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Iceberg Trajectory Model: Real-Time Verification

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ICEBERG TRAJECTORY MODEL - REAL-TIME VERIFICATION

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SUMMARY

In 1985 the Environmental Studies Research Funds (formerly, the Environmental Studies Revolving Funds) financed the development of an Operational Iceberg Trajectory Forecasting Model for the Grand Banks of Newfoundland (de Margerie et al., 1986) as a potential ice management tool to support offshore oil field activity. A recommendation arising from the work called for a field implementation of the model in order to compile comments and suggestions from users. One of the objectives of the present study, which was initiated by the ESRF in 1990, addressed this recommendation. The second objective of the work was to undertake a verification of the iceberg position predictions that were output by the model, the first to be undertaken using an independent data set.

The initial intention was to conduct a real-time trial of the model during the 1991 iceberg season, if drilling activity and iceberg conditions allowed. The first drilling program of the season was conducted by BP Resources Canada Limited and project commencement was held up awaiting the spudding of the PB et al Thorvald P-24 well. Unfortunately, Thorvald P-24 was spudded very late in the iceberg season and no free-drifting iceberg position data became available in 1991. As an alternative, a simulated operational trial was conducted using data from the 1990 season. To the extent possible the trials were conducted in a manner that simulated a normal operational routine.

Trials were run with track data for nine icebergs. Eighty-four predicted trajectories were produced resulting in a total of 590 verifiable positions. A few tests were conducted using observed winds as well as forecast winds to examine the effects of wind forecast errors. In addition, several comparisons of the model predictions at one forecast lead time were made with the output of a simple steady course model and with the assumption of persistence. The results, which must be treated with great caution, give an initial indication of the skill of the model at one lead time.

During the course of the trials, a number of short-comings of the software were identified which would be expected to limit its acceptability by offshore operators. In broad terms they

can be divided into one of two categories: operational short-comings and weaknesses of the user interface. Operationally, there are three common ice management scenarios that are not adequately handled by the present version of the software. First, the model can only process and display the predicted track of one iceberg at a time. Second, the model assumes that all icebergs are free floating and will predict grounded icebergs to move. Third, the model assumes that all icebergs are free drifting; no mechanism has been implemented to deal with icebergs under tow. These operational considerations need to be addressed if the model software is to be developed further.

The model software was designed as a stand-alone system. Since it cannot share data with other systems, a certain amount of data entry duplication is inevitable. This is not desirable in an operational setting as it is inefficient and increases the risk of making data entry errors. Further, aerial reconnaissance of sea ice conditions and iceberg positions is a routine and integral component of ice management programs. Software is required to assimilate, edit, store, and display these data. If further development of the operational model is contemplated, consideration should be given to expanding the capabilities of the model to communicate at some level with other software systems.

Many short-comings and limitations of the software relate to the user interface, specifically to the input of data and the presentation of the model output. The short-comings are detailed in the body of the text. In each case suggestions and recommendations for improvements are provided. It is expected that many of the recommendations could be implemented with relatively little effort. Some, however, may require changes to the basic structure of the program.

A verification analysis was undertaken to investigate predictive accuracy. It was found that values of the error statistics increased rapidly with time. This was not unexpected as the model provides confidence intervals around the individual forecast positions which were seen to increase in size rapidly with forecast lead time. The analysis results show, however, that the model performed slightly better than expected, an indication that the modelers may have been conservative in the error estimates.

RÉSUMÉ

En 1985, la mise au point d'un modèle opérationnel de prévision de trajectoires d'icebergs pour les Grands Bancs de Terre-Neuve (de Margerie et coll., 1986) a été financée au moyen du Fonds de recherche pour l'étude de l'environnement (FREE) (antérieurement le Fonds renouvelable pour l'étude de l'environnement) à titre d'outil éventuel de gestion pour le soutien de l'activité pétrolière au large. À l'issue des travaux exécutés, il était recommandé de mettre en oeuvre le modèle sur le terrain afin de compiler des commentaires et suggestions de la part d'utilisateurs. L'un des objectifs de la présente étude, entreprise sous l'égide du FREE en 1990, était la mise en oeuvre de cette recommandation. Le deuxième objectif des travaux consistait à entreprendre une vérification des positions d'icebergs prévues par le modèle, la première telle vérification à être entreprise au moyen d'un ensemble indépendant de données.

À l'origine il était prévu d'effectuer un essai du modèle en temps réel pendant la saison de circulation des icebergs de 1991, si les activités de forage et les conditions glacielles le permettaient. Le premier programme de forages de la saison a été mené par la BP Resources Canada Limited et le début de ce projet a été retardé jusqu'au battage du puits Thorvald P-24 des BP et coll. Malheureusement, le battage du Thorvald P-24 a été effectué très tard pendant la saison et aucune donnée de position d'iceberg dérivant librement ne fut disponible en 1991. À titre de solution de remplacement, un essai opérationnel simulé a été effectué avec des données de la saison de 1990. Les essais ont été effectués de manière à simuler dans la mesure du possible une procédure opérationnelle normalevii

Des essais ont été effectués avec les données sur les trajectoires de neuf icebergs. On a

produit quatre-vingt-quatre trajectoires prévues comportant au total 590 positions vérifiables. quelques essais ont été effectués en utilisant les vents observés ainsi que les vents prévus afin d'examiner les effets d'erreurs de prévision des vents. De plus, à plusieurs reprises les prévisions du modèle après un intervalle de prévision ont été comparées aux sorties d'un modèle de trajectoire régulière simple avec la persistance comme hypothèse. Les résultats, qui doivent être interprétés avec une grande prudence, fournissent une indication initiale de l'aptitude du modèle aprés un intervalle de prévision.

Pendant les essais, un certain nombre de points faibles du modèle, qui en limiteraient l'acceptabilité par des exploitants au large, ont été identifiés. Ces points faibles peuvent être répartis en deux grandes catégories : points faibles opérationnels et imperfections de l'interface destinée aux utilisateurs. Du point de vue opérationnel, trois scénarios communs en gestion des glaces ne sont pas adéquatement traités dans l'actuelle version du logiciel. Premièrement, le modèle ne permet de traiter et d'afficher qu'une seule trajectoire prévue d'iceberg à la fois. Deuxièmement, le modèle suppose que tous les icebergs flottent librement et prédira que les icebergs échoués se déplaceront. Troisièmement, le modèle prévoit que tous les icebergs dérivent librement; aucun mécanisme n'a été mis en oeuvre pour traiter les icebergs remorqués. Un développement plus poussé du logiciel devrait tenir compte de ces considérations d'ordre opérationnel.

Le logiciel du modèle a été conçu comme un système autonome. Puisqu'il ne permet pas de partager des données avec d'autres systèmes, une certaine duplication d'introduction de données est inévitable. Cela n'est pas souhaitable en situation opérationnelle puisqu'inneficace et multipliant les risques d'erreurs lors de l'introduction des données. De plus, la reconnaissance aérienne des conditions glacielles en mer et des positions des icebergs constitue une composante régulière et intégrale des programmes de gestion des glaces. Le logiciel est nécessaire pour l'assimilation, la mise en forme, le stockage et l'affichage de ces données. Si une mise au point plus poussée du modèle est envisagée, il faudrait prendre en considération une expansion des possibilités du modèle permettant la communication avec d'autres systèmes de logiciels à un niveau quelconque.

Un grand nombre des inconvénients et des limites du logiciel ont trait à l'interface pour utilisateurs et spécifiquement à l'introduction des données ainsi qu'à la présentation des sorties du modèle. Ces inconvénients sont abordés de manière détaillée dans le texte. Dans chaque cas, des suggestions et des recommandations d'améliorations sont fournies. La mise en oeuvre d'un grand nombre de ces recommandations n'exigerait que relativement peu d'efforts. Certaines d'entre elles pourraient cependant exiger des modifications de la structure fondamentale du programme.

Une analyse de vérification a été entreprise afin d'étudier la précision des prévisions. Il a été constaté que les valeurs des statistiques d'erreur augmentaient rapidement en fonction du temps. Cela n'était pas inattendu puisque le modèle fournit des intervalles de confiance autour des positions prévues individuelles dont les dimensions augmentent rapidement en fonction de l'intervalle de prévision. Les résultats de l'analyse montrent cependant que le modèle a fonctionné de manière légèrement supérieure aux attentes, ce qui indique que les modélisateurs peuvent avoir été prudents lors des estimations d'erreurs.

1. INTRODUCTION

1.1 BACKGROUND

In 1985 the Environmental Studies Research Fund (ESRF) awarded a contract to ASA Consulting Ltd. of Dartmouth, N.S, for the development of an operational iceberg drift prediction model. Based on previous work by Garrett (1985) and Garrett et al. (1985), the software development of the Operational Iceberg Trajectory Forecasting Model for the Grand Banks was completed in 1986. A description of the model and its implementation is contained in de Margerie et al. (1986).

Although developed over five years ago, the iceberg trajectory forecasting model had not been subjected to independent testing in an operational setting. In 1990 the ESRF initiated a study to evaluate the model in terms of its functional operation and predictive capability in a real-time operational test. The work was awarded to OCEANS Ltd. of St. John's, working in association with Atlantic Airways Limited and Ian Jordaan and Associates Ltd.

1.2 SCOPE

Four recommendations for further investigation were given in de Margerie et al. Ranked first was a recommendation to conduct a real-time trial of the Operational Iceberg Trajectory Forecasting Model. This work addresses that recommendation. Two primary objectives were identified. The first was to obtain an appreciation of the model function in an operational environment, assessing its strengths and weaknesses in order to prepare a list of suggestions for improvement. The second objective was to evaluate its usefulness as an ice management tool by measuring the predictive accuracy of the model output through a verification analysis. In addition, certain other assessments were to be made. These included obtaining a measure of the predictive skill of the model in comparison to a control, and reviewing the approach to risk assessment used in the model.

Since the model assessment was to be based on a real-time test, the premise from the outset was that all decisions regarding data inputs that were not directly addressed in the Users Manual (ASA Consulting Ltd., 1986) would be made by the operators following common sense or customary operational practice. This extended to the methods used to handle the wind inputs including the extraction of forecast winds from the marine weather forecasts, contingencies for handling of missing data if any, and so forth. Operational considerations were also to be of primary importance in the design of the verification analysis procedure: the resulting error statistics were to be physically meaningful, readily understood, and useful for assessing the reliability of model predictions.

1.3 PROJECT ORGANIZATION

The project was organized into two phases, each consisting of a number of tasks. In Phase I the iceberg trajectory model was installed and set-up on an microcomputer system and some initial trials were conducted. The purpose was to become familiar with the model function prior to conducting the operational tests in Phase II of the project. Phase II included operational trials of the model, forecast verification, evaluation of results, and preparation of the project report.

Initially it was intended to carry out model trials in a real-time operation. However, with the limited drilling activity on the Grand Banks in recent years coupled with the uncertainty of iceberg severity on the Grand Banks, it had been proposed to conduct a simulated "real-time" test if events or conditions should conspire to preclude the undertaking of an operational test during 1991. As this was the case, a simulated trial was conducted using data gathered during the drilling of the Petro-Canada et al. Kings Cove A-26 well on the Grand Banks in 1990.

OCEANS Ltd. was responsible for the organization and management of the project as a whole and for the verification of the model output. The operational program was carried out by personnel from Atlantic Airways Limited having extensive experience in all aspects of ice management operations on board drillships and drilling rigs, and from shore-based ice offices. These individuals were responsible for the installation of the model, conducting the model runs, and preparing the output data files. Additionally, they were responsible for preparing a summary of operator comments and suggestions regarding the function of the model in an operational setting. Dr. Ian Jordaan of Ian Jordaan and Associates Ltd. was asked to review and comment on the model formulation for computation of the risk of impact with the rig.

1.4 REPORT ORGANIZATION

Section 2 of this report discusses the set-up and operational use of the iceberg trajectory forecasting model. It also contains a description of the data inputs and the model outputs from the trials. Section 3 discusses the model function and the user interface. With each issue raised, recommendations and suggestions for improvements are given. Verification of the model output is discussed in Section 4, with results presented in graphical and tabular form. Section 5, contributed by Dr. Jordaan, contains a review of the risk assessment formulation. Finally, in Section 6, conclusions and recommendations arising from the operational test and verification assessment are given. Four appendices are included with this report. The first provides a comparison of the forecast and actual wind velocities that were used in the trials. Appendix II contains a series of predicted trajectories for Iceberg 071. Appendix III contains a discussion of the model output for Iceberg 424 from the 1985 iceberg season. The last appendix contains polar plots of the forecast errors for lead times from 2 hours through 24 hours.

2. SOFTWARE INSTALLATION AND OPERATION

2.1 MODEL INSTALLATION AND SET-UP

An executable version of the model software and the associated data files were supplied by the ESRF Program Officer at project start-up. The package was found to be complete, with the exception of a program required to print the wind file (PWINDS.COM). A request was made to obtain the routine, but it was not available. Its absence was found not to be important in the operational tests, but the inability to print the file precluded confirmation of wind velocity inputs during the verification analysis phase.

The minimum computer hardware needed to install and run the model includes an IBM PC or compatible microcomputer with at least 256K RAM, one double-sided floppy disk drive, a Colour Graphics Adaptor (CGA) board, and an Epson graphics printer or equivalent for hard copy output. The model software was installed on a 80386 based microcomputer system following the instructions contained in the User Manual (ASA Consulting Ltd., 1986). The installation procedure was found to be well documented and straight forward, requiring only a few minutes time. No difficulties were experienced in the installation, nor with the set-up of the model. The observational accuracy of the position data was set to 750 metres, the estimated value suggested by ASA Consulting Ltd. based on 1984 and 1985 iceberg position data. The rig position coordinates (latitude and longitude) were set to the position of the Petro-Canada et al. Kings Cove A-26 well on the Grand Banks.

2.2 OPERATIONAL METHODOLOGY

Model operation is relatively straight forward and only a short amount of time was necessary to become familiar with the program function. Once the rig location and iceberg position observation accuracy have been entered, operation of the model requires only input of observed iceberg positions, observed wind velocity at the time of the latest position report, and forecast wind velocities at 12 hour intervals out to a maximum lead time of 48 hours. Certain other ancillary information not critical to the position predictions may be entered as well. This includes the input of up to two watch circle radii and the establishment of an allowable risk level.

2.2.1 Input Data

A number of iceberg tracks from the 1990 Kings Cove A-26 data set were selected for the trials; in general, icebergs having the longest, free-drifting tracks were selected. Many of the observed icebergs, however, had been towed for a period of time; of those, only the untowed portion of the tracks were used in the trials. By and large, the useable portions of the observed iceberg tracks for the 1990 season were quite short. In all, portions of nine individual iceberg tracks from the 1990 data set were used in the test. Position data for eight of the iceberg tracks had been obtained from standby vessel reports, while information for one iceberg was obtained, in part, from standby vessel reports and, later, by radar measurements from the drill rig. All iceberg position data were referenced to the rig position and were input to the model as a range and bearing from the rig, rather than in the latitude and longitude format.

de Margerie et al. (1986) state that "preferably near-surface wind, i.e., 10 m" is desirable. The Users Manual (ASA Consulting Ltd., 1986), however, does not include any reference to a preferred or recommended height of the wind velocity data. For drilling rigs used on the Grand Banks, anemometers are typically located on top of the derrick at heights of approximately 80 m above the sea surface. In the case of the Sedco 710, the rig employed to drill the Kings Cove A-26 well, the anemometer level was approximately 75 meters above sea level at normal drilling draft. Since wind data measured at this level is the norm, the recorded wind velocities without adjustment to the 10 m level were used in the trial.

Forecast wind speed and direction information was extracted from marine weather and sea state forecasts valid for the drilling area. Petroleum companies operating on the continental margin of Canada are required to arrange to have marine weather forecasts available on a regular basis to support drilling activities. Routine site-specific marine forecasts are provided by firms specializing in the provision of marine meteorological services. Regularly scheduled forecasts are transmitted to the rig two or four times each day as required under the terms of the contract. Typically, forecast wind direction, mean speed, and maximum speed for the anemometer level are given at six hour intervals out to the maximum lead time offered by the numerical weather prediction guidance products. In practice this is 42 or 36 hours into the future depending on the issue time of the forecast. Beyond the maximum lead time, a more general outlook of expected wind velocities is provided for days 3, 4, and 5.

Appendix I shows the forecast winds used in the trials. Observed wind velocities at the forecast times are also shown. Some of the scheduled forecasts were not available. The accuracy of the wind forecasts can be seen by comparing the actual winds with the forecast winds.

2.2.2 Operational Routine

The methodology employed to run the model followed very closely the procedures that would have been followed in a real-time operation on board a drilling platform, or at an ice management office ashore. After entering the first two observed positions for an individual iceberg, and the observed and forecast wind velocities, the model was run to produce a predicted trajectory extending beyond the maximum verifiable lead time. A printout of the forecast positions was made; screen information such as the closest approach, time to closest approach, chance of impact with the rig, and the radius of the 95% confidence circles were manually transcribed onto the printout at three hourly intervals. The radii of the confidence circles were obtained by measuring the screen display, since this information was not provided elsewhere.

This procedure was repeated for each additional observed position of the iceberg that was available. When completed each prediction was assigned an individual identification number based on the original iceberg number, the number of prior fixes available, and whether it was an observed track, a predicted track using forecast winds, or a predicted track using observed winds.

The model output was then manually entered into Atlantic Airways offshore environmental computer system, from which intermediate data files were prepared and track plots produced.

2.3 MODEL OUTPUT GENERATED

Working with nine iceberg tracks, eighty-four individual model runs were made using forecast winds. This resulted in a total of 590 verifiable position predictions out to a maximum lead time of 39.5 hours. Seven runs were made using observed winds rather than forecast winds, giving a total of 50 verifiable positions to a maximum lead time of 38.5 hours. This was done to examine improvements that would be realized if the wind forecasts had been correct. Table 1 lists the individual tracks that were output during the model trials.

Appendix II contains the series of predicted trajectories for Iceberg 071. Each plot shows the observed track (labelled 17100) and a predicted trajectory with positions plotted at hourly intervals. The trajectory labelled 27102 was output after two observed iceberg positions were entered into the model; the one labelled 27107 was produced after the seventh position was entered. The plots shown in Appendix II were output by the Atlantic Airways environmental data management system. Labels were printed at the end points of the trajectories.

At the request of the Scientific Advisor, tests were also conducted with data for Iceberg 424 from the 1985 iceberg season. Re-numbered 99 in these trials, twenty-two forecast tracks were run giving a total of 259 verifiable positions for Iceberg 424. Data for Iceberg 424 may have formed part of the model development data set since track data from both the 1984 and the 1985 iceberg seasons were used. A discussion of the output for Iceberg 424 is contained in Appendix III.

Table 1

OUTPUT TRACK LABELS

Iceberg		Track Labels		
ID	Berg	Observed	Predicted Tracks	
No.	Size	Track	Forecast winds	Observed winds
01[1]	MB[2]	10100	20102 to 20107	-
16	SB	11600	21602 to 21609	31603
17	SB	11700	21702 to 21708	31703
18[3]	SB	11800	21802 to 21812	31803
32	MB	13200	23202 to 23218	-
34	MB	13400	23402 to 23419	33403
36	SB	13600	23602 to 24003	33603
40	BB	14000	24002 to 24006	34003
70	MB	17000	27002 to 27005	37003
71	SB	17100	27102 to 27107	-
99[4]	SB	19900	29902 to 29922	-

1 Iceberg numbers from 01 to 71 are from the 1990 data set.

2 MB = medium iceberg, SB = small iceberg, BB = Bergy bit.

3 Iceberg 18 is a continuation of the number 16 after a period when a few observations were made over an extended period of time.

4 Number 99 is Iceberg 424 from the 1985 iceberg season.

3. MODEL FUNCTION AND USER INTERFACE

No difficulties were experienced with the installation and initial set-up of the model software. The procedures were found to be clearly and concisely described in the User Manual. Similarly, the program operation was found to be well explained in the documentation, and little time was required for the operators to become fully familiar with the program function. Once in the working directory, the program is initiated by typing the word "start" on the command line. A start-up screen is presented; this is followed by a screen containing a disclaimer and software copyright information. The software then requests the current date and the name of the iceberg database. A new database is created by typing in a new name. Once provided the main screen display is presented and program is ready for use.

Most of the main screen is taken up with a chart display. The scale is not adjustable and the rig position is fixed in the centre. A side bar on the right hand side of the screen is used for displaying numerical information such as iceberg number, mass, probability of impact, and so forth. Function keys serve as the means by which the user selects options, calls up the data editor, and runs the model. In general, the software was found to be quite robust, however, the program would terminate and the user would be returned to the operating system if a printer was not available when a printout of predicted positions was requested.

To most users of software products, the design of the user interface is extremely important in determining the general acceptance of the product. This section addresses various aspects of the user interface that were found to be weak. The critique is intended to be constructive, and suggestions and recommendations for improvement are given with each point discussed. It is expected that many of the recommendations could be implemented relatively easily.

Date and Time Inputs

The current version of the program contains a mix of formats for data entry that reduce operator efficiency. Date components, for example, are separated by slashes (i.e., YY/MM/DD) while with time, the hours and minutes are separated by a colon (i.e., HH:MM). This precludes the use of the numeric key pad for data entry and, in practice, was found to result in frequent entry errors.

It is suggested that the date be normally read from the system clock with an option provided to manually change it if desired. Manual entry of the date would be improved with the format "YYMMDD", avoiding the delimiters. It is recommended that time be manually entered with the simple format of "HHMM".

Iceberg Information

Other than position information, the model software allows for only the input of iceberg size and mass into the database. Only a single field is available for size. In the operational trials, iceberg length was input to the model.

It is recommended that the software be modified to allow for the input of iceberg length, width, height, draft, and perhaps an estimate of the above waterline block coefficient. With these data an estimated mass could be computed internally, rather than external to the model. A field to contain the iceberg type (tabular, pinnacled, dry docked, etc.) would be appropriate as well.

Position Data Input

The position of the drilling rig is input to the model using latitude and longitude coordinates. Iceberg positions may be entered using latitude and longitude or, optionally, as a range and bearing from the drilling unit. Data entry of latitude and longitude employs the unconventional format of degrees and decimal degrees. This format is not used operationally. Converting from the conventional degrees, minutes, and seconds (i.e., DDMMSS.ss) or degrees and minutes (i.e., DDMM.m) is time consuming and increases the chances of making blunders.

The option of entering iceberg position as a range and bearing is a useful feature, particularly when dealing with icebergs that are located within radar range of the drill rig. Most iceberg positions, however, are obtained from standby vessel or ice surveillance aircraft reports, which use the conventional degrees and minutes format.

When entering iceberg position data, time must also be entered. On occasion, there may be situations when more than 24 hours have elapsed between position observations. In these instances a problem will arise since there is no means available by which the date can be entered.

It is recommended that the format for latitude and longitude be changed to reflect conventional practice: degrees, minutes, and seconds for rig positions; and degrees, minutes, and tenths of minutes for iceberg fixes. A means of entering the date of the position observation should be provided as well.

Wind Velocity Data

The model requires input of the observed wind speed and direction at the time of the most recent iceberg position fix (0 hour) and the forecast wind velocities for 12, 24, 36, and 48 hours into the future. It also requires that the entire wind record be updated each time a new iceberg fix is entered. Manual entry and re-entry of forecast wind data is likely to result in errors on occasion.

The data entry prompt requests wind speed first, then direction. Operationally, it is customary to log direction followed by speed. It is recommended that order be changed to reflection common practice and that the term "Bearing" which used as the prompt be replaced with the word "Direction". In the present version of the software, no error checking of the wind data is done. For example, it is possible to enter any values, including directions in excess of 360 degrees.

As discussed earlier, the most common source of forecast winds is from marine weather forecasts valid for the drilling area. Frequently, in light wind conditions the term "variable" is used for wind direction in light wind conditions. In these instances the operator would be required to interpolate a direction for input to the model. Moreover, forecasts are given for specific times of the day while the model formulation requires forecast wind speed and directions at 12 hour intervals beginning at the most recent observation time. As these times are likely to be different in most instances, an interpolation procedure has be established by the user.

Some offshore operators have, in the past, obtained wind velocity forecasts in grid point format covering the area of operations. Since manual input of wind velocities is required with the model software, interpolation of the data over the grid and temporally would be required. As an added complication, grid point winds would typically be output directly from Numerical Weather Prediction (NWP) models. While NWP model output serves as the basic guidance material upon which forecasts are prepared, there will be times when the forecast winds given in a rig area forecast will differ significantly from the grid point winds output from a specific NWP model.

The issue of the height of the wind inputs was discussed in the previous section. Briefly though, anemometers on drilling rigs are typically located about 80 m above the sea surface and wind forecasts available on a rig are normally for the anemometer height. de Margerie et al. (1986) state that wind speeds near 10 m are preferred, while the User Manual does not specify a wind level height. Wind speed differences between 10 and 80 m can be significant at times, particularly when the atmospheric conditions in the boundary layer are stable.

The provision of wind data to geophysical models needs careful consideration. Ideally, for an iceberg drift model, grid point wind forecasts valid for a specified height would be available routinely for the area of operation; moreover, such forecasts should be entirely consistent with site-specific rig forecasts at all times. Once defined by the developers, the specification of the wind data should be clearly documented in the User Manual.

It is recommended that the software be modified to provide for separate files for the observed and forecast winds. The observed wind could then be read from an environmental data file, avoiding re-entry of the observed wind velocity into two independent systems. Also, if 10 m level winds are specified by the model developers, then a surface boundary layer (SBL) model should be incorporated into the software to adjust the wind speed from the anemometer measurement. The input parameters required by a SBL model, other than the anemometer level wind speed, could also be read from the environmental observation data file.

Forecast wind velocities read from a separate file should be interpolated under program control to provide the model inputs at the required times. An option to use either the well site forecast winds or grid point data should be offered. Wind speeds extracted from the well site forecast could be reduced to the 10 m level using a SBL model. The source of the grid point data would dictate what processing would be necessary to provide an estimate of the 10 m winds. If rig forecasts are to be used, some guidance should be provided to the user with regard to handling wind directions that are forecast as "variable".

Times of Iceberg Predictions

The model software outputs iceberg position predictions at one hour intervals beginning at the time of the most recent fix. As this is somewhat inconvenient, it is recommended that position predictions be output on the hour starting with the following hour. While the length of the forecast period is easily changed by the user, an option to enable the user to choose the interval at which predictions are to be output should be incorporated.

Number of Icebergs

The model software is limited to handling one iceberg at a time, a limitation that is recognized in the model documentation (de Margerie et al., 1986). It is, however, easy to switch to another iceberg in the database to run a prediction. Never-the-less, it would be a definite asset to be able to display the positions of all icebergs on plot and to output track predictions of all, or selected, icebergs concurrently.

Chart Display

The rectilinear chart display is fixed at 60 miles in a north-south direction and about 72 miles in an east-west direction. This limitation presents a problem in resolving small changes in the track of an iceberg, a factor that is extremely important when dealing with icebergs at close range. In addition, it is not possible to display an iceberg track, or part of a track, that is greater than 30 to 35 miles from the rig. With the large lead time required to move a rig in the event of an approaching iceberg, it is quite common for icebergs to be tracked at ranges of 50 miles or greater. Furthermore, long range planning usually involves considering icebergs within 100 miles of the rig.

It is recommended that the chart display be modified to allow, as a minimum, a user selectable scale and preferably other display formats such as a Mercator projection chart and a PPI or polar plot display. Higher resolution graphics and the use of colour would serve to improve the screen display. An ability to zoom on user selected points on the screen would also enhance the software product.

Graphic Display of Iceberg Tracks

Apart from the lack of detail mentioned above, it is very difficult to differentiate between the observed track and the predicted track. Moreover, the present position of an iceberg can not be identified on the monitor. Again, only one iceberg track can be displayed at a time. These limitations would be important in an operational situation, where the ice observer would have to use the display to brief senior rig management on potential iceberg problems.

It is recommended that the display graphics be modified to indicate the present position of an iceberg, and that the observed track be differentiated from the predicted track. This could be done by the use of either symbols or colour, or perhaps a mix of both.

Side Bar Display

Most of the information presented in the side bar is operationally useful. However, the display does not include iceberg drift velocity, either actual or forecast. Drift speed of an iceberg is required to compute the radii of action or alert zones around a rig, factors that are used routinely in ice management decision making.

It is recommended that the tabulated side bar be modified to indicate the observed direction and speed of the iceberg computed from the most recent position reports. This could replace the "Lead Time . . ." display as this is of little use operationally since each offshore operator uses different alert zone calculation formulas.

Hard Copy Output

Two forms of hard copy output can be generated: a printed listing of iceberg positions, and a printout of the screen display.

The printed listing available to the user is limited to a numbered, sequential list of observed and predicted iceberg positions in DD.dddd format. Since the predicted positions are not time stamped, the user must manually correlate the numbered list with the time of the position observations to establish at what point in the listing the forecast begins. Forecast positions must then be labelled in one hour increments from the time of the last position fix.

Other than iceberg number, no other information is given on the listing to identify the iceberg. At times, it was found that the iceberg number was not printed in the header of the printout.

It is recommended that the hard copy output be redesigned with operational factors taken into consideration. The hard copy output should include as a minimum:

a) iceberg identification number, size and type classification, physical dimensions, and mass;
b) time and date stamped positions in DDMM.m format, with positions identified as being observed or forecast;
c) range and bearing from the rig location; and,
d) course and speed of the iceberg.

Other data should be provided as well; for example, the radius of the 95% confidence circles, and, perhaps, the probability of impact with the drill rig with each position prediction.

Hard copy output of iceberg trajectories is only available as screen printouts. The resolution is limited, the scales in the X and Y are not necessarily equal, and the product is slow to produce. Moreover, the output has the same short-comings that were identified in the discussion on the graphics display. A significant improvement would be achieved if the graphics products could be output to a plotter.

General Comments

For the most part, individual predicted trajectories appeared quite reasonable at the time the forecast was made. On occasion, however, certain output was found to be inconsistent with expectation and with the previous and subsequent runs of the model. This typically appeared as a reversal of direction of the iceberg at the beginning of the forecast period after a change of date had occurred. This suggests that the software contains a minor bug that should be corrected.

The operational model software was designed as a stand-alone system with no means of communication with other software provided. Observed iceberg position files and the wind data file are in a binary format with the data accessible only through the internal database. No output files are generated by the present version of the software. To meet normal archival and reporting requirements, however, a means of obtaining iceberg information and observations from the database should be provided. The information that would be required includes iceberg characteristics (size, type, dimensions, mass), time-stamped iceberg fixes, source of the position observation (radar, supply vessel, aircraft), and status at the time of fix (grounded, under tow, etc.).

There are three operational situations that the present version of the model software cannot handle. As mentioned above the software is only capable of processing and displaying a predicted track for one iceberg at a time. This limitation is quite restrictive since it is not unusual that two or more icebergs are monitored concurrently. The other short-comings relate to the handling of grounded and towed iceberg, both common occurrences on the Grand Banks. No means is available of indicating that an iceberg is grounded, therefore, as all icebergs are assumed to be free floating, grounded icebergs will be forecast to move. Similarly, there is no means of indicating whether an ice mass is under tow, or being otherwise managed. Predictions made during a tow will be made without consideration of a towing force. Consideration should be given to these operational scenarios if further software development work is contemplated.

4. MODEL OUTPUT VERIFICATION

4.1 PURPOSE AND SCOPE OF VERIFICATION

Short range environmental forecasting services for marine users are required for two reasons. Ultimately, the most important purpose is to provide warnings of conditions that may endanger the safety of personnel or threaten the integrity of facilities and operations. At lower priority, short term forecast products are valued for solely economic reasons, as planning tools to improve operational efficiency in an effort reduce costs or increase the potential for profit. Since the iceberg trajectory model was developed for operational use by petroleum companies to support drilling activities on the Grand Banks, it is appropriate that the verification be carried out in a manner that serves the same interests.

The verification that was carried out documents the accuracy of the model output in a manner that is meaningful from an operational point of view. In particular, it concentrates on the magnitude and direction of the forecast errors generally rather than attempting to examine the reasons for the behavior of the model.

Error statistics and plots derived from the model output in the simulated operational test are presented in the following section. Section 4.3 briefly discusses the influence of errors in the forecast winds. A comparison is made of the prediction errors that occurred using forecast winds with the errors obtained using observed winds, in effect, using perfect wind forecasts.

While statistical measures of the absolute accuracy of the forecast errors are valuable in establishing the confidence that one is justified in placing in a prediction, it is useful to compare the output of one methodology with some control or, alternatively, with another forecasting procedure. In this manner, the relative skill of the methodology can be established. Skill of the iceberg trajectory model is discussed in section 4.4.

4.2 VERIFICATION OF SIMULATED OPERATIONAL TRIALS

4.2.1 General

This section contains a discussion of the accuracy of the iceberg position forecasts output during the simulated operational trials. The results are applicable for the forecast methodology as a whole, for they incorporate the effects of many factors. Prediction errors may be due to the errors in the forecast wind velocities, possible errors in the observed iceberg position data, impact of operator decisions (see following paragraph), undetected operator data entry errors, and the errors arising from the model assumptions and formulation.

Decisions made by the operator which may have had impact on the model results related only to the input of the forecast wind data. Since the forecast times did not generally correspond with the forecast lead times that were dictated by the time of the latest iceberg position fix, it was necessary to make a decision on the approach to be taken. In the simulated test, the operator used the forecast winds for the nearest available forecast time rather than interpolating between values. Had interpolation between forecast values been done to determine the inputs, the results of the predictions would most likely have been somewhat different.

Still other sources of error may be attributable to the post processing operations that were required. Since the model software does not provide for file output, it was necessary to manually re-enter the prediction data into computer files in order to carry out the verification analyses. This work, in addition to being time consuming, was subject to data entry errors. While every effort was made to ensure that the data were correct, it is possible that some errors may not have been detected. Finally, a linear interpolation procedure was used to interpolate between the predicted positions in order to obtain positions at verification times. Slight differences in error may have arisen had a different method been used.

Although the tests covered a range of actual and forecast wind conditions, and included iceberg sizes from bergy bits to medium sized icebergs, it is emphasized that the results of the verification analysis must be considered as being applicable for only those data tested. The extent to which the results can be generalized is not known.

In keeping with the stated goal of the verification analysis, forecast errors and error statistics discussed in this and subsequent sections are given in conventional operational units; in particular, distance errors are expressed in nautical miles.

4.2.2 Results and Discussion

Figure 1 is a plot showing the distance errors in nautical miles against forecast lead time for all 590 position predictions output in the test. The range of the errors is seen to increase fairly rapidly with lead time. In a few instances the separation between the predicted position and the actual position exceeded one nautical mile (1852 m) per hour. This rate of separation can be compared with the average iceberg drift speed in the Hibernia area of approximately 0.4 knots (see Mobil Oil Canada, Ltd., 1985).

Concentrations of points are seen at intervals of two hours, at least until a lead time of 16 hours. As the individual tracks were generally quite short, there are relatively few verification points beyond 24 hours. Figure 2 is a polar plot showing the prediction errors at a lead time of 6 hours. To increase the amount of data slightly, all predictions within 15 minutes of the indicated lead time were included on the plot. Distance errors are given in nautical miles, with the diagram scaled to the include the largest distance error for that lead time. The direction of the error, although labelled following mathematical convention, shows the true orientation of the error; a forecast error to the north is above the center point while an easterly error is to the right.

Appendix IV contains polar plots of the forecast errors at a two hour intervals out to a lead time of 24 hours. A review of the plots suggests a slight bias in the prediction errors, particularly for the shorter lead times. Figure 3 shows the average position error for each lead time out to 18 hours. A bias toward the east is evident at all lead times. Moreover, for lead times out to 14 hours, the direction of the prediction errors is biased toward the northeast. At 16 and 18 hours the bias is toward the southeast. The reason for the bias is not immediately obvious.

Forecast error statistics for lead times out to 24 hours are shown in Table 2. The number of verification points, N, includes all data within 15 minutes of the indicated lead time. RMSE is the root mean square error. The 95 percent circular error probable (.95CEP) is the radius containing 95 percent of the forecast errors. As the number of verification points decreases rapidly with time, little confidence can be placed in the statistics at the longer lead times. Figure 4 graphically illustrates certain forecast error statistics.

After running the model to obtain a predicted trajectory, the user may request the software to display confidence circles around the predicted positions. The confidence circles have a radius of 1.65 times the standard error (de Margerie et al., 1986) and indicate the area having a 0.95 probability of containing the iceberg. As stated earlier, screen measurements of the radius of the confidence circles were made at three hour intervals during the operational tests. In Figure 5, the mean radius of the confidence circles (MR95CC) with error bars at one standard deviation are shown at 3 hour intervals out to 24 hours. Also, shown are the values of the radius containing 95% of the prediction errors (RC95PE) at two hour intervals out to a lead time of 18 hours.

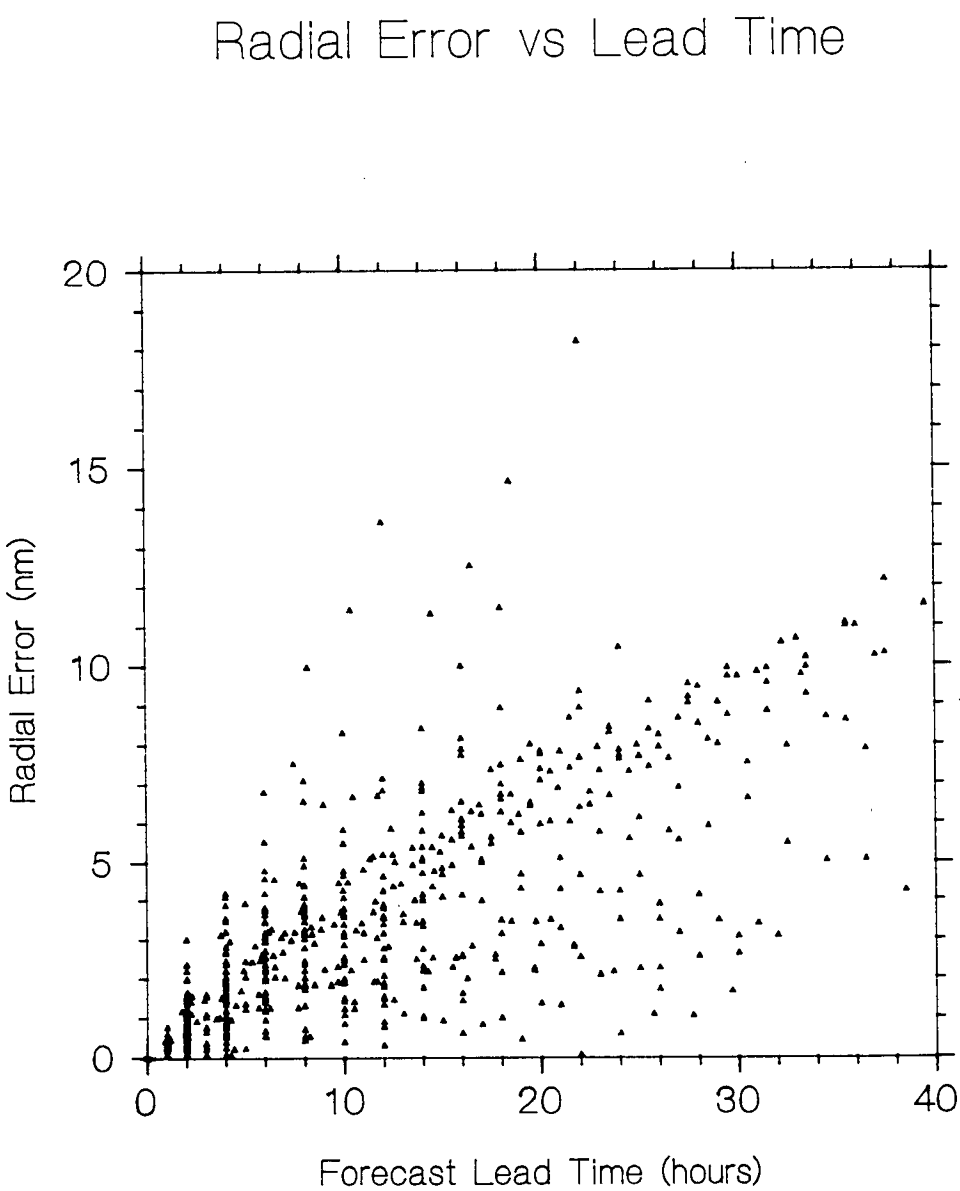


Figure 1. Radial distance error versus forecast lead time

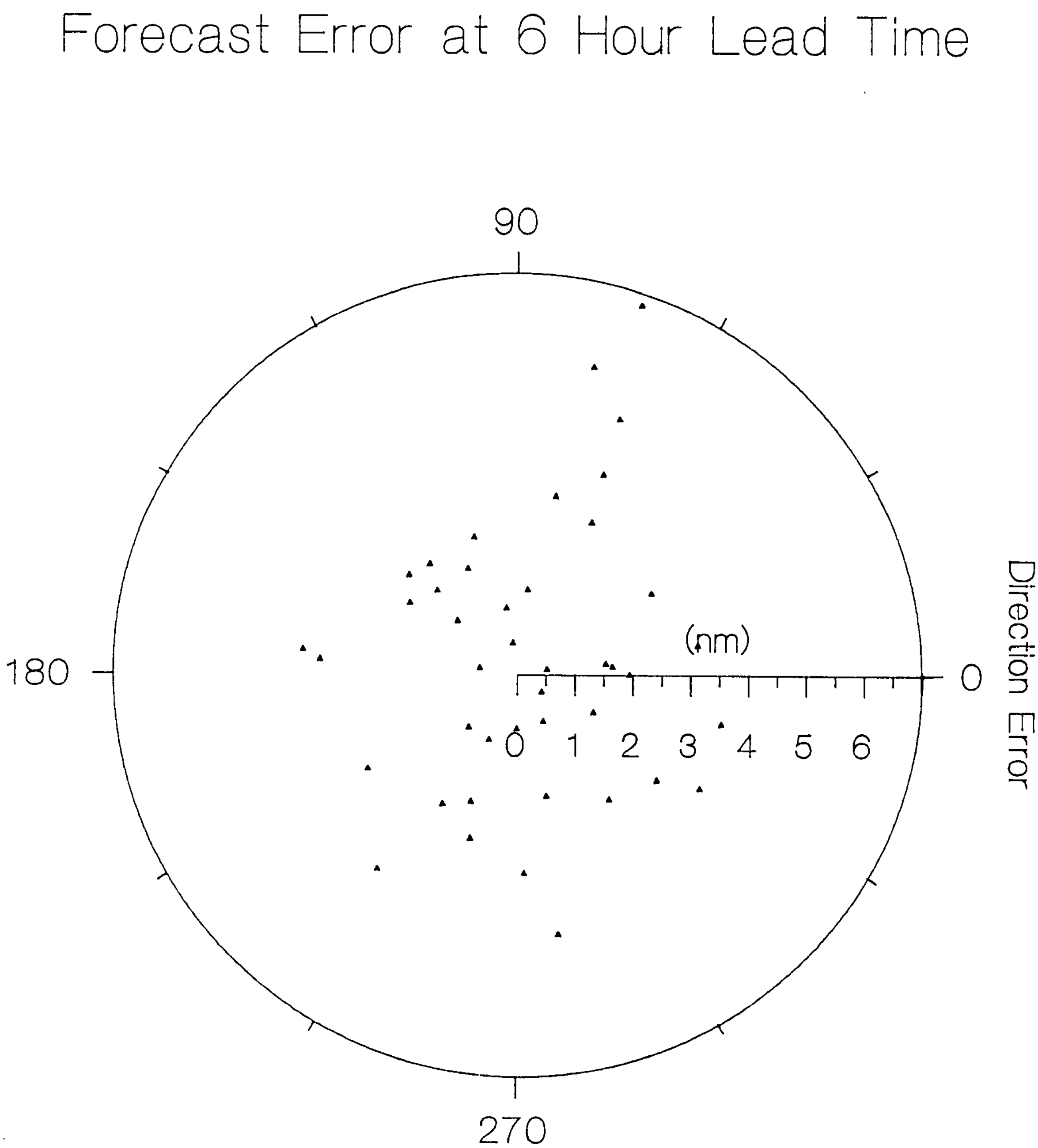


Figure 2. Forecast error at 6 hour lead time

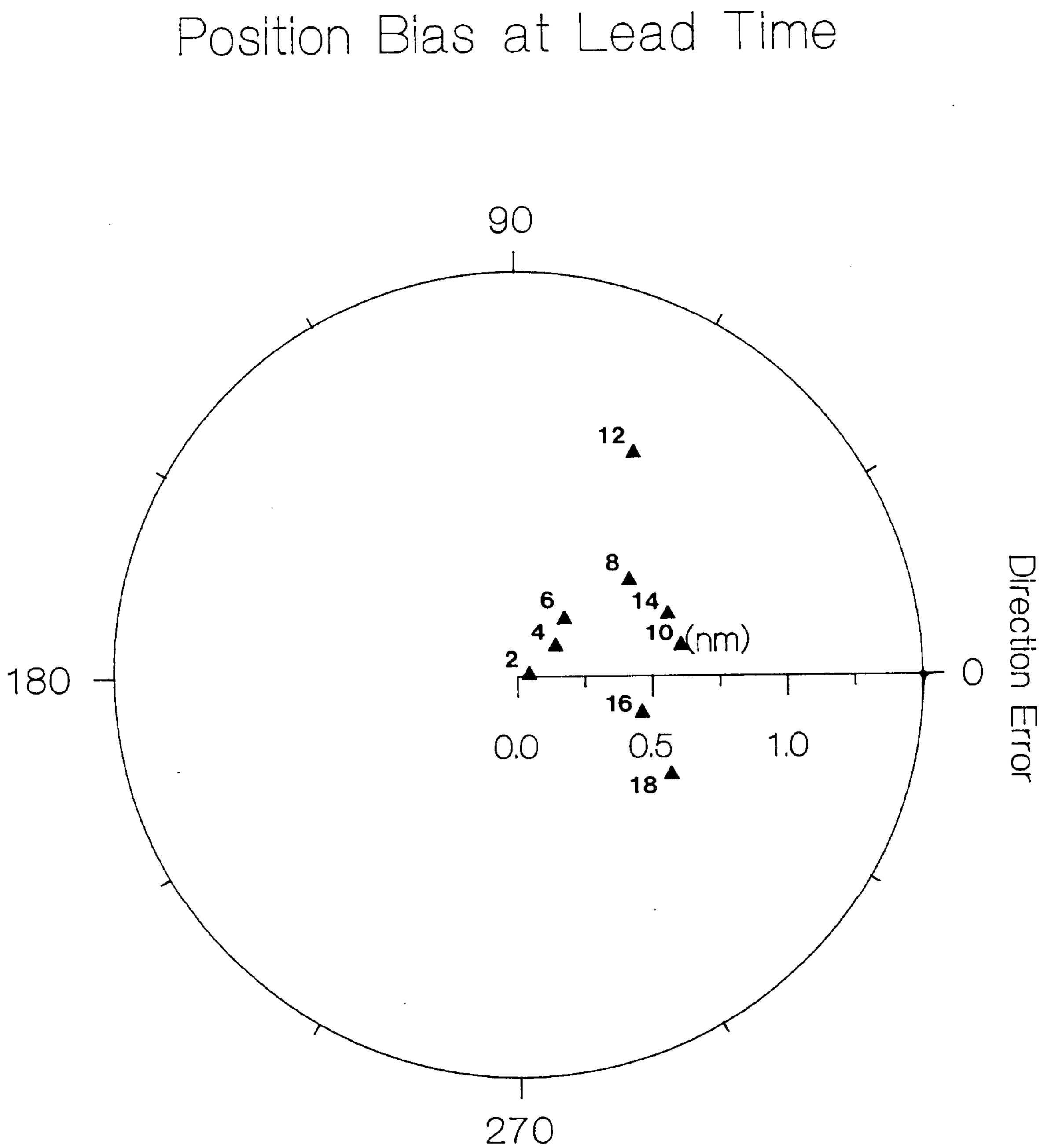


Figure 3. Average position error at lead times from 2 to 18 hours

Table 2

FORECAST ERROR STATISTICS

Forecast Lead Time (hours)

	2	4	6	8	10	12	14	16	18	20	22	24
N	66	57	43	37	31	28	23	17	12	9	9	7
Mean	0.9	1.7	2.5	3.3	3.2	3.6	4.2	5.0	5.9	5.7	7.3	6.0
Median	0.8	1.5	2.5	3.2	3.2	3.3	4.0	5.8	6.4	7.1	7.7	7.6
RMSE	1.1	2.0	2.9	3.8	3.6	4.4	4.6	5.7	6.5	6.2	8.7	6.8
.95CEP	2.0	3.7	4.7	6.8	5.7	7.0	7.0	9.1	10.2	7.8	13.8	9.2
Max	3.0	4.2	6.8	10.0	8.3	13.6	8.4	10.0	11.5	7.8	18.2	10.5

Mean, Median, RMSE, .95CEP, and
Maximum given in nautical miles

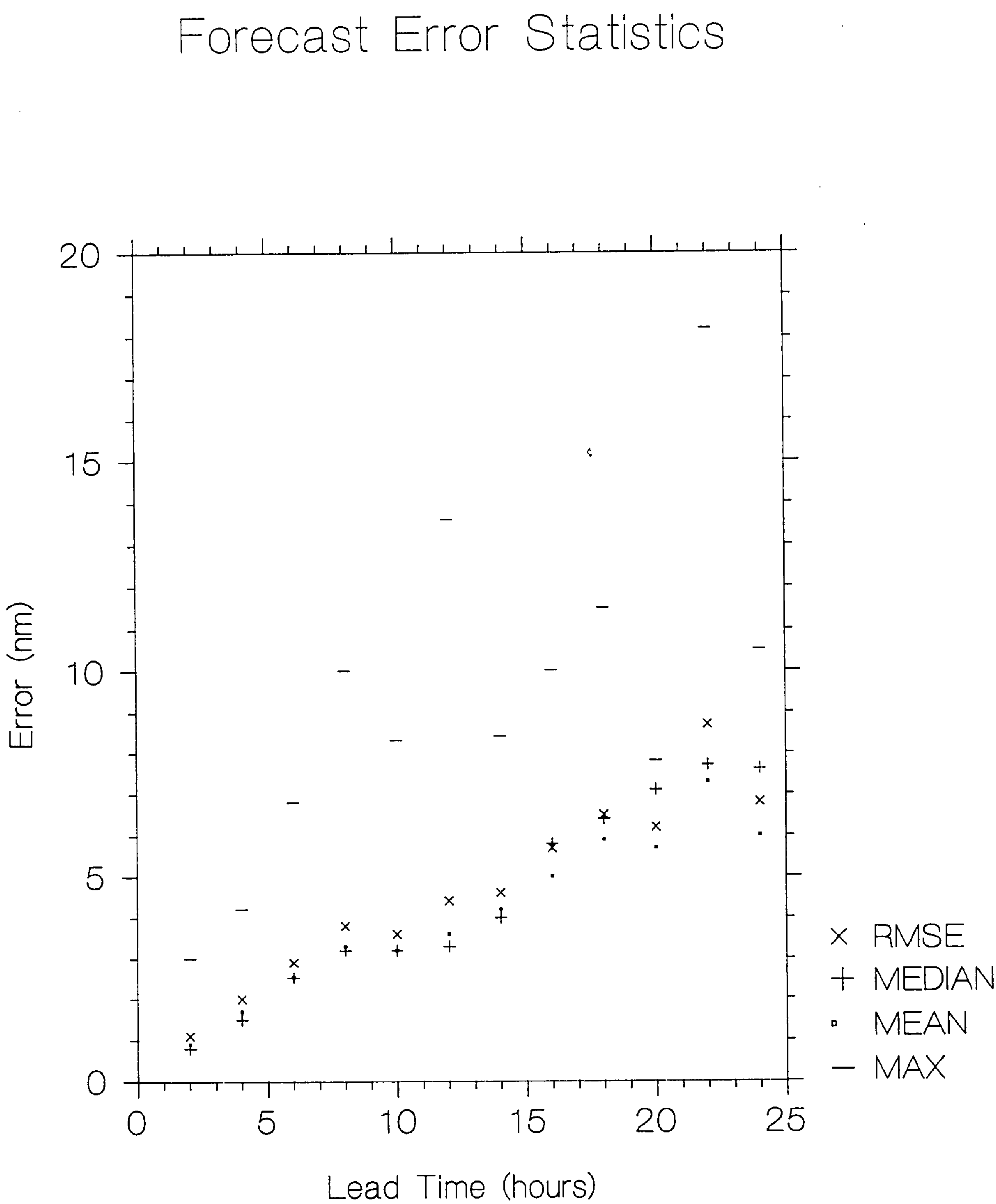


Figure 4. Forecast error statistics

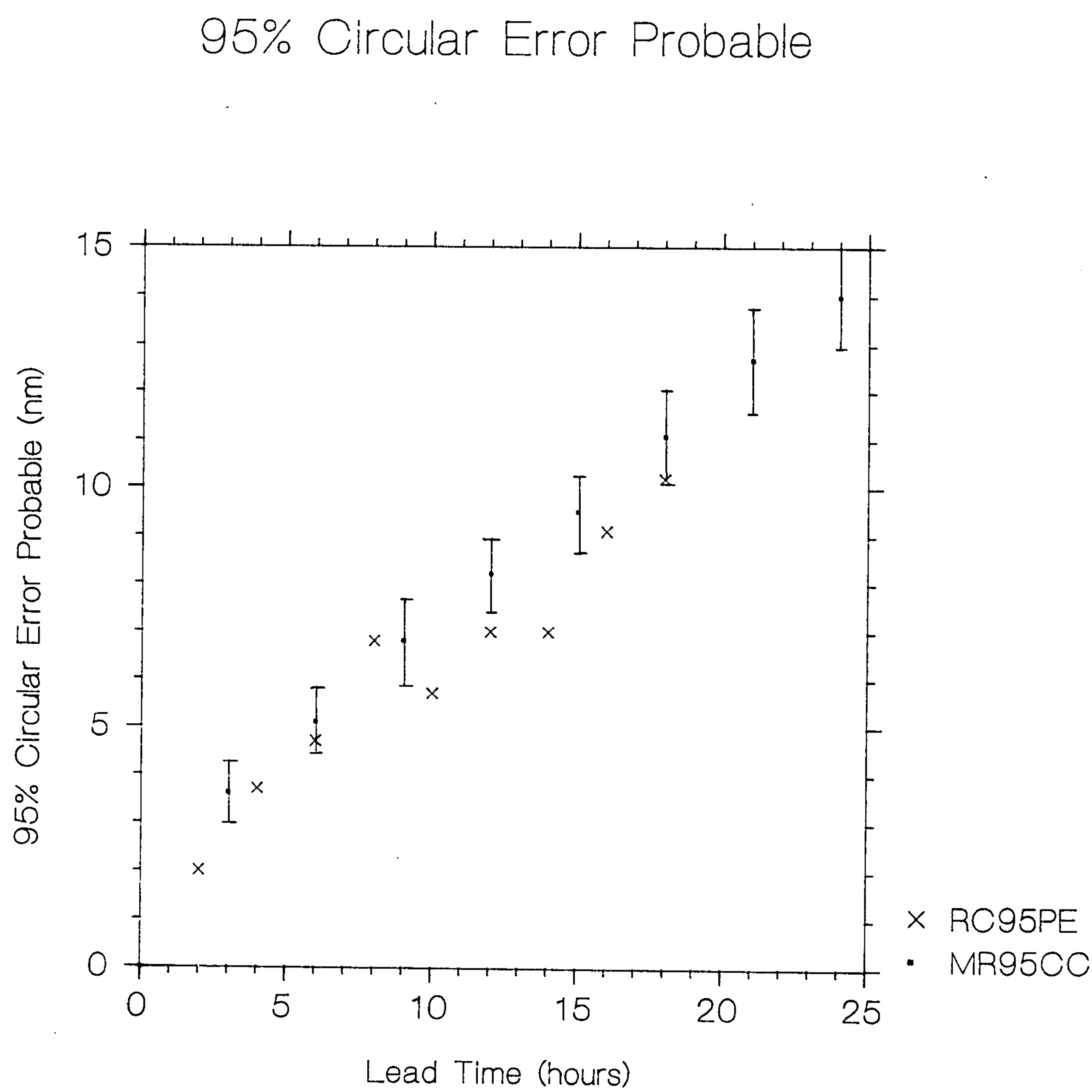


Figure 5. 95% Circular error probable

Despite the rather large radii of the confidence circles, the comparison suggests that the model performed better during the operational test than indicated by the size of the confidence circles. The size of the confidence circles output by the model would appear to be conservative.

The percent exceedence of the forecast error for lead times of 6, 12, and 18 hours is shown in Figures 6, 7, and 8, respectively. Once again, the plots are based on relatively few data obtained from the operational test; consequently, the extent to which the information may be generalized is not known.

4.3 EFFECTS OF FORECAST WIND ERRORS

To obtain some indication of the effects of incorrect wind forecasts on the accuracy of the predicted iceberg positions, seven model runs were duplicated using observed winds rather than forecast winds. In each case the runs were made after three positions had been entered. A total of 50 verifiable predictions were obtained with lead times ranging from 1 hour to a maximum of 38.5 hours.

Figure 9 is a plot showing the radial error against forecast lead time using forecast winds while Figure 10 shows the results with observed winds. A scatter plot of radial error obtained with observed winds against radial error with forecast winds is shown in Figure 11. For the cases using forecast wind velocities, the maximum error was 11.0 nautical miles and the sum of the radial distance errors for the 50 cases was 164 nautical miles. With observed winds the maximum error was 9.7 nautical miles and the sum of the errors was 155 nautical miles.

For these few cases tested, a small improvement in overall forecast accuracy would have been realized if the wind forecast had been correct. This result was expected, however, since only limited testing could be carried out, it is not possible to draw conclusions about the potential improvement to be realized if more accurate wind forecasts were available. One would expect, however, that more confidence could be placed in a predicted iceberg trajectory in cases when greater confidence in the wind forecast is justified.

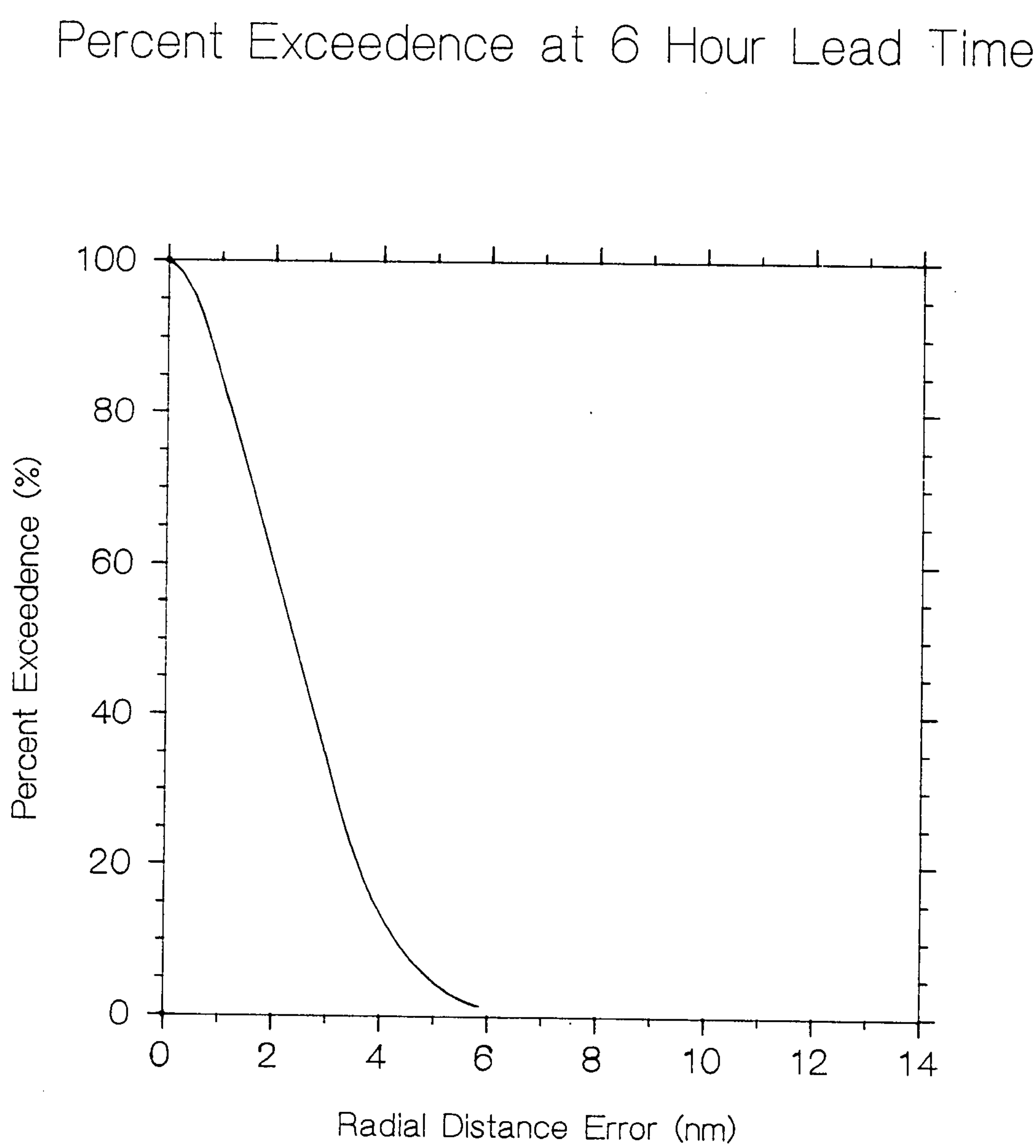


Figure 6. Percent exceedence of forecast errors at 6 hour lead time

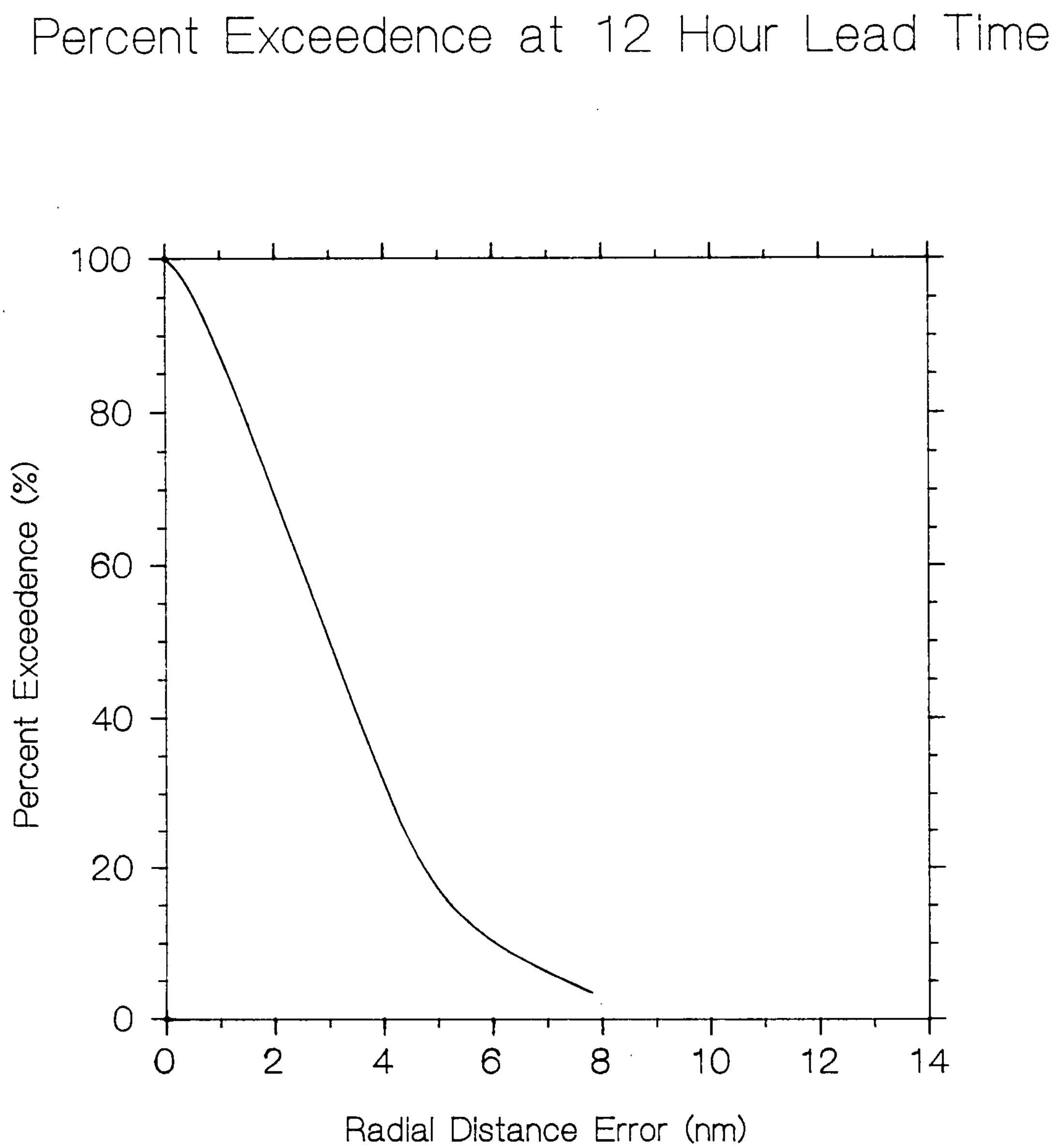


Figure 7. Percent exceedence of forecast errors at 12 hour lead time

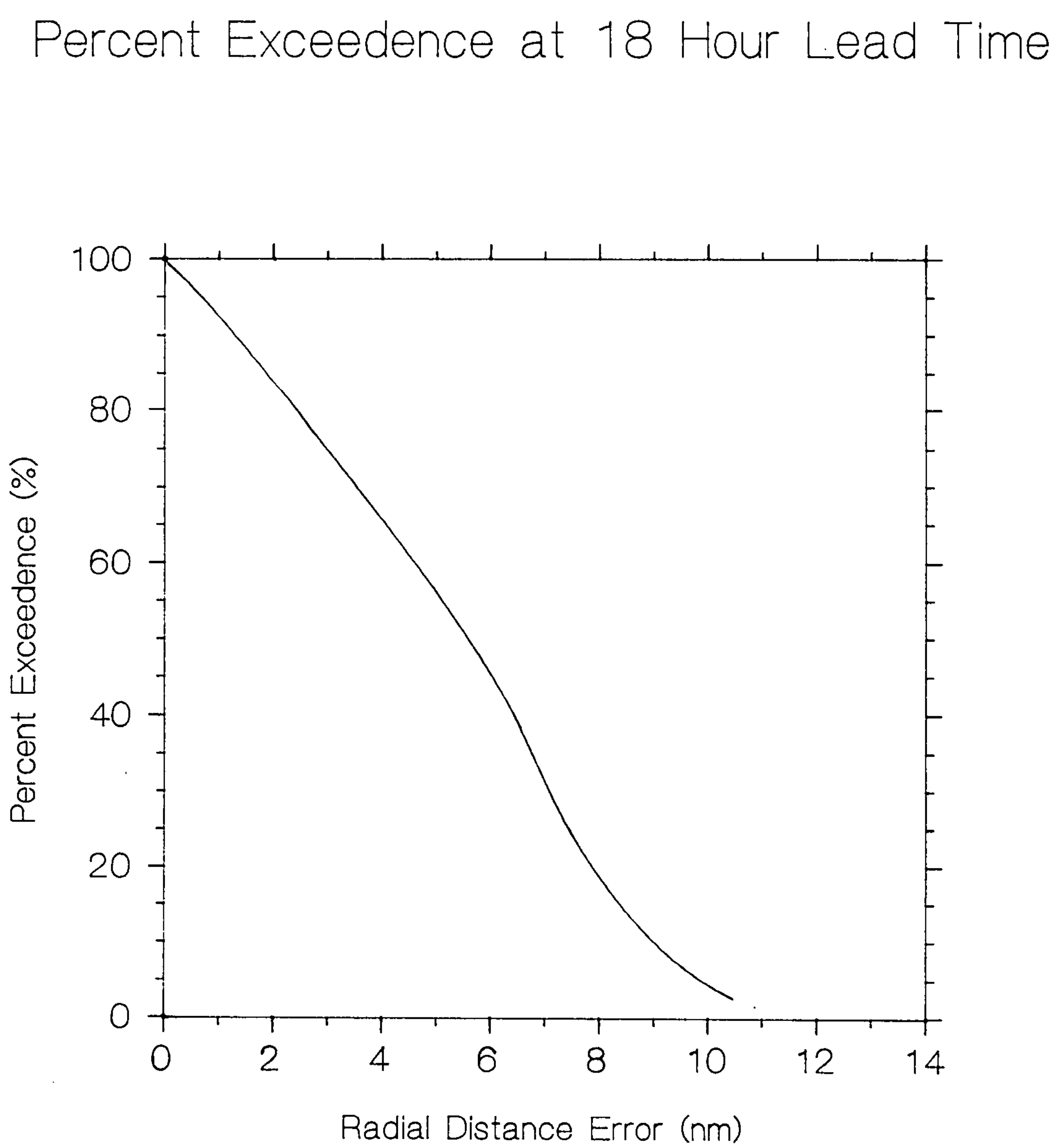


Figure 8. Percent exceedence of forecast errors at 18 hour lead time

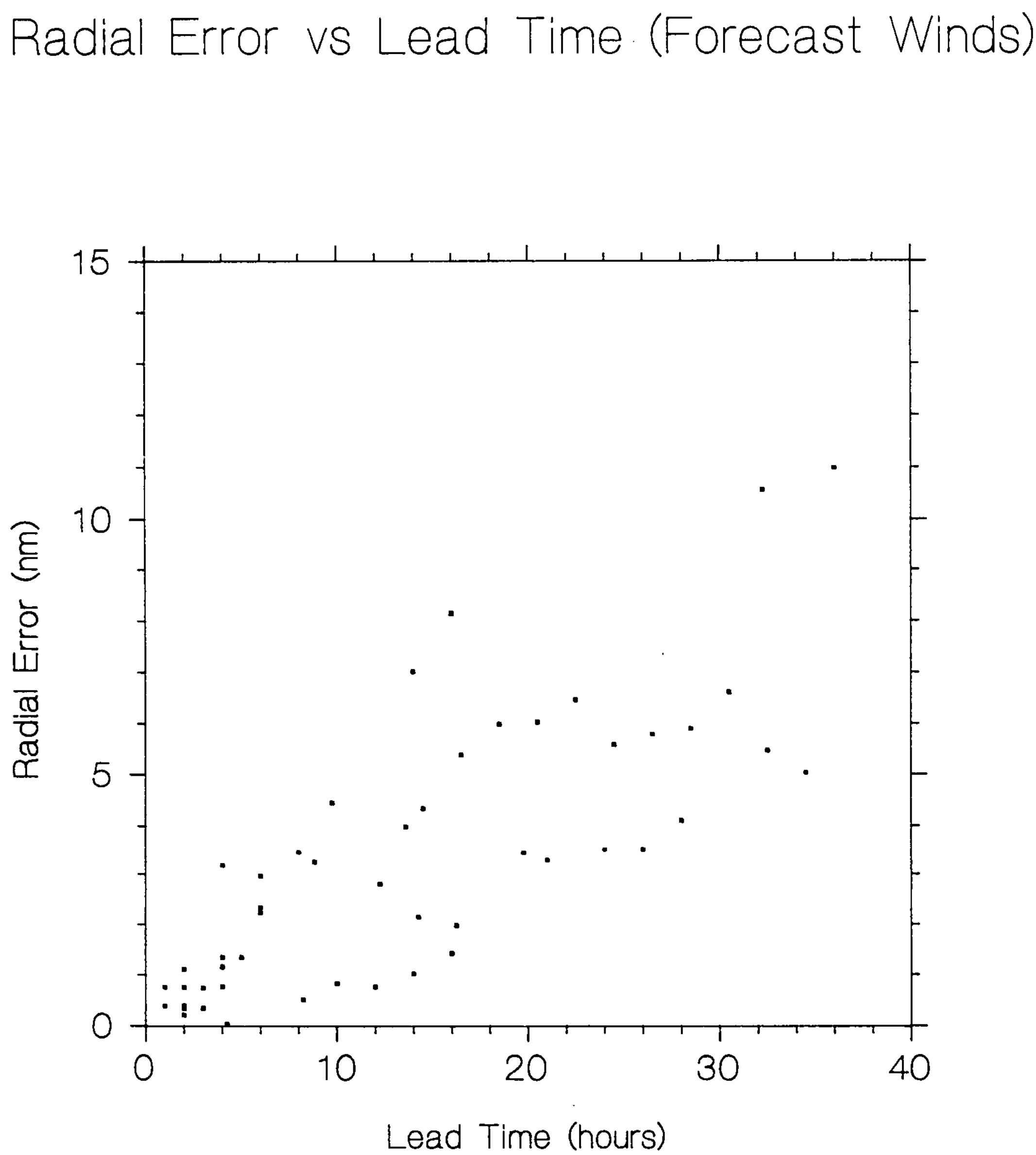


Figure 9. Radial distance error versus forecast lead time
Seven cases with forecast winds

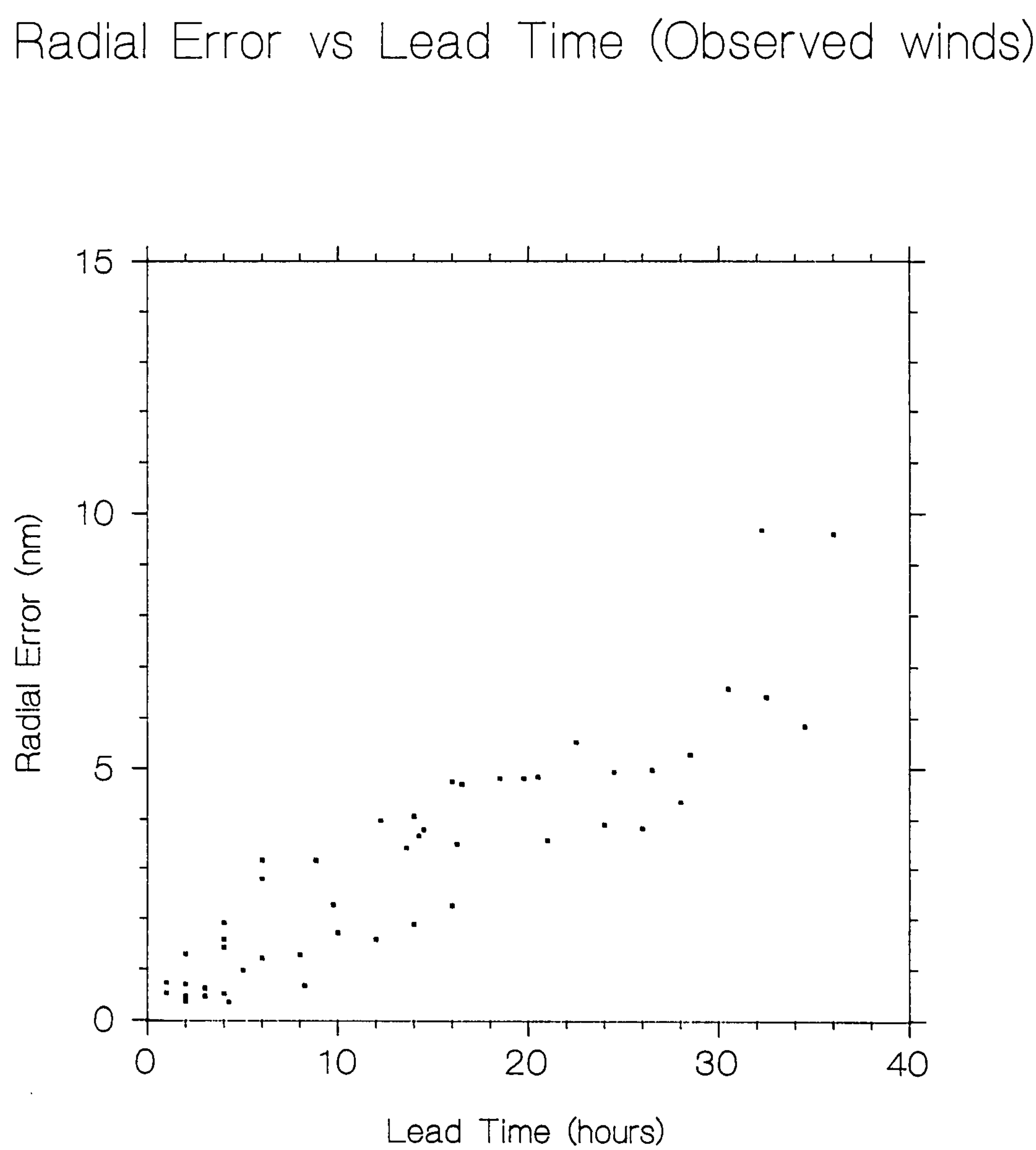


Figure 10. Radial distance error versus forecast lead time
Seven cases with observed winds

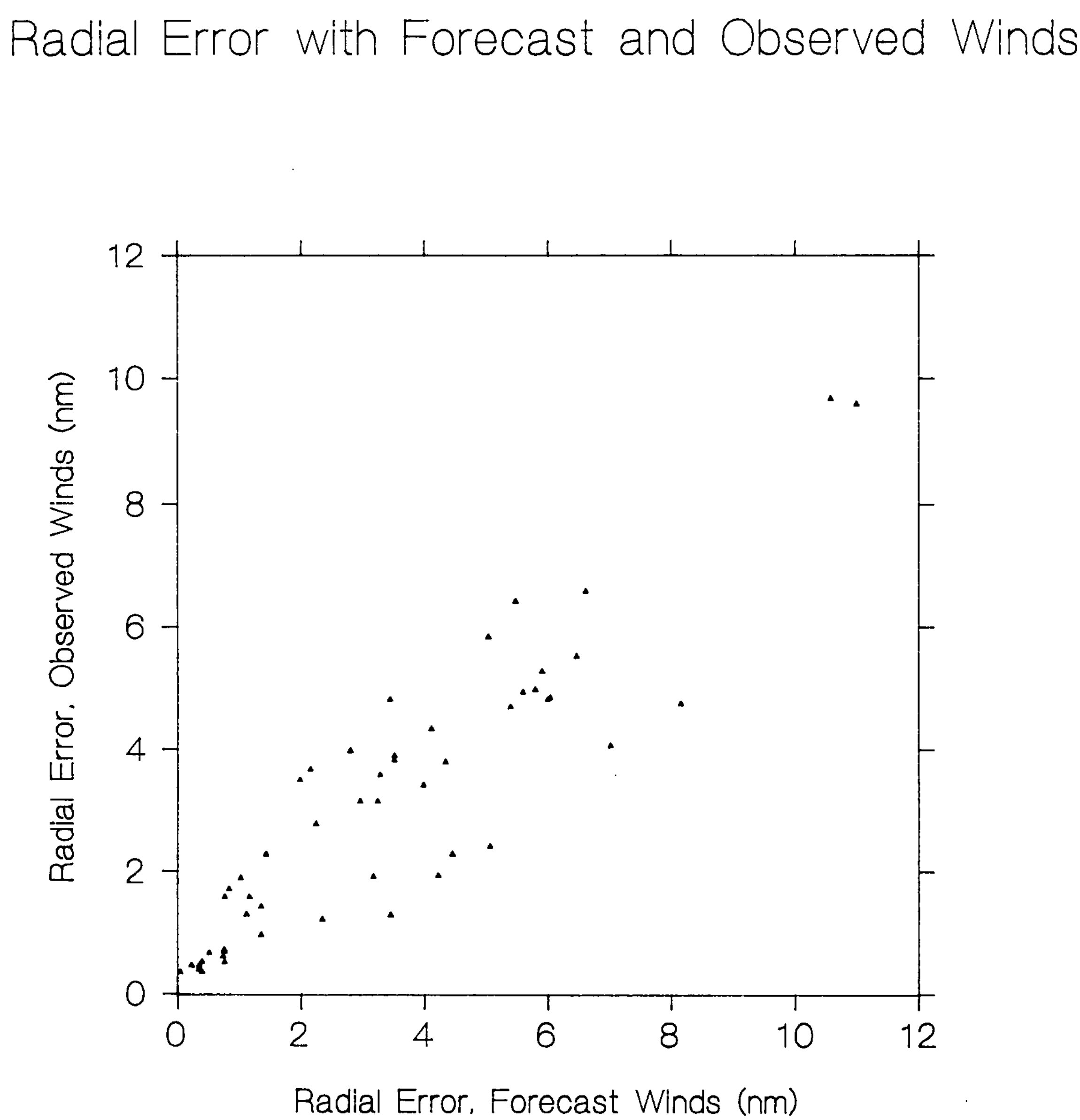


Figure 11. Radial error with forecast and observed winds

4.4 PREDICTIVE SKILL

Predictive skill may be evaluated by comparing model output with some control. In the field of meteorology, for example, the control might be climatology, persistence, or perhaps a random forecast. Predictive skill might also be rated relative to another forecast methodology that may be more, or less, sophisticated than the model under review. To obtain a preliminary indication of the skill of the Operational Iceberg Trajectory Forecasting Model for the Grand Banks, the accuracy of the model output was compared with a forecast assuming persistence and with predictions made using a simple, steady course model. Unfortunately, as only a few comparisons for one forecast period could be made, generalizations regarding model skill can not be made.

Persistence assumes no motion of the iceberg through the forecast period. The simple forecast model assumed that the iceberg would continue on a steady course at a constant speed for a few hours into the future. This latter approach has commonly been used by ice observers on board drilling platforms to make an estimate of the short term trajectory of an iceberg.

Nine independent comparisons for a forecast period of roughly six hours were made, one trial case being picked from each iceberg track for which data were available. The test cases were selected by choosing the first instance from each iceberg track that met the following criteria:

- there were at least two position reports available within the six hours period prior to last position fix; and,
- a verifiable position with a lead time between five and seven hours was available.

The steady course method used was entirely objective. The iceberg velocity between the last two position reports was calculated; then, using the same direction and speed, the position of the iceberg was computed for the verifiable lead time. The forecast error computed for the nine cases is given in Table 3. The table also contains the errors for the operational model predictions and the errors for the assumption of persistence of position over the forecast period.

For the cases tested, the total distance error was 25.5 nautical miles for the operational model, 25.2 for the steady course assumption, and 35.1 nautical miles for the assumption of persistence of position. Distance errors for the trajectory model were less than the errors for the straight line projection in three cases, greater in four cases, and virtually the same in two instances. Compared with persistence, the model errors were smaller in five cases and greater in four instances, one being only marginally greater. In three instances, the errors assuming persistence were very much larger than the model errors.

The ratio of the mean distance error of the control to the mean distance error of the model predictions provides a measure of relative skill. A value of 1 indicates no difference in performance between the techniques; values less than 1 mean that the model was less skillful and scores greater than 1 indicate that the model was more skillful. For the 9 cases tested with forecast lead times of approximately 6 hours, the ratio of forecast errors assuming a steady course projection to that of model output equaled 1.0; for the assumption of persistence, the ratio was 1.4.

For short lead times, it is expected that the accuracy of position predictions using a using a recently measured iceberg velocity would be comparable to the model accuracy, however, for longer lead times, it is expected that the model output would be better. The limited testing that was done does not allow conclusive statements to be made about the skill of the operational model.

Table 3

ERRORS FOR MODEL OUTPUT, STRAIGHT LINE PROJECTIONS, AND PERSISTENCE

Track No.	Lead time Hr Min	Model error Brg °T	Model error Rng nm	SLP error Brg °T	SLP error Rng nm	Persistence Brg °T	Persistence Rng nm
20104	6 11	012.0	3.18	356.9	3.01	012.2	6.15
21603	6 00	199.9	2.34	177.9	0.84	214.8	3.63
21705	6 00	276.7	3.74	289.5	4.96	265.6	6.25
21803	6 00	303.7	2.24	310.7	1.89	305.0	2.11
23207	6 20	128.0	3.25	136.3	3.17	082.7	2.63
23406	5 50	209.9	2.59	172.7	2.57	237.8	1.62
24003	5 00	097.4	1.35	135.2	1.68	172.3	3.63
27003	6 00	195.8	2.96	201.7	3.35	036.0	1.97
27104	6 00	023.0	3.80	026.1	3.75	028.3	7.11
	Mean		2.83		2.80		3.90

5. NOTES ON OPERATIONAL ASPECTS OF PROBABILISTIC MODELLING

The references Garrett 1984, Garrett 1985, Garrett *et al* 1985 and de Margerie *et al* 1986 have been reviewed with regard to the operation aspects of the model. The key aspect is the use of a Gaussian distribution for the position of an iceberg, centred on the mean (predicted) position. Thus,

$$f_s(s) = \frac{2s}{\sigma^2} e^{-s^2/\sigma^2} \qquad (1)$$

where $f_2(s)$ = probability density function, s = distance from the predicted position and σ = standard deviation, based on R.M.S. position error.

Equation (1) can be derived from a two-dimensional Gaussian distribution with Cartesian coordinates (X, Y) that are interchangeable, with independence between X and Y. The distribution is symmetrical about the expected position, thus it is based on zero expected velocity (i.e. neglecting mean flow). This will not be a good assumption for a period after the last observation, and should be evaluated in terms of accuracy.

The probability of impact is calculated from the density just described, evaluated at the rig position and assumed to be locally uniform. This density (p′) is multiplied by the area of the critical circle, giving the value (p′Δa) of the iceberg being in the circle, where Δa= area of circle. The assumption of a locally uniform distribution will be reasonable if the rig area is small compared to the standard deviation σ. Runs conducted and shown in the various reports demonstrate that the standard deviation grows quickly - this a reasonable result and reflects the difficulty in estimating the iceberg trajectory.

The probability of an impact with the rig per unit is usually calculated using a formula of the kind

$$p_i(t) = p\bar{v}(W+D) \qquad (2)$$

where $\rho_i(t)$ = probability of impact per unit time, $\bar{v}$ = mean scalar component of velocity, W = width of structure, D = average diameter of bergs, and ρ = spatial density of icebergs (number per unit area). Equation (2) is based on uniform probability density of icebergs in a spatial sense.

In the trajectory model, the probability of the rig being in the critical zone (as described above) is used by Garrett et al. to calculate the probability of impact of any time after the most recent fix; it was then used in a risk model in which the "cumulative" probability over the forecast period is calculated. This model is not very clearly presented (for example, the use of the word "cumulative" is different from the usual usage in probability theory. The cumulative probability of impact in the trajectory model is in fact the probability integrated over time.)

The authors take into account the time factor by integrating ($p'\Delta a$) over the forecast time and dividing by the average time it takes the berg to cross the critical circle, Tp. In the calculation of the latter value, an expected value of velocity was introduced which appears to be in contradiction to the assumption in obtaining (p'). The logic in the development of the equation for rig impact needs careful review.

An alternative would be to use an equation similar to (2) above, taking into account the probability density of the scalar velocity component. The uniform spatial density could be modified taking into account the trajectory model, i.e. the probability density of the iceberg being at various positions.

Concluding Remarks

A probabilistic model of the estimated position of the iceberg and for collision with the rig are valuable potential tools for comparing various models; for example a simpler trajectory model could be compared to the present one using these methods. The present probabilistic model needs evaluation and assessment as to the range of validity of the assumptions.

Any definition of acceptable risk needs careful consideration of consequences, including the risk to human life.

6. CONCLUSIONS AND RECOMMENDATIONS

Drilling activity and iceberg conditions in 1991 did not combine to provide an opportunity to conduct a real-time test of the Operational Iceberg Trajectory Forecasting Model for the Grand Banks of Newfoundland. As an alternative the model was subjected to a simulated "real-time" trial using data from the 1990 iceberg season. Two objectives were identified:

1. to comment on the model function in an operational environment and make suggestions for improvements; and,
2. to evaluate the predictive accuracy of the model output using an independent data set.

It is believed that the simulated operational test was sufficiently realistic to offer the following conclusions and recommendations.

6.1 FUNCTIONAL OPERATION OF THE MODEL

The ease of learning, simplicity of use, and speed of operation are notable characteristics of the model software. These are important for real-time operational use, particularly where a number of users are involved. The software was found to be quite robust and, by and large, appeared to function correctly. However, in a few instances the predicted trajectories were found to be inconsistent with the previous and subsequent output. This was manifested in direction reversals at the beginning of the forecast period when a change of date had occurred.

On the whole, the model software does not contain unnecessary or useless features to burden the user. The software does contain, however, a valuable feature that is not generally provided in most environmental prediction models. The option to display 0.95 probability confidence circles around the predicted positions provides the user with useful information about the degree of reliability that can be placed in the prediction. More will be said about confidence circles in the following section.

The user interface was discussed in some detail in Section 3 of this report. With each point raised, specific recommendations or suggestions for improvements were given. The recommendations will not be repeated here, but will be summarized in a following section. It is expected that implementation of some of the interface recommendations could be done with little effort or expense, other suggested modifications, however, may require changes to the basic structure of the program.

A rather severe limitation of the present version of the Operational Iceberg Trajectory Forecasting Model is its inability to process more than one iceberg at a time. In addition, there are two other operational situations encountered frequently on the Grand Banks that cannot be handled by the operational model. The model assumes that all icebergs are free floating and free drifting. No means is available of indicating whether an iceberg is grounded, or whether it is being towed or otherwise managed. Thus, grounded icebergs are forecast to drift and towed icebergs are predicted to move without consideration of the towing force. Should a decision be made to carry out further development work, the software should be modified to handle these common operational scenarios.

The operational model was developed as a stand-alone system to assist in ice management operations offshore. As such, manual entry of iceberg fixes and wind data is required. Use of the operational model on board a drilling rig would require a certain amount of duplication of data entry effort on the part of the ice observer, since wind data would normally be entered into an environmental data file. Inefficiencies in the operational routine must be avoided wherever possible since the demands on an ice observer's time are especially great when icebergs pose a potential threat to drilling operations. For use offshore, therefore, iceberg drift prediction software should be integrated in some manner with other environmental data logging software. A further improvement in operational efficiency could be achieved if the software were modified to have the forecast winds read from a file. Data entry errors would be reduced or eliminated and, furthermore, the necessity of having the ice observer subjectively interpolate wind values between forecast times would also be eliminated.

Aerial reconnaissance of pack ice and iceberg conditions is an integral component of ice management practice on the Grand Banks. Indeed, much of the data on iceberg positions are obtained from aerial surveys. In normal practice, use is made of an ice data management system to assimilate and process these data to produce charts showing the current sea ice conditions and iceberg distribution. In the future certain remote sensing systems may offer the potential for acquiring iceberg position information over large areas on a synoptic basis. The requirement to manage and process iceberg data obtained by these means needs to be addressed if further development work on the operational model is contemplated.

6.2 MODEL OUTPUT VERIFICATION

The predicted iceberg positions output by the model were interpolated to the times of the iceberg fixes for verification against the observed position data. The results presented in section 4 are valid for the methodology as a whole for they include the effects of wind forecast errors, operator decisions, post processing operations, and so forth in addition to the model assumptions and implementation. The amount of data that could be processed was limited and therefore, the extent to which the results can be applied generally is not known. Furthermore, since the usable portions of iceberg tracks from the 1990 data set were quite short, the number of verification points decreases rapidly with lead time. The confidence that can be placed in the error statistics decreases accordingly and, therefore, caution needs to be exercised when using and discussing the results.

The values of the error statistics were found to increase quite rapidly with lead time. Although only a few cases were examined, it was found that only marginal improvement was achieved when actual winds rather than forecast winds were used. A large portion of the error appears to be result of inaccurate currents being applied in the model. This information is inferred from actual current measurements near Kings Cove A-26 in 1990 which show little resemblance to the current values used in the model. For M_2, the only tidal constituent where the model inputs are known, the tidal ellipse at Kings Cove A-26 is more elongated making the v-component less than the value used in the model. Furthermore, the mean velocity was an order of magnitude smaller than the mean velocity shown in the model's look-up tables. The problem of inaccurate currents is not unique to this model, but a problem for all iceberg drift prediction models. This problem is enhanced in regions like the Grand Banks where the current variability in the synoptic range due to atmospheric forcing is greater than the mean velocity. Significant improvement in the prediction of iceberg motion will only be achieved with improved current forecasting. It is recommended, therefore, that efforts be made to develop more appropriate current values for the model to use.

A finding of some significance is that relating to the size of the confidence circles (see Table 2 and Figure 5). The results suggest that for the selected iceberg trajectories, the modelers have been conservative in their estimates of the confidence circles and that the model performed slightly better than expected. The provision of confidence information provides valuable information for the user and should be retained in future versions of the model.

6.3 LIST OF RECOMMENDATIONS

The following lists collect together the recommendations for improvements of the Operational Iceberg Trajectory Forecasting Model for the Grand Banks have been made throughout the report. They have been organized under several catagories, particularly operational considerations and user interface recommendations. It is apparent that some of the recommendations could fall under either classification.

General

It was found that a reversal of iceberg direction occurred at the start of the first predicted trajectory made following a change of date. This software bug should be corrected.

Operational Considerations

1. The model software should be modified to process and display all or selected icebergs being monitored, rather than only a single iceberg.
2. The internal database should be re-configured to allow flagging of grounded and towed iceberg. Predictions made for grounded icebergs should show no motion. An appropriate means of handling towed icebergs should be implemented by the modelers. One option would be to allow for the application of a towing force in the modelling equation; if this is not considered practical then, at a minimum, the user should be made aware that a predicted trajectory of an iceberg under tow is made without regard for the towing force.
3. The database design should be modified to accept additional iceberg information to assist in re-identification. In addition to iceberg length, fields for width, height, draft, and an estimate of the above waterline block coefficient should be provided. Iceberg mass could then be computed internally, rather than externally to the software. Also, a field to indicate iceberg type should be provided.
4. A means of communication with other software systems should be implemented in order to:
   - read observed wind data from an environmental data file;
   - read forecast wind velocities from grid point data files and, optionally, from a file containing site-specific marine forecast parameters;
   - accept iceberg position data from external sources such as aerial reconnaissance reports; and,
   - output iceberg information and position data to meet normal archival and reporting requirements.

User Interface

An upgrade of the user interface is required if the Iceberg Trajectory Forecasting Model for the Grand Banks is to be used operationally. The use of a graphical user interface accepting both keyboard and mouse inputs would be appropriate, but significant improvements would be realized if the following recommendations were implemented. It is expected that most of these recommendations could be made relatively easily.

1. Date entry format should be changed from "YY/MM/DD" to "YYMMDD".
2. Time entry format should be changed from "HH:MM" to "HHMM".
3. Latitude/longitude data entry formats should be changed from degrees and tenths of degrees to degrees, minutes, and seconds for drilling rig positions and degree, minutes and tenths of minutes for iceberg positions. The option for entering iceberg position data using bearing and range from the drilling rig should be retained.
4. An option to enter the date of an iceberg fix should be provided.
5. The database should be modified to include a field for the source of iceberg position data (supply vessel name, rig radar, aircraft call sign).
6. Manually entered wind velocity data should start with direction followed by speed. The prompt "Bearing" should be changed to "Direction".
7. Error checking of all data entered into the model should be provided.
8. Implementation of a surface boundary layer model should be considered to adjust anemometer level wind speeds to the height specified by the modelers. The routine may also be used to adjust grid point wind forecasts, if required.
9. A routine should be implemented to interpolate grid point wind forecasts and site-specific wind forecasts to the times required by the model.
10. Position predictions are output at hourly intervals beginning one hour from the time of the last position fix. For consistency, predictions should be output on the hour at hourly, or other user selected, intervals.
11. The current speed and direction of the iceberg should be displayed on the monitor as iceberg drift speed is required to compute radii of alert zones around the rig.
12. A choice of graphics displays should be offered; specifically, a Mercator projection and a PPI or polar plot display having a user selectable scale. The use of colour and zoom capability would enhance the graphics display.

13. Higher resolution graphics are essential to resolve changes in the motion of icebergs. Furthermore, a means of differentiating between the observed track and the predicted trajectory should be provided on the display. The most recent iceberg fix should be clearly indicated.

14. The printout of predicted positions should be changed to include:
    - iceberg identification number, size and type classification, physical dimensions, and mass;
    - time and date stamped iceberg positions in degrees, minutes and tenths of minutes format with positions identified as being observed or predicted;
    - range and bearing of the iceberg from the rig;
    - course and speed of the iceberg;
    - radius of the 95% confidence circle; and,
    - probability of impact with the rig.

15. An improvement in the quality of the hard copy graphics output is required.

Other Recommendations

1. The probabilistic model needs evaluation and assessments as to the range of validity of the assumptions.

2. Efforts should be made to develop more appropriate current values in the look-up tables for the model to use.

APPENDIX I

Forecast and Actual Wind Directions and Speeds
Petro-Canada et al. Kings Cove A-26
1990

FORECAST AND ACTUAL WIND DIRECTIONS AND SPEEDS

Date and time in GMT - 1990

Format: ddff where dd = direction/10 (degrees true) and ff = speed (knots)

ICEBERG 01

Issue time — Forecast Valid Time

March	15/20	16/02	16/08	16/14	16/20	17/02
15/18	3322	3119	2916	2916	2916	2915
16/06			misg	misg	misg	misg
Actual	3419	n/a	2720	2321	2710	n/a

ICEBERG 16 and 17

April	12/19	13/01	13/07	13/13	13/19	14/01	14/07	14/13	14/19	15/01	15/07
12/15	2145	2245	2336	2625	2918	3215					
12/20		2340	2530	2620	2718	2915	2812	2712			
13/08				2620	2618	2616	2816	2712	2516	2418	
13/20						2912	2812	2712	2812	2912	3010
14/08								2410	2310	2412	2412
14/20										2906	2808
Actual	2046	n/a	2720	2518	2713	n/a	2306	2303	2903	n/a	2906

April	15/13	15/19	16/01	16/07	16/13	16/19	17/01	17/07	17/13	17/19
13/20	3010									
14/08	2412	2310	2310							
14/20	2708	2406	1506	1512	1618					
15/08	2610	2210	1508	1612	1716	1921	2124			
15/20			1208	1414	1620	1826	1932	2038	2040	
16/08					misg	misg	misg	misg	misg	misg
16/20							2032	2134	2228	2226
Actual	2705	2902	n/a	1805	1616	1627	n/a	2034	1842	1840

ICEBERGS 32,34,36,40

April	21/01	21/07	21/13	21/19	22/01	22/07	22/13	22/19	23/01	23/07
20/20	0214	0412	0612	0915	1215	1518	1822			
21/08			0212	0212	0412	1016	1420	1520	1922	
21/20					2808	2210	2215	2220	2222	2022
22/03	(* valid time 22/05Z)				2412*	2214	2216	2220	1922	1722
22/08							2116	1718	1620	1624
22/20									2014	2018
Actual	2905	2907	2904	2707	2508	2311	1814	1811	1615	1422

April	23/13	23/19	24/01	24/07	24/13	24/19
21/20	2022					
22/03	1722					
22/08	1624	1726	1728			
22/20	1920	1922	1826	1726	1726	
23/08	1222	1025	0925	0425	0125	0125
23/15		1827	1827	1829	1829	0125
23/20		1730	1830	1931	1829	1726
23/03			1738	1838	1932	1828
24/08					1738	2032
Actual	1826	1832	1636	1638	1640	2028

ICEBERGS 70 and 71

May	16/01	16/07	16/13	16/19	17/01	17/07	17/13	17/19	18/01	18/07	18/13
15/20	3310	3310	3310	3210	3112	3310	3310				
16/08			3310	3410	3610	0110	0110	0210	0310		
16/20					0110	0212	0316	0318	0320	0324	0326
17/08							0416	0418	0422	0425	0428
17/20									0332	0438	0442
Actual	n/a	3410	3610	3608	0211	0216	0220	0227	0233	0236	0529

APPENDIX II

Series of Predicted Trajectories for Iceberg 071

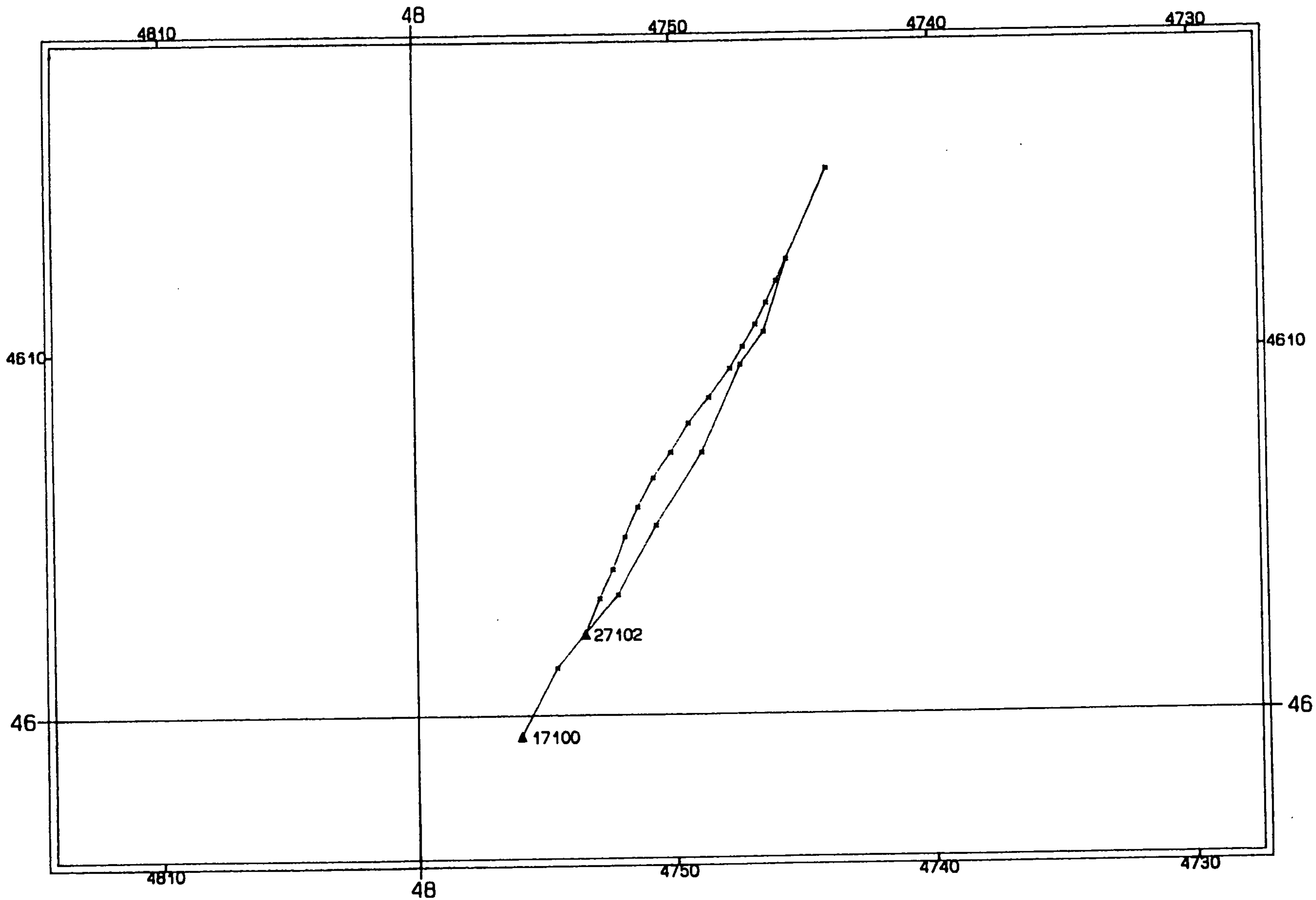


Figure II-1. Predicted trajectory at 0630 GMT, May 17, 1990

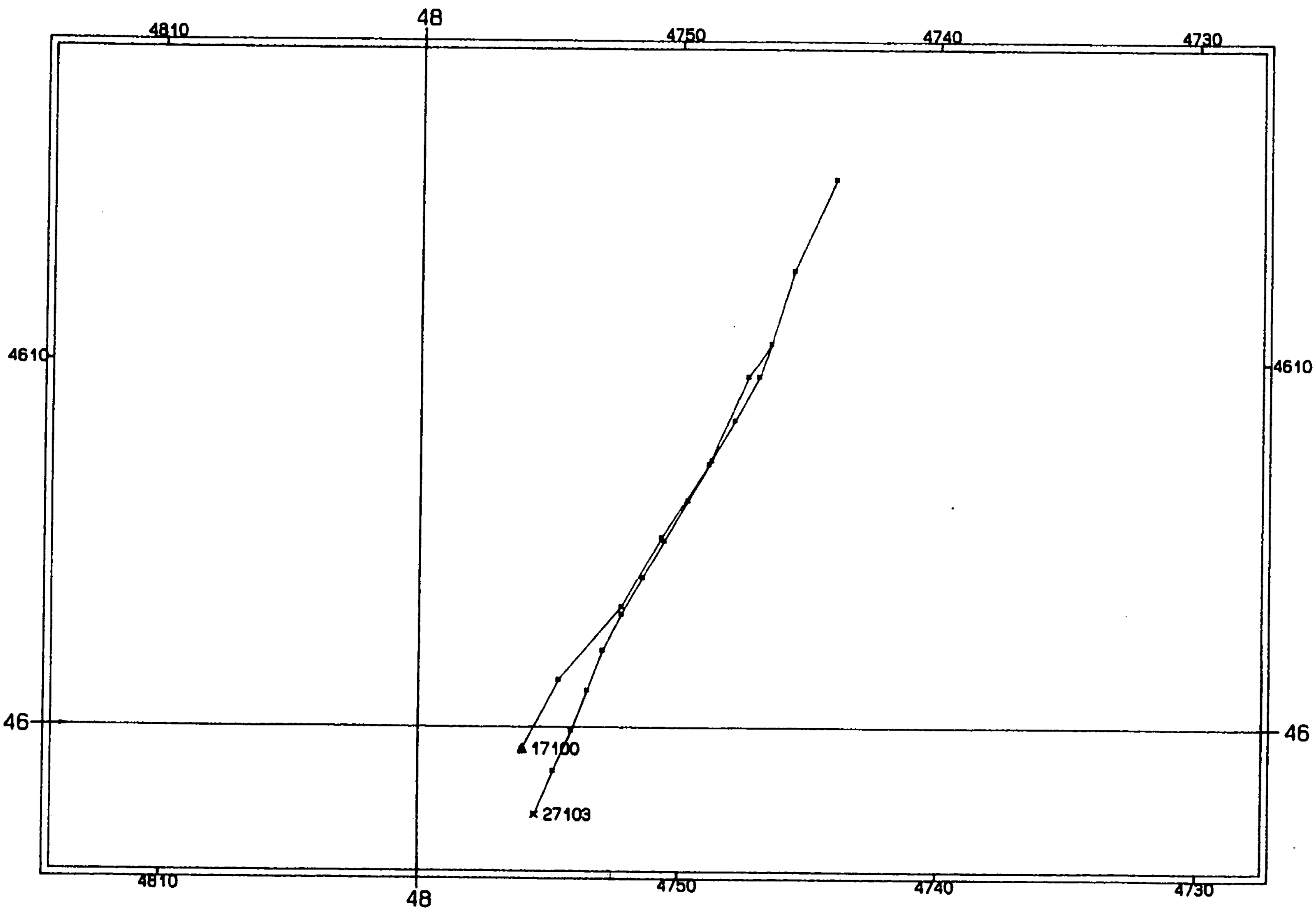


Figure II-2. Predicted trajectory at 0830 GMT, May 17, 1990

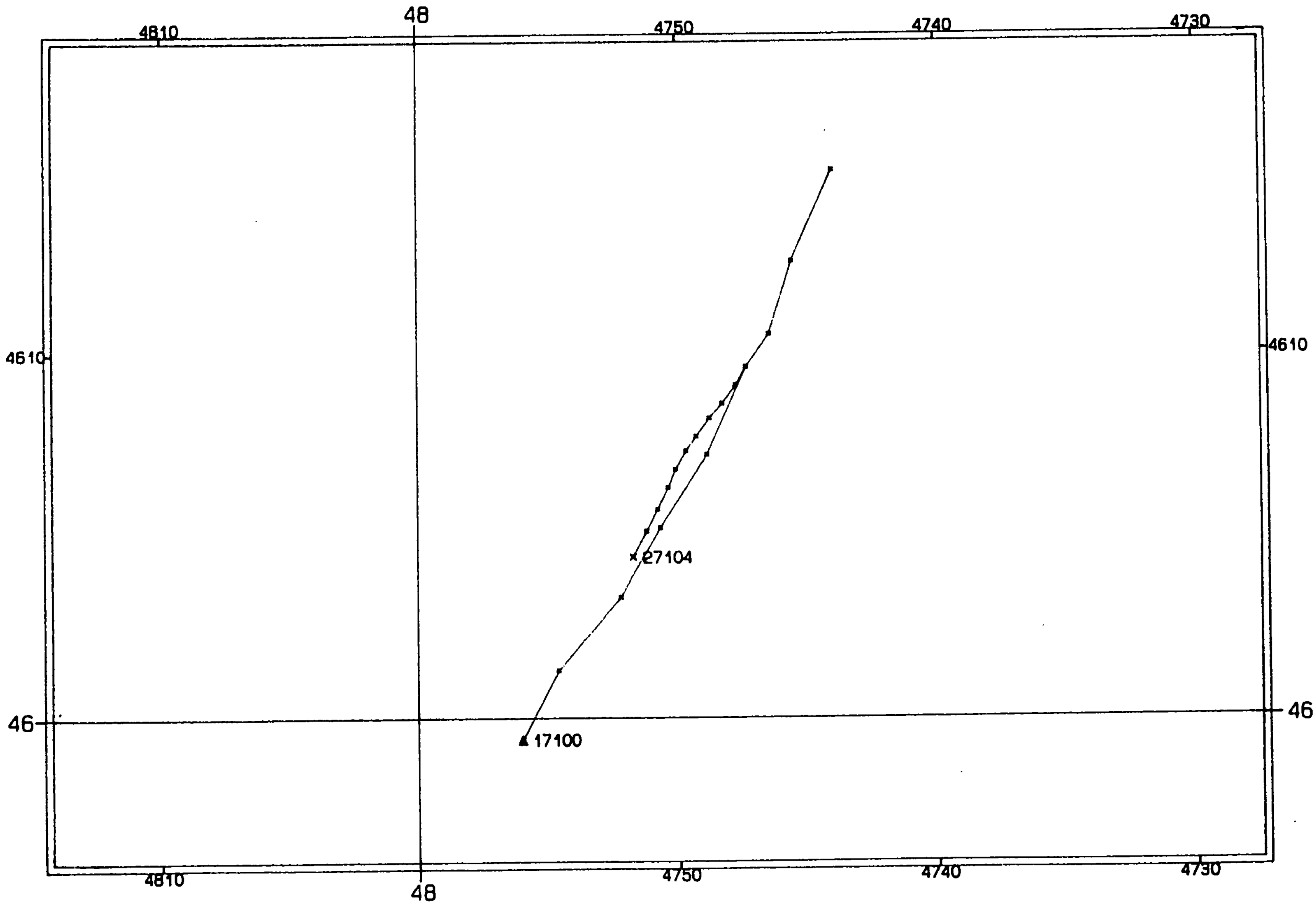


Figure II-3. Predicted trajectory at 1030 GMT, May 17, 1990

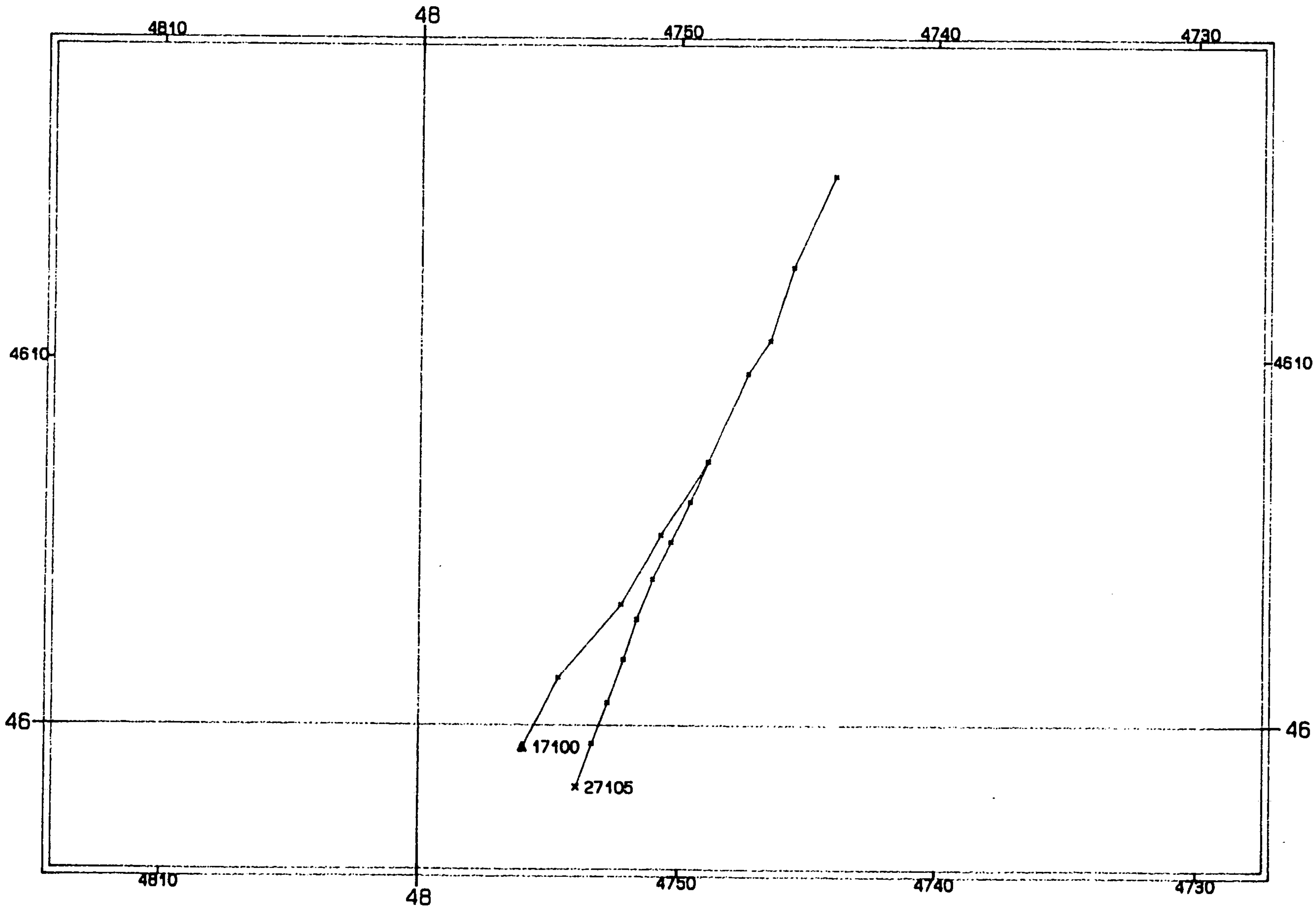


Figure II-4. Predicted trajectory at 1230 GMT, May 17, 1990

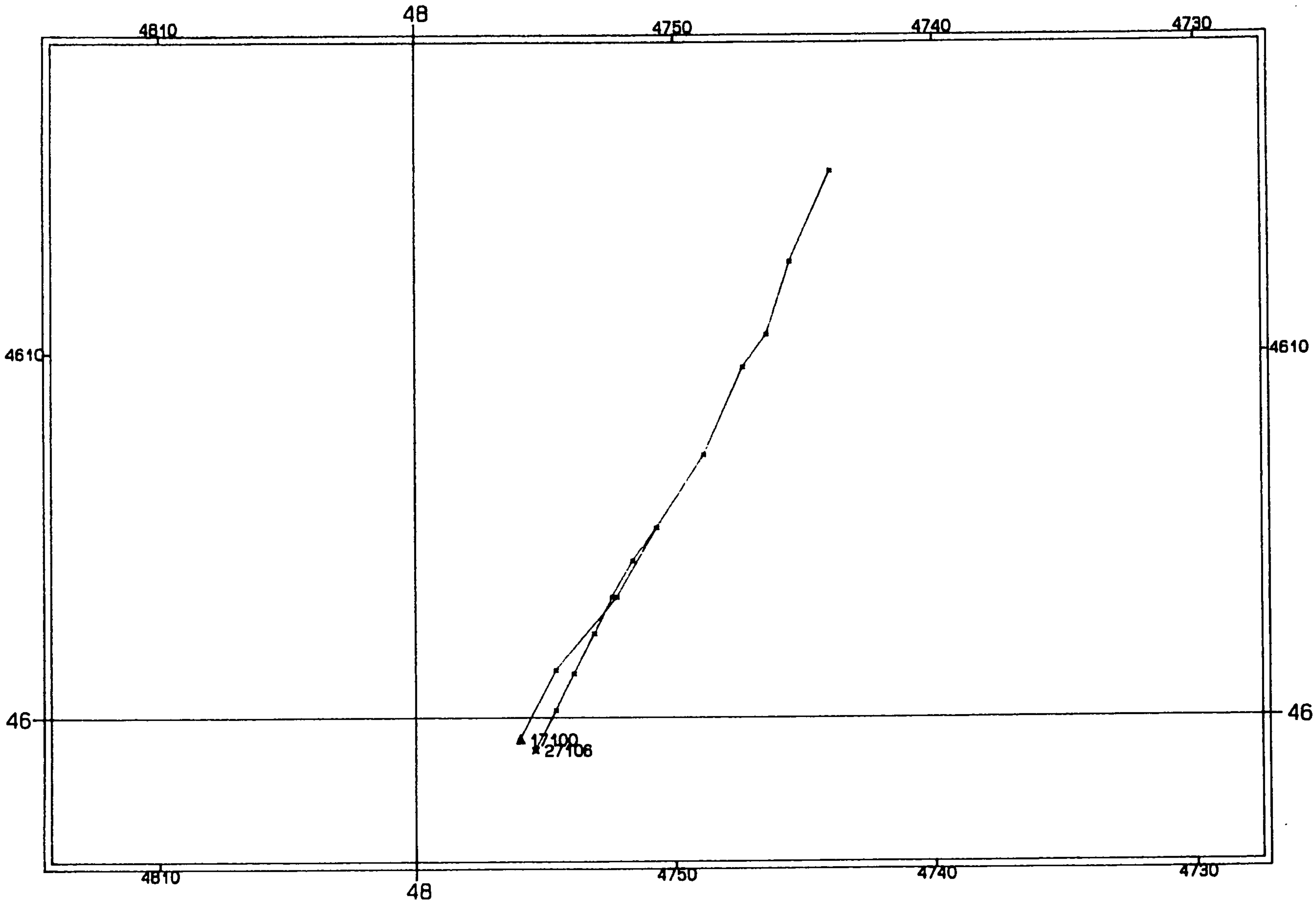


Figure II-5. Predicted trajectory at 1430 GMT, May 17, 1990

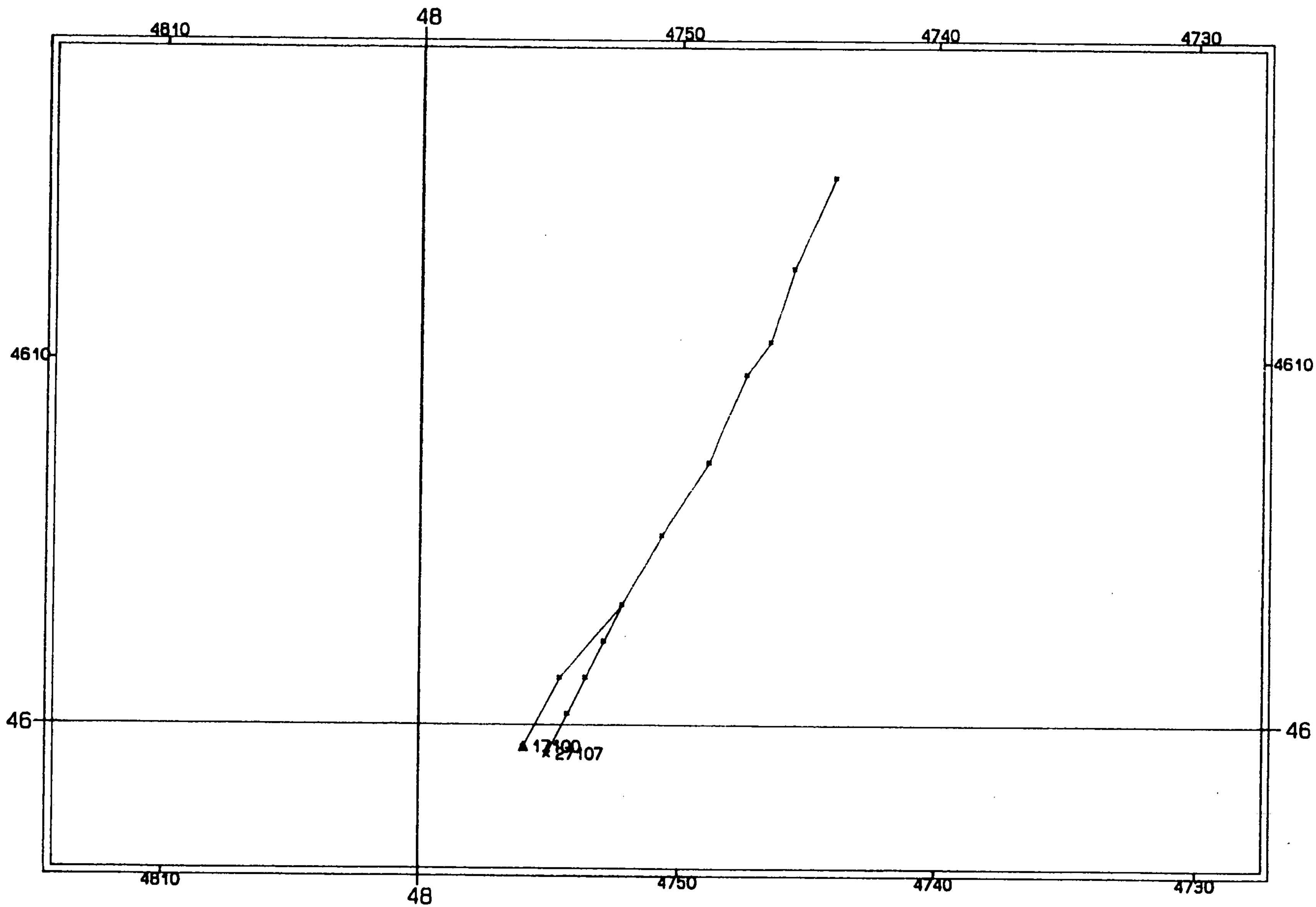


Figure II-6. Predicted trajectory at 1630 GMT, May 17, 1990

APPENDIX III

Iceberg 424

ICEBERG 424

At 0600 GMT, April 09, 1985, a small iceberg, referred to as Iceberg 424, was located approximately 28.7 nautical miles southwest of the Husky/Bow Valley et al. North Ben Nevis P-93 well (46°42'49" N, 48°28'34" W). Over the following 48 hour period, Iceberg 424 drifted generally north-northeastward to lie 10.5 nautical miles west-southwest of North Ben Nevis P-93 at 0600 GMT, April 11, 1985. Wind observations taken on board the drilling unit Bow Drill 3 (see Table III-1) at North Ben Nevis P-93 show that strong southwesterly gales prevailed at the beginning of the period. The strong southwest gales decreased steadily on April 9th to become light in the evening. Overnight, light south-southeast winds shifted into the west before dawn then veered gradually to become strong south-southeasterly for a few hours around mid-day on April 10th. Moderate southeast winds in the afternoon backed into the east to become near gale force in the early evening. During the late evening the winds veered into the south at gale force. Overnight on April 10th, strong gale force south-southwesterly winds prevailed in the area.

From 0600 to 0900 GMT on April 11th, the iceberg moved 3.7 miles northeastward to lie 7.6 nautical miles west of the well while the winds veered into the west and increased to storm force. The iceberg then turned eastward heading almost directly toward the Bow Drill 3. With this an attempt was made to move the rig off location. One anchor, however, could not be released and, to obtain maximum distance from the iceberg, the drilling unit was swung clear on the anchor chain. At 1346 GMT the iceberg was located 2.05 nautical miles west of the well. This was the last position report logged until well after the iceberg passed the well as certain personnel, including the two weather/ice observers, were evacuated from the rig at 1453 GMT. Between 0900 and 1400 GMT when the last wind observation was taken, the winds remained westerly but gradually decreased to gale force. The estimated closest point of approach to the well was 0.1 nautical miles.

The forecast wind data used in the model trials with Iceberg 424 were extracted from site-specific marine forecasts valid for the North Trinity H-71 well. This well was located approximately 12.6 nautical miles to the south of the North Ben Nevis P-93 well. Table III-2 shows the forecast wind velocities for North Trinity H-71 as well as the wind observations from the Bow Drill 3 at the valid times. A comparison shows that the wind velocity was rather poorly forecast throughout the period.

Twenty-two predictions were made between 1130 GMT, April 09, 1985 and 1349 GMT, April 11, 1985. From these, there were a total of 259 verifiable position predictions with lead times of 48 hours or less.

Figures III-1 to III-5 show the observed track and predicted trajectories early in the period. The position of North Ben Nevis P-93 is indicated by the small square. The track identified as 19900 represents the observed track, while the other track on each chart is the predicted trajectory. The last figure in the identifier indicates the number of position fixes available at forecast time. Track labels appear at the end of the trajectories. Hourly positions are indicated on the predicted trajectory. Figure III-4 shows a reversal of direction of the iceberg, an inconsistency apparently related to the change of date.

Figures III-6 through III-10 show the predicted trajectories after the 9th, 10th, 11th, and 12th positions were entered, respectively. The time interval between each position observation was three hours. The differences between the predicted trajectories in the series are great. A second direction reversal is seen with the trajectory shown in Figure III-10. Again, this trajectory prediction was the first to be made following a change of date. Figures III-11 through III-16 show the predicted trajectories in the final few hours before the iceberg passed by North Ben Nevis P-93. All of the predicted trajectories after 1006 GMT on April 11 show the iceberg passing close to the well.

With the exception of the final few hours before Iceberg 424 passed the well site, the model output showed a great deal of variability and rather large forecast errors. This is summarized in Figure III-17 which shows the forecast distance errors against lead time for all of the position predictions for lead times of 48 hours or less.

Table III-1

North Ben Nevis P-93

1985

Observed Wind Direction and Speed

Time (GMT)	April 09	April 10	April 11
0000	1842	0000	1635
0100	2042	1610	1834
0200	2045	1613	1842
0300	2343	2010	2042
0400	2343	2009	2041
0500	2342	2712	2046
0600	2343	2909	2046
0700	2339	3412	2048
0800	2537	0509	2552
0900	2533	0505	2764
1000	2528	0504	2756
1100	2525	1108	2746
1200	2526	1414	2744
1300	2524	1619	2741
1400	2523	1819	2736
1500	2523	1626	n/a
1600	2519	1622	n/a
1700	2519	1110	n/a
1800	2514	1416	n/a
1900	2314	1414	n/a
2000	2516	0918	n/a
2100	2512	0920	n/a
2200	2310	0933	n/a
2300	2304	0924	n/a

Table III-2

FORECAST WIND DIRECTION (T) AND SPEED (knots)
Vicinity North Ben Nevis P-93
1985

Issue Time	Forecast Valid Time										
April	09/12	09/18	10/00	10/06	10/12	10/18	11/00	11/06	11/12	11/18	12/00
09/06	2635	1820	1125	0325	3020	3420					
09/18			1712	1315	0720	0425	0130	3432			
10/06					2310	9910	0320	3625	3430		
10/12							9910	3535	3432	3020	2615
11/06									3240	3025	2720
11/18											2720
Actual	2526	2514	0000	2909	1414	1416	1635	2046	2744	n/a	n/a

Note: Direction of 99 was forecast as "variable"

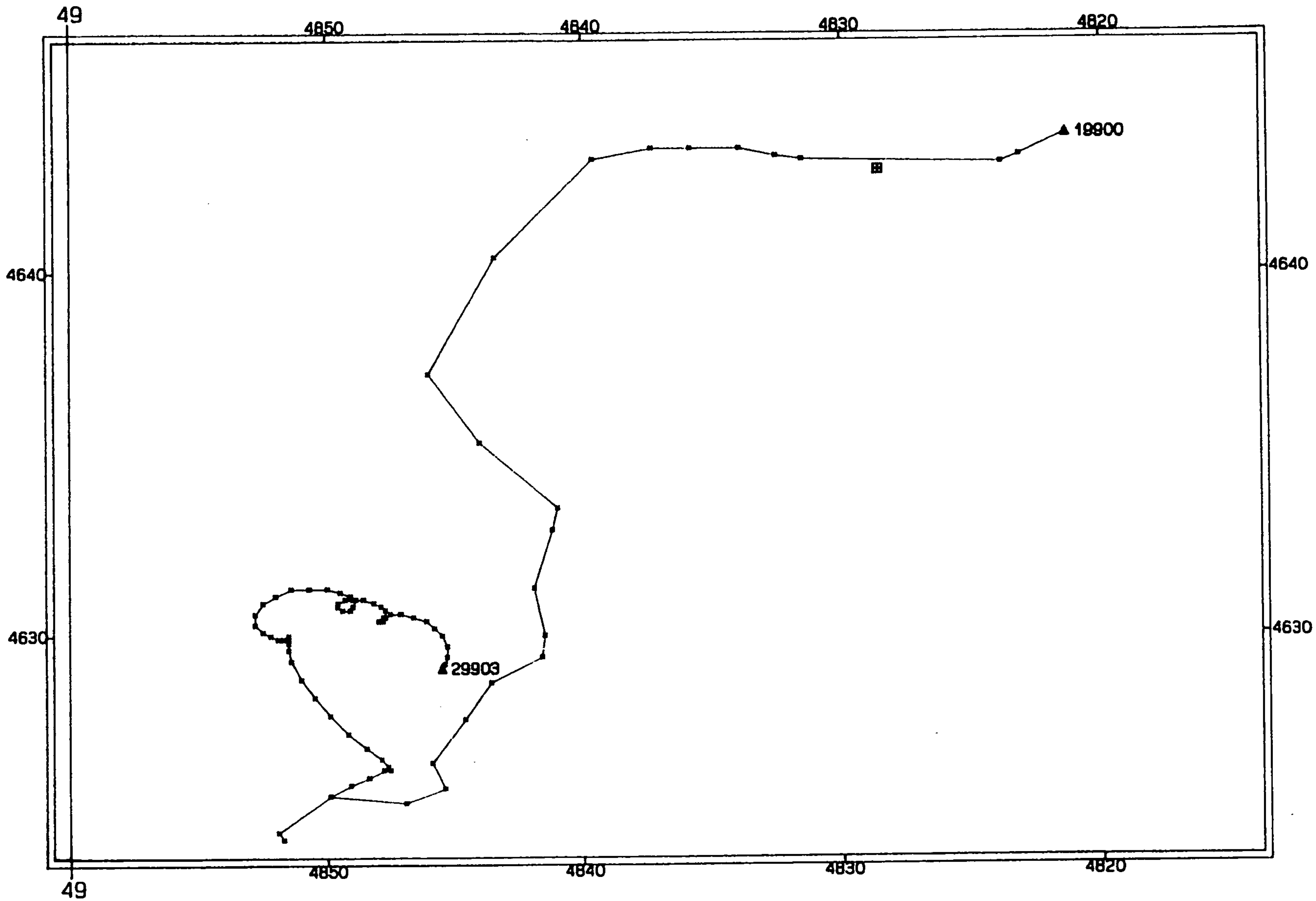


Figure III-1. Predicted trajectory for Iceberg 424 from 1430 GMT, April 9, 1985

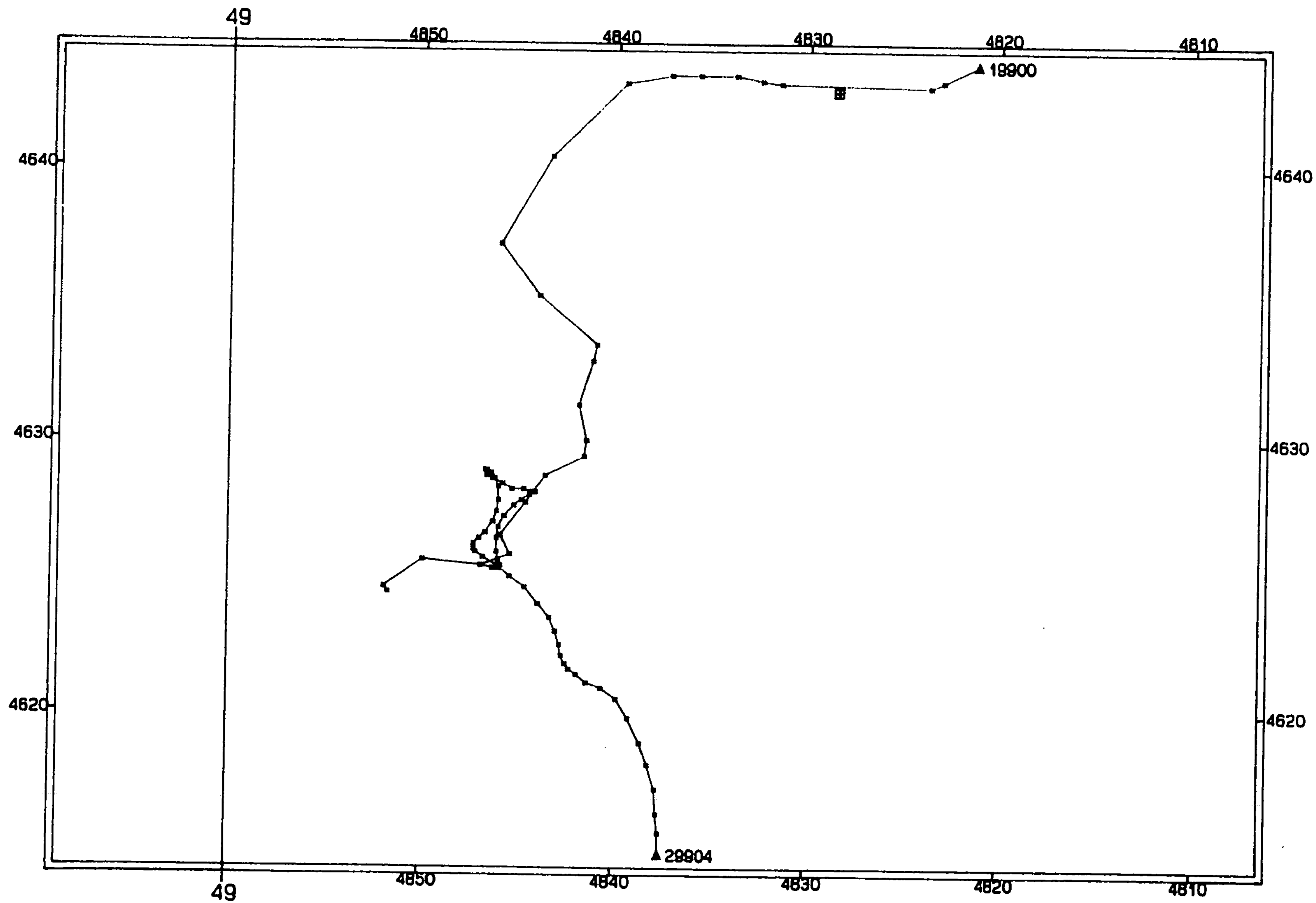


Figure III-2. From 1800 GMT, April 9, 1985

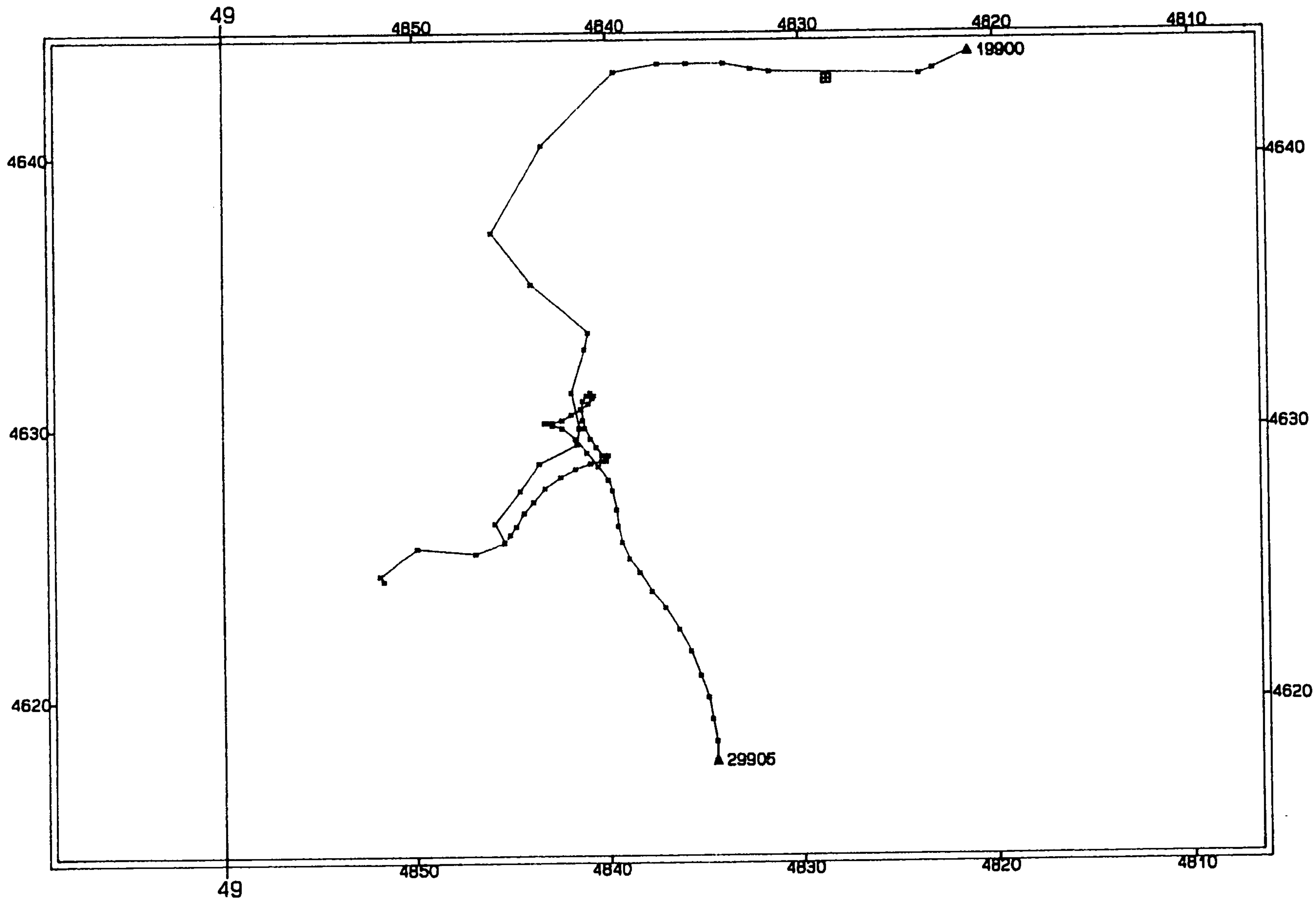


Figure III-3. From 2100 GMT, April 9, 1985

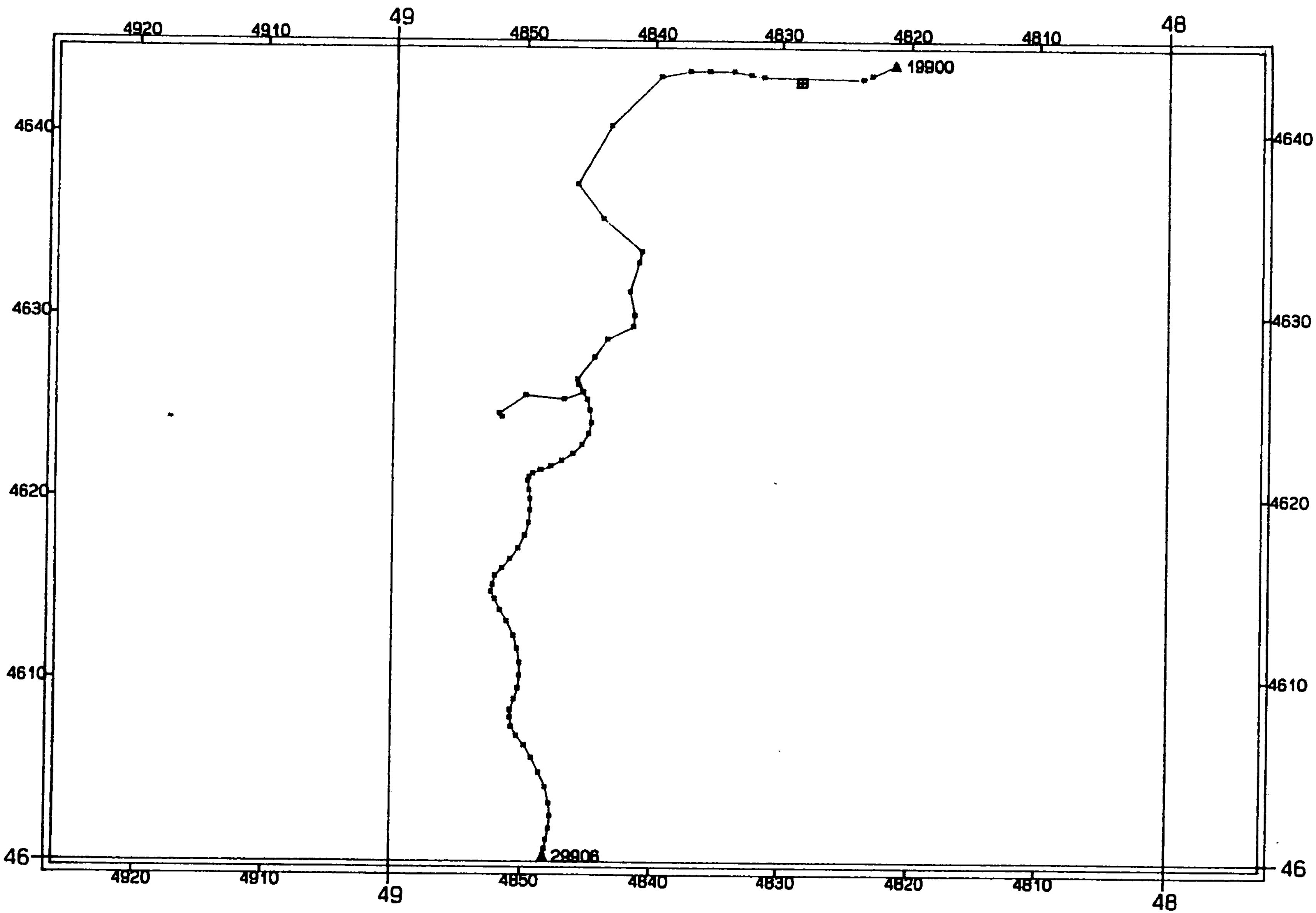


Figure III-4. From 0030 GMT, April 10, 1985

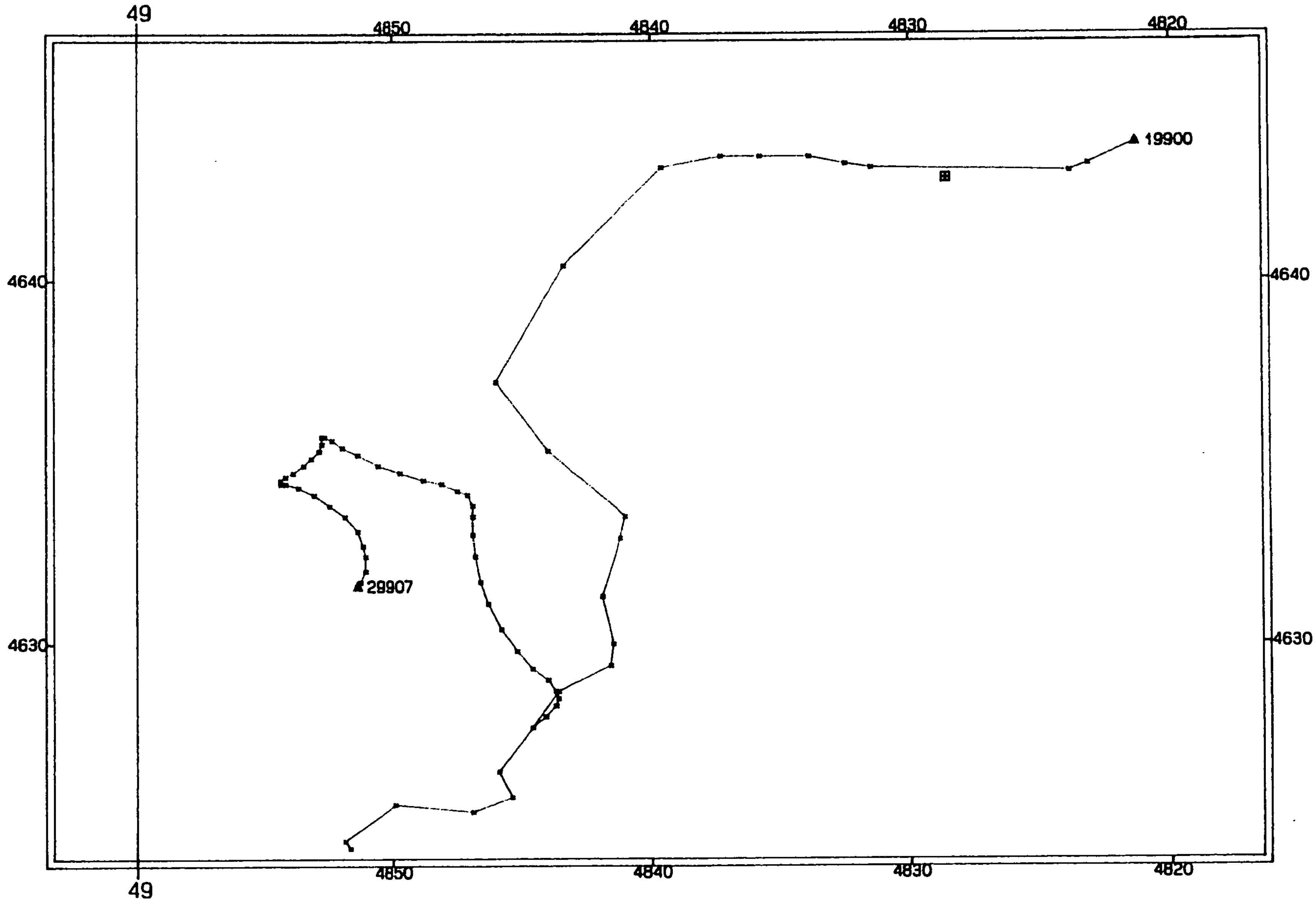


Figure III-5. From 0300 GMT, April 10, 1985

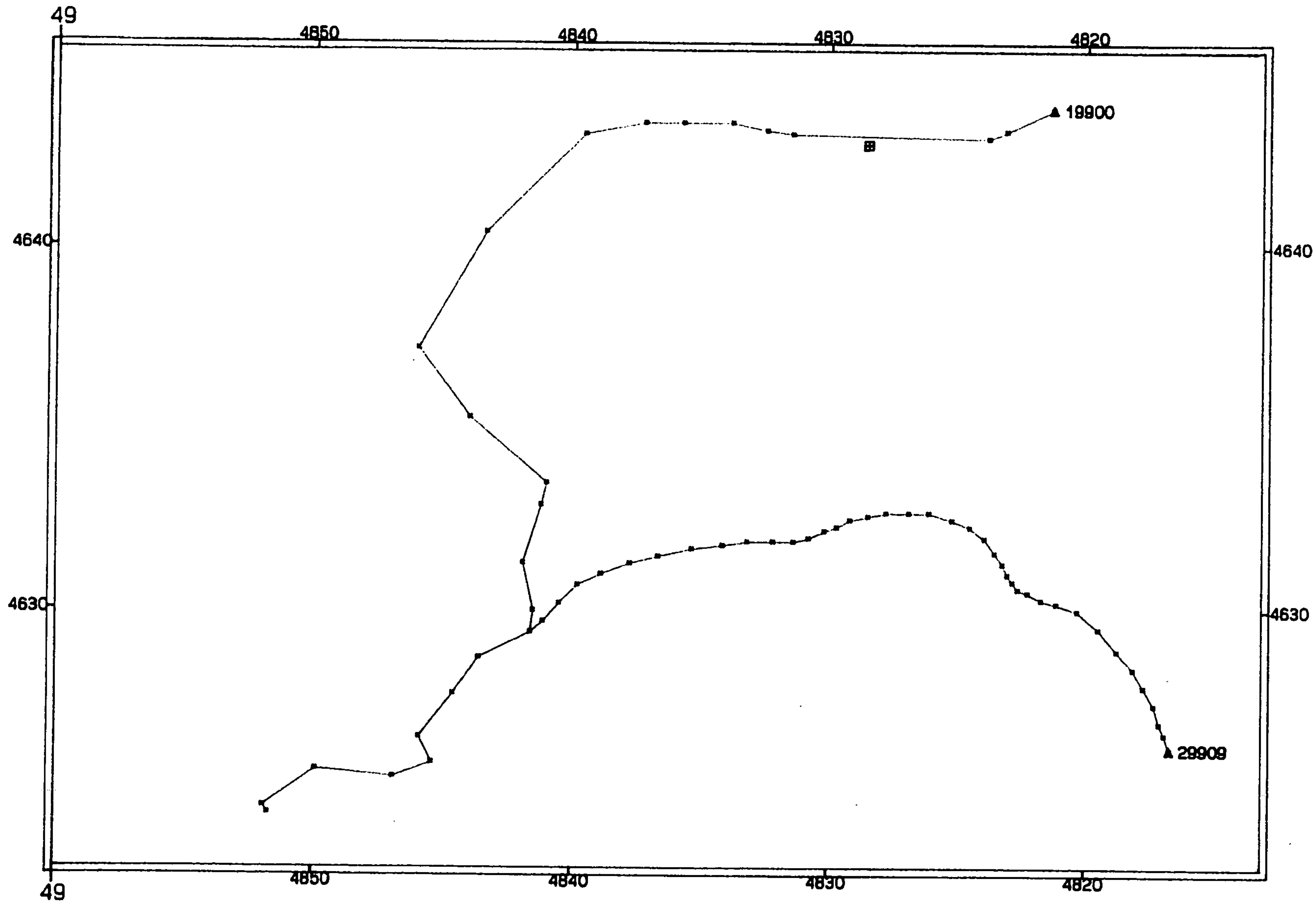


Figure III-6. From 0900 GMT, April 10, 1985

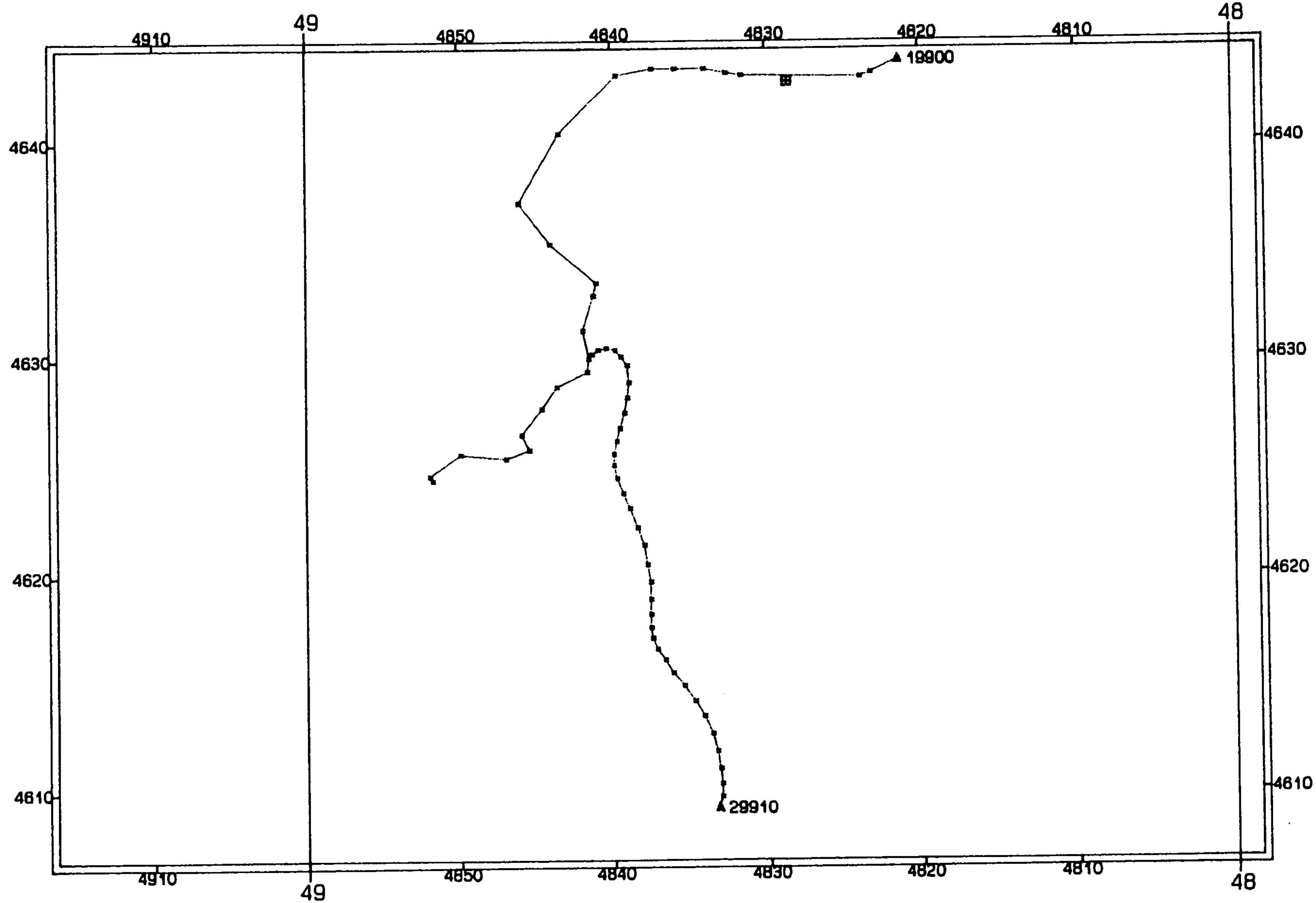


Figure III-7. From 1200 GMT, April 10, 1985

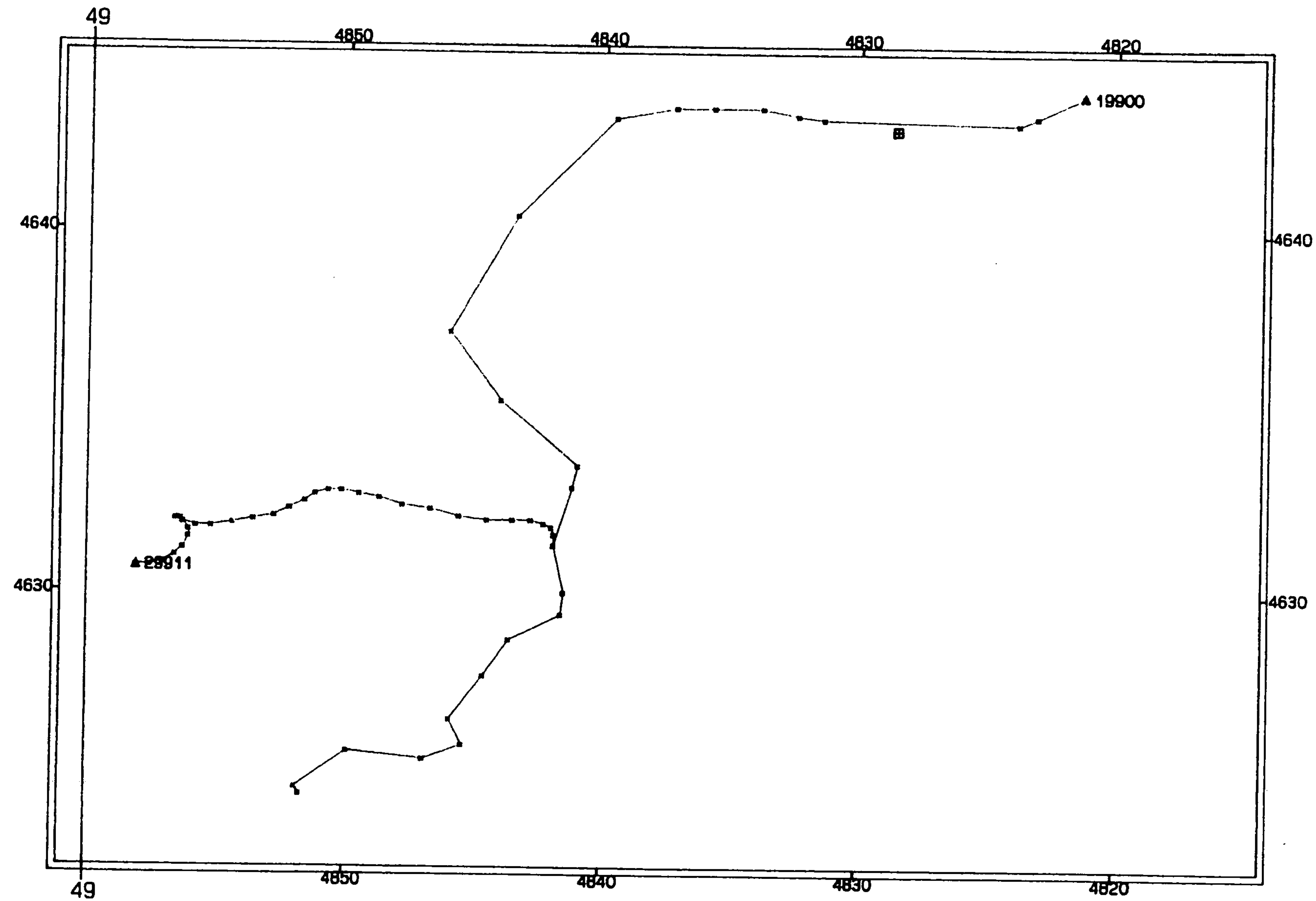


Figure III-8. From 1500 GMT, April 10, 1985

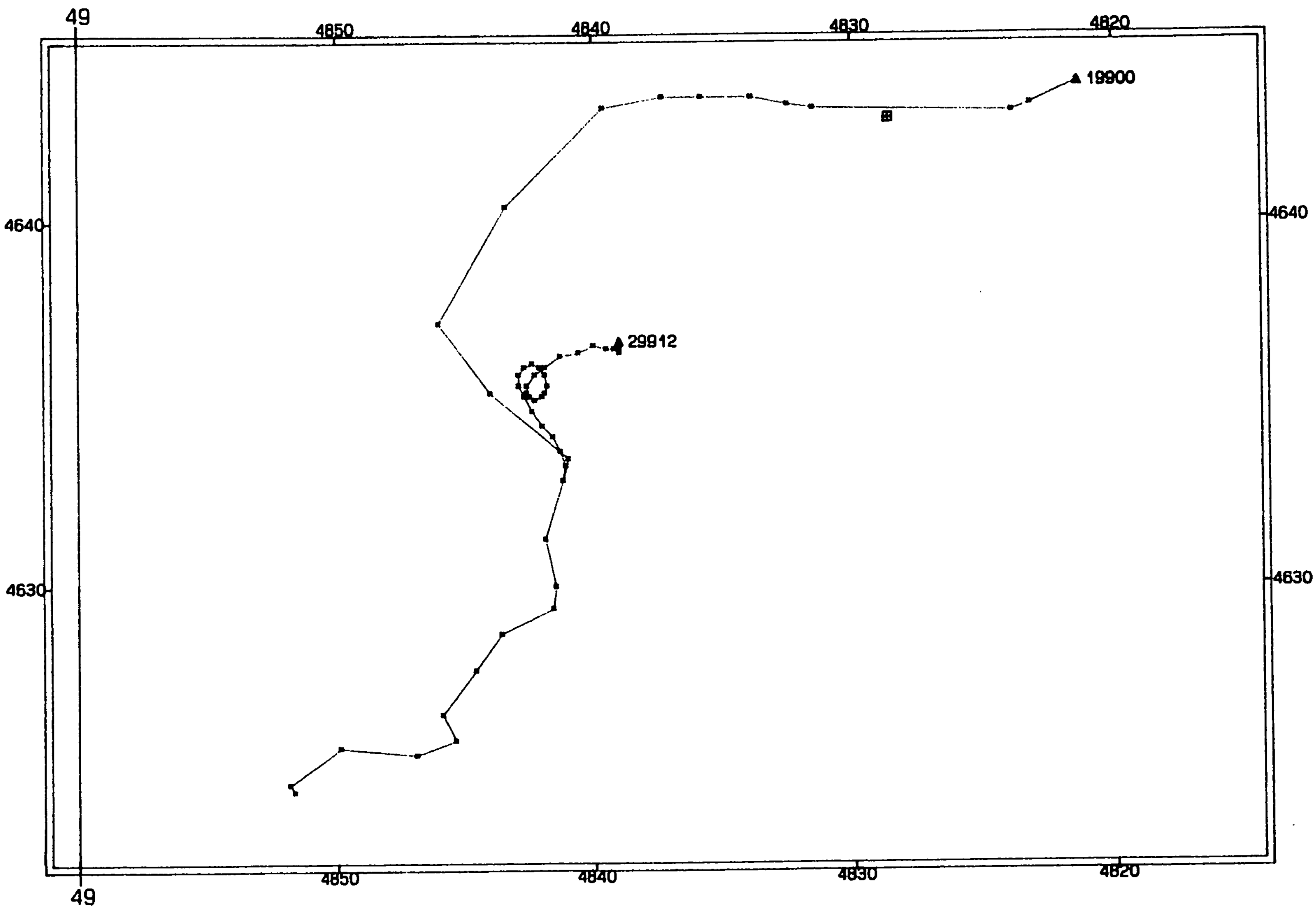


Figure III-9. From 1800 GMT, April 10, 1985

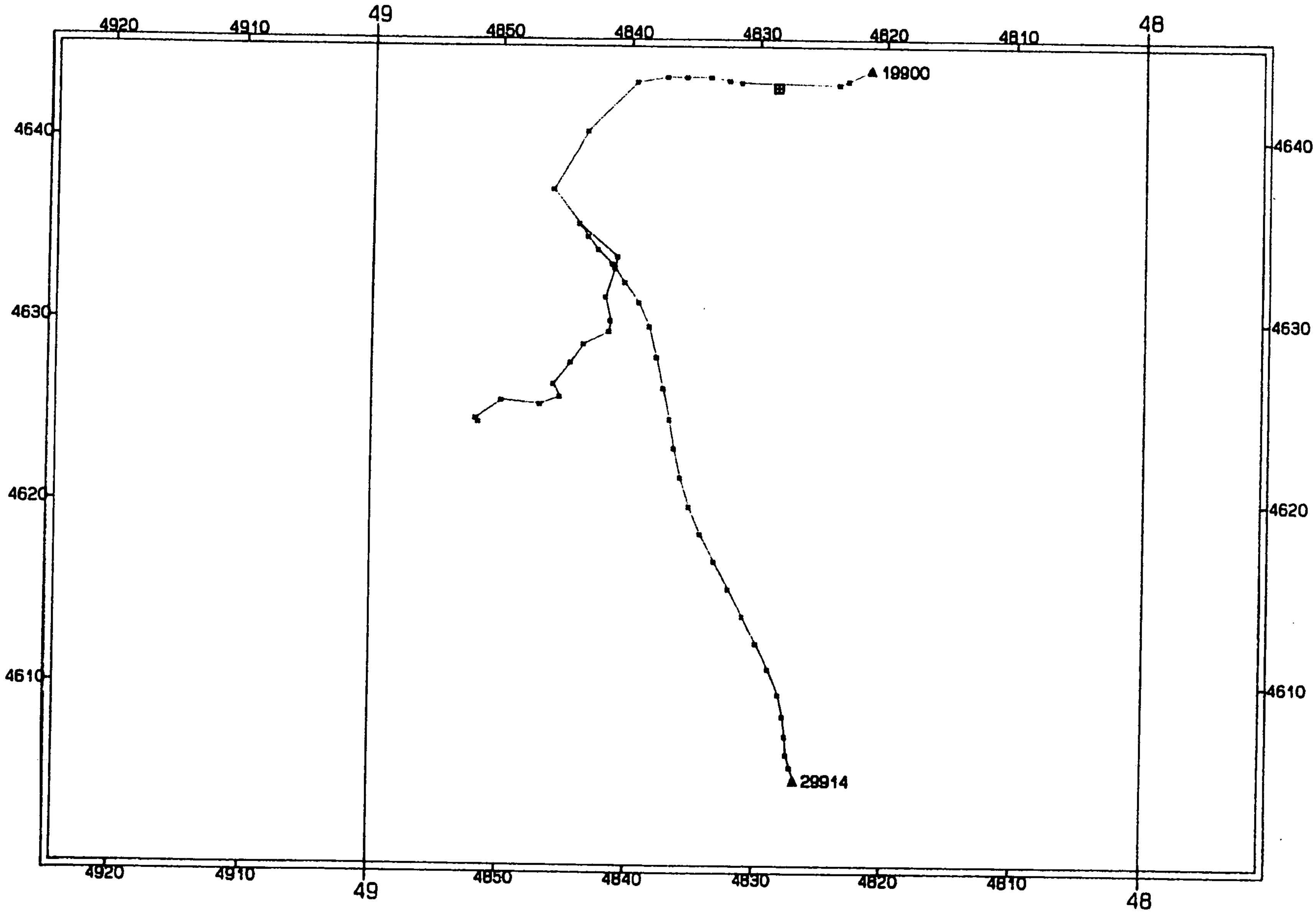


Figure III-10. From 0000 GMT, April 11, 1985

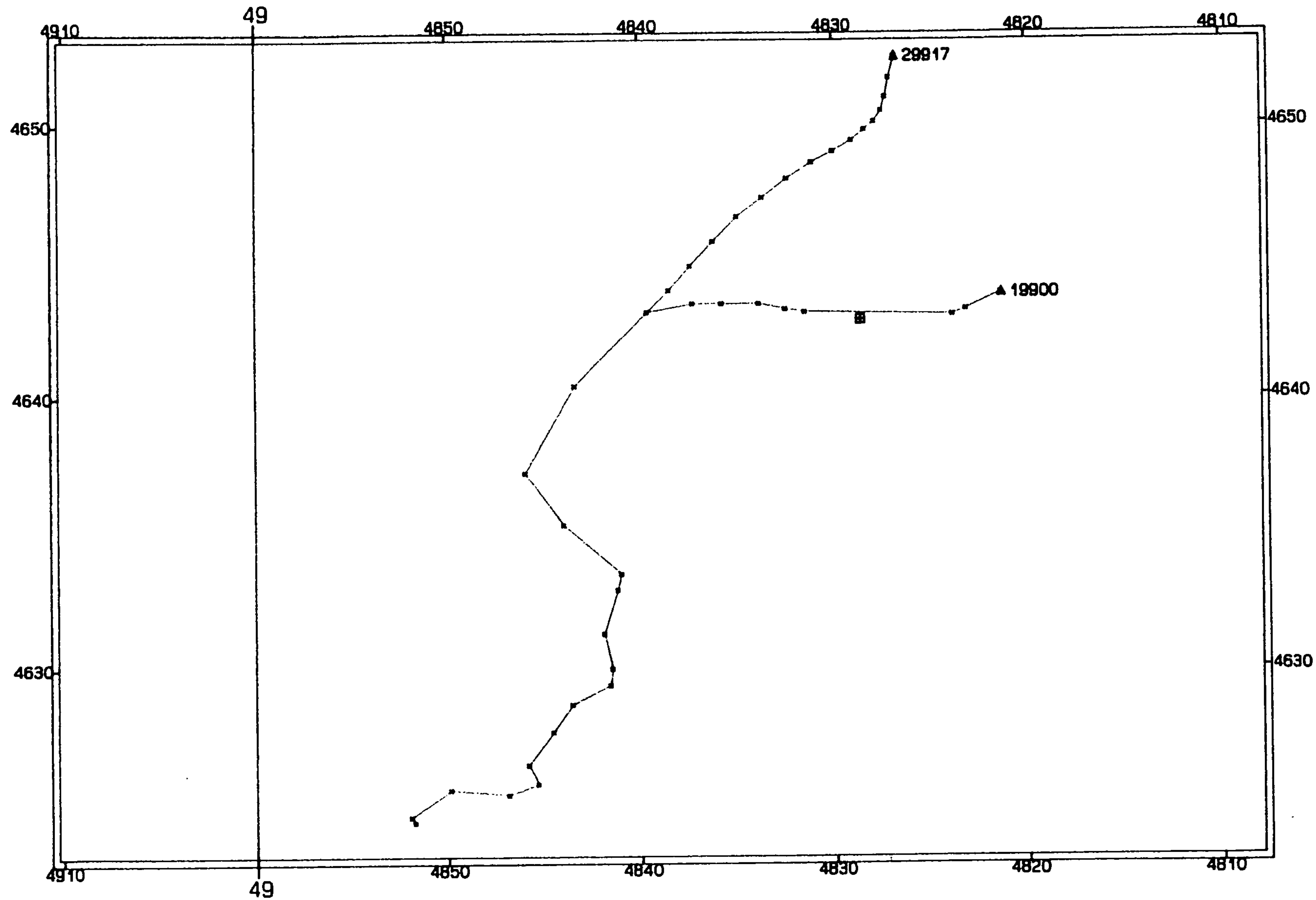


Figure III-11. From 0900 GMT, April 11, 1985

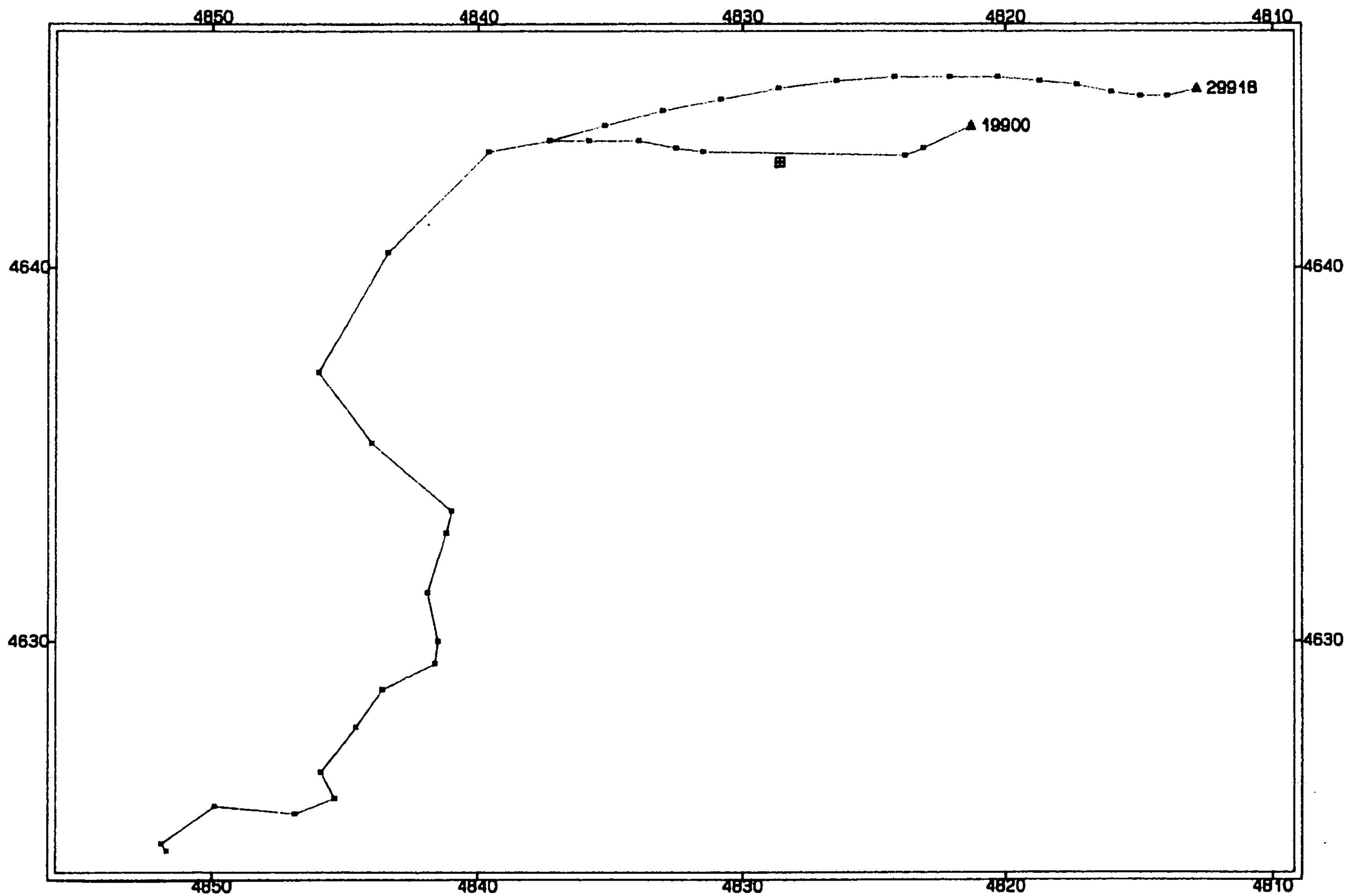


Figure III-12. From 1006 GMT, April 11, 1985

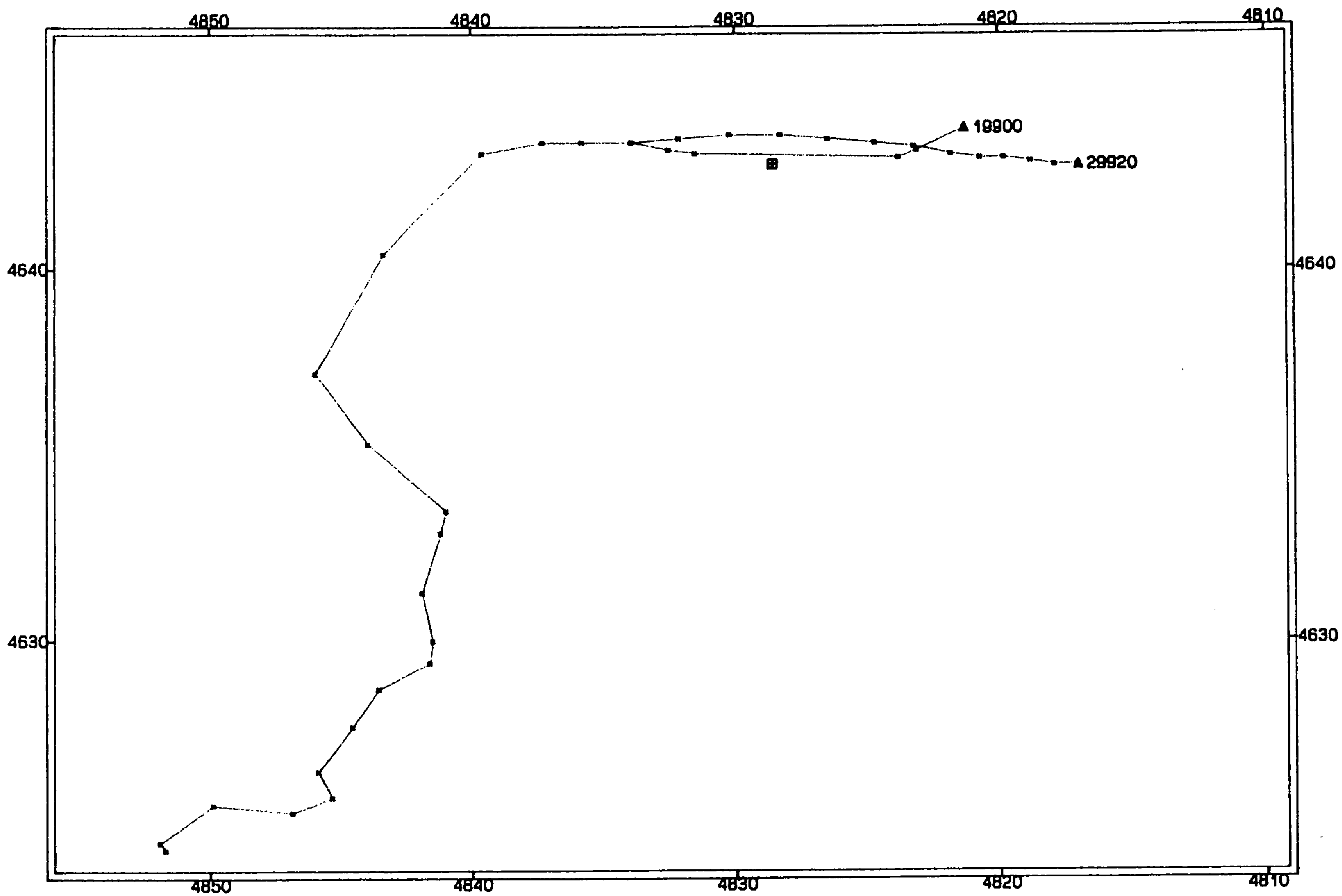


Figure III-14. From 1217 GMT, April 11, 1985

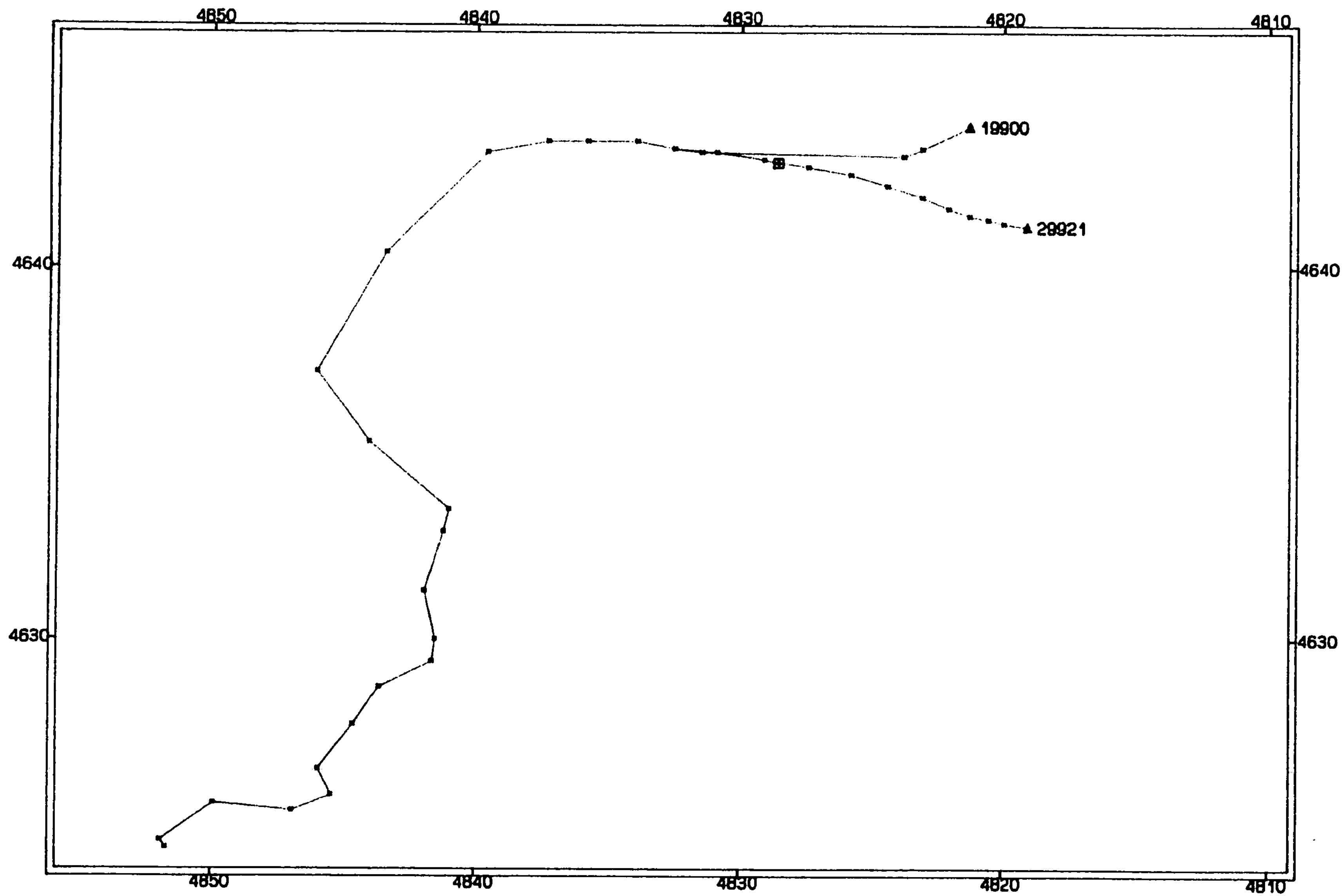


Figure III-15. From 1304 GMT, April 11, 1985

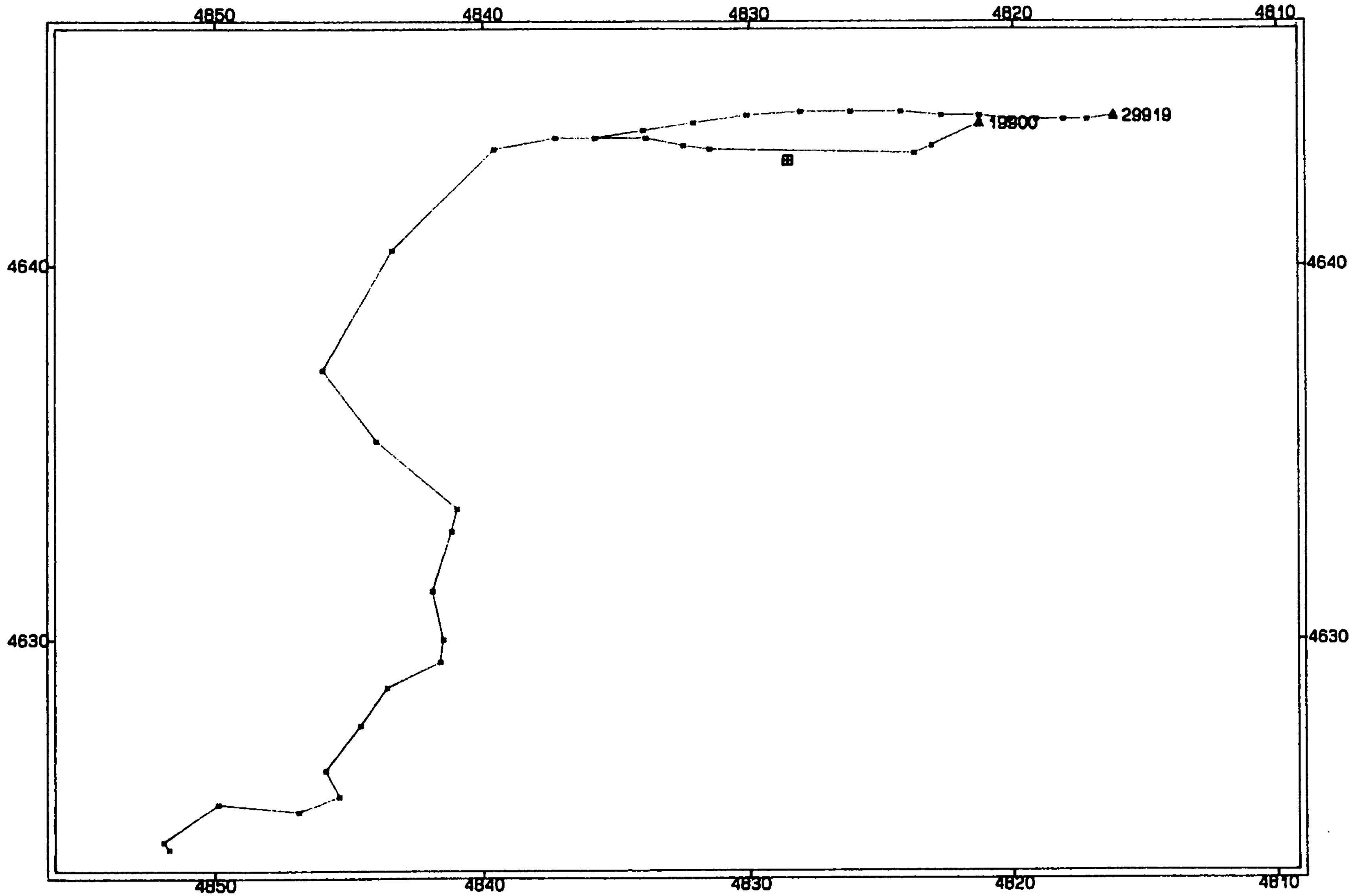


Figure III-13. From 1109 GMT, April 11, 1985

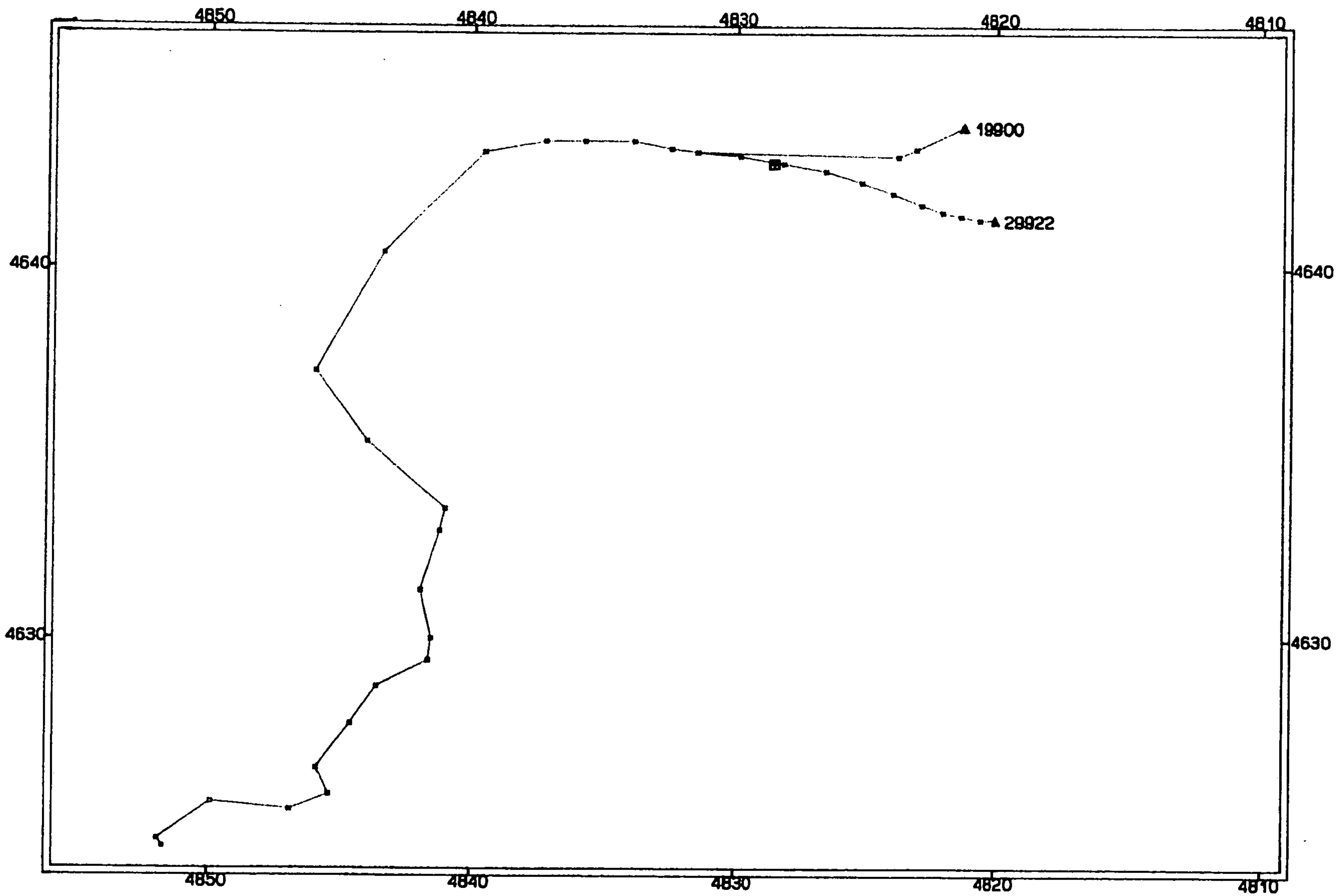


Figure III-16. From 1346 GMT, April 11, 1985

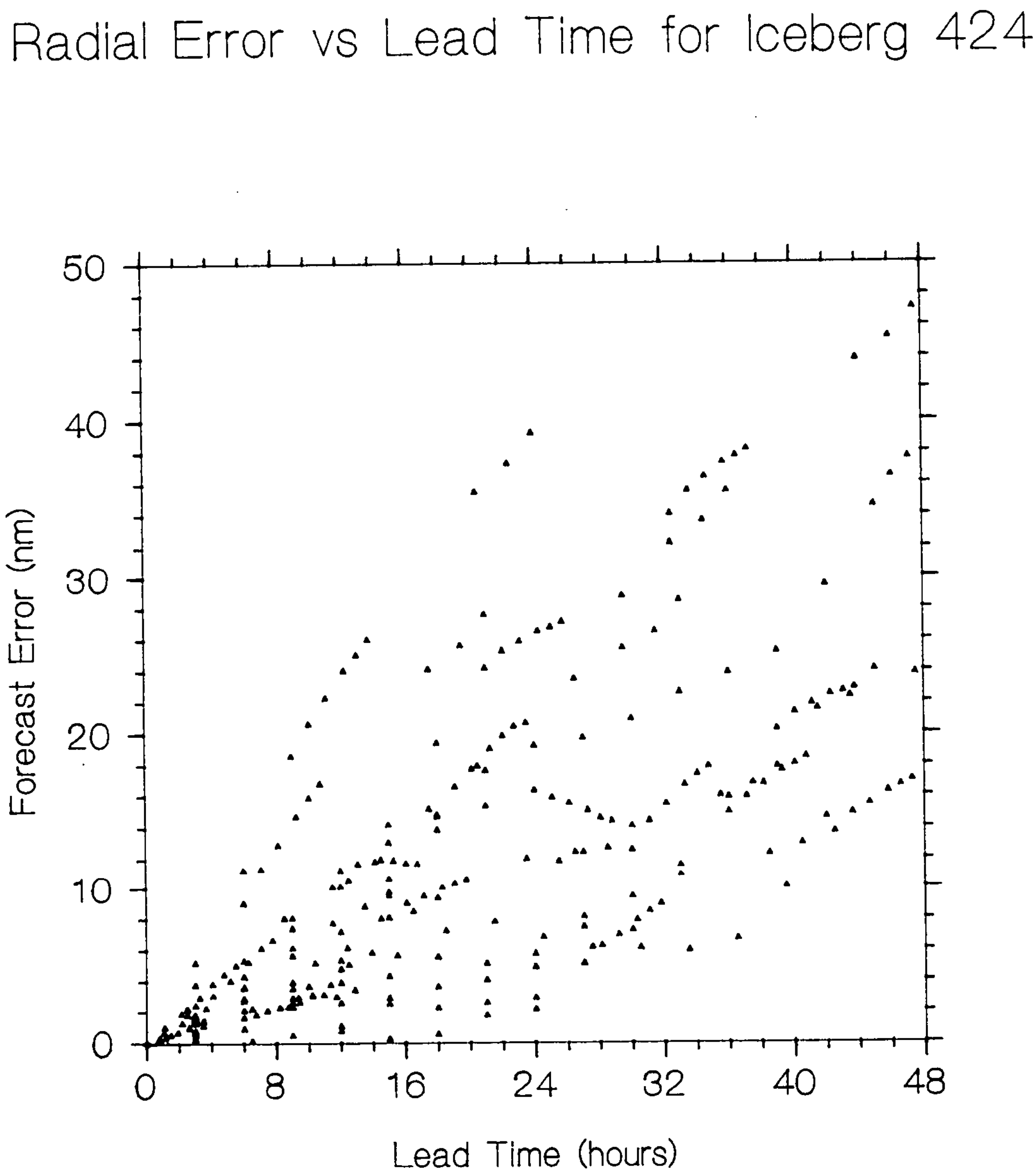
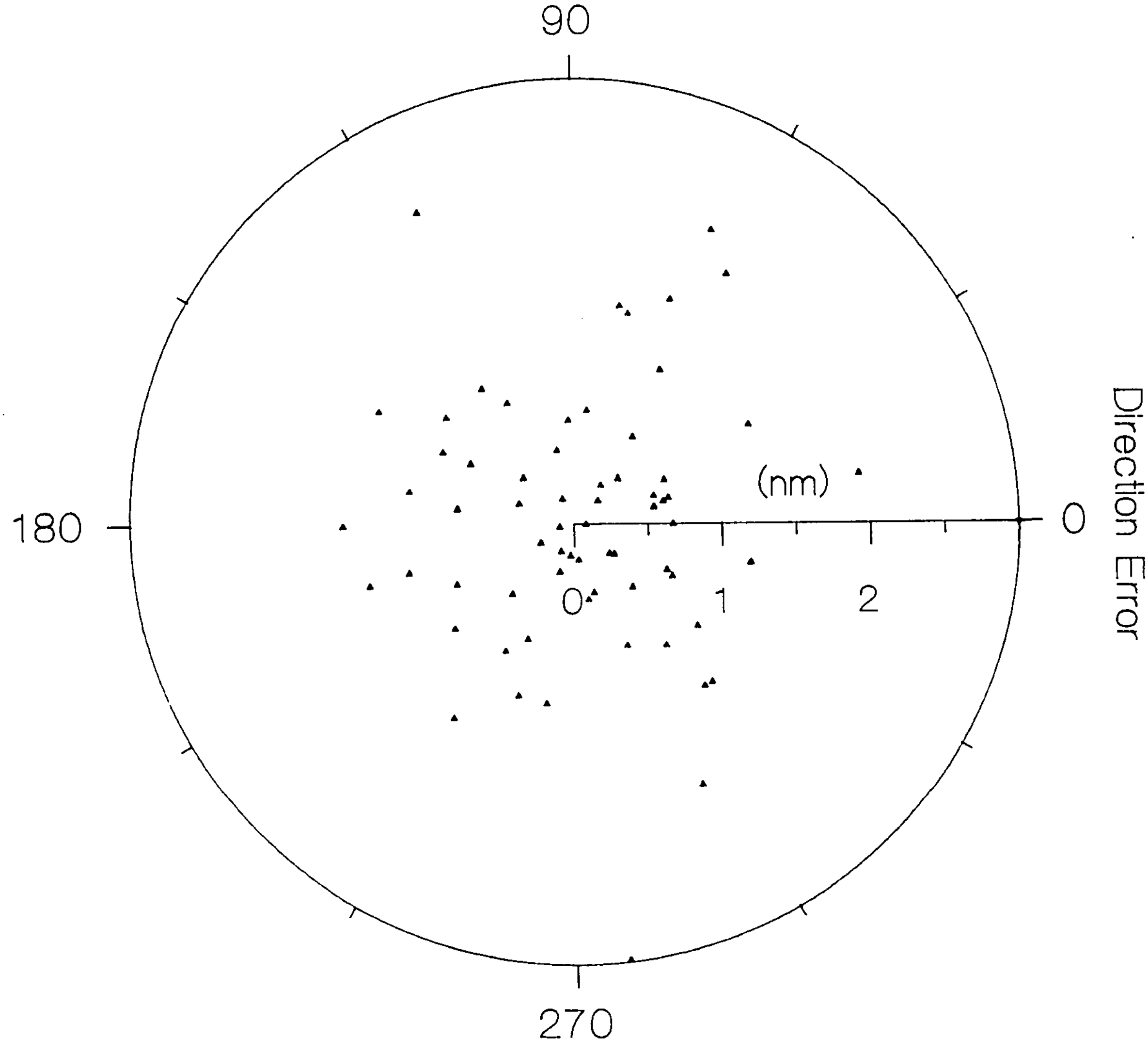


Figure III-17. Forecast error versus lead time for Iceberg 424

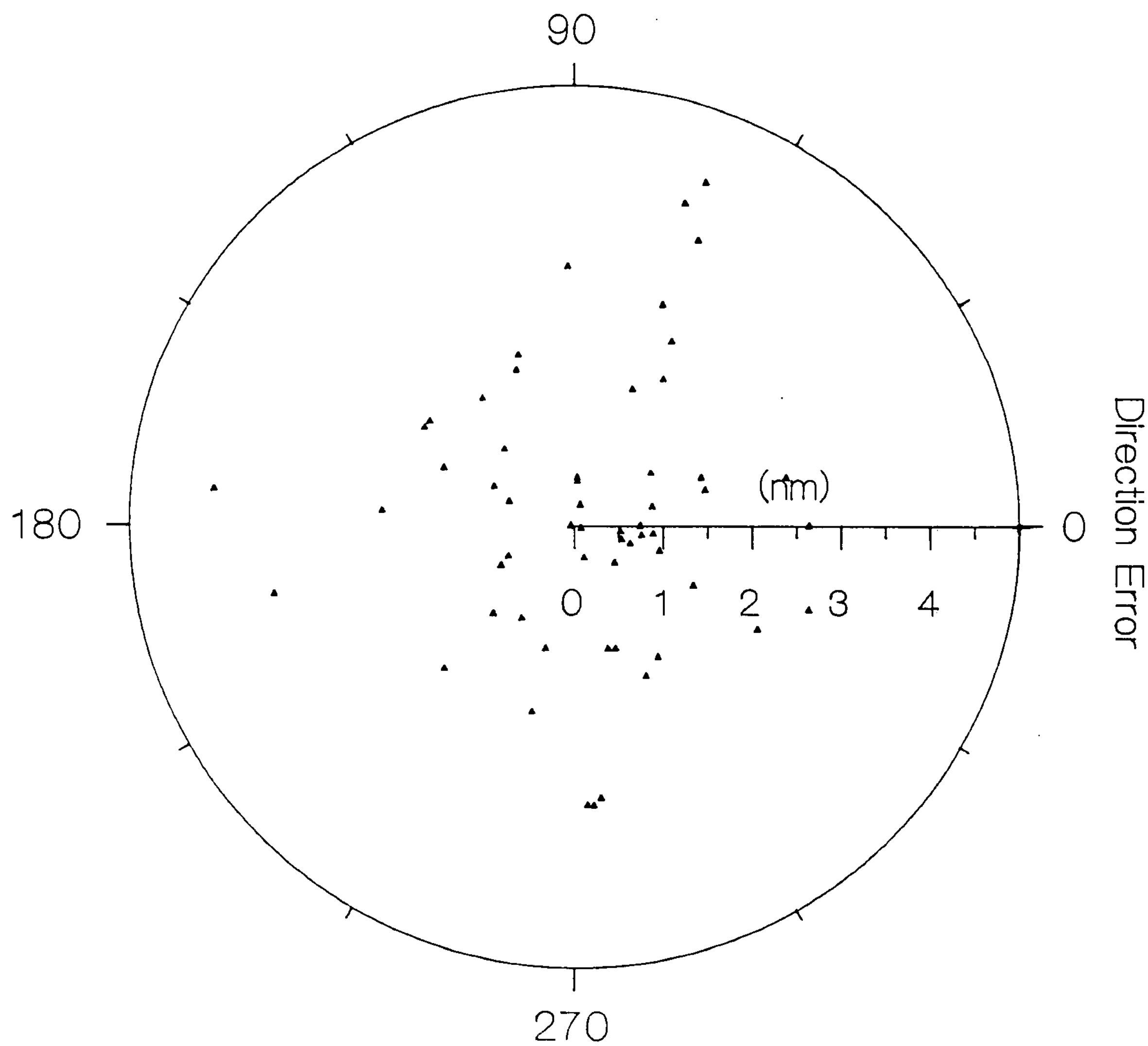
APPENDIX IV

Polar Plots of Forecast Errors for Lead Times
From 2 Hours Through 24 Hours

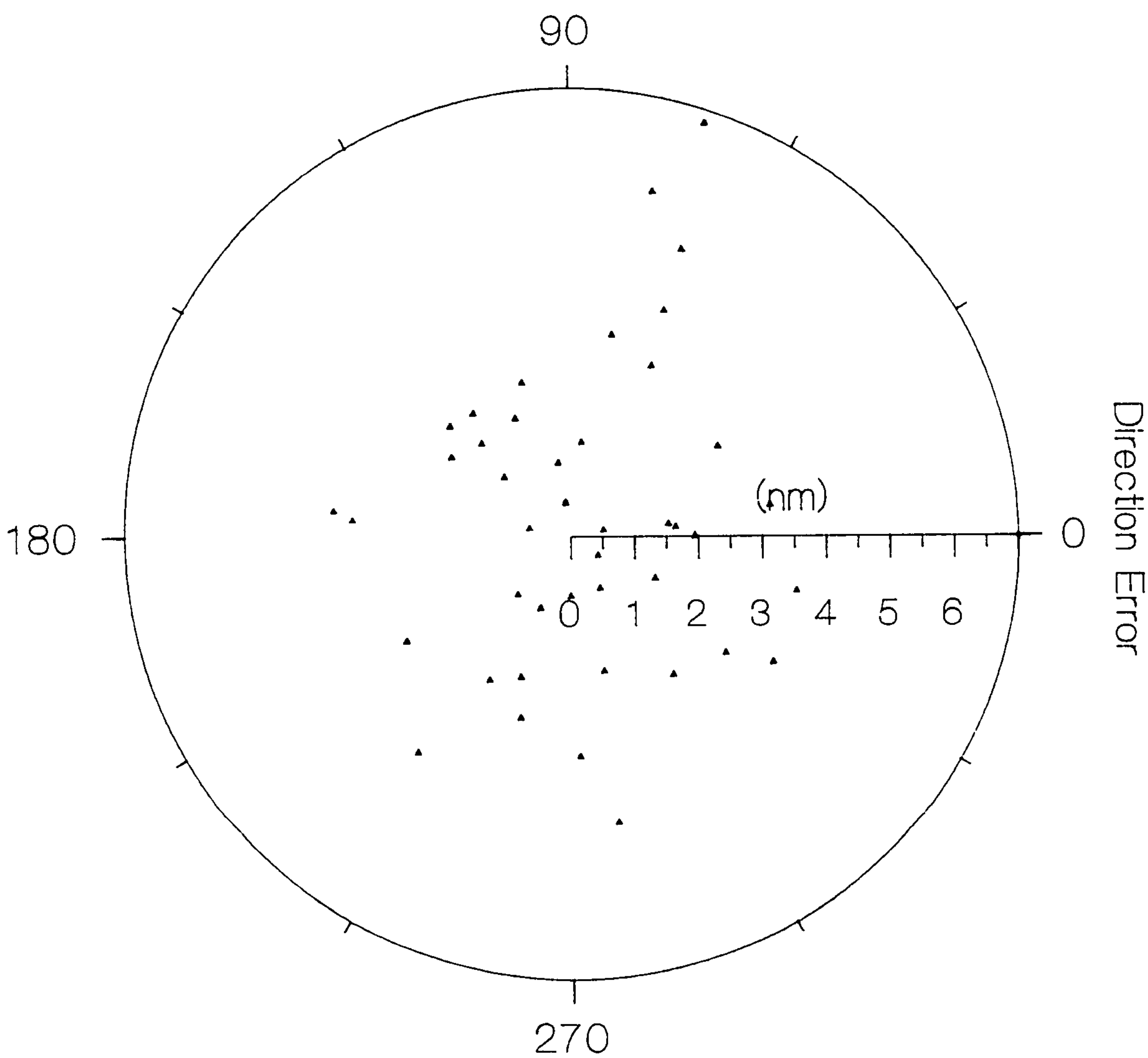
Forecast Error at 2 Hour Lead Time



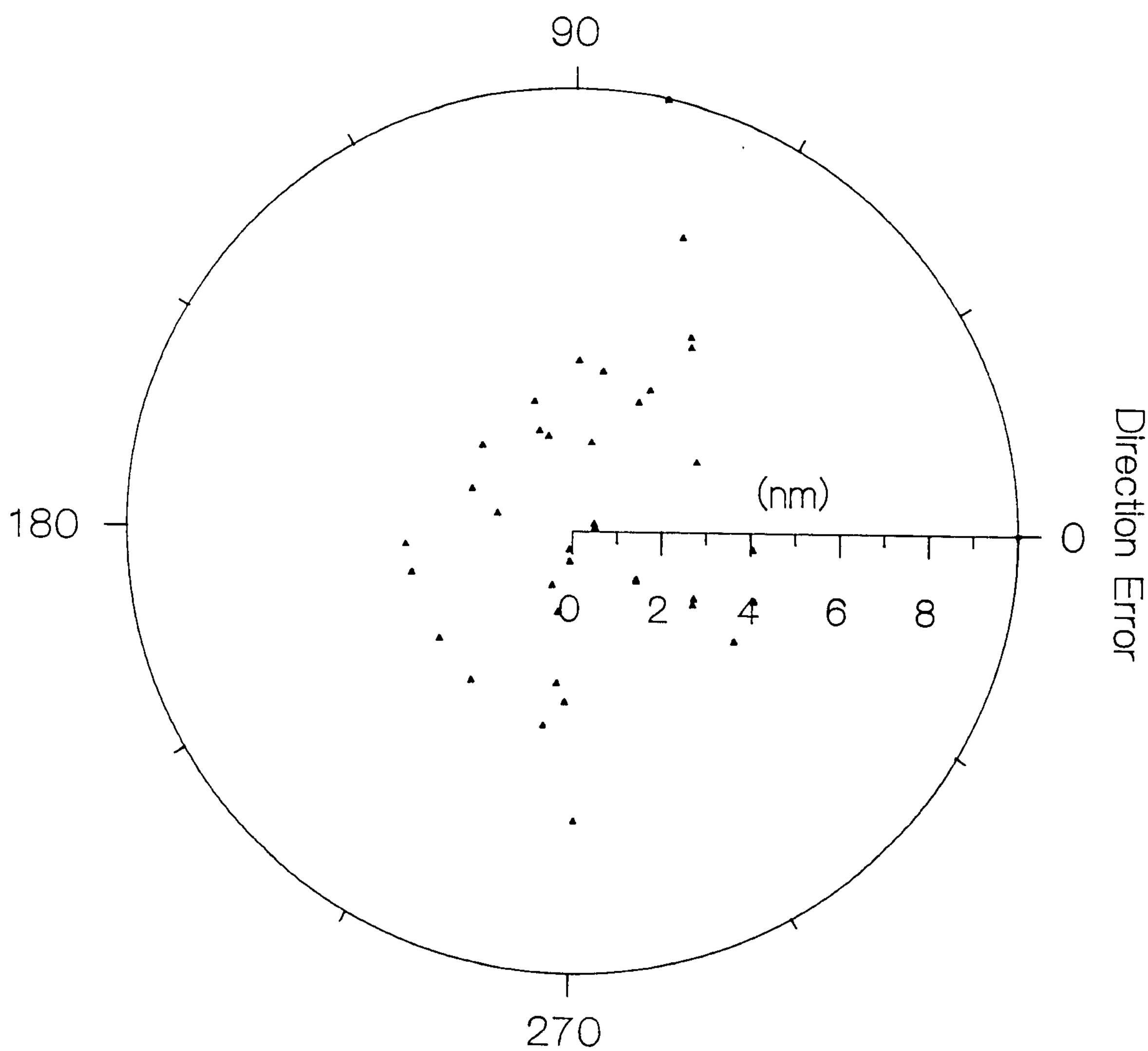
Forecast Error at 4 Hour Lead Time



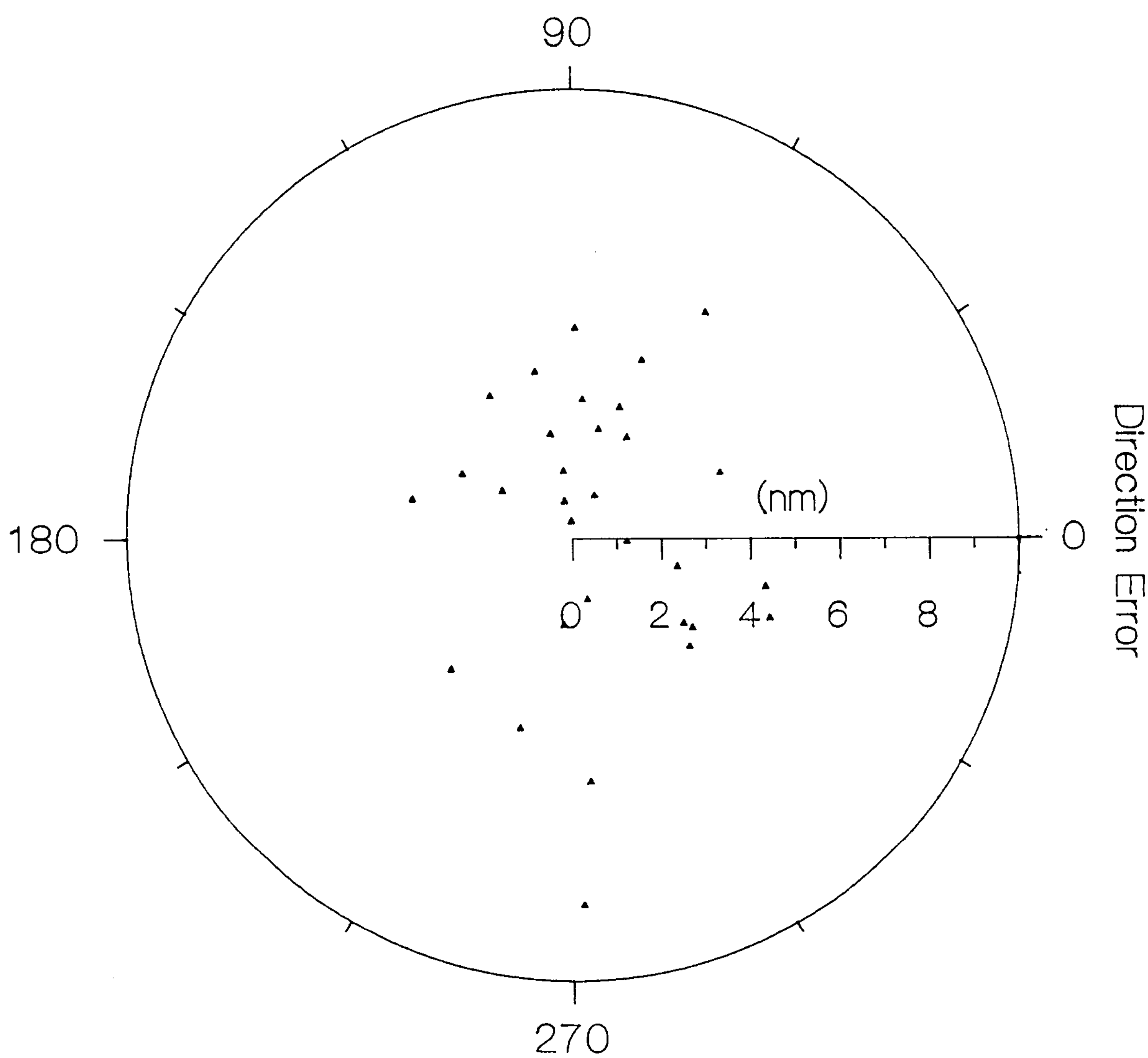
Forecast Error at 6 Hour Lead Time



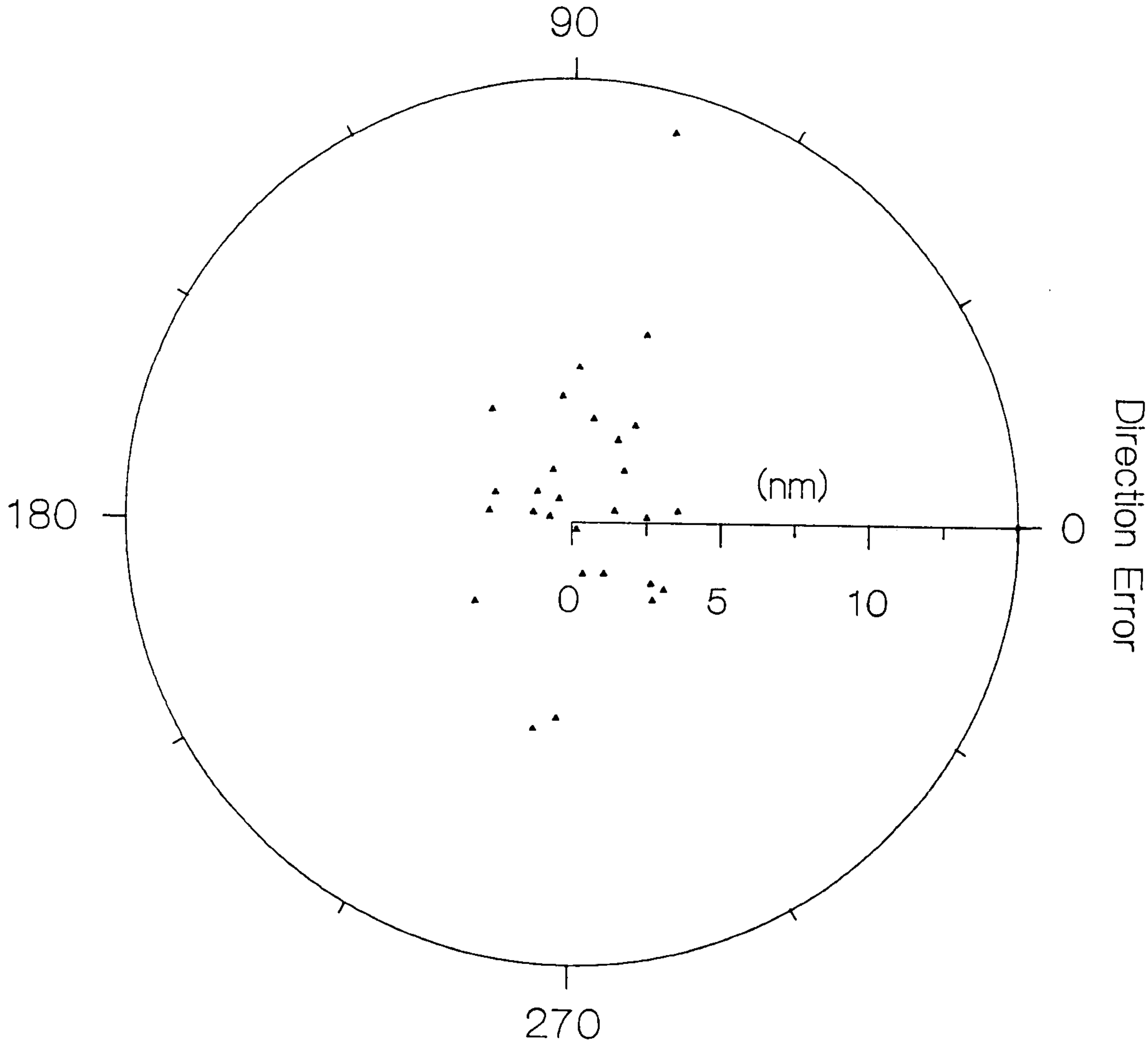
Forecast Error at 8 Hour Lead Time



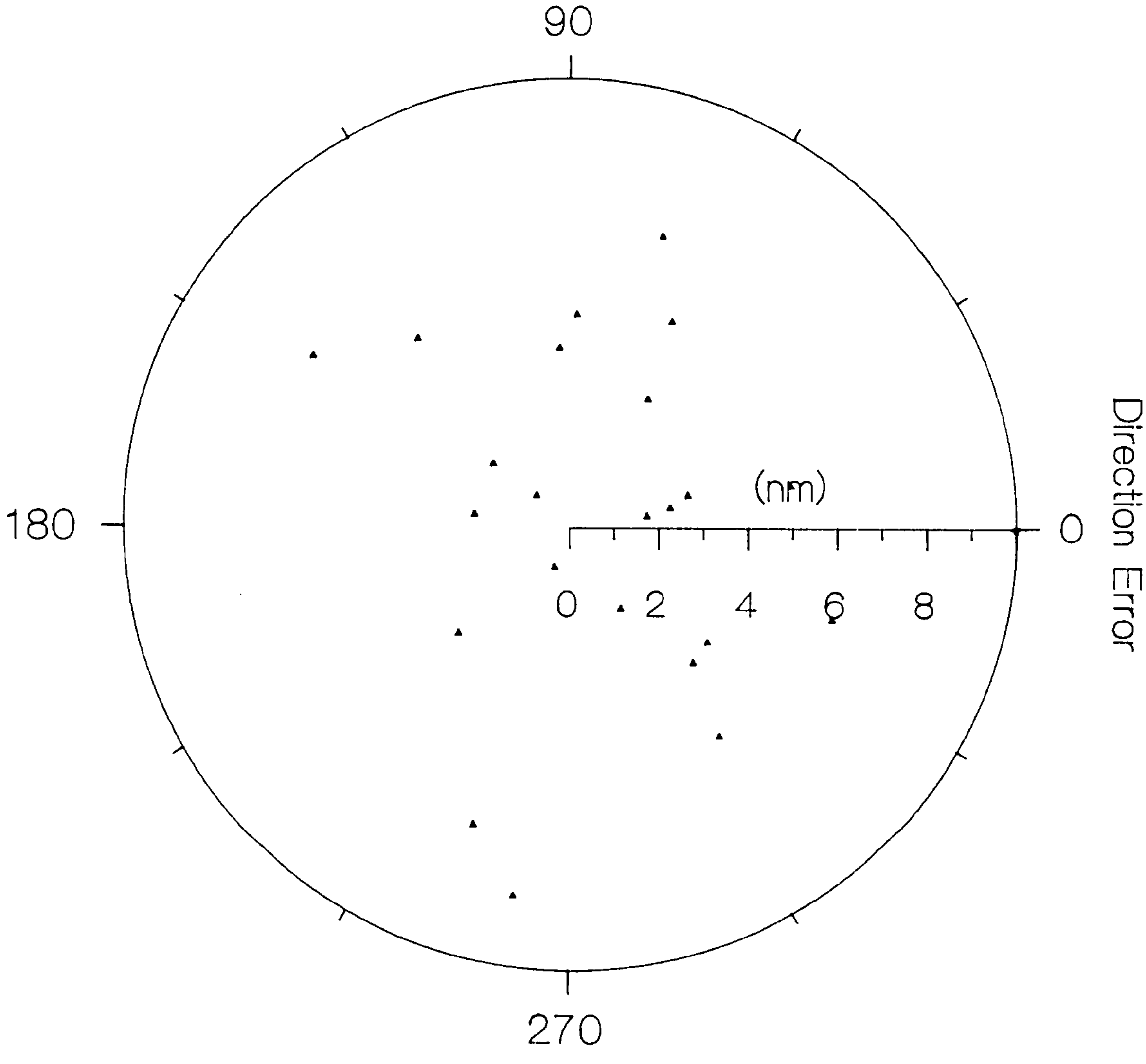
Forecast Error at 10 Hour Lead Time



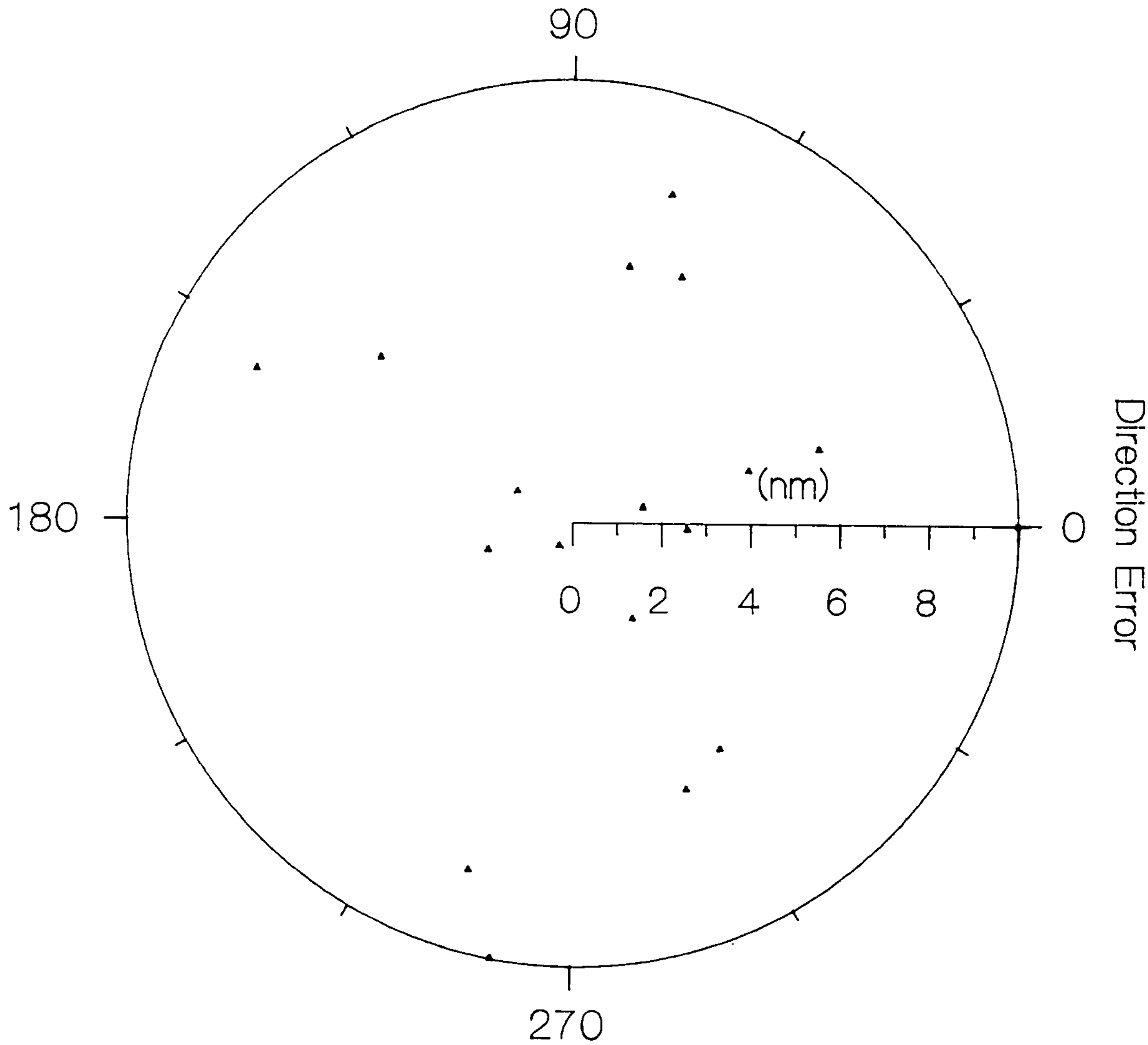
Forecast Error at 12 Hour Lead Time



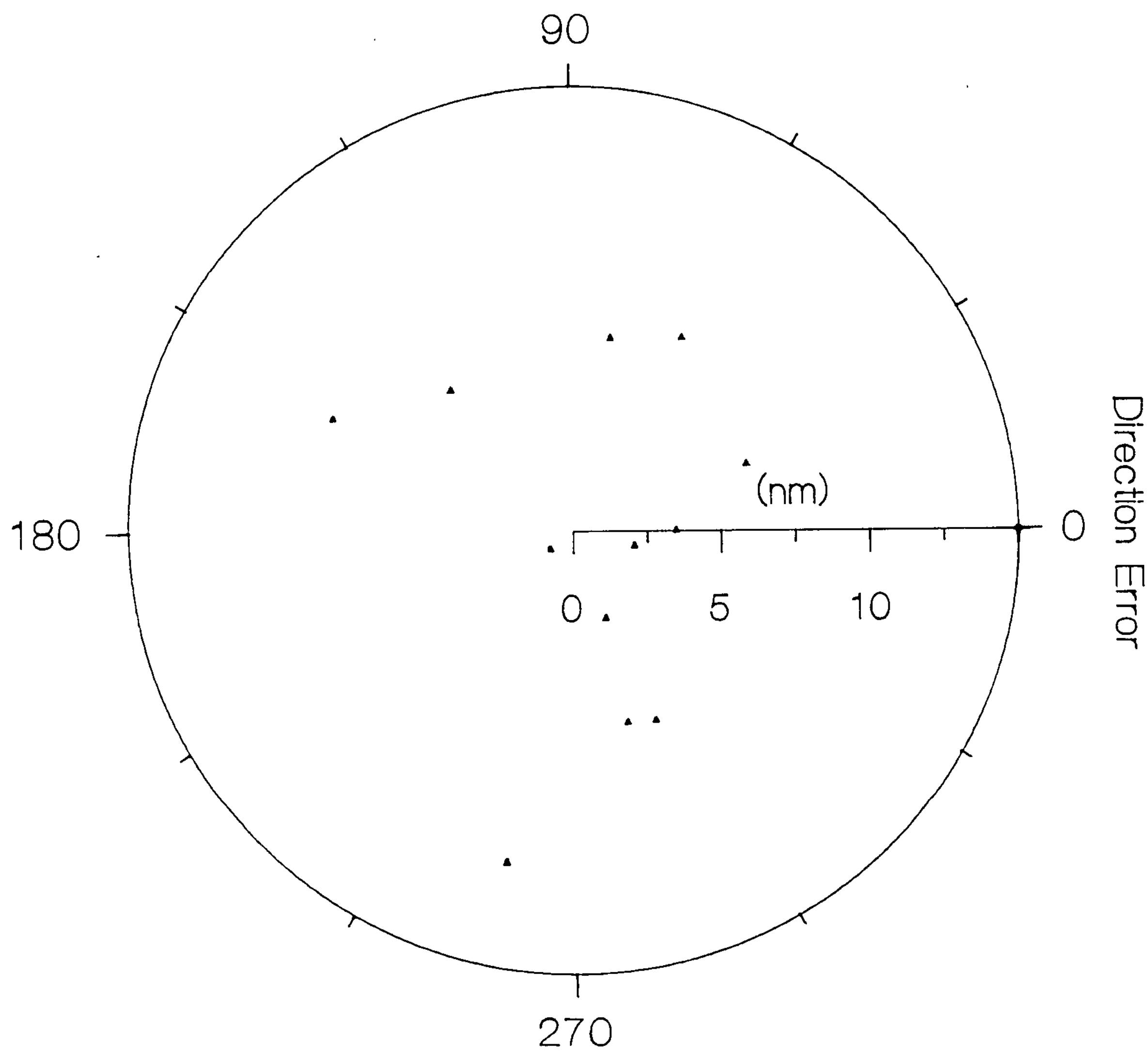
Forecast Error at 14 Hour Lead Time



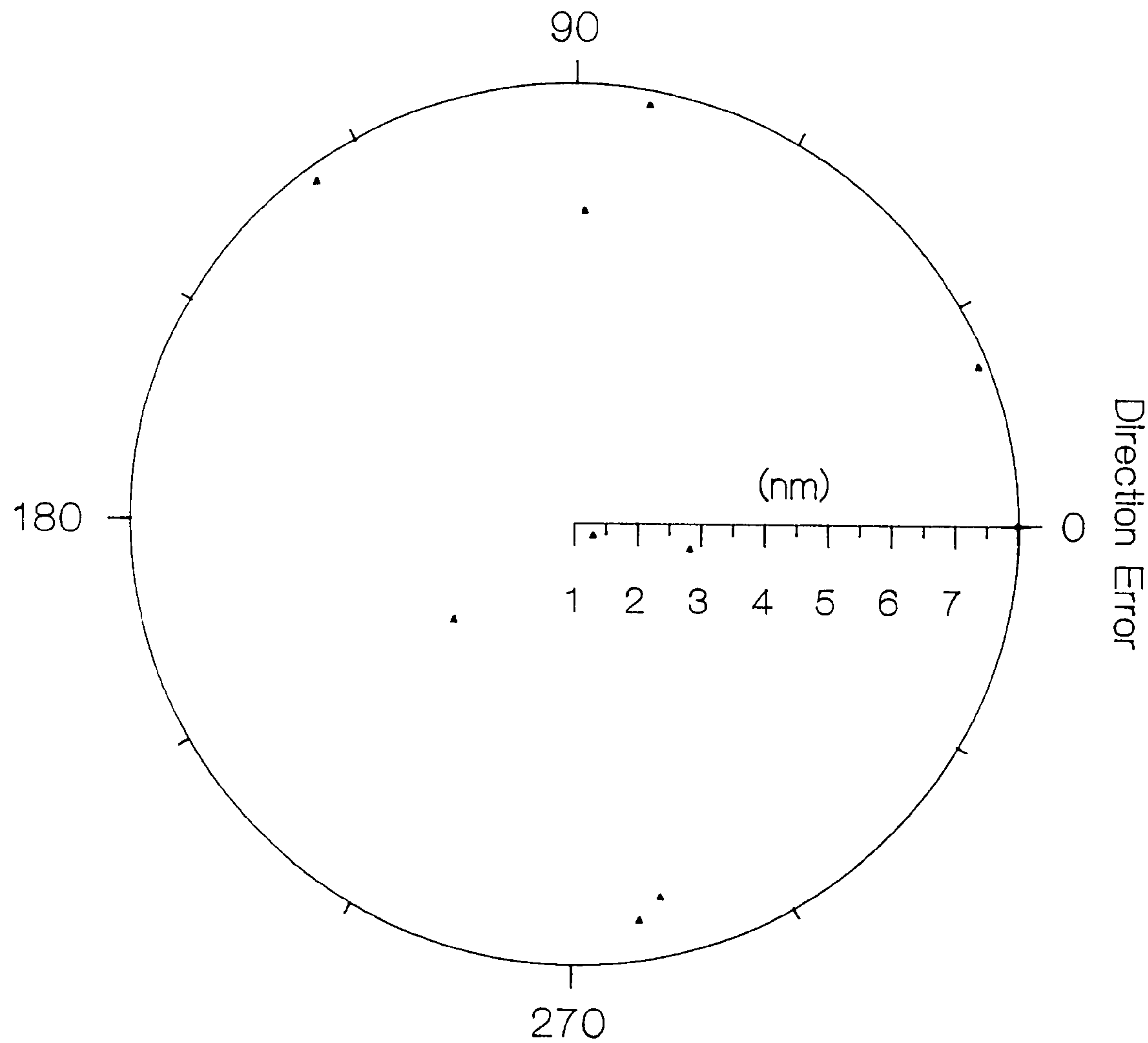
Forecast Error at 16 Hour Lead Time



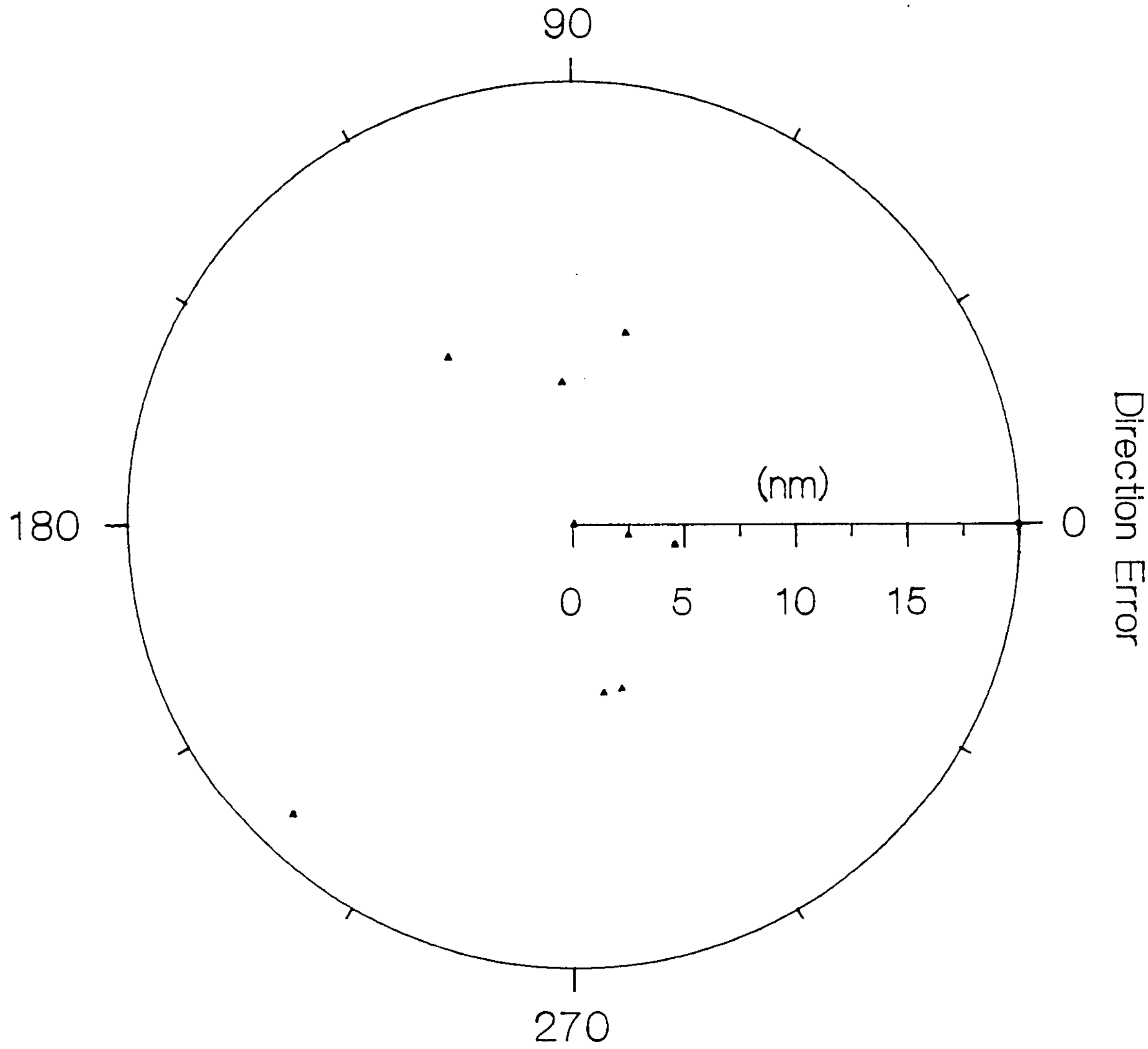
Forecast Error at 18 Hour Lead Time



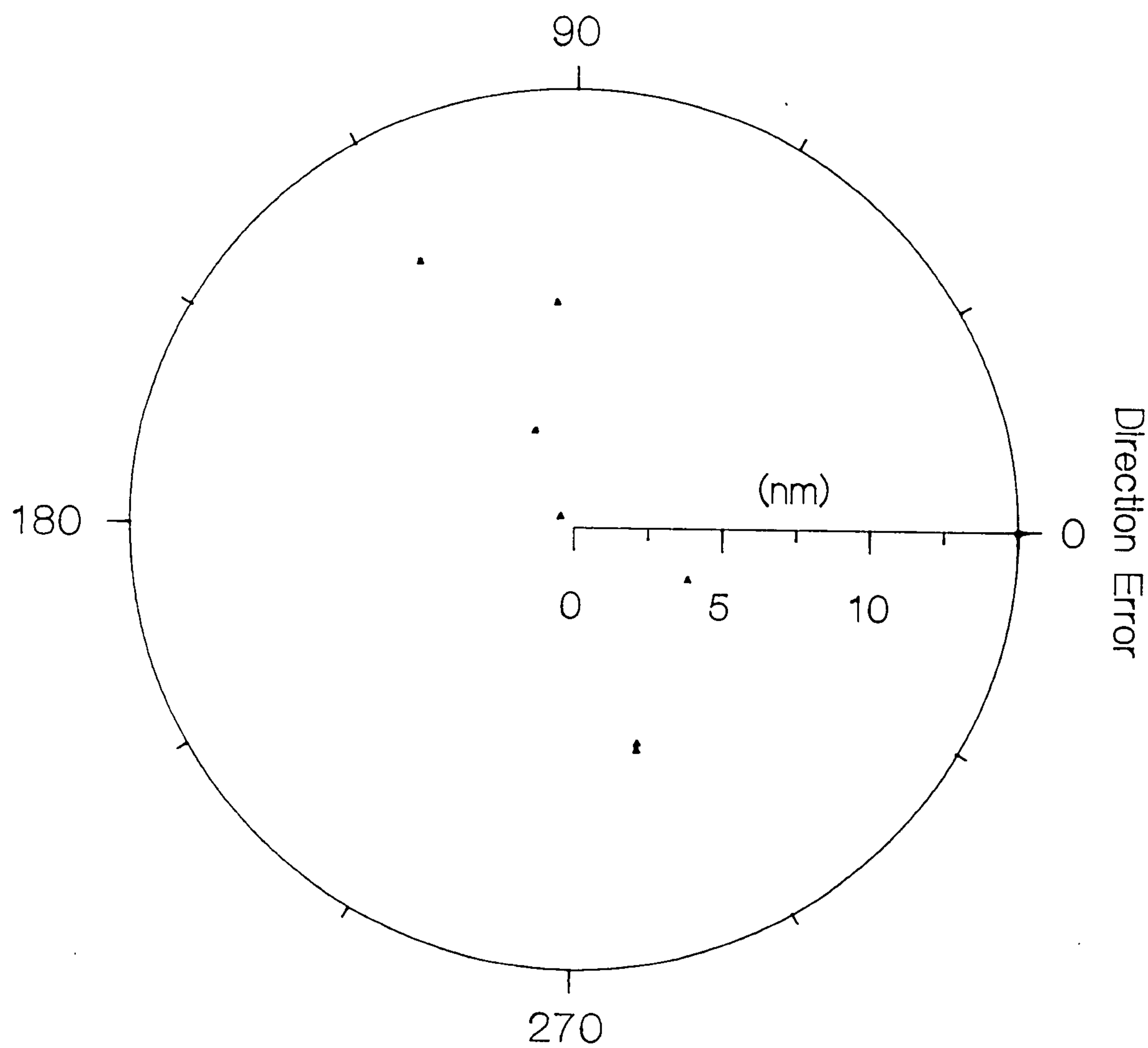
Forecast Error at 20 Hour Lead Time



Forecast Error at 22 Hour Lead Time



Forecast Error at 24 Hour Lead Time



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