| 11 | 42/360 = .11667 | 1/ 60 |
| 12 | 48/360 = .13333 | 1/ 60 |
| 13 | 57/360 = .15833 | 1/ 30 |
| 14 | 75/360 = .20833 | 1/ 15 |
| 15 | 111/360 = .30833 | 2/ 15 |

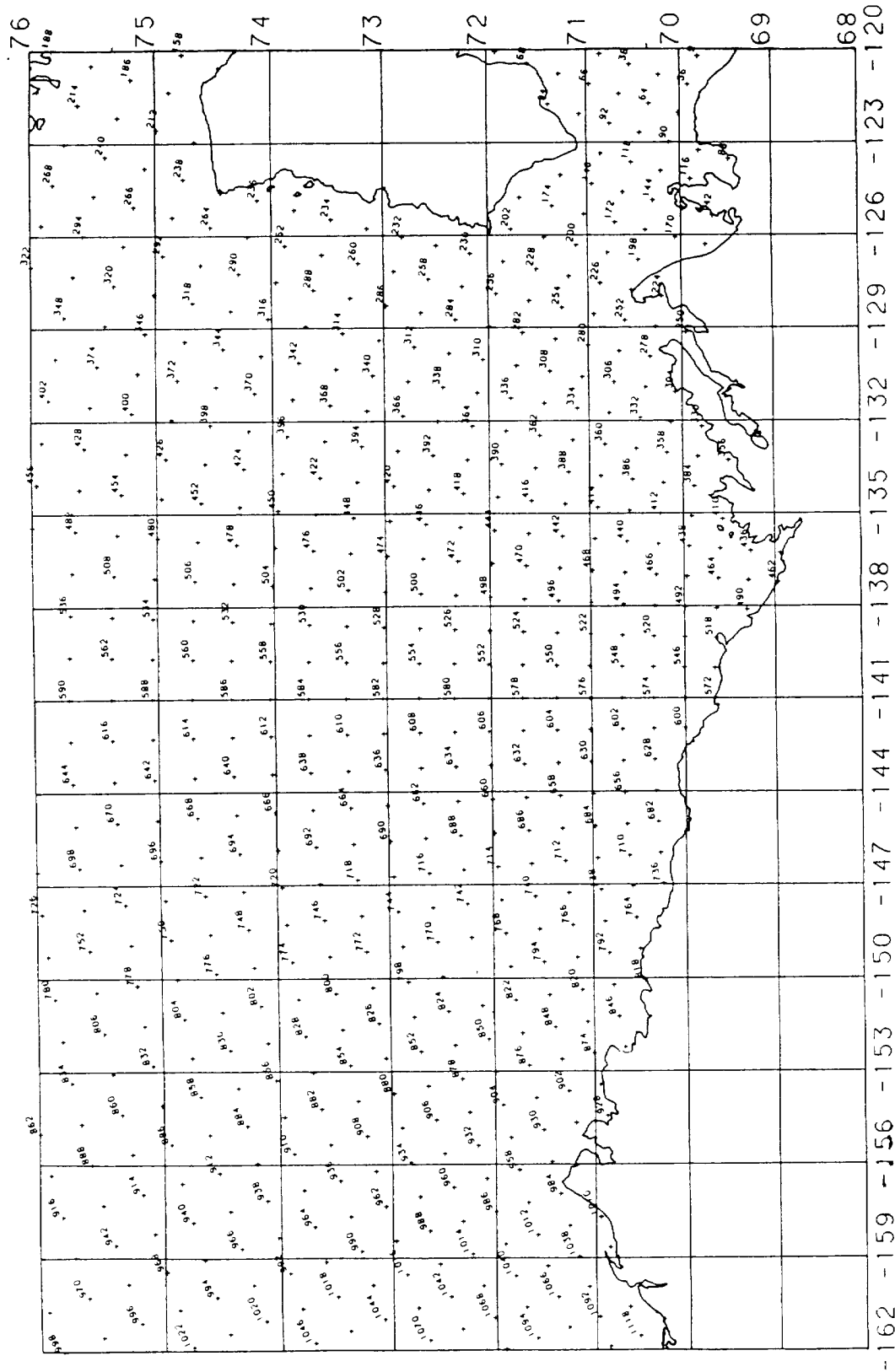


Figure 5.1 ODGP Model Grid for the Beaufort Sea

5.3 BASIC PROPAGATION SCHEME

The propagation scheme is basically interpolatory. Convergence of meridians (great circle effects) is modelled. This scheme, whose dispersion properties are described in detail by Greenwood, Cardone, and Lawson (1985), has been used with success by Oceanweather in its wave models set-up since the industry-sponsored Gulf of Alaska Pilot Study (GAPS), carried out in 1978. The scheme was first described by Greenwood and Cardone (1977).

5.4 DEEP-WATER SOURCE-TERM ALGORITHMS

The variants of the ODGP spectral/growth model were applied in this model, one for deepwater grid point, the second at shallow water grid points (points with water depth less than 200 m.)

The original ODGP algorithm was implemented in a wave model as a subroutine called CMPE24. While a few changes in the code and numerics of this subroutine have been effected since the original version was developed in the ODGP-Analysis Phase (ODGP-AP), the calibration of this spectral growth/dissipation algorithm and the quantitative behaviour of hindcasts of tropical and extratropical cyclones have not changed. The algorithm is described in most detail in the original ODGP-AP report (proprietary to ODGP-AP participants) and most recently in the public domain in MacLaren Plansearch Limited (1985).

A slightly modified version of the ODGP spectral/growth algorithm (ODGP2) was developed in 1983, and has been used operationally since then. The subroutine which implements the modified algorithm is called CMPE27. The changes affect only the behaviour of the high-frequency part of the wave spectrum, and were made in order to make the so-called saturation range of the spectrum more responsive to the stage of wave development. CMPE27 differs from CMPE24 in the following three particulars:

1. The integrated band (0.24167 hz to 3.0 hz) is not automatically saturated by the local wind, but is subject to grow, propagate, and dissipate.
2. The f^{-4} range in the representation of the high-frequency tail of saturated spectrum in the ODGP algorithm is not used, as an f^{-5} representation through out the tail is assumed.

3. Phillips "constant" is allowed to float as a function of sea state, specifically,

$$\alpha = 0.0081(E_{\text{sat}}/E)^{0.23}$$

where E is the non-dimensional total variance and E_{sat} is the fully-developed value of same.

5.5 SHALLOW-WATER PROPAGATION AND DEPTH GRID

The propagation scheme of the shallow-water model is analogous to that used in the deep-water model. In the construction of the table of propagation coefficients at each grid point and for each frequency and direction bin, a numerical shallow-water tracing program is used instead of the simple spherical trigonometric calculation of the ray path in the deep-water program. Effects of shoaling and refraction over an irregular bathymetry as resolved on the model grid are included.

The depth field was derived from the digital database produced at the U.S. National Geophysical Data Centre (NGDC), known as ETOPO5. That database is stored on one 6250 bpi magnetic tape and resolves the global topography/bathymetry on a 5 minute grid.

Depths are assigned to the wave model grid by simply averaging all ETOPO5 grid depths which lie within a grid box defined by each point. Since there are typically 12 or 16 ETOPO5 depths within a rectangle represented by each grid point, the binning effects considerable smoothing of the depth field, and no further smoothing was applied. At a few points near shore, the depth was limited to a minimum depth of 7.5 m, to avoid computational problems with the ray-tracing routine.

The assignment of grid points to land or sea was made by digitizing the coastline off standard charts, plotting the digitized coastline together with the entire grid array, then manually reading off those points which lie on land. The grid was then replotted to check the assignments. After deletion of land points, the grid contains 614 active points. A facility is included in any given run to treat as land, grid point which lie within an ice field.

5.6 SHALLOW-WATER SOURCE TERMS

A shallow-water version of the ODGP spectral growth algorithm (CMPE24/ CMPE27) has been under development since 1984. The first significant test of the algorithm against field measurements was made during the Canadian Atlantic Storms Project (CASP), which was carried out on the Canadian Scotian Shelf in the period January – March 1986. The performance of the model hindcasts, which were carried out as part of a real-time analysis/ forecast system, exceeded that of the several other operational and research shallow-water models which also participated in the experiment (Eid and Cardone, 1987).

The modifications of the ODGP deep-water routine spectral/growth subroutine made to extend the model to shallow water are:

- 1) transformation of the fully-developed Pierson-Moskowitz spectrum to shallow water;
- 2) calculation of an explicit attenuation associated with bottom friction, which is modelled after the comprehensive treatment of Grant and Madsen (1982);
- 3) calculation of the exponential growth rate using the shallow-water celerity; and
- 4) adoption of wave-number scaling of the high-frequency saturation range of the spectrum, with the equilibrium range coefficient, α , expressed as a function of the stage of wave development.

A somewhat more detailed description of these aspects of the model is given in Appendix B .

5.7 WIND FIELD SPECIFICATION

Wind fields are specified by the methodology described by Cardone et al. (1980) for marine winds, which combines winds calculated from pressure fields through a marine planetary boundary layer model (MPBL) with winds specified by kinematic analysis of direct wind observations. The

kinematic analysis is applied on a small part of the whole analysis area, since, unlike mid-latitude oceanic regions in which ship reports are relatively numerous, in-situ reports in the Canadian Beaufort are available only near the coast and, in recent years, only in areas of offshore drilling. The model domain extends from 68°N to 76°N and 120°W to 162°W as shown in Figure 1.1 . The grid size was chosen to be 1° latitude by 3° longitude.

The wind field analysis method used in the present study is described in detail in a number of previous publications, MacLaren Plansearch Limited (1987) and (1989), Agnew et al. (1989). Only a brief description is provided here.

The six-hourly synoptic surface analysis weather charts were obtained from the available sources. These include the Beaufort Weather Office (BWO), the Arctic Weather Centre (AWC), the Canadian Meteorological Centre (CMC) and the NOAA 6-hourly northern hemisphere surface analysis charts. In addition, marine observations and wind records from six coastal land stations were obtained from AES' archives (on magnetic tapes). These data were plotted on a base map for each storm and used for reanalysis of the pressure fields.

All charts were reanalysed using all available data (including microfilms). The previously hindcast wind fields (15 old storms) were reviewed and some cases were revisited where the hindcast duration was extended to cover storm peaks and decay.

The gridded pressure fields derived from the above hand-drawn analysis charts were then used to provide the objective analysis wind fields using Cardone's marine planetary boundary layer (MPBL) model.

Over open water, or water with less than five-tenths ice cover, winds were calculated from the MPBL, which in general requires the following parameters at each grid point: sea level pressure gradient; horizontal air transport gradient (baroclinicity effect); air sea temperature difference (stratification effect). Air and sea temperature fields are not digitized in general, though if available the air-sea temperature difference may be specified at grid points. The horizontal air temperature gradient is specified from climatological data.

The MPBL provides unbiased and reasonably accurate surface winds over open water, when accurate inputs are specified, and acceleration terms are small. The atmospheric boundary layer over sea-ice is rather complicated, even for relatively small fractional covers (about four-tenths or more). The surface wind stress, and the near surface wind field, averaged over a region depends not only on the external conditions of the PBL, but also sensitivity on the details of the distribution and structure of the sea ice, the buoyancy flux associated with leads and polynas, and height of the shallow inversions often characterizing arctic boundary layers.

For the purpose of wave modelling, only MPBL winds were provided. The impact of errors on surface winds due to sea-ice is small and is limited to areas in the immediate vicinity of the ice edge.

The kinematic wind fields are by far the most accurate and least biased winds, primarily because the method allowed a thorough re-analysis of the evolution of the wind field. Kinematic analysis also

allows the wind fields to represent effects not well modelled by pressure–wind transformation techniques, such as temporal variations in surface pressure gradients, and deformation in surface winds near the downstream of coasts. However, the degree of accuracy of such analysis is primarily a function of available observations.

The transformation of wind speed measured at coastal stations by equivalent over–water speed was considered in the present study. The orographic effect of the Brooks Mountain Range on the coastal winds was also used in the kinematic analysis.

Kinematic analysis is a manual process that involves the following basic steps: (1) assembling and plotting all synoptic observations of wind speed and direction, and sea level pressure, from rigs, ships and land stations at 6–hourly intervals on a suitable base map projection for the storm event of usually 2–4 days duration; (2) identification and rejection of erroneous and unrepresentative observations to the extent possible; (3) construction of a continuity chart which defines the movements of storm centres, fronts and other significant features of the surface wind field; (4) construction of streamlines and isotachs; and (5) gridding of wind speed and direction by hand from the streamline/isotach fields.

For the purpose of wave modelling, the period over which wind fields must be specified in selected storm ranges between 2 and 4 days. The storm period may be considered to be composed of three phases: (1) a spinup period (24–48 hrs); (2) the period in which the major storm crosses the region and generates maximum sea states; and (3) the period from 12–24 hours after the occurrence of peak states, during which the wind field no longer plays a critical role in the hindcast but which should be modelled nevertheless so the hindcast wave series will include an adequate period of wave decay at the sites of interest.

The kinematic analysis domain extended from 69°N to 73°N and from 123°W to 144°W (Figure 1.1) which includes most ship/rig locations and represents the average to maximum open–water area in the Canadian Beaufort Sea.

Finally, a blend of the objective and kinematic analyses is carried out with the kinematic analysis reserved for the most critical parts of the wind field as mentioned previously. In this manner, the method is rather a spatial blending of objective and kinematic analysis winds in lieu of local blending at a certain weighting factor. In this case, the kinematic winds replaced the winds derived from the pressure field in the interior of the kinematic domain and were blended with the pressure–derived winds along the boundaries of that domain (i.e., some smoothing was applied).

5.8 DESCRIPTION OF ICE EDGES FOR HINDCAST STORMS

Ice edges for the storms were mapped primarily from AES daily ice analysis charts.

The AES daily ice charts are prepared from four sources: reconnaissance, satellite images, ship observations, and shore reports. Each chart indicates the sources used and the date of the source data. Usually all four sources were available and within a day or two of the map date. In some cases either the reconnaissance or satellite data were unavailable, but the majority of the charts included all four sources. Daily ice charts were obtained for every third day of each storm period (e.g., for the storm of Sept 29–Oct 2 1984, ice charts for Sept 29 and Oct 1 were used).

Generally the 5 tenths ice edge was mapped for every third day of the storm period. There were a few exceptions to this rule. If the ice edge did not move appreciably during a storm duration (more than 30 n.mi.) and the wind was not blowing from the west, then ice edge with the most open water was chosen to represent the storm (i.e., Oct 1 1984 was used for the storm of Sept 29 to Oct 2 1984). Four storms were treated in this manner. For two other easterly storms, the AES weekly chart was used to map the ice edge. As AES ice charts, weekly or daily, were unavailable for the storm of Sept. 23 to 26 1970, the ice chart presented in Lindsay (1977) for Sept 12 was used.

The daily ice charts tended to cover the area from the west coast of Banks Island to Point Barrow, although in some cases they only extended slightly west of Barter Island. Weekly ice charts were used to fill in the ice edge for the remainder of the study area. Selecting the appropriate weekly chart and combining it with the daily chart was a time-consuming process.

Edges of 3 tenths concentration were included on the ice edge map if the 3 tenths and 5 tenths ice edge differed by more than 60 n.mi. (Note: this rule was applied very conservatively, and generally differences of 30 n.mi. were mapped).

Table 5.2 provides a list of ice edge charts for the top 30 hindcast storms; their dates and number of charts for each storm are indicated. The ice charts are provided in Appendix C .

In addition, the digital ice data base at the Canadian Climate Centre, AES, Downsview was also accessed using the CRISP package. It provided ice concentration charts for the verification storms as described in the next chapter. The ice edges obtained from this source were compared with those mapped from AES daily ice charts. Statistical ice charts, i.e. the percentage of occurrences of any ice, were obtained from "the marine climatological Atlas – Canadian Beaufort Sea" by Agnew, Spicer and Maxwell (1987). It presents semi-monthly charts provided in contour intervals of 98%, 90%, 70%, 50%, 30% and 10%. In the present study, three cases: 98%, 50%, 30% occurrences were used (see Appendix C).

Table 5.2**ICE EDGE CHARTS FOR TOP 30 STORMS****BEAUFORT SEA WAVE STUDY (15 OLD STORMS)**

| Storm No. | Period Start | Period End | No. of Charts | Ice Edge Chart Date |
|-----------|--------------|------------|---------------|-------------------------|
| 198 | 70091300 | 70091612 | 1 | Sept. 12, 1970 |
| 302 | 77082512 | 77082800 | 2 | August, 25 & 28, 1977 |
| 310 | 77092312 | 77092600 | 1 | Sept. 30 |
| 326 | 78092800 | 78100100 | 1 | Sept. 28 - Oct. 1, 1978 |
| 327 | 78100600 | 78101012 | 1 | Oct. 9, 1978 |
| 334a | 79092912 | 79100618 | 1 | Oct. 4, 1978 |
| 350 | 80082812 | 80090400 | 2 | Aug. 28 - Sept. 3, 1980 |
| 366 | 81080100 | 81080412 | 1 | Aug. 4, 1981 |
| 369 | 81081600 | 81081900 | 1 | Aug. 16, 1981 |
| 371 | 81083000 | 81090200 | 2 | Aug. 30 - Sept. 2, 1981 |
| 376 | 81092700 | 81092900 | 1 | Sept. 29, 1981 |
| 380 | 82072600 | 82080200 | 1 | July 26, 1982 |
| 392 | 82092000 | 82092300 | 1 | Sept. 20, 1982 |
| 405 | 82101900 | 82102700 | 2 | Oct. 18 & 22, 1982 |
| 475 | 85091600 | 85091900 | 1 | Sept. 16, 1985 |

Table 5.2 (cont'd)**BEAUFORT SEA WAVE STUDY (15 NEW STORMS)**

| Storm No. | Period Start | Period End | No. of Charts | Ice Edge Chart Date |
|-----------|--------------|------------|---------------|-------------------------|
| 270 | 75080900 | 75081112 | 2 | Aug. 8 & 11, 1975 |
| 274 | 75082512 | 75082900 | 2 | Aug. 22 & 29, 1975 |
| 282 | 76081112 | 76081400 | 2 | Aug. 11 & 14, 1976 |
| 293 | 76092800 | 76100200 | 2 | Sept. 25 & Oct. 1, 1978 |
| 325 | 78091900 | 78092212 | 1 | Sept. 22, 1978 |
| 333 | 79091400 | 79091712 | 2 | Sept. 14 & 17, 1979 |
| 335 | 79100812 | 79101112 | 1 | Oct. 8, 1979 |
| 386 | 82081912 | 82082212 | 2 | Aug. 19 & 22, 1982 |
| 391 | 82091600 | 82091800 | 2 | Sept. 16 & 19, 1982 |
| 446 | 84082500 | 84082800 | 2 | Aug. 24 & 28, 1984 |
| 456 | 84092900 | 84100212 | 1 | Oct. 1, 1984 |
| 483 | 86082200 | 86082400 | 2 | Aug. 22 & 25, 1986 |
| 487 | 86090800 | 86091000 | 1 | Sept. 8 & 11, 1986 |
| 492 | 87082800 | 87090212 | 2 | Aug. 28 & 31, 1987 |
| 507 | 88080200 | 88080506 | 2 | Aug. 2 & 5, 1988 |

Additional Charts: October 6, 1977
August 8 and 11, 1986

6.0 HINDCAST VERIFICATION

This section provides the results of a preliminary verification of model hindcasts. For this purpose, five recent storms were selected from the Top 50 Storm List (Table 4.2). These particular verification storms were selected from those included in the previous wind field hindcast studies carried out by MacLaren Plansearch Limited and Oceanweather Inc. (1988 and 1989).

6.1 VERIFICATION CASES

The following five storms were selected from the final storm selection list for model verification.

| <u>STORM #</u> | <u>HINDCAST PERIOD</u> | | <u>VERIFICATION PERIOD</u> | |
|----------------|------------------------|------------|----------------------------|------------|
| | <u>START</u> | <u>END</u> | <u>START</u> | <u>END</u> |
| 1 | 770825–12 | 770828–00 | 770826–09 | 770828–00 |
| 2 | 780928–00 | 781001–00 | 780929–06 | 781001–00 |
| 3 | 810816–00 | 810819–00 | 810816–12 | 810818–00 |
| 4 | 810830–00 | 810903–00 | 810830–12 | 810903–00 |
| 5 | 820920–00 | 820923–00 | 820920–12 | 830922–00 |

The wind fields were hindcast in the previous study by MPL and OWI (1987, 89). These wind fields of the above storms were used directly in verification runs.

The ice edge used in each hindcast was determined using ice concentration charts from CRISP, a program which extracts data from the AES ice database. The ice edges used in the model were the 5/10 contours from the ice chart closest in time to the storm period. The following ice charts were used for the hindcasts:

August 23–24, 1977
 September 26–27, 1978
 August 18–19, 1981
 September 1–2, 1981
 September 21–22, 1982

Hand drawn ice edge charts were also produced to verify the above CRISP produced charts as described previously (see Appendix C). The final hindcast used the best presentation of ice edge from the above two sources.

6.2 WAVE VERIFICATION DATA

The amount of wave and wind measurements in the Beaufort Sea is limited to the amount of activity in the area. The verification storms were chosen during time periods when waverider buoy data were available. In addition to the waverider measurements, MANMAR (Manual Marine) observations from rigs were also available and were used to compare observed and modelled winds.

The locations of the observation on measurement sites are listed in Table 6.1 , and shown in Figure 6.1 .

Table 6.1 Locations of Waverider Buoys and Rigs

| MEDS # | LAT (°N) | LONG (°W) | SITE/RIG | WATER DEPTH (M) | NEAREST GRID POINT | MODEL DEPTH (M) |
|--------|----------|-----------|----------------|-----------------|--------------------|-----------------|
| 1977 | | | | | | |
| 190 | 70.1 | 133.6 | GULF I | 33. | 358 | 36.02 |
| 191 | 70.1 | 136.4 | GULPH II | 43. | 439 | 41.75 |
| 192 | 70.2 | 132.8 | CANMAR I | 34. | 331 | 22.06 |
| 193 | 70.4 | 135.1 | CANMAR II | 64. | 413 | 57.35 |
| 194 | 70.0 | 134.4 | ISSERK | 14. | 384 | 10.09 |
| | 70.5 | 136.3 | EXPLORER III | — | 439 | 41.7 |
| 1978 | | | | | | |
| 192 | 70.2 | 132.7 | CANMAR I | 31. | 358 | 36.02 |
| 193 | 70.4 | 135.1 | CANMAR II | 57. | 413 | 57.35 |
| 1981 | | | | | | |
| 196 | 70.5 | 134.1 | EXPLORER III | 60. | 386 | 42.78 |
| 201 | 70.1 | 134.4 | EXPLORER II | 27. | 385 | 36.02 |
| | 70.2 | 135.1 | EXPLORER I | — | 412 | 39.47 |
| 1982 | | | | | | |
| 196 | 70.4 | 136.5 | EXPLORER III | 58. | 439 | 41.75 |
| 201 | 70.4 | 134.0 | EXPLORER II | 60. | 386 | 42.78 |
| 204 | 69.8 | 136.0 | TARSUIT ISLAND | 21. | 411 | 18.38 |
| 205 | 69.9 | 134.5 | ITIIYOK ISLAND | 14. | 384 | 10.09 |
| 206 | 70.0 | 131.2 | MCINLEY BAY | 8. | 304 | 10.12 |
| | 70.6 | 134.2 | IRKALUK | — | 386 | 42.78 |
| | 70.7 | 134.0 | EXPLORER IV | — | 386 | 42.78 |

6.3 VERIFICATION PROCEDURES

The following evaluation methods were applied:

1. Time Series Plots of Hindcasts vs. Observations

For each storm, time series of the hindcast wind speed and direction, significant wave height, peak period, and vector mean wave direction were plotted with the corresponding measured values at the selected evaluation sites. The time series can be found in Appendix D .

2. Statistical Comparison of Hindcasts vs. Observations

A quantitative statistical analysis was carried out to provide an overall evaluation of the model predictions. The statistical parameters considered in this study are:

$$\begin{aligned} \text{Mean Error (Bias)} &= \Sigma (X_1 - X_2) / \text{NPTS} \\ \text{Mean Absolute Error} &= \Sigma |X_1 - X_2| / \text{NPTS} \\ \text{Root Mean Square Error (RMSE)} &= [\Sigma (X_1 - X_2)^2 / \text{NPTS}]^{1/2} \\ \text{Scatter Index (\%)} &= (\text{RMSE}/\text{AVE}) \times 100 \end{aligned}$$

where X_1 is the hindcast value

X_2 is the observed value

AVE is the mean of observed values

NPTS is the number of data pairs

These statistics were provided for each site for significant wave height and peak period. Table 6.2 presents the above evaluation results.

BEAUFORT SEA HINDCAST
MANMAR, WAVERIDER AND MODEL GRID POINT LOCATIONS
All Storms

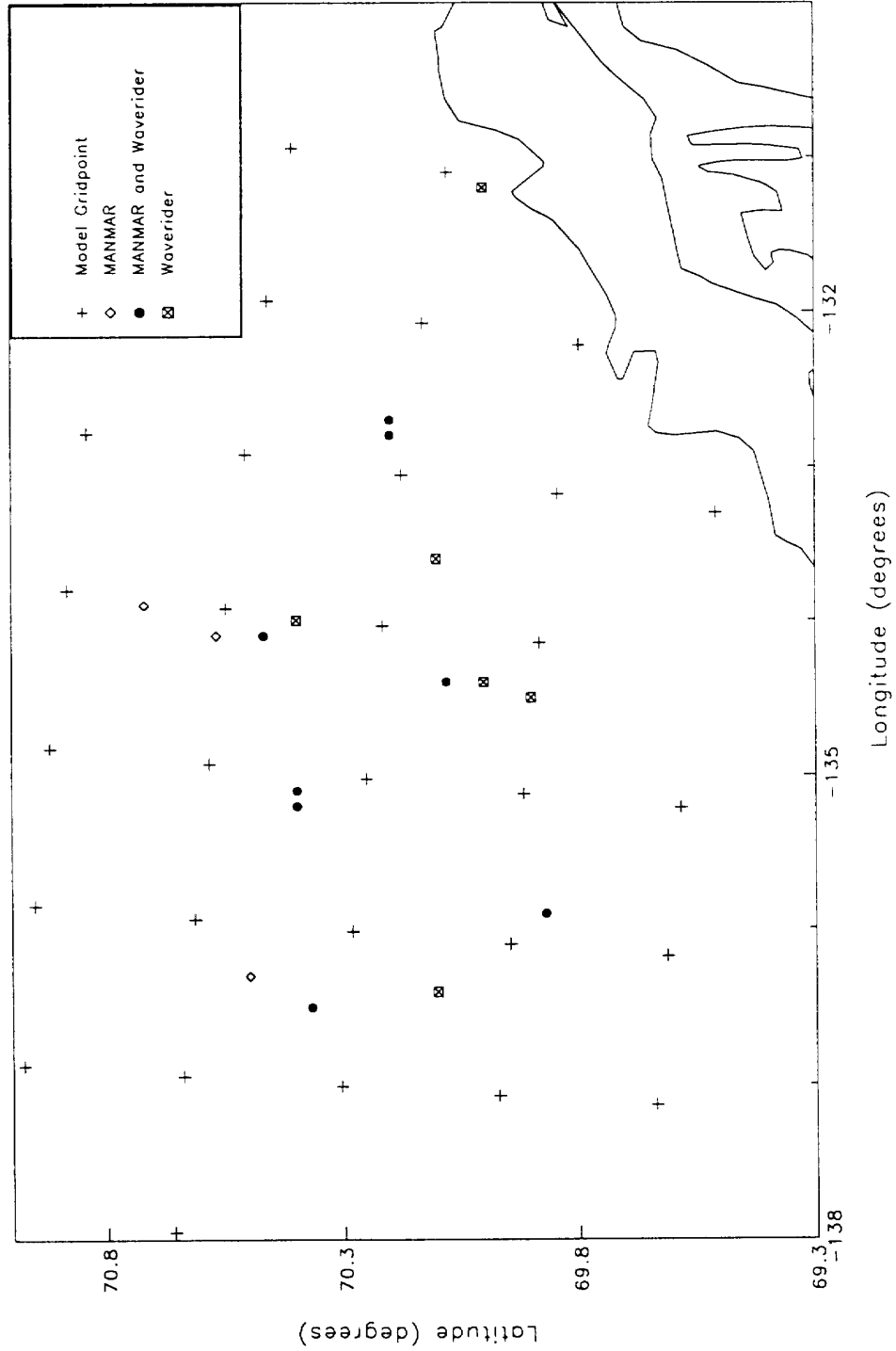


Figure 6.1 Beaufort Sea Verification Sites

3. Peak-to-Peak Comparisons

In Table 6.3 , storm peak values of H_S and T_p are listed for measured data and model predictions. These values were then used to evaluate the storm peak parameters of the models.

4. Scatter Plots and Linear Regression Analysis

The correlation between measured and hindcast parameters was carried out using linear regression analysis. The scatter plots in Figures 6.2 and 6.3 show the correlation between measured and model values for both H_S and T_p.

Table 6.2
Hindcast Verification Statistics

| Var | Storm Date | Num of Points | Average Obs | Standard Dev. | Average Model | Standard Dev | Mean Err | Absolute Mean Err | RMSE | Scatter Index | Corr Coef |
|-----|------------|---------------|-------------|---------------|---------------|--------------|----------|-------------------|------|---------------|-----------|
| HS | 770825 | 63 | 1.38 | 0.65 | 1.43 | 0.54 | 0.05 | 0.26 | 0.34 | 24.64 | 0.856 |
| | 780928 | 28 | 1.76 | 0.17 | 2.13 | 0.16 | 0.37 | 0.42 | 0.46 | 26.29 | -0.320 |
| | 810816 | 19 | 2.37 | 0.62 | 2.79 | 0.53 | 0.42 | 0.58 | 0.67 | 28.41 | 0.585 |
| | 820920 | 36 | 2.29 | 0.53 | 2.55 | 0.57 | 0.25 | 0.34 | 0.40 | 17.35 | 0.847 |
| | OVERALL | 146 | 1.81 | 0.70 | 2.02 | 0.74 | 0.21 | 0.35 | 0.44 | 24.06 | 0.861 |
| | 810830 | 33 | 1.64 | 0.49 | 3.04 | 0.45 | 1.40 | 1.40 | 1.48 | 90.54 | 0.492 |
| TP | 770825 | 63 | 7.10 | 1.05 | 5.08 | 1.34 | -2.02 | 2.03 | 2.50 | 35.15 | 0.268 |
| | 780928 | 28 | 7.15 | 0.64 | 7.16 | 0.28 | 0.01 | 0.59 | 0.83 | 11.64 | -0.549 |
| | 810816 | 19 | 6.75 | 0.85 | 7.26 | 1.09 | 0.51 | 1.30 | 1.50 | 22.16 | -0.039 |
| | 820920 | 36 | 7.24 | 0.57 | 7.79 | 0.82 | 0.55 | 0.84 | 0.94 | 12.95 | 0.439 |
| | OVERALL | 146 | 7.10 | 0.87 | 6.43 | 1.59 | -0.67 | 1.36 | 1.82 | 25.70 | 0.150 |
| | 810830 | 33 | 6.31 | 1.27 | 8.06 | 0.65 | 1.74 | 1.93 | 2.04 | 32.37 | 0.548 |

Table 6.3

Storms Peak-to-Peak Comparison Statistics

| MEDS BUOY | WAVERIDER | | ODGP grid point | ODGP | |
|---|-----------|-----------|-----------------------|-----------|-----------|
| | Hs (m) | Tp (s) | | Hs (m) | Tp (s) |
| Storm period - 770825:1200 to 770828:0000 | | | | | |
| 191 | 3.2 | 8.0 | 439 | 2.4 | 6.9 |
| 190 | 1.8 | 7.6 | 358 | 1.9 | 5.8 |
| 192 | 1.2 | 8.0 | 331 | 1.4 | 6.0 |
| 192 | 1.2 | 8.0 | 358 | 1.9 | 5.8 |
| 193 | 1.9 | 7.2 | 413 | 2.2 | 6.2 |
| Storm period - 780929:0600 to 781001:0000 | | | | | |
| 192 | 1.8 | 7.2 | 331 | 2.2 | 7.4 |
| 192 | 1.8 | 7.2 | 358 | 2.4 | 7.6 |
| 193 | 1.9 | 8.0 | 413 | 2.4 | 7.3 |
| Storm period - 810816:1200 to 810819:0000 | | | | | |
| 196 | 3.4 | 8.0 | 386 | 3.5 | 8.3 |
| 201 | 3.1 | 7.6 | 411 | 3.0 | 7.4 |
| 201 | 3.1 | 7.6 | 385 | 3.4 | 8.4 |
| Storm period - 810830:1200 to 810903:0000 | | | | | |
| 196 | 2.4 | 7.2 | 386 | 3.6 | 8.6 |
| 196 | 2.4 | 7.2 | 412 | 3.3 | 8.4 |
| 196 | 2.4 | 7.2 | 413 | 3.5 | 8.6 |
| 201 | 1.5 | 4.6 | 385 | 3.4 | 8.5 |
| Storm period - 820920:1200 to 820922:0000 | | | | | |
| 204 | 2.8 | 7.2 | 411 | 2.4 | 8.8 |
| 206 | 0.9 | 5.7 | 304 | 1.8 | 7.4 |
| 196 | 3.3 | 8.0 | 439 | 3.4 | 9.1 |
| 201 | 3.3 | 7.6 | 386 | 3.4 | 8.4 |
| 205 | 2.2 | 6.5 | 384 | 2.2 | 8.5 |

Peak to Peak Comparison -- All Storms Except 810830

Depths > 20 m

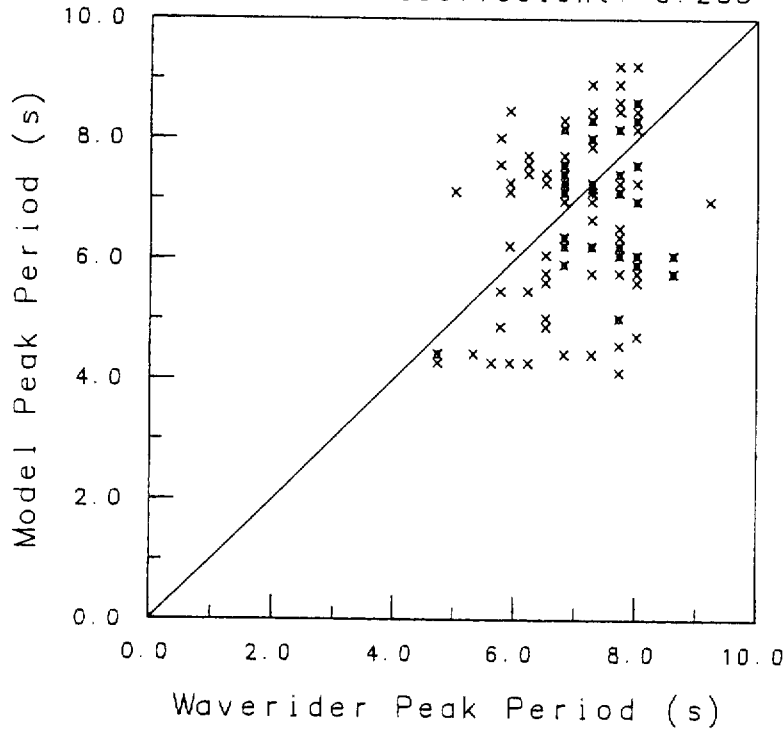
| Var | Num of Points | Average Obs | Standard Dev. | Average Model | Standard Dev | Mean Err | Absolute Mean Err | RMSE | Scatter Index | Corr Coef |
|-----|------------------|----------------|------------------|------------------|-----------------|-------------|----------------------|------|------------------|--------------|
| HS | 11 | 2.58 | 0.64 | 2.52 | 0.76 | -0.06 | 0.30 | 0.38 | 14.73 | 0.872 |
| TP | 11 | 7.44 | 1.08 | 7.67 | 0.33 | 0.24 | 1.00 | 1.15 | 15.51 | 0.013 |

Peak to Peak Comparison -- All Storms

| | | | | | | | | | | |
|----|----|------|------|------|------|-------|------|------|-------|--------|
| HS | 13 | 2.71 | 0.59 | 2.43 | 0.75 | -0.28 | 0.40 | 0.55 | 20.23 | 0.778 |
| TP | 13 | 7.86 | 0.65 | 7.40 | 0.87 | -0.46 | 0.82 | 1.26 | 16.08 | -0.173 |

Comparison of Waverider vs. Model
 All Storms Except 810830
 Water Depths > 20 m

Number of Points: 125
 Correlation Coefficient: 0.253



No. of
 Samples
 x 1
 ■ 2-5
 ■ >5

Number of Points: 125
 Correlation Coefficient: 0.826

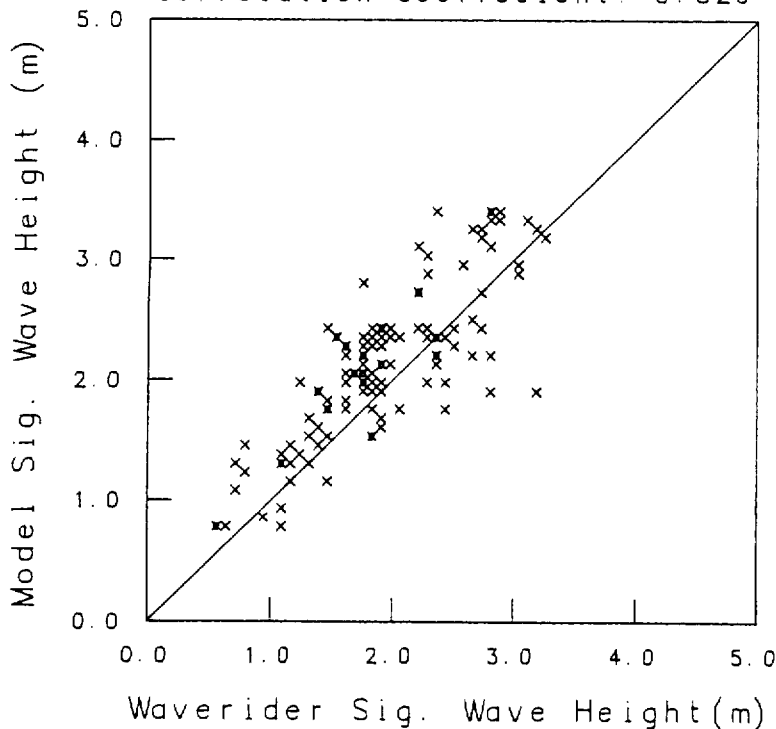


Figure 6.2 Scatter Diagrams of Measured vs. Hindcast Data

MEASURED versus MODEL FOR BEAUFORT SEA
 Peak To Peak Comparison
 All Storms Except 810830
 Depths > 20 m

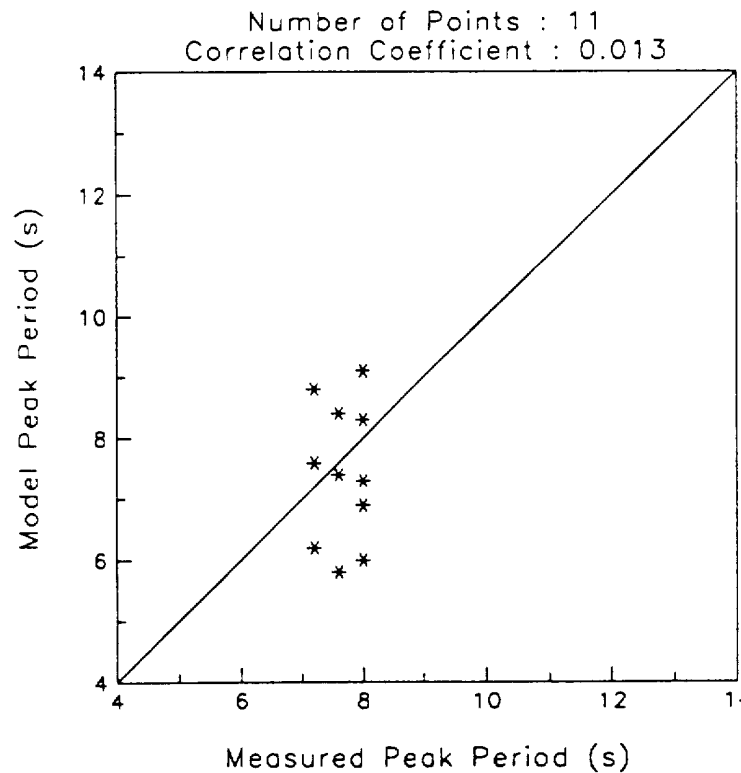
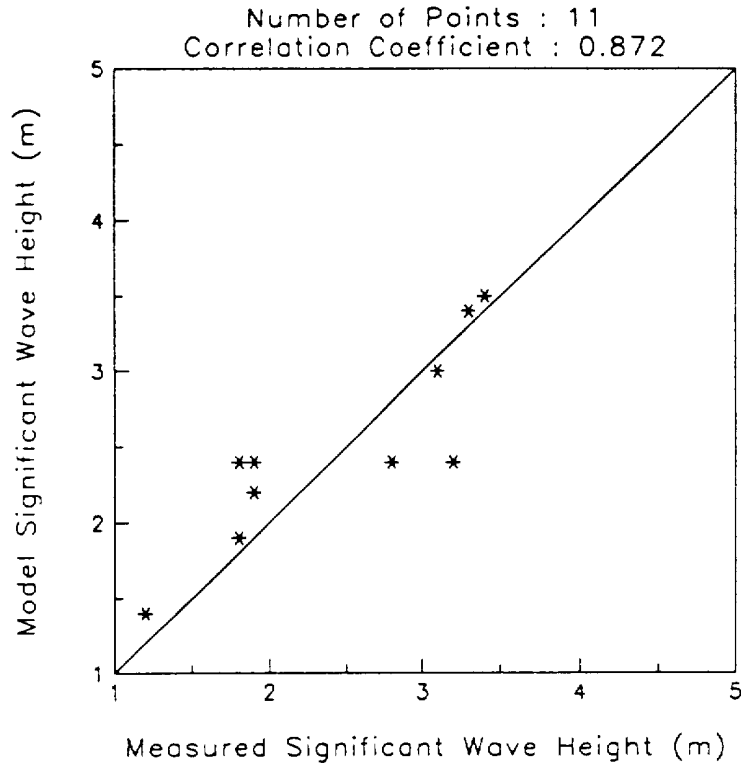


Figure 6.3 Scatter Diagrams of Peak-to-Peak Comparison

6.4 STORM-BY-STORM VERIFICATION RESULTS

Storm #1 – August 25 – 28, 1977

Synoptic Evolution: This storm most resembles pattern 4 (see Figure 4.1) of the Beaufort Weather Office storm patterns. Initially, a trough extends northwestward into the Canadian Beaufort with light northeasterly winds of 10–15 knots in the eastern part (see Explorer 1 wind comparison) and northerly winds of about 20 knots in the western part (see Explorer II wind comparison). Evidently, late on the 26th, a small scale low pressure system developed in the central part of the exploration areas, just east of Explorer III, which experienced wind speeds up to 40 knots for a brief time, followed by nearly calm winds early on the 27th. This low gradually fills, with little movement, during the 28th. The kinematic analyses, as originally derived, captured the larger scale features of the wind field evolution, but apparently did not fully resolve the small scale features near the developing mesoscale low centre on the 27th. The effect of this small scale system on the wave field is discussed below.

Ice Cover: According to the ice chart for this storm (Appendix C), the area between the shore and 73°N was almost completely ice-free, providing fetch lengths of at least 150 n. mi. upwind of the available measurement sites. The width of the transition zone between ice-free conditions and the solid ice-pack is rather narrow, and probably less than 30 n. mi. wide. Therefore, the "effective ice edge" offshore specified in the wave model as the locus of 5/10 coverage is probably a reasonable measure of the fetch restriction.

Hindcast Evaluation: At Kopanoar, the model appeared to spin-up in time to capture the peak in wave height which occurred early on the 27th, just as the observed wind speeds drop. Observed and hindcast wave heights vary little thereafter. At Ukalerk, in the eastern region, the wave heights were quite low and hindcast accurately. Peak period was hindcast to be 1–2 seconds lower than observed. Basically the same type of measured-hindcast differences characterize the comparison at WR-190. At WR 194, winds are not available and the measurement record is incomplete, but the indications are that the hindcast wave height history is too high. WR-194 is in 14 m water depth, but the cause of the hindcast overspecification is more likely overspecification of wind speed, since this waverider is near the calm centre of the small scale low. WR-191, on the other hand is in the area west of WR-194 which probably experienced a wind speed history like that observed at Explorer III, as the measured peak late on the 26th is missing in the hindcast.

Summary: Hindcast-measured differences in this basically low intensity event appear to be dominated by the failure of the kinematic analysis to resolve a small scale cyclonic disturbance embedded in broad scale trough of low pressure extending over the central Canadian Beaufort. A reanalysis and regridding of the wind field at higher resolution could confirm this suspicion.

Storm #2 – September 28, 1978 – October 1, 1978

Synoptic Evolution: This case is a definite BOW Pattern 1 (eastward moving low). The centre of the parent low pressure system was located far north of the exploration areas, near 75°N, and the wind

flow over the Canadian Beaufort was basically westerly at speeds of around 20 knots. The Brooks range induced some enhancement of this westerly flow as indicated by coastal observations in the western part of the area offshore Herschel Island. As the low moved eastward, wind directions gradually veered from westerly to northwesterly with little change in speed. Wind speed and direction are specified quite well for this hindcast, as shown in the comparisons at Kopanoar and Ukalerk.

Ice Cover: The ice charts for this event indicated that the ice-pack was moving southward during the period hindcast. The 5/10 contour was interpolated between positions indicated on two ice charts (September 28th and October 1st) straddling the time of peak wave conditions. The interpolated contour lies basically east-west along 72°N of the exploration areas, though on the U.S. side of the Beaufort, it lies closer to 71.5°N, with lower concentrations southward to the shore. On the Canadian side, the charts indicate less than 1/10 concentration south of the pack ice.

Hindcast Evaluation: Waverider measured wave histories were available to two sites, both in intermediate water depths (30–50 m). Both of these locations show similar storm responses, as wave heights built from near calm conditions early on the 28th to reach its maximum height of about 2 m 24 hours later, with little change thereafter during the period hindcast. The hindcast began about 18 hours later than the beginning of the observed buildup, and thereafter the hindcast could benefit from additional spin-up period. As a result of the late start, the hindcast peak wave heights lag the observed by about 12 hours, but eventually the storm peak is well specified at both sites. Peak period is also well specified.

Summary: Overall, winds and sea states are well specified at two widely separated measurement sites in this case. Since the ice-edge is well north of the site, and winds are basically westerly, ice-induced fetch restrictions play a minor role in this storm, and peak seas are basically limited by upwind shoreline geometry, wind speed and, to a very limited extent, storm duration.

Storm #3 – August 16, 1981 – August 19, 1981

Synoptic Evolution: This case fits a BWO Pattern type 3 as a low developed in the southern Canadian Beaufort Sea on August 16 in a pre-existing trough. As the low was undergoing initial development, surface winds in the drilling areas were light and shifting from southeast to westerly. As the low moved rapidly northeastward and intensified, the westerly to west-northwesterly winds over the drilling areas increased to about 30 knots early on the 17th, and then decreased steadily as the storm centre moved further away. Observed surface wind histories were available at three sites. There are relatively small but temporally coherent differences between observed and modelled winds, mainly a slight underspecification of the storm peaks early on the 17th by about 4 knots at Kopanoar and Koakoak, and nearly 10 knots at Issungnak, where a lull around midday the 17th is also missed.

Ice Cover: The ice distribution was more complicated in this case than in the preceding cases, especially to the west of the measurement sites, where the ice chart indicated that a band of up to 7/10 coverage ice extended southeastward to the coast, from the main pack edge which lied along 72°N. For the adopted 5/10 contour (invariant with time through the hindcast), the implied fetch upwind of the measurement sites varied significantly for small changes in wind direction. Further adding to the

complexity is the indication of ice cover of lesser concentrations located well south and east of the main pack.

Hindcast Evaluation: At Kopanoar, only MANMAR wave estimates were available, and these suggest that the storm peak was underspecified by about 1 m. However, just 20 n. mi. to the east at Koakoak, the waverider record confirms a fairly accurate hindcast. To the south at Issungnak, the wave hindcast also lies within about 0.5 m of the waverider record leading up to the storm peak, while differences between MANMAR and waverider wave height estimates are larger than 1 m at times. The peak period associated with peak sea states is rather well specified at both waverider sites.

Summary: At waverider measurement sites, the wave hindcast verifies well, while at the MANMAR site, differences are larger. However, at sites with both MANMAR and waverider histories, differences between the alternate "observed" wave series are often larger than the difference between measured and hindcast wave height histories.

Storm #4 – August 31, 1981 – September 3, 1981

Synoptic Evolution: This case most resembles BWO Pattern 5, as a quasi-stationary pattern of strong northwesterly flow covered the Canadian Beaufort between a large high pressure over the western Beaufort and a large low pressure system over Banks Island. Surface winds were observed at three sites and range within 20–30 knots. Modelled wind directions and speeds agree closely with the observed winds at all sites, the small differences attributable to anemometer level variations (precise heights are not known) and averaging interval limitations.

Ice-Cover: The ice chart analyses are similar to those of the previous case, except that the shoreward ice extension of 5/10 or greater ice shown west of the exploration areas in the previous case (two weeks earlier) has been analyzed as having diminished in concentration to less than 5/10. Therefore the ice edge adopted for the hindcast placed the 5/10 contour near 72°N along virtually the entire Beaufort Sea. However, there is undoubtedly some ice south of this contour of quite variable concentration, and in areas quite close and to the west (and upwind) of the measurement sites.

Hindcast Evaluation: A striking feature of the wave hindcast of this case at all measurement sites is the overprediction of wave height, and corresponding overspecification of peak period. At Kopanoar, only MANMAR observations are available, and while at Koakoak, the MANMAR and waverider determination agree closely, at Issungnak the alternate estimates disagree greatly. Indeed, at Issungnak, it is hard to reconcile the waverider peak wave height of about 1 m in view of the MANMAR estimates of about 4 m.

Summary: In view of the well defined and rather accurately specified wind field in this case, it is tempting to attribute the positive bias in the wave height hindcast to the assumption of unrestricted fetch to the west of the measurement sites. This would suggest that even low concentrations of ice can inhibit wave growth in fetch-limited conditions and that a more physically correct treatment of ice within a wave model, together with a precise specification of the ice field, is required. However, before this conclusion can be accepted, the rather large differences between the MANMAR and

waverider wave estimates seen in this case should be investigated. This storm results were excluded from the overall error statistics shown in Tables 6.2 and 6.3 .

Storm #5 – September 20, 1982 – September 22, 1982

Synoptic Evolution: This is a classic BWO Pattern 7 event, characterized by prolonged and fairly steady east to east–northeast flow. Winds were not specified with uniform

accuracy in all areas however. At Explorer I, in the southern part of the measurement array, observed wind speeds were 30–40 knots, while analyzed winds were closer to 25 knots. At Explorer II and IV, located well offshore, measured and modeled winds were in good agreement, with peak wind speeds of about 30 knots. To the west, at Explorer II, modeled wind speeds were a few knots larger than observed.

Ice Cover: The ice–pack edge was well defined for this case and the 5/10 contour was taken to lie in an east–west orientation along the north of 73°N. In this easterly regime, therefore, ice does not affect the upwind fetch at all.

Hindcast Evaluation: There is a measurement site well east of the main exploration area nearshore (WR–206). The wave hindcast is positively biased there, but since there are no wind measurement stations nearby to validate the modelled winds, it is not possible to identify the source of this hindcast error. Sea states are rather low, however, in this area for this type of storm. At WR–204 the hindcast verifies well, despite the apparent underspecification of wind speed. Possibly, the observed winds at nearby Explorer I are biased high due to anemometer level or platform effects. Near Explorer II and IV, only MANMAR wave data are available, and definite evaluation is not advisable. However, at WR–205 in 14 m water depth, located just east of Explorer I, the sea state history is reproduced very well.

Summary: Differences between measured and hindcast wave histories are small. Sea states are specified well at most sites in this case.

6.5 OVERALL CONCLUSIONS

1. Where surface wind fields verify well against measured wind data, and where the ice edge is sharply defined and well located, the wave hindcasts verify well against waverider measurements, with scatter index in the order of 24% for H_s and 25% for T_p , and 0.44m and 2s RMSE for H_s and T_p , respectively. For peak–to–peak comparison, better error statistics were found (e.g. 0.38m RMS and 14.7% SI for H_s and 1.2s RMS and 15.5% SI for T_p).
2. Small scale features in the wind fields can induce significant percentage errors in peak sea states at least in storms of low–moderate intensity. In the most severe storms, small scale features should have less impact, though every attempt should be made to minimize wind errors in all storms hindcast.
3. Effect of partial ice cover may need to be accounted for in the wave hindcast process. This requires research into the effects of partial ice cover on the wave model source terms as well as on wave propagation, and very accurate determination of ice concentration in historical storms.

7.0 HINDCAST PRODUCTION

7.1 WIND FIELD HINDCAST

The wind fields for the final top 30 storms were specified using the techniques and procedures described previously. The wind fields for the "old" 15 storms which were previously hindcast for AES (Table 5.2) were reviewed, some cases needed to be extended to cover the entire storm duration and some cases needed further refinements. Wind fields were developed for the new 15 storms. The 6-hourly gridded wind fields (given at 10 m above MSL) were then input to the ODGP Beaufort Sea wave model.

7.2 ICE EDGE SPECIFICATIONS

The ice edge specifications were prepared for input to the wave model as described previously (all ice edge charts used in this study are provided in Appendix C). As mentioned, two regimes were considered:

- a) actual ice edge occurred during each storm; and
- b) climatological ice edge (i.e. 98%, 50% and 30% occurrences of any ice).

The actual ice edge was produced from careful analysis of the AES daily and weekly ice charts whereas the climatological ice edge was obtained from the semi-monthly charts of Agnew et al. (1987). The appropriate ice edge was digitized for each case. It was assumed that the ice edge remained constant during each storm, i.e. only one ice edge was used for each storm. The required ice edges were digitized and used as input to the wave model.

7.3 WAVE HINDCAST PRODUCTION

The ODGP Beaufort Sea spectral wave model was executed for the top 30 storms with the four different ice edge scenarios as mentioned above (i.e. total 120 runs). The hindcast results (both wind and wave) were archived and delivered to AES on magnetic tapes. The archived data included all gridded wind fields, all wave fields (H_s , T_p and vector mean direction) at all active (water) grid points. In addition detailed model hindcast results (i.e. wind speed, direction, wave height, period and direction, and directional wave spectral variance (15 frequencies x 24 directions) were provided at a selected 51 grid points in the model domain.

These 51 grid points were selected in the dominant open water region of the Canadian Beaufort Sea extending for 120°W to 150°W and from 69°N to 72°N. It covers all offshore hydrocarbon exploration areas. Figure 7.1 shows the 51 grid points at which the hindcast data were archived and extremal analysis results were provided.

For each storm, the peak significant wave height and corresponding peak period, wave mean direction, wind speed and direction were compiled, and other parameters were computed (i.e. ratios of H_{max}/H_s and H_c/H_s) at each of the 51 points. The peak H_s was identified at each of the 51 grid points. This information was used in the extremal analysis as described in Chapter 8.0 .

The peak significant wave height at each of the 51 grid point is given on a map of the study area for each storm as shown in Appendix E . As shown, the Minuk storm (September 16, 1985) was the most severe storm in the selected 30 cases. It produced a maximum significant wave height of 5.40 m at grid point #492 (approximately 70°N, 138°W) and about 5.0 m near the Minuk site. This storm was a subject of several studies by Esso Resources Canada Limited as it resulted in washing away the artificial island at the Minuk site. As shown in the next chapter, this storm would have a return period greater than 50 years. It should also be noted that the ice edge for this storm (Appendix C) was less than the median ice edge (i.e. smaller fetch), i.e. a larger wave height would have been produced if this storm was combined with a larger open water area. This is investigated further in the next chapter.

A summary of model hindcast results for each storm at a selected number of locations in the study area is presented in Table 7.1 . It provides peak wind speed and direction, peak H_s and corresponding T_p , and wave direction for the four ice edge scenarios.

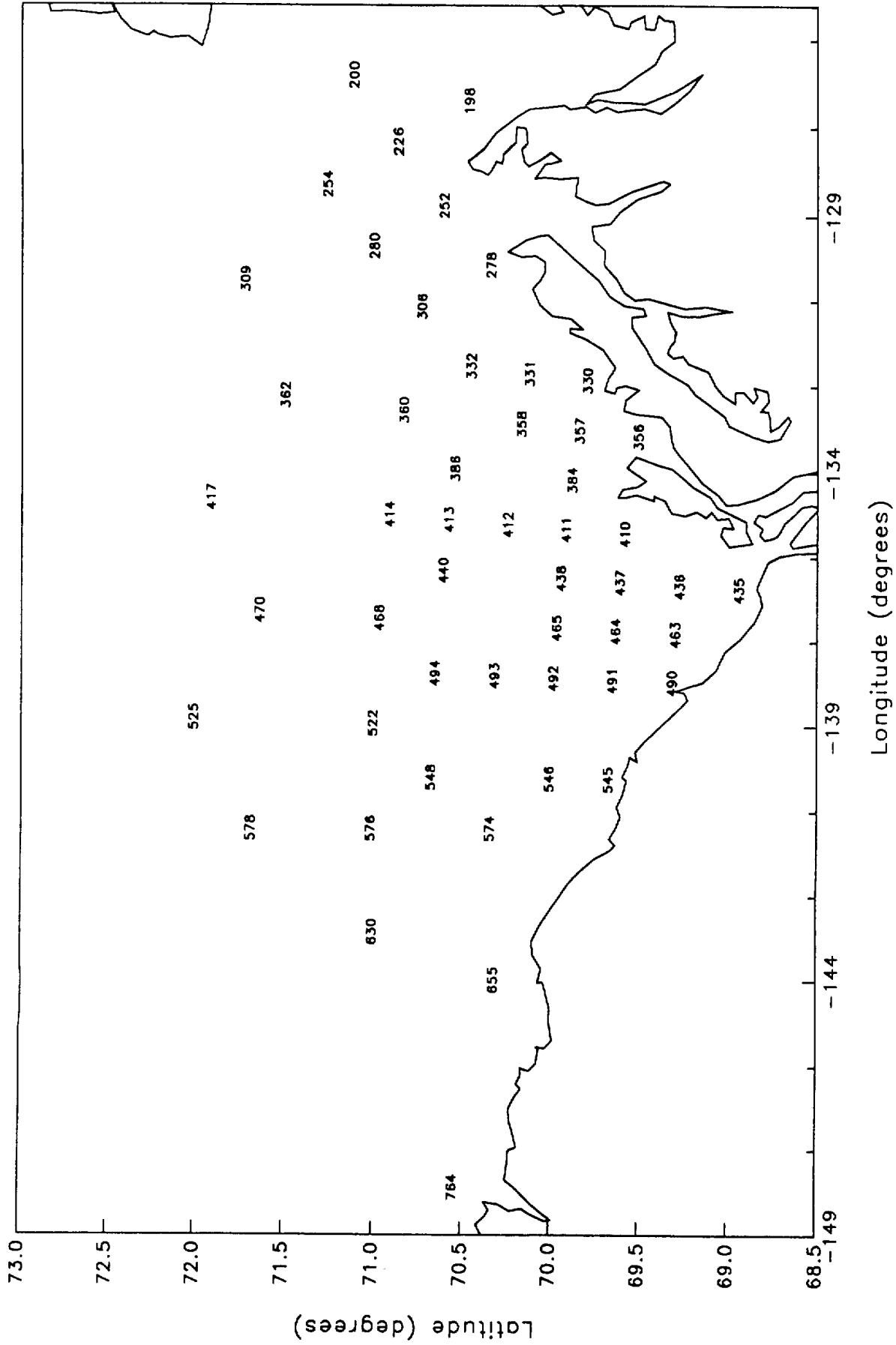


Figure 7.1 Selected 51 Grid Points At Which Model Hindcasts Were Archived

Table 7.1 Model Hindcast Results at Selected Locations

STORM PEAKS AT 360 AT 70.84N, 132.79W

| STORM | WIND | | REAL ICE EDGE | | | 98% OCCUR EDGE | | | 50% OCCUR EDGE | | | 30% OCCUR EDG | | |
|-------|------|-----|---------------|-----|-----|----------------|------|-----|----------------|------|-----|---------------|-----|-----|
| | SPD | DIR | HS | TP | VMD | HS | TP | VMD | HS | TP | VMD | HS | TP | VMD |
| 1 | 18.9 | 309 | 4.5 | 9.2 | 97 | 4.9 | 9.7 | 124 | 4.1 | 8.7 | 90 | --- | --- | --- |
| 2 | 14.9 | 270 | 3.4 | 8.2 | 89 | 3.9 | 8.8 | 98 | 2.9 | 7.1 | 57 | --- | --- | --- |
| 3 | 17.2 | 270 | 3.5 | 8.2 | 43 | 4.8 | 9.5 | 100 | 3.8 | 8.6 | 84 | --- | --- | --- |
| 4 | 16.3 | 24 | --- | --- | --- | 3.4 | 8.1 | 218 | 2.6 | 7.2 | 226 | --- | --- | --- |
| 5 | 15.4 | 77 | 3.3 | 8.1 | 259 | 3.3 | 8.1 | 259 | 3.3 | 8.0 | 261 | --- | --- | --- |
| 6 | 7.7 | 331 | 1.5 | 6.0 | 149 | 1.5 | 6.0 | 149 | 1.3 | 4.3 | 218 | --- | --- | --- |
| 7 | 13.4 | 230 | 2.9 | 7.6 | 55 | 2.9 | 7.6 | 55 | 2.9 | 7.6 | 54 | --- | --- | --- |
| 8 | 17.4 | 87 | 3.7 | 8.2 | 266 | 3.7 | 8.2 | 266 | 3.7 | 8.2 | 267 | --- | --- | --- |
| 9 | 9.2 | 314 | 2.2 | 7.1 | 112 | 2.3 | 7.2 | 121 | 2.1 | 7.1 | 107 | --- | --- | --- |
| 10 | 15.4 | 48 | 3.2 | 8.0 | 244 | 3.6 | 8.3 | 238 | 2.8 | 7.3 | 253 | --- | --- | --- |
| 11 | 15.9 | 98 | 3.0 | 7.2 | 271 | 3.0 | 7.2 | 270 | 3.0 | 7.2 | 273 | --- | --- | --- |
| 12 | 13.9 | 70 | 3.2 | 8.1 | 255 | 3.2 | 8.1 | 254 | 2.9 | 7.7 | 265 | --- | --- | --- |
| 13 | 16.1 | 99 | 3.3 | 7.4 | 276 | 3.3 | 7.5 | 275 | 3.1 | 7.3 | 280 | --- | --- | --- |
| 14 | 14.8 | 267 | 3.7 | 8.6 | 94 | 4.2 | 9.2 | 101 | 3.3 | 8.1 | 88 | --- | --- | --- |
| 15 | 16.2 | 320 | 3.2 | 7.4 | 144 | 3.5 | 8.1 | 147 | 2.4 | 6.2 | 133 | --- | --- | --- |
| 16 | 14.7 | 302 | 3.6 | 8.3 | 120 | 3.8 | 9.0 | 122 | 2.8 | 7.1 | 108 | --- | --- | --- |
| 17 | 15.7 | 310 | 3.3 | 7.7 | 128 | 4.2 | 9.5 | 132 | 3.0 | 7.3 | 102 | --- | --- | --- |
| 18 | 16.0 | 42 | 3.8 | 8.4 | 226 | 3.8 | 8.4 | 225 | 3.5 | 8.1 | 232 | --- | --- | --- |
| 19 | 20.9 | 310 | 4.4 | 9.2 | 124 | 4.6 | 9.3 | 121 | --- | --- | --- | --- | --- | --- |
| 20 | 16.6 | 290 | 4.0 | 8.6 | 110 | 4.4 | 9.3 | 112 | 3.5 | 8.1 | 102 | --- | --- | --- |
| 21 | 13.4 | 320 | 3.2 | 8.1 | 127 | 3.3 | 8.1 | 128 | 3.1 | 7.7 | 46 | --- | --- | --- |
| 22 | 15.6 | 88 | 3.4 | 8.2 | 263 | 3.4 | 8.2 | 263 | 3.4 | 8.2 | 264 | --- | --- | --- |
| 23 | 18.2 | 281 | 3.7 | 8.2 | 86 | 5.2 | 10.2 | 100 | --- | --- | --- | --- | --- | --- |
| 24 | 18.3 | 336 | --- | --- | --- | 4.4 | 8.6 | 160 | 3.5 | 7.2 | 161 | --- | --- | --- |
| 25 | 12.1 | 81 | --- | --- | --- | 2.2 | 5.9 | 263 | 2.1 | 5.9 | 268 | --- | --- | --- |
| 26 | 21.4 | 281 | --- | --- | --- | 6.2 | 10.9 | 106 | 5.4 | 10.4 | 93 | --- | --- | --- |
| 27 | 15.0 | 327 | 2.3 | 5.9 | 130 | 3.9 | 8.9 | 143 | 2.9 | 7.0 | 135 | --- | --- | --- |
| 28 | 15.7 | 138 | 3.0 | 7.1 | 308 | 3.0 | 7.1 | 308 | 3.0 | 7.1 | 309 | --- | --- | --- |
| 29 | 15.6 | 301 | 3.9 | 9.3 | 122 | 4.3 | 9.8 | 128 | 3.3 | 8.1 | 95 | --- | --- | --- |
| 30 | 17.9 | 319 | 3.7 | 8.1 | 122 | 4.4 | 9.2 | 134 | 2.8 | 7.1 | 115 | --- | --- | --- |

SPD: Wind speed in (m/s)

DIR: Wind direction (coming from)

HS: Significant wave height in (m)

TP: Peak period in (s)

VMD: Wave vector mean direction (towards)

Table 7.1 (cont'd)

STORM PEAKS AT 437 AT 69.61N, 136.17W

| STORM | WIND | | REAL ICE EDGE | | | 98% OCCUR EDGE | | | 50% OCCUR EDGE | | | 30% OCCUR EDG | | |
|-------|------|-----|---------------|------|-----|----------------|------|-----|----------------|------|-----|---------------|-----|-----|
| | SPD | DIR | HS | TP | VMD | HS | TP | VMD | HS | TP | VMD | HS | TP | VMD |
| 1 | 22.4 | 294 | 3.8 | 9.3 | 119 | 4.0 | 9.5 | 121 | 3.6 | 9.3 | 122 | 3.2 | 8.1 | 113 |
| 2 | 17.7 | 282 | 2.8 | 8.1 | 112 | 3.1 | 8.5 | 117 | 2.8 | 8.1 | 112 | --- | --- | --- |
| 3 | 18.2 | 273 | 2.8 | 8.1 | 101 | 3.5 | 9.6 | 113 | 3.1 | 8.5 | 106 | 2.8 | 8.1 | 101 |
| 4 | 15.1 | 30 | 2.1 | 7.2 | 203 | 2.4 | 8.2 | 203 | 2.2 | 7.4 | 203 | 2.0 | 7.1 | 204 |
| 5 | 11.6 | 20 | 2.1 | 8.4 | 193 | 2.1 | 8.5 | 192 | 2.0 | 8.4 | 198 | --- | --- | --- |
| 6 | 12.3 | 308 | 2.5 | 8.3 | 137 | 2.5 | 8.3 | 137 | 2.2 | 7.2 | 135 | 1.8 | 5.8 | 132 |
| 7 | 12.4 | 244 | 1.7 | 5.8 | 78 | 1.7 | 5.8 | 78 | 1.7 | 5.8 | 78 | 1.6 | 4.6 | 72 |
| 8 | 17.9 | 74 | 2.5 | 8.5 | 236 | 2.5 | 8.5 | 236 | 2.5 | 8.5 | 236 | 2.3 | 8.2 | 238 |
| 9 | 14.9 | 308 | 2.8 | 8.3 | 131 | 2.8 | 8.3 | 132 | 2.7 | 8.2 | 129 | 2.3 | 7.0 | 124 |
| 10 | 15.8 | 47 | 2.4 | 8.2 | 216 | 2.5 | 8.4 | 212 | --- | --- | --- | --- | --- | --- |
| 11 | 13.6 | 90 | 1.7 | 8.1 | 247 | 1.7 | 8.1 | 247 | 1.7 | 8.1 | 247 | 1.6 | 7.1 | 249 |
| 12 | 19.0 | 90 | 2.4 | 8.2 | 247 | 2.4 | 8.2 | 247 | 2.3 | 8.0 | 251 | --- | --- | --- |
| 13 | 16.9 | 92 | 1.9 | 7.1 | 259 | 1.9 | 7.1 | 259 | --- | --- | --- | --- | --- | --- |
| 14 | 14.4 | 272 | 2.5 | 8.4 | 109 | 2.7 | 9.3 | 112 | 2.2 | 7.1 | 105 | 1.9 | 5.7 | 100 |
| 15 | 14.5 | 337 | 2.3 | 7.2 | 160 | 2.5 | 8.0 | 159 | 1.9 | 5.8 | 160 | 1.8 | 5.6 | 158 |
| 16 | 13.1 | 297 | 2.4 | 8.0 | 130 | 2.5 | 8.4 | 130 | 2.2 | 7.1 | 124 | 1.9 | 5.7 | 119 |
| 17 | 12.5 | 313 | 2.1 | 7.3 | 147 | 2.5 | 8.6 | 144 | 2.0 | 7.1 | 141 | 1.7 | 5.7 | 136 |
| 18 | 15.1 | 16 | 2.7 | 8.4 | 198 | 2.7 | 8.6 | 189 | 2.7 | 8.3 | 199 | 2.3 | 7.1 | 202 |
| 19 | 19.8 | 310 | 3.5 | 9.3 | 134 | 3.7 | 9.4 | 134 | 2.8 | 7.1 | 131 | --- | --- | --- |
| 20 | 17.7 | 290 | 3.0 | 8.2 | 121 | 3.2 | 9.1 | 123 | 2.9 | 8.1 | 117 | 2.5 | 7.0 | 115 |
| 21 | 15.3 | 316 | 2.7 | 8.2 | 135 | 2.8 | 8.2 | 135 | 2.5 | 7.5 | 130 | 2.0 | 5.9 | 125 |
| 22 | 10.4 | 41 | 1.8 | 9.2 | 216 | 1.8 | 9.2 | 216 | 1.8 | 9.2 | 216 | 1.5 | 4.4 | 258 |
| 23 | 20.4 | 273 | --- | --- | --- | 4.0 | 10.3 | 112 | --- | --- | --- | --- | --- | --- |
| 24 | 18.0 | 324 | 2.7 | 7.1 | 148 | 3.1 | 8.3 | 151 | 3.0 | 8.1 | 150 | 2.7 | 7.1 | 150 |
| 25 | 16.5 | 111 | 1.8 | 4.3 | 279 | 1.8 | 4.3 | 278 | 1.8 | 4.3 | 278 | --- | --- | --- |
| 26 | 22.1 | 286 | 4.4 | 10.6 | 118 | 4.7 | 10.7 | 121 | 4.4 | 10.5 | 117 | 3.6 | 8.7 | 109 |
| 27 | 18.1 | 320 | 3.1 | 8.3 | 138 | 3.5 | 9.3 | 142 | 3.1 | 8.2 | 139 | 2.6 | 7.1 | 138 |
| 28 | 11.1 | 296 | 2.0 | 7.7 | 122 | 2.0 | 7.7 | 122 | 1.9 | 7.2 | 121 | 1.6 | 5.6 | 118 |
| 29 | 16.6 | 300 | 3.2 | 9.1 | 135 | 3.3 | 9.3 | 136 | 2.8 | 8.1 | 130 | 2.4 | 7.0 | 128 |
| 30 | 16.1 | 314 | 2.9 | 8.3 | 136 | 3.0 | 8.4 | 138 | 2.5 | 7.1 | 128 | 2.2 | 6.0 | 124 |

Table 7.1 (cont'd)

STORM PEAKS AT 463 AT 69.30N, 137.20W

| STORM | WIND | | REAL ICE EDGE | | | 98% OCCUR EDGE | | | 50% OCCUR EDGE | | | 30% OCCUR EDG | | |
|-------|------|-----|---------------|-----|-----|----------------|------|-----|----------------|-----|-----|---------------|-----|-----|
| | SPD | DIR | HS | TP | VMD | HS | TP | VMD | HS | TP | VMD | HS | TP | VMD |
| 1 | 19.3 | 302 | 3.8 | 9.2 | 129 | 3.8 | 9.3 | 130 | 3.6 | 8.6 | 128 | 3.1 | 7.4 | 123 |
| 2 | 15.0 | 290 | 2.7 | 7.2 | 116 | 3.0 | 8.3 | 125 | 2.8 | 7.2 | 117 | --- | --- | --- |
| 3 | 17.8 | 275 | 2.8 | 7.0 | 104 | 3.4 | 9.3 | 116 | 3.2 | 8.1 | 111 | 2.8 | 7.0 | 104 |
| 4 | 14.4 | 30 | 2.5 | 7.2 | 206 | 2.7 | 8.2 | 206 | 2.5 | 7.5 | 205 | 2.4 | 7.0 | 211 |
| 5 | 12.1 | 54 | 2.4 | 8.7 | 224 | 2.4 | 8.7 | 224 | 2.3 | 8.3 | 205 | --- | --- | --- |
| 6 | 12.9 | 310 | 2.8 | 8.1 | 142 | 2.8 | 8.1 | 142 | 2.5 | 7.1 | 140 | 2.2 | 5.9 | 137 |
| 7 | 11.4 | 219 | 1.7 | 4.9 | 51 | 1.7 | 4.9 | 51 | 1.7 | 4.9 | 51 | 1.7 | 4.7 | 48 |
| 8 | 15.3 | 71 | 2.7 | 8.8 | 232 | 2.7 | 8.8 | 232 | 2.7 | 8.7 | 232 | 2.5 | 8.1 | 235 |
| 9 | 14.0 | 311 | 2.9 | 8.1 | 138 | 2.9 | 8.1 | 138 | 2.8 | 7.6 | 137 | 2.4 | 6.7 | 131 |
| 10 | 14.3 | 54 | 2.6 | 8.1 | 220 | 2.8 | 8.4 | 218 | --- | --- | --- | --- | --- | --- |
| 11 | 12.9 | 90 | 2.1 | 6.6 | 249 | 2.1 | 6.6 | 249 | 2.1 | 6.6 | 249 | 2.0 | 6.2 | 252 |
| 12 | 18.5 | 90 | 2.7 | 8.1 | 251 | 2.7 | 8.1 | 251 | 2.7 | 7.9 | 252 | --- | --- | --- |
| 13 | 16.3 | 92 | 2.4 | 6.9 | 261 | 2.4 | 6.9 | 261 | --- | --- | --- | --- | --- | --- |
| 14 | 13.6 | 272 | 2.5 | 8.2 | 112 | 2.6 | 9.3 | 115 | 2.2 | 6.9 | 107 | 2.0 | 5.6 | 100 |
| 15 | 12.6 | 356 | 2.3 | 7.0 | 170 | 2.5 | 7.4 | 168 | 2.0 | 5.8 | 171 | 2.0 | 5.7 | 170 |
| 16 | 11.5 | 300 | 2.3 | 7.2 | 133 | 2.5 | 7.8 | 132 | 2.2 | 7.0 | 129 | 2.0 | 5.7 | 123 |
| 17 | 11.1 | 319 | 2.2 | 7.1 | 147 | 2.4 | 8.1 | 146 | 2.2 | 7.0 | 145 | 1.9 | 5.7 | 144 |
| 18 | 16.4 | 21 | 3.1 | 8.4 | 200 | 3.1 | 8.4 | 200 | 3.0 | 8.3 | 201 | 2.7 | 7.3 | 202 |
| 19 | 18.1 | 310 | 3.5 | 8.6 | 137 | 3.6 | 9.2 | 137 | 2.7 | 6.9 | 133 | 2.2 | 5.9 | 125 |
| 20 | 15.5 | 290 | 2.8 | 7.5 | 125 | 3.1 | 9.2 | 127 | 2.8 | 7.2 | 122 | 2.5 | 6.3 | 117 |
| 21 | 15.1 | 313 | 2.9 | 7.7 | 137 | 3.0 | 8.0 | 137 | 2.7 | 7.2 | 133 | 2.2 | 5.8 | 126 |
| 22 | 8.8 | 34 | 1.9 | 9.2 | 217 | 1.9 | 9.2 | 217 | 1.9 | 9.2 | 217 | 1.7 | 6.9 | 232 |
| 23 | 20.7 | 268 | --- | --- | --- | 3.8 | 9.4 | 113 | --- | --- | --- | --- | --- | --- |
| 24 | 16.8 | 321 | 2.8 | 7.1 | 151 | 3.2 | 8.2 | 153 | 3.1 | 7.7 | 152 | 2.8 | 7.1 | 158 |
| 25 | 15.6 | 100 | 2.3 | 6.6 | 270 | 2.3 | 6.5 | 268 | 2.3 | 6.6 | 269 | --- | --- | --- |
| 26 | 21.1 | 283 | 4.2 | 9.8 | 121 | 4.3 | 10.4 | 123 | 4.2 | 9.8 | 120 | 3.5 | 8.2 | 110 |
| 27 | 16.8 | 320 | 3.2 | 8.2 | 142 | 3.6 | 9.2 | 144 | 3.1 | 8.0 | 143 | 2.7 | 7.0 | 141 |
| 28 | 11.3 | 300 | 2.1 | 6.9 | 125 | 2.1 | 6.9 | 125 | 2.0 | 6.4 | 125 | 1.8 | 5.7 | 118 |
| 29 | 15.8 | 300 | 3.3 | 9.1 | 139 | 3.3 | 9.2 | 139 | 2.9 | 7.7 | 136 | 2.5 | 6.6 | 133 |
| 30 | 14.9 | 317 | 3.0 | 8.0 | 141 | 3.1 | 8.3 | 142 | 2.6 | 7.0 | 137 | 2.3 | 5.9 | 130 |

Table 7.1 (cont'd)

STORM PEAKS AT 492 AT 69.99N, 138.05W

| STORM | WIND | | REAL ICE EDGE | | | 98% OCCUR EDGE | | | 50% OCCUR EDGE | | | 30% OCCUR EDG | | |
|-------|------|-----|---------------|------|-----|----------------|------|-----|----------------|------|-----|---------------|-----|-----|
| | SPD | DIR | HS | TP | VMD | HS | TP | VMD | HS | TP | VMD | HS | TP | VMD |
| 1 | 19.5 | 310 | 4.6 | 9.4 | 129 | 4.7 | 9.5 | 130 | 4.2 | 8.4 | 123 | 2.5 | 7.1 | 115 |
| 2 | 17.4 | 290 | 3.2 | 7.2 | 105 | 3.8 | 9.1 | 115 | 3.2 | 7.3 | 105 | --- | --- | --- |
| 3 | 19.8 | 275 | 2.7 | 6.9 | 20 | 4.6 | 9.9 | 110 | 3.8 | 8.1 | 101 | 2.7 | 6.9 | 20 |
| 4 | 14.1 | 40 | 2.7 | 7.2 | 225 | 3.2 | 8.1 | 226 | 2.8 | 7.4 | 225 | 2.3 | 7.0 | 235 |
| 5 | 14.9 | 70 | 3.5 | 8.8 | 244 | 3.5 | 8.8 | 244 | 3.4 | 8.5 | 244 | --- | --- | --- |
| 6 | 14.9 | 320 | 3.4 | 8.2 | 148 | 3.4 | 8.2 | 148 | 2.9 | 7.1 | 164 | 1.9 | 5.7 | 135 |
| 7 | 13.6 | 240 | 2.3 | 5.9 | 67 | 2.3 | 5.9 | 67 | 2.3 | 5.9 | 67 | 1.8 | 5.7 | 32 |
| 8 | 16.0 | 70 | 3.9 | 9.1 | 246 | 3.9 | 9.2 | 245 | 3.9 | 9.1 | 246 | 3.2 | 8.1 | 253 |
| 9 | 19.2 | 310 | 3.6 | 7.6 | 135 | 3.7 | 7.7 | 136 | 3.5 | 7.3 | 131 | 2.3 | 6.6 | 120 |
| 10 | 17.5 | 50 | 3.6 | 8.1 | 255 | 4.0 | 9.1 | 232 | 3.7 | 8.2 | 251 | --- | --- | --- |
| 11 | 14.9 | 90 | 3.1 | 8.0 | 258 | 3.1 | 8.0 | 258 | 3.1 | 8.0 | 258 | 2.6 | 7.0 | 266 |
| 12 | 19.5 | 90 | 3.9 | 8.2 | 259 | 3.9 | 8.2 | 258 | 3.8 | 8.2 | 261 | --- | --- | --- |
| 13 | 18.0 | 90 | 3.6 | 8.0 | 268 | 3.6 | 8.0 | 268 | 2.6 | 7.3 | 258 | --- | --- | --- |
| 14 | 14.9 | 280 | 3.2 | 8.2 | 106 | 3.5 | 9.5 | 109 | 2.7 | 6.9 | 97 | 1.9 | 5.7 | 33 |
| 15 | 12.0 | 0 | 2.0 | 5.8 | 182 | 2.7 | 7.5 | 171 | 1.9 | 5.7 | 177 | 1.4 | 4.4 | 180 |
| 16 | 12.4 | 299 | 2.7 | 7.1 | 129 | 3.1 | 8.2 | 132 | 2.5 | 6.0 | 116 | 1.6 | 5.5 | 108 |
| 17 | 10.9 | 319 | 2.2 | 6.3 | 151 | 3.0 | 9.0 | 144 | 2.2 | 6.3 | 148 | 1.5 | 5.5 | 150 |
| 18 | 15.9 | 30 | 3.9 | 9.1 | 214 | 4.0 | 9.1 | 214 | 3.7 | 8.6 | 217 | 2.6 | 7.2 | 223 |
| 19 | 19.0 | 310 | 4.0 | 8.4 | 135 | 4.3 | 9.1 | 136 | --- | --- | --- | --- | --- | --- |
| 20 | 17.9 | 290 | 3.1 | 7.2 | 117 | 3.9 | 8.8 | 120 | 3.2 | 7.2 | 112 | 2.1 | 6.0 | 105 |
| 21 | 14.4 | 320 | 3.3 | 8.1 | 139 | 3.4 | 8.2 | 140 | 2.9 | 7.2 | 132 | 1.9 | 5.7 | 43 |
| 22 | 10.4 | 57 | 2.9 | 9.2 | 239 | 2.9 | 9.2 | 239 | 2.9 | 8.9 | 245 | 2.3 | 6.9 | 270 |
| 23 | 24.6 | 270 | --- | --- | --- | 5.3 | 9.6 | 107 | --- | --- | --- | --- | --- | --- |
| 24 | 16.9 | 320 | 2.1 | 6.3 | 178 | 3.6 | 7.8 | 156 | 3.2 | 7.2 | 152 | 2.2 | 6.3 | 179 |
| 25 | 18.0 | 110 | 3.4 | 7.3 | 283 | 3.5 | 7.4 | 282 | 3.4 | 7.4 | 282 | --- | --- | --- |
| 26 | 23.1 | 285 | 5.4 | 10.3 | 113 | 5.7 | 10.6 | 117 | 5.3 | 10.3 | 112 | 3.0 | 8.1 | 94 |
| 27 | 16.9 | 320 | 3.5 | 8.0 | 137 | 4.3 | 9.3 | 146 | 3.3 | 7.2 | 138 | 2.1 | 5.8 | 137 |
| 28 | 15.3 | 120 | 2.7 | 6.0 | 288 | 2.7 | 6.0 | 288 | 2.7 | 6.0 | 288 | 2.5 | 6.0 | 295 |
| 29 | 16.9 | 300 | 4.1 | 9.1 | 138 | 4.2 | 9.3 | 138 | 3.2 | 7.2 | 138 | 2.0 | 5.7 | 138 |
| 30 | 15.4 | 320 | 3.3 | 8.0 | 142 | 3.7 | 8.4 | 142 | 2.7 | 6.1 | 126 | --- | --- | --- |

Table 7.1 (cont'd)

STORM PEAKS AT 574 AT 70.35N, 141.00W

| STORM | WIND | | REAL ICE EDGE | | | 98% OCCUR EDGE | | | 50% OCCUR EDGE | | | 30% OCCUR EDG | | |
|-------|------|-----|---------------|-----|-----|----------------|------|-----|----------------|-----|-----|---------------|-----|-----|
| | SPD | DIR | HS | TP | VMD | HS | TP | VMD | HS | TP | VMD | HS | TP | VMD |
| 1 | 20.4 | 312 | 4.2 | 8.5 | 132 | 4.5 | 9.3 | 132 | 3.5 | 7.3 | 128 | --- | --- | --- |
| 2 | 18.4 | 290 | --- | --- | --- | 3.4 | 7.7 | 118 | --- | --- | --- | --- | --- | --- |
| 3 | 18.1 | 275 | --- | --- | --- | 4.1 | 9.6 | 112 | 2.3 | 6.9 | 88 | --- | --- | --- |
| 4 | 12.1 | 41 | --- | --- | --- | 2.8 | 7.7 | 232 | --- | --- | --- | --- | --- | --- |
| 5 | 13.2 | 73 | 3.4 | 8.5 | 254 | 3.4 | 8.6 | 253 | 3.2 | 8.7 | 258 | --- | --- | --- |
| 6 | 13.3 | 334 | 2.9 | 7.4 | 164 | 3.0 | 7.5 | 164 | 1.7 | 5.7 | 159 | --- | --- | --- |
| 7 | 11.0 | 240 | 1.8 | 5.6 | 66 | 1.8 | 5.6 | 66 | 1.8 | 5.6 | 66 | --- | --- | --- |
| 8 | 14.2 | 80 | 3.8 | 8.9 | 259 | 3.8 | 9.1 | 259 | 3.6 | 9.2 | 261 | --- | --- | --- |
| 9 | 15.7 | 320 | 2.8 | 7.0 | 145 | 2.9 | 7.1 | 147 | 2.6 | 6.0 | 143 | --- | --- | --- |
| 10 | 18.7 | 87 | 3.7 | 8.1 | 267 | 4.2 | 8.8 | 262 | --- | --- | --- | --- | --- | --- |
| 11 | 12.9 | 90 | 3.2 | 8.3 | 265 | 3.2 | 8.3 | 265 | 3.1 | 8.3 | 267 | --- | --- | --- |
| 12 | 19.0 | 100 | 4.2 | 8.6 | 269 | 4.2 | 8.7 | 268 | 3.9 | 8.5 | 271 | --- | --- | --- |
| 13 | 16.0 | 86 | 3.8 | 8.5 | 269 | 3.8 | 8.5 | 269 | --- | --- | --- | --- | --- | --- |
| 14 | 14.8 | 274 | 3.0 | 8.1 | 102 | 3.4 | 9.4 | 106 | 1.8 | 5.7 | 81 | --- | --- | --- |
| 15 | 9.9 | 351 | --- | --- | --- | 1.9 | 5.8 | 159 | --- | --- | --- | --- | --- | --- |
| 16 | 11.7 | 304 | --- | --- | --- | 2.7 | 7.2 | 135 | --- | --- | --- | --- | --- | --- |
| 17 | 10.6 | 313 | --- | --- | --- | 2.9 | 8.3 | 139 | 1.5 | 5.5 | 147 | --- | --- | --- |
| 18 | 13.9 | 20 | 3.4 | 8.6 | 220 | 3.5 | 8.6 | 219 | 3.0 | 7.4 | 222 | --- | --- | --- |
| 19 | 16.3 | 307 | 2.8 | 7.0 | 133 | 3.3 | 7.8 | 135 | --- | --- | --- | --- | --- | --- |
| 20 | 16.7 | 280 | --- | --- | --- | 3.3 | 8.1 | 116 | 1.9 | 5.7 | 99 | --- | --- | --- |
| 21 | 12.9 | 320 | 2.8 | 7.5 | 146 | 3.0 | 8.0 | 147 | 2.4 | 7.0 | 138 | --- | --- | --- |
| 22 | 12.2 | 80 | 3.1 | 8.2 | 255 | 3.1 | 8.2 | 255 | 3.0 | 8.3 | 258 | --- | --- | --- |
| 23 | 22.2 | 284 | --- | --- | --- | 4.7 | 9.3 | 116 | --- | --- | --- | --- | --- | --- |
| 24 | 14.9 | 316 | --- | --- | --- | 2.7 | 6.7 | 155 | 1.9 | 5.8 | 150 | --- | --- | --- |
| 25 | 19.3 | 110 | 4.0 | 8.4 | 285 | 4.1 | 8.4 | 283 | 4.0 | 8.4 | 285 | --- | --- | --- |
| 26 | 23.5 | 290 | 4.8 | 9.2 | 116 | 5.4 | 10.1 | 122 | 4.7 | 9.2 | 114 | --- | --- | --- |
| 27 | 16.6 | 324 | 2.9 | 7.0 | 141 | 3.9 | 8.4 | 147 | 2.0 | 5.8 | 143 | --- | --- | --- |
| 28 | 9.5 | 117 | 2.5 | 7.4 | 281 | 2.5 | 7.5 | 279 | 2.4 | 7.4 | 283 | --- | --- | --- |
| 29 | 15.8 | 310 | 3.7 | 8.4 | 143 | 3.8 | 8.6 | 143 | 2.4 | 6.0 | 128 | --- | --- | --- |
| 30 | 14.2 | 320 | --- | --- | --- | 3.2 | 7.5 | 146 | --- | --- | --- | --- | --- | --- |

8.0 EXTREMAL ANALYSIS OF HINDCAST DATA

8.1 BASIC APPROACH

Given the typical configuration of the mean ice edge in the Canadian Beaufort and the importance of northwesterly and westerly winds on the extreme wind climate, it is natural to expect that the ice climate and the storm climate both affect the extreme wave climate. A proper treatment of this interaction has never been implemented for several reasons. Most of all, the interaction of the cyclone properties (tracks, frequencies, intensities) and the ice climate, if any, is not well understood in most areas. On the one hand, if they are linked as most approaches assume, then one need only to hindcast historical events in which the joint occurrence of strong storms and open ice conditions provide the high wave occurrence. Extrapolation of the population of occurrences above a threshold provides the extreme wave climate, then severe historical storms which happened in a short historical period not to have occurred jointly with open-water, would have not been properly considered. Given a long enough period of history, perhaps 100 years, this probably would not matter. But given only 20 years, we believe the possibility that the storm and ice climates are independent should be considered more rigorously. As discussed in chapter 2.0, Empirical Orthogonal Function (EOF) technique may be used in this case. However this is beyond the scope of this study and should be the subject of future investigations.

A relatively simple treatment of the joint probabilities may be formulated as follows:

1. Select an extreme storm population without regard to the actual ice cover except, of course, only select storms from within the calendar period susceptible to open water (i.e. June – October); it would be desirable that the size of the population be large enough to include also the top-ranked storms which occurred jointly with fairly open-water conditions and which therefore represent the high-wave events within the 20–30 years period sampled;
2. Develop effective over-water wind fields for each storm;
3. Hindcast each storm a number of times (i.e. 4 in the present study): one with the actual ice cover and the rest with an ice edge specified at positions with a given probability of occurrence (i.e. 98%, 50%, 30%) such as shown in Appendix C which corresponds to the bi-weekly intervals;
4. At each target grid point of interest subject the population of peak storm wave heights generated to the following extrapolations, using an appropriate extremal distribution:
 - a) N storms in Y years (where N is the actual number of storms and Y is the actual number of years, i.e. 20), for sub-population generated in hindcasts which used the actual ice edge.
 - b) N storms in Y years for the code of the three separate sub-populations developed for the ice edge for each probability level.
 - c) $N \times 3$ storms in $Y \times 3$ years, where all peaks corresponding to all probability levels are grouped together (i.e. 90 storms in 60 years).

Each of the above analyses will yield a series of extreme significant wave heights as a function of return period. The first series (a) corresponds more or less to the traditional approach. The second

series (b) may be quite useful in defining extremes for certain engineering problems where the extreme wave climate conditioned on a specified ice condition (say the ice conditions in a year in which a certain construction project is to be carried out) is more important than the long term extreme wave climate. The third series (c) will correspond to the best estimate of the true extreme wave distribution if the storm climatology and the ice cover climatology are taken as independent, which we may expect to be the case in the Canadian Beaufort.

For each series of hindcasts stratified as above, the usual approaches to estimating parameters associated with the extreme significant waves may be followed. Our standard extremal analysis software accounts for variable storm build-up and decay rates in the specification of maximum individual wave height (H_{\max}), crest height (H_c), and estimates peak periods using correlations developed from the hindcast database. It includes different distributions (e.g. Gumbel, Borgman) and a number of fitting techniques (e.g. Linear regression, method of moments and maximum likelihood method). It provides graphical representation of results with 90% and 95% confidence limits plotted. For the present study, and in order to be consistent with other similar studies we carried out for the east and west coasts, Gumbel distribution with method of moment fit is used to provide extreme value estimates as described below.

8.2 ANALYSIS TECHNIQUE

The wave model provided time histories of the following quantities at each grid point of the selected 51 sites which are used in the statistical analysis of extremes:

| | | |
|------------|---|--|
| H_s | = | significant wave height (m) |
| T_p | = | spectral peak period (s) |
| θ_d | = | vector mean wave direction (degrees-going towards) |
| W_s | = | wind speed (m/s) |
| θ_w | = | wind direction (degrees-coming from) |

The basic approach was to carry out site specific extremal analysis of hindcast peaks-over-threshold (POT), at each of the selected grid locations. Site averaging was not considered necessary or desirable for the following reasons:

- 1) a reasonably large number of storms were hindcast, thereby providing a reasonably large population of peaks at each grid location;
- 2) the meteorological properties of storms responsible for wave generation vary gently across basins. This tends to minimize the kind of sampling variations which site averaging is intended to suppress; and
- 3) the site specific approach may preserve real variations in extremes of wave height and period, associated with fine-scale variations in the complicated shoreline geometry which bounds the study area.

The objective of the analysis was to determine long term statistical distributions of significant and maximum individual wave height, crest height, and associated wind speed, for sub-populations of storms stratified into sectors of wave approach direction for selected grid points, and omni-directional extremes at all points. It was found, however, that no more than two broad directional sectors (NW and NE) could be justified at any point based upon the given hindcast population of storms. The number of storms in each

directional sector was not sufficient to provide reasonable population for directional extreme analysis. Therefore only omni-directional extreme analysis was carried out in the present study. Finally, estimates of extremes for quantities which were not extrapolated, such as T_p , and quantities extrapolated, such as H_s were provided. Correlations were developed from the hindcast data at each grid point between such quantities.

In the remainder of this section, a more detailed description of each of the key steps of the statistical analysis is given. The statistical models and fitting techniques are well established and have been described in several previous studies (e.g. Muir and El-Shaarawi, 1986, see also CCC, 1991).

8.3 CALCULATION OF MAXIMUM AND CREST HEIGHTS

It is by now well known that the statistics of individual wave heights and crest heights in naturally occurring sea states deviate from predictions of the theoretical Rayleigh distribution. A large number of alternative distributions have been proposed. We have adopted the empirical distribution of Forristall (1978) for maximum individual wave height, and the Jahns–Wheeler distribution with Haring, Osborne, and Spencer’s (HOS) empirical constants (Haring and Heideman, 1978) for crest height in a wide range of water depths. HOS have also proposed a distribution of maximum individual wave heights which nominally provides maximum heights about 2 percent lower than Forristall’s, but whose constants may be adjusted slightly to provide essentially the same results as Forristall (1978).

The various distributions cited above provide estimates of maximum wave height (H_{max}) and crest height (H_c) in runs of n individual waves, expressed usually as zero-crossing waves. In our standard approach, we use Borgman’s (1973) integral expression to account for the effect of the actual buildup and decay for each individual storm on the effective number of waves in a storm at a site. This expression used significant wave period, T_s , to relate the period properties of the seaway to the effective number of individual waves. Other approaches have included the use of an average normalized buildup and decay for all storms, or the simple adoption of a constant storm duration. The computation may also be carried out with different relationships between T_s and zero-crossing period, T_z , and properties of the hindcast spectrum, such as T_p or the spectral moments.

In the calculation of H_{max} in this study, the distribution of Forristall (1978) and the method of Borgman (1973) was applied throughout. The adopted H_{max} at each site and in each storm was taken as the median of the fitted distribution. This method uses the significant wave period, T_s , directly from the hindcast spectrum as computed from the zeroth and first moments (M_0 and M_1).

In the calculation of H_c , the method of HOS was adopted, except that as for H_{max} the actual buildup and decay in each storm was used following the method of Borgman (1973). In this calculation, T_z was calculated from T_p using the constant ratio T_z/T_p of 0.74 found empirically to characterize storm sea states in extratropical storms.

The analysis techniques were described in more detail in the Canadian Climate Centre (1991). It should be noted here that the above techniques are derived for deepwater wave conditions. Other techniques may be applied to site specific shallow water sites.

8.4 EXTREMAL ANALYSIS METHODS

The objective of the extremal analysis was to describe extremes at all contiguous (51) grid locations (see Figure 7.1):

- H_s versus risk (i.e. annual exceedance probability or return period)
- W_s versus risk (wind speed which corresponds to the peak H_s in each storm).

At a selected subset of grid locations a more detailed analysis of the extremes was carried out in order to determine:

- 1) effective ratios of H_{\max}/H_s and H_c/H_s based on the analysis described above;
- 2) H_{\max} and H_c versus risk (or return period); and
- 3) peak spectral periods T_p associated with peak H_s from the relation $T_p = A (H_s)^B$.

At these "representative" grid locations, a further analysis of the extremes was considered. This included sensitivity of extremes to assumed distribution, fitting thresholds, and directional stratification.

The results of the above analyses were presented in both tabular and graphical forms. The following methods were applied in the analysis.

Extreme Value Distribution

The recommended extreme value distribution is the Gumbel:

$$\Pr \{x \leq X\} = \exp [-\exp (-(x-a)/b)]$$

Borgman distribution was also applied for comparison with Gumbel:

$$\Pr \{x \leq X\} = \exp [-\exp (-(x^2-a)/b)]$$

where x is the parameter to be fitted (e.g. H_s); a and b are constants determined from the fitting of the hindcast data.

The chosen fitting scheme is the method of moments (MOM). This is in line with what AES use in their Marine Statistics (MAST) System and also previous hindcast studies carried out by MPL/OWI for the east coast and west coast of Canada. The Maximum Likelihood Method (MLM) was also checked and was found to produce results similar to those produced by the Method of Moments.

For most environmental data, the Gumbel distribution, fitted by the method of moments has been accepted as appropriate for representing the probability distribution for extremes. As described by Muir and El-Shaarawi (1986), the method of moments is simple, robust, and is unbiased for the Gumbel type distribution. The method involves equating the sample moments (i.e. mean and variance) to the moments derived from the distribution and solving for the estimated parameters. In the present study, the so-called plotting position was determined using the "exact" expression given by Carter and Challenor (1983).

Return Period

The return period, T , is calculated from the cumulative distribution function:

$$P_T = 1 - \frac{Y}{NT}$$

where N is the number of samples from Y years. Correlating the candidate distribution, $\Pr \{x \leq X\}$, to the above distribution of return period T yields:

$$X_T = [a - b \ln (-\ln (P_T))]^C$$

where $c = 1$ for Gumbel and 0.5 for Borgman distributions.

Numerical Solution

The Gumbel distribution fitted to the extreme value series (whether annual maximum or peak-over-threshold) by the method of moments is simply represented by:

$$X_T = x_{\text{mean}} + K_T \cdot s$$

where X_T is the value of the variable equalled or exceeded once in the return period T ; x_{mean} and s are the mean and the standard deviation respectively, of the hindcast series of extremes; K_T is a frequency factor dependent on the return period obtained from:

$$K_T = -(\sqrt{6/\pi}) \{0.5772 + \ln [\ln(T/(T-1))]\}$$

Confidence Limits

The extreme values calculated from the above approach represent the "best fit" estimates. However it is necessary to provide the confidence intervals for this estimate (e.g. 90% or 95%). The confidence interval is given by the range:

$$X_T - t(\alpha)s_e \text{ to } X_T + t(\alpha)s_e$$

where: $s_e = \beta \cdot s/n$

$$\beta = (1 + 1.14 K_T + 1.1 K_T^2)$$

and $t(\alpha)$ is the student t -distribution value corresponds to confidence level α for n samples.

The span of the upper limit (UL) to Lower Limit (LL) values normalized by the best fit (i.e., $[UL - LL]/\text{mean}$) is a relative measure of the goodness-of-fit. It should be noted that these confidence limits address only statistical characteristics of input data, and not the possible errors in storm selection and hindcast accuracy.

All other parameters (i.e. T_p , H_{max} and H_c) are derived from the estimated extreme H_s for given return periods (or probability of occurrence). The derived values are based on the mean or best-fit values of H_s and the methods described in the previous section. The above equations were used to provide the desired extremes both in tabular and graphical forms as shown in the following section.

8.5 ANALYSIS RESULTS

The hindcast peak significant wave height for each storm at each of the selected 51 grid points (Appendix E) were input to the extremal analysis program to produce the expected design values for the following return periods:

2, 5, 10, 25, 50 and 100 years.

This was done for the four groups of ice edge scenarios:

- 1) actual ice edge
- 2) 98% occurrences of ice edge
- 3) 50% occurrences of ice edge

- 4) 30% occurrences of ice edge

Additional run was made using all storms with the three climatological ice edge combined, i.e. total number of storms $N = 30$ storms \times 3 ice edge scenarios = 90 storms, total number of years $Y = 20$ years \times 3 ice edges = 60 years. It should be noted that the number of storms (N) at a given grid point in each group depends on the location of the site (grid point) with respect to ice field (i.e. if the grid point in question happened to be in the ice, there will be no hindcast value for this particular storm, and the total valid events or storms would be 29, and so on).

8.5.1 Sensitivity Analysis

Detailed extremal analysis was carried out at a number of grid points in the study area. The results are discussed below. The grid points at which the detailed analysis was carried out are:

| <u>Grid Point #</u> | <u>Latitude</u> | <u>Longitude</u> | <u>Model Water Depth (m)</u> |
|---------------------|-----------------|------------------|------------------------------|
| 360 | 70.84 | 132.79 | 56.50 |
| 384 | 69.88 | 134.15 | 10.10 |
| 437 | 69.61 | 136.17 | 8.65 closest to Minuk |
| 463 | 69.30 | 137.20 | 18.60 |
| 492 | 69.99 | 138.05 | 136.30 |
| 574 | 70.35 | 141.00 | 174.10 |
| 435 | 68.94 | 136.32 | 7.50 |
| 464 | 69.64 | 137.14 | 30.15 |

The results are presented in Figures 8.1 – 8.5 . The results are provided for the actual ice edge scenario.

Effect of Wave Height Threshold

Extremal analysis was carried out with different wave height thresholds for each population at selected grid points. In the selection of the thresholds; first, all events were used in the extremal analysis; second, the thresholds were chosen such that the remaining population produced best fit (best regression correlation).

It was found, in general, the lower thresholds provided slightly higher extreme wave heights than those calculated with higher thresholds, at large return periods (50–100 years).

Gumbel Versus Borgman Distributions

A number of extreme value distributions and fitting techniques were checked (i.e. Gumbel versus Borgman distribution using MOM or MLM fit). Figure 8.1 – 8.5 present the extremal analysis results using Gumbel and Borgman distributions.

It can be concluded from the above that the extremal analysis results are slightly affected by the type of distribution tested and the threshold value used with Gumbel providing higher values than Borgman. In the final analysis, the Gumbel distribution was used with the top number of storms which produced the best-fit regression line (i.e. the number of storms and the thresholds used in the extremal analysis varied from one grid point to another, for each ice edge scenario, as shown in the next section).

GRID POINT 360 AT 70.840 N, 132.79 W

GUMBEL - Method of Moments

23 storms

Wave height threshold = 2.90 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | 10% U.L. (m) | TP (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------------|--------|----------|--------|
| 2 | 3.5 | 3.6 | 3.6 | 8.1 | 6.4 | 3.6 |
| 5 | 3.9 | 4.1 | 3.6 | 8.6 | 7.1 | 3.9 |
| 10 | 4.1 | 4.4 | 3.6 | 8.9 | 7.5 | 4.2 |
| 30 | 4.5 | 4.9 | 3.6 | 9.3 | 8.2 | 4.6 |
| 50 | 4.6 | 5.1 | 3.6 | 9.5 | 8.5 | 4.7 |
| 100 | 4.9 | 5.5 | 3.6 | 9.7 | 8.9 | 5.0 |

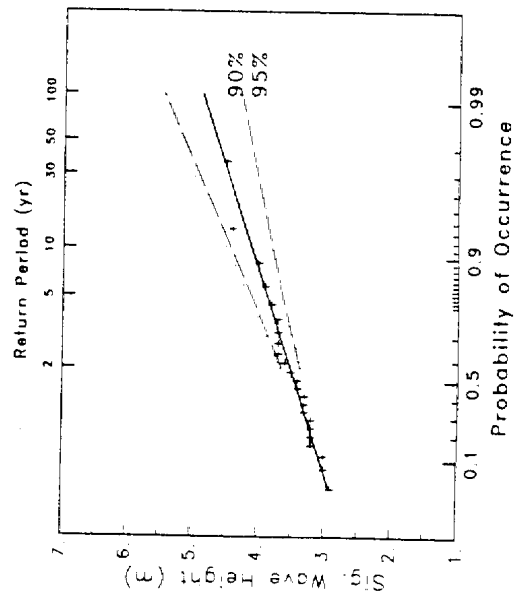
Tp, Hmax, and Hc were calculated using

$$T_p = 4.098 H_s^{0.547}$$

$$H_{max} = 1.826 H_s$$

$$H_c = 1.020 H_s$$

Correlation = 0.99



GUMBEL - Method of Moments

26 storms

Wave height threshold = 1.50 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | 10% U.L. (m) | TP (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------------|--------|----------|--------|
| 2 | 3.4 | 3.6 | 3.6 | 8.0 | 6.2 | 3.5 |
| 5 | 3.9 | 4.3 | 3.6 | 8.6 | 7.2 | 4.0 |
| 10 | 4.3 | 4.8 | 3.6 | 8.9 | 7.9 | 4.4 |
| 30 | 4.9 | 5.5 | 3.6 | 9.4 | 8.9 | 5.0 |
| 50 | 5.1 | 5.9 | 3.6 | 9.6 | 9.4 | 5.2 |
| 100 | 5.5 | 6.3 | 3.6 | 9.9 | 10.0 | 5.6 |

Tp, Hmax, and Hc were calculated using

$$T_p = 4.693 H_s^{0.438}$$

$$H_{max} = 1.825 H_s$$

$$H_c = 1.021 H_s$$

Correlation = 0.91

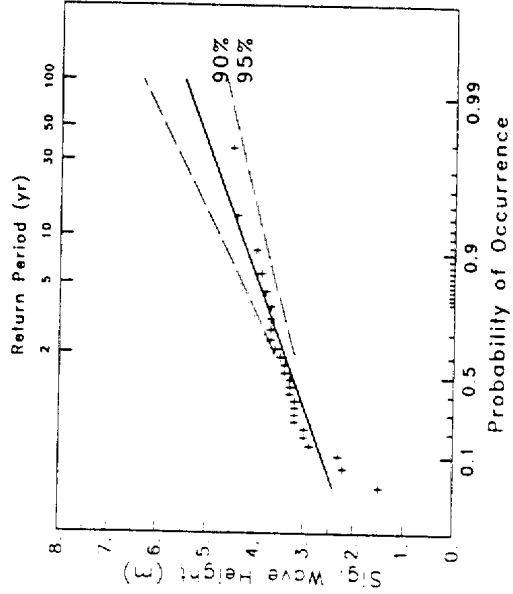


Figure 8.1 Extremal Analysis Results At Grid Point #360 (Actual Ice Edge)

GRID POINT 360 AT 70.840 N, 132.79 W

BORGMAN - Method of Moments

23 storms

Wave height threshold = 2.90 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | 95% U.L. (m) | Wave Height (m) | Wave Height (m) | Wave Height (m) |
|--------------------|--------------|--------------|--------------|-----------------|-----------------|-----------------|
| | | | | Hmax | Wave Height | Hc |
| 2 | 3.5 | 4.3 | 8.2 | 6.5 | 3.6 | |
| 5 | 3.9 | 4.9 | 8.6 | 7.1 | 4.0 | |
| 10 | 4.1 | 5.3 | 8.9 | 7.5 | 4.2 | |
| 30 | 4.4 | 5.8 | 9.3 | 8.1 | 4.5 | |
| 50 | 4.6 | 6.0 | 9.4 | 8.3 | 4.7 | |
| 100 | 4.7 | 6.3 | 9.6 | 8.7 | 4.8 | |

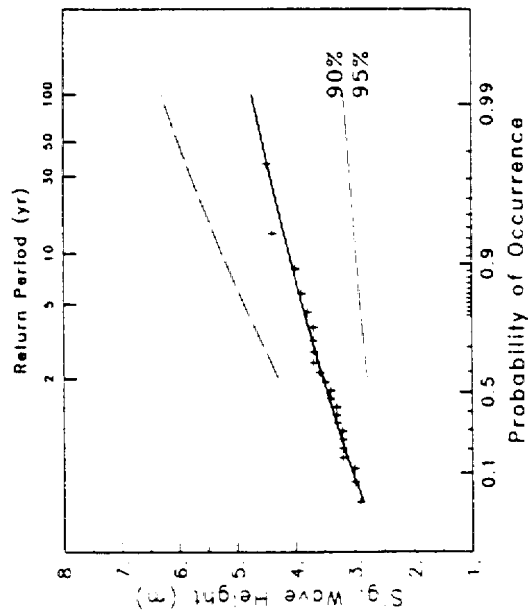
Tp, Hmax, and Hc were calculated using

$$T_p = 4.098 H_s^{0.547}$$

$$H_{max} = 1.826 H_s$$

$$H_c = 1.020 H_s$$

Correlation = 0.99



BORGMAN - Method of Moments

26 storms

Wave height threshold = 1.50 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | 95% U.L. (m) | Wave Height (m) | Wave Height (m) | Wave Height (m) |
|--------------------|--------------|--------------|--------------|-----------------|-----------------|-----------------|
| | | | | Hmax | Wave Height | Hc |
| 2 | 3.5 | 4.3 | 8.1 | 6.3 | 3.5 | |
| 5 | 3.9 | 4.9 | 8.5 | 7.2 | 4.0 | |
| 10 | 4.2 | 5.4 | 8.8 | 7.7 | 4.3 | |
| 30 | 4.6 | 6.0 | 9.2 | 8.4 | 4.7 | |
| 50 | 4.8 | 6.3 | 9.3 | 8.7 | 4.9 | |
| 100 | 5.0 | 6.6 | 9.5 | 9.1 | 5.1 | |

Tp, Hmax, and Hc were calculated using

$$T_p = 4.693 H_s^{0.438}$$

$$H_{max} = 1.825 H_s$$

$$H_c = 1.021 H_s$$

Correlation = 0.94

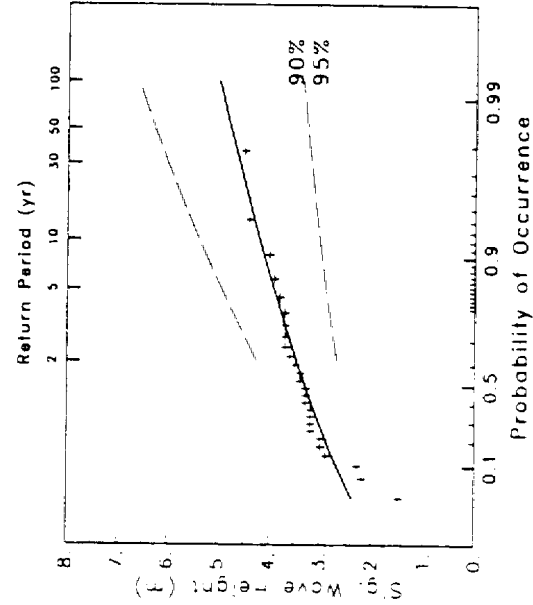


Figure 8.1 (cont'd)

GRID POINT 437 AT 69.612 N, 136.17 W

BORGMAN - Method of Moments

29 storms

Wave height threshold = 1.67 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | 10% U.L. (m) | TP (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------------|--------|----------|--------|
| 2 | 2.8 | 3.5 | 2.1 | 8.3 | 5.0 | 2.8 |
| 5 | 3.3 | 4.2 | 2.6 | 9.0 | 5.9 | 3.3 |
| 10 | 3.6 | 4.7 | 3.0 | 9.3 | 6.5 | 3.6 |
| 30 | 4.0 | 5.3 | 3.4 | 9.8 | 7.2 | 4.0 |
| 50 | 4.2 | 5.6 | 3.6 | 10.0 | 7.5 | 4.2 |
| 100 | 4.4 | 6.0 | 3.8 | 10.2 | 8.0 | 4.4 |

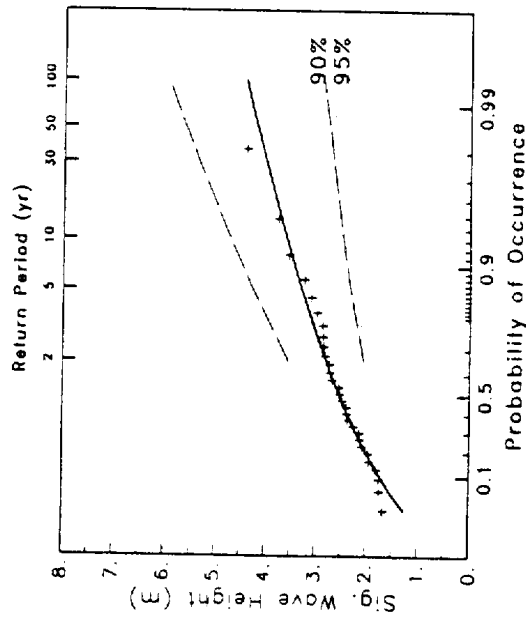
TP, Hmax, and Hc were calculated using

$$T_p = 5.315 H_s^{0.439}$$

$$H_{max} = 1.802 H_s$$

$$H_c = 0.999 H_s$$

Correlation = 0.98



GRID POINT 437 AT 69.612 N, 136.17 W

GUMBEL - Method of Moments

29 storms

Wave height threshold = 1.70 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | 10% U.L. (m) | TP (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------------|--------|----------|--------|
| 2 | 2.7 | 2.9 | 2.5 | 8.2 | 4.9 | 2.7 |
| 5 | 3.2 | 3.5 | 2.9 | 8.9 | 5.8 | 3.2 |
| 10 | 3.6 | 4.0 | 3.2 | 9.3 | 6.5 | 3.6 |
| 30 | 4.1 | 4.7 | 3.7 | 9.9 | 7.5 | 4.1 |
| 50 | 4.4 | 5.1 | 3.9 | 10.1 | 7.9 | 4.4 |
| 100 | 4.7 | 5.5 | 4.1 | 10.5 | 8.5 | 4.7 |

TP, Hmax, and Hc were calculated using

$$T_p = 5.350 H_s^{0.432}$$

$$H_{max} = 1.802 H_s$$

$$H_c = 0.999 H_s$$

Correlation = 0.99

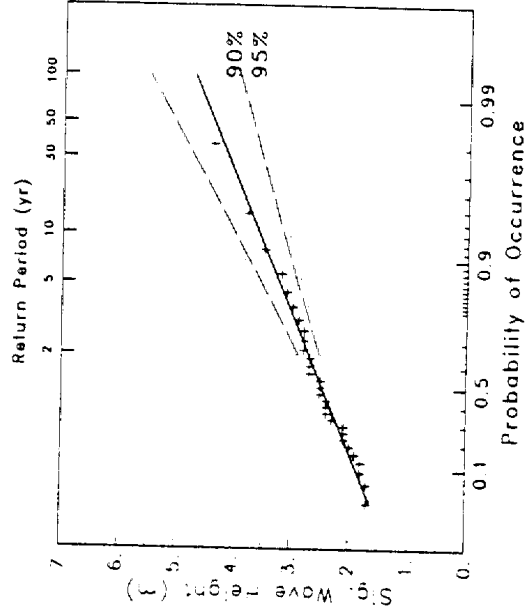


Figure 8.2 Extremal Analysis Results at Grid Point #437 (Actual Ice Edge)

GRID POINT 463 AT 69.300 N, 137.20 W

GUMBEL Method of Moments

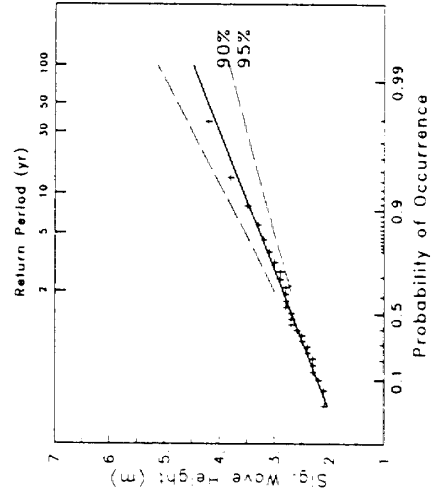
27 storms
Wave height threshold = 2.10 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | TP (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 2.9 | 3.0 | 7.9 | 5.2 | 2.9 |
| 5 | 3.3 | 3.5 | 8.5 | 5.9 | 3.3 |
| 10 | 3.6 | 3.9 | 8.9 | 6.4 | 3.6 |
| 30 | 4.0 | 4.5 | 9.4 | 7.3 | 4.0 |
| 50 | 4.2 | 4.8 | 9.6 | 7.6 | 4.2 |
| 100 | 4.5 | 5.1 | 9.9 | 8.1 | 4.5 |

Tp, Hmax, and Hc were calculated using

$Tp = 4.751 Hs^{0.461}$
 $Hmax = 1.812 Hs$
 $Hc = 1.009 Hs$

Correlation = 0.99



GUMBEL - Method of Moments

29 storms
Wave height threshold = 1.70 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | TP (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 2.8 | 3.0 | 7.9 | 5.1 | 2.9 |
| 5 | 3.3 | 3.5 | 8.5 | 5.9 | 3.3 |
| 10 | 3.6 | 4.0 | 8.9 | 6.5 | 3.6 |
| 30 | 4.1 | 4.6 | 9.5 | 7.4 | 4.1 |
| 50 | 4.3 | 4.9 | 9.7 | 7.8 | 4.3 |
| 100 | 4.6 | 5.3 | 10.0 | 8.3 | 4.6 |

Tp, Hmax, and Hc were calculated using

$Tp = 4.826 Hs^{0.478}$
 $Hmax = 1.812 Hs$
 $Hc = 1.009 Hs$

Correlation = 0.99

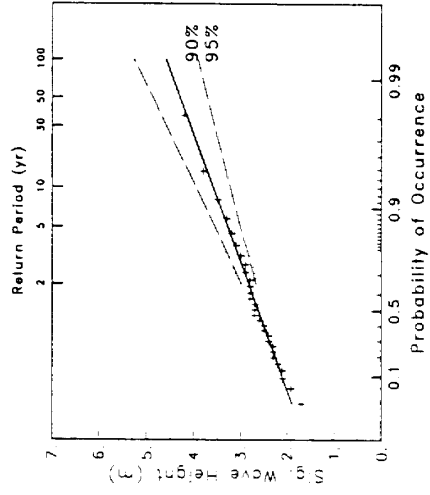


Figure 8.3 Extremal Analysis Results At Grid Point #463 (Actual Ice Edge)

GRID POINT 492 AT 69.990 N, 138.05 W

BORGMAN - Method of Moments

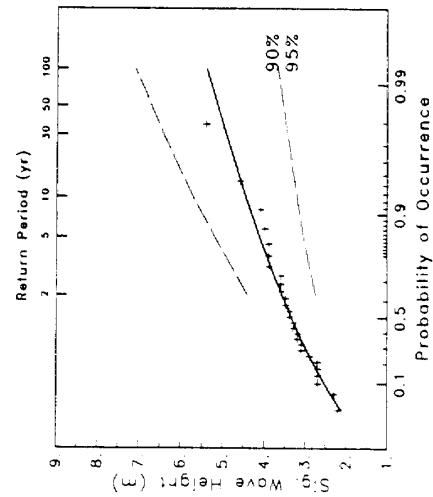
27 storms
Wave height threshold = 2.20 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | TP (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 3.6 | 4.4 | 8.2 | 6.4 | 3.6 |
| 5 | 4.1 | 5.2 | 8.9 | 7.4 | 4.1 |
| 10 | 4.5 | 5.7 | 9.3 | 8.0 | 4.5 |
| 30 | 4.9 | 6.4 | 9.9 | 8.9 | 5.0 |
| 50 | 5.1 | 6.7 | 10.1 | 9.2 | 5.2 |
| 100 | 5.4 | 7.1 | 10.4 | 9.7 | 5.4 |

TP, Hmax, and Hc were calculated using

TP = 3.928 Hs^{0.578}
Hmax = 1.800 Hs
Hc = 1.006 Hs

Correlation = 0.98



GRID POINT 492 AT 69.990 N, 138.05 W

GUMBEL - Method of Moments

27 storms
Wave height threshold = 2.20 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | TP (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 3.5 | 3.7 | 8.1 | 6.3 | 3.5 |
| 5 | 4.1 | 4.4 | 8.9 | 7.3 | 4.1 |
| 10 | 4.5 | 4.9 | 9.3 | 8.0 | 4.5 |
| 30 | 5.1 | 5.7 | 10.1 | 9.1 | 5.1 |
| 50 | 5.3 | 6.1 | 10.4 | 9.6 | 5.4 |
| 100 | 5.7 | 6.6 | 10.8 | 10.3 | 5.8 |

TP, Hmax, and Hc were calculated using

TP = 3.928 Hs^{0.578}
Hmax = 1.800 Hs
Hc = 1.006 Hs

Correlation = 0.98

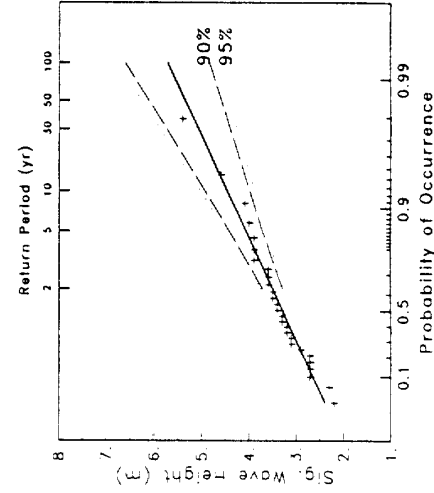


Figure 8.4 Extremal Analysis Results At Grid Point #492 (Actual Ice Edge)

GRID POINT 574 AT 70.350 N, 141.00 W

GUMBEL - Method of Moments

19 storms

Wave height threshold = 2.50 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | 1p (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 3.3 | 3.5 | 8.0 | 5.9 | 3.3 |
| 5 | 3.8 | 4.2 | 8.5 | 6.9 | 3.9 |
| 10 | 4.2 | 4.7 | 8.8 | 7.6 | 4.2 |
| 30 | 4.7 | 5.5 | 9.2 | 8.5 | 4.8 |
| 50 | 5.0 | 5.8 | 9.4 | 9.0 | 5.0 |
| 100 | 5.3 | 6.3 | 9.7 | 9.6 | 5.3 |

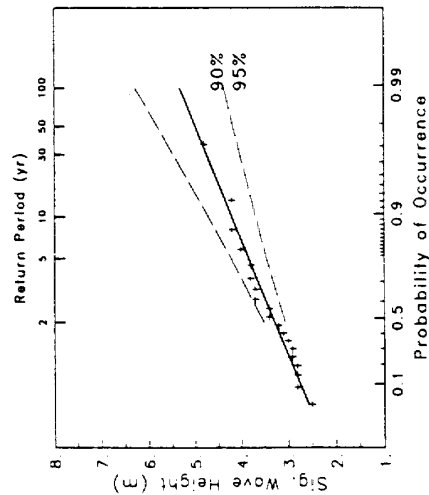
1p, Hmax, and Hc were calculated using

$$1p = 4.937 H_s^{0.403}$$

$$H_{max} = 1.800 H_s$$

$$H_c = 1.005 H_s$$

Correlation = 0.99



GUMBEL - Method of Moments

20 storms

Wave height threshold = 1.80 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | 1p (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 3.2 | 3.5 | 7.9 | 5.8 | 3.2 |
| 5 | 3.8 | 4.3 | 8.5 | 6.9 | 3.9 |
| 10 | 4.3 | 4.8 | 9.0 | 7.7 | 4.3 |
| 30 | 4.9 | 5.7 | 9.6 | 8.8 | 4.9 |
| 50 | 5.2 | 6.1 | 9.8 | 9.3 | 5.2 |
| 100 | 5.5 | 6.6 | 10.2 | 10.0 | 5.6 |

1p, Hmax, and Hc were calculated using

$$1p = 4.514 H_s^{0.474}$$

$$H_{max} = 1.801 H_s$$

$$H_c = 1.007 H_s$$

Correlation = 0.97

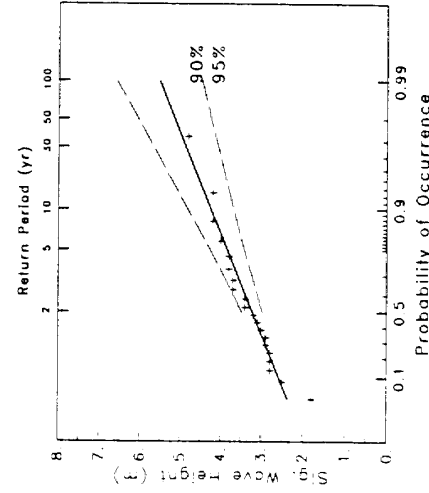


Figure 8.5 Extremal Analysis Results At Grid Point #574 (Actual Ice Edge)

8.5.2 Stratification of Storm Population by Direction

The storm population at each of the three grid points was stratified by wave direction as shown in Figure 8.6 (for actual ice edge and for 98% ice edge). As shown the given size of the population is not sufficient to provide full directional extreme analysis. It can be seen that only two broad directional sectors may be used:

- East to NE and NW (each with 10 – 15 storms)

This is not enough to warrant reliable extremal analysis estimates. Therefore no further analysis was considered.

8.5.3 Final Results

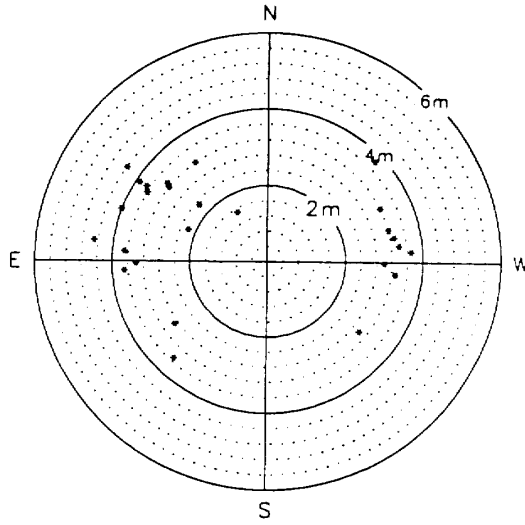
The extremal analysis was then executed for all 51 grid points (Figure 7.1). The results are presented in Tables 8.1 – 8.5 as follows:

1. Maximum wind speed vs. return period (2 – 100 yr.) or risk factor (0.5 – 0.01) (Table 8.1)
2. Significant wave height vs. return period or risk factor: with real ice edge (Table 8.2), 98% ice edge (Table 8.3), 50% ice edge (Table 8.4), and 30% ice edge (Table 8.5). The results in these tables are based on the best fit of regression line to hindcast values, i.e. highest correlation coefficient.

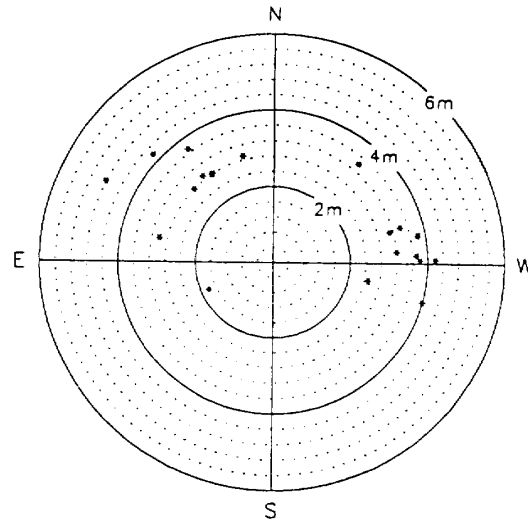
In these Tables only "active" (open-water) grid points are presented (dashed lines indicate the grid point is in ice). The values presented are the best-fit H_s and 90% confidence level upper limit for return periods 2, 5, 10, 25, 50 and 100 years. The tables also show the number of storms used in the final analysis at each grid point.

DISTRIBUTION OF STORM WAVE HEIGHTS
BY DIRECTION
REAL ICE EDGE

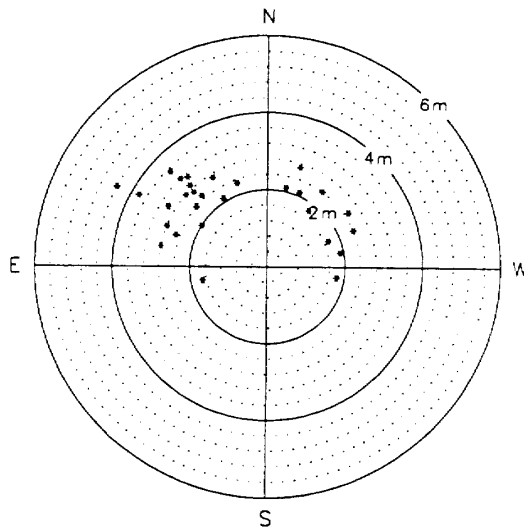
Grid Point 360 – 70.84 N, 132.79 W
26 storms



Grid Point 574 – 70.35 N, 141.0 W
20 storms



Grid Point 437 – 69.6 N, 136.2 W
29 storms



Grid Point 463 – 69.3 N, 137.2 W
29 storms

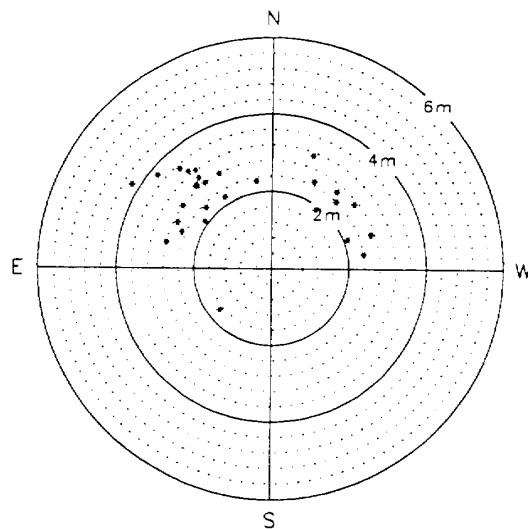
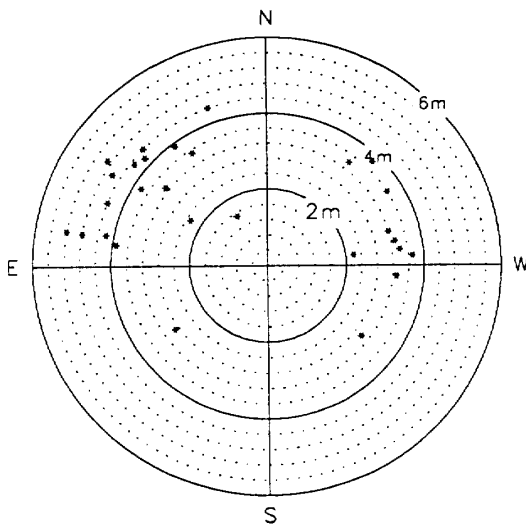


Figure 8.6

DISTRIBUTION OF STORM WAVE HEIGHTS
BY DIRECTION
98% OCCURRENCE OF ICE EDGE

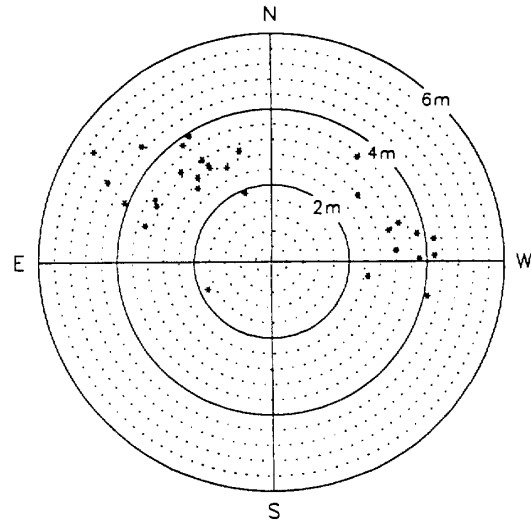
Grid Point 360 – 70.84 N, 132.79 W

30 storms



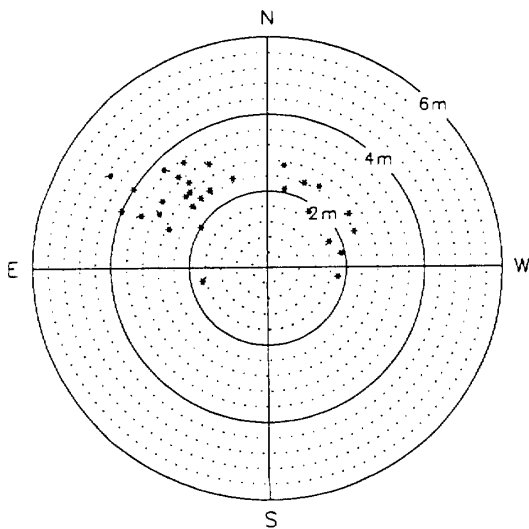
Grid Point 574 – 70.35 N, 141.0 W

30 storms



Grid Point 437 – 69.6 N, 136.2 W

30 storms



Grid Point 463 – 69.3 N, 137.2 W

30 storms

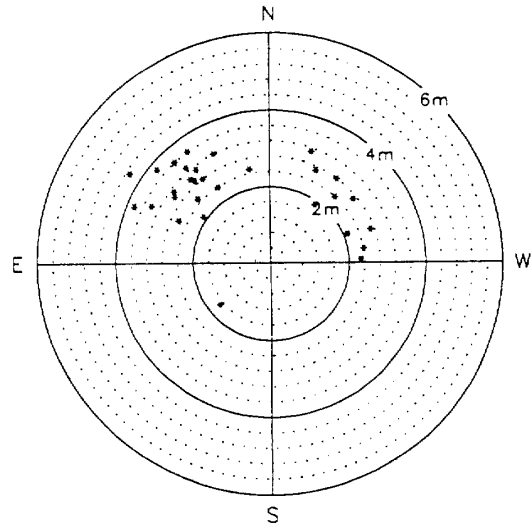


Figure 8.6 (cont'd)

Table 8.6 presents the extremal analysis results for the joint probability scenario where the three climatological ice edges were combined.

The results of the above analyses are also presented graphically on a base map at each of the 51 grid points. Figures 8.7 – 8.11 show the 100 year significant wave height fields for the real ice edge, the 98%, 50% and 30% ice edges, and the overall (combined) three climatological ice edge scenarios i.e. joint probability, respectively.

Table 8.7 provides a summary of the 100 year design significant wave heights at each grid point for all ice edge scenarios studied. The table provides a quick comparison of the extreme wave height estimates for each ice edge scenario.

Detailed analysis results are presented at the previously selected grid points. The results are shown in figures 8–12 – 8–15 for the joint probability case. It provides the design H_s and T_p , H_{max} and H_c for given return periods, and the probability of occurrences vs. H_s curves with 90% and 95% confidence limits shown. The analysis was carried out using all storms available at these points.

Finally, contour presentations of the 100 year return period significant wave height, maximum wave height and the corresponding wind speed are given in Figures 8–16 to 8–18, for actual ice edge. Similar contour maps are provided for the 98% ice edge, and for the combined climatological ice edge (joint probability) case as shown in Figures 8–19 throughout 8–22. The joint probability analysis results provide the design wave parameters in the study area.

Table 8.1 Summary of Extremal Analysis Results At 51 Grid Points
Peak Wind Speed

SUMMARY OF EXTREMAL ANALYSIS RESULTS AT ALL GRID POINTS IN STUDY AREA
 MAXIMUM WIND SPEED

| grid point | risk factor | | .50 | | 0.20 | | 0.10 | | 0.04 | | 0.02 | | 0.01 | | NUM PTS | |
|------------|-------------|----------|---------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|------|---------|----|
| | Lat (N) | Long (W) | return period | Best 90% Fit U.L. m/s | Best 90% Fit U.L. m/s | Best 90% Fit U.L. m/s | Best 90% Fit U.L. m/s | Best 90% Fit U.L. m/s | Best 90% Fit U.L. m/s | Best 90% Fit U.L. m/s | Best 90% Fit U.L. m/s | Best 90% Fit U.L. m/s | Best 90% Fit U.L. m/s | | | |
| 198 | 70.47 | 126.82 | 2 yr | 15.4 | 15.9 | 16.7 | 17.5 | 17.6 | 18.7 | 18.8 | 20.3 | 19.6 | 21.5 | 20.5 | 22.6 | 25 |
| 200 | 71.12 | 126.34 | 2 yr | 15.3 | 15.8 | 16.7 | 17.6 | 17.6 | 18.8 | 18.8 | 20.4 | 19.8 | 21.7 | 20.7 | 22.9 | 25 |
| 226 | 70.87 | 127.57 | 2 yr | 15.9 | 16.4 | 17.2 | 18.1 | 18.1 | 19.3 | 19.3 | 20.9 | 20.2 | 22.0 | 21.1 | 23.2 | 25 |
| 252 | 70.61 | 128.78 | 2 yr | 16.4 | 16.8 | 17.6 | 18.4 | 18.4 | 19.5 | 19.5 | 20.9 | 20.3 | 22.0 | 21.1 | 23.1 | 24 |
| 254 | 71.27 | 128.36 | 2 yr | 16.0 | 16.5 | 17.4 | 18.3 | 18.3 | 19.5 | 19.6 | 21.2 | 20.5 | 22.4 | 21.4 | 23.6 | 25 |
| 278 | 70.35 | 129.96 | 2 yr | 16.6 | 17.1 | 18.0 | 18.9 | 19.0 | 20.2 | 20.3 | 21.9 | 21.2 | 23.2 | 22.1 | 24.4 | 25 |
| 280 | 71.01 | 129.58 | 2 yr | 16.9 | 17.4 | 18.2 | 19.0 | 19.1 | 20.2 | 20.3 | 21.8 | 21.1 | 22.9 | 22.0 | 24.1 | 25 |
| 306 | 70.74 | 130.77 | 2 yr | 17.0 | 17.5 | 18.3 | 19.1 | 19.1 | 20.2 | 20.3 | 21.7 | 21.1 | 22.8 | 21.9 | 23.9 | 26 |
| 309 | 71.73 | 130.23 | 2 yr | 16.0 | 16.4 | 17.1 | 17.8 | 17.8 | 18.8 | 18.7 | 20.1 | 19.4 | 21.0 | 20.1 | 22.0 | 22 |
| 330 | 69.80 | 132.22 | 2 yr | 17.3 | 18.0 | 19.3 | 20.5 | 20.7 | 22.3 | 22.5 | 24.7 | 23.8 | 26.4 | 25.2 | 28.2 | 29 |
| 331 | 70.13 | 132.08 | 2 yr | 17.7 | 18.4 | 19.6 | 20.8 | 21.0 | 22.6 | 22.7 | 24.8 | 24.0 | 26.5 | 25.3 | 28.2 | 28 |
| 332 | 70.46 | 131.93 | 2 yr | 17.5 | 18.1 | 19.1 | 20.1 | 20.2 | 21.5 | 21.6 | 23.4 | 22.7 | 24.8 | 23.7 | 26.2 | 27 |
| 356 | 69.51 | 133.30 | 2 yr | 16.8 | 17.5 | 18.8 | 20.0 | 20.2 | 21.8 | 21.9 | 24.1 | 23.2 | 25.8 | 24.5 | 27.6 | 28 |
| 357 | 69.84 | 133.18 | 2 yr | 17.7 | 18.4 | 19.7 | 20.9 | 21.1 | 22.7 | 22.8 | 25.0 | 24.2 | 26.8 | 25.5 | 28.6 | 29 |
| 358 | 70.17 | 133.05 | 2 yr | 17.9 | 18.6 | 19.7 | 20.9 | 21.0 | 22.6 | 22.7 | 24.7 | 23.9 | 26.4 | 25.2 | 28.0 | 28 |
| 360 | 70.84 | 132.79 | 2 yr | 17.6 | 18.1 | 19.0 | 19.9 | 20.0 | 21.1 | 21.2 | 22.8 | 22.1 | 24.0 | 23.0 | 25.2 | 26 |
| 362 | 71.50 | 132.50 | 2 yr | 16.6 | 17.1 | 17.9 | 18.6 | 18.7 | 19.8 | 19.8 | 21.2 | 20.7 | 22.3 | 21.5 | 23.4 | 27 |
| 384 | 69.88 | 134.15 | 2 yr | 18.1 | 18.8 | 20.1 | 21.4 | 21.6 | 23.3 | 23.4 | 25.7 | 24.8 | 27.5 | 26.1 | 29.4 | 27 |
| 386 | 70.55 | 133.92 | 2 yr | 17.8 | 18.4 | 19.5 | 20.6 | 20.7 | 22.1 | 22.2 | 24.1 | 23.4 | 25.6 | 24.5 | 27.1 | 28 |
| 410 | 69.58 | 135.21 | 2 yr | 17.8 | 18.5 | 19.7 | 20.9 | 21.0 | 22.7 | 22.6 | 24.9 | 23.8 | 26.5 | 25.0 | 28.2 | 22 |
| 411 | 69.92 | 135.12 | 2 yr | 18.3 | 19.2 | 20.7 | 22.1 | 22.3 | 24.2 | 24.4 | 27.0 | 26.0 | 29.1 | 27.6 | 31.1 | 29 |
| 412 | 70.25 | 135.03 | 2 yr | 18.3 | 19.0 | 20.4 | 21.7 | 21.9 | 23.6 | 23.8 | 26.1 | 25.2 | 27.9 | 26.6 | 29.8 | 29 |
| 413 | 70.59 | 134.93 | 2 yr | 18.0 | 18.7 | 19.9 | 21.0 | 21.1 | 22.6 | 22.8 | 24.8 | 24.0 | 26.4 | 25.2 | 28.0 | 28 |
| 414 | 70.92 | 134.82 | 2 yr | 17.8 | 18.4 | 19.6 | 20.7 | 20.9 | 22.3 | 22.5 | 24.5 | 23.7 | 26.1 | 24.9 | 27.7 | 28 |
| 417 | 71.92 | 134.49 | 2 yr | 16.1 | 16.5 | 17.2 | 18.0 | 18.0 | 19.0 | 18.9 | 20.3 | 19.7 | 21.3 | 20.4 | 22.2 | 22 |
| 435 | 68.94 | 136.32 | 2 yr | 16.3 | 17.0 | 17.9 | 19.1 | 19.0 | 20.5 | 20.3 | 22.4 | 21.3 | 23.8 | 22.3 | 25.1 | 18 |
| 436 | 69.28 | 136.25 | 2 yr | 16.4 | 17.2 | 18.5 | 19.8 | 20.0 | 21.7 | 21.9 | 24.2 | 23.3 | 26.1 | 24.7 | 28.0 | 28 |
| 437 | 69.61 | 136.17 | 2 yr | 17.3 | 18.1 | 19.6 | 20.9 | 21.2 | 23.0 | 23.3 | 25.8 | 24.8 | 27.8 | 26.4 | 29.8 | 30 |
| 438 | 69.95 | 136.10 | 2 yr | 18.2 | 19.0 | 20.5 | 21.9 | 22.2 | 24.0 | 24.3 | 26.8 | 25.8 | 28.9 | 27.4 | 30.9 | 30 |
| 440 | 70.62 | 135.93 | 2 yr | 17.8 | 18.4 | 19.7 | 20.8 | 21.0 | 22.5 | 22.7 | 24.7 | 24.0 | 26.4 | 25.2 | 28.1 | 30 |
| 463 | 69.30 | 137.20 | 2 yr | 16.4 | 17.1 | 18.5 | 19.7 | 19.9 | 21.6 | 21.7 | 24.1 | 23.1 | 25.9 | 24.5 | 27.7 | 27 |
| 464 | 69.64 | 137.14 | 2 yr | 17.2 | 18.0 | 19.5 | 20.9 | 21.2 | 23.1 | 23.3 | 25.9 | 24.9 | 28.0 | 26.5 | 30.1 | 30 |
| 465 | 69.97 | 137.07 | 2 yr | 18.1 | 18.9 | 20.5 | 21.9 | 22.2 | 24.1 | 24.4 | 26.9 | 26.0 | 29.1 | 27.6 | 31.2 | 30 |
| 468 | 70.98 | 136.87 | 2 yr | 17.7 | 18.3 | 19.5 | 20.5 | 20.7 | 22.2 | 22.3 | 24.3 | 23.5 | 25.8 | 24.7 | 27.4 | 30 |
| 470 | 71.65 | 136.73 | 2 yr | 16.4 | 17.0 | 18.0 | 18.9 | 19.1 | 20.3 | 20.5 | 22.2 | 21.5 | 23.6 | 22.6 | 25.0 | 29 |
| 490 | 69.32 | 138.15 | 2 yr | 16.5 | 17.2 | 18.4 | 19.7 | 19.8 | 21.5 | 21.5 | 23.8 | 22.8 | 25.6 | 24.1 | 27.3 | 25 |
| 491 | 69.65 | 138.10 | 2 yr | 17.3 | 18.2 | 19.6 | 20.9 | 21.1 | 23.0 | 23.0 | 25.6 | 24.5 | 27.5 | 26.0 | 29.5 | 26 |
| 492 | 69.99 | 138.05 | 2 yr | 18.2 | 19.1 | 20.6 | 22.0 | 22.2 | 24.2 | 24.3 | 27.0 | 25.9 | 29.1 | 27.4 | 31.1 | 27 |
| 493 | 70.33 | 138.01 | 2 yr | 17.9 | 18.8 | 20.3 | 21.7 | 22.0 | 23.8 | 24.1 | 26.6 | 25.7 | 28.7 | 27.3 | 30.8 | 30 |
| 494 | 70.66 | 137.96 | 2 yr | 17.9 | 18.6 | 20.0 | 21.3 | 21.5 | 23.2 | 23.4 | 25.7 | 24.9 | 27.6 | 26.3 | 29.5 | 30 |
| 522 | 71.01 | 138.93 | 2 yr | 17.6 | 18.4 | 19.6 | 20.9 | 21.0 | 22.7 | 22.8 | 25.1 | 24.2 | 26.9 | 25.5 | 28.7 | 27 |
| 525 | 72.02 | 138.82 | 2 yr | 15.8 | 16.4 | 17.4 | 18.4 | 18.5 | 19.9 | 20.0 | 21.8 | 21.0 | 23.2 | 22.1 | 24.7 | 27 |
| 545 | 69.68 | 140.03 | 2 yr | 16.6 | 17.5 | 19.0 | 20.4 | 20.6 | 22.5 | 22.6 | 25.3 | 24.1 | 27.3 | 25.7 | 29.3 | 26 |
| 546 | 70.01 | 140.02 | 2 yr | 17.2 | 18.2 | 19.9 | 21.4 | 21.7 | 23.8 | 24.1 | 26.9 | 25.8 | 29.3 | 27.6 | 31.6 | 29 |
| 548 | 70.68 | 139.98 | 2 yr | 17.1 | 17.9 | 19.5 | 21.0 | 21.2 | 23.2 | 23.4 | 26.0 | 25.1 | 28.2 | 26.7 | 30.3 | 30 |
| 574 | 70.35 | 141.00 | 2 yr | 16.9 | 17.8 | 19.5 | 21.1 | 21.4 | 23.5 | 23.7 | 26.6 | 25.5 | 28.9 | 27.2 | 31.2 | 29 |
| 576 | 71.02 | 141.00 | 2 yr | 17.1 | 18.0 | 19.7 | 21.3 | 21.5 | 23.6 | 23.8 | 26.7 | 25.6 | 29.0 | 27.3 | 31.2 | 29 |
| 578 | 71.69 | 141.00 | 2 yr | 15.9 | 16.7 | 18.1 | 19.4 | 19.6 | 21.3 | 21.5 | 23.9 | 23.0 | 25.8 | 24.4 | 27.7 | 29 |
| 630 | 71.01 | 143.07 | 2 yr | 15.9 | 16.8 | 18.6 | 20.2 | 20.4 | 22.6 | 22.9 | 25.8 | 24.7 | 28.2 | 26.5 | 30.6 | 29 |
| 655 | 70.33 | 143.99 | 2 yr | 14.9 | 15.9 | 17.8 | 19.6 | 19.9 | 22.2 | 22.5 | 25.7 | 24.5 | 28.3 | 26.5 | 30.9 | 30 |
| 764 | 70.55 | 148.08 | 2 yr | 12.9 | 13.8 | 15.3 | 16.9 | 17.0 | 19.1 | 19.2 | 22.0 | 20.8 | 24.1 | 22.4 | 26.3 | 26 |

Table 8.2 Summary of Extremal Analysis Results At 51 Grid Points
Significant Wave Height - Real Ice Edge

SUMMARY OF EXTREMAL ANALYSIS RESULTS AT ALL GRID POINTS IN STUDY AREA

SIGNIFICANT WAVE HEIGHT

A) REAL ICE EDGE

| risk factor return period | | .50 2 yr | | 0.20 5 yr | | 0.10 10 yr | | 0.04 25 yr | | 0.02 50 yr | | 0.01 100 yr | | NUM PTS |
|------------------------------|------------------------|-------------|-------------|--------------|-------------|---------------|-------------|---------------|-------------|---------------|-------------|----------------|-------------|------------|
| grid point | Lat (N) Long (W) | Best Fit | 90% U.L. | Best Fit | 90% U.L. | Best Fit | 90% U.L. | Best Fit | 90% U.L. | Best Fit | 90% U.L. | Best Fit | 90% U.L. | |
| | | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | |
| 198 | 70.47 126.82 | 3.1 | 3.3 | 3.5 | 3.8 | 3.8 | 4.2 | 4.2 | 4.6 | 4.4 | 5.0 | 4.7 | 5.4 | 24 |
| 200 | 71.12 126.34 | 3.2 | 3.4 | 3.7 | 4.0 | 4.0 | 4.4 | 4.4 | 5.0 | 4.7 | 5.4 | 5.1 | 5.8 | 25 |
| 226 | 70.87 127.57 | 3.4 | 3.6 | 3.9 | 4.2 | 4.2 | 4.6 | 4.6 | 5.2 | 4.9 | 5.6 | 5.2 | 6.0 | 25 |
| 252 | 70.61 128.78 | 2.8 | 2.9 | 3.2 | 3.5 | 3.5 | 3.9 | 3.9 | 4.4 | 4.2 | 4.7 | 4.4 | 5.1 | 28 |
| 254 | 71.27 128.36 | 3.3 | 3.5 | 3.7 | 4.0 | 4.0 | 4.3 | 4.3 | 4.8 | 4.5 | 5.1 | 4.8 | 5.4 | 21 |
| 278 | 70.35 129.96 | 2.5 | 2.6 | 2.9 | 3.2 | 3.2 | 3.6 | 3.6 | 4.1 | 3.9 | 4.5 | 4.2 | 4.9 | 26 |
| 280 | 71.01 129.58 | 3.4 | 3.5 | 3.8 | 4.0 | 4.0 | 4.3 | 4.3 | 4.8 | 4.6 | 5.1 | 4.8 | 5.4 | 22 |
| 306 | 70.74 130.77 | 3.3 | 3.5 | 3.8 | 4.0 | 4.0 | 4.4 | 4.4 | 4.9 | 4.7 | 5.2 | 4.9 | 5.6 | 24 |
| 309 | 71.73 130.23 | 3.0 | 3.1 | 3.3 | 3.5 | 3.5 | 3.8 | 3.7 | 4.2 | 3.9 | 4.4 | 4.0 | 4.7 | 12 |
| 330 | 69.80 132.22 | 2.2 | 2.4 | 2.6 | 2.9 | 2.9 | 3.3 | 3.3 | 3.8 | 3.6 | 4.1 | 3.9 | 4.5 | 28 |
| 331 | 70.13 132.08 | 3.2 | 3.4 | 3.7 | 4.0 | 4.0 | 4.4 | 4.4 | 4.9 | 4.7 | 5.3 | 5.0 | 5.7 | 26 |
| 332 | 70.46 131.93 | 3.4 | 3.6 | 3.8 | 4.1 | 4.1 | 4.5 | 4.5 | 5.0 | 4.8 | 5.4 | 5.1 | 5.8 | 27 |
| 356 | 69.51 133.30 | 1.6 | 1.7 | 1.9 | 2.1 | 2.1 | 2.3 | 2.4 | 2.7 | 2.6 | 3.0 | 2.8 | 3.2 | 29 |
| 357 | 69.84 133.18 | 2.7 | 2.8 | 3.0 | 3.2 | 3.3 | 3.6 | 3.6 | 4.0 | 3.8 | 4.3 | 4.0 | 4.6 | 26 |
| 358 | 70.17 133.05 | 3.4 | 3.6 | 3.9 | 4.1 | 4.1 | 4.5 | 4.5 | 5.0 | 4.8 | 5.3 | 5.0 | 5.7 | 26 |
| 360 | 70.84 132.79 | 3.5 | 3.7 | 3.9 | 4.1 | 4.1 | 4.4 | 4.4 | 4.9 | 4.7 | 5.2 | 4.9 | 5.5 | 23 |
| 362 | 71.50 132.50 | 3.1 | 3.3 | 3.5 | 3.7 | 3.7 | 4.0 | 3.9 | 4.4 | 4.1 | 4.7 | 4.3 | 4.9 | 14 |
| 384 | 69.98 134.15 | 2.9 | 3.0 | 3.3 | 3.5 | 3.6 | 3.9 | 4.0 | 4.4 | 4.2 | 4.8 | 4.5 | 5.2 | 29 |
| 386 | 70.55 133.92 | 3.5 | 3.7 | 3.9 | 4.2 | 4.2 | 4.6 | 4.6 | 5.1 | 4.9 | 5.4 | 5.1 | 5.8 | 25 |
| 410 | 69.58 135.21 | 1.9 | 2.0 | 2.2 | 2.4 | 2.4 | 2.6 | 2.7 | 3.0 | 2.9 | 3.3 | 3.1 | 3.5 | 29 |
| 411 | 69.92 135.12 | 3.2 | 3.3 | 3.6 | 3.9 | 3.9 | 4.3 | 4.3 | 4.8 | 4.7 | 5.2 | 5.0 | 5.7 | 30 |
| 412 | 70.25 135.03 | 3.5 | 3.7 | 3.9 | 4.2 | 4.2 | 4.6 | 4.6 | 5.0 | 4.8 | 5.4 | 5.1 | 5.7 | 25 |
| 413 | 70.59 134.93 | 3.5 | 3.7 | 4.0 | 4.2 | 4.2 | 4.6 | 4.6 | 5.1 | 4.9 | 5.4 | 5.1 | 5.8 | 25 |
| 414 | 70.92 134.82 | 3.5 | 3.6 | 3.9 | 4.1 | 4.1 | 4.5 | 4.4 | 4.9 | 4.7 | 5.2 | 4.9 | 5.5 | 20 |
| 417 | 71.92 134.49 | 2.2 | 2.4 | 2.7 | 3.0 | 2.9 | 3.4 | 3.3 | 3.9 | 3.6 | 4.3 | 3.8 | 4.7 | 14 |
| 435 | 68.94 136.32 | 1.2 | 1.3 | 1.4 | 1.5 | 1.5 | 1.7 | 1.7 | 1.9 | 1.8 | 2.1 | 1.9 | 2.2 | 27 |
| 436 | 69.28 136.25 | 1.9 | 2.1 | 2.3 | 2.6 | 2.6 | 2.9 | 3.0 | 3.4 | 3.2 | 3.8 | 3.5 | 4.1 | 29 |
| 437 | 69.61 136.17 | 2.7 | 2.9 | 3.2 | 3.5 | 3.6 | 4.0 | 4.1 | 4.6 | 4.4 | 5.1 | 4.7 | 5.5 | 29 |
| 438 | 69.95 136.10 | 3.3 | 3.5 | 3.8 | 4.1 | 4.2 | 4.5 | 4.6 | 5.1 | 4.9 | 5.5 | 5.2 | 5.9 | 29 |
| 440 | 70.62 135.93 | 3.5 | 3.6 | 3.9 | 4.2 | 4.2 | 4.6 | 4.6 | 5.1 | 4.9 | 5.5 | 5.2 | 5.9 | 26 |
| 463 | 69.30 137.20 | 2.8 | 3.0 | 3.3 | 3.5 | 3.6 | 3.9 | 4.0 | 4.4 | 4.2 | 4.8 | 4.5 | 5.2 | 28 |
| 464 | 69.64 137.14 | 3.2 | 3.4 | 3.7 | 4.0 | 4.0 | 4.4 | 4.5 | 5.0 | 4.8 | 5.5 | 5.2 | 5.9 | 29 |
| 465 | 69.97 137.07 | 3.4 | 3.6 | 3.9 | 4.2 | 4.3 | 4.7 | 4.7 | 5.2 | 5.0 | 5.7 | 5.4 | 6.1 | 29 |
| 468 | 70.98 136.87 | 3.4 | 3.6 | 4.0 | 4.3 | 4.3 | 4.8 | 4.8 | 5.5 | 5.2 | 6.0 | 5.5 | 6.4 | 24 |
| 470 | 71.65 136.73 | 2.7 | 2.8 | 3.0 | 3.2 | 3.2 | 3.4 | 3.4 | 3.7 | 3.5 | 3.9 | 3.6 | 4.1 | 13 |
| 490 | 69.32 138.15 | 2.5 | 2.7 | 2.9 | 3.1 | 3.2 | 3.5 | 3.5 | 3.9 | 3.7 | 4.2 | 4.0 | 4.6 | 26 |
| 491 | 69.65 138.10 | 3.4 | 3.6 | 3.9 | 4.2 | 4.2 | 4.7 | 4.7 | 5.3 | 5.0 | 5.7 | 5.4 | 6.2 | 26 |
| 492 | 69.99 138.05 | 3.5 | 3.7 | 4.1 | 4.4 | 4.5 | 4.9 | 5.0 | 5.6 | 5.3 | 6.1 | 5.7 | 6.6 | 27 |
| 493 | 70.33 138.01 | 3.5 | 3.7 | 4.1 | 4.4 | 4.5 | 4.9 | 5.0 | 5.6 | 5.3 | 6.1 | 5.7 | 6.6 | 25 |
| 494 | 70.66 137.96 | 3.5 | 3.6 | 3.9 | 4.2 | 4.2 | 4.5 | 4.5 | 5.0 | 4.8 | 5.4 | 5.0 | 5.7 | 21 |
| 522 | 71.01 138.93 | 3.0 | 3.2 | 3.5 | 3.8 | 3.8 | 4.2 | 4.2 | 4.8 | 4.5 | 5.2 | 4.8 | 5.6 | 20 |
| 525 | 72.02 138.82 | 2.4 | 2.6 | 2.8 | 3.1 | 3.0 | 3.4 | 3.2 | 3.7 | 3.4 | 4.0 | 3.6 | 4.3 | 12 |
| 545 | 69.68 140.03 | 3.0 | 3.2 | 3.4 | 3.7 | 3.7 | 4.1 | 4.1 | 4.6 | 4.3 | 4.9 | 4.6 | 5.3 | 21 |
| 546 | 70.01 140.02 | 3.3 | 3.5 | 3.8 | 4.2 | 4.2 | 4.6 | 4.6 | 5.2 | 4.9 | 5.7 | 5.2 | 6.1 | 20 |
| 548 | 70.68 139.98 | 3.1 | 3.3 | 3.6 | 4.0 | 4.0 | 4.5 | 4.5 | 5.1 | 4.8 | 5.6 | 5.2 | 6.1 | 22 |
| 574 | 70.35 141.00 | 3.3 | 3.5 | 3.8 | 4.2 | 4.2 | 4.7 | 4.6 | 5.3 | 5.0 | 5.8 | 5.3 | 6.3 | 19 |
| 576 | 71.02 141.00 | 2.8 | 3.0 | 3.3 | 3.6 | 3.6 | 4.0 | 4.0 | 4.6 | 4.3 | 5.0 | 4.5 | 5.3 | 19 |
| 578 | 71.69 141.00 | 2.5 | 2.7 | 3.0 | 3.3 | 3.3 | 3.7 | 3.6 | 4.3 | 3.9 | 4.7 | 4.2 | 5.1 | 15 |
| 630 | 71.01 143.07 | 2.9 | 3.1 | 3.4 | 3.8 | 3.8 | 4.3 | 4.2 | 4.9 | 4.5 | 5.3 | 4.8 | 5.8 | 15 |
| 655 | 70.33 143.99 | 2.4 | 2.7 | 3.1 | 3.5 | 3.5 | 4.1 | 4.1 | 4.9 | 4.5 | 5.4 | 4.9 | 6.0 | 22 |
| 764 | 70.55 148.08 | 1.7 | 1.9 | 2.1 | 2.4 | 2.4 | 2.9 | 2.8 | 3.4 | 3.1 | 3.8 | 3.4 | 4.2 | 21 |

Table 8.3 Summary of Extremal Analysis Results At 51 Grid Points
Significant Wave Height - 98% Ice Edge

B) 98% FREQUENCY OF OCCURRENCE ICE EDGE

| grid point | risk factor return period | | .50 2 yr | | 0.20 5 yr | | 0.10 10 yr | | 0.04 25 yr | | 0.02 50 yr | | 0.01 100 yr | | NUM PTS |
|------------|---------------------------|----------|--------------|--------------|--------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|----------------|--------------|---------|
| | Lat (N) | Long (W) | Best Fit (m) | 90% U.L. (m) | Best Fit (m) | 90% U.L. (m) | Best Fit (m) | 90% U.L. (m) | Best Fit (m) | 90% U.L. (m) | Best Fit (m) | 90% U.L. (m) | Best Fit (m) | 90% U.L. (m) | |
| 198 | 70.47 | 126.82 | 3.4 | 3.6 | 3.9 | 4.3 | 4.3 | 4.8 | 4.8 | 5.4 | 5.1 | 5.9 | 5.5 | 6.4 | 25 |
| 200 | 71.12 | 126.34 | 3.6 | 3.9 | 4.3 | 4.8 | 4.8 | 5.4 | 5.5 | 6.3 | 6.0 | 6.9 | 6.4 | 7.6 | 27 |
| 226 | 70.87 | 127.57 | 3.7 | 4.0 | 4.4 | 4.8 | 4.9 | 5.5 | 5.5 | 6.3 | 5.9 | 6.9 | 6.4 | 7.5 | 27 |
| 252 | 70.61 | 128.78 | 3.2 | 3.4 | 3.8 | 4.1 | 4.1 | 4.6 | 4.6 | 5.3 | 5.0 | 5.8 | 5.4 | 6.3 | 27 |
| 254 | 71.27 | 128.36 | 3.8 | 4.0 | 4.5 | 4.9 | 5.0 | 5.5 | 5.6 | 6.3 | 6.0 | 6.9 | 6.5 | 7.5 | 27 |
| 278 | 70.35 | 129.96 | 2.8 | 3.0 | 3.4 | 3.8 | 3.8 | 4.3 | 4.4 | 5.1 | 4.8 | 5.6 | 5.2 | 6.1 | 28 |
| 280 | 71.01 | 129.58 | 3.8 | 4.0 | 4.4 | 4.8 | 4.9 | 5.4 | 5.4 | 6.1 | 5.8 | 6.6 | 6.2 | 7.2 | 27 |
| 306 | 70.74 | 130.77 | 3.8 | 4.1 | 4.5 | 4.9 | 4.9 | 5.4 | 5.5 | 6.2 | 5.9 | 6.8 | 6.3 | 7.3 | 27 |
| 309 | 71.73 | 130.23 | 3.7 | 4.0 | 4.3 | 4.7 | 4.8 | 5.2 | 5.3 | 6.0 | 5.7 | 6.5 | 6.1 | 7.0 | 27 |
| 330 | 69.80 | 132.22 | 2.4 | 2.6 | 3.0 | 3.3 | 3.3 | 3.7 | 3.8 | 4.3 | 4.1 | 4.8 | 4.5 | 5.2 | 30 |
| 331 | 70.13 | 132.08 | 3.7 | 3.9 | 4.3 | 4.7 | 4.7 | 5.2 | 5.2 | 6.0 | 5.6 | 6.5 | 6.0 | 7.0 | 24 |
| 332 | 70.46 | 131.93 | 3.9 | 4.1 | 4.5 | 4.9 | 5.0 | 5.5 | 5.5 | 6.3 | 6.0 | 6.8 | 6.4 | 7.4 | 27 |
| 356 | 69.51 | 133.30 | 1.7 | 1.8 | 2.1 | 2.3 | 2.3 | 2.6 | 2.6 | 3.0 | 2.8 | 3.3 | 3.1 | 3.6 | 28 |
| 357 | 69.84 | 133.18 | 2.9 | 3.1 | 3.3 | 3.6 | 3.6 | 3.9 | 3.9 | 4.4 | 4.2 | 4.7 | 4.4 | 5.1 | 24 |
| 358 | 70.17 | 133.05 | 3.9 | 4.1 | 4.5 | 4.8 | 4.9 | 5.4 | 5.4 | 6.1 | 5.8 | 6.6 | 6.2 | 7.1 | 26 |
| 360 | 70.84 | 132.79 | 4.1 | 4.3 | 4.7 | 5.1 | 5.1 | 5.7 | 5.7 | 6.4 | 6.1 | 6.9 | 6.5 | 7.5 | 27 |
| 362 | 71.50 | 132.50 | 3.9 | 4.1 | 4.4 | 4.8 | 4.8 | 5.3 | 5.3 | 6.0 | 5.7 | 6.5 | 6.1 | 6.9 | 27 |
| 384 | 69.88 | 134.15 | 3.2 | 3.4 | 3.7 | 4.0 | 4.0 | 4.5 | 4.5 | 5.1 | 4.8 | 5.6 | 5.2 | 6.0 | 25 |
| 386 | 70.55 | 133.92 | 4.0 | 4.3 | 4.7 | 5.1 | 5.2 | 5.7 | 5.7 | 6.5 | 6.2 | 7.1 | 6.6 | 7.6 | 29 |
| 410 | 69.58 | 135.21 | 2.0 | 2.1 | 2.3 | 2.5 | 2.6 | 2.8 | 2.9 | 3.2 | 3.1 | 3.5 | 3.3 | 3.8 | 29 |
| 411 | 69.92 | 135.12 | 3.5 | 3.7 | 4.1 | 4.5 | 4.5 | 5.1 | 5.1 | 5.8 | 5.5 | 6.3 | 5.9 | 6.8 | 28 |
| 412 | 70.25 | 135.03 | 4.0 | 4.2 | 4.6 | 5.0 | 5.0 | 5.5 | 5.5 | 6.2 | 5.9 | 6.7 | 6.3 | 7.2 | 27 |
| 413 | 70.59 | 134.93 | 4.1 | 4.3 | 4.7 | 5.1 | 5.1 | 5.6 | 5.7 | 6.4 | 6.1 | 6.9 | 6.5 | 7.5 | 29 |
| 414 | 70.92 | 134.82 | 4.1 | 4.3 | 4.7 | 5.1 | 5.2 | 5.7 | 5.8 | 6.5 | 6.2 | 7.1 | 6.6 | 7.6 | 29 |
| 417 | 71.92 | 134.49 | 3.4 | 3.6 | 4.0 | 4.5 | 4.5 | 5.1 | 5.2 | 5.9 | 5.6 | 6.5 | 6.1 | 7.1 | 30 |
| 435 | 68.94 | 136.32 | 1.3 | 1.3 | 1.4 | 1.5 | 1.5 | 1.6 | 1.6 | 1.8 | 1.7 | 2.0 | 1.8 | 2.1 | 24 |
| 436 | 69.28 | 136.25 | 2.0 | 2.1 | 2.4 | 2.7 | 2.7 | 3.0 | 3.1 | 3.5 | 3.4 | 3.9 | 3.6 | 4.3 | 30 |
| 437 | 69.61 | 136.17 | 3.0 | 3.2 | 3.6 | 3.9 | 4.0 | 4.4 | 4.5 | 5.1 | 4.9 | 5.7 | 5.3 | 6.2 | 28 |
| 438 | 69.95 | 136.10 | 3.7 | 3.9 | 4.2 | 4.5 | 4.6 | 5.1 | 5.1 | 5.7 | 5.5 | 6.2 | 5.8 | 6.7 | 29 |
| 440 | 70.62 | 135.93 | 4.1 | 4.3 | 4.7 | 5.0 | 5.1 | 5.6 | 5.7 | 6.3 | 6.1 | 6.9 | 6.5 | 7.4 | 30 |
| 463 | 69.30 | 137.20 | 3.1 | 3.2 | 3.5 | 3.8 | 3.8 | 4.2 | 4.2 | 4.7 | 4.5 | 5.1 | 4.8 | 5.5 | 27 |
| 464 | 69.64 | 137.14 | 3.5 | 3.7 | 4.0 | 4.4 | 4.4 | 4.9 | 4.9 | 5.5 | 5.3 | 6.0 | 5.6 | 6.5 | 28 |
| 465 | 69.97 | 137.07 | 3.8 | 4.0 | 4.3 | 4.7 | 4.7 | 5.2 | 5.2 | 5.8 | 5.6 | 6.3 | 6.0 | 6.8 | 30 |
| 468 | 70.98 | 136.87 | 4.0 | 4.1 | 4.5 | 4.8 | 4.9 | 5.3 | 5.3 | 5.9 | 5.7 | 6.4 | 6.0 | 6.8 | 29 |
| 470 | 71.65 | 136.73 | 3.5 | 3.7 | 4.1 | 4.4 | 4.5 | 5.0 | 5.1 | 5.7 | 5.5 | 6.3 | 5.9 | 6.8 | 30 |
| 490 | 69.32 | 138.15 | 2.8 | 2.9 | 3.1 | 3.3 | 3.3 | 3.6 | 3.6 | 4.0 | 3.8 | 4.3 | 4.1 | 4.6 | 22 |
| 491 | 69.65 | 138.10 | 3.7 | 3.9 | 4.2 | 4.6 | 4.6 | 5.0 | 5.0 | 5.6 | 5.4 | 6.1 | 5.7 | 6.5 | 26 |
| 492 | 69.99 | 138.05 | 3.9 | 4.1 | 4.5 | 4.8 | 4.9 | 5.4 | 5.4 | 6.0 | 5.8 | 6.6 | 6.2 | 7.1 | 29 |
| 493 | 70.33 | 138.01 | 4.0 | 4.2 | 4.5 | 4.9 | 4.9 | 5.3 | 5.4 | 6.0 | 5.8 | 6.5 | 6.1 | 7.0 | 29 |
| 494 | 70.66 | 137.96 | 3.8 | 4.0 | 4.3 | 4.6 | 4.6 | 5.0 | 5.1 | 5.6 | 5.4 | 6.0 | 5.7 | 6.4 | 29 |
| 522 | 71.01 | 138.93 | 3.6 | 3.8 | 4.1 | 4.5 | 4.5 | 5.0 | 5.0 | 5.7 | 5.4 | 6.2 | 5.8 | 6.7 | 29 |
| 525 | 72.02 | 138.82 | 3.2 | 3.4 | 3.7 | 4.1 | 4.1 | 4.5 | 4.5 | 5.1 | 4.9 | 5.5 | 5.2 | 6.0 | 28 |
| 545 | 69.68 | 140.03 | 3.3 | 3.4 | 3.7 | 3.9 | 3.9 | 4.3 | 4.3 | 4.7 | 4.5 | 5.1 | 4.8 | 5.4 | 25 |
| 546 | 70.01 | 140.02 | 3.6 | 3.8 | 4.1 | 4.4 | 4.5 | 4.9 | 4.9 | 5.5 | 5.2 | 5.9 | 5.6 | 6.3 | 27 |
| 548 | 70.68 | 139.98 | 3.6 | 3.8 | 4.2 | 4.6 | 4.7 | 5.2 | 5.2 | 5.9 | 5.6 | 6.4 | 6.0 | 7.0 | 29 |
| 574 | 70.35 | 141.00 | 3.6 | 3.8 | 4.2 | 4.6 | 4.6 | 5.1 | 5.1 | 5.7 | 5.5 | 6.2 | 5.8 | 6.7 | 28 |
| 576 | 71.02 | 141.00 | 3.3 | 3.5 | 3.8 | 4.1 | 4.2 | 4.6 | 4.6 | 5.2 | 5.0 | 5.6 | 5.3 | 6.1 | 28 |
| 578 | 71.69 | 141.00 | 3.2 | 3.4 | 3.8 | 4.1 | 4.1 | 4.5 | 4.6 | 5.1 | 4.9 | 5.6 | 5.3 | 6.1 | 28 |
| 630 | 71.01 | 143.07 | 3.4 | 3.6 | 3.9 | 4.3 | 4.3 | 4.8 | 4.8 | 5.4 | 5.1 | 5.9 | 5.4 | 6.4 | 22 |
| 655 | 70.33 | 143.99 | 2.9 | 3.1 | 3.4 | 3.7 | 3.7 | 4.1 | 4.1 | 4.6 | 4.3 | 5.0 | 4.6 | 5.4 | 22 |
| 764 | 70.55 | 148.08 | 1.9 | 2.1 | 2.4 | 2.7 | 2.7 | 3.1 | 3.1 | 3.6 | 3.4 | 4.0 | 3.7 | 4.4 | 29 |

Table 8.4 Summary of Extremal Analysis Results At 51 Grid Points
Significant Wave Height - 50% Ice Edge

C) 50% FREQUENCY OF OCCURRENCE ICE EDGE

| grid point | risk factor return period | | .50 2 yr | | 0.20 5 yr | | 0.10 10 yr | | 0.04 25 yr | | 0.02 50 yr | | 0.01 100 yr | | NUM PTS |
|------------|---------------------------|----------|--------------|--------------|--------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|----------------|--------------|------------|
| | Lat (N) | Long (W) | Best Fit (m) | 90% U.L. (m) | Best Fit (m) | 90% U.L. (m) | Best Fit (m) | 90% U.L. (m) | Best Fit (m) | 90% U.L. (m) | Best Fit (m) | 90% U.L. (m) | Best Fit (m) | 90% U.L. (m) | |
| 198 | 70.47 | 126.82 | 3.0 | 3.1 | 3.4 | 3.6 | 3.6 | 3.9 | 3.9 | 4.4 | 4.2 | 4.7 | 4.4 | 5.0 | 23 |
| 200 | 71.12 | 126.34 | 2.9 | 3.1 | 3.4 | 3.8 | 3.8 | 4.2 | 4.2 | 4.8 | 4.6 | 5.3 | 4.9 | 5.7 | 23 |
| 226 | 70.87 | 127.57 | 3.2 | 3.3 | 3.6 | 3.9 | 4.0 | 4.4 | 4.4 | 4.9 | 4.7 | 5.4 | 5.0 | 5.8 | 25 |
| 252 | 70.61 | 128.78 | 2.7 | 2.8 | 3.1 | 3.3 | 3.3 | 3.6 | 3.6 | 4.1 | 3.9 | 4.4 | 4.1 | 4.7 | 27 |
| 254 | 71.27 | 128.36 | 2.9 | 3.1 | 3.4 | 3.8 | 3.8 | 4.3 | 4.2 | 4.9 | 4.6 | 5.4 | 4.9 | 5.8 | 22 |
| 278 | 70.35 | 129.96 | 2.4 | 2.6 | 2.9 | 3.2 | 3.2 | 3.6 | 3.6 | 4.2 | 3.9 | 4.6 | 4.3 | 5.0 | 28 |
| 280 | 71.01 | 129.58 | 3.1 | 3.3 | 3.6 | 3.8 | 3.9 | 4.2 | 4.3 | 4.8 | 4.5 | 5.2 | 4.8 | 5.6 | 25 |
| 306 | 70.74 | 130.77 | 3.2 | 3.3 | 3.7 | 4.0 | 4.0 | 4.4 | 4.4 | 5.0 | 4.8 | 5.4 | 5.1 | 5.9 | 28 |
| 330 | 69.80 | 132.22 | 2.2 | 2.4 | 2.7 | 2.9 | 3.0 | 3.3 | 3.3 | 3.8 | 3.6 | 4.2 | 3.9 | 4.6 | 26 |
| 331 | 70.13 | 132.08 | 3.1 | 3.3 | 3.7 | 4.0 | 4.0 | 4.5 | 4.5 | 5.1 | 4.9 | 5.5 | 5.2 | 6.0 | 28 |
| 332 | 70.46 | 131.93 | 3.3 | 3.5 | 3.8 | 4.1 | 4.1 | 4.5 | 4.6 | 5.1 | 4.9 | 5.5 | 5.2 | 6.0 | 28 |
| 356 | 69.51 | 133.30 | 1.6 | 1.7 | 1.9 | 2.1 | 2.1 | 2.4 | 2.4 | 2.8 | 2.6 | 3.0 | 2.8 | 3.3 | 27 |
| 357 | 69.84 | 133.18 | 2.6 | 2.8 | 3.0 | 3.2 | 3.2 | 3.6 | 3.6 | 4.0 | 3.8 | 4.3 | 4.1 | 4.7 | 25 |
| 358 | 70.17 | 133.05 | 3.3 | 3.5 | 3.8 | 4.1 | 4.2 | 4.6 | 4.6 | 5.2 | 4.9 | 5.6 | 5.3 | 6.0 | 28 |
| 360 | 70.84 | 132.79 | 3.2 | 3.4 | 3.8 | 4.1 | 4.2 | 4.6 | 4.6 | 5.2 | 5.0 | 5.7 | 5.3 | 6.2 | 27 |
| 384 | 69.88 | 134.15 | 2.7 | 2.9 | 3.2 | 3.5 | 3.5 | 3.9 | 3.9 | 4.4 | 4.2 | 4.8 | 4.5 | 5.3 | 29 |
| 386 | 70.55 | 133.92 | 3.3 | 3.5 | 3.9 | 4.2 | 4.2 | 4.7 | 4.7 | 5.3 | 5.1 | 5.8 | 5.4 | 6.2 | 28 |
| 410 | 69.58 | 135.21 | 1.8 | 1.9 | 2.1 | 2.3 | 2.3 | 2.6 | 2.6 | 3.0 | 2.8 | 3.2 | 3.0 | 3.5 | 27 |
| 411 | 69.92 | 135.12 | 3.0 | 3.2 | 3.5 | 3.8 | 3.8 | 4.2 | 4.3 | 4.8 | 4.6 | 5.2 | 4.9 | 5.6 | 29 |
| 412 | 70.25 | 135.03 | 3.4 | 3.6 | 3.9 | 4.2 | 4.2 | 4.6 | 4.7 | 5.2 | 5.0 | 5.7 | 5.4 | 6.1 | 29 |
| 413 | 70.59 | 134.93 | 3.3 | 3.5 | 3.9 | 4.2 | 4.2 | 4.7 | 4.7 | 5.3 | 5.1 | 5.8 | 5.4 | 6.2 | 28 |
| 414 | 70.92 | 134.82 | 3.1 | 3.3 | 3.7 | 4.1 | 4.1 | 4.7 | 4.7 | 5.4 | 5.1 | 6.0 | 5.5 | 6.5 | 24 |
| 435 | 68.94 | 136.32 | 1.2 | 1.3 | 1.4 | 1.5 | 1.5 | 1.7 | 1.7 | 1.9 | 1.8 | 2.1 | 2.0 | 2.3 | 25 |
| 436 | 69.28 | 136.25 | 1.9 | 2.1 | 2.3 | 2.6 | 2.6 | 2.9 | 3.0 | 3.4 | 3.2 | 3.8 | 3.5 | 4.1 | 27 |
| 437 | 69.61 | 136.17 | 2.6 | 2.8 | 3.1 | 3.4 | 3.5 | 3.9 | 3.9 | 4.5 | 4.2 | 4.9 | 4.6 | 5.4 | 27 |
| 438 | 69.95 | 136.10 | 3.2 | 3.3 | 3.6 | 3.9 | 3.9 | 4.3 | 4.4 | 4.9 | 4.7 | 5.3 | 5.0 | 5.7 | 29 |
| 440 | 70.62 | 135.93 | 3.3 | 3.5 | 3.8 | 4.2 | 4.2 | 4.7 | 4.7 | 5.4 | 5.1 | 5.9 | 5.5 | 6.4 | 28 |
| 463 | 69.30 | 137.20 | 2.7 | 2.9 | 3.2 | 3.4 | 3.5 | 3.9 | 3.9 | 4.4 | 4.2 | 4.8 | 4.5 | 5.2 | 27 |
| 464 | 69.64 | 137.14 | 3.0 | 3.2 | 3.6 | 3.9 | 3.9 | 4.3 | 4.4 | 4.9 | 4.7 | 5.4 | 5.0 | 5.8 | 27 |
| 465 | 69.97 | 137.07 | 3.2 | 3.4 | 3.7 | 4.1 | 4.1 | 4.5 | 4.6 | 5.1 | 4.9 | 5.6 | 5.2 | 6.0 | 28 |
| 468 | 70.98 | 136.87 | 2.8 | 3.1 | 3.4 | 3.8 | 3.8 | 4.3 | 4.3 | 5.0 | 4.6 | 5.5 | 5.0 | 6.0 | 22 |
| 490 | 69.32 | 138.15 | 2.4 | 2.5 | 2.8 | 3.0 | 3.0 | 3.3 | 3.3 | 3.8 | 3.6 | 4.1 | 3.8 | 4.4 | 25 |
| 491 | 69.65 | 138.10 | 3.1 | 3.3 | 3.7 | 4.1 | 4.1 | 4.6 | 4.6 | 5.3 | 5.0 | 5.8 | 5.4 | 6.3 | 27 |
| 492 | 69.99 | 138.05 | 3.1 | 3.5 | 3.9 | 4.2 | 4.3 | 4.7 | 4.8 | 5.4 | 5.1 | 5.9 | 5.5 | 6.4 | 28 |
| 493 | 70.33 | 138.01 | 3.3 | 3.5 | 3.9 | 4.2 | 4.3 | 4.7 | 4.8 | 5.4 | 5.2 | 5.9 | 5.5 | 6.4 | 27 |
| 494 | 70.66 | 137.96 | 3.1 | 3.3 | 3.6 | 3.9 | 3.9 | 4.4 | 4.4 | 5.0 | 4.7 | 5.4 | 5.0 | 5.9 | 24 |
| 522 | 71.01 | 138.93 | 1.6 | 1.9 | 2.4 | 2.9 | 2.8 | 3.5 | 3.3 | 4.2 | 3.6 | 4.8 | 4.0 | 5.3 | 11 |
| 545 | 69.68 | 140.03 | 2.7 | 2.9 | 3.2 | 3.5 | 3.5 | 3.9 | 3.9 | 4.5 | 4.2 | 4.9 | 4.5 | 5.3 | 21 |
| 546 | 70.01 | 140.02 | 3.0 | 3.2 | 3.5 | 3.9 | 4.0 | 4.5 | 4.5 | 5.2 | 4.9 | 5.7 | 5.3 | 6.2 | 25 |
| 548 | 70.68 | 139.98 | 2.4 | 2.7 | 3.0 | 3.5 | 3.4 | 4.0 | 3.9 | 4.7 | 4.3 | 5.2 | 4.7 | 5.8 | 17 |
| 574 | 70.35 | 141.00 | 2.6 | 2.9 | 3.4 | 3.9 | 3.9 | 4.6 | 4.5 | 5.5 | 5.0 | 6.1 | 5.5 | 6.8 | 21 |

Table 8.5 Summary of Extremal Analysis Results At 51 Grid Points
Significant Wave Height - 30% Ice Edge

D) 30% FREQUENCY OF OCCURRENCE ICE EDGE

| risk factor return period | | | .50 2 yr | | 0.20 5 yr | | 0.10 10 yr | | 0.04 25 yr | | 0.02 50 yr | | 0.01 100 yr | | NUM PTS |
|------------------------------|------------|-------------|-------------|-------------|--------------|-------------|---------------|-------------|---------------|-------------|---------------|-------------|----------------|-------------|------------|
| grid point | Lat (N) | Long (W) | Best Fit | 90% U.L. | Best Fit | 90% U.L. | Best Fit | 90% U.L. | Best Fit | 90% U.L. | Best Fit | 90% U.L. | Best Fit | 90% U.L. | |
| | | | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | |
| 198 | 70.47 | 126.82 | 2.6 | 2.7 | 2.9 | 3.1 | 3.0 | 3.3 | 3.3 | 3.6 | 3.4 | 3.9 | 3.6 | 4.1 | 16 |
| 226 | 70.87 | 127.57 | 2.0 | 2.2 | 2.5 | 2.9 | 2.8 | 3.2 | 3.1 | 3.7 | 3.3 | 4.0 | 3.5 | 4.4 | 11 |
| 252 | 70.61 | 128.78 | 2.2 | 2.3 | 2.5 | 2.7 | 2.7 | 2.9 | 2.9 | 3.2 | 3.1 | 3.5 | 3.2 | 3.7 | 20 |
| 278 | 70.35 | 129.96 | 2.1 | 2.2 | 2.4 | 2.7 | 2.7 | 3.0 | 3.0 | 3.5 | 3.2 | 3.8 | 3.5 | 4.1 | 21 |
| 306 | 70.74 | 130.77 | 2.3 | 2.5 | 2.7 | 2.9 | 2.9 | 3.2 | 3.1 | 3.6 | 3.3 | 3.9 | 3.5 | 4.1 | 15 |
| 330 | 69.80 | 132.22 | 2.1 | 2.2 | 2.4 | 2.6 | 2.6 | 3.0 | 2.9 | 3.4 | 3.1 | 3.7 | 3.4 | 4.0 | 20 |
| 331 | 70.13 | 132.08 | 2.7 | 2.8 | 3.1 | 3.4 | 3.4 | 3.8 | 3.7 | 4.2 | 4.0 | 4.6 | 4.3 | 5.0 | 21 |
| 332 | 70.46 | 131.93 | 2.6 | 2.7 | 2.9 | 3.2 | 3.2 | 3.6 | 3.5 | 4.0 | 3.8 | 4.3 | 4.0 | 4.7 | 21 |
| 356 | 69.51 | 133.30 | 1.5 | 1.6 | 1.8 | 1.9 | 2.0 | 2.2 | 2.2 | 2.5 | 2.4 | 2.8 | 2.5 | 3.0 | 23 |
| 357 | 69.84 | 133.18 | 2.3 | 2.4 | 2.7 | 2.9 | 2.9 | 3.2 | 3.2 | 3.7 | 3.5 | 4.0 | 3.7 | 4.3 | 23 |
| 358 | 70.17 | 133.05 | 2.8 | 2.9 | 3.2 | 3.5 | 3.5 | 3.8 | 3.8 | 4.3 | 4.1 | 4.7 | 4.3 | 5.0 | 21 |
| 384 | 69.88 | 134.15 | 2.3 | 2.5 | 2.7 | 3.0 | 3.0 | 3.4 | 3.4 | 3.9 | 3.6 | 4.2 | 3.9 | 4.6 | 22 |
| 386 | 70.55 | 133.92 | 2.0 | 2.2 | 2.5 | 2.9 | 2.8 | 3.3 | 3.1 | 3.8 | 3.3 | 4.1 | 3.6 | 4.5 | 11 |
| 410 | 69.58 | 135.21 | 1.6 | 1.7 | 1.9 | 2.1 | 2.1 | 2.4 | 2.4 | 2.8 | 2.6 | 3.1 | 2.8 | 3.4 | 23 |
| 411 | 69.92 | 135.12 | 2.6 | 2.7 | 3.0 | 3.2 | 3.3 | 3.6 | 3.6 | 4.1 | 3.9 | 4.4 | 4.1 | 4.8 | 22 |
| 412 | 70.25 | 135.03 | 2.6 | 2.7 | 3.0 | 3.2 | 3.2 | 3.6 | 3.5 | 4.0 | 3.8 | 4.4 | 4.0 | 4.7 | 21 |
| 435 | 68.94 | 136.32 | 1.1 | 1.2 | 1.4 | 1.5 | 1.5 | 1.7 | 1.7 | 1.9 | 1.8 | 2.1 | 2.0 | 2.3 | 22 |
| 436 | 69.28 | 136.25 | 1.8 | 1.9 | 2.2 | 2.4 | 2.4 | 2.7 | 2.7 | 3.2 | 3.0 | 3.5 | 3.2 | 3.9 | 23 |
| 437 | 69.61 | 136.17 | 2.2 | 2.3 | 2.6 | 2.9 | 3.0 | 3.4 | 3.4 | 3.9 | 3.7 | 4.3 | 4.0 | 4.8 | 22 |
| 438 | 69.95 | 136.10 | 2.6 | 2.8 | 3.0 | 3.3 | 3.3 | 3.6 | 3.6 | 4.1 | 3.9 | 4.5 | 4.1 | 4.8 | 22 |
| 463 | 69.30 | 137.20 | 2.3 | 2.5 | 2.7 | 3.0 | 3.0 | 3.4 | 3.3 | 3.8 | 3.6 | 4.2 | 3.9 | 4.5 | 23 |
| 464 | 69.64 | 137.14 | 2.5 | 2.7 | 3.0 | 3.3 | 3.3 | 3.7 | 3.7 | 4.2 | 4.0 | 4.6 | 4.2 | 5.0 | 21 |
| 465 | 69.97 | 137.07 | 2.5 | 2.7 | 2.9 | 3.2 | 3.2 | 3.6 | 3.5 | 4.0 | 3.8 | 4.4 | 4.0 | 4.7 | 21 |
| 490 | 69.32 | 138.15 | 2.0 | 2.1 | 2.3 | 2.5 | 2.5 | 2.8 | 2.7 | 3.1 | 2.9 | 3.3 | 3.1 | 3.6 | 18 |
| 491 | 69.65 | 138.10 | 2.5 | 2.7 | 3.0 | 3.3 | 3.3 | 3.7 | 3.7 | 4.2 | 4.0 | 4.7 | 4.3 | 5.1 | 22 |
| 492 | 69.99 | 138.05 | 2.2 | 2.3 | 2.6 | 2.8 | 2.8 | 3.2 | 3.1 | 3.6 | 3.4 | 4.0 | 3.6 | 4.3 | 19 |

Table 8.6 Summary of Extremal Analysis Results At 51 Grid Points
Significant Wave Height - Joint Probability (Combined Ice Edge)

E) JOINT PROBABILITY (98% + 50% + 30% FREQUENCY OF OCCURRENCE ICE EDGE)

| risk factor return period | | | 0.20 5 yr | | 0.10 10 yr | | 0.04 25 yr | | 0.02 50 yr | | 0.01 100 yr | | NUM PTS |
|------------------------------|------------|-------------|--------------|-------------|---------------|-------------|---------------|-------------|---------------|-------------|----------------|-------------|------------|
| grid point | Lat (N) | Long (W) | Best Fit | 90% U.L. | Best Fit | 90% U.L. | Best Fit | 90% U.L. | Best Fit | 90% U.L. | Best Fit | 90% U.L. | |
| | | | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | (m) | |
| 198 | 70.47 | 126.82 | 3.5 | 3.7 | 4.0 | 4.3 | 4.5 | 5.0 | 5.0 | 5.5 | 5.4 | 6.0 | 80 |
| 200 | 71.12 | 126.34 | 3.7 | 4.0 | 4.2 | 4.6 | 4.9 | 5.5 | 5.5 | 6.1 | 6.0 | 6.8 | 66 |
| 226 | 70.87 | 127.57 | 3.8 | 4.1 | 4.4 | 4.8 | 5.1 | 5.6 | 5.6 | 6.2 | 6.1 | 6.8 | 70 |
| 252 | 70.61 | 128.78 | 3.3 | 3.5 | 3.7 | 3.9 | 4.2 | 4.5 | 4.6 | 5.0 | 4.9 | 5.5 | 81 |
| 254 | 71.27 | 128.36 | 3.8 | 4.1 | 4.4 | 4.8 | 5.1 | 5.7 | 5.7 | 6.4 | 6.2 | 7.1 | 55 |
| 278 | 70.35 | 129.96 | 3.0 | 3.2 | 3.4 | 3.6 | 3.9 | 4.2 | 4.3 | 4.7 | 4.6 | 5.1 | 81 |
| 280 | 71.01 | 129.58 | 3.8 | 4.1 | 4.4 | 4.8 | 5.0 | 5.6 | 5.5 | 6.2 | 6.0 | 6.8 | 59 |
| 306 | 70.74 | 130.77 | 3.9 | 4.1 | 4.4 | 4.7 | 5.1 | 5.5 | 5.5 | 6.1 | 6.0 | 6.7 | 77 |
| 309 | 71.73 | 130.23 | 3.5 | 3.9 | 4.1 | 4.7 | 4.9 | 5.7 | 5.4 | 6.4 | 5.9 | 7.1 | 30 |
| 330 | 69.80 | 132.22 | 2.7 | 2.9 | 3.0 | 3.2 | 3.4 | 3.7 | 3.7 | 4.1 | 4.0 | 4.4 | 80 |
| 331 | 70.13 | 132.08 | 3.8 | 4.0 | 4.2 | 4.5 | 4.8 | 5.2 | 5.2 | 5.7 | 5.7 | 6.2 | 81 |
| 332 | 70.46 | 131.93 | 4.0 | 4.2 | 4.5 | 4.8 | 5.1 | 5.5 | 5.5 | 6.1 | 6.0 | 6.6 | 81 |
| 356 | 69.51 | 133.30 | 1.9 | 2.0 | 2.1 | 2.3 | 2.4 | 2.6 | 2.6 | 2.9 | 2.8 | 3.1 | 80 |
| 357 | 69.84 | 133.18 | 3.1 | 3.2 | 3.4 | 3.6 | 3.7 | 4.0 | 4.0 | 4.4 | 4.3 | 4.7 | 80 |
| 358 | 70.17 | 133.05 | 4.0 | 4.2 | 4.4 | 4.7 | 5.0 | 5.4 | 5.4 | 5.8 | 5.8 | 6.3 | 81 |
| 360 | 70.84 | 132.79 | 4.1 | 4.4 | 4.6 | 5.0 | 5.3 | 5.8 | 5.7 | 6.4 | 6.2 | 7.0 | 58 |
| 362 | 71.50 | 132.50 | 3.6 | 4.1 | 4.2 | 4.8 | 4.9 | 5.7 | 5.4 | 6.4 | 5.9 | 7.0 | 30 |
| 384 | 69.88 | 134.15 | 3.3 | 3.5 | 3.7 | 3.9 | 4.1 | 4.5 | 4.5 | 4.9 | 4.8 | 5.3 | 81 |
| 386 | 70.55 | 133.92 | 4.1 | 4.3 | 4.6 | 4.9 | 5.2 | 5.7 | 5.7 | 6.3 | 6.2 | 6.9 | 70 |
| 410 | 69.58 | 135.21 | 2.2 | 2.3 | 2.4 | 2.5 | 2.7 | 2.9 | 2.9 | 3.2 | 3.1 | 3.4 | 80 |
| 411 | 69.92 | 135.12 | 3.6 | 3.8 | 4.0 | 4.3 | 4.5 | 4.9 | 4.9 | 5.3 | 5.3 | 5.8 | 81 |
| 412 | 70.25 | 135.03 | 4.0 | 4.3 | 4.5 | 4.8 | 5.1 | 5.5 | 5.5 | 6.0 | 6.0 | 6.5 | 81 |
| 413 | 70.59 | 134.93 | 4.1 | 4.4 | 4.6 | 5.0 | 5.2 | 5.7 | 5.7 | 6.3 | 6.1 | 6.8 | 63 |
| 414 | 70.92 | 134.82 | 4.1 | 4.4 | 4.6 | 5.0 | 5.2 | 5.8 | 5.7 | 6.4 | 6.2 | 7.0 | 54 |
| 417 | 71.92 | 134.49 | 3.2 | 3.6 | 3.8 | 4.3 | 4.4 | 5.2 | 4.9 | 5.8 | 5.4 | 6.4 | 30 |
| 435 | 68.94 | 136.32 | 1.4 | 1.5 | 1.5 | 1.6 | 1.7 | 1.9 | 1.9 | 2.0 | 2.0 | 2.2 | 80 |
| 436 | 69.28 | 136.25 | 2.3 | 2.4 | 2.6 | 2.8 | 2.9 | 3.2 | 3.2 | 3.5 | 3.5 | 3.8 | 80 |
| 437 | 69.61 | 136.17 | 3.2 | 3.4 | 3.6 | 3.8 | 4.1 | 4.4 | 4.4 | 4.9 | 4.8 | 5.3 | 79 |
| 438 | 69.95 | 136.10 | 3.8 | 3.9 | 4.1 | 4.4 | 4.6 | 5.0 | 5.0 | 5.4 | 5.4 | 5.9 | 81 |
| 440 | 70.62 | 135.93 | 4.1 | 4.4 | 4.6 | 4.9 | 5.1 | 5.6 | 5.6 | 6.2 | 6.0 | 6.7 | 58 |
| 463 | 69.30 | 137.20 | 3.2 | 3.4 | 3.5 | 3.8 | 4.0 | 4.3 | 4.3 | 4.7 | 4.6 | 5.0 | 80 |
| 464 | 69.64 | 137.14 | 3.6 | 3.8 | 4.0 | 4.3 | 4.5 | 4.9 | 4.9 | 5.3 | 5.3 | 5.8 | 79 |
| 465 | 69.97 | 137.07 | 3.9 | 4.1 | 4.3 | 4.6 | 4.8 | 5.2 | 5.2 | 5.7 | 5.6 | 6.2 | 80 |
| 468 | 70.98 | 136.87 | 3.9 | 4.2 | 4.3 | 4.7 | 4.9 | 5.5 | 5.4 | 6.0 | 5.8 | 6.6 | 52 |
| 470 | 71.65 | 136.73 | 3.3 | 3.7 | 3.8 | 4.3 | 4.4 | 5.1 | 4.8 | 5.6 | 5.2 | 6.1 | 30 |
| 490 | 69.32 | 138.15 | 2.8 | 3.0 | 3.1 | 3.1 | 3.5 | 3.8 | 3.8 | 4.1 | 4.1 | 4.5 | 80 |
| 491 | 69.65 | 138.10 | 3.8 | 4.0 | 4.2 | 4.5 | 4.8 | 5.2 | 5.2 | 5.7 | 5.6 | 6.2 | 79 |
| 492 | 69.99 | 138.05 | 4.0 | 4.2 | 4.5 | 4.8 | 5.1 | 5.6 | 5.6 | 6.2 | 6.1 | 6.7 | 79 |
| 493 | 70.33 | 138.01 | 4.0 | 4.3 | 4.5 | 4.8 | 5.1 | 5.6 | 5.5 | 6.1 | 5.9 | 6.6 | 58 |
| 494 | 70.66 | 137.96 | 3.8 | 4.1 | 4.2 | 4.6 | 4.7 | 5.2 | 5.1 | 5.6 | 5.5 | 6.1 | 54 |
| 522 | 71.01 | 138.93 | 3.4 | 3.7 | 3.9 | 4.4 | 4.6 | 5.2 | 5.0 | 5.8 | 5.5 | 6.4 | 41 |
| 525 | 72.02 | 138.82 | 3.1 | 3.4 | 3.5 | 4.0 | 4.1 | 4.7 | 4.4 | 5.2 | 4.8 | 5.7 | 30 |
| 545 | 69.68 | 140.03 | 3.3 | 3.5 | 3.7 | 4.0 | 4.1 | 4.6 | 4.5 | 5.0 | 4.9 | 5.4 | 55 |
| 546 | 70.01 | 140.02 | 3.7 | 3.9 | 4.1 | 4.5 | 4.7 | 5.2 | 5.1 | 5.7 | 5.5 | 6.2 | 56 |
| 548 | 70.68 | 139.98 | 3.5 | 3.9 | 4.0 | 4.5 | 4.7 | 5.2 | 5.1 | 5.8 | 5.6 | 6.3 | 47 |
| 574 | 70.35 | 141.00 | 3.6 | 3.9 | 4.2 | 4.6 | 4.8 | 5.4 | 5.3 | 6.0 | 5.8 | 6.6 | 51 |
| 576 | 71.02 | 141.00 | 3.2 | 3.5 | 3.7 | 4.1 | 4.2 | 4.9 | 4.7 | 5.4 | 5.1 | 6.0 | 37 |
| 578 | 71.69 | 141.00 | 3.1 | 3.4 | 3.5 | 4.0 | 4.1 | 4.7 | 4.5 | 5.2 | 4.9 | 5.7 | 30 |
| 630 | 71.01 | 143.07 | 3.1 | 3.5 | 3.7 | 4.2 | 4.4 | 5.1 | 4.9 | 5.7 | 5.4 | 6.4 | 37 |
| 655 | 70.33 | 143.99 | 2.8 | 3.1 | 3.2 | 3.6 | 3.8 | 4.3 | 4.2 | 4.9 | 4.6 | 5.4 | 40 |
| 764 | 70.55 | 148.08 | 1.9 | 2.1 | 2.2 | 2.6 | 2.7 | 3.1 | 3.0 | 3.5 | 3.3 | 3.9 | 38 |

BEAUFORT SEA 100 YR WAVES REAL ICE EDGE

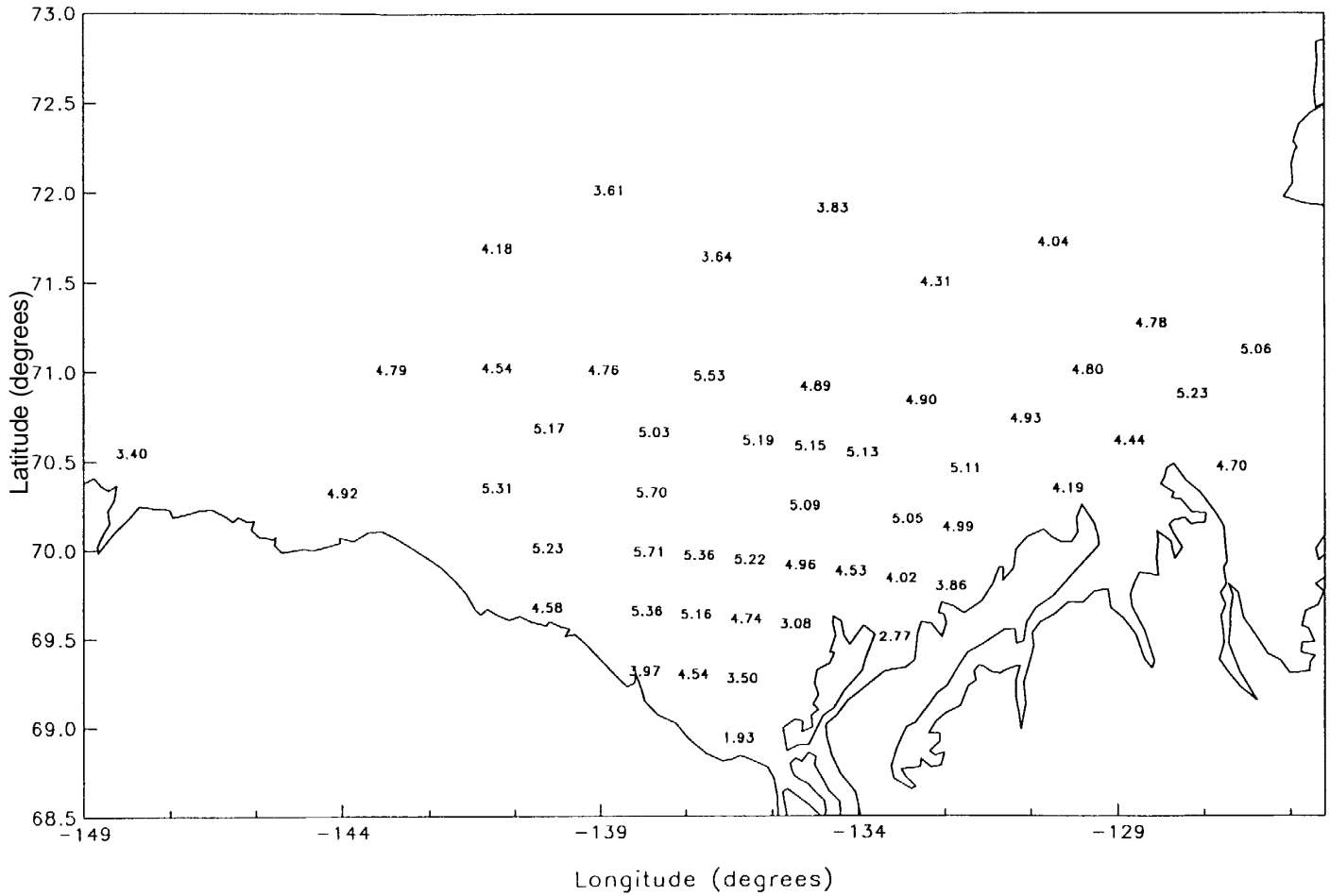


Figure 8.7 100-Year Significant Wave Height - Real Ice Edge

BEAUFORT SEA 100 YR WAVES

98% Occurrence of Ice Edge

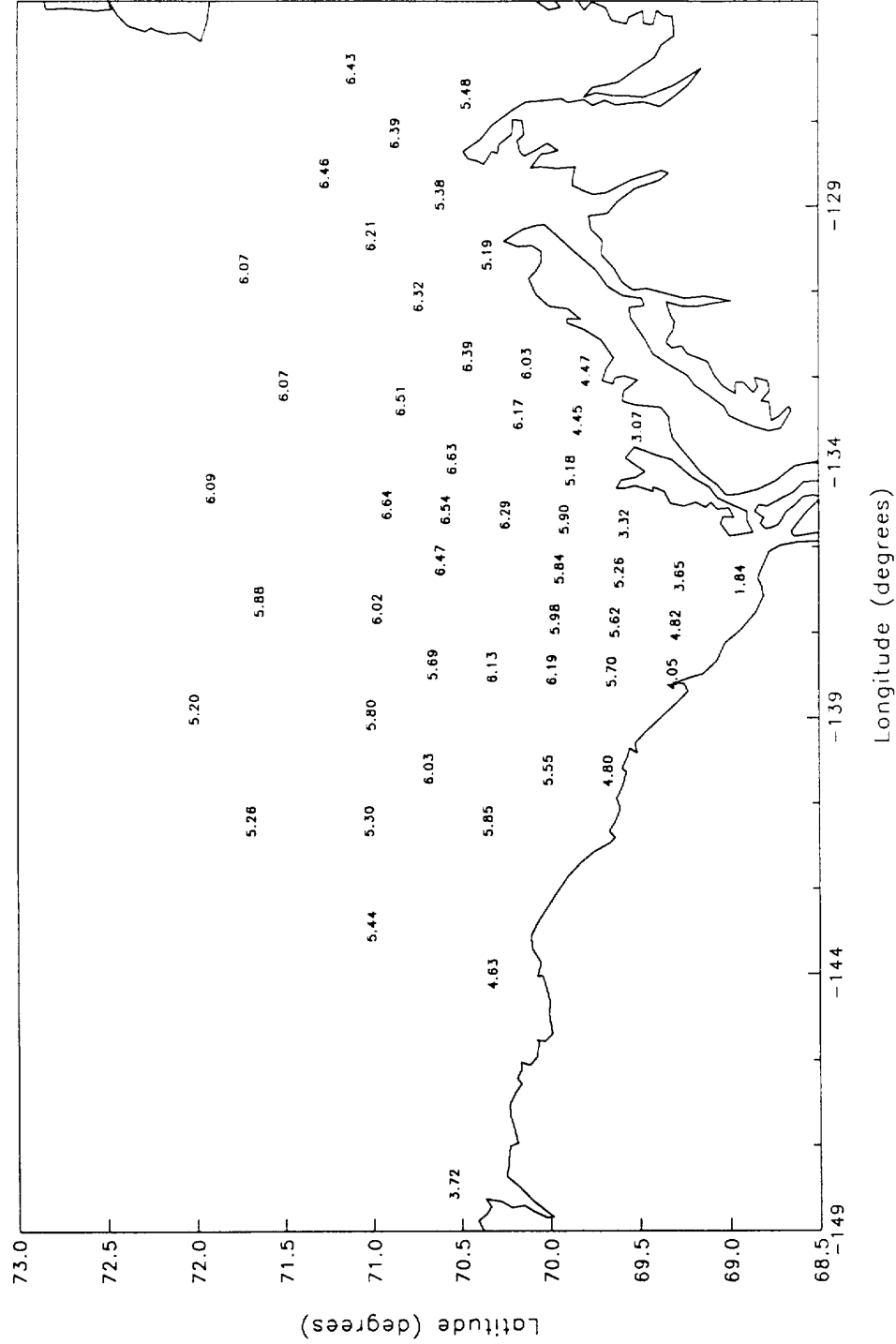


Figure 8.8 100-Year Significant Wave Height - 98% Ice Edge

BEAUFORT SEA 100 YR WAVES
50% Occurrence of Ice Edge

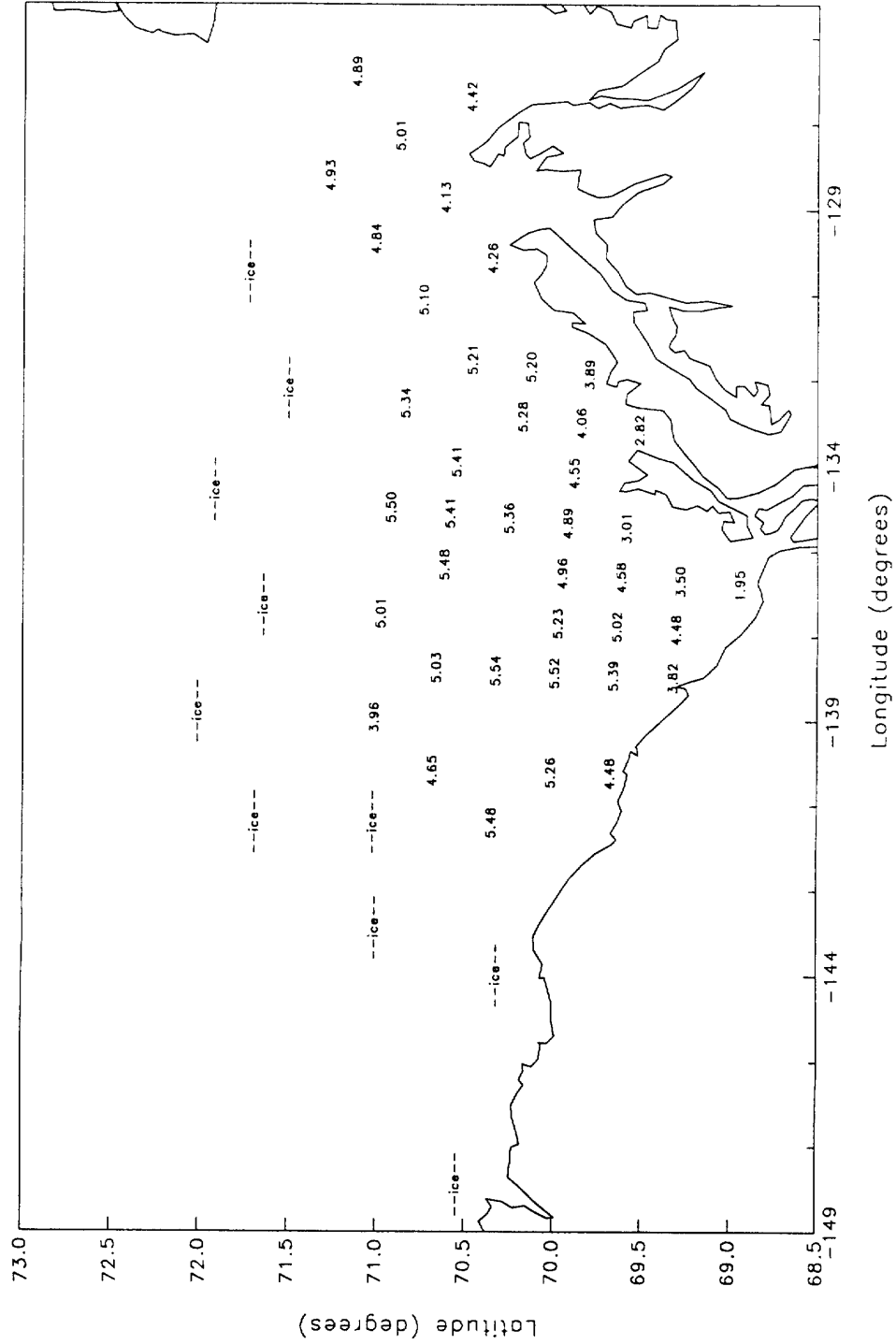
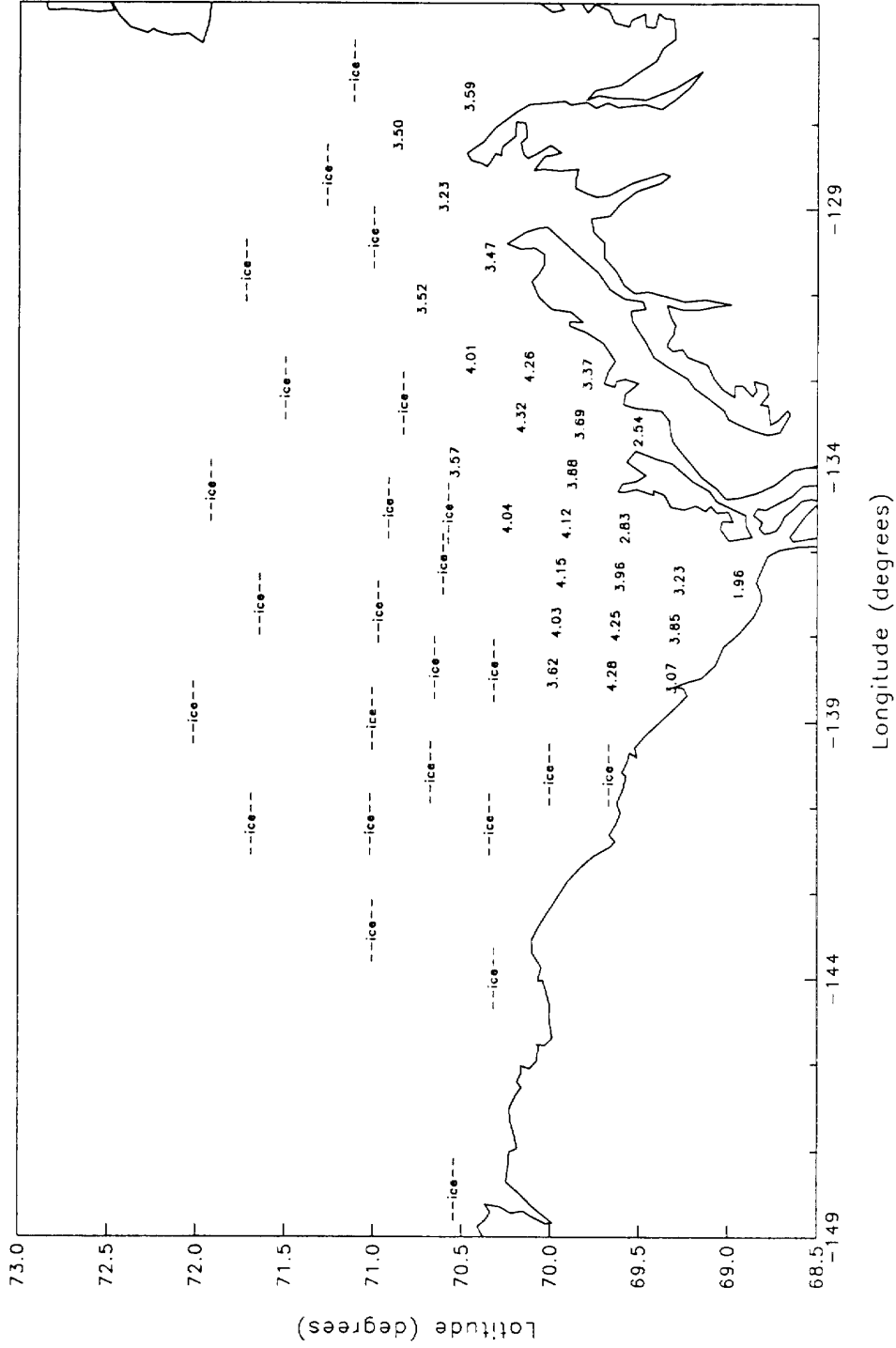


Figure 8.9 100-Year Significant Height - 50% Ice Edge

BEAUFORT SEA 100 YR WAVES
30% Occurrence of Ice Edge



8-30

Figure 8.10 100-Year Significant Wave Height - 30% Ice Edge

BEAUFORT SEA 100 YR WAVES
JOINT PROBABILITY (98% + 50% + 30% ICE EDGE)

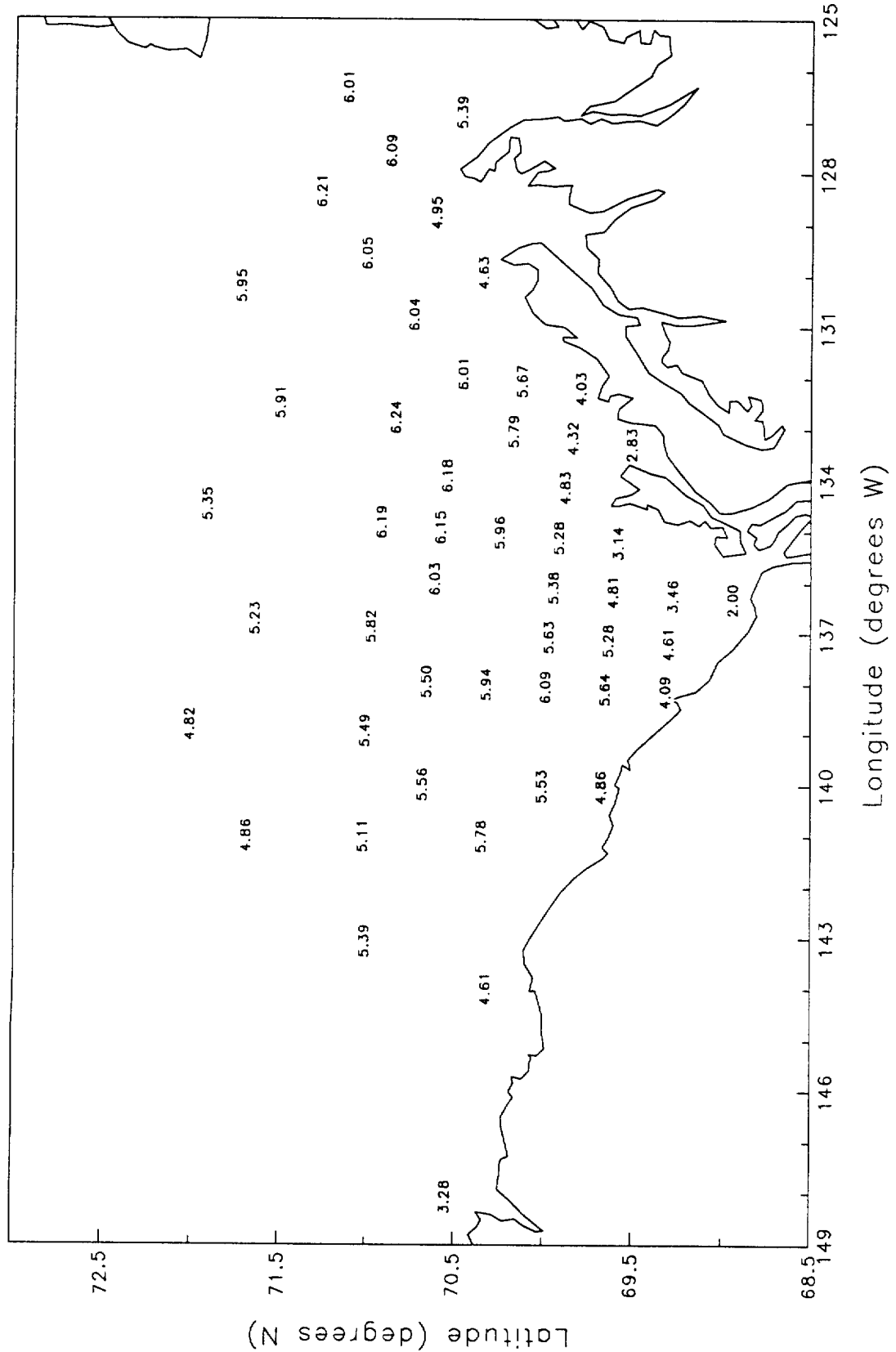


Figure 8.11 100-Year Significant Wave Height - Joint Probability

**Table 8.7 Summary of 100 Year Significant Wave Height
For Different Ice Edge Scenarios**

| Grid Point | Latitude (N) | Longitude (W) | Real edge | 98% ice edge | 50% ice edge | 30% ice edge | Joint Probability |
|------------|--------------|---------------|-----------|--------------|--------------|--------------|-------------------|
| 198 | 70.47 | 126.82 | 4.70 | 5.48 | 4.42 | 3.59 | 5.4 |
| 200 | 71.12 | 126.34 | 5.06 | 6.43 | 4.89 | ---- | 6.0 |
| 226 | 70.87 | 127.57 | 5.23 | 6.39 | 5.01 | 3.50 | 6.1 |
| 252 | 70.61 | 128.78 | 4.44 | 5.38 | 4.13 | 3.23 | 4.9 |
| 254 | 71.27 | 128.36 | 4.78 | 6.46 | 4.93 | ---- | 6.2 |
| 278 | 70.35 | 129.96 | 4.19 | 5.19 | 4.26 | 3.47 | 4.6 |
| 280 | 71.01 | 129.58 | 4.80 | 6.21 | 4.84 | ---- | 6.0 |
| 306 | 70.74 | 130.77 | 4.93 | 6.32 | 5.10 | 3.52 | 6.0 |
| 309 | 71.73 | 130.23 | 4.04 | 6.07 | ---- | ---- | 5.9 |
| 330 | 69.80 | 132.22 | 3.86 | 4.47 | 3.89 | 3.37 | 4.0 |
| 331 | 70.13 | 132.08 | 4.99 | 6.03 | 5.20 | 4.26 | 5.7 |
| 332 | 70.46 | 131.93 | 5.11 | 6.39 | 5.21 | 4.01 | 6.0 |
| 356 | 69.51 | 133.30 | 2.77 | 3.07 | 2.82 | 2.54 | 2.8 |
| 357 | 69.84 | 133.18 | 4.02 | 4.45 | 4.06 | 3.69 | 4.3 |
| 358 | 70.17 | 133.05 | 5.05 | 6.17 | 5.28 | 4.32 | 5.8 |
| 360 | 70.84 | 132.79 | 4.90 | 6.51 | 5.34 | ---- | 6.2 |
| 362 | 71.50 | 132.50 | 4.31 | 6.07 | ---- | ---- | 5.9 |
| 384 | 69.88 | 134.15 | 4.53 | 5.18 | 4.55 | 3.88 | 4.8 |
| 386 | 70.55 | 133.92 | 5.13 | 6.63 | 5.41 | 3.57 | 6.2 |
| 410 | 69.58 | 135.21 | 3.08 | 3.32 | 3.01 | 2.83 | 3.1 |
| 411 | 69.92 | 135.12 | 4.96 | 5.90 | 4.89 | 4.12 | 5.3 |
| 412 | 70.25 | 135.03 | 5.09 | 6.29 | 5.36 | 4.04 | 6.0 |
| 413 | 70.59 | 134.93 | 5.15 | 6.54 | 5.41 | ---- | 6.1 |
| 414 | 70.92 | 134.82 | 4.89 | 6.64 | 5.50 | ---- | 6.2 |
| 417 | 71.92 | 134.49 | 3.83 | 6.09 | ---- | ---- | 5.4 |
| 435 | 68.94 | 136.32 | 1.93 | 1.84 | 1.95 | 1.96 | 2.0 |
| 436 | 69.28 | 136.25 | 3.50 | 3.65 | 3.50 | 3.23 | 3.5 |
| 437 | 69.61 | 136.17 | 4.74 | 5.26 | 4.58 | 3.96 | 4.8 |
| 438 | 69.95 | 136.10 | 5.22 | 5.84 | 4.96 | 4.15 | 5.4 |
| 440 | 70.62 | 135.93 | 5.19 | 6.47 | 5.48 | ---- | 6.0 |
| 463 | 69.30 | 137.20 | 4.54 | 4.82 | 4.48 | 3.85 | 4.6 |
| 464 | 69.64 | 137.14 | 5.16 | 5.62 | 5.02 | 4.25 | 5.3 |
| 465 | 69.97 | 137.07 | 5.36 | 5.98 | 5.23 | 4.03 | 5.6 |
| 468 | 70.98 | 136.87 | 5.53 | 6.02 | 5.01 | ---- | 5.8 |
| 470 | 71.65 | 136.73 | 3.64 | 5.88 | ---- | ---- | 5.2 |
| 490 | 69.32 | 138.15 | 3.97 | 4.05 | 3.82 | 3.07 | 4.1 |
| 491 | 69.65 | 138.10 | 5.36 | 5.70 | 5.39 | 4.28 | 5.6 |
| 492 | 69.99 | 138.05 | 5.71 | 6.19 | 5.52 | 3.62 | 6.1 |
| 493 | 70.33 | 138.01 | 5.70 | 6.13 | 5.54 | ---- | 5.9 |
| 494 | 70.66 | 137.96 | 5.03 | 5.69 | 5.03 | ---- | 5.5 |
| 522 | 71.01 | 138.93 | 4.76 | 5.80 | 3.96 | ---- | 5.5 |
| 525 | 72.02 | 138.82 | 3.61 | 5.20 | ---- | ---- | 4.8 |
| 545 | 69.68 | 140.03 | 4.58 | 4.80 | 4.48 | ---- | 4.9 |
| 546 | 70.01 | 140.02 | 5.23 | 5.55 | 5.26 | ---- | 5.5 |
| 548 | 70.68 | 139.98 | 5.17 | 6.03 | 4.65 | ---- | 5.6 |
| 574 | 70.35 | 141.00 | 5.31 | 5.85 | 5.48 | ---- | 5.8 |
| 576 | 71.02 | 141.00 | 4.54 | 5.30 | ---- | ---- | 5.1 |
| 578 | 71.69 | 141.00 | 4.18 | 5.26 | ---- | ---- | 4.9 |
| 630 | 71.01 | 143.07 | 4.79 | 5.44 | ---- | ---- | 5.4 |
| 655 | 70.33 | 144.00 | 4.92 | 4.63 | ---- | ---- | 4.6 |
| 764 | 70.55 | 148.08 | 3.40 | 3.72 | ---- | ---- | 3.3 |

GRID POINT 360 AT 70.840 N, 132.79 W

GUMBEL - Method of Moments

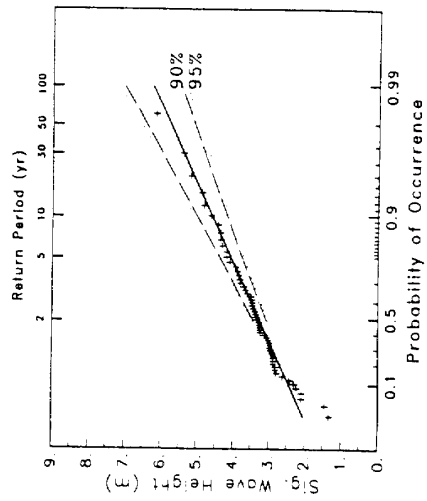
58 storms
Wave height threshold = 1.34 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | 100% U.L. (m) | Wave Height (m) | Wave Period (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|---------------|-----------------|-----------------|----------|--------|
| 2 | 3.2 | 3.4 | 3.4 | 7.8 | 5.9 | 3.3 | 3.3 |
| 5 | 4.1 | 4.4 | 4.4 | 8.8 | 7.4 | 4.1 | 4.1 |
| 10 | 4.6 | 5.0 | 5.0 | 9.4 | 8.3 | 4.7 | 4.7 |
| 30 | 5.4 | 6.0 | 6.0 | 10.2 | 9.8 | 5.5 | 5.5 |
| 50 | 5.7 | 6.4 | 6.4 | 10.6 | 10.5 | 5.8 | 5.8 |
| 100 | 6.2 | 7.0 | 7.0 | 11.1 | 11.4 | 6.3 | 6.3 |

Ip, Hmax, and Hc were calculated using

Ip = 4.189 Hs^{0.332}
Hmax = 1.821 Hs
Hc = 1.018 Hs

Correlation = 0.99



GRID POINT 384 AT 69.882 N, 134.15 W

GUMBEL - Method of Moments

81 storms
Wave height threshold = 1.72 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | 100% U.L. (m) | Wave Height (m) | Wave Period (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|---------------|-----------------|-----------------|----------|--------|
| 2 | 2.7 | 2.9 | 2.9 | 7.9 | 4.9 | 2.8 | 2.8 |
| 5 | 3.3 | 3.5 | 3.5 | 8.8 | 5.9 | 3.3 | 3.3 |
| 10 | 3.7 | 3.9 | 3.9 | 9.4 | 6.6 | 3.7 | 3.7 |
| 30 | 4.2 | 4.6 | 4.6 | 10.3 | 7.6 | 4.2 | 4.2 |
| 50 | 4.5 | 4.9 | 4.9 | 10.7 | 8.1 | 4.5 | 4.5 |
| 100 | 4.8 | 5.3 | 5.3 | 11.2 | 8.7 | 4.8 | 4.8 |

Ip, Hmax, and Hc were calculated using

Ip = 4.275 Hs^{0.332}
Hmax = 1.800 Hs
Hc = 1.000 Hs

Correlation = 1.00

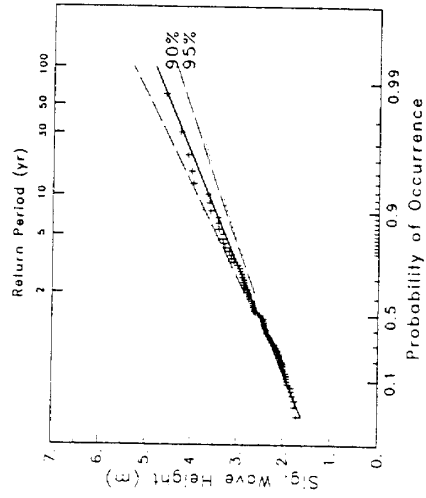


Figure 8.12 Final Extreme Analysis Results - Joint Probability

GRID POINT 435 AT 68.942 N, 136.32 W

GUMBEL -- Method of Moments

80 storms

Wave height threshold = 0.68 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | Ip (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 1.2 | 1.2 | 4.7 | 2.2 | 1.2 |
| 5 | 1.4 | 1.5 | 5.1 | 2.5 | 1.4 |
| 10 | 1.5 | 1.6 | 5.4 | 2.8 | 1.6 |
| 30 | 1.8 | 1.9 | 5.8 | 3.2 | 1.8 |
| 50 | 1.9 | 2.0 | 6.0 | 3.4 | 1.9 |
| 100 | 2.0 | 2.2 | 6.3 | 3.6 | 2.1 |

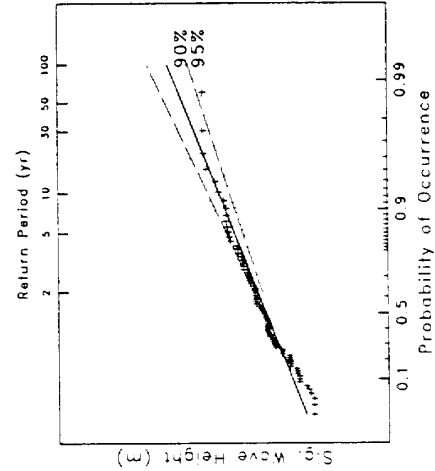
Ip, Hmax, and Hc were calculated using

$$I_p = 4.275 H_s^{0.551}$$

$$H_{max} = 1.828 H_s$$

$$H_c = 1.031 H_s$$

Correlation = 0.98



GRID POINT 437 AT 69.612 N, 136.17 W

GUMBEL -- Method of Moments

79 storms

Wave height threshold = 1.50 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | Ip (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 2.6 | 2.7 | 7.9 | 4.7 | 2.6 |
| 5 | 3.2 | 3.4 | 8.8 | 5.7 | 3.2 |
| 10 | 3.6 | 3.8 | 9.4 | 6.4 | 3.6 |
| 30 | 4.2 | 4.5 | 10.3 | 7.5 | 4.2 |
| 50 | 4.4 | 4.9 | 10.7 | 8.0 | 4.5 |
| 100 | 4.8 | 5.3 | 11.2 | 8.7 | 4.8 |

Ip, Hmax, and Hc were calculated using

$$I_p = 4.528 H_s^{0.576}$$

$$H_{max} = 1.811 H_s$$

$$H_c = 1.006 H_s$$

Correlation = 1.00

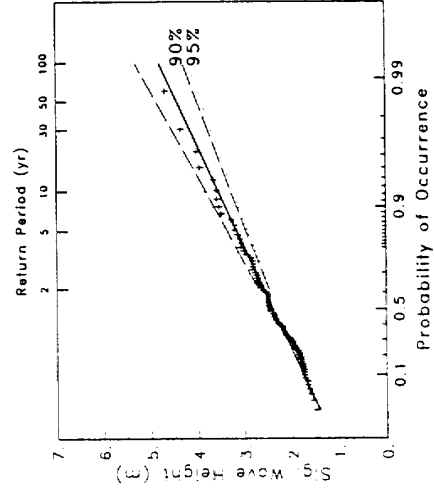


Figure 8.13 Final Extreme Analysis Results - Joint Probabilities

GRID POINT 463 AT 69.300 N, 137.20 W

GUMBEL - Method of Moments

80 storms

Wave height threshold = 1.66 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | Ip (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 2.7 | 2.8 | 7.6 | 4.9 | 2.7 |
| 5 | 3.2 | 3.4 | 8.4 | 5.8 | 3.2 |
| 10 | 3.5 | 3.8 | 8.9 | 6.4 | 3.6 |
| 30 | 4.1 | 4.4 | 9.7 | 7.4 | 4.1 |
| 50 | 4.3 | 4.7 | 10.0 | 7.8 | 4.3 |
| 100 | 4.6 | 5.0 | 10.5 | 8.4 | 4.7 |

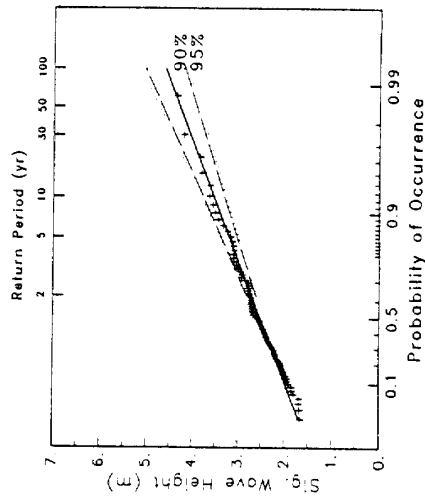
Ip, Hmax, and Hc were calculated using

Ip = 4.175 Hs^{0.841}

Hmax = 1.815 Hs

Hc = 1.011 Hs

Correlation = 1.00



GRID POINT 464 AT 69.635 N, 137.14 W

GUMBEL - Method of Moments

79 storms

Wave height threshold = 1.91 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | Ip (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 3.1 | 3.2 | 7.7 | 5.5 | 3.1 |
| 5 | 3.6 | 3.8 | 8.5 | 6.6 | 3.7 |
| 10 | 4.0 | 4.3 | 9.1 | 7.3 | 4.1 |
| 30 | 4.6 | 5.0 | 9.8 | 8.4 | 4.7 |
| 50 | 4.9 | 5.3 | 10.2 | 8.9 | 5.0 |
| 100 | 5.3 | 5.8 | 10.6 | 9.6 | 5.3 |

Ip, Hmax, and Hc were calculated using

Ip = 4.022 Hs^{0.845}

Hmax = 1.812 Hs

Hc = 1.012 Hs

Correlation = 1.00

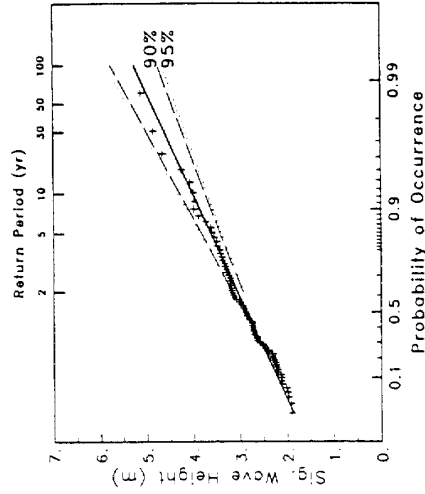


Figure 8.14 Final Extreme Analysis Results - Joint Probability

GRID POINT 492 AT 69.990 N, 138.05 W

GUMBEL - Method of Moments

79 storms

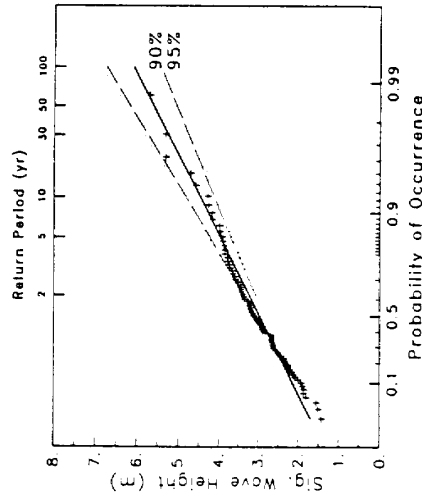
Wave height threshold = 1.43 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | Ip (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 3.2 | 3.4 | 7.8 | 5.8 | 3.3 |
| 5 | 4.0 | 4.2 | 8.7 | 7.2 | 4.0 |
| 10 | 4.5 | 4.8 | 9.4 | 8.1 | 4.5 |
| 30 | 5.3 | 5.7 | 10.3 | 9.5 | 5.3 |
| 50 | 5.6 | 6.2 | 10.6 | 10.1 | 5.7 |
| 100 | 6.1 | 6.7 | 11.1 | 11.0 | 6.2 |

Ip, Hmax, and Hc were calculated using

$I_p = 4.015 H_s^{0.333}$
 $H_{max} = 1.809 H_s$
 $H_c = 1.011 H_s$

Correlation = 0.99



GRID POINT 574 AT 70.350 N, 141.00 W

GUMBEL - Method of Moments

51 storms

Wave height threshold = 1.45 m

| Return Period (yr) | Best Fit (m) | 90% U.L. (m) | Ip (s) | Hmax (m) | Hc (m) |
|--------------------|--------------|--------------|--------|----------|--------|
| 2 | 2.8 | 3.0 | 7.3 | 5.1 | 2.8 |
| 5 | 3.6 | 3.9 | 8.4 | 6.6 | 3.7 |
| 10 | 4.2 | 4.6 | 9.0 | 7.5 | 4.2 |
| 30 | 4.9 | 5.6 | 9.9 | 8.9 | 5.0 |
| 50 | 5.3 | 6.0 | 10.3 | 9.6 | 5.4 |
| 100 | 5.8 | 6.6 | 10.8 | 10.5 | 5.9 |

Ip, Hmax, and Hc were calculated using

$I_p = 4.251 H_s^{0.330}$
 $H_{max} = 1.810 H_s$
 $H_c = 1.012 H_s$

Correlation = 0.98

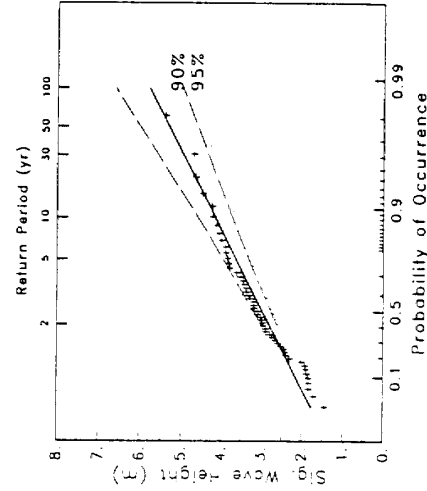


Figure 8.15 Final Extreme Analysis Results - Joint Probability

BEAUFORT SEA 100 YR SIGNIFICANT WAVE HEIGHT (m)
REAL ICE EDGE

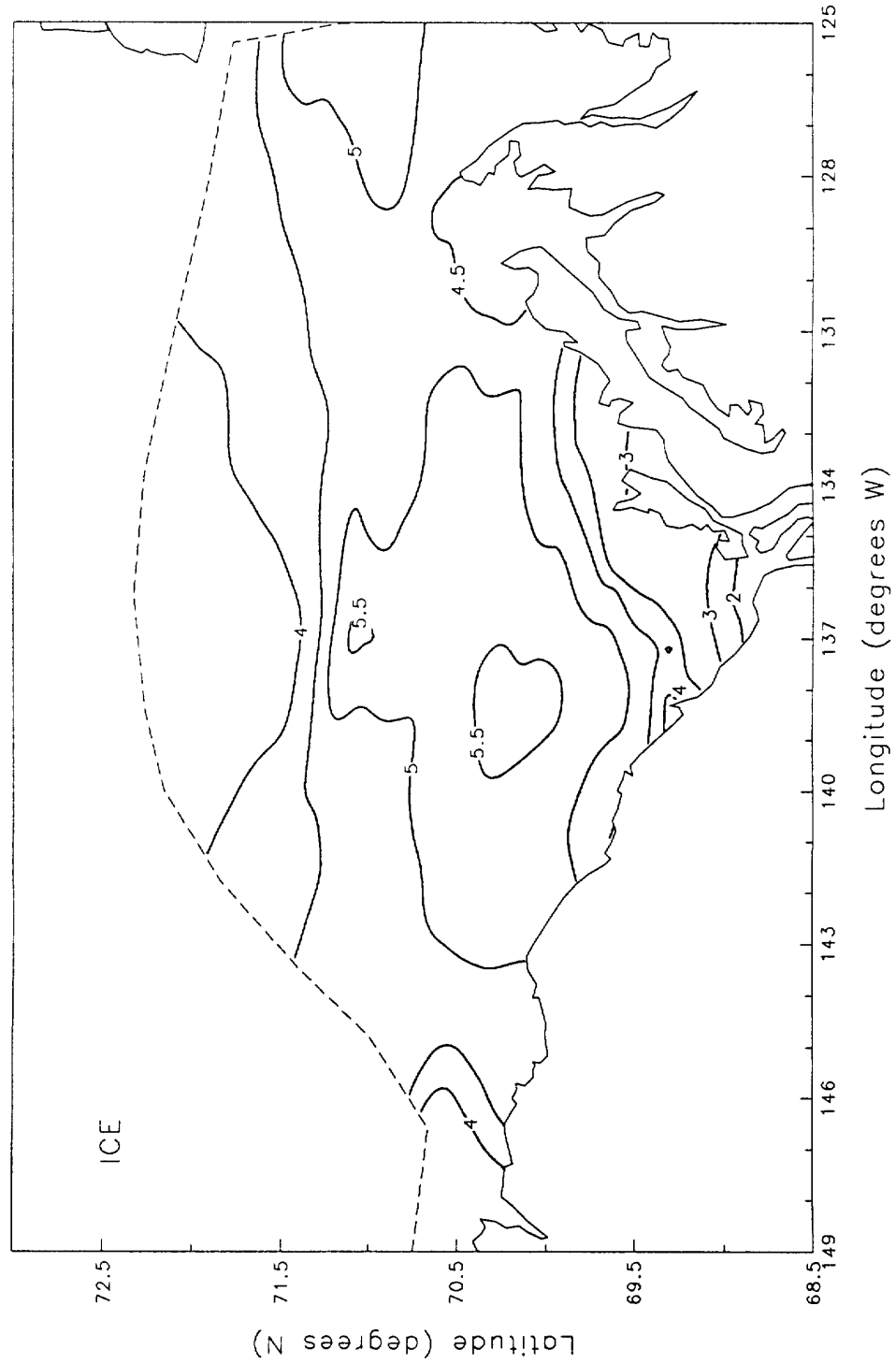


Figure 8.16

BEAUFORT SEA 100 YR MAXIMUM WAVE HEIGHT (m)

REAL ICE EDGE

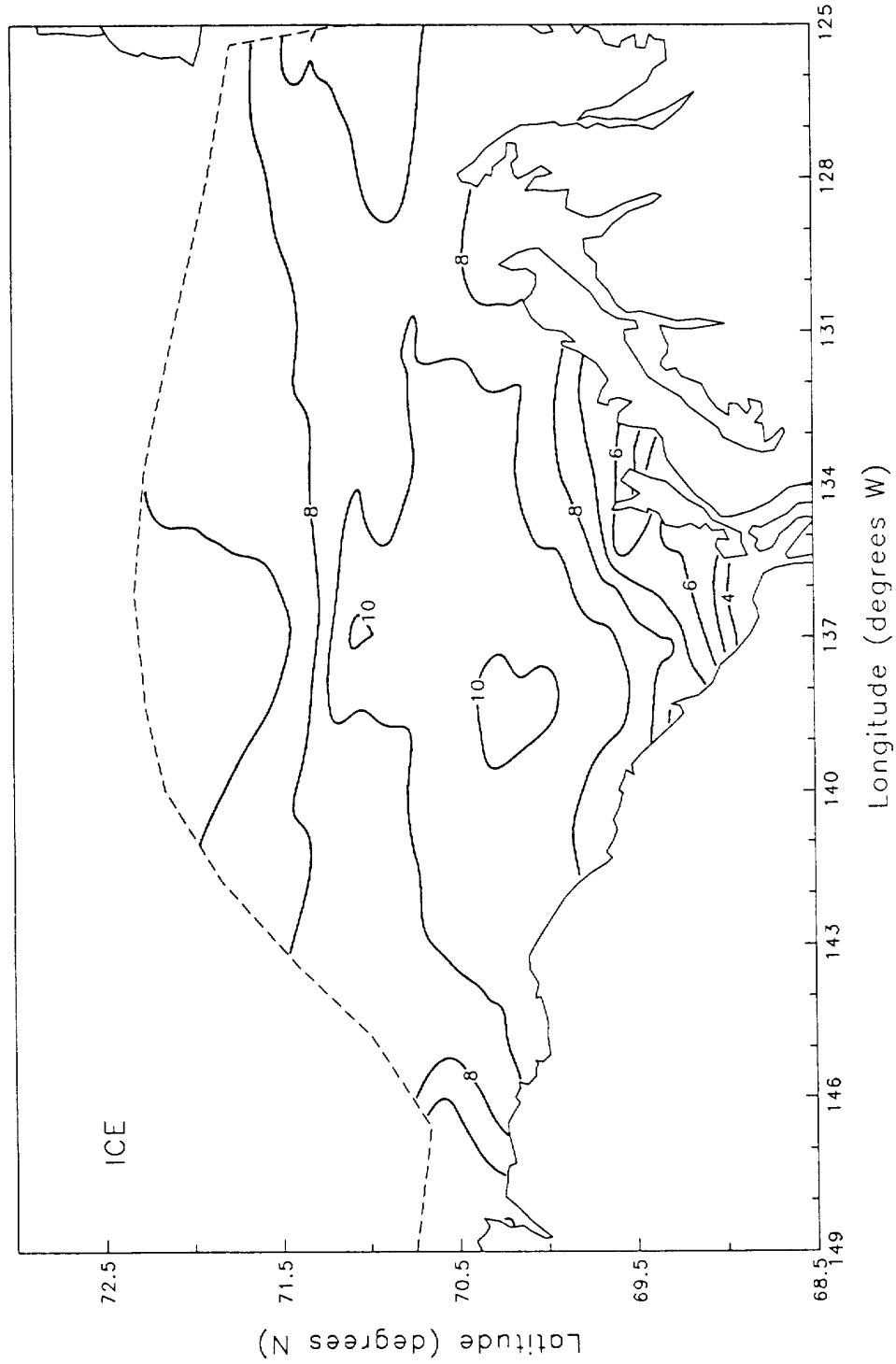


Figure 8.17

BEAUFORT SEA 100 YR WINDS (m/s)

REAL ICE EDGE

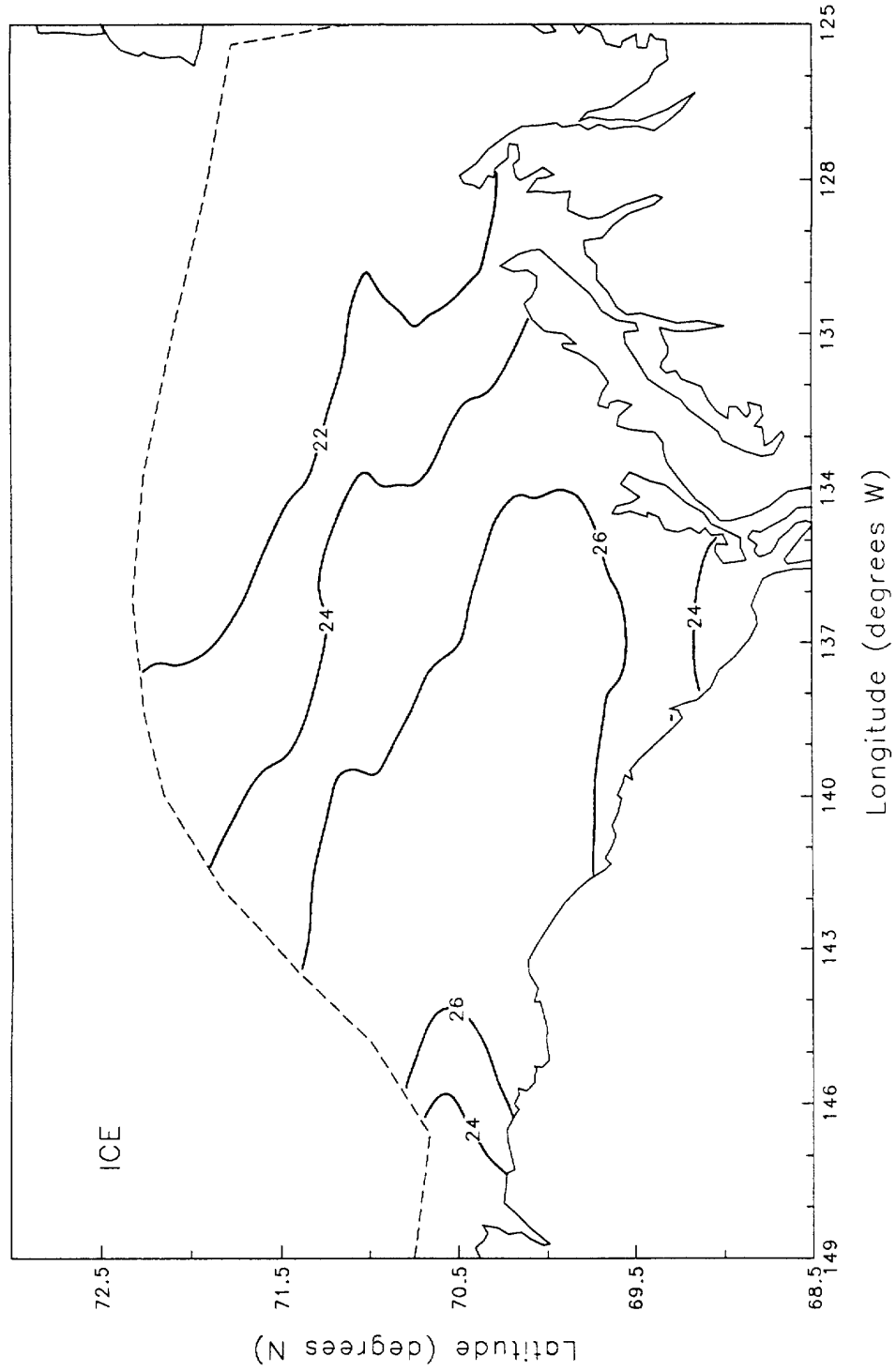


Figure 8.18

BEAUFORT SEA 100 YR SIGNIFICANT WAVE HEIGHT (m)

98% Occurrence of Ice Edge

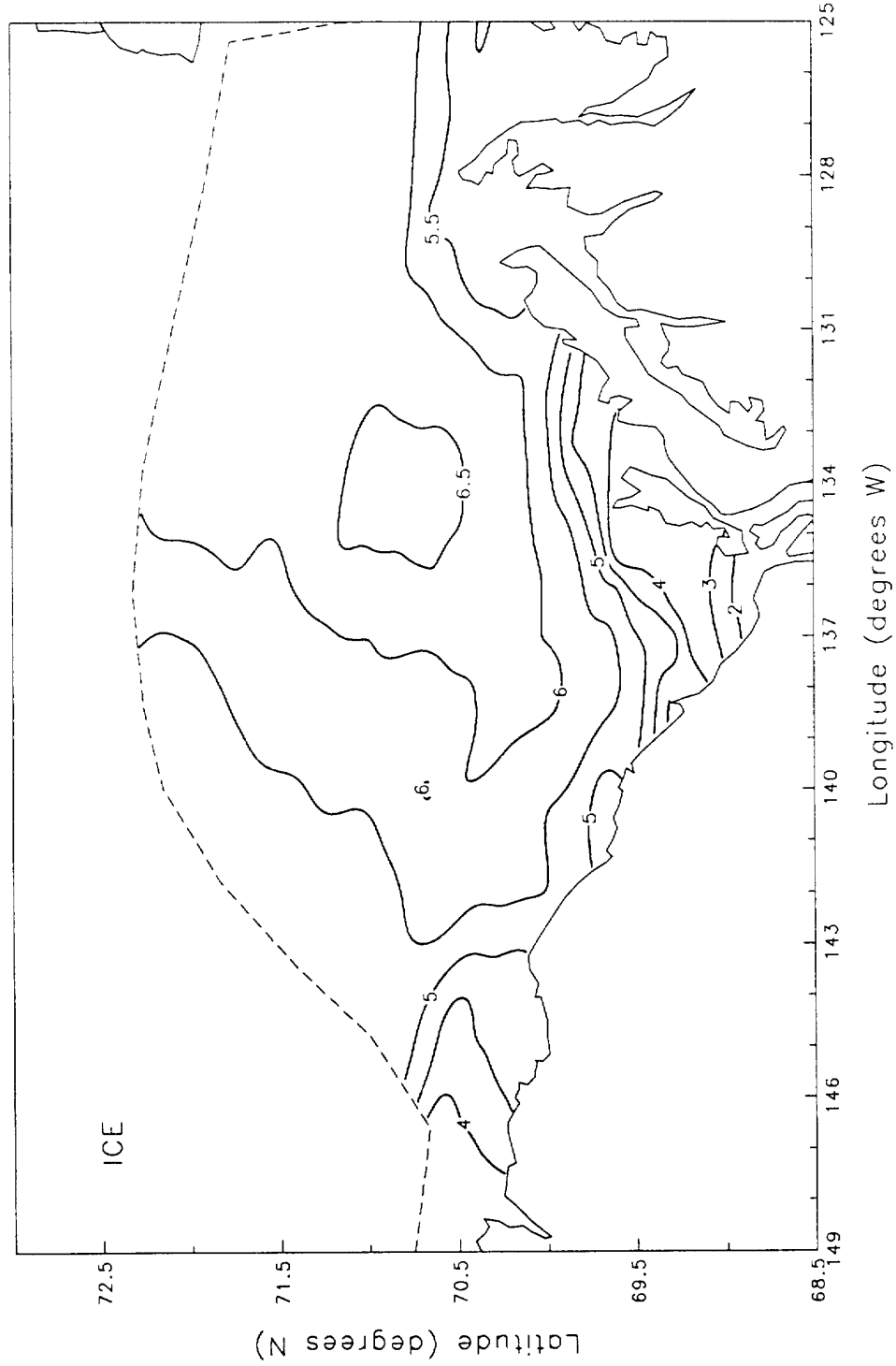


Figure 8.19

BEAUFORT SEA 100 YR MAXIMUM WAVE HEIGHT (m)

98% Occurrence of Ice Edge

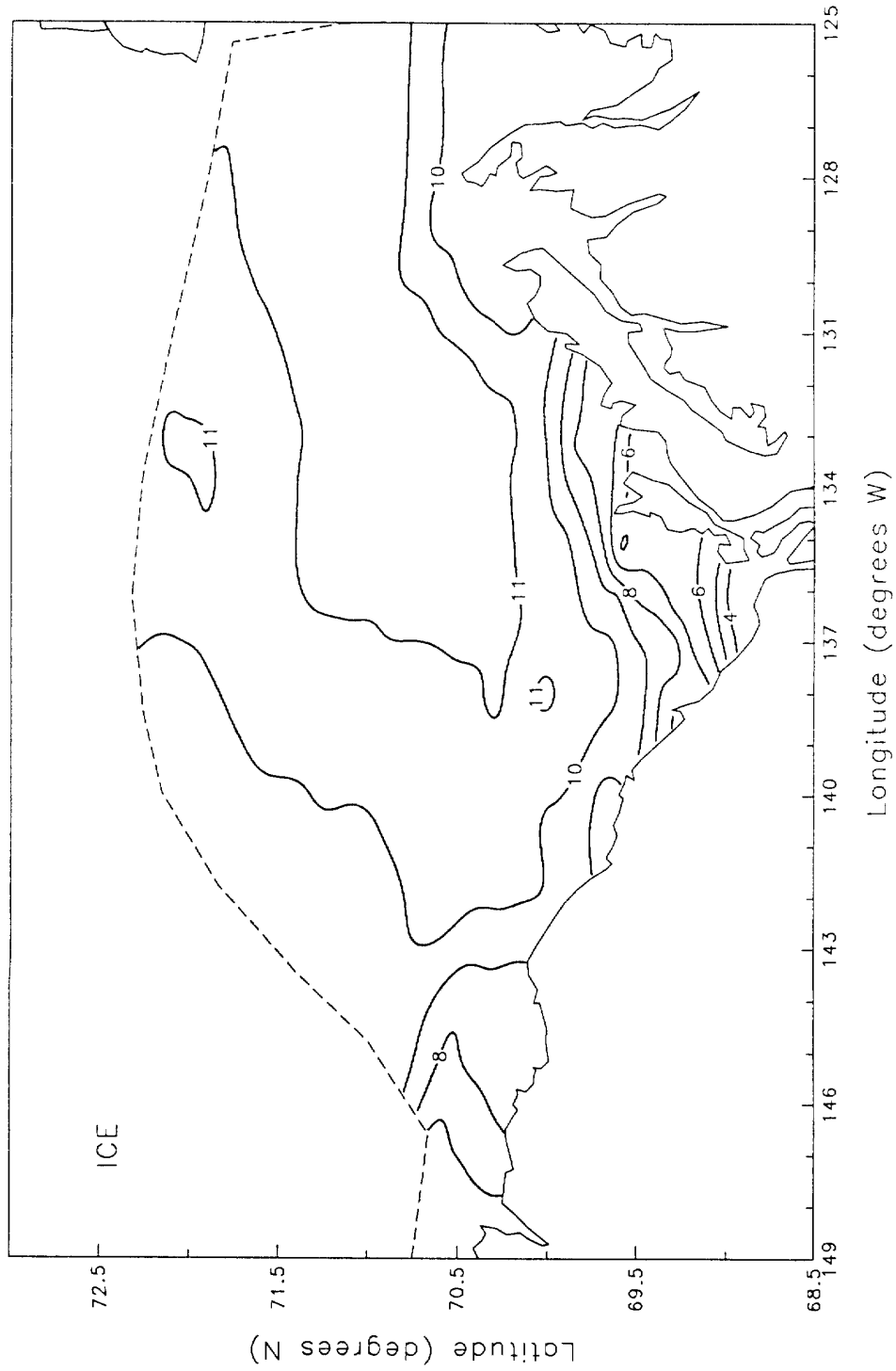


Figure 8.20

BEAUFORT SEA 100 YR SIGNIFICANT WAVE HEIGHT (m)

JOINT PROBABILITY (98% + 50% + 30% ICE EDGE)

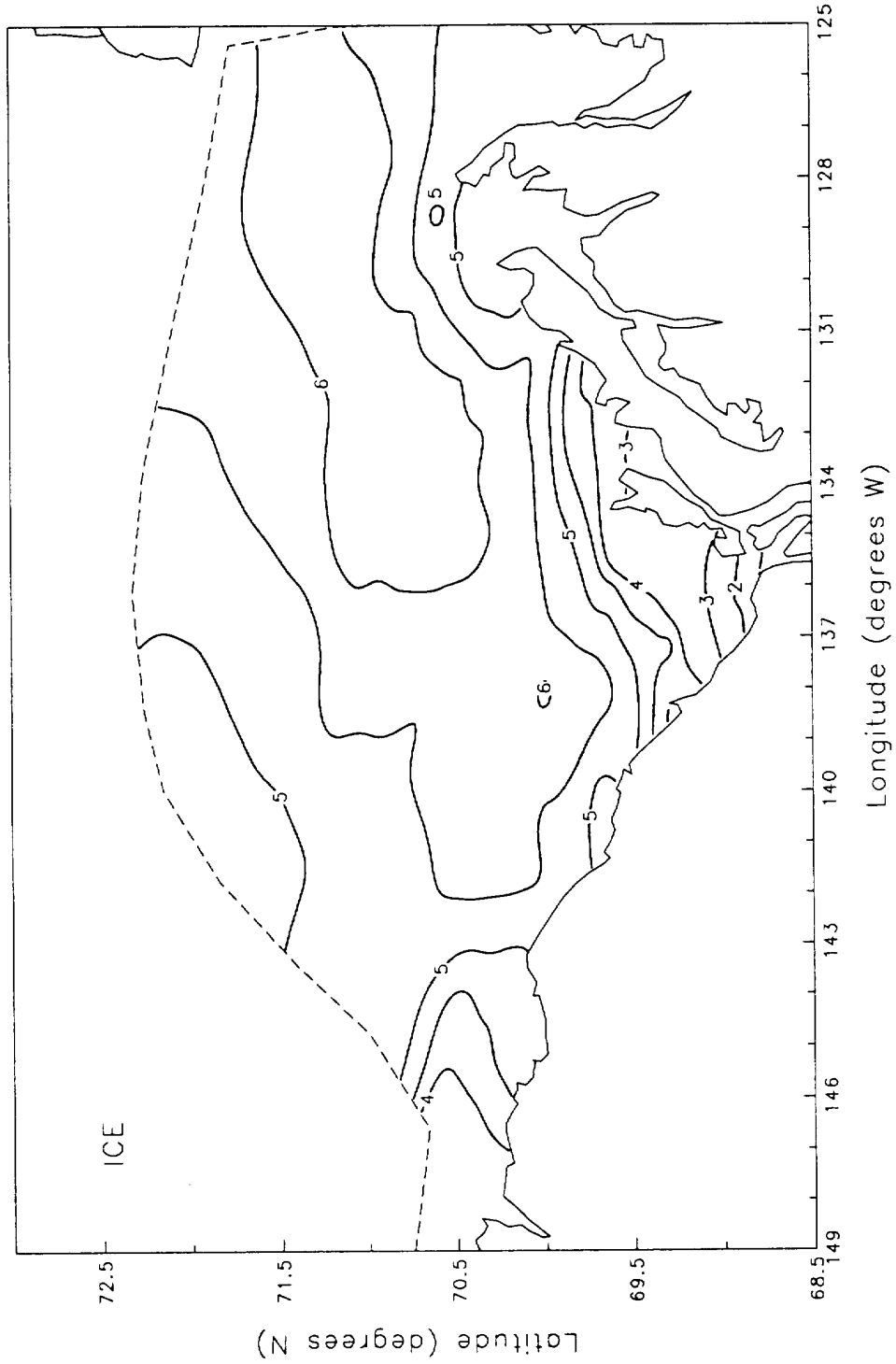


Figure 8.21

BEAUFORT SEA 100 YR MAXIMUM WAVE HEIGHT (m)
JOINT PROBABILITY (98% + 50% + 30% ICE EDGE)

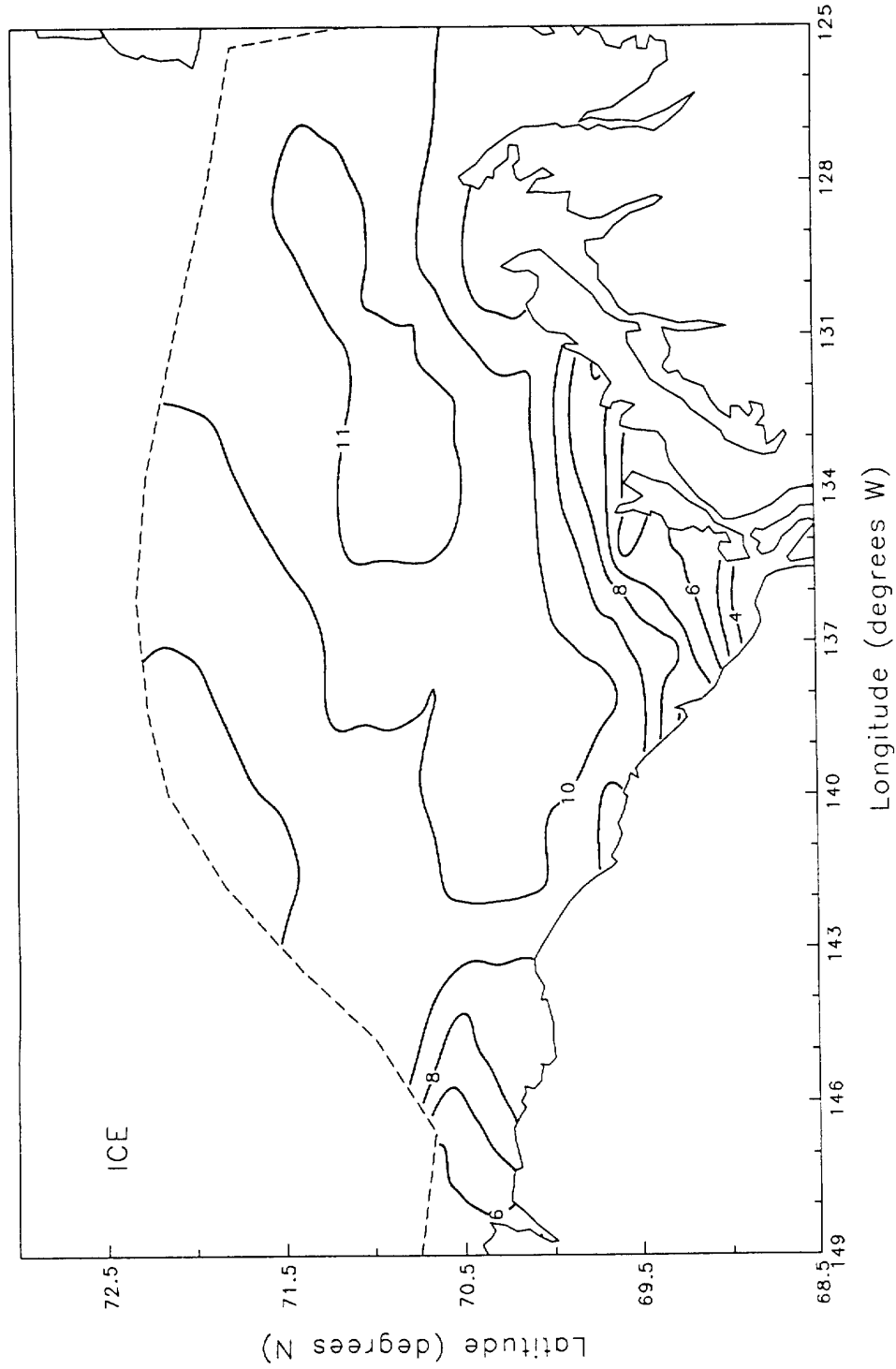


Figure 8.22

8.6 DISCUSSION

The extremal analysis results presented in previous sections provided the expected design parameter's values at different risk levels (or return periods) in the open water region of the Canadian Beaufort. The analysis was provided for different ice edge scenarios, real ice and climatological ice. The hindcast storms with real ice edge were slightly higher than those hindcast with median (50% occurrence) ice edge. This is due to the storm selection criteria which biased the larger open water conditions. The 98% ice edge (which represents the maximum open water conditions in the Canadian Beaufort) provided extreme value results which were found to be in the range from 5% to 60%, with an average of about 20%, higher than those obtained using actual ice edge. As shown the effect of the extent of the ice edge on storm hindcasts and in turn the extremal analysis results varies from one site to another, with the largest differences are in the northern and middle parts of the study area. The 100 year significant wave height for 98% ice edge was found to be as high as 2.25 m greater than that estimated with the real ice edge at some locations (see Table 8.7).

The results of the joint probability scenario provided values which are lower than those obtained using 98% ice edge (i.e. maximum open water) scenario and higher than those obtained using real ice edge as one would expect. The following table provides a comparison between the results at the locations of the highest values for each scenario.

Table 8.8 Maximum 100 Year H_s (m) For Different Ice Edge Scenarios

| Grid Point | Corresponding Wind Speed (m/s) | Real Ice Edge | | 98% Ice Edge | | Joint Probability | |
|------------|--------------------------------|---------------|----------|--------------|----------|-------------------|----------|
| | | Most Prob. | 90% U.L. | Most Prob. | 90% U.L. | Most Prob. | 90% U.L. |
| 492 | 18.2 | 5.7* | 6.6 | 6.2 | 7.1 | 6.1 | 6.7 |
| 414 | 17.8 | 4.9 | 5.5 | 6.6* | 7.6 | 6.2* | 7.0 |
| 360 | 17.6 | 4.9 | 5.5 | 6.5 | 7.5 | 6.2* | 7.0 |

Maximum value in study area for each ice edge scenario.

As shown, the joint probability extreme values seem to reasonably represent the design wave parameters in the Beaufort Sea. It is therefore, suggested that these values be used as recommended design wave parameters for the study area. The extreme wind speeds which correspond to extreme wave heights are also provided for calculation of combined loads on offshore structures.

The results presented in this study were compared with the previous studies. Figure 8.23 shows a comparison of extreme value distribution of significant wave heights from various hindcast studies including the present study. As shown, the present study provided estimates of the extreme wave heights which lie between Seaconsult (1989) and Hydrotechnology (1980) estimates. Our values presented in Figure 8.23 represent three different locations: the first is in relatively shallow water at grid point #464 (30 m depth) which is near Tarsiut exploration site, the second at G.P. #437 in very shallow water (8.65 m depth) near Minuk, and the third provides the offshore deepwater location at G.P #360 (see Figure 7.1 for map location).

Minuk Storm (September 16–18, 1985)

The present hindcast results of the Minuk storm agree well with the previous extensive studies by Seaconsult (1987, 89) and Baird & Associates (1987). The best estimates of the peak H_s and T_p as suggested by these studies were 4.2 m and 10.5 s, respectively with dominant direction = 300°. Our peak hindcast values for this storm are $H_s = 4.4$ m, $T_p = 10.6$ s and vector mean wave direction = 298°. From the present extreme analysis results (Figures 8.13 and 8.14 for the nearest grid points #437 and 464) it is estimated that the Minuk storm would have had a return period between 25–50 years. The 100 year H_s at this site is estimated to be in the order of 5.0 m and $T_p = 10.5$ s, which is close to the values suggested in previous studies.

The final contour presentations of 100 year values (Figures 8.21 and 8.22) show the spatial variation of the design values in the study area. Detailed extreme value distributions are given for selected grid points which represent a variety of wave climate conditions in the study area. The maximum 100 year significant wave height in the study area is 6.2 ± 0.8 m for 90% confidence limits.

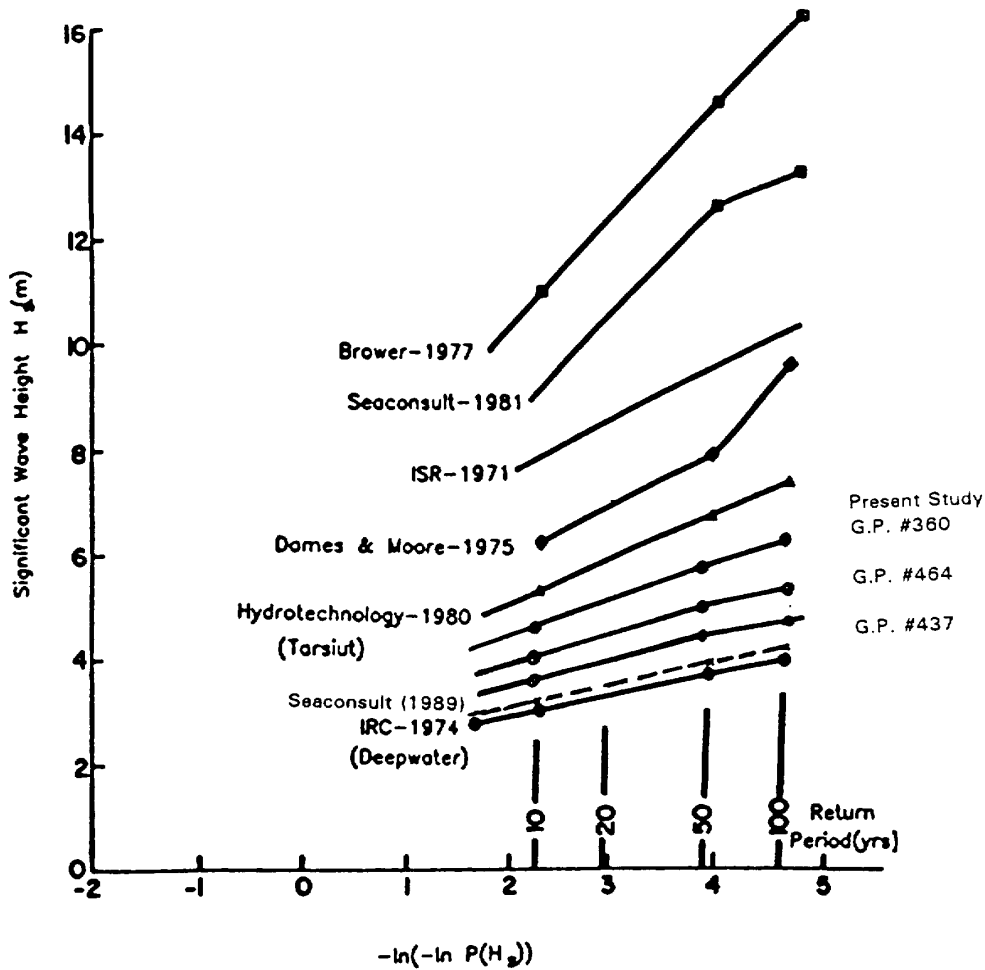


Figure 8.23 Comparison of Extreme Value Distribution of Significant Wave Heights for the Beaufort Sea from Various Hindcast Studies.

9.0 SUMMARY AND RESULTS

9.1 SUMMARY

The objective of this study was to develop new and definitive estimates of the extreme wave climate in the Canadian Beaufort Sea, with emphasis on offshore exploration areas in deep and shallow water. A hindcast approach was adopted, which includes the following traditional steps: (1) assembly of a comprehensive data base of archived historical meteorological data, wave measurements and ice cover; (2) identification and ranking of historical storm occurrences during the potential open-water season, over as long an historical period as allowed by the data, and selection of a population of storms for hindcasting; (3) adaptation and validation of the most accurate numerical hindcasting procedures to specify time histories of surface wind fields, surface wave fields and directional spectra in each hindcast storm; (4) hindcast of 30 selected historical storms; (5) statistical analysis of hindcast extremes at selected model grid points in order to estimate the significant wave height, maximum individual wave height and crest height, and associated wind speed and wave period, associated with rare return intervals.

The Beaufort Sea presents a number of special problems, not normally encountered in extreme wave climate studies of Northern Hemisphere mid-latitude basins. The main problems are: (1) the relative scarcity of historical meteorological data, including almost a total absence of transient ship reports, which are the main data source in mid-latitude problems; (2) the highly variable and complex nature of sea-ice cover, which can be expected to exert a significant control over the wave field. The lack of data complicates both the storm selection process, and the ability to accurately specify wind fields in selected historical storms. The presence of sea ice also complicates the storm selection process, and the hindcast process, since accurate hindcasts depend to some extent on the ability to specify ice-cover in selected events accurately.

The study was divided into two Phases. Phase I included an extensive literature review, assembly of historical meteorological data and offshore data including wave measurements, and sea-ice data, the main stages of the storm selection process, and adaption and validation of the hindcast methodology. Phase II included final selection of the hindcast storms, the production hindcasts themselves, and the extremal analysis.

The review of all known previous wind/wave climate studies of the Canadian Beaufort confirmed the need for a new study. For example, estimates of the 100-year maximum significant wave height in deep water varied among the studies published to date from about 4m to nearly 16m with no indication that a consensus was emerging from the many studies carried out over the past decade. Previous studies, however, did contribute information useful to the data assembly and storm selection tasks.

The data base assembly was intended to be comprehensive. In addition to data contributed in previous studies, the data assembly tapped raw data sources in so far as possible, including the archives of the Atmospheric Environment Service (AES), the NOAA National Climatic Data Centre (NCDC), the Marine Environmental Data Service (MEDS), and the offshore industry. The data base assembled includes microfilm series of weather maps prepared in real-time at the AES Beaufort Weather Office and NOAA's National Meteorological Centre (NMC), digital files of surface observations from land stations, transient ships, and offshore drilling rigs, and wave observations from MEDS buoys moored near exploratory rigs. The processing facilities of the AES Climate Centre (CAH), including MAST, LAST, DUST and CRISP were also extensively utilized. Where data could not be obtained or accessed in computer compatible form,

hard copies were obtained (e.g. selected maps not microfilmed, and logs of offshore observations from rigs (MANMAR).

The storm selection work was designed to identify historical storms based upon their ability to generate high sea-states within the study area. Thus, while a number of storms which may be high ranked for their ability to generate strong ocean currents and cause significant erosion of artificial islands are included in the storm selection, the hindcast population does not necessarily include the top-ranked members of the population of "erosion" storms.

The first step in the process was to identify all storms which occurred in the potential ice-free part of the year (June 15 – Nov 15), between 1957 – 1988. The first pass through all of the data sources noted above provided a Master Candidate List (MCL) of 1,087 events. The MCL was distilled in stages to a final list of 50 hindcast candidates from which the actual population of 30 storms hindcast was selected. The distillation process used both objective storm intensity and ranking procedures, and subjective assessments made by experienced synoptic meteorologists.

The presence of ice complicated the storm selection, since it is not known whether, during the warm season, the storm climatology and ice cover climatology of the basin are coupled. The location of the ice edge relative to long term normals was evaluated in the 50 storms selected, and the ice edge was found to lie offshore of climatology in the mean. This could be attributed to the fact that measured wave heights influenced the storm selection. To better account for the variability and uncertainty of extremes associated with ice edge effects, it was decided to hindcast each storm with four different ice-edge specifications, taking in each instance the 5/10 concentration as the limiting boundary for wave generation and propagation purposes. The four specifications were: (1) the actual ice edge during the storm, taken as fixed during the whole event; (2) climatological ice edges for three probability levels: 98%, 50% and 30% occurrences. Actual ice edges were produced from careful analysis of the AES daily and weekly ice charts, whereas climatological ice edges were taken from the semi-monthly charts also produced at AES. Separate extremal analyses were carried for each population of hindcasts, and for the combined probabilistic ice edge hindcasts.

The wind and wave hindcast methodology adapted to the basin has already undergone substantial refinement and validation in previous studies of this type, including several studies in Arctic basins, including the Chukchi Sea and U.S. Beaufort Seas. The wind field analysis procedure has been also applied recently in several Canadian Beaufort studies. The specification of wind fields includes a complete reanalysis of the evolution of the surface pressure field, starting with the best archived maps assembled, and adding additional ship and offshore rig data which may not have been available in real time. Wind fields are calculated from the pressure fields using a proven marine planetary boundary layer model (MPBL). The domain of the analysis is 68–76N, 120–162W on a grid of points spaced 1 degree latitude by 3 degrees longitude. In areas where direct wind observations reveal deficiencies in the MPBL winds, kinematic analysis is carried out, the resulting streamline and isotach analyses are hand-gridded and the kinematic winds then supersede the MPBL winds.

The ODGP wave hindcast model, as adapted recently to shallow water, is used for the wave hindcasts. The grid spacing is 20 n. mi. While the model has been validated in several previous studies carried out in Canada, including studies associated with the CASP and LEWEX and LIMEX programs, and the major PERD East Coast and West Coast extreme wave climate studies, this study included a substantial validation of the wave hindcasts in the Canadian Beaufort. The validation involved hindcasting five storms of the types

which characterize the selected storm population, and comparing hindcast and measured sea states at several sites located in different water depths, in each event.

The validation showed that when wind fields verify well against measured winds at offshore sites, and the ice edge location is well known and sharply defined, the wave hindcasts verify well. Comparisons of measured and hindcast time histories indicate hindcast errors of 24% in significant wave height (H_S) and 25% in spectral peak period (T_P) or 0.44m and 2 RMS, respectively. The statistical and time series comparisons show a high degree of agreement between the measured and hindcast wave parameters.

For external analysis, however, the most important aspect of the model is its ability to predict the storm peak accurately. Therefore, the peak to peak comparisons are considered to be of significant importance for evaluating model predictions.

Comparisons of hindcast and measured storm peaks at evaluation sites, yield an average bias (mean difference) of -0.06m in H_S and $+0.24\text{s}$ in T_P , and RMS differences of 0.38m in H_S and 1.2s in T_P with scatter indices of 14.7% and 15.5% in H_S and T_P respectively. These results, taken together with skillful time history comparisons, compare favourably with those exhibited in other recent comprehensive hindcast studies carried out in mid-latitude regions.

The production phase of the study included the hindcast of 30 storms, which, for four perturbations on ice edge, required 120 separate runs. Time histories of wind fields and selected integrated properties of the wave spectrum were archived at all model grid points for each run. At a subset of 51 grid points, distributed mainly over the parts of the Canadian Beaufort of interest to offshore hydrocarbon exploration operations, more detailed model results were saved, including all of the integrated properties as well as the full directional wave spectrum.

The extremal analysis was carried out at each of the 51 points on a site-specific basis. That is, no site-averaging or smoothing of extremes was deemed necessary given the fairly smooth spatial distribution of hindcast storm peaks, which itself is believed to be due to the scale of forcing wind field and the regularity of the bottom topography. At each point, five separate populations of storm peaks were subjected to the analysis, one for each of the four ice edge treatments, and one which combined the populations of the hindcasts for the three climatological ice edge specifications, the latter serving to approximate the true extremal wave distribution under the assumption that the storm climatology and the ice cover climatology are independent.

While resolution of the extremes into directional sectors was investigated, it was deemed that only omni-directional extremes could be reliably estimated. Prior to the site-specific analysis, peaks of maximum individual wave height (H_M) and crest height (H_C) were calculated for each storm at each point using well known statistical distributions, which operate on the entire time history of sea state at a site in a storm. These results were used to estimate the effective ratios of H_M/H_S and H_C/H_S at each point, to be applied later to extrapolated H_S .

The extrapolation of hindcast peak H_S and maximum wind speed (WM) for each subpopulation of peaks at each point was based upon the GUMBEL distribution, using the method of moments to fit the distribution, and varying the threshold of admittance of storm peaks until the fit was achieved which maximized the correlation coefficient of the best-fit regression line. Sensitivity analysis on the effect of the distribution (the Borgman distribution was also tried) and the fitting method were carried out before the final scheme was adopted. The sensitivity of the final extremes, however, to distribution, fitting scheme and threshold were small in general.

9.2 RESULTS

The results of the extremal analysis constitute the principal study product. At 51 points, these include estimates of extreme WM for return period between 2 and 100 years, and estimates of extreme H_S (best fit and upper 90% confidence level) for the same return periods, and for each ice edge dependent subpopulation, That is, real ice edge, 98% probability, 50% probability and 30% probability, and all three climatological ice edges combined. Results for the sensitivity studies as noted above, and an assessment of the directional distribution of hindcast (not extrapolated) extremes is presented for 8 grid points.

For the population of hindcast peaks using the actual ice–edge, extreme 100–year H_S varied from about 2m at the shallowest depths modelled (about 7.5m depth) to 5.7m in deep water. These extremes turned out to be slightly higher than the extremes derived for those derived from hindcasts made with the median (50%) ice edge. As expected, extremes derived from the hindcast peaks with the 98% ice edge (which represents maximum open water) were higher, ranging between 5% and 60% higher with an average increase of 20%. In real terms the increase was as great as 2.25m in H_S . The results of the joint ice edge probability analysis provided extremes lower than those obtained using 98% ice edge and higher than those using the real ice edge. These results (i.e. from ice edge probability analysis) are the recommended extremes for design, i.e. the 100–year extreme H_S of 6.2+/- 0.8m for 90% confidence limits. Comparison of these new results with existing estimates indicate that our extremes are at the lower end of the wide range of extremes provided by previous studies.

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APPENDIX A
CANDIDATE STORM LISTS

TABLE A.1

MASTER CANDIDATE LIST
Top 512 storms for the Beaufort Sea

Sources:

A Severe storms over the Canadian Western High Arctic 1957-1983 Report #87-2
 B Beaufort Weather and Ice Office Annual Summaries (1976-1985)
 C Arctic petroleum Operator's Association,1983:Beaufort Sea Hindcast Study 1970-1982. APOA study 203
 D Seaconsult 1986: An extreme value analysis of storm wave power at Minuk
 E BAIRD & Associates,1987: Estimation of the wave power at Minuk I-53 1960-1985
 F Bucley and Budgell, 1988: Meteorologically induced currents in the Beaufort Sea.
 G Seaconsult 1989: Design storm characteristic, Amiligak Region, Beaufort Sea
 H Maclaren Plansearch database
 I Seaconsult 1987: Wind and wave Hindcast for the storm of September 15 to 19, 1985
 J Seaconsult 1986: Analysis of the ADGO Wave measurements for the storm of September 15 to 19, 1985
 K Baird & Associates, 1987: Estimation of the wave climate at Minuk I-53 during the storm of September 15 to 19, 1985.
 L COADS.wave waves >= 1.5 m
 M COADS.wind winds >= 25 kts
 N LAST.wind winds >= 25 kts
 P RIG.wave waves >= 1.5 m
 R RIG.wind winds >= 25 kts
 S SPASM central pressure <= 970 mb
 T MPL HINDCAST
 V MEDS

| | START | END | DUR | OBS | WIND | | COMBINED SEA | | | SEVERITY INDEX | MINT CENT | WAVERIDER | SOURCE |
|----|----------|-----------|-----|-----|-------|-----|--------------|-----|-----|----------------|-----------|-----------|--------|
| | YYMMDDHH | YYMMDDHH | | | SPD | DIR | HS | TP | DIR | | PRESSURE | HS TP | |
| | | | | | (kts) | | (m) | (s) | | (mb) | (m) (s) | | |
| 1 | 57071206 | -57071509 | 75 | 17 | 34. | 100 | 1.5 | 5.0 | 070 | 2550 | | | L,M,N |
| 2 | 57072518 | -57072706 | 36 | 4 | 23. | 330 | 2.5 | 8.0 | 340 | 828 | | | L |
| 3 | 57072821 | -57072821 | 1 | 1 | 10. | 270 | 2.0 | 6.0 | 200 | 10 | | | L |
| 4 | 57080603 | -57080706 | 27 | 3 | 20. | 070 | 1.5 | 5.0 | 070 | 540 | | | L |
| 5 | 57080900 | -57080915 | 15 | 5 | 34. | 230 | 3.0 | 8.0 | 230 | 510 | | | L,M |
| 6 | 57081809 | -57081809 | 1 | 1 | 12. | 070 | 5.5 | 5.0 | 200 | 12 | | | L |
| 7 | 57082703 | -57082806 | 27 | 3 | 23. | 110 | 2.0 | 6.0 | 050 | 621 | | | L |
| 8 | 57091623 | -57091705 | 6 | 2 | 30. | 320 | | | | 180 | | | N |
| 9 | 57092717 | -57092820 | 27 | 6 | 35. | 110 | | | | 945 | | | N |
| 10 | 57100205 | -57100220 | 15 | 4 | 30. | 230 | | | | 450 | | | N |
| 11 | 57102820 | -57102823 | 3 | 2 | 26. | 090 | | | | 78 | | | N |
| 12 | 57110411 | -57110423 | 12 | 5 | 32. | 070 | | | | 384 | | | N |
| 13 | 58072017 | -58072020 | 3 | 2 | 26. | 090 | 0.0 | 6.0 | 020 | 78 | | | M,N |
| 14 | 58080412 | -58080506 | 18 | 2 | 15. | 050 | 1.5 | 6.0 | 040 | 270 | | | L |
| 15 | 58081608 | -58081617 | 9 | 4 | 28. | 090 | | | | 252 | | | N |
| 16 | 58082318 | -58082500 | 30 | 5 | 23. | 050 | 2.5 | 6.0 | 030 | 690 | | | L |
| 17 | 58090606 | -58090606 | 1 | 1 | 23. | 200 | 1.5 | 5.0 | 210 | 23 | | | L |
| 18 | 58092506 | -58100800 | 306 | 52 | 25. | 320 | | | | 7650 | 962.5 | | N,S |
| 19 | 58101317 | -58101411 | 18 | 4 | 30. | 050 | | | | 540 | | | N |
| 20 | 58102818 | -58110314 | 140 | 26 | 35. | 090 | | | | 4900 | 966.8 | | N,S |
| 21 | 58110620 | -58110723 | 27 | 7 | 32. | 110 | | | | 864 | | | N |
| 22 | 59070911 | -59071017 | 30 | 4 | 31. | 250 | | | | 930 | | | N |

TABLE A.1 (continued)

| | | | | | | | | | | |
|----|-------------------|-----|----|-----|-----|-----|-----|-----|------|-------|
| 23 | 59071417-59071505 | 12 | 2 | 32. | 340 | | | | 384 | N |
| 24 | 59071717-59072011 | 66 | 7 | 45. | 360 | 0.0 | 6.0 | 020 | 2970 | M,N |
| 25 | 59072615-59072800 | 33 | 9 | 40. | 290 | 1.5 | 6.0 | 290 | 1320 | L,M |
| 26 | 59072911-59072923 | 12 | 2 | 35. | 020 | | | | 420 | N |
| 27 | 59080111-59080211 | 24 | 6 | 30. | 360 | 0.0 | 6.0 | 290 | 720 | M,N |
| 28 | 59080905-59081003 | 22 | 2 | 28. | 270 | 0.5 | 5.0 | 300 | 616 | M,N |
| 29 | 59082815-59082900 | 9 | 2 | 30. | 120 | 0.0 | 5.0 | 300 | 270 | M |
| 30 | 59082909-59082912 | 3 | 2 | 21. | 160 | 1.5 | 5.0 | 170 | 63 | L |
| 31 | 59090403-59090406 | 3 | 2 | 20. | 090 | 1.5 | 5.0 | 090 | 60 | L |
| 32 | 59090417-59090611 | 42 | 10 | 30. | 050 | | | | 1260 | N |
| 33 | 59091017-59091217 | 48 | 7 | 43. | 230 | | | | 2064 | N |
| 34 | 59091218-59091218 | 1 | 1 | 15. | 180 | 2.0 | 6.0 | 210 | 15 | L |
| 35 | 59092503-59092703 | 48 | 14 | 28. | 290 | | | | 1344 | N |
| 36 | 59093006-59100216 | 58 | 38 | 39. | 140 | | | | 2262 | N |
| 37 | 59100317-59100523 | 54 | 36 | 37. | 360 | | | | 1998 | N |
| 38 | 59101300-59101511 | 59 | 26 | 35. | 270 | | | | 2065 | N |
| 39 | 59101717-59102005 | 60 | 14 | 34. | 230 | | | | 2040 | N |
| 40 | 59102100-59102500 | 96 | 17 | 28. | 110 | | | | 2688 | N,S |
| 41 | 59102913-59103011 | 22 | 24 | 40. | 090 | | | | 880 | N |
| 42 | 59103117-59110417 | 96 | 43 | 48. | 230 | | | | 4608 | N |
| 43 | 59110905-59111017 | 36 | 5 | 30. | 270 | | | | 1080 | N |
| 44 | 59111405-59111514 | 33 | 13 | 32. | 320 | | | | 1056 | N |
| 45 | 60071111-60071117 | 6 | 2 | 32. | 270 | | | | 192 | N |
| 46 | 60071906-60071918 | 12 | 2 | 39. | 320 | 0.0 | 5.0 | 100 | 468 | M |
| 47 | 60072017-60072117 | 24 | 3 | 30. | 320 | | | | 720 | N |
| 48 | 60072300-60072306 | 6 | 2 | 31. | 060 | 0.0 | 5.0 | 100 | 186 | M |
| 49 | 60072600-60072906 | 78 | 12 | 58. | 070 | 0.0 | 5.0 | 100 | 4524 | M,N |
| 50 | 60073118-60080115 | 21 | 4 | 26. | 090 | 2.0 | 6.0 | 040 | 546 | L,N |
| 51 | 60080418-60080600 | 30 | 5 | 47. | 110 | 0.0 | 5.0 | 100 | 1410 | M |
| 52 | 60081917-60082200 | 55 | 8 | 31. | 320 | 3.5 | 5.0 | 310 | 1705 | L,M,N |
| 53 | 60082320-60082605 | 57 | 20 | 37. | 290 | | | | 2109 | N |
| 54 | 60082818-60083018 | 48 | 3 | 39. | 320 | 0.0 | 8.0 | 290 | 1872 | M |
| 55 | 60091211-60091512 | 73 | 20 | 55. | 135 | 0.0 | 8.0 | 290 | 4015 | M,N |
| 56 | 60091706-60091718 | 12 | 2 | 25. | 090 | 0.0 | 8.0 | 290 | 300 | M |
| 57 | 60091815-60091918 | 27 | 9 | 27. | 320 | 2.0 | 6.0 | 280 | 729 | L,M |
| 58 | 60092217-60092411 | 42 | 28 | 30. | 090 | | | | 1260 | N |
| 59 | 60092700-60092900 | 48 | 7 | 29. | 270 | 1.5 | 8.0 | 250 | 1392 | L,M |
| 60 | 60100517-60101112 | 139 | 23 | 33. | 230 | | | | 4587 | N,S |
| 61 | 60101711-60101714 | 3 | 2 | 26. | 140 | | | | 78 | N |
| 62 | 60101910-60101912 | 2 | 2 | 27. | 240 | 0.0 | 8.0 | 250 | 54 | M |
| 63 | 60102022-60102318 | 68 | 15 | 49. | 110 | 0.0 | 8.0 | 250 | 3332 | M |
| 64 | 60103012-60103018 | 6 | 2 | 25. | 050 | 0.0 | 8.0 | 250 | 150 | M |
| 65 | 60110302-60110406 | 28 | 4 | 28. | 050 | 0.0 | 8.0 | 250 | 784 | M |
| 66 | 60110522-60110609 | 11 | 8 | 30. | 110 | | | | 330 | N |
| 67 | 60110818-60110906 | 12 | 4 | 30. | 090 | 0.0 | 8.0 | 250 | 360 | M |
| 68 | 60110911-60111017 | 30 | 8 | 48. | 270 | | | | 1440 | N |
| 69 | 61061611-61061711 | 24 | 2 | 30. | 320 | | | | 720 | N |
| 70 | 61062211-61062314 | 27 | 5 | 29. | 090 | | | | 783 | N |
| 71 | 61062811-61062817 | 6 | 2 | 26. | 320 | | | | 156 | N |
| 72 | 61071100-61071106 | 6 | 2 | 28. | 100 | 1.0 | 5.0 | 100 | 168 | M |
| 73 | 61071212-61071218 | 6 | 2 | 33. | 240 | 1.0 | 5.0 | 240 | 198 | M |

TABLE A.1 (continued)

| | | | | | | | | | | | |
|-----|-------------------|-----|----|-----|-----|-----|------|-----|------|-------|-------|
| 74 | 61071317-61071500 | 31 | 6 | 48. | 320 | 2.1 | 5.0 | 342 | 1488 | | M,N |
| 75 | 61071700-61071800 | 24 | 2 | 28. | 130 | 0.5 | 5.0 | 130 | 672 | | M |
| 76 | 61081217-61081317 | 24 | 5 | 30. | 320 | | | | 720 | | N |
| 77 | 61082300-61082303 | 3 | 2 | 26. | 360 | 1.0 | 5.0 | 350 | 78 | | M |
| 78 | 61082423-61082520 | 21 | 22 | 37. | 050 | | | | 777 | | N |
| 79 | 61082715-61082806 | 15 | 4 | 35. | 090 | 2.0 | 5.0 | 130 | 525 | | L,M,N |
| 80 | 61090615-61090706 | 15 | 4 | 32. | 200 | 1.1 | 5.0 | 144 | 480 | | M |
| 81 | 61090717-61090810 | 17 | 4 | 28. | 090 | | | | 476 | | N |
| 82 | 61091209-61091212 | 3 | 2 | 32. | 160 | 1.5 | 0.0 | | 96 | | L,M |
| 83 | 61111411-61111523 | 36 | 4 | 35. | 230 | | | | 1260 | | N |
| 84 | 62062719-62062801 | 6 | 5 | 28. | 090 | | | | 168 | | N |
| 85 | 62071900-62071906 | 6 | 3 | 24. | 080 | 2.0 | 5.0 | 090 | 144 | | L |
| 86 | 62072115-62072506 | 87 | 20 | 50. | 290 | 4.0 | 5.0 | 080 | 4350 | | L,M |
| 87 | 62072506-62072506 | 1 | 1 | 26. | 080 | 4.0 | 5.0 | 080 | 26 | | M |
| 88 | 62072511-62072603 | 16 | 3 | 28. | 140 | | | | 448 | | N |
| 89 | 62072805-62072917 | 36 | 9 | 39. | 290 | | | | 1404 | | N |
| 90 | 62080311-62080317 | 6 | 6 | 28. | 090 | | | | 168 | | N |
| 91 | 62081816-62081919 | 27 | 5 | 27. | 070 | | | | 729 | | N |
| 92 | 62082200-62082203 | 3 | 2 | 22. | 020 | 1.5 | 5.0 | 050 | 66 | | L |
| 93 | 62082618-62082619 | 1 | 2 | 28. | 290 | | | | 28 | | N |
| 94 | 62083108-62083117 | 9 | 9 | 30. | 360 | | | | 270 | | N |
| 95 | 62090311-62090715 | 100 | 34 | 56. | 310 | 9.5 | 16.0 | 310 | 5600 | | L,M,N |
| 96 | 62090805-62090811 | 6 | 2 | 26. | 270 | | | | 156 | | N |
| 97 | 62090903-62091106 | 51 | 14 | 48. | 250 | 8.0 | 6.0 | 230 | 2448 | | L,M |
| 98 | 62091618-62091623 | 5 | 4 | 27. | 090 | | | | 135 | | N |
| 99 | 62092617-62092705 | 12 | 3 | 30. | 250 | | | | 360 | | N |
| 100 | 62092706-62100118 | 108 | 19 | 26. | 110 | | | | 2808 | 968.5 | N,S,T |
| 101 | 62101200-62101205 | 5 | 3 | 28. | 050 | | | | 140 | | N |
| 102 | 62101300-62101606 | 78 | 14 | 26. | 160 | | | | 2028 | 957.2 | N,S |
| 103 | 62102419-62102611 | 40 | 20 | 33. | 140 | | | | 1320 | | N |
| 104 | 62110112-62110718 | 150 | 26 | 30. | 090 | | | | 4500 | 961.6 | N,S |
| 105 | 63061817-63061823 | 6 | 2 | 43. | 270 | | | | 258 | | N |
| 106 | 63062408-63062518 | 34 | 13 | 30. | 090 | | | | 1020 | | N |
| 107 | 63070523-63070617 | 18 | 5 | 29. | 270 | | | | 522 | | N |
| 108 | 63072503-63072506 | 3 | 2 | 24. | 090 | 1.5 | 5.0 | 090 | 72 | | L |
| 109 | 63072805-63073017 | 60 | 9 | 31. | 320 | | | | 1860 | | N |
| 110 | 63081605-63081711 | 30 | 13 | 35. | 290 | | | | 1050 | | N |
| 111 | 63082311-63082323 | 12 | 2 | 52. | 230 | 5.5 | 16.0 | 220 | 624 | | L,M,N |
| 112 | 63091418-63091506 | 12 | 3 | 25. | 100 | 2.5 | 6.0 | 120 | 300 | | L,M |
| 113 | 63100217-63100423 | 54 | 27 | 39. | 250 | | | | 2106 | | N |
| 114 | 63100905-63100923 | 18 | 8 | 30. | 140 | | | | 540 | | N |
| 115 | 63101406-63101718 | 84 | 15 | 33. | 340 | | | | 2772 | 963.9 | N,S |
| 116 | 63102006-63102306 | 72 | 13 | 25. | 070 | | | | 1800 | 949.2 | N,S |
| 117 | 63102900-63102923 | 23 | 5 | 27. | 020 | | | | 621 | | N |
| 118 | 63103012-63110518 | 150 | 34 | 41. | 090 | | | | 6150 | 953.1 | N,S |
| 119 | 64062505-64062605 | 24 | 14 | 35. | 270 | | | | 840 | | N |
| 120 | 64062711-64062717 | 6 | 2 | 30. | 270 | | | | 180 | | N |
| 121 | 64062911-64062923 | 12 | 2 | 28. | 270 | | | | 336 | | N |
| 122 | 64071111-64071117 | 6 | 2 | 27. | 360 | | | | 162 | | N |
| 123 | 64071311-64071323 | 12 | 3 | 30. | 290 | | | | 360 | | N |
| 124 | 64081218-64081317 | 23 | 2 | 26. | 090 | | | | 598 | | N |

TABLE A.1 (continued)

| | | | | | | | | | | | |
|-----|-------------------|-----|----|-----|-----|-----|------|-----|------|-------|---------|
| 125 | 64082011-64082217 | 54 | 23 | 43. | 250 | | | | 2322 | | N |
| 126 | 64090323-64090417 | 18 | 6 | 32. | 320 | | | | 576 | | N |
| 127 | 64091105-64091123 | 18 | 4 | 30. | 320 | | | | 540 | | N |
| 128 | 64102211-64102310 | 23 | 6 | 30. | 140 | | | | 690 | | N |
| 129 | 64102618-64103006 | 84 | 16 | 30. | 140 | | | | 2520 | 969.7 | N,S |
| 130 | 65061620-65061705 | 9 | 4 | 26. | 090 | | | | 234 | | N |
| 131 | 65071500-65071509 | 9 | 4 | 33. | 070 | 3.5 | 5.0 | 050 | 297 | | L,M |
| 132 | 65080215-65080221 | 6 | 3 | 29. | 110 | 2.0 | 5.0 | 120 | 174 | | L,M |
| 133 | 65080617-65080706 | 13 | 5 | 32. | 320 | | | | 416 | | N |
| 134 | 65092101-65092211 | 34 | 6 | 30. | 290 | | | | 1020 | | N |
| 135 | 65100515-65100611 | 20 | 20 | 31. | 110 | | | | 620 | | N |
| 136 | 65101500-65101906 | 102 | 18 | 30. | 290 | | | | 3060 | 964.3 | N,S |
| 137 | 65102305-65102405 | 24 | 22 | 33. | 110 | | | | 792 | | N |
| 138 | 65102523-65102623 | 24 | 4 | 30. | 320 | | | | 720 | | N |
| 139 | 65102923-65103105 | 30 | 5 | 34. | 270 | | | | 1020 | | N |
| 140 | 65110505-65110505 | 1 | 1 | 39. | 270 | | | | 39 | | N |
| 141 | 65110711-65110717 | 6 | 2 | 30. | 270 | | | | 180 | | N |
| 142 | 65111217-65111305 | 12 | 4 | 40. | 230 | | | | 480 | | N |
| 143 | 65111312-65111600 | 60 | 11 | 28. | 110 | | | | 1680 | 969.0 | N,S |
| 144 | 66061923-66062017 | 18 | 4 | 30. | 320 | | | | 540 | | N |
| 145 | 66081921-66082006 | 9 | 4 | 22. | 090 | 1.5 | 5.0 | 090 | 198 | | L |
| 146 | 66082912-66082918 | 6 | 2 | 31. | 040 | 3.4 | 6.0 | 066 | 186 | | L,M |
| 147 | 66091017-66091023 | 6 | 2 | 32. | 290 | | | | 192 | | N |
| 148 | 66091411-66091417 | 6 | 2 | 32. | 320 | | | | 192 | | N |
| 149 | 66091500-66092021 | 141 | 21 | 27. | 320 | 1.5 | 5.0 | 270 | 3807 | 959.2 | L,M,N,S |
| 150 | 66102912-66110300 | 108 | 19 | 23. | 190 | 2.9 | 10.0 | 116 | 2484 | 965.7 | L,S |
| 151 | 66110511-66110517 | 6 | 2 | 28. | 290 | | | | 168 | | N |
| 152 | 67081912-67081912 | 1 | 1 | 8. | 030 | 4.0 | 5.0 | 030 | 8 | | L |
| 153 | 67090121-67090221 | 24 | 8 | 30. | 040 | 1.0 | 5.0 | 060 | 720 | | M |
| 154 | 67091112-67091206 | 18 | 3 | 32. | 080 | 1.0 | 10.0 | 080 | 576 | | M |
| 155 | 67091518-67091600 | 6 | 3 | 25. | 060 | 1.5 | 8.0 | 060 | 150 | | L,M |
| 156 | 67091811-67091817 | 6 | 2 | 30. | 090 | | | | 180 | | N |
| 157 | 67100311-67100323 | 12 | 2 | 30. | 320 | | | | 360 | | N |
| 158 | 67100523-67100611 | 12 | 3 | 35. | 180 | | | | 420 | | N |
| 159 | 67100612-67101118 | 126 | 22 | 27. | 260 | 1.5 | 5.0 | 260 | 3402 | 957.9 | L,M,S |
| 160 | 67101611-67101911 | 72 | 10 | 39. | 290 | | | | 2808 | | N |
| 161 | 67102912-67110606 | 186 | 32 | 21. | 150 | 3.6 | 5.0 | 150 | 3906 | 958.9 | L,S |
| 162 | 68063017-68070111 | 18 | 2 | 30. | 320 | | | | 540 | | N |
| 163 | 68071403-68071406 | 3 | 2 | 30. | 050 | 2.2 | 5.0 | 040 | 90 | | M |
| 164 | 68081700-68081706 | 6 | 2 | 27. | 080 | 2.0 | 6.0 | 090 | 162 | | L |
| 165 | 68081706-68081706 | 1 | 1 | 27. | 080 | 2.0 | 6.0 | 080 | 27 | | M |
| 166 | 68090706-68090803 | 21 | 4 | 30. | 270 | 3.8 | 6.0 | 270 | 630 | | L,M |
| 167 | 68092112-68092200 | 12 | 3 | 26. | 200 | 5.6 | 6.0 | 271 | 312 | | L,M |
| 168 | 68092306-68092318 | 12 | 3 | 32. | 250 | 1.8 | 14.0 | 239 | 384 | | L,M |
| 169 | 68100323-68100405 | 6 | 2 | 27. | 290 | | | | 162 | | N |
| 170 | 68100418-68100418 | 1 | 1 | 16. | 060 | 3.6 | 12.0 | 059 | 16 | | L |
| 171 | 68101712-68101719 | 7 | 7 | 31. | 090 | | | | 217 | | N |
| 172 | 68102503-68102600 | 21 | 22 | 30. | 070 | | | | 630 | | N |
| 173 | 68102600-68102600 | 1 | 1 | 30. | 160 | 3.6 | 14.0 | 167 | 30 | | M |
| 174 | 68102701-68102817 | 40 | 42 | 39. | 090 | | | | 1560 | | N |
| 175 | 68110612-68111112 | 120 | 21 | 30. | 090 | | | | 3600 | 969.2 | N,S |

TABLE A.1 (continued)

| | | | | | | | | | | | | | |
|-----|-------------------|-----|----|-----|-----|------|------|-----|------|-------|-----|---|-------------|
| 176 | 68111511-68111523 | 12 | 3 | 28. | 290 | | | | 336 | | | | N |
| 177 | 69071603-69071621 | 18 | 3 | 25. | 280 | 0.0 | 14.0 | 167 | 450 | | | | M |
| 178 | 69072611-69072623 | 12 | 3 | 30. | 290 | | | | 360 | | | | N |
| 179 | 69080505-69080523 | 18 | 3 | 30. | 320 | | | | 540 | | | | N |
| 180 | 69080709-69080806 | 21 | 4 | 37. | 140 | 0.0 | 14.0 | 167 | 777 | | | | M |
| 181 | 69082023-69082105 | 6 | 2 | 27. | 360 | | | | 162 | | | | N |
| 182 | 69090403-69090418 | 15 | 2 | 28. | 110 | 0.0 | 14.0 | 167 | 420 | | | | M |
| 183 | 69091003-69091109 | 30 | 9 | 33. | 070 | 2.0 | 5.0 | 070 | 990 | | | | L,M |
| 184 | 69091818-69092000 | 30 | 6 | 30. | 100 | 1.5 | 5.0 | 120 | 900 | | | | L,M |
| 185 | 69092708-69092711 | 3 | 2 | 27. | 180 | | | | 81 | | | | N |
| 186 | 69100218-69100900 | 150 | 26 | 30. | 290 | | | | 4500 | 966.7 | | | N,S |
| 187 | 69102417-69102717 | 72 | 18 | 32. | 270 | | | | 2304 | | | | N |
| 188 | 69110116-69110314 | 46 | 31 | 32. | 090 | | | | 1472 | | | | N |
| 189 | 70072818-70072900 | 6 | 3 | 30. | 070 | 0.0 | 5.0 | 060 | 180 | | | | M |
| 190 | 70073012-70073019 | 7 | 6 | 28. | 110 | | | | 196 | | | | N |
| 191 | 70080206-70080318 | 36 | 6 | 30. | 300 | 2.0 | 5.0 | 280 | 1080 | | | | L,M,N |
| 192 | 70080506-70080518 | 12 | 3 | 26. | 110 | 2.0 | 6.0 | 110 | 312 | | | | M |
| 193 | 70080518-70080612 | 18 | 5 | 26. | 110 | 2.0 | 6.0 | 110 | 468 | | | | L |
| 194 | 70080812-70080906 | 18 | 4 | 20. | 030 | 1.5 | 5.0 | 030 | 360 | | | | L |
| 195 | 70082721-70083000 | 51 | 5 | 25. | 310 | 2.5 | 5.0 | 325 | 1275 | | | | L,M |
| 196 | 70090218-70090716 | 118 | 37 | 45. | 110 | 4.5 | 12.0 | 330 | 5310 | | 3.6 | 8 | C,L,M,N |
| 197 | 70090921-70091105 | 32 | 4 | 30. | 210 | 1.5 | 5.0 | 250 | 960 | | | | L,M,N |
| 198 | 70091313-70091512 | 47 | 28 | 63. | 240 | 5.6 | 7.0 | 284 | 2961 | 968 | 2.5 | 6 | A,C,L,N,N,T |
| 199 | 70091706-70091812 | 30 | 3 | 23. | 320 | 2.0 | 5.0 | 180 | 690 | | | | L |
| 200 | 70100618-70100618 | 1 | 1 | 26. | 050 | 2.0 | 5.0 | 050 | 26 | | | | L |
| 201 | 70101211-70101302 | 15 | 4 | 30. | 320 | | | | 450 | | | | N |
| 202 | 70101512-70101512 | 1 | 1 | 33. | 060 | 1.0 | 5.0 | 060 | 33 | | | | M |
| 203 | 70101816-70101905 | 13 | 10 | 35. | 160 | | | | 455 | | | | N |
| 204 | 70102017-70102123 | 30 | 25 | 35. | 160 | | | | 1050 | | | | N |
| 205 | 70110117-70110123 | 6 | 4 | 35. | 270 | | | | 210 | | | | N |
| 206 | 70110300-70110307 | 7 | 5 | 26. | 070 | | | | 182 | | | | N |
| 207 | 70110700-70111212 | 132 | 23 | | | | | | 0 | 962.7 | | | S |
| 208 | 71070100-71070100 | 1 | 1 | 40. | 300 | 10.6 | 22.0 | 282 | 40 | | | | L,M |
| 209 | 71072806-71072806 | 1 | 1 | 19. | 260 | 1.5 | 5.0 | 260 | 19 | | | | L |
| 210 | 71072900-71073003 | 27 | 9 | 30. | 270 | 0.0 | 22.0 | 282 | 810 | | | | C,M,N |
| 211 | 71080303-71080315 | 12 | 6 | 28. | 360 | 2.6 | 6.7 | | 336 | | | | C,N |
| 212 | 71080318-71080708 | 86 | 18 | 37. | 250 | 0.0 | 22.0 | 282 | 3182 | | | | M |
| 213 | 71082218-71082306 | 72 | 5 | 26. | 360 | 2.9 | 7.1 | | 2520 | | 2.9 | 7 | C,N |
| 214 | 71090306-71090412 | 30 | 26 | 34. | 090 | 0.0 | 22.0 | 282 | 1020 | | | | M,N |
| 215 | 71090806-71090806 | 1 | 1 | 27. | 200 | 1.1 | 5.0 | 099 | 27 | | | | M |
| 216 | 71092312-71092312 | 1 | 1 | 12. | 350 | 6.0 | 5.0 | 350 | 12 | | | | L |
| 217 | 71100200-71100200 | 1 | 1 | 24. | 220 | 2.0 | 12.0 | 220 | 24 | | | | L |
| 218 | 71102100-71102118 | 18 | 5 | 35. | 260 | | | | 630 | | | | N |
| 219 | 71103000-71103018 | 18 | 2 | 29. | 290 | | | | 522 | | | | N |
| 220 | 71110106-71110418 | 84 | 8 | 37. | 270 | | | | 3108 | | | | N |
| 221 | 71111021-71111212 | 39 | 39 | 32. | 090 | | | | 1248 | | | | N |
| 222 | 72081302-72081400 | 22 | 2 | 25. | 320 | 1.0 | 5.0 | 100 | 550 | | | | M |
| 223 | 72081418-72081500 | 6 | 2 | 16. | 100 | 1.5 | 5.0 | 100 | 96 | | | | L |
| 224 | 72081806-72081900 | 18 | 2 | 25. | 100 | 1.5 | 8.0 | 110 | 450 | | | | L |
| 225 | 72081900-72081906 | 6 | 2 | 27. | 110 | 1.5 | 6.0 | 100 | 162 | | | | M |
| 226 | 72082012-72082012 | 1 | 1 | 30. | 090 | 2.0 | 5.0 | 090 | 30 | 1001 | | | A,L |

TABLE A.1 (continued)

| | | | | | | | | | | | |
|-----|-------------------|----|----|-----|-----|-----|------|-----|------|-------|-----------|
| 227 | 72082012-72082112 | 24 | 5 | 50. | 320 | 2.0 | 5.0 | 090 | 1200 | | M,N,T |
| 228 | 72082400-72082522 | 46 | 17 | 35. | 320 | 0.0 | 5.0 | 090 | 1610 | | M,N |
| 229 | 72083000-72083006 | 6 | 2 | 17. | 110 | 2.0 | 5.0 | 110 | 102 | | L |
| 230 | 72090110-72090209 | 23 | 12 | 40. | 290 | 3.7 | 7.0 | | 920 | | C,L,N |
| 231 | 72090506-72090506 | 1 | 1 | 15. | 100 | 1.5 | 6.0 | 100 | 15 | | L |
| 232 | 72090700-72090806 | 30 | 4 | 24. | 090 | 1.5 | 6.0 | 080 | 720 | | I |
| 233 | 72091012-72091018 | 6 | 2 | 23. | 080 | 1.5 | 6.0 | 080 | 138 | | L |
| 234 | 72091200-72091318 | 42 | 1 | | | 2.7 | 6.6 | | 0 | | C |
| 235 | 72091606-72091706 | 24 | 2 | 31. | 340 | 2.5 | 5.0 | 330 | 744 | | L,M |
| 236 | 72091914-72092002 | 12 | 2 | 34. | 250 | 0.0 | 6.0 | 340 | 408 | | M |
| 237 | 73072100-73072112 | 12 | 6 | 48. | 280 | | | | 576 | | N,T |
| 238 | 73090200-73090218 | 18 | 4 | 27. | 090 | 2.9 | 8.0 | 135 | 486 | | L,M |
| 239 | 73090406-73090412 | 6 | 2 | 26. | 130 | 1.1 | 5.0 | 156 | 156 | | M |
| 240 | 73090612-73090718 | 30 | 5 | 25. | 100 | 6.5 | 12.0 | 103 | 750 | | L,M |
| 241 | 73090912-73091006 | 18 | 4 | 27. | 300 | 1.5 | 5.0 | 330 | 486 | | L,M,N |
| 242 | 73091500-73091700 | 48 | 6 | 32. | 270 | 3.5 | 7.0 | 300 | 1536 | | L,M,N |
| 243 | 73092515-73092515 | 1 | 1 | 3. | 180 | 3.0 | 5.0 | 180 | 3 | | L |
| 244 | 74080115-74080215 | 24 | 4 | 40. | 250 | 0.0 | 6.0 | 250 | 960 | | M |
| 245 | 74080618-74080700 | 6 | 2 | 36. | 090 | 0.0 | 6.0 | 250 | 216 | | M |
| 246 | 74080919-74081121 | 50 | 26 | 42. | 250 | 0.0 | 6.0 | 250 | 2100 | | M,N |
| 247 | 74081400-74081510 | 34 | 25 | 30. | 290 | 0.0 | 6.0 | 250 | 1020 | | M,N |
| 248 | 74081800-74081803 | 3 | 2 | 20. | 320 | 1.5 | 5.0 | 320 | 60 | | L |
| 249 | 74081805-74082006 | 49 | 22 | 37. | 290 | 1.5 | 5.0 | 310 | 1813 | | L,M,N |
| 250 | 74082321-74082321 | 1 | 1 | 20. | 090 | 1.5 | 5.0 | 090 | 20 | | L |
| 251 | 74083106-74083106 | 1 | 1 | 10. | 090 | 5.5 | 6.0 | 090 | 10 | | L |
| 252 | 74090214-74090214 | 1 | 1 | 26. | 300 | | | | 26 | | N |
| 253 | 74090317-74090403 | 10 | 11 | 35. | 260 | | | | 350 | | N |
| 254 | 74090406-74090500 | 18 | 4 | 43. | 340 | 0.0 | 5.0 | 330 | 774 | | M |
| 255 | 74090606-74090618 | 12 | 2 | 26. | 100 | 1.5 | 5.0 | 100 | 312 | | M |
| 256 | 74090618-74090812 | 42 | 3 | 26. | 100 | 2.0 | 6.0 | 080 | 1092 | | L |
| 257 | 74091000-74091000 | 1 | 1 | 20. | 090 | 1.5 | 5.0 | 090 | 20 | | L |
| 258 | 74091606-74091700 | 18 | 4 | 29. | 100 | 2.6 | 5.8 | | 522 | | C,L,M |
| 259 | 74101108-74101313 | 53 | 17 | 30. | 240 | | | | 1590 | | N |
| 260 | 74101512-74101714 | 50 | 14 | 30. | 270 | | | | 1500 | | N |
| 261 | 74102310-74102410 | 24 | 25 | 43. | 270 | | | | 1032 | | N |
| 262 | 74102512-74102912 | 96 | 71 | 36. | 090 | | | | 3456 | | N |
| 263 | 74103012-74103118 | 30 | 7 | 30. | 080 | | | | 900 | 969.5 | N,S |
| 264 | 74110319-74110406 | 11 | 12 | 30. | 070 | | | | 330 | | N |
| 265 | 75071906-75071910 | 4 | 3 | 27. | 290 | | | | 108 | | N |
| 266 | 75072022-75072120 | 22 | 15 | 29. | 290 | | | | 638 | | N |
| 267 | 75072603-75072609 | 6 | 3 | 30. | 050 | 0.0 | 6.0 | 100 | 180 | | M |
| 268 | 75072909-75072918 | 9 | 3 | 26. | 240 | 4.5 | 9.0 | 360 | 234 | | M |
| 269 | 75080615-75080621 | 6 | 3 | 26. | 340 | 1.5 | 5.0 | 340 | 156 | | L,M |
| 270 | 75080815-75081118 | 75 | 29 | 40. | 280 | 4.7 | 10.0 | 310 | 3000 | 2.4 6 | L,M,V |
| 271 | 75080908-75081108 | 48 | 5 | 28. | 300 | | | | 1344 | | N |
| 272 | 75080921-75081203 | 1 | 1 | | | 2.4 | | | 0 | | D |
| 273 | 75081800-75081903 | 27 | 4 | 61. | 310 | 1.5 | 5.0 | 040 | 1647 | | L,M |
| 274 | 75082606-75082814 | 56 | 29 | 45. | 230 | 5.0 | 0.0 | 270 | 2520 | 2.2 6 | D,L,M,N,V |
| 275 | 75083003-75083015 | 12 | 2 | 56. | 090 | 0.0 | 0.0 | 270 | 672 | | M |
| 276 | 75090112-75090200 | 12 | 4 | 28. | 270 | 1.5 | 5.0 | 270 | 336 | | L,M,N |
| 277 | 75090606-75090800 | 42 | 7 | 34. | 050 | 2.0 | 5.0 | 030 | 1428 | | L,M,N |

TABLE A.1 (continued)

| | | | | | | | | | | | | | |
|-----|-------------------|-----|-----|-----|-----|-----|------|-----|-------|-------|-----|---|------------------------------------|
| 278 | 75091212-75091400 | 36 | 4 | 29. | 260 | 2.9 | 6.0 | 230 | 1044 | | | | L, M, N |
| 279 | 75091712-75092312 | 144 | 15 | 33. | 230 | 4.0 | 6.0 | 070 | 4752 | | | | L, M, N |
| 280 | 75092421-75092701 | 52 | 27 | 35. | 270 | 1.0 | 5.0 | 120 | 1820 | | | | M, N |
| 281 | 76080922-76081005 | 7 | 7 | 25. | 100 | 2.0 | 6.0 | | 175 | | | | P, R |
| 282 | 76081121-76081423 | 72 | 61 | 35. | 050 | 4.3 | 6.2 | | 2520 | 2.8 | 6 | | B, C, D, L, M, N, P, R, V |
| 283 | 76081422-76081615 | 41 | 14 | 29. | 130 | 1.5 | 0.0 | | 1189 | | | | R |
| 284 | 76082109-76082213 | 28 | 42 | 40. | 270 | 2.0 | 5.0 | | 1120 | 2.2 | 6 | | D, L, M, N, P, R, V |
| 285 | 76082312-76082400 | 12 | 5 | 30. | 300 | 0.5 | 5.0 | | 360 | | | | N, R |
| 286 | 76082510-76082904 | 90 | 41 | 34. | 090 | 2.0 | 5.0 | | 3060 | | | | M, N, P, R |
| 287 | 76090501-76090514 | 13 | 12 | 30. | 280 | 2.0 | 5.0 | | 390 | | | | P, R |
| 288 | 76090816-76091009 | 41 | 67 | 32. | 090 | 3.0 | 6.0 | | 1312 | | | | M, N, P, R |
| 289 | 76091018-76091203 | 1 | 1 | | | 2.6 | | | 0 | 2.6 | 7 | | D, V |
| 290 | 76091204-76091707 | 123 | 148 | 30. | 120 | 3.0 | 6.0 | | 3690 | 963.0 | 1.8 | 8 | M, N, P, R, S |
| 291 | 76091907-76092218 | 80 | 88 | 37. | 120 | 3.0 | 5.0 | 220 | 2960 | | 1.7 | 6 | L, M, N, P, R |
| 292 | 76092323-76092706 | 79 | 55 | 38. | 090 | 4.6 | 7.0 | 073 | 3002 | | | | L, M, N, P, R |
| 293 | 76092814-76100208 | 90 | 166 | 32. | 070 | 4.0 | 6.0 | 070 | 2880 | 1.9 | 6 | | L, M, P, R, V |
| 294 | 76100412-76100500 | 12 | 2 | 33. | 050 | 0.0 | 6.0 | 070 | 396 | | | | M |
| 295 | 76101017-76101110 | 17 | 22 | 25. | 290 | 2.0 | 6.0 | | 425 | | | | P, R |
| 296 | 76101112-76101812 | 168 | 29 | 35. | 190 | 1.5 | 5.0 | | 5880 | 965.4 | | | N, P, R, S |
| 297 | 76101813-76102012 | 47 | 26 | 35. | 290 | 0.0 | 5.0 | | 1645 | | | | N, R |
| 298 | 77080600-77081306 | 174 | 152 | 33. | 090 | 2.2 | 6.0 | 080 | 5742 | 1.8 | 6 | | L, M, N, P, R |
| 299 | 77081308-77081713 | 101 | 87 | 37. | 100 | 1.5 | 5.0 | 080 | 3737 | | | | N, P, R |
| 300 | 77081718-77081800 | 6 | 2 | 28. | 300 | 0.0 | 6.0 | 080 | 168 | | | | M |
| 301 | 77082105-77082509 | 100 | 36 | 35. | 090 | 2.0 | 6.0 | 130 | 3500 | | | | L, M, R |
| 302 | 77082512-77082918 | 102 | 59 | 41. | 320 | 3.4 | 6.9 | | 4182 | 3.2 | 8 | | B, C, D, E, F, L, M, N, P, R, T, V |
| 303 | 77083115-77090201 | 58 | 31 | 32. | 310 | 2.5 | 6.0 | 320 | 1856 | | | | D, P, R |
| 304 | 77090318-77090318 | 1 | 2 | 23. | 240 | 1.5 | 5.0 | 240 | 23 | | | | L |
| 305 | 77090506-77090512 | 6 | 2 | 17. | 280 | 1.5 | 5.0 | 280 | 102 | | | | L |
| 306 | 77090603-77090921 | 90 | 55 | 36. | 120 | 2.5 | 6.0 | 350 | 3240 | | | | D, L, M, P, R, V |
| 307 | 77091100-77091522 | 118 | 33 | 32. | 130 | 3.5 | 6.0 | 055 | 3776 | | | | D, L, M, P, R, V |
| 308 | 77091903-77091905 | 2 | 2 | 26. | 080 | 1.0 | 5.0 | 080 | 52 | | | | R |
| 309 | 77092018-77092100 | 6 | 2 | 20. | 060 | 2.0 | 5.0 | 030 | 120 | | | | L |
| 310 | 77092100-77092214 | 38 | 60 | 42. | 270 | 3.0 | 6.0 | 290 | 1596 | 2.9 | 7 | | D, N, P, R, V |
| 311 | 77092309-77092808 | 119 | 173 | 40. | 160 | 3.0 | 6.0 | 150 | 4760 | | | | D, F, L, M, N, P, R, T, V |
| 312 | 77092818-77100411 | 137 | 60 | 32. | 280 | 3.0 | 5.0 | 020 | 4384 | | | | D, L, M, N, P, R, T, V |
| 313 | 77100515-77101213 | 166 | 179 | 45. | 130 | 3.5 | 5.0 | 120 | 7470 | 2.2 | 8 | | B, D, F, N, P, R, T, V |
| 314 | 77101306-77101309 | 3 | 4 | 17. | 360 | 1.5 | 5.0 | 040 | 51 | | | | P |
| 315 | 77101400-77101613 | 61 | 32 | 31. | 060 | 2.6 | 6.1 | | 1891 | 960.3 | | | C, N, P, R, S |
| 316 | 77101720-77101913 | 41 | 28 | 30. | 110 | 2.0 | 5.0 | | 1230 | | | | P, R |
| 317 | 77102100-77102306 | 54 | 22 | 54. | 150 | 2.5 | 6.0 | 100 | 2916 | 950.2 | | | N, P, R, S |
| 318 | 78081715-78081715 | 1 | 1 | 10. | 340 | 1.5 | 5.0 | 340 | 10 | | | | L |
| 319 | 78082017-78082112 | 19 | 13 | 33. | 220 | 0.0 | 5.0 | | 627 | | | | R |
| 320 | 78082304-78082712 | 104 | 54 | 40. | 300 | 3.1 | 6.7 | | 4160 | | | | C, E, N, R |
| 321 | 78082900-78090900 | 240 | 211 | 40 | 090 | 2.7 | 6.0 | 037 | 9600 | 2.7 | 8 | | B, C, D, F, L, M, N, R, T, V |
| 322 | 78090906-78091412 | 126 | 54 | 38. | 030 | 6.3 | 8.0 | 062 | 4788 | 969.0 | 1.9 | 7 | L, M, R, S, V |
| 323 | 78091519-78091715 | 44 | 31 | 47. | 310 | 3.4 | 8.0 | 003 | 2068 | | | | D, L, N, R, P, V |
| 324 | 78091812-78091812 | 1 | 1 | 23. | 090 | 2.0 | 5.0 | 090 | 23 | | | | L |
| 325 | 78091900-78092206 | 91 | 99 | 40. | 070 | 7.5 | 12.0 | 098 | 3640 | 3.6 | 10 | | B, C, D, L, M, N, R, V |
| 326 | 78092900-78100303 | 99 | 98 | 45. | 280 | 3.5 | 5.0 | | 4455 | 2.4 | 9 | | M, N, R, T, V |
| 327 | 78100600-78101004 | 100 | 162 | 50 | | 3.5 | 7.0 | | 5000 | | | | B, F, M, N, R, T |
| 328 | 78101206-78102412 | 294 | 62 | 42. | 220 | | | | 12348 | 968.4 | | | M, N, R, S |

TABLE A.1 (continued)

| | | | | | | | | | | | |
|-----|-------------------|-----|-----|-----|-----|------|-----|-----|-------|-------|---|
| 329 | 79081310-79081904 | 138 | 279 | 38. | 100 | 4.5 | 5.0 | 070 | 5244 | | D, L, M, N, P, R, V |
| 330 | 79082002-79082600 | 142 | 94 | 37. | 100 | 3.0 | 5.0 | 280 | 5254 | | D, F, L, M, N, P, R, T, V |
| 331 | 79090709-79090719 | 10 | 11 | 20. | 110 | 2.0 | 6.0 | 100 | 200 | | L, P |
| 332 | 79090900-79090913 | 13 | 14 | 12. | 300 | 1.5 | 5.0 | 290 | 156 | | L, P |
| 333 | 79091110-79091923 | 205 | 448 | 36. | 070 | 4.0 | 6.0 | 090 | 7380 | | 2.5 9 D, L, M, N, P, R, V |
| 334 | 79092106-79100705 | 383 | 339 | 95. | 100 | 4.5 | 6.0 | 100 | 36385 | 965.2 | 2.4 7 B, C, D, E, F, L, M, N, P, R, S, T, V |
| 335 | 79100800-79101720 | 236 | 441 | 40. | 110 | 4.5 | 6.0 | 080 | 9440 | | 2.0 6 B, D, L, M, N, P, R, V |
| 336 | 79101820-79101923 | 27 | 60 | 27. | 100 | 2.5 | 8.0 | 110 | 729 | | L, M, P, R |
| 337 | 79102112-79102606 | 114 | 122 | 45. | 060 | 0.5 | 5.0 | 070 | 5130 | 953.9 | M, N, R, S, T |
| 338 | 79102718-79102816 | 22 | 4 | 27. | 080 | 1.5 | 5.0 | 040 | 594 | | L, M, N |
| 339 | 79103012-79103021 | 9 | 4 | 30. | 130 | 0.0 | 5.0 | 070 | 270 | | M, R |
| 340 | 80071300-80071418 | 42 | 25 | 31. | 090 | 2.0 | 5.0 | 080 | 1302 | | M, N, P, R |
| 341 | 80071915-80072006 | 15 | 3 | 25. | 070 | 1.5 | 5.0 | 070 | 375 | | L, M |
| 342 | 80072504-80072700 | 44 | 37 | 30. | 290 | 2.6 | 6.9 | | 1320 | | C, L, N, P, R |
| 343 | 80073000-80080120 | 81 | 67 | 29. | 070 | 2.7 | | | 2349 | | B, L, M, P, R |
| 344 | 80080613-80080713 | 24 | 13 | 30. | 130 | 1.5 | 5.0 | 140 | 720 | | L, P, R |
| 345 | 80081021-80081101 | 4 | 5 | 16. | 080 | 1.5 | 5.0 | 040 | 64 | | P |
| 346 | 80081515-80081902 | 83 | 59 | 26. | 300 | 2.0 | 5.0 | 060 | 2158 | | N, P, R |
| 347 | 80082308-80082310 | 2 | 3 | 26. | 150 | 0.5 | 5.0 | 140 | 52 | | R |
| 348 | 80082510-80082511 | 1 | 2 | 0. | 000 | 1.5 | 5.0 | 300 | 0 | | P |
| 349 | 80082722-80082800 | 2 | 2 | 27. | 250 | 1.0 | 5.0 | 260 | 54 | | R |
| 350 | 80082800-80082816 | 120 | 12 | 22. | 280 | 2.0 | 5.0 | 240 | 2640 | | 3.3 8 P, T, V |
| 351 | 80082900-80090503 | 171 | 117 | 40. | 280 | 3.7 | | | 6840 | | B, D, F, N, P, R |
| 352 | 80090621-80090713 | 16 | 8 | 30. | 220 | 1.5 | 5.0 | 240 | 480 | | P, R |
| 353 | 80090906-80090909 | 3 | 3 | 25. | 290 | 0.5 | 5.0 | 300 | 75 | | R |
| 354 | 80091321-80091800 | 99 | 56 | 40. | | 3.7 | | | 3960 | | B, N, P, R |
| 355 | 80092102-80092106 | 4 | 3 | 25. | 340 | 1.5 | 5.0 | 350 | 100 | | P, R |
| 356 | 80092306-80092318 | 12 | 2 | 33. | 270 | | | | 396 | | N |
| 357 | 80092704-80100918 | 302 | 59 | 35. | 080 | 2.5 | 6.0 | 080 | 10570 | 955.3 | B, M, N, P, R, S |
| 358 | 80101012-80101112 | 24 | 2 | 28. | 120 | | | | 672 | | N |
| 359 | 80101606-80101712 | 30 | 4 | 36. | 240 | | | | 1080 | | N |
| 360 | 80102306-80102513 | 55 | 31 | 31. | 100 | | | | 1705 | | N |
| 361 | 81071600-81072104 | 124 | 108 | 34. | 100 | 5.0 | 5.0 | 110 | 4216 | | B, M, N, P, R |
| 362 | 81072214-81072300 | 10 | 11 | 18. | 130 | 1.5 | 5.0 | 130 | 180 | | P |
| 363 | 81072414-81072420 | 6 | 9 | 19. | 100 | 1.5 | 5.0 | 080 | 114 | | P |
| 364 | 81072503-81072513 | 10 | 12 | 28. | 140 | 1.0 | 5.0 | 120 | 280 | | R |
| 365 | 81072615-81073023 | 104 | 153 | 38. | 130 | 4.0 | 5.0 | 110 | 3952 | | B, L, M, N, P, R, V |
| 366 | 81080200-81080421 | 70 | 201 | 40 | | 4.0 | | | 2800 | | B, D, E, F, L, M, N, P, R, T, V |
| 367 | 81080705-81081021 | 88 | 140 | 32. | 090 | 3.0 | 5.0 | 090 | 2816 | | D, L, M, N, P, R |
| 368 | 81081218-81081418 | 48 | 52 | 30. | 120 | 2.5 | 5.0 | 090 | 1440 | | L, M, P, R |
| 369 | 81081600-81081812 | 60 | 125 | 45. | 290 | 6.0 | 5.0 | 290 | 2700 | | B, D, E, F, L, M, N, P, R, T, V |
| 370 | 81081900-81082523 | 167 | 212 | 35. | 310 | 3.5 | 6.0 | 080 | 5845 | 967.3 | C, D, E, L, M, N, P, R, S, V |
| 371 | 81082808-81090212 | 124 | 299 | 45. | 240 | 4.0 | 8.0 | 270 | 5580 | | B, C, D, F, L, M, N, P, R, T, V |
| 372 | 81090405-81090612 | 55 | 40 | 35. | 330 | 2.5 | 5.0 | 330 | 1925 | | M, N, P, R |
| 373 | 81090704-81091013 | 81 | 94 | 30. | 090 | 3.0 | 6.0 | 100 | 2430 | | N, P, R |
| 374 | 81091506-81092106 | 144 | 268 | 36. | 080 | 4.5 | 8.0 | 090 | 5184 | | B, C, D, E, L, M, N, P, R, V |
| 375 | 81092523-81092606 | 7 | 8 | 18. | 050 | 5.0 | 5.0 | 090 | 126 | | P |
| 376 | 81092700-81100811 | 275 | 710 | 36. | 040 | 5.0 | 8.0 | 020 | 9900 | | B, C, D, E, F, M, N, P, R, T, V |
| 377 | 81100913-81100913 | 1 | 1 | 22. | 130 | 10.0 | 5.0 | 120 | 22 | | P |
| 378 | 82071901-82072217 | 88 | 67 | 35. | 350 | 3.0 | 6.3 | | 3080 | | B, C, E, N, R |
| 379 | 82072321-82072507 | 34 | 20 | 36. | 300 | 0.0 | 5.0 | 100 | 1224 | | R |

TABLE A.1 (continued)

| | | | | | | | | | |
|-----|-------------------|-----|-----|---------|------|-----|-----------|-------|------------------------------|
| 380 | 82072614-82072912 | 70 | 111 | 50. | 5.0 | 6.4 | 3500 | 1008 | A, B, N, P, R, T, V |
| 381 | 82073018-82080706 | 180 | 142 | 32. 250 | 2.5 | 5.0 | 5760 | | P, R |
| 382 | 82081208-82081211 | 3 | 3 | 26. 080 | | | 78 | | N |
| 383 | 82081215-82081300 | 9 | 3 | 27. 090 | 3.5 | 6.0 | 090 243 | | L, M |
| 384 | 82081300-82081422 | 46 | 137 | 43. 150 | 3.0 | 6.0 | 1978 | | N, P, R |
| 385 | 82081703-82081912 | 57 | 23 | 30. 310 | 2.0 | 5.0 | 1710 | | N, P, R |
| 386 | 82081912-82082309 | 93 | 121 | 38. 280 | 3.5 | 6.0 | 3534 | | B, D, E, M, N, P, R, V |
| 387 | 82082505-82082702 | 45 | 45 | 32. 110 | 1.5 | 5.0 | 1440 | | P, R |
| 388 | 82083000-82090110 | 58 | 129 | 34. 070 | 2.5 | 5.0 | 1972 | | P, R |
| 389 | 82090218-82090900 | 160 | 310 | 34. 050 | 2.5 | 6.0 | 5440 | | D, N, P, R, V |
| 390 | 82090914-82091315 | 97 | 229 | 34. 100 | 2.7 | | 3298 | | D, M, P, R, V |
| 391 | 82091522-82091802 | 52 | 53 | 41. 230 | 3.0 | 5.0 | 2132 | | B, D, N, P, R, V |
| 392 | 82091900-82092321 | 117 | 268 | 41. 110 | 4.0 | 6.0 | 110 4797 | | B, D, F, L, M, N, P, R, T, V |
| 393 | 82092623-82092700 | 1 | 2 | 25. 010 | 1.5 | 5.0 | 25 | | P, R |
| 394 | 82100101-82100200 | 23 | 29 | 20. 030 | 1.5 | 5.0 | 460 | | P |
| 395 | 82100200-82101000 | 192 | 151 | 34. 299 | 3.0 | | 6528 | 965.3 | B, E, N, P, R, S |
| 396 | 82101000-82101612 | 156 | 127 | 36. 320 | 3.0 | 6.0 | 5616 | 964.4 | B, N, P, R, S |
| 397 | 82101717-82102806 | 253 | 147 | 54. 270 | 4.0 | | 13662 | 967.3 | B, F, N, P, R, S, T |
| 398 | 82102918-82103118 | 48 | 6 | 36. 220 | | | 1728 | | N |
| 399 | 83070100-83070200 | 24 | 2 | 28. 320 | 0.0 | 6.0 | 110 672 | | M |
| 400 | 83070118-83070216 | 22 | 2 | 28. 090 | | | 616 | | N |
| 401 | 83070217-83070318 | 25 | 0 | 30 | 1.0 | | 750 | | B |
| 402 | 83071220-83071300 | 4 | 5 | 20. 320 | 1.5 | 5.0 | 80 | | P |
| 403 | 83071521-83071700 | 27 | 17 | 20. 320 | 1.5 | 5.0 | 540 | | P |
| 404 | 83072006-83072018 | 12 | 13 | 18. 080 | 1.5 | 5.0 | 216 | | P |
| 405 | 83072500-83073000 | 120 | 119 | 32. 100 | 15.0 | 6.0 | 3840 | | B, P, R |
| 406 | 83080105-83080505 | 96 | 195 | 32. 260 | 13.5 | 5.0 | 297 3072 | | L, M, N, P, R |
| 407 | 83080606-83080606 | 1 | 1 | 14. 080 | 5.0 | 0.0 | 080 14 | | L |
| 408 | 83080701-83081022 | 93 | 91 | 31. 140 | 3.0 | 5.0 | 2883 | | B, M, P, R |
| 409 | 83081422-83081712 | 62 | 67 | 27. 080 | 4.0 | 6.0 | 1674 | | L, P, R, V |
| 410 | 83081812-83081812 | 1 | 1 | 14. 160 | 2.0 | 5.0 | 14 | | P |
| 411 | 83081900-83081906 | 6 | 2 | 20. 140 | 2.1 | 5.0 | 150 120 | | L |
| 412 | 83082012-83082412 | 88 | 75 | 30. 110 | 6.8 | 6.0 | 110 2640 | | B, L, P, R, V |
| 413 | 83082413-83082414 | 1 | 2 | 20. 350 | 3.0 | 5.0 | 20 | | P |
| 414 | 83082718-83082800 | 6 | 3 | 20. 310 | 2.0 | 5.0 | 120 | | L, P |
| 415 | 83082917-83091200 | 295 | 179 | 45. 280 | 5.4 | 6.0 | 262 13275 | | B, D, L, M, N, P, R, V |
| 416 | 83091422-83091618 | 44 | 25 | 30. 330 | 2.0 | 5.0 | 1320 | | B, M, N, P, R |
| 417 | 83092012-83092014 | 2 | 2 | 28. 170 | 1.5 | 5.0 | 56 | | P, R |
| 418 | 83110700-83111212 | 132 | 24 | 45. 150 | 0.0 | 5.0 | 310 5940 | 962.3 | B, F, M, N, R, S, T |
| 419 | 83111512-83111612 | 24 | 3 | 30. 310 | 0.0 | 5.0 | 310 720 | | M |
| 420 | 83112118-83112200 | 6 | 2 | 33. 160 | 0.0 | 5.0 | 310 198 | | M |
| 421 | 84061522-84061522 | 1 | 1 | 25. 070 | | | 25 | | N |
| 422 | 84061621 | 11 | 0 | | | | 0 | | H |
| 423 | 84062221-84062404 | 31 | 24 | 25. 070 | 2.0 | 5.0 | 775 | | P, R |
| 424 | 84062505 | 41 | 0 | | 2.0 | | 0 | | H |
| 425 | 84062521-84062712 | 39 | 23 | 30. 080 | 3.0 | 5.0 | 1170 | | H, P, R |
| 426 | 84062900-84062900 | 1 | 1 | 26. 090 | | | 26 | | N |
| 427 | 84062913 | 18 | 0 | | 2.0 | | 0 | | H |
| 428 | 84062915-84063008 | 17 | 32 | 27. 080 | 2.0 | 5.0 | 459 | | P, R |
| 429 | 84070120-84070223 | 27 | 18 | 25. 010 | 2.0 | 5.0 | 675 | | H, P, R |
| 430 | 84070701 | 8 | 0 | | 1.0 | | 0 | | H |

TABLE A.1 (continued)

| | | | | | | | | | | | |
|-----|-------------------|-----|----|-----|-----|-----|------|-----|------|-------|-----------|
| 482 | 86081918-86082006 | 12 | 2 | 30. | 290 | | | | 360 | | N |
| 483 | 86082118-86082512 | 90 | 26 | 36. | 320 | 5.1 | 9.0 | 331 | 3240 | | M,N |
| 484 | 86082612-86082612 | 1 | 1 | 20. | 160 | 1.5 | 5.0 | 160 | 20 | | L |
| 485 | 86090306-86090306 | 1 | 1 | 20. | 100 | 2.5 | 8.0 | 100 | 20 | | L |
| 486 | 86090312-86090412 | 24 | 7 | 30. | 270 | | | | 720 | | N |
| 487 | 86090706-86091712 | 246 | 32 | 32. | 120 | 4.0 | 8.0 | 110 | 7872 | 3.2 | 5 L,M,N |
| 488 | 86091912-86091918 | 6 | 2 | 25. | 200 | | | | 150 | | N |
| 489 | 86092100-86092118 | 18 | 10 | 30. | 340 | 0.0 | 14.0 | 160 | 540 | | M,N |
| 490 | 86093000-86100100 | 18 | 24 | 30. | | | | | 540 | 3.5 | 6 H |
| 491 | 87082400-87082512 | 36 | 4 | 25. | 290 | 2.5 | 6.0 | 280 | 900 | | L,M,N,V |
| 492 | 87082800-87090106 | 102 | 68 | 46. | 270 | 6.5 | 6.0 | 260 | 4692 | 3.5 | 9 L,M,N,V |
| 493 | 87090500-87090618 | 42 | 11 | 35. | 320 | 2.0 | 6.0 | 300 | 1470 | | L,M,N |
| 494 | 87090817-87090822 | 5 | 5 | 33. | 240 | | | | 165 | | N |
| 495 | 87090906-87090906 | 1 | 1 | 24. | 280 | 1.5 | 5.0 | 280 | 24 | | L |
| 496 | 87091300-87091418 | 42 | 7 | 34. | 320 | 4.5 | 8.0 | 260 | 1428 | | L,M,N,V |
| 497 | 87101400-87101606 | 54 | 19 | 33. | 110 | | | | 1782 | | N |
| 498 | 87102106-87102900 | 186 | 32 | 30. | 250 | | | | 5580 | 959.2 | N,S |
| 499 | 87103118-87110118 | 24 | 3 | 34. | 260 | | | | 816 | | N |
| 500 | 87110406-87110606 | 48 | 5 | 30. | 090 | | | | 1440 | | N |
| 501 | 87110712-87111600 | 204 | 30 | 28. | 110 | | | | 5712 | 968.4 | N,S |
| 502 | 88061618-88061816 | 46 | 7 | 26. | 090 | | | | 1196 | | N |
| 503 | 88062920-88070318 | 94 | 21 | 29. | 080 | 0.0 | 8.0 | 260 | 2726 | | M,N |
| 504 | 88071206-88071206 | 1 | 1 | 23. | 090 | 2.0 | 5.0 | 090 | 23 | | L |
| 505 | 88071212-88071219 | 7 | 6 | 27. | 090 | | | | 189 | | N |
| 506 | 88072206-88072212 | 6 | 2 | 25. | 290 | | | | 150 | | N |
| 507 | 88080103-88080500 | 93 | 61 | 38. | 310 | 4.3 | 8.0 | 288 | 3534 | 2.7 | L,M,N |
| 508 | 88101218-88101406 | 36 | 12 | 36. | 110 | 4.5 | 5.0 | 110 | 1296 | | L,M,N |
| 509 | 88101512-88101806 | 66 | 47 | 43. | 260 | | | | 2838 | | N |
| 510 | 88102000-88102318 | 90 | 16 | 45. | 220 | | | | 4050 | | N |
| 511 | 88111400-88111412 | 12 | 2 | 26. | 090 | | | | 312 | | N |

TABLE A.2

TOP 160 - Storm list for the Beaufort Sea

(Storms selected from top 512 storms. Selection criteria : Hs .GE 2.0 m or if there is only one observation, wind speed .GE.30.)

SOURCES:

- A Severe storms over the Canadian Western High Arctic 1957-1983 Report #87-2
 B Beaufort Weather Office Annual Summaries (1976-1985)
 C Arctic Petroleum Operator's Association, 1983: Beaufort Sea Hindcast Study 1970-1982.
 APOA Study 203
 D Seaconsult, 1986: An extreme value analysis of Storm Wave Power at Minuk.
 E Baird & Associates, 1987: Estimation of the Wave Climate of Minuk I-53 1960-1985
 F Buckley and Budgell, 1988: Meteorologically Induced Currents in the Beaufort Sea
 G Sea Consult, 1989: Design Storm Characteristic, Amuligak Region, Beaufort Sea
 H Maclaren Plansearch Database
 I Seaconsult 1987: Wind and wave Hindcast for the storm of September 15 to 19, 1985
 J Seaconsult 1986: Analysis of the ADGO Wave Measurements for the storm of September 15 to 18, 1985
 K Baird & Associates, 1987: Estimation of the Wave Climate at Minuk I-53 during the storm of September 15 to 19, 1985
 L COADS.wave waves >= 1.5 m
 M COADS.wind winds >= 25 kts
 N LAST.wind winds >= 25 kts
 P RIG.wave waves >= 1.5 m
 R RIG.wind winds >= 25 kts
 S SPASM central pressure <= 970 mb
 T MPL HINDCAST
 V MEDS

| | START YYMMDDHH | END YYMMDDHH | DUR | OBS | WIND | | COMBINED SEA | | SEVERITY INDEX | MINT CENT PRESSURE (mb) | WAVERIDER | | SOURCE |
|---|-----------------------|-----------------|-----|-----|--------------|-----|--------------|---------------|-------------------|-------------------------------|-----------|-----------|---------|
| | | | | | SPD (kts) | DIR | HS (m) | TP DIR (s) | | | HS | TP (s) | |
| | 2 57072518-57072706 | | 36 | 4 | 23. | 330 | 2.5 | 8.0 | 340 | 828 | | | L |
| | 5 57080900-57080915 | | 15 | 5 | 34. | 230 | 3.0 | 8.0 | 230 | 510 | | | L,M |
| | 6 57081809-57081809 | | 1 | 1 | 12. | 070 | 5.5 | 5.0 | 200 | 12 | | | L |
| | 52 60081917-60082200 | | 55 | 8 | 31. | 320 | 3.5 | 5.0 | 310 | 1705 | | | L,M,N |
| | 74 61071317-61071500 | | 31 | 6 | 48. | 320 | 2.1 | 5.0 | 342 | 1488 | | | L,M,N |
| * | 86 62072115-62072506 | | 87 | 20 | 50. | 290 | 4.0 | 5.0 | 080 | 4350 | | | L,M |
| * | 87 62072506-62072506 | | 1 | 1 | 26. | 080 | 4.0 | 5.0 | 080 | 26 | | | L,M |
| | 95 62090311-62090715 | | 100 | 34 | 56. | 310 | 9.5 | 6.0 | 310 | 5600 | | | L,M |
| | 97 62090903-62091106 | | 51 | 14 | 48. | 250 | 8.0 | 6.0 | 230 | 2448 | | | L,M |
| | 100 62092706-62100118 | | 108 | 19 | 26. | 110 | | | | 2808 | 968.5 | | M,N,S,T |
| | 111 63082311-63082323 | | 12 | 2 | 52. | 230 | 5.5 | 6.0 | 220 | 624 | | | L,M,N |
| | 131 65071500-65071509 | | 9 | 4 | 33. | 070 | 3.5 | 5.0 | 050 | 297 | | | L,M |
| | 146 66082912-66082918 | | 6 | 2 | 31. | 040 | 3.4 | 6.0 | 066 | 186 | | | L,M |
| | 150 66102912-66110300 | | 108 | 19 | 23. | 190 | 2.9 | 10.0 | 116 | 2484 | 965.7 | | L,S |
| | 152 67081912-67081912 | | 1 | 1 | 8. | 030 | 4.0 | 5.0 | 030 | 8 | | | L |
| | 161 67102912-67110606 | | 186 | 32 | 21. | 150 | 3.6 | 5.0 | 150 | 3906 | 958.9 | | L,S |
| | 163 68071403-68071406 | | 3 | 2 | 30. | 050 | 2.2 | 5.0 | 040 | 90 | | | L,M |

TABLE A.2 (continued)

| | | | | | | | | | | | | | |
|------|-------------------|-----|-----|-----|-----|-----|------|-----|------|-------|-----|---|-------------------------|
| 166 | 68090706-68090803 | 21 | 4 | 30. | 270 | 3.8 | 6.0 | 270 | 630 | | | | L,M |
| 167 | 68092112-68092200 | 12 | 3 | 26. | 200 | 5.6 | 6.0 | 271 | 312 | | | | L,M |
| 183 | 69091003-69091109 | 30 | 9 | 33. | 070 | 2.0 | 5.0 | 070 | 990 | | | | L,M |
| 196 | 70090218-70090716 | 118 | 37 | 45. | 110 | 4.5 | 12.0 | 330 | 5310 | | 3.6 | 8 | C,L,M,N,V |
| 198 | 70091313-70091512 | 47 | 28 | 63. | 240 | 5.6 | 7.0 | 284 | 2961 | 968 | 2.5 | 6 | A,C,L,M,N,T,V |
| 208 | 71070100-71070100 | 1 | 1 | 40. | 300 | 8.0 | 22.0 | 282 | 40 | | | | L,M |
| 210 | 71072900-71073003 | 27 | 9 | 30. | 270 | 2.9 | 7.0 | 282 | 810 | | 2.9 | 7 | C,M,N,V |
| 211 | 71080303-71080315 | 12 | 6 | 28. | 360 | 2.6 | 6.7 | | 336 | | 2.6 | 7 | C,N,V |
| *213 | 71082218-71082306 | 12 | 5 | 26. | 360 | 2.9 | 7.1 | | 312 | | 2.9 | 7 | C,N,V |
| *216 | 71092312-71092312 | 1 | 1 | 12. | 350 | 6.0 | 5.0 | 350 | 12 | | | | L |
| 226 | 72082012-72082012 | 1 | 1 | 30. | 090 | 2.0 | 5.0 | 090 | 30 | 1001 | | | A,L |
| 227 | 72082012-72082112 | 24 | 5 | 50. | 320 | 2.0 | 5.0 | 090 | 1200 | | | | L,M,N,T |
| 230 | 72090110-72090209 | 23 | 12 | 40. | 290 | 3.7 | 7.0 | 310 | 920 | | | | C,L,N |
| 234 | 72091200-72091318 | 42 | 1 | | | 2.7 | 6.6 | | 0 | | | | C |
| 235 | 72091606-72091706 | 24 | 2 | 31. | 340 | 2.5 | 5.0 | 330 | 744 | | | | L,M |
| 237 | 73072100-73072112 | 12 | 6 | 48. | 280 | | | | 576 | | | | L,M,T |
| 238 | 73090200-73090218 | 18 | 4 | 27. | 090 | 2.9 | 8.0 | 135 | 486 | | | | L,M |
| 240 | 73090612-73090718 | 30 | 5 | 25. | 100 | 6.5 | 12.0 | 103 | 750 | | | | L,M |
| 242 | 73091500-73091700 | 48 | 6 | 32. | 270 | 3.5 | 7.0 | 300 | 1536 | | | | L,M,N |
| 251 | 74083106-74083106 | 1 | 1 | 10. | 090 | 5.5 | 6.0 | 090 | 10 | | | | L |
| 258 | 74091606-74091700 | 18 | 4 | 29. | 100 | 2.6 | 5.8 | 100 | 522 | | | | C,L,M |
| 268 | 75072909-75072918 | 9 | 3 | 26. | 240 | 4.5 | 9.0 | 360 | 234 | | | | L,M |
| 270 | 75080815-75081118 | 75 | 29 | 40. | 280 | 4.7 | 10.0 | 310 | 3000 | | 2.4 | 6 | L,M,V |
| 274 | 75082606-75082814 | 56 | 29 | 45. | 230 | 5.0 | 0.0 | 270 | 2520 | | 2.2 | 6 | D,L,M,N,V |
| 277 | 75090606-75090800 | 42 | 7 | 34. | 050 | 2.0 | 5.0 | 030 | 1428 | | | | L,M,N |
| 278 | 75091212-75091400 | 36 | 4 | 29. | 260 | 2.9 | 6.0 | 230 | 1044 | | | | L,M,N |
| 279 | 75091712-75092312 | 144 | 15 | 33. | 230 | 4.0 | 6.0 | 070 | 4752 | | | | L,M,N |
| 282 | 76081121-76081423 | 72 | 61 | 35. | 050 | 4.3 | 6.2 | | 2520 | | 2.8 | 6 | B,C,D,L,M,N,P,R,V |
| 284 | 76082109-76082213 | 28 | 42 | 40. | 270 | 2.2 | 6.0 | 290 | 1120 | | 2.2 | 6 | D,L,M,N,P,R,V |
| 286 | 76082510-76082904 | 90 | 41 | 34. | 090 | 2.0 | 5.0 | | 3060 | | | | M,N,P,R |
| 288 | 76090816-76091009 | 41 | 67 | 32. | 090 | 3.0 | 6.0 | | 1312 | | 2.0 | 6 | M,N,P,R,V |
| 289 | 76091018-76091203 | 1 | 1 | | | 2.6 | | | 0 | | 2.6 | 7 | D,V |
| 290 | 76091204-76091707 | 123 | 148 | 30. | 120 | 3.0 | 6.0 | | 3690 | 963.0 | 1.8 | 8 | M,N,P,R,S,V |
| 291 | 76091907-76092218 | 80 | 88 | 37. | 120 | 3.0 | 5.0 | 220 | 2960 | | 1.7 | 6 | L,M,N,P,R |
| 292 | 76092323-76092706 | 79 | 55 | 38. | 090 | 4.6 | 7.0 | 073 | 3002 | | | | L,M,N,P,R |
| 293 | 76092814-76100208 | 90 | 166 | 32. | 070 | 4.0 | 6.0 | 070 | 2880 | | 1.9 | 7 | L,M,P,R,V |
| 298 | 77080600-77081306 | 174 | 152 | 33. | 090 | 2.2 | 6.0 | 080 | 5742 | | 1.8 | 6 | L,M,N,P,R |
| 301 | 77082105-77082509 | 100 | 36 | 35. | 090 | 2.0 | 6.0 | 130 | 3500 | | | | L,M,R |
| 302 | 77082512-77082918 | 102 | 59 | 41. | 320 | 3.4 | 6.9 | 290 | 4182 | | 3.2 | 8 | B,C,D,E,F,L,M,N,P,R,T,V |
| 303 | 77083115-77090201 | 58 | 31 | 32. | 310 | 2.5 | 6.0 | 320 | 1856 | | 2.2 | | D,P,R |
| 306 | 77090603-77090921 | 90 | 55 | 36. | 120 | 2.5 | 6.0 | 350 | 3240 | | 2.3 | 7 | D,L,M,P,R,V |
| 307 | 77091100-77091522 | 118 | 33 | 32. | 130 | 3.5 | 6.0 | 055 | 3776 | | 2.1 | 6 | D,L,M,P,R,V |
| 310 | 77092100-77092214 | 38 | 60 | 42. | 270 | 3.0 | 6.0 | 290 | 1596 | | 2.9 | 7 | D,N,P,R,V |
| 311 | 77092309-77092808 | 119 | 173 | 40. | 160 | 3.0 | 6.0 | 150 | 4760 | | 2.6 | 6 | D,P,L,M,N,P,R,T,V |
| 312 | 77092818-77100411 | 137 | 60 | 32. | 280 | 3.0 | 5.0 | 020 | 4384 | | 2.2 | 7 | D,L,M,N,P,R,T,V |
| 313 | 77100515-77101213 | 166 | 179 | 45. | 130 | 3.5 | 5.0 | 120 | 7470 | | 2.2 | 8 | B,D,F,N,P,R,T,V |
| 315 | 77101400-77101613 | 61 | 32 | 31. | 060 | 2.6 | 6.1 | 060 | 1891 | 960.3 | 1.9 | 7 | C,N,P,R,S |
| 317 | 77102100-77102306 | 54 | 22 | 54. | 150 | 2.5 | 6.0 | 100 | 2916 | 950.2 | | | N,P,R,S |
| 320 | 78082304-78082712 | 104 | 54 | 40. | 300 | 3.1 | 6.7 | | 4160 | | | | C,E,N,R |
| 321 | 78090100-78090900 | 240 | 211 | 40. | 090 | 2.7 | 6.0 | 037 | 9600 | | 2.7 | 8 | B,C,D,F,L,M,N,R,T,V |
| 322 | 78090906-78091412 | 126 | 54 | 38. | 030 | 6.3 | 8.0 | 062 | 4788 | 969.0 | 1.9 | 7 | L,M,R,S,V |
| 323 | 78091519-78091715 | 44 | 31 | 47. | 310 | 3.4 | 8.0 | 003 | 2068 | | 2.4 | 8 | D,L,N,R,V |

TABLE A.2 (continued)

| | | | | | | | | | | | | | |
|------|-------------------|-----|-----|-----|-----|------|------|-----|-------|-------|-----|----|------------------------------------|
| 325 | 78091900-78092206 | 91 | 99 | 40. | 070 | 7.5 | 12.0 | 098 | 3640 | | 3.6 | 10 | B, C, D, L, M, N, R, V |
| 326 | 78092900-78100303 | 99 | 98 | 45. | 280 | 3.5 | 5.0 | | 4455 | | 2.4 | 9 | M, N, R, T, V |
| 327 | 78100600-78101004 | 100 | 162 | 50 | 080 | 3.5 | 7.0 | | 5000 | | | | B, F, M, N, R, T |
| 329 | 79081310-79081904 | 138 | 279 | 38. | 100 | 4.5 | 5.0 | 070 | 5244 | | 2.4 | 7 | D, L, M, N, P, R, V |
| 330 | 79082002-79082600 | 142 | 94 | 37. | 100 | 3.0 | 5.0 | 280 | 5254 | | 2.4 | 8 | D, F, L, M, N, P, R, T, V |
| 333 | 79091110-79091923 | 205 | 448 | 36. | 070 | 4.0 | 6.0 | 090 | 7380 | | 2.5 | 8 | D, L, M, N, P, R, V |
| 334 | 79092118-79092412 | 66 | 42 | 35. | 080 | 4.5 | 6.0 | 100 | 2310 | 965.2 | 2.4 | 7 | B, C, D, E, F, L, M, N, P, R, S, V |
| 334a | 79092900-79100806 | 246 | 68 | 42. | 080 | 3.5 | 6.0 | | 10332 | | | | B, C, D, E, F, L, M, N, P, R, S, T |
| 335 | 79100800-79101720 | 236 | 441 | 40. | 110 | 4.5 | 6.0 | 080 | 9440 | | 2.0 | 6 | B, D, L, M, N, P, R, V |
| 336 | 79101820-79101923 | 27 | 60 | 27. | 100 | 2.5 | 8.0 | 110 | 729 | | | | L, M, P, R |
| 337 | 79102112-79102606 | 114 | 122 | 45. | 060 | 0.5 | 5.0 | 070 | 5130 | 953.9 | | | M, N, R, S, T |
| 342 | 80072504-80072700 | 44 | 37 | 30. | 290 | 2.6 | 6.9 | 070 | 1320 | | | | C, L, N, P, R |
| 343 | 80073000-80080120 | 81 | 67 | 29. | 070 | 2.7 | 6.0 | 070 | 2349 | | | | B, L, M, P, R |
| 350 | 80082800-80082816 | 16 | 12 | 22. | 280 | 3.3 | 8.0 | 240 | 352 | | 3.3 | 8 | G, P, T, V |
| 351 | 80082900-80090503 | 171 | 117 | 40. | 280 | 3.7 | 8.0 | 280 | 6840 | | 3.3 | 8 | B, D, F, N, P, R, V |
| 354 | 80091321-80091800 | 99 | 56 | 40. | 130 | 3.7 | 6.0 | 100 | 3960 | | 1.9 | 6 | B, N, P, R |
| 357 | 80092704-80100918 | 302 | 59 | 35. | 080 | 2.5 | 6.0 | 080 | 10570 | 955.3 | | | B, M, N, P, R, S |
| 361 | 81071600-81072104 | 124 | 108 | 34. | 100 | 5.0 | 5.0 | 110 | 4216 | | 2.0 | 6 | B, M, N, P, R |
| 365 | 81072615-81073023 | 104 | 153 | 38. | 130 | 4.0 | 5.0 | 110 | 3952 | | 1.9 | 6 | B, L, M, N, P, R, V |
| 366 | 81080200-81080421 | 70 | 201 | 40 | 310 | 4.0 | 5.0 | 310 | 2800 | | 2.7 | 7 | B, D, E, F, L, M, N, P, R, T, V |
| 367 | 81080705-81081021 | 88 | 140 | 32. | 090 | 3.0 | 5.0 | 090 | 2816 | | 2.0 | 7 | D, L, M, N, P, R |
| 368 | 81081218-81081418 | 48 | 52 | 30. | 120 | 2.5 | 5.0 | 090 | 1440 | | | | L, M, P, R |
| 369 | 81081600-81081812 | 60 | 125 | 45. | 290 | 6.0 | 5.0 | 290 | 2700 | | 3.4 | 8 | B, D, E, F, L, M, N, P, R, T, V |
| 370 | 81081900-81082523 | 167 | 212 | 35. | 310 | 3.5 | 6.0 | 080 | 5845 | 967.3 | 2.3 | 7 | C, D, E, L, M, N, P, R, S, V |
| 371 | 81082808-81090212 | 124 | 299 | 45. | 240 | 4.0 | 8.0 | 270 | 5580 | | 2.4 | 7 | B, C, D, F, L, M, N, P, R, T, V |
| 372 | 81090405-81090612 | 55 | 40 | 35. | 330 | 2.5 | 5.0 | 330 | 1925 | | | | M, N, P, R |
| 373 | 81090704-81091013 | 81 | 94 | 30. | 090 | 3.0 | 6.0 | 100 | 2430 | | | | N, P, R |
| 374 | 81091506-81092106 | 144 | 268 | 36. | 080 | 4.5 | 8.0 | 090 | 5184 | | 2.3 | 7 | B, C, D, E, L, M, N, P, R, V |
| 375 | 81092523-81092606 | 7 | 8 | 18. | 050 | 5.0 | 5.0 | 090 | 126 | | | | P |
| 376 | 81092700-81092912 | 275 | 710 | 36. | 040 | 5.0 | 8.0 | 020 | 9900 | | 2.8 | 8 | B, C, D, E, F, M, N, P, R, T, V |
| 377 | 81100913-81100913 | 1 | 1 | 22. | 130 | 10.0 | 5.0 | 120 | 22 | | 3.5 | | P |
| 378 | 82071901-82072217 | 88 | 67 | 35. | 350 | 3.0 | 6.3 | | 3080 | | 2.5 | 6 | B, C, E, N, R |
| 380 | 82072614-82072912 | 70 | 111 | 50. | 280 | 5.0 | 6.4 | | 3500 | 1008 | 3.4 | 8 | A, B, N, P, R, T, V |
| 381 | 82073018-82080706 | 180 | 142 | 32. | 250 | 2.5 | 5.0 | | 5760 | | 1.8 | 9 | P, R |
| 383 | 82081215-82081300 | 9 | 3 | 27. | 090 | 3.5 | 6.0 | 090 | 243 | | | | L, M |
| 384 | 82081300-82081422 | 46 | 137 | 43. | 150 | 3.0 | 6.0 | | 1978 | | 2.0 | 6 | N, P, R |
| 386 | 82081912-82082309 | 93 | 121 | 38. | 280 | 3.5 | 6.0 | | 3534 | | 2.8 | | B, D, E, M, N, P, R, V |
| 388 | 82083000-82090110 | 58 | 129 | 34. | 070 | 2.5 | 5.0 | | 1972 | | | | P, R |
| 389 | 82090218-82090900 | 160 | 310 | 34. | 050 | 2.5 | 6.0 | | 5440 | | 2.3 | 6 | D, N, P, R, V |
| 390 | 82090914-82091315 | 97 | 229 | 34. | 100 | 2.7 | 7.0 | | 3298 | | 2.7 | 7 | D, M, P, R, V |
| 391 | 82091522-82091802 | 52 | 53 | 41. | 230 | 3.0 | 5.0 | | 2132 | | 2.4 | 7 | B, D, N, P, R, V |
| 392 | 82091900-82092321 | 117 | 268 | 41. | 110 | 4.0 | 6.0 | 110 | 4797 | | 3.3 | 8 | B, D, F, L, M, N, P, R, T, V |
| 395 | 82100200-82101000 | 192 | 151 | 34. | 290 | 3.0 | 8.0 | | 6528 | 965.3 | | | B, E, N, P, R, S |
| 396 | 82101000-82101612 | 156 | 127 | 36. | 320 | 3.0 | 6.0 | | 5616 | 964.4 | | | B, N, P, R, S |
| 397 | 82101717-82102806 | 253 | 147 | 54. | 270 | 4.0 | 5.0 | | 13662 | 967.3 | | | B, F, N, P, R, S, T |
| 405 | 83072500-83073000 | 120 | 119 | 32. | 100 | 2.0 | 6.0 | | 3840 | | | | B, P, R |
| 406 | 83080105-83080505 | 96 | 195 | 32. | 260 | 2.0 | 5.0 | 297 | 3072 | | | | B, L, M, N, P, R |
| 407 | 83080606-83080606 | 1 | 1 | 14. | 080 | 5.0 | 0.0 | 080 | 14 | | | | L |
| 408 | 83080701-83081022 | 93 | 91 | 31. | 140 | 3.0 | 5.0 | | 2883 | | | | B, M, P, R |
| 409 | 83081422-83081712 | 62 | 67 | 27. | 080 | 4.0 | 6.0 | 020 | 1674 | | 1.5 | 6 | L, P, R, V |
| 412 | 83082012-83082412 | 88 | 75 | 30. | 110 | 6.8 | 6.0 | 110 | 2640 | | 1.8 | 6 | B, L, P, R, V |
| 415 | 83082917-83091200 | 295 | 179 | 45. | 280 | 5.4 | 6.0 | 262 | 13275 | | | | B, D, L, M, N, P, R, V |

TABLE A.2 (continued)

| | | | | | | | | | | | | |
|------|-------------------|-----|-----|-----|-----|-----|-----|-----|------|-------|-------|------------------------------------|
| 418 | 83110700-83111212 | 132 | 24 | 45. | 150 | | | 310 | 5940 | 962.3 | | B, F, M, R, S, T |
| 422 | 84061621-84061710 | 11 | | 21. | 045 | | | | | 231 | | B |
| 425 | 84062521-84062712 | 39 | 23 | 30. | 080 | 3.0 | 5.0 | | | 1170 | | B, P, R |
| 428 | 84062915-84063008 | 17 | 32 | 27. | 080 | 2.0 | 5.0 | | | 459 | 2.0 | P, R |
| 429 | 84070120-84070223 | 27 | 18 | 25. | 010 | 2.0 | 5.0 | | | 675 | 2.0 | B, P, R |
| 436 | 84071709-84072009 | 72 | 55 | 35. | 250 | 2.0 | 5.0 | | | 2520 | 2.0 | B, N, P, R |
| 440 | 84072901-84073006 | 30 | 7 | 23. | 230 | 1.5 | 5.0 | | | 690 | 1.5 | B, R |
| 444 | 84080810-84081213 | 99 | 88 | 36. | 180 | 2.5 | 6.0 | 270 | | 3564 | 2.2 | D, B, N, P, R, V |
| 445 | 84081318-84082105 | 99 | 88 | 37. | 100 | 1.5 | 5.0 | | | 6623 | 1.7 | B, N, P, R, V |
| 446 | 84082400-84082800 | 96 | 122 | 38. | 360 | 2.5 | 5.0 | 280 | | 3648 | | E, B, N, P, R |
| 447 | 84090218-84090218 | 1 | 1 | 25. | 110 | | | 310 | | 25 | | M |
| 448 | 84090803-84090803 | 1 | 1 | 22. | 090 | 1.5 | 5.0 | 090 | | 22 | | B, L |
| 450 | 84090908-84091100 | 40 | 9 | 29. | 080 | 3.0 | 5.0 | | | 1160 | 3.0 | P, R |
| 452 | 84091223-84091309 | 10 | | 23. | 090 | 1.0 | 5.0 | | | 230 | | B, R |
| 454 | 84091509-84091923 | 110 | 143 | 38. | 090 | 2.5 | 5.0 | 100 | | 4180 | | B, L, M, N, P, R |
| 455 | 84092411-84092603 | 40 | 89 | 38. | 150 | 3.2 | 8.0 | 190 | | 1520 | | B, L, P, R |
| 456 | 84092803-84100120 | 89 | 131 | 34. | 110 | 4.0 | 5.0 | 350 | | 3026 | | B, N, P, R |
| 457 | 84100200-84101218 | 258 | 52 | 30. | 080 | 3.0 | 5.0 | 040 | | 7740 | 962.0 | B, N, R, S |
| 458 | 84101618-84101906 | 60 | 9 | 37. | 200 | | | | | 2220 | | B, N, R |
| 459 | 84102218-84102906 | 156 | 65 | 45. | 280 | | | | | 7020 | | B, N, R |
| 461 | 84110302-84110321 | 19 | | 23. | 315 | | | | | 437 | | B |
| 465 | 84111001-84111017 | 16 | | 22. | 315 | | | | | 352 | | B |
| 466 | 85080612-85080917 | 77 | 66 | 32. | 130 | 2.0 | 5.0 | | | 2142 | | B, R |
| 467 | 85081505-85081706 | 49 | 18 | 30. | 290 | 2.5 | 5.0 | 323 | | 1470 | | B, L, N, P, R |
| 473 | 85090103-85090318 | 63 | 40 | 34. | 110 | 3.5 | 5.0 | | | 2520 | 3.5 | B, L, P, R |
| 475 | 85091221-85091906 | 153 | 312 | 50. | 280 | 6.0 | 6.0 | 280 | | 7650 | | B, E, F, I, J, K, L, M, N, P, R, T |
| 476 | 85092013-85092211 | 46 | 34 | 35. | 220 | 2.0 | 5.0 | | | 1610 | | M, N, P, R |
| 478 | 85092622-85093014 | 88 | 64 | 42. | 270 | 2.0 | 5.0 | 280 | | 3696 | | L, M, N, P, R |
| 480 | 85110700-85111418 | 186 | 36 | 45. | 140 | | | | | 8370 | 969.0 | B, N, R, S |
| 483 | 86082118-86082512 | 90 | 26 | 36. | 320 | 5.1 | 9.0 | 331 | | 3240 | 3.2 | H, M, N |
| 485 | 86090306-86090306 | 1 | 1 | 20. | 100 | 2.5 | 8.0 | 100 | | 20 | 2.2 | H, L, V |
| 487 | 86090706-86091712 | 246 | 32 | 32. | 120 | 4.0 | 8.0 | 110 | | 7872 | 3.0 | H, L, M, N |
| 490 | 86093000-86100100 | 18 | 24 | 30. | 100 | 3.5 | 6.0 | 100 | | 540 | 3.5 | H, L |
| *491 | 87082400-87082512 | 36 | 4 | 25. | 290 | 2.5 | 6.0 | 280 | | 900 | 2.0 | L, M, N, V |
| *492 | 87082800-87090106 | 102 | 68 | 46. | 270 | 6.5 | 6.0 | 260 | | 4692 | 3.5 | L, M, N, V |
| 493 | 87090500-87090618 | 42 | 11 | 35. | 320 | 2.0 | 6.0 | 300 | | 1470 | | L, M, N |
| 496 | 87091300-87091418 | 42 | 7 | 34. | 320 | 4.5 | 8.0 | 260 | | 1428 | 1.7 | L, M, N, V |
| 507 | 88080103-88080500 | 93 | 61 | 38. | 310 | 4.3 | 8.0 | 288 | | 3534 | 2.7 | L, M, N |
| 508 | 88101218-88101406 | 36 | 12 | 36. | 110 | 4.5 | 5.0 | 110 | | 1296 | | L, M, N |

* Combined into one event in the final top 50 storms

Note : Events 334 and 334a are two separates storms which were considered as one in the top 500 list.

APPENDIX B

ODGP SHALLOW WATER SPECTRAL GROWTH/DISSIPATION ALGORITHM

ODGP SHALLOW WATER SPECTRAL GROWTH/DISSIPATION

In recent years, two new concepts have been introduced to describe shallow-water wave transformations. The first concept follows from the theoretical finding that non-linear wave-wave interactions, which are now generally believed to play an important role in the deep-water spectral energy balance, are greatly enhanced in shallow water. Over a sloping bottom these interactions, though intrinsically energy conserving, effectively act to cause attenuation of wave height, as energy transferred from the vicinity of the spectral peak to higher frequencies is lost through wave breaking in the so-called saturation range of the spectrum. The second new concept is turbulent bottom friction, which depends sensitively on bottom-sediment properties and sediment-transport processes. These newer bottom friction theories, for which there is increasing experimental support, predict much higher friction coefficients than molecular viscosity theories.

These concepts have led to the introduction of a number of new shallow-water wave prediction models, but the properties of these models vary widely, and a number of controversial issues which affect the quantitative performance of these models in storm situations have yet to be resolved. This had led to a number of intercomparison studies involving alternate models. Several such studies are underway in the U.S., Canada, and Europe which may provide a clearer picture of the relevant physics for shallow-water transformation (the first phase of one of the most extensive intercomparisons, known as SHIP and supported by a consortium of U.S. oil companies, has been completed, and a second Phase, SHIP2, will proceed this year). One of the seeming consequences of the dominance of one or both of the above source terms in the process of shallow-water transformations (over the classical effects of shoaling and refraction which, except in highly inhomogeneous bottom conditions, are relatively slight in comparison) is the recent finding that wind/wave spectra in shallow water follow a self-similar form that can be described by the so-called TMA spectrum (Bouws et al., 1984).

The TMA spectrum, which has been shown to fit well literally thousands of measured spectra from the North Sea and Atlantic continental shelf, has been interpreted by Bouws et al. (1985) as an upper limit to finite-depth spectra in wind seas propagating through sloping bottoms typical of those over which the TMA spectrum was defined.

A second apparent source term of importance, especially for wave components of longer period than that of the spectral peak, is bottom friction due to bottom-sediment properties, ripple formations, and sediment transport to be modelled.

Mechanisms Modelled

The growth algorithm, called CMPE28GG, can be explained by starting with CMPE24. The following changes are made to the algorithm of CMPE24 to yield that of CMPE28A.

1. The reference spectrum is computed as Pierson-Moskowitz without an ω^{-4} range. Several traditional approximations in the numerics combine to yield

$$\alpha = 8.18559 \times 10^{-3}.$$

2. The Pierson-Moskowitz peak frequency is computed from the wind speed:

$$\omega = 0.8790132 \frac{g}{U_{19.5}}$$

where $U_{19.5}$ is wind speed at 19.5 m above sea level. This numeric implies that the constant β in the P-M spectral formula, nominally 0.74, is here taken as 0.7462625. The corresponding shallow-water wave number (k) is obtained as

$$K \tanh(kd) = \frac{\omega^2}{g}$$

and the fully-developed shallow-water total variance as

$$E_{\text{tot}} = 0.2 \times 8.18559 \times 10^{-3} \times k^{-2}$$

- At the beginning of each time step, the rms bottom excursions and rms bottom velocity are computed from

$$a^2_{\text{rms}} = \sum \frac{s(i)}{\sinh^2 k_i d}$$

$$U^2_{\text{rms}} = \sum \frac{s(i) \omega_i^2}{\sinh^2 k_i d}$$

where $s(i)$ is the variance component (not the spectral density), integrated over all directions, in frequency bin i ; ω_i is the nominal radian frequency ($2 \pi f$) in that bin; d is water depth (in feet in the code used; but the combination kd is dimensionless); and k_i is the scalar wave number computed from the shallow-water dispersion relation

$$\frac{\omega^2}{g} = k \tanh kd$$

- The α used in computing the tail of the spectrum is allowed to float according to Resio's (1981) correlation:

$$\alpha = \alpha_0 \left(\frac{E}{E_{pm}} \right)^{-2.3}$$

where

$$\alpha_o = 8.18559 \times 10^{-3} \text{ and } E_{pm} = 0.2\alpha_o g^2 \omega^{-4}$$

5. A bottom-friction factor, FW, is computed, following Grant and Madsen (1982), as the greatest of three tentative factors:

- a) a smooth-flow friction factor depending on the Reynolds number

$$Re = 2.005^2 \frac{U_{rms} a_{rms}}{\nu}$$

where ν is the kinematic viscosity of sea water (a_{rms} is rms value of bottom excursion and U_{rms} is bottom orbital velocity). (For very small values of bottom excursion, the code in SHALLOW3 yields an unphysically high value of FW).

- b) a skin-friction factor, depending on the ratio of bottom excursion to sand-grain diameter (a sand-grain diameter of 0.2 mm was assumed throughout).
- c) a friction factor reflecting the ability of the bottom velocity to raise ripples; it is a non-dimensional function of bottom excursion, bottom velocity, gravity, sand-grain diameter, and excess of the density of sand over the density of water.

6. For each frequency band, the rate of dissipation, with dimension T^{-1} , is computed as

$$-FW \times U_{rms} \times \frac{\sinh^2 k_i}{g\omega_i^2}$$

7. The A-term (linear growth) is computed as in CMPE24; the B-term (exponential growth) is a function of $\frac{u_*}{c}$, where c is now the shallow-water celerity

$$c = \left(\frac{g}{\omega}\right) \tanh\left(\omega \frac{d}{c}\right)$$

8. For each frequency-direction bin, the algebraic sum of B-term and dissipation is taken: this can be positive, negative or zero. (The case where growth exactly balances bottom friction must be regarded to prevent division by zero). Because the growth rate can be arbitrarily close to zero, the function

$$\exp(B \Delta t) - 1,$$

naturally occurring in the growth algorithm, is used in the floating-point computational form

$$\exp(B \Delta t) - 1 = 2 \exp\left(B \frac{\Delta t}{2}\right) \sinh\left(B \frac{\Delta t}{2}\right)$$

9. After upwind components are dissipated, as in CMPE24, to total variance, E , is computed by summing over 360 frequency-directional bins. The floating α is recomputed from

$$\alpha = 8.18559 \cdot 10^{-3} \left(\frac{E}{E_{tot}}\right)^{-2.3}$$

where E_{tot} was defined in equation (1) above. The bands to the right of the P-M peak are now computed to the k-scaled tail density

$$\frac{dS}{dk} = \frac{1}{2} \alpha k^{-3},$$

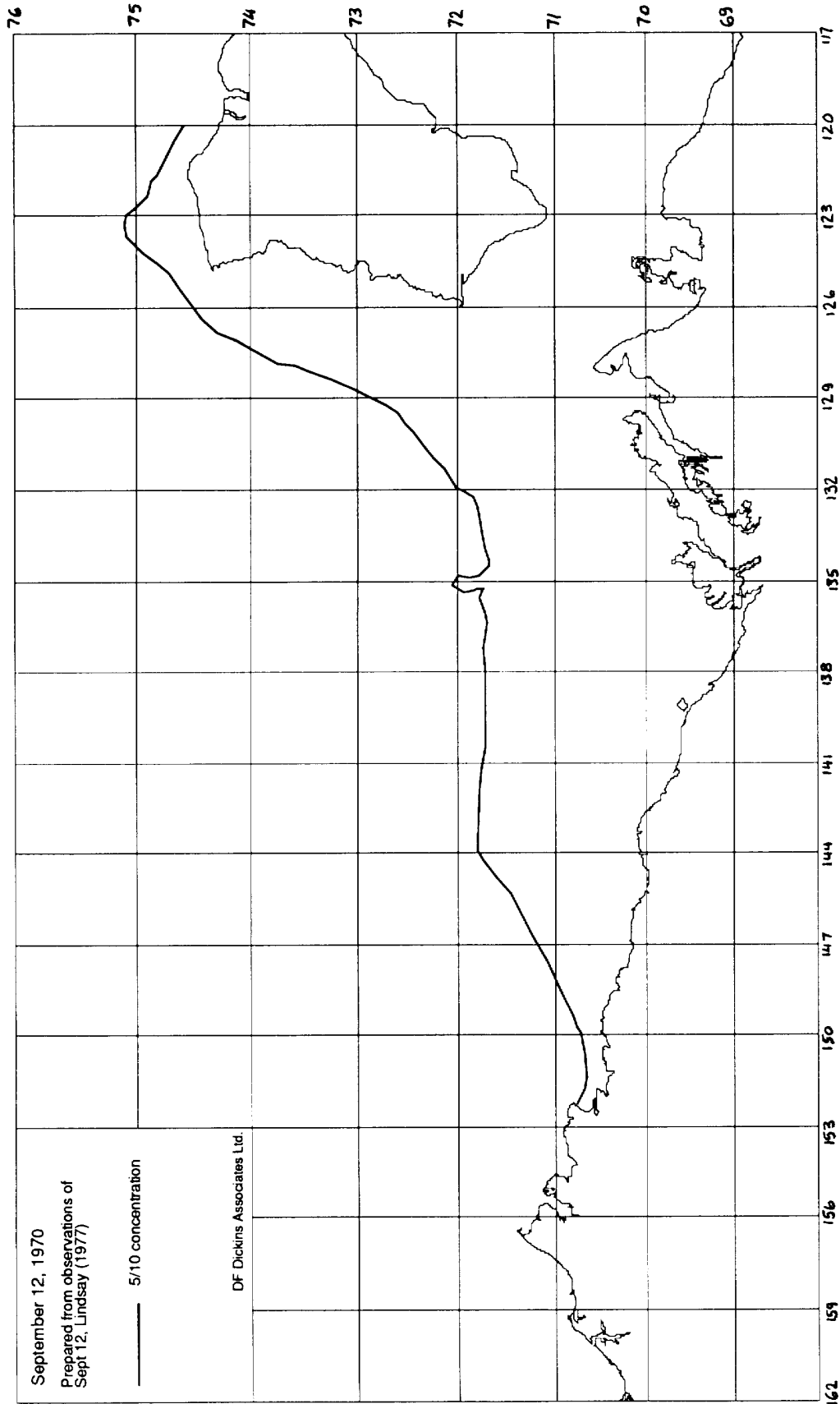
frequency-direction bins (in downwind directions) that exceed the integral of this density, spread into directions according to the SWOP (Cote et al., 1960) distribution, are cut back.

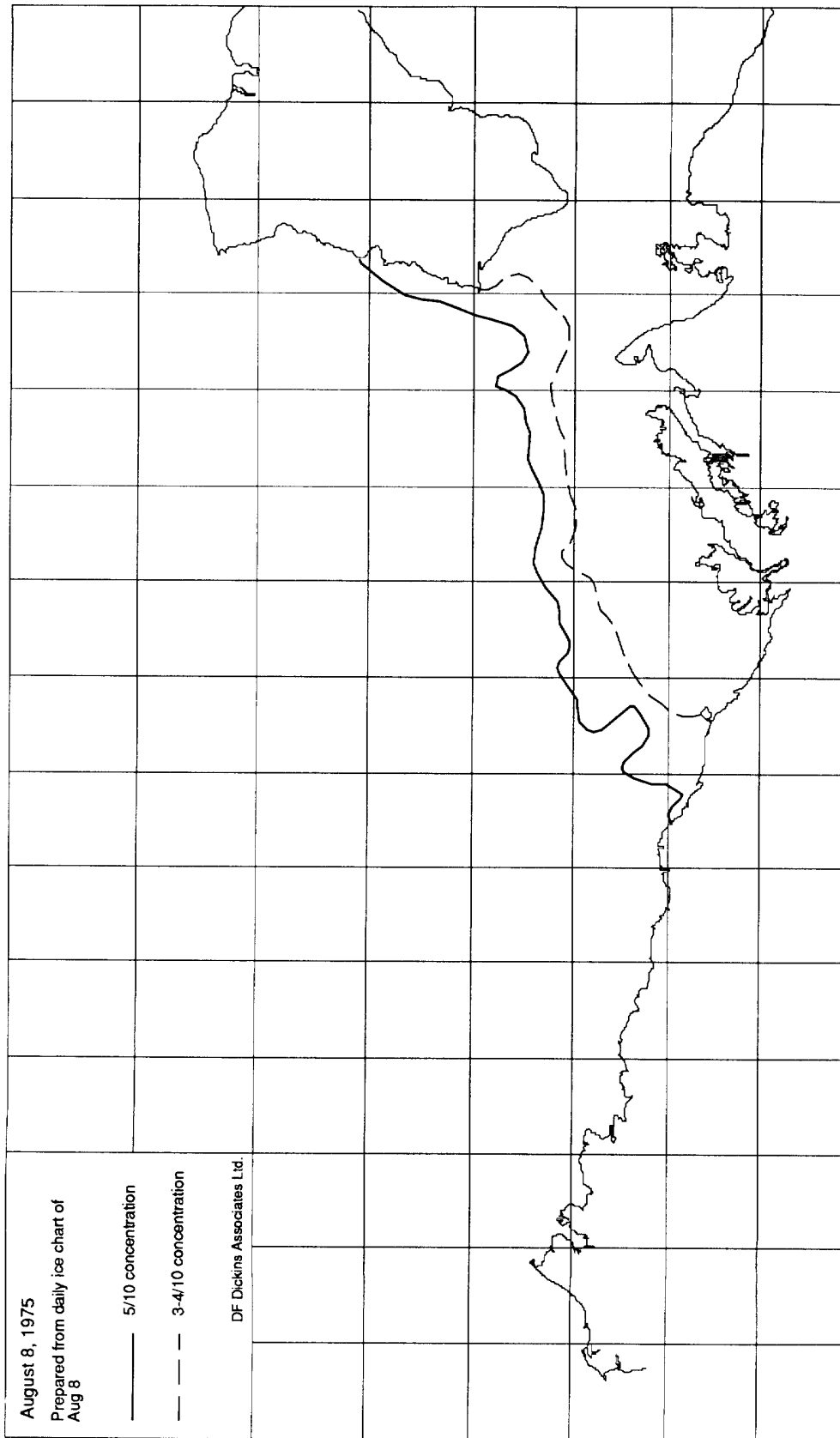
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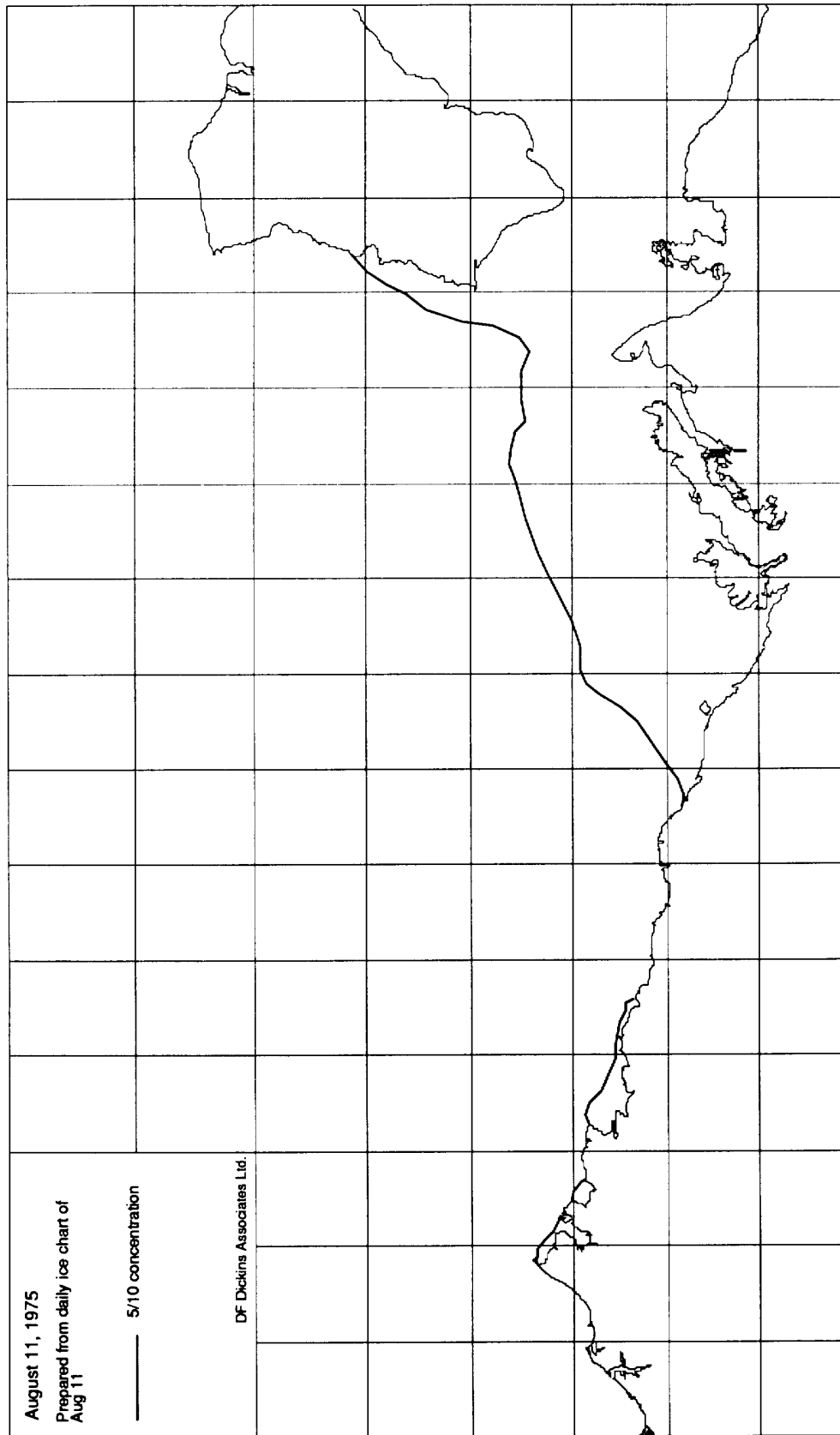
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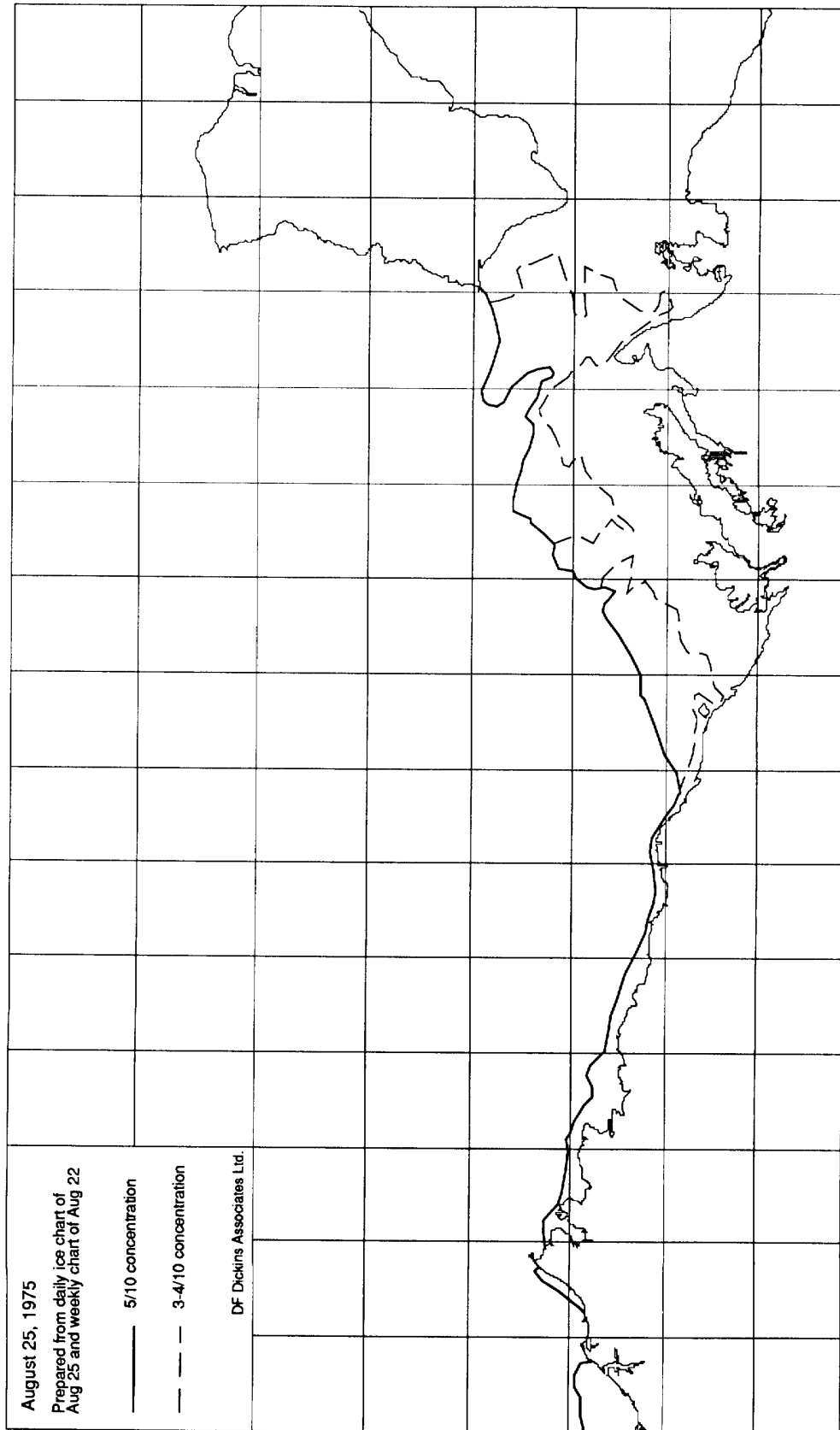
APPENDIX C**ICE CHARTS**

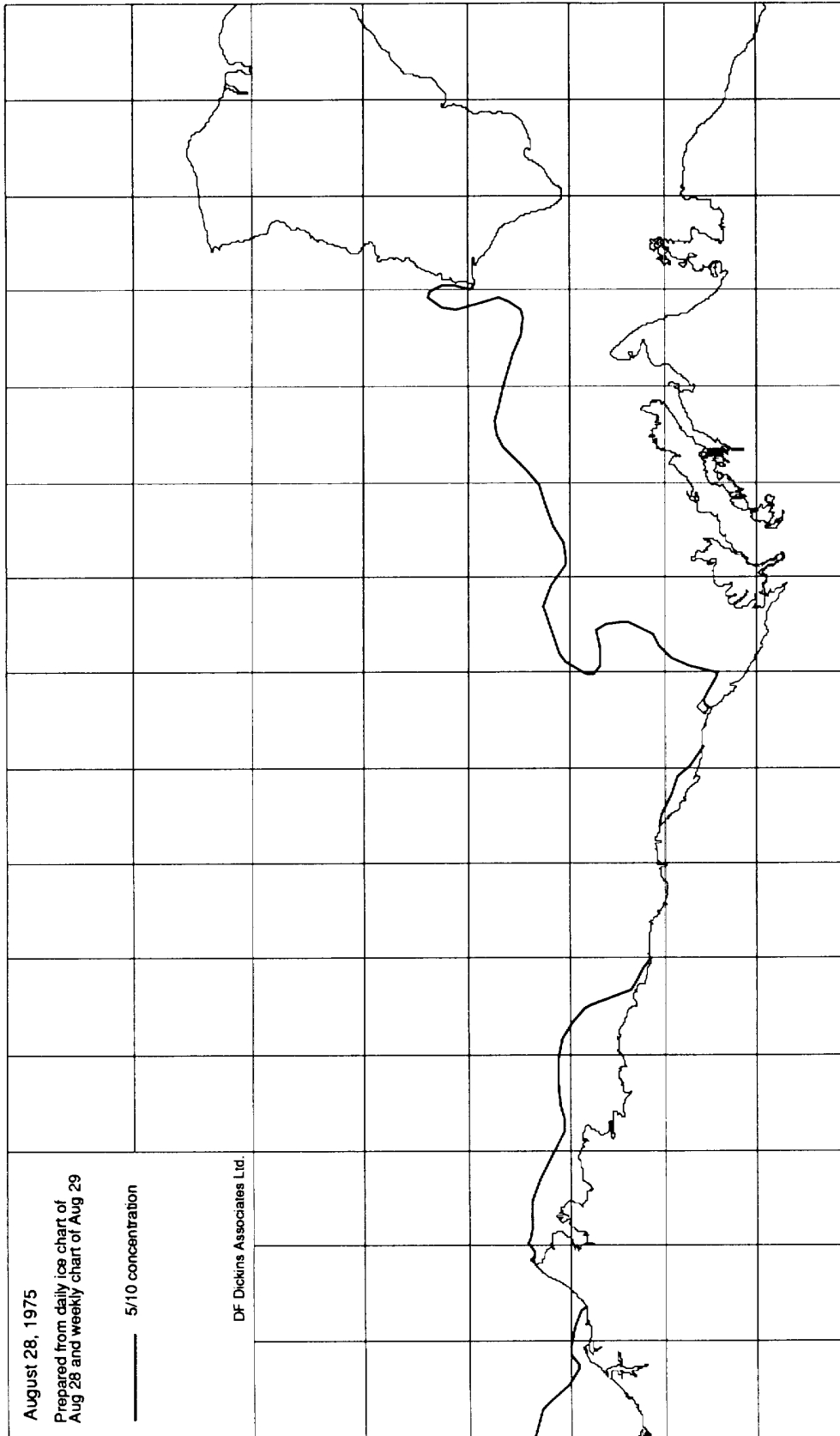
- **Top 30 Hindcast Storms**
- **Climatology Charts**

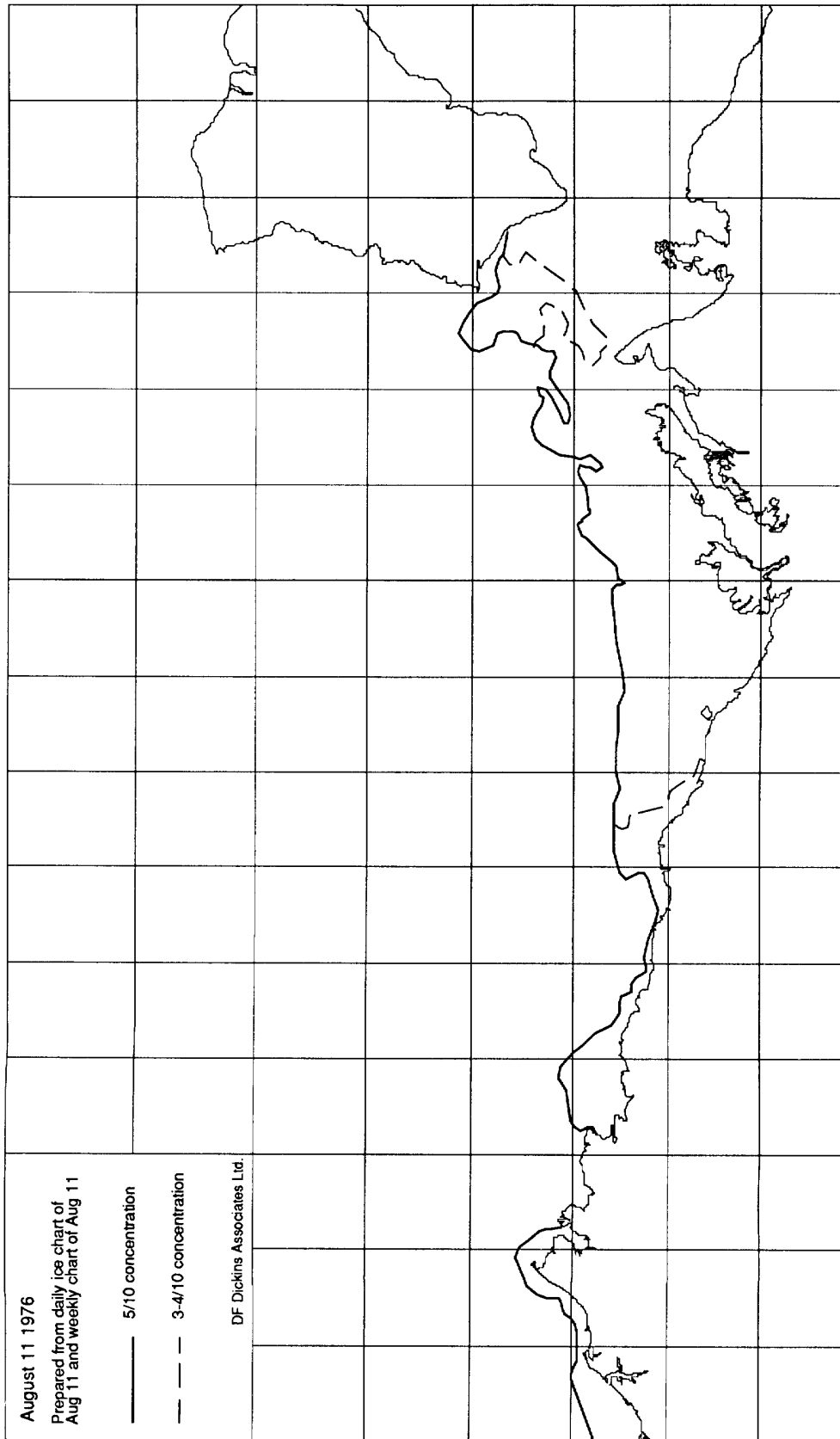


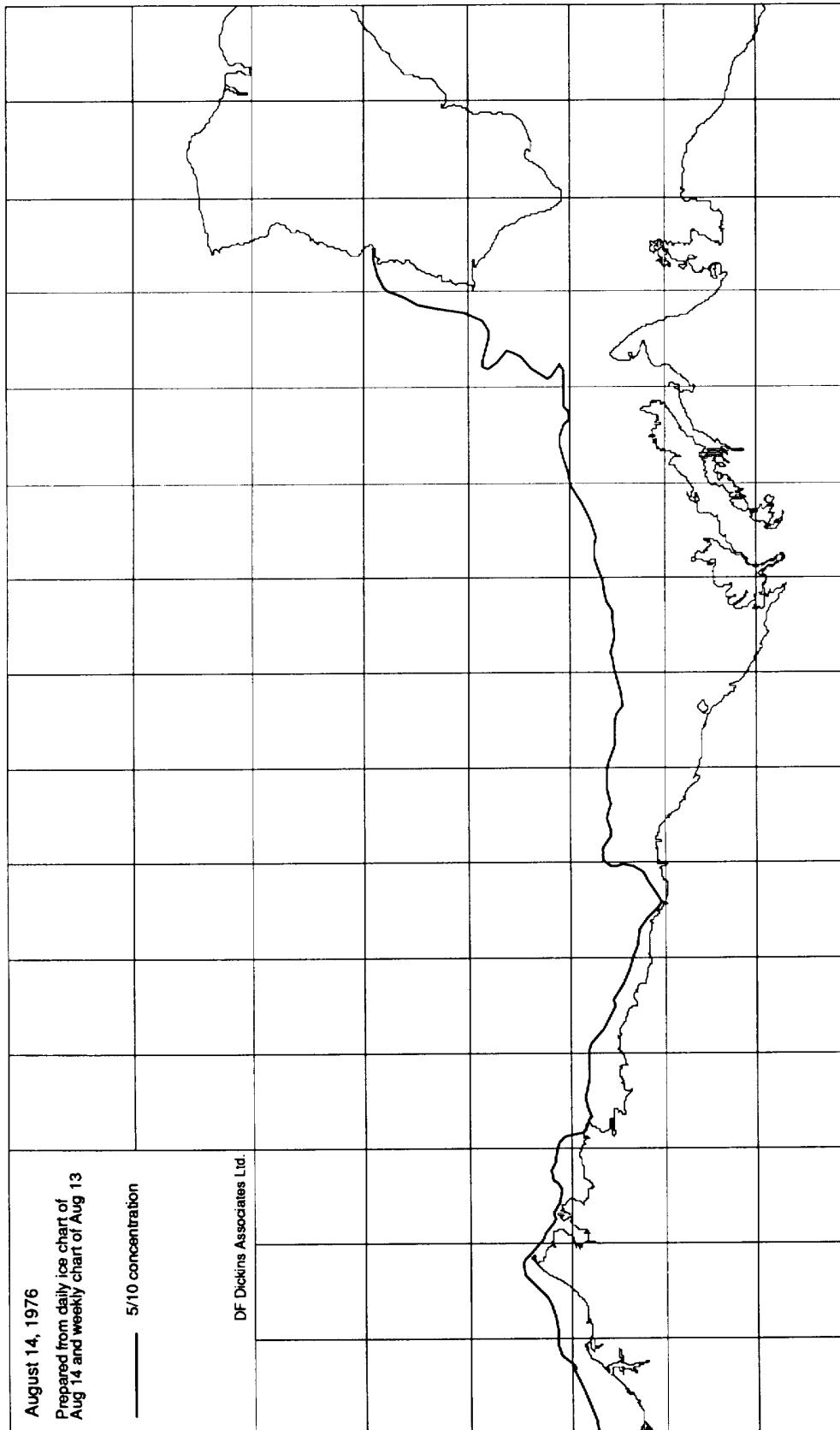


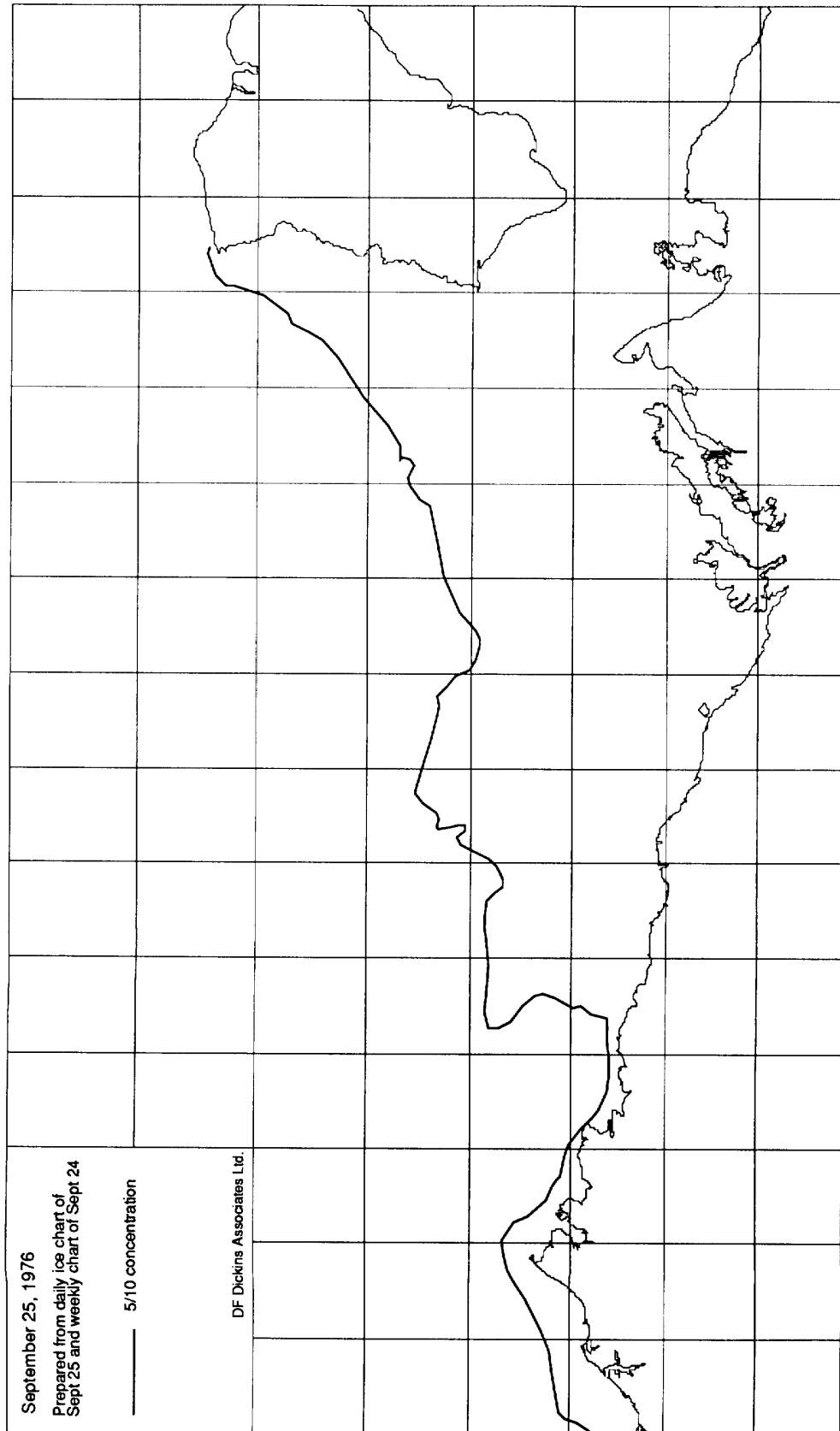


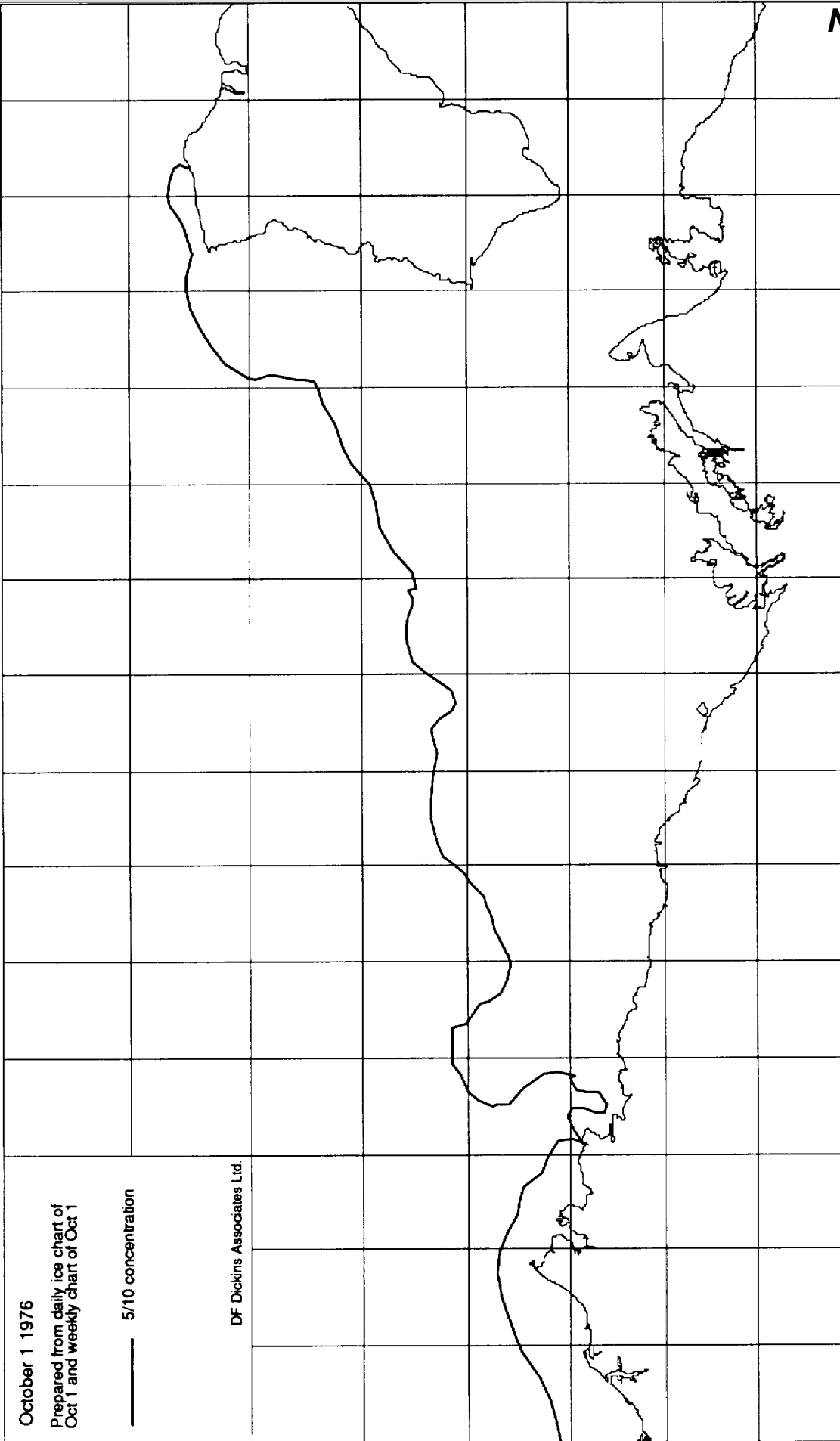


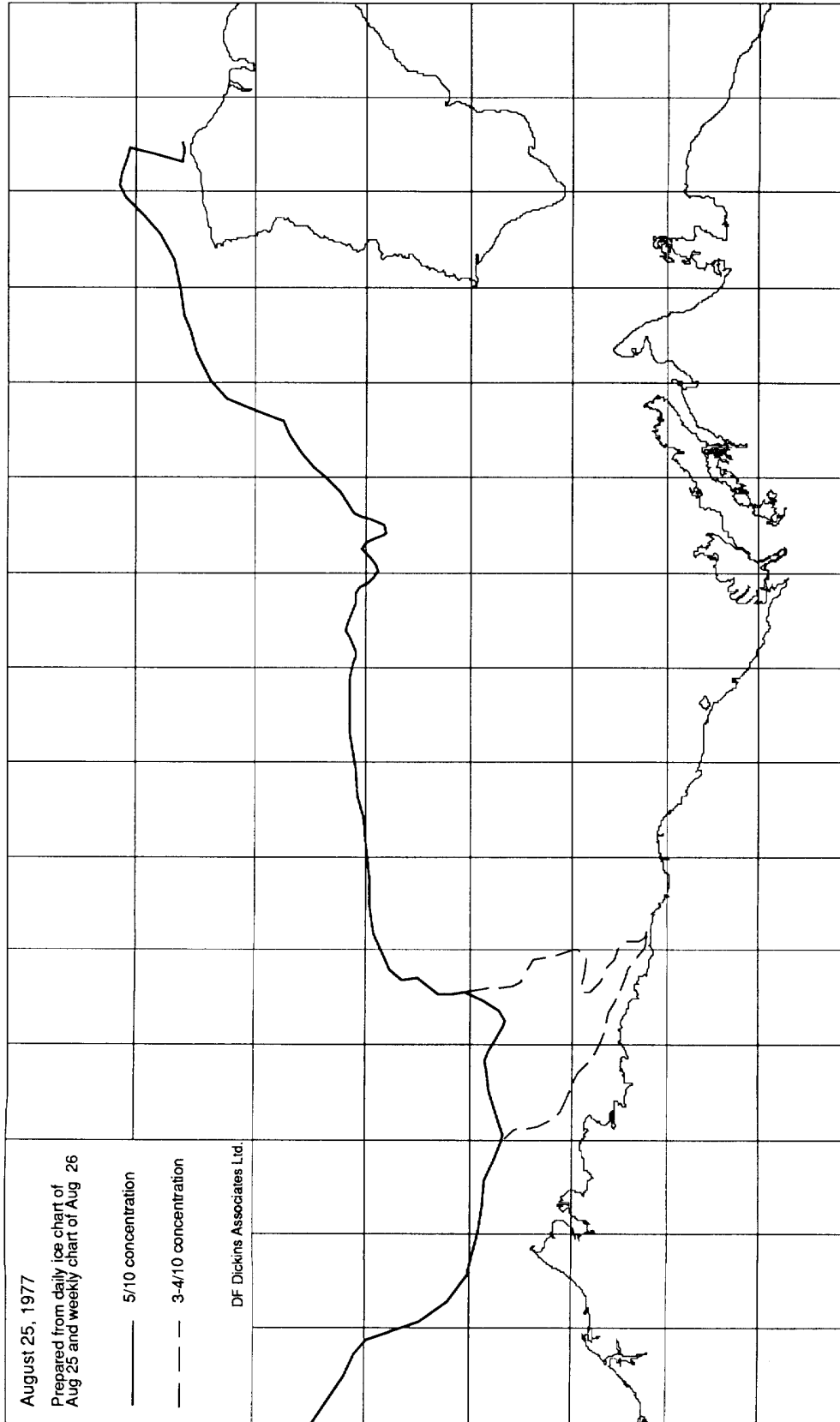


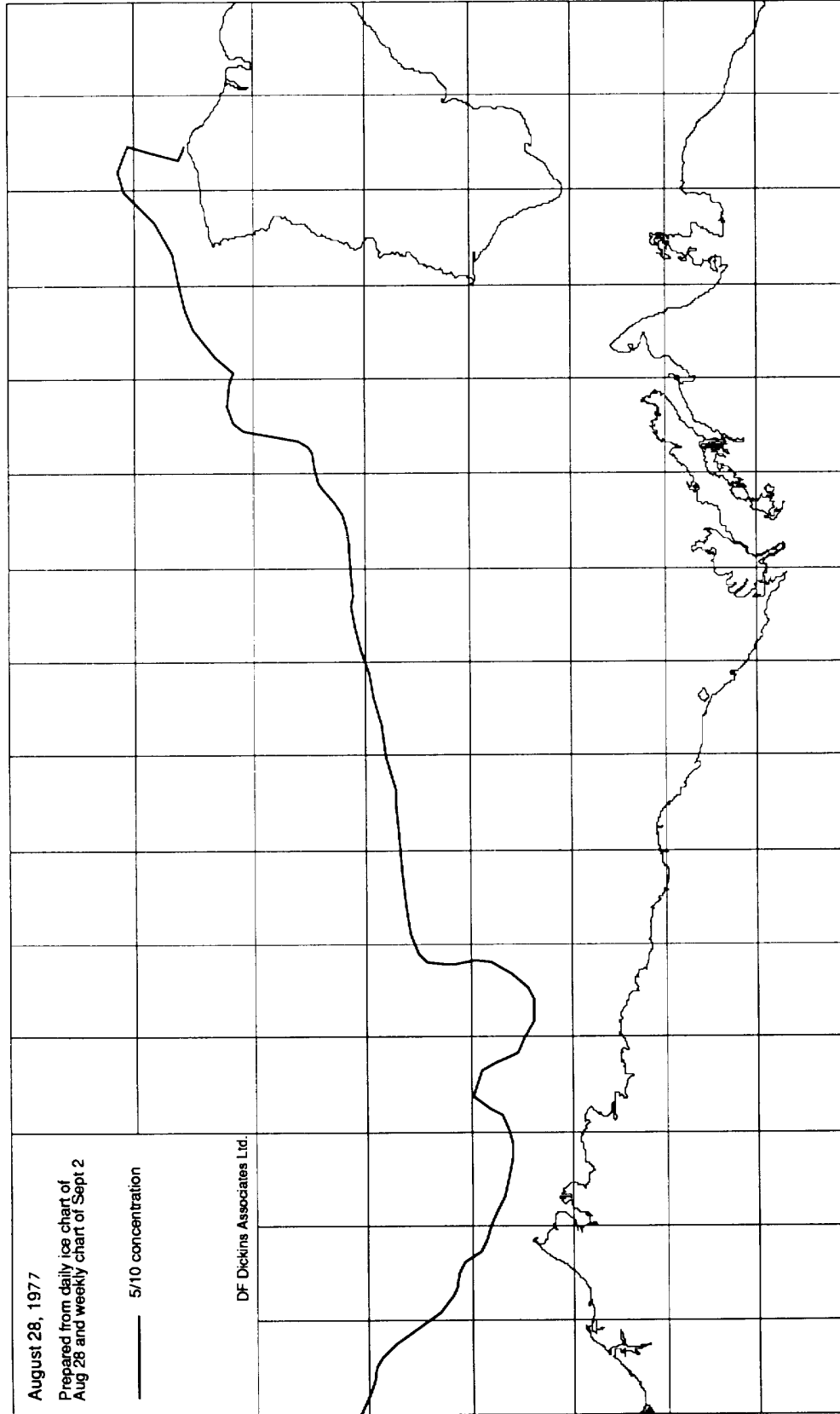


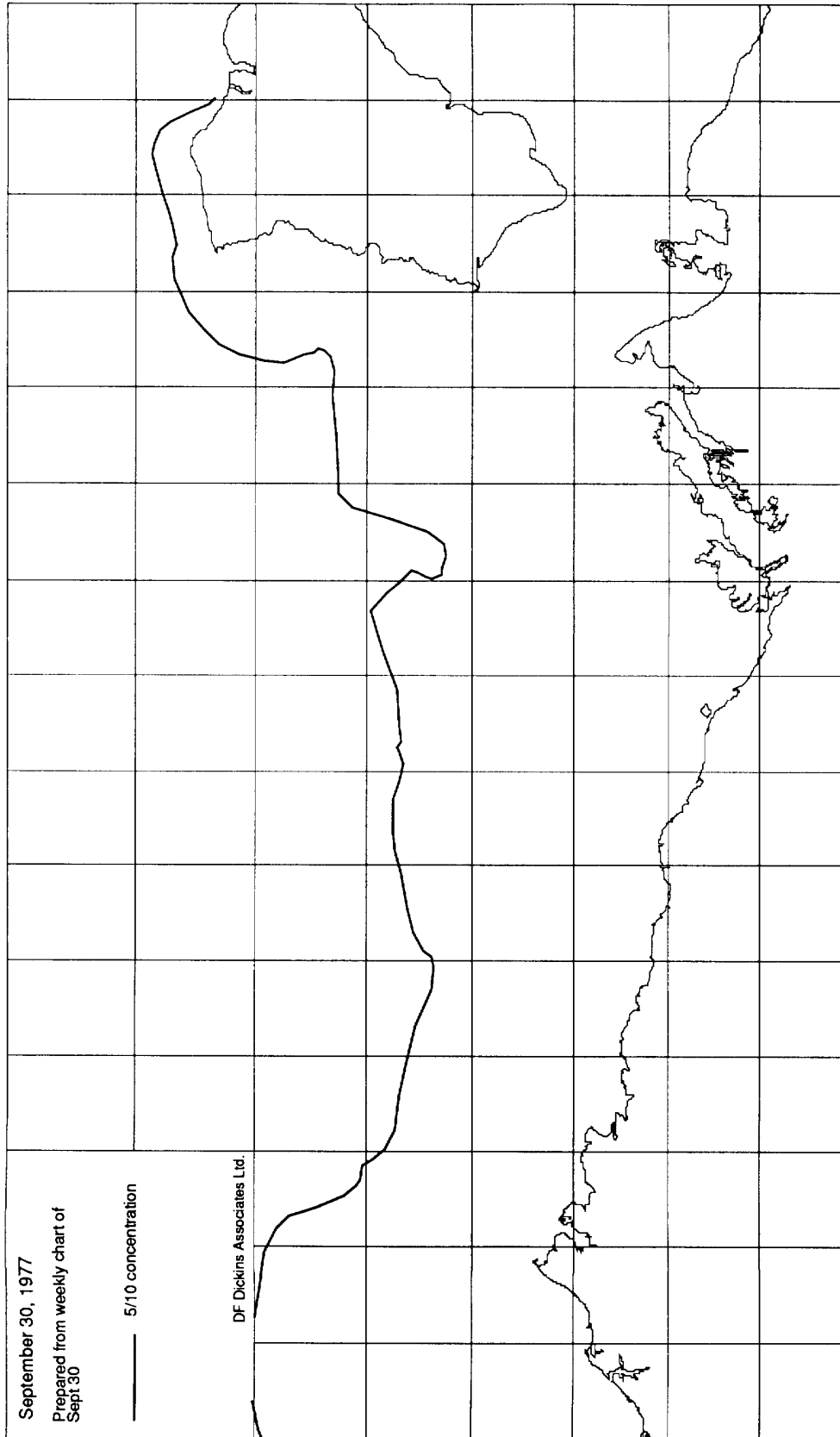


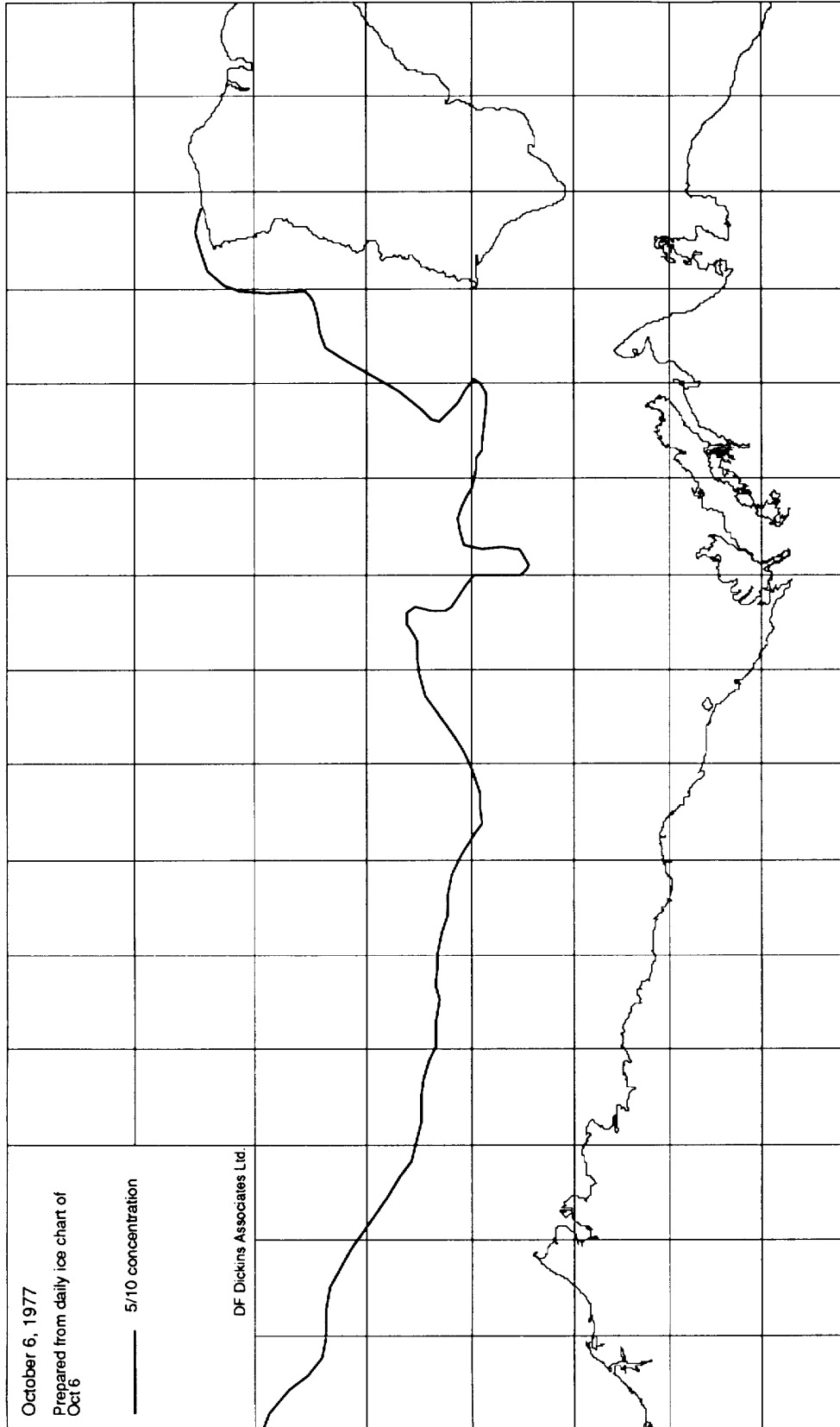


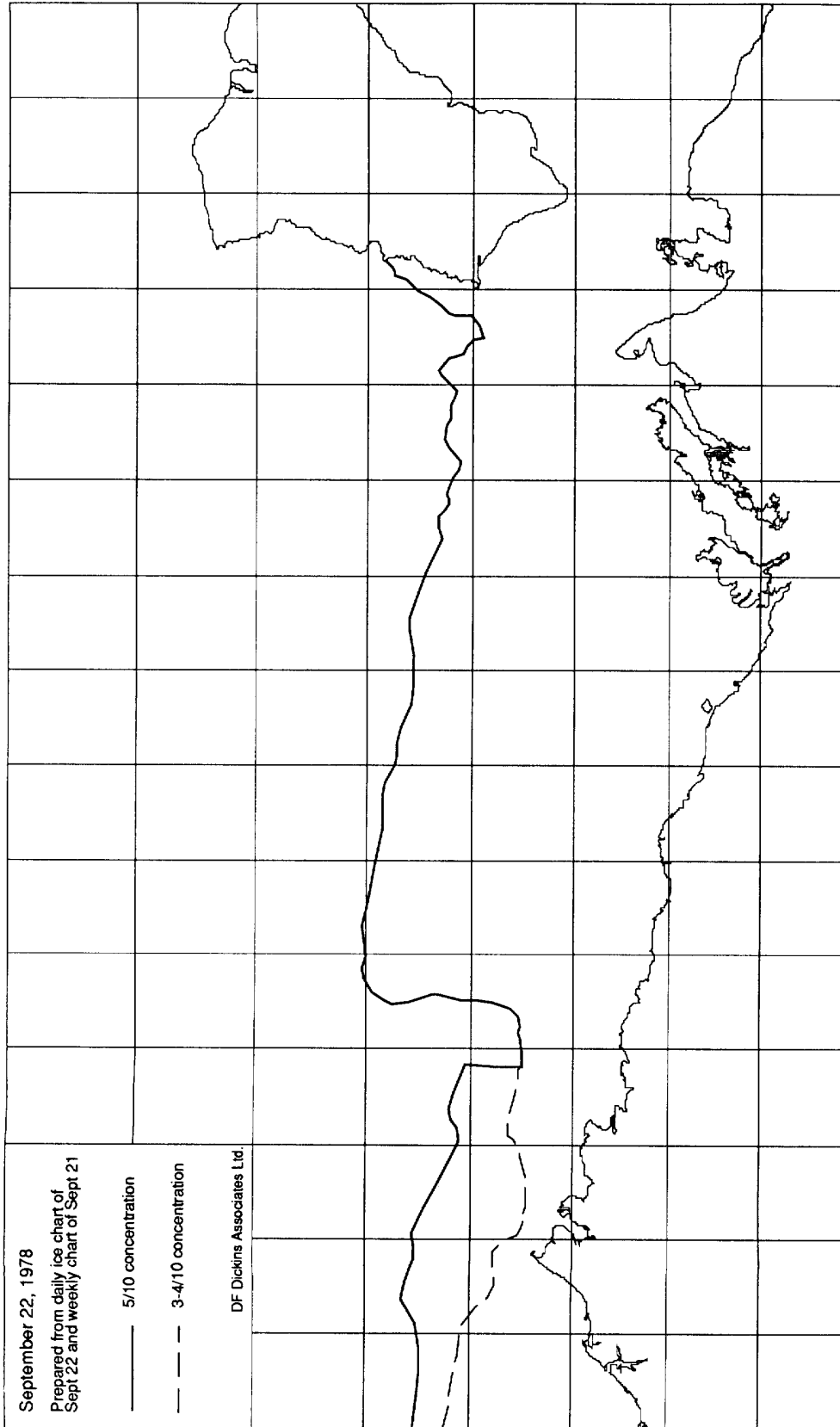


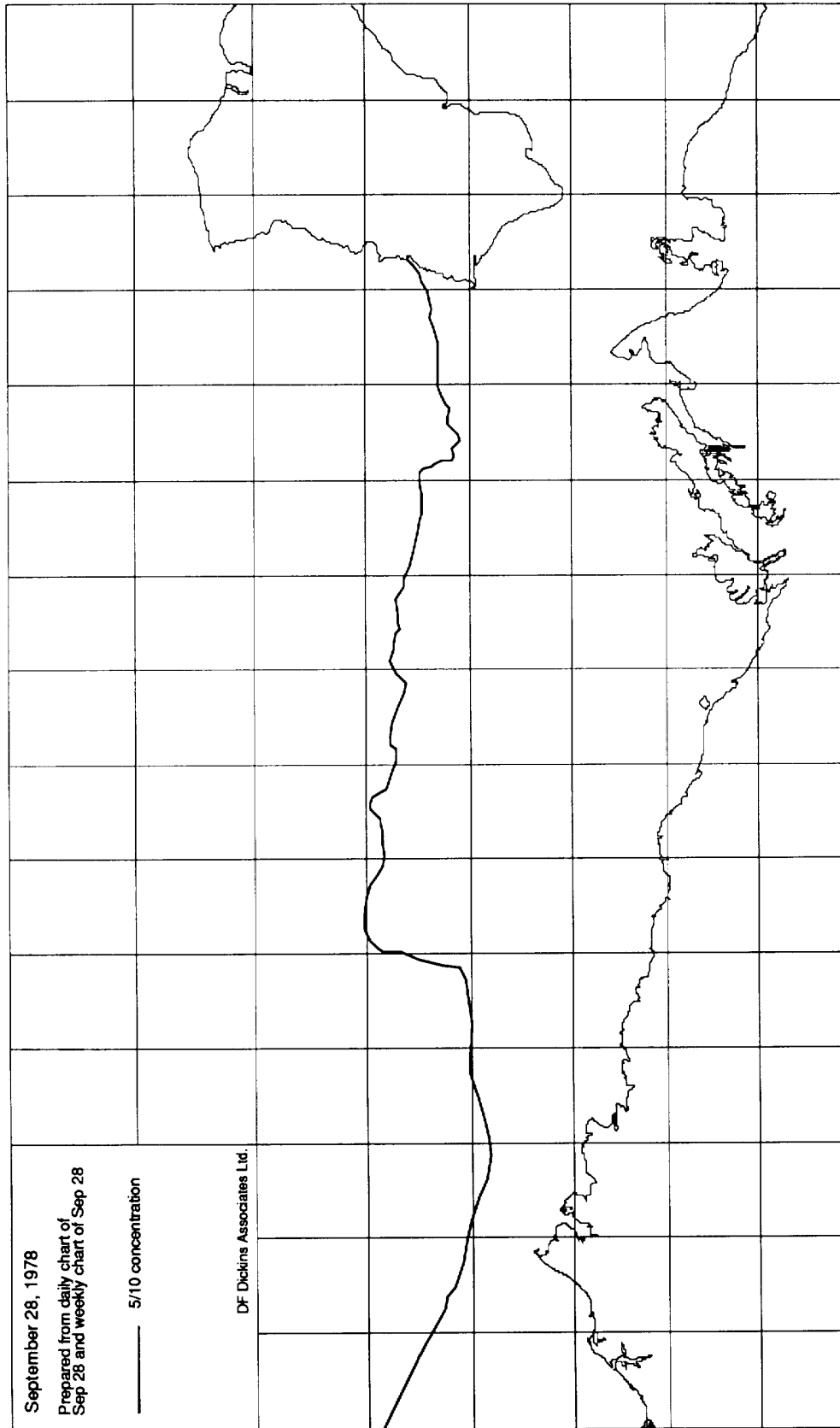


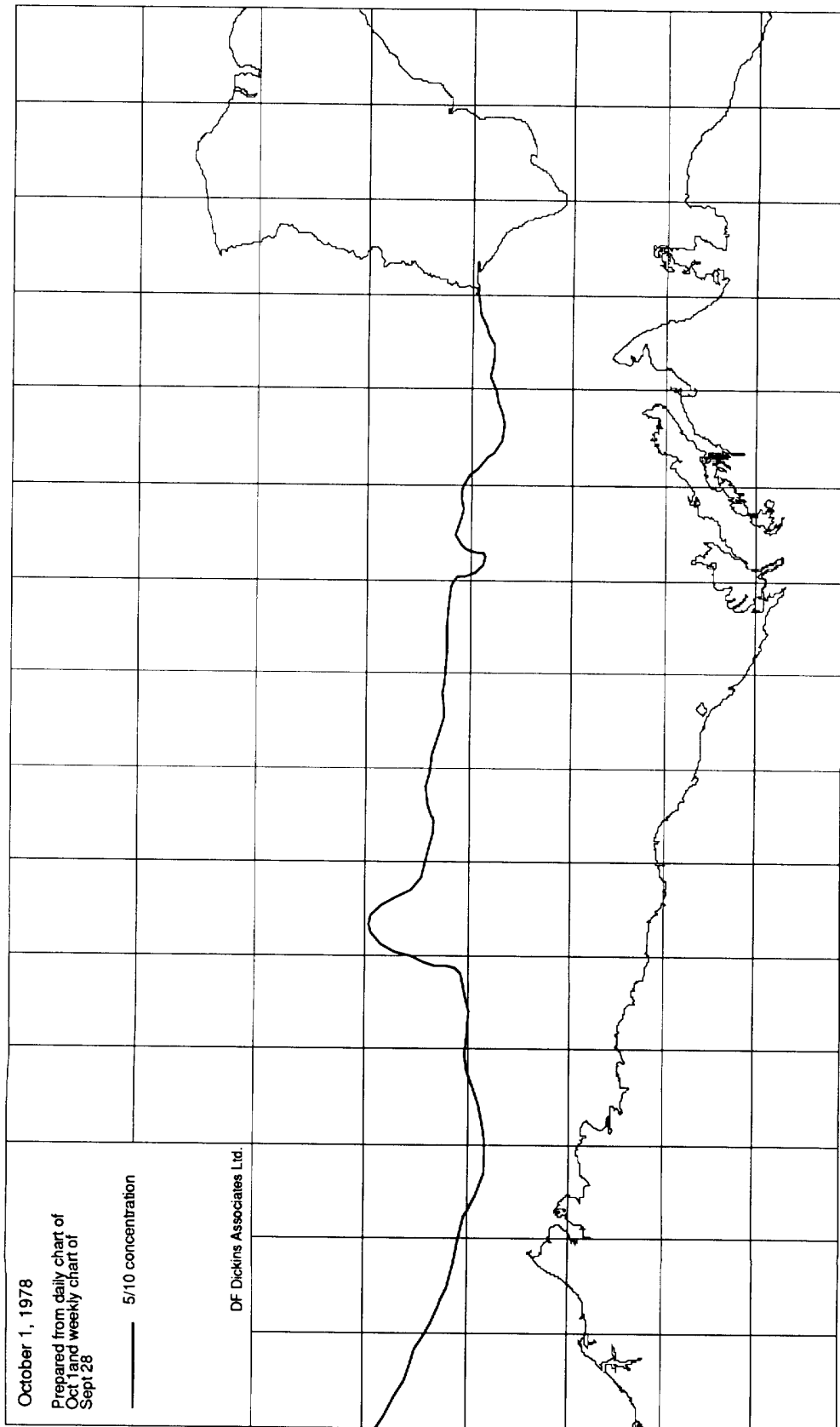


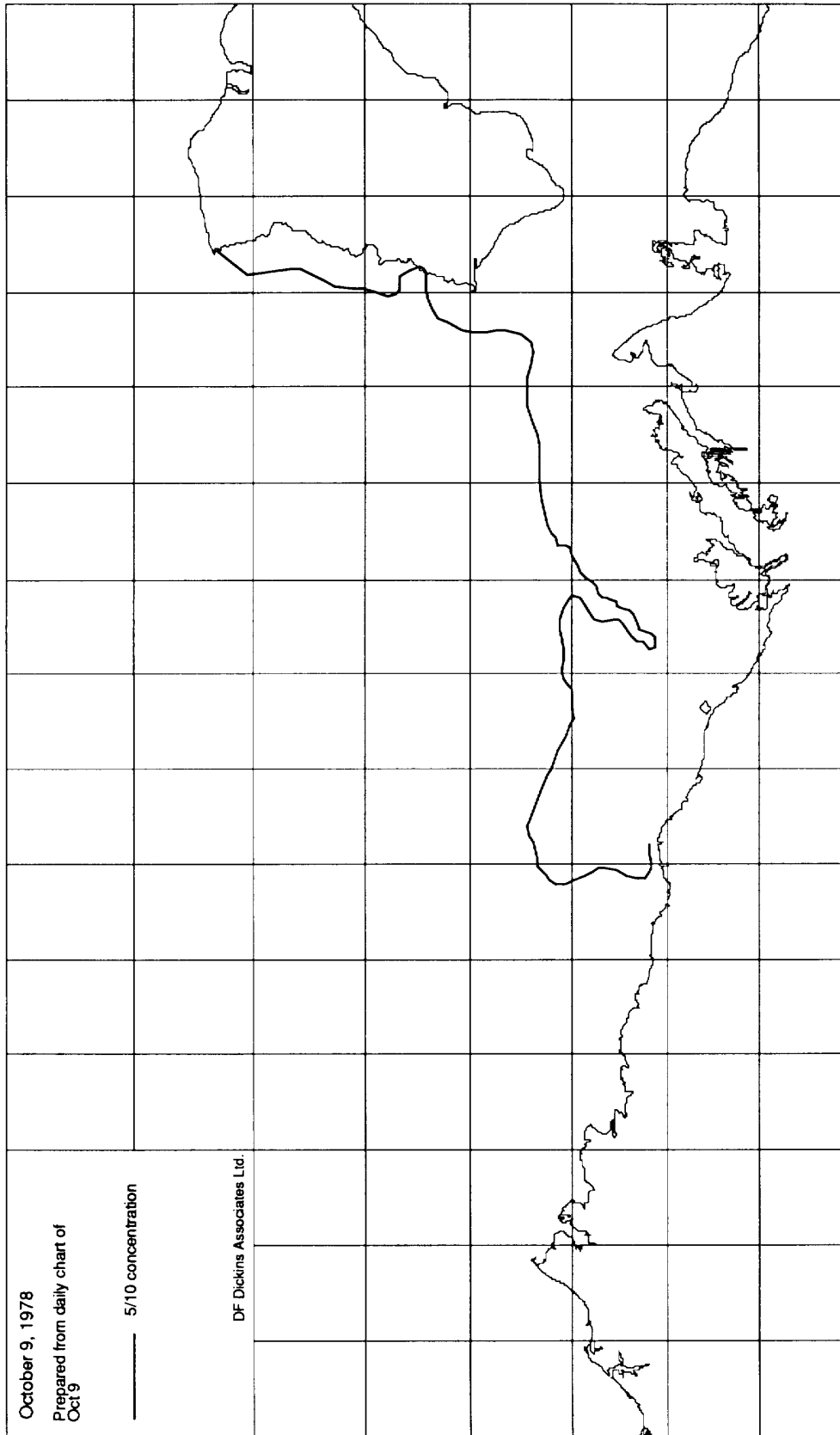




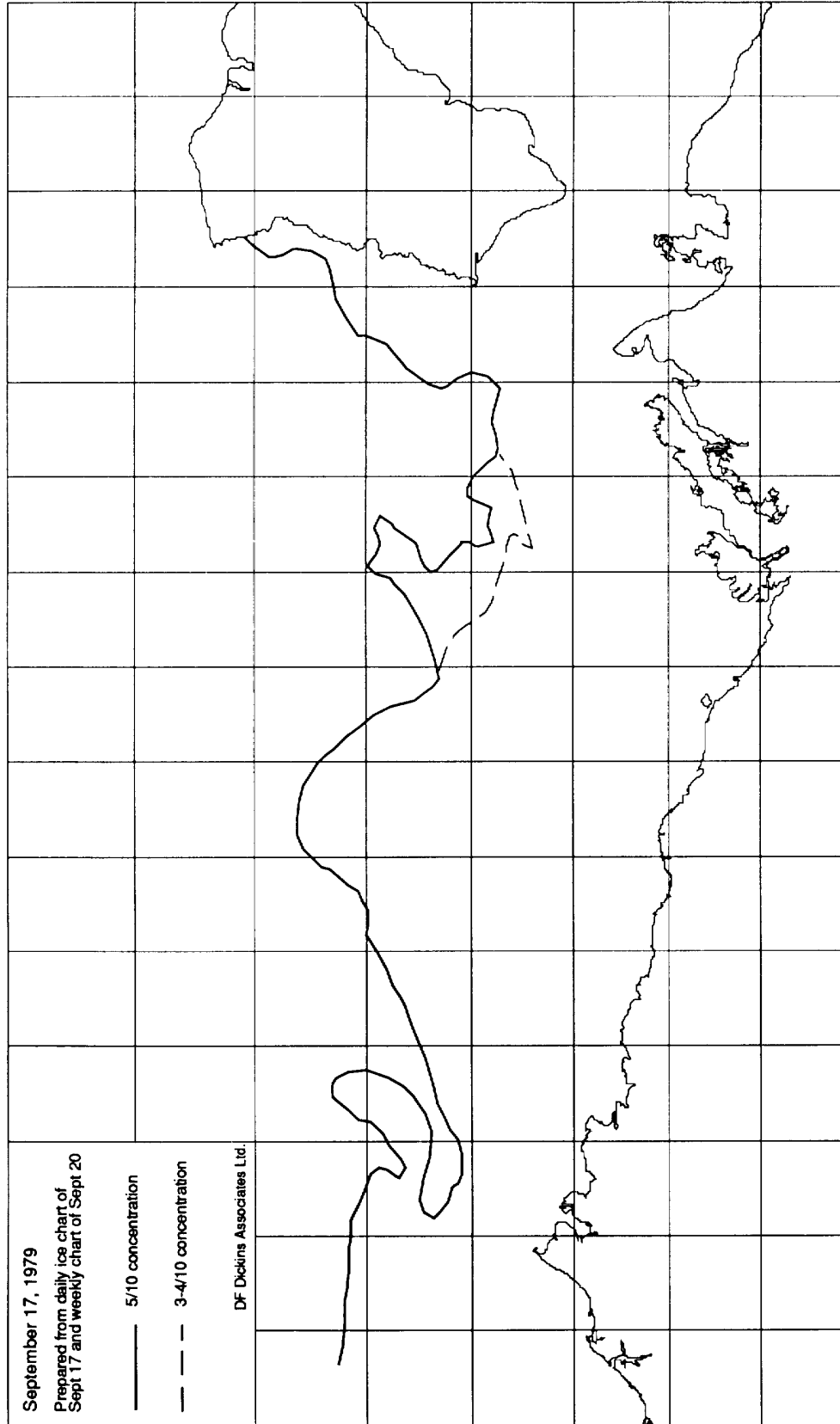


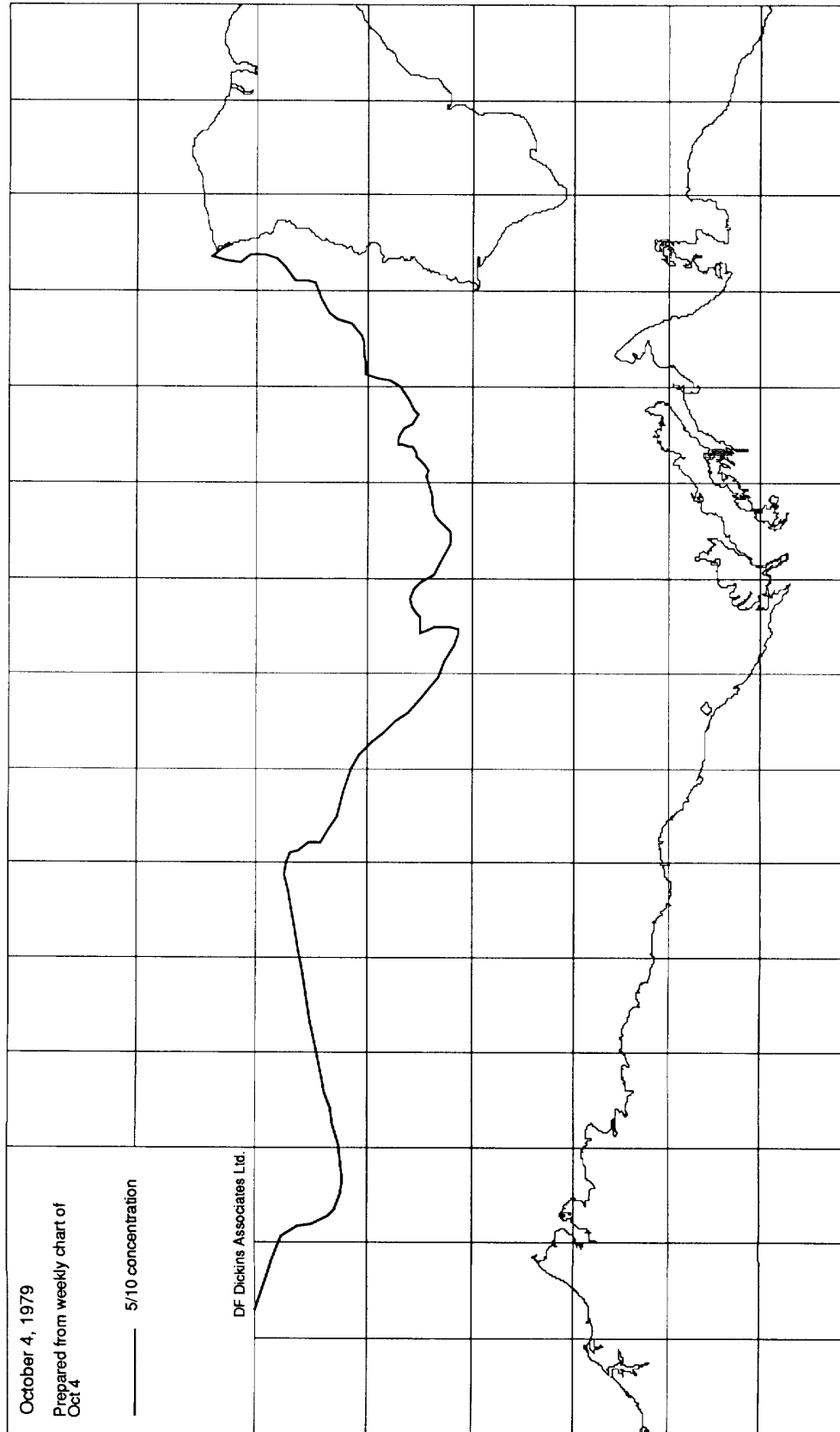


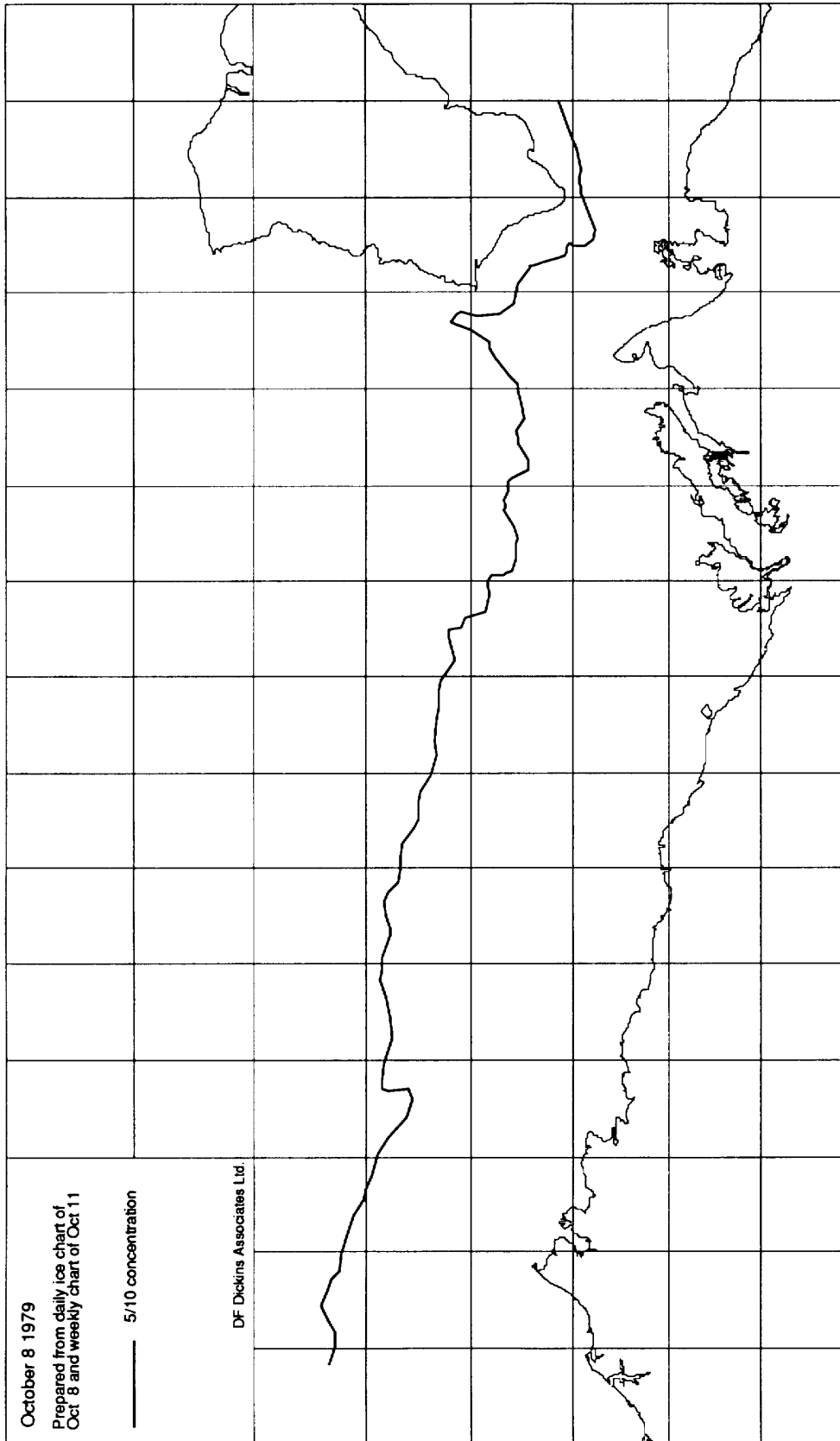


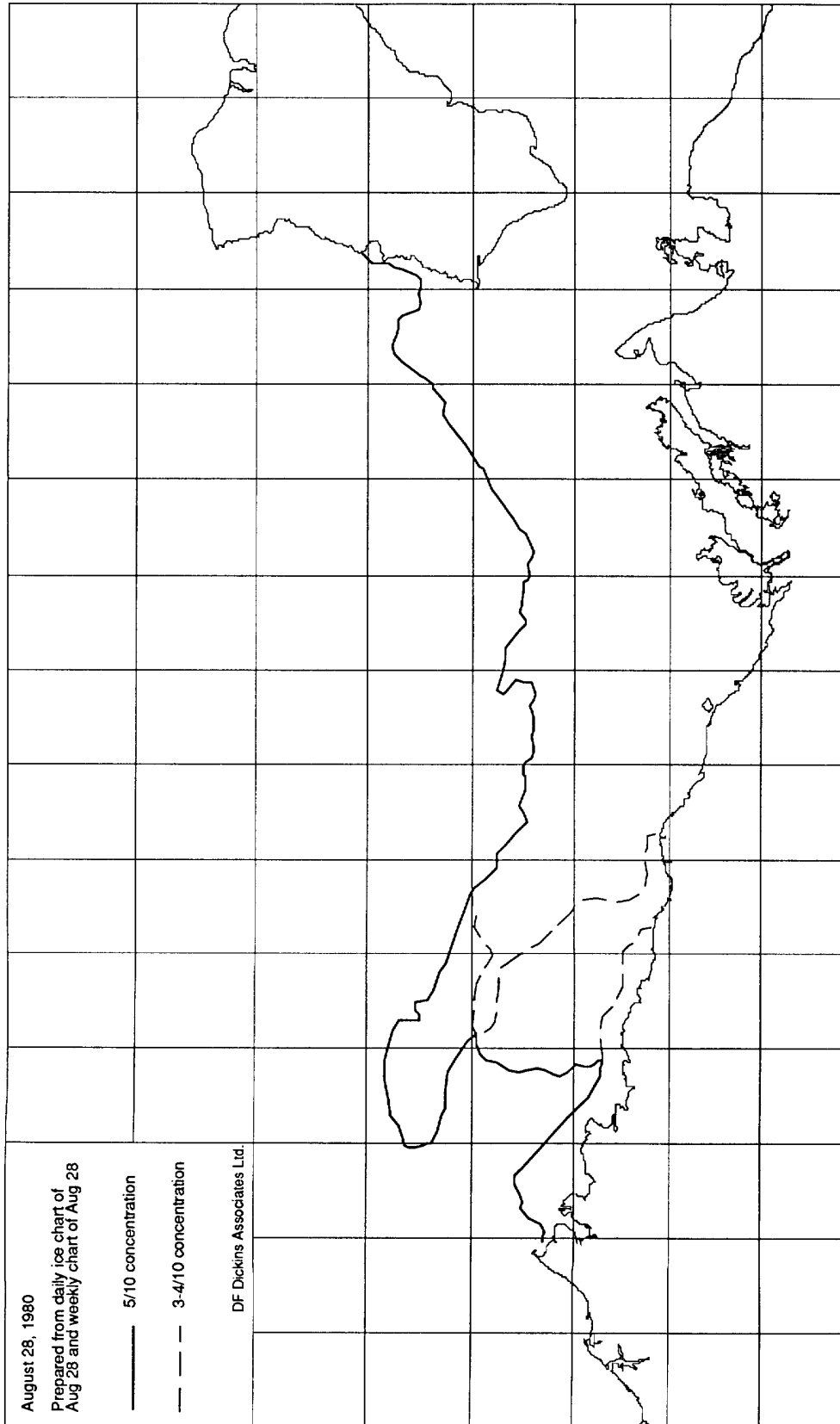


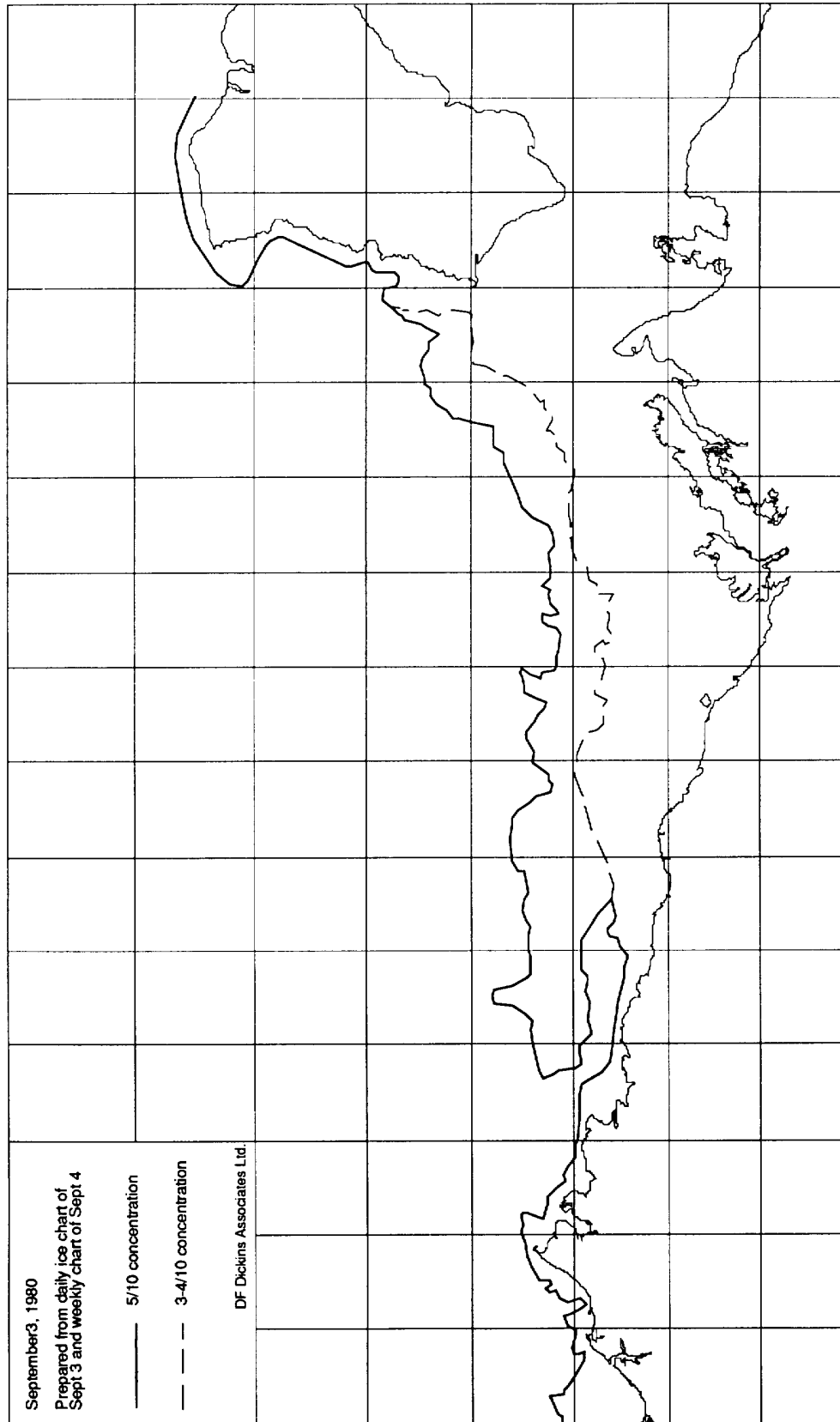


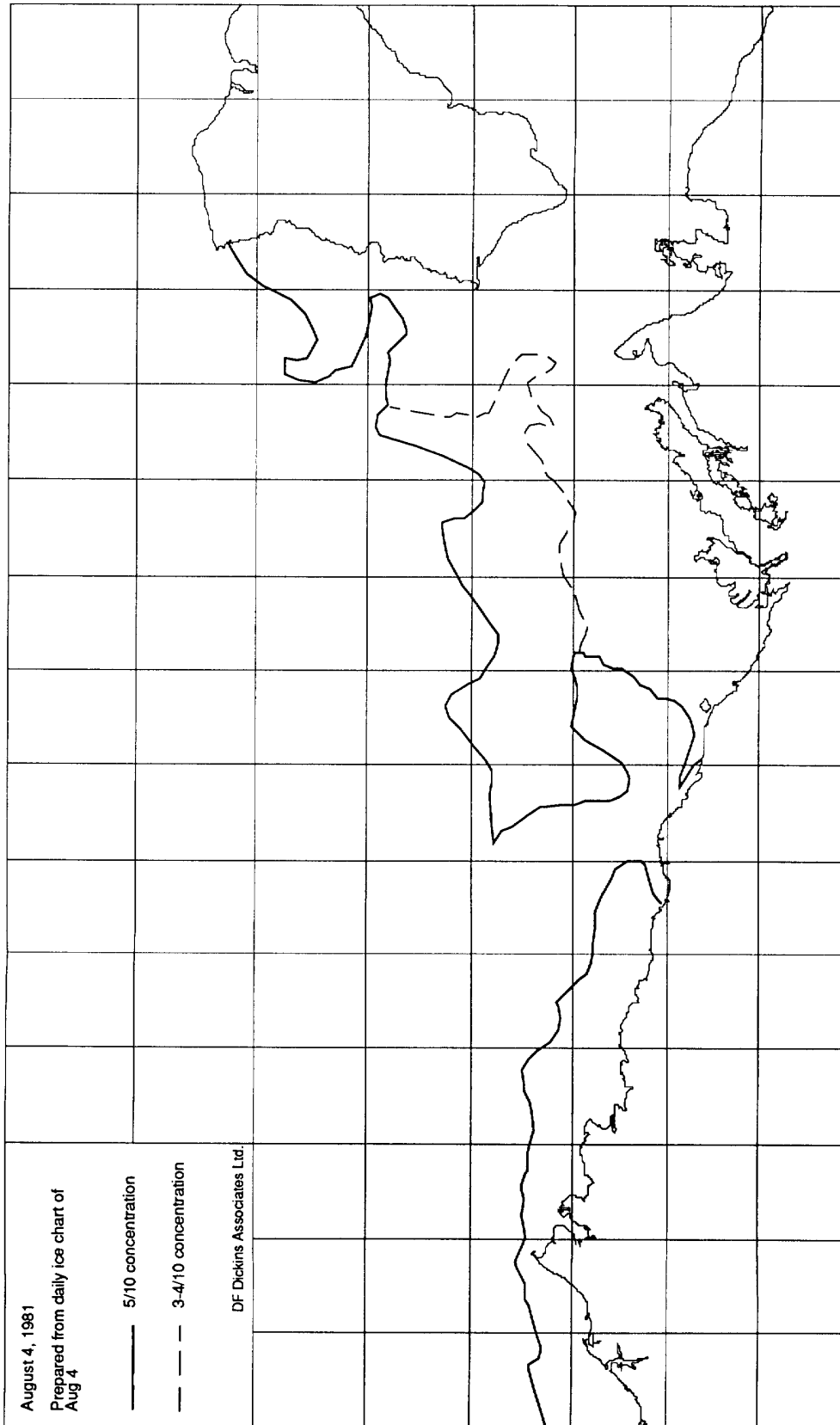


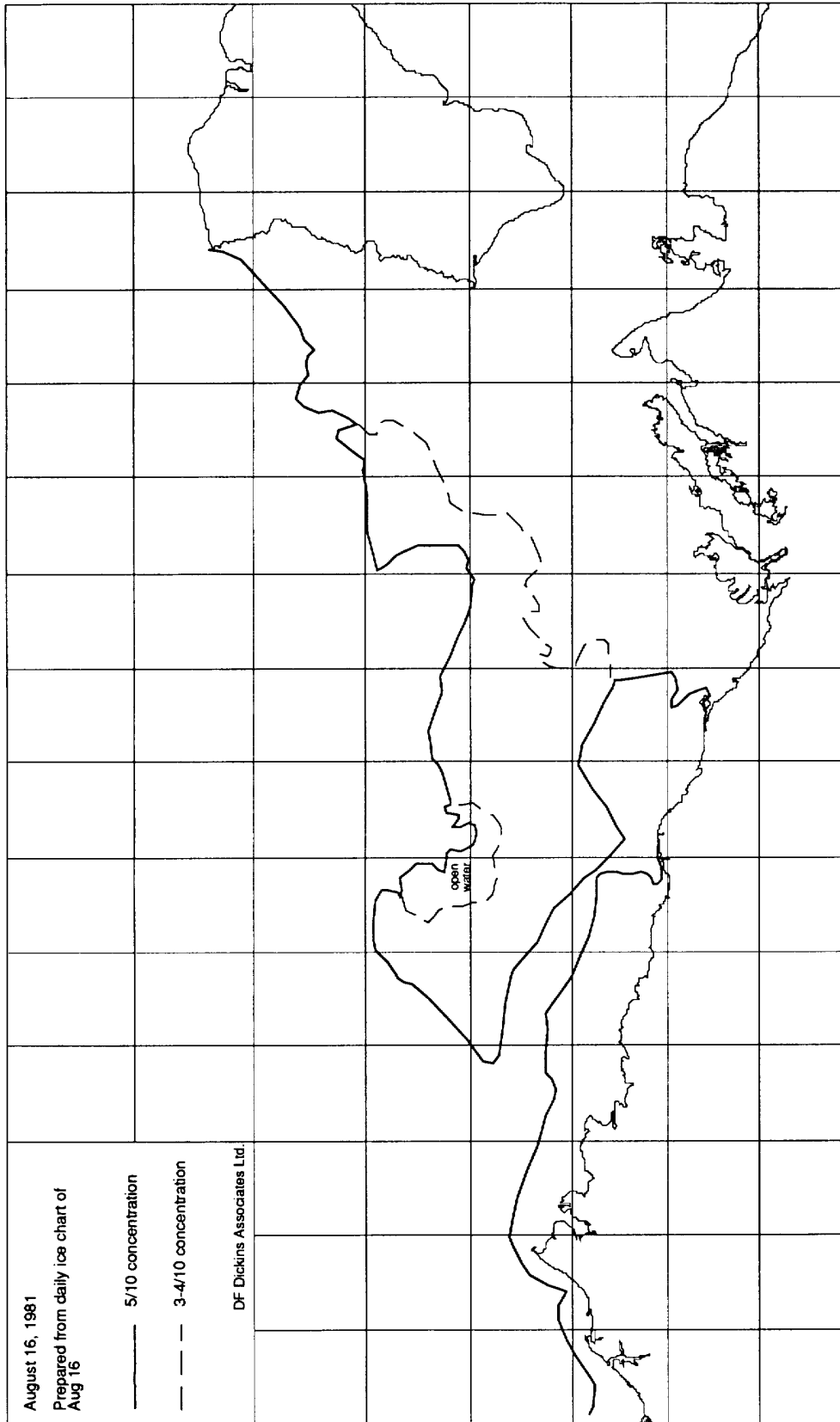


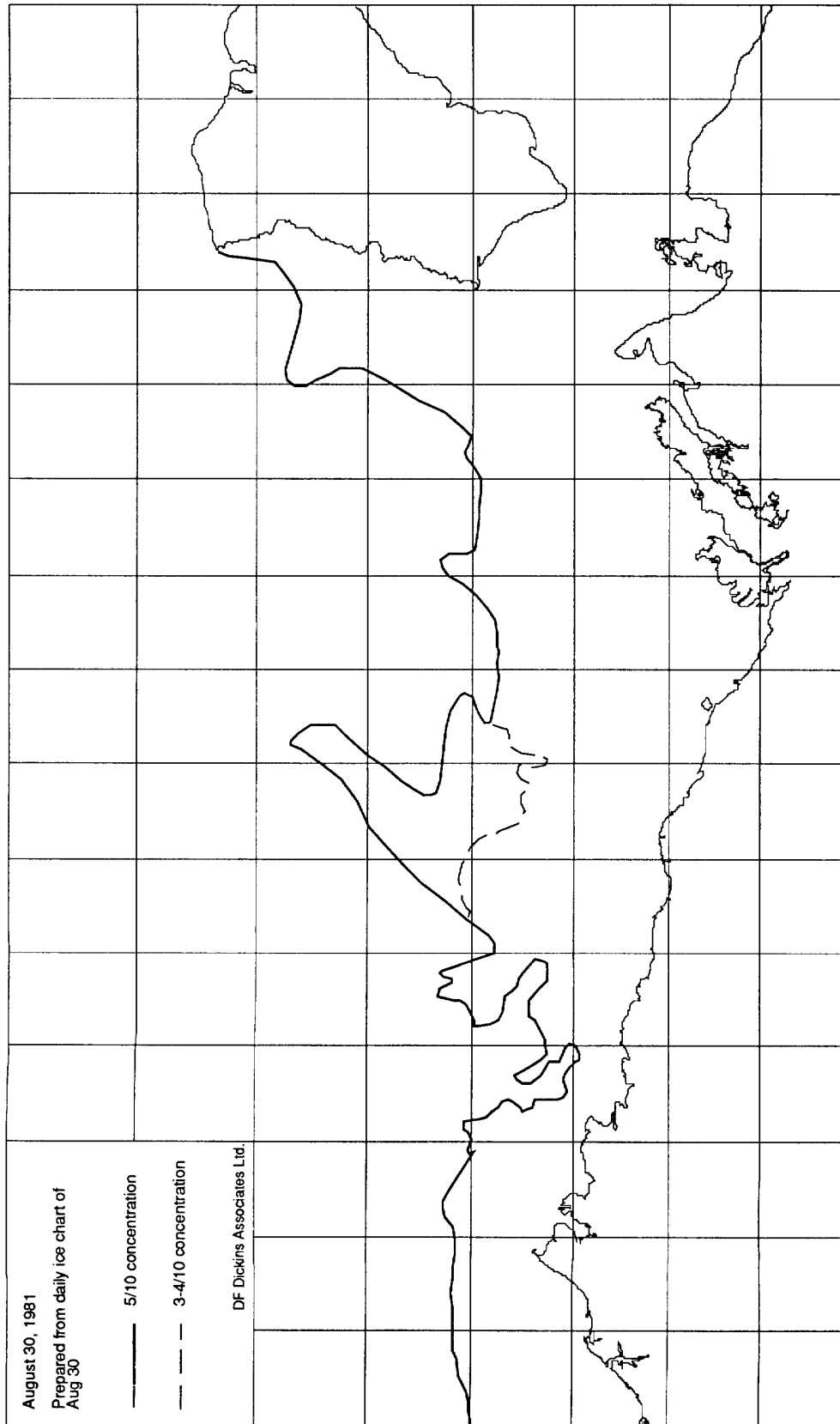


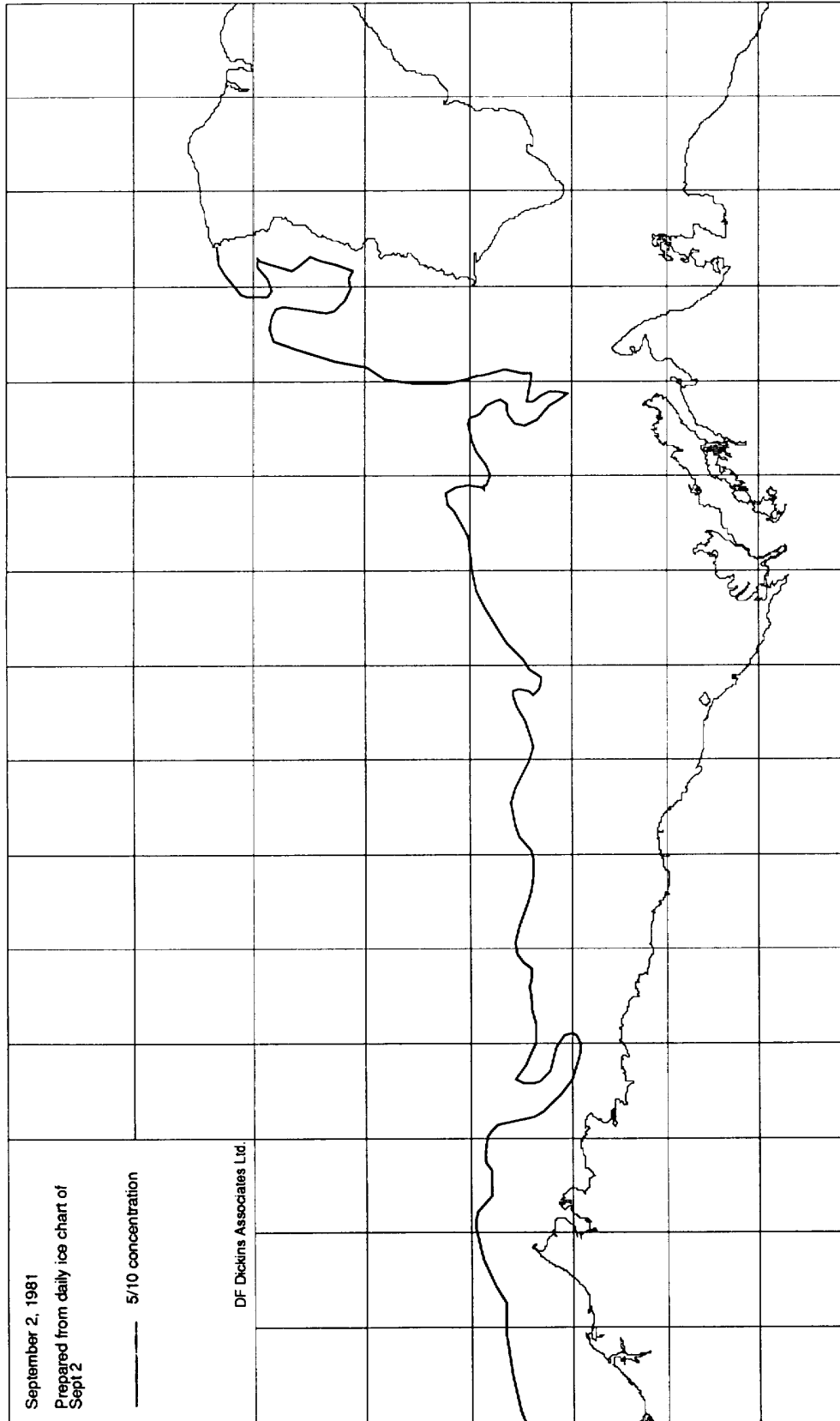


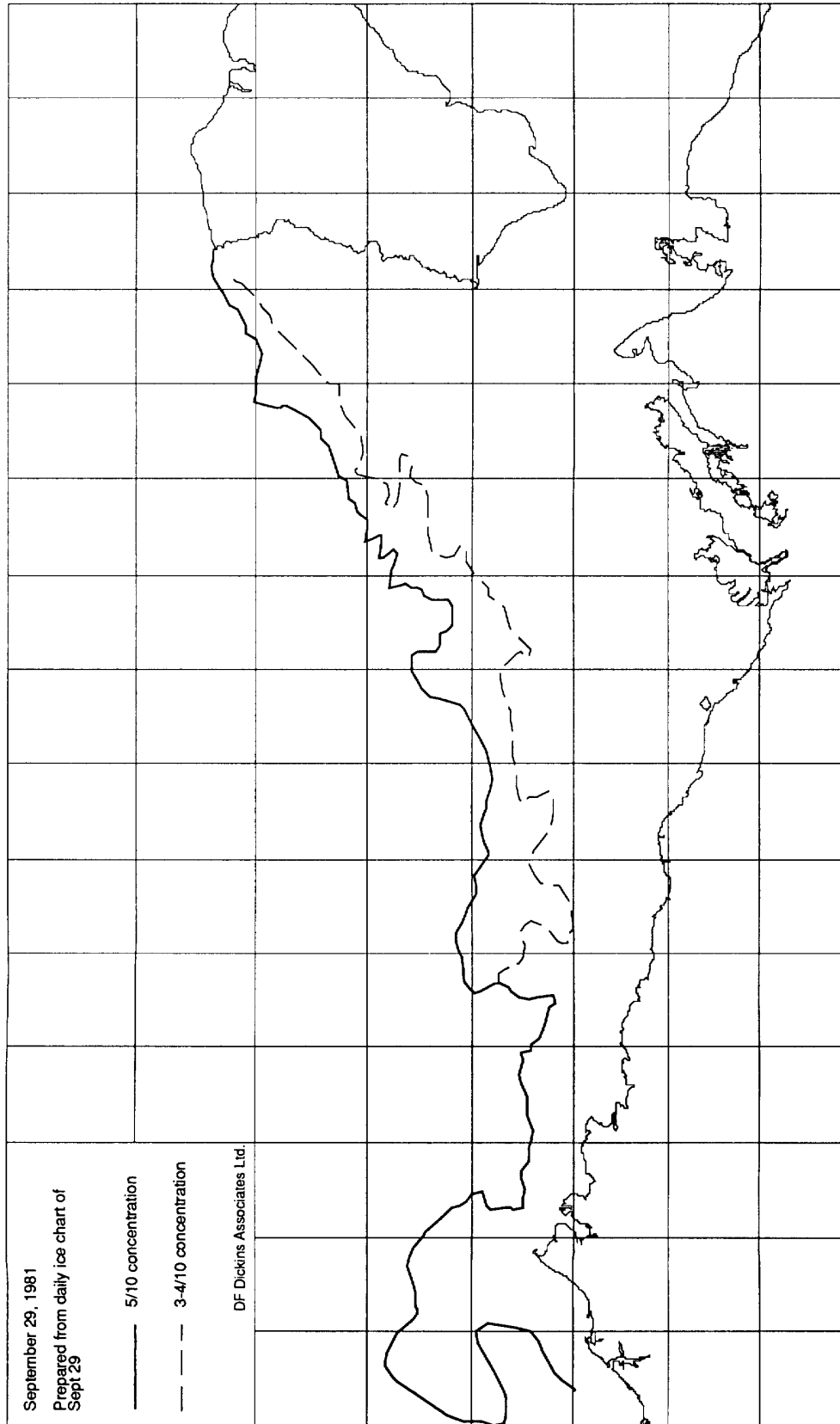


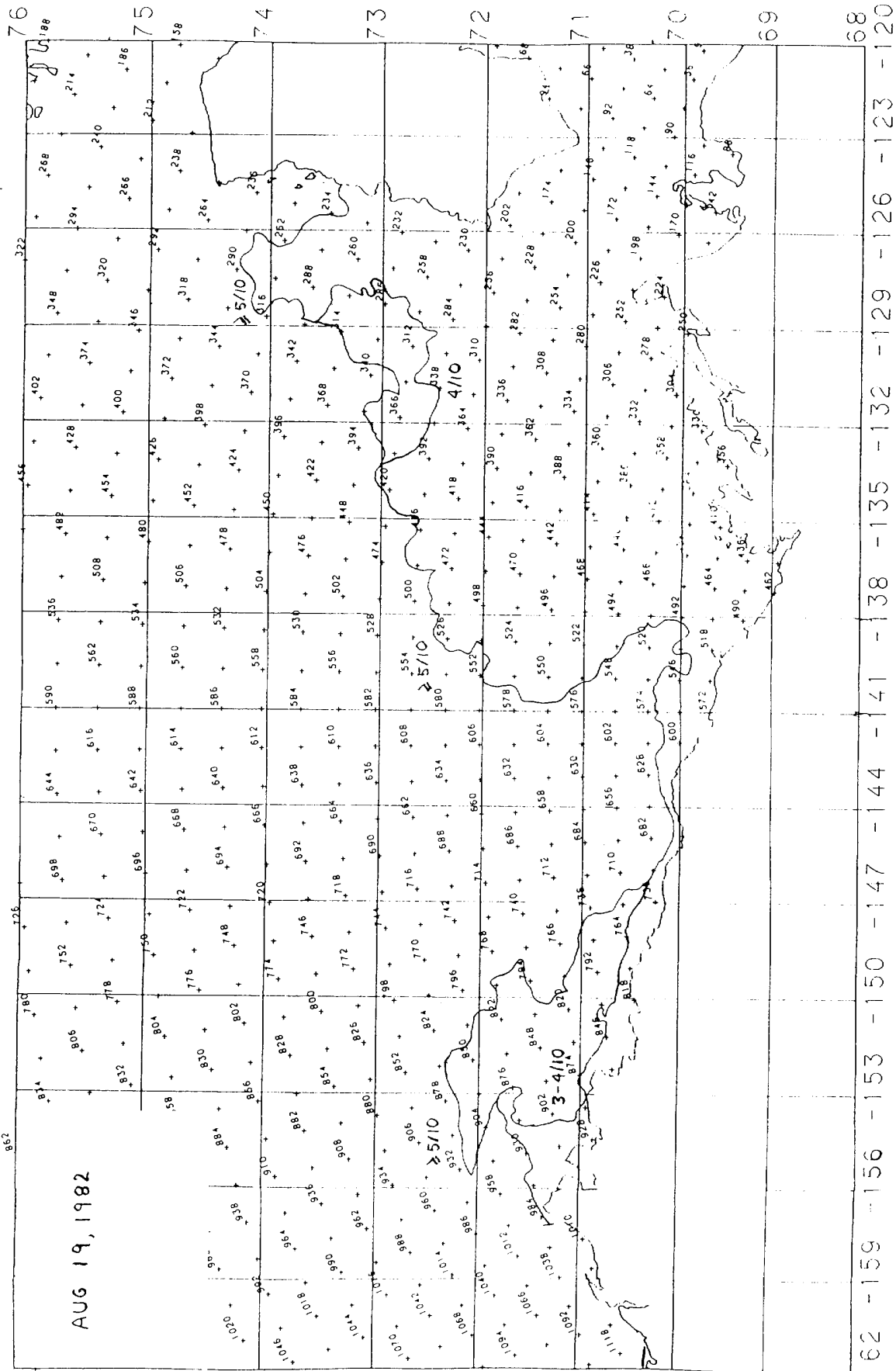




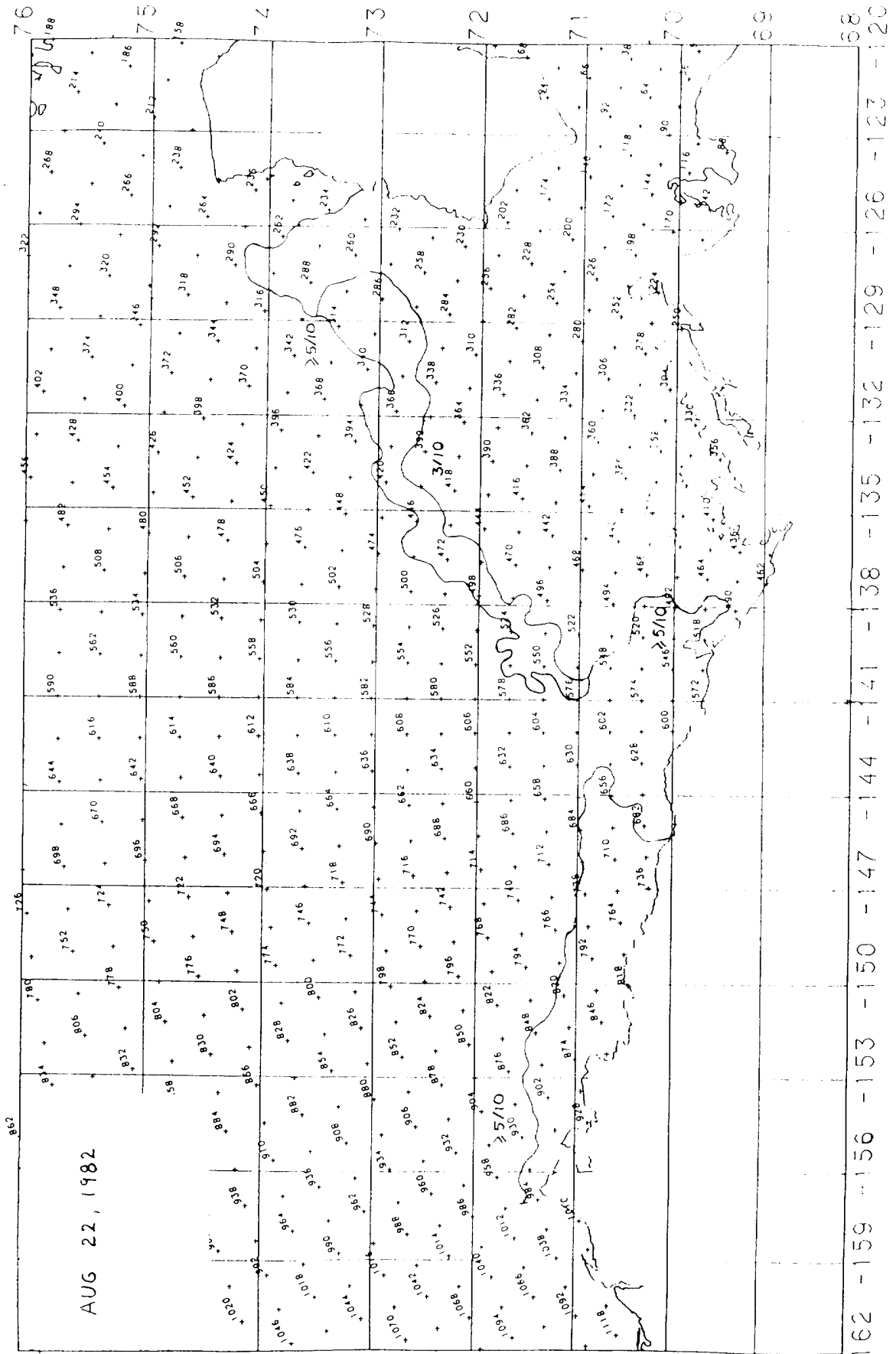




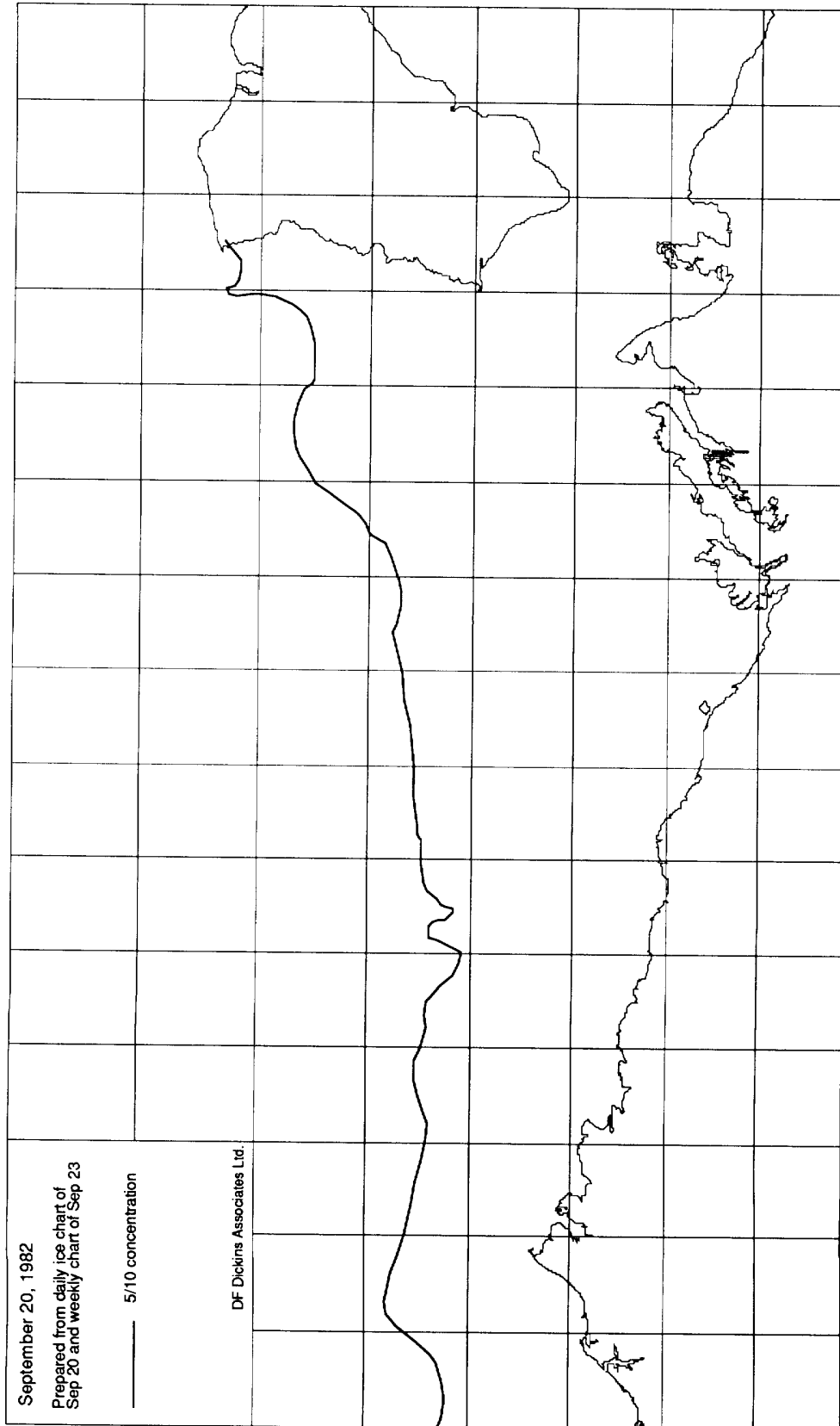


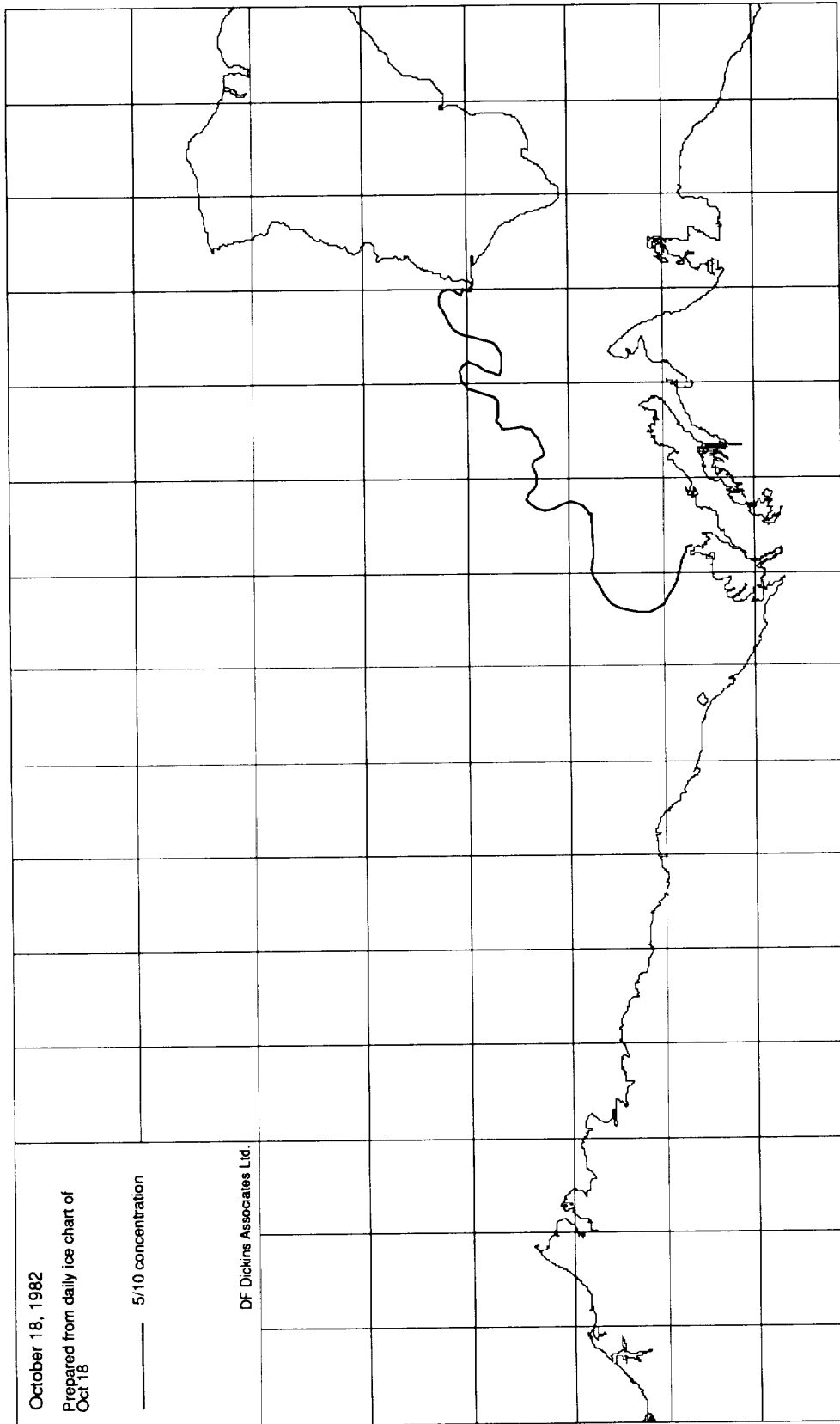


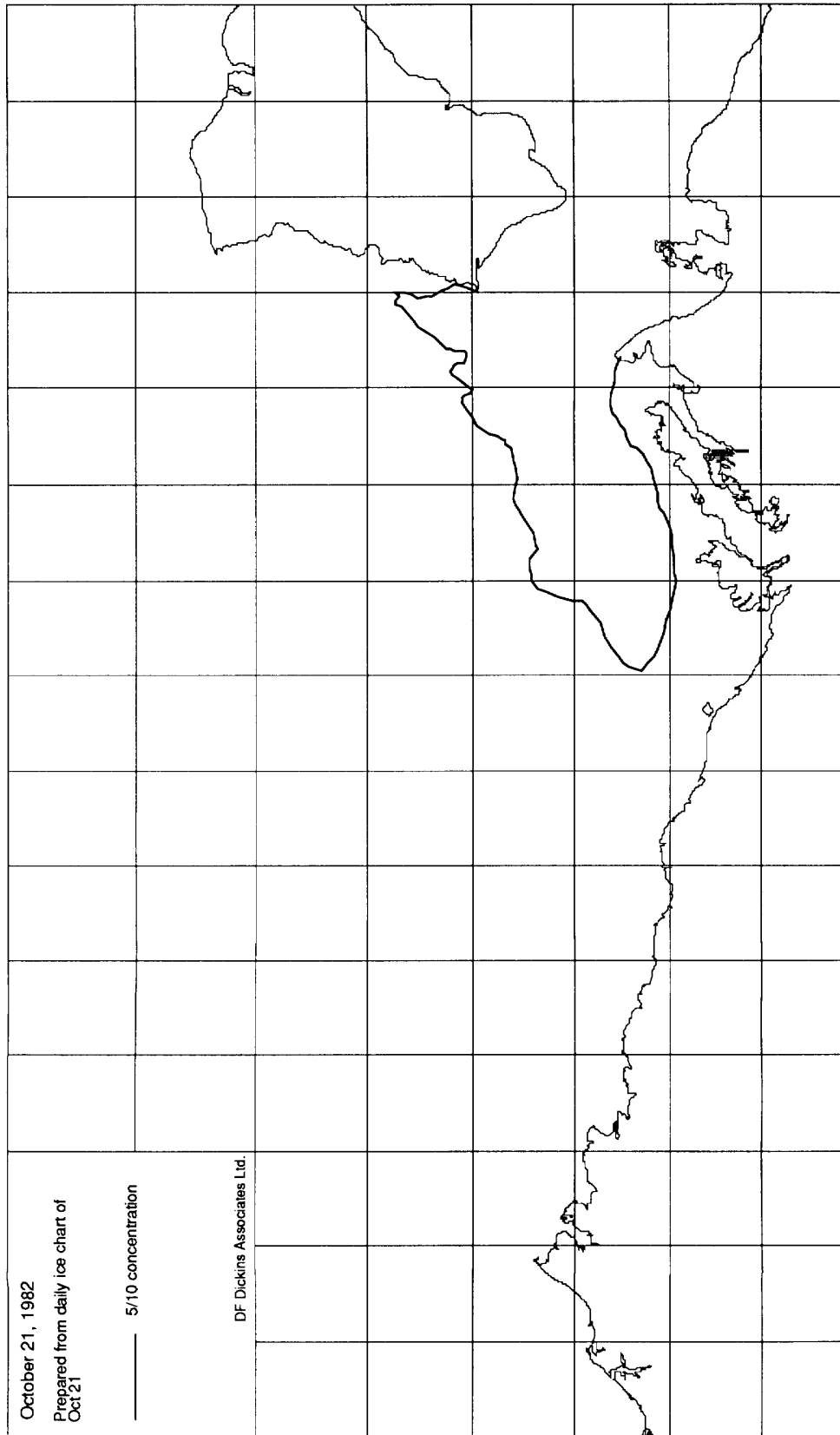
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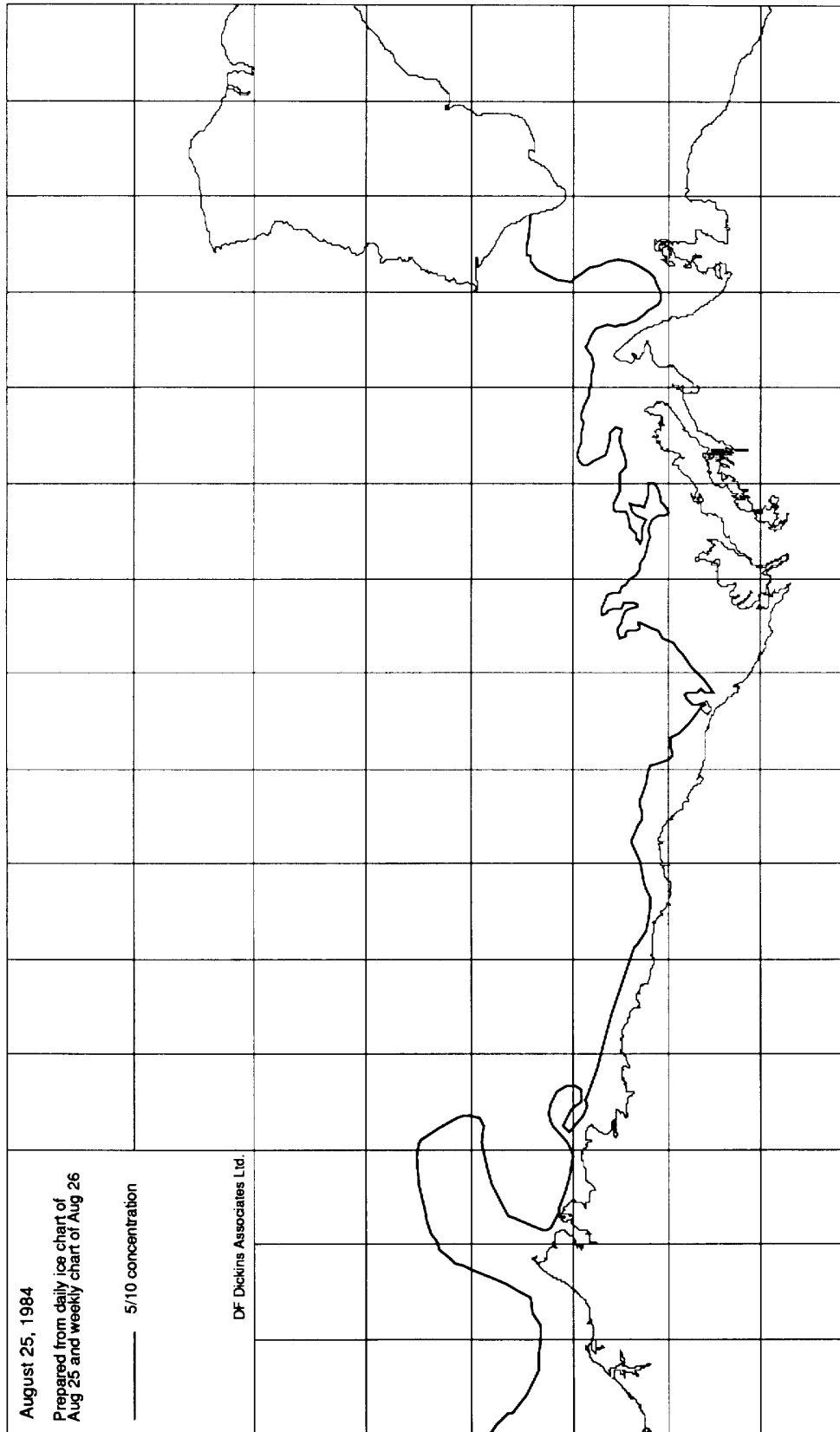


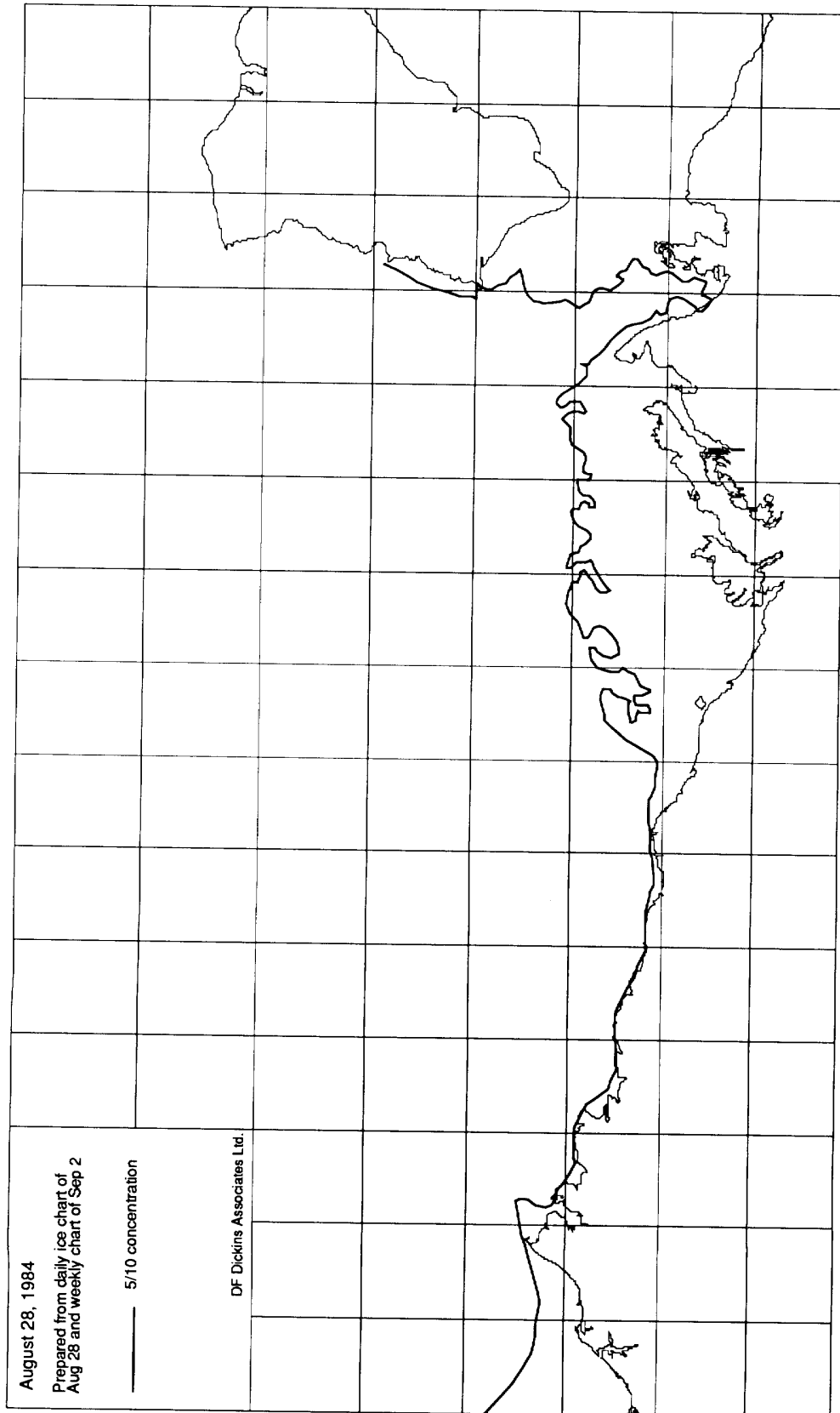
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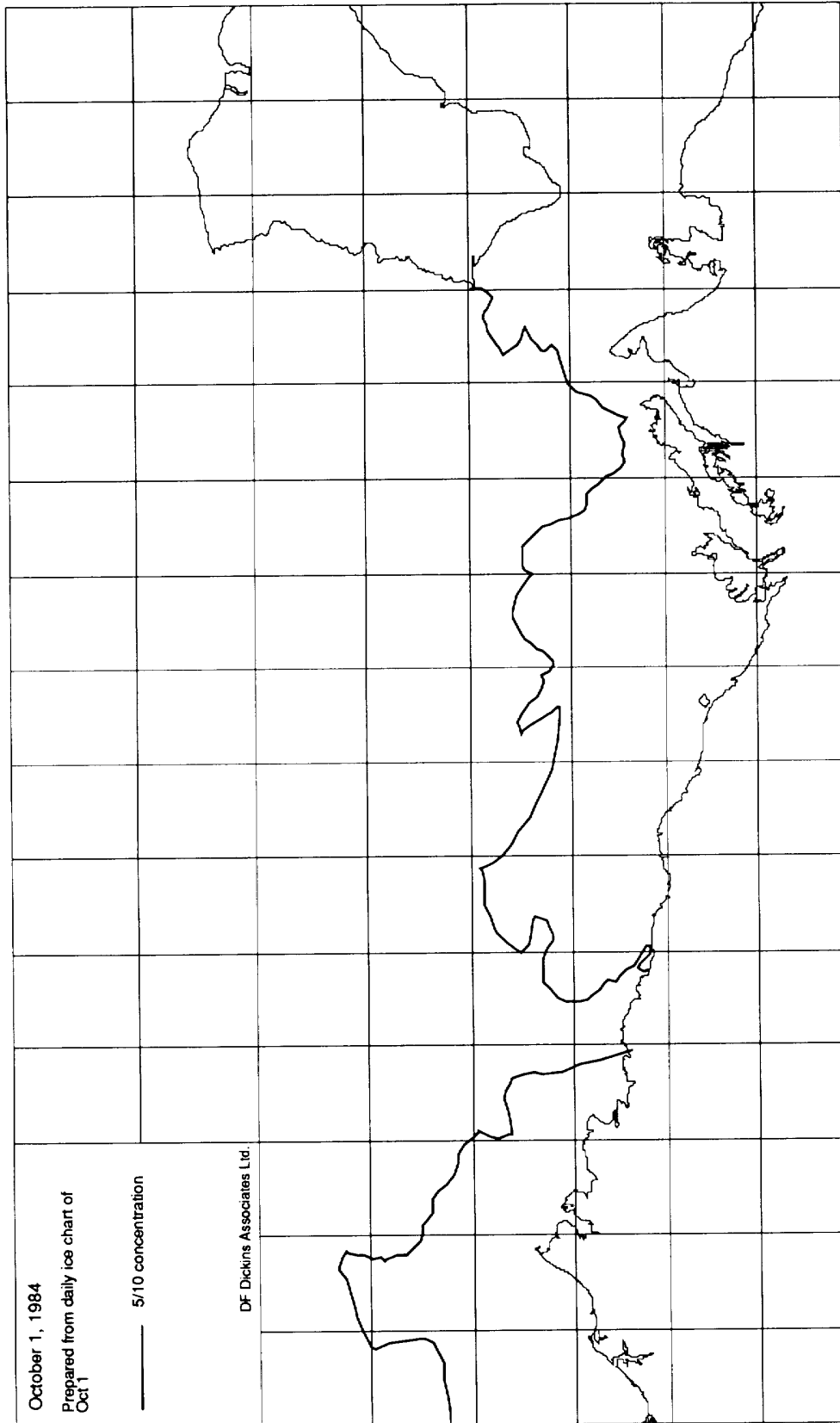


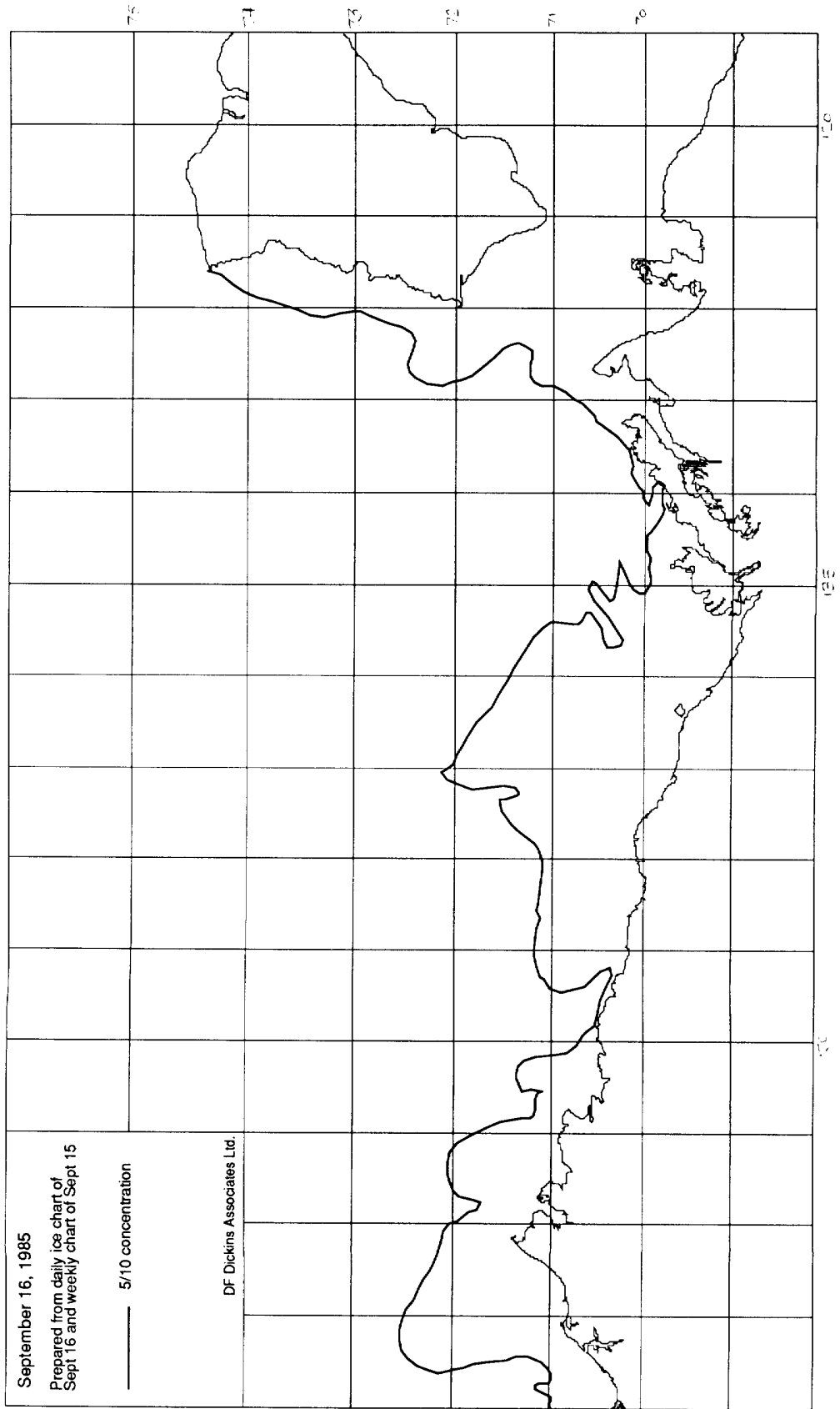


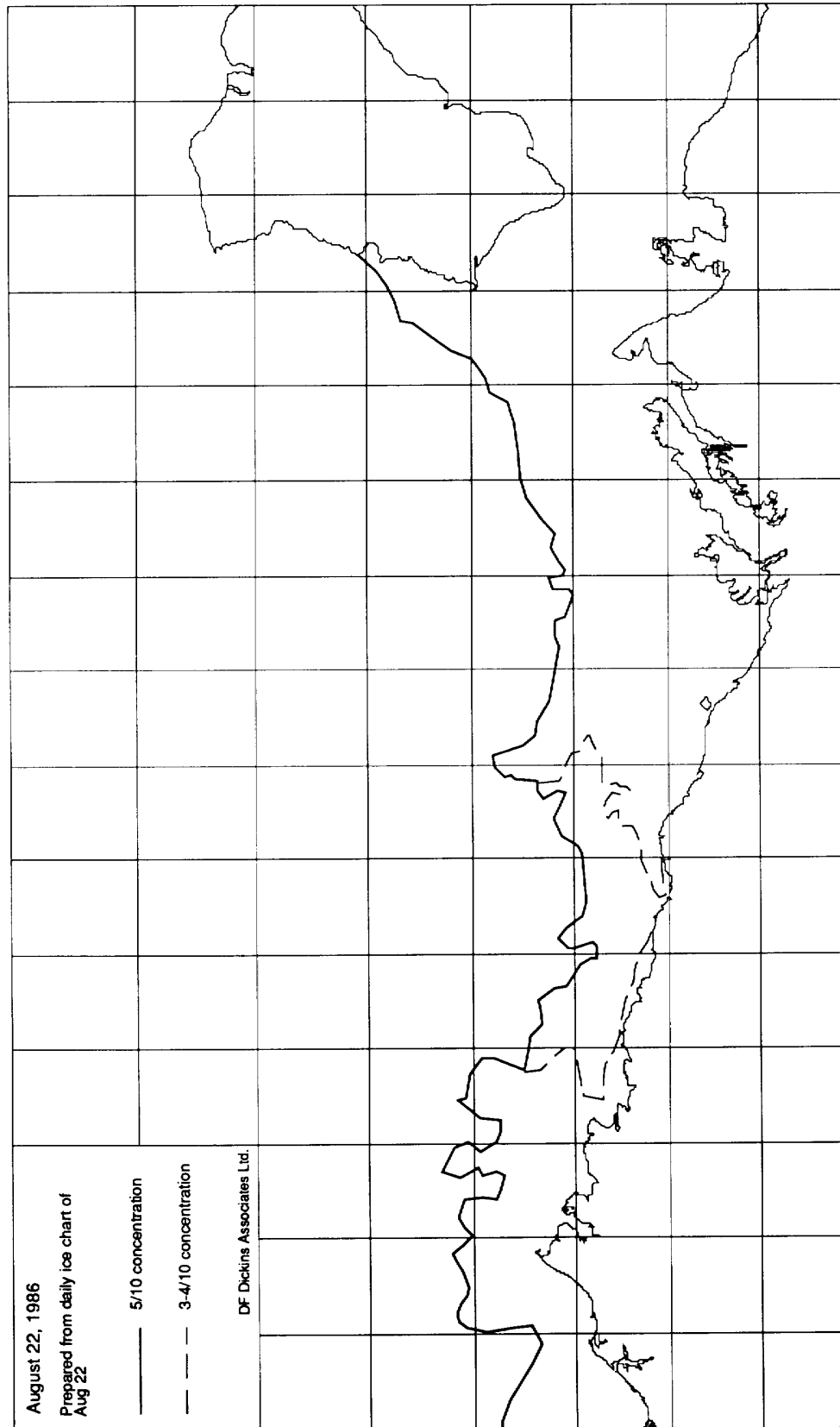


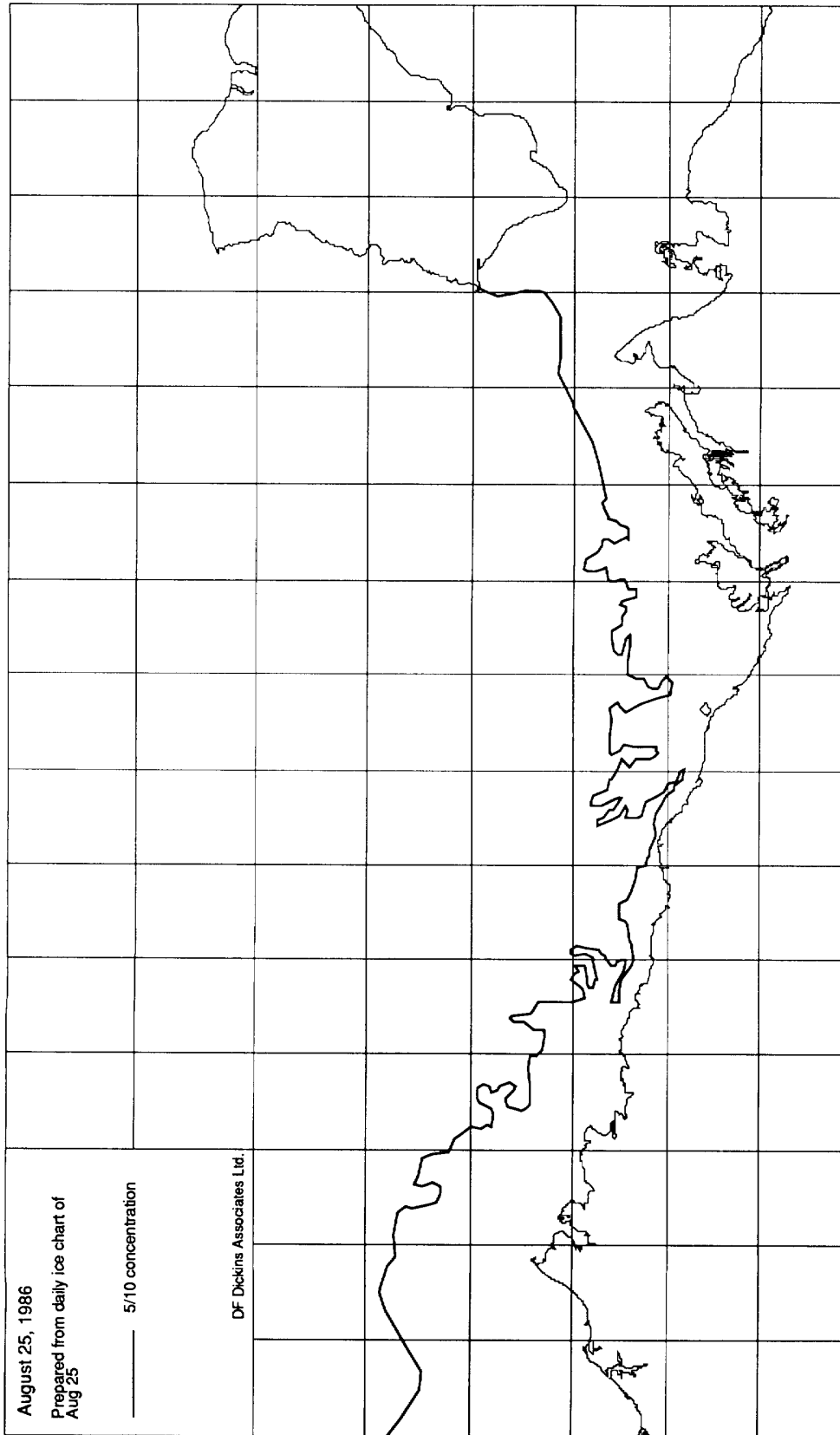


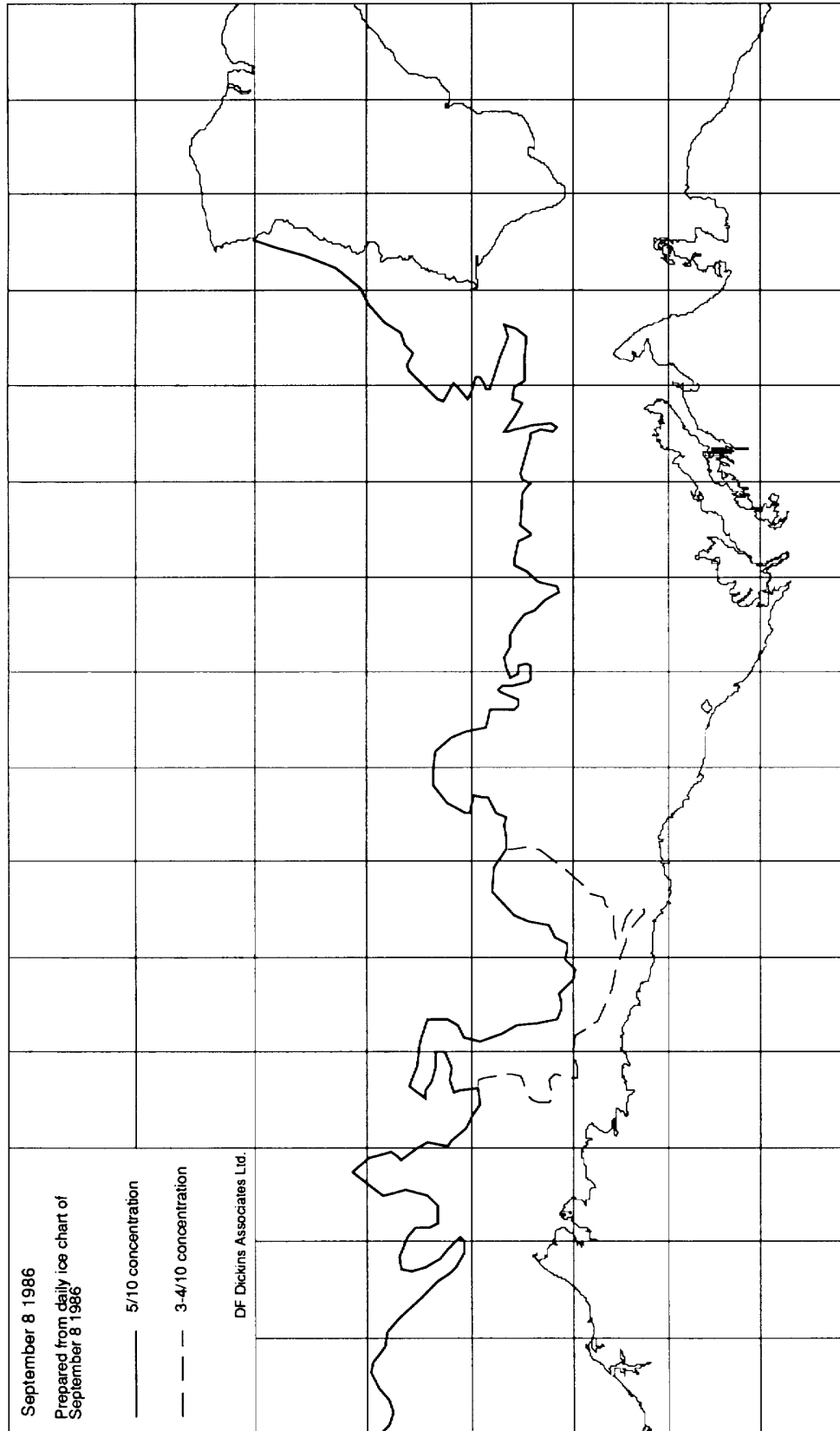


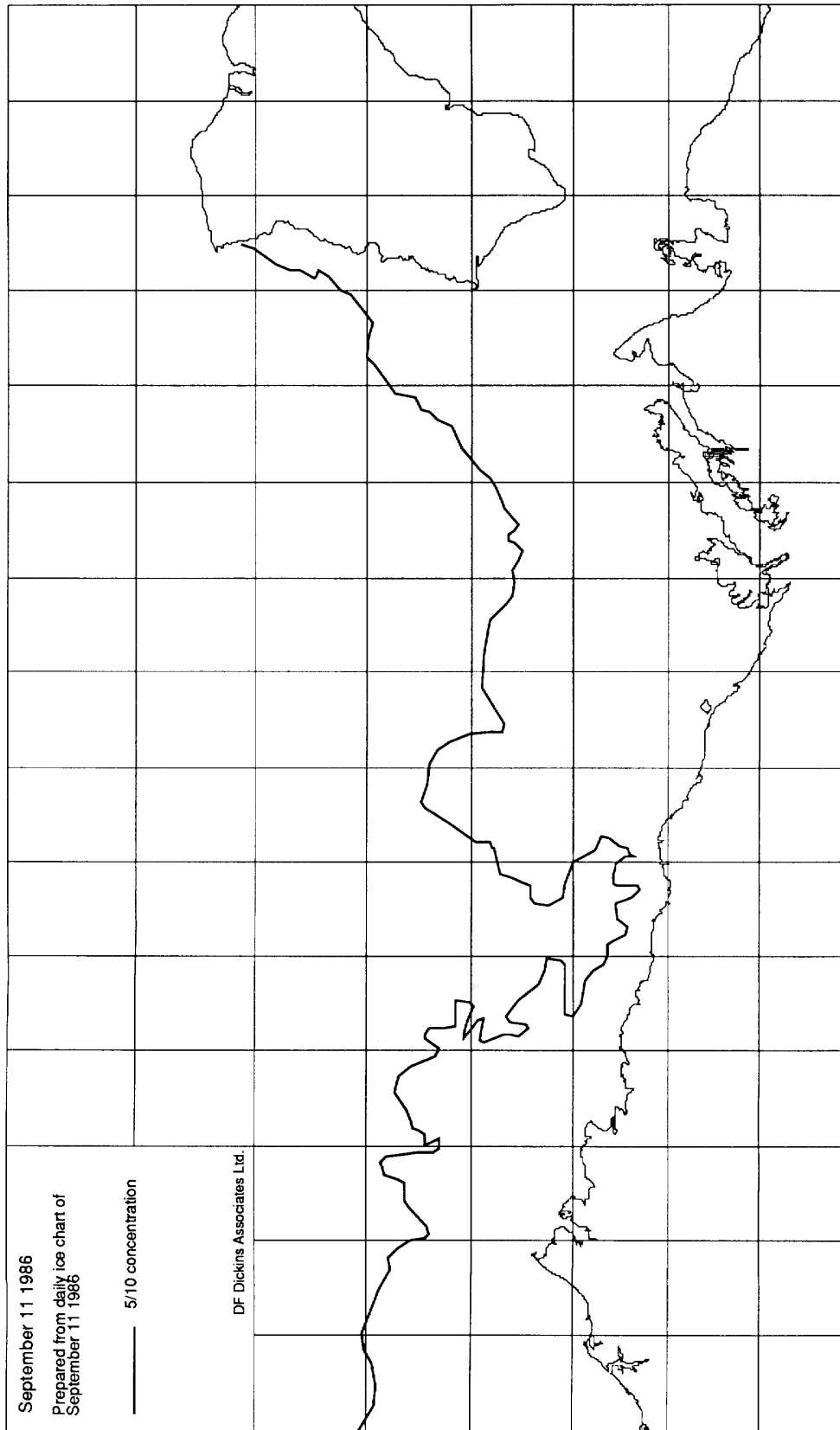


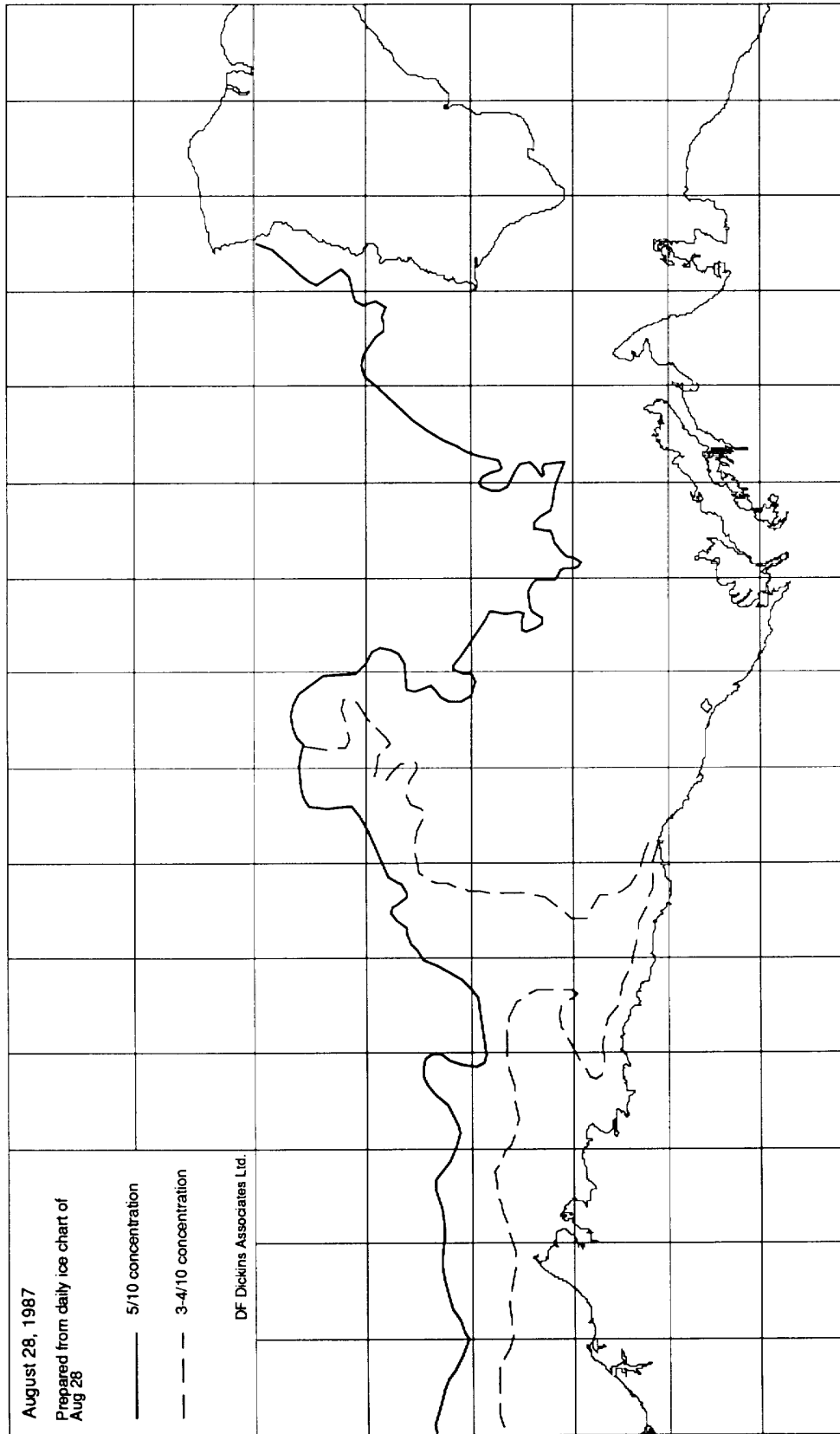




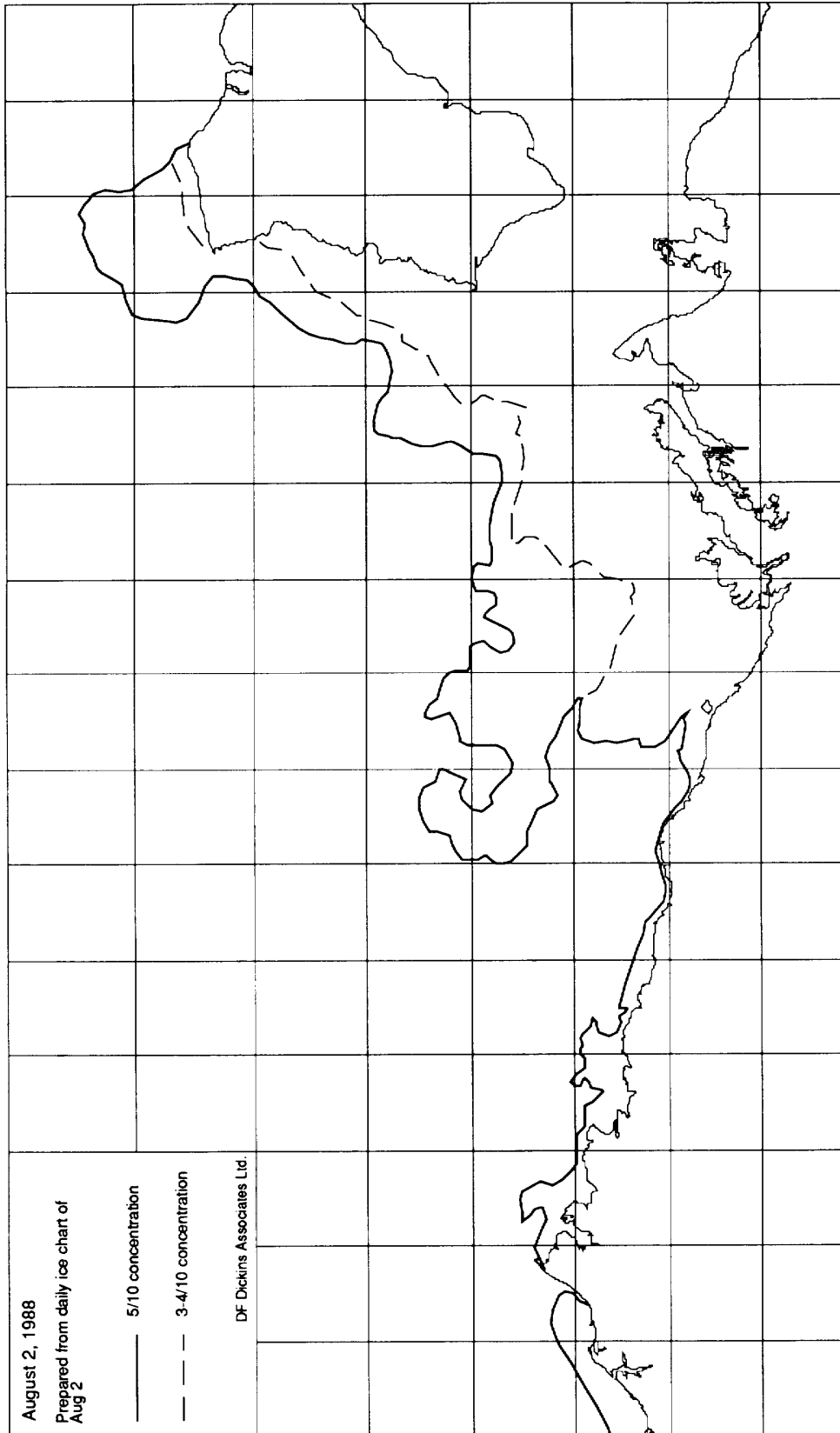


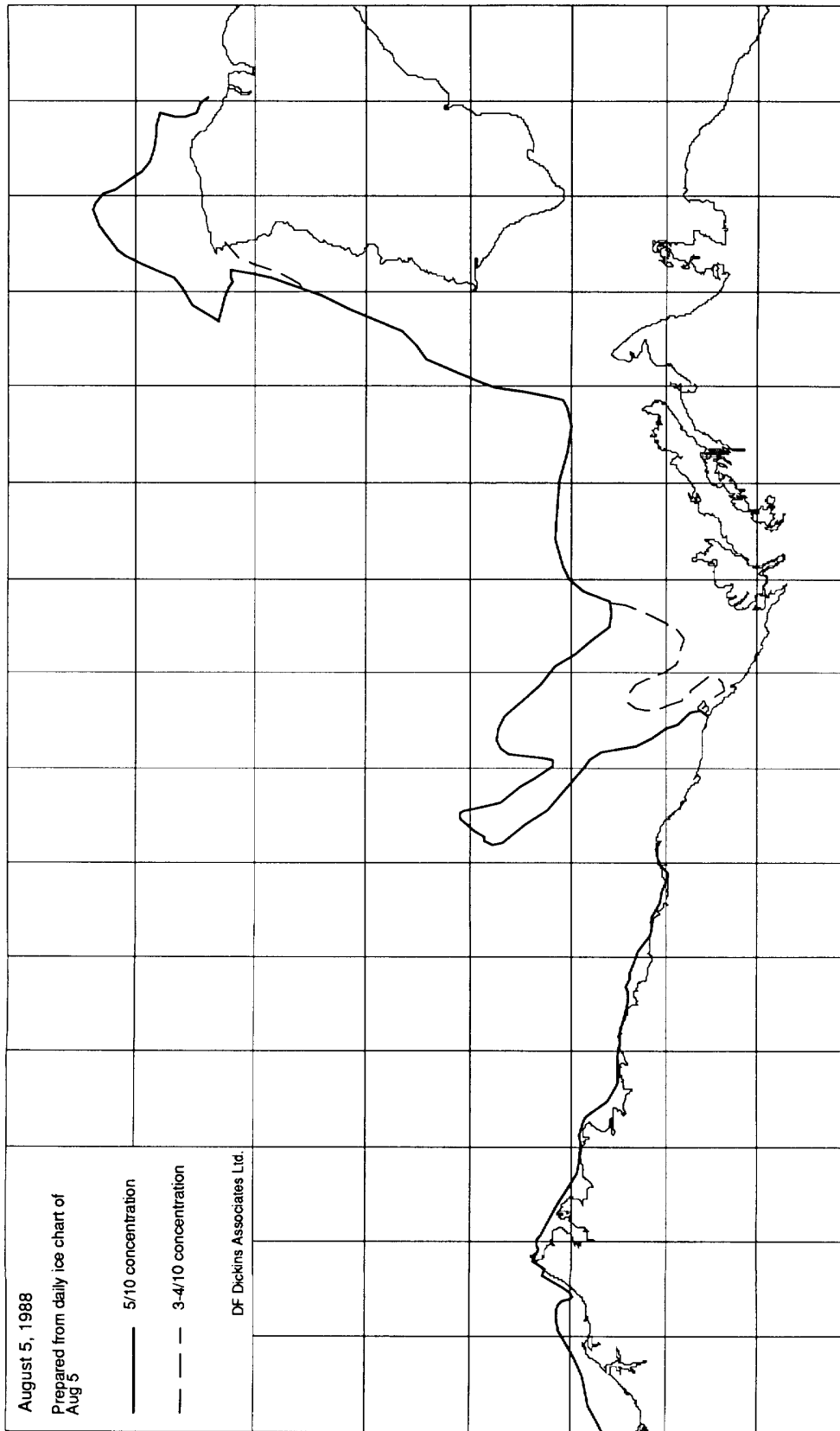






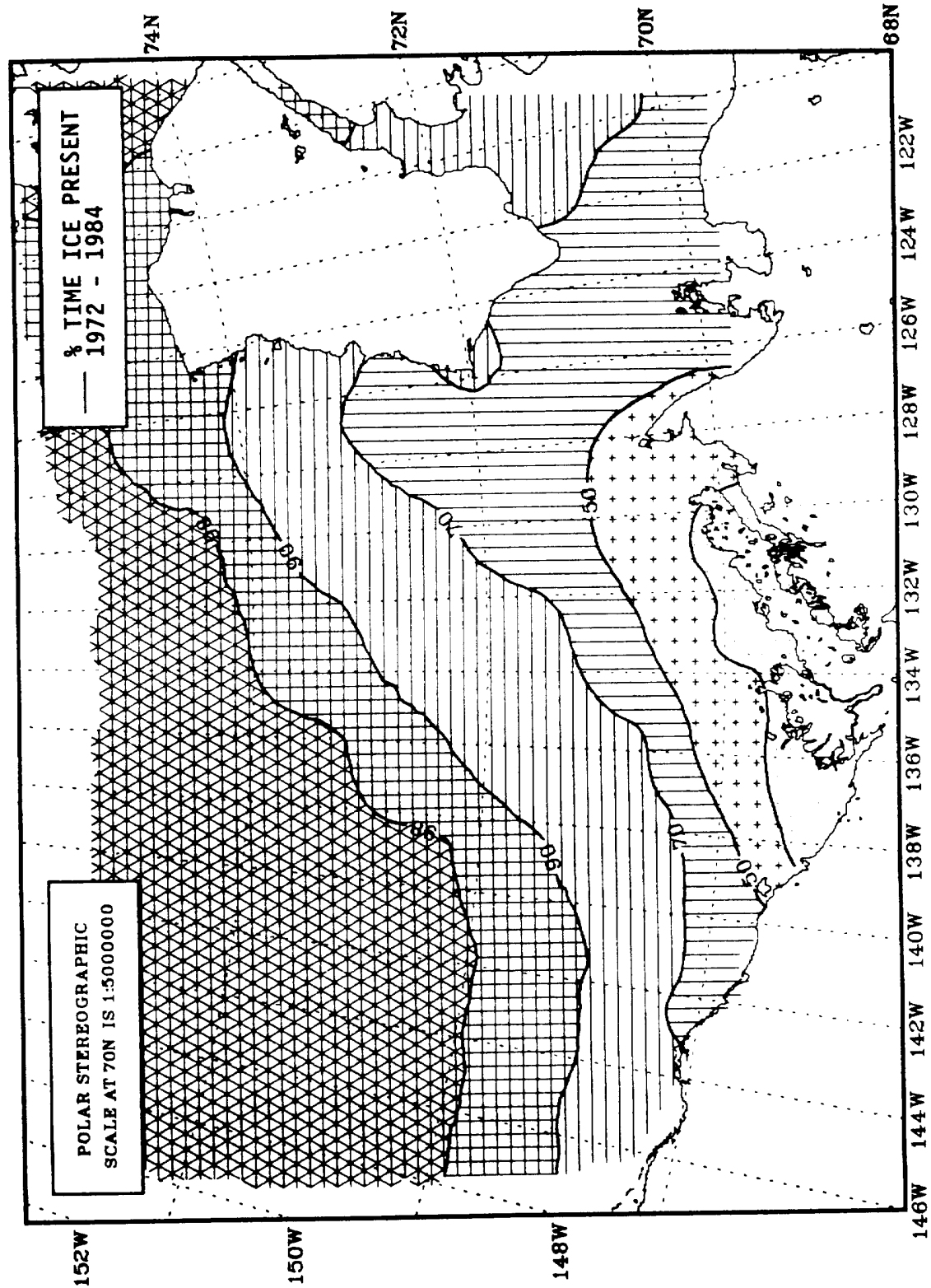




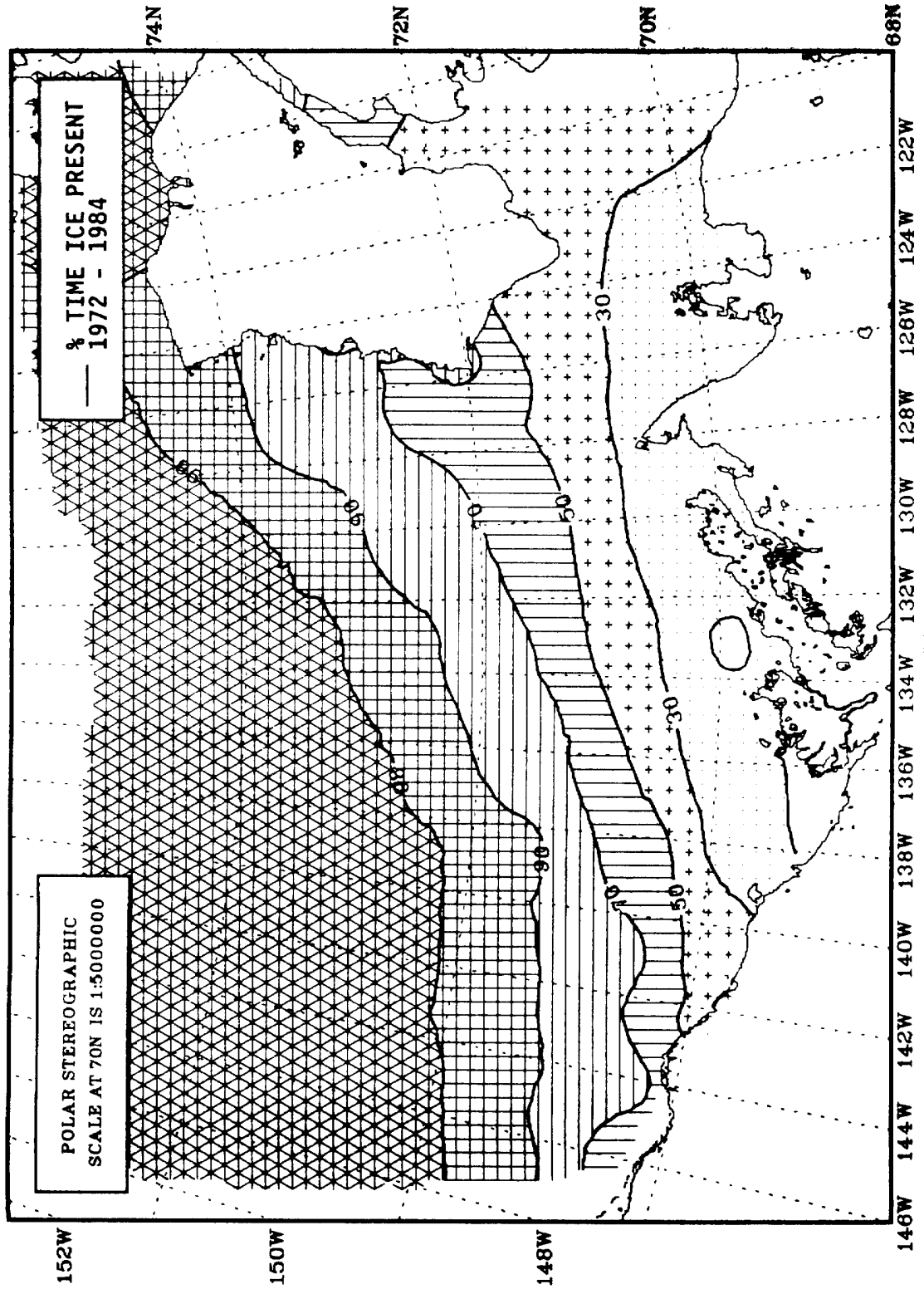


PERCENTAGE OCCURRENCE OF ANY ICE

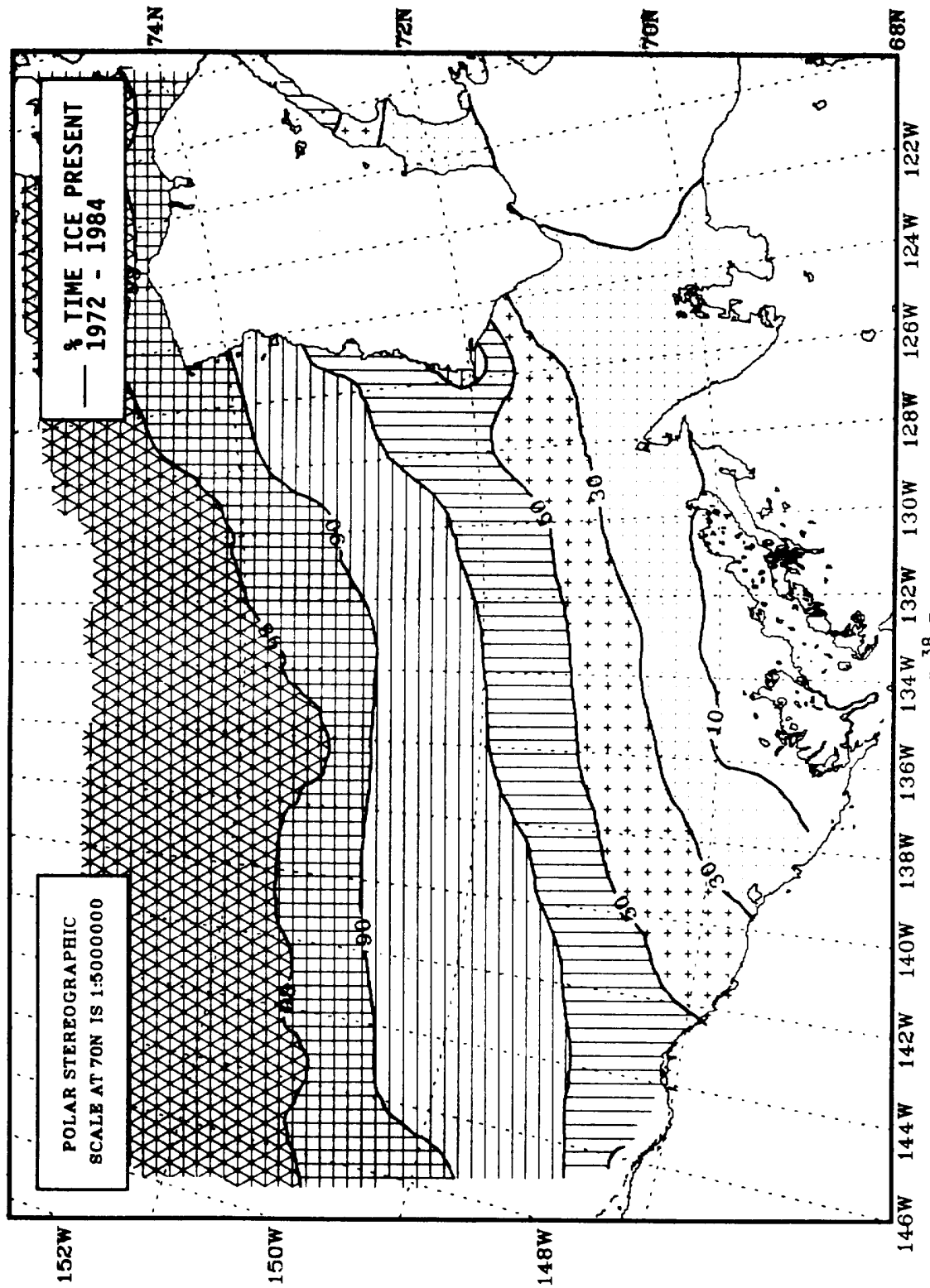
JUL 16 - JUL 31



PERCENTAGE OCCURRENCE OF ANY ICE AUG 1 - AUG 15

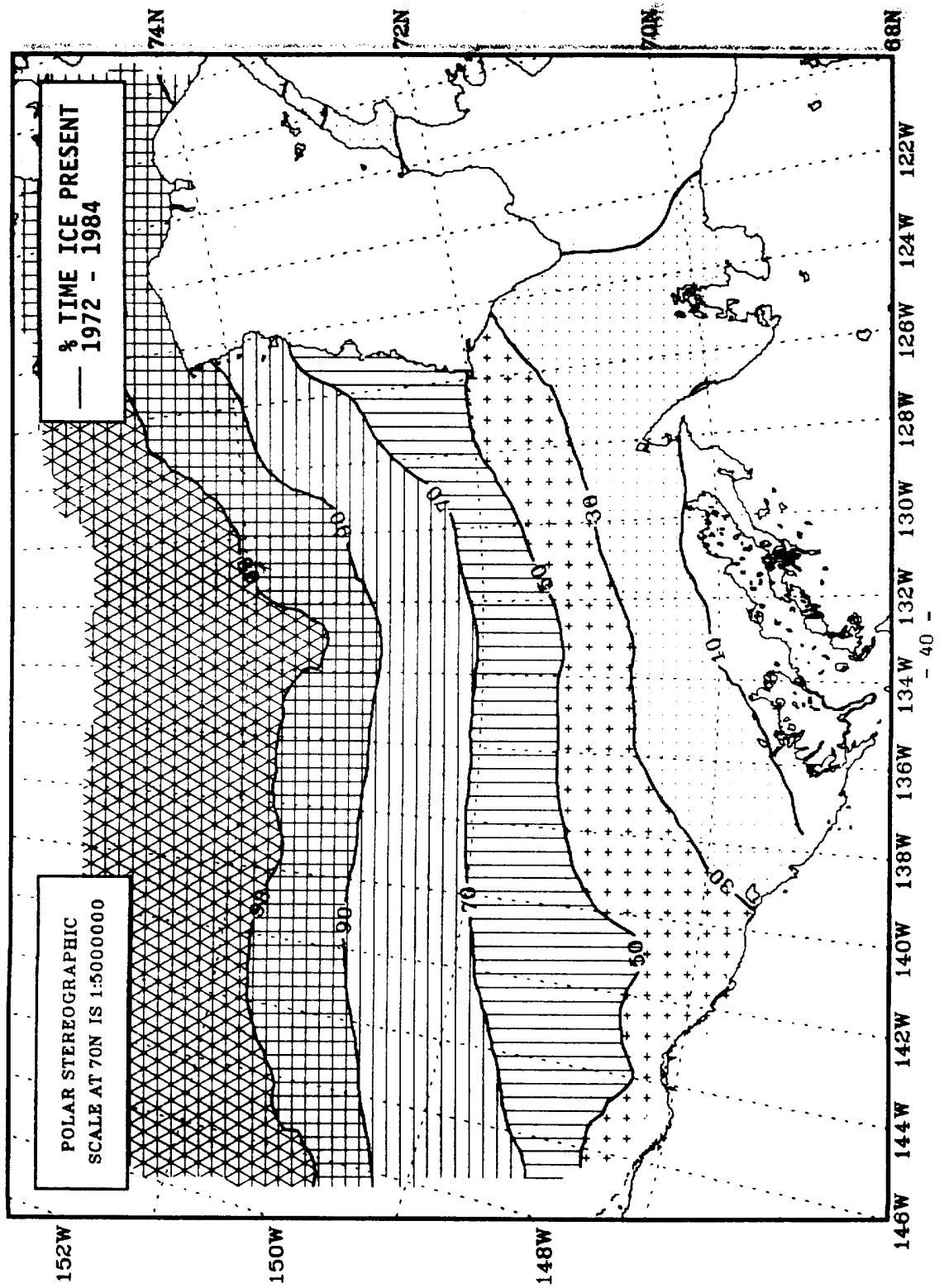


PERCENTAGE OCCURRENCE OF ANY ICE AUG 16 - AUG 31



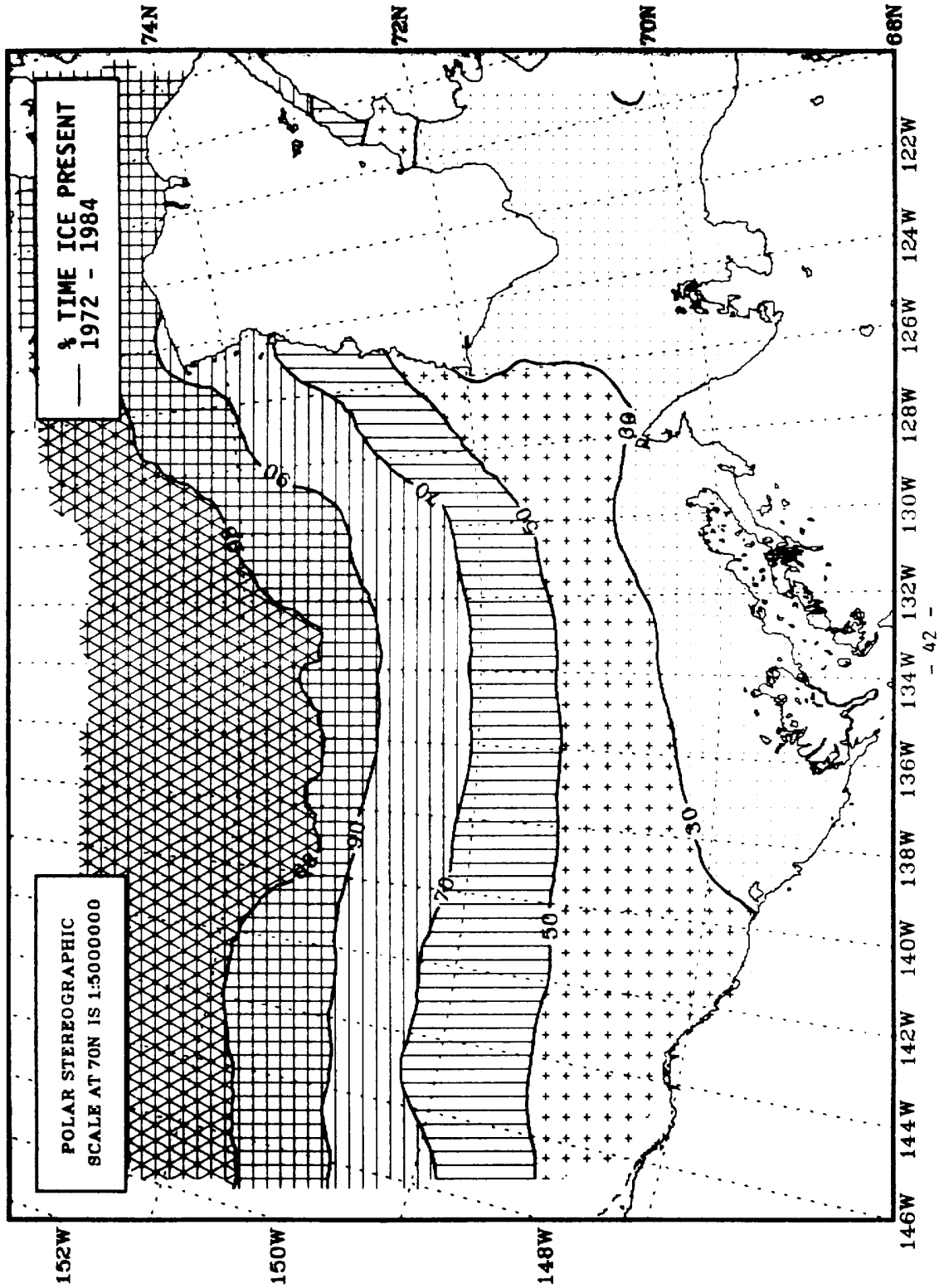
PERCENTAGE OCCURRENCE OF ANY ICE

SEP 1 - SEP 15



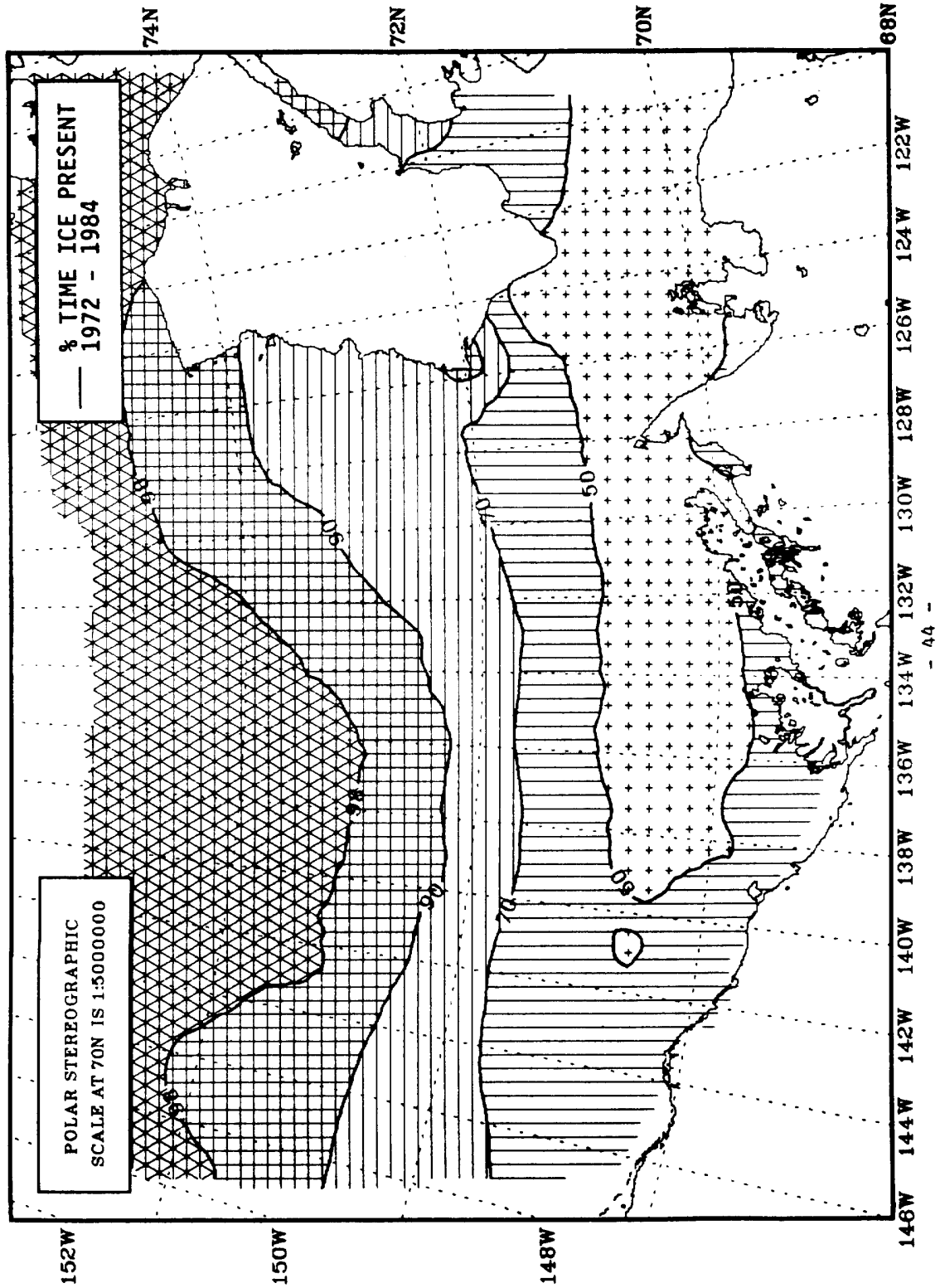
PERCENTAGE OCCURRENCE OF ANY ICE

SEP 16 - SEP 30

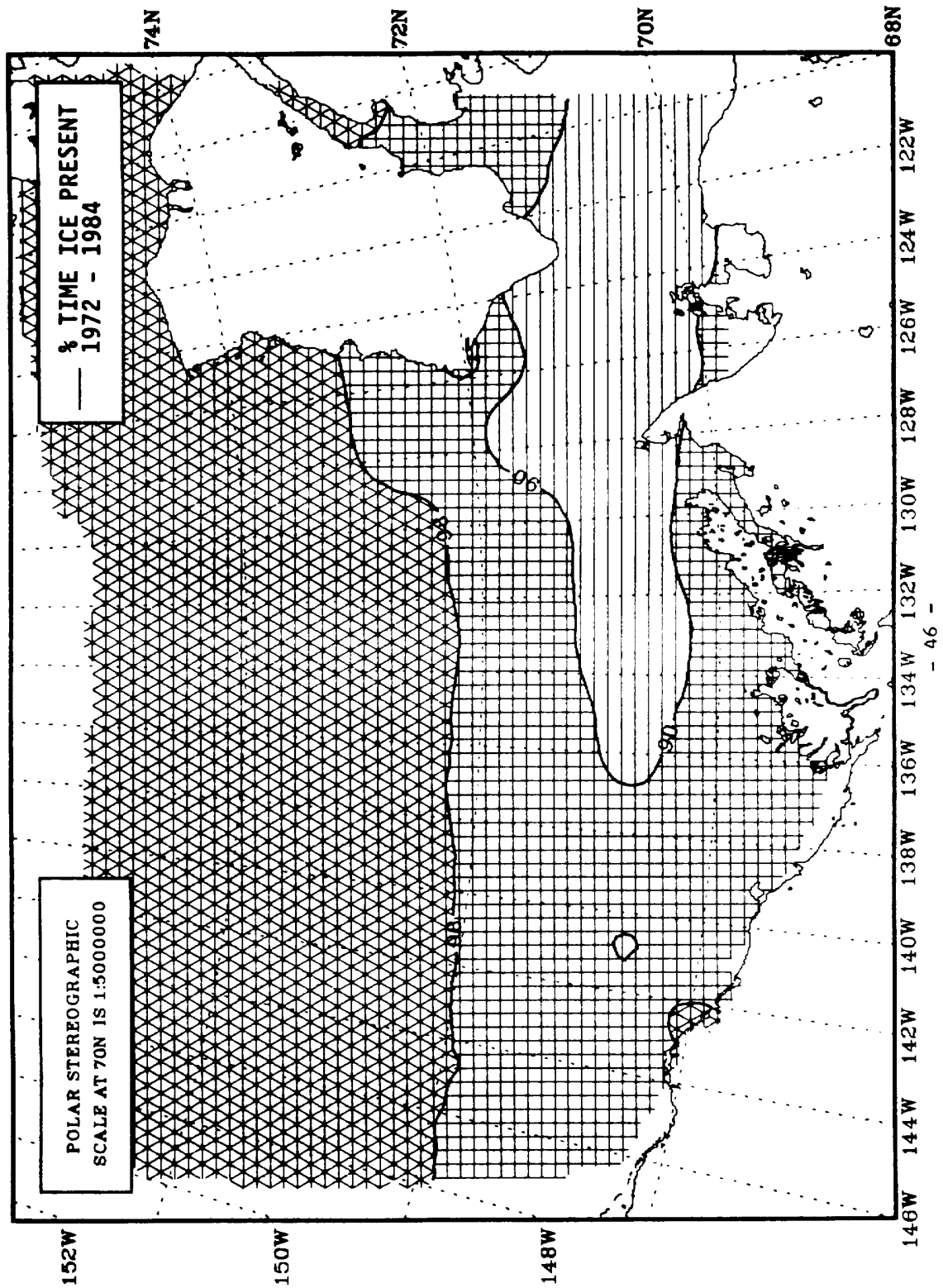


PERCENTAGE OCCURRENCE OF ANY ICE

OCT 1 - OCT 15



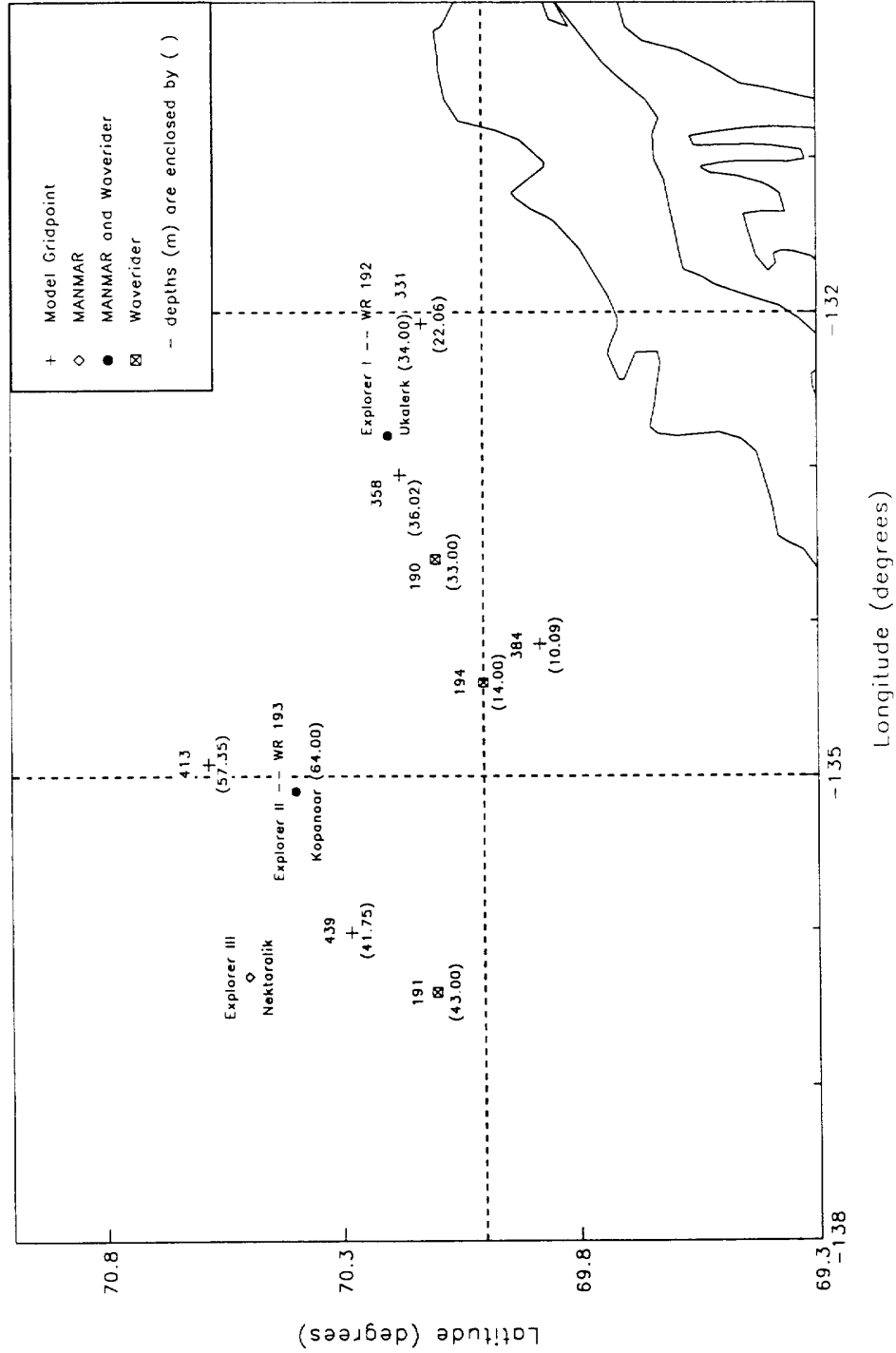
PERCENTAGE OCCURRENCE OF ANY ICE OCT 16 - OCT 31



APPENDIX D
VERIFICATION RESULTS TIME SERIES PLOTS

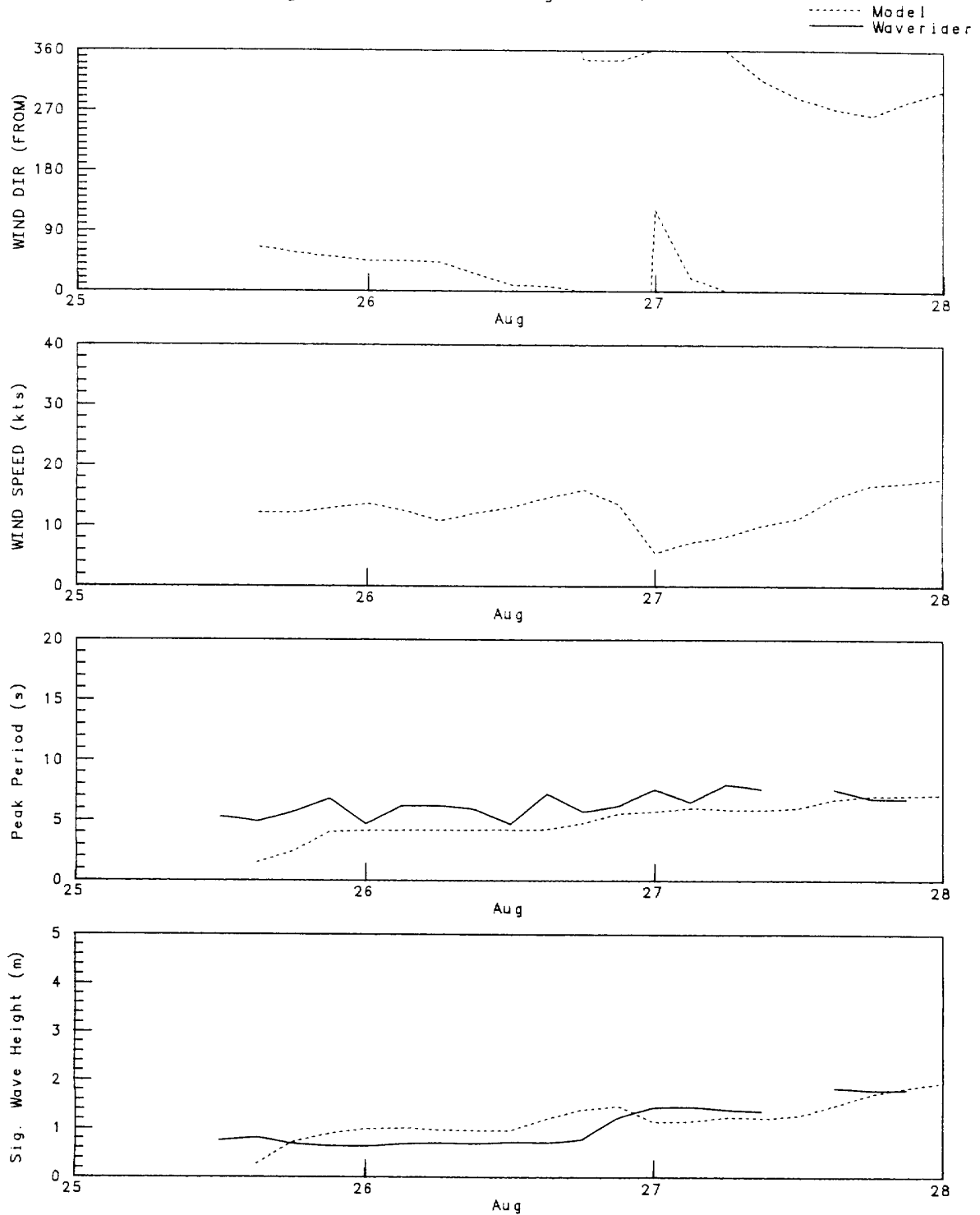
BEAUFORT SEA HINDCAST

MANMAR, WAVERIDER AND MODEL GRID POINT LOCATIONS & DEPTHS
 August 25, 1977 to August 28, 1977



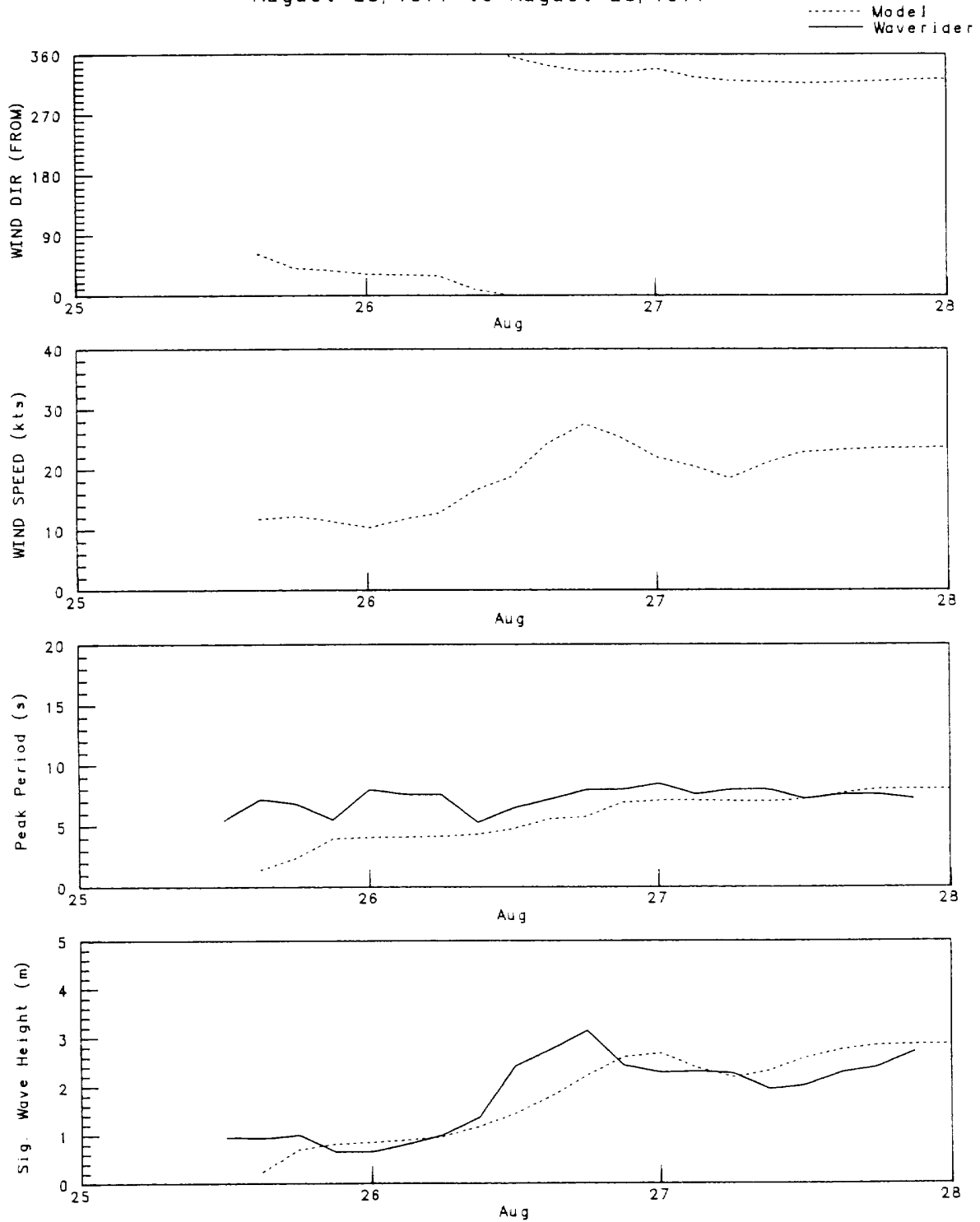
BEAUFORT SEA STORM VERIFICATION

GRID POINT 358 - WR 190
 August 25, 1977 to August 28, 1977



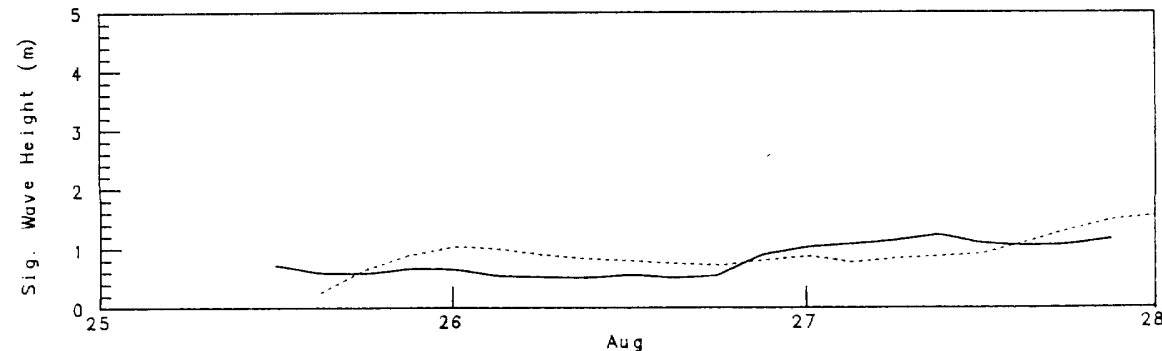
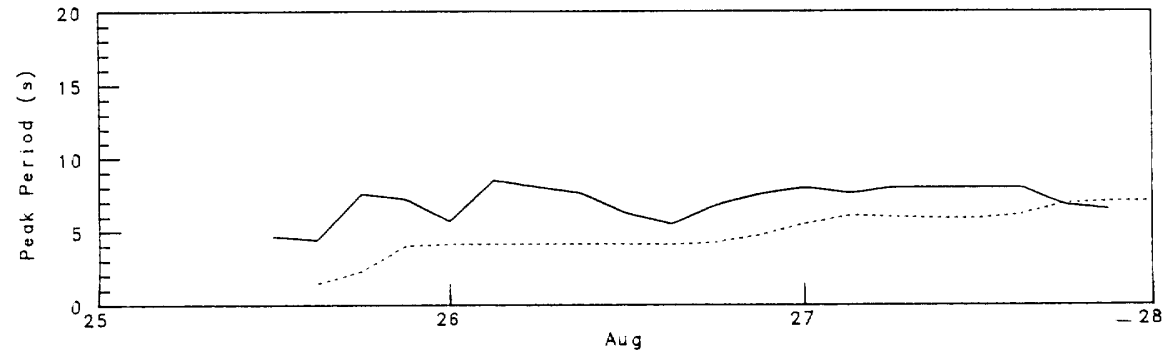
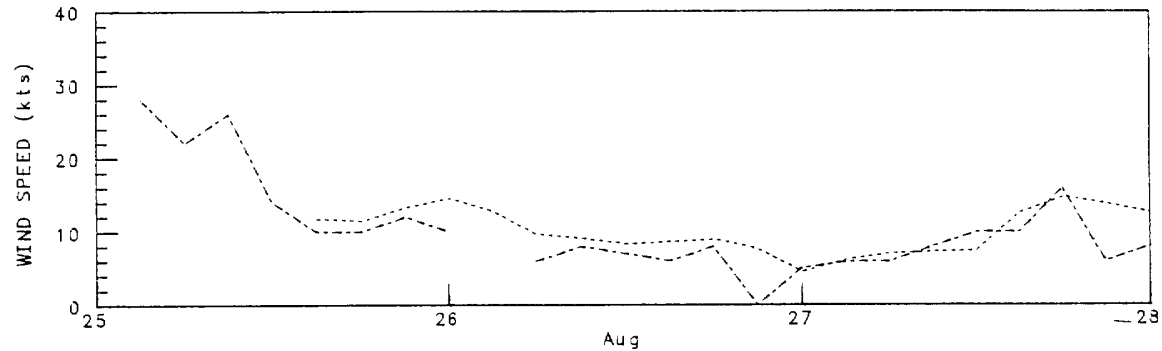
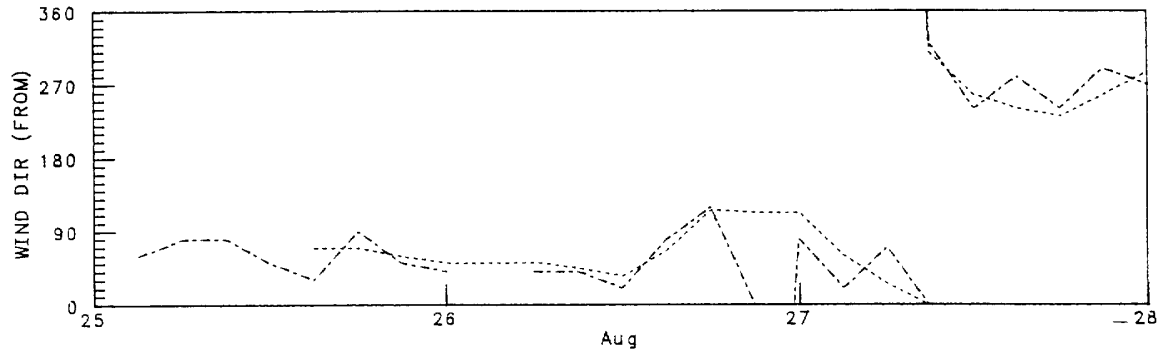
BEAUFORT SEA STORM VERIFICATION

GRID POINT 439 - WR 191
August 25, 1977 to August 28, 1977



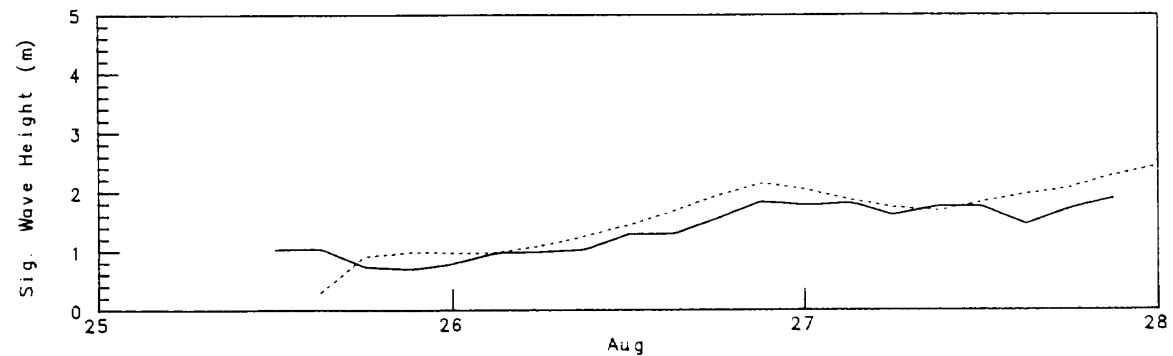
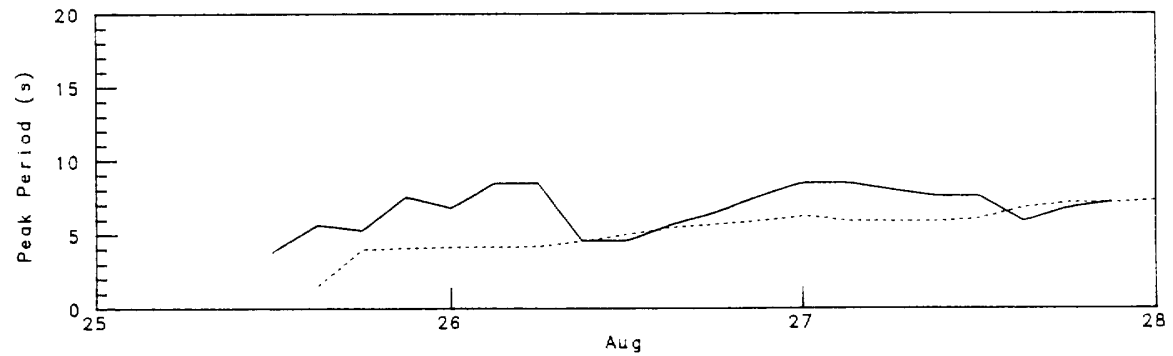
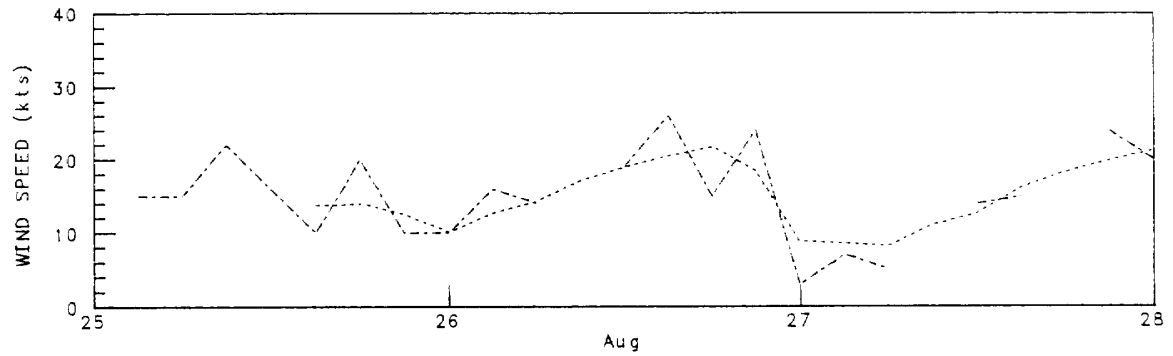
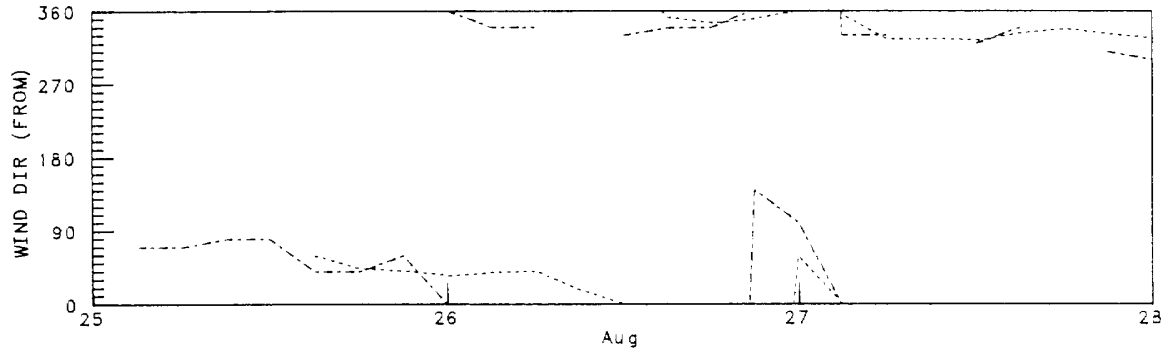
BEAUFORT SEA STORM VERIFICATION
 GRID POINT 331 - EXPLORER I, UKALERK - WR 192
 August 25, 1977 to August 28, 1977

----- Manmar
 Model
 _____ Waverider



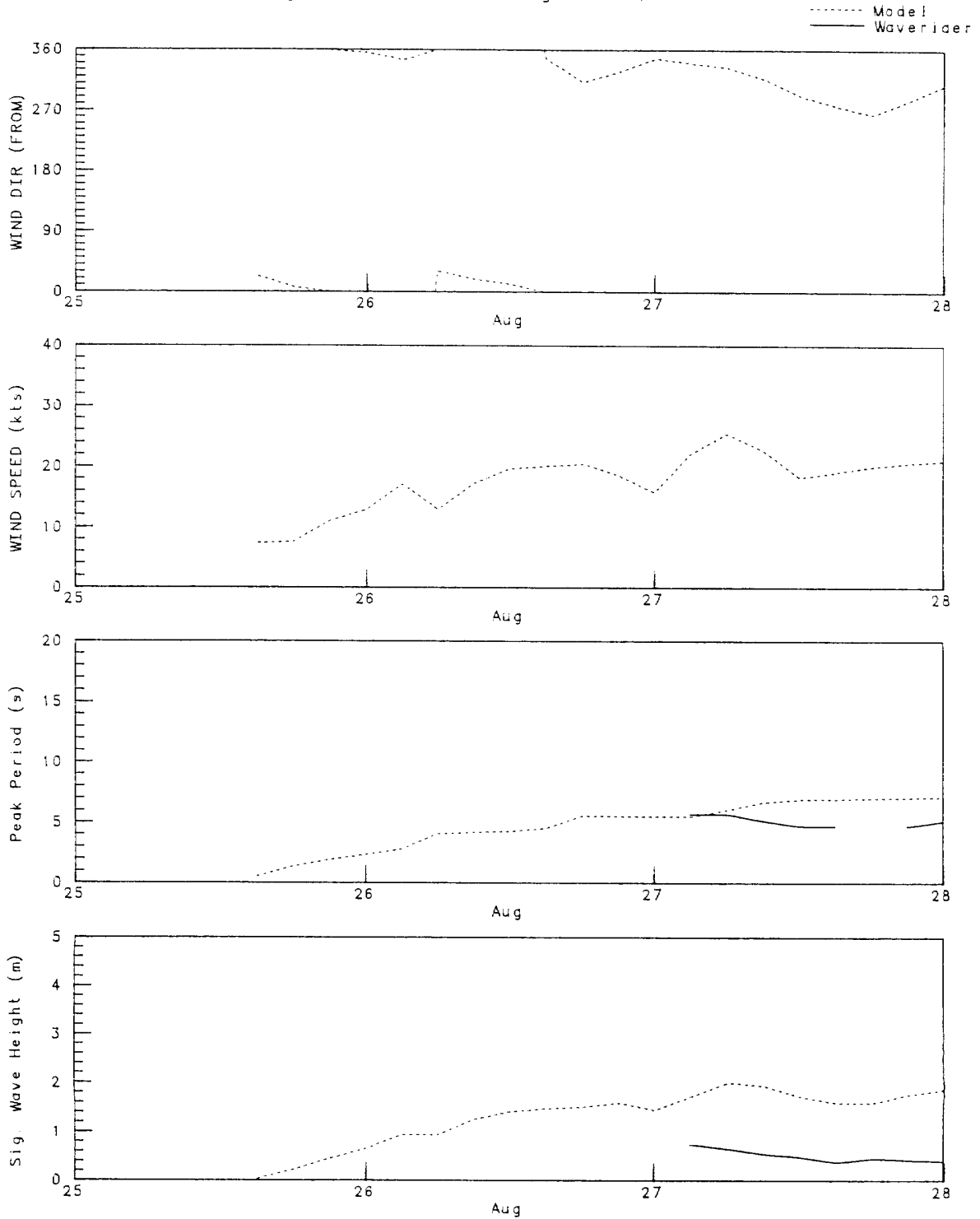
BEAUFORT SEA STORM VERIFICATION
GRID POINT 413 - EXPLORER II, KOPANOAR - WR 193
August 25, 1977 to August 28, 1977

Manmar
Model
Waverider



BEAUFORT SEA STORM VERIFICATION

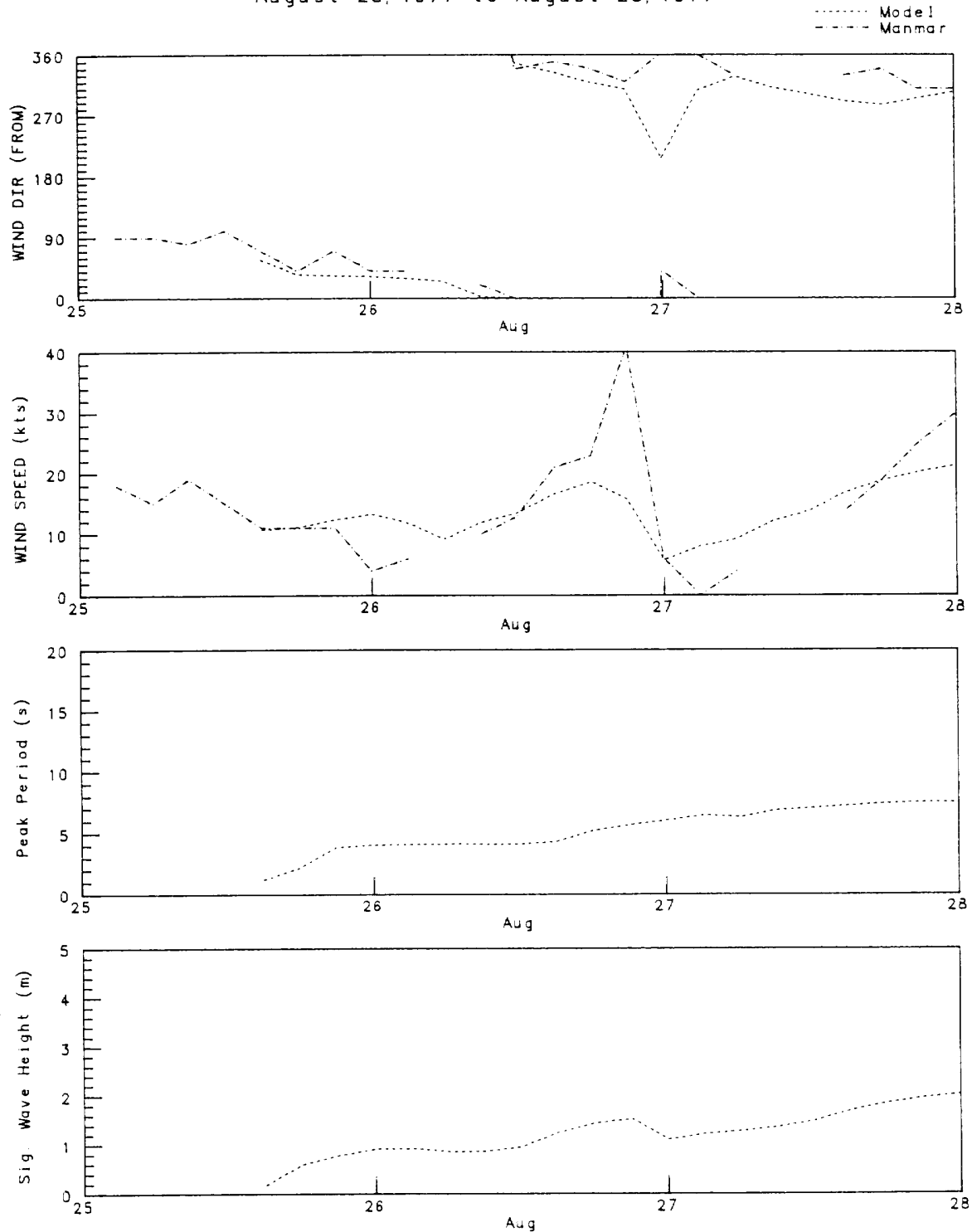
GRID POINT 384 - WR 194
August 25, 1977 to August 28, 1977



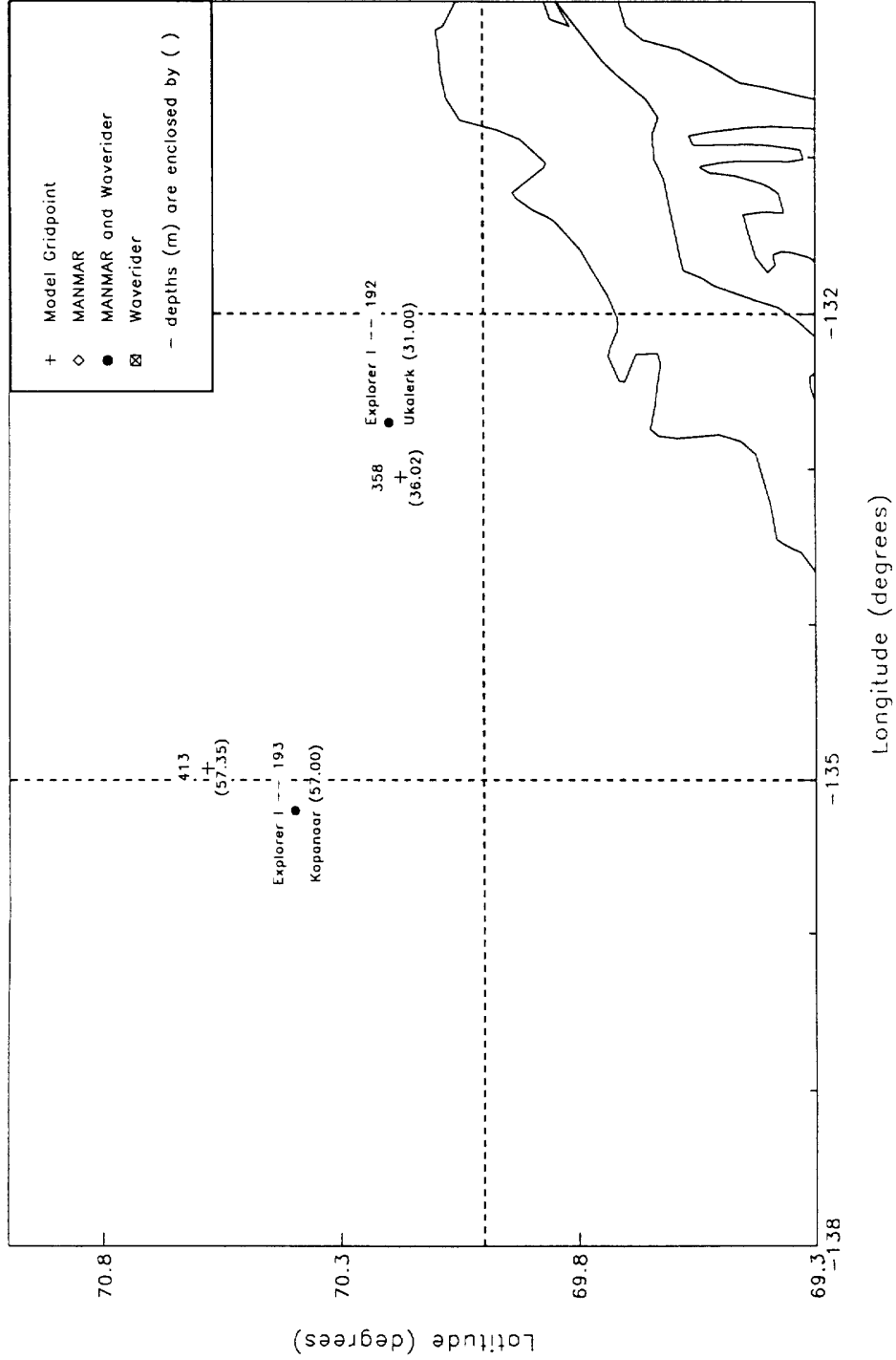
BEAUFORT SEA STORM VERIFICATION

GRID POINT 384 - EXPLORER III, NEKTORALIK

August 25, 1977 to August 28, 1977



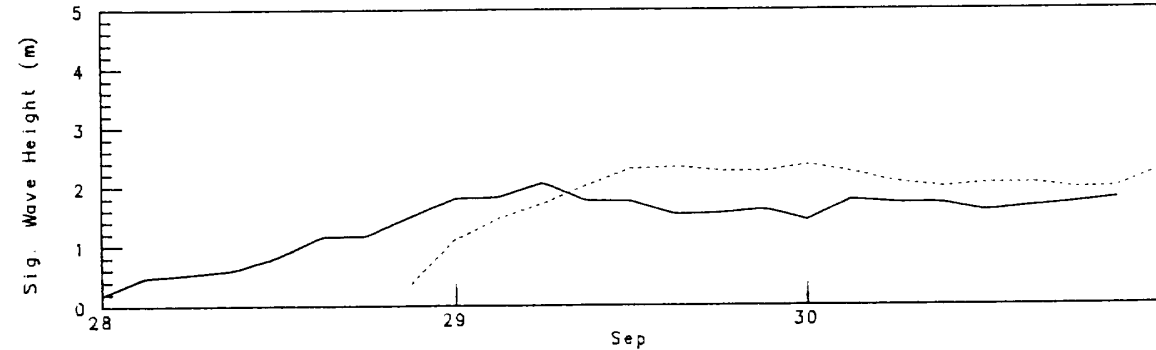
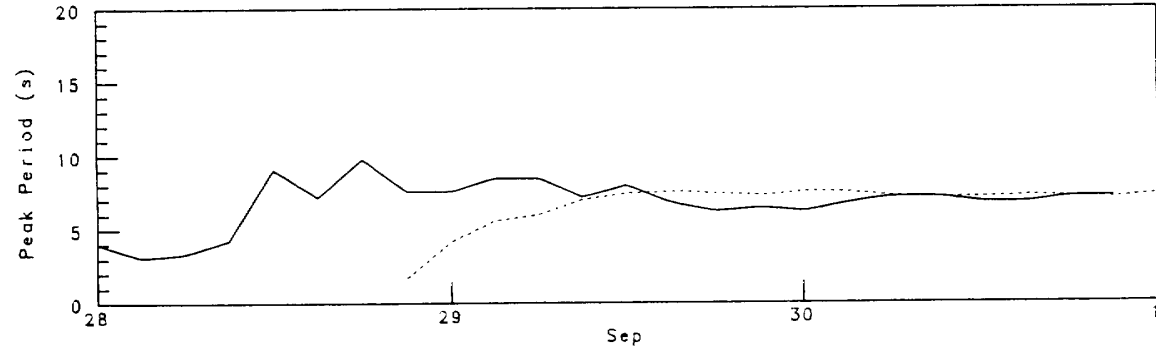
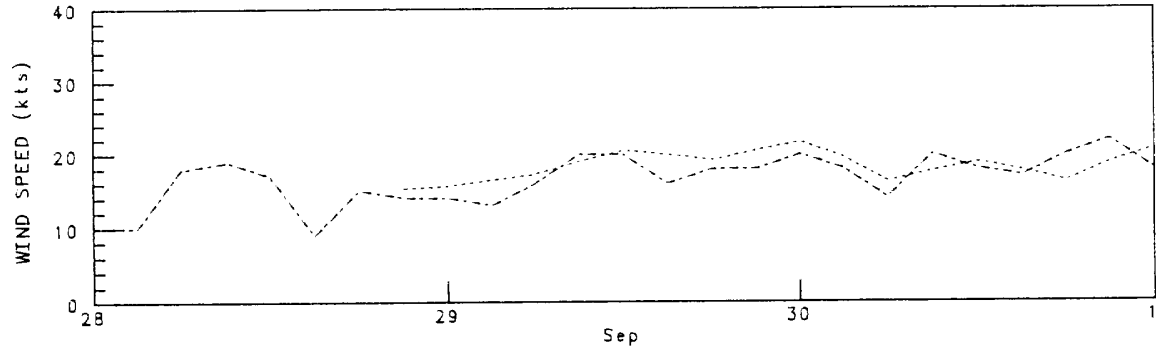
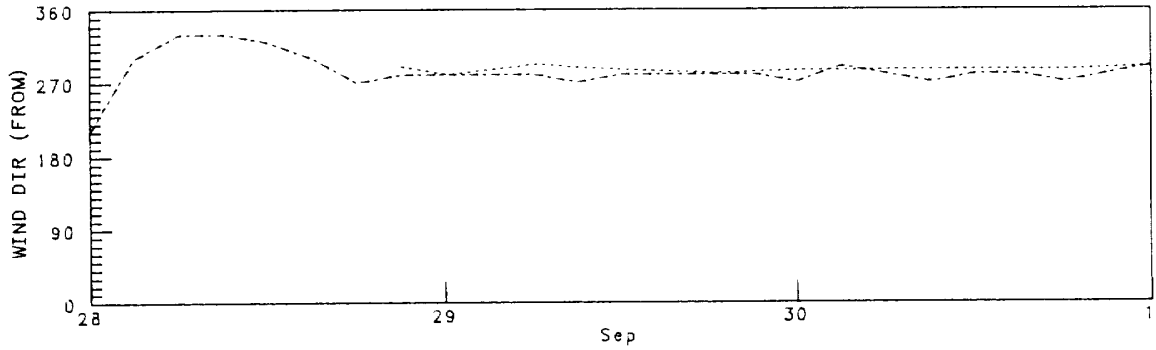
BEAUFORT SEA HINDCAST
MANMAR, WAVERIDER AND MODEL GRID POINT LOCATIONS & DEPTHS
September 28, 1978 to October 1, 1978



BEAUFORT SEA STORM VERIFICATION

GRID POINT 358 - EXPLORER I, UKALERK - WR 192
 September 28 1978 to October 1, 1978

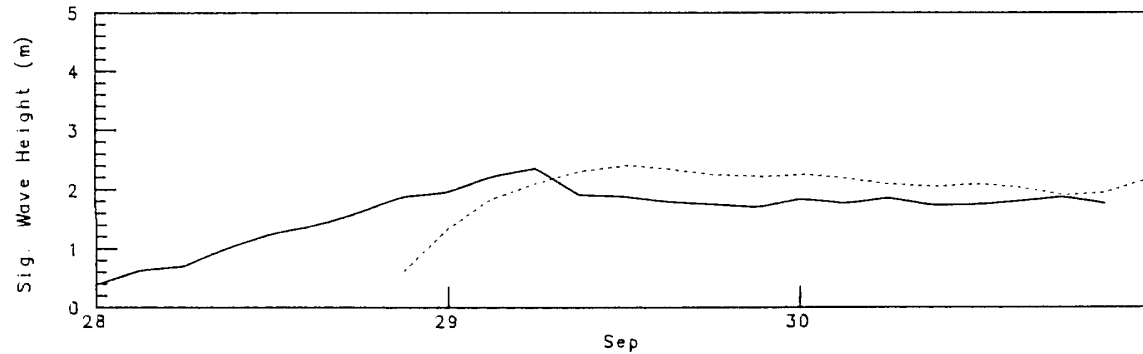
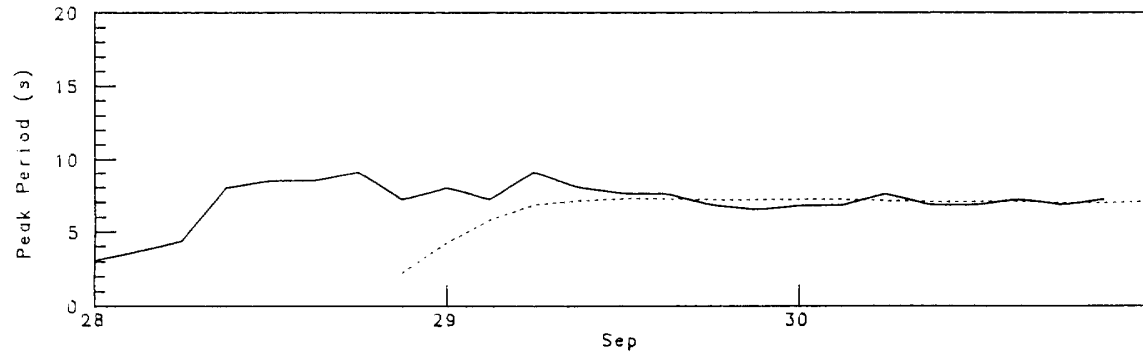
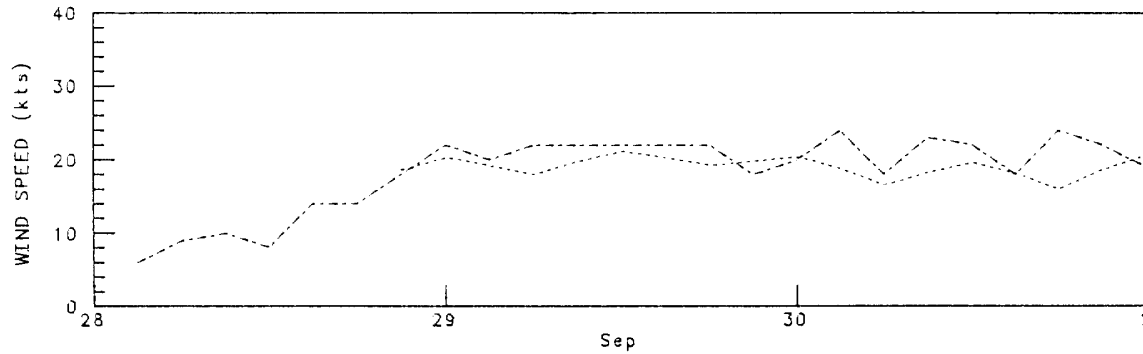
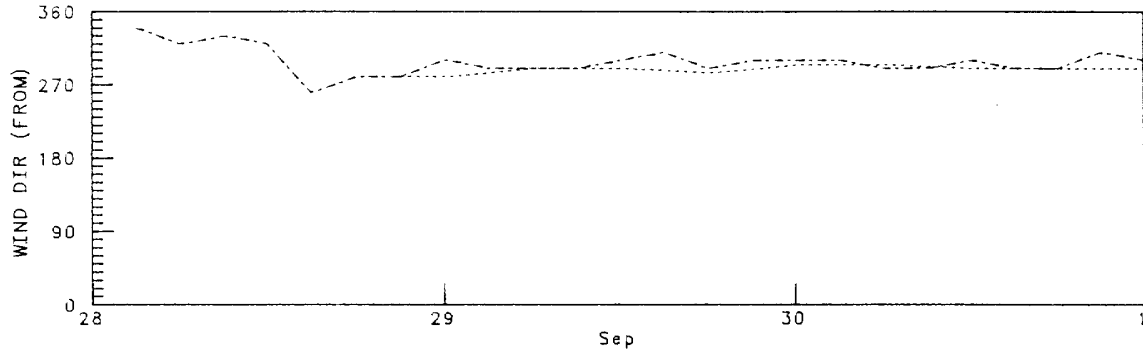
--- Manmar
 Model
 — Waverider



BEAUFORT SEA STORM VERIFICATION

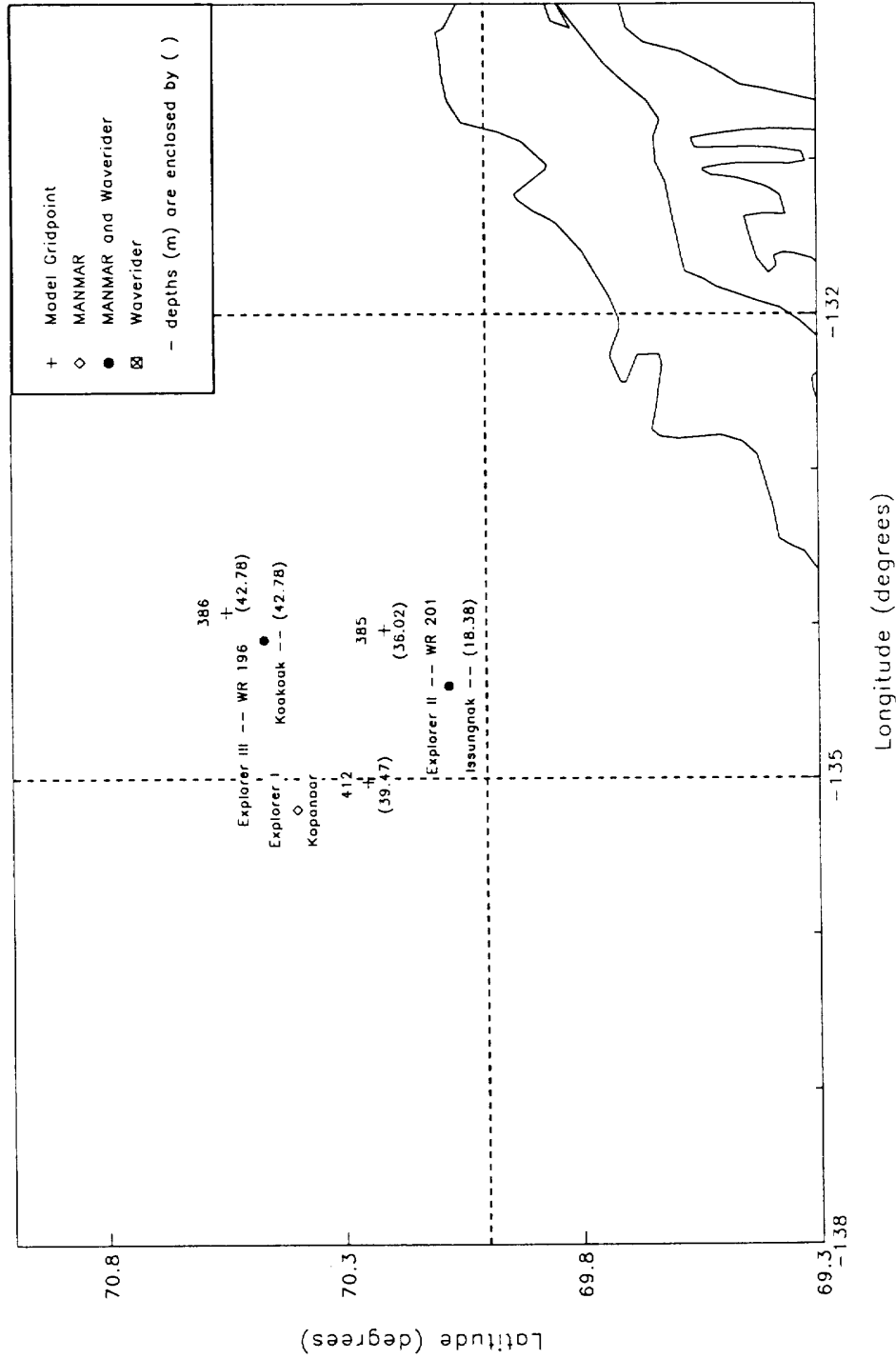
GRID POINT 413 - EXPLORER I, KOPANOAR - WR 193
September 28, 1978 to October 1, 1978

--- Manmar
--- Model
— Waverider



BEAUFORT SEA HINDCAST

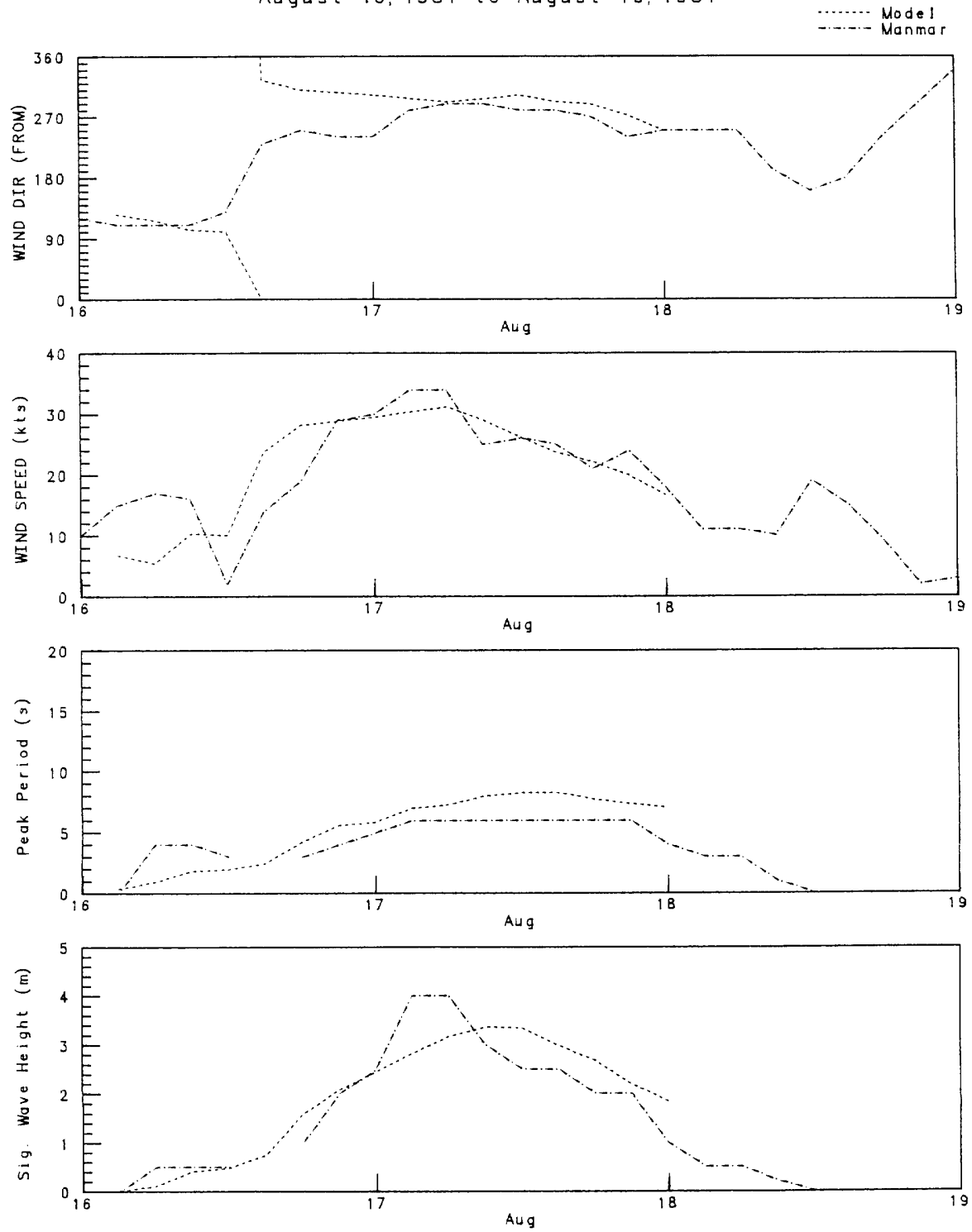
MANMAR, WAVERIDER, AND MODEL GRID POINT LOCATIONS & DEPTHS
August 16, 1981 to August 19, 1981



BEAUFORT SEA STORM VERIFICATION

GRID POINT 412 - EXPLORER I, KOPANOAR

August 16, 1981 to August 19, 1981

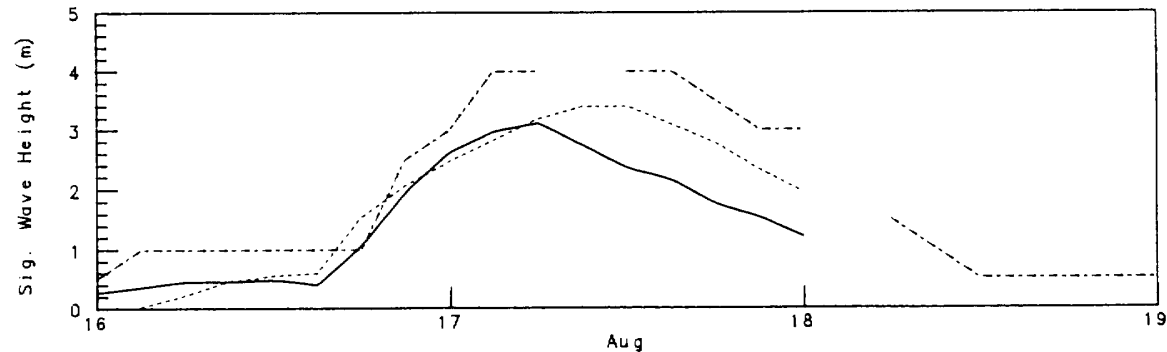
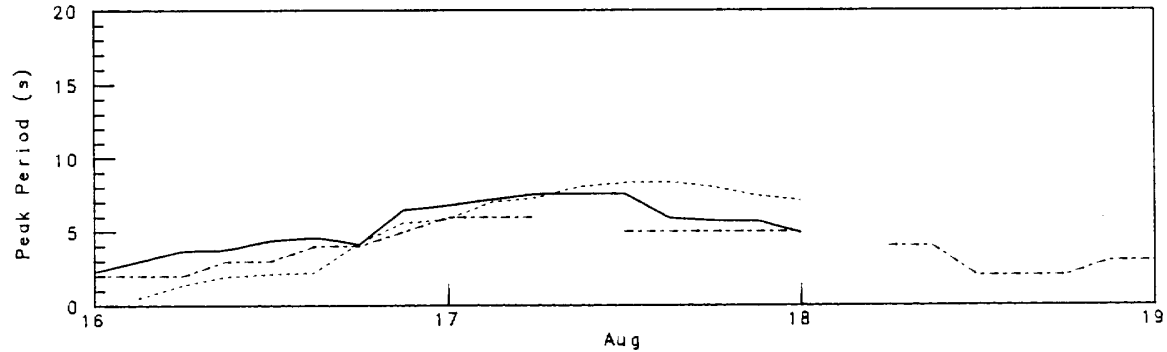
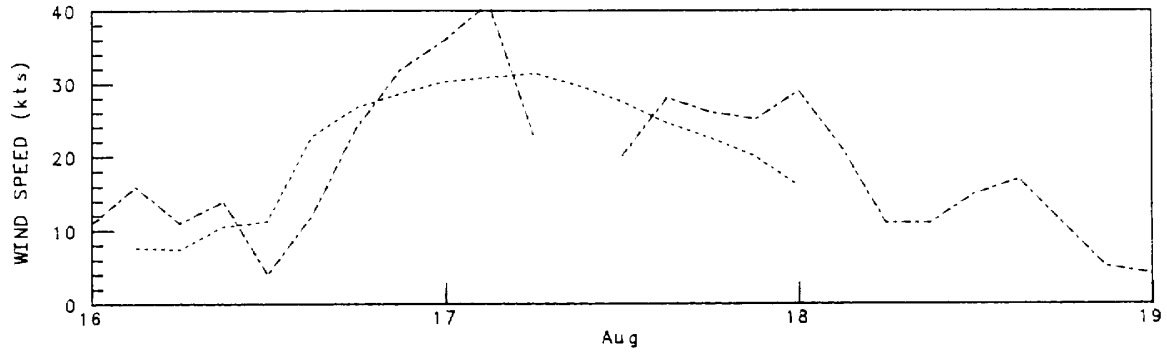
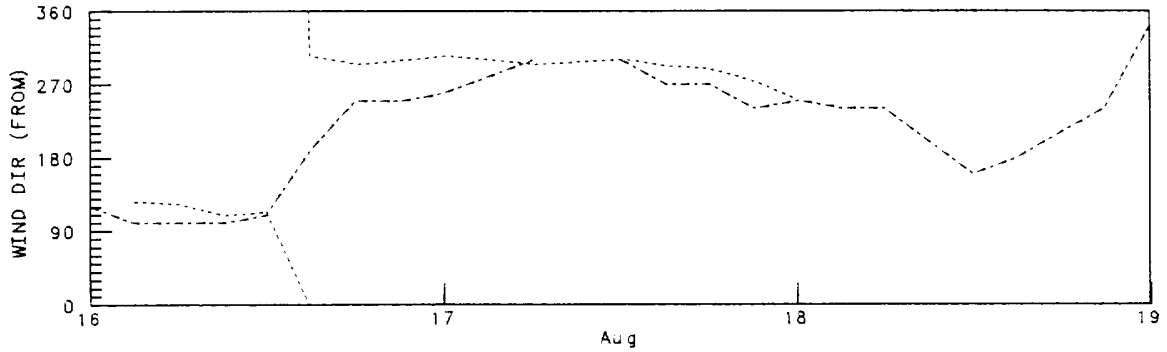


BEAUFORT SEA STORM VERIFICATION

GRID POINT 385 - EXPLORER II, ISSUNGNAK - WR 201

August 16, 1981 to August 19, 1981

--- Manmar
 - - - Model
 — Waverider

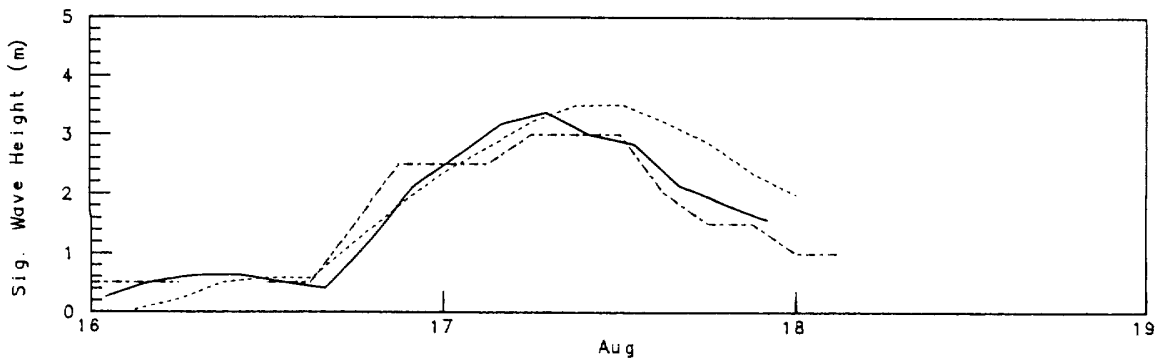
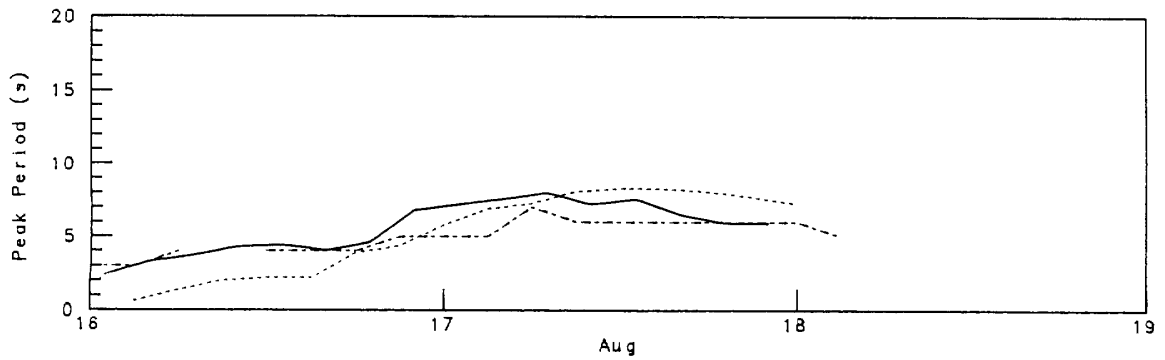
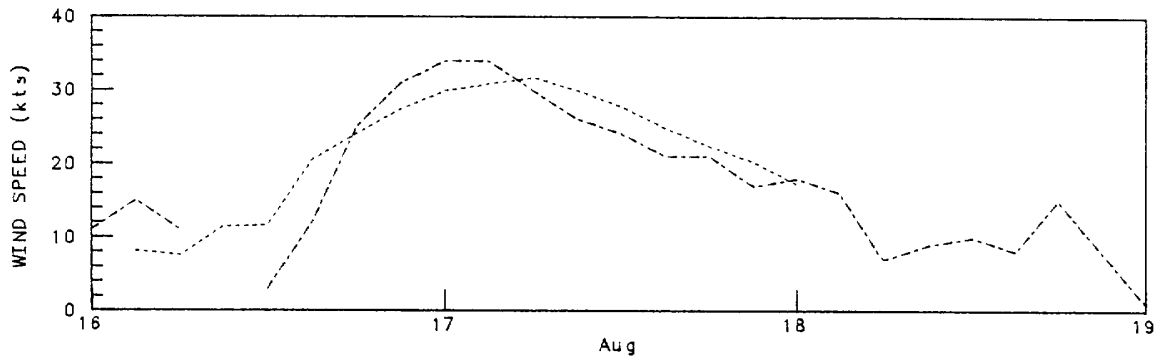
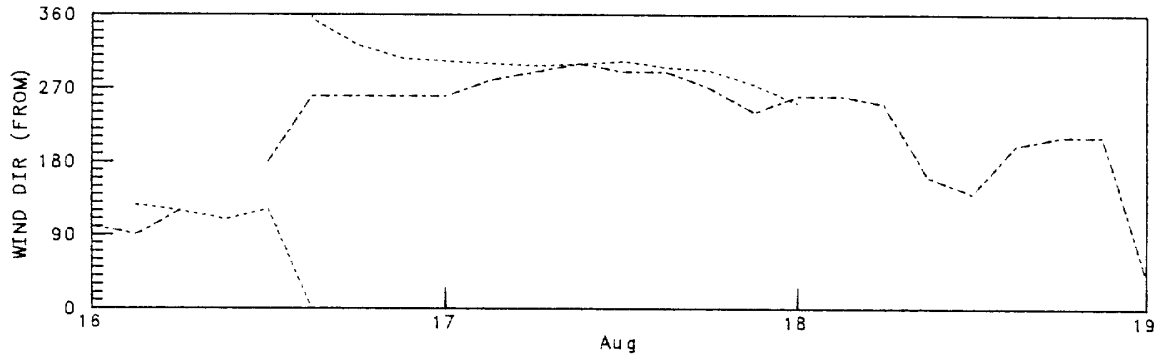


BEAUFORT SEA STORM VERIFICATION

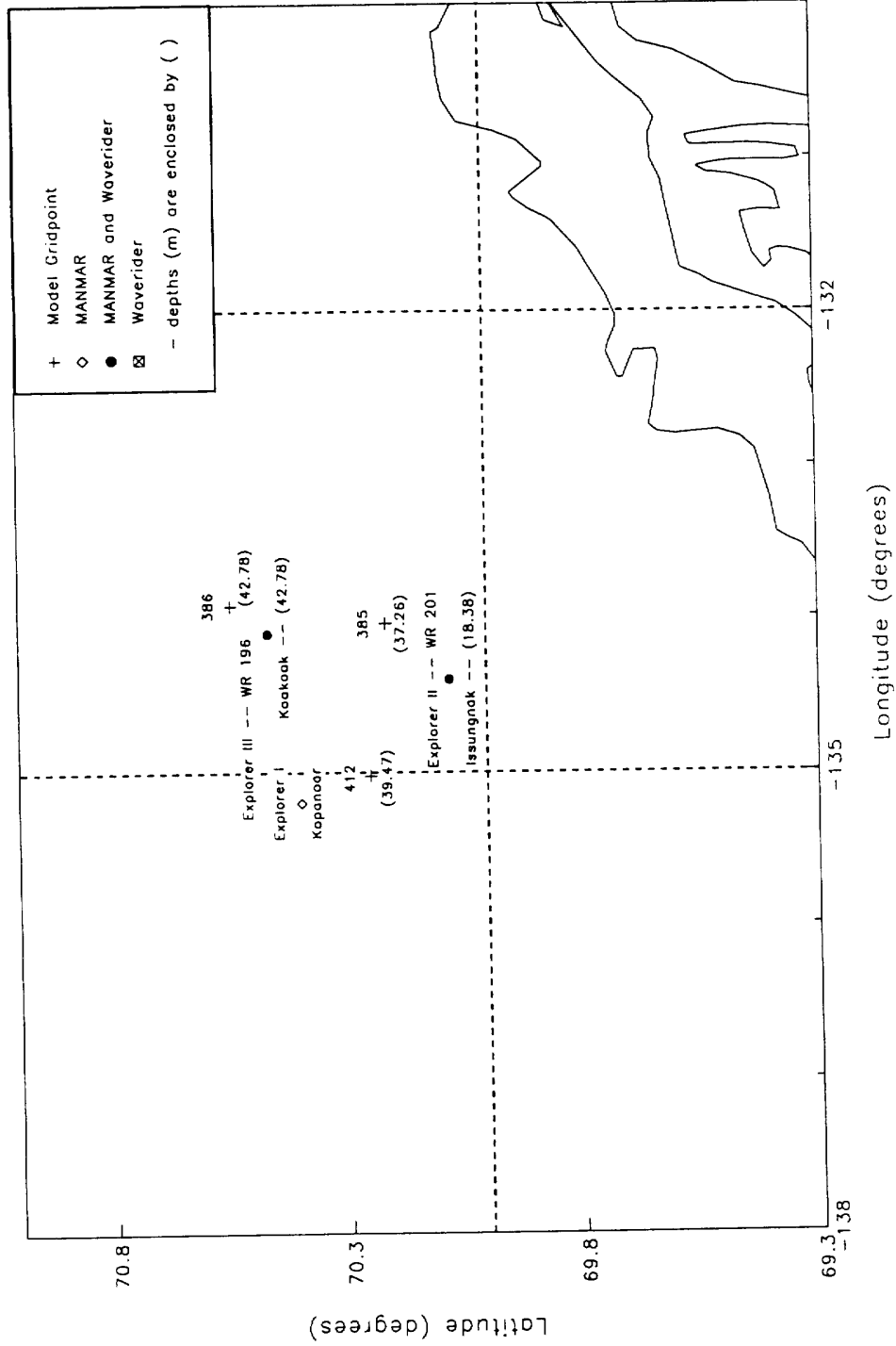
GRID POINT 386 - EXPLORER III, KOAKOAK - WR 196

August 16, 1981 to August 19, 1981

--- Manmar
 - - - Model
 — Waverider



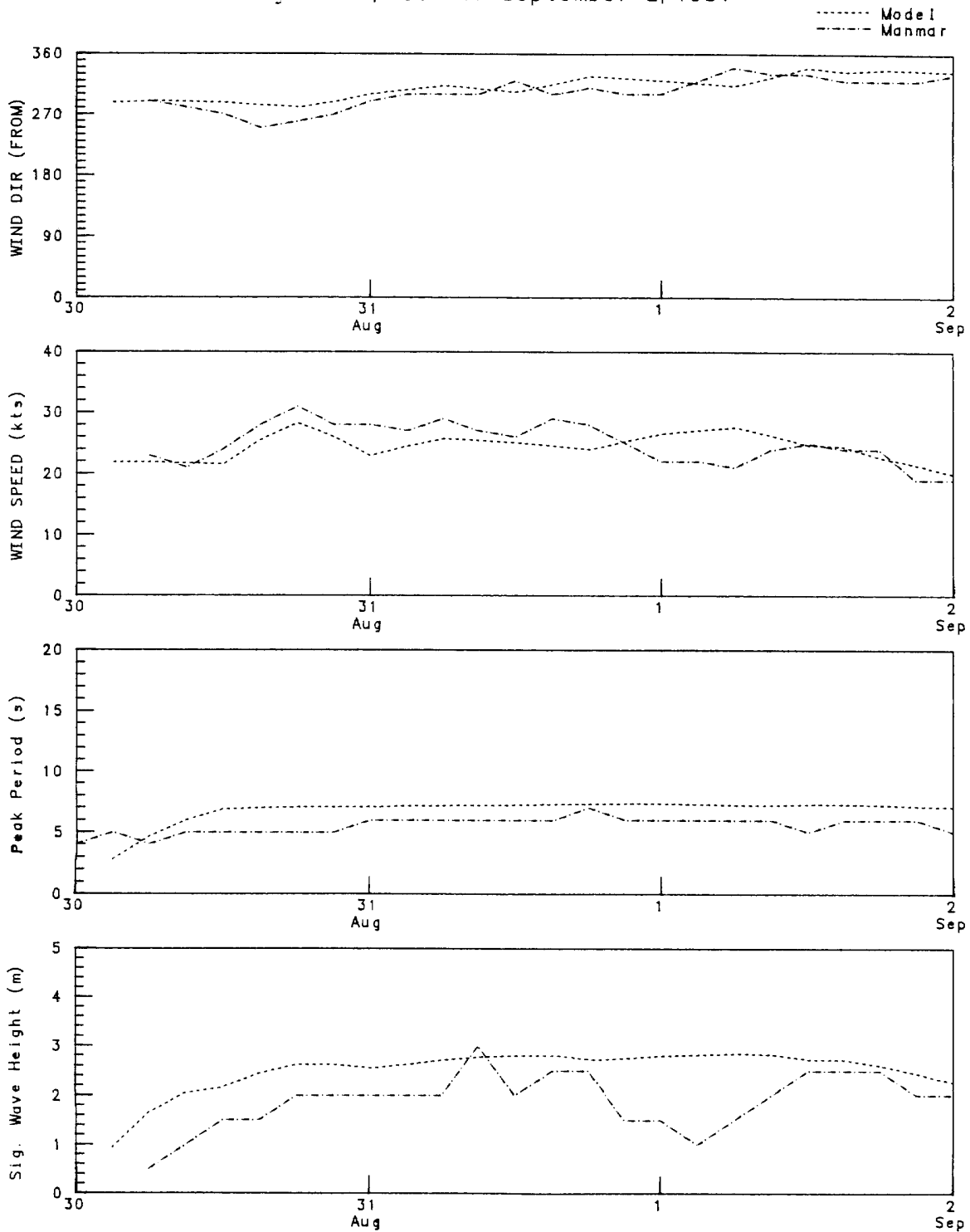
BEAUFORT SEA HINDCAST
 MANMAR, WAVERIDER, AND MODEL GRID POINT LOCATIONS & DEPTHS
 August 30, 1981 to September 2, 1981



BEAUFORT SEA STORM VERIFICATION

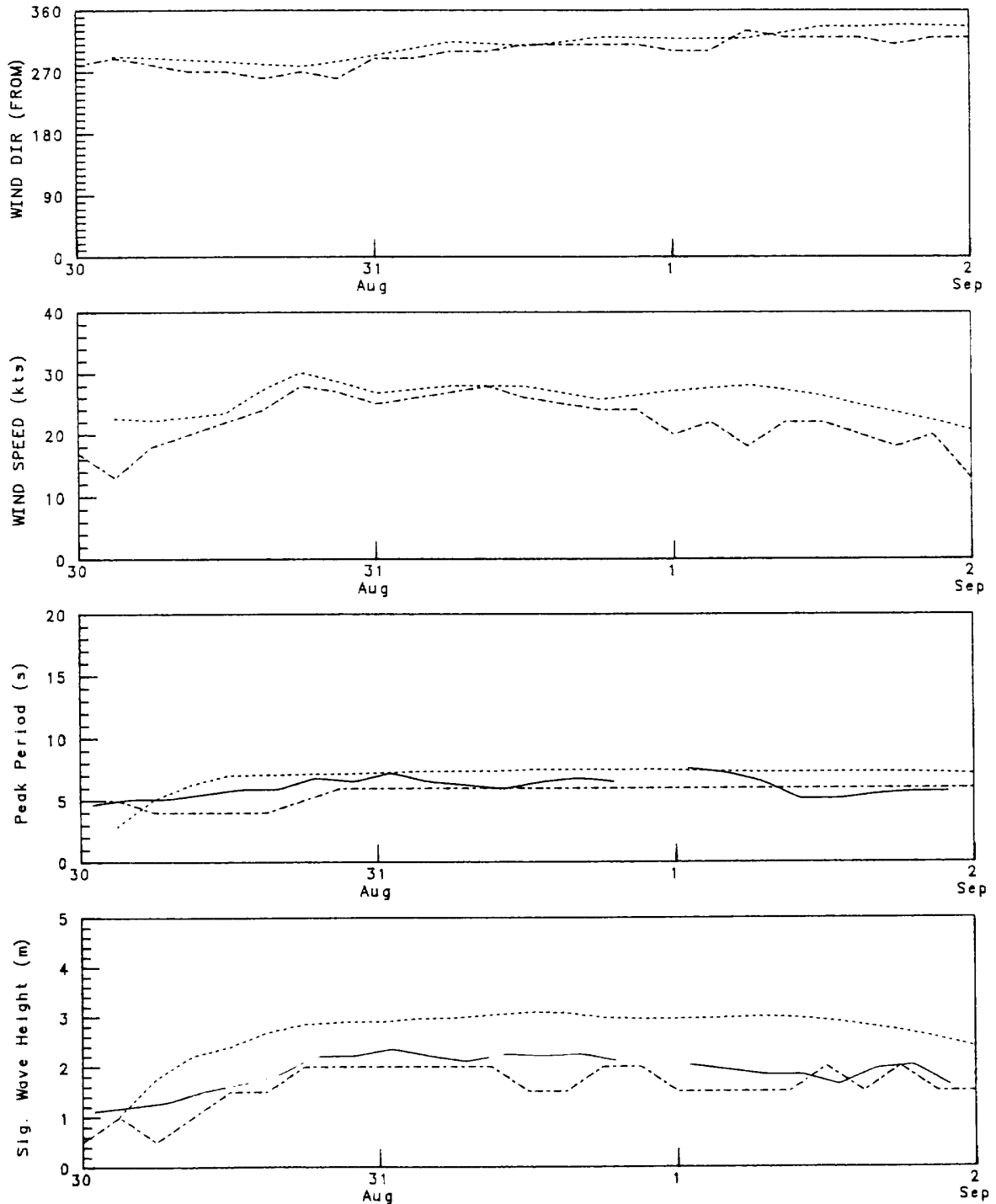
GRID POINT 412 - EXPLORER I, KOPANOAR

August 30, 1981 to September 2, 1981



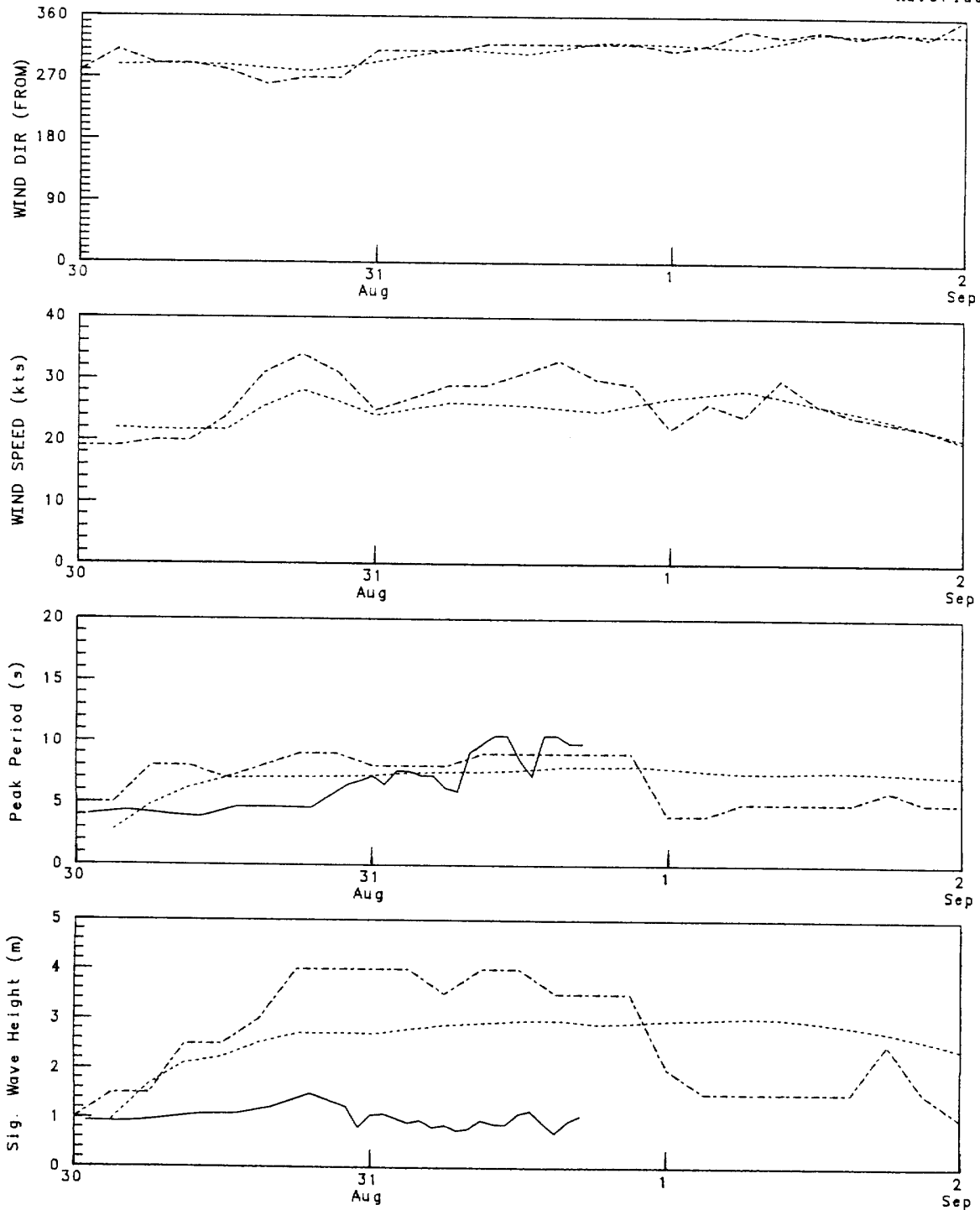
BEAUFORT SEA STORM VERIFICATION
 GRID POINT 386 - EXPLORER III, KOAKOAK - WR 196
 August 30, 1981 to September 2, 1981

----- Manmar
 Model
 _____ Waverider

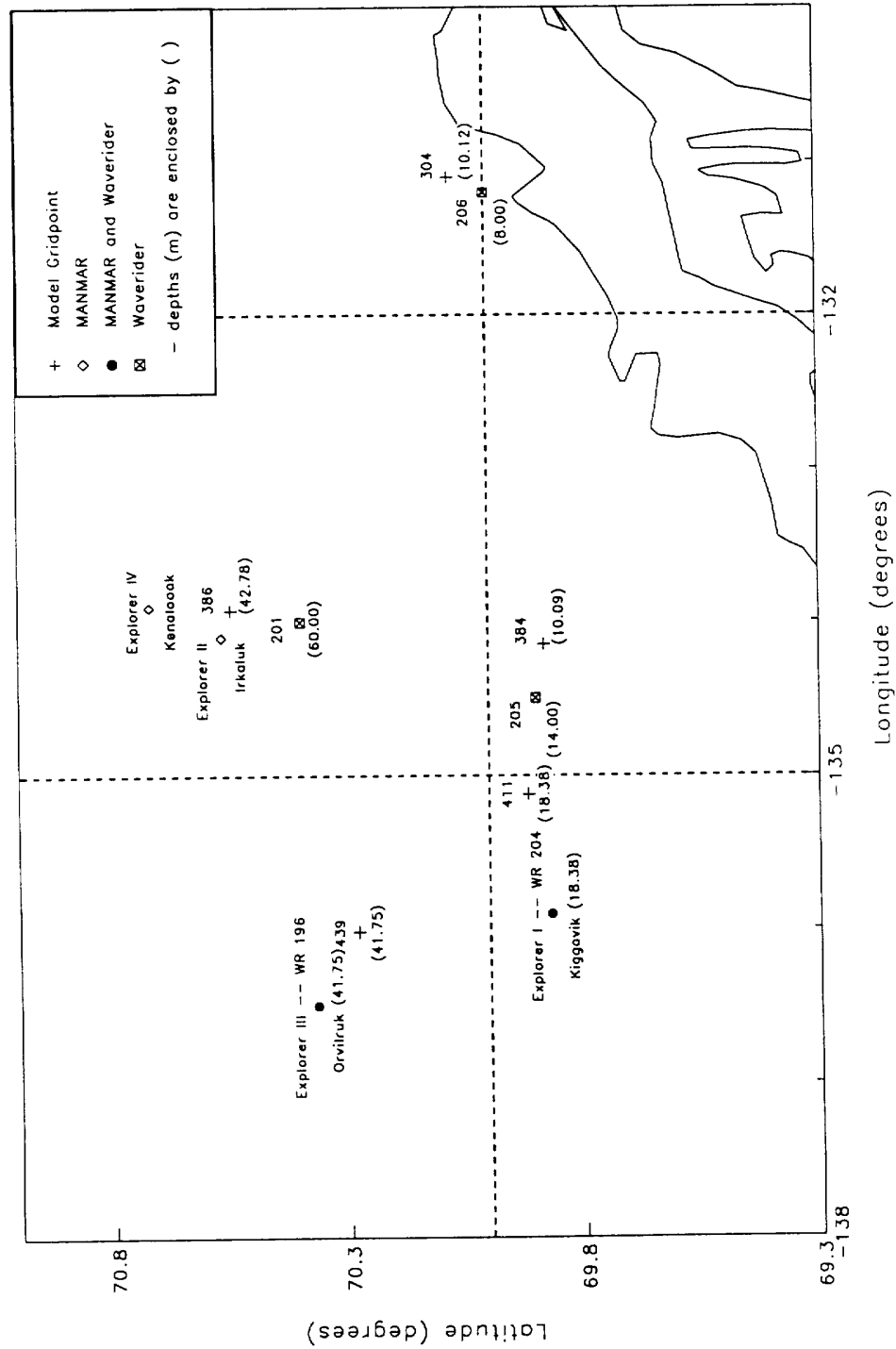


BEAUFORT SEA STORM VERIFICATION
 GRID POINT 385 - EXPLORER II, ISSUNGNAK - WR 201
 August 30, 1981 to September 2, 1981

----- Manmar
 Model
 _____ Waverider



BEAUFORT SEA HINDCAST
 MANMAR, WAVERIDER AND MODEL GRID POINT LOCATIONS & DEPTHS
 September 20, 1982 to September 23, 1982

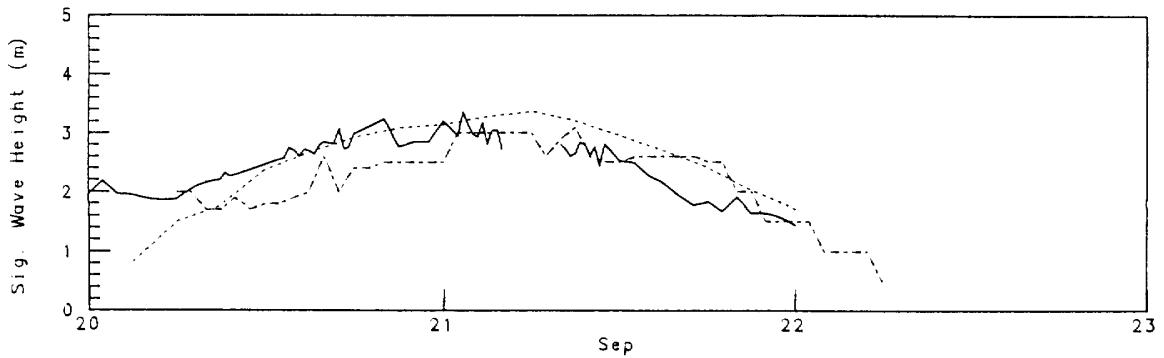
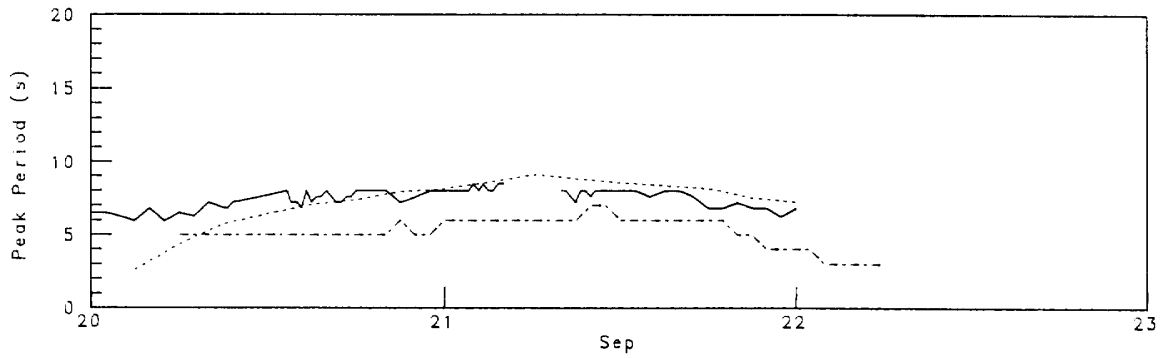
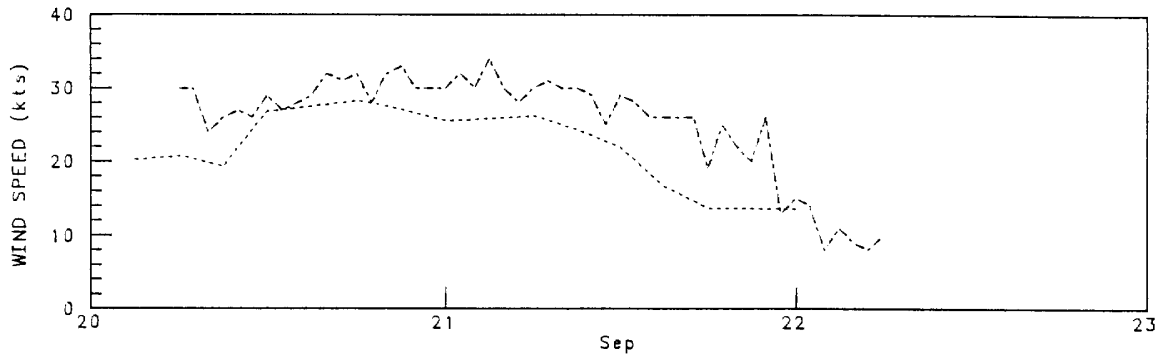
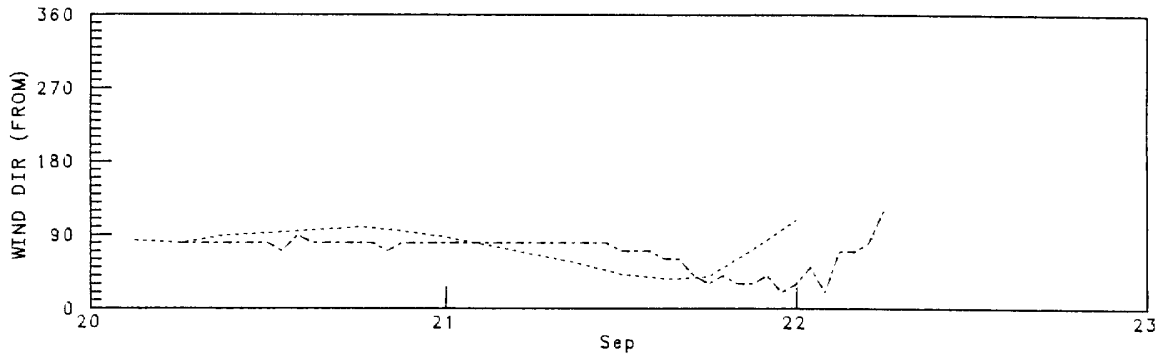


BEAUFORT SEA STORM VERIFICATION

GRID POINT 439 - EXPLORER III, ORVILRUK - WR 196

September 20, 1982 to September 23, 1982

----- Manmar
 Model
 _____ Waverider

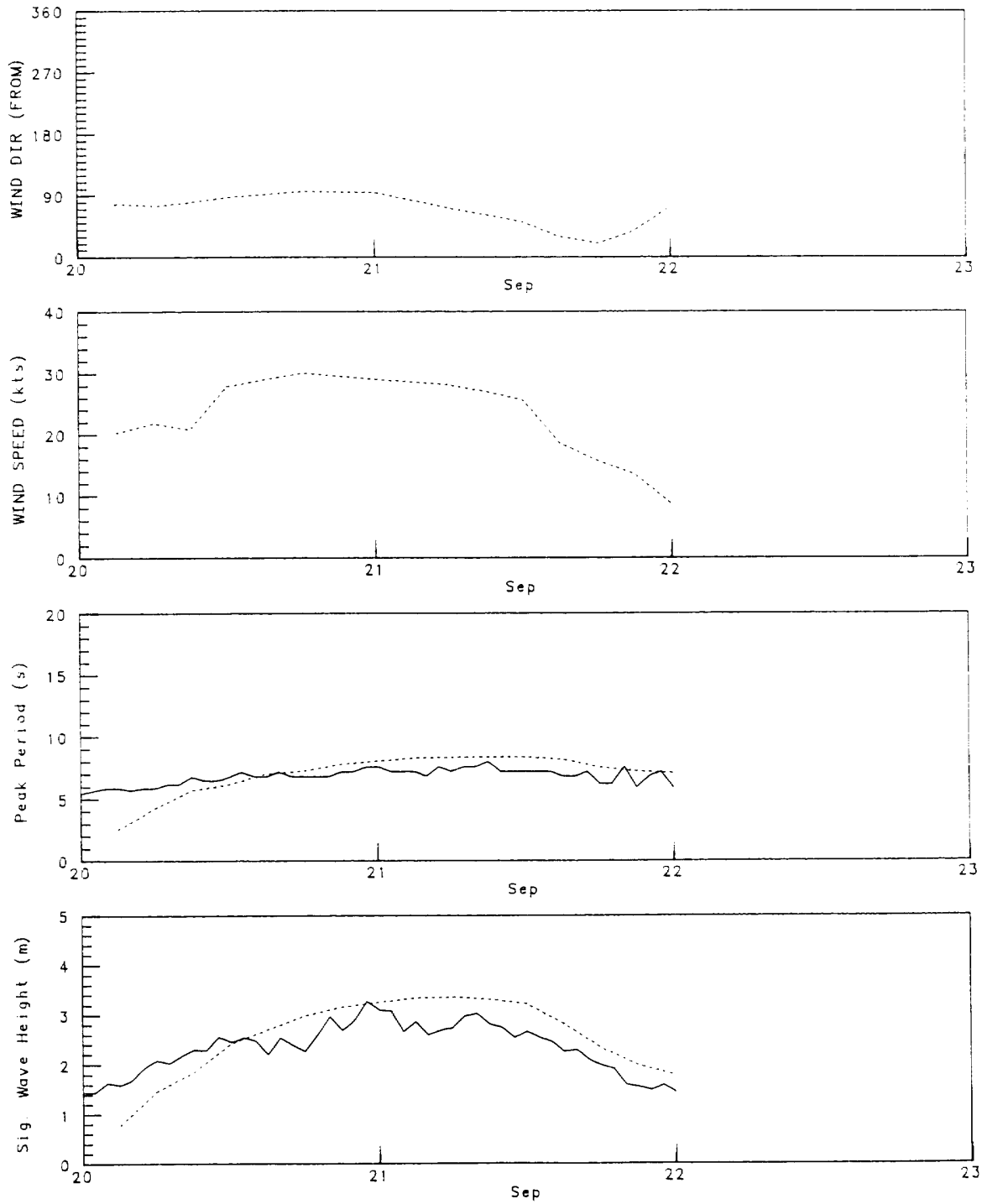


BEAUFORT SEA STORM VERIFICATION

GRID POINT 386 - WR 201

September 20, 1982 to September 23, 1982

..... Model
 ——— Waverider

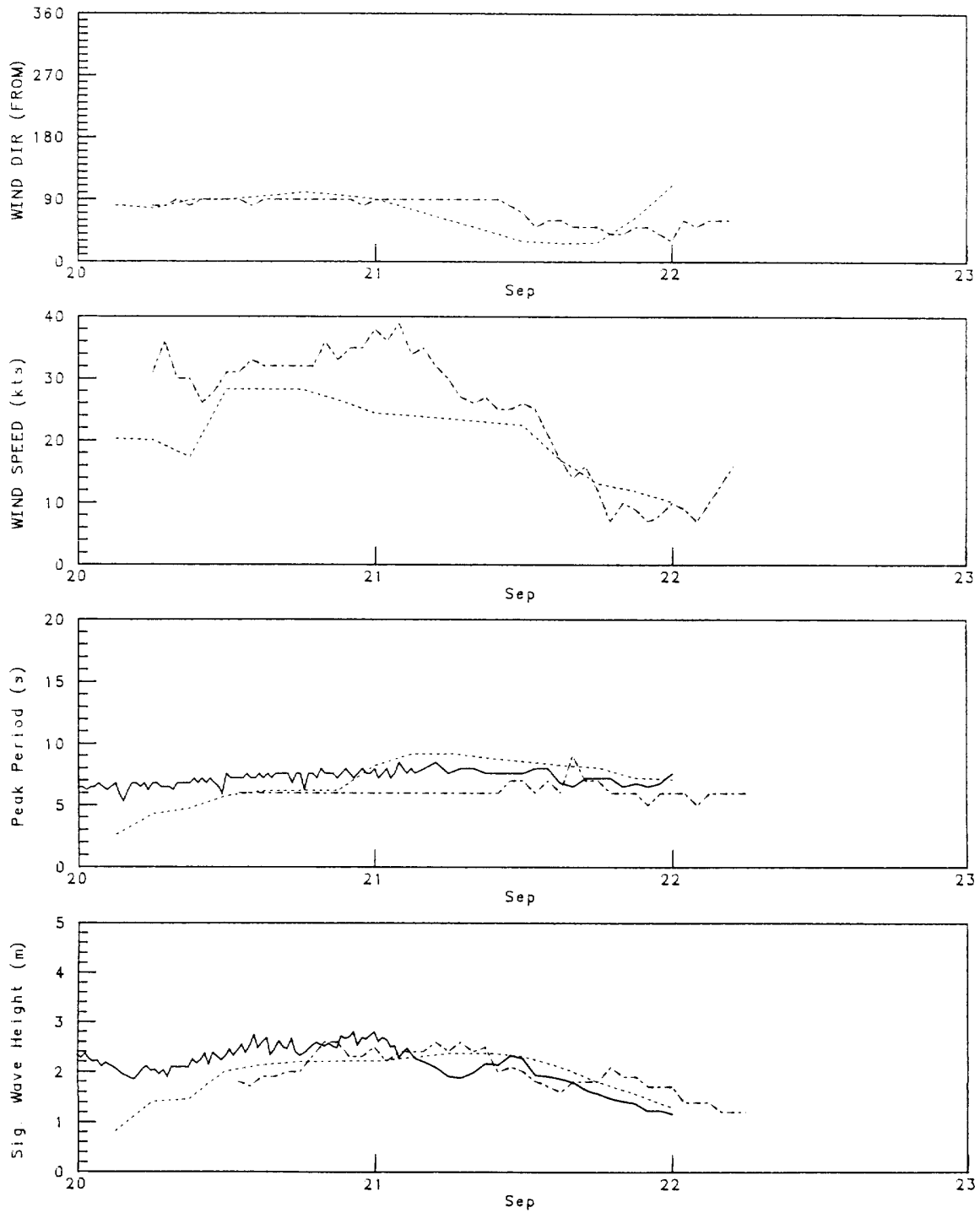


BEAUFORT SEA STORM VERIFICATION

GRID POINT 411 - EXPLORER I, KIGGAVIK - WR 204

September 20, 1982 to September 23, 1982

Manmar
Model
Waverider

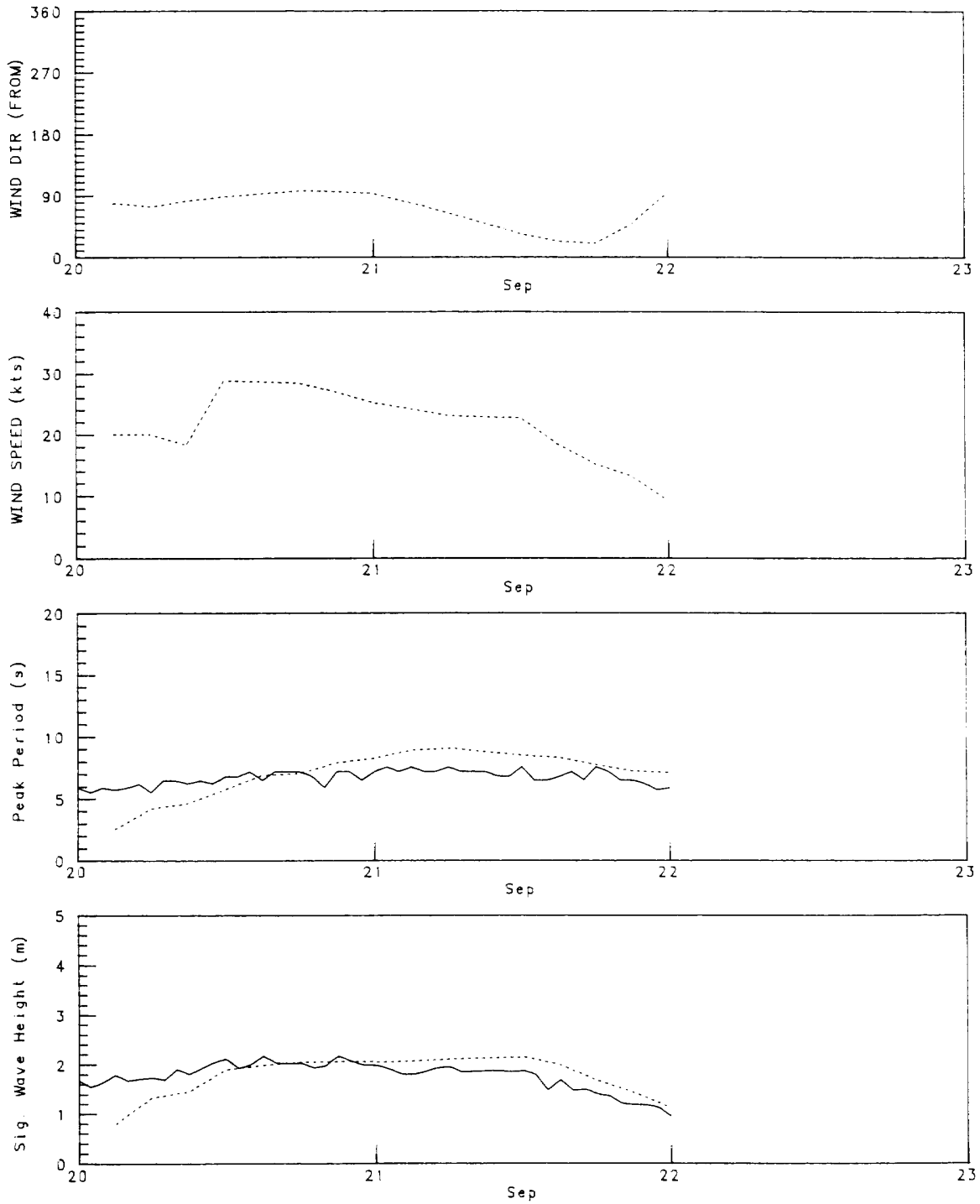


BEAUFORT SEA STORM VERIFICATION

GRID POINT 384 - WR 205

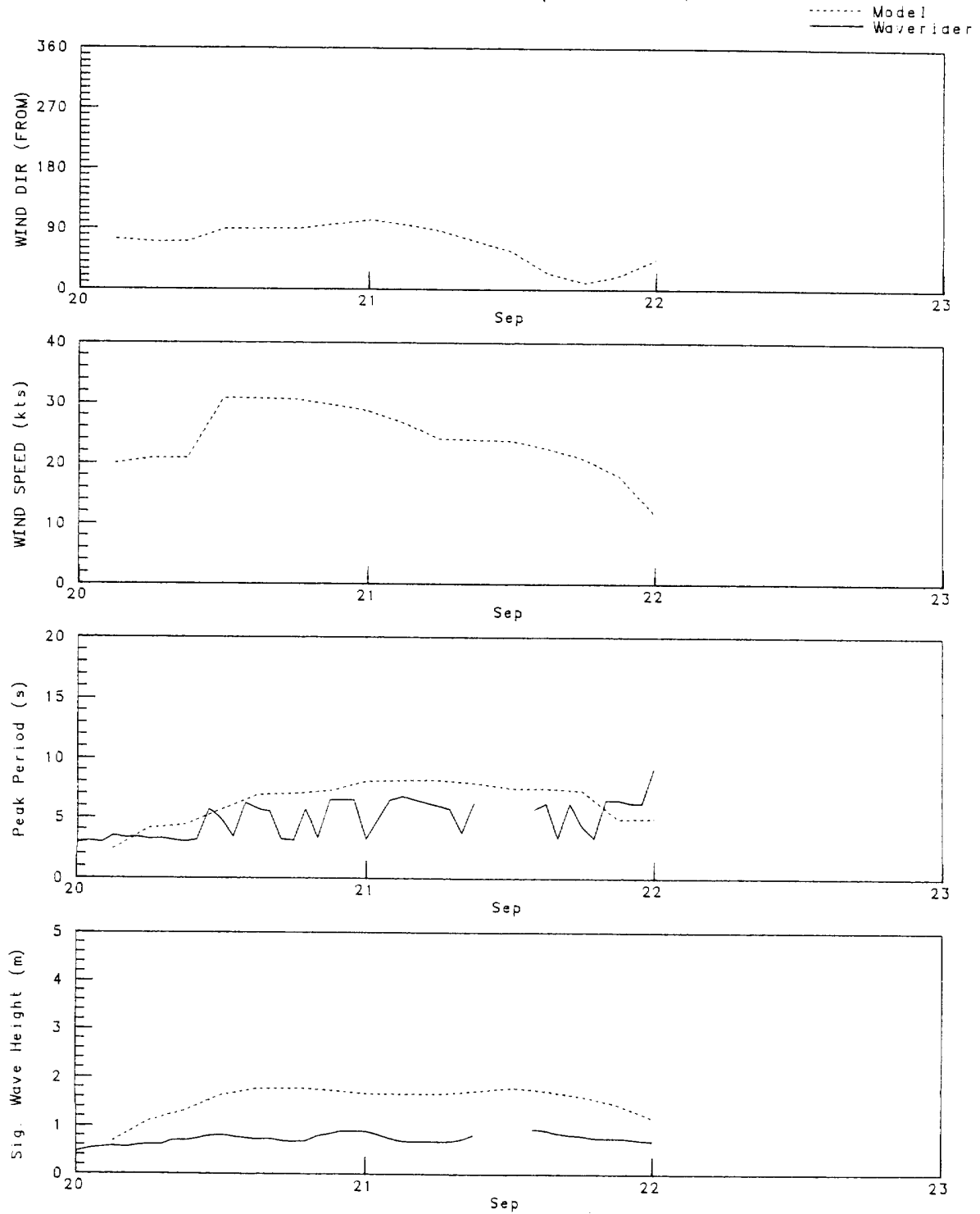
September 20, 1982 to September 23, 1982

..... Model
 ——— Waverider



BEAUFORT SEA STORM VERIFICATION

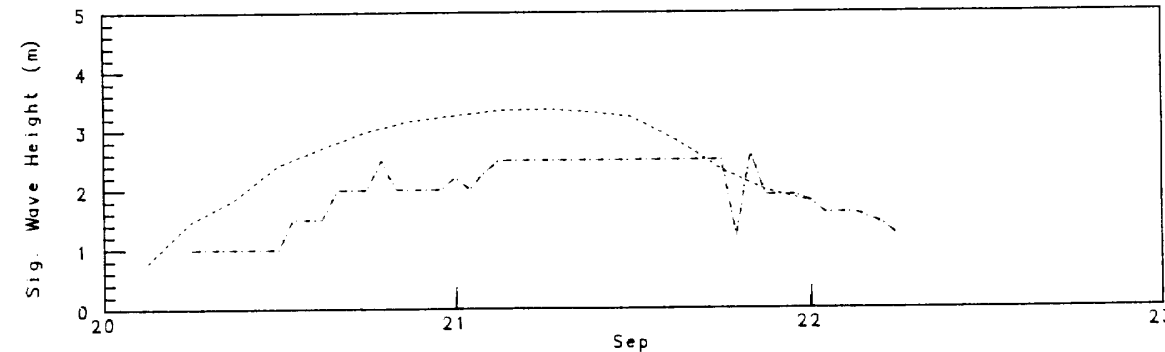
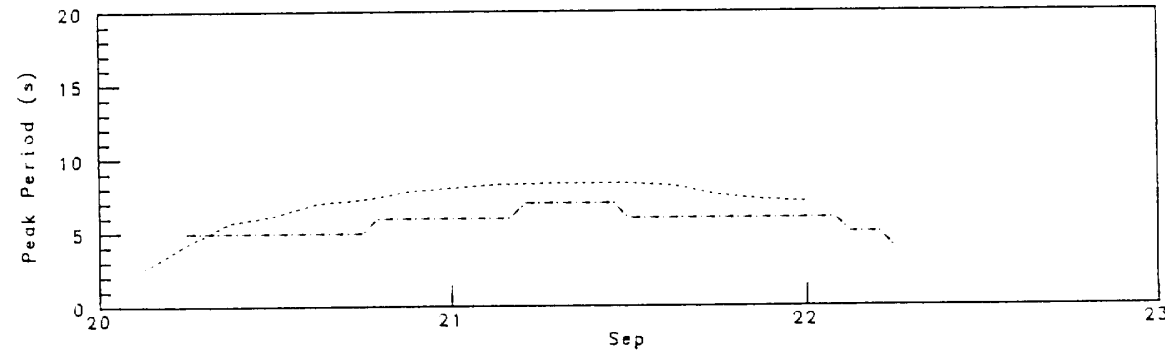
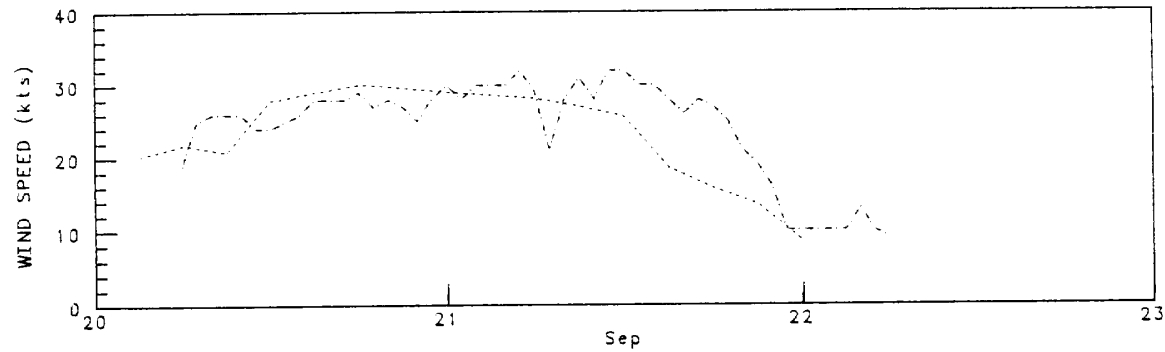
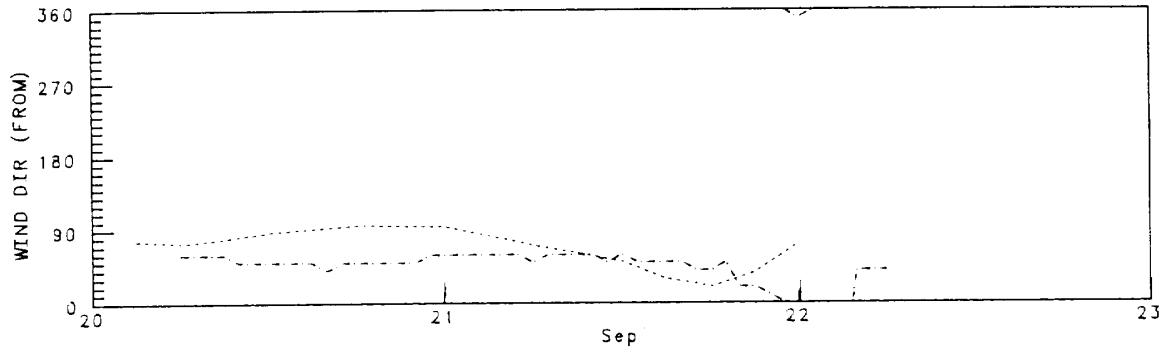
GRID POINT 304 - WR 206
September 20, 1982 to September 23, 1982



BEAUFORT SEA STORM VERIFICATION

GRID POINT 386 - EXPLORER II, IRKALUK
 September 20, 1982 to September 23, 1982

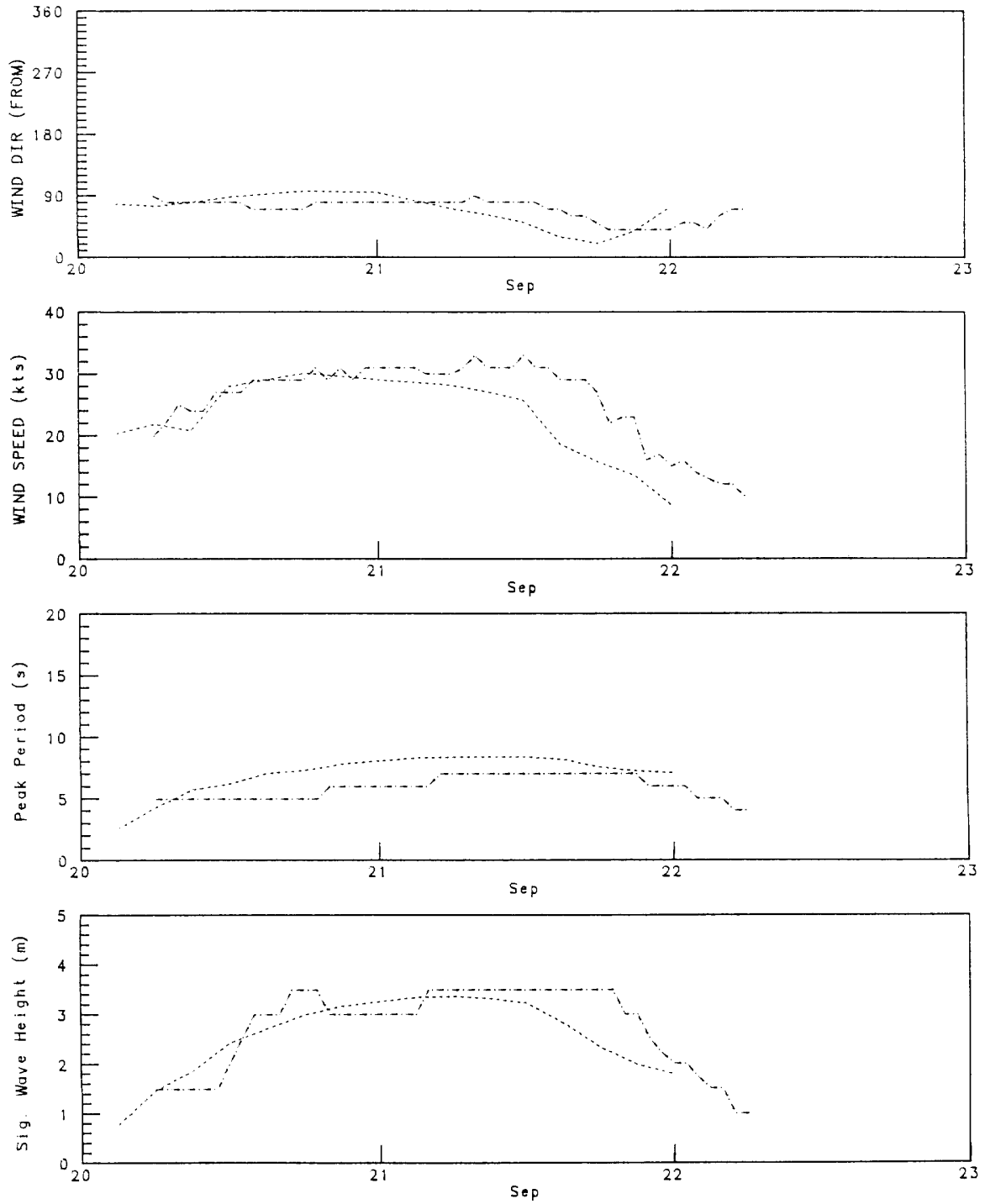
Model
 Manmar



BEAUFORT SEA STORM VERIFICATION

GRID POINT 386 - EXPLORER IV, KENALOOKAK
 September 20, 1982 to September 23, 1982

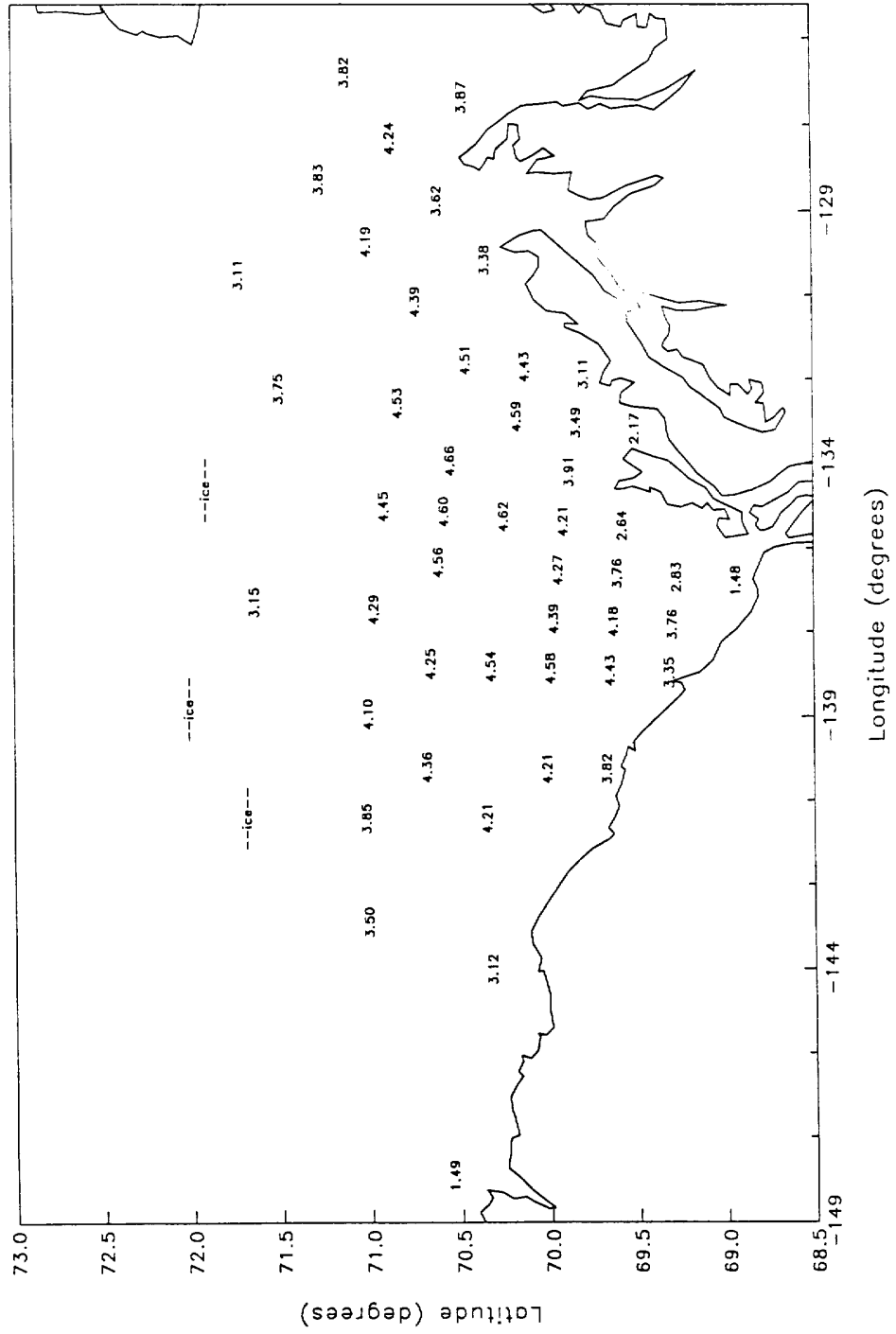
Model
 Manmar



APPENDIX E
WAVE HINDCAST RESULTS
PEAK SIGNIFICANT WAVE HEIGHT FIELDS
FOR TOP 30 STORMS

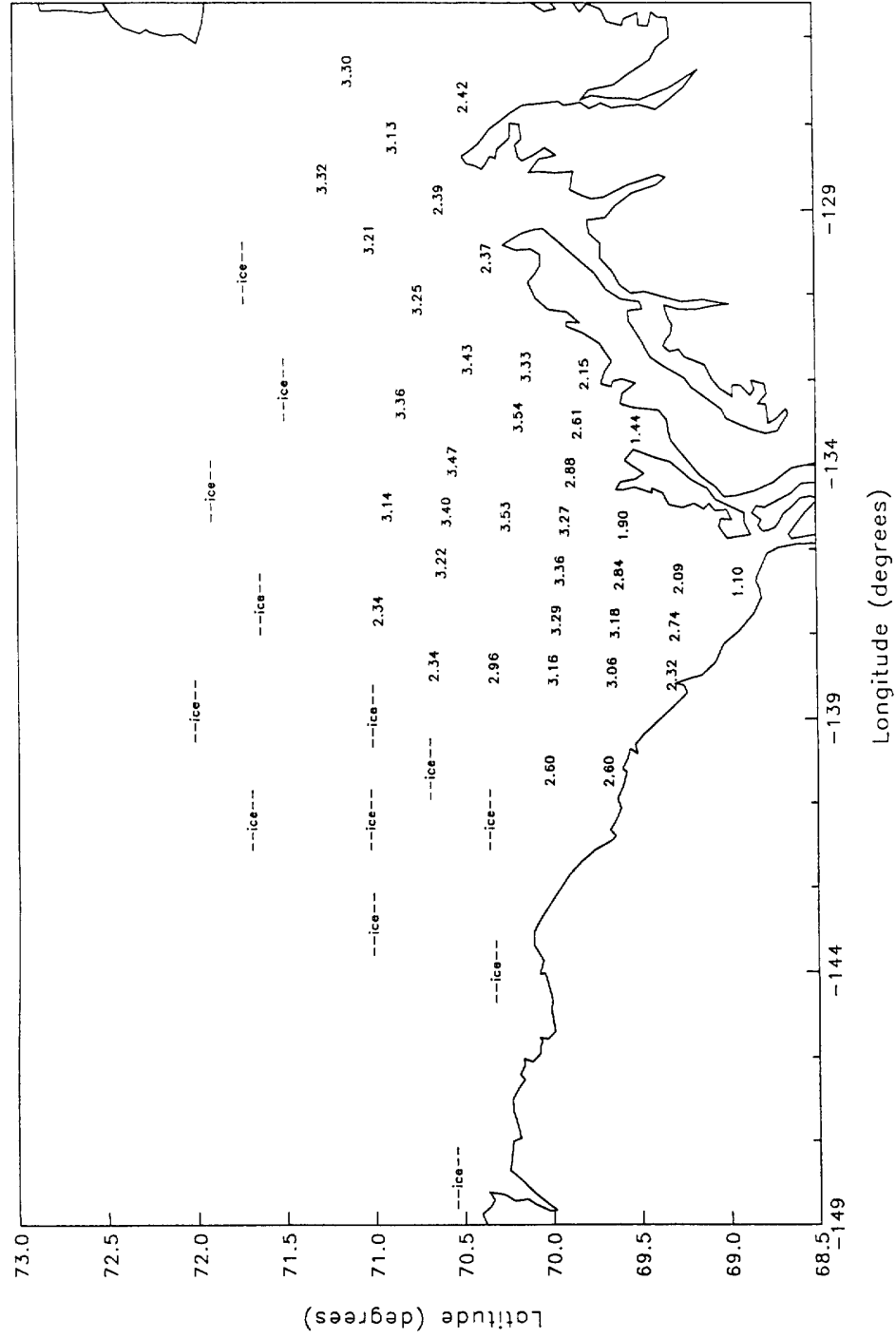
BEAUFORT SEA STORM

7009



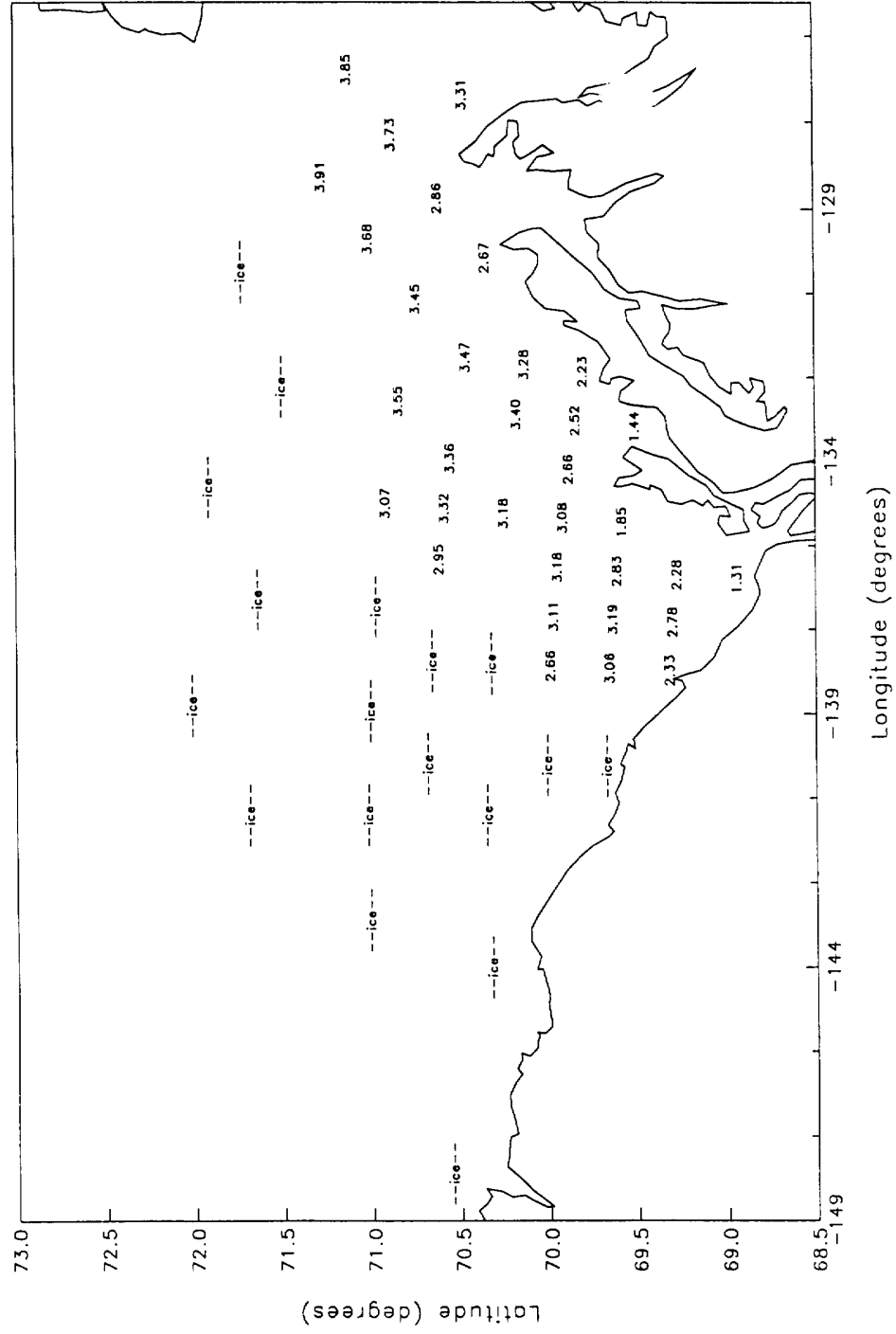
BEAUFORT SEA STORM

7508A



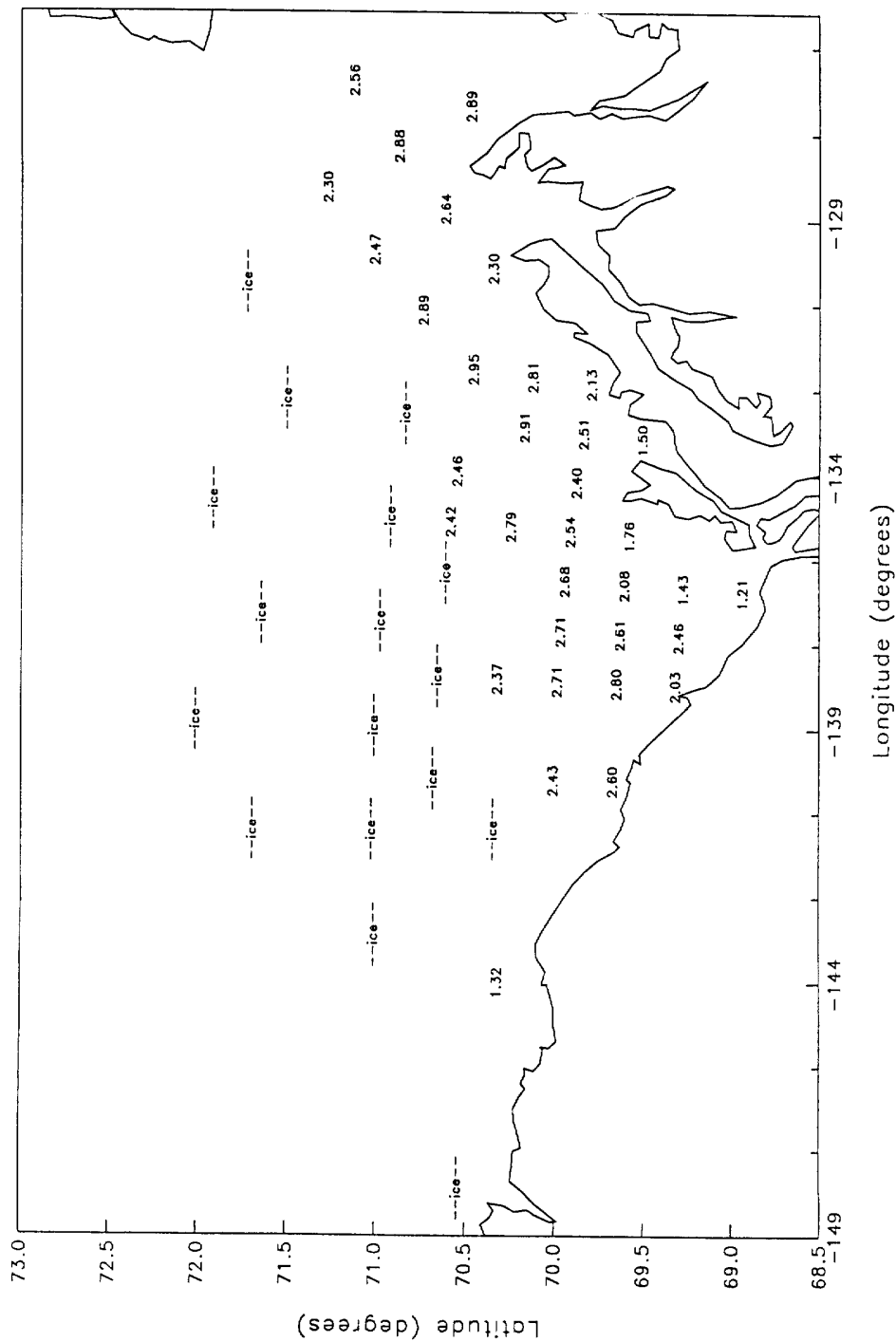
BEAUFORT SEA STORM

7508B



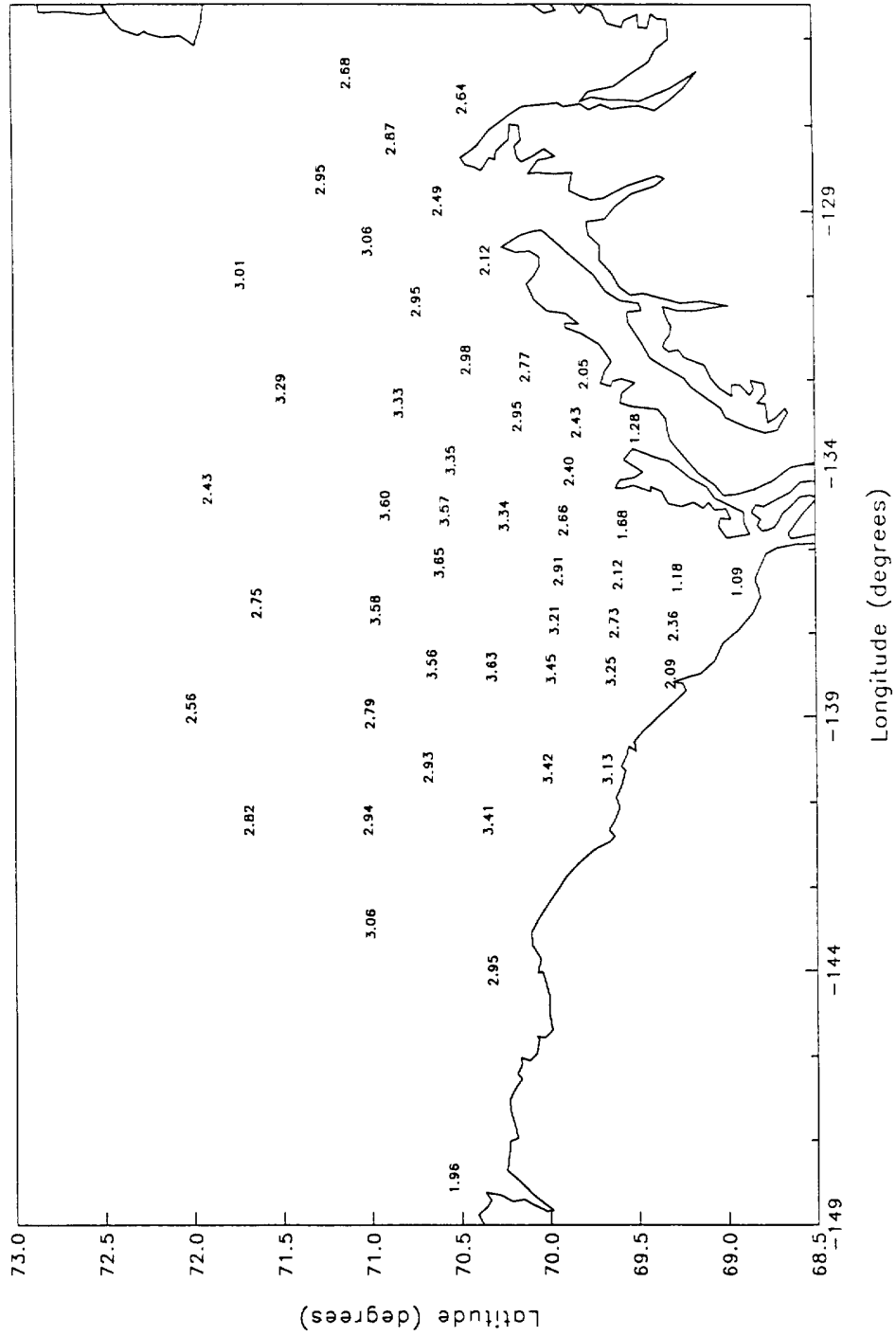
BEAUFORT SEA STORM

7608



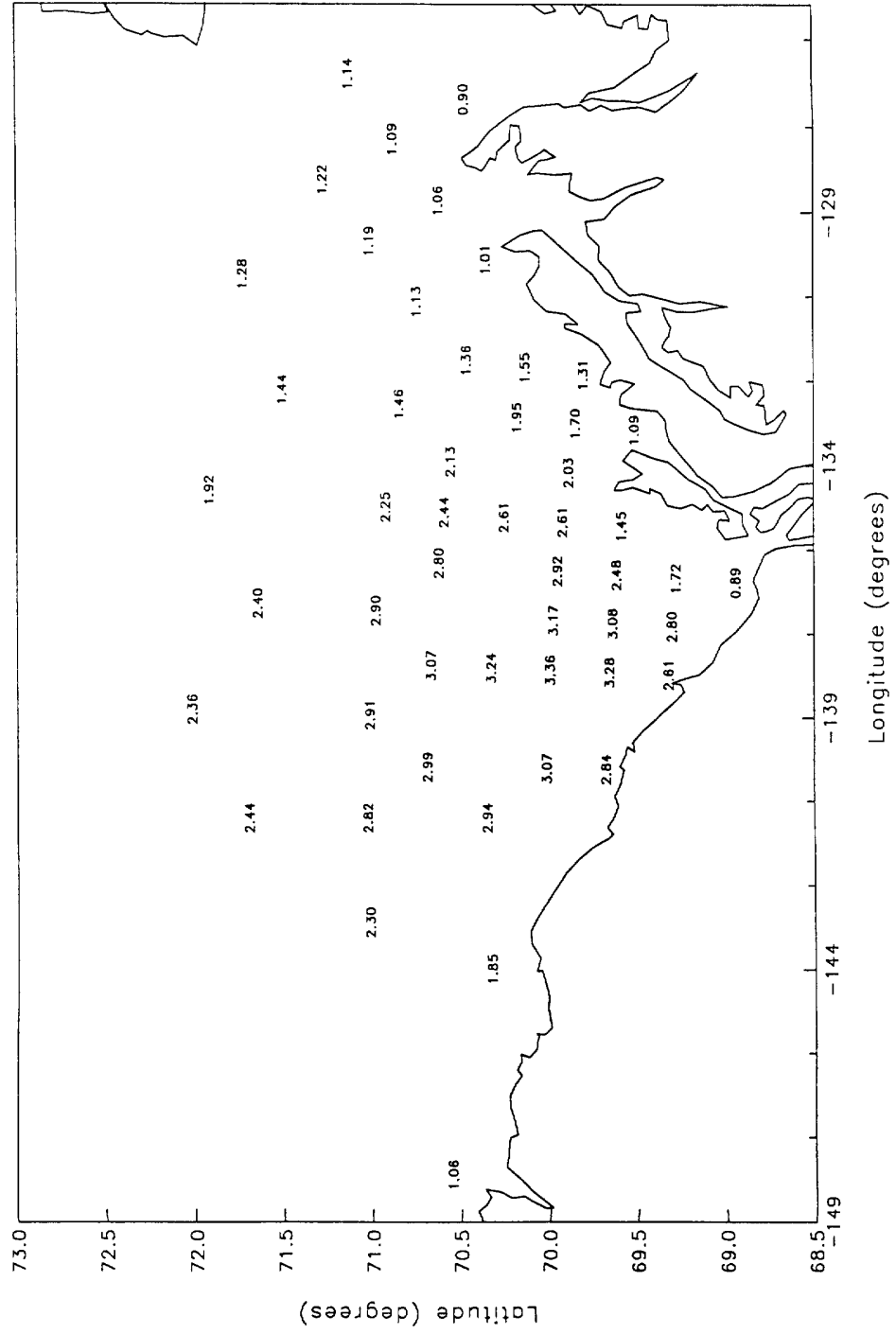
BEAUFORT SEA STORM

7609



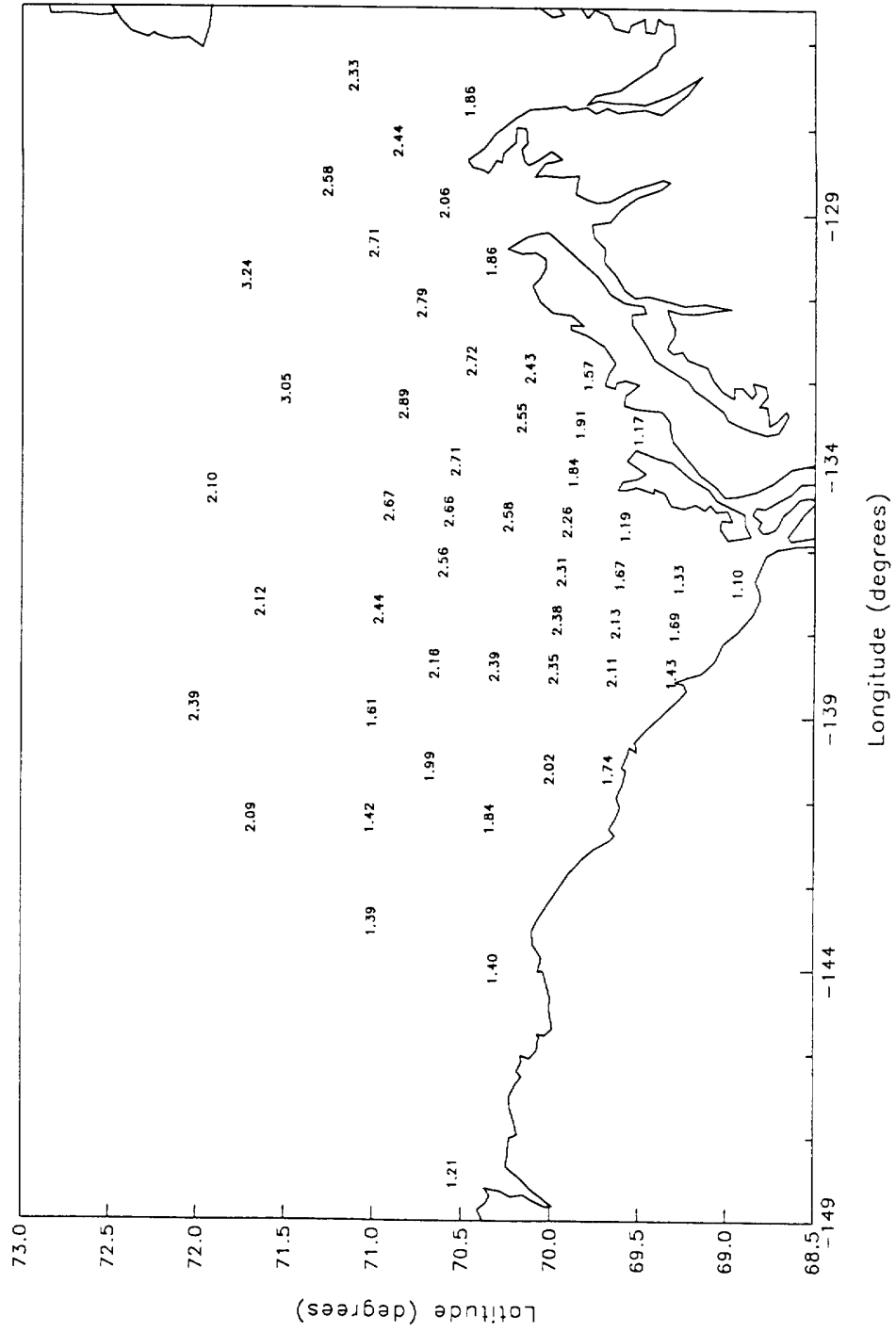
BEAUFORT SEA STORM

7708



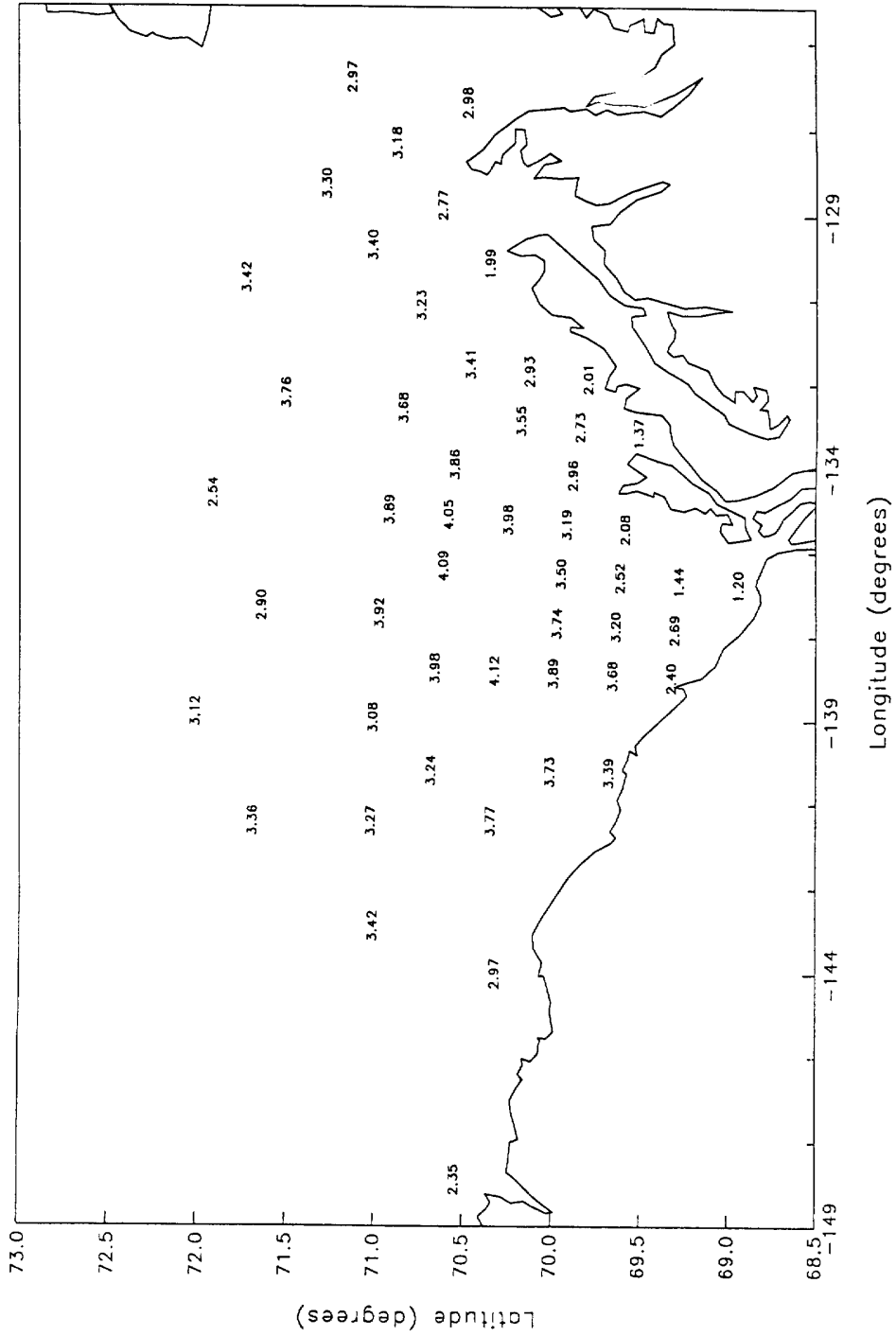
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7709

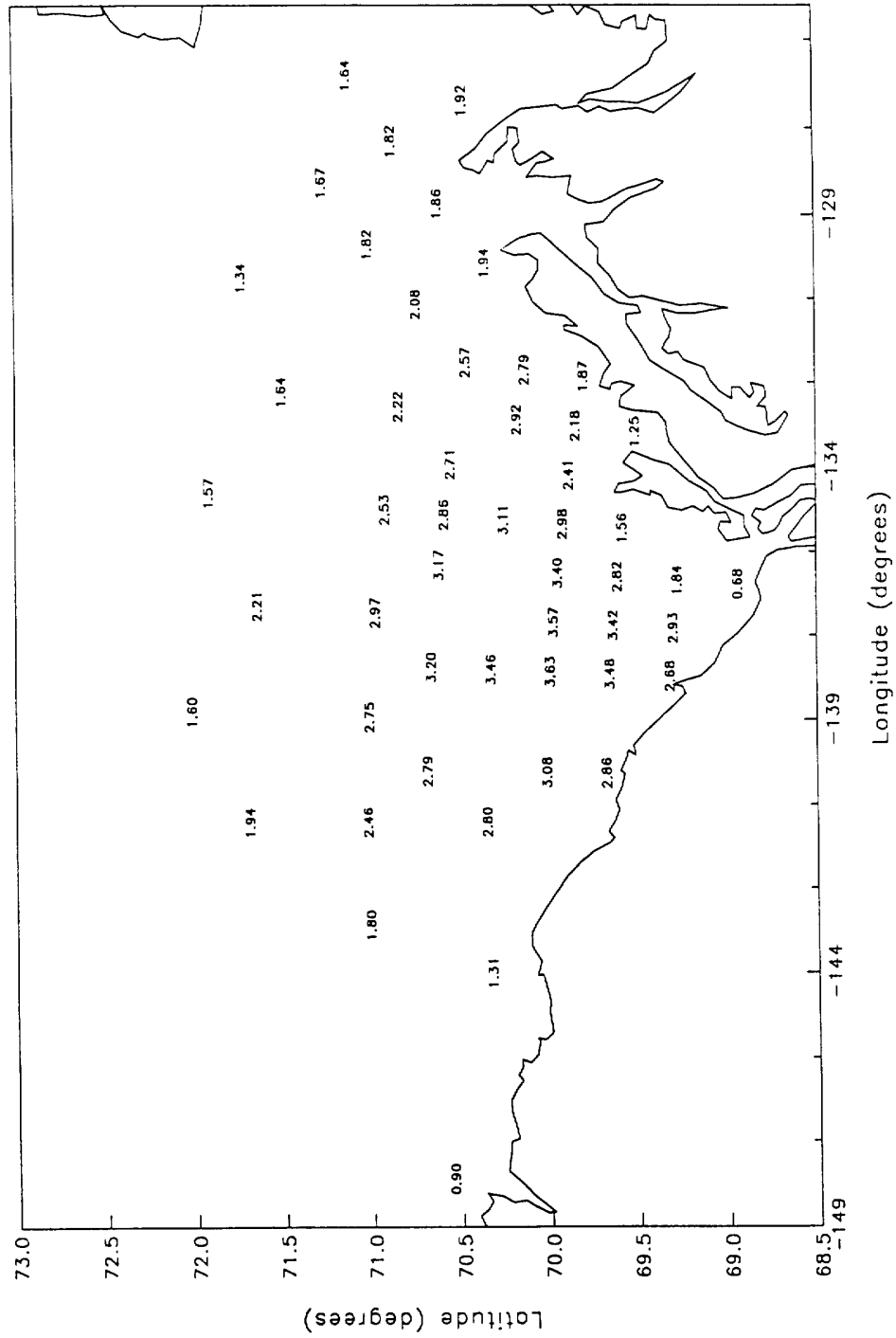


BEAUFORT SEA STORM

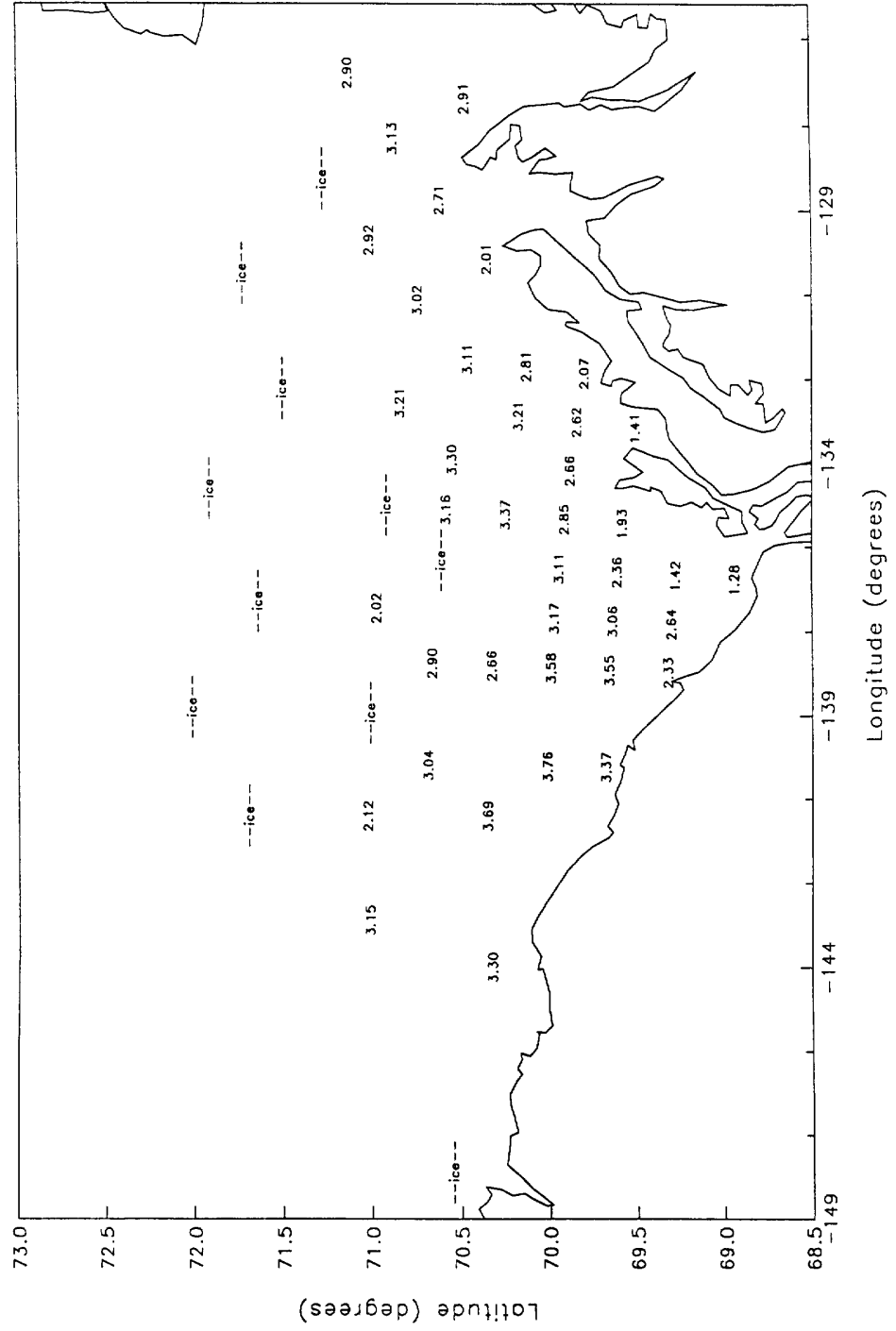
7809



BEAUFORT SEA STORM
7810A

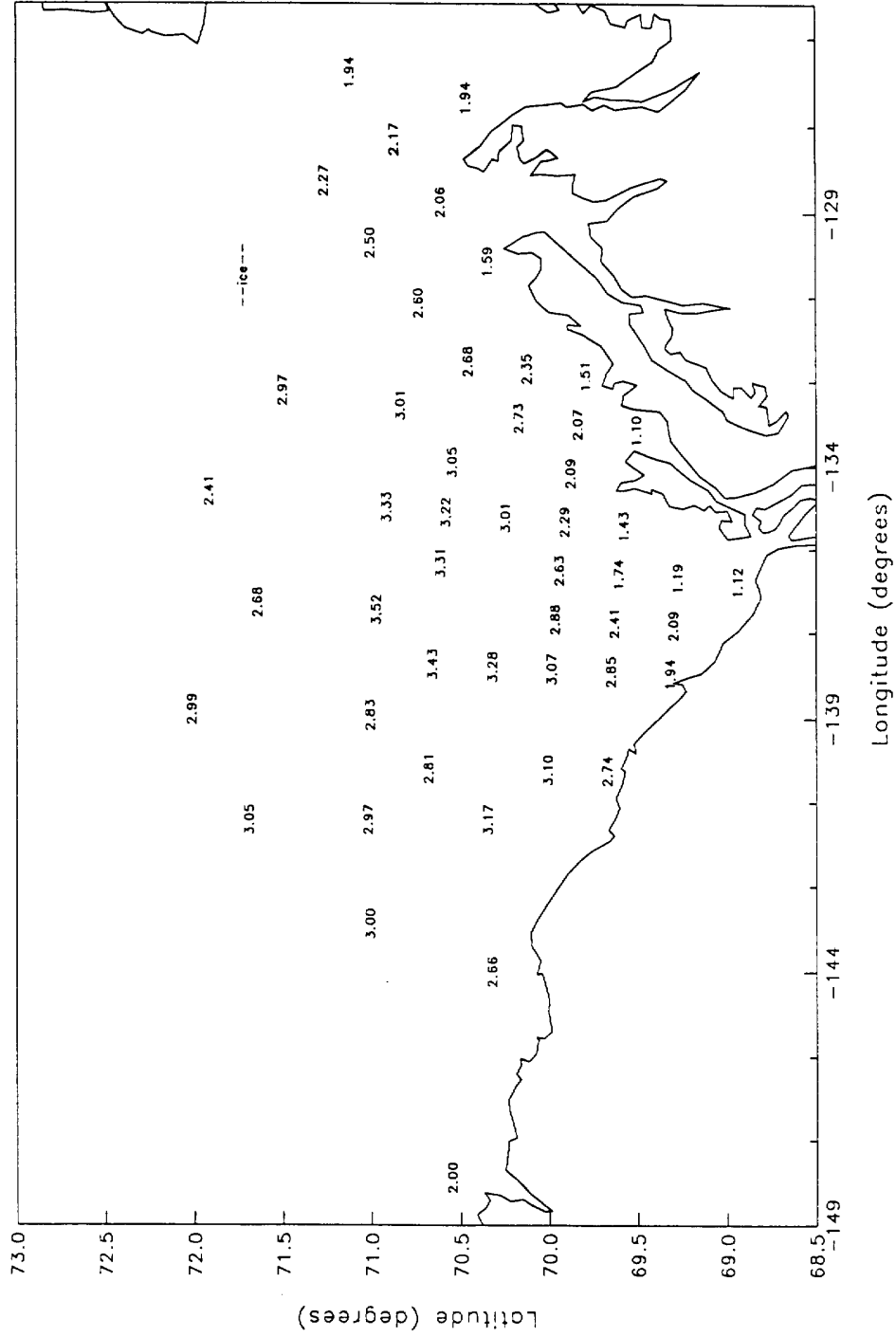


BEAUFORT SEA STORM
7810B

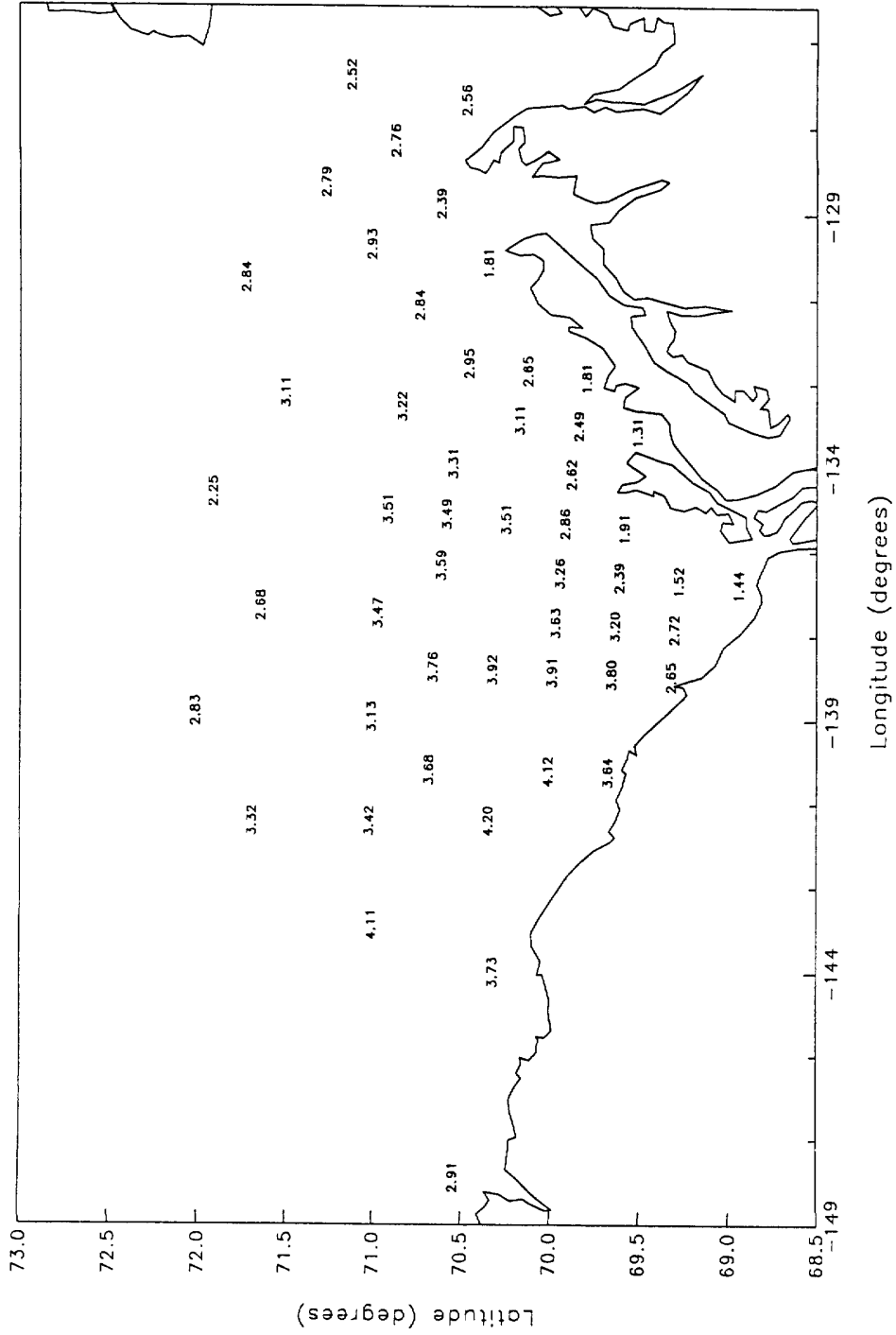


BEAUFORT SEA STORM

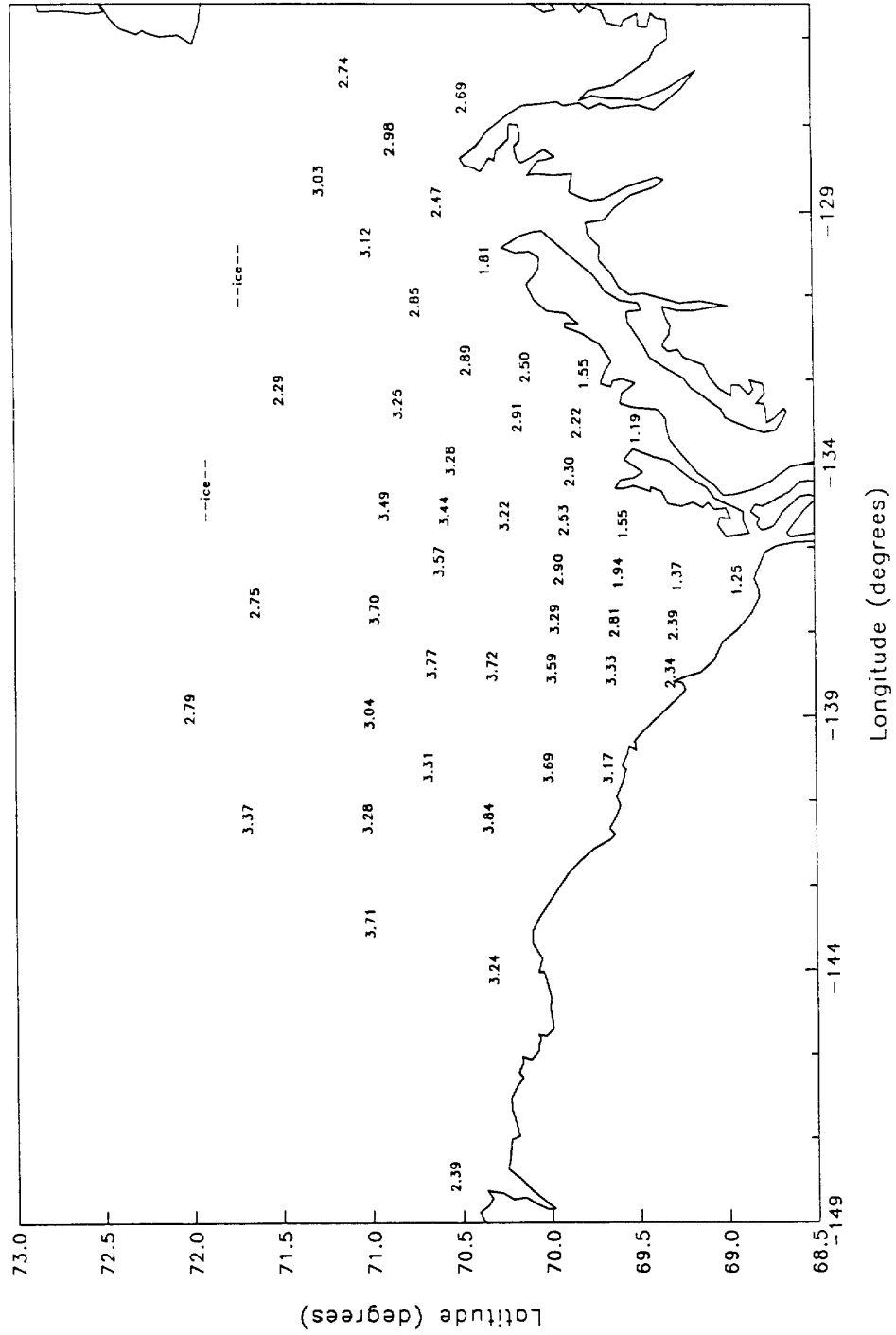
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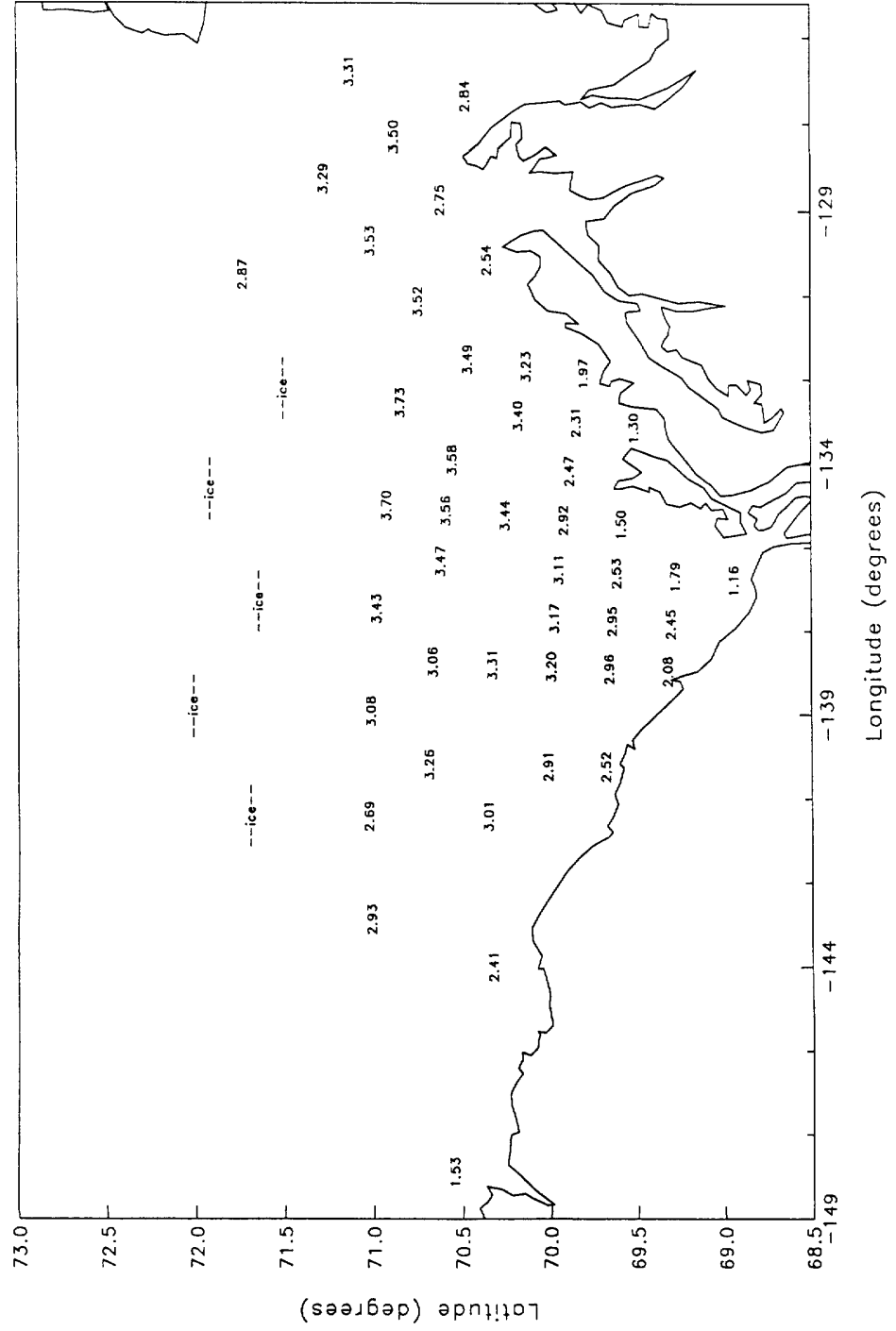


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7910B



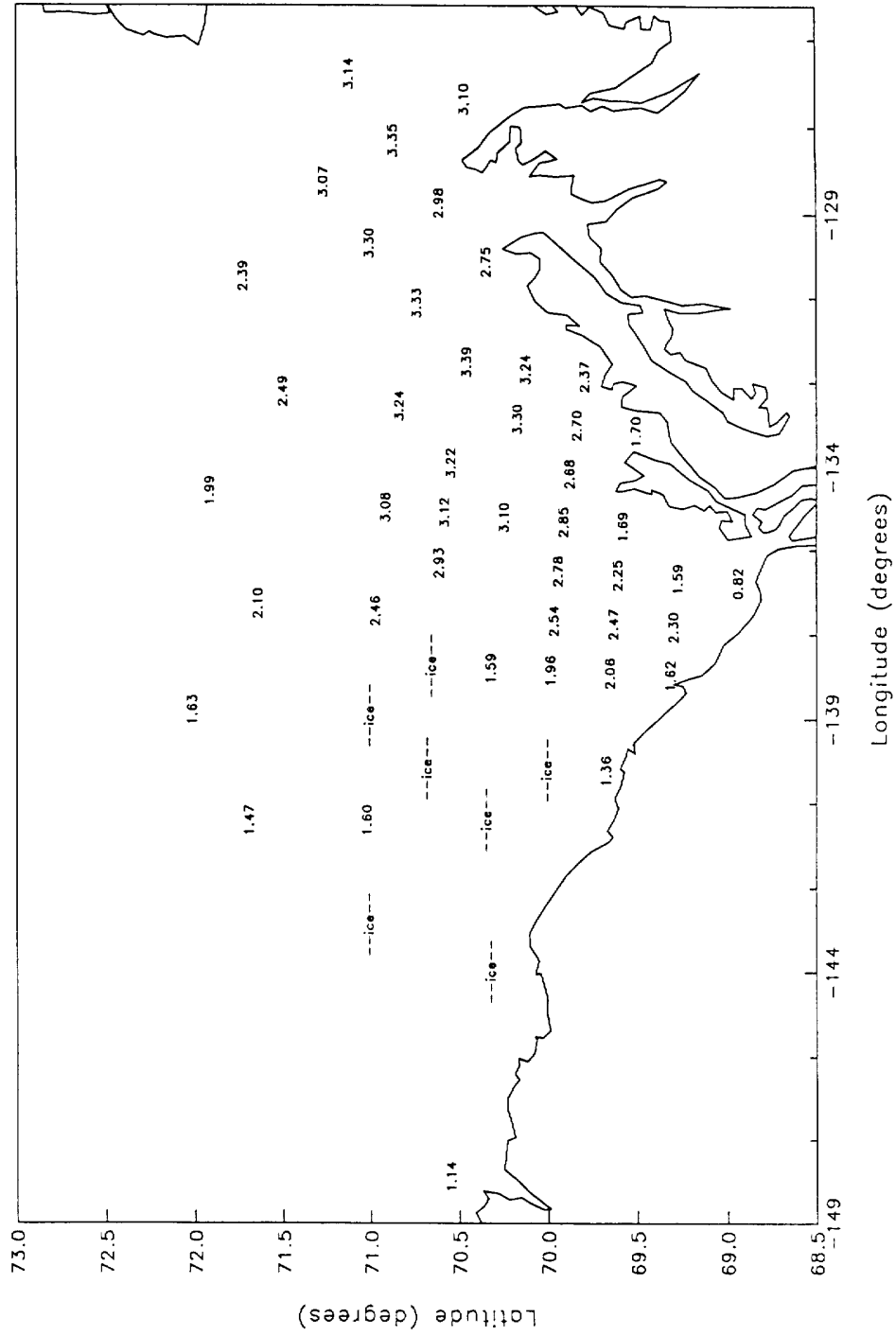
BEAUFORT SEA STORM

8008



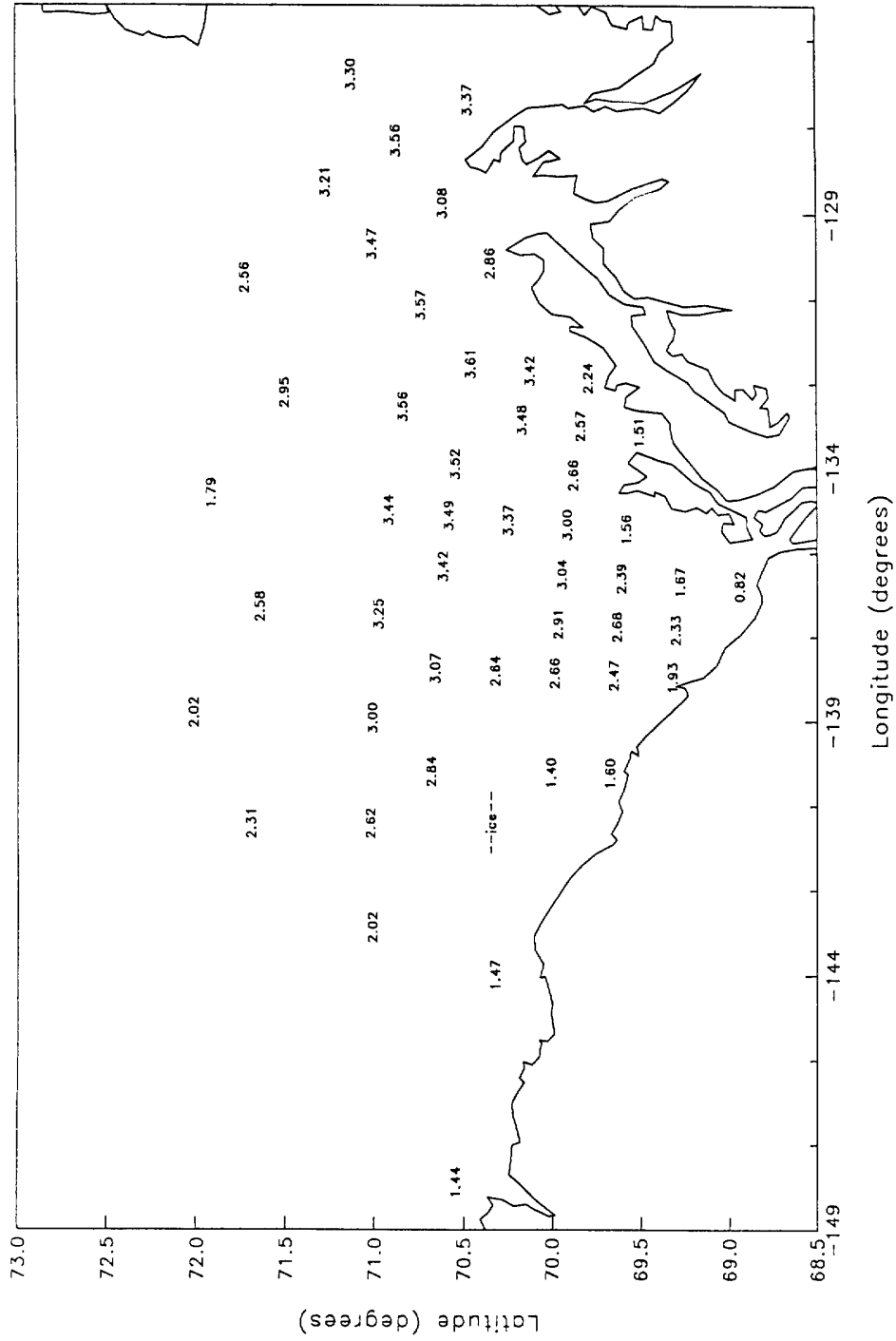
BEAUFORT SEA STORM

8108A



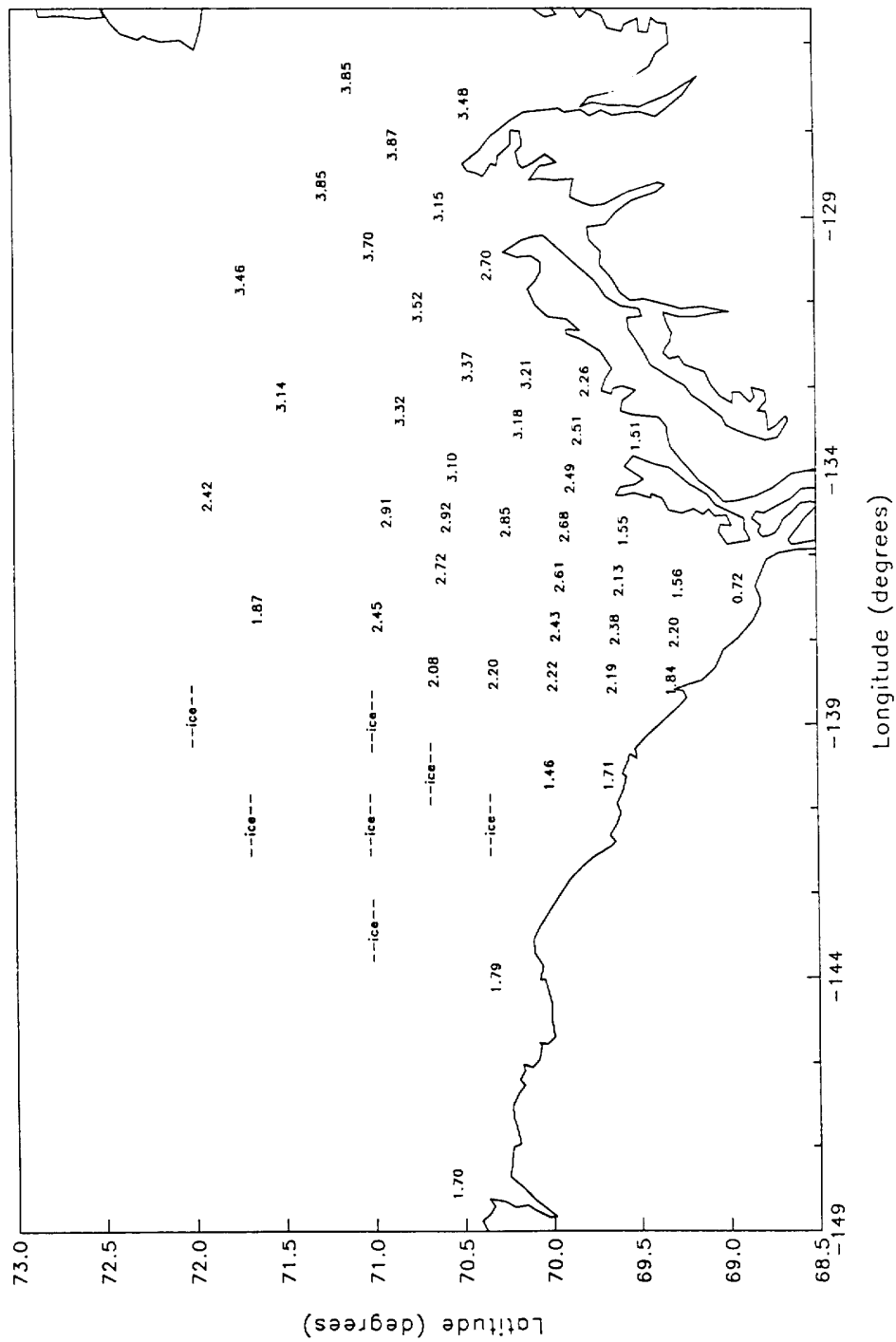
BEAUFORT SEA STORM

8108B



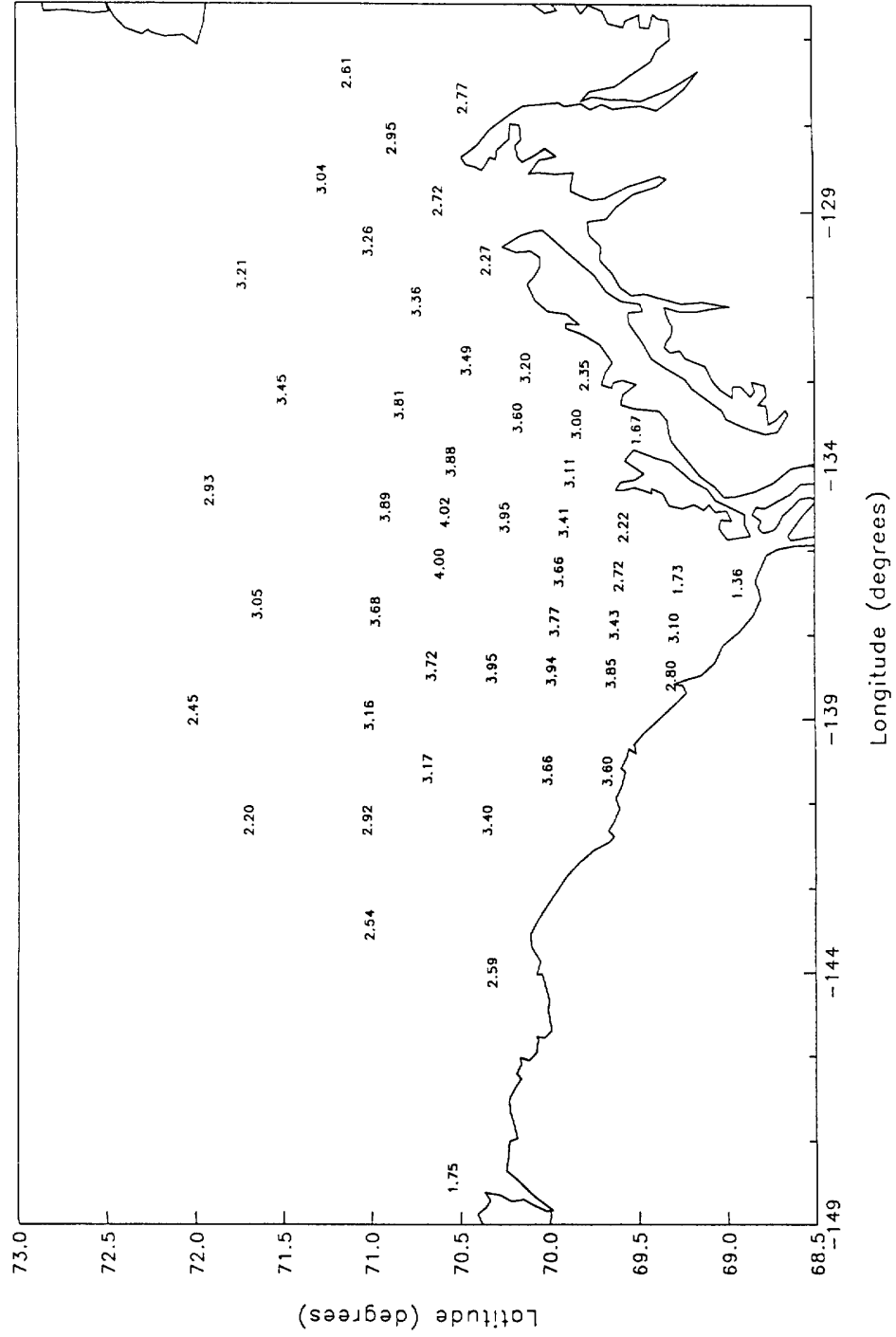
BEAUFORT SEA STORM

8108C



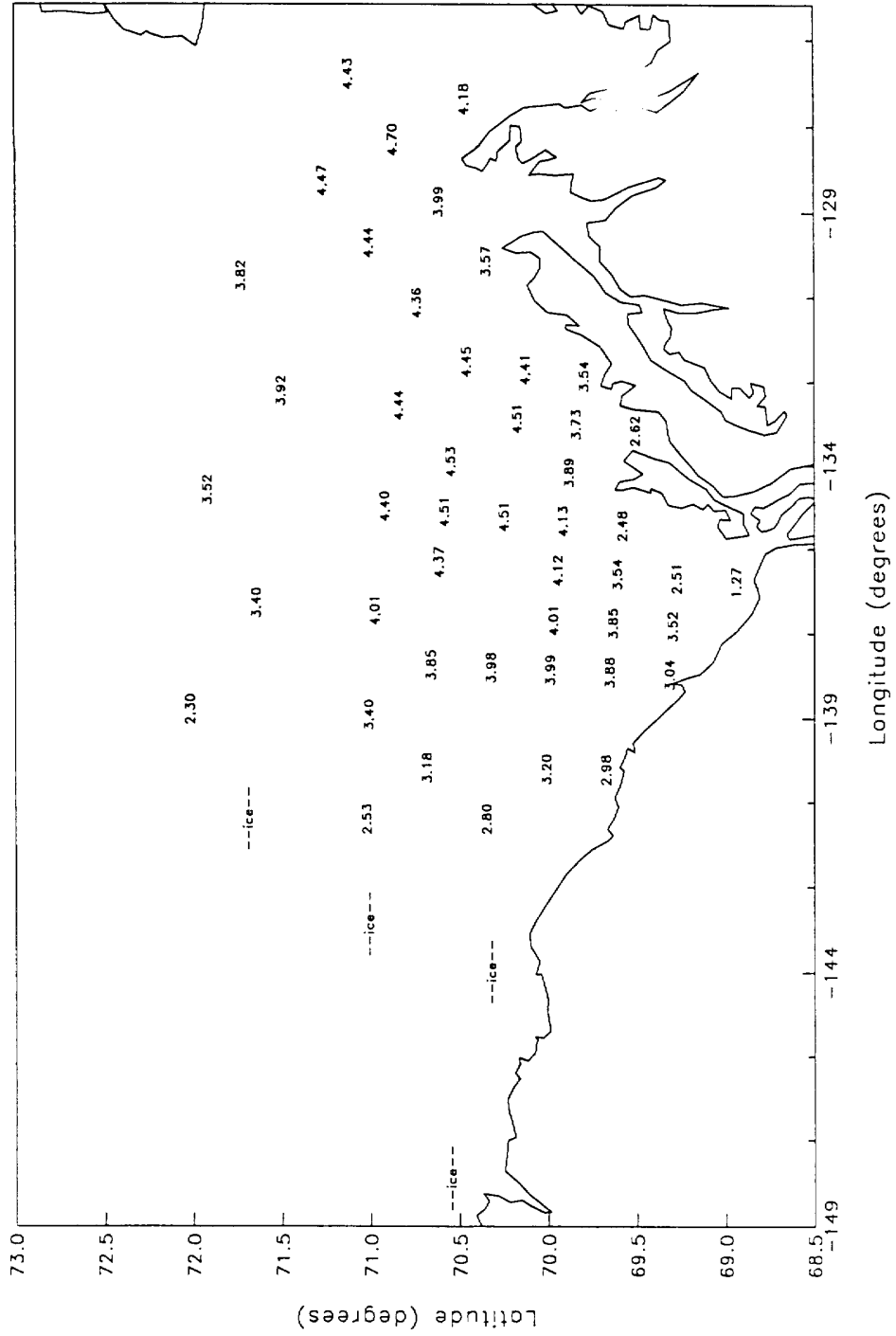
BEAUFORT SEA STORM

8109

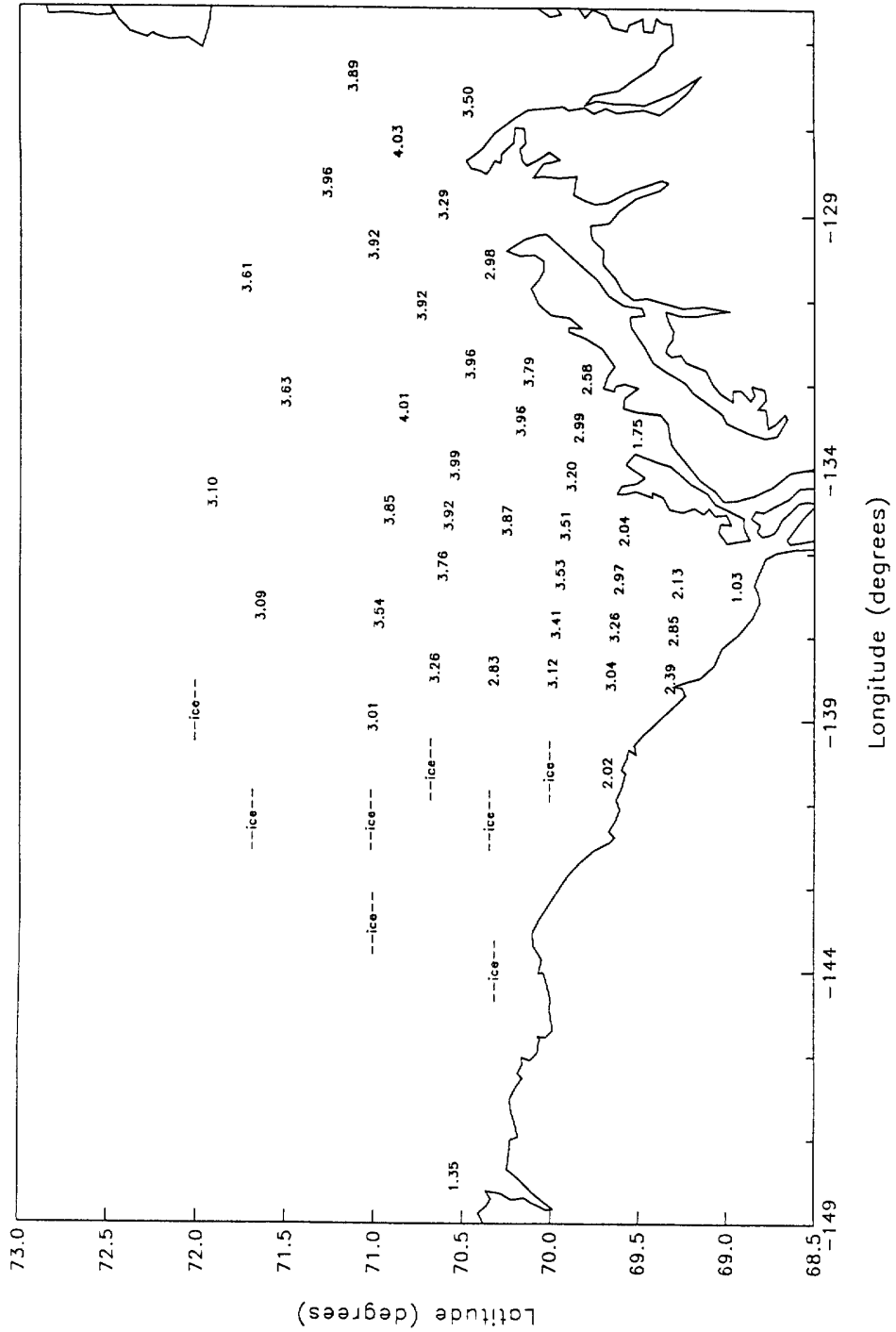


BEAUFORT SEA STORM

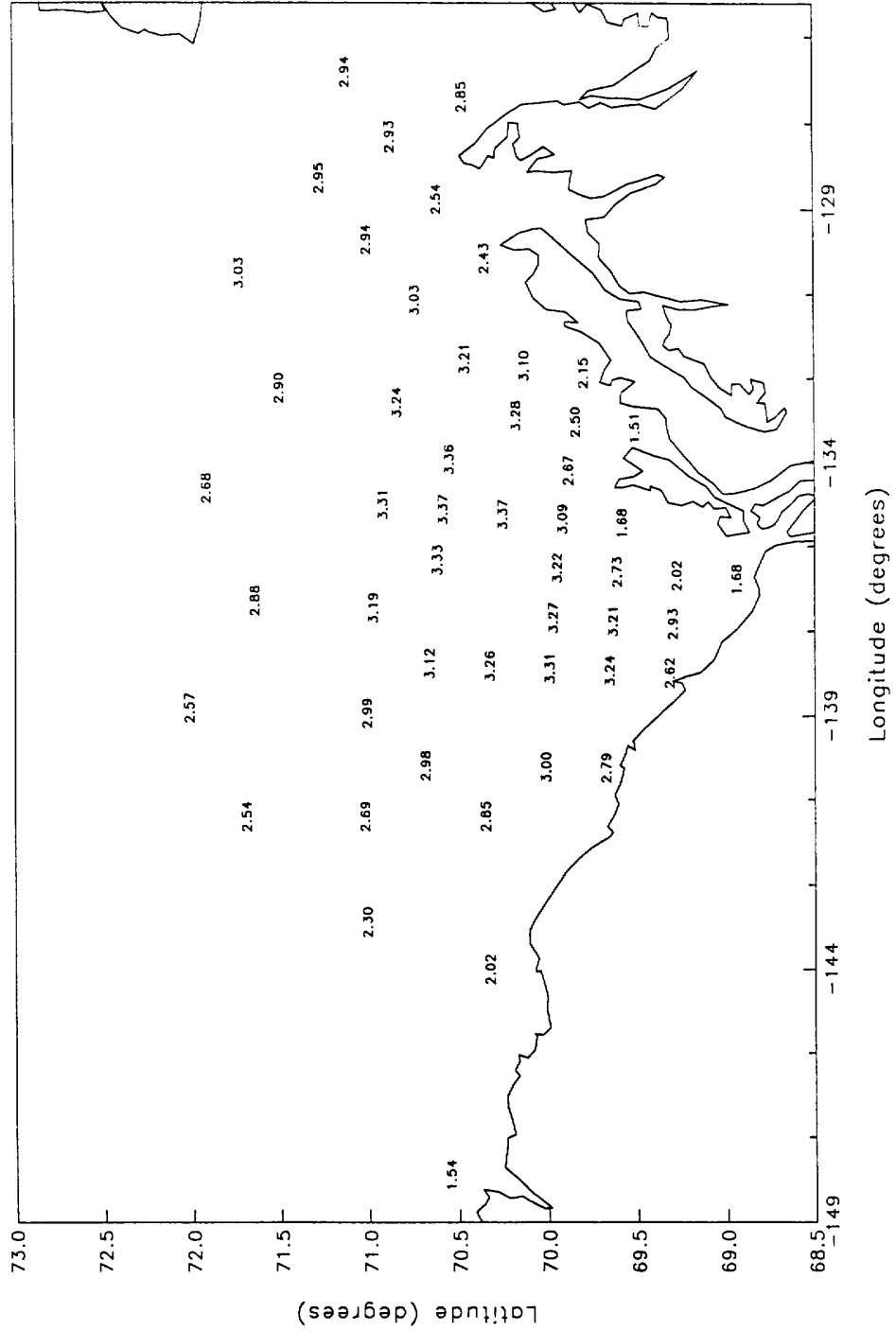
8207



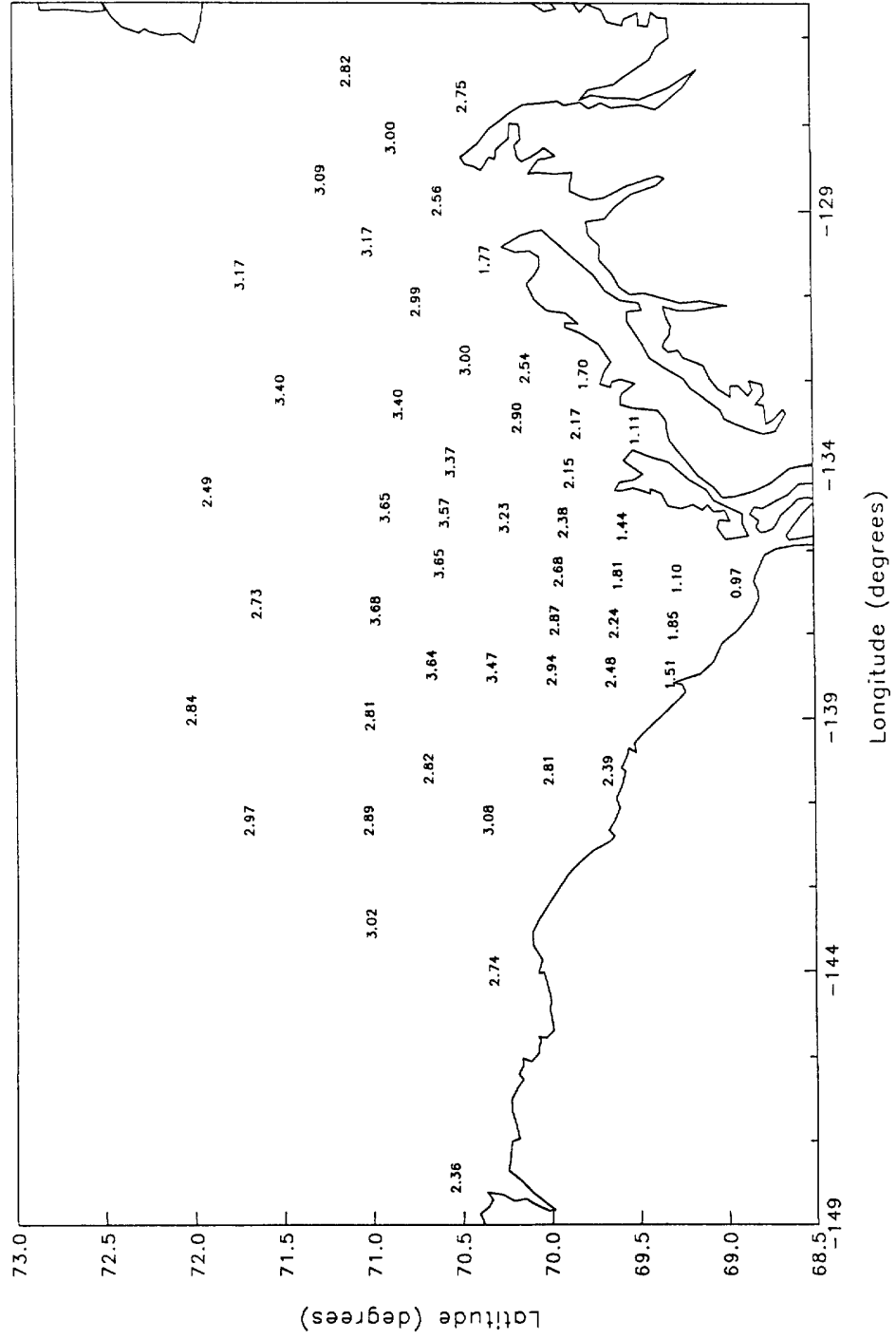
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8208



BEAUFORT SEA STORM
8209A

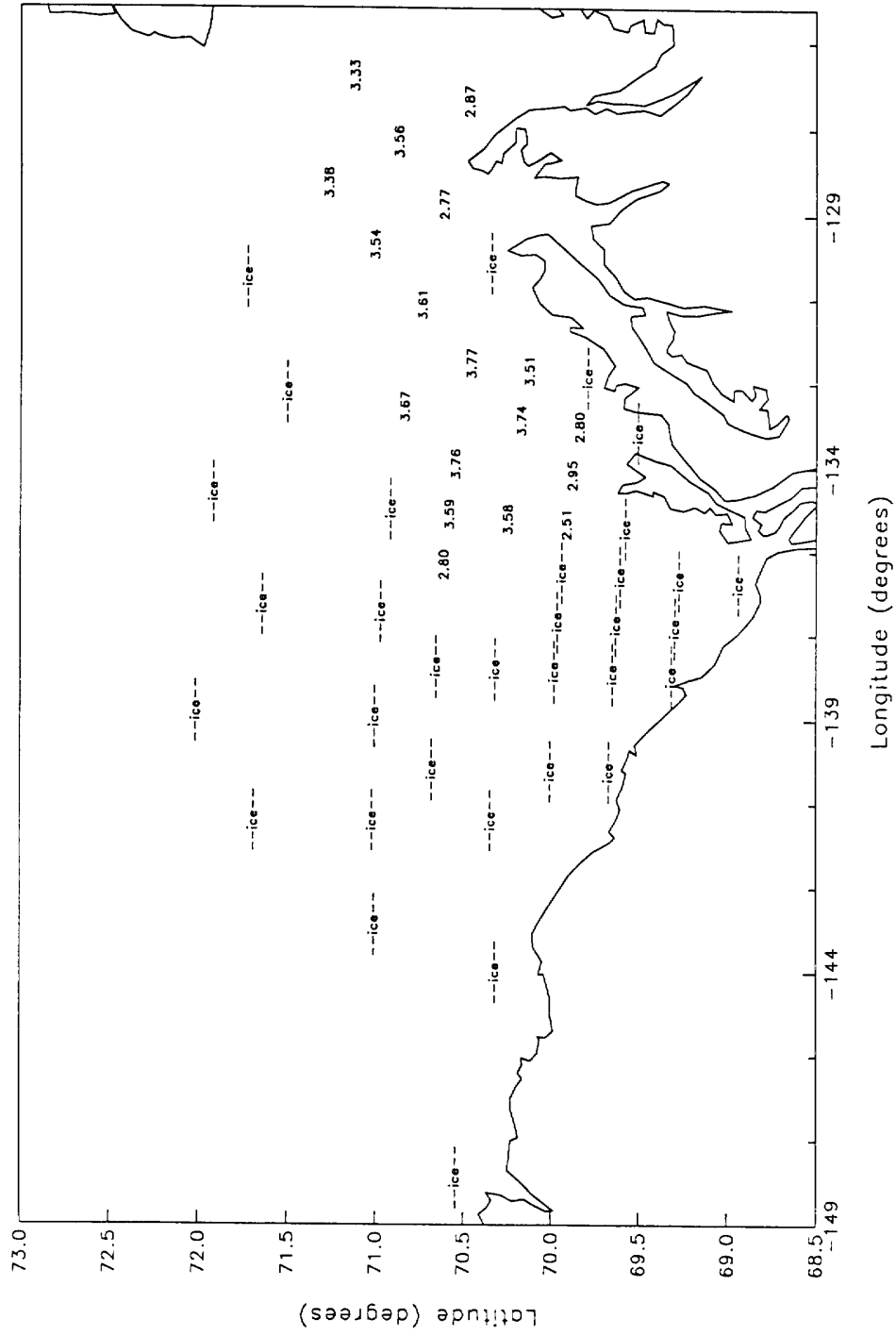


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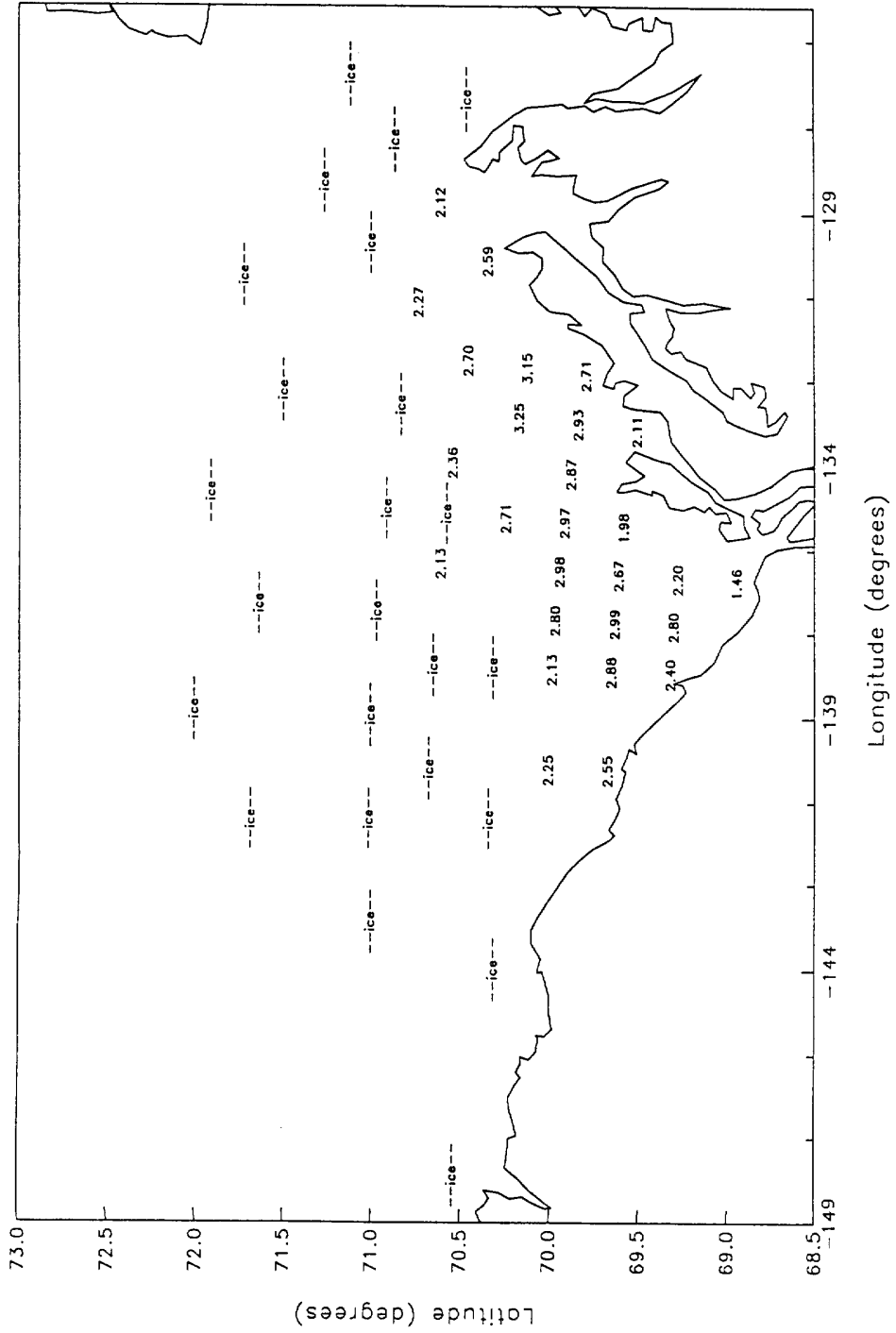
BEAUFORT SEA STORM

8210



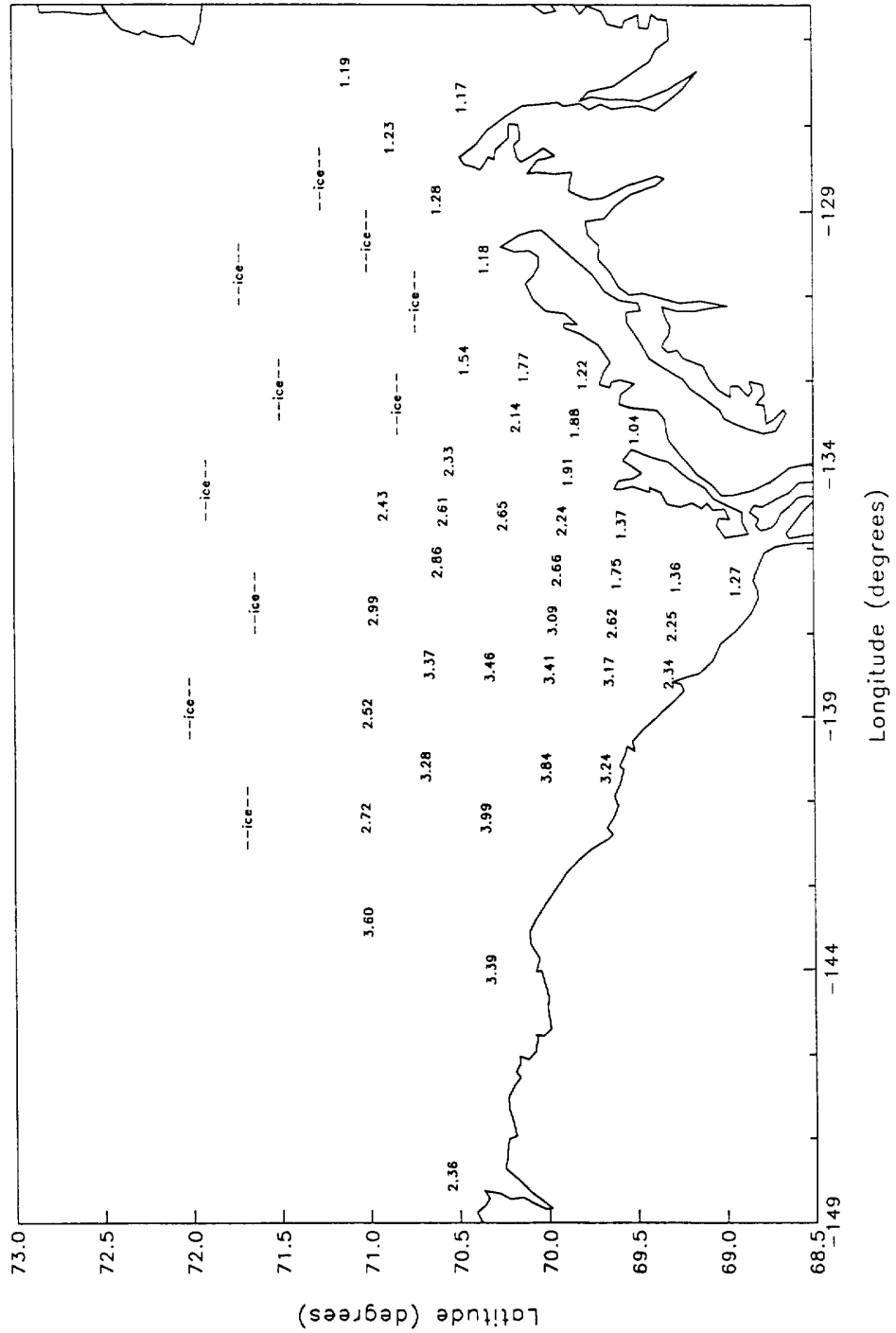
BEAUFORT SEA STORM

8408



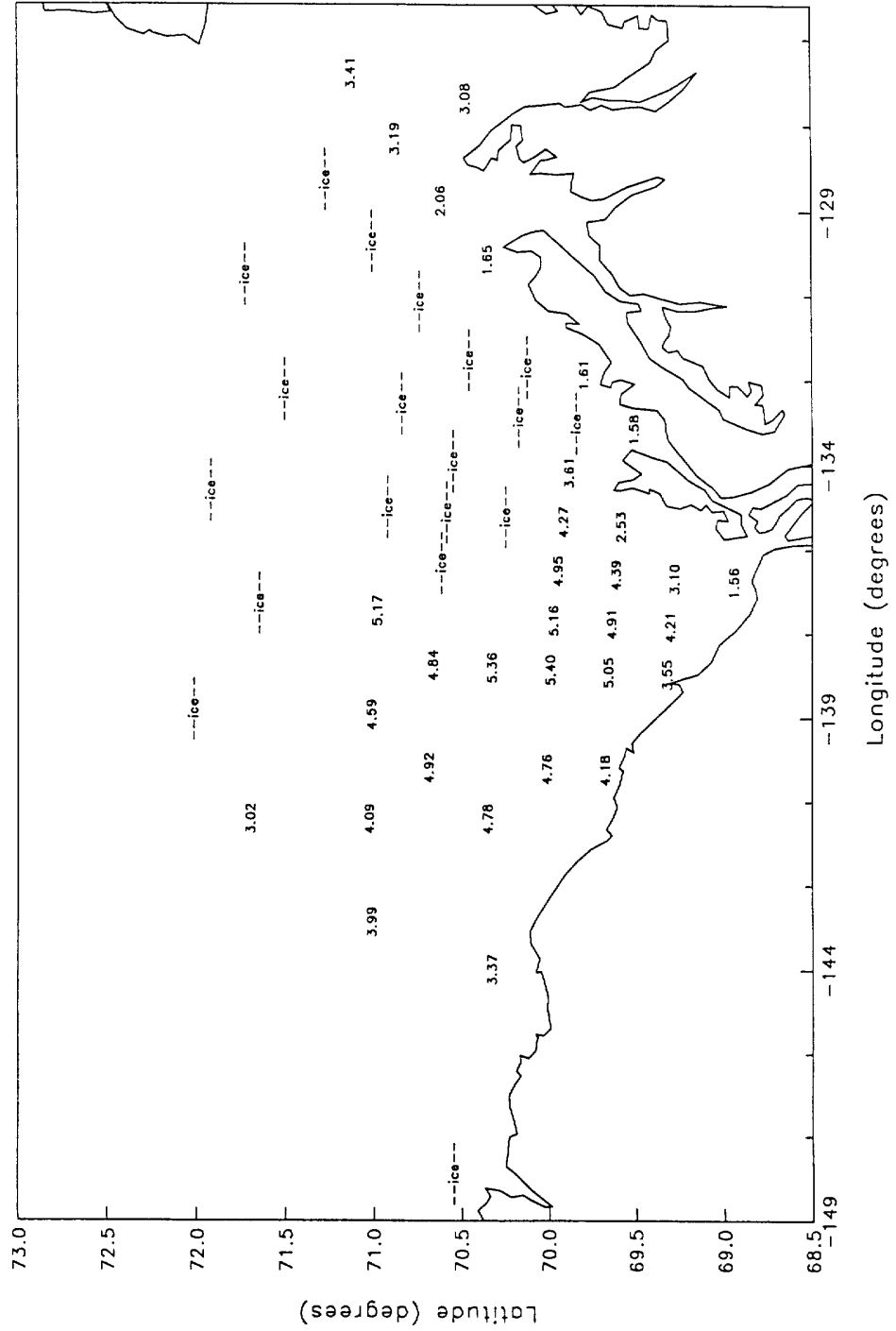
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8410



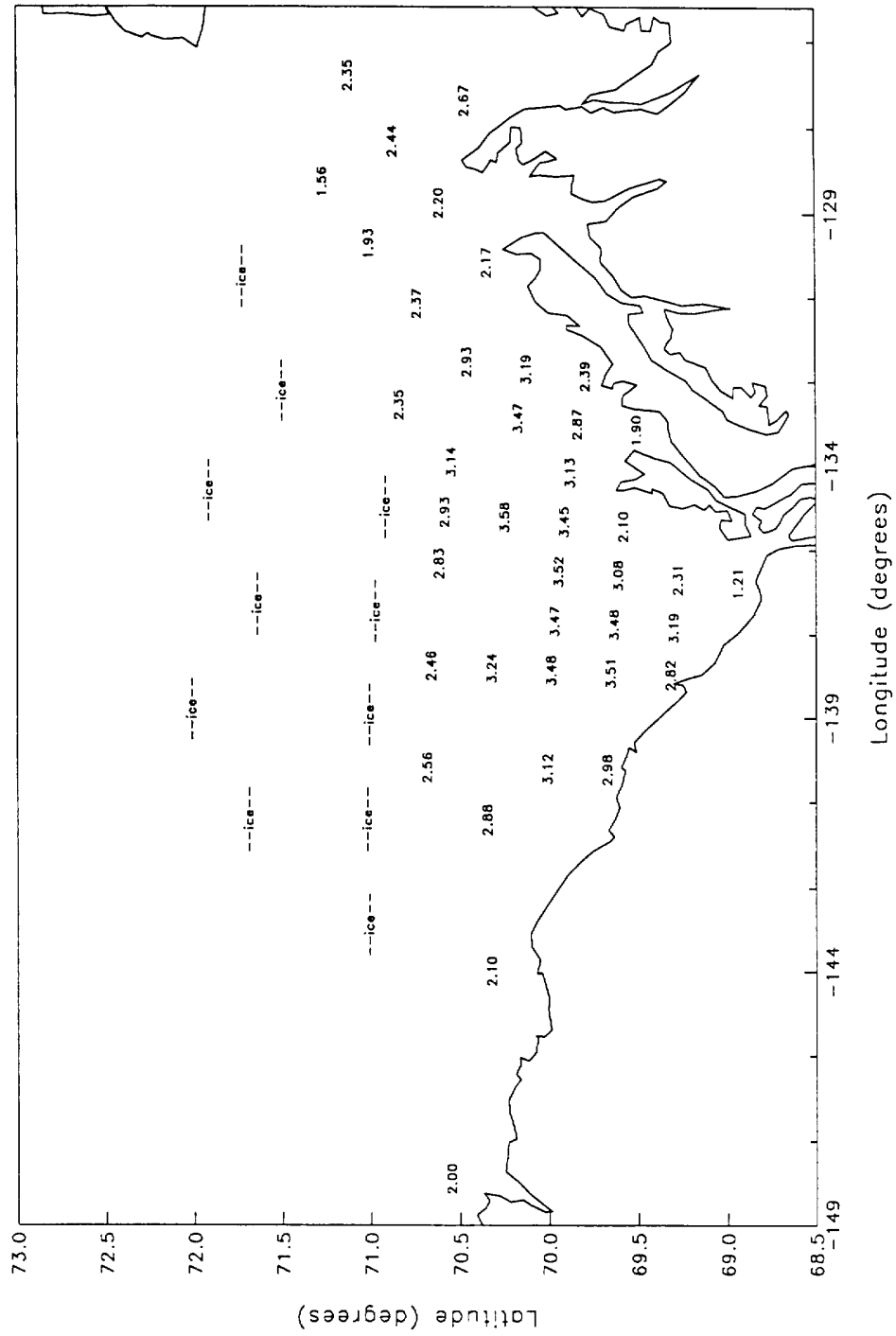
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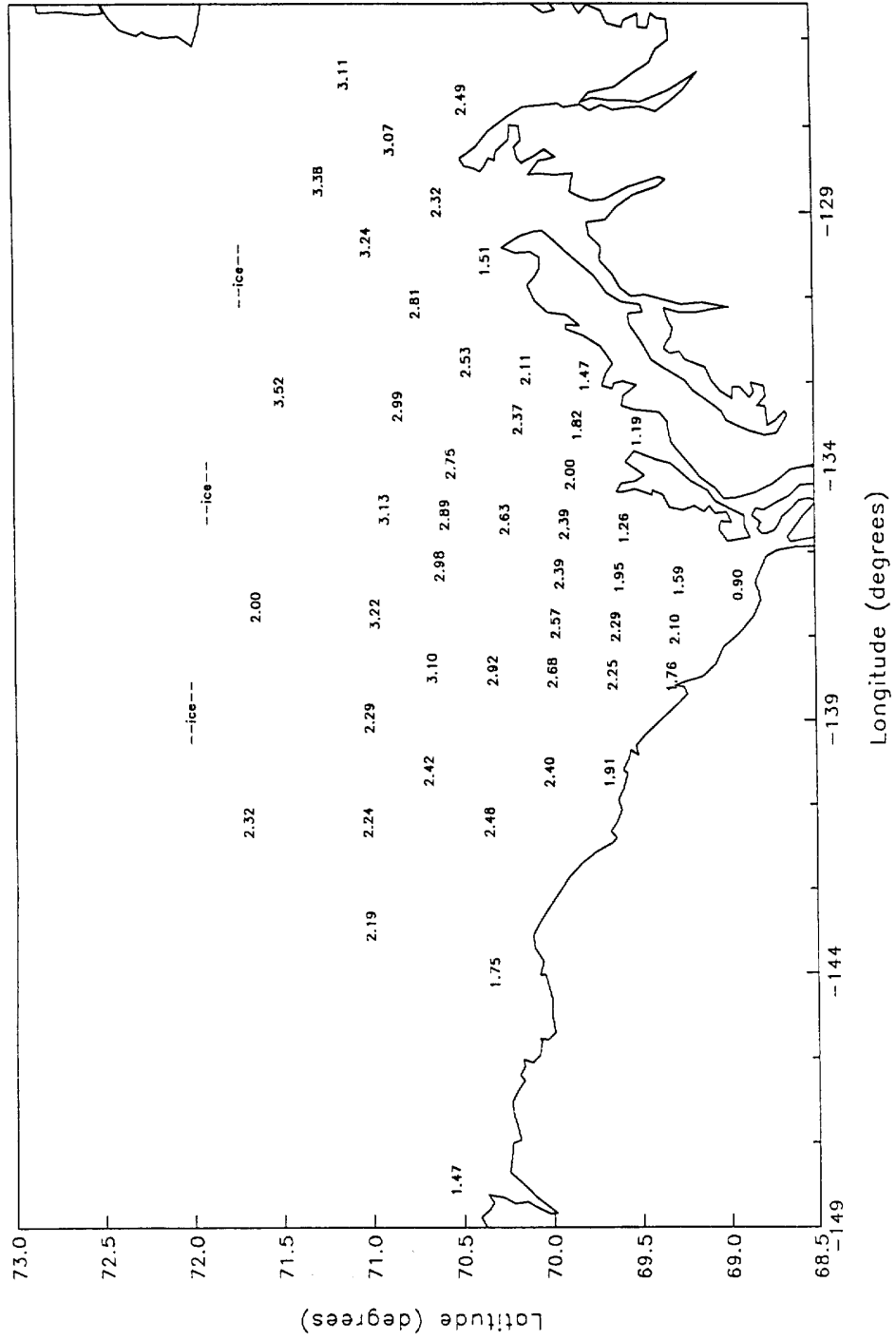


BEAUFORT SEA STORM

8608

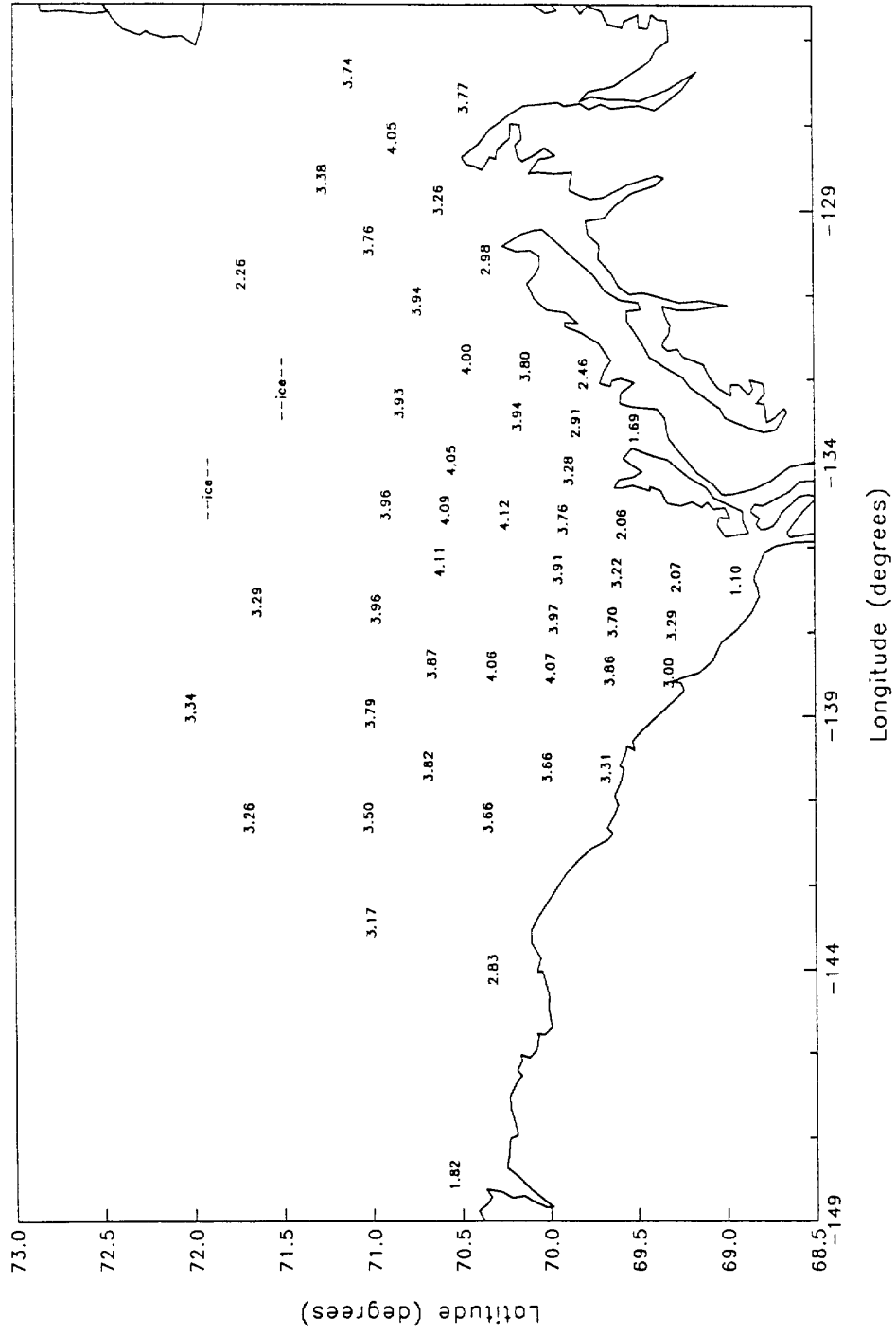


BEAUFORT SEA STORM 8609



BEAUFORT SEA STORM

8708



BEAUFORT SEA STORM

8808

