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FINAL REPORT

BEAUFORT SEA COASTAL SEDIMENT STUDY (continuation)

EVALUATION OF INSHORE WAVE CLIMATE AND COASTAL SEDIMENT TRANSPORT PREDICTION TECHNIQUES AT KING POINT, YUKON

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Beaufort Sea Coastal Sediment Study: 1. Evaluation of inshore wave climate and coastal sediment transport prediction techniques at King Point Yukon. 2. Effects of a structure at King Point , Yukon.

Keith Philpott Consulting Ltd. 1987.

This Open file contains two reports concerning sediment transport at King Point, Yukon Territory, which follow the development of a wave hindcast model for shallow water conditions in the Canadian Beaufort Sea by Keith Philpott Consulting Ltd. (GSC Open File No. 1259). The first report presents the results of a comparison between the numerical model results and field data collected at King Point. The second uses the hindcast model to predict the effects of a pier structure on the littoral sediment transport regime.

The study was carried out under contract by Keith Philpott Consulting Ltd. as part of the Northern Oil and Gas Action Program (NOGAP) Project D.1: Beaufort Sea Coastal Zone Geotechnics. The report has not been edited by the Geological Survey of Canada and statements contained herein do not necessarily reflect the views or policies of the Government of Canada.

P.R. Hill
Scientific Authority

ABSTRACT

This study was intended to evaluate a series of coastal processes estimation techniques using field data measured at King Point, Yukon Territories during an earlier study by Dobrocky Seatech Ltd. The techniques and phenomena to be considered were parametric wave hindcasting, spectral wave refraction, wave generated alongshore currents and alongshore sediment transport, and surge induced coastal profile adjustment. The measured data from the earlier study were not of sufficient quality to enable the study to be conducted as thoroughly as intended. However, it was possible to examine the wave hindcasting process in detail over a moderate four day storm, improving the understanding of wave generation at King Point. Different methods of predicting bottom roughness and its influence on alongshore currents and alongshore sediment transport were also investigated but there was not sufficient data to determine the best method. Profile response due to onshore-offshore sediment transport could not be evaluated with the available data.

The effect of a coastal structure at King Point was evaluated in a separate report which is also bound in this cover.

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The assistance of R. Gillie of Dobrocky Seatech Ltd. in assessing the field program data is also acknowledged.

Executive Summary

Introduction

The study presented in this report was performed as part of the Beaufort Sea Coastal Zone Geotechnics Project, Northern Oil and Gas Action Program (NOGAP) Project D1. The objective of the project is to provide public information on the coastal zone as required by the Government of Canada for land use planning and by industry for the design of shore based facilities. The particular objectives of the work undertaken by Keith Philpott Consulting Limited (KPCL) were a critical evaluation of numerical estimation techniques of coastal processes (including the prediction of deepwater wave climate, wave transformation from offshore to nearshore, alongshore currents and sediment transport both cross shore and alongshore); and secondly an assessment of the impact of a structure on the coastal processes at King Point (discussed in a separate report although bound with this volume).

The numerical estimation techniques had been previously applied at King Point and six other sites in the Canadian Beaufort Sea in an earlier Beaufort Coastal Project study performed by KPCL. Details of the models applied may be found in the report (Pinchin et al., 1985, GSC Open File 1259). Within the present study it was intended to evaluate the performance of these models through comparison of predicted data to measured field data obtained in a field program implemented at King Point by Dobrocky Seatech Limited late in the summer of 1985 (see Gillie, 1985).

Field Program

Unfortunately, the extent to which the numerical modelling techniques could be evaluated was considerably restricted by shortcomings within the design and implementation of the field program. The field program design provided for:

- nearshore wave height, period and direction measurements with two Sea Data directional wave/current meters deployed at depths of 2.6 and 5.6 m. below near sea level

- current measurements with five electromagnetic Aanderaa current meters deployed at depths of 5, 7.5, 10, 12.5 and 15 m. below near sea level

- Wind speed, direction and barometric pressure from an Aanderaa recording weather station.

- Measurement of 17 separate cross sections of the beach and nearshore profile along a 2 km long section of the barrier beach.
- bottom sediment samples taken on the beach and at a depth of 20 m for each survey line.
- suspended sediment samples taken using a pumping method at the shallower Sea Data instrument with intake elevations 20 and 50 cm above the bed.
- littoral environment observations including estimates of wind speed and direction, nearshore wave height, period and angle of approach, alongshore current speed and direction, foreshore slope and beach sediment characteristics.

A brief review of the field program is presented as a prelude to the evaluation of the numerical modelling that was performed, and to elucidate the shortcomings in the field program to avoid repetition of the errors in future coastal process field measurement programs.

Perhaps the most critical design shortcoming was the choice of deployment sites for the wave gauges and current meters. The instruments were located at the junction of two reaches of beach with different orientations. Existing numerical modelling techniques are best suited to long straight beaches where the pertinent wave characteristics are spatially constant alongshore. This was clearly not the case at the chosen deployment site.

A second criticism concerning the deployment locations of the wave and current instruments and the sediment sampling (both surficial and suspended sediment) was their lack of proximity to the surf zone, where most sediment transport occurs. All of the instruments were located well outside the surf zone during the one moderate period of wave action. No bottom or suspended sediment samples were taken in the surf zone. According to the previous wave climate study by Pinchin et. al., (1985), the probability of a storm occurring which would have produced surf zone data at the chosen instrument locations, within the 18 days of instrument deployment, was less than 15 percent (15%).

The profile survey also proved to be of much less use than it might have been. Each of the 17 profiles was measured only once. Furthermore, most of the profiles were closely similar in shape. The evaluation of profile change with the passing of storms requires several measurements of the same profile throughout the study.

Difficulties were also encountered in the recording and reduction of the wave and current data. None of the Aanderaa current meters produced usable data (the instruments were either lost, dragged or came in contact with the bottom). This was presumably due to inadequate mooring, because the velocities that were recorded at the Sea Data instruments were not excessive. Of the Sea Data measurements, only the wave heights and periods at the outer station could be used with any confidence. The directional data at the inner station was also usable but was derived rather unconventionally from orbital velocity data and is somewhat suspect.

Overall the field program was unsuccessful in providing the data needed for evaluation numerical models. While some valuable data were collected the full potential of the field program was not realized. No information was collected within the surf zone where most information is required for evaluation of coastal processes. Many of the above mentioned problems would have been avoided had a representative of the team performing the numerical analysis participated in the design and supervision of the field program.

Wave Hindcasting

Turning to the evaluation of the numerical estimation techniques, the derivation of a deepwater wave climate using a parametric hindcasting model is first examined. Deepwater waves are synthesized using hourly wind data. Wind data was obtained for four locations in addition to the King Point measurements. The stations included three land based AES weather stations at Komokuk Beach, Shingle Point and Tuktoyaktuk, and one offshore station at the drill ship Explorer III. The Shingle Point winds most closely matched the King Point winds in speed and direction.

Calibration hindcasts were performed against non-directional deepwater wave data collected by Dome Petroleum in 1985 at a location west of Herschel Island, near the Explorer III wind station. The offshore wind data from Explorer III provided by far the best prediction of actual wave conditions at the Dome site. The measured wind speeds were first adjusted to account for boundary layer conditions and then, during calibration, reduced twenty percent (20%) to yield accurate estimates of significant wave height and peak wave period. The wind data from Tuktoyaktuk produced reasonable results while the wind data from King Point did not produce acceptable results.

The next test of the hindcast model involved prediction of deepwater waves offshore of the site and transformation of these waves (using spectral techniques) to the nearshore Sea Data recording stations. Unfortunately, since no offshore measured data was available at the site this became an evaluation of the combination of the hindcast model and the spectral wave transformation model. However, the latter model has already been proved to be very accurate in a separate study which included both offshore and nearshore measured data at a particular site (See Fleming et al., 1986).

The only wind data set which yielded hindcast results which remotely resembled the inshore wave data measured at the site was the King Point data. The Explorer III wind data which provided a good wave prediction at the offshore Dome site did not yield good results at King Point.

The lack of success at calibrating the hindcast model to the measured waves at King Point using the available wind data sets was explained by examining the weather conditions throughout the measurement period. The `storm' event (which had a peak nearshore wave height of only 0.6 m) was caused by a low pressure system moving from west to east and centered over the coastline. The direction of the track of the storm may be considered typical for the open water season in the Beaufort, however generally it occurs further offshore. The track of the storm under examination was such that none of the wind stations provided an accurate description of the wind within the generating fetch throughout the passage of the storm. However, had the storm centre been located further offshore, it is likely that the winds within the generating fetch could have been represented by the King Point recorded winds.

These findings lead to several conclusions about parametric wave hindcasting at King Point. The accuracy of predicting storm events from a local wind station is extremely sensitive to the specific track of the low pressure system related to the storm. Poor hindcasts can be expected when the center of the low follows the coastline as it did during the field program. More accurate hindcasts are possible when the low pressure system takes a more common track further offshore. This requires further investigation. However, there remains a need for local wind data collection at King Point for design purposes if indeed King Point becomes a centre of activity in future Beaufort Sea development plans.

A quantitative method of evaluating hindcast wave results in comparison to measured data using skill test techniques was developed and implemented. It augments the visual comparison but cannot be considered as a replacement for visual comparison.

A separate evaluation of the spectral wave transformation model was not possible due to the absence of concurrent directional wave measurements at a deepwater station offshore of the site.

Alongshore Currents and Sediment Transport

Alongshore currents are generated by waves breaking on a shoreline at an oblique angle. The detailed sediment transport predictors have been developed on the common assumption that wave action mobilizes the sediment while a superimposed current transports the suspended sediment. Therefore, prediction of the alongshore current distribution forms an integral part of the predictive process for sediment transport.

Within the report the theories and the various parameters involved in the prediction are presented. However, on the basis of the available data (which consisted of a single recording station well outside the surf zone) insight into the evaluation of these parameters was not possible, although some general comments have been made.

Considering the position of the instrument outside the surf zone very appreciable currents were measured (up to 0.4 m/s). These currents could not be attributed to the generation mechanisms of breaking waves. It is most likely that they were caused by wind stresses from winds blowing almost shore parallel. The effect of wind stress on currents both inside and outside the surf zone must be significant during periods of shore parallel winds as experienced during the particular low pressure event being examined. The influence of wind generated currents on coastal processes at King Point deserves further investigation.

No information was available from the field program to evaluate either alongshore or cross shore sediment transport predictors in detail. However, the site is well suited to a field study to evaluate sediment transport since the east end of the barrier beach acts as a sediment trap (being a convergent node of sediment transport). Surveys of several profiles over time would provide valuable information to this end. More information is required on sediment characteristics and bottom bedforms within the surf zone. Both alongshore currents and sediment transport are very sensitive to bottom roughness. Finally, tidal variation has little influence on sediment transport, although surges are very important.

Effects of a Structure at King Point

This is a summary of the second report contained in these covers.

The King Point site consists of a barrier beach bounded on either side by eroding bluffs. Consequently, this is not an ideal site for the application of a beach plan shape evolution model since potential sediment transport is probably not realized in the bluff sections.

However, successful application of the model was achieved at this site with the aid of estimated bluff recession rates and infilling rates of the barrier beach. These values were used to calibrate the model. The calibrated model successfully predicted the actual beach plan evolution from 1970 - 1983 (taken from air photos) using hourly directional wave data from a numerical wave climate analysis.

The effect of a hypothetical coastal structure located midway along the barrier beach and acting as a total littoral barrier was assessed by applying the wave climate from 1970 - 1983. The structure caused the historical zone of deposition at the east end of the barrier beach to be shifted to the west side of the structure.

Immediately east of the structure erosion is restricted by the sheltering effect of the structure. Disposition at the east end of the barrier beach continued but at a much reduced rate. There is wide variation in yearly alongshore wave power. In the scenario investigated there was more deposition at the coastal structure in 1971 than in all the other years combined.

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1 Introduction

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1. Introduction

1.1 Purpose

The study presented in this report was performed as part of the Beaufort Sea Coastal Zone Geotechnics Project, Northern Oil and Gas Action Project (NOGAP) Project D1. The objective of the project is to provide public information on the coastal zone as required by government for land use planning and by industry for the design of shore based facilities. Specific areas of interest include rates of coastline recession, rates and directions of sediment transport and analysis of wave and weather conditions around the Beaufort Sea.

Keith Philpott Consulting Limited was previously involved in the Beaufort Sea Coastal Zone Geotechnics Project performing the Beaufort Sea Coastal Sediment Study (Pinchin et al, 1985; GSC open file 1259). That study involved the application of advanced coastal process numerical estimation techniques to seven sites in the Canadian Beaufort Sea. The numerical techniques concerned involved the following processes:

- generation of offshore waves;
- transformation of offshore waves to the nearshore zone;
- wave induced generation of alongshore currents;
- alongshore sediment transport;
- nearshore coastal profile adjustment;
- influence of surges on coastal processes;
- impact of a typical structure on coastal processes.

King Point (see Figure 1.1) was considered a key location, the most likely site for the next shore based facility in the Canadian Beaufort Sea. For this reason it was selected for study of the impact of a structure and generally was treated in more detail than the other six sites throughout the earlier study.

This present study is a continuation of the earlier work. It deals with King Point only.

The study had two main objectives; 1) a critical evaluation of the estimation techniques used in the earlier study and 2) assessment of the impact on coastal processes of a structure at a different location than previously considered. The results of the second analysis are included as a separate report but bound under the same cover as this report. The first objective was to be met by estimating sediment transport rates during the 1986 open water season using the same techniques employed during the earlier study. These results would then be compared to data collected during a coastal zone field data collection program conducted at King Point. This evaluation of the predicted data would then assist in interpretation of the earlier study including the reasons for any shortcomings that might have occurred.

The field data collection program is described in detail in Gillie (1985), and summarized and evaluated in Chapter 2 of this report.

1.2 Beaufort Sea Coastal Sediment Study Recapitulation

The main objective of the earlier study was to generate data of direct value to those in Government and Industry responsible for detailed planning of shore-based facilities, pipeline shore crossings and the like. This was accomplished by applying advanced coastal process numerical estimation techniques at seven sites in the Canadian Beaufort Sea; Kay Point, King Point, Pauline Cove and Stokes Point in the Yukon Territories and Atkinson Point, North Head and Tuktoyaktuk in the North West Territories. Three types of numerical models were applied at these sites; 1) wave hindcasting; 2) nearshore wave transformation; and 3) coastal sediment transport. While the first two model groups did not directly yield data concerning coastal sediment processes they were considered to represent the most crucial aspects of the study. The prerequisite for the prediction of sand transport on beaches is a sound definition of nearshore hydrodynamic conditions. For beach problems this essentially means that the nearshore wave climate must be accurate both in terms of wave height and wave direction. The analyses undertaken at King Point are summarized in the following paragraphs. Because of the complex sheltering due to adjacent coastal forms at some of the other sites intricate procedures were developed that did not have to be applied at King Point. These procedures included effective depths of fetches varying with time and direction, as well as simultaneous wave generation in deep and shallow water. The procedures are discussed in Pinchin et al, (1985) and are not reviewed here.

1.2.1 Deepwater Wave Hindcasting

Deepwater wave conditions were synthesized using a parametric hindcast procedure that utilizes wind speed, wind duration and over water fetch length to yield single estimates of significant wave height, significant wave period and mean wave direction. A detailed description of the model is presented in Pinchin et al, (1985).

Because one of the main objectives of the study was to generate data it was decided to hindcast over the longest possible period for which wind records existed. Tuktoyaktuk, for which wind records extend back to 1970 was the only viable source. The standard information required for the wind hindcast is one or three hourly wind speed and direction data measured to the nearest ten degrees. Because a complete and continuous data set meeting this requirement did not exist, three heterogeneous sets of data from two Atmospheric Environment Canada recording stations, Tuktoyaktuk and Tuktoyaktuk A, were combined to produce an acceptable data set. Linear interpolation over a number of missing data gaps was required. None of the gaps exceeded 12 hours duration. This composite data set allowed hindcasting of 14 years of hourly wave data.

The overland wind speeds were adjusted to account for differences in overland and overwater boundary layer friction using a Beaufort Sea wind speed ratio curve developed by Baird and Hall (1980). This relationship was derived after they performed an extensive review of wind speed ratios used in previous hindcasts. However, a more restricted study on winds in the area suggested that onshore winds above 20 km/h should be higher than proposed by Baird and Hall (Danard and Gray, 1984). This was not investigated.

Fetch lengths were taken from hydrographic charts for land restricted fetches and from weekly ice charts for fetches which were restricted by ice. The limit of the fetch was taken as the boundary of the 3/10 ice concentration, that is to say ice concentrations up to 2/10 were included as part of the wave generating fetch. Ice limited fetch lengths were defined on a daily basis by interpolating between the weekly chart data. Because a number of sites were being investigated a common fetch point was selected for the four western sites.

This approximation was acceptable for longer fetches because hindcasting is relatively insensitive to fetch length and the distances from the sites to the common fetch point were small compared to the fetch length. Figure 1.2 shows the common fetch sectors for a typical ice location chart. Site specific fetch data was used for land restricted fetches and for occasions when the ice edge was close to the site. Figure 1.3 shows the local fetch sectors for King Point.

The hindcast procedure was calibrated by hindcasting to locations where measured wave data existed and comparing the predicted and measured data. Two stations with relatively long durations (with respect to other stations) were selected. Directional wave measurements did not exist. Calibrations were performed against approximately six weeks of data from Marine Environment Data Services (MEDS) station 191. Verification hindcasts were performed against approximately 7 weeks of data from MEDS station 50, (See Figures 3.10 and 3.11).

A number of parametric hindcast equations and procedural options were investigated, and the combination which gave the best results was selected for the 14 year hindcasts. The determination of the best combination of parametric model and other optional parameters was ultimately a matter of judgement. Although some aspects are easily recognized as being different it was not always obvious that one trial hindcast was definitely better or worse than another. The SMB parametric equations (Bretschneider, 1973) were selected over the Darbyshire and Draper (Carter, 1983) and JONSWAP (HRS, 1982) parametric equations. The best hindcasts were produced when linear wave decay and a wind divergence angle of 60 degrees were used. The wind divergence angle is the maximum difference between an existing wave direction and the direction of winds that contribute to the wave condition rather than generating a new wave train in the wind direction. In general there was a tendency for the calibration and verification hindcasts to under predict measured occurrences of large waves. A detailed check of the largest of these under-predictions showed that the measured wave could not be hindcast even with an exaggerated overland to overwater wind speed ratio. It was also found that the calibration was poor during periods of rapidly changing winds at Tuktoyaktuk. Most of these problems were attributed to the remoteness of the wind measuring station from the wave measurement station.

1.2.2 Nearshore Wave Transformation

Wave transformation analyses carried out in the previous study consisted of applying spectral transfer techniques with backward tracked wave rays. This involved digitizing the seabed from the shoreline out to reasonably deep water, about 30 m. This data was used to construct a number of depth grids which form the basis of the wave ray tracking computations. A total of 9 grids were used to represent the sea bed at King Point, as shown in Figure 1.4. Linear wave rays paths were computed using the "circular arc" method developed by Abernathy and Gilbert (1975). The ray paths were tracked from inshore locations at regular angular intervals for a number of wave periods as required to define the whole range of offshore sea states. Deepwater wave spectra were decomposed into a number of component waves defined by a direction and period. Each component was individually transferred inshore along a wave ray path considering the effects of shoaling and refraction and recombined to produce inshore directional spectra. The directional spectra were integrated over the range of inshore directions to produce one dimensional frequency spectra. These spectra were then checked to ensure that they did not contain more energy than possible for the given depth of water as specified by the KKZ finite depth equilibrium spectrum theory (Kitaigorodskii et al., 1975). The resulting shallow water wave heights and mean wave directions when considered along with the deepwater wave heights and directions produced wave transfer coefficients that could be applied to all the deepwater sea states.

Because backward tracked ray techniques were employed the inshore wave climate was defined at a series of "nodes" for each site examined. These nodes were located beyond the breaker zone, typically around the four or five meter contour. At each of the sites investigated two nodes were used to produce 14 years of nearshore wave data for computing potential alongshore sediment transport rates. At King Point an additional three nodes, for a total of five, were used to define the nearshore wave climate while investigating the effects of a structure.

The effects of storm surge on the wave transformation process was investigated by assuming a surge height 1.75 m above the normal tidal range. However, in comparing nearshore wave transformations at different water levels it must be realized that the node locations are adjusted to maintain the specified water depth when the water level is changed.

Consequently, if the bathymetric contours are regular and parallel to the shoreline the wave transformation process is not influenced by the change in water level. Any change would therefore have to be due to irregularities of the bathymetry. As can be seen in Figure 1.5 the surge effects were minor at King Point.

1.2.3 Coastal Sediment Transport

Three sets of numerical models were applied to investigate the coastal sediment regime; 1) to estimate potential alongshore sediment transport rates, 2) to examine coastal profile adjustment due to cross-shore sediment transport, and 3) to first predict the evolution of the King Point barrier beach and to then investigate the effect of a structure on that beach. Each of these analyses is discussed below.

Alongshore Sediment Transport

Potential alongshore transport rates for the 14 year study period were estimated at two locations at each site with twelve alongshore transport predictions. These comprised three variants of the U.S. Army's Coastal Engineering Research Centre (CERC) original total energy bulk alongshore sediment transport model as well as nine different detailed predictors which provide a cross-shore distribution of the alongshore transport rate. The bulk models were based on CERC (1974), Swart (1976b) and Sayao and Kamphuis (1982). The detailed predictor models were based on Bijker (1967), the Swart (1976a) adaptation of Engelund and Hansen (1967), Swart (1976b), Willis (1978), can de Graff and van Overeem (1979), Nielsen (1979), Nielsen et al. (1978), Fleming (1977), and Swart and Lenhoff (1980).

These models were simultaneously evaluated using a "package" approach by applying all the models at each site. The program used was originally developed for research purposes. It was intended to be a "test-bench" for making objective comparisons among the different sediment transport models by applying exactly the same input data set to all models. When applied to the twelve locations (two nodes at each of six sites) in the previous study, for any one location answers varied among the twelve models by as much as three orders of magnitude. While these results were not all assumed to be valid they did serve to dispel any misconception about the accuracy of coastal sediment transport estimates that might be engendered by applying only one model.

The study confirmed that there are major shortcomings with the available models for the prediction of alongshore transport. The bulk transport models produced stable results and are generally believed to be accurate within half an order of magnitude under appropriate circumstances. However, they provide no detail and little insight into the sediment transport process. The detailed predictors, on the other hand, do provide insight into the sediment transport process but exhibit notable instabilities. This, in many cases, can be attributed to applying a model to conditions outside those considered in the development of the model. For example, 7 of the 12 models were considered invalid at Atkinson Point because of the fine grain sizes. These models all produced unrealistically high results, possibly because of underestimation of the threshold of motion of fine grain sizes with turbulent flow and possibly due to the dependence of these models on shear stress. The shear stress is computed from bed form models which can become unstable at fine grain sizes.

However, in considering the preceding discussion, it must be realized that all of the models drew from a common input data set and that all of the parameters were applied in an entirely consistent manner. That is to say, for example, that the same roughness model was used in the evaluation of the longshore current friction factor as was used for the evaluation of the shear terms in the various sediment transport models. Similarly, exactly the same assumptions were made for all of the sediment transport models tested. It must be recognized that this approach is not always consistent with the original derivation of all of the sediment transport models, however, it is the only rational basis on which the different models may be compared. It must be appreciated that the development of detailed alongshore sediment transport models is still in its infancy and most of these models have not yet been thoroughly tested under a representative range of conditions. Also, and possibly more important, are the facts that a) most of the models were derived from modifications of unidirectional flow sediment transport techniques; and that b) they depend on a complex chain of interrelated computations several parts of which were originally derived under rather different boundary conditions, often only at laboratory scale. These models would have produced more realistic results if they had been calibrated individually, but, in the absence of proper calibration data the package deal approach was taken to provide an objective comparison of the different sediment transport models.

Profile Adjustment

Changes in beach profile geometry due to changes in wave and water level conditions during storm surges were investigated with a model developed by D. H. Swart using his onshore-offshore sediment transport theory (Swart, 1974). The model computed changes in the nearshore profile as a function of gradients in onshore-offshore sediment transport based on the difference between the current actual profile and an equilibrium profile corresponding to the current wave and water level conditions. This model was implemented at one inshore node for five of the seven sites where sufficient data existed (Atkinson Point, Kay Point, King Point, Stokes Point and Tuktoyaktuk).

The model was calibrated against a measured profile at each site to ensure that the model could reproduce a representative measured profile under the action of a typical wave climate. The typical wave climate for this calibration was defined by randomizing a statistical summary of the 14 year wave hindcast data. Surges were not considered in the calibration process because they could not be related to the randomized wave data or to the representative profiles.

Quite often the profile that resulted from a trial calibration run was different from the input profile. The measured profile could have been non-typical due to profile composition or to antecedent conditions such as recent large storms or ice effects. Equally plausible was the possibility that the assumptions underlying the calibration process were not always valid. Questionable assumptions included that there was only a small year to year variation in the wave climate, and conservation of sediment over time.

The second stage of the nearshore profile adjustment analysis was in effect a surge sensitivity study of nearshore profiles including estimates for shoreline retreat during large storms. Typically, a two to three day storm event was synthesized using the largest wave events in the fourteen year hindcasts superimposed on varying storm surge water level profiles. At each site, the model was usually run first with no surge then with at least two different levels of peak surge.

Effect of a Structure

The effect of a hypothetical structure located at the west end of the barrier beach at King Point was investigated through the application of a beach plan shape model. The structure was assumed to be a total littoral barrier allowing no bypassing of littoral sediment.

A one-line model was used to compute the changes in the planform of the shoreline due to spatial and temporal variations in alongshore sediment transport rates. Inshore wave conditions were computed at five nearshore nodes using the spectral transfer program to provide a detailed description of the nearshore wave climate.

The model was calibrated by reproducing the natural evolution of the barrier beach between 1970 and 1983. This was accomplished after model parameters had been adjusted to account for the difference between actual and potential sediment transport rates.

A more complete description of the model, including the results of an analysis with a structure in the centre of the barrier beach is presented in the report by Nairn (1987) bound with this report.

1.2.4. Results at King Point

The King Point site includes a 50 m high ice rich eroding cliff to the west and lagoon with a 2 km. long barrier beach at its eastern end, (see Figure 1.6). Similar cliffs about 20 m high occur east of the lagoon. Recession rates for the cliffs 10 to 20 km west of King Point have been estimated about about 1 metre per annum by Harper et al (1985) and Gillie (private communication). The cliffs to the east, within about a half a kilometre of the lagoon, were subject to higher recession rates of about 3 m/a. Further to the east the rates were 1.5 to 2.5 m/a (Gillie, private communication). Textural composition of the cliffs suggests that 5 to 10% of the material was coarse enough to remain in the littoral zone.

The lagoon was evidently formed by transgressive breaching of a lake. Its depth was about 3 meters in the nineteen fifties. According to air photos, the barrier was complete in 1970. Sixteen years earlier it was a spit which extended from the west, about three-quarters of the distance across the mouth of the lagoon. The net eastward transport required to produce the change was estimated at 20,000 m^3/a (Gillie, private communication).

The alongshore sediment transport results as computed by the numerical package showed a gross potential transport rate near the east end of the beach of about 32,000 m^3/a. This was similar to sediment budget estimates of actual littoral transport from bluff recession rates and beach infilling rates. The net transport along the cliffs to the west of the barrier beach was estimated at only 3,000 m^3/a directed to the west. Figure 1.6 shows the best estimates of potential sediment transport rates after accounting for some unrealistic model results.

The surge sensitivity analysis at King Point indicated that there would be less alongshore sediment transport at the higher water levels. This was related to a narrowing of the surf zone caused by the partial submergence of a steep bluff at node 2 and assuming a much less steep slope landward of the barrier beach at node 1.

A more detailed examination of the littoral cell in the vicinity of King Point was possible through the results of the beach plan shape model BPLAN. It was run from 1970 to 1983, without a structure. The relative magnitudes and directions of sediment transport are shown in Figure 1.7.

It was evident that there was a divergent sediment transport node just west of the west end of the barrier beach and a convergent node at the east end of the beach. The shoreline is probably transgressing throughout the littoral cell except at the convergent node which has been a zone of deposition.

It was difficult to estimate the rate of progression of the shoreline at the convergent node since a significant proportion of the littoral sediment was removed from the beach face by overwashing of the barrier beach. In other words the barrier beach is also growing back further into the lagoon. However, it was evident that the beach at King Point is a rapidly developing feature.

Calibration of the profile adjustment model to the measured profile at King Point did not prove to be entirely successful. The resulting profile was higher and less steep than the actual measured profile. It was concluded that part of the reason for the poor match related to actual overwashing of the barrier beach. Consequently, the resultant profile from the calibration run, rather than the measured profile, was chosen as the representative profile for further analyses.

Figures 1.8 to 1.10 show the results of the synthesized storm at mean water level and two surge levels. The shoreline retreat at the mean water level increased with a rise in water level to a maximum of 4.75 m for a peak surge of 1.65 m above MWL. Figure 1.10 also shows a major flattening of the beach face in which the crest of the beach berm retreated about 50 metres and rose more than a metre in elevation. Due to the low evaluation of the crest of the barrier such changes are not likely to occur at King Point. The results may be interpreted as an indication of overwashing on the real beach.

1.2.5 Conclusions

Indications of unusual combinations of profile slope and particle size on the coasts of the Beaufort Sea were noted, but unfortunately geomorphological and sedimentological data is too sparse to perform adequate quantitative studies. There is a lack of nearshore profile measurements including cliff recession and sediment texture data and no repeated observation to determine time variation. For spits and barriers measurements should extend over the beach crest into the waterbody behind. Although some data was collected at King Point for this study (Gillie, 1985), there is still a shortage of both sediment and profile data. This is discussed in more detail in Section 2.3.

Deficiencies in available wind, water level and wave data were also noted. There is a need to maintain homogeneous, complete wind records at more places in the area. Water level records were found to be inadequate. It is essential to eliminate interruptions in water level recording at Tuktoyaktuk and to establish another permanent water level recording station on the Yukon coast.

Wave measurements are becoming more plentiful but are not adequate for calibration of wave prediction models. There is a need for:

- directional wave measurements;
- station records of longer duration over several consecutive seasons;
- more reliable records without interruptions;
- shallow water wave measurements;

The former study showed that surges per se have relatively little effect on the rates of alongshore sediment transport for a given wave condition, increasing the annual mean rate by 10 % in only one case.

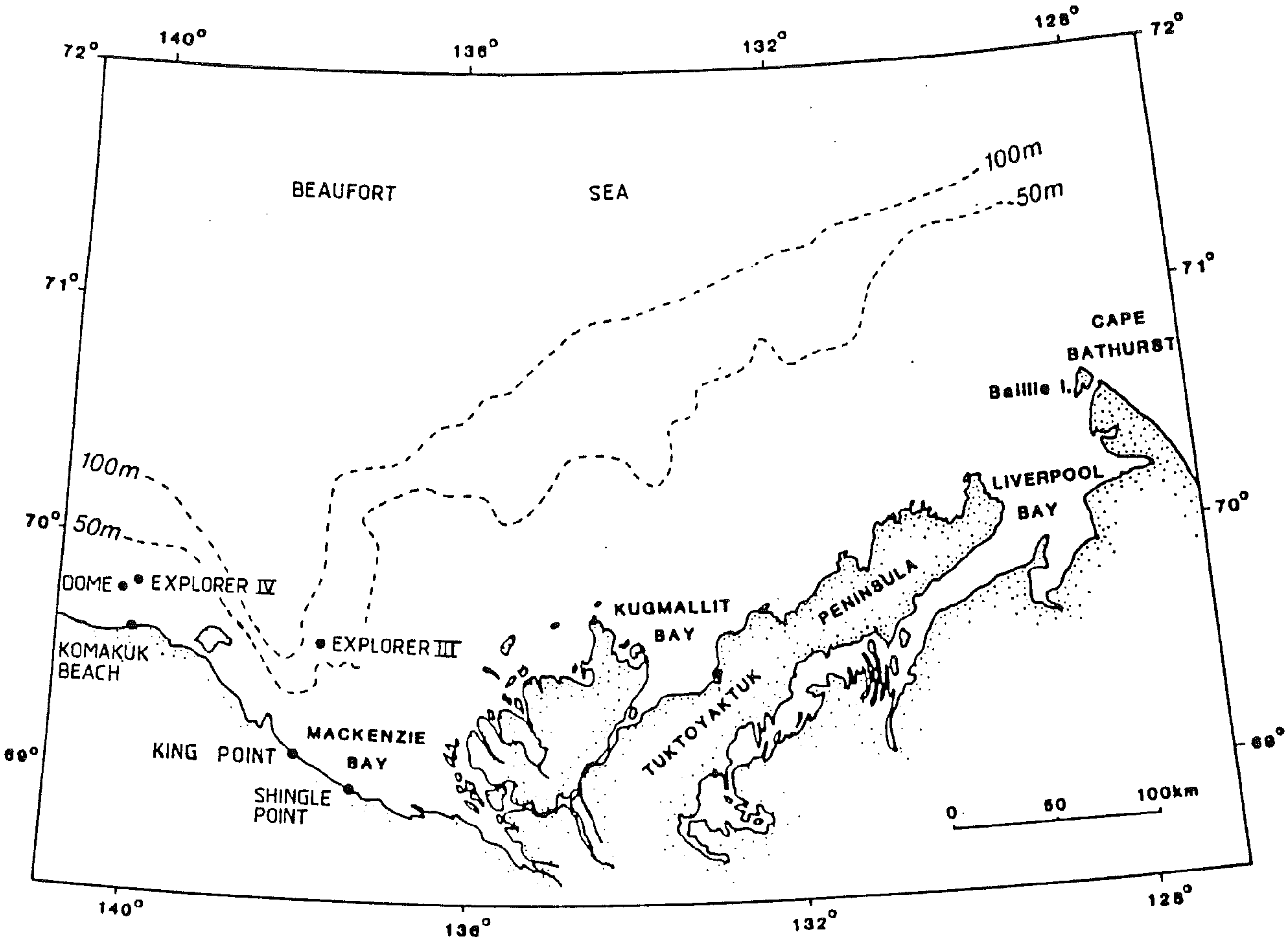
In contrast, surges have a major impact on nearshore profiles. However, reported instances of massive recessions due to the combined effect of surge and melting ground ice could not be confirmed.

The twelve alongshore sediment transport predictors used in the study produced a wide range of results for potential transport rates when applied to the six sites on the Beaufort Sea. The cause was believed to be due to the combinations of wave climate, profile geometry and sediment texture encountered in that study. Further investigation is required to determine whether these conditions are specific to the Arctic, indicating that further specific development of the models is required, or whether these conditions are more universally typical, indicating that there is just a restricted range of conditions under which these models may now be applied.

In addition to limitations engendered by the special conditions of the Arctic, specific limitations of the beach profile adjustment model became apparent as the study proceeded. However, some successful model runs were obtained showing credible increases in shoreline retreat under surge conditions. Of course ground ice melt phenomena, the decisive ingredient in some major surge induced shore retreats, could not be accounted for by this model.

The beach evolution model though it was applied at King Point under less than ideal conditions was successfully calibrated against actual coastal changes mapped from air photos. The advantages of a beach plan model in the investigation of macro-scale coastal changes was noted.

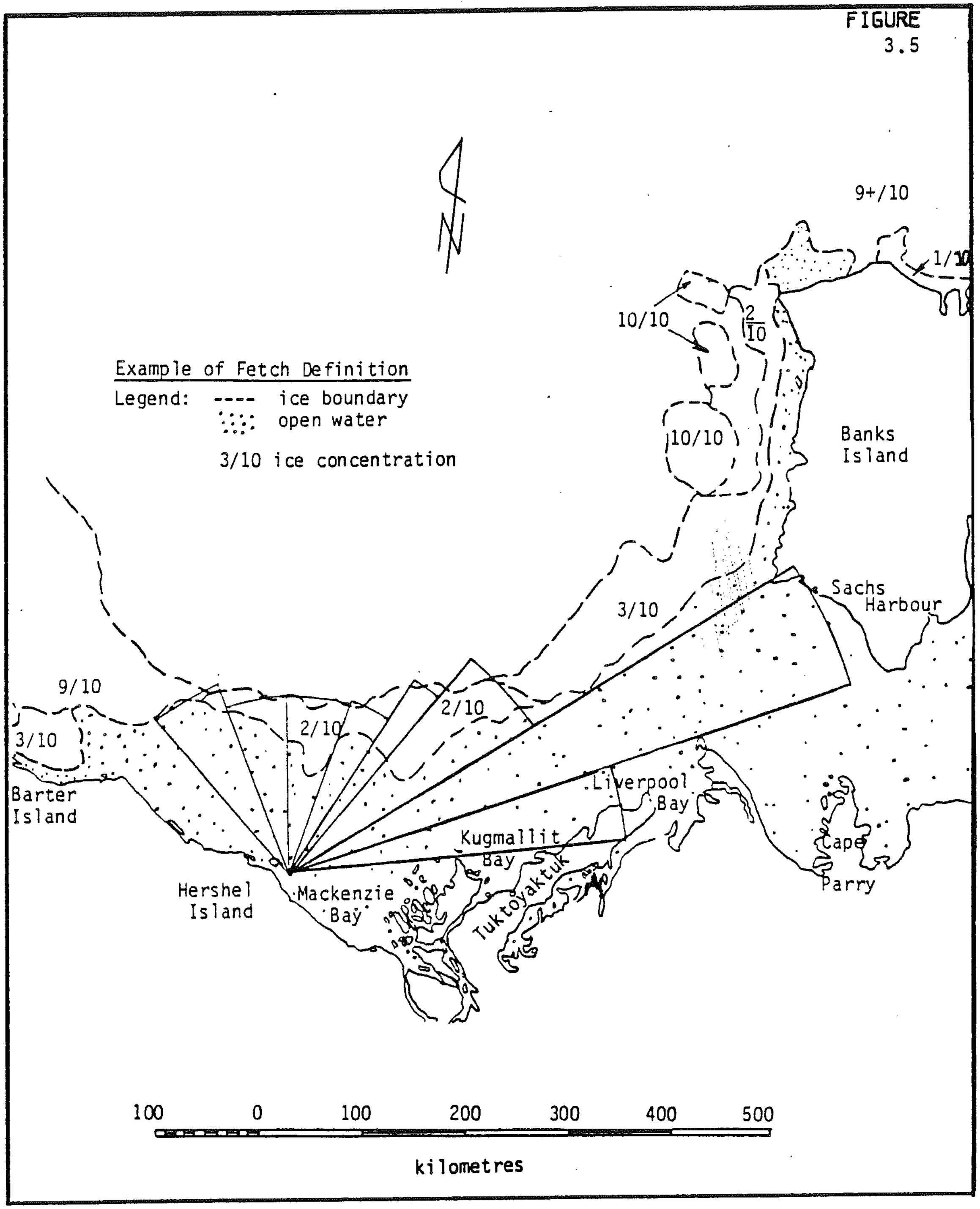
FIGURE 1.1



after Harper and Penland 1982

KING POINT SEDIMENT TRANSPORT STUDY	Date: 15 Mar 87
	Scales as shown
Study Area	Checked by:
	Keith Philpott Consulting Limited

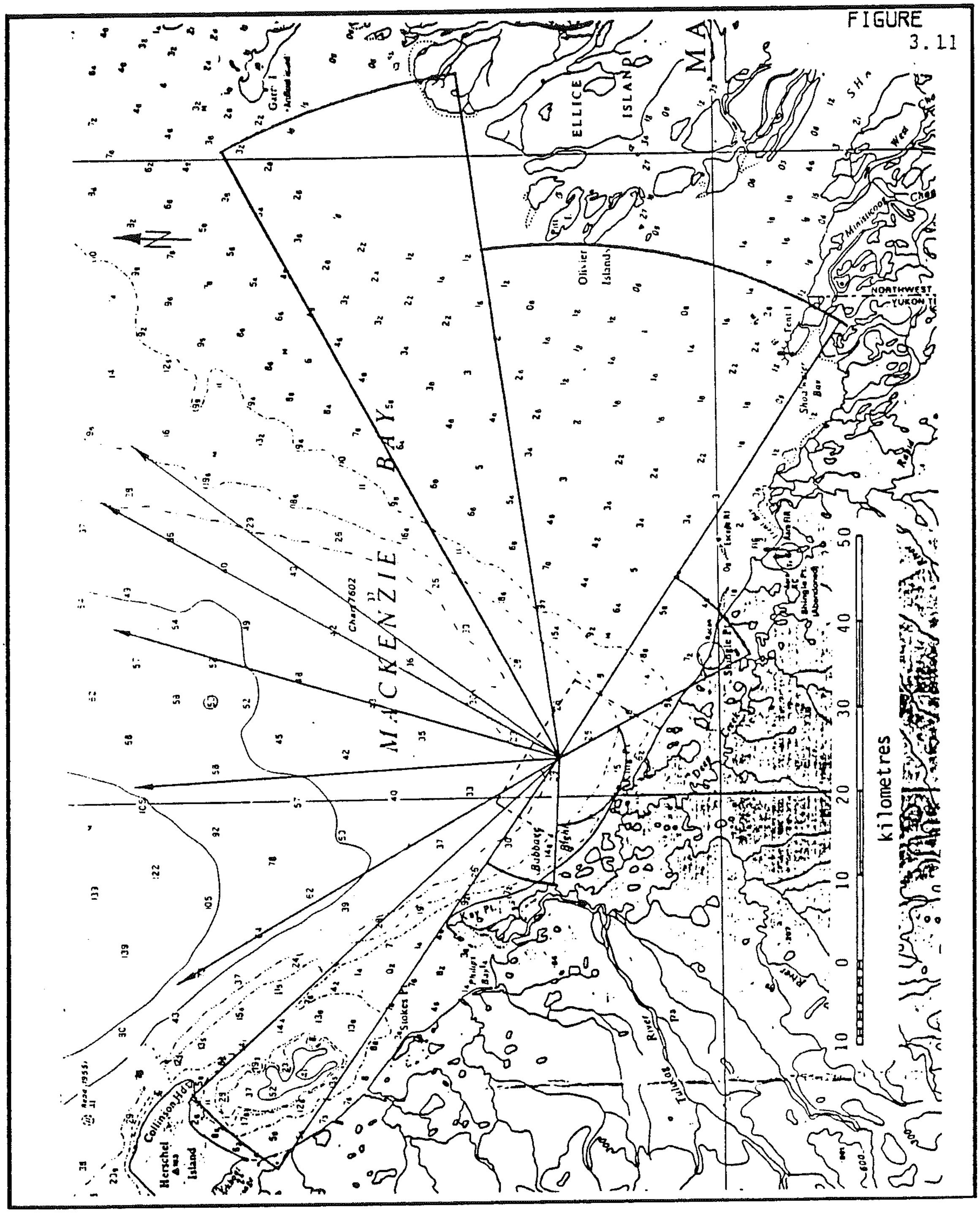
FIGURE
1.2



from Pinchin et al. 1985

KING POINT SEDIMENT TRANSPORT STUDY	Date: 15 Mar 87
	Scales as shown
Distant Hindcast Fetch Sectors	Checked by:
	Keith Philpott Consulting Limited

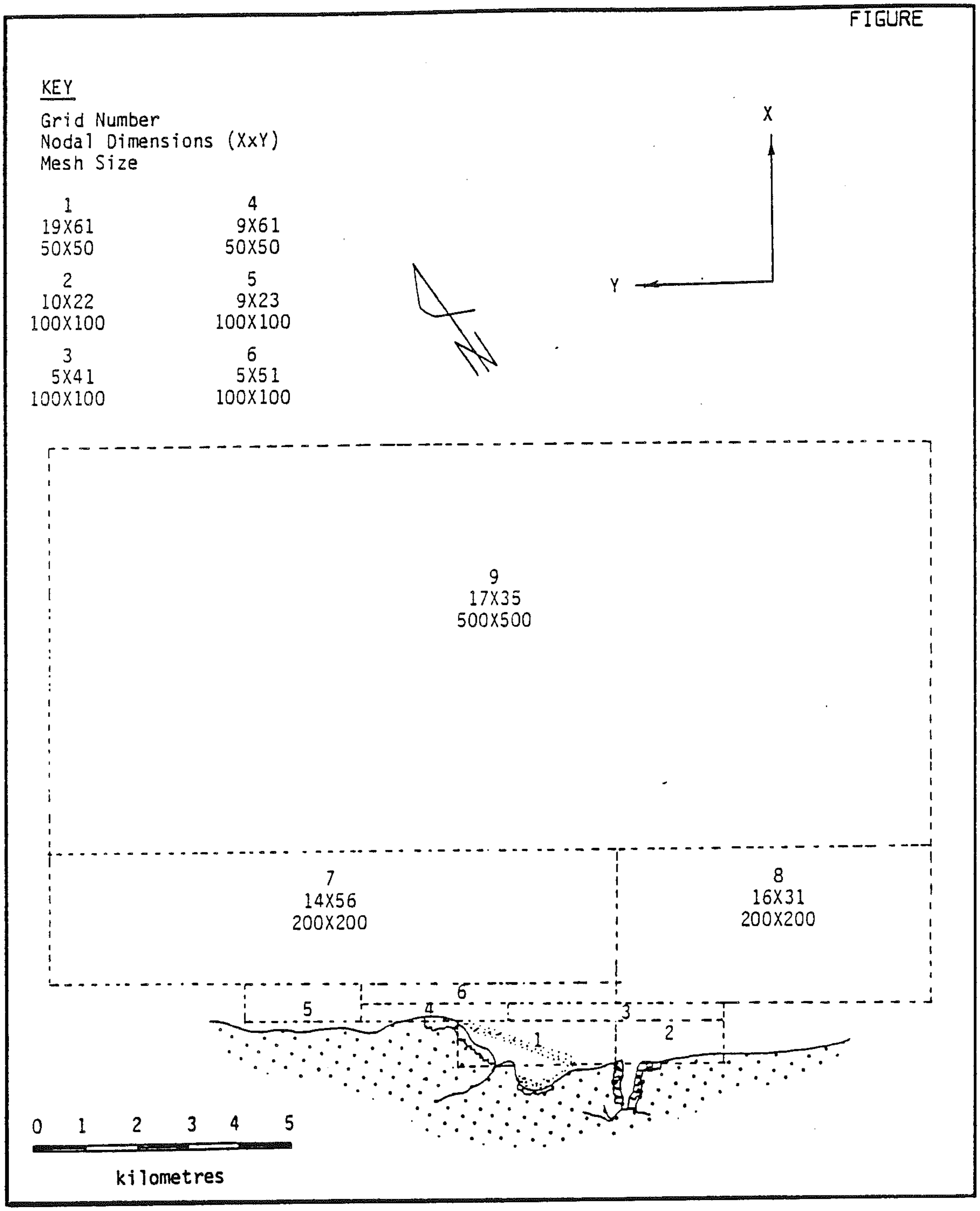
FIGURE
1.3



from Pinchin et al. 1985

KING POINT SEDIMENT TRANSPORT STUDY	Date: 15 Mar 87
	Scales as shown
Local Hindcast Fetch Sectors	Checked by:
	Keith Philpott Consulting Limited

FIGURE
1.4

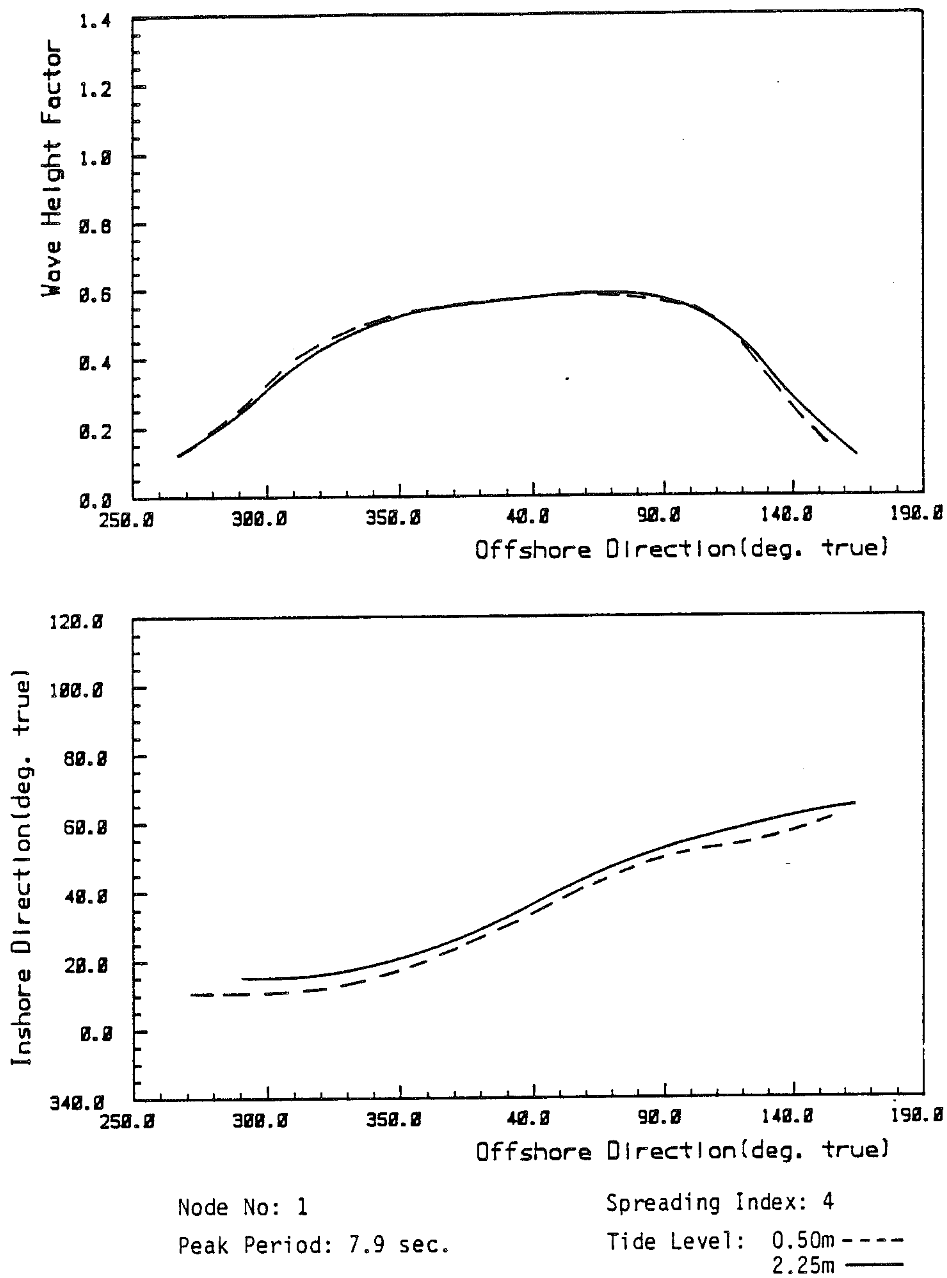


from Pinchin et al. 1985

KING POINT SEDIMENT TRANSPORT STUDY	Date: 15 Mar 87
	Scales as shown
Nodal Dimensions and Mesh Size of Wave Refraction Grids	Checked by:
	Keith Philpott Consulting Limited

FIGURE 1.5

FIGURE 5.2



from Pinchin et al. 1985

KING POINT SEDIMENT TRANSPORT STUDY

Effect of Storm Surge on Wave Transformation

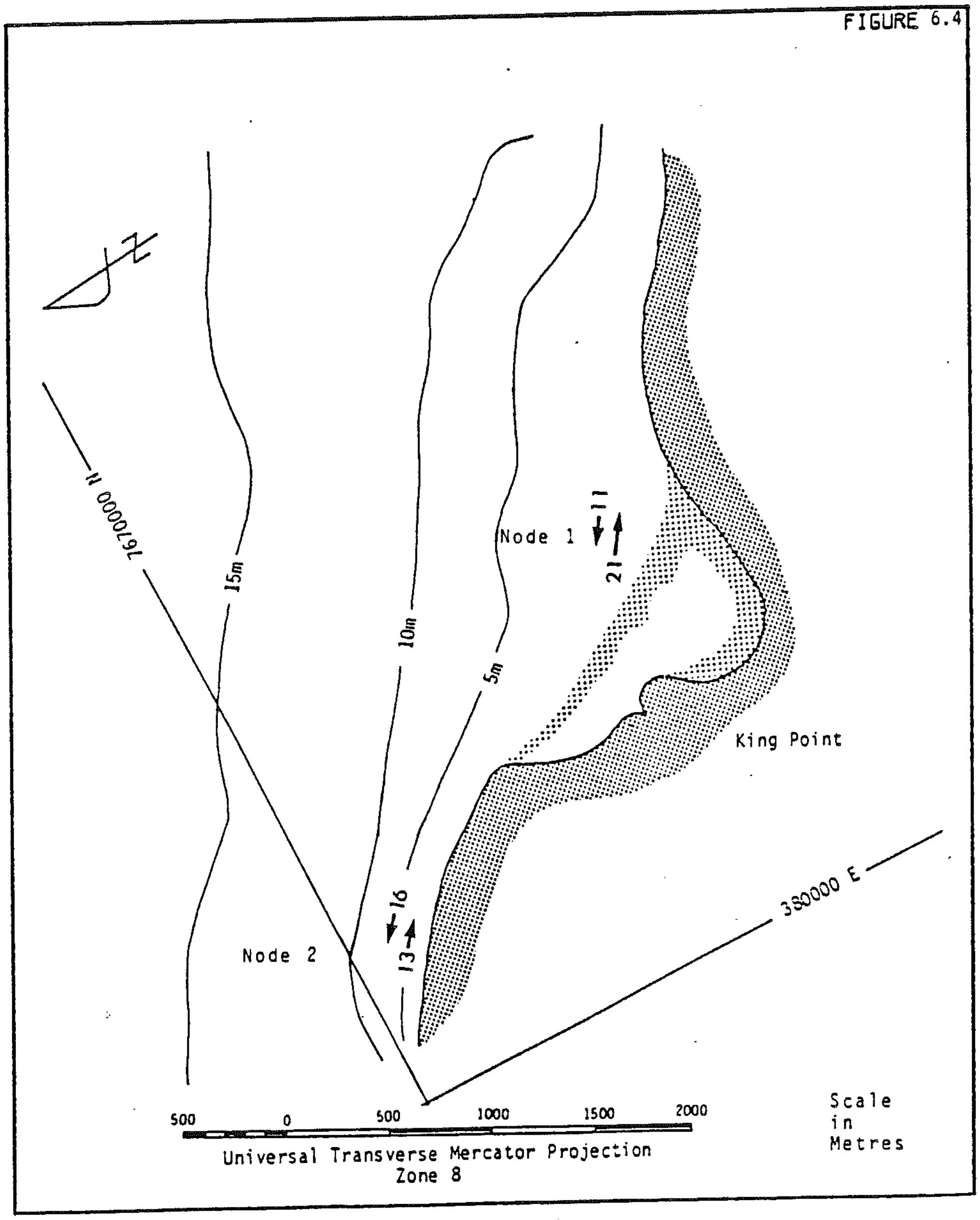
Date: 15 Mar 87

Scales as shown

Checked by:

Keith Philpott Consulting Limited

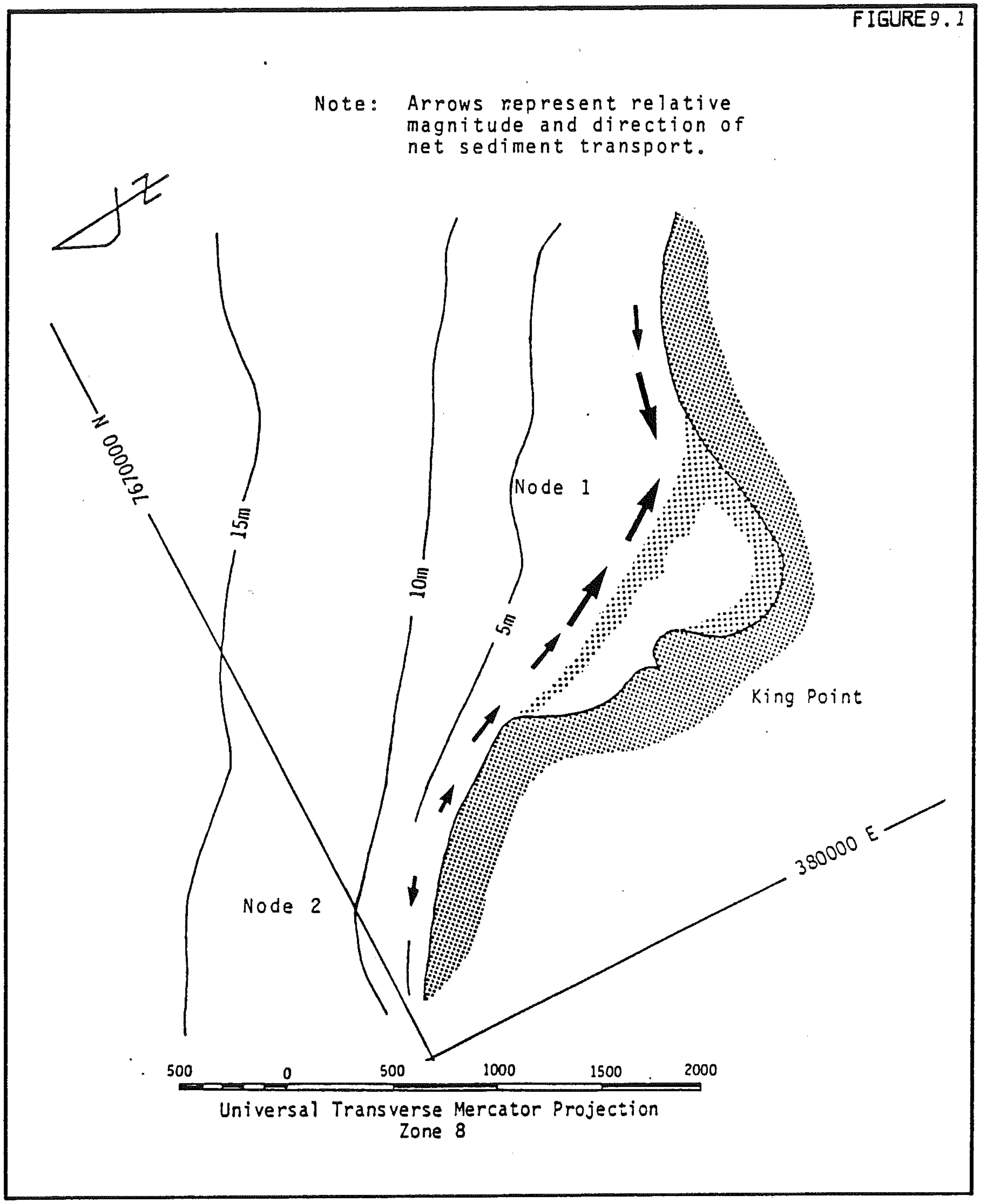
FIGURE 1.6



from Pinchin et al. 1985

KING POINT SEDIMENT TRANSPORT STUDY	Date: 15 Mar 87
	Scales as shown
Best Estimate of Potential Sediment Transport Rates 1000's cu.m.	Checked by:
	Keith Philpott Consulting Limited

FIGURE 1.7

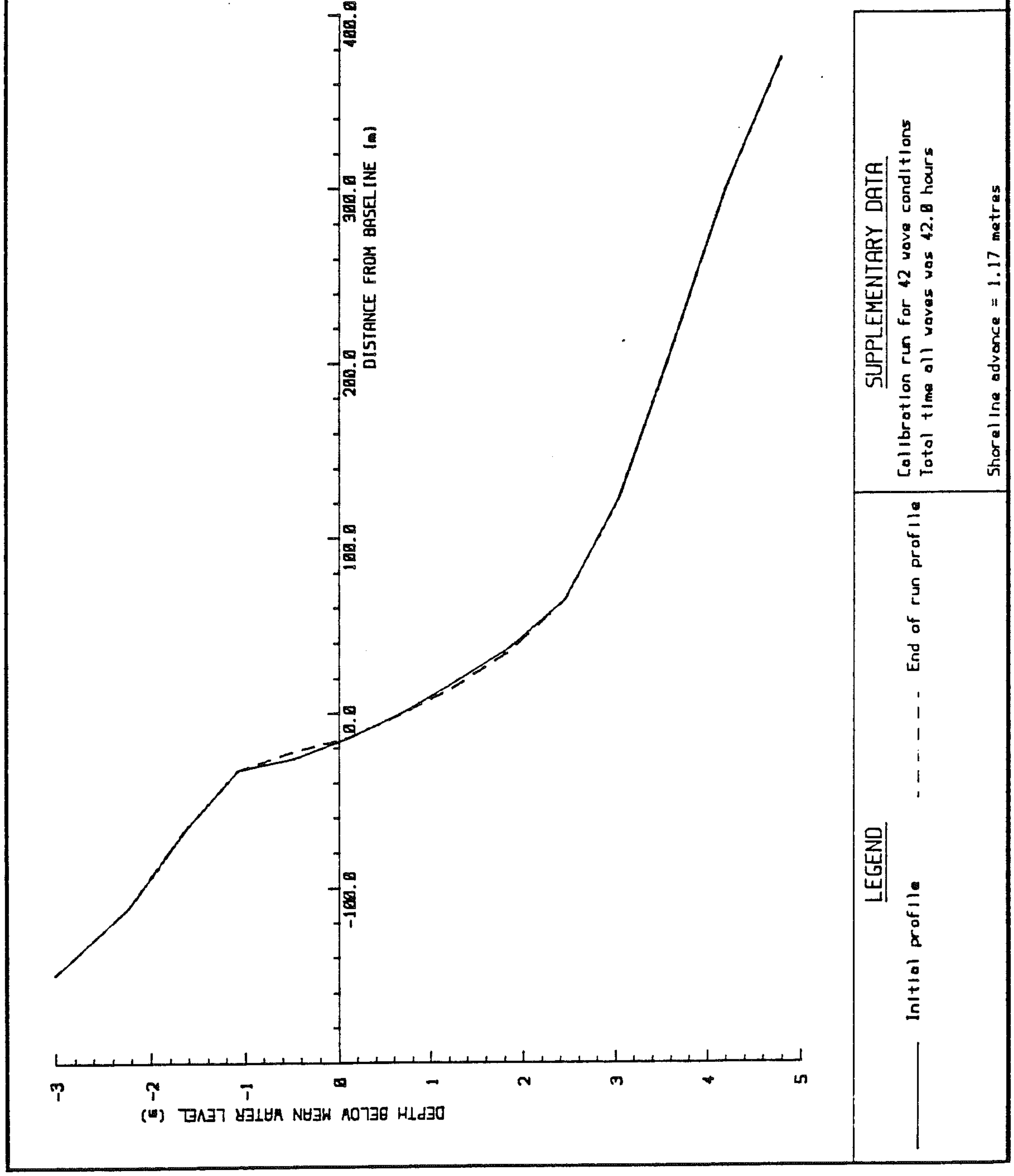


from Pinchin et al. 1985

KING POINT SEDIMENT TRANSPORT STUDY	Date: 15 Mar 87
	Scales as shown
Coastal Processes at King Point	Checked by:
	Keith Philpott Consulting Limited

FIGURE
1.8

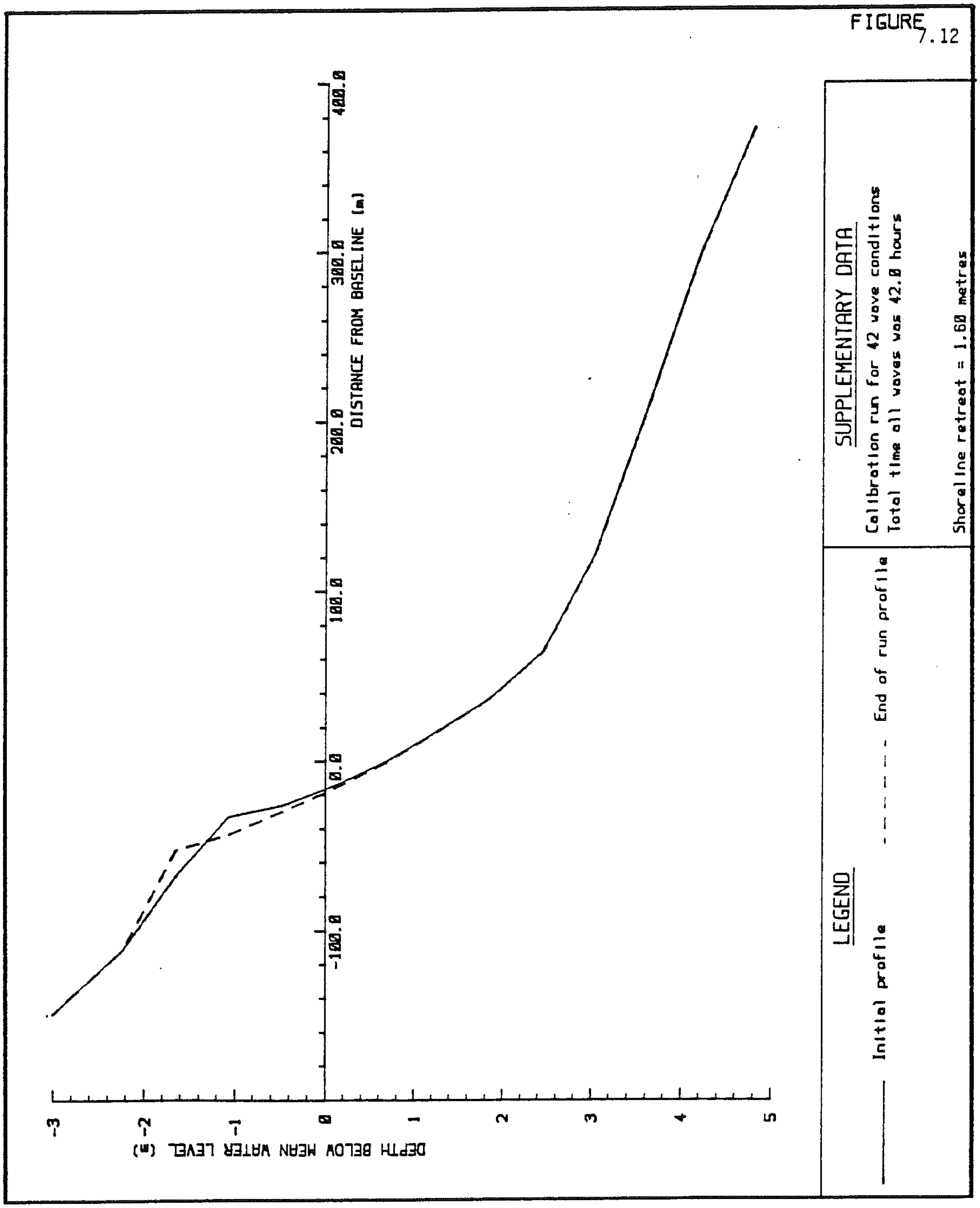
FIGURE
7.11



from Pinchin et al. 1985

KING POINT SEDIMENT TRANSPORT STUDY	Date: 15 Mar 87
	Scales as shown
Profile Adjustment Analysis With No Storm Surge	Checked by:
	Keith Philpott Consulting Limited

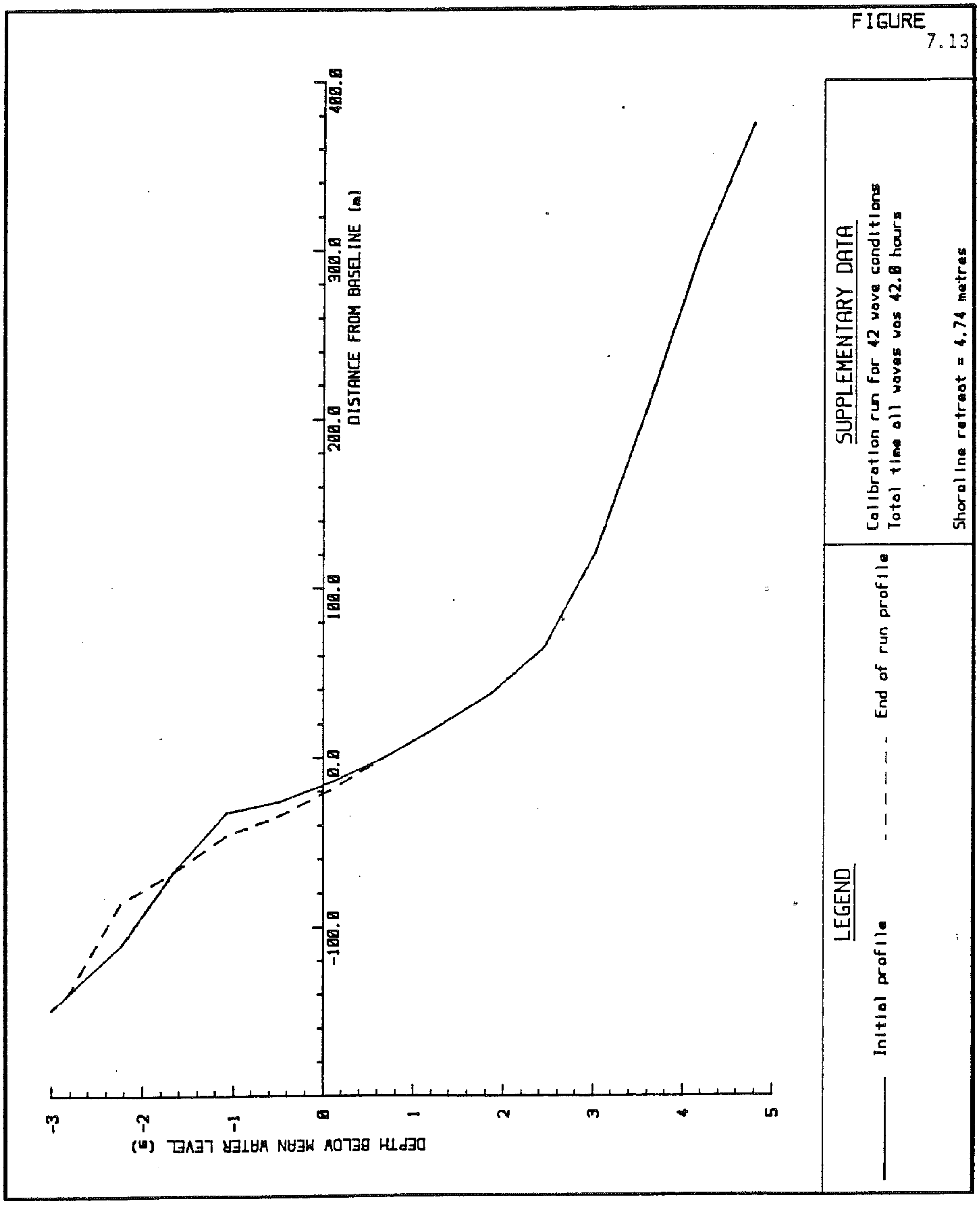
FIGURE
1.9



from Pinchin et al. 1985

KING POINT SEDIMENT TRANSPORT STUDY	Date: 15 Mar 87
	Scales as shown
Profile Adjustment Analysis With 1.0 m Storm Surge	Checked by:
	Keith Philpott Consulting Limited

FIGURE
1.10



from Pinchin et al. 1985

KING POINT SEDIMENT TRANSPORT STUDY	Date: 15 Mar 87
	Scales as shown
Profile Adjustment Analysis With 1.65 m Surge	Checked by:
	Keith Philpott Consulting Limited

2 Field Program

2. Field Program

The King Point data collection program was designed and supervised by the Geological Survey of Canada. The program was implemented by Dobrocky Seatech Limited in the late summer of 1985, as described in detail in Gillie (1985) and summarized below.

2.1 General Description

The site camp was established at King Point and occupied from August 24 to September 16, 1985. The King Point barrier beach, lagoon and nearshore areas were surveyed once at each of 17 cross sections along a 2 kilometre length of shoreline. Sediment samples were collected from the active beach and nearshore areas. A recording weather station measured wind speed and direction and barometric pressure.

Coastal currents were measured with five Aanderaa current meters deployed at 5, 7.5, 10, 12.5 and 15 m depths but the meters at 7.5 and 12.5 m were not recovered. Wave height, period and direction measurements were taken at depths of 5.6 and 2.6 m but data reduction showed some of these measurements to be erroneous. The shallower meter also measured currents. Approximately daily measurements and observations were made of the beach face environment as part of a Littoral Environment Observation program and samples of suspended sediment were collected to coincide with nearshore current recordings. Figures 2.1 and 2.2 show the instrument locations and survey lines and the period of field operations, respectively.

2.2 Application of Field Program Data

This section briefly discusses the application of the various data collected during the program. A more detailed assessment of the data and discussion of its application may be found in the appropriate sections of chapters 3 to 5 where the numerical modelling performed under this study is presented.

2.2.1 Wind Data

An Aanderra weather station was deployed near the midpoint of the barrier beach (Figure 2.1) to measure wind speed, wind direction and barometric pressure (Gillie, 1985). The anenometer cup wheel was located 10 m above the ground, or 12 m above sea level. Usable data was recorded from August 26 to September 14, 1985.

Average wind speeds and directions were measured at 15 minute intervals for the duration of the instrument deployment. For this study however, every fourth record was used to provide hourly values of wind speed and direction in the hindcast program. No wind speed factors were applied during the hindcast procedure to account for the difference in overland and overwater wind speeds.

The King Point wind data was used as a benchmark for the comparison of other nearby wind data sets. Plots of the wind speed and direction comparisons are presented in Figure 3.1 to 3.6 and discussed in Section 3. The application of the King Point wind data in the hindcast procedure is discussed in Section 3.2. The barometric pressure data was not used in the study.

2.2.2 Wave Data

In order to record directional wave spectra and current velocities in the nearshore and offshore zones, two Sea Data instruments were deployed during the field program (Gillie, 1985). A Sea Data 621 directional wave/current meter was deployed approximately 20 m offshore in 2.6 m of water and a Sea Data 635-12 directional wave/current meter/tide gauge was deployed approximately 400 m offshore in 5.6 m of water. Data was recovered from August 29 to September 11 at the outermost gauge and to September 14 at the innermost gauge.

It had originally been intended that the measured wave data would be used to verify hindcast nearshore wave heights, periods and direction and would also be used as direct input for sediment transport calculations. Both data sets would have been used for the wave hindcast verification but only the nearshore wave data would have been used for sediment transport calculations. However, during the data reduction stage it was discerned that the pressure data from the Sea Data 621 (the innermost gauge) was erroneous and hence the desired wave characteristics could not be determined (Dobrocky Seatech Ltd., private communication).

Because the wave data from the 621 gauge was not available the wave data from the outermost nearshore gauge, the Sea Data 635-12, was instead used a input for the sediment transport predictors. The computed significant wave heights, peak periods and mean directions from the 635-12 data are shown in table 2.1.

For many of these records the wave direction was not calculable due to a large scatter in the data. Because the directions were missing the wave heights and periods from these instances could not be used in the sediment transport predictions, although they could be used to validate the inshore hindcast wave data. However, when the valid measured data, i.e. the data with directions, was used for sediment transport predictions, a number of problems occurred due in part to numerical overflows caused by using very small wave heights in some of the computations. These small wave heights themselves were in some instances the result of refraction associated with a large direction change between the wave measurement gauge and the breaker line. Further review of the measured wave directions exposed a number of apparent discrepancies.

During the period 1800 h September 1 to 0600 h September 3 the wave directions were from between 350 and 012 degrees true, with most of the waves close to true north. The shoreline normal had an azimuth of about 31 degrees along the instrument deployment line and hence the waves were approaching the shoreline from about 30 degrees to the west. This would have produced alongshore currents directed to the south east yet many of the measured current directions from the Sea Data 621 and the current and wave directions from the littoral environment observations during this period (discussed in Section 2.2.7) were in a northwest direction. The conclusion from this was that the actual directions at the Sea Data 635-12 were approximately 30 degrees clockwise from the "recorded" values. Also, during the period 1200 h September 4 to 0600 h September 5, when some of the largest waves occurred, the measured wave directions were actually directed offshore at the 635-12 site. Again, it must be concluded that the actual directions are more clockwise. Although it is difficult to estimate by how much, a difference of 30 degrees is again possible.

The results of the spectral transformation analyses (see Section 3.5) indicated that a wave of 4 seconds period could not reach the location of the 635-12 gauge from a direction less than 325 degrees true. This model has been proven to be very accurate in predicting wave directions (Fleming et al, 1986) and it was thus concluded that the Sea Data 635-12 measured wave directions were incorrect.

This conclusion was discussed with R. Gillie of Dobrocky Seatech who confirmed that there was a problem with the wave direction computations. A source of error was detected and corrected and wave directions were recomputed for two of the records; 15 +/- 10 degrees for 0900 h September 2 and 315 +/- 10 degrees for 1800 h for September 4.

Comparing these values to those in Table 2.1 it can be seen that differences of only 10 degrees and 7 degrees were found. These differences were within the error estimate of the revised values and so it was concluded that the revised directions showed no significant improvement.

Because of the importance of the wave direction in the prediction of the alongshore currents and sediment transport it was concluded that a factor of 30 degrees could not be added just because it was felt that this was an appropriate amount. It was decided however, that if this estimate of 30 degrees could reasonably be supported or verified then we could add 30 degrees and still place some reliance on the measured data.

It seemed that the most reasonable way of verifying the Sea Data 635-12 directions would have been to compare those directions to the directions from the Sea Data 621 gauge. As mentioned earlier, the Sea Data 621 wave characteristics could not be determined because of the condition of the measured pressure data. However, Gillie was able to synthesize the wave directions from a spectral density analysis of the Sea Data 621 current meter velocity components. He had plotted a histogram of the current directions for two wave conditions and found the directions associated with the highest spectral densities agreed well with the littoral environment observation nearshore wave direction estimates, (See Section 2.2.7).

Dobrocky Seatech was therefore commissioned to perform a spectral analysis of the Sea Data 621 orbital current directions. Their results were presented in a table and plot format, as shown in Figures 2.3 and 2.4, for each wave condition between 1800 h September 1 and 2100 h September 3. This period had previously been determined to contain the only wave heights large enough to generate alongshore currents that could be modelled. For each wave condition the plot was inspected to determine the frequency of the highest energy density associated with locally generated seas, as opposed to swell. The direction and period associated with this frequency were selected as peak period and mean direction for the wave condition. A peak period of 5.1 seconds and a mean direction of 54 degrees were selected for the wave condition described in Figures 2.3 and 2.4.

The wave periods synthesized for the Sea Data 621 wave data with this method were compared to the computed wave periods from the measured Sea Data 635-12 wave data, as shown in Figure 2.5. The results were similar enough that is was concluded that although the syntheses method was not precise it did provide a good enough estimate of the wave periods, and hence, it was hoped, the wave directions.

A simple refraction analysis was performed on the synthesized Sea Data 621 wave directions to relate them to the 635-12 directions. The analysis used a Snell's law method assuming a plane beach condition. Because the shoreline was curved at the location of the wave gauges and not plane, two analysis were performed, one for the two most extreme beach orientations that could be assumed, 31 degrees and 45 degrees true. A representative value would have been somewhere between these two extremes. The results of these analyses, shown in Table 2.2, indicated that; 1) the range of assumed beach azimuths do not have a significant effect on the results; and 2) the results from the simple analysis are not at all representative of the measured wave directions from the Sea Data 635-12. It must be remembered that a difference of about 30 degrees was anticipated, or difference of Zero in the 1st two columns of Table 2.2.

Because a consistent difference was not found it was concluded that the wave directions from the 635-12 could not be increased by 30 degrees to produce reliable values. Therefore, the wave directions from the 635-12 wave data could not confidently be used in further analysis.

2.2.3 Nearshore Current Data

Near-bottom currents were measured in line offshore of the site with five Aanderaa current meters. Two of the meters were not recovered. The three recovered meters were deployed at 5, 10, and 15 m depths. The 15 m deep current meter had been dragged approximately 300 m from its original deployment site. Each of the three recovered meters was found coated with mud, indicating contact with the seabed at a severe angle of inclination from the vertical (Gillie, 1985).

Currents were also recorded by the Sea Data 621 and Sea Data 635-12 instruments discussed in Section 2.2.2. The Sea Data 621 directional wave/current meter was equipped with a Marsh-McBirney spherical electromagnetic current sensor. The sensor was 0.5 m above the bed and took 17 minute samples at 3 hour intervals. It has been estimated that such measurements can be made with an error of about +/- 10% (Gillie, 1985).

Upon recovery it was found that the Sea Data 635-12 had fallen over sometime during the deployment and that data had been collected for only 256 seconds every 3 hours rather than the intended 1024 seconds. Because it was not known when the instrument fell, it was not known how much of the data was affected or in fact, how the data was affected. It is possible the instrument falling was the cause of the incorrect wave direction data (Section 2.2.2) but this was not confirmed. The comparison of wave periods, shown in Figure 2.5, indicates that the wave periods were accurately measured.

The locations of the Sea Data gauges and the shoremost two Aanderaa metres are shown in Figure 2.1. The Sea Data 621 was approximately 20 m from the beach in about 2.6 m of water, almost outside the surf zone during most of the study period. However this was the only gauge that could provide any data relevant to this study because the remaining gauges were placed much too far offshore to be used to measure wave generated alongshore currents. The resultant current from the X-Y components at the Sea Data 621 was generally shore parallel and was therefore used in comparison the longshore current predictions, as discussed in Chapter 4.

2.2.4. Suspended Sediment Data

A total of 16 suspended sediment samples were taken using a pumping method. A gasoline powered pump was used to draw water through an intake hose attached to one of the tripod legs of the Sea Data 621 nearshore wave/current meter. Sample intake elevations of 20 and 50 cm above the seabed were used.

All sediment sampled was fine sand or finer sediment (minor accounts of silt/clay). Concentration values ranged from less than 0.003 to 0.13 g/l. This data was qualitively compared to suspended sediment concentrations predicted by the Nielsen, (1979) sediment transport model in Section 5.4.

2.2.5. Bottom Sediment Data

Surficial and bottom sediment samples were collected to define the sediment characteristics of the active beach and nearshore areas. Bottom samples were also collected by divers at the Aanderaa current meter deployment sites.

The beach sediment samples, taken at the berm and midswash locations on the active beach, were collected at each of the 17 survey ranges. Nearshore samples were also taken at 20 and 50 m offshore for each survey range. No samples were taken between the swash zone and 20 m offshore.

A representative grain size distribution was taken from the samples 20 m offshore for use in the alongshore sediment transport estimates. This distribution was assumed to be characteristic of the material in the most active transport zone but this assumption may not be valid because the surf zone was less than 20 m wide.

2.2.6. Profile Data

Profile data was measured along the 17 survey ranges shown in Figure 2.1 Profiles across the King Point barrier were measured from the lagoon water line to water depths of 1 to 1.5 m below sea level. Profiles seaward of this point, as well as through the lagoon, were measured by echo sounder. Each profile was measured only once, although the measuring did take place over a few days. Comparison of plots showed that the profiles were very similar up to about 200 m offshore.

2.2.7. Littoral Environment Observations

A littoral environment observation program was conducted at King Point between September 1 and 14. This technique was initially established by the U.S. Army Corps of Engineers as a means of acquiring data on coastal phenomena at low cost. It employs simple measurements and visual estimates of littoral environment variables including: wind speed and direction; nearshore wave height, period, and angle of approach; longshore current speed and direction; foreshore slope and beach sediment characteristics.

These observations were considered to have been of reasonable but limited accuracy (Gillie, 1985). They were used in this study for a qualitative comparison to the data measured by instrument. They assisted in determining that there was a problem with the directions measured at the outermost nearshore gauge, the Sea Data 635-12.

2.3 Evaluation of Field Program

The field contractor stated that the original objectives of the King Point field program were successfully met. The purpose of collecting that information was "to develop an understanding of coastal zone sediment transport characteristics and to provide data which could be used to calibrate numerical models of sediment transport applicable to the King Point field sites" (Gillie, 1985). While the data collected may help to improve our basic understanding of sediment transport a number of problems become apparent when, in this study, the data was applied to the numerical models. These problems related to the quality of the reduced data as well as to a number of shortcomings in the design of the field program itself.

Perhaps the most critical design shortcoming was the choice of deployment sites for the wave gauges and current meters. The instruments were deployed in a more or less straight line offshore of a strongly curved section of beach at the eastern end of 2 kilometers of straight beach. The numerical model used to predict alongshore current, which drives the alongshore sediment transport, assume a constant normal alongshore radiation stress. This is not the case at a curved section of shoreline; the only place it could reasonably be assumed constant is on a straight shoreline. Preliminary results from an ongoing investigation show a potential reduction of the computed maximum alongshore current by more than 50% when acceleration is considered (Rodgers, 1987). This was based on model tests with circular islands where the curvature is much greater than at the King Point Beach.

As is discussed later in this report problems were encountered trying to match the predicted alongshore currents to the measured alongshore currents. The effect of the shoreline curvature on the measured data cannot be easily estimated but had the instruments been deployed in say the middle of the barrier beach this would not have been an issue.

The problem of identifying the reasons for the difference between the predicted and measured currents was exasperated by the fact that none of the instruments were deployed in the surf zone. The shoremost current data, from the Sea Data 621 gauge, was measured about 20 m offshore in a water depth of about 2.6 m. Assuming a breaker index of 0.8 the largest significant wave height measured by the Sea Data 621, 0.6 m, would have a significant breaker depth of only 0.8 m, much less than the 2.6 m depth at the gauge deployment site.

This means that even during the most severe wave conditions only the very outer limit of the wave generated alongshore current distribution was being measured. To produce a significant breaker depth of 2.6 m a 2 m significant wave height would be required. This event has an associated return period of about 1 year at King Point (Pinchin et al., 1986). Assuming that storms can be considered to occur randomly during the 4 month open water season the probability of experiencing the 1 year wave during the 18 days of instrument operation would be less than 15%. This is low enough that it should not reasonably have been expected.

Ideally all of the current meters should have been placed across the surf zone to measure both the alongshore and offshore variation in the current. While this was not possible given the equipment constraints, a better deployment of the available meters could have produced more usable data. The data from the Aanderaa current meters provided no assistance in evaluating the coastal sediment processes. The meters should have been deployed in an offshore line extending through the surf zone. However, the adequacy of the mooring system for surf zone deployment might be questioned considering 2 of the 5 Aanderaa current meters were lost, one was dragged and the two others came in contact with the bottom. Wave-generated velocities within the surf zone are virtually considered to be 2 to 4 times greater in magnitude than outside the surf zone.

A total of 17 offshore profiles were measured along the beach but they were each measured only once. Repeated profiling to determine the changes in profiles over the course of the field study was required and would have produced much more valuable data. Because the measured profiles were so similar the number of initial profiles taken could have been easily reduced. If profile comparisons had been made in the field, some of the effort expended surveying the 17 profiles could have been directed towards later surveys of a smaller number of the profiles.

The most apparent consequence of not knowing the time changes in profile shapes was that the profile adjustment model could not be evaluated. An accurate description of before and after storm profiles would have enabled the profile adjustment model to be calibrated against wave conditions rather than by the method used in the previous study (summarized in Sections 1.2.3).

Bottom sediment samples were taken in the mid swash zone and at 20 m offshore, but as previously mentioned the most active sediment transport zone was less than 20 m wide. This means that the sediment sizes of material being transported is still not known. Numerical estimation of the alongshore current and sediment transport is heavily dependent on the bed form roughness which is directly related to the sediment size.

Bottom samples were taken at each of the 17 profile lines. As with the bottom profiling, it would have been more efficient to have collected samples along fewer profiles.

Overall, the field program cannot be considered to have been successful in providing the data needed for evaluating numerical models. While some valuable data were collected the full potential of the field program was not realized. No information was collected within the surf zone where the most information was required for evaluation of coastal processes. The above mentioned problems would have been alleviated or avoided had a representative of the team performing the numerical analysis participated in the design and supervision of the field measurement program.

Table 2.1 Results From Dobrocky Seatech 635-12 Directional Wave Gauge

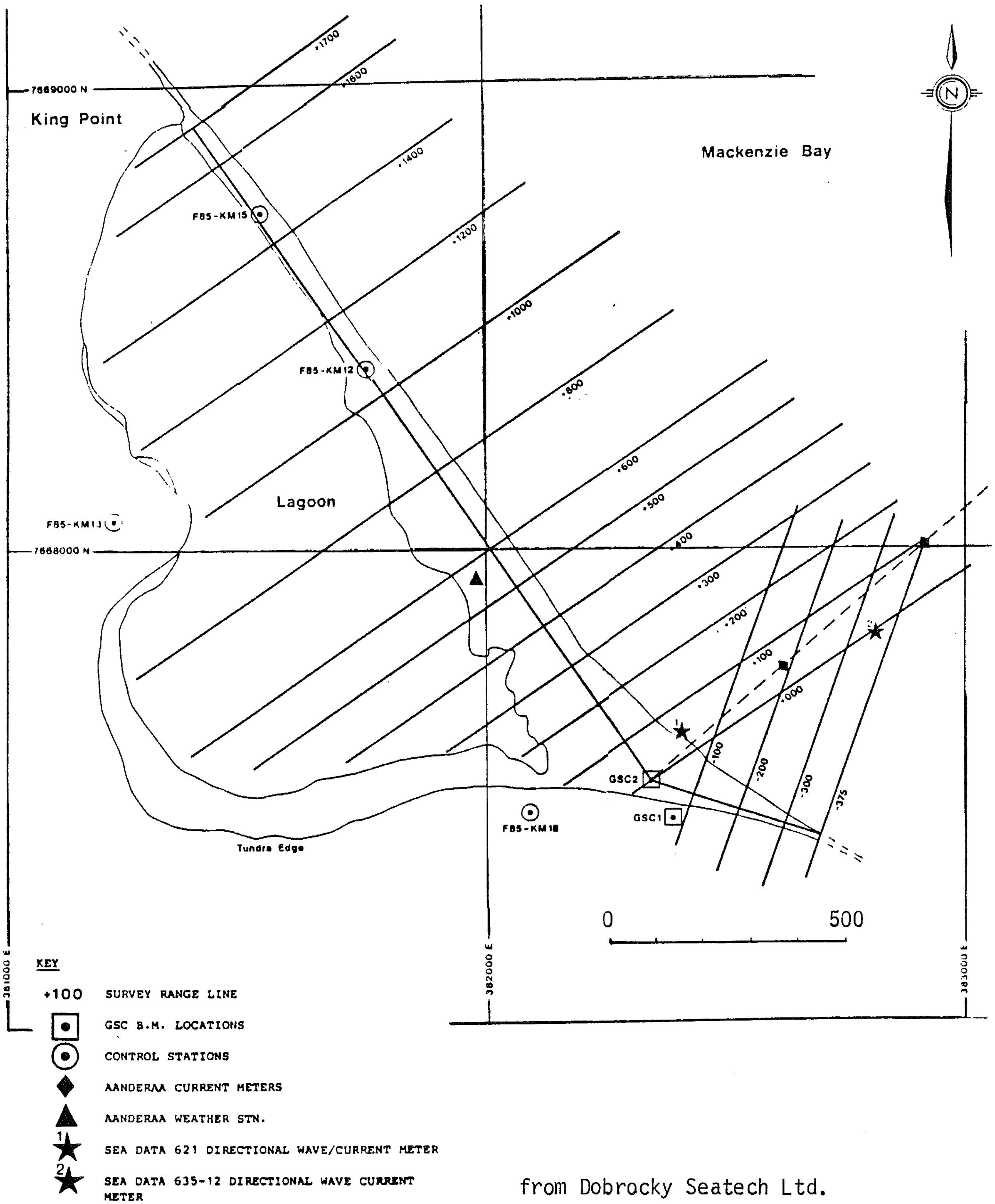
HR	MO	DA	Hs	Tp	DIR
00	08	30	.018	2.72	
03	08	30	.014	4.27	70.
06	08	30	.017	3.76	85.
09	08	30	.012	3.76	52.
12	08	30	.010	3.37	52.
15	08	30	.009	4.27	70.
18	08	30	.009	2.98	102.
21	08	30	.006	4.00	
00	08	31	.006	2.61	80.
03	08	31	.007	9.14	
06	08	31	.009	4.00	80.
09	08	31	.008	4.27	
12	08	31	.006	4.57	97.
15	08	31	.007	3.88	122.
18	08	31	.025	2.61	82.
21	08	31	.049	2.84	
00	09	01	.074	3.37	
03	09	01	.133	4.00	
06	09	01	.160	4.13	
09	09	01	.132	4.27	220.
12	09	01	.144	4.13	
15	09	01	.113	3.66	
18	09	01	.248	5.12	5.
21	09	01	.181	4.74	358.
00	09	02	.240	5.12	350.
03	09	02	.221	4.74	350.
06	09	02	.346	5.57	0.
09	09	02	.380	5.57	5.
12	09	02	.402	5.12	355.
15	09	02	.435	5.33	355.
18	09	02	.457	5.12	358.
21	09	02	.409	5.12	0.
00	09	03	.488	5.57	3.
03	09	03	.336	5.53	0.
06	09	03	.251	5.12	12.
09	09	03	.222	4.75	332.
12	09	03	.153	5.12	345.
15	09	03	.138	4.74	352.
18	09	03	.155	5.57	345.
21	09	03	.268	3.56	305.
00	09	04	.431	4.13	317.
03	09	04	.560	5.12	340.
06	09	04	.470	5.53	345.
09	09	04	.376	4.57	337.
12	09	04	.425	4.57	305.
15	09	04	.608	4.74	317.
18	09	04	.527	5.12	308.
21	09	04	.441	4.74	315.
03	09	05	.333	4.27	315.
06	09	05	.167	5.12	320.
09	09	05	.160	4.92	300.
12	09	05	.136	3.46	252.
15	09	05	.132	3.88	275.
18	09	05	.096	4.41	
21	09	05	.086	4.00	
00	09	06	.105	3.56	
03	09	06	.079	4.27	
06	09	06	.074	4.57	
09	09	06	.072	4.57	
12	09	06	.066	4.41	317.
15	09	06	.046	4.13	90.
18	09	06	.034	4.27	92.
21	09	06	.046	4.74	70.
00	09	07	.065	3.56	82.
03	09	07	.010	4.57	255.
06	09	07	.130	4.92	
09	09	07	.203	4.57	
12	09	07	.210	4.74	268.
15	09	07	.134	4.13	280.
18	09	07	.083	4.27	
21	09	07	.050	4.27	
00	09	08	.023	3.56	
03	09	08	.073	3.56	220.
06	09	08	.035	4.74	200.
09	09	08	.031	4.74	198.
12	09	08	.035	4.74	305.
15	09	08	.029	16.0	305.
18	09	08	.031	5.33	
21	09	08	.441	5.33	315.
00	09	09	.482	5.82	313.
03	09	09	.524	7.11	320.
06	09	09	.152	6.10	
09	09	09	.139	6.10	
12	09	09	.097	5.82	2.
15	09	09	.135	5.57	
18	09	09	.111	5.33	
21	09	09	.091	4.74	
00	09	10	.128	3.76	
03	09	10	.150	4.27	
06	09	10	.144	4.27	
09	09	10	.136	4.27	
12	09	10	.084	4.00	135.
15	09	10	.085	3.76	140.
18	09	10	.061	3.66	
21	09	10	.043	3.28	
00	09	11	.029	3.12	105.

Blank directions indicate records where there was too much scatter in the direction to resolve a representative direction.

TABLE 2.2 Wave Direction Comparison

Wave Period	Synthesized Direction at 621	635-12 Direction plus 30°	Computed Direction From Simple Refraction — Beach Normal Azimuth 31°	Computed Direction From Simple Refraction — Beach Normal Azimuth 45°	Difference Between Measured +30° and Computed Directions at 635-12 — Beach Normal Azimuth 31°	Difference Between Measured +30° and Computed Directions at 635-12 — Beach Normal Azimuth 45°
5.1	54	35	63	57	28	22
4.8	50	28	57	52	29	24
5.3	49	20	56	51	36	31
5.1	50	20	56	51	36	31
5.3	54	30	63	57	33	27
5.3	71	35	91	81	56	46
5.1	59	25	70	64	45	39
6.1	78	25	--	94	--	69
5.6	81	28	--	98	--	70
5.3	73	30	95	84	65	54
5.6	76	33	105	89	72	56
5.1	73	30	95	84	65	54
5.1	51	42	58	53	16	11
5.1	49	2	55	50	53	48
5.3	44	15	48	47	33	32
4.8	46	22	52	48	30	25
4.8	44	15	48	46	33	31
3.7	161	35	141	--	106	--
2.9	112	47	--	--	--	--
4.2	137	15	--	--	--	--
4.5	40	7	43	51	36	44
3.7	159	35	135	--	100	--
5.3	169	647	146	--	159	--
5.1	172	338	153	--	175	--
4.5	175	345	161	137	176	152
5.1	4	340	68	106	88	126
4.2	7	345	62	97	77	112
4.8	19	350	47	80	57	90
5.3	16	345	51	85	66	100
5.8	11	343	60	86	77	113
6.7	170	350	145	--	155	--

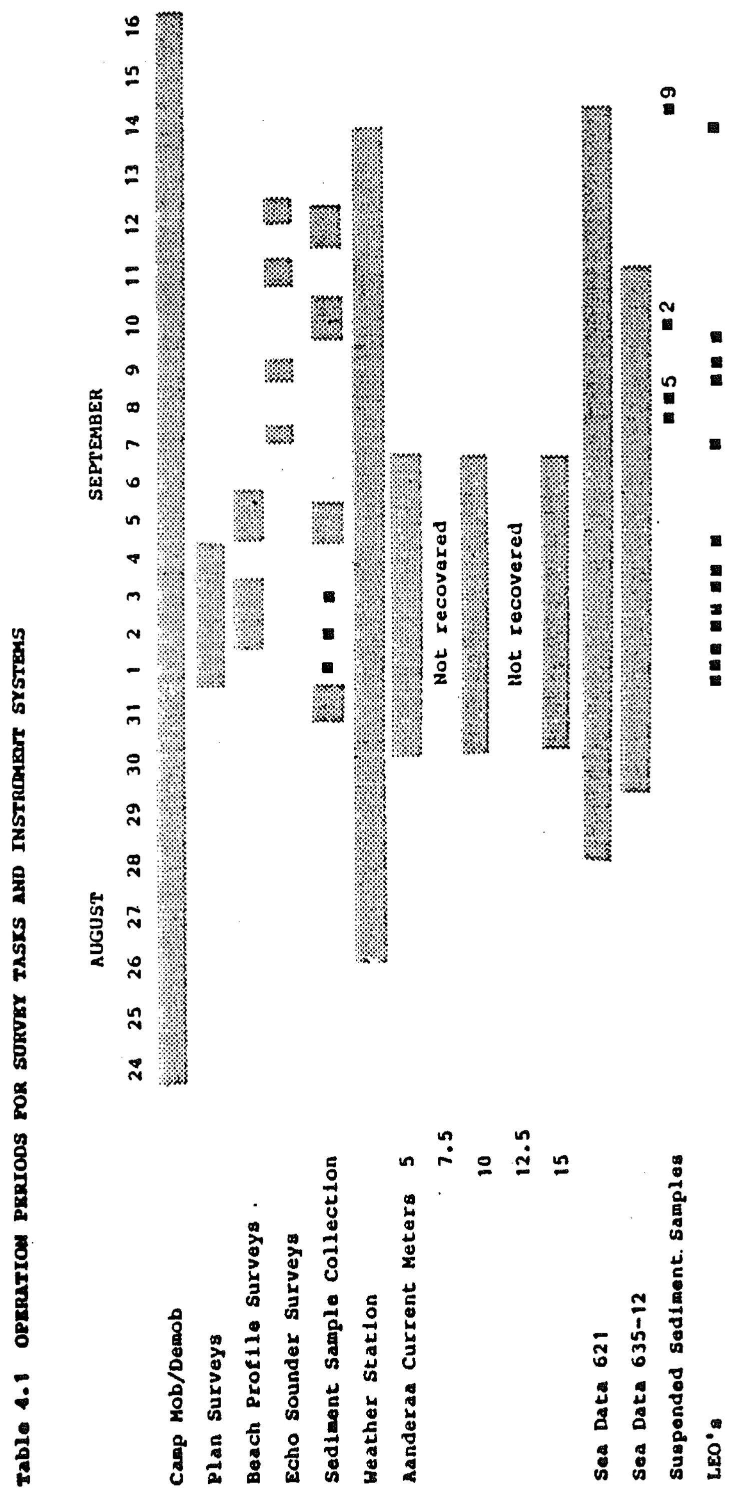
FIGURE 2.1



from Dobrocky Seatech Ltd.

KING POINT SEDIMENT TRANSPORT STUDY	Date: 14 Apr 86
	Scales as shown
Plan Showing Instrument Location and Survey Lines	Checked by:
	Keith Philpott Consulting Limited

FIGURE
2.2



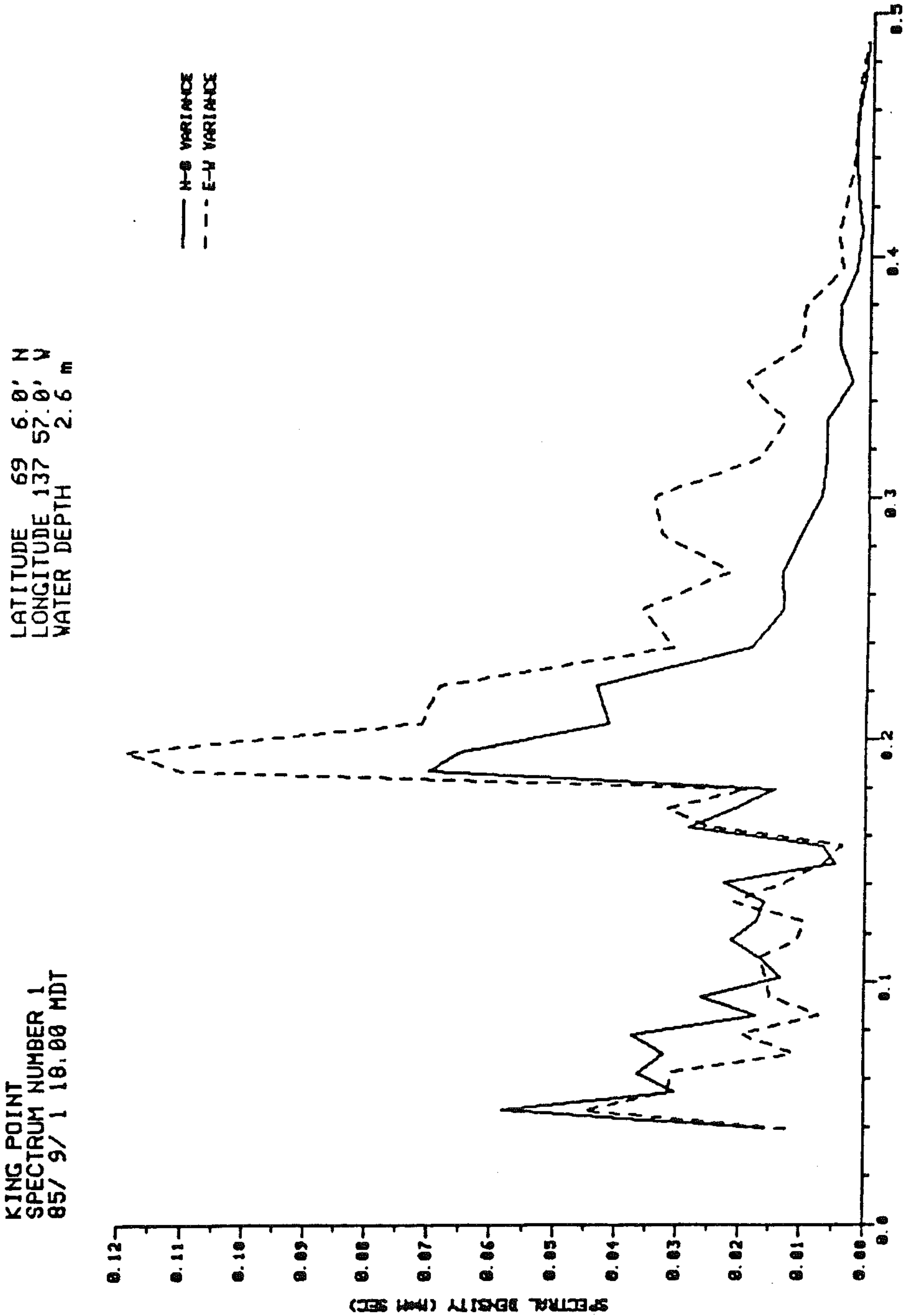
from Gillie, 1985

KING POINT SEDIMENT TRANSPORT STUDY

Operation Periods For Survey
Tasks and Instrument Systems

Date: 15 Mar 87
Scales as shown
Checked by:
Keith Philpott
Consulting Limited

FIGURE
2.3



from Dobrocky Seatech Ltd.

KING POINT SEDIMENT TRANSPORT STUDY	Date: 15 Mar 87
	Scales as shown
Wave Orbital Current Spectral Density Plot	Checked by:
	Keith Philpott Consulting Limited

FIGURE
2.4

KING POINT
Spectrum Number 1
85/ 9/ 1 18: 0 MDT

Latitude 69 6.0' N
Longitude 137 57.0' W
Water depth 2.6 m

FREQUENCY (HZ)	PERIOD (SEC)	DIRECTION (DEG.T)	DIRECTIONAL SPREAD	N-S VAR (M^2 SEC)	E-W VAR (M^2 SEC)
0.03906	25.6	39.55	43.17	1.5730E-02	1.2400E-02
0.04687	21.3	40.48	29.65	5.8237E-02	4.5176E-02
0.05469	18.3	45.81	49.50	3.0579E-02	3.1523E-02
0.06250	16.0	42.47	21.96	3.6322E-02	3.1048E-02
0.07031	14.2	22.76	38.34	3.2189E-02	1.1149E-02
0.07812	12.8	32.45	35.33	3.7409E-02	1.9666E-02
0.08594	11.6	28.82	31.45	1.7305E-02	7.0900E-03
0.09375	10.7	35.27	28.90	2.6303E-02	1.5092E-02
0.10156	9.8	47.71	25.57	1.3311E-02	1.5638E-02
0.10937	9.1	45.40	33.32	1.6518E-02	1.6868E-02
0.11719	8.5	30.55	38.25	2.1585E-02	1.0744E-02
0.12500	8.0	32.26	40.57	1.7242E-02	9.5970E-03
0.13281	7.5	49.30	18.56	1.5936E-02	2.1013E-02
0.14062	7.1	35.23	27.20	2.2688E-02	1.2802E-02
0.14844	6.7	52.11	36.53	4.5640E-03	6.5171E-03
0.15625	6.4	33.23	35.35	6.5536E-03	3.5856E-03
0.16406	6.1	43.12	20.17	2.8393E-02	2.5214E-02
0.17187	5.8	51.88	25.82	2.1028E-02	3.1649E-02
0.17969	5.6	49.91	32.23	1.4443E-02	1.8824E-02
0.18750	5.3	52.01	19.33	7.0089E-02	1.0983E-01
0.19531	5.1	54.23	18.00	6.5169E-02	1.1900E-01
0.20703	4.8	53.56	19.88	4.1290E-02	7.1359E-02
0.22266	4.5	51.88	15.58	4.3545E-02	6.8693E-02
0.23828	4.2	54.07	28.34	1.8296E-02	3.0826E-02
0.25391	3.9	61.20	24.49	1.3340E-02	3.6246E-02
0.26953	3.7	56.56	44.00	1.3567E-02	2.2193E-02
0.28516	3.5	66.50	33.28	1.0586E-02	3.3338E-02
0.30078	3.3	82.06	39.78	7.3523E-03	3.4360E-02
0.31641	3.2	75.09	50.78	6.5520E-03	1.7210E-02
0.33203	3.0	72.76	57.83	6.4842E-03	1.3240E-02
0.34766	2.9	87.43	32.30	2.5721E-03	1.9662E-02
0.36328	2.8	90.08	59.16	4.6725E-03	1.0815E-02
0.37891	2.6	70.65	51.15	4.3144E-03	1.0050E-02
0.39453	2.5	97.42	61.17	2.0098E-03	4.2300E-03
0.41016	2.4	72.98	38.75	1.3547E-03	4.9386E-03
0.42578	2.3	92.04	66.74	1.9405E-03	3.5236E-03
0.44141	2.3	52.29	62.21	2.1673E-03	2.5905E-03
0.45703	2.2	42.53	48.99	2.2845E-03	2.0806E-03
0.47266	2.1	80.05	66.91	1.0064E-03	1.7542E-03
0.48828	2.0	63.49	66.27	5.4061E-04	7.7563E-04
0.50391	2.0	52.44	54.12	7.9791E-04	1.0163E-03

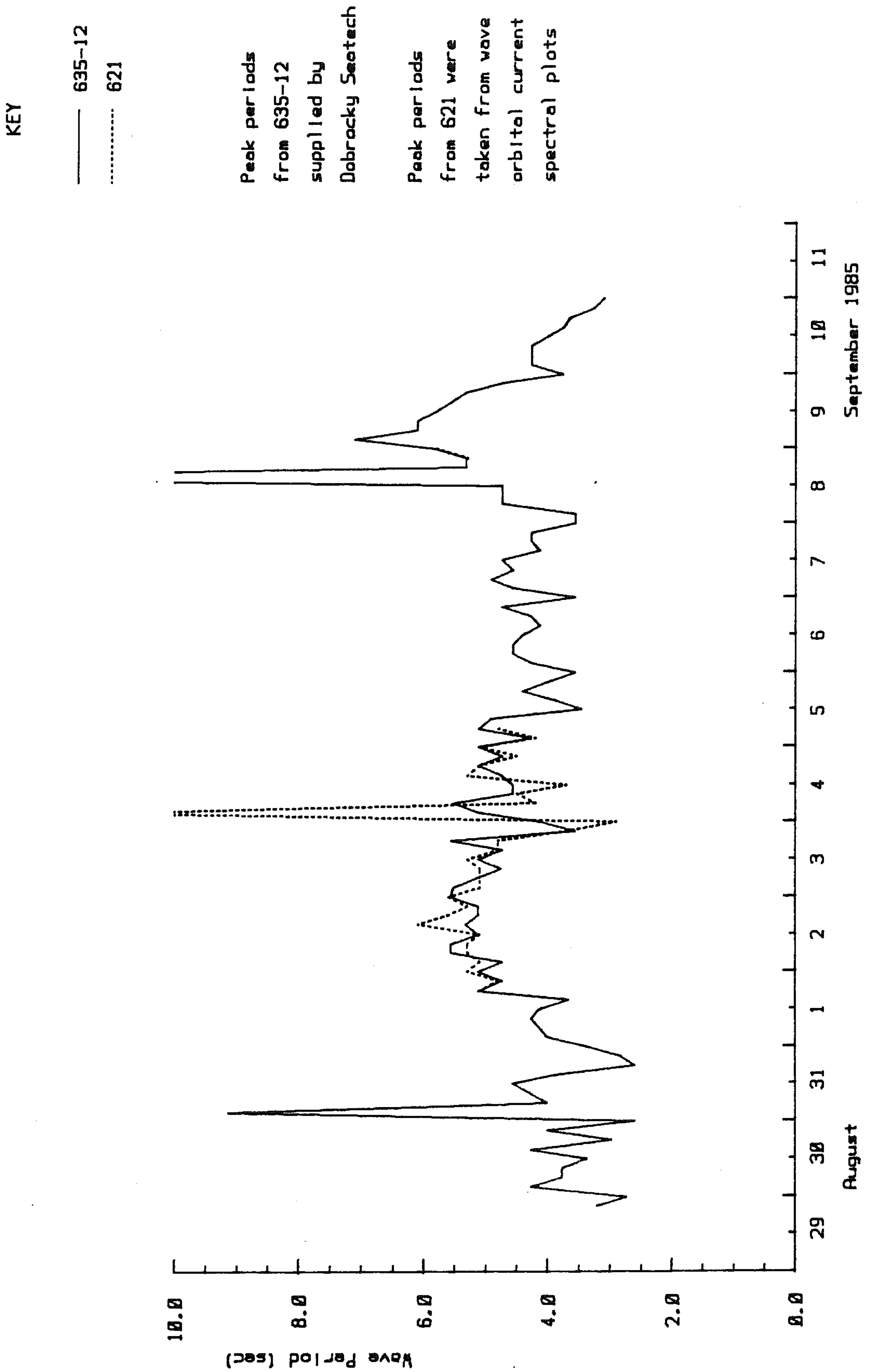
from Dobrocky Seatech Ltd.

KING POINT SEDIMENT TRANSPORT STUDY

Wave Orbital Current Spectral Density

Date: 15 Mar 87
Scales as shown
Checked by:
Keith Philpott Consulting Limited

FIGURE 2.5



Wave Periods from 621 and 635-12 Instruments

KING POINT SEDIMENT TRANSPORT STUDY	Date: 14 Oct 86
	Scales as shown
Comparison of Measured Inshore Wave Periods	Checked by:
	Keith Philpott Consulting Limited

3 Synthesis of Wave Climate

3. Synthesis of Wave Climate

Wave conditions at the site were estimated by first synthesizing deepwater wave conditions and then refracting the deepwater waves to the site. The deep water waves were synthesized by hindcasting with recorded wind data. This section describes the steps involved; how winds measured at the site were compared to other nearby overland and overwater wind data; how calibrations of the wave hindcast model were performed for a deepwater location where wave conditions had been measured; and how hindcasts were then made for the selected deepwater location offshore of the King Point site and finally transferred inshore using the results of a spectral transfer wave refraction analysis.

3.1 Hindcast Procedure

The same wave hindcast procedure is used in this study as in the earlier study (Pinchin et al., 1985). It is only summarized here. A more detailed description of the model and its application to the Beaufort Sea is provided in the earlier report. The procedure averages hourly wind records to produce a series of wind speeds, durations and directions. Parametric hindcast equations use the wind speed and duration along with the overwater fetch length in the wind direction to estimate significant wave height and significant wave period. In the previous study wave direction was assumed to be coincident to wind direction. In this study a routine based on the work of Donelan (1980) was also used to allow non-coincident wind and wave directions. Donelan found that when a wave becomes fetch limited the wave direction will shift towards a longer fetch if the reduced generating force of the wind (cosine component) in the longer direction is greater than the generating effect in the direction of the wind. An earlier investigation of the Donelan effective fetch routine showed that a more accurate prediction of wave direction, wave height and wave period could be realized (Fleming et al., (1986).

Fetch lengths were taken from hydrographic charts for land restricted fetches and from weekly ice charts for fetches which were restricted by ice. Ice limited fetch lengths were defined on a daily basis by interpolating between the weekly chart data. The limit of ice coverage was taken as the boundary of the 3/10 ice concentration, that is to say ice concentrations up to 2/10 were included as part of the wave generating fetch.

3.2 Wind Data Comparison

The first stage of the wind analysis involved comparing wind data measured at the King Point site with data from nearby recorders. Four stations were selected for this comparison; Komakuk Beach, Shingle Point, Tuktoyaktuk and Explorer III (see Figure 1.1). The first three are land based AES weather data collection stations and Explorer III is a drill ship owned by Canmar.

The initial data comparison was performed by plotting recorded wind speeds and directions for the duration of the wind data measured at King Point. These plots are presented in Figures 3.1 to 3.4. It can be seen that overall the Shingle Point wind data most closely represented the King Point wind data. There was a consistently good match between the two sites with little discrepancy in the wind speeds. The Shingle Point wind speeds tended to be slightly lower than the King Point winds at higher wind speeds and slightly higher than the King Point winds at lower wind speeds.

On the other hand neither of the two land stations, Tuktoyaktuk and Komakuk Beach, provided a good comparison. Both of these stations tended to significantly under predict the King Point wind speeds at high King Point winds and over predict the King Point wind speeds at low King Point winds. This is the same trend as seen in the Shingle Point wind comparison but much more exaggerated.

It is quite evident that the Shingle Point winds best matched the King Point winds for the three land based stations considered. This is not surprising since Shingle Point is the closest station to King Point and has similar surrounding terrain. The Komakuk Beach winds were not expected to closely match the King Point winds because of the proximity of the Komakuk station to the foothills of the British and Buckland mountains, which are less than 10 km to the south. Figure 3.5 shows a comparison of annual and summer winds roses for the three AES land stations examined. It can be seen that mountains have a strong effect on the Komakuk beach winds by channelling winds in an east-west direction, along the mountain range.

Figure 3.4 shows the comparison of wind data from King Point and the offshore data from Explorer III. Each of the previously examined data sets was measured 10 m above the land but the Explorer anemometer was 27 m above the water.

Because of this height difference, the Explorer wind speeds had to be reduced to account for the frictional difference caused by boundary layer effects. If the winds are neutral or unstable then the 1/7th power law will adequately represent the boundary layer changes over the range of elevations here. A neutral stability class is defined as when the difference in air and water temperature (air-water) is between -3.4 degrees C and +3.4 degrees C and an unstable class is when the temperature difference is between -3.5 degrees C and
-10.4 degrees C (Phillips and Irbe, 1978). Water temperatures never exceeded 5 degrees C and air temperatures range from 2 to 3 degrees down to -10 to -15 degrees, thus keeping the boundary layer in the neutral to unstable range. The Explorer III wind speeds were therefore reduced using the 1/7th power law

$$\frac{V_1}{V_2} = \frac{(h_1)}{(h_2)}^{\frac{1}{7}} \qquad (3.1)$$

where, V_1 = windspeed at height h_1
and V_2 = windspeed at height h_2

Once reduced, the offshore wind data from Explorer III (Figure 3.4) also did not provide a consistently good match with the winds measured at the King Point site. Both the wind speeds and directions were similar from the 7th to the 12th of September but the speeds differed during most of the rest of the comparison period. The King Point winds were significantly higher than the offshore winds during the August 27 - 29 storm but were significantly lower than the offshore winds during the September 1 - 2 storm. The wind records were ranked in order of similarity to the measurements at King Point as follows: Shingle Point was most similar, Explorer III next, then Tuktoyaktuk and Komakuk. Differences between records at the various stations showed no discernible pattern. There appeared to be no simple correlation that could be used to reliably predict wind at one station from another.

Because offshore wind data usually provides more accurate wind data for hindcasting than land based data, the data collected at Explorer III was compared to another offshore data set, collected from Explorer IV. The location of Explorer IV is also shown in Figure 1.1. The comparison between the two overwater stations is shown in Figure 3.6.

From Figure 3.6 it can be seen that winds measured at the two overwater stations were quite similar. As with the previous comparisons, there was a greater variation in direction than speeds.

3.3 Verification Hindcasts - Offshore

It was found by comparing plots that Shingle Point wind data best matched the King Point wind data but this does not necessarily mean that either Shingle Point or King Point wind data will produce the best hindcast results at King Point. The hindcast procedure used in this study and the earlier study (Pinchin et al., 1985) is based on parametric relations, the simplest method available for hindcasting. Because these models assume a constant wind speed and direction over the fetch they provide their most accurate estimates when the meteorological disturbances that produce the winds are large compared to the fetches used in the hindcast.

Examination of the wind comparison plots (Figures 3.1 to 3.6) shows that the wind recordings are not constant over the region. If a non representative set of wind data is used in hindcasting then the model will not predict the actual wave conditions that occurred. Assessing whether a given set of wind data is representative and appropriate for hindcasting is the most difficult aspect of performing the hindcast. Many theories, relationships and methods exist for producing hindcast compatible wind data by modifying data measured under a number of conditions and at various types of location. However, like most methods, these have their limitations and require certain assumptions that cannot always be met. The most reliable method of evaluating a given wind data set for its value in hindcasting is to perform trial or verification hindcasts to a location where measured wave data exists, and to compare the hindcast results with the measurements. Once a wind data set has been chosen the hindcast procedure options may then be evaluated to optimize the hindcast results.

The only deepwater wave data measured during 1985 was collected by Dome Petroleum west of Hershel Island (see Figure 1.1), at 69°45'84"N, 140°14'37"W. Data coverage was from August 26 to September 11, 1985. Significant wave height and peak period computed from the measurements were given. Wave direction data was not. Verification hindcasts were performed at the location of the wave measurements using concurrent wind data from each of the stations examined, except Komakuk Beach.

The results of these hindcasts are presented in Figures 3.7 to 3.15 and discussed below. Table 3.1 lists the hindcasts performed.

Figure 3.7 shows the results of the Hindcast using winds measured at Tuktoyaktuk. The wave heights and periods are both predicted with an acceptable degree of accuracy, but are not considered to be a good match. There is both underprediction and overprediction of the measured data but the general patterns of peaks and valleys are similar. There are a few instances of overprediction of wave period but the overall tendency seems to be under prediction of wave period.

The hindcast was then rerun increasing the Tuktoyaktuk wind speeds using the relationship developed by Baird and Hall (1980). Figure 3.8 shows the hindcast result; Figure 3.9 shows the wind speed factors applied. This wind speed factoring is intended to account for the difference between overland and overwater friction. It was derived by comparing frequency of occurrence histograms of overland measurements at Tuktoyaktuk and overwater measurements at offshore islands Ukalerk and Kopanoar. The same overland to overwater wind speed transfer function was utilized in the hindcasting performed in Pinchin et al., (1985). The predicted wave periods were judged closer to the measured periods than when no wind speed factor was used but were still not considered acceptable. The storm of September 1 - 3 is slightly better matched in magnitude (but not duration) but the overprediction of wave heights on September 5 - 6 and September 10 is again poor. Overall this hindcast seems similar to the accuracy of the calibration analysis from Pinchin et al., (1985), as reproduced in Figures 3.10 and 3.11.

Figure 3.12 shows the result of the hindcast using the Shingle Point winds. At first it appears that the storm of September 1 - 3 was reproduced but with a considerable time lag. The lag would be in the order of 60 hours! It can only be coincidence that the peaks of the measured and hindcast storms have similar magnitudes in this manner. These results must therefore be considered to be quite poor.

Figure 3.13 shows the results of the hindcast using the King Point wind data. As expected it is very similar to the results of the hindcast that used the Shingle Point wind data. This hindcast was then rerun with the Donelan effective fetch routine. The results are presented in Figure 3.14. It can be seen that there was virtually no difference between the analyses with and without the effective fetch routine.

The results of the hindcast with the offshore wind data measured at Explorer III are shown in Figures 3.15 to 3.19. In the first hindcast, Figure 3.15, the wind data was factored to account for the difference in boundary layer effects at the anemometer height of 27 m and the hindcast required height of 10 m. The wind speeds were modified using the $1/7^{th}$ power law, equation 3.1.

The trends in the hindcast and measured data were very similar but both the wave heights and periods were overestimated. Even with these over predictions, however, it is clear that the Explorer III wind data most closely represented the actual winds that generated the measured wave data.

In an attempt to better match the measured wave data, the Explorer III wind speeds were further reduced to account for the overprediction of both wave height and period. A factor of 0.9 was first tried (Figure 3.16) and then a factor of 0.8 (Figure 3.17). It can be seen that the hindcast results from the Explorer III winds, adjusted for the boundary layer effects and then factored by 0.8, provided very good estimates of the actual wave heights and periods. Finally, the Donelan effective fetch routine was checked using the factored Explorer III wind data (Figure 3.18). A comparison of hindcast results with and without the Donelan routine is shown in Figure 3.19. The most significant difference with the Donelan fetch routine occurred on August 27 and 28 and the predicted wave heights and periods were actually less accurate then the predictions without the fetch routine. The Donelan version did improve the accuracy of the prediction on September 7 but it must be concluded that overall the Donelan fetch routine made little difference.

Based on the results of the calibration hindcasts, it can be seen that the offshore wind data from Explorer III provided by far the best prediction of actual wave conditions at the Dome site. The measured wind speeds were first adjusted to account for boundary layer conditions and then reduced a further twenty percent to finally produce accurate estimates of significant wave height and peak wave period. The wind data from Tuktoyaktuk produced acceptable but not good results. The wind data from Shingle Point and King Point did not produce acceptable results.

The variation in the hindcast results from the different wind data might be interpreted as indicating that the winds are variable over the generating area. If this is the case then the use of a parametric hindcast model in this area would have to be questioned. The model assumes that wind speed and direction are effectively uniform and steady over the entire open water fetch for a minimum duration. When this is not the case then the model can produce inaccurate results. The hindcast results with the Explorer winds, however, are quite good. This suggests that the model is working properly and that the winds are sufficiently uniform over the generating area. It may therefore be concluded that parametric hindcasting can be used in this area of the Beaufort Sea if overwater wind data can be obtained. According to the present evidence, land based wind recording stations must be considered generally less effective for parametric hindcasting in the Beaufort Sea.

3.4 Site Hindcasts - Offshore

As was done in the previous study (Pinchin et al., 1985), site wave conditions were synthesized by hindcasting to an offshore deepwater location and then transferring these waves to nearshore nodes with spectral transfer refraction techniques. The offshore hindcast was performed at the same location as in the earlier study, about 8 km offshore (see Figure 1.3). A total of 6 alternative hindcasts were performed using 4 wind data sources; Explorer III, Tuktoyaktuk, King Point and Komakuk Beach. The Explorer III wind data was expected to produce the best hindcast results because of its accuracy when calibrated against the Dome wave measurement site (Section 3.3). This supposition could not be verified at the deepwater hindcast site because of the absence of wave measurements there. The hindcast results were evaluated after they had been refracted inshore to the location of the Sea Data 635-12 wave gauge (See Section 2.2.2). This evaluation is presented in Section 3.6. Table 3.2 summarizes the alternative hindcasts performed offshore of the site. The results of the hindcasts are discussed in Section 3.6.

3.5 Wave Refraction Analysis

The deepwater wave climate was transformed into a corresponding shallow water climate at or near the breaker line using a spectral transfer technique. The wave refraction analysis used the same sea bed depth grids and wave ray data developed in the 1985 Beaufort Sea Coastal Sediment Study (Pinchin et al., 1985) with modifications to the nearshore spectral shape using the TMA spectrum.

A more complete description of the method, including equations, may be found in Pinchin et al., (1985), Fleming et al., (1984) and Fleming et al., (1986). The two principal components of the computational software are a linear wave refraction model and a spectral transfer post processor. The first model computes wave ray paths from a location near the breaker line to deep water, using the circular arc ray tracking technique developed by Abernathy and Gilbert (1975). These paths are computed by considering the effects of water depth on linear wave propagation direction as the wave rays pass over a numerical depth grid representing the sea floor. The spectral transfer post processor then uses the wave ray paths to predict the amount of wave energy that may be refracted to the nearshore location. A shallow water spectrum is discretized into a number of elements; the number being defined by the number of wave ray paths computed in the first part of the analysis.

In this study wave rays were tracked from 300 to 120 degrees true north at one degree intervals for wave periods of 2.0, 2.5, 3.2, 4.0, 5.0, 6.3, 7.9, 10.0, 12.6, and 15.9 seconds. This gave 1810 wave rays or elements per inshore spectrum.

In this method each element of the inshore spectrum is represented by one wave ray path. It is possible to compute the total energy of the nearshore spectrum by computing the wave energy density that exists at the deepwater direction of each wave ray for any given sea-state, as represented by a directional spectrum. The deepwater energy density is thus transferred along the wave ray paths to the nearshore location considering shoaling and refraction effects.

Once the wave energy density is computed for each element of the inshore spectrum, the spectrum is integrated over the range of directions to yield a one dimensional frequency spectrum. The energy density within each frequency band is then compared to the theoretical maximum energy that may exist at the nearshore location. An energy saturation limit is defined by the depth dependent TMA spectrum (Bouws et al., 1984). If the energy density at any frequency in the predicted spectrum exceeds that of the TMA spectrum, then the predicted energy density is reduced to the limiting value of the TMA spectrum.

The only difference between the wave refraction analysis performed for this study and the earlier analysis performed for the 1985 study (Pinchin et al., 1985) is that in the earlier study a different depth dependent limiting spectral form was considered; the KKZ spectrum (Kitigorodskii et al., 1975).

Once the predicted inshore frequency spectrum is checked for saturation it is again integrated to compute the total energy in the inshore spectrum. The inshore significant wave height, which is related to the total inshore energy, when divided by the offshore significant wave height provides a wave height factor which includes the effects of shoaling, refraction and spectral saturation.

The wave direction shift is found from the difference between the directions of the peaks of the offshore and inshore directional wave energy spectra.

By considering a wide range of offshore sea states, as defined by a peak wave period, a mean direction, and the theoretical JONSWAP spectrum (Hasselman et al., 1973), a series of wave height factors and direction shifts was computed to cover all possible sea states. Figure 3.20 shows the wave refraction analysis results for a peak period of 4.0 seconds. This analysis pertains to the Sea Data 635-12 wave gauge deployment location.

3.6 Site Hindcast - Inshore

Each wave hourly condition from the six alternative offshore site hindcasts was transferred to the nearshore wave gauge node using the results of the spectral transfer analysis discussed in Section 1.5. The six corresponding sequences of predicted inshore waves were then compared to the inshore measured wave heights and periods from the Sea Data 635-12 wave gauge (Section 2.2.2), as shown in Figures 3.21 to 3.28. The predicted wave directions were refracted further inshore using plare beach assumptions, to the location of the Sea Data 621 wave gauge for which wave directions had been determined. The predicted wave directions were then compared to the directions synthesized from the orbital velocity spectral analyses (Section 2.2.2) as shown in Figure 3.29 to 3.31. The results of these comparisons are discussed below.

On the basis of the verification hindcasts to the location of the deepwater measured wave data (Section 3.3) it was anticipated that the best inshore predictions would be produced by using the Explorer III wind data corrected to 10 m height and then factored by 0.8. (see Figure 3.18).

However, as seen in Figure 3.21 the predicted and measured inshore wave heights and periods do not agree well at all. The predicted periods were consistently low and the predicted wave heights were generally high but not at all similar to the measured data. It was evident that these differences were not merely the effect of factoring the adjusted wind speeds because the overall trends of the predicted and measured data were dissimilar. In this hindcast the predicted peak period was assumed to be equal to 1.15 times the significant period predicted by the SMB parametric equation (Bretschneider, 1973).

A second hindcast was performed assuming an inflated ratio of peak to significant periods of 1.45. This value was chosen purposely to hindcast a closer match to the measured periods and to see what effect this change in period would have on the refracted nearshore wave heights. As can be seen from Figure 3.22 the overall effect was to reduce the predicted wave heights but to leave the pattern essentially unchanged. It was concluded from this that the poor match between the predicted and measured nearshore wave conditions was not the result of wave period sensitivity in the wave refraction analysis.

An earlier evaluation of the spectral refraction technique had been performed as part of the Canadian Coastal Sediment Study (C2S2) (Fleming et al., 1986). In this evaluation offshore measured directional wave data was transferred inshore and compared to nearshore measured directional wave data. It was found that the spectral transfer technique was capable of a very accurate representation of the actual wave refraction effect. Figures 3.23 and 3.24 from C2S2 show the effects of wave refraction on wave height and wave period, respectively. Both figures show measured offshore versus measured nearshore data in Plot a and the predicted nearshore versus measured nearshore in Plot b.

Because the refraction model is known to work accurately it was at first concluded that the difference between the measured and predicted nearshore wave data at King Point was likely the result of a poor hindcasting estimate of the offshore wave conditions. A third hindcast was therefore performed with the Explorer III wind data to see if considering the Donelan effective fetches would significantly improve the results. As can be seen in Figure 3.25 use of the Donelan effective fetch made virtually no difference. Because this was the same result found at the Dome measured wave data site (Section 3.3) consideration of the Donelan effective fetches was discontinued.

Because an acceptable match between the predicted and measured nearshore wave data had not been achieved with the hindcasts with the Explorer III wind data, the other nearby wind sources were also considered.

Figures 3.26, 3.27 and 3.28 show the results using the Tuktoyaktuk, King Point and Komakuk Beach wind data, respectively. The King Point and Komakuk Beach winds were not modified; the Tuktoyaktuk wind speeds were factored using the overland to overwater transfer function derived by Baird and Hall (1980). The Komakuk winds were not considered in the hindcasting to the Dome measured data (Section 3.3) because it was anticipated that they would produce poor results due to the orographic effects previously noted. This was supported by the site hindcast (Figure 3.28).

As with the Explorer III winds, the hindcast with the Tuktoyaktuk winds underpredicted the wave periods and overpredicted the wave heights. The trends of the predicted and measured wave heights were not similar.

The King Point winds' hindcast also tended to overpredict the wave heights and underpredict the wave periods but in this case there was a similarity between the patterns of predicted and measured wave heights. The shape of the September 3 to 5 storm was reasonably well reproduced, particularly when compared to the results from the other hindcasts. The wave heights from late on September 8 to early on September 9 were well reproduced but this is suspect considering the underprediction of the wave period during this time. Overall the hindcast using King Point wind showed more instances of calms than the other hindcasts. This may have been caused by a greater occurrence of offshore winds at King Point than at the other sites. Despite these calms the King Point wind hindcast came closest to matching the measured wave heights and periods.

It must also be noted that there is a difference by a factor of 3 between the wave height scales for the offshore hindcasts (Figures 3.7 to 3.19). This leads to visual exaggeration of the differences between the measured and predicted wave heights at the inshore location.

The comparison of the predicted and measured wave directions (Figures 3.29 to 3.31) did not assist in determining possible reasons for the poor matches of wave height and period. Unfortunately there was so much error associated with the measured directions that it was difficult to attach any significance to the comparison. The hindcast directions were refracted to the site of the Sea Data 621 gauge using plane beach assumptions in a region where the beach is not plane. Furthermore the hindcast periods were significantly lower than the measured periods and the hindcast periods were used in the refraction analysis. Had the higher periods been used then greater wave direction changes would have been predicted.

The measured directions, on the other hand, were estimated from a spectral analysis of the wave orbital velocities (see Section 2.2.2) and no estimate of the reliability of this method was provided. It was obvious that the offshore directions on September 3 and 4 were not realistic because these were at the peak of the storm. The offshore directions during this period were replotted as onshore (computed direction minus 180 degrees) on the assumption that there might have been a 180 degree error in orbital directions. These arbitrary changes were closer to the hindcast values on September 4 but not on September 3. The 180 degree error hypothesis was therefore not convincing.

3.7 Discussion of Hindcast Results

Two sets of hindcast data were used to evaluate the hindcasting procedure; the deepwater hindcast from the Dome wave measurement site (Section 3.4), and the site hindcast refracted to the nearshore location of the Sea Data 635-12 gauge (Section 3.6). Assessment of the results at the Sea Data gauge were complicated by the fact that the hindcast wave data was numerically refracted to the site and that possible error associated with the measured data could not be determined. It was obvious that the measured directions from the Sea Data 635-12 gauge were in error and therefore the accuracy of 635-12 wave heights and periods had to be questioned as well. The wave periods at the Sea Data 621, as synthesized from the wave orbital velocities (Section 2.2.2), matched the 635-12 periods reasonably well, thus increasing confidence in the 635-12 wave heights and periods. This good comparison also tended to increase confidence in the synthesized wave directions at the 621 except that the offshore directions found on September 3 and 4 were physically not possible. Also, because the hindcast wave directions at the location of the Sea Data 635-12 were refracted to the location of the Sea Data 621 using plane beach assumptions, little confidence could be placed in the results. The shoreline and offshore contours curved concave seaward at the instrument deployment site making a plane beach assumption invalid.

The use of the spectral wave refraction analysis to provide wave heights and periods at the Sea Data 635-12 gauge introduced further error into the estimation process. The extent of that error could not be determined in the absence of deepwater measured wave data offshore of the site.

On the basis of previous analyses at a different site it was concluded that this error was not large although it did affect the results.

The ability to well predict the offshore waves but not the nearshore waves with the Explorer wind data and to well predict the inshore waves but not the offshore waves with the King Point wind data led to the conclusion that both wind data sets were of good quality and suitable for hindcasting but only at specific locations and not over the entire region.

Standard Environment Canada surface weather charts were obtained to assist in understanding the reasons for the variations of the hindcast results. The charts are produced four times daily at hours 0000, 0600, 1200, and 1800 GMT.

The charts show the surface weather patterns over the Beaufort Sea by including isobarometric lines, weather station data summaries and, sometimes, storm fronts. The charts covering the period over which the nearshore wave data was collected, August 29 to September 5, are included in Appendix B.

The storm that caused the highest wave conditions (September 1 to 4) at both the Dome and King Point wave measurement sites was examined in detail to discern why the different hindcasts behaved as they did. Extracts of the surface weather charts from September 1 to September 4 are reproduced in Figure 3.33 to 3.36. As explained in Figure 3.32 these extracts show the wind speed and direction measured at the Komakuk Beach, Explorer III, Shingle Point, and Tuktoyaktuk sites. A second offshore site was also included to help discern the wind patterns. This station was not identified. Table 3.3 shows the values of the wind data, with the speeds as factored for hindcasting, from the stations of interest during the storm examined in detail. The King Point winds were not shown on the surface weather charts because they were not included in the AES weather data collection program.

The wave heights recorded at the site slowly started to build late on August 31, reaching a peak late on September 2. The wave heights had considerably reduced by noon September 3 but peaked again by midnight September 3. There was another abatement in wave height, although not as much as previously, followed by another peak, the highest during the storm, at 3:00 p.m. on September 4. A significant wave height of 0.6 m was recorded at that time. The wave heights reduced after this peak as the storm passed.

The storm passed from west to east over the course of the four days. On the weather charts a low pressure area was identified just west of the site at 0600 h (local time) September 1. This low pressure area seems to have stayed west of the site as a warm and cool air mass contact developed along the coastline, passing over the site, at 1800 h September 1.

A low pressure trough extended along the coastline at 0600 h September 2 turning into a low pressure region with closed isobars west of the site by 1200 h. This low pressure area then started to move eastward with the centre of the low over the site at 0600 and 1200 h September 3, then turned south moving landward over the Mackenzie Delta.

The factored winds at Explorer III were steady at almost 30 km/h and generally from the east during the first peak of the storm. The winds started from the east at noon on August 31 and approached 30 km/h at about 2200 h. As seen from Figure 3.21 the waves hindcast with the Explorer winds were close to the peak hindcast heights by midnight on August 31.

The overwater fetch to the site of the Dome measured waves was 180 km, and the hindcast waves reach a fetch-limited sea-state at noon on September 1. As evidenced by Figure 3.17 the waves at the Dome site were generated by this steady east wind.

The winds measured at King Point, on the other hand, were not steady during this period. They were directed slightly onshore at midnight on August 31 but shifted offshore at 0600h, back onshore at noon and again offshore at 1800 h. As can be seen in Figure 3.33 a closed isobar is located over the site at 1800 h, causing roughly south winds at the King Point anenometer, east winds at the Explorer anenometer and probably south east winds over the actual fetch to King Point. This caused an overestimation of the hindcast waves with the Explorer winds and no hindcast waves with the King Point winds while the waves were actually increasing at the site.

The winds measured at Tuktoyaktuk were usually similar in direction to the Explorer III winds during the entire storm, but the wind speeds were consistently lower as the storm developed. The wind speeds at Tuktoyaktuk didn't approach the speeds at Explorer III until September 2 when they then exceeded the Explorer winds. This exception was actually due to the wind speed factors applied; the measured Explorer winds were consistently higher than the measured Tuktoyaktuk winds.

The winds at Tuktoyaktuk were most likely lower than the Explorer winds because of the difference in overland and overwater friction rather than location of the measurement site with respect to the storm centre. From Figure 3.33 it can be seen that the overwater winds at the station offshore of Tuktoyaktuk were similar to the winds at Explorer III. This means that the overland to overwater wind speed factors applied to the Tuktoyaktuk wind speeds were not high enough during September 1.

The hindcast to the Dome wave site with the factored Tuktoyaktuk wind data was late predicting the start of the storm on September 1 because of the low wind speeds. From Figures 3.21, 3.26, and 3.27 the rise in wave heights at the site appear to have been more accurately predicted with the Tuktoyaktuk wind data than the Explorer or King Point wind data but this actually seems to have occurred by coincidence. The Tuktoyaktuk wind directions were allowing the hindcast program to use a fetch length greater than was occurring but the low wind speeds caused an "underprediction" of the wave heights that would have been generated over the longer fetch.

The winds at Explorer III remained near 30 km/h from the east through September 2, causing an overestimation of the waves at King Point and an accurate representation of the waves at the Dome site. The centre of the storm remained over the region with a low pressure trough extending along the coastline from Point Barrow to Tuktoyaktuk Peninsula by 0600 h. This resulted in west winds being recorded at King Point while east winds were being recorded offshore. The continuing growth of the measured waves at King Point through this period indicated that the winds over the fetch remained from the east rather than switching to a westward direction.

The Tuktoyaktuk wind directions were generally similar to the Explorer wind directions through September 2 and 3 but there were instances of large discrepancies in the wind speed. The Tuktoyaktuk wind speeds were low from 1800 h September 2 through to 1800 h September 3 with the exception of 1200 h September 3. This again indicates that the wind speed factors applied to the Tuktoyaktuk winds were low. This caused the Tuktoyaktuk winds hindcast to miss the September 3 wave height peak at the Dome site that the Explorer III hindcast predicted. These lower wind speeds, however, also resulted in lower wave heights being predicted for the King Point site. The Tuktoyaktuk winds hindcast to King Point (Figure 3.26) did show some reduction in wave height, but not as much as actually occurred.

Because of the low pressure ridge which developed along the coastline the King Point winds were offshore during this period. This caused the hindcasts with the King Point winds to miss the wave height peaks at both the Dome site and King Point site.

By 1200 h September 3 the centre of the low was passing over the site giving quite different wind directions at each of the recording stations; 300 degrees at King Point, 10 degrees at Explorer III and 90 degrees at Tuktoyaktuk. At 1800 h the winds at Explorer III had shifted eastward, coming from 70 degrees but the King Point winds had shifted westward, coming from 315 degrees.

As can be seen from the hindcast plots the Explorer wind and Tuktoyaktuk wind hindcasts showed a reduction of wave heights; the King Point wind hindcasts showed an increase in wave height. The Dome measured wave heights did reduce over this period and this reduction was well predicted by both the Explorer and Tuktoyaktuk hindcasts but not the King Point wind hindcast. On the other hand, the waves at King Point were increasing, as predicted by the King Point wind hindcast but not the Explorer wind or the Tuktoyaktuk wind hindcasts.

The results of the hindcasts to the Dome wave measurement site indicated that:

i The winds were constant over the wave generating fetches.

ii The Explorer wind data, once factored, was truly representative of the actual winds over the fetches.

iii The factored Tuktoyaktuk wind data was marginally representative of the winds over the fetches.

iv The winds measured at the other land based stations were not representative of the winds over the Dome site fetches.

The Explorer wind data produced the best hindcast results because the winds always approached the Explorer site from a long overwater water fetch and were not influenced by a change from overland to overwater boundary layer friction. From Figures 3.4 and 3.17 it can be seen that the only time during the hindcast that the Explorer III recorded sustained winds from the south, an offshore direction, was on September 7 and 8. This corresponds to some of the least accurate wave predictions from the Explorer wind data.

It is important to note that the Explorer winds did not produce the best hindcast results until the wind speeds had been reduced 20 per cent. This was done after the wind speeds had been adjusted for boundary layer effects using the well accepted 1/7th power low (equation 3.1).

The implication of this is that wind data should not be used for hindcasting until it has been calibrated, it at all possible. Even though this wind data would have been considered ideal for hindcasting, because it was overwater data not overland, it did not produce the best results. However, just because this storm had to be factured, one should not automatically assume that a similar factor should be applied to all wind speeds or to all storms.

This emphasizes the need for more measured overwater wind data and concurrently measured wave data in order to investigate this type of occurrence over a wider range of environmental conditions.

It can be surmised that the land based stations did not provide good estimates of the Dome wave data in part because of the effects of land friction on the winds but more likely from the position of the storm centre with respect to the wind stations. Essentially the winds being recorded at the land stations were different from the winds generating the waves. As the low pressure centres travelled along the coastline the winds at the coast tended to be offshore. There are two possible reasons that Tuktoyaktuk provided the best overland winds for hindcasting to the Dome site. A straight offshore wind from Tuktoyaktuk would be from about the southeast whereas an offshore wind from King Point would be from the southwest. The winds that generated the waves at the Dome site from September 1 to 3 were generally from the east, and were therefore already much closer to straight offshore at Tuktoyaktuk than at the other sites. It is also possible that the effect of rapidly changing wind directions associated with the passing of the centre of a low pressure area was not as significant at Tuktoyaktuk. The particular storm examined moved landward up the Mackenzie Valley and did not pass directly over Tuktoyaktuk.

It was noted that for most of September 1, 2 and 3, the wind speed factors applied to the Tuktoyaktuk winds were not high enough to produce similar wind speeds as recorded at the Explorer site. From Table 3.3, it can be seen that the majority of time this occurred the Tuktoyaktuk winds were from an overland direction. It can also be seen that when the Tuktoyaktuk wind speeds were higher than the Explorer wind speeds, the Tuktoyaktuk winds were blowing onshore. Because only one storm was examined, it cannot be concluded that the Baird and Hall (1980) wind speed factors are not accurate. However, the above noted discrepancy does warrant consideration of the need to consider wind direction when developing overland to overwater wind speed ratios for overland recording stations located near the coast. One should reasonably expect that for any given wind speed, the overwater to overland wind speed ratio would be higher for a wind approaching the station from the landward direction than the seaward direction.

The results of the hindcasts to King Point indicated that:

i The winds that generated the waves at King Point were from a different direction than those that were simultaneously generating waves at the Dome site.

ii The offshore measured wind data did not represent the winds that generated the waves at King Point.

iii The King Point measured wind data was representative of the winds that generated the waves during the latter half of the storm.

iv The other overland wind stations did not record data representative of the winds that generated the waves at King Point.

The most likely reason that the winds generating the site waves were different from the winds generating the waves at the Dome site was due to the path of the storm that generated the waves. The centre of the low pressure area travelled along the coastline generating east winds offshore, but southeast through southwest winds along the coastline. The winds blowing over Mackenzie Bay, generating waves at the site, were likely between the winds offshore and at the coastline. From Figures 3.33 to 3.36 it can be seen that the two offshore wind stations were usually recording similar wind directions while the overland stations were usually quite different.

For the particular storm examined it can be concluded that the offshore wind data was quite good for hindcasting to the offshore site but not to King Point. The Tuktoyaktuk winds were acceptable but not good for hindcasting to the offshore site and were also not good for King Point. The winds measured at King Point were not suitable for hindcasting to the offshore site but provided the best hindcast to the site. This site hindcast could, although not excellent, be considered as reasonably good, but it must be remembered that the hindcast waves were refracted inshore before they were compared to the measured data. The error associated with the refraction analysis was not quantified. The Komakuk wind data did not produce an acceptable hindcast either the King Point site or the Dome site. The effective fetch routine based on findings by Donelan (1980) did not show a significant difference at either of the hindcast sites with the wind data considered.

Burns (1973) prepared maps of principal and secondary weather system trajectories for twelve months of the year with an analysis of the percentage of time that a system was located in a given area.

The envelopes of the secondary trajectories, as well as the position percentages are presented in Figures 3.37 and 3.38. There were no trajectories of primary lows presented for the summer months.

Hodgins and Harry (1982) examined 12 years of meteorological data to identify occurrences of extreme storm events for the purpose of defining extreme wave events. A total of 43 extreme storms were identified by examining surface weather charts and applying four criteria:

i The low must have had a closed cyclonic circulation implied by at least one closed pressure isobar;

ii The system must have had an identifiable history, as a low pressure centre; or as a trough, for at least 24 hours;

iii The system must have had geostrophic winds of 25 knots or greater at one point in its history; and

iv The system must have caused westerly quadrant winds in the southeastern Beaufort Sea during or immediately following its passage over the area. In addition upper level support must have existed for the weather system (Hodgins and Harry, 1982).

These extreme storms were then categorized as belonging to one of three classes, based primarily on storm trajectory, as shown in Figure 3.39. The storm of September 1 to September 4, 1985 would have been classified as a Class B storm if it had been strong enough to have met the above criteria for an extreme event. Criteria i and ii were met as can be seen from the surface weather charts in Appendix B, but it was not investigated to see if Criteria iii and iv were met. Hodgins and Harry (1982) determined that 18 of the 43 extreme storms belonged in Class B. They found that the interannual variability of occurrence of storms was small but that the distribution of storms within the 4 month summer season differed between classes. There were more Class B storms during the summer than Class A or Class c. Figure 3.40 shows the trajectories of the 18 Class B storms.

From the work of Burns (1973) and Hodgins and Harry (1982) it can be seen that the storm of September 1 to 4 1985 followed a common trajectory and therefore was not a rare event. The implication of this was that the problems associated with hindcasting to the King Point site may have occurred frequently. However, from Figure 3.40 it can be seen that a large number of the extreme storms passed with the centre of the storm further offshore.

This is contrary to the percentage of trajectories presented in Burns (1973) (See Figure 3.37) but Burns does caution that those trajectories may be misleading because of the sensitivity of the analysis to the selection and placement of grid points. This caution however, cannot be quantified without a comparison with the storm trajectory definition methods used by Hodgins and Harry (1982).

One would expect that with storms centred further offshore the problems encountered with the hindcasting would be less severe. The various wind measurement stations considered would then be more likely to experience similar winds and the winds over Mackenzie Bay would be more like those farther offshore.

A more sophisticated hindcast model, say a spectral model using a wind field developed from pressure gradients, may have been able to better predict the site wave conditions, but this is not certain. The parametric model used in this study did produce good results with the King Point wind data. The results of this study did show that parametric hindcast models work. Perhaps the best way to utilize these models is to use more sophisticated methods of developing the wind field itself. This is in fact the strength of many more sophisticated 2-dimensional hindcast models.

3.8 Skill Test Evaluation of Hindcast Results

The evaluation of the hindcast results, both offshore (Section 3.3) and inshore (Section 3.6) was based on a visual comparison of plots of predicted and measured wave height and period. In this study the wind data source, the wind speed factors and the fetch lengths (straight vs. effective) were varied, but in the previous study (Pinchin et al., 1985) a number of model operational parameters were also varied. Those parameters included the wind divergence angle, the fetch depth, the rate of wave decay, the maximum allowable wind duration and the parametric hindcast equations utilized.

The determination of the best combination of wind data factoring, parametric model and program parameters is ultimately a matter of judgement. Although some aspects were easily recognizable as being different it was not always obvious that one trial hindcast was better or worse than another. For this reason some quantitative method of selecting the best hindcast was desired.

Previous investigation by the authors found that problems arise when computing standard statistical values such as root mean square deviation and correlation coefficient. Very large RMS deviations and very poor correlation coefficients were sometimes experienced when the visual comparison showed the hindcasts to be quite reasonable. The cause was often small leads and lags between the two data sets. The statistical analyses were performed between simultaneous measured and predicted values and therefore did not consider leads and lags. For example, the correlation coefficients for the Dome measured wave heights and the wave heights hindcast with the factored Tuktoyaktuk winds was only 0.56, implying poor correlation, yet the hindcast was visually judged as providing acceptable results. Another reason for this difference is that when the visual comparison was made, the storms naturally were given more weight than periods of low wave activity.

Dingman and Bedford (1986) found that general parametric statistical calculations used in model verification studies were not adequate for evaluating storm surge models. High coefficients of correlation and small RMS values could be obtained, indicating a good overall model performance, but they didn't guarantee an accurate hindcast of the extreme water level events, the most critical aspect of the storm surge. They found however, that non-parametric skill tests were successful in revealing the performance of a model in predicting the extreme water level events and their time of occurrence.

Their skill tests were model evaluation procedures specifically designed to test the ability of the numerical models to accurately predict major aspects of the simulation. Three tests were applied. In the first test an arbitrary scoring system assigned a maximum number of points when a model predicted the maximum or minimum water levels with the smallest percentage variation from the measured levels. The second test assigned points for the accurate prediction of the time of occurrence of the maximum and minimum values. The third test computed the number of times during the growth and decay of the storm that the predicted water level was within 20% of the measured value. A score was given at each hour, dependent upon the percentage error, and the sum of all the scores was used to indicate the model performance.

Because Dingman and Bedford (1986) had successfully applied this method to storm surge modelling it was concluded that a similar approach could also succeed with wave hindcast modelling.

A skill test similar to the third test utilized by Dingman and Bedford (1986) was therefore developed. This skill test calculated the relative error of the predicted wave heights and periods and assigned a score based on that error. The scores awarded for the error were the same as used by Dingman and Bedford (1986) and are shown in Figure 3.41. The relative error was computed using a weighted product of wave height and period, as shown in Figure 3.41. This was intended to allow an evaluation of hindcasts with respect to different end uses of the hindcast data.

For example, using exponents x=1 and y=0 would evaluate wave heights only. This could be used to select which of a number of hindcasts best represented the measured data when the hindcast was to be used for estimating deep water wave height persistence. If on the other hand the hindcast data was desired for use in a bulk sediment transport formula then exponents of x=2 and y=1 might be used. (The CERC (1974) bulk sediment transport formula is of the term $q=kH^2T \sin (2A)$ where "k" is constant, H = breaking wave height, T = wave period and A = breaker angle).

To allow for leads and lags between the hindcast and measured data the model was set up to allow for a consistent lag of up to 9 hours for either data set. In other words, one of the data sets could be offset with respect to the other but that same offset would apply for the duration of the period being investigated.

The total score, however, gives no indication of whether the predicted results tended to be consistently higher, consistently lower, or equally higher and lower than the measured data.

This aspect was determined by computing what was termed positive and negative inverse scores. The inverse score was the sum of (10 - score) from each hour tested so that the more a predicted value was higher or lower than the measured value the greater the positive and negative inverse score would be. Therefore a high negative and low positive inverse score would indicate that the predicted data was consistently low.

Because the nearshore hindcast data did not provide as good a match to the measured data (see Section 3.6) the skill test was run with the offshore wave data. The results of 5 hindcast tests are presented in Tables 3.4 and 3.5. Table 3.4 shows the results from two analyses of the same hindcast with different values of the exponents x and y.

The data count and score count indicate the number of comparisons that were made and the number of times a score was given, respectively. A negative phase indicates the hindcast data lagged the measured data. Table 3.5 shows the results from the phase with the highest score for four different combinations of the exponents x and y for the 5 hindcasts.

The Explorer winds hindcast EX3-03, obviously the best hindcast when examined visually, consistently received the highest score. The Shingle Point winds hindcast, obviously the worst match of all the hindcasts tested, also consistently received the lowest score. The inverse scores from the EX3-03 wave height only comparison (exponent x=1; y=0) indicated that the overpredictions and underpredictions were roughly balanced but that there were more overpredictions. From Figure 3.17 it can be seen that they were roughly balanced but it was not obvious whether more underpredictions or overpredictions had occurred. The wave period only analysis, on the other hand, indicated that there was a strong tendency towards underprediction. From Figure 3.17 it can be seen that that was the result of the obvious swell waves on August 30 and 31. That swell also caused the phase of -8 to produce the best overall score.

Because of the presence of the swell the wave heights actually appeared to have been predicted more accurately than the wave periods, over the duration of the hindcast. The wave heights however, received a much lower total score than the periods. This was because the wave heights were numerically much smaller than the wave periods, so the wave height absolute error had to be much smaller than the period absolute error to have the same relative error, and hence the same score. This could cause erroneous results if wave heights and periods are being considered together (i.e. neither exponent x nor y equals 0).

Based on these preliminary results it can be concluded that while this particular method of evaluating hindcast results has some shortcomings the potential for using skill tests is good. Because these results are preliminary further work needs to be done before any final conclusions can be drawn.

From the above discussion it is apparent that some mechanism needs to be used to exclude data that should not be tested, such as the swell waves on August 30 and 31. This may be best accomplished by using skill tests in conjunction with visual examination of the results rather than instead of visual examination. It is also clear that some sort of weighting must be applied to the magnitude of the numbers being tested.

This would prevent problems associated with comparing wave heights and periods together as well as a large number of insignificant events giving the same score as a small number of significant events. This latter possibility, however, could also be reduced by careful selection of the events that are tested.

3.9 Conclusions

It may be concluded that parametric hindcasting can work in the Beaufort Sea but an accurate description of the overwater wind field is essential. This is neither surprising nor a new conclusion. There is a need for overwater wind data and concurrently measured wave data to first evaluate the overwater wind data and then compare it to concurrently measured overland wind data. The hindcasting performed in this study found that the measured overwater wind data did not produce satisfactory hindcast results until the wind speeds had been reduced by 20 per cent.

This value was determined by hindcasting with the measured winds to a deepwater location where wave heights and periods had been measured. However, because of the limited duration of these measurements, it would be inappropriate to assume that a reduction of 20 percent should be applied to all of the wind speeds measured at that particular overwater station (the Canmar drill ship Explorer III). The reasons for the required wind speed factoring may well have been particular to the period examined.

It was also found that the overwater wind data did not produce good hindcast results at the King Point site. This was shown to be due to the location of the centre of the low pressure zone as the storm examined passed the site. It was also shown, however, that this type of west to east storm trajectory is quite common during the open water season, although the proximity of the centre of the low to the coast was somewhat unusual.

There is a strong need for more site wave data before any definitive conclusions may be drawn about hindcasting to King Point. If the more frequently occurring offshore storms provide steady winds across the open water fetches, then quite accurate hindcast results may be achieved.

The hindcasts performed with the Tuktoyaktuk wind data, to both the offshore site and the nearshore site, were marginally acceptable but not good. It was shown that one well predicted segment of the storm at the King Point nearshore site was likely the result of an overestimation of the fetch length, combined with an underestimation of the wind speed.

For the storm examined, it was shown that the overland to overwater wind speed factors developed for Tuktoyaktuk winds by Baird and Hall (1980) tended to underpredict the overwater wind speed when the winds were offshore and overpredict the overwater wind speeds when the winds were onshore. Further investigation of the wind data is warranted to determine whether a direction dependent overland to overwater wind speed ratio should be considered.

Because the King Point nearshore wave data was of such short duration, it is not possible to extrapolate the conclusions of this study to the 14 year hindcasts performed by Pinchin et al., (1985). However, considering the results obtained by hindcasting with other land-based wind data during this study, it may be concluded that the earlier 14 years hindcasts provided the most accurate results possible, given the methods used. A more accurate hindcast could be possible with: a) the overland to overwater wind speed ratio made to vary with wind direction; assuming b) that there is sufficient data available to determine a directional wind ratio relationship.

The insight to wave generation at King Point obtained through examining the surface weather charts and storm trajectories leads to the conclusion that utilizing raw measured wind data decreases the accuracy of a hindcast. This is not surprising considering that the definition of the overwater wind field is the most important aspect of hindcasting. It is easy to state that hindcasting must be augmented by examination of synoptic weather charts and storm trajectories but one must also consider the level of effort required in order to apply this approach to the prediction of a long-term climate, such as 14 years. Such an approach would not have been possible within the scope of the previous study (Pinchin et al., 1985).

Finally, it was concluded that while the method of utilizing skill tests for evaluating hindcast results as examined in this study showed encouraging results, further work is required to develop their full potential.

TABLE 3.1 Calibration Hindcasts to Dome Measured Wave Data

Figure	Wind Data Source	Wind Speed Factor	Fetch	Hindcast Run Number
3.7	Tuktoyaktuk	None	straight	TUK-01
3.8	Tuktoyaktuk	B & H *	straight	TUK-02
3.12	Shingle Point	None	straight	SH-01
3.13	King Point	None	straight	KP-01
3.14	King Point	None	Donelan**	KP-02
3.15	Explorer III	Boundary layer correction	straight	EX3-01
3.16	Explorer III	B.L. x 0.9	straight	EX3-02
3.17	Explorer III	B.L. x 0.8	straight	EX3-03
3.18	Explorer III	B.L. x 0.8	Donelan	EX3-04

* Wind speed factor developed by Baird and Hall (1980) and used in Pinchin et al., (1985).

** Effective fetch direction following work by Donelan (1980)

Table 3.2. King Point Site Hindcasts

Hindcast Run Number	Wind Data Source and Speed Factor	Fetches	Tp/Ts [1]	Figure
KPO1	Explorer III height corr x 0.8	Straight	1.15	3.21
KPO2	Explorer III height corr x 0.8	Straight	1.45	3.22
KPO3	Explorer III height corr x 0.8	Donelan	1.15	3.25
KPO4	Tuktoyaktuk Baird & Hall (1980) factors	Straight	1.15	3.26
KPO5	King Point no factors	Straight	1.5	3.27
KPO6	Komakuk Beach no factors	Straight	1.5	3.28

1. ratio of peak period to significant period

Table 3.3. Recorded Wind Data during September 1 to 4 storm.

		Directions (°True)				Factored Speeds (km/h) as used in hindcasts			
Day	Hr	KING	EXPLORER III	TUK	SHINGLE	KING[1]	EXPLORER III[2]	TUK[3]	SHINGLE[1]
1.	0	124	102*	70	110	17	27*	11	19
	6	168	120	110	160	2	30	11	11
	12	112	110	120	110	24	28	16	7
	18	205	110	100	200	28	28	16	30
2.	0	129	90	80	160	15	30	25	22
	6	273	90	80	290	6	26	28	11
	12	97	30	80	---	6	26	33	---
	18	103	90	50	110	13	32	21	19
3.	0	114	110	95*	120	28	28	21*	24
	6	248	70	80	250	21	24	16	13
	12	300	10	90	240	16	6	18	11
	18	315	70*	90	320	37	26*	16	22
4.	0	321	10	50	330*	38	23	21	29*
	6	329	340	30	340	30	13	18	37
	12	321	360	350	320	36	14	21	19
	18	318	340	350	340	44	23	25	33
5.	0	324	330	350	320	35	27	16	33

1. No wind speed factors applied
2. Wind speeds height corrected then factored by 0.8
3. Wind speeds factored following Baird and Hall (1980)

* Interpolated values

Table 3.4 Skill Test Output

MEASURED DATA FILE IS C:DOME.TIS
PREDICTED DATA FILE IS C:EX3-03.TIS
ANALYSIS DATES 28/08/85 to 10/09/85

$H^1 T^0$

Phase	Inv.	scores	Score	Data Count	Score Count
-9	-305.0	435.0	220.0	96	35
-8	-314.0	454.0	212.0	98	33
-7	-300.0	452.0	238.0	99	35
-6	-283.0	416.0	261.0	96	37
-5	-267.0	418.0	295.0	98	42
-4	-266.0	443.0	281.0	99	38
-3	-270.0	430.0	260.0	96	36
-2	-271.0	432.0	277.0	98	41
-1	-256.0	453.0	281.0	99	39
0	-246.0	435.0	279.0	96	41
1	-266.0	414.0	300.0	98	43
2	-255.0	385.0	350.0	99	47
3	-246.0	359.0	355.0	96	48
4	-265.0	384.0	331.0	98	44
5	-285.0	359.0	346.0	99	46
6	-276.0	340.0	344.0	96	47
7	-297.0	351.0	332.0	98	44
8	-316.0	353.0	321.0	99	45
9	-333.0	329.0	298.0	96	43

HIGHEST SCORE FOR PHASE 3

$H^0 T^1$

Phase	Inv.	scores	Score	Data Count	Score Count
-9	-381.0	45.0	504.0	93	71
-8	-373.0	44.0	523.0	94	71
-7	-380.0	55.0	515.0	95	69
-6	-348.0	58.0	514.0	92	69
-5	-361.0	62.0	517.0	94	68
-4	-390.0	64.0	496.0	95	66
-3	-366.0	58.0	496.0	92	66
-2	-393.0	76.0	471.0	94	65
-1	-395.0	75.0	490.0	96	65
0	-369.0	76.0	485.0	93	64
1	-419.0	79.0	462.0	96	61
2	-412.0	74.0	484.0	97	63
3	-412.0	74.0	464.0	95	62
4	-438.0	82.0	450.0	97	59
5	-441.0	78.0	451.0	97	57
6	-435.0	96.0	409.0	94	57
7	-445.0	114.0	391.0	95	53
8	-443.0	109.0	398.0	95	54
9	-430.0	96.0	404.0	93	54

HIGHEST SCORE FOR PHASE -8

Table 3.5 Skill Test Results

Hindcast run	Skill test exponents x	y	Inverse Scores (neg.)	(pos.)	Score	Phase
EX3-03	1	0	-246.0	359.0	355.0	3
TUK-02	1	0	-295.0	470.0	255.0	-4
TUK-01	1	0	-439.0	376.0	215.0	-4
EX3-01	1	0	-84.0	752.0	164.0	-6
SH-01	1	0	-290.0	575.0	65.0	0
EX3-03	0	1	-373.0	44.0	523.0	-8
EX3-01	0	1	-198.0	289.0	473.0	-9
TUK-02	0	1	-503.0	172.0	315.0	9
TUK-01	0	1	-629.0	120.0	241.0	9
SH-01	0	1	-393.0	276.0	221.0	8
EX3-03	1	1	-309.0	291.0	360.0	1
TUK-02	1	1	-378.0	362.0	240.0	-5
EX3-01	1	1	-129.0	652.0	179.0	-9
TUK-01	1	1	-491.0	367.0	132.0	9
SH-01	1	1	-294.0	516.0	80.0	5
EX3-03	2	1	-330.0	361.0	279.0	2
TUK-02	2	1	-381.0	455.0	144.0	2
TUK-01	2	1	-550.0	338.0	102.0	-9
EX3-01	2	1	-167.0	715.0	88.0	-8
SH-01	2	1	-295.0	557.0	38.0	5

Hindcast Runs

EX3-01 : Explorer III wind data, height corrected ; Figure 3.15

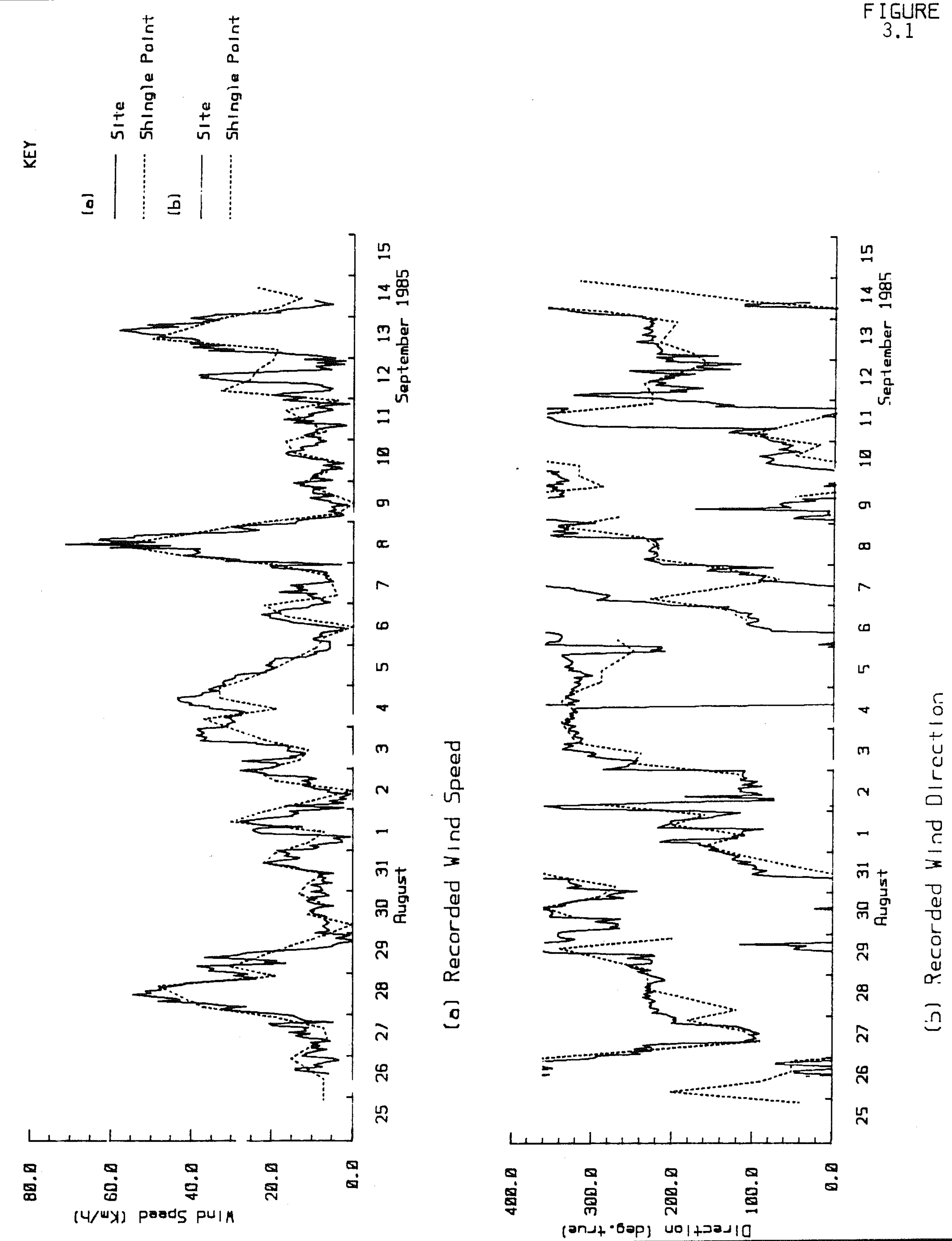
EX3-03 : Explorer III wind data, height corrected x 0.8 ; Figure 3.17

TUK-01 : Tuktoyaktuk wind data ; Figure 3.7

TUK-01 : Tuktoyaktuk wind data with Baird and Hall (1980) wind speed factor ; Figure 3.8

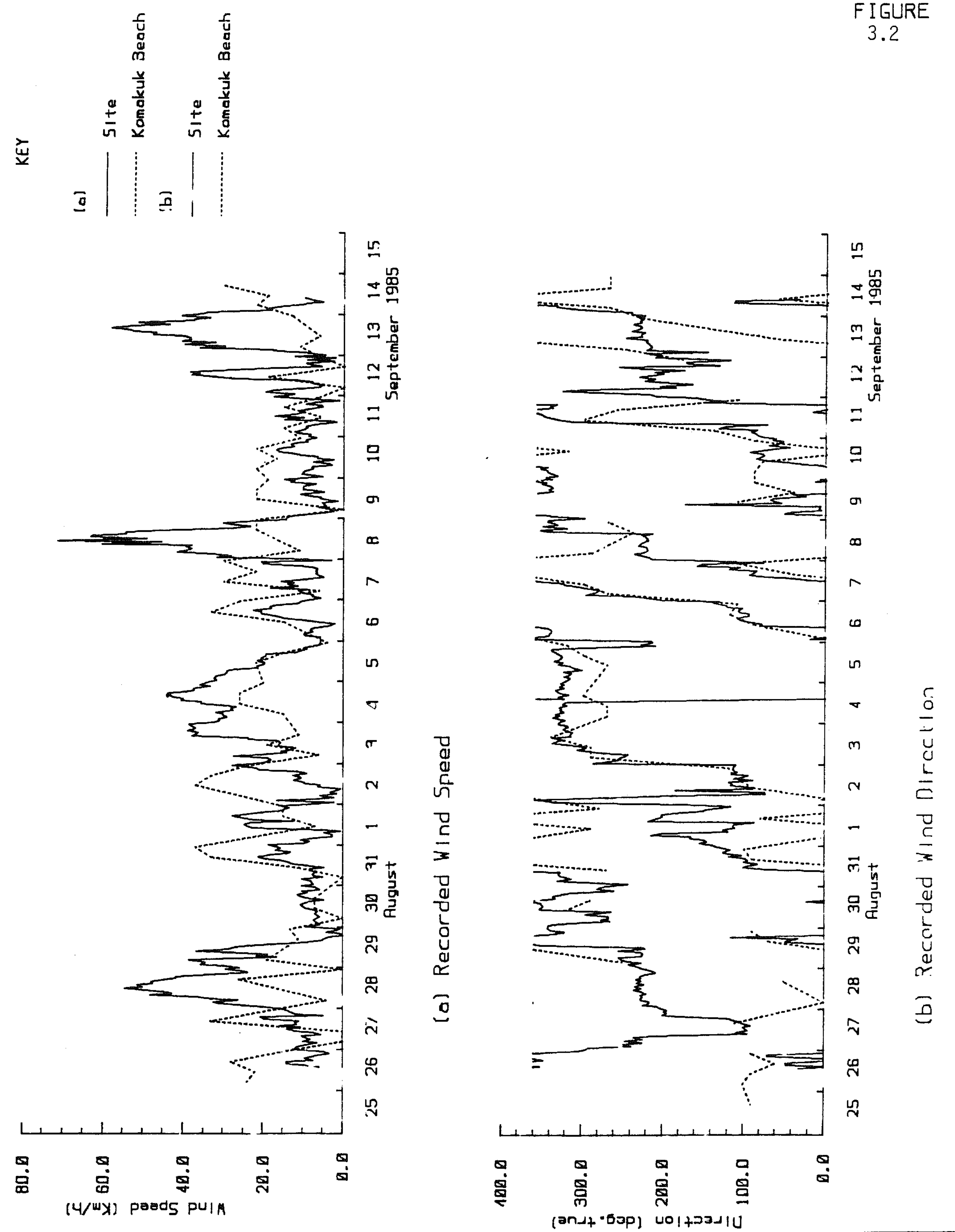
SH-01 : Shingle Point wind data ; Figure 3.12

FIGURE 3.1



KING POINT SEDIMENT TRANSPORT STUDY	Date: 18 Mar 86
	Scales as shown
Comparison of Site and Shingle Point Overland Wind Data	Checked by:
	Keith Philpott Consulting Limited

FIGURE 3.2

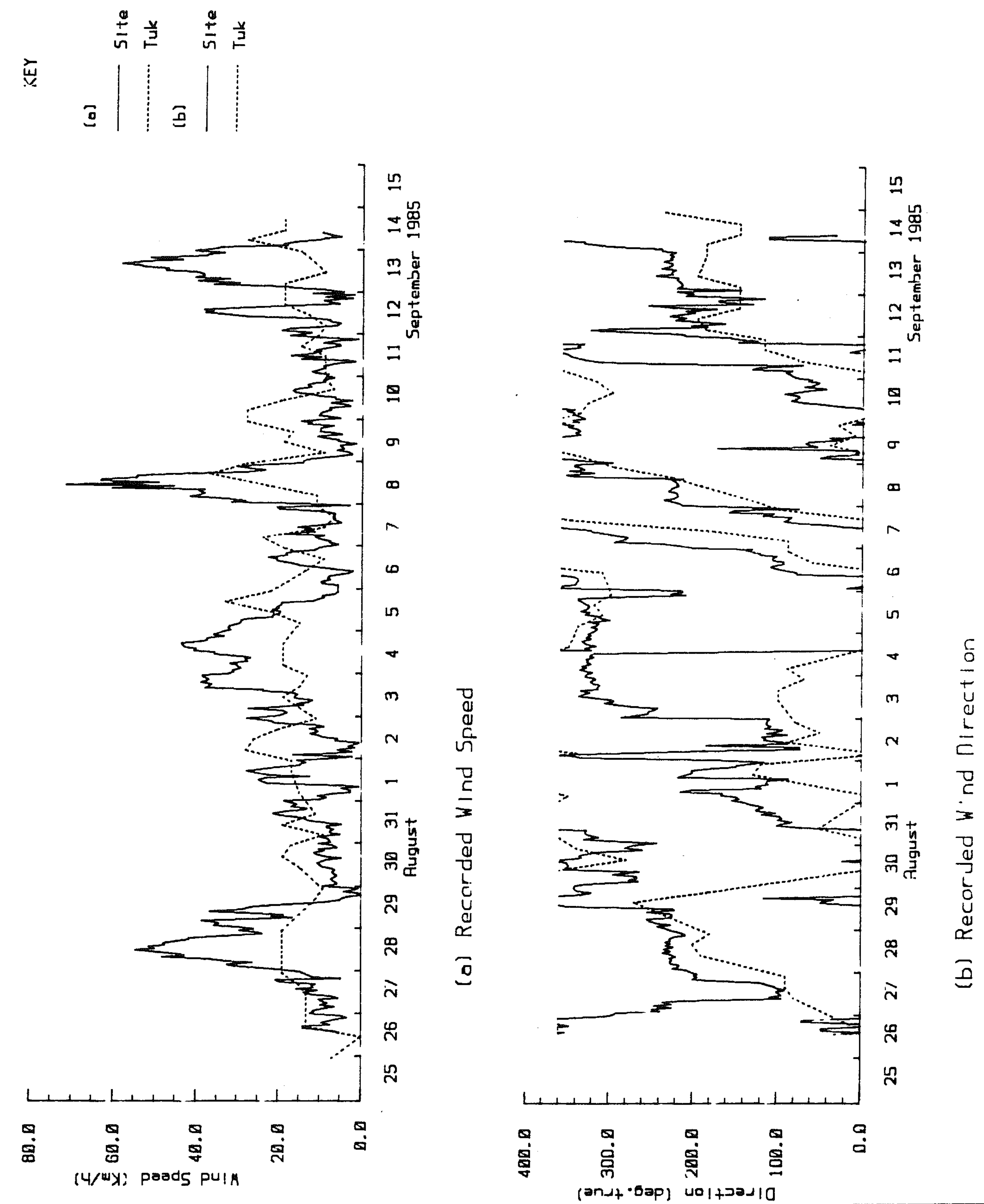


(a) Recorded Wind Speed

(b) Recorded Wind Direction

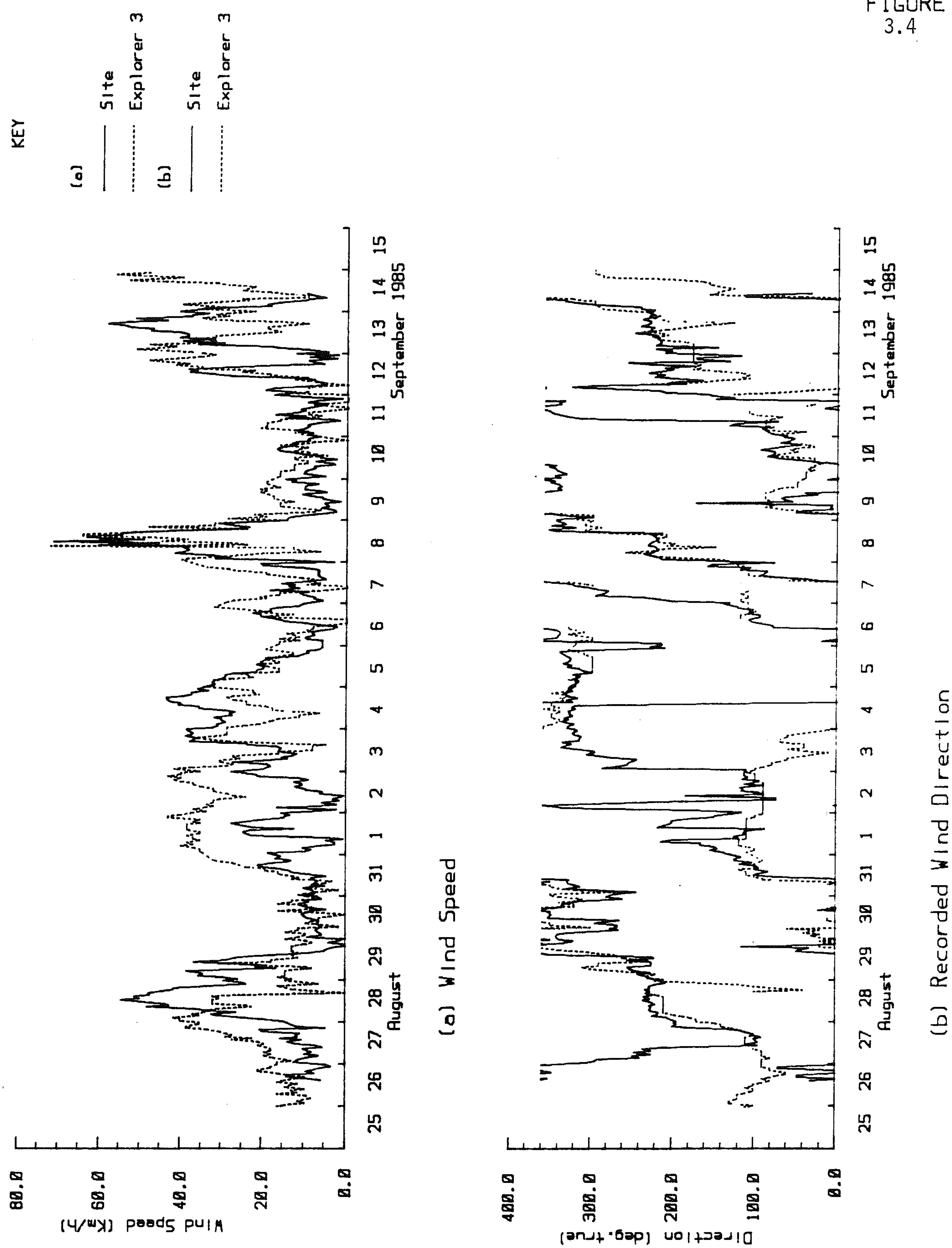
KING POINT SEDIMENT TRANSPORT STUDY	Date: 18 Mar 86
	Scales as shown
Comparison of Site and Komakuk Beach Overland Wind Data	Checked by:
	Keith Philpott Consulting Limited

FIGURE 3.3



KING POINT SEDIMENT TRANSPORT STUDY	Date: 18 Mar 86
	Scales as shown
Comparison of Site and Tuk Overland Wind Data	Checked by:
	Keith Philpott Consulting Limited

FIGURE 3.4

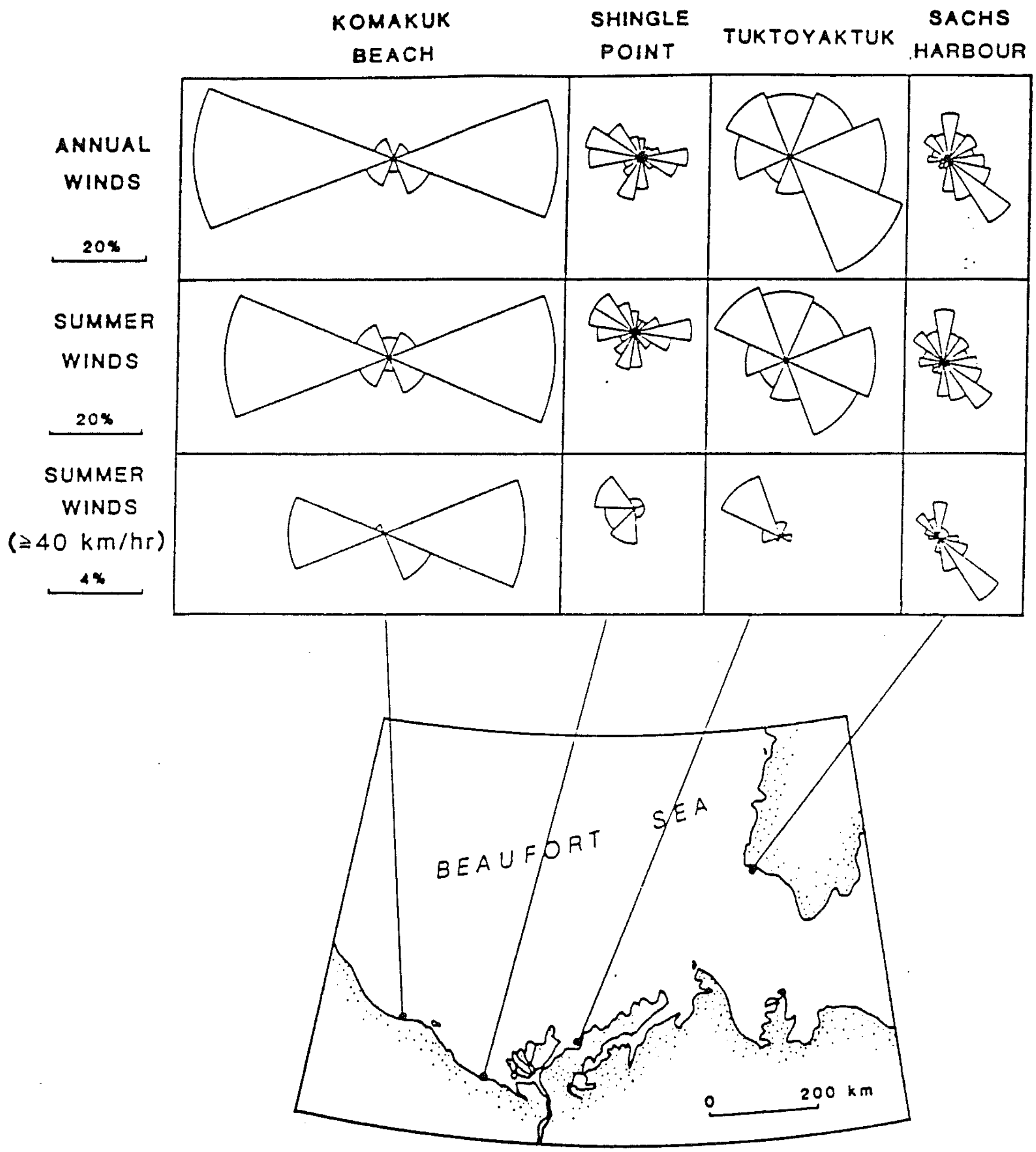


KING POINT SEDIMENT TRANSPORT STUDY

Comparison of Site and Height Corrected Explorer 3 Overwater Wind Data

Date: 14 Apr 86	
Scales as shown	
Checked by:	
Keith Philpott Consulting Limited	

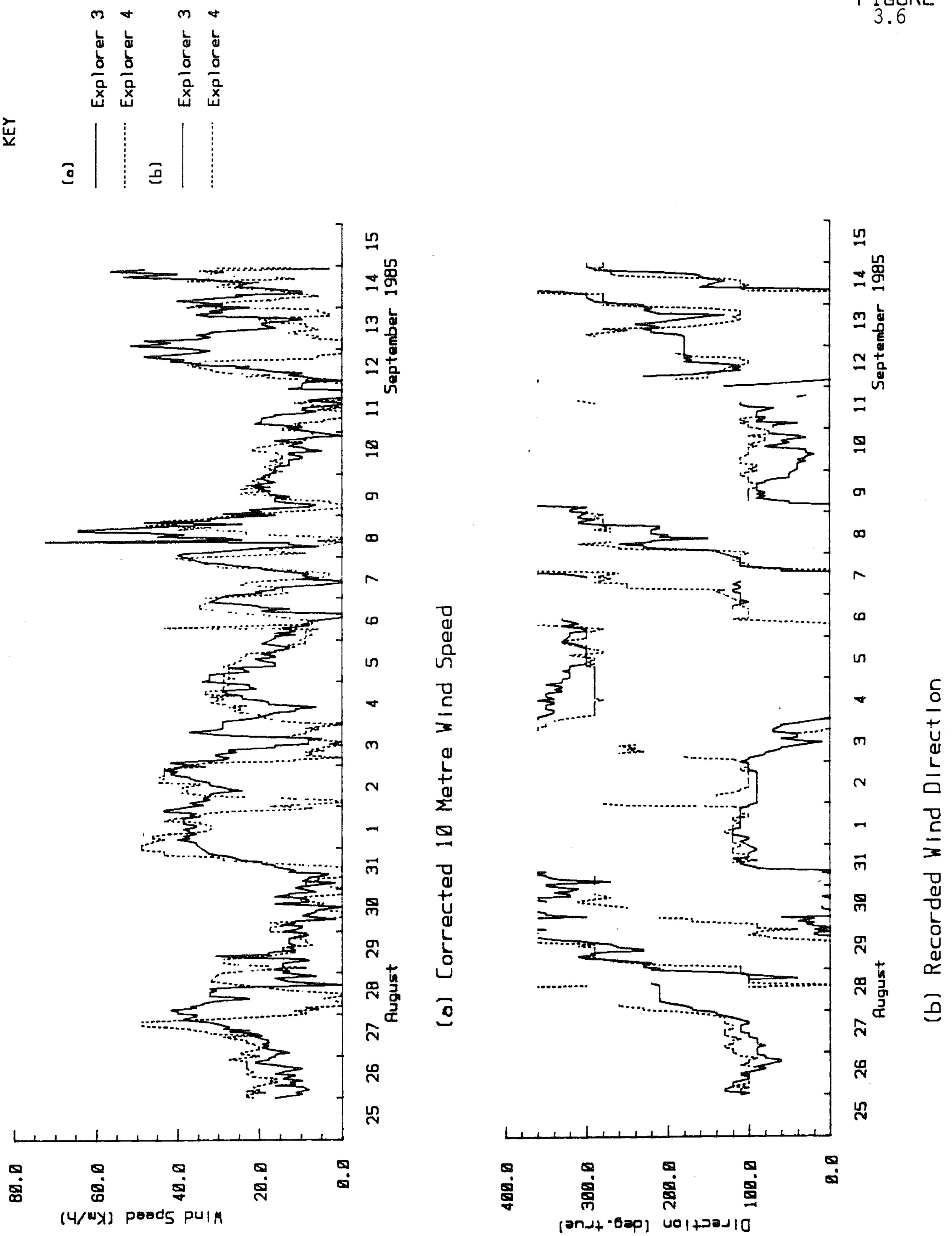
FIGURE
3.5



from Harper and Penland, 1982

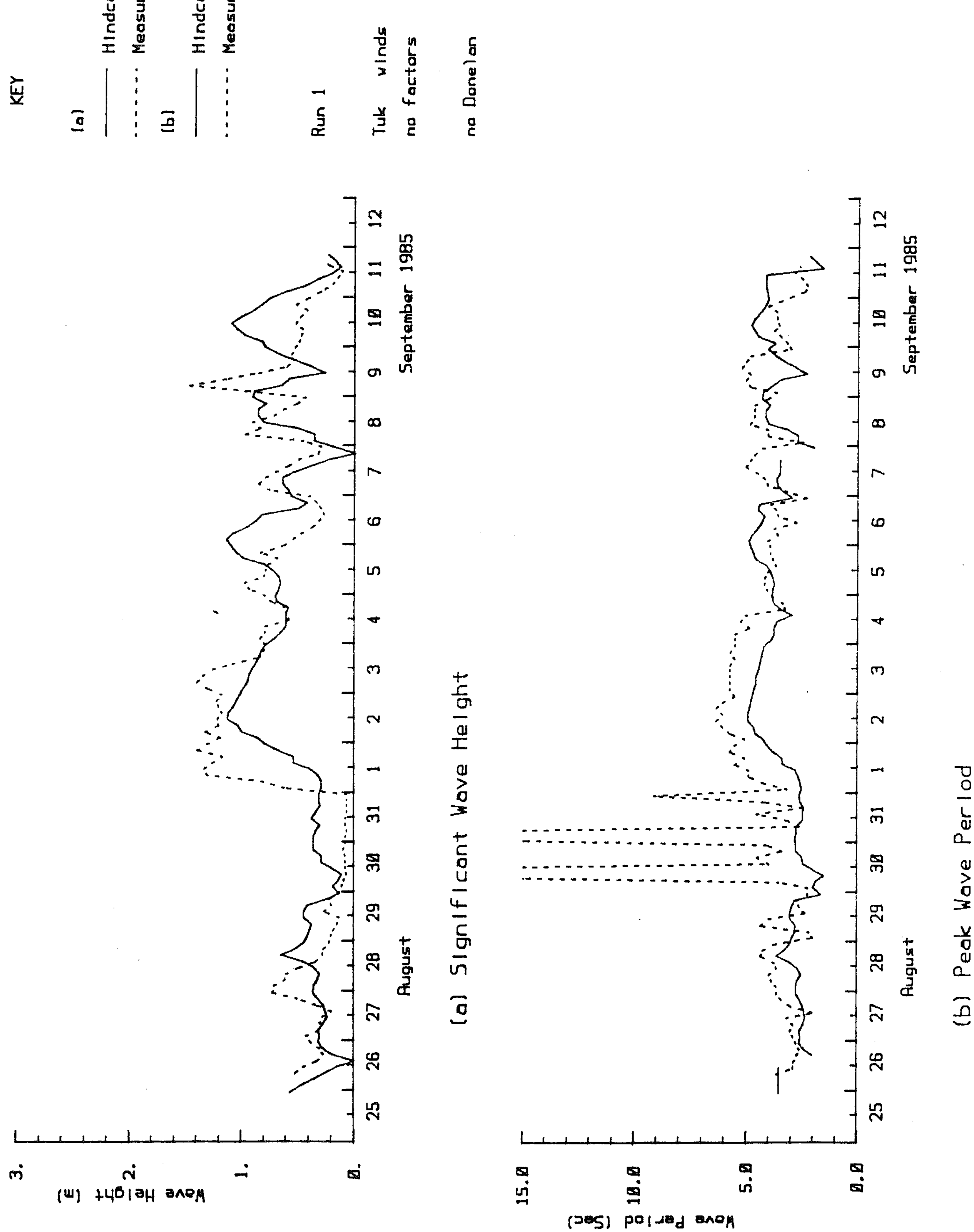
KING POINT SEDIMENT TRANSPORT STUDY	Date: 7 Apr 86
	Scales as shown
Beaufort Sea Wind Distribution	Checked by:
	Keith Philpott Consulting Limited

FIGURE 3.6



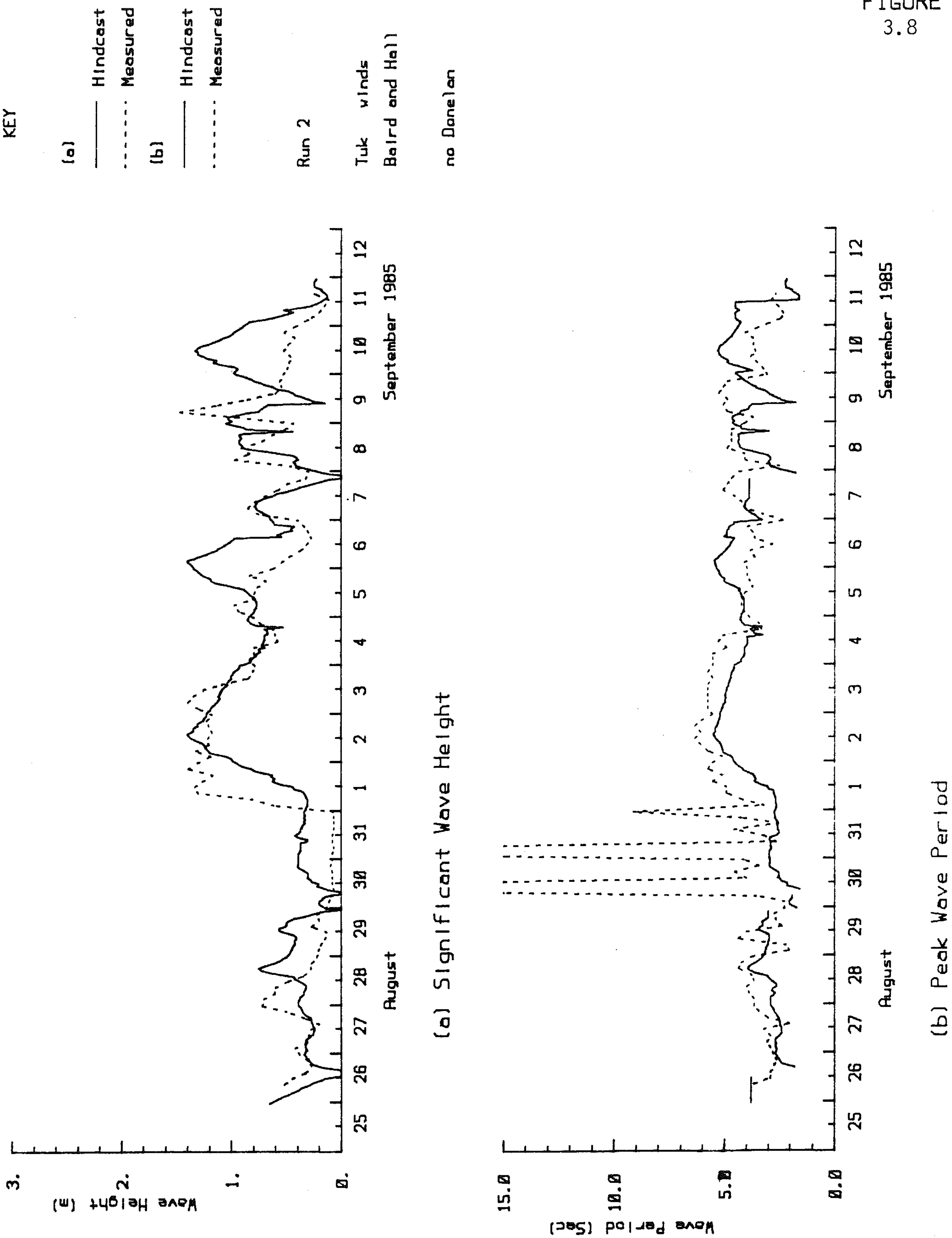
KING POINT SEDIMENT TRANSPORT STUDY	Date: 14 Apr 86
	Scales as shown
Comparison of Height Corrected Overwater Wind Data from Explorer Drill Ships	Checked by:
	Keith Philpott Consulting Limited

FIGURE 3.7



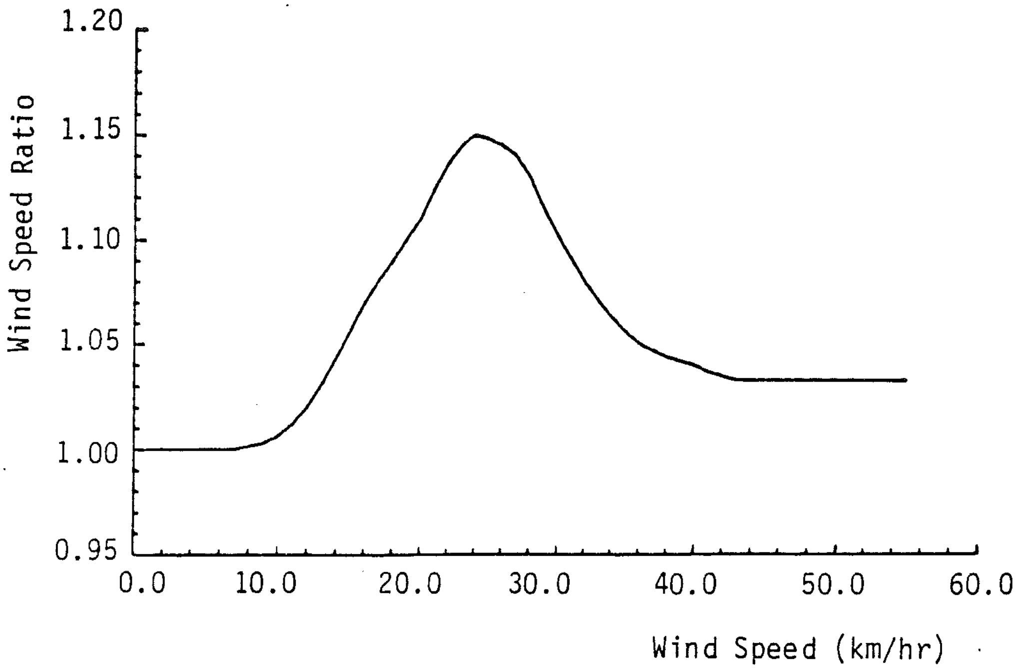
KING POINT SEDIMENT TRANSPORT STUDY	Date: 8 Aug 86
	Scales as shown
Hindcast Calibration - Tuk A Winds, Run 1	Checked by:
	Keith Philpott Consulting Limited

FIGURE 3.8



KING POINT SEDIMENT TRANSPORT STUDY	Date: 8 Aug 86
	Scales as shown
Hindcast Calibration - Tuk A Winds, Run 2	Checked by:
	Keith Philpott Consulting Limited

FIGURE
3.9

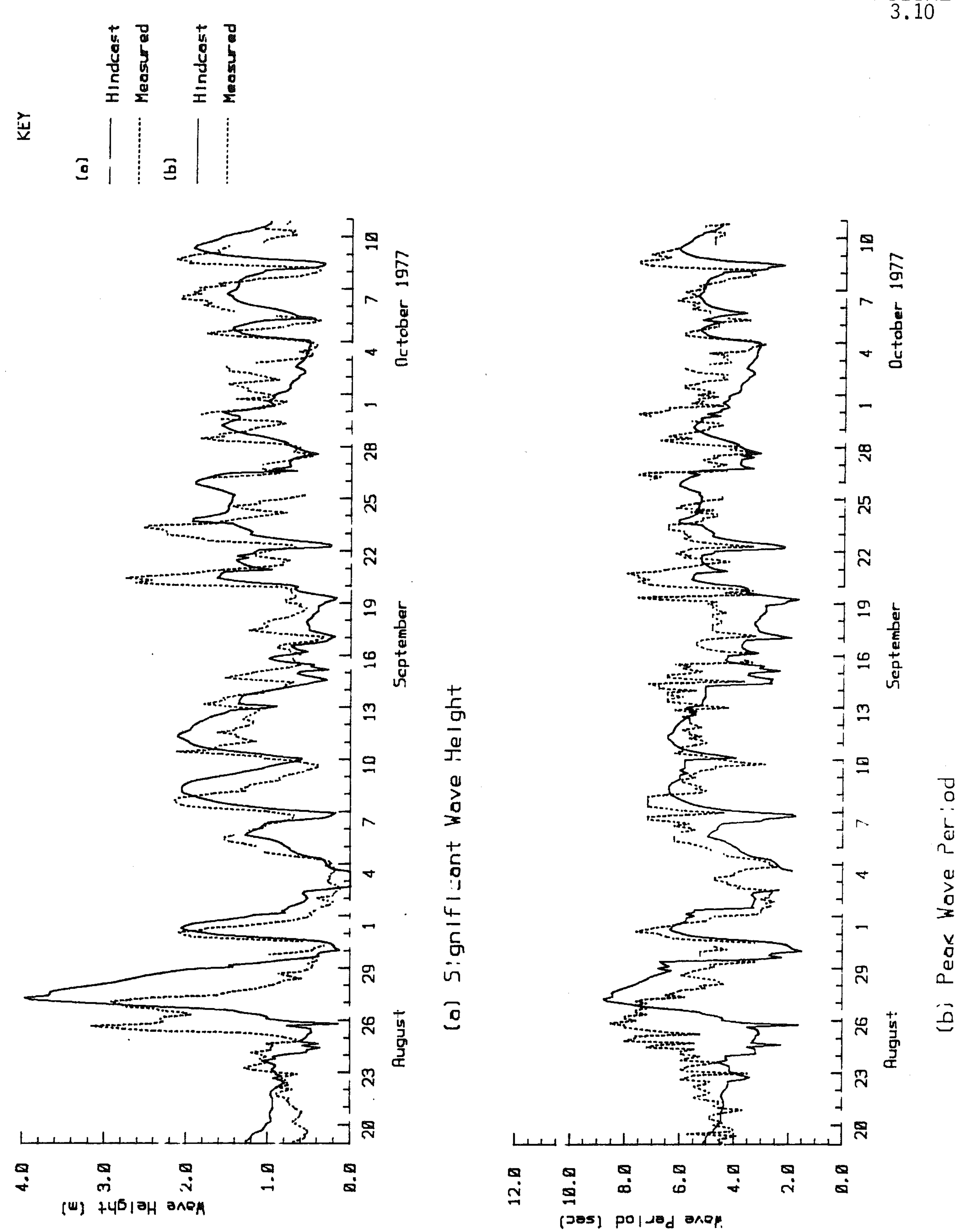


Overwater to Overland Wind Speed Ratio

from Baird and Hall 1980

KING POINT SEDIMENT TRANSPORT STUDY	Date: 7 Apr 86
	Scales as shown
Overwater to Overland Wind Speed Ratio	Checked by:
	Keith Philpott Consulting Limited

FIGURE
3.10

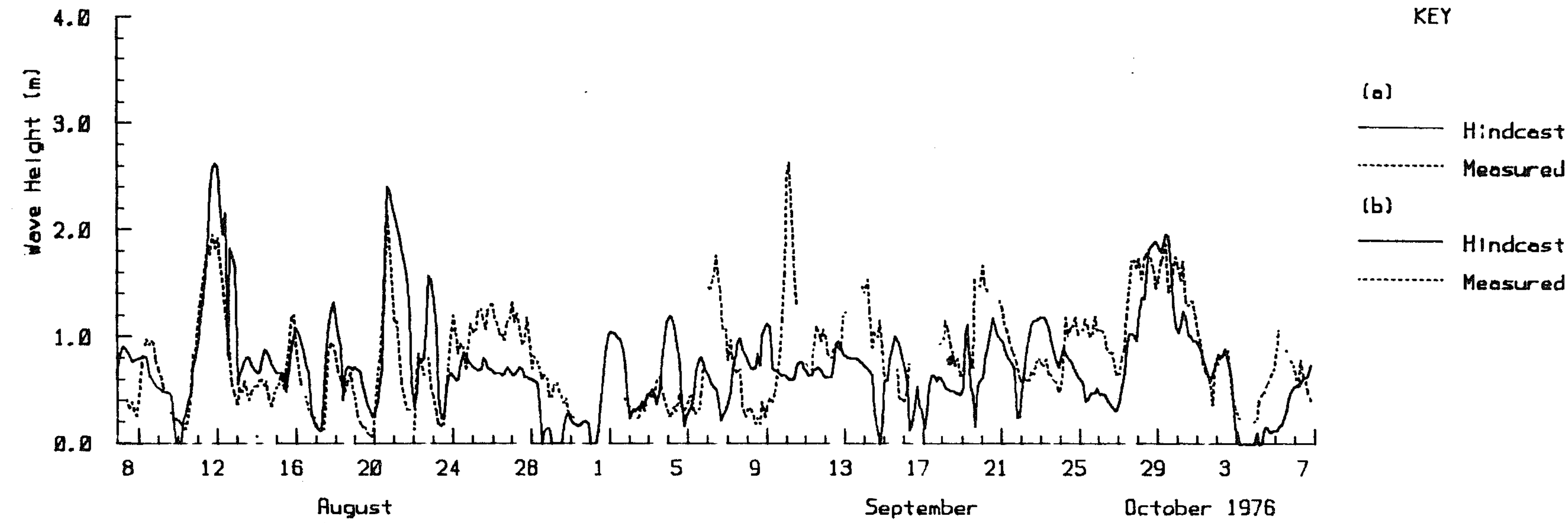


KING POINT SEDIMENT TRANSPORT STUDY

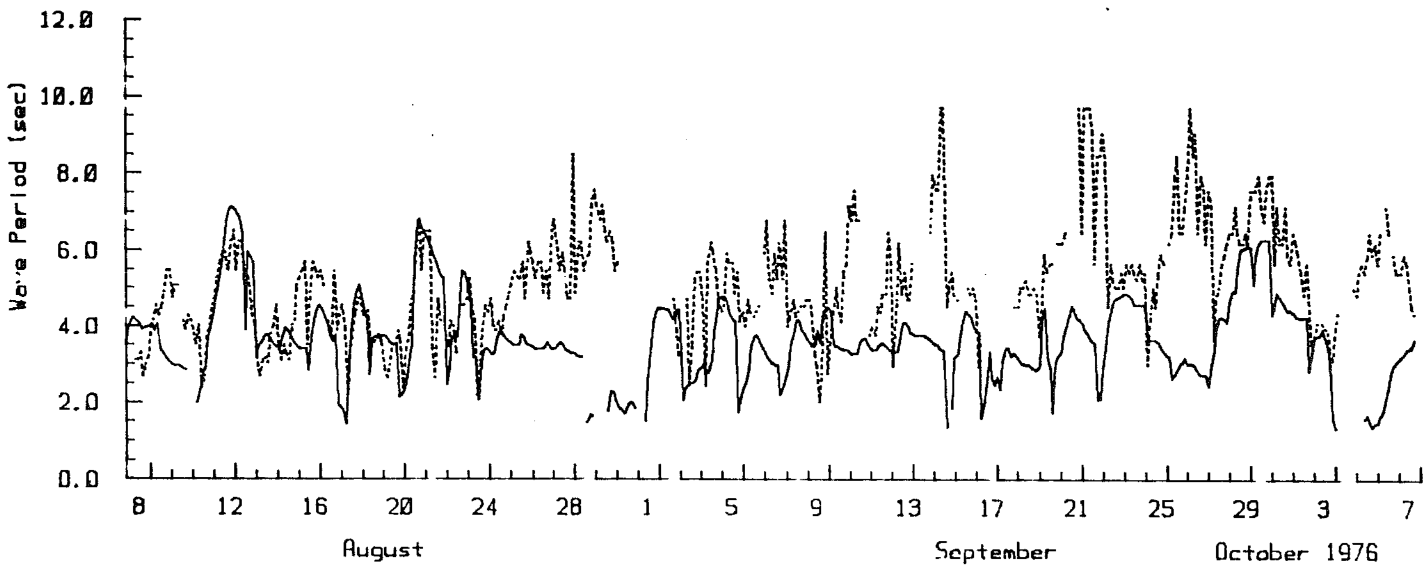
Previous Hindcast Calibration for MEDS Station 191

Date: 24 Mar 80	
Scales as shown	
Checked by:	
Keith Philpott Consulting Limited	

FIGURE 3.11



(a) Significant Wave Height



(b) Peak Wave Period

KING POINT SEDIMENT TRANSPORT STUDY

Previous Hindcast Calibration for MEDS Station 50

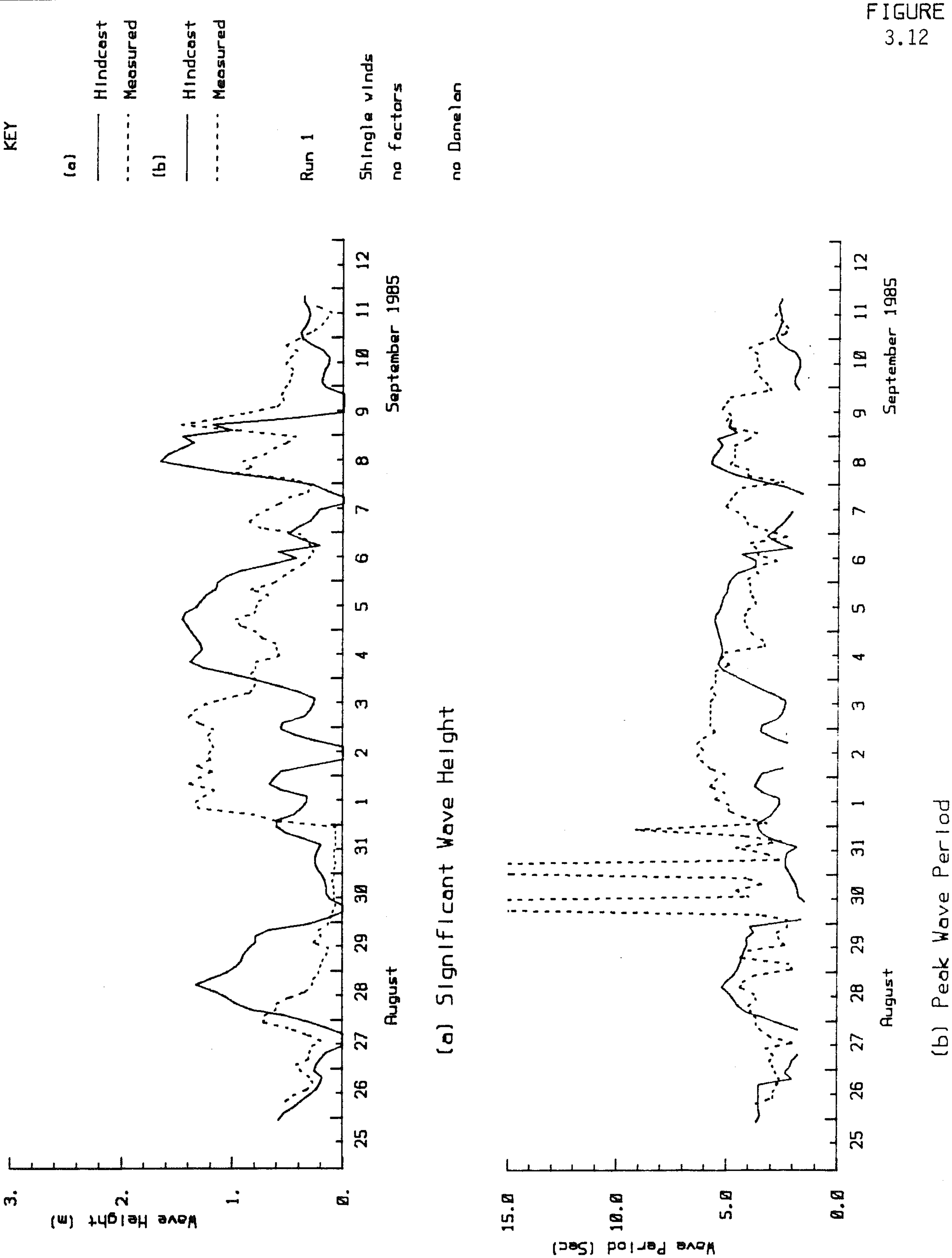
Date: 24 Mar 86

Scales as shown

Checked by:

Keith Philpott Consulting Limited

FIGURE 3.12



(a) Significant Wave Height

(b) Peak Wave Period

KING POINT SEDIMENT TRANSPORT STUDY

Hindcast Calibration - Shingle Winds, Run 1

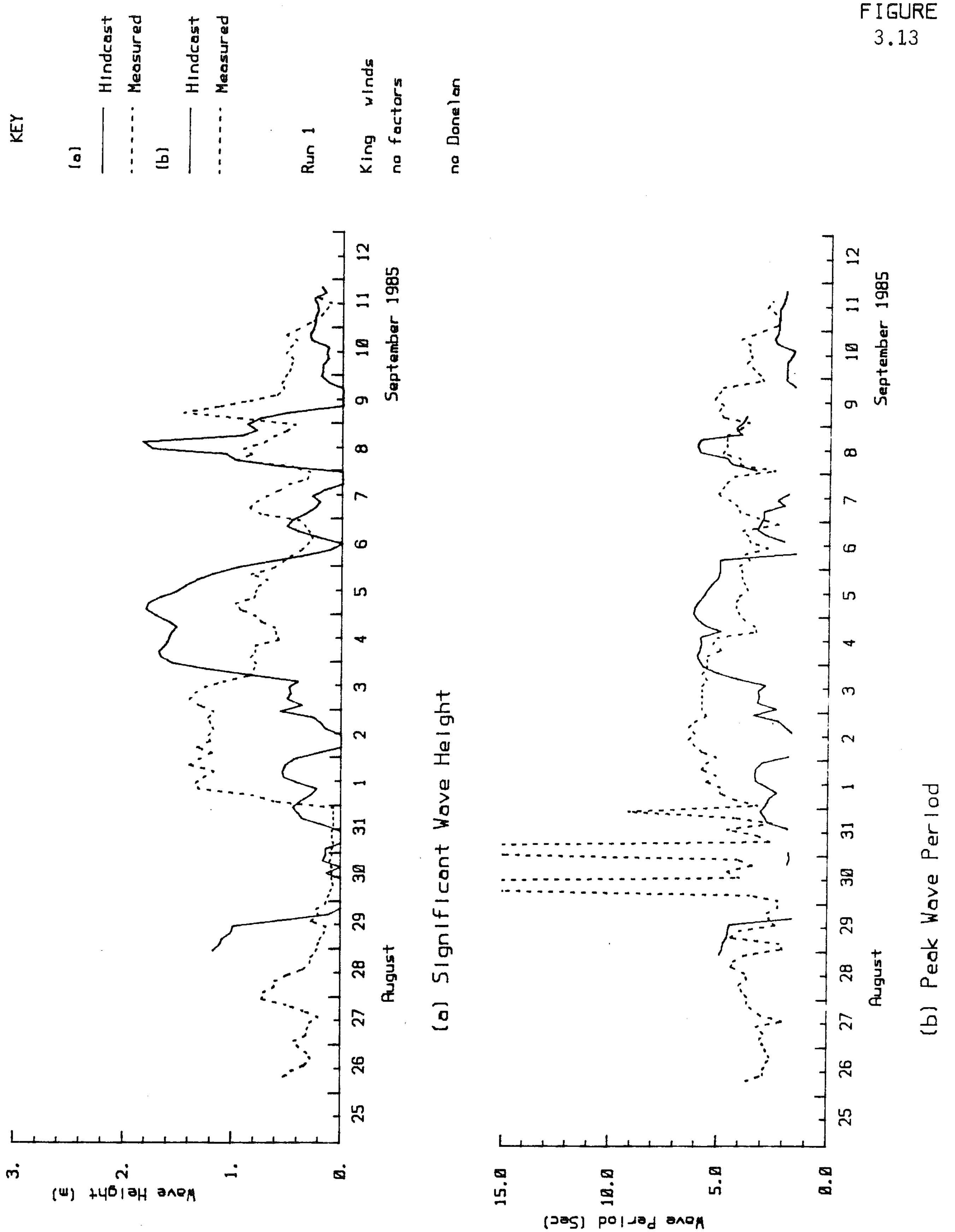
Date: 8 Aug 86

Scales as shown

Checked by:

Keith Philpott Consulting Limited

FIGURE 3.13



KING POINT SEDIMENT TRANSPORT STUDY

Hindcast Calibration - King Point Winds, Run 1

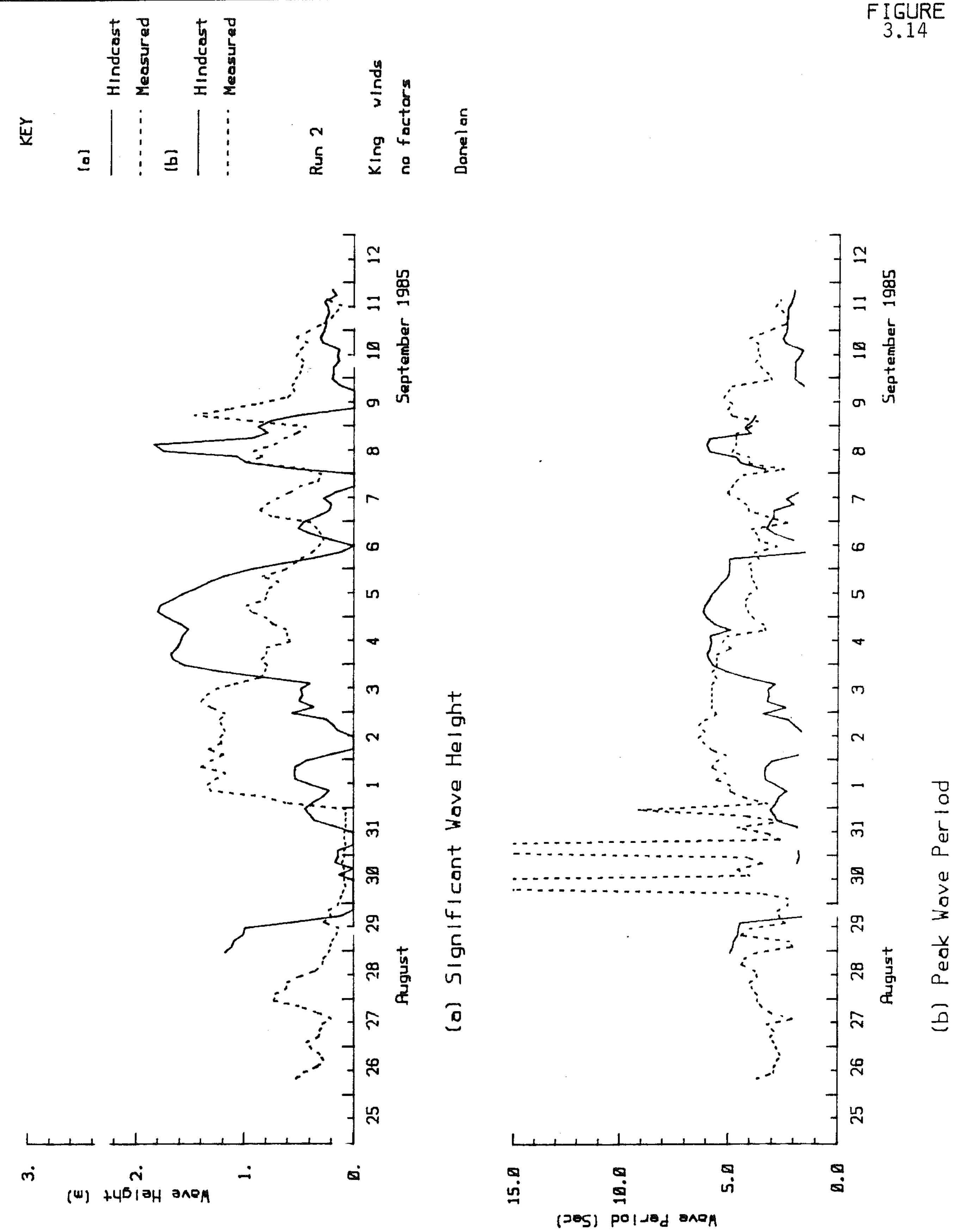
Date: 8 Aug 86

Scales as shown

Checked by:

Keith Philpott Consulting Limited

FIGURE 3.14



KING POINT SEDIMENT TRANSPORT STUDY

Hindcast Calibration - King Point Winds, Run 2

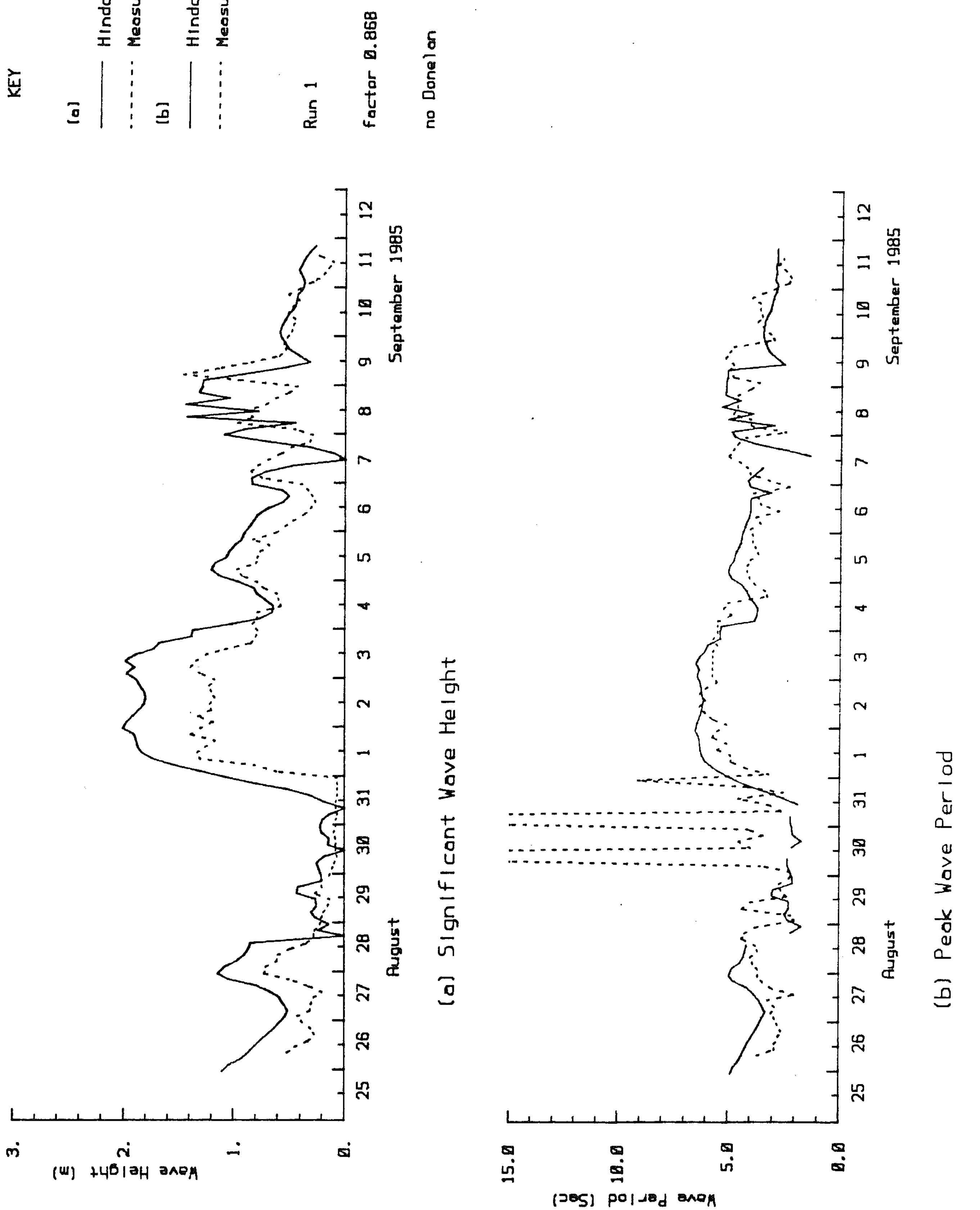
Date: 8 Aug 86

Scales as shown

Checked by:

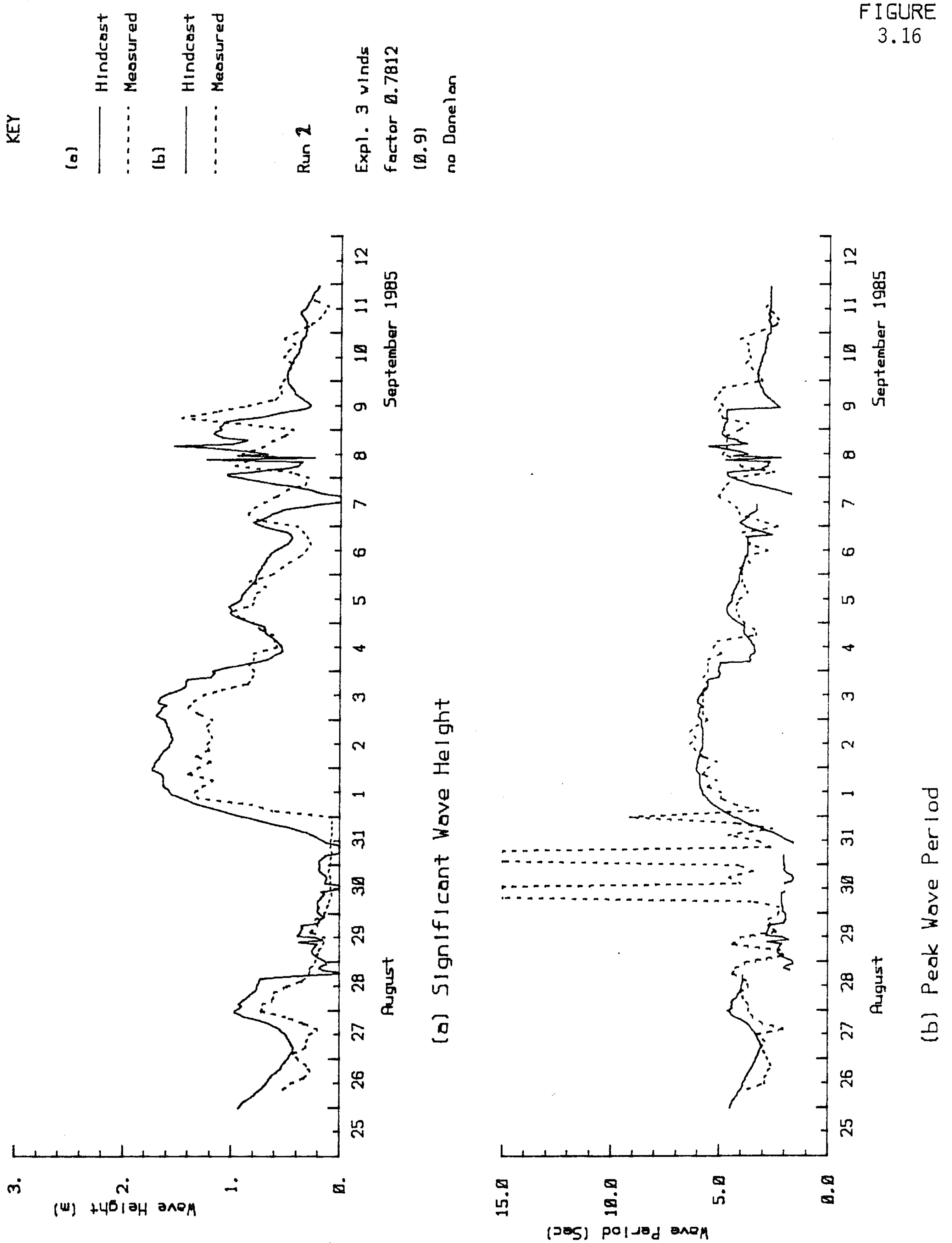
Keith Philpott Consulting Limited

FIGURE
3.15



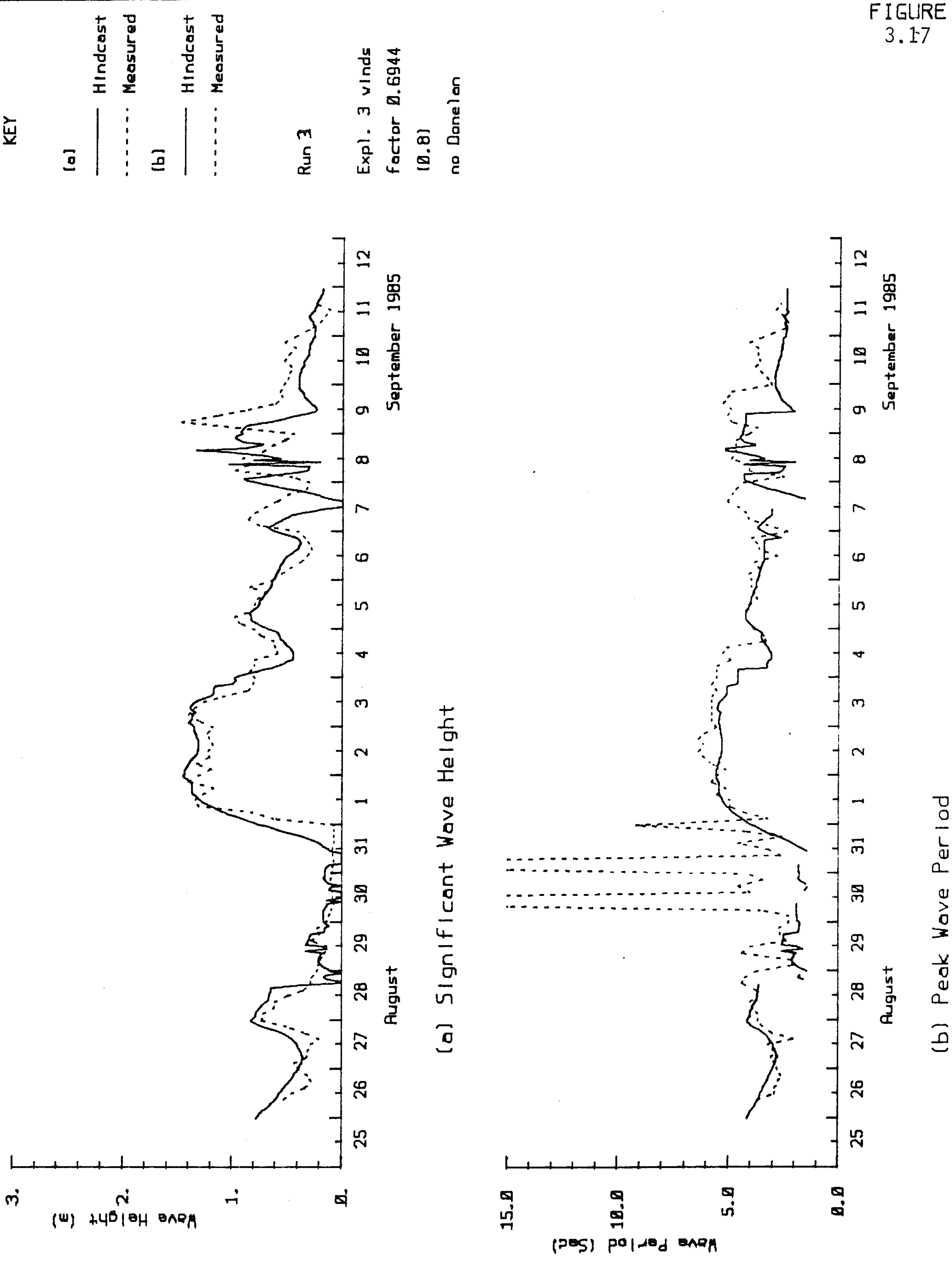
KING POINT SEDIMENT TRANSPORT STUDY	Date: 8 Aug 86
	Scales as shown
Hindcast Calibration - Explorer 3 Winds, Run 1	Checked by:
	Keith Philpott Consulting Limited

FIGURE
3.16



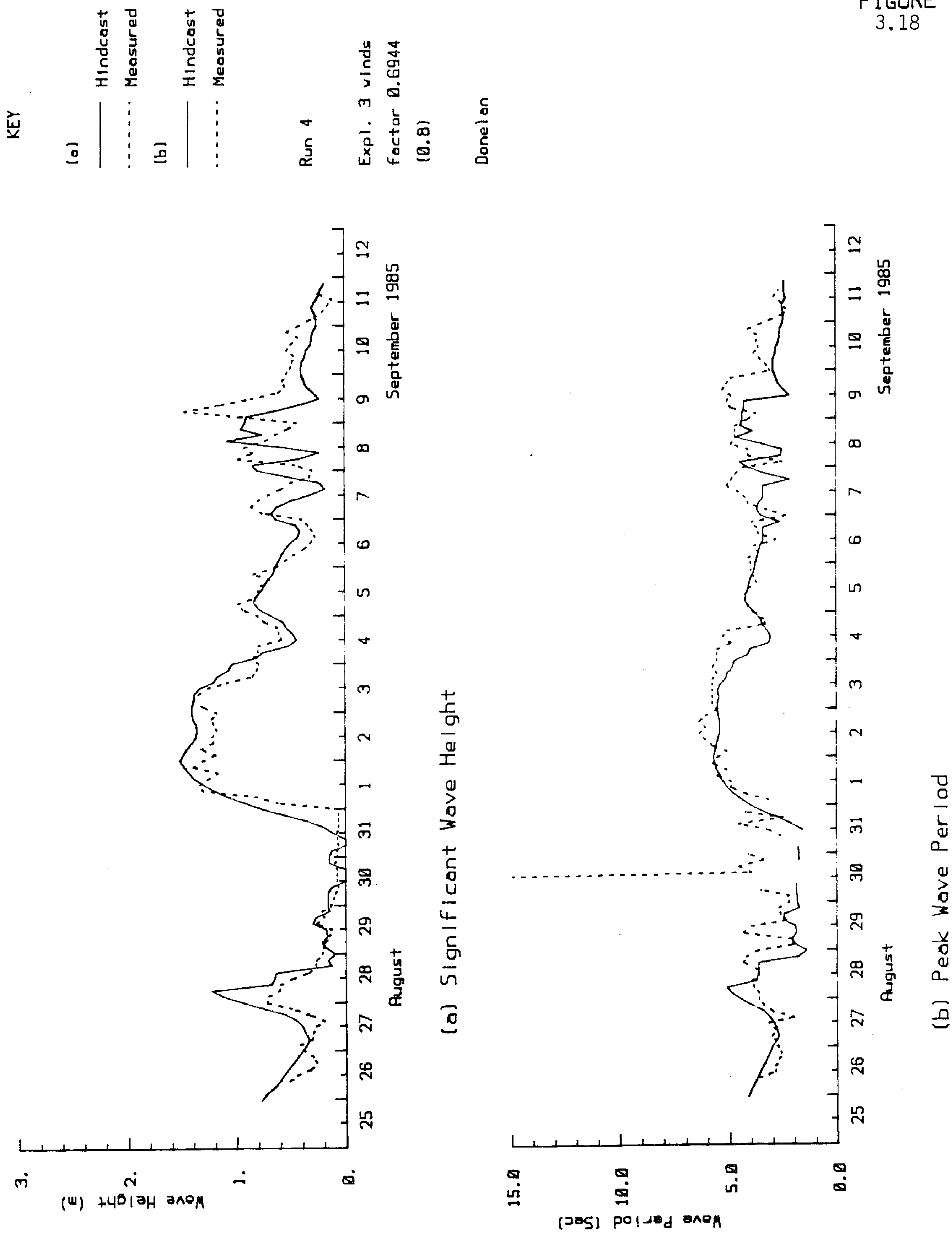
KING POINT SEDIMENT TRANSPORT STUDY	Date: 8 Aug 86
	Scales as shown
Hindcast Calibration - Explorer 3 Winds, Run 2	Checked by:
	Keith Philpott Consulting Limited

FIGURE 3.17



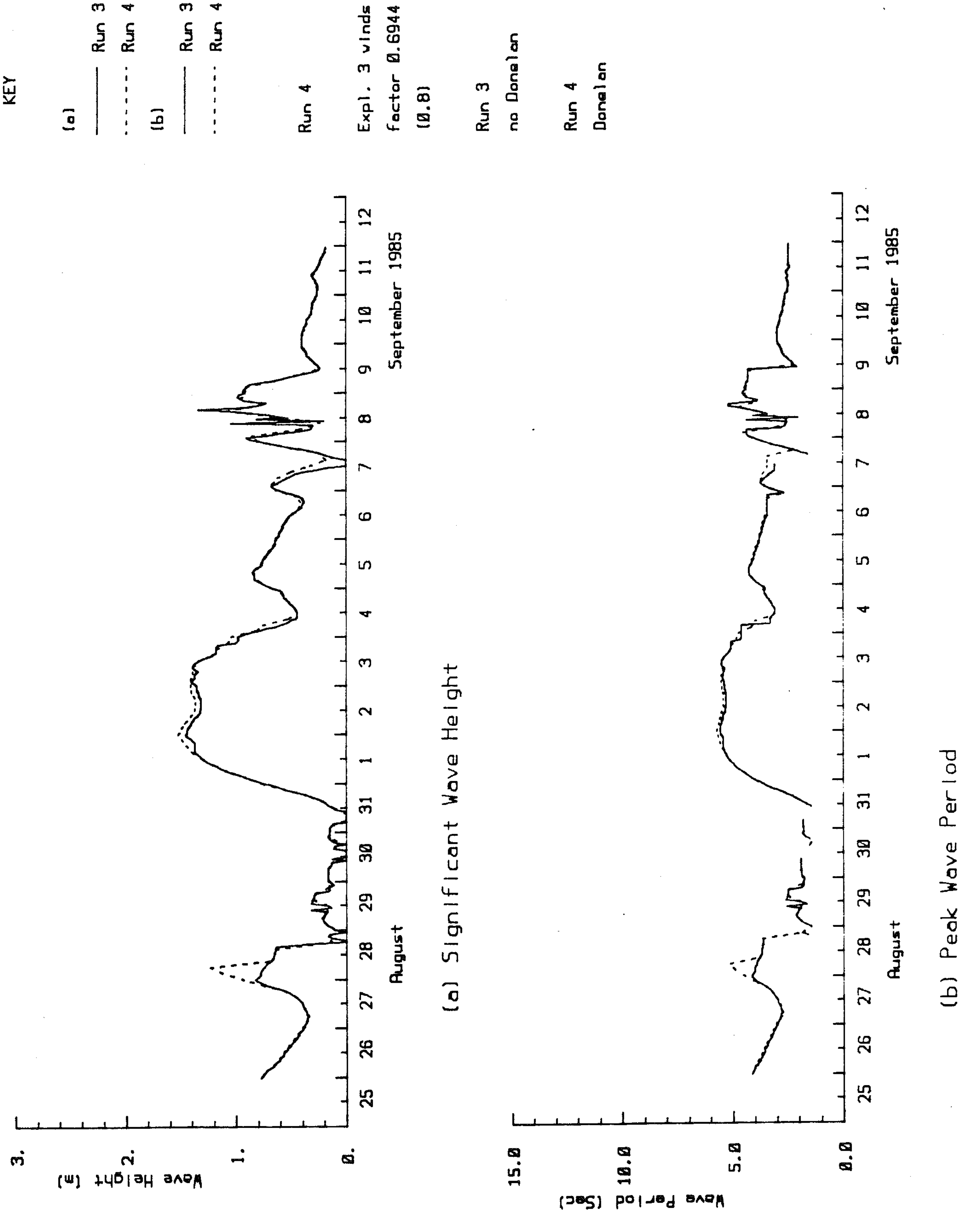
KING POINT SEDIMENT TRANSPORT STUDY	Date: 8 Aug 86
	Scales as shown
	Checked by:
Hindcast Calibration - Explorer 3 Winds, Run 3	Keith Philpott Consulting Limited

FIGURE 3.18



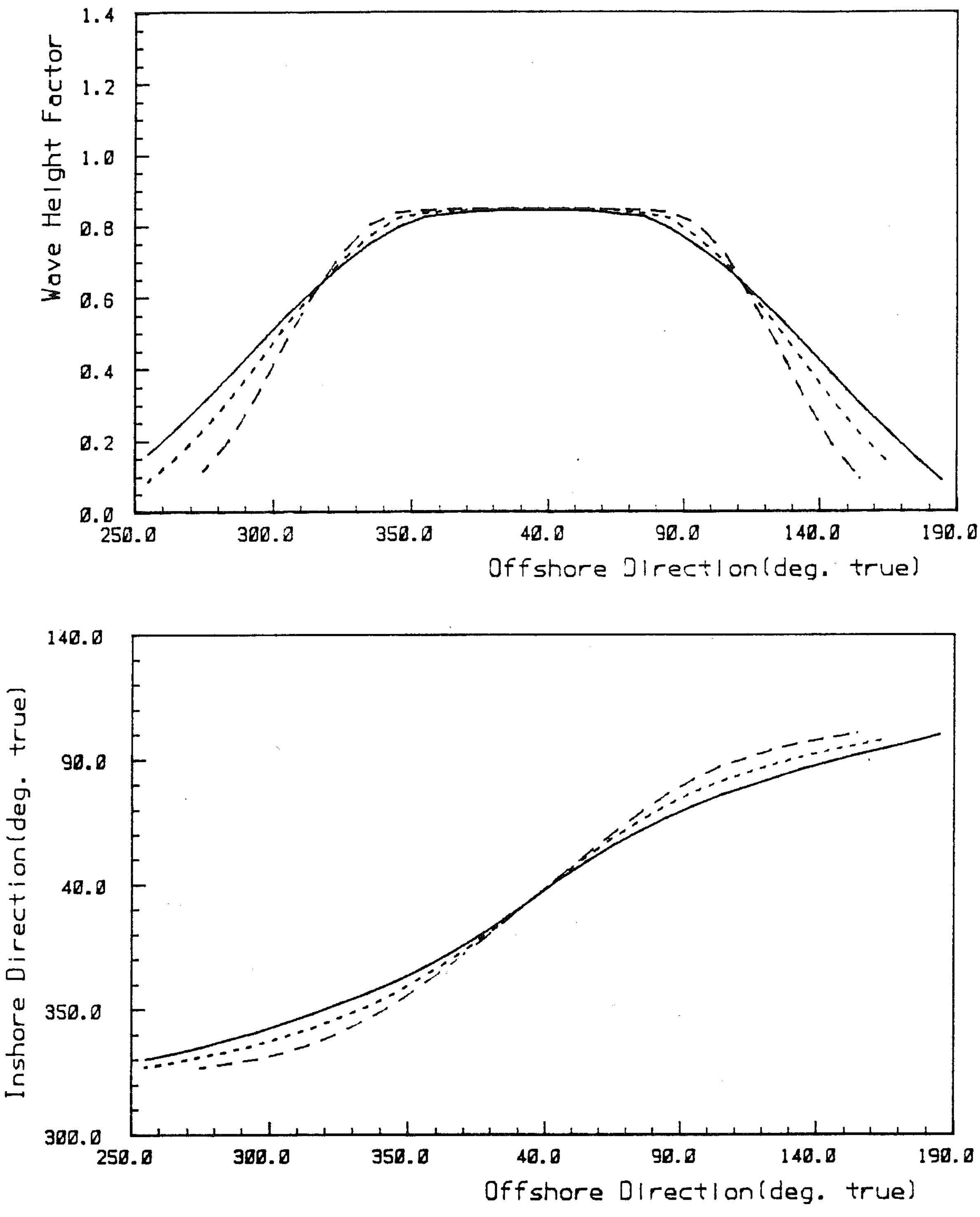
KING POINT SEDIMENT TRANSPORT STUDY	Date: 9 Aug 86
	Scales as shown
Hindcast Calibration - Explorer 3 Winds, Run 4	Checked by:
	Keith Philpott Consulting Limited

FIGURE
3.19



KING POINT SEDIMENT TRANSPORT STUDY	Date: 9 Aug 86
	Scales as shown
	Checked by:
Hindcast Calibration - Explorer 3 Winds, Runs 3 & 4	Keith Philpott Consulting Limited

FIGURE
3.20



Node No: 1 | Spreading Index: 2 ————

Tide Level: 0.40 m. | 4 - - - - - - -

Peak Period: 4.0 secs | 10 — — — —

KING POINT SEDIMENT TRANSPORT STUDY

King Point: Wave Spectrum Transformation Results for Node Number 01

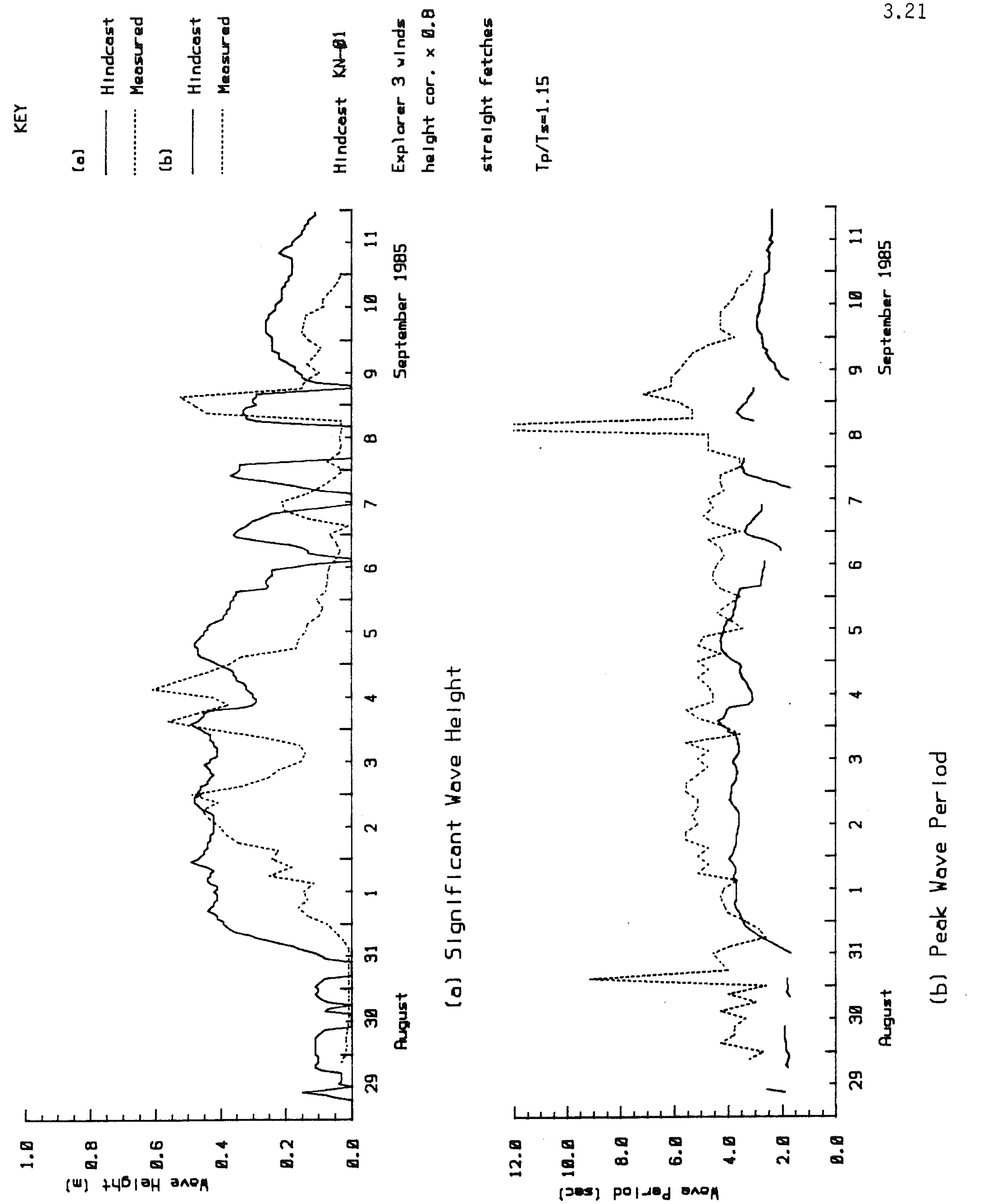
Date: 9 Apr 86

Scales as shown

Checked by:

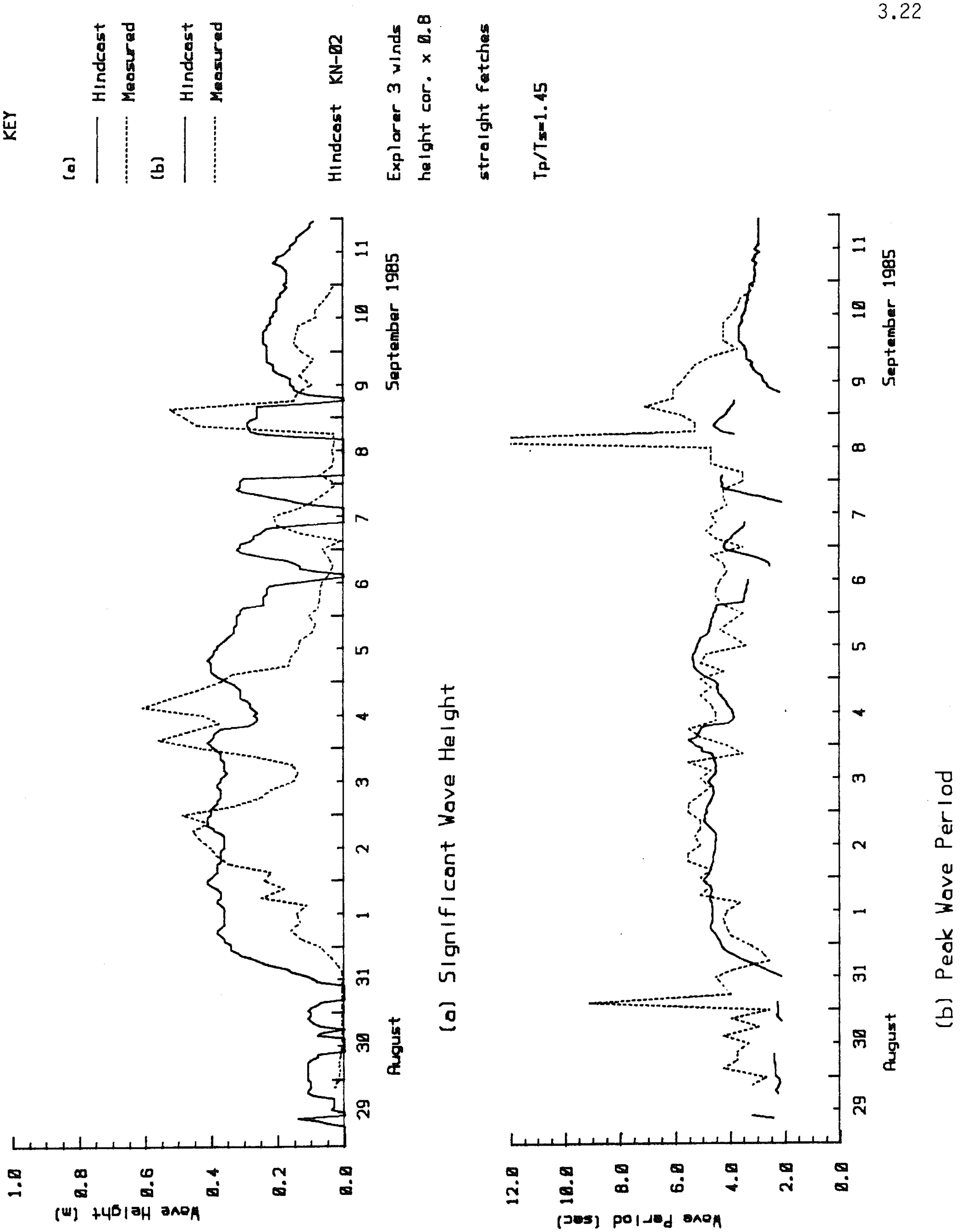
Keith Philpott Consulting Limited

FIGURE
3.21



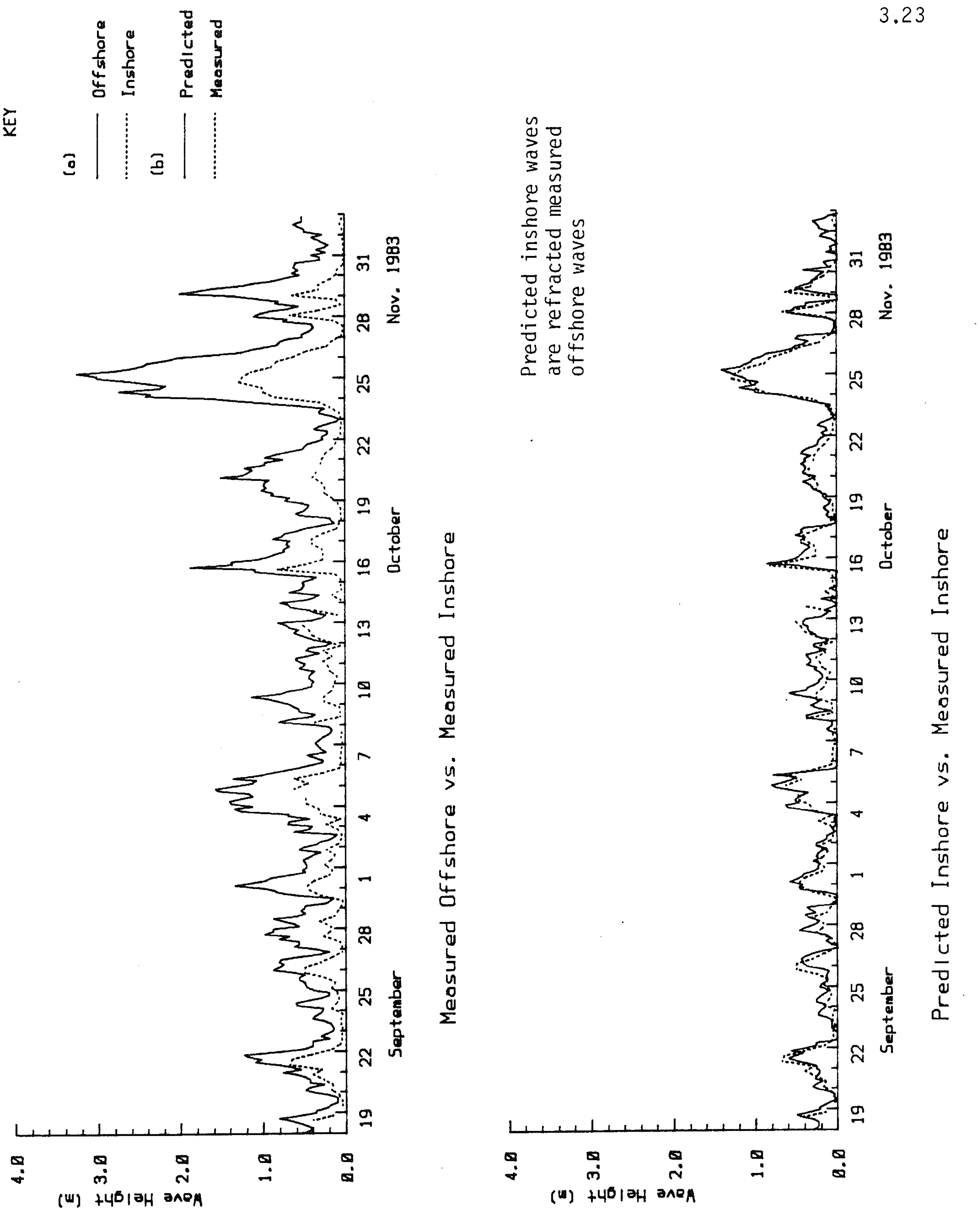
KING POINT SEDIMENT TRANSPORT STUDY	Date: 11 Feb 87
	Scales as shown
Comparison of Predicted and Measured Inshore Waves	Checked by:
Hindcast Run KN-01	Keith Philpott Consulting Limited

FIGURE 3.22



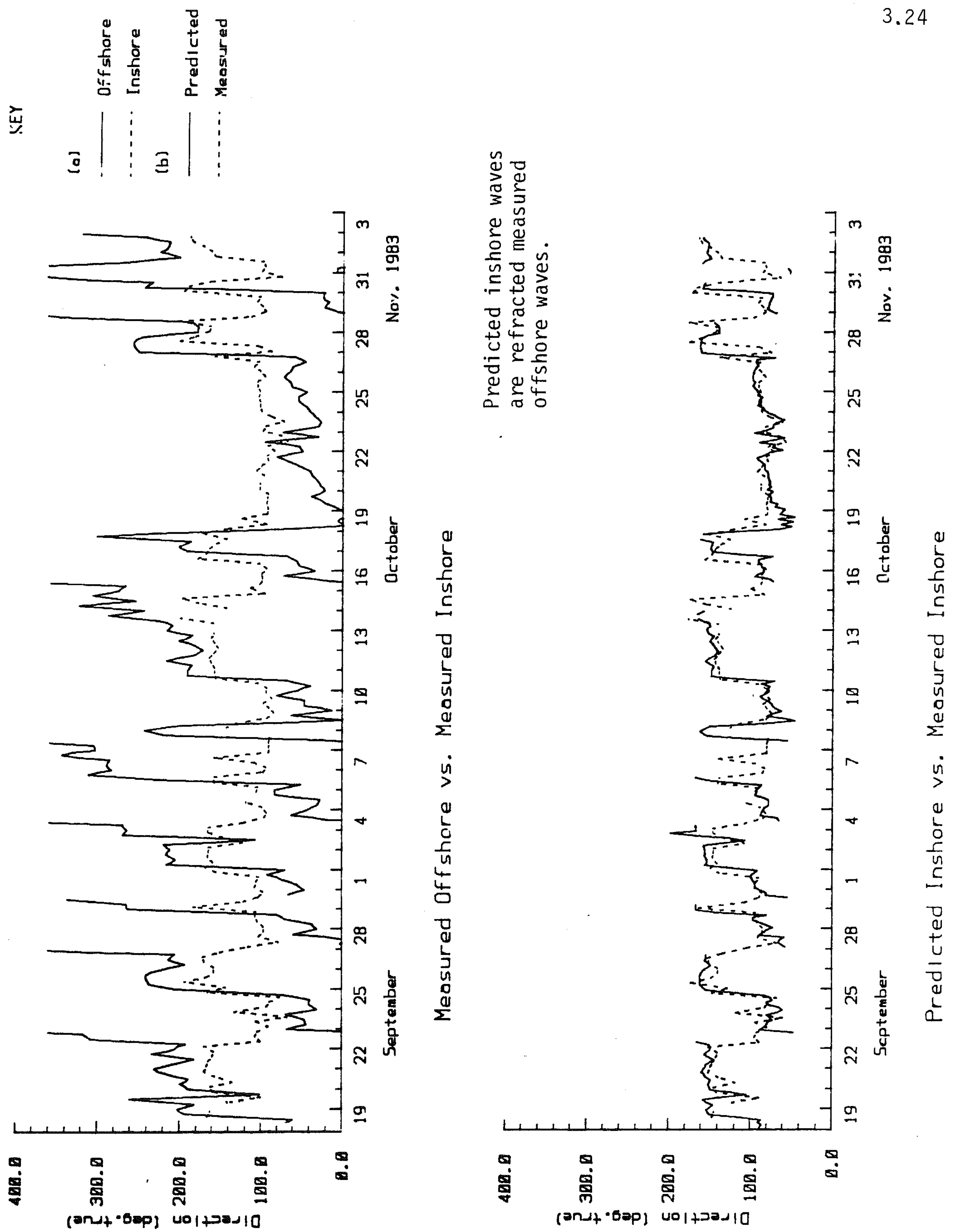
KING POINT SEDIMENT TRANSPORT STUDY	Date: 11 Feb 87
	Scales as shown
Comparison of Predicted and Measured Inshore Waves Hindcast Run KN-02	Checked by:
	Keith Philpott Consulting Limited

FIGURE 3.23

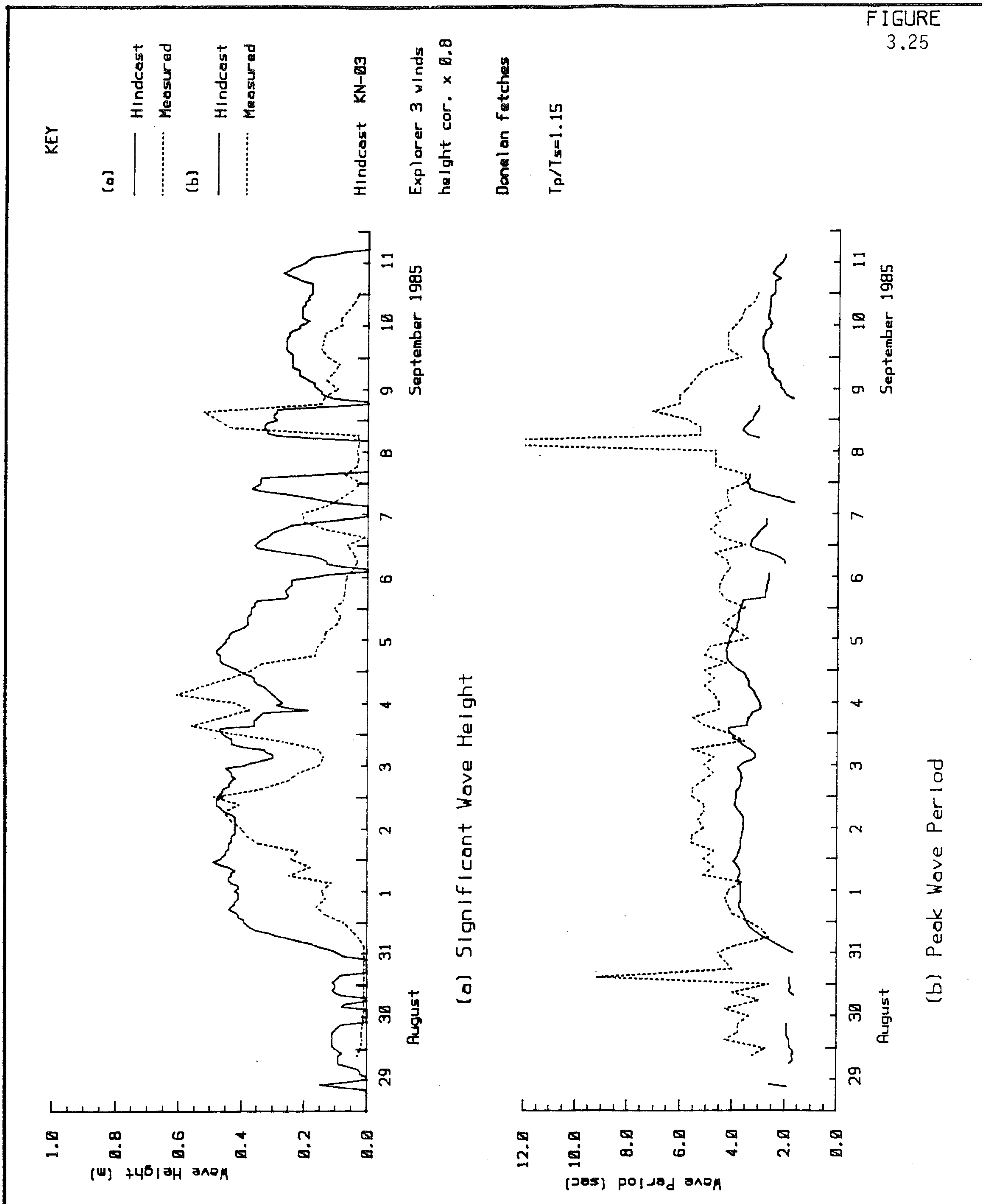


	Date: 2 Apr 86
	Scales as shown
	Checked by:
Effects of Wave Refraction on Wave Height	Keith Philpott Consulting Limited

FIGURE
3.24

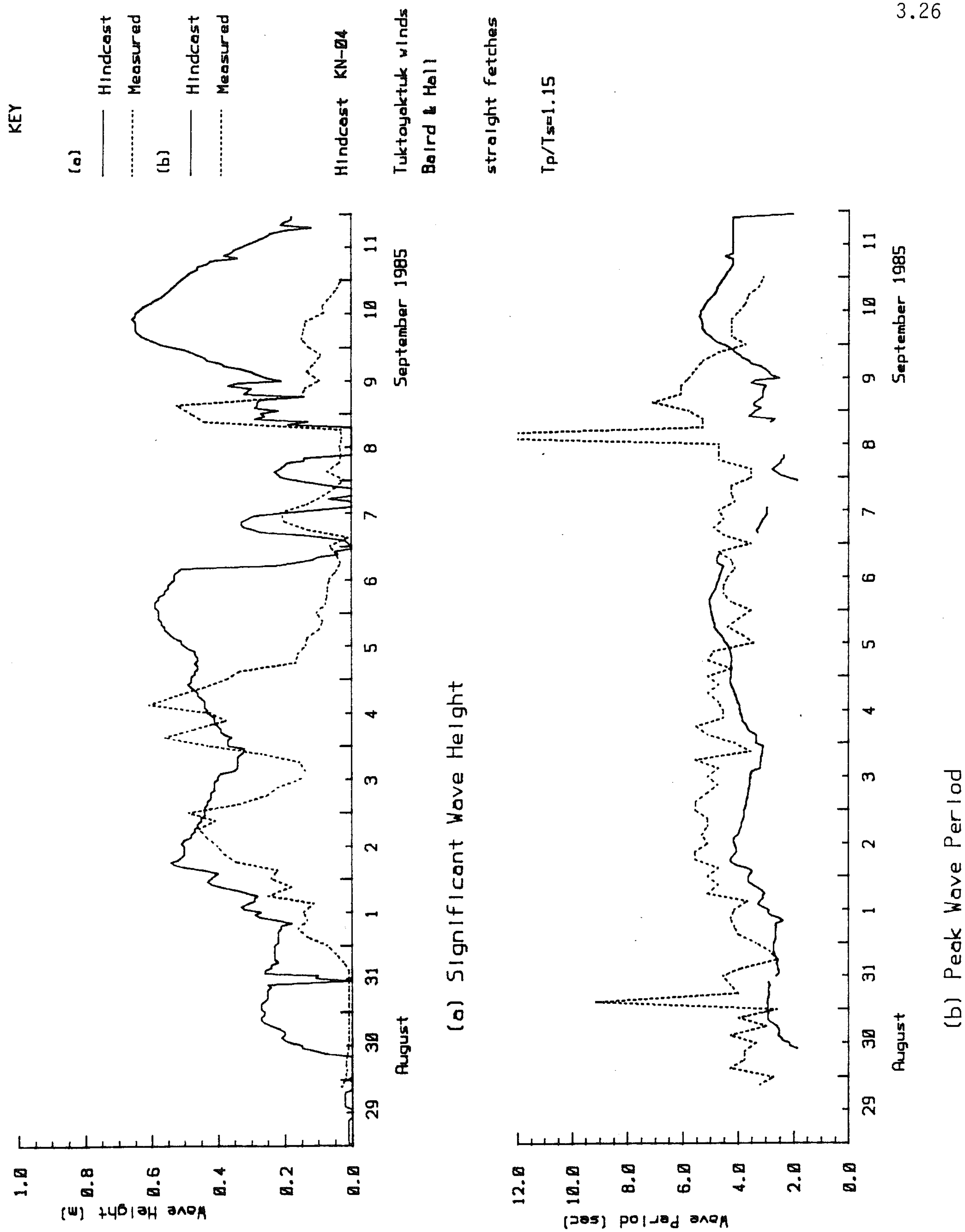


	Date: 2 Apr 86
	Scales as shown
Effects of Wave Refraction on Wave Direction	Checked by:
	Keith Philpott Consulting Limited



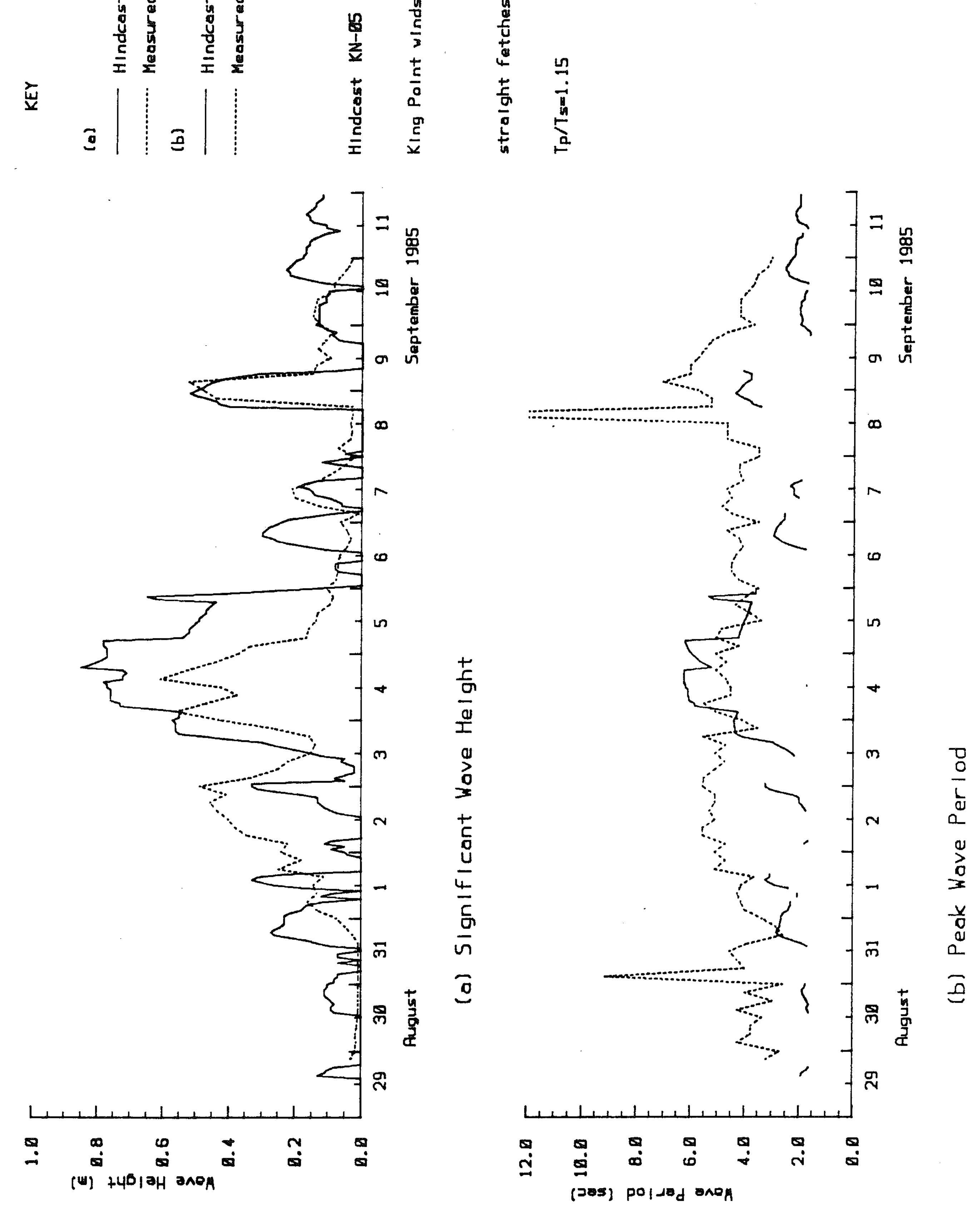
KING POINT SEDIMENT TRANSPORT STUDY	Date: 11 Feb 87
	Scales as shown
Comparison of Predicted and Measured Inshore Waves	Checked by:
Hindcast Run KN-03	Keith Philpott Consulting Limited

FIGURE
3.26



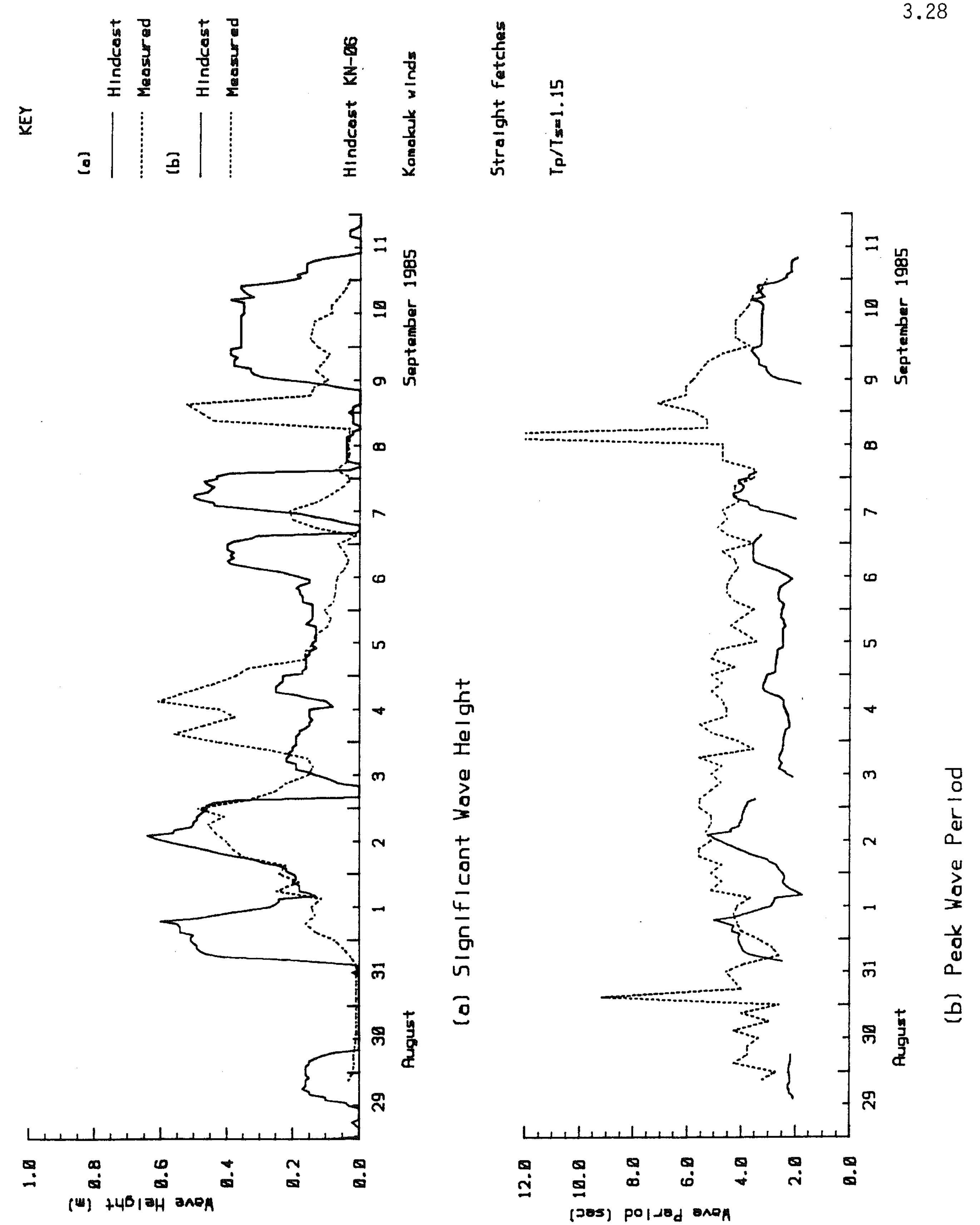
KING POINT SEDIMENT TRANSPORT STUDY	Date: 11 Feb 87
	Scales as shown
Comparison of Predicted and Measured Inshore Waves Hindcast Run KN-04	Checked by:
	Keith Philpott Consulting Limited

FIGURE
3.27



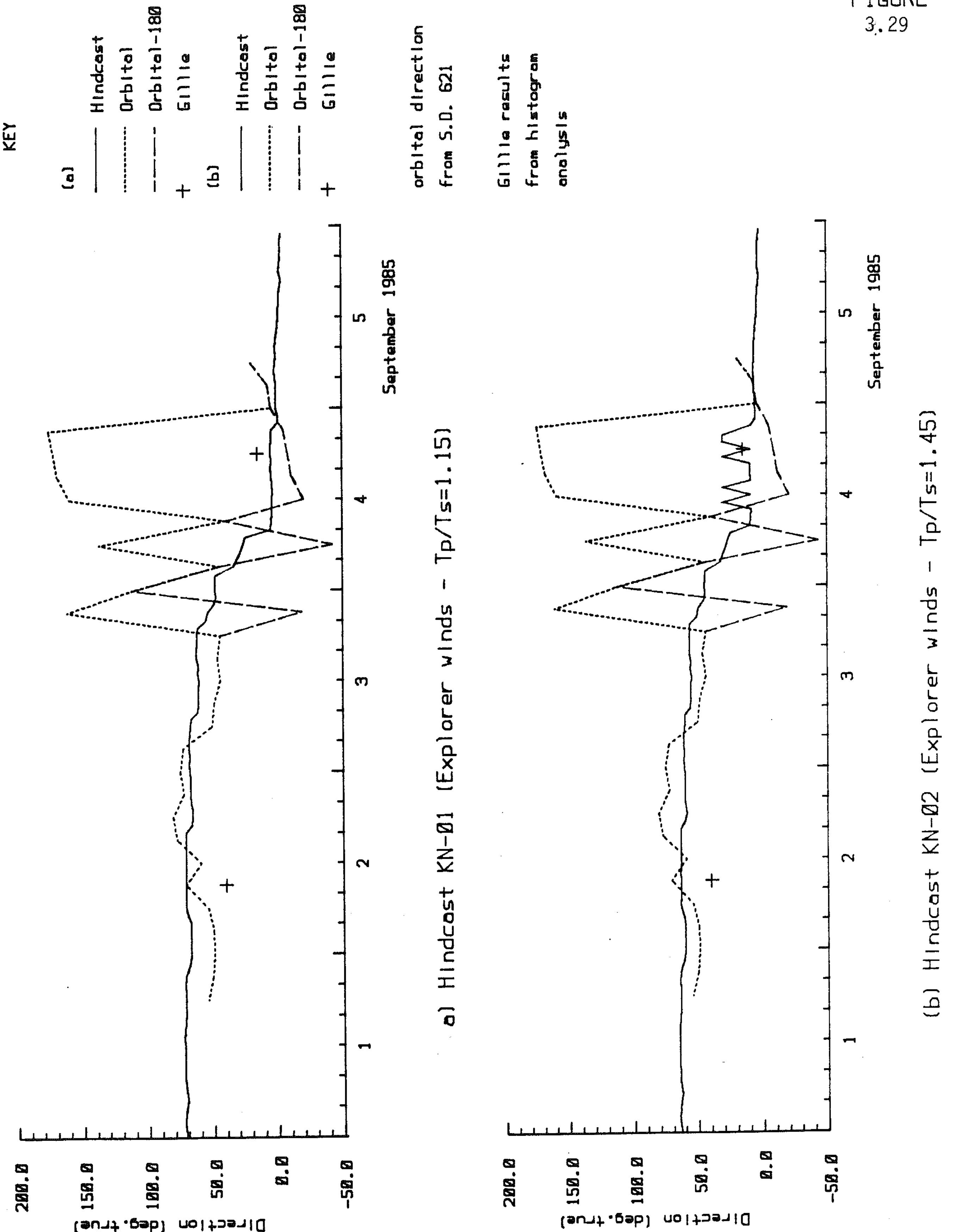
KING POINT SEDIMENT TRANSPORT STUDY	Date: 11 Feb 87
	Scales as shown
Comparison of Predicted and Measured Inshore Waves	Checked by:
Hindcast Run KN-05	Keith Philpott Consulting Limited

FIGURE
3.28



KING POINT SEDIMENT TRANSPORT STUDY	Date: 11 Feb 87
	Scales as shown
Comparison of Predicted and Measured Inshore Waves	Checked by:
Hindcast Run KN-06	Keith Philpott Consulting Limited

FIGURE
3.29

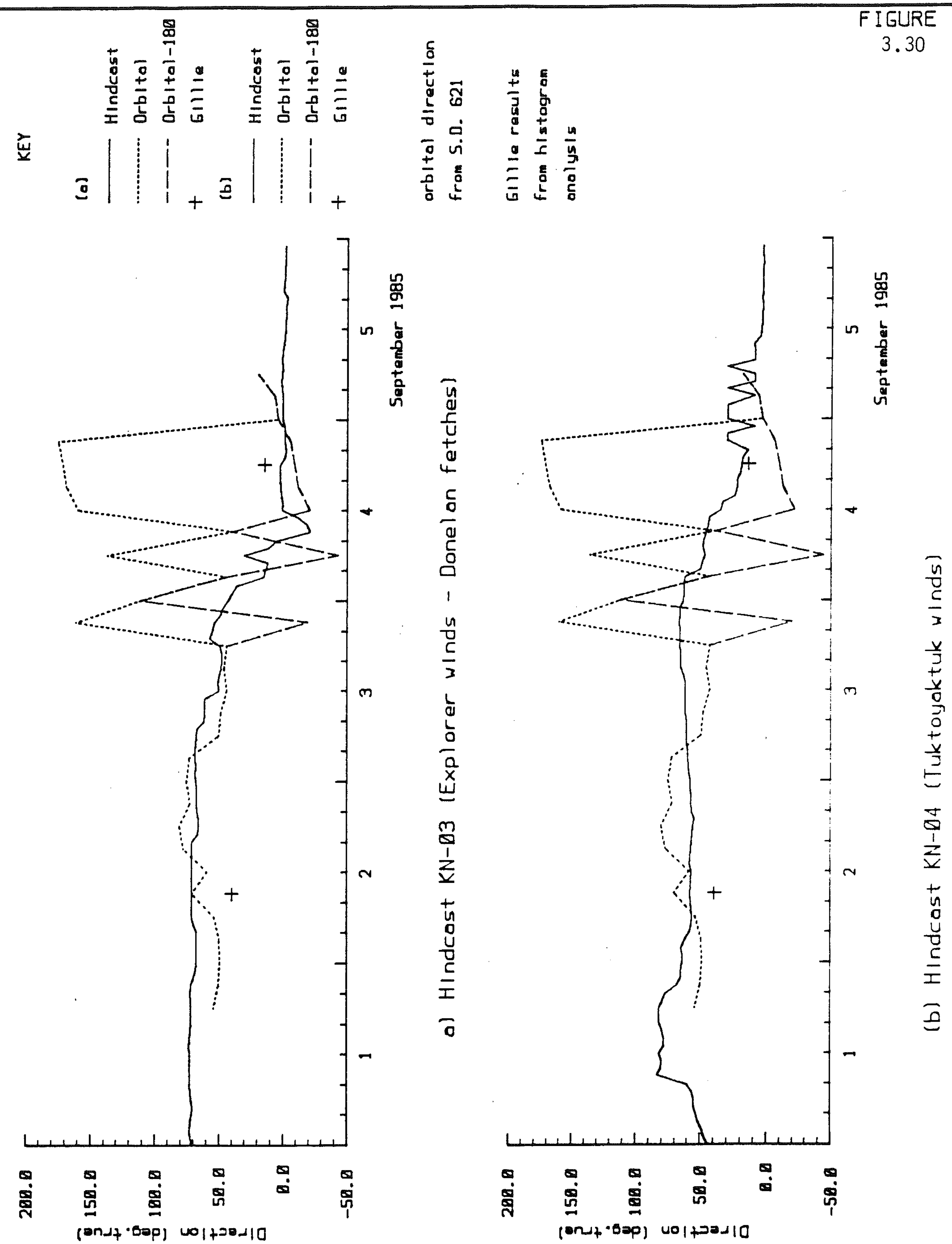


a) Hindcast KN-01 (Explorer winds - Tp/Ts=1.15)

(b) Hindcast KN-02 (Explorer winds - Tp/Ts=1.45)

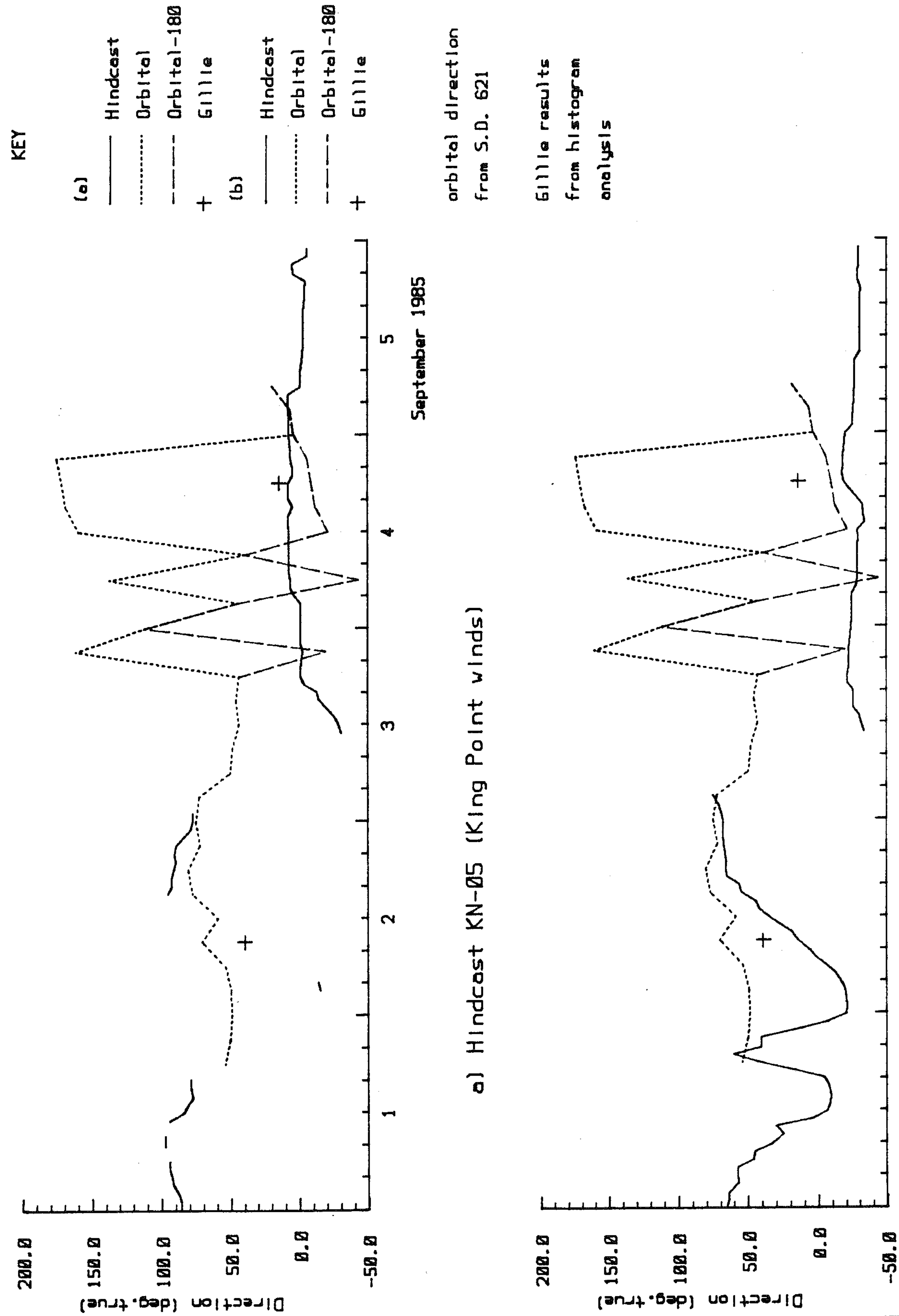
KING POINT SEDIMENT TRANSPORT STUDY	Date: 14 Feb 87
	Scales as shown
Comparison of Nearshore Wave Directions Hindcasts KN-01 & KN-02	Checked by:
	Keith Philpott Consulting Limited

FIGURE
3.30



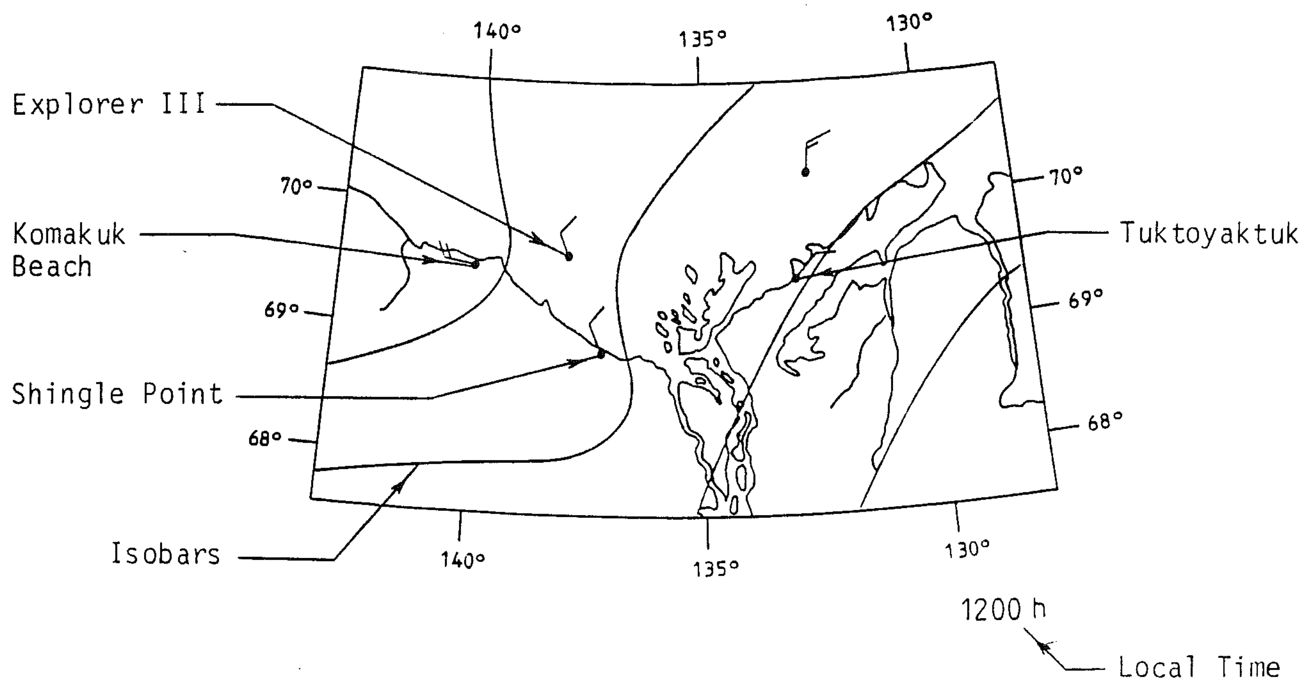
KING POINT SEDIMENT TRANSPORT STUDY	Date: 14 Feb 87
	Scales as shown
Comparison of Nearshore Wave Directions	Checked by:
Hindcasts KN-03 & KN-04	Keith Philpott Consulting Limited

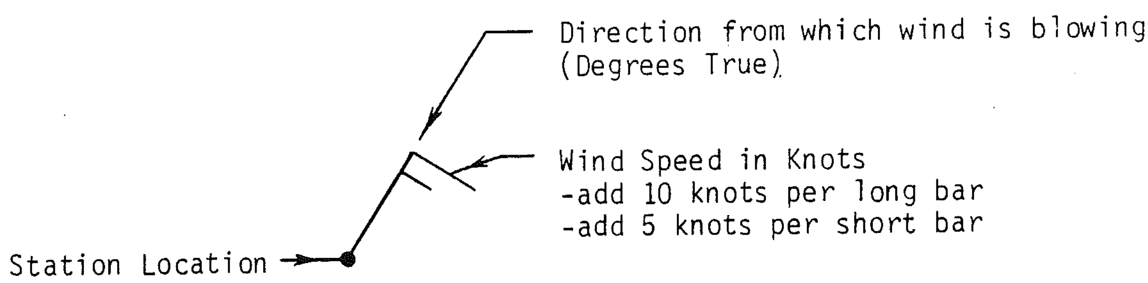
FIGURE 3.31



KING POINT SEDIMENT TRANSPORT STUDY	Date: 14 Feb 87
	Scales as shown
Comparison of Nearshore Wave Directions Hindcasts KN-05 & KN-06	Checked by:
	Keith Philpott Consulting Limited

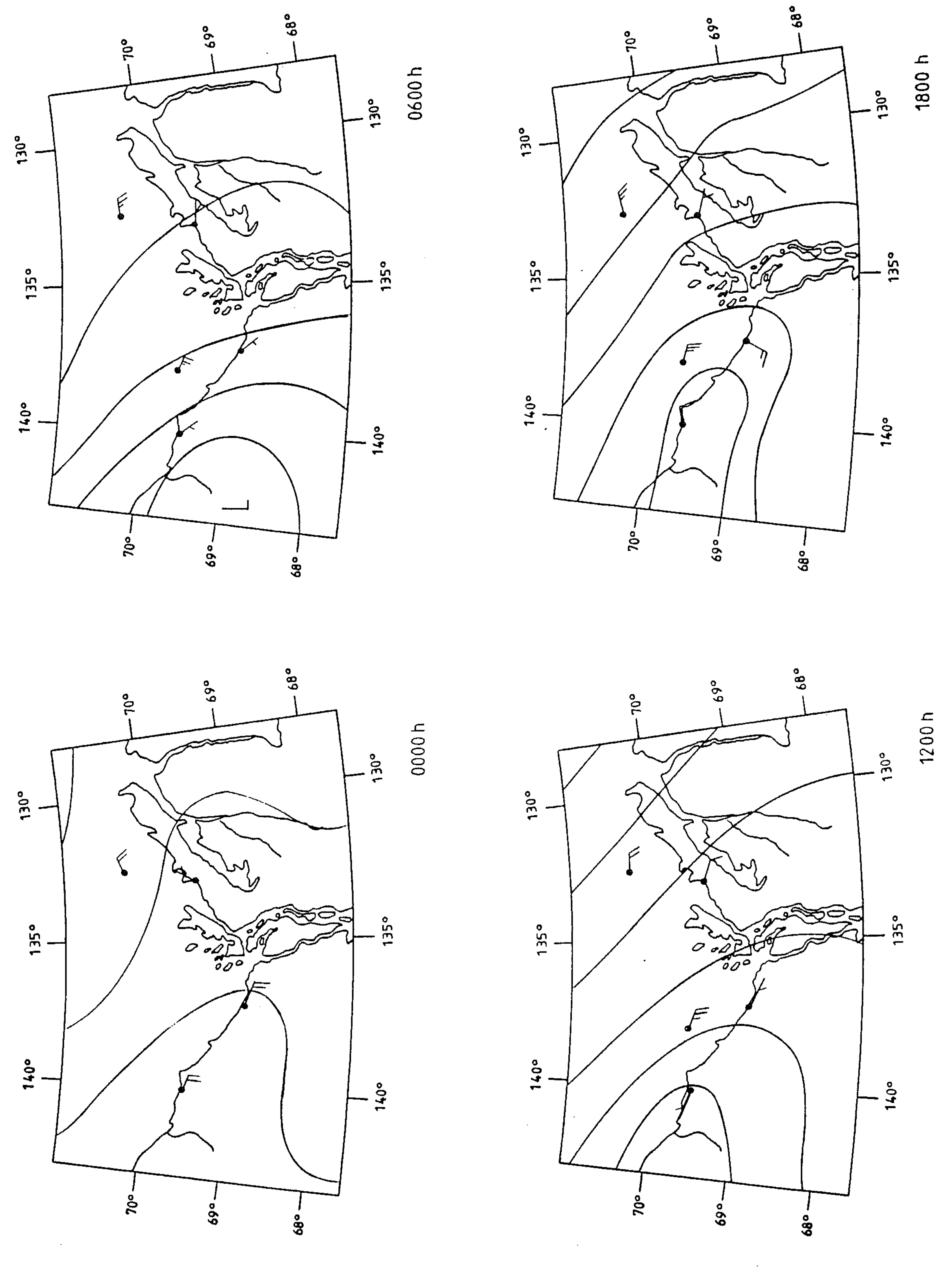
FIGURE
3.32





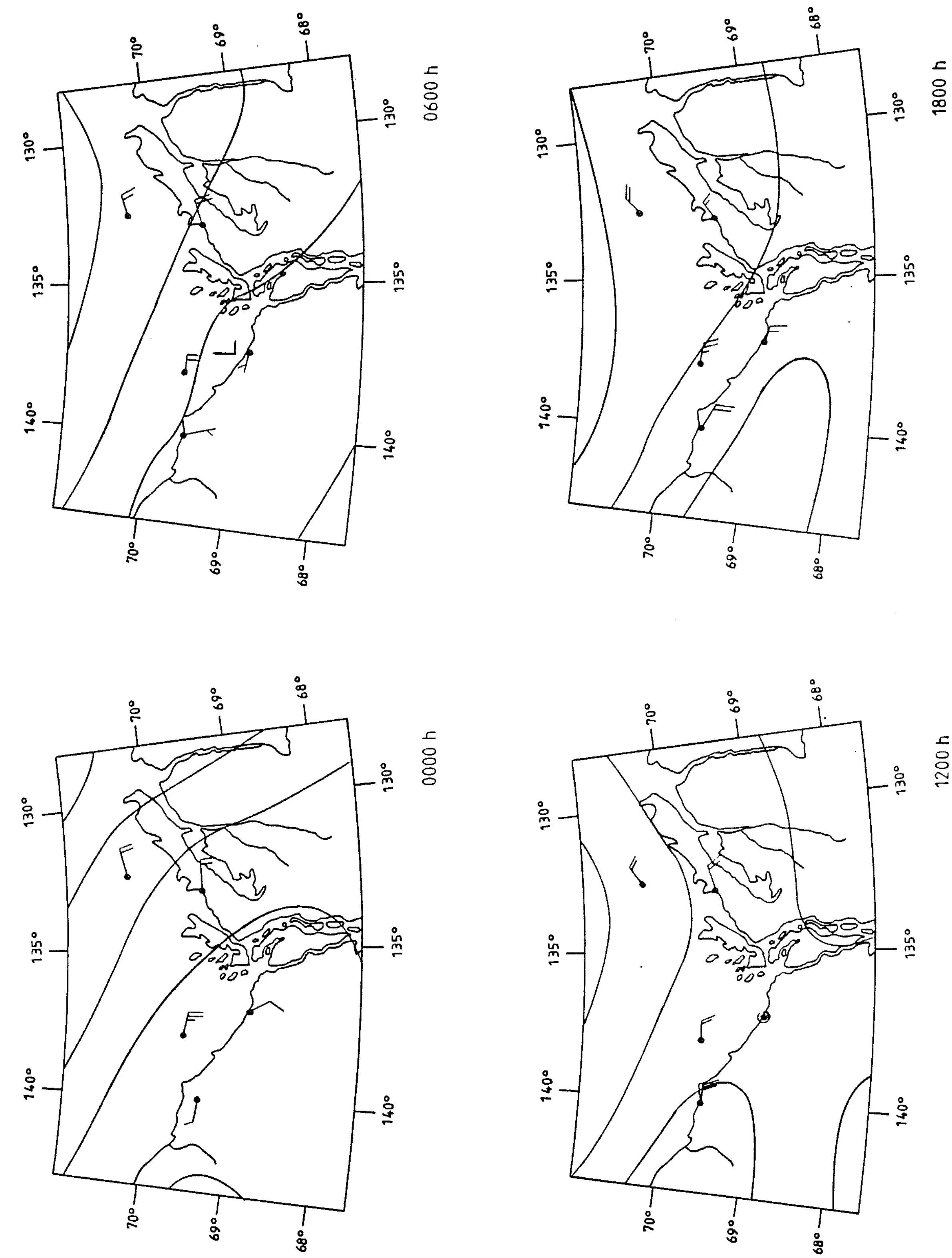
KING POINT SEDIMENT TRANSPORT STUDY	Date: 12 Feb 87
	Scales as shown
Key to Extracts from Synoptic Weather Charts	Checked by:
	Keith Philpott Consulting Limited

FIGURE 3.33



KING POINT SEDIMENT TRANSPORT STUDY	Date: 12 Feb 87
Extracts from Synoptic Weather Charts September 1, 1985	Checked by:
	Keith Philpott Consulting Limited

FIGURE
3.34



KING POINT SEDIMENT TRANSPORT STUDY

Extracts from Synoptic Weather Charts

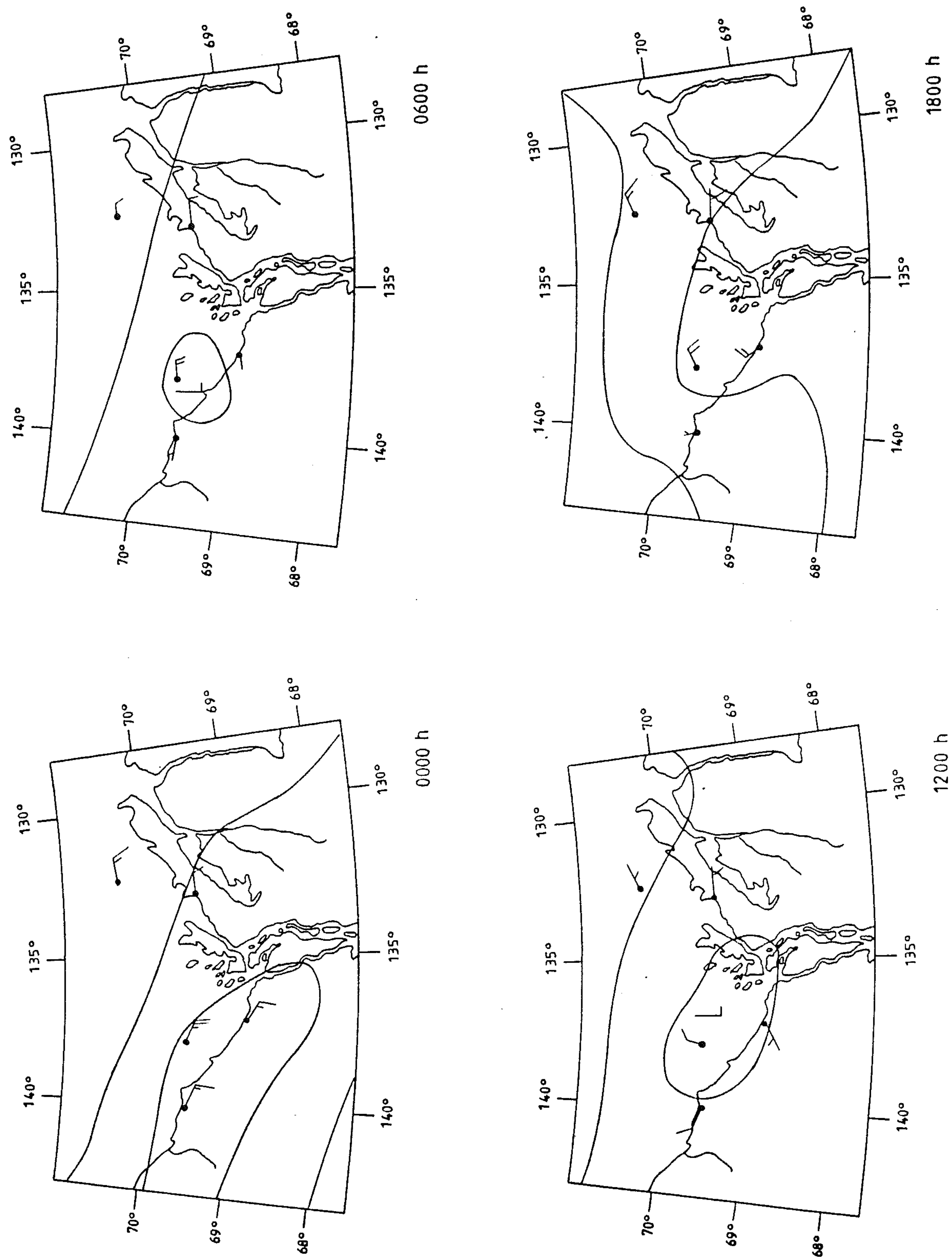
September 2, 1985

Date: 12 Feb 87

Checked by:

Keith Philpott Consulting Limited

FIGURE
3.35



KING POINT SEDIMENT TRANSPORT STUDY

Extracts from Synoptic Weather Charts

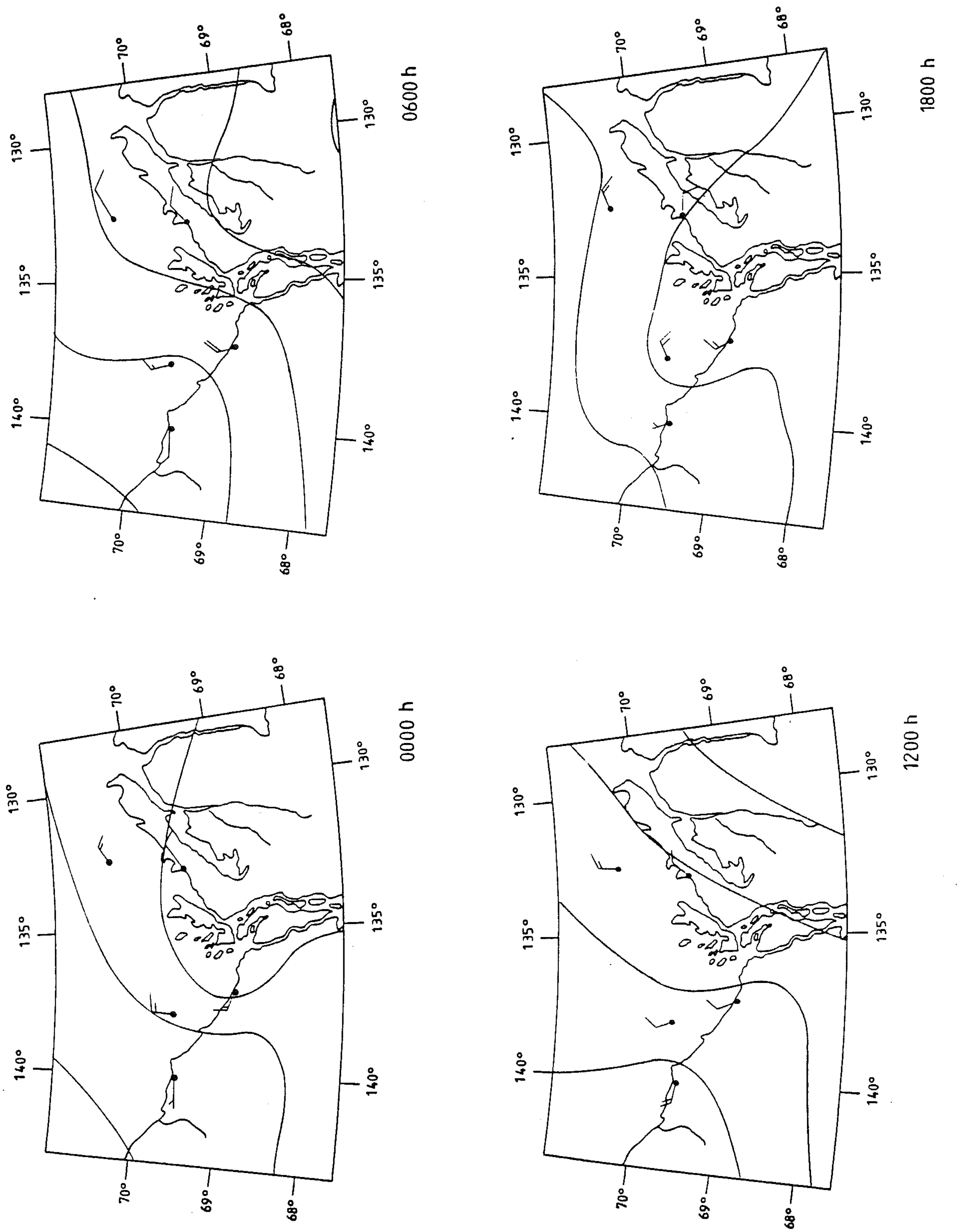
September 3, 1985

Date: 12 Feb 87

Checked by:

Keith Philpott Consulting Limited

FIGURE
3.36



KING POINT SEDIMENT TRANSPORT STUDY	Date: 12 Feb 87
	Scales as shown
Extracts from Synoptic Weather Charts September 4, 1985	Checked by:
	Keith Philpott Consulting Limited

FIGURE
3.37

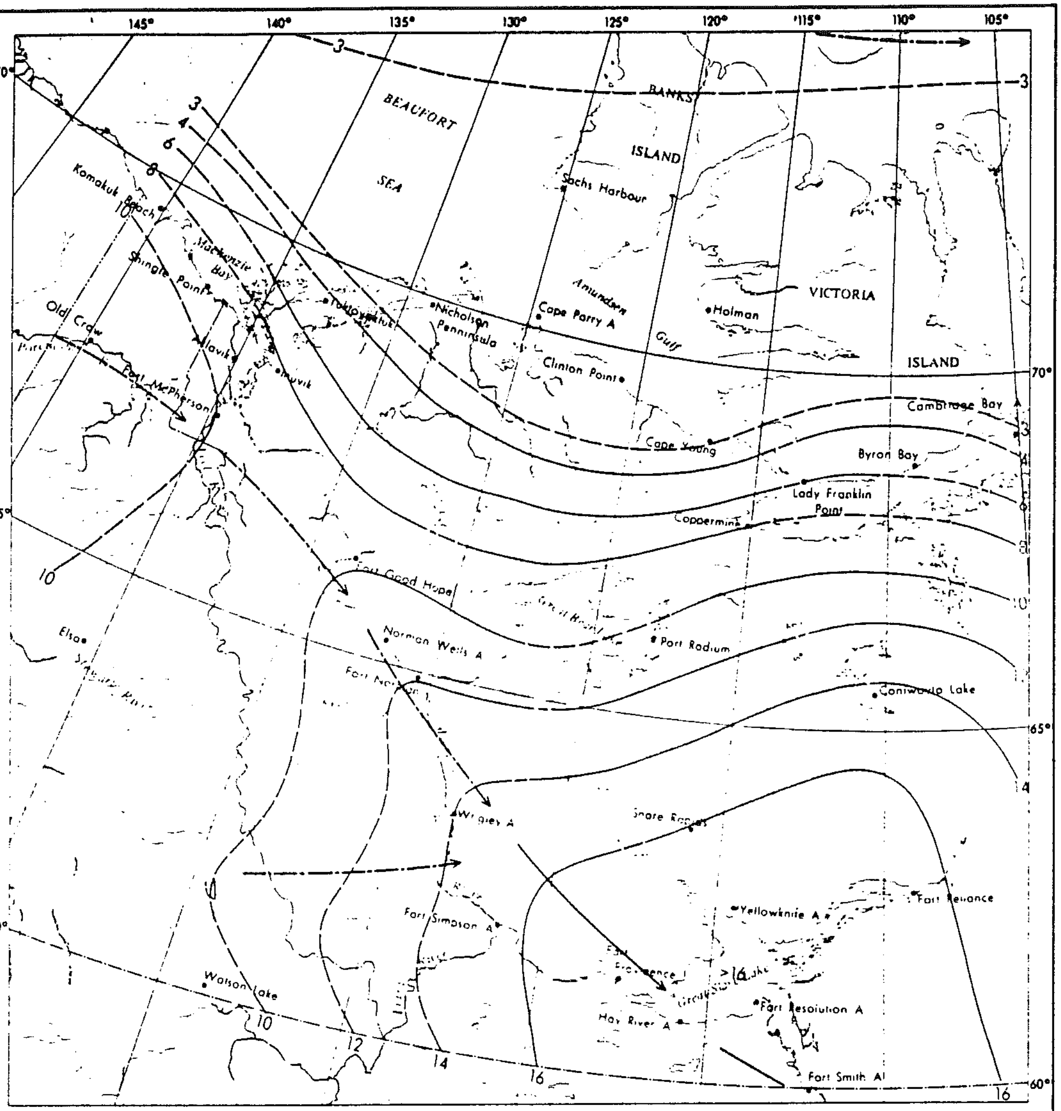


Figure 2.32
JULY
LOW TRAJECTORIES WITH PERCENTAGES
OF TIME THAT CYCLONIC CENTRES
OCCUPY A 10° LATITUDE BY 10° LONGITUDE
AREA (CENTRED AT 65°N 120°W)
Based on : Berry, et al (1953)
: Klein (1957)
: Prostjkova (1968)

from Burns 1973

KING POINT SEDIMENT TRANSPORT STUDY

Low Trajectories

Date: 18 Mar 87
Scales as shown
Checked by:
Keith Philpott
Consulting Limited

FIGURE
3.38

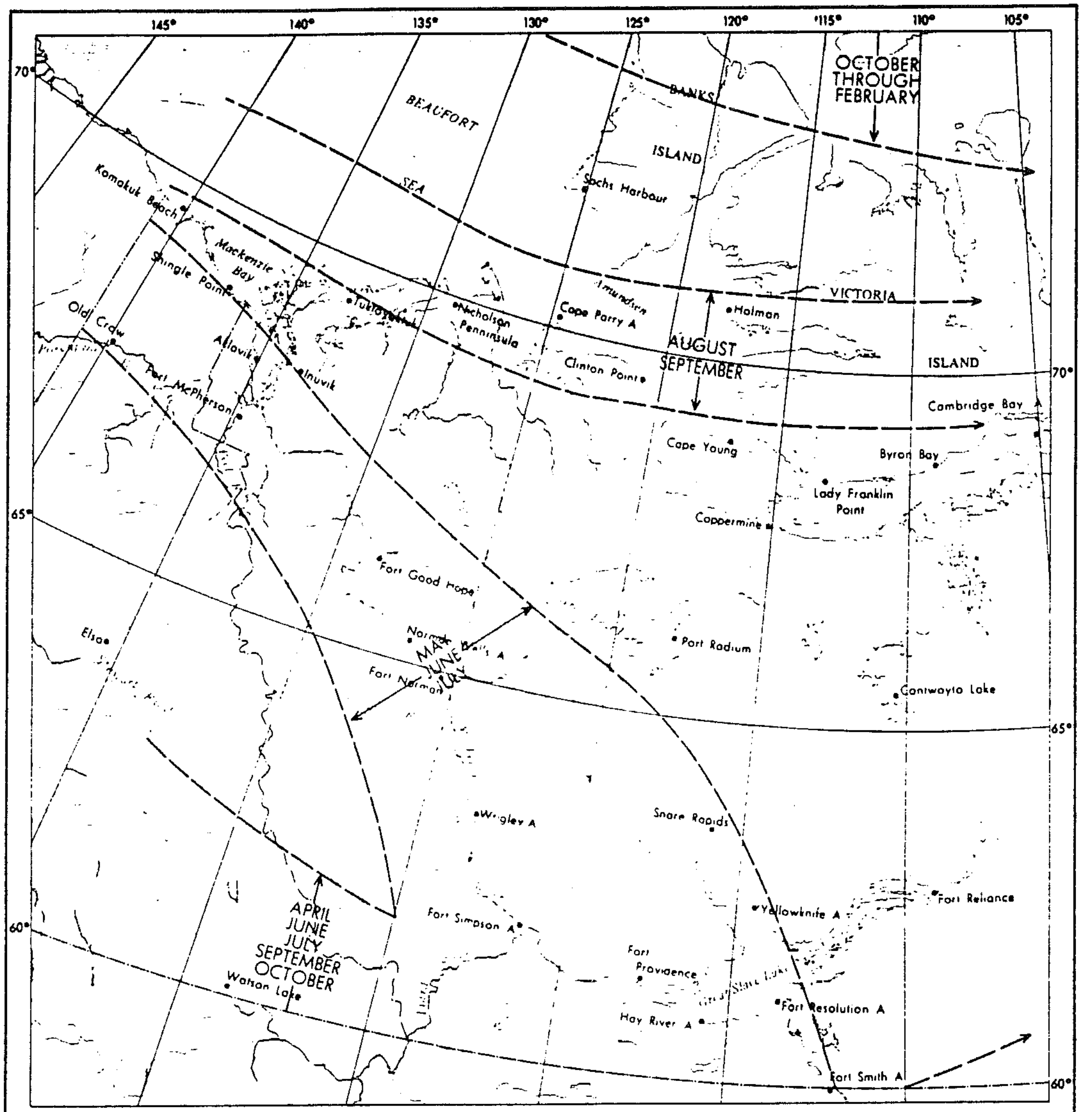


Figure 2.38
CORRIDORS OF 'SECONDARY' LOWS
Based on : Berry, et al (1953)
: Klein (1957)
: Prostjkova (1968)

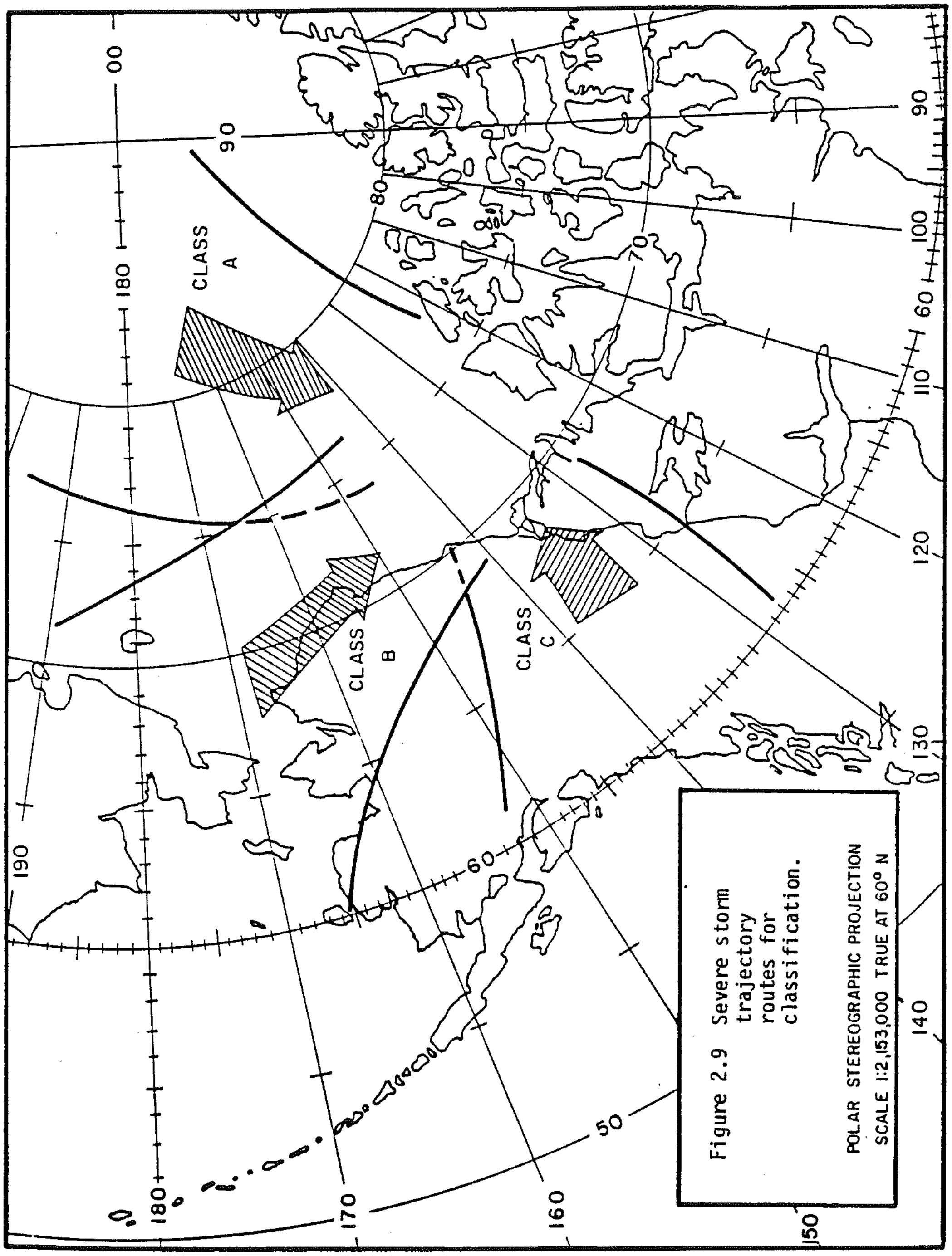
LEGEND
Border of Corridor of Secondary Lows

Scale in Statute Miles
100 50 0 100 200

from Burns 1973

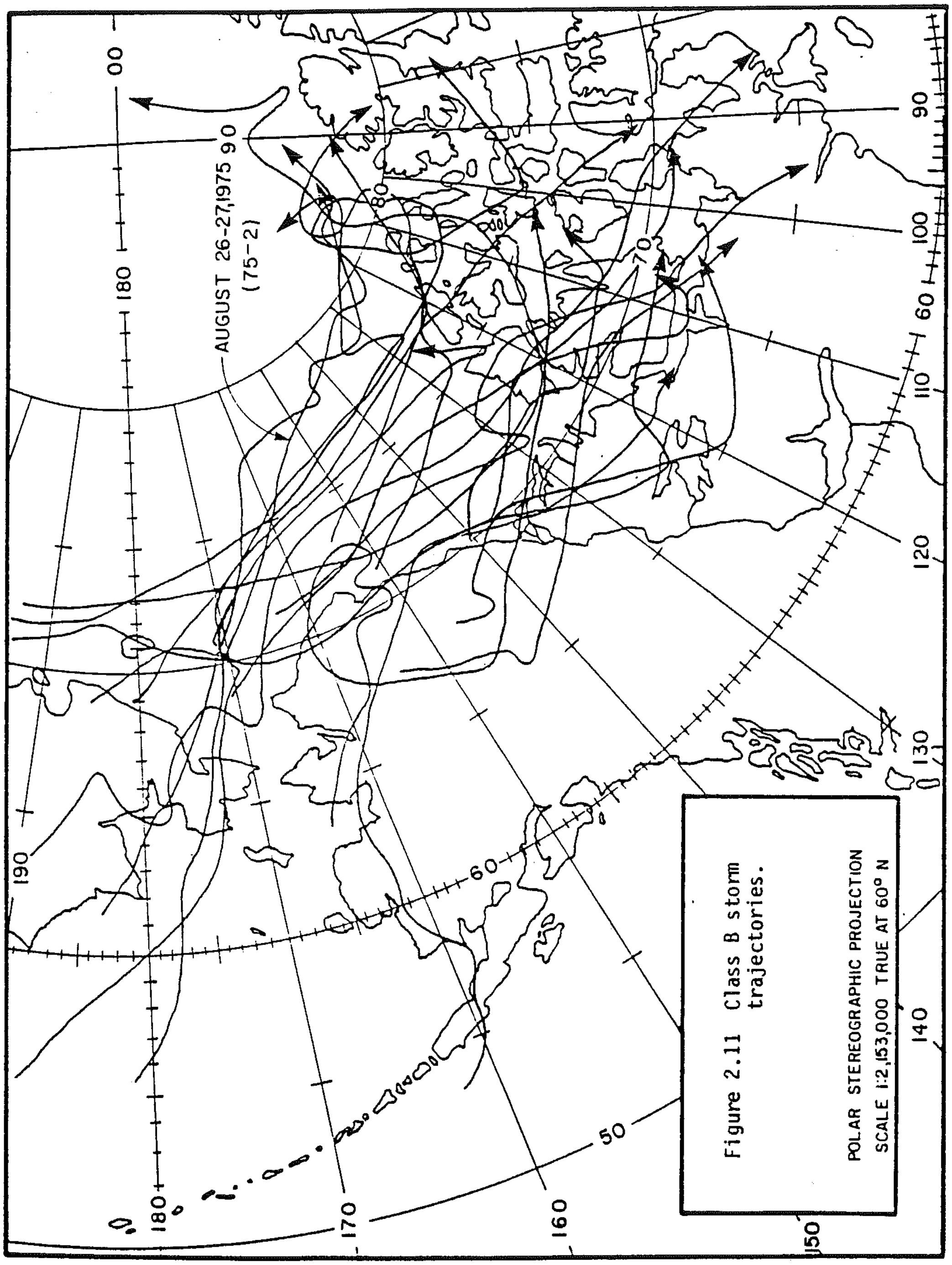
KING POINT SEDIMENT TRANSPORT STUDY	Date: 18 Mar 87
	Scales as shown
Corridors of Secondary Lows	Checked by:
	Keith Philpott Consulting Limited

FIGURE
3.39



from Hodgins and Harry 1982

KING POINT SEDIMENT TRANSPORT STUDY	Date: 18 Mar 87
	Scales as shown
Hodgins and Harry Severe Storm Trajectory Routes	Checked by:
	Keith Philpott Consulting Limited



from Hodgins and Harry 1982

KING POINT SEDIMENT TRANSPORT STUDY	Date: 18 Mar 87
	Scales as shown
Hodgins and Harry Class B Storm Trajectories	Checked by:
	Keith Philpott Consulting Limited

FIGURE 3.41

Score based on the value of the relative error statistic

$$e = \frac{H_p^x \cdot T_p^y - H_m^x \cdot T_m^y}{H_m^x \cdot T_m^y} \times 100\ \%$$

where
e = relative error
H = wave height
T = wave period
subscript p = predicted
subscript m = measured
x and y are user defined values for weighting

Points	Relative Error (%)
10	$e < 5$
9	$5 \le e < 7$
8	$7 \le e < 10$
7	$10 \le e < 11$
6	$11 \le e < 12$
5	$12 \le e < 15$
4	$15 \le e < 16$
3	$16 \le e < 17$
2	$17 \le e < 18$
1	$18 \le e < 20$
0	$e \ge 20$

KING POINT SEDIMENT TRANSPORT STUDY

Skill Test Procedure for Wave Hindcast Evaluation

Date: 7 Apr 86
Scales as shown
Checked by:
Keith Philpott Consulting Limited

4 Synthesis of Alongshore Currents

4. Synthesis of Alongshore Currents

4.1 Theoretical Considerations

Longshore currents are generated by waves breaking on a shoreline at an oblique angle. The detailed sediment transport predictors have been developed on the basis that wave action mobilizes the sediment while a superimposed current transports the mobilized sediment. Therefore, prediction of the longshore current distribution forms an integral part of the predictive process for sediment transport.

The longshore current magnitude and distribution in the surf zone is dependent upon:

a) breaking wave height and period
b) wave breaking angle
c) profile shape
d) bed roughness

Evaluation of a) and b) are usually provided by wave refraction analysis applied to an offshore climate or by direct measurements of the nearshore wave climate. The choice of the shore normal azimuth plays an important role here. Almost all present theoretical development is based on alongshore currents generated by spilling breakers. Some caution should be exercised in evaluating results for steep slopes and plunging breakers such as at King Point.

Roughness length is the parameter most open to question. In the absence of bedforms the roughness can be approximated as a function of the bottom sediment grain size (Kamphuis, 1975). In the presence of bedforms the roughness length is related to both ripple height and ripple steepness. Ripple height and steepness must be predicted and are a function of the fluid orbital motion at the bed, the grain size distribution and the density of the sediment. Since the wave parameters and often the sediment characteristics vary through the surf zone the bed roughness and friction factor should also vary through the surf zone. However, it is necessary to stipulate a single value for the current theories applied and accordingly the breaker line values are used. Bedforms measurements within the surf zone are very limited and consequently predictions are based on data under unbroken waves. While this will introduce significant error, it is the only option currently available to engineers.

4.2 Methodology

A complete description of the theory underlying the model used in this study is given in Fleming et al., (1984). This is based on an earlier publication (Fleming and Swart, 1982) in which the theories proposed by Battjes (1974) were adapted to allow for contribution to the shear term by longshore current itself. As well the friction coefficient was rationalized as a function of beach slope and both wave and current friction factors. The numerical model used for prediction of longshore currents has been described in some detail in Fleming et al. (1984) and Pinchin et al. (1985).

A basic input to the model is a time series of wave data at a nearshore point. This may be transformed from deepwater through a wave refraction analysis or may be directly measured. In this case the Sea Data 635-12 measurements of directional wave data provided nearshore values in a depth of 5.6 m, approximately 400 m from shore, (see Figure 4.2). Inshore of this point the model used plane bed refraction assumptions to determine breaker conditions and subsequent propogation through the surf zone. The errors associated with the recorded wave directions (see Section 2.2.2) were not discovered until after a large number of analyses had been performed. This point is discussed in more detail later.

The relative mass density of the sediment was taken as 1.65, the bed material porosity as 0.6 and the water temperature as 5 degrees Celsius. The grain size distribution required for different aspects of the computation was taken as follows:

D16	D25	D35	D50	D65	D75	D84	D90	
0.16	0.18	0.10	0.22	0.27	0.30	0.34	0.38	(mm)

This distribution was characteristic of the material 20 m offshore of the water line, near the bottom of the steep nearshore slope, and was assumed to be characteristic of material in the most active transport zone. The distribution was selected by averaging the distributions presented in Gillie (1985) from profile lines -200, -100, 0, and +100 shown in Figure 2.1. The sediment is much coarser in the swash zone.

The model calculates an effective beach slope for each wave condition. This is taken as the breaker depth to breaker distance ratio, the latter being the distance from the still water line to the breaker line. The assumed effective beach slope is therefore a variable dependent upon wave conditions, water levels and nearshore profile geometry. The beach profile is represented by a number of zones which should be small enough to be adequately represented by a single value of water depth. Figure 4.1 shows the profile which corresponds to field survey line 0+00 (Gillie, 1985).

As discussed in Section 2.2.2 it was discovered during the course of this study that the recorded wave directions from the Sea Data 635-12 directional wave gauge were erroneous. This discovery was made in part due to the results of the alongshore current synthesis. Because the wave directions were not correct it follows that the predicted breaker angles and thus the predicted alongshore currents were also not correct. This means that only a qualitative assessment of the model behaviour under various conditions can be presented. It was not possible, on the basis of the available data, to determine which combination of theories and parameters produced the best results.

The parameters and theories examined included water level, alongshore current model, mixing parameter, friction factor, shoreline normal azimuth and wave climate. In the previous study (Pinchin et al., 1985) the water level was assumed constant at the mean water level because a full fourteen years of tide data was not available. The alongshore currents were calculated based on the Battjes (1974) theoretical approach. This solution used a momentum balance equation with radiation stress as the driving force and bed shear as the resisting force. The Battjes model considers linear random waves based on a Rayleigh distribution of wave heights in shallow water. The roughness length was taken as an expression proposed by Swart (1976a) which includes both ripple height and ripple steepness as computed using the methods of Swart and Lenhoff (1980).

In this study tide level data was available, allowing the model to change the water level with each wave condition. This meant that the water line could move up and down the profile, allowing different effective slopes for similar wave conditions. This could in turn cause a different current velocity distribution across the profile. Both constant and variable water levels were examined.

A second alongshore current theory was considered following the approach of Longuet-Higgins (1970a,b). Like the Battjes (1974) model this model is based on a momentum balance equation with radiation stress and bed shear, but it considers regular rather than random linear waves. A lateral mixing parameter is required to prevent a current discontinuity seaward of the break point.

Four roughness models were used for comparative purposes. Kamphuis (1975) proposed a flat bed roughness of 2xD90 based on grain size roughness alone. (D90 refers to the grain size for which 90% of the sediment distribution by weight is smaller) Swart (1976a) proposed a bedform roughness model utilizing ripple length and ripple steepness. These values were determined using the prediction techniques of Nielson (1978), Swart and Lenhoff (1980) and Mogridge and Kamphuis (1972).

The three bedform roughness models may be used to determine both ripple height and ripple length as a function of local water depth, wave height, wave period, sediment size and relative sediment density. These formulations are essentially empirical and primarily based on physical model tests together with some limited field data.

Each of the formulations was developed from data under unbroken waves and application within the surf zone may not be entirely valid. However, it is the only approach currently available. As well as the four roughness models (the Kamphuis flat bed model and the Swart roughness models using three ripple prediction techniques a fixed friction coefficient of 0.01 was also considered.

As discussed previously it was determined that the measured wave directions from the Sea Data 635-12 wave gauge were incorrect. An estimate of the order of the error was made by varying the shoreline normal azimuth, which has the same effect as changing the wave approach angle or the offshore wave direction. Alongshore current predictions were also made with the wave height and period from the Sea Data 635-12 wave gauge but with directions from the Sea Data 621 gauge. As well three hindcast nearshore wave data sets were considered.

It is clear from the above that there is a possibility of examining a very great number of combinations of roughness model, grain size variation, water level variation and measured or predicted wave climates. As indicated earlier, generally the measured wave climate was used. Based on experience in a similar study (Canadian Coastal Sediment Study, Fleming et al., 1986) a series of model runs was selected to elucidate the differences between the two longshore current theories and the influence of different variables used as input. The longshore current model runs considered are summarized in Table 4.1 and below:

i) The initial model run examines the Battjes (1974) longshore current model with Swart and Lenhoff (1980) ripple model and a constant (mean) water level.

ii) The variation of friction factor through the use of different ripple roughness and grain roughness models is investigated for the Battjes (irregular wave, no mixing) version of the longshore current model and a variable water level. (Runs 2-5).

iii) Longuet-Higgins' current model (monochromatic waves with mixing parameter) is examined at constant and variable water levels with Swart and Lenhoff ripple generation and with a constant friction factor (0.01). Also, the effect of the mixing parameter, P is tested. (Runs 7-10).

iv) Using the Battjes model the sensitivity of currents to the shore normal azimuth is examined for variable water level with the Swart and Lenhoff ripple generation (Runs 11 and 12).

v) Lastly the longshore currents are determined from different wave climates using the Battjes model with Swart and Lenhoff ripples and variable water levels. The wave climates include the Sea Data 635-12 measured wave heights and periods with the synthesized Sea Data 621 wave directions (Run 13) and hindcasts using Explorer III, Tuktoyaktuk and King Point wind data (Runs 14-16 respectively).

4.3 Discussion of Results

Prior to evaluating the current models and the various parameters, some mention should be made of the relationship between the currents measured by the Sea Data 621 instrument and the actual wave induced currents within the surf zone.

As discussed earlier, the Sea Data 621 instrument was located well outside the surf zone during the period examined. Although alongshore currents generally diminish rapidly beyond the surf zone the Sea Data 621 still measured appreciable currents. Assuming the measurements are accurate, this leads to two possible scenarios; a) conventional theory does not apply to this very steep beach and associated plunging breakers; and/or b) the currents are not wave induced.

Visser (1984) conducted laboratory experiments with regular waves and found the alongshore current distribution did extend twice the breaker distance offshore even for plunging breakers.

The Sea Data 621 current measurement instrument was located in the 7th profile zone seaward of the still water level (Figure 4.1). With only one exception all of the test runs using the measured wave data failed to predict any significant currents at the instrument location. For this reason predicted currents were usually plotted for profile zones 1, 2, and 3.

The effects of allowing a variable water level can be seen in Figure 4.3. It is difficult to discern the water level effect since the fluctuations are almost entirely due to the semidiurnal tides with no evidence of surges. As one might expect the greatest change took place in zone 1, the zone closest to shore. With the constant water level (Figure 4.3a) the current in zone 1 tends to be more steady than in the other zones, exhibiting longer durations of relatively constant current.

The current in zone 1 with the variable water levels, however, is much less steady and actually follows the trends of the water level fluctuations. The differences between the constant and variable water levels in zone 2 are not significant. As zone 2 contains by far the highest currents it can be concluded that the effect of considering variable water levels due to tides only is not of major importance at King Point.

The effects of the four different roughness generators and a constant friction factor on the Battjes model with a variable water level are shown in Figures 4.3b, 4.4, and 4.5. The Mogridge/Kamphuis ripple roughness causes a reduction of the predicted current, compared to Swart and Lenhoff, throughout the period examined. The Nielsen ripple model, the Kamphuis 2D90 flat bed model and a constant of 0.01 respectively predict increasingly higher currents. The actual friction factors calculated for each of the four models are presented in Figure 4.6a and may be compared to the often assumed constant value of 0.01. In general, the friction factors were lowest during the larger waves. Roughness varied from the greatest to the least in the order of Mogridge and Kamphuis, Swart and Lenhoff, Nielsen and 2D90 with all values greater than 0.01. It is interesting to observe that during the periods of largest waves when bedforms may be washed out or flattened the Nielsen ripple generator predicted values approach the Kamphuis 2D90 predictor which is indeed for flat beds.

The variation of the friction factor generated with the Swart/Lenhoff model due to water levels is shown in Figure 4.6b. Compared to the variation between the different roughness models the water level variation is insignificant. However, the friction factors do show a trend to decrease as water level increases.

Figures 4.7 and 4.8 show results from the Longuet-Higgins current model with constant and variable water levels, different values of the mixing parameter P and constant (0.01) versus Swart and Lenhoff friction factors. From Figure 4.7 it can be seen that the effect of variable water levels with the Longuet-Higgins current model was even less notable than with the Battjes model. As with Battjes the use of a constant friction factor of 0.01 caused an extreme increase in the predicted currents. The influence of the Longuet-Higgins mixing parameter can be seen in Figure 4.3 A mixing parameter of P = 0.2 predicts a current higher than Battjes whereas a mixing parameter of P = 0.9 predicts a lower current than Battjes.

The influence of the shoreline normal azimuth was investigated with the Battjes current model and the Swart and Lenhoff friction generator. Changing the shore normal azimuth is analogous to transposing the measured wave directions, by 7 degrees in Figure 4.10a and by 30 degrees in Figure 4.10b.

Clearly the pattern of predicted currents in the latter figure was the only example to resemble the trend of measured currents. It was this match that in part led to the conclusion that the measured directions from the Sea Data 635-12 wave gauge were in error by about 30 degrees.

Figure 4.11 shows the currents predicted with the Battjes velocity model and Swart and Lenhoff friction generator when the synthesized directions from the Sea Data 621 wave gauge were substituted for the erroneous measured directions from the Sea Data 635-12 gauge. Only the peak in currents measured early September 4 was predicted.

Figures 4.12 to 4.14 show the results of the current predictions made with the hindcast wave data. Clearly none of these predictions match the measured currents. Each of the analyses with alternate wave climates (Runs 13 to 16) used variable water levels, Battjes currents and Swart and Lenhoff frictions. These results should therefore be compared to Run 2 (Figure 4.3). Aside from the variable water level, which was not found to have a significant effect, this was the method used in the previous study (Pinchin et al., 1985).

Sherman and Greenwood (1985) have shown that wind stress exerts a significant force in driving the alongshore currents. In a study of a barred beach profile on the Canadian Great Lakes they found wind stress accounted for between 50 and 90 percent of the measured current for the particular study site. Obviously the wind-driven component is most significant when the wind direction is parallel to the shoreline.

There are two periods where the winds are relatively shore parallel but blowing on a slightly onshore direction. These periods as from 1200 h to 2400 h September 2 and from 0300 h September 4 through the end of current measurements, as shown in Figure 4.15. During both of these periods, there is a good correlation between the wind speed and alongshore current, with the exception of about the last 7 hours of September 3, where the wind speed is relatively steady but the alongshore current is still increasing.

Considering the findings of Sherman and Greenwood (1985), it is likely that the measurements of currents were effected by wind stress. This possibility was not examined within the terms of reference of this study but certainly deserves consideration.

4.4 Conclusions

The following conclusions are based on a qualitative assessment of the predicted alongshore currents. Because of the errors associated with the measured wave directions and the location of the current sensor, no quantitative evaluation can be made.

The measured currents were much higher than had been was anticipated, considering that the location of the recording station was well outside the surf zone. In the discussion of results it was assumed that predicted currents that followed the same trend as the measured currents were more realistic than predicted currents that didn't. However, this may not be an entirely valid assumption, particularly when the reasons for the high predicted currents have not been resolved. A likely explanation for the strong currents outside the surf zone is wind stress, in which case the currents within the surf zone would be similar to the measured values outside the surf zone. The effects of wind-generated currents may be important at King Point considering that local weather conditions often result in shore parallel winds during the open water season. However, the significance of wind-induced currents cannot be truly evaluated without measured currents in the surf zone, and preferably during significantly larger wave conditions than were encountered during this study.

The consideration of variable water levels had a negligible effect on the predicted alongshore currents because only tide level fluctuations were considered, not surges. The maximum tidal variation during this period was less than +/- 0.2 m. It can therefore be concluded that not considering variable water levels at King Point did not have an adverse effect on the results from the earlier study (Pinchin et al., 1985). The effects of storm surges on alongshore sediment transport were investigated in that study.

The predicted currents following the Longuet-Higgins (1970a,b) and Battjes (1974) theories were similar. It was not possible to conclude whether one was more accurate than the other.

The friction factors computed with the three ripple generators were all higher than those computed with the flat bed grain roughness. The computed friction factors from these four methods were all higher than the constant value of 0.01. Longuet-Higgins suggested that the friction factor should be in order of 0.01 but this has been interpreted by many to mean exactly 0.01. This, according to the four theories, is not the case at King Point.

Again, because of the errors associated with the measured wave directions and the uncertainties associated with the measured currents it was not possible to conclude that any friction factor model produced better results than the others. The Swart and Lenhoff (1980) ripple model, which was used in the previous study (Pinchin et al., 1985) produced roughly average results with respect to the other models.

The different wave climates had a significant effect on the predicted currents, but the poor quality of the different climates prevented any real assessment of the behaviour of the alongshore current models.

Table 4.1 Alonghsore Current Predictions

Run	Water Level(1)	Current Model(2)	Mixing Parameter	Friction Model(3)	Shoreline normal (true)	Wave Climate(4)	Figure
1	C	B		S/L	31	635	4.3
2	V	B		S/L	31	635	4.3
3	V	B		M/K	31	635	4.4
4	V	B		N	31	635	4.4
5	V	B		2D90	31	635	4.5
6	V	B		0.01	31	635	4.5
7	C	L-H	0.2	S/L	31	635	4.7
8	V	L-H	0.2	S/L	31	635	4.7
9	V	L-H	0.2	0.01	31	635	4.8
10	V	L-H	0.9	S/L	31	635	4.8
11	V	B		S/L	24	635	4.10
12	V	B		S/L	1	635	4.10
13	V	B		S/L	31	635/621	4.11
14	V	B		S/L	31	KP-02	4.12
15	V	B		S/L	31	KP-04	4.13
16	V	B		S/L	31	KP-05	4.14

(1) c = constant at mean water level; v = variable tide levels

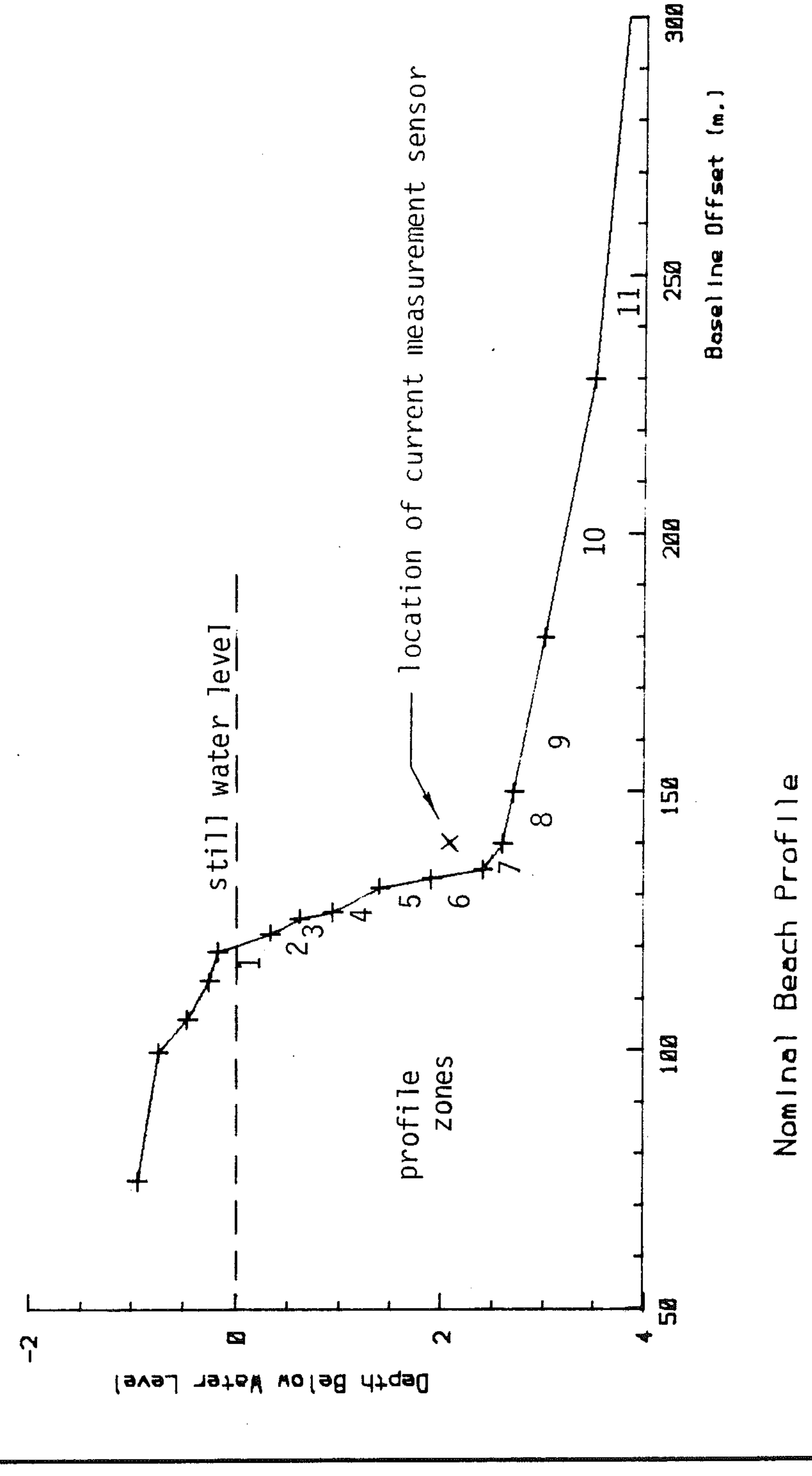
(2) B = Battjes (1974); L-H = Longuett-Higgins (1970 a,b)

(3) S/L = Swart and Lenhoff (1980); M/K = Modgridge and Kamphuis (1972); N = Nielsen (1978); 2D90 = 2 times D90 grain size (Kamphuis 1975)

Note: Run 2 corresponds to method used in previous study (Pinchin et al 1985)

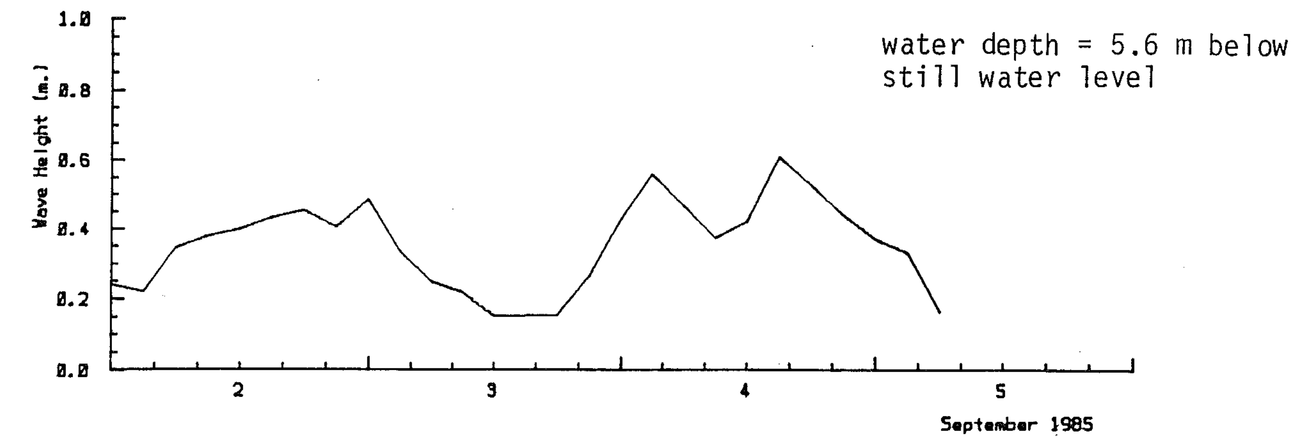
(4) 635 = Sea Data 635-12 measured wave data; KN-?? = hindcast run??, see Section 3. 635/621 = S.D. 635-12 wave heights and periods with S.D. 621 directions

FIGURE
4.1

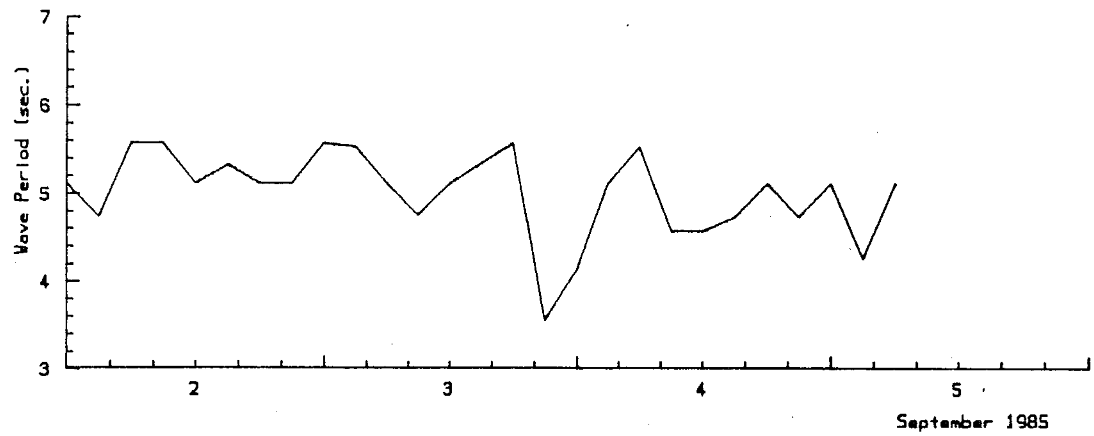


KING POINT SEDIMENT TRANSPORT STUDY	Date: 8 Apr 86
	Scales as shown
Beach Profile Based on Survey Line at 0+00	Checked by:
	Keith Philpott Consulting Limited

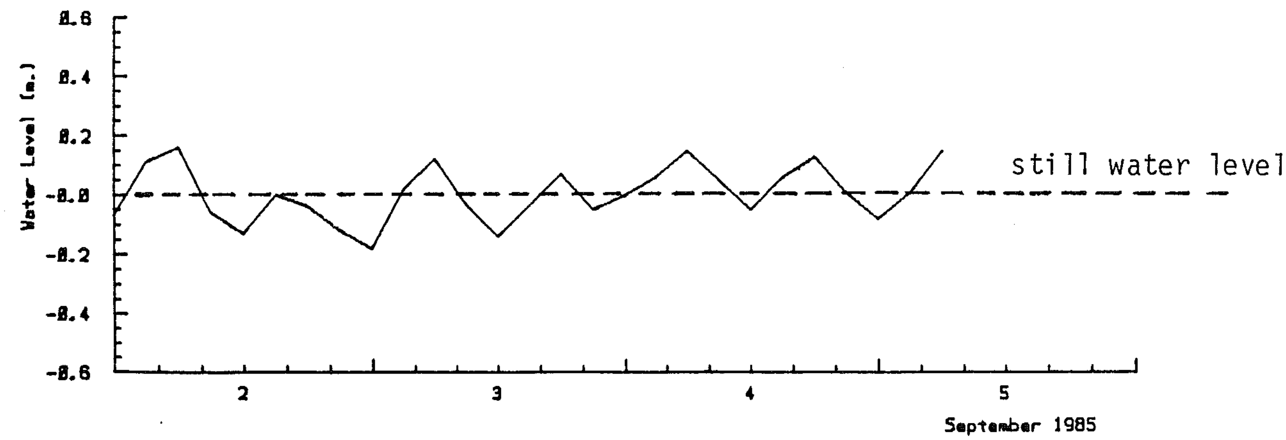
FIGURE
4.2



Wave Height vs. Time



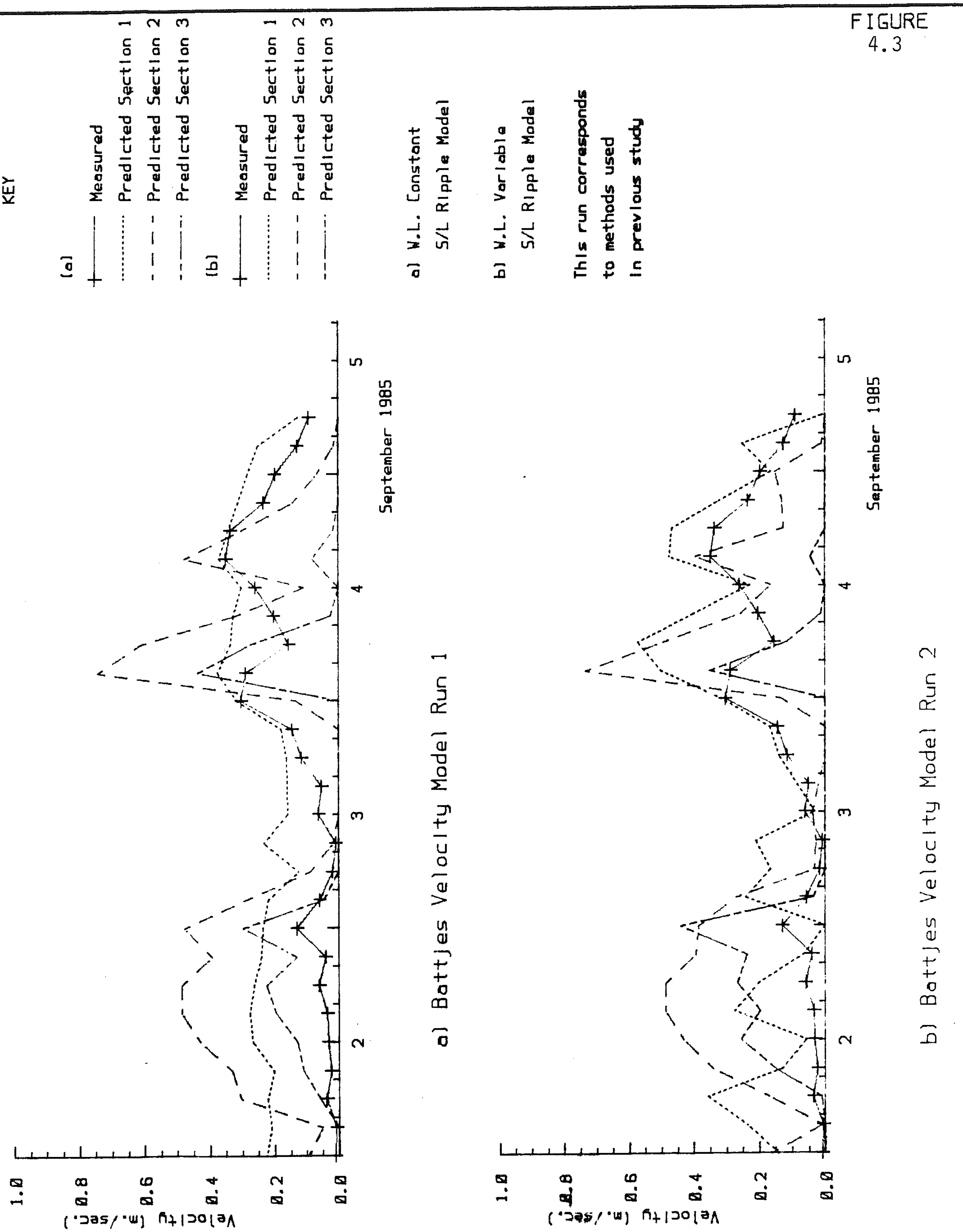
Wave Period vs. Time



Tide Level Above Mean Water Level vs. Time

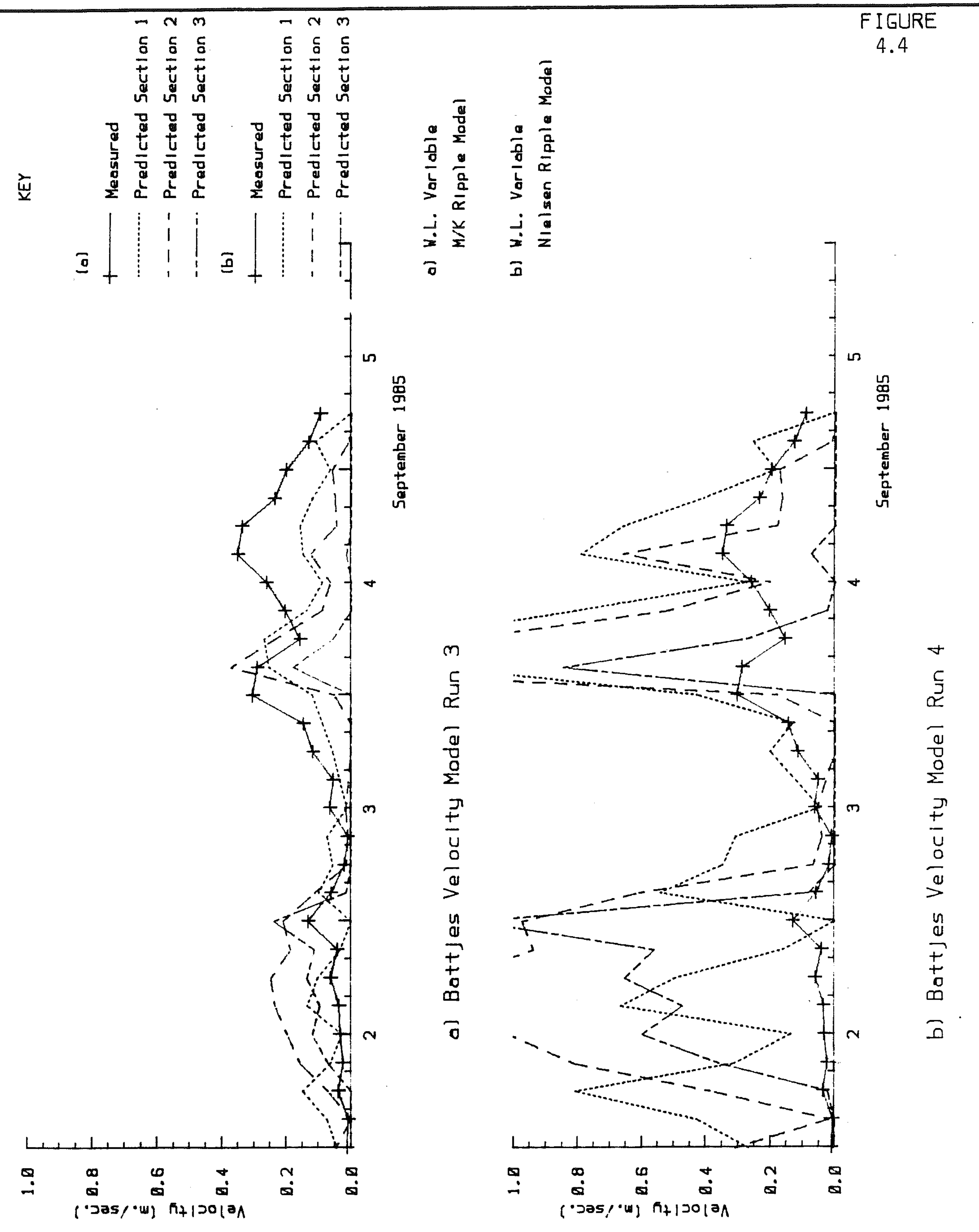
KING POINT SEDIMENT TRANSPORT STUDY	Date: 7 Apr 86
	Scales as shown
Storm used for Alongshore Current Predictions	Checked by:
	Keith Philpott Consulting Limited

FIGURE 4.3



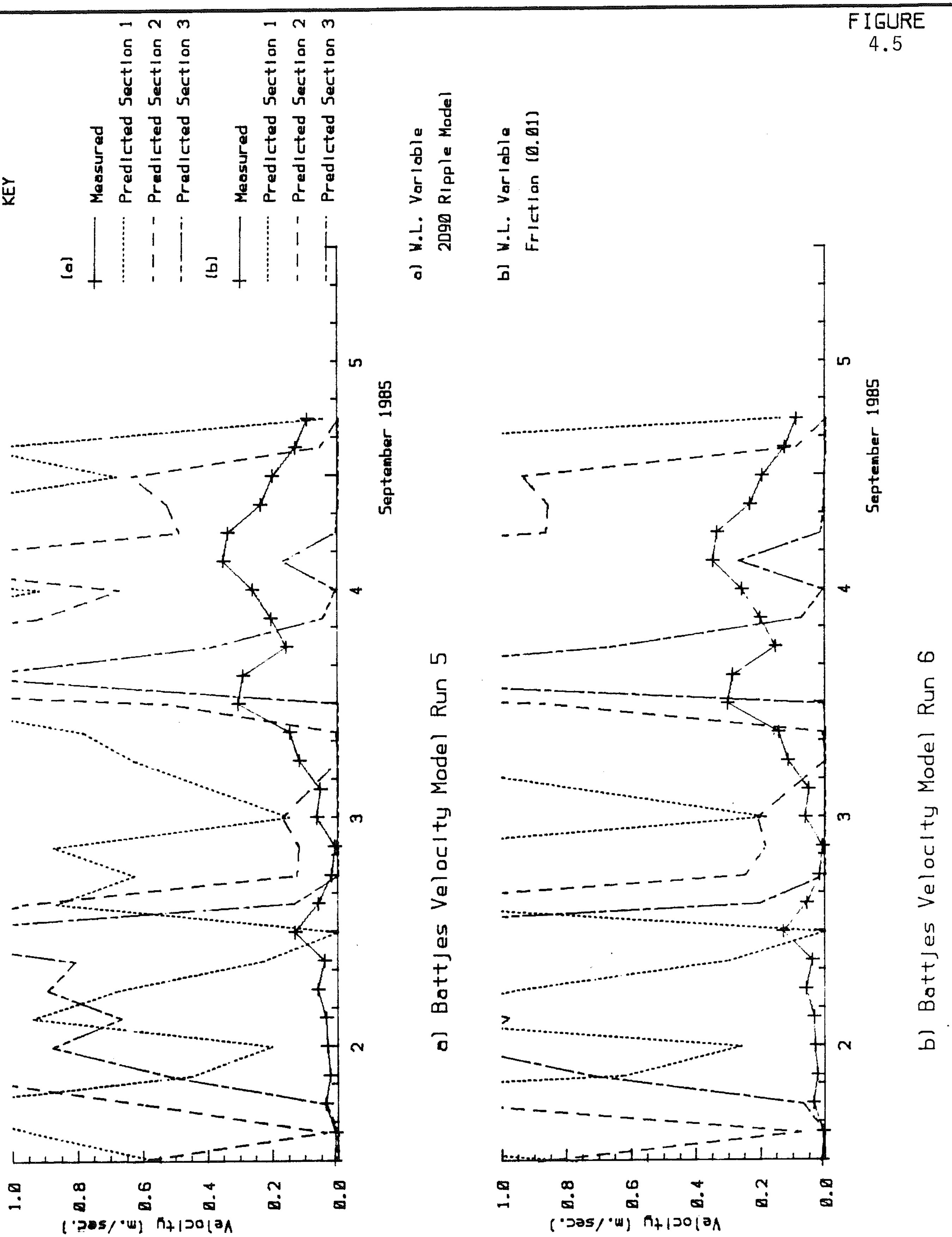
KING POINT SEDIMENT TRANSPORT STUDY	Date: 7 Apr 86
	Scales as shown
Longshore Current Velocity Measurements and Predictions	Checked by:
	Keith Philpott Consulting Limited

FIGURE
4.4



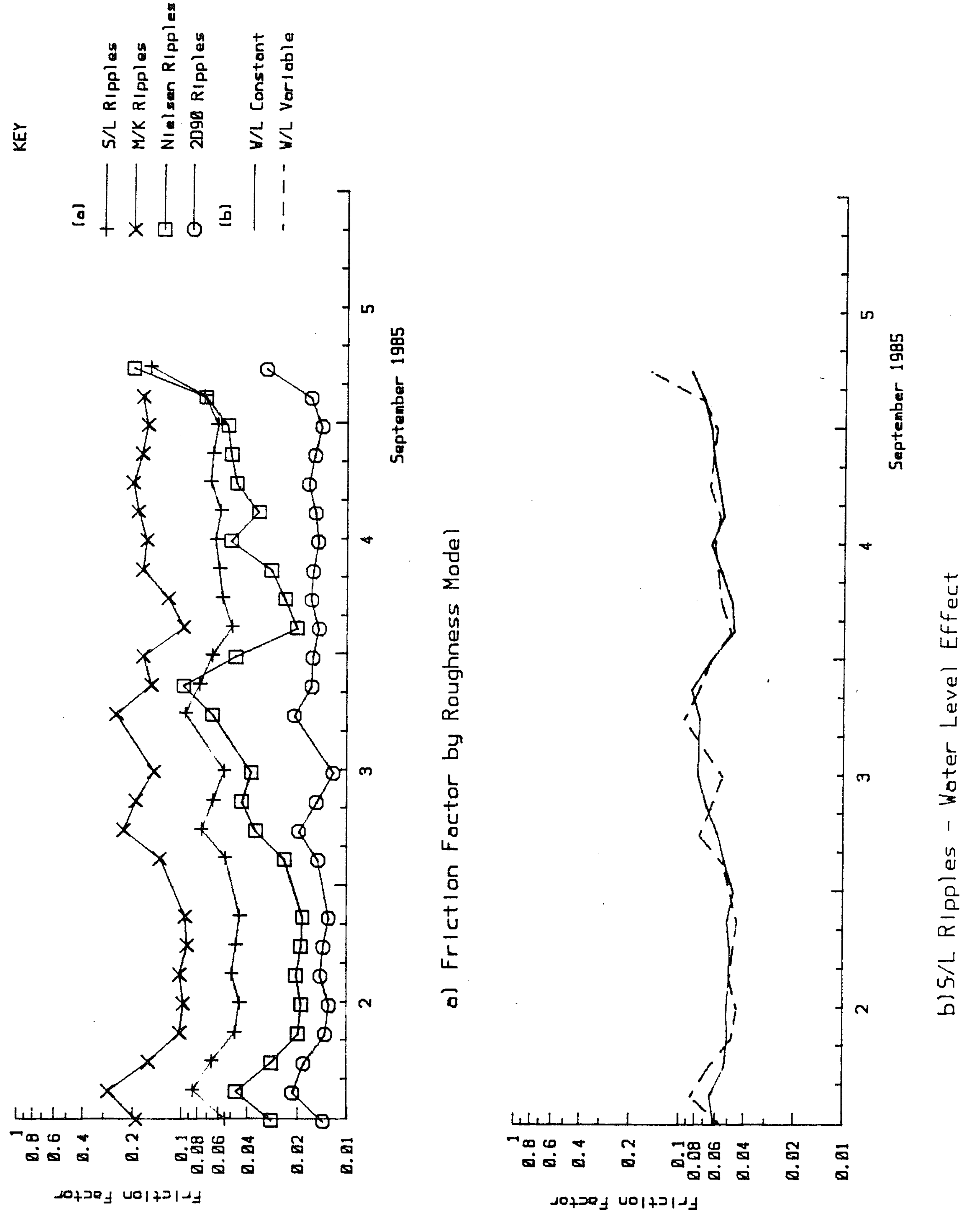
KING POINT SEDIMENT TRANSPORT STUDY	Date: 7 Apr 86
	Scales as shown
Longshore Current Velocity Measurements and Predictions	Checked by:
	Keith Philpott Consulting Limited

FIGURE
4.5



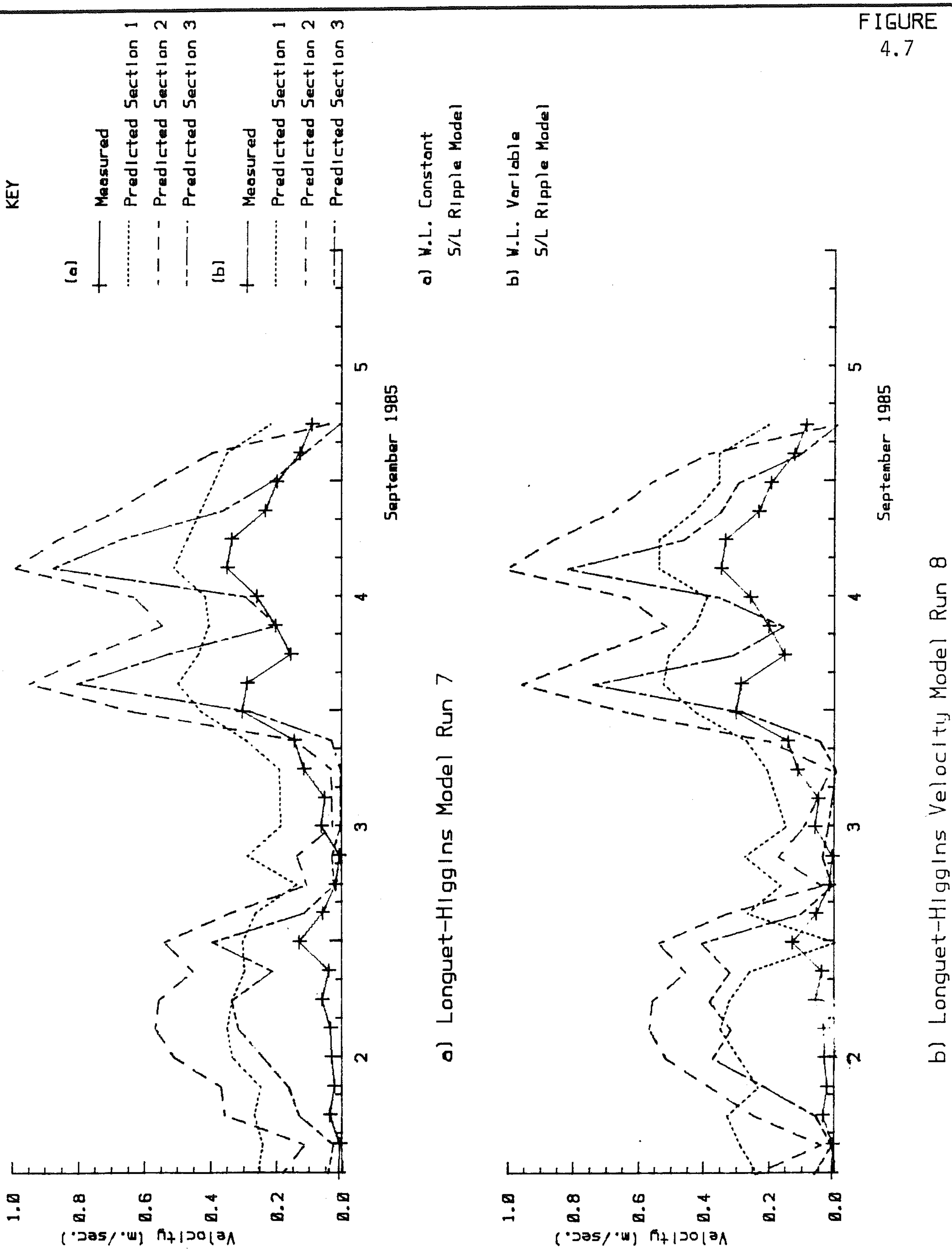
KING POINT SEDIMENT TRANSPORT STUDY	Date: 7 Apr 86
	Scales as shown
Longshore Current Velocity Measurements and Predictions	Checked by:
	Keith Philpott Consulting Limited

FIGURE
4.6



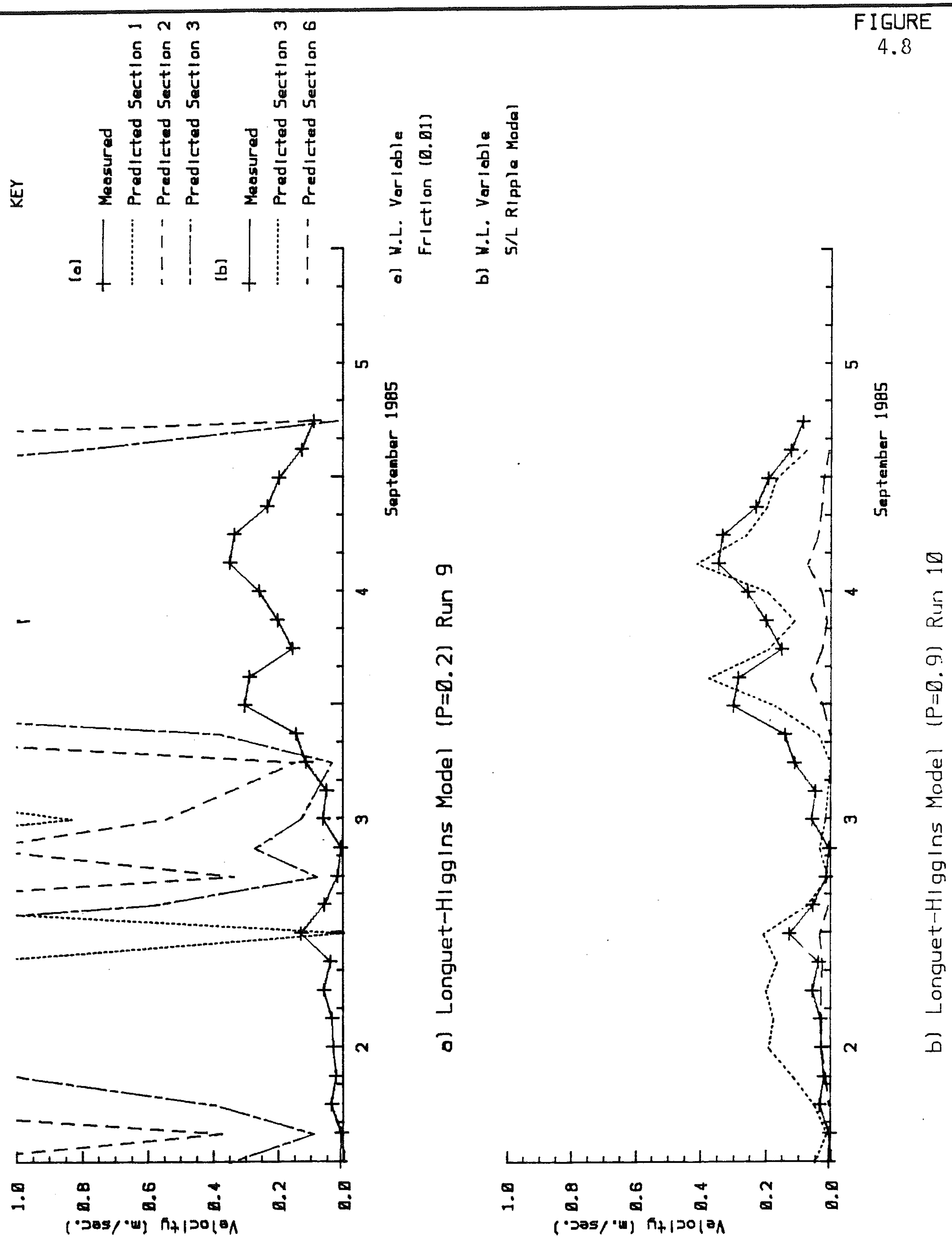
KING POINT SEDIMENT TRANSPORT STUDY	Date: 7 Apr 86
	Scales as shown
	Checked by:
Variation of Longshore Current Friction Factor	Keith Philpott Consulting Limited

FIGURE
4.7



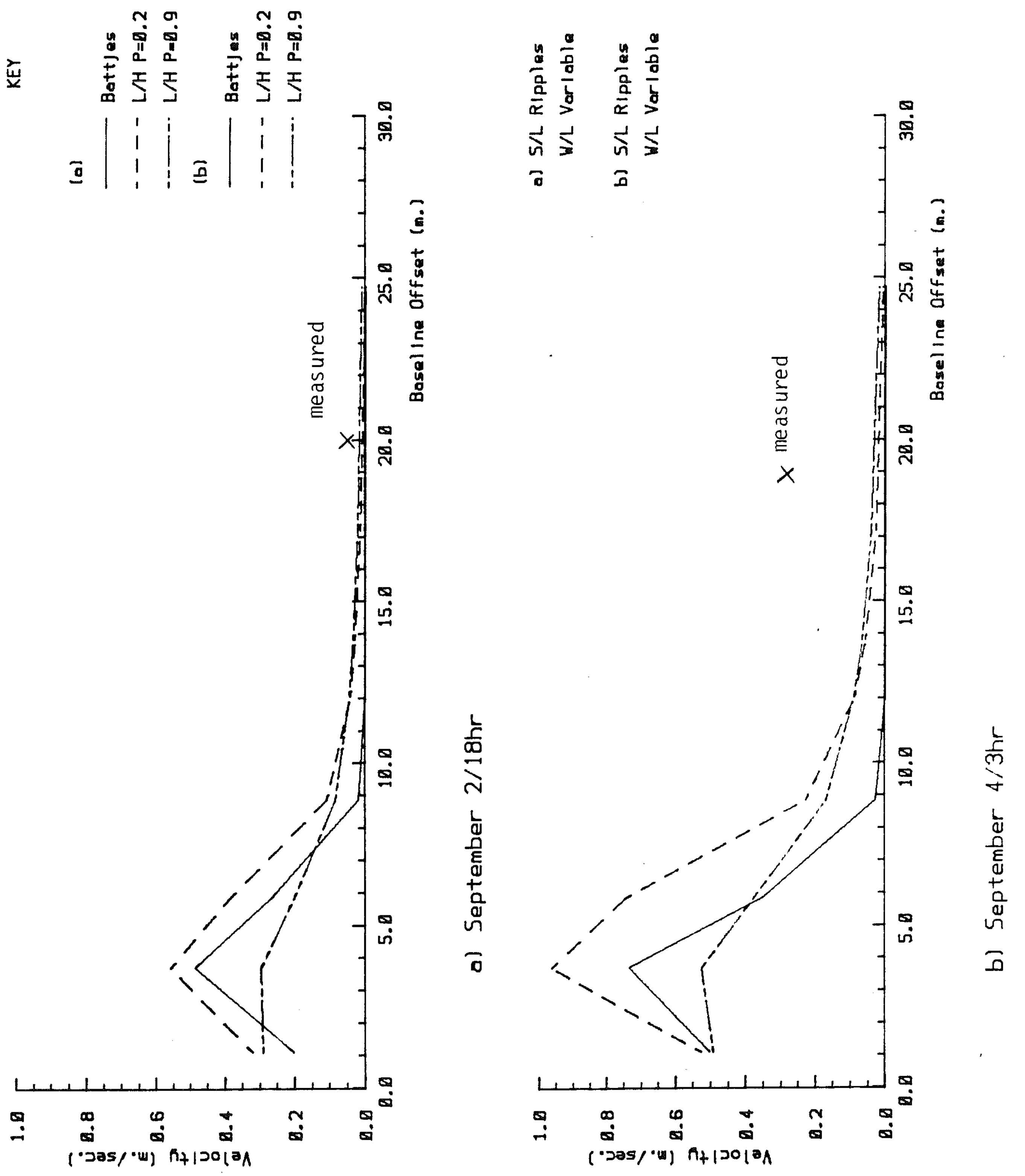
KING POINT SEDIMENT TRANSPORT STUDY	Date: 7 Apr 86
	Scales as shown
Longshore Current Velocity Measurements and Predictions	Checked by:
	Keith Philpott Consulting Limited

FIGURE
4.8



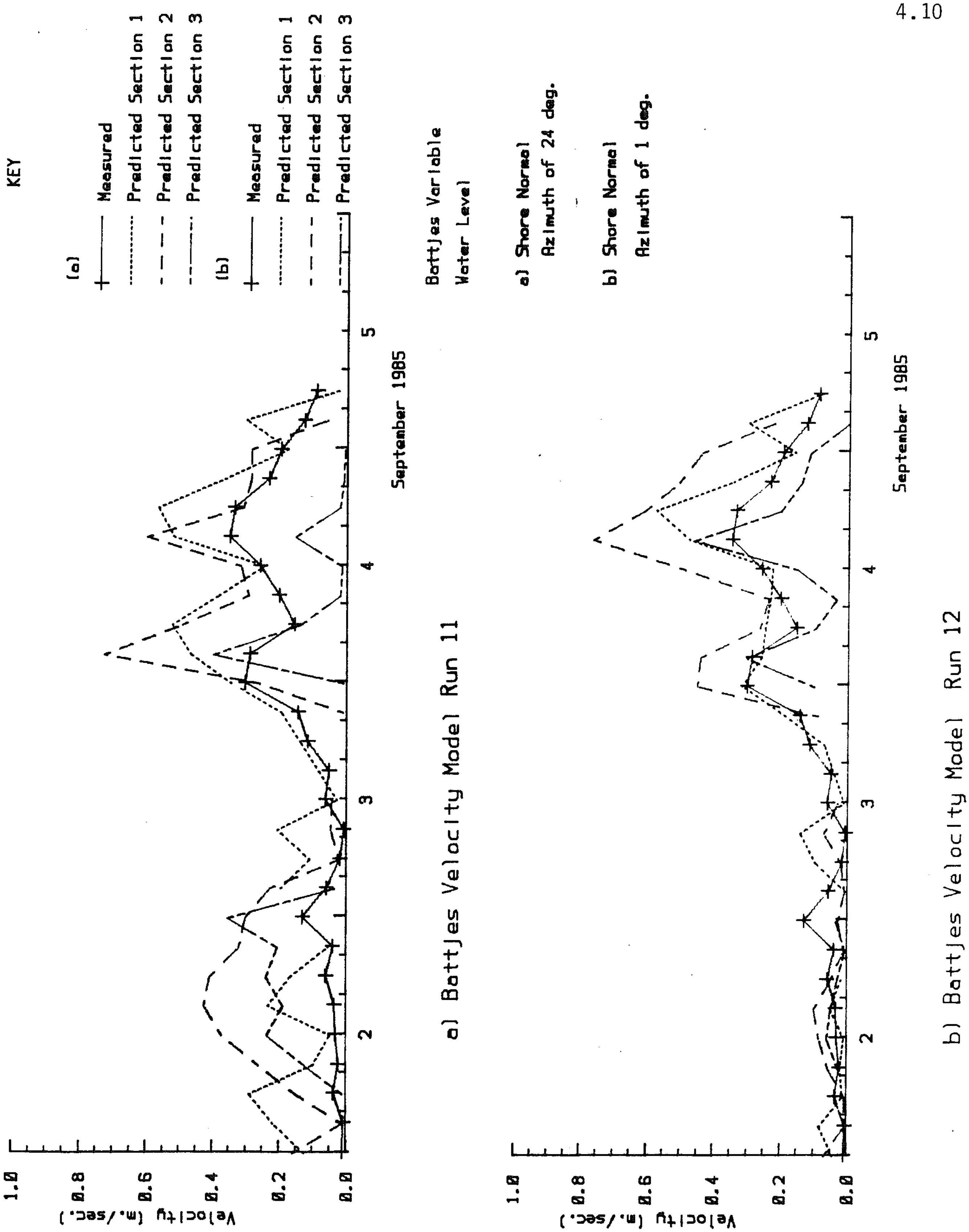
KING POINT SEDIMENT TRANSPORT STUDY	Date: 7 Apr 86
	Scales as shown
Longshore Current Velocity Measurements and Predictions	Checked by:
	Keith Philpott Consulting Limited

FIGURE
4.9



KING POINT SEDIMENT TRANSPORT STUDY	Date: 7 Apr 86
	Scales as shown
Longshore Current Velocity Profiles According to Mixing Parameter	Checked by:
	Keith Philpott Consulting Limited

FIGURE
4.10

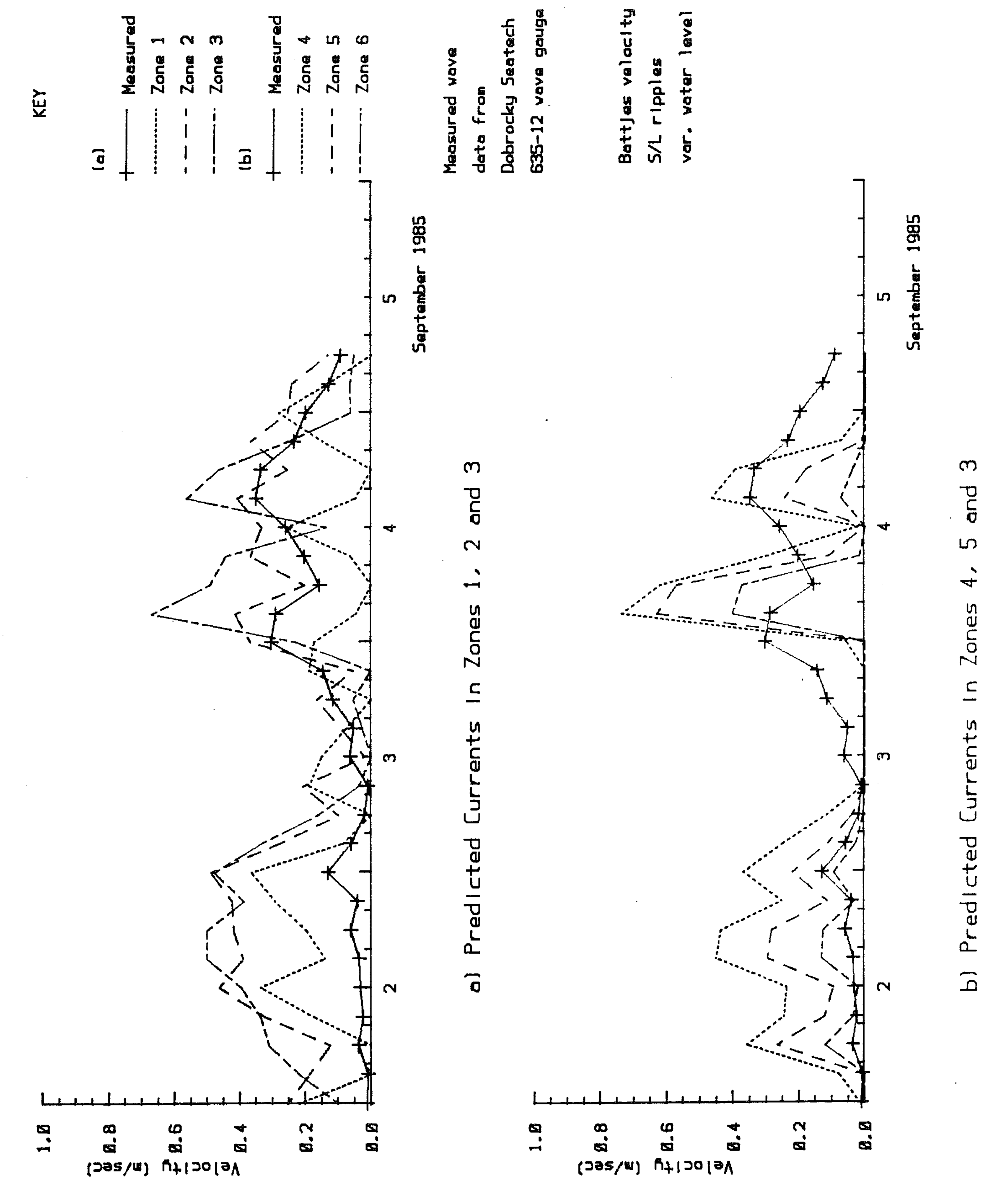


a) Battjes Velocity Model Run 11

b) Battjes Velocity Model Run 12

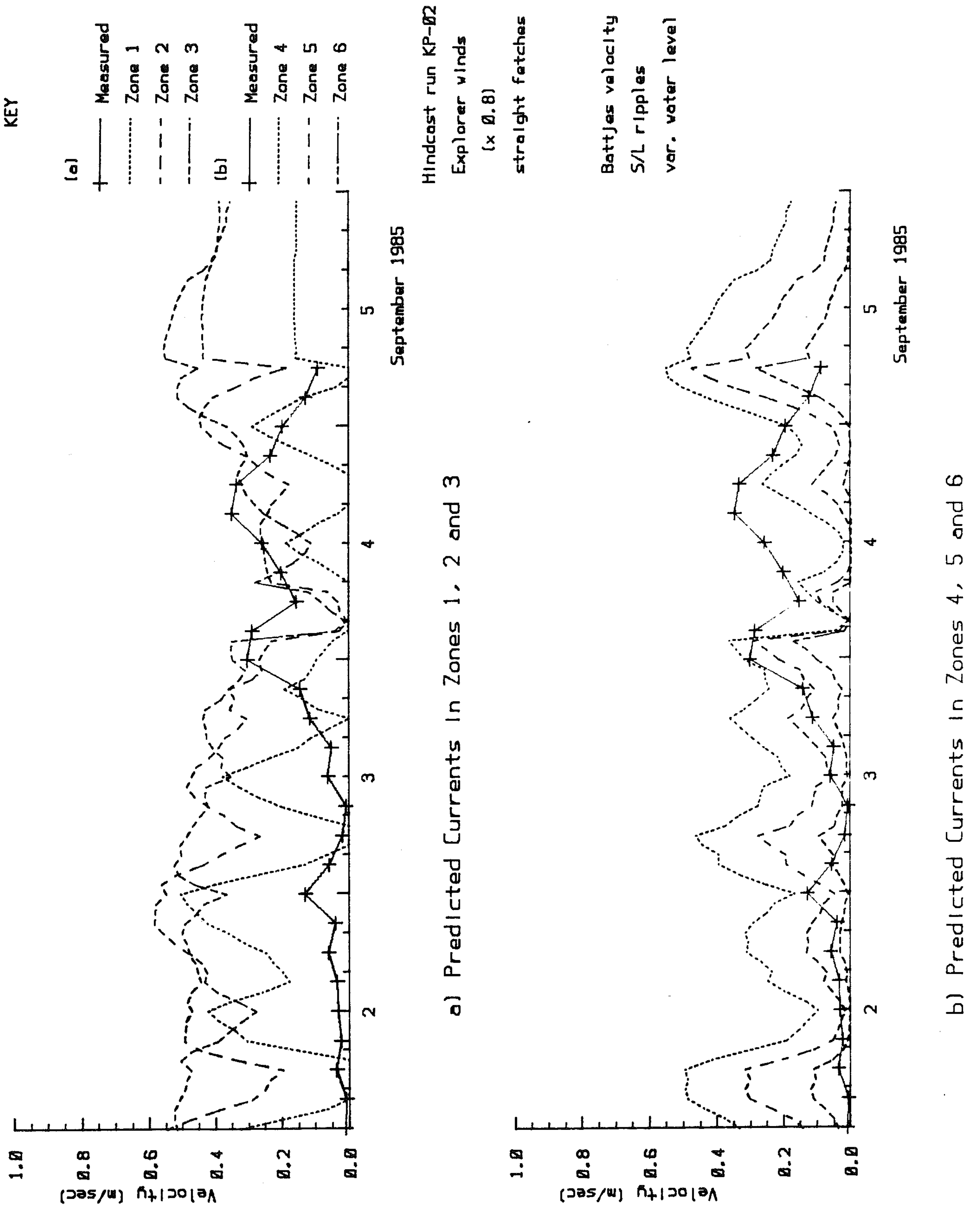
KING POINT SEDIMENT TRANSPORT STUDY	Date: 8 Apr 86
	Scales as shown
Longshore Current Velocity Measurements and Predictions	Checked by:
	Keith Philpott Consulting Limited

FIGURE 4.11



KING POINT SEDIMENT TRANSPORT STUDY	Date: 17 Nov 86
	Scales as shown
Longshore Current Velocity Predictions Run 13	Checked by:
(Sea Data 635-12/621 Waves)	Keith Philpott Consulting Limited

FIGURE
4.12

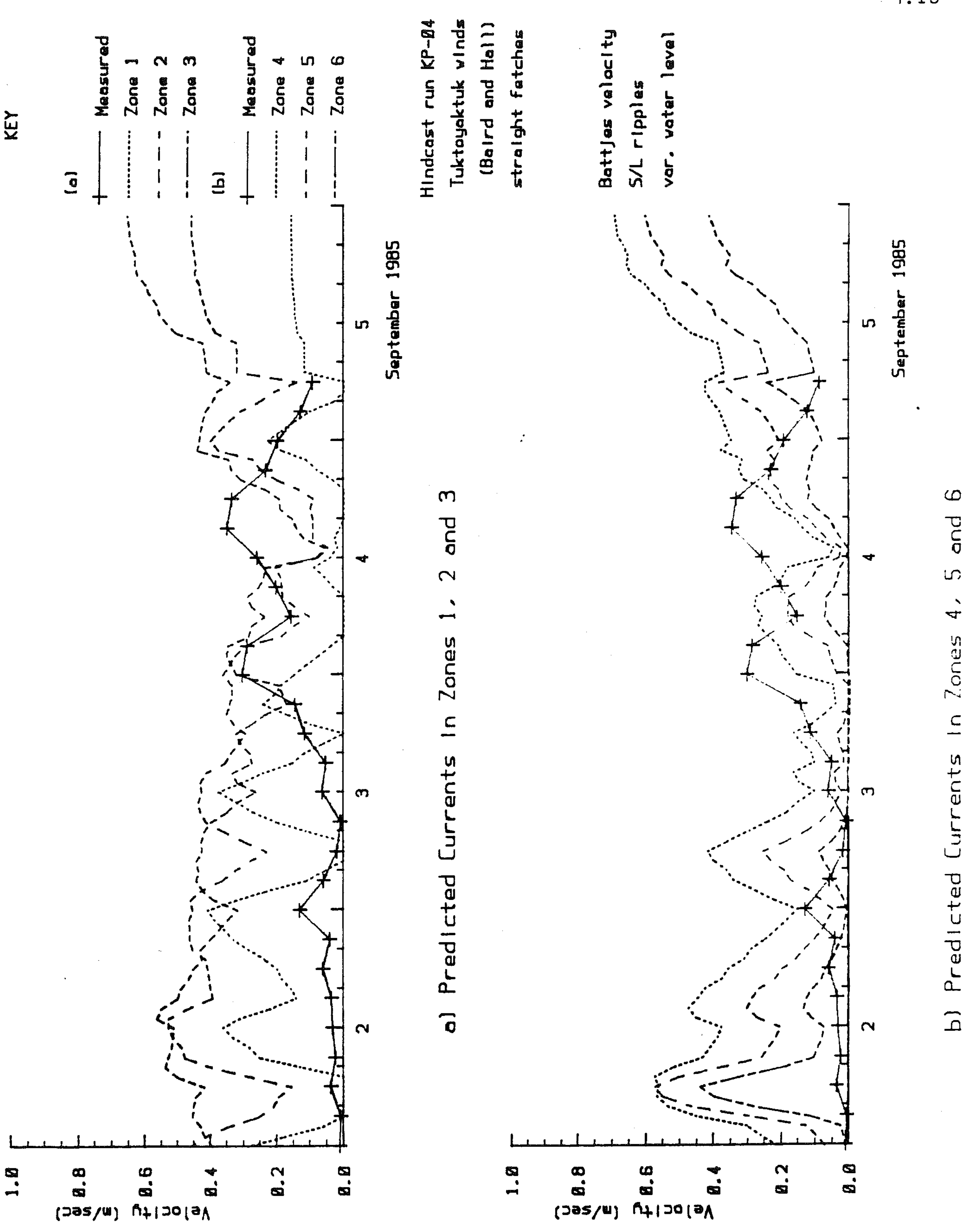


a) Predicted Currents In Zones 1, 2 and 3

b) Predicted Currents In Zones 4, 5 and 6

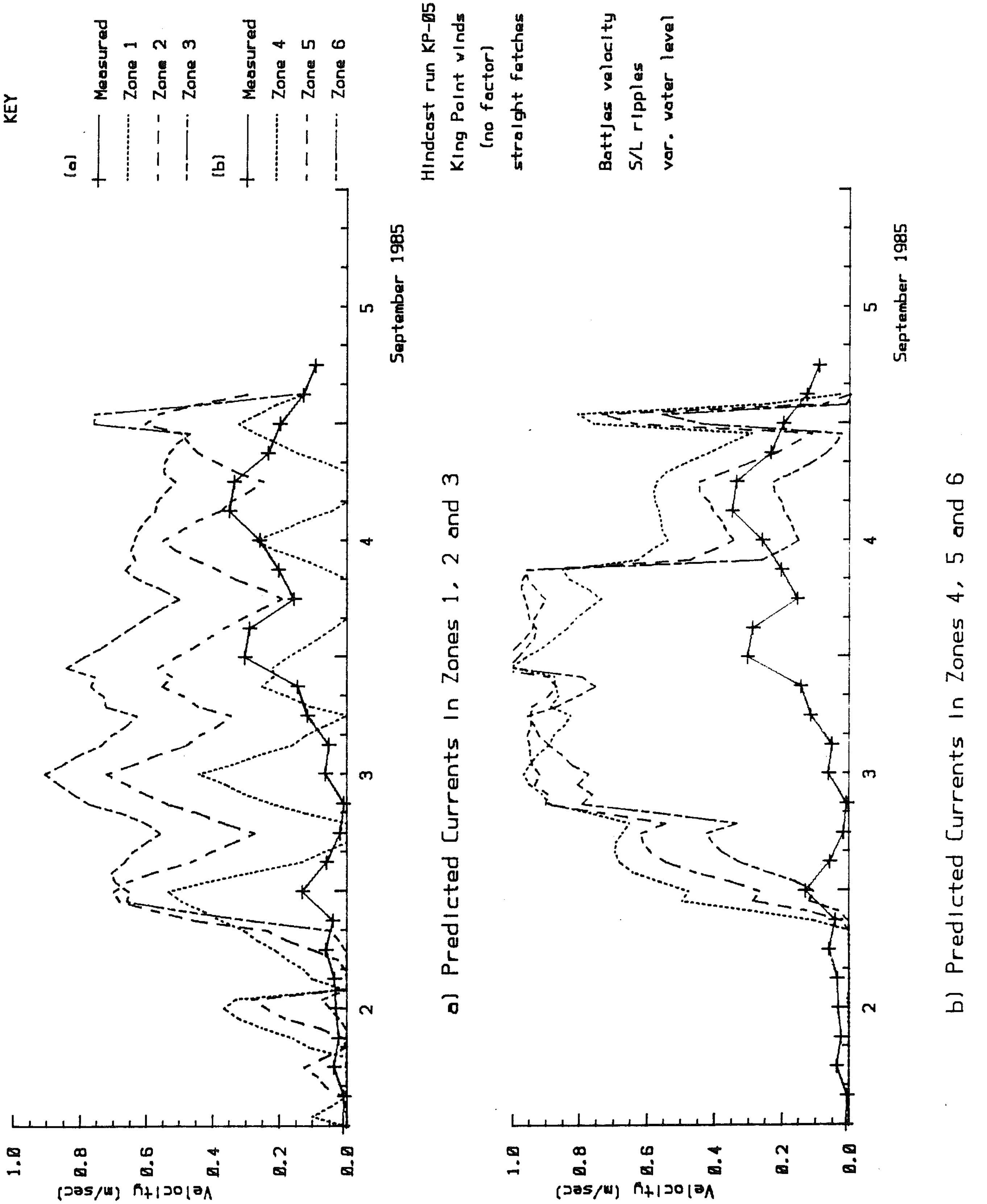
KING POINT SEDIMENT TRANSPORT STUDY	Date: 1Ø Mar 87
	Scales as shown
Longshore Current Velocity Predictions Run 14	Checked by:
(Wave Hindcast Run KP-Ø2)	Keith Philpott Consulting Limited

FIGURE 4.13



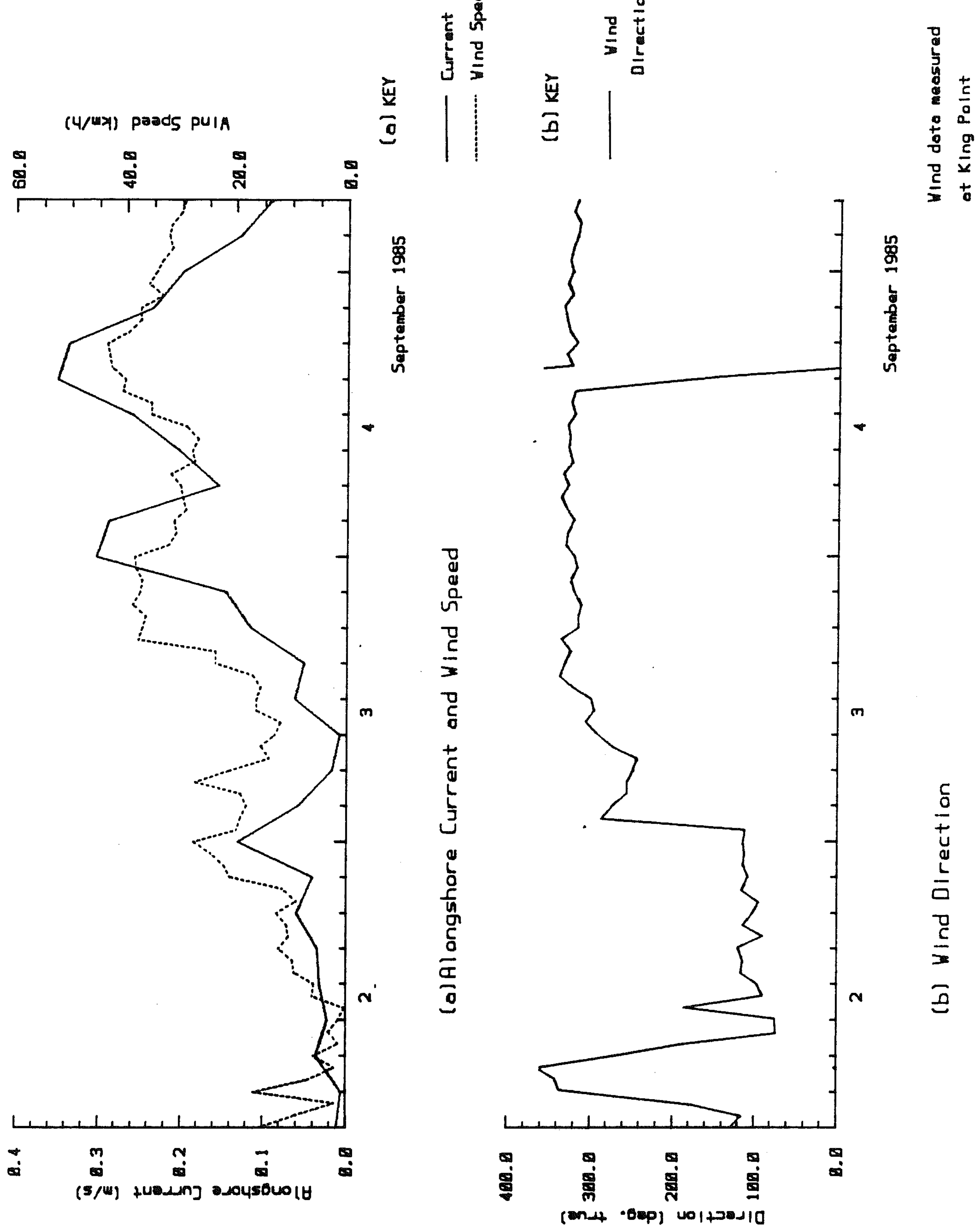
KING POINT SEDIMENT TRANSPORT STUDY	Date: 1Ø Mar 87
	Scales as shown
Longshore Current Velocity Predictions Run 15 (Wave Hindcast Run KP-Ø4)	Checked by:
	Keith Philpott Consulting Limited

FIGURE
4.14



KING POINT SEDIMENT TRANSPORT STUDY	Date: 1Ø Mar 87
	Scales as shown
Longshore Current Velocity Predictions Run 16	Checked by:
(Wave Hindcast Run KP-Ø5)	Keith Philpott Consulting Limited

FIGURE
4.15



KING POINT SEDIMENT TRANSPORT STUDY	Date: Nov. 11, 1986
	Scales as shown
Comparison of Measured Current and Measured Winds	Checked by:
	Keith Philpott Consulting Limited

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5 Alongshore Sediment Transport

5. Alongshore Sediment Transport

5.1 Field Conditions

In general measured wave heights and periods within the study period were relatively low in terms of their capacity to transport sediment. Gillie (1985) reported plunging or surging breakers throughout the study period in his littoral environment observations. The surf zone was very narrow and limited to the steep (1:10) foreshore slope.

5.2 Theoretical Considerations

Predictors for alongshore movement of sediment may be broadly divided into two classes. Firstly there are the bulk energy models for which the computation of alongshore current velocities is avoided and alongshore transport volumes are directly related to the alongshore component of wave energy flux. The simplest of this class of model, the CERC (1974) formula relies on the wave height and the angular difference between the wave and the beach normal at the breaker line.

Two models recently developed at Queen's University introduce the further parameters beach slope, grain size and wave period. Both these models are improved versions of the Queen's model used in the previous study. The Queen's 1 model (Kamphuis et al., 1986) is based strictly on field data whereas the Queen's 2 (Sayao et al., 1986) model is based on laboratory data. The beach slope for these models is computed the same as for the alongshore currents, using the breaker depth to breaker distance ratio.

The second class of models is the group of detailed predictors that rely on local wave and water depth conditions to mobilize the sediment and rely on some superimposed current, to transport the sediment. Consequently the total process of alongshore sediment transport prediction requires both a current velocity model and a sediment transport model, the two of which should not be treated independently. This is because many of the underlying assumptions relating to variation of wave height in the surf zone, effective roughness and the influence of currents or bottom roughness are common to both processes.

Theoretical considerations relating to the alongshore current predictors have been described in Section 4.2. To summarize, the friction factor was tested both as a constant nominal value as well as a function of local roughness. The local roughness was determined by firstly using one of three ripple models to estimate ripple heights and wave lengths as a function of sediment grading, bottom orbital velocity, bottom orbital diameter and relative density of sediment. This calculation is based on breaker line conditions and whilst the consideration of sediment grading and wave conditions through the surf zone is feasible, it is a refinement that cannot be readily justified with respect to other approximations that need to be made en route to the derivation of the alongshore current formulations. It may also be appreciated that the number of possible combinations of variables is too large to enable detailed variations of sediment size across the surf zone to be properly evaluated.

The ripple dimensions are used to calculate a roughness length as a function of ripple height and ripple steepness. This in turn is used to evaluate the wave friction factor which is one of the parameters in the expression for alongshore current friction factor proposed by Fleming and Swart (1982). The other terms are the current Chezy coefficient and the beach slope. As the current friction factor is required to calculate the current at the breaker line it is necessary to perform a number of iterations to converge on an appropriate solution.

A summary of the formulation of the detailed sediment transport predictors is given in Chapter 6 of the Beaufort Sea Coastal Sediment Study (Pinchin et al., 1985). All such models rely on a shear force acting on the bed as a means of entraining sediment, albeit in a number of different forms. In each zone of the profile the effective wave height is evaluated by clipping an assumed Rayleigh distributed sea state according to the the wave breaking criterion. This together with the alongshore current in that zone provides all of the information required to drive the sediment transport models.

Apart from the application of different ripple or grain roughness models which lead to a roughness length there are no parameter variations within the sediment transport models themselves and they are treated as self contained units. Clearly the effects of different alongshore current distributions, sediment grading and wave height magnitudes must have a direct influence. The effects of beach slope and wave direction also have an indirect influence.

5.3 Discussion of Sediment Transport

Because there was no usable wave data and no information about the volume of sediment actually transported that occurred during the field study there was little that could be done to evaluate the sediment transport predictions. Some suspended sediment data was collected during the field study and is discussed in the following section.

In Section 4.3 it was shown that considering the water level fluctuations due to tides had a negligible effect on the prediction of alongshore currents. From Figure 5.1 it can be seen that the effect on predicted alongshore sediment rates was also negligible. Figure 5.1 shows the net sediment transport rate for the CERC (1974) and Queen's 2 (Sayao et al, 1985) bulk transport models and the Nielsen (1979) and Swart and Lenhoff (1980) detailed predictor models. Figure 5.2 shows the same results as Figure 5.1 but plots cumulative volume of sediment transport rather than net transport rates. All of the sediment transport model results could not be shown clearly on one plot, so the Nielsen model was chosen to represent the bed load and suspend load type models and Swart and Lenhoff was chosen to represent the Ackers and White type models.

The effect on sediment transport from considering different roughness models is shown in Figure 5.3. Because the roughness computations do not effect the bulk transport models, only the representative detailed predictor results are shown. For both the Nielsen (1979) and Swart and Lenhoff (1980) models the predicted volumes of sediment transported, ranked from highest to lowest, were from the Kamphuis (1975) flat bed grain roughness 2 x D90, the Nielsen (1978) ripple model, the Swart and Lenhoff (1980) ripple model and the Mogridge and Kamphuis (1972) ripple model. As expected this ranking corresponds to the lowest to highest friction factor ranking shown in Figure 4.6a.

As with the alongshore currents, no conclusions could be drawn as to which roughness method produced the most realistic results. The different roughness models did produce a wider range of results than the use of either of the sediment transport models with the same roughness. Because none of the other models can be shown to have produced better results, the Swart and Lenhoff (1980) ripple generator should be used in the alongshore current model discussed in this study. This is because the prediction of the alongshore current uses the alongshore friction factor formulation of Swart and Fleming (1982). This alongshore friction factor is an empirical expression derived using the Swart and Lenhoff (1980) ripple predictor. Although it was done here for comparative purposes it is not truly valid to consider a different ripple model without recalibrating the empirical coefficients used in the friction factor formulation.

The effect of considering different mixing parameters with the Longuet-Higgins (1970a,b) alongshore current model is shown in Figure 5.4. The difference in sediment transport volumes between mixing parameters of 0.2 and 0.9 with either of the sediment transport models is greater than the difference between the two transport models with the same mixing parameter.

The effect of assumed grain size distribution on the sediment transport rates was also investigated. As mentioned earlier the grain size distribution was computed by averaging the size from the samples collected 20 m offshore of survey lines -200, -100, and +100. A fine grain size distribution was defined from the sediment sample collected 50 m offshore of line +100, and a coarse distribution was defined from the 20 m offshore sample at 000 (Gillie, 1985). These distributions were as follows:

D16	D25	D35	D50	D65	D75	D84	D90	(millimeters)
.09	.11	.11	.13	.15	.16	.20	.21	fine (50 m offshore)
.16	.18	.20	.22	.27	.30	.34	.38	average (20 m offshore)
.19	.22	.29	.37	.72	1.41	2.20	3.0	coarse (20 m offshore)

As can be seen from Figure 5.5 the grain size distribution has a significant effect on the predicted sediment transport volumes. Because the CERC (1974) bulk sediment transport model did not consider grain size the Queen's 1 (Kamphuis et al., 1986) bulk model results were shown. The two Queen's bulk models predicted similar results for the fine grain size distribution, but showed some difference for the coarse distribution. There was a very significant difference between the fine and coarse sediment transport results for the Swart and Lenhoff (1980) model but very little difference for the Nielsen (1979) model.

These results indicate that a reasonable amount of care should be taken in selecting the appropriate sediment grading and this should relate to the active sediment zone. In this case the overall extremes have been used deliberately to determine the possible variance that might occur on the basis of a single sediment sample. It may be concluded that as long as a reasonable number of representative samples are collected this should not be a problem.

Special mention should be made of the Nielsen model which showed a much smaller sensitivity to grain size distribution. The reason for this may well be that the coarser grading resulted in a relatively rougher bed than for the finer grading. In the Nielsen model this would result in greater reference concentrations and hence higher sediment transport rates. This is peculiar to the particular combination of sediment sizes and wave conditions tested and is not necessarily incorrect. The basic principle that ripples may reduce in size at higher flows and result in less sediment movement is well accepted in unidirectional flow situations.

The nearshore wave data produced by refracting the Tuktoyaktuk wind hindcast was used to compute transport rates with the Queen's 2 bulk transport model. The results showed a westerly transport of 2,600 m^3 and an easterly transport of 2,200 m^3 during the September 1 to 5 storm. These results indicate no significant net sediment transport during the storm. The actual long term net sediment transport at this location is also close to zero as evidenced by the morphological evolution of the barrier beach. It is interesting to note, but most likely coincidental, that this effect was reproduced with the sediment transport modelling even though the wave hindcast modelling was considered to have produced poor quality results.

5.4 Suspended Sediment Concentrations

Accurate computation of sediment transport rates with the detailed predictors relies on an accurate definition of the suspended sediment concentration throughout the water column. In this section field measurements are compared with predictions from the Nielsen (1979) model for breaking waves. This model is based on laboratory measurements of suspended sediment concentration under breaking waves.

Field measurements of suspended sediment concentration were made using a suction sampling technique (Gillie, 1985). The intake hose was attached to the Sea Data 621 instrument located just outside the breaker zone. The inlet opening was 1.9 cm and intake velocities ranged from 58 to 75 cm/s. Samples were taken at either 20 cm or 50 cm above the bed. Results measured within the study period under investigation here are presented in Table 5.1; they range from 0.05 to 0.10 g/l.

The wave height measured at the Sea Data 635-12 instrument for 0 hr, September 9 was 0.5 m. Not surprisingly, the sediment transport models, including the Nielsen (1979) model for breaking waves do not predict any suspended concentration at the instrument location (20 m offshore in a water depth of 2.6 m) for this particular wave condition. However, within the surf zone the Nielsen (1979) model does predict concentrations from 5.7 to 9.2 g/l, with very little vertical gradient in the concentration.

Clearly, the sediment concentration measurements offer nothing in the way of verification for the detailed sediment transport predictors. However, Sternberg et al., (1984) have reported mean sediment concentrations in the surf zone of 2-12 g/l, measured under wave conditions with a significant wave height of 0.5 m at Leadbetter Beach in California. Also, Antsyferov et al., (1983) indicate that within the breaker zone during a storm, sediment concentration is approximately 10 g/l with very little vertical variation. They also mention that outside the surf zone concentrations can reach 1 g/l 1-3 cm above the bed.

5.5 Conclusions

Because of the lack of measured data the implications of the above discussed sediment transport predictions cannot be quantified. Large differences in transport rates were produced by varying the method of computing bed roughness but no one specific method could be singled out as being superior to the others. As well, the selection of mixing parameter in the Longuet-Higgins alongshore current predictions was found to significantly effect the volume of predicted sediment transport. Predicted results were also sensitive to the assumed sediment particle sizes but effect varied between sediment transport models. The effect of considering variable waters due to the semi-diurnal tide was not found to be significant.

These results, however, cannot be related to the results of the previous study (Pinchin et al., 1985) because of the episodic nature of sediment transport. The storm period examined in this study was not significant in its capacity to transport sediment and any extrapolation of these results to the 14 year period examined previously could prove to be erroneous.

Table 5.1

SUSPENDED SEDIMENT SAMPLE DATA

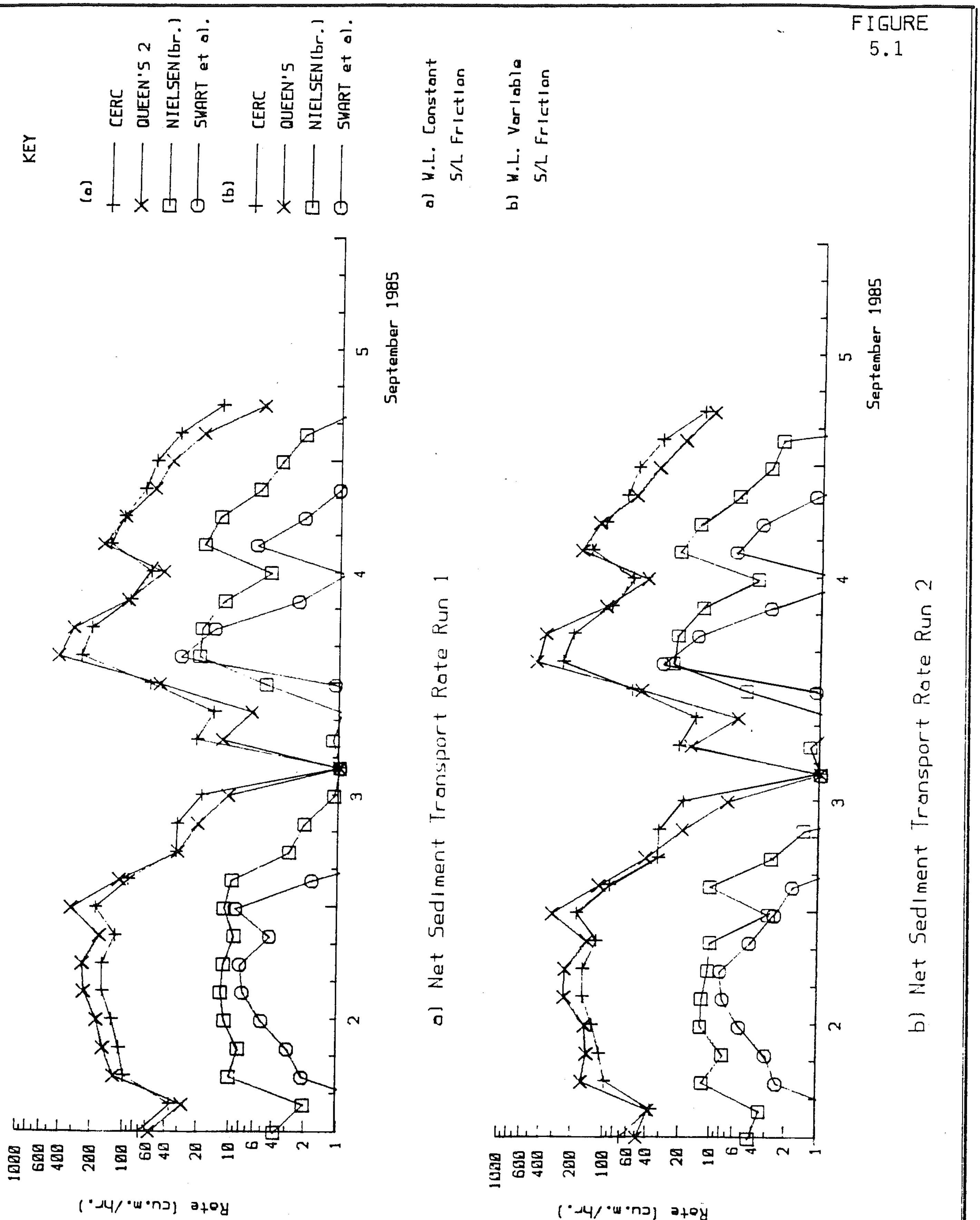
Sample Id	Date	Time (MDT)	Sample Height (cm)	Concentration (g/l)
1	8 Sept/85	22:00	50	0.10
2	9 Sept/85	00:01	50	0.09
3	9 Sept/85	00:04	50	0.06
4	9 Sept/85	00:06	50	0.05
5	9 Sept/85	00.08	50	0.05

NOTE:

1. All samples were 7 litres.
2. Sample durations varied from 33 to 43 sec.
3. Sample delay between hose intake and outlet was approximately 60 seconds.

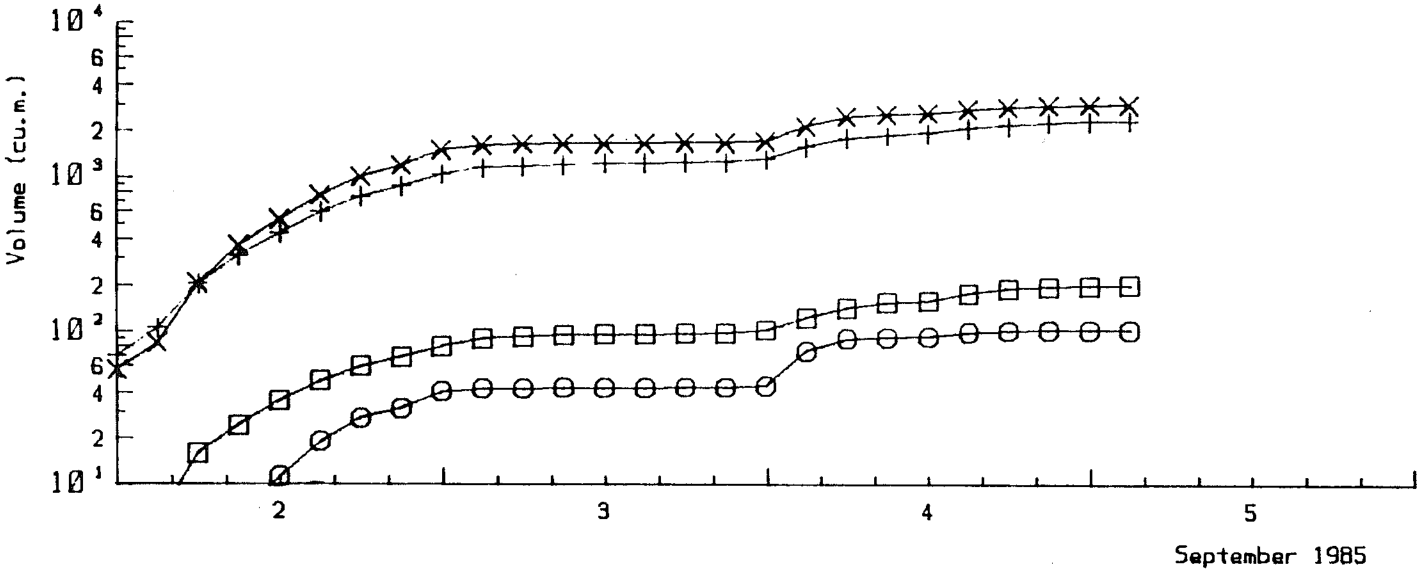
From: Gillie (1985).

FIGURE 5.1

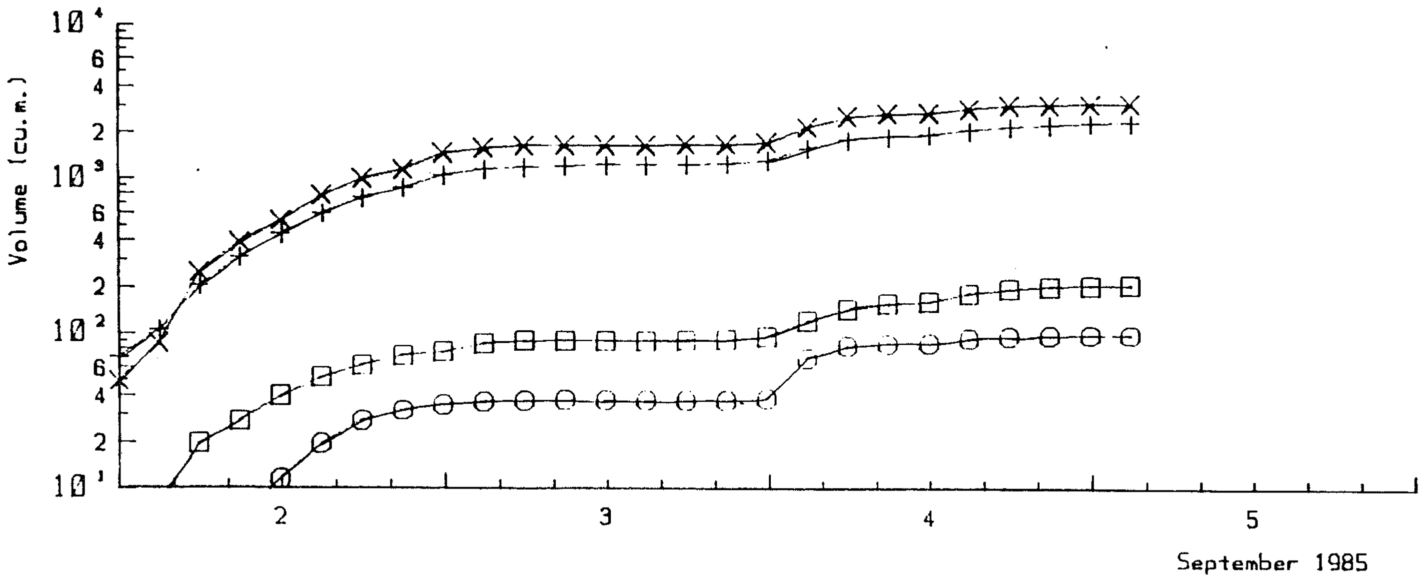


KING POINT SEDIMENT TRANSPORT STUDY	Date: 7 Apr 86
	Scales as shown
Variation of Sediment Transport Rates using Battjes Velocity Model	Checked by:
	Keith Philpott Consulting Limited

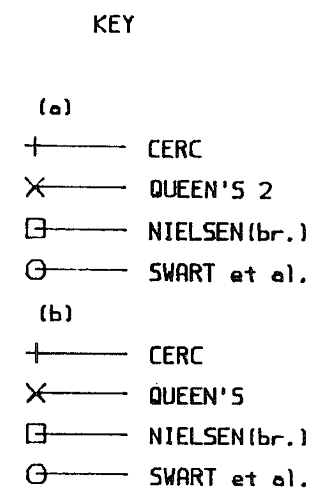
FIGURE 5.2



a) Cumulative Sediment Transport Run 1



b) Cumulative Sediment Transport Run 2



a) W.L. Constant
S/L Friction

b) W.L. Variable
S/L Friction

KING POINT SEDIMENT TRANSPORT STUDY

Variation of Sediment Transport Rates using Battjes Velocity Model

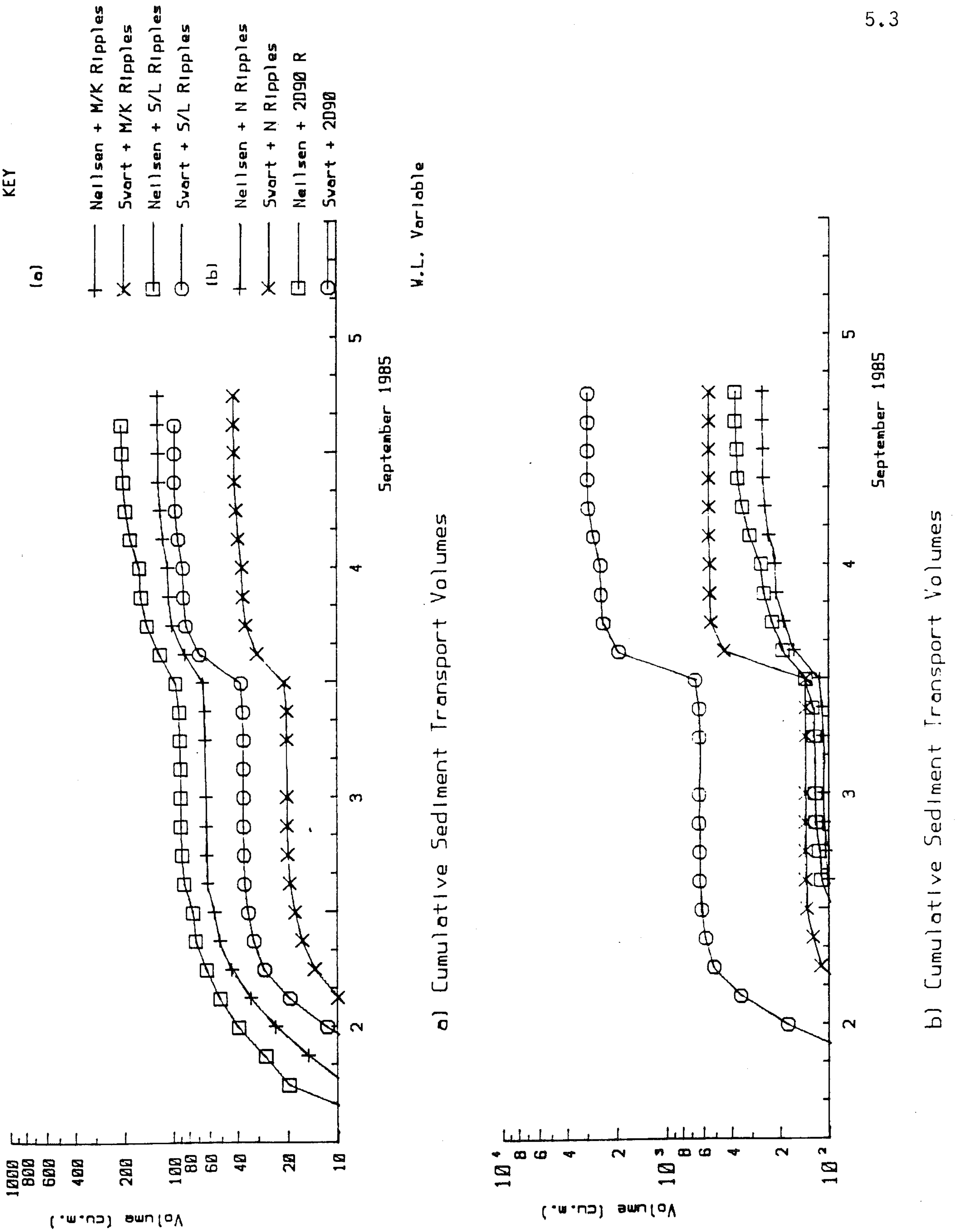
Date: 7 Apr 86

Scales as shown

Checked by:

Keith Philpott Consulting Limited

FIGURE
5.3



KING POINT SEDIMENT TRANSPORT STUDY

Influence of Roughness Model on Sediment Transport Rates, Battjes Model

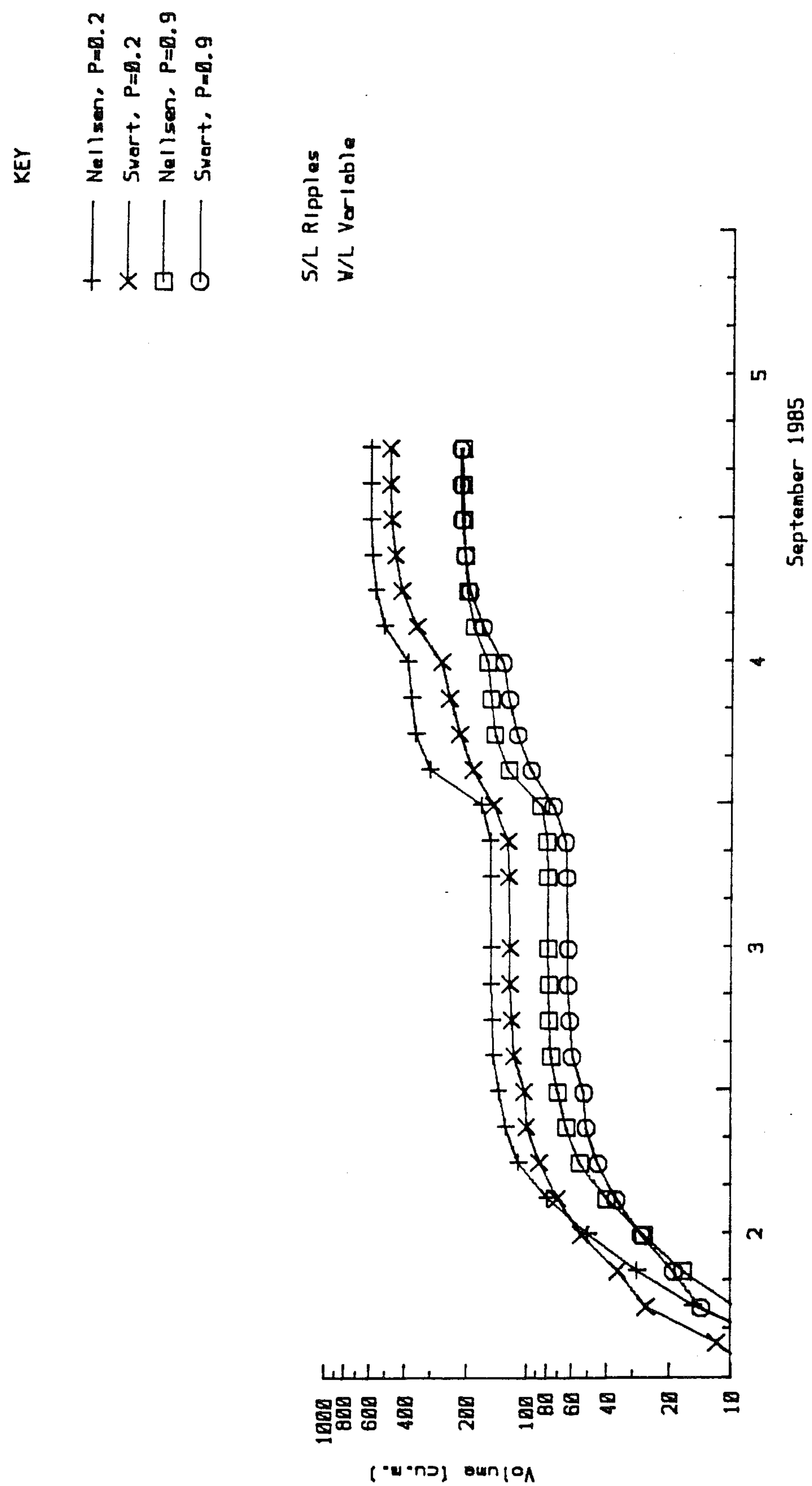
Date: 8 Apr 86

Scales as shown

Checked by:

Keith Philpott Consulting Limited

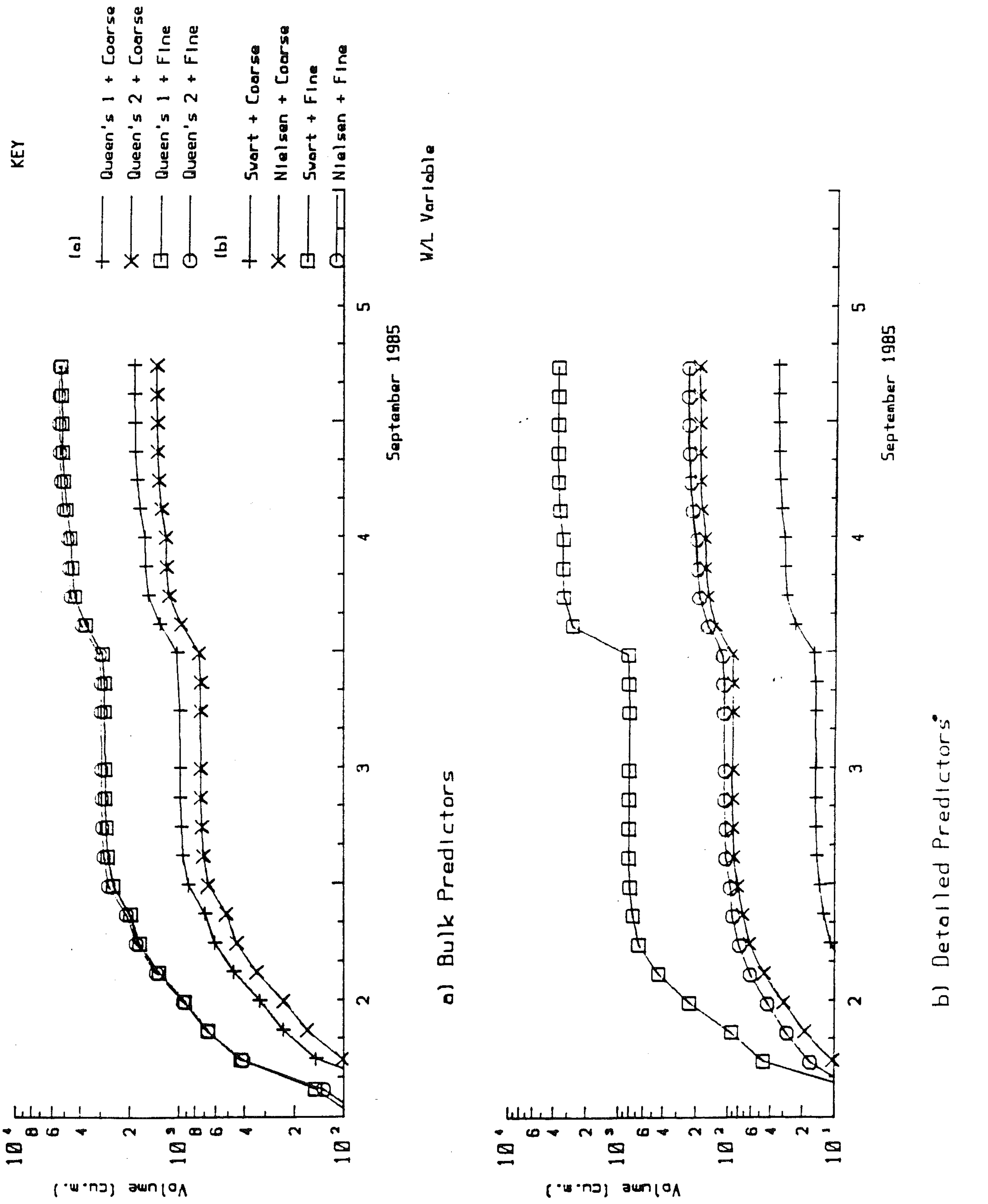
FIGURE
5.4



a) Cumulative Sediment Transport Volumes

KING POINT SEDIMENT TRANSPORT STUDY	Date: 8 Apr 86
	Scales as shown
Influence of Lateral Mixing on Transport Rates, Longuett Higgins	Checked by:
	Keith Philpott Consulting Limited

FIGURE 5.5



KING POINT SEDIMENT TRANSPORT STUDY	Date: 8 Apr 86
	Scales as shown
Influence of Sediment Grading on Bulk and Detailed Sediment Transport Predictors	Checked by:
	Keith Philpott Consulting Limited

6 Conclusions

6. Conclusions

The objective of this study was to provide a critical evaluation of the coastal processes estimation techniques used in the earlier Beaufort Sea Coastal Sediment Study (Pinchin et al., 1985). This objective was to be met by estimating sediment transport volumes during a specified study period during the 1985 summer season. These estimates would then be compared to data collected during a coastal zone data collection program conducted at King Point by Dobrocky Seatech Ltd.,(Gillie, 1985).

It was concluded that, overall, the field program did not provide the data required to perform a comprehensive evaluation of the sediment transport estimation techniques. While some valuable data were collected the full potential of the field program was not realized. Basic problems inherent to the design of the field program precluded the possibility of collecting all of the required data. Other problems associated with the reduction of the measured data caused the quality of some of it to be seriously questioned. The problems associated with the field program design are discussed in Section 2.3. Problems encountered with the measured data are discussed below where applicable.

One moderate storm event was experienced during the field program, producing a maximum wave height of 0.6m at the wave recorder (5.6m depth of water). The pattern of storm waves occurred with two peaks separated by a period of low wave activity as the storm centre passed over the site. The storm centre moved from west to east generally following the coastline to the Mackenzie Delta where it then turned landward.

Measured wave data was collected at a deepwater site northwest of Hershel Island and at the nearshore gauge at King Point. Measured wind from one water and four land sites were used for hindcasting. The land sites included Tuktoyaktuk and King Point. Tuktoyaktuk wind data had been used for hindcasting in the previous study, (Pinchin et al., 1985).

Perhaps the most informative aspect of the study of coastal processes at King Point and how they effect estimation techniques was gained through the hindcast exercise. The hindcast is one of the most crucial aspects of the study. The prerequisite for the prediction of sand transport on beaches is a sound definition of the nearshore hydrodynamic conditions. If non realistic hindcast results are used to determine the nearshore wave conditions then the sediment transport estimates will not be valid.

On the basis of the hindcasts to the deepwater wave measurement site, it was concluded that the winds recorded at the overwater station, Explorer III, were representative of the winds that generated the measured waves. The winds from Tuktoyaktuk were partially representative and produced only marginally acceptable hindcast wave data. The other land recorded wind data was not representative of the winds over the fetch and produced unacceptable hindcast results. It was felt that overland winds were non-representative in part because of the difference in overland and overwater boundary layer friction, which tends to produce more offshore winds at the coastline, but more importantly because of the effect of rapidly changing wind direction experienced as the centre of the low pressure area passed over the wind recording stations as the storm moved along the coast.

It was deduced from the hindcasts to the King Point site that the winds generating the waves at the offshore wave hindcast site were from a different direction than the winds generating the waves at King Point. The wind data measured at King Point was representative of the over fetch winds during the latter half of the storm. None of the other wind data was representative. Differences were due to the path followed by the storm. It must be recognized, however, that the King Point hindcast data was compared to measured data after the hindcast data had been refracted inshore. The error introduced by the refraction analysis could not be quantified. For the particular storm examined it was found that none of the measured wind data sets fully described the winds that generated the waves. It therefore follows that if the 14 years of Tuktoyaktuk wind data used in the previous study included the effects of a significant number of similar storms then the hindcast results would be of questionable value for all such occurrences. Hodgins and Harry (1982) showed that storms with a similar trajectory were the most prevalent type of severe storm encountered in the summer months. Their classification included 11 storms that travelled from west to east following the trend of the shoreline. However, scrutiny of the exact trajectories for the storms in that classification showed that most of the storm centres were further offshore.

Our conclusions regarding the use of the Tuktoyaktuk winds for hindcasting to King Point for the storm examined in this study do not necessarily apply to storms centred further offshore. The validity of hindcasting those storms at King Point with Tuktoyaktuk wind data would therefore have to be investigated separately.

Considering the results obtained by hindcasting with the other available land-based wind data during the study, it may be concluded that the earlier 14 year hindcasts provided the most accurate results possible, given the methods used. While the Tuktoyaktuk wind data did not provide an ideal description of the overwater wind field, it was the best available with a sufficient duration as required for a long-term hindcast.

An investigation into the use of skill tests for evaluating hindcast results showed encouraging results. While the particular method examined in this study was not ideal the potential for this type of test is quite good. Further work along these lines is certainly warranted.

The measured alongshore currents and suspended sediment concentrations proved of no value in assessing the behavior of the predicted alongshore sediment transport rates. Both data sets were collected well outside the surf zone, where no significant alongshore transport occurs.

While sediment transport outside the surf is negligible, significant alongshore currents were never the less measured. These currents were not adequately using the techniques applied in the earlier study, (Pinchin et al., 1985), which considered only currents generated by waves within the surf zone. A qualitative assessment of the measured currents indicated that they may have been due to wind stress resulting from nearshore parallel winds. Further investigation of this possibility, including the effect and significance of wind-generated currents within the surf zone is warranted.

On the basis of the predicted results it was concluded that ignoring tide induced water level fluctuations would not adversely effect the quality of either the alongshore current or sediment transport predictions.

The results from the Longuet-Higgins (1970 a,b) and Battjes (1974) alongshore velocity models were similar and neither one could be considered to produce superior results. The Battjes model, however, is simpler to apply because it does not require the selection of a mixing parameter.

The use of four different bottom roughness models produced a wide range of values of friction factor and correspondingly wider ranges of alongshore current and alongshore sediment transport. Again, because of the lack of usable measured sediment transport data no conclusions could be drawn about which models produced the most realistic results. It was noted however that all four models produced friction factors higher than the often assumed constant value of 0.01. It was also noted that the bottom roughness model used in the previous study (Pinchin et al., 1985) produced results close to the average of all the results evaluated.

It was found that the sediment transport results from the Tuktoyaktuk wind hindcast were consistent with the morphological evolution of the barrier beach, however the relatively small scale and short duration of the storm examined, and the episodic nature of sediment transport precludes any real comparison of these events with longer term trends.

To sum up:

- The results of this study cannot be used to assess the results of the earlier Beaufort Sea Coastal Sediment Study (Pinchin et al., 1985).
- Limitations associated with hindcasting the storm examined are now much better understood. While this greater understanding is certainly valuable, its implications with respect to the earlier study have not been fully determined.

7 Recommendations

7. Recommendations

Based on the work reported herein and the conclusion drawn, the following recommendations may be made:

1. In order to make full use of the data collected during the 1985 field study, the relationship between wind stress and the alongshore currents measured by Sea Data 621 gauge, should be investigated. At this stage, this would best be done by attempting to model the measured currents using existing theory. This should be done with the King Point wind data and preferably also with the Tuktoyaktuk wind data at least one source of overwater wind data.

2. In order to attempt to improve our understanding of the long-term sediment transport regime at King Point, by utilizing the findings of this study, the following steps should be taken:

   a) Compare the Tuktoyaktuk wind data to concurrently recorded overwater wind data to see if a direction dependent relationship exists between the overland and overwater wind speeds.

   b) Identify the storms which produced the highest predicted volumes of sediment transport at King Point and examine surface weather charts for those storms. This would help to determine whether the wind field characteristics identified during this study existed during the periods of high sediment transport.

3. Additional measured data is required to fully evaluate the predictive techniques used in both this study and the earlier study by Pinchin et al., (1985). Additional data collected should include:

   a) Wave height, period and direction measured at a deepwater location offshore of King Point.

   b) Wave height, period and direction measured just outside the surf zone.

   c) Alongshore currents measured within the surf zone. Ideally this would include enough measurements to determine the velocity distribution across the surf zone.

   d) Wave height distribution measured through the surf zone.

   e) Suspended sediment concentrations within the surf zone.

   f) Nearshore profiles, (see Recommendation #4).

Ideally the above listed data would be collected concurrently and over as long a duration as possible. If it is not possible to collect all of this data and priorities must be determined, then the purpose of collecting the data must be considered.

If the ultimate objective of collecting the data is to improve our knowledge of sediment transport processes at King Point, then the collection of the deepwater wave data should be given highest priority and collection of concurrent nearshore wave data, just outside the surf zone, should be given the next priority. The deepwater data should be measured over the duration of at least 1 open water season.

A sound definition of the nearshore wave climate is a prerequisite for the accurate prediction of sediment transport on beaches. To improve our ability to predict the sediment transport rates at any given site, we must first confirm that we are able to accurately predict the nearshore wave heights, periods and directions.

If the ultimate objective of collecting the data is to improve our knowledge of sediment transport in general, then collection of the nearshore wave data, just outside the surf zone, would have the highest priority. This data could then be directly input to the sediment transport models. Data, such as alongshore currents and actual volumes of sediment transported, would also have to be measured to ultimately evaluate the modelling process.

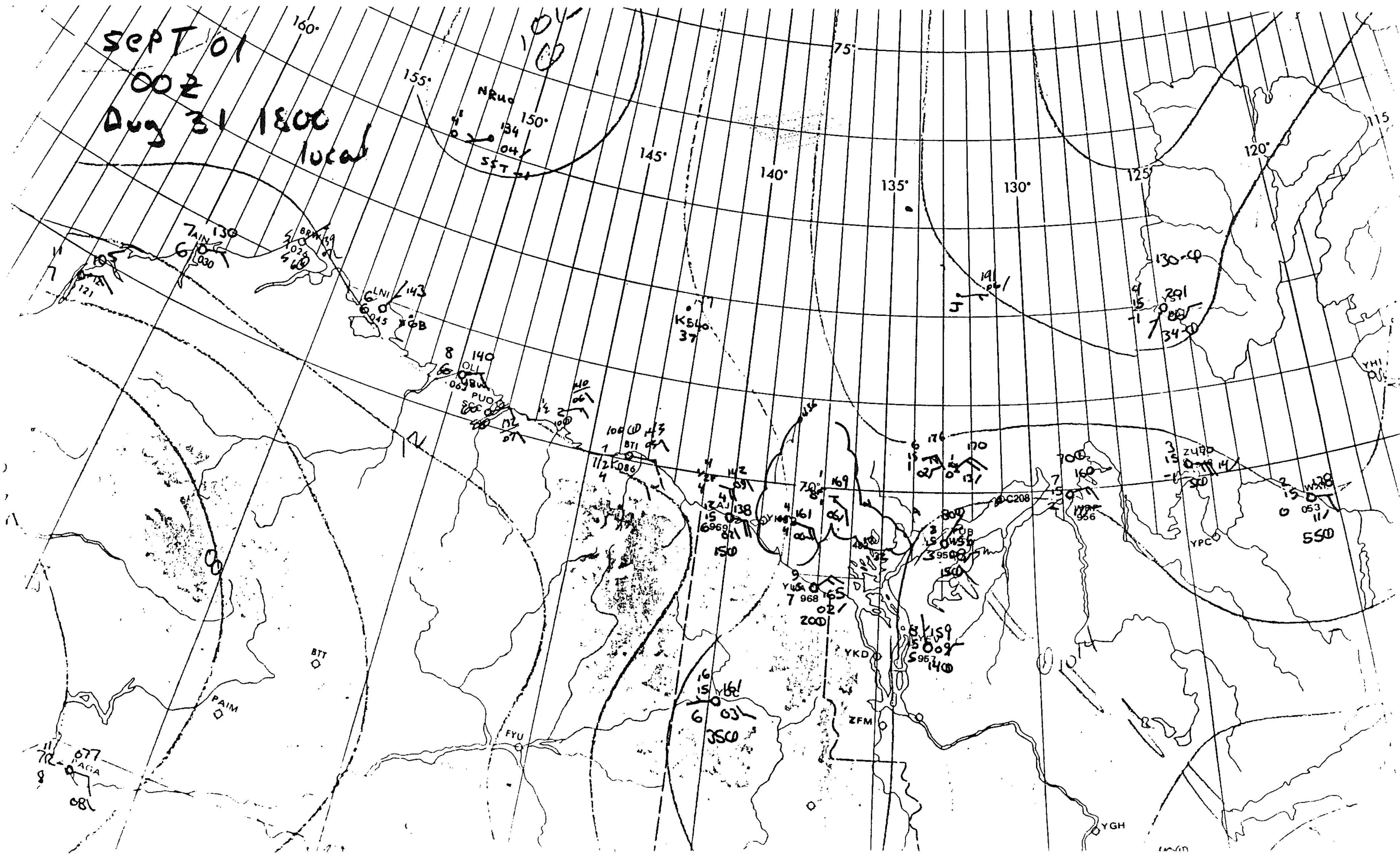
Because of the current state of knowledge of coastal processes, measurement of surf zone currents should be viewed as more valuable than measurement of surf zone wave-height decay. Knowledge of the wave height decay process is important to coastal processes but as more has been done involving the prediction of currents, there is a much larger knowledge base upon which to draw.

Because of the difficulties encountered in the collection of suspended sediment data and large uncertainty usually associated with such data, we view suspended sediment measurements as useful but of the lowest priority.

4. Irrespective of whether any of the above mentioned data is collected in future studies, we recommend that nearshore profiles continue to be measured at King Point. Every effort should be made to monitor the evolution of King Point over the coming years.

This could be accomplished by reporting profile measurements along the section of beach surveyed in 1985 but would also require profiling over a distance of at least 1 kilometre to the east of station 0+00 from Gillie (1985), (See Figure 2.1). A time series of profiles would allow calibration of the profile adjustment model but would also provide an estimate of the actual sediment transport rates at King Point. This is possible because there is a convergent sediment transport node at King Point.

5. In order to prevent a recurrence of the problems encountered with the field program design, we recommend that for any similar field measurement programs, an experienced numerical modeller of coastal processes participate in the measurement program design and supervision.



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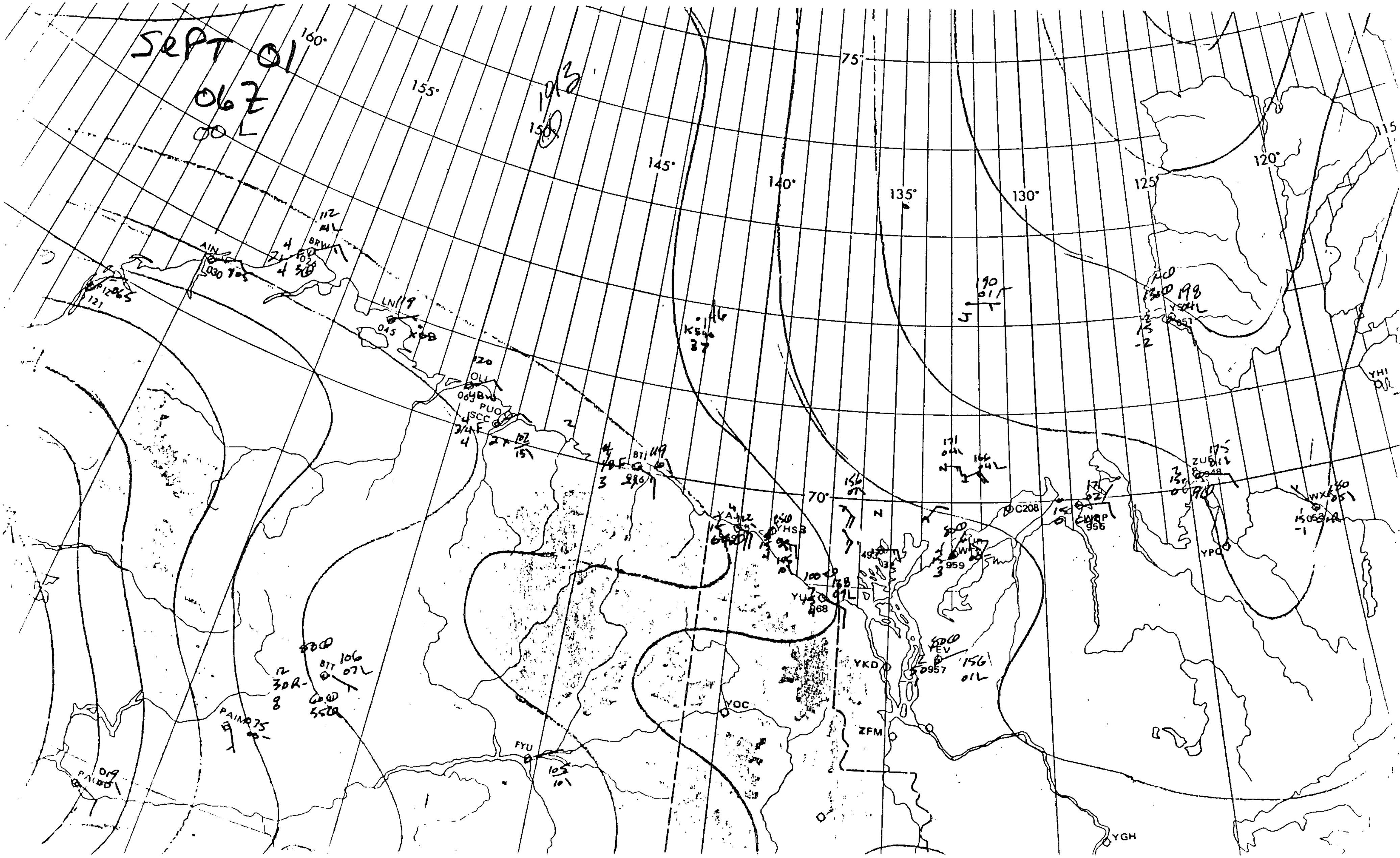
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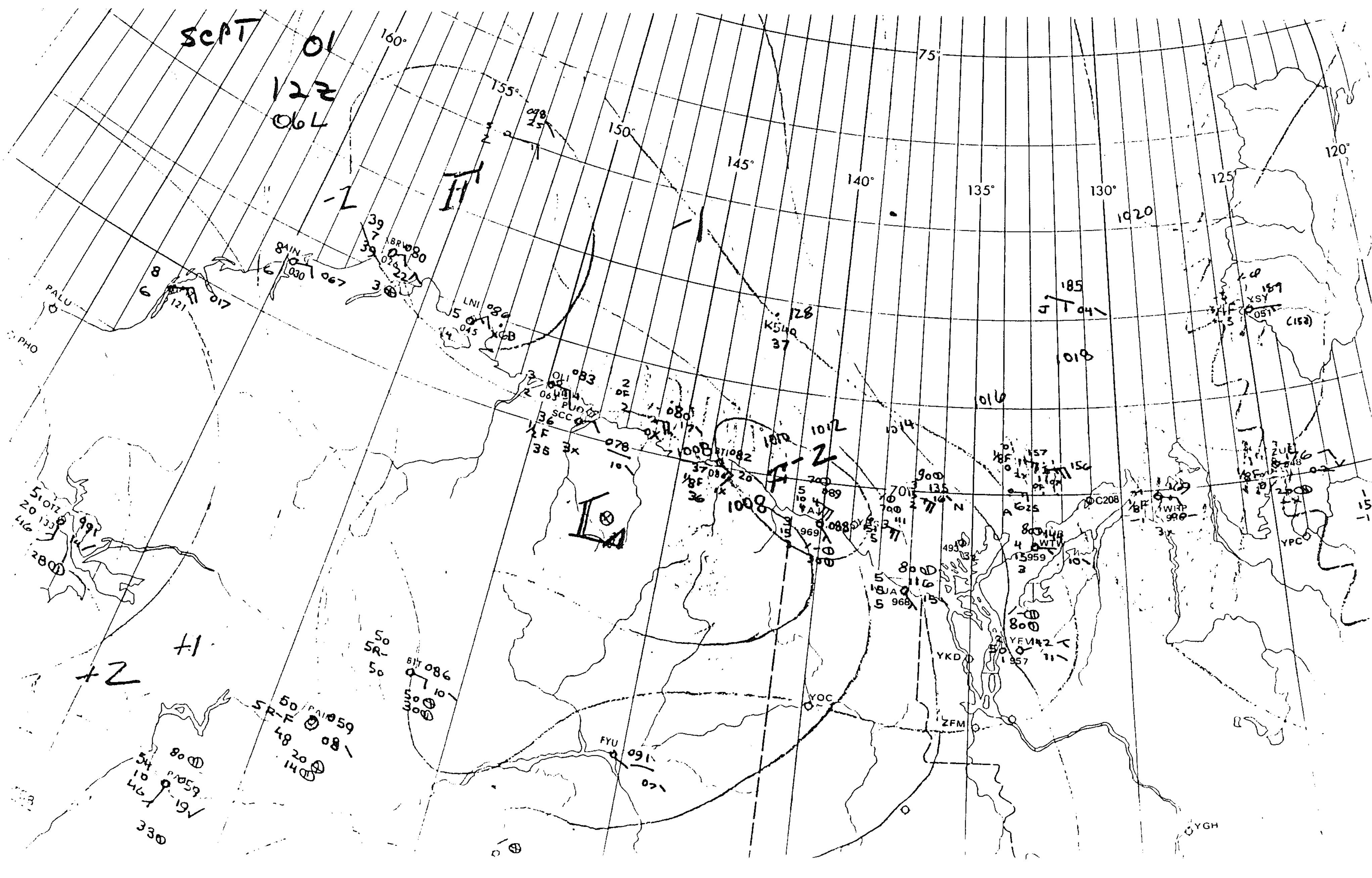
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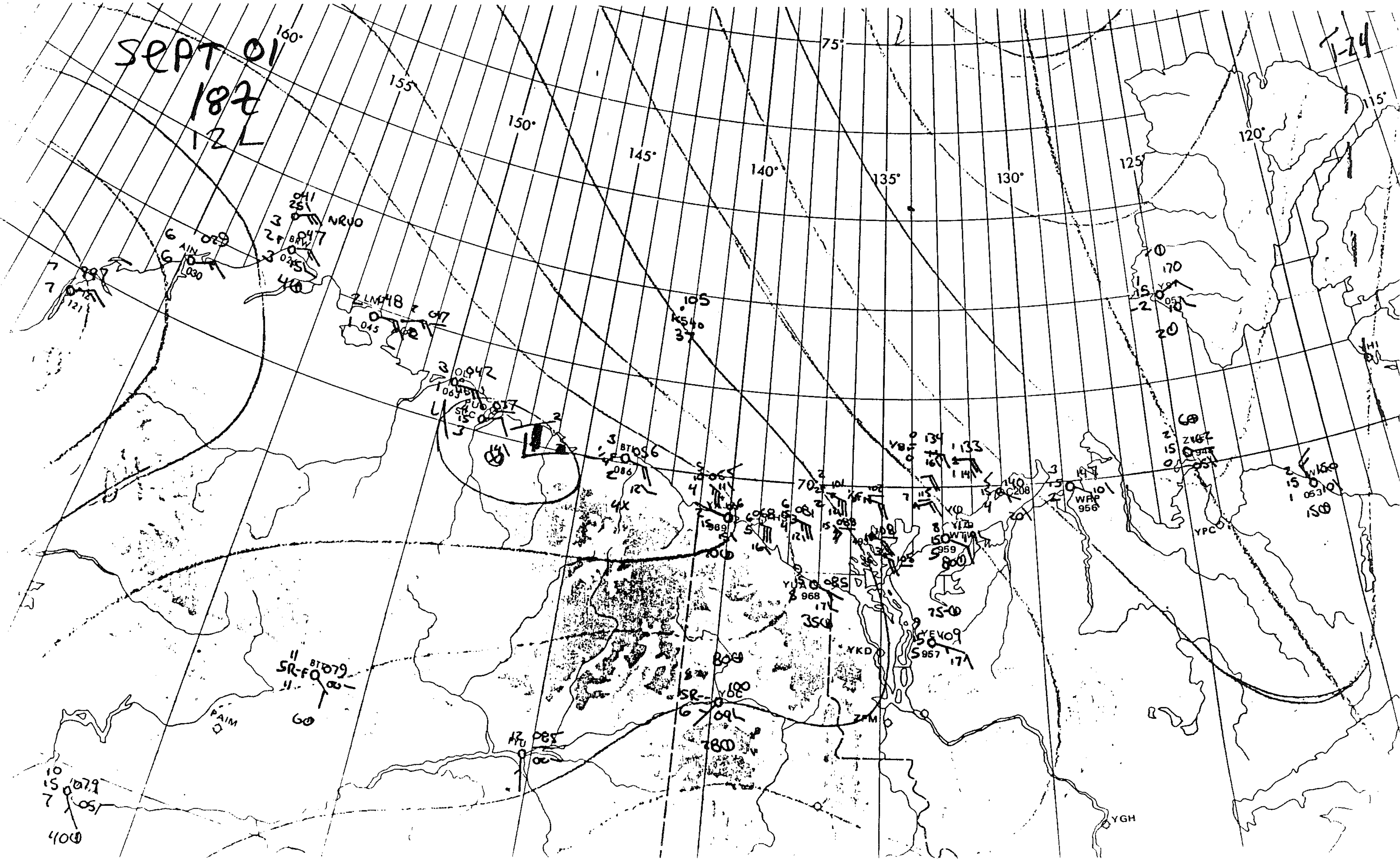
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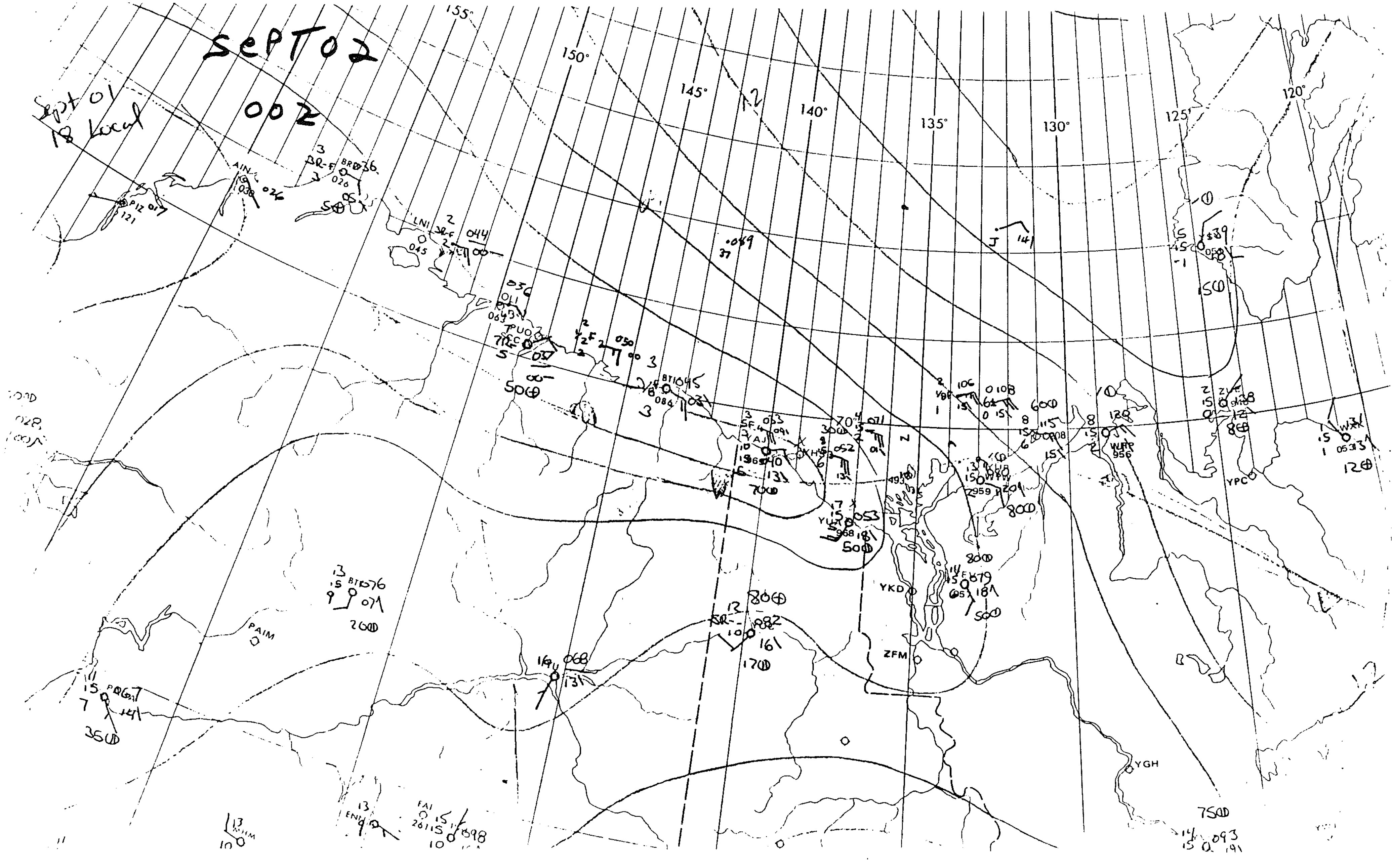
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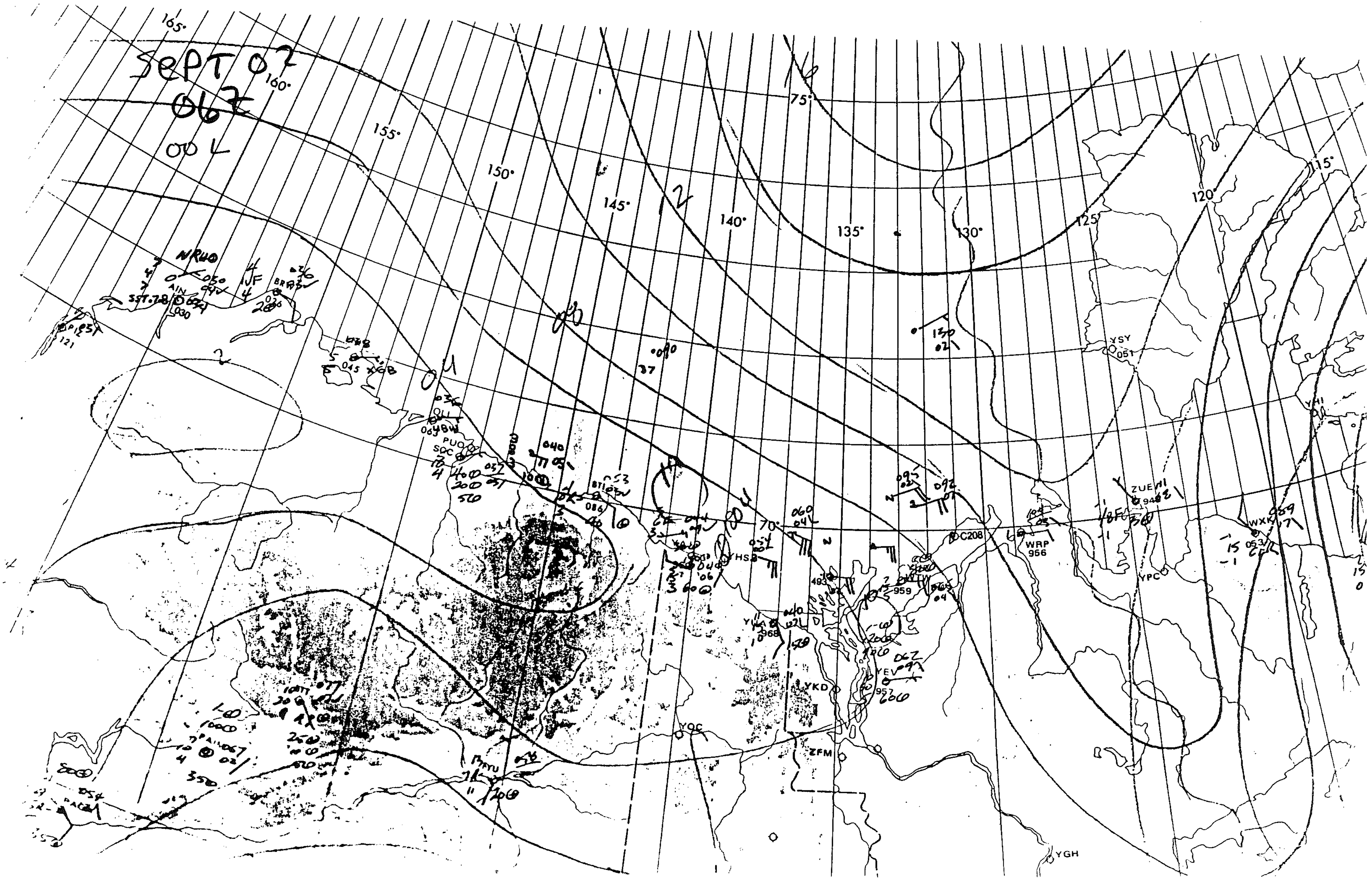
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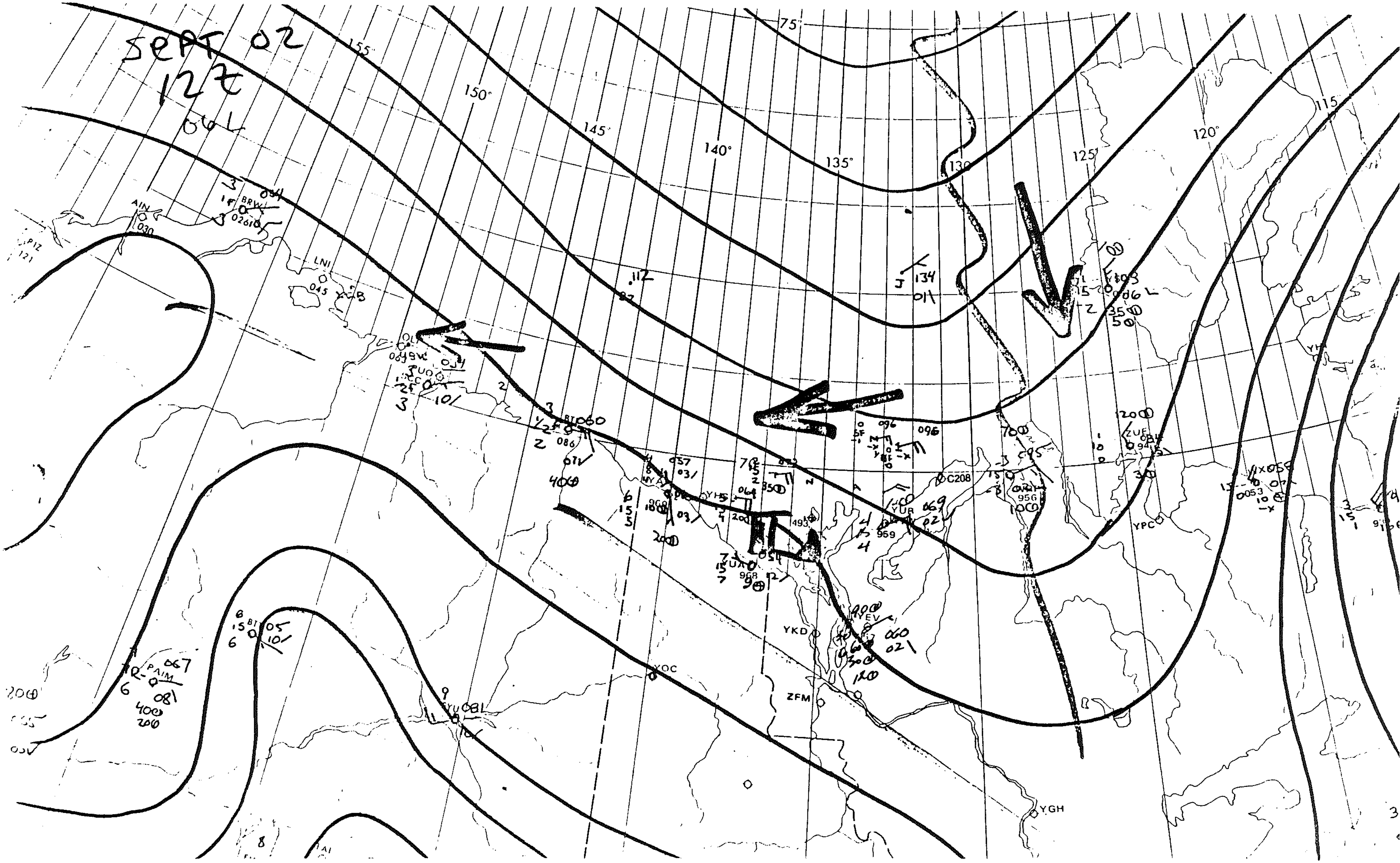
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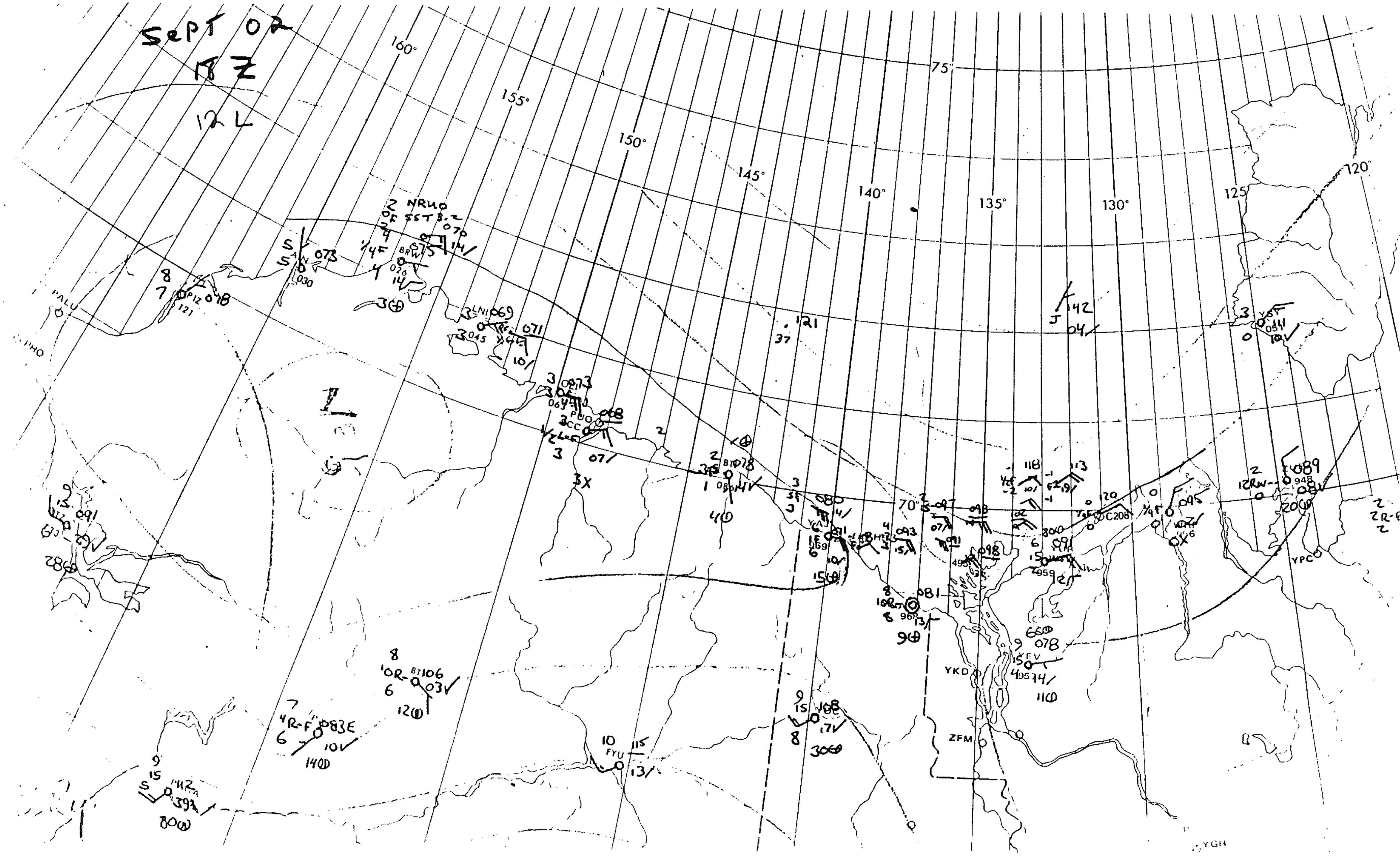

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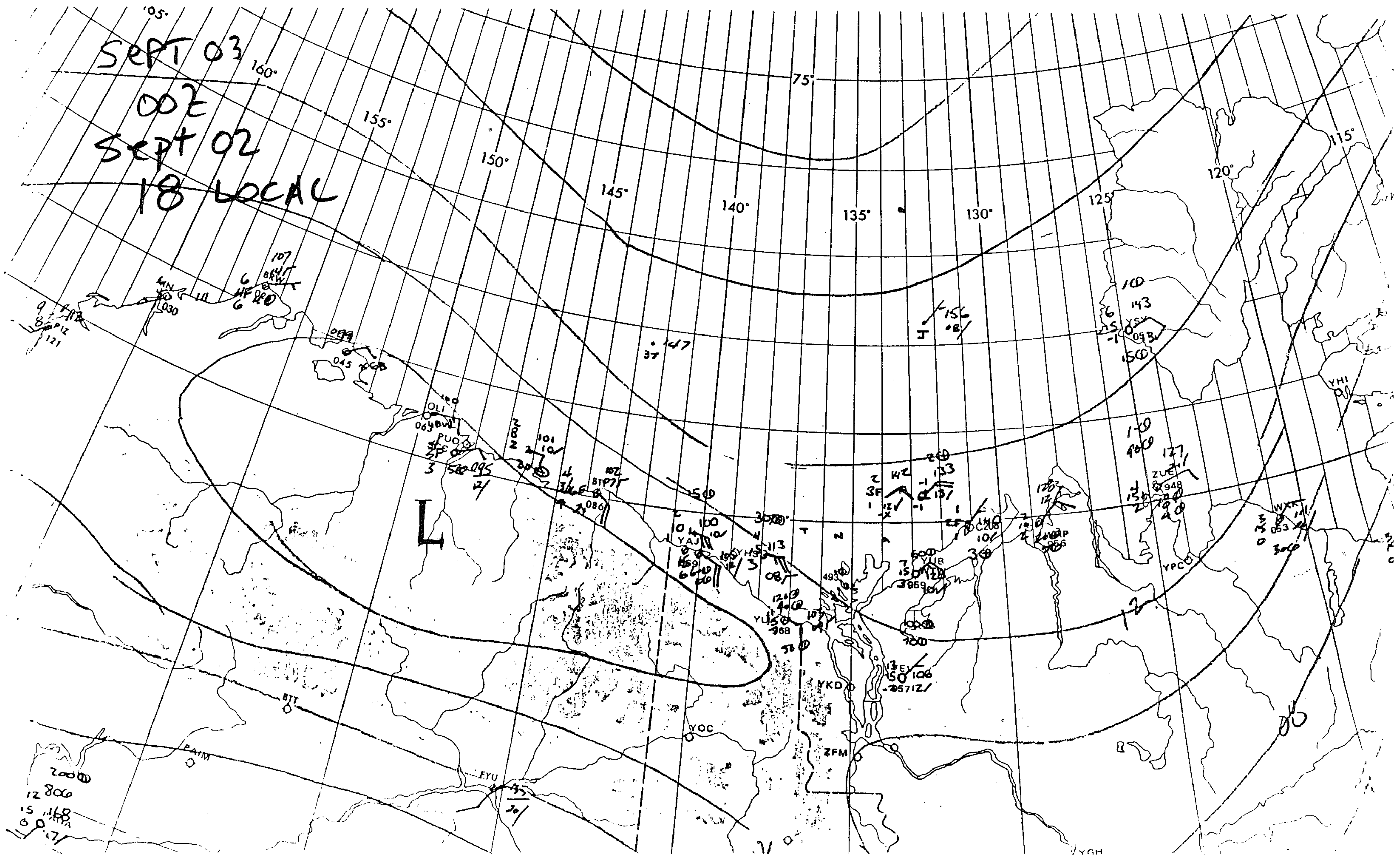
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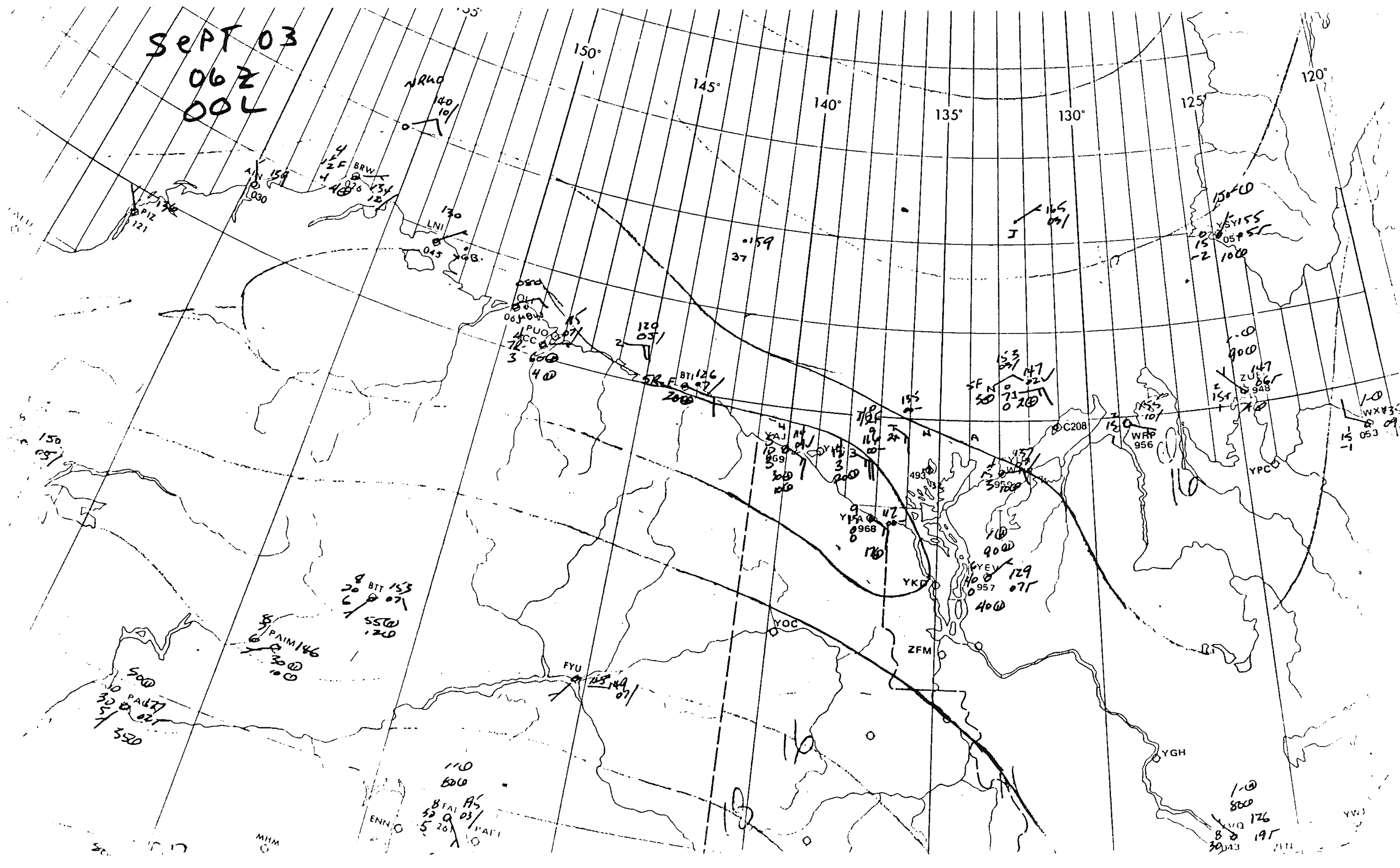

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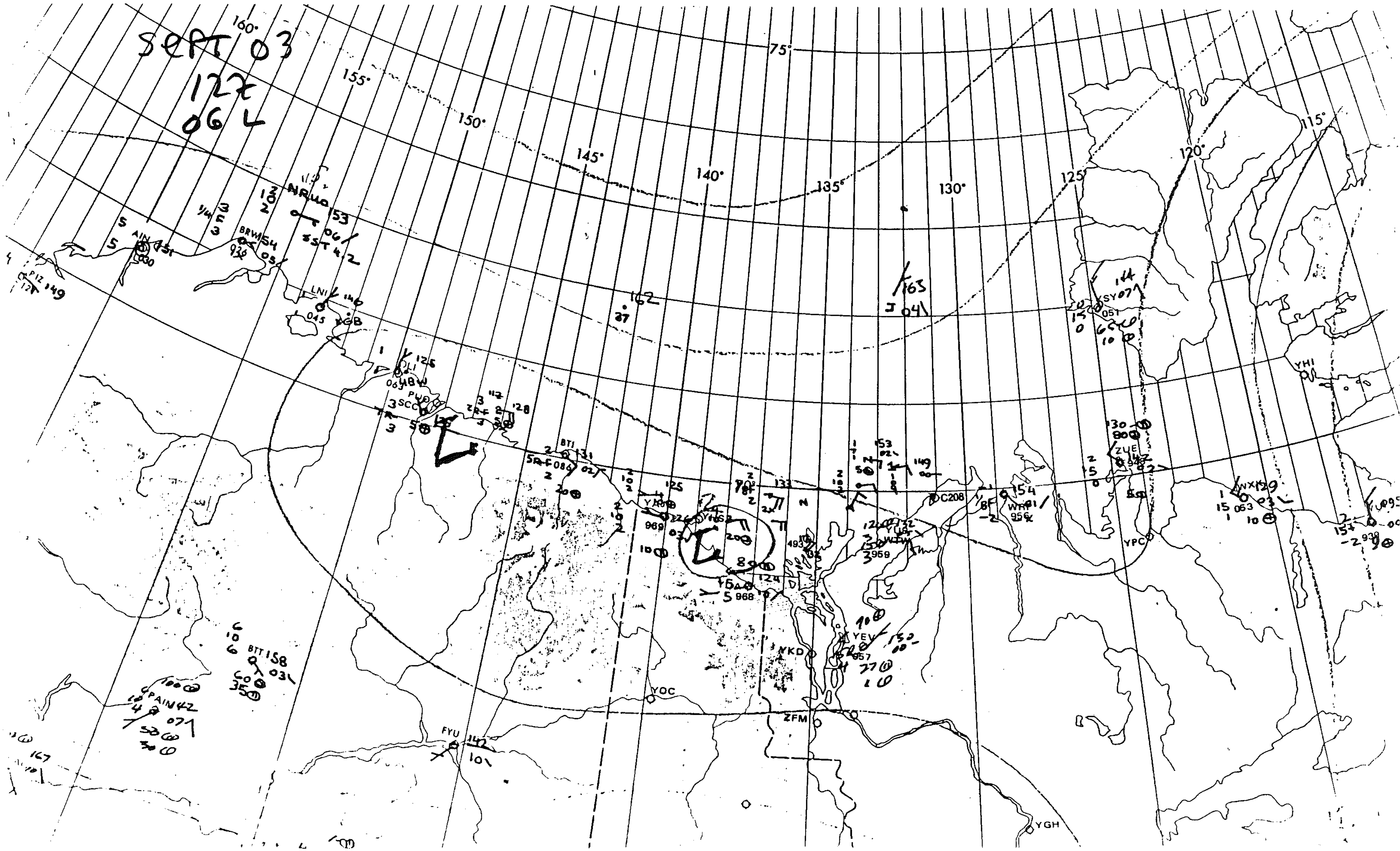
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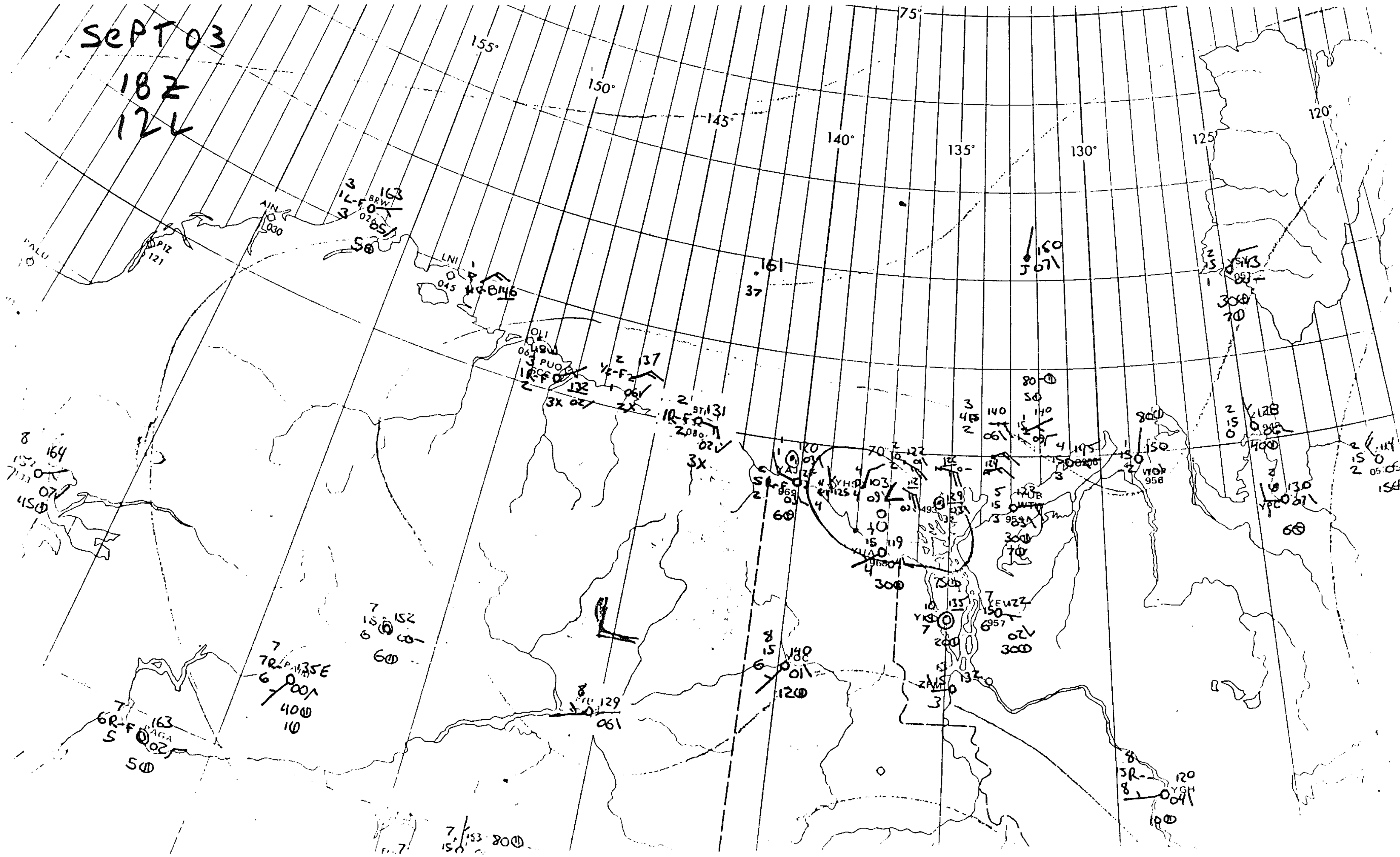
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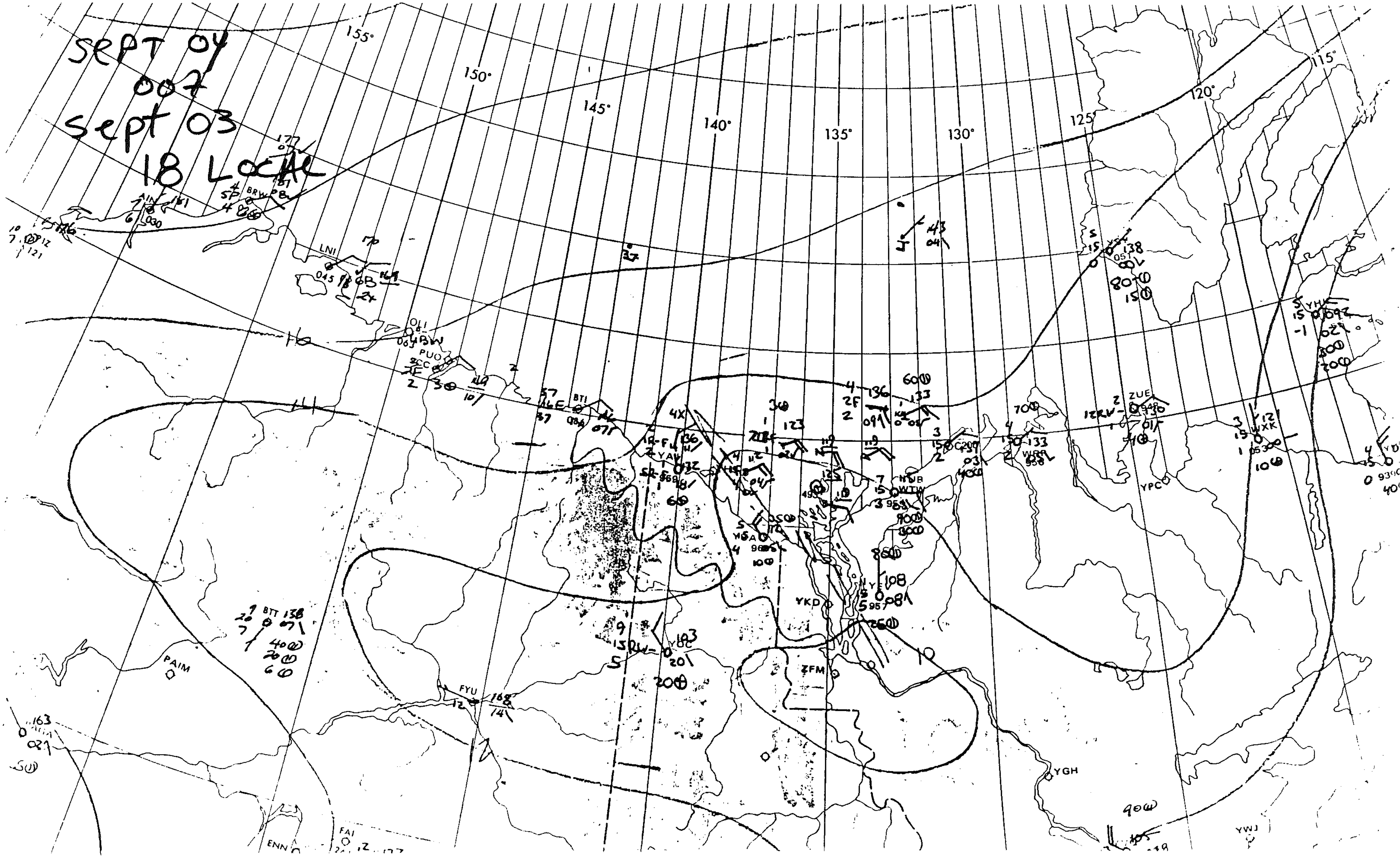
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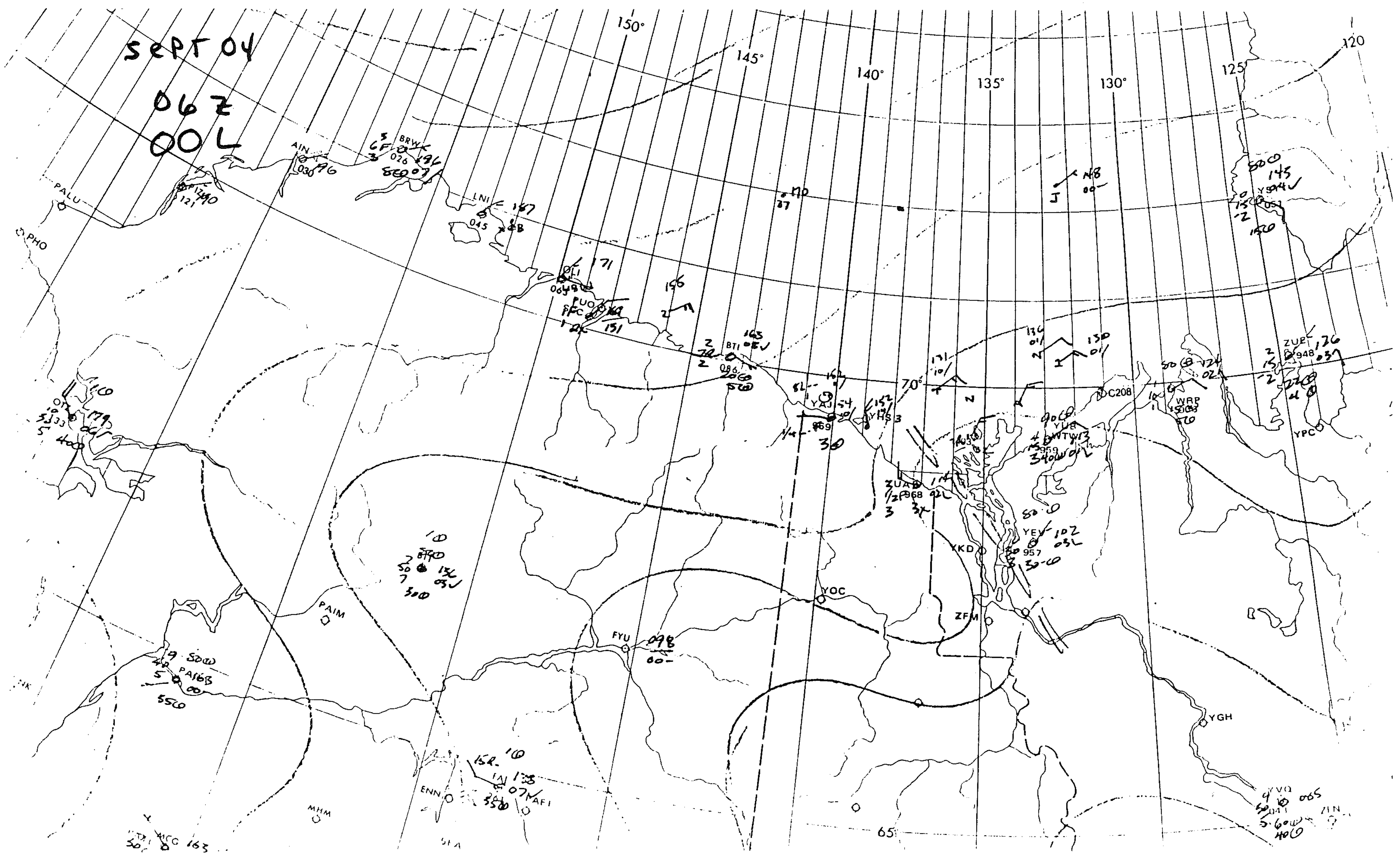
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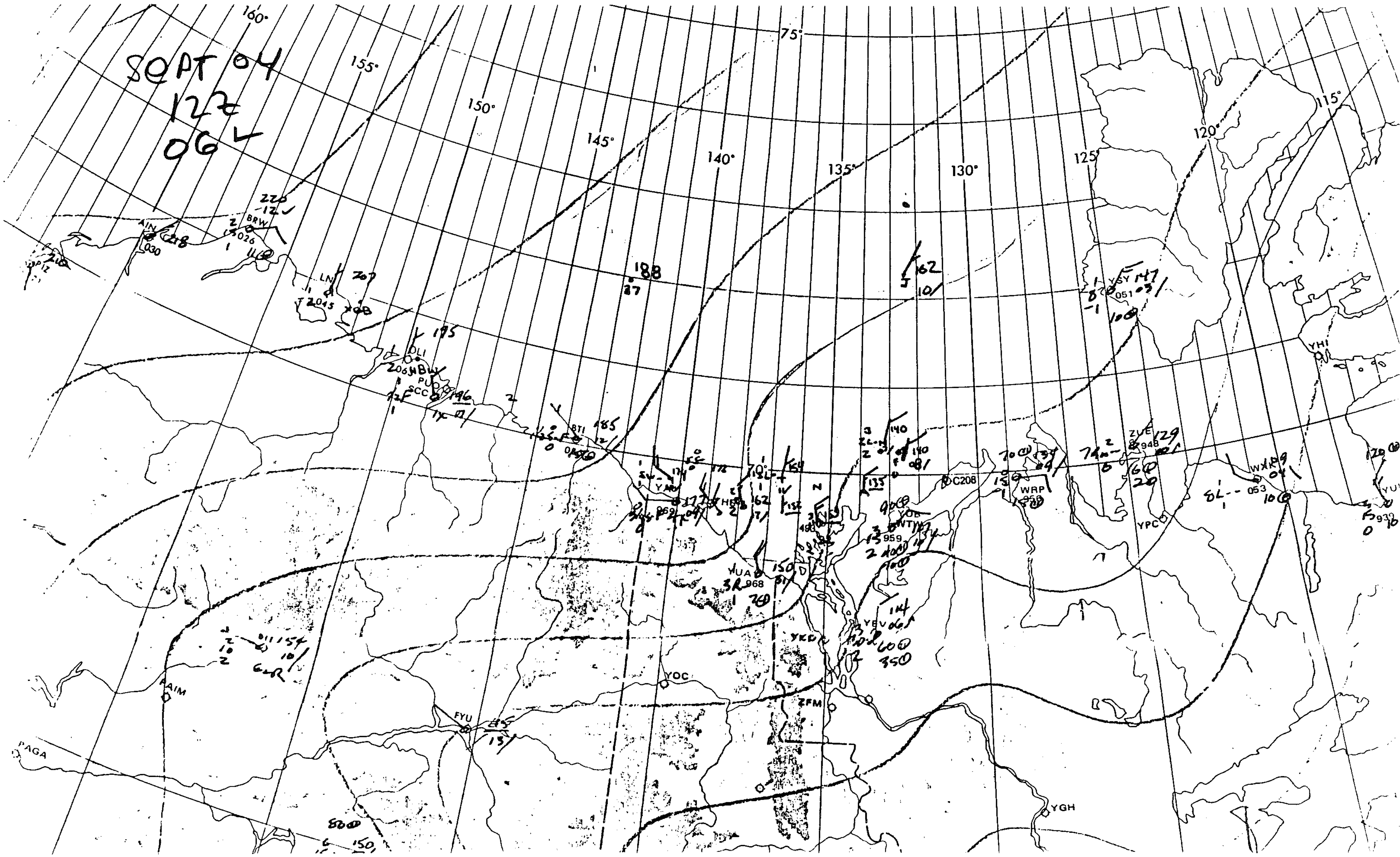
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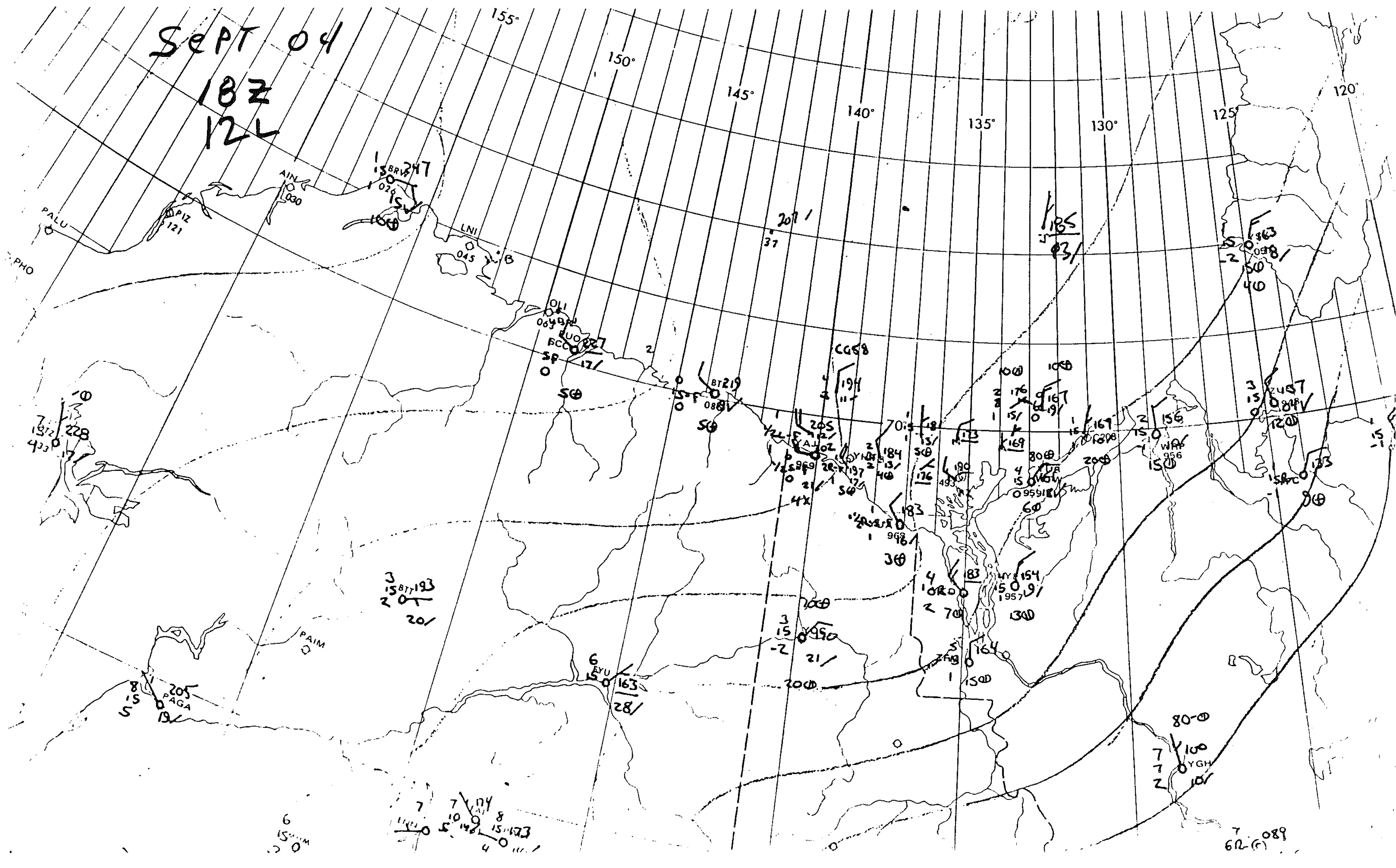
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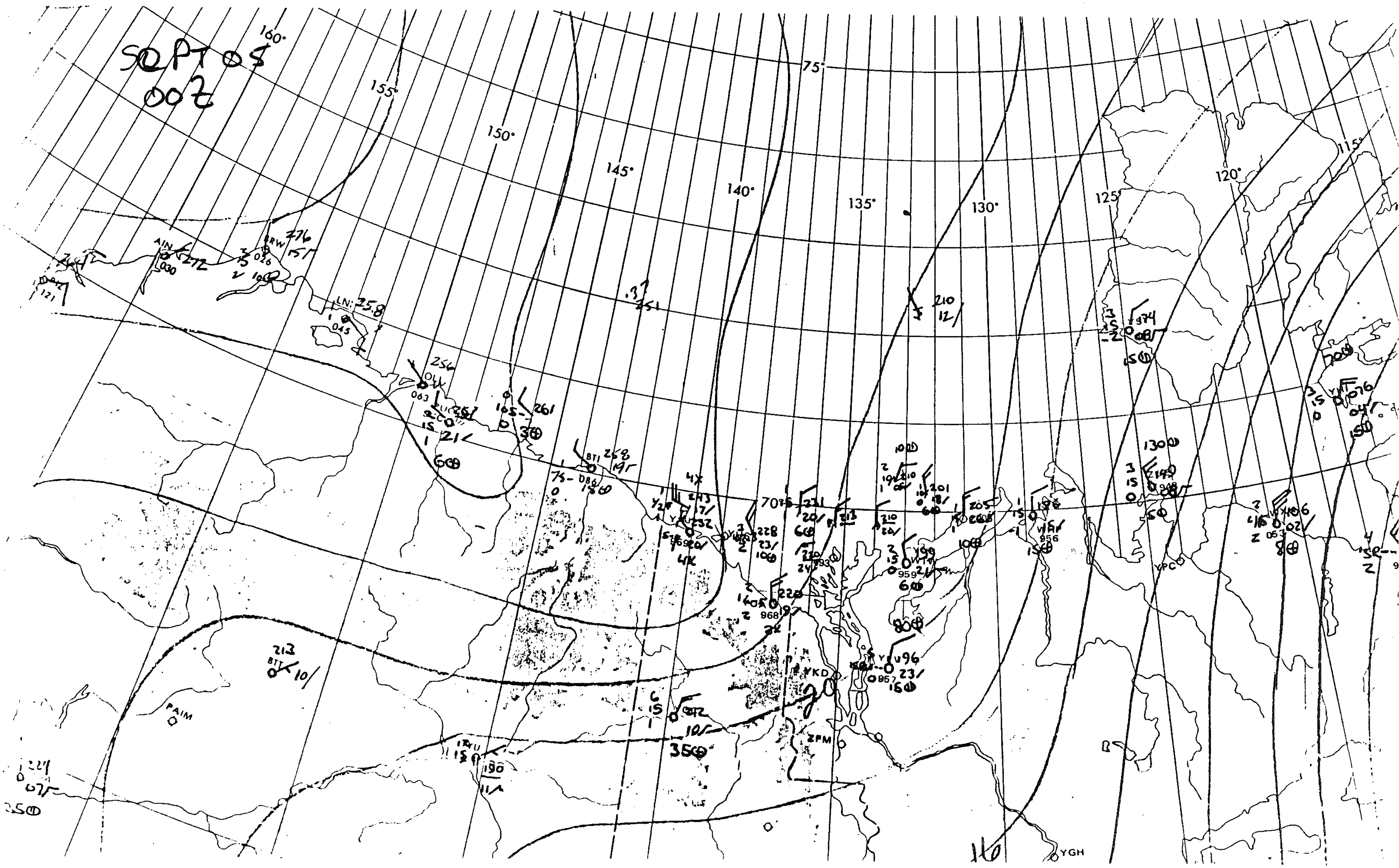
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THE GEOLOGICAL SURVEY OF CANADA

ENERGY, MINES AND RESOURCES, CANADA

FINAL REPORT

BEAUFORT SEA COASTAL SEDIMENT STUDY (continuation)

EFFECTS OF A STRUCTURE AT KING POINT, YUKON

R.B. Nairn

April, 1987

KEITH PHILPOTT CONSULTING LIMITED

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ABSTRACT

The effect of a coastal structure located midway along the barrier beach at King Point, Yukon, was determined by applying 14 years of hindcast hourly wave data with a one-line beach plan shape numerical model. The synthesis of the wave data and calibration of the beach plan shape model were part of an earlier investigation. The structure was assumed to act as a total littoral barrier.

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Effects of a Structure At King Point

1. Introduction

The objective was to determine the effect of a hypothetical structure located midway along the barrier beach at King Point, Yukon (Figure 1). The structure, in the form of a jetty or causeway, was assumed to be a total littoral barrier allowing no bypassing of sediment.

A beach plan shape evolution model (BPLAN) was used to investigate this problem. The model computes changes in the planform of a shoreline due to spatial and temporal variations in alongshore sediment transport rates. It uses wave data in strict chronological order and updates shoreline geometry at the end of each wave condition so as to simulate the actual evolution. Coastal planform adjustments for the period from 1970 to 1983 were determined.

In a previous study (GSC open file 1259, Pinchin et al., 1985) the beach plan evolution was determined for the same time period with and without a coastal structure. The present study examines beach plan development with an altered structure position using input data from the previous study. Also, BPLAN has been improved since the previous study to account for the effects of sheltering and diffraction and to utilize a bulk transport model developed by Kamphuis et al., (1986).

2. Theoretical Background

The model (BPLAN) is a one-line shoreline change model based on the Pelnard-Considere (1956) principle which assumes that the shoreline erodes or accretes in parallel slices. A simple equation of continuity illustrates the basic principle, as follows:

$$\frac{\partial Qx}{\partial x} + \frac{h\partial y}{\partial t} = 0 \qquad (1)$$

where Qx is the littoral transport rate at point x, h is the active beach height below and above water and $\partial y/\partial t$ represents the rate of shoreline retreat or advance, (See Figure 2.)

FIGURE 7

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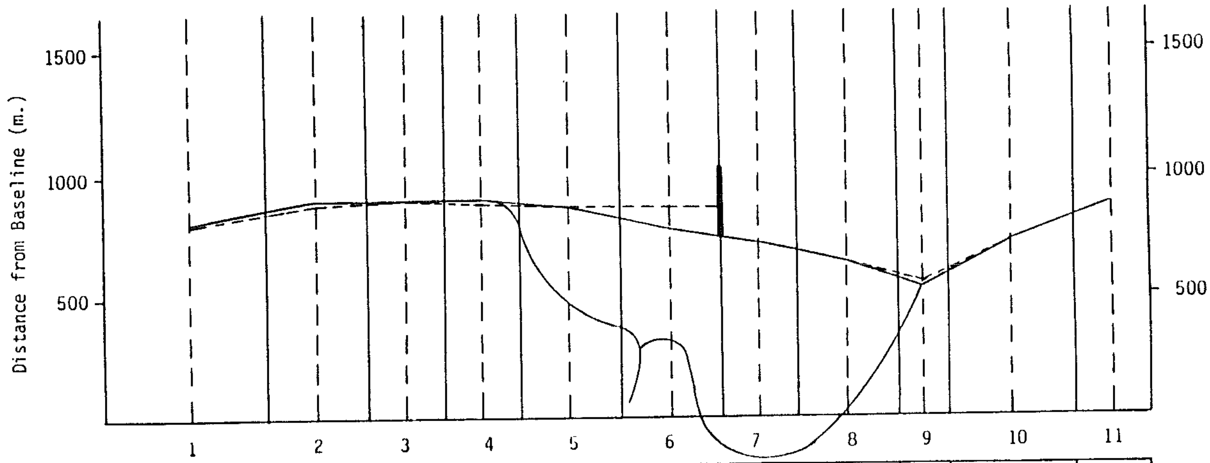

Shoreline Change	0.0	0.1	-1.5	-2.2	-1.8	-2.4	0.3	0.0	1.6	0.4	0.7	
Cumulative Change	-11.0	-17.9	0.0	-11.5	4.2	82.2	-2.5	-2.3	15.1	1.5	2.6	
Net Drift	-13.3	-13.6	-13.8	-11.6	-8.3	-4.8	0.0	-0.4	-0.4	-5.2	-8.5	-11.9

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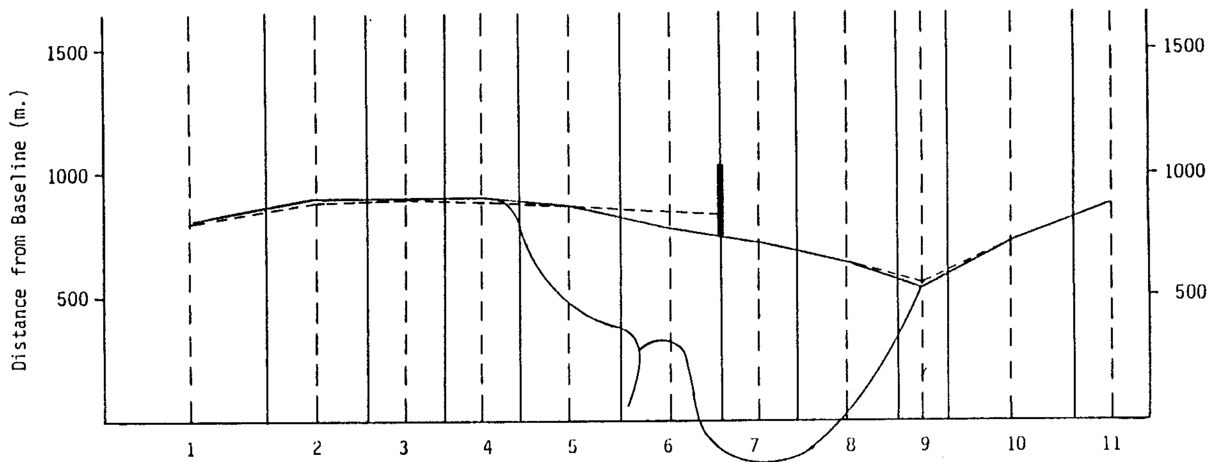

Shoreline Change	-0.4	-0.6	-4.5	-4.6	-4.8	-7.4	-0.3	0.0	4.1	1.2	2.0	
Cumulative Change	-11.4	-18.5	-4.6	-16.1	-0.6	74.8	-2.8	-2.3	19.1	2.7	4.5	
Net Drift	-40.5	-39.3	-38.0	-31.3	-24.3	-14.8	0.0	0.4	0.4	-11.8	-20.6	-29.4

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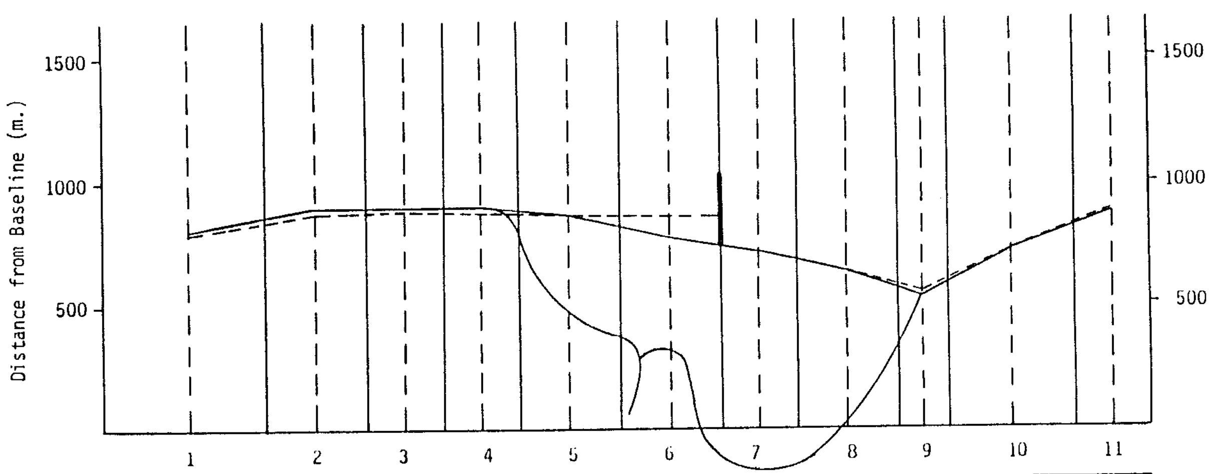
1980



Shoreline Change	-3.6	-5.8	-3.0	-3.2	-1.3	4.9	-0.8	-0.1	3.4	1.5	2.5	
Cumulative Change	-15.0	-24.3	-7.6	-19.3	-1.9	79.6	-3.6	-2.4	22.5	4.2	7.0	
Net Drift	-25.3	-13.8	-2.2	2.3	7.1	9.7	0.0	1.2	1.4	-8.7	-20.0	-31.3

FIGURE 8

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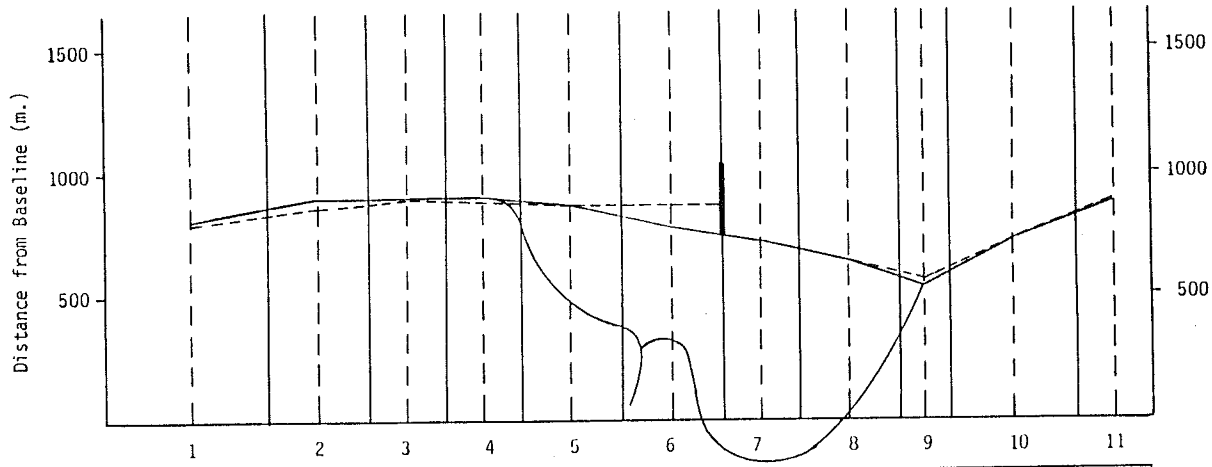

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Shoreline Change	-2.3	-3.8	1.0	-0.9	2.1	11.4	-0.8	0.0	2.7	-0.6	1.0
Cumulative Change	-17.3	-28.1	-6.6	-20.2	0.1	91.0	-4.4	-2.4	25.2	4.8	8.1

Net Drift	11.8	19.4	27.0	25.5	26.9	22.8	0.0	1.2	1.3	-6.7	-11.4	-16.0

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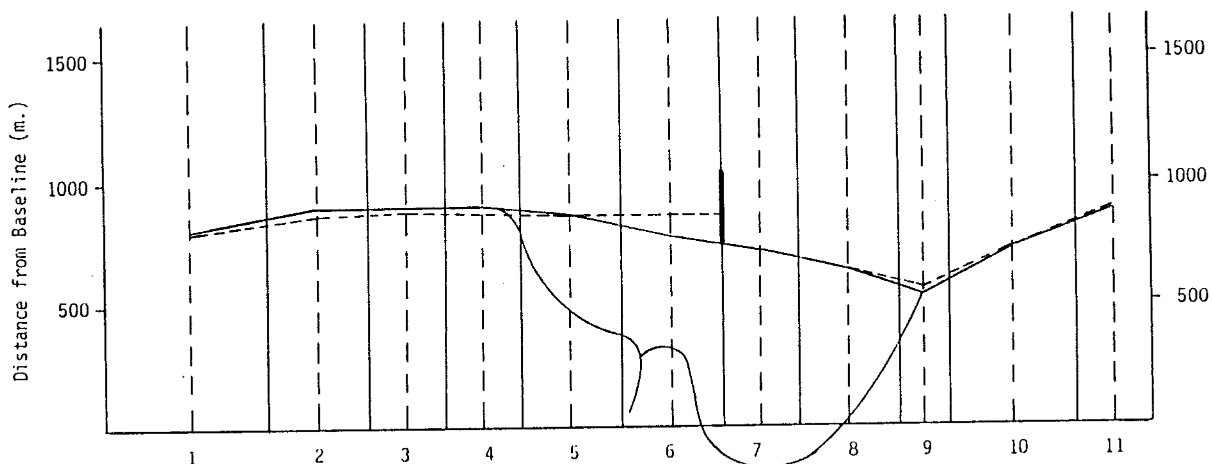
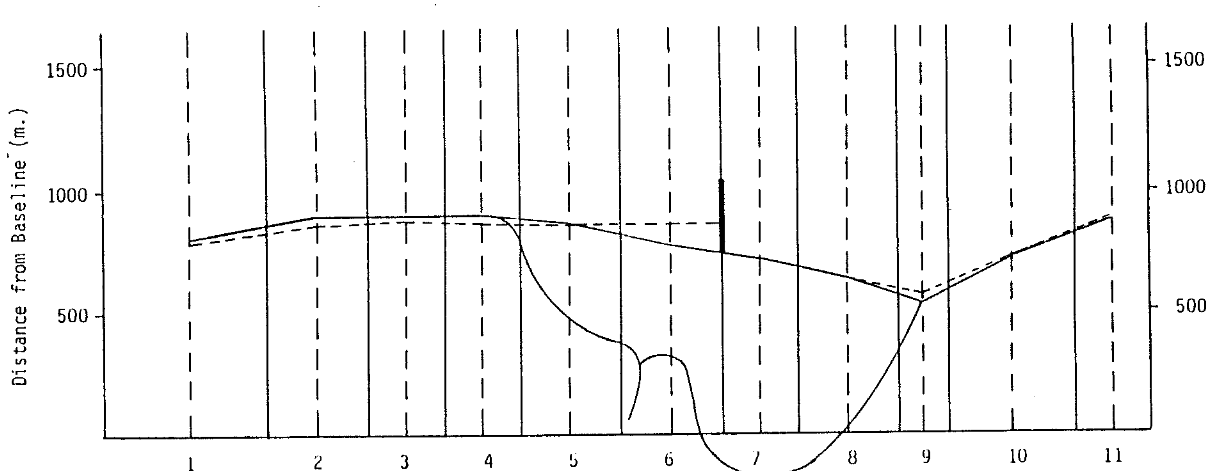
1982



	1	2	3	4	5	6	7	8	9	10	11
Shoreline Change	-0.1	-0.2	-4.9	-2.4	-3.0	-6.5	-0.3	0.3	3.4	1.2	1.9
Cumulative Change	-17.4	-28.3	-11.5	-22.7	-2.8	84.6	-4.7	-2.2	28.6	6.0	10.0

Net Drift	-3.1	-30.3	-30.0	-22.6	-18.9	-12.9	0.0	0.4	-0.1	-10.2	-19.0	-27.7

2o
1983



	1	2	3	4	5	6	7	8	9	10	11
Shoreline Change	-0.3	-0.5	0.1	-0.9	-0.5	0.0	-0.3	0.1	1.7	0.2	0.3
Cumulative Change	-17.7	-28.8	-11.4	-23.6	-3.4	84.5	-5.1	-2.1	30.3	6.2	10.3

Net Drift	-4.3	-3.3	-2.3	-2.5	-1.1	0.0	0.0	0.4	0.2	-5.0	-6.5	-7.9

APPENDIX

Diffraction Coefficients/Angle Sector
based on structure to 5m contour or 500m offshore at wave node 7

ANGLE

DRIFT CALC. NODE	310-324.5	324.5-339.5	339.5-354.5	354.5-360.	0.-9.5	9.5-24.5	24.5-39.5	39.5-54.5	54.5-69.5	69.5-84.5	84.5-99.5	99.5-114.5	114.5-129.5	129.5-140.
10	0.3	0.55	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
9	0.18	0.22	0.4	0.6	0.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
8	0.14	0.14	0.22	0.30	0.30	0.65	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0
7	0.12	0.14	0.15	0.22	0.22	0.3	0.3	1.0	0.3	0.3	0.22	0.15	0.14	0.12
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.65	0.4	0.22	0.17	0.13
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.55	0.25	0.15
4	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.55	0.20
3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.75	0.25
2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.89	0.35
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.90	0.35

With the present limits of knowledge, only potential alongshore transport rates, which assume unlimited availability of sand, can be computed directly. Similarly, there is an underlying assumption that all of the material eroded from the active beach face is transported as littoral material; possible offshore losses of fine material or overwash losses of material are neglected with BPLAN. However, where field data is available for calibration it is possible to approximate the effects of restricted sand supply and offshore or backshore losses in BPLAN.

Assume the actual alongshore transport rate Qx is equal to αQp, where Qp is the potential transport rate and α is a factor less than 1. Also, if part of the erosion product of an eroding face of height h is lost offshore then the second term in Equation 1 becomes $Bh\partial y/\partial t$ where B is the fraction of erosion product that is not lost offshore. The case of an accreting beach face where a proportion of the material is either "lost" over a barrier beach, or offshore, can be similarly represented, although in that case B is greater than unity. With these two adjustments, equation 1 becomes

$$\alpha\frac{\partial Qp}{\partial x} + Bh\frac{\partial y}{\partial t} = 0 \qquad (2)$$

For simplicity the two factors may be combined:

$$\frac{\partial Qp}{\partial x} + \frac{Bh\partial y}{\alpha\partial t} = 0 \qquad (3)$$

It will be clear from Equation 3 that the application of a single factor to the beach height, in effect the use of a fictitious height, suffices to calibrate the model to account for either or both of actual alongshore transport rates and losses from the beach face. The factor can be varied from one segment of beach to another as required. Generally, different factors apply to zones of erosion and accretion.

The sediment transport rate was determined using a bulk energy model developed by Kamphuis et al., (1986). This model has the advantage of including both beach slope and grain size in its formulation. The equation was developed from both field and laboratory data and in a recent study at Pointe-Sapin (Fleming et al., 1985) it provided the best results among common bulk energy models.

2.1 Input Data and Operation

The definition of the shoreline at King Point is shown in Figure 3. The coast was divided into 11 sections and the shape was determined by the offset from a baseline (dashed lines in Figure 3). The 1970 shoreline was used to define the initial condition. A hypothetical structure which allows no bypassing is placed between Sections 6 and 7. The structure is assumed to extend 300 m offshore to a depth of 5 m.

The profile slopes and grain size data were determined from survey by Dobrocky Seatech (Harper et al., 1985). The slopes were assumed to vary for each beach section while a D50 of 0.3 mm was taken for all the beach sections. The input data is presented in Table 1.

The inshore wave climate was defined at five nodes shown on Figure 3. The wave characteristics were interpolated at seven more locations to provide twelve littoral drift calculation points (these points fall on the solid lines in Figure 3). The model was applied using fourteen years of sequential hindcast data (1970 - 1983). Waves are refracted from the inshore node (at a depth of 4 m) to the breakpoint using plane beach refraction, assuming the contours are locally parallel to the shoreline.

Diffraction coefficients are applied at each drift calculation node. The coefficients were predetermined for each node and for 14 different incident angle sectors based on the method of Wiegel presented in the Shore Protection Manual (CERC, 1984). These coefficients are presented in the Appendix.

Table 1

Application of the Beach Plan Model at King Point

Conditions With a Structure

Operating Condition for Final Run 1979 - 1983

No. of beach sections = 11

Initial beach offsets at each section (1 to 11):
400.0, 300.0, 400.0, 200.0, 500.0, 300.0
650.0, 400.0, 300.0, 300.0, 400.0

Beach slopes at each section (1 - 11)
.037, .033, .025, .025, .021, .021, .010, .008, .006, .007,
.021

Grain size used for each section was 0.30 mm.

Angle of baseline normal to true north = 47.0°

Refraction data specified at drift calculation points:
2, 4, 8, 10, 11

Refraction data given at 4.0 m contour

Calibration height (for section 1 to 11):
5.0, 5.0, 5.0, 5.0, 5.0, 5.0, 5.0, 5.0, 15.0, 15.0, 15.0

Drift calculation point 1 is an open boundary

Drift calculation point 7 is a long groyne

Drift calculation point 12 is an open boundary

Notes: 1. Distances and heights are in metres; angles in degrees.

2. Calibration beach height equals (actual height) X (height factor)

The potential littoral drift rate was calculated using the most recent Queens University model (Kamphuis et al., 1986). The amount of erosion or accretion is determined by the difference in the littoral drift entering and leaving a beach section. The shoreline position offsets change with each wave condition and therefore the beach plan shape is redefined after each wave. This ensures that shoreline change is properly evolutionary (i.e. in correct chronological sequence).

3. Inferred Actual Littoral Drift

All sediment transport models determine the potential maximum alongshore transport rate which is only realized when there is an unlimited supply of sand. Ideally, beach plan shape models should only be applied where there is a fully developed beach with an unlimited sand supply. Often at King Point the potential transport may not be realized since there are no fully developed beaches east or west of the barrier beach.

At King Point the actual sediment transport was estimated by using recession rates of the bluffs east and west of the barrier beach (McDonald and Lewis, 1973; Harper et al., 1985). Confidence in this approximation was strengthened by a separate calculation of infilling of the barrier beach over a period of fourteen years, 1956 - 1970.

The composition of the bluffs east and west of King Point were estimated from information included in McDonald and Lewis (1973). The information included sediment particle size distribution and the percentage ice content. The volume of sand and gravel which might be expected to be moved as littoral drift was then taken as a percentage of the total volume per metre alongshore (bluff height multiplied by the recession rate). This calculation indicated that actual average drift was about 15,000 - 25,000 cu. m/yr from the west and 5000 cu. m/yr from the east. The separate analysis for the infilling of the barrier beach produced an estimate for average gross littoral transport of 21,000 cu. m/yr is similar to the result determined from the recession rates. Gillie (1985) has estimated that the gross sediment transport is 20,000 - 40,000 cu. m/yr with 75% of the total originating from the west.

4. Cohesive Shore Erosion

The erosion of cohesive shorelines is directly related to the downcutting of the nearshore profile by the dissipation of wave energy (Philpott, 1985). Visible bluff erosion is merely an effect of the causative downcutting.

Sediment transport calculations give an indication of the magnitude of wave energy reaching the shore, as well as the potential or maximum littoral drift. However, littoral drift deficit calculations, which are the basic principle behind morphological development in true beaches, cannot be applied to cohesive shore erosion. Hence, the bluff recession predicted by the BPLAN model can only bear resemblance to the actual observed rates through artificial calibration of beach height factors (using the principle described for Equation 3). For instance, the beach heights in beach Sections 10 and 11 were increased to create smaller and more reasonable bluff recession rates. The beach height in Section 9 was also increased to compensate for excessive amounts of predicted sediment transport from the east.

It is apparent that in order to apply a beach plan model and produce accurate results for the case of a barrier beach bounded by cohesive shoreline, good estimates of actual sediment transport entering the beach system are required. Fortunately this information was available for King Point as described in Section 3.

5. Form of Results

The results are presented in Figures 4 - 8. The beach position is shown for each year compared to the 1970 shoreline, the cumulative and yearly beach position changes are also tabulated. Arrows show the relative magnitude and direction of the net littoral drift during the particular year at each of the drift calculation nodes and the net drift is tabulated below the shoreline change formation.

6. Discussion of Results

6.1 Actual vs. Potential Littoral Drift

In order to assess the accuracy of the results it is first necessary to examine the predicted infilling rates versus actual inferred and observed values (See Section 3). With the placement of a structure which does not undergo bypassing between beach Section 6 and 7 sediment from the west is trapped in beach Section 6 and sediment from the east collects in beach Sections 9 - 11.

Table 2 shows the actual and predicted annual infilling rates. The predicted infilling rate can be determined from the product of beach height, cumulative beach change and the width of the beach section .

Table 2 - Infilling Rates (cu. m/yr)

Originating from	Predicted BPLAN	Inferred KPCL	Gillie(1985)
the West	12,000	20,000.	30,000.
the East	13,000	5,000.	10,000.

The predicted value for sediment accumulation from the west (in beach Section 6) is reasonable considering that additional material would also have been deposited and subsequently eroded from the neighbouring section and transported to the west.

BPLAN overpredicts the accumulation in beach Sections 9 - 11 east of the structure. Subsequently, the beach height calibration factor in Sections 9 - 11 have been increased from 5 to 15 m to compensate for the overprediction. This allowance improves the accuracy of the shoreline change prediction.

6.2 Variability in Alongshore Wave Power

The form in which the results are predicted serve to show the radical variability in the magnitude and direction of alongshore power from year to year. While the net drift may have been similar in some years the total drift to the east and to the west was quite different in almost every year. The most remarkable anomaly is 1971 during which a long open water season and numerous heavy storms from the west combined to produce half the total volume predicted to be deposited in beach Section 6 just west of the structure (approximately 90,000 cu. m). The variability is related to a combination of the length of the open water season and the severity of the wind climate in the open water season.

The actual variability in alongshore sediment transport may be less dramatic. Consider that the process of cohesive shoreline erosion is related to the downcutting of profiles and successive bluff failures. These failures produce an insurgence of beach sand into the littoral drift regime. It seems possible that the bluff failures may not occur during the year of largest downcutting but will nonetheless occur soon thereafter. This would tend to smooth out the year to year variation described above.

6.3 Morphological Development Predicted by BPLAN

The model results indicate that Section 6 east of the structure acts as a sediment trap. While sediment can be deposited from the west, waves from the east do not remove material in this section, due to the sheltering effect of the structure. Similarly there is a shelter zone just east of the structure where very little erosion occurs. Deposition on the east side of the structure is limited to Sections 9 - 11 because of the local shoreline orientation. The rate of deposition would not be as great in the absence of a structure. Bluff erosion west of the barrier beach can be expected to continue with little or no influence from the structure.

To summarize, the structure simply acts to shift a zone of sediment trapping from the historical position at the east end of the barrier beach to a new location at the west side of the structure. Deposition will continue at the east end of the barrier beach (Sections 9 - 11) but at a much reduced rate.

7. Conclusions

The King Point site consists of a barrier beach banded on either side by eroding bluffs. Consequently, this is not an ideal site for the application of a beach plan shape evolution model, since potential sediment transport is probably not realized in the bluff sections. However, successful application of the model was achieved at this site with the aid of estimated bluff recession rates and infilling rates of the barrier beach. These values were used to calibrate the model. The calibrated model successfully predicted the actual beach plan evaluation from 1970-1983 (taken from air photos) using hourly directional wave data from a numerical wave climate analysis.

The effect of a hypothetical coastal structure located midway along the barrier beach and acting as a total littoral barrier, was assessed by applying the wave climate from 1970-1983. The structure caused the historical zone of deposition at the east end of the barrier beach to be shifted to the west side of the structure. Immediately east of the structure, erosion is restricted by the sheltering effect of the structure. Deposition of the east end of the barrier beach continued but at a much reduced rate. There is wide variation in yearly alongshore wave power. In the scenario investigated, there was more deposition at the coastal structure in 1971 than in all the other years combined.

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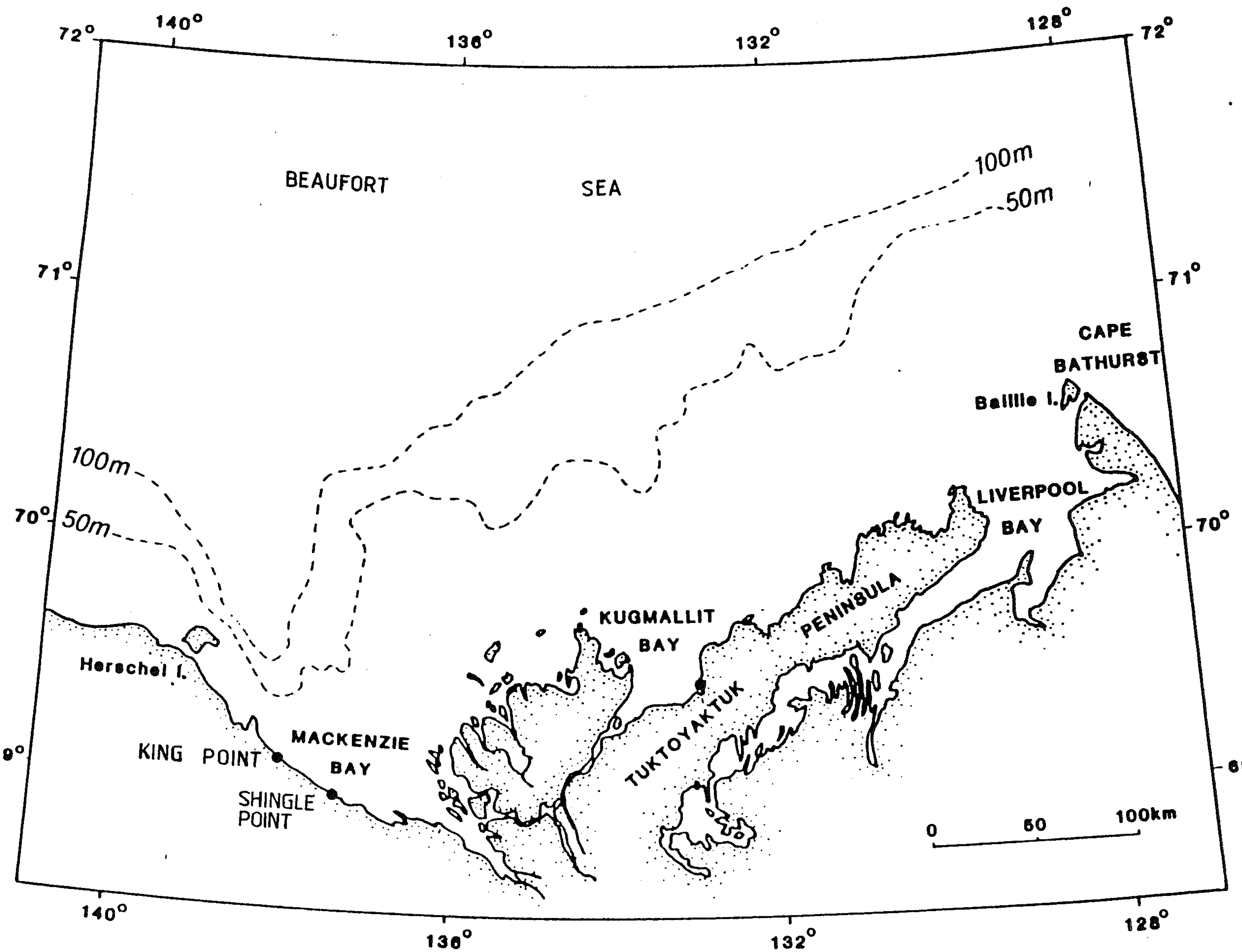
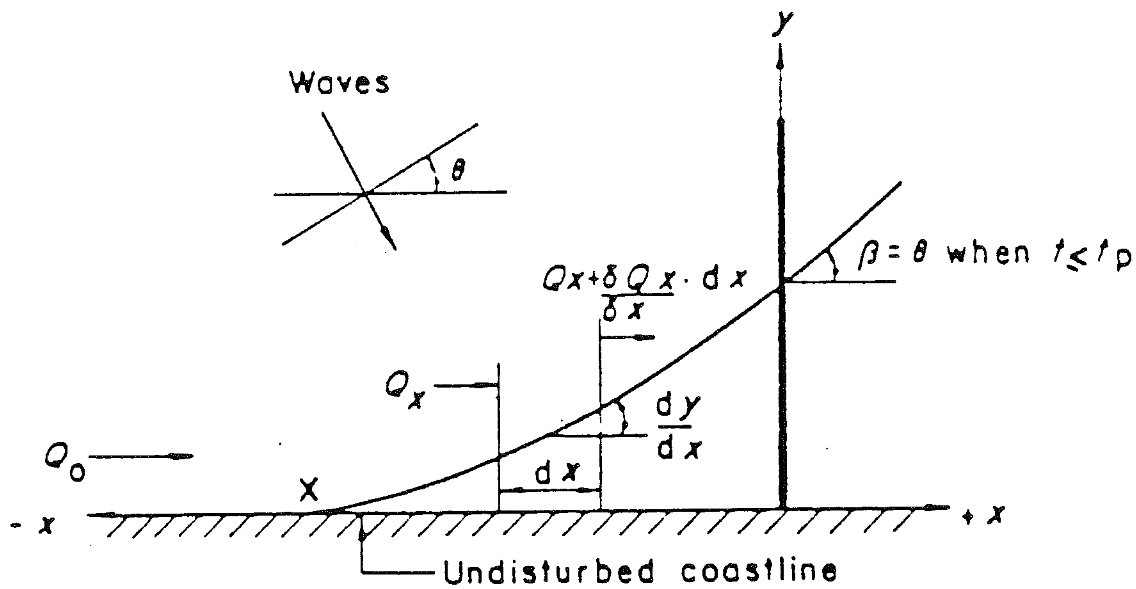
Pinchin, B.M., R.B. Nairn, and K.L. Philpott. 1985. Beaufort Sea Coastal Sediment Study - Numerical Estimation of Sediment Transport and Nearshore Profile Adjustment at Coastal Sites in the Canadian Beaufort Sea. Report for Department of Indian and Northern Affairs and The Geological Survey of Canada, Department of Energy, Mines, and Resources, Canada.

FIGURE 1 King Point, Yukon



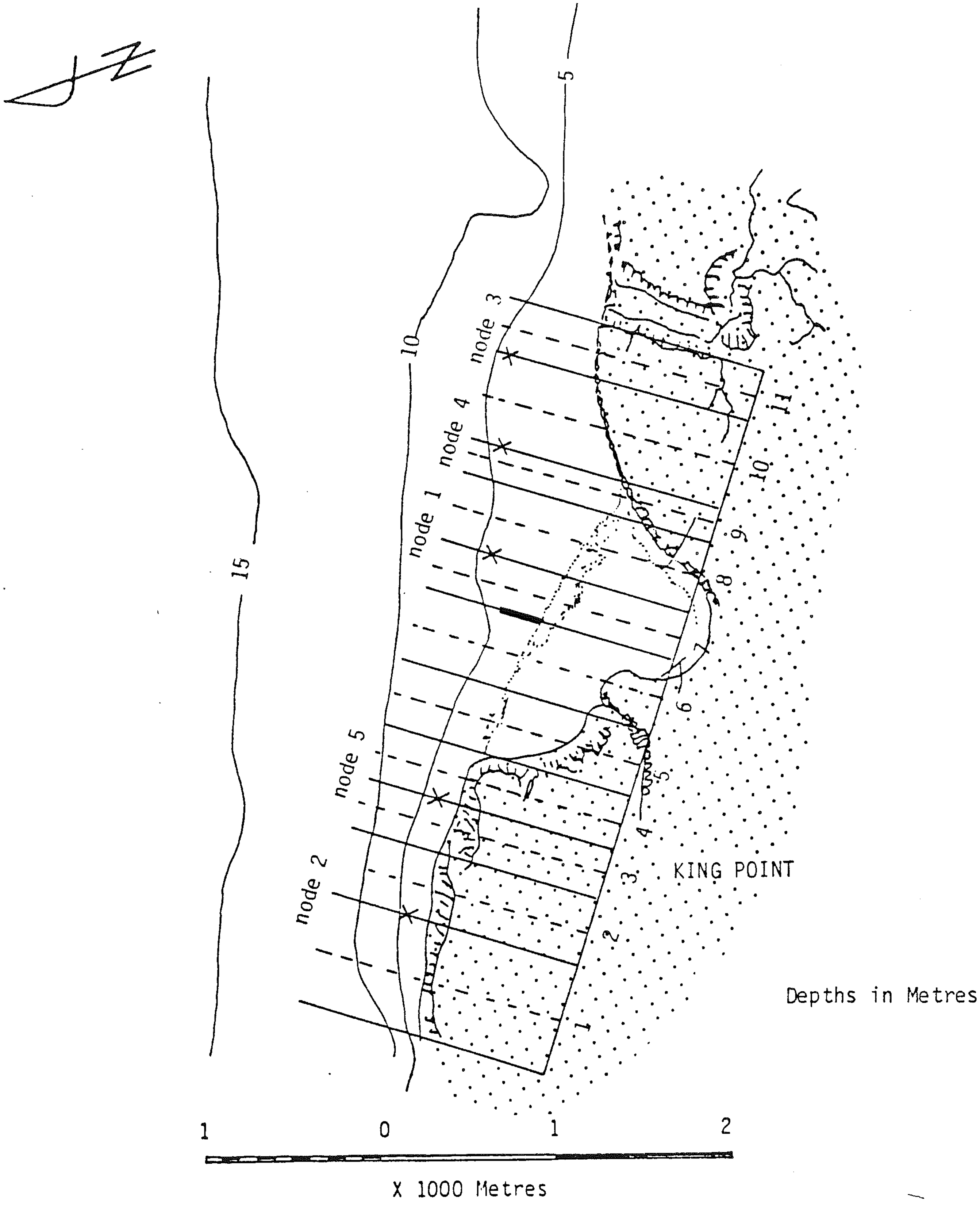
after Harper and Penland 1982

FIGURE 2



(after Muir Wood and Fleming, 1981)

KING POINT SEDIMENT TRANSPORT STUDY	Date: 18 Apr 86
	Scales as shown
Reference Diagram for Beach Evolution Models	Checked by:
	Keith Philpott Consulting Limited



KING POINT SEDIMENT TRANSPORT STUDY

Baseline Location for Beach Plan Evolution Model

Date: 18 Apr 86

Scales as shown

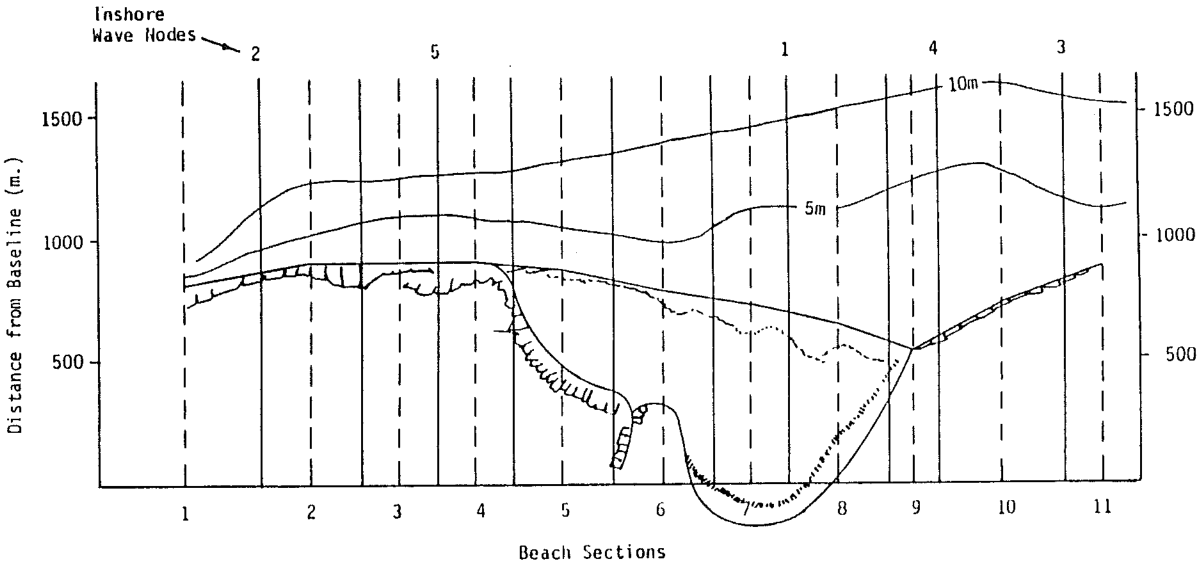
Checked by:

Keith Philpott Consulting Limited

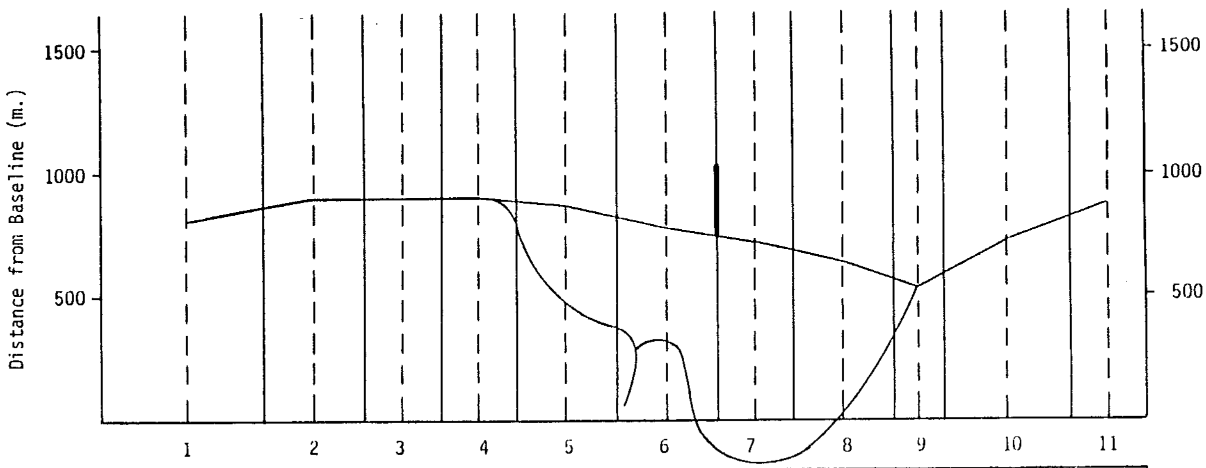
Yearly Shoreline Change 1970 - 1983

FIGURE 4

2a



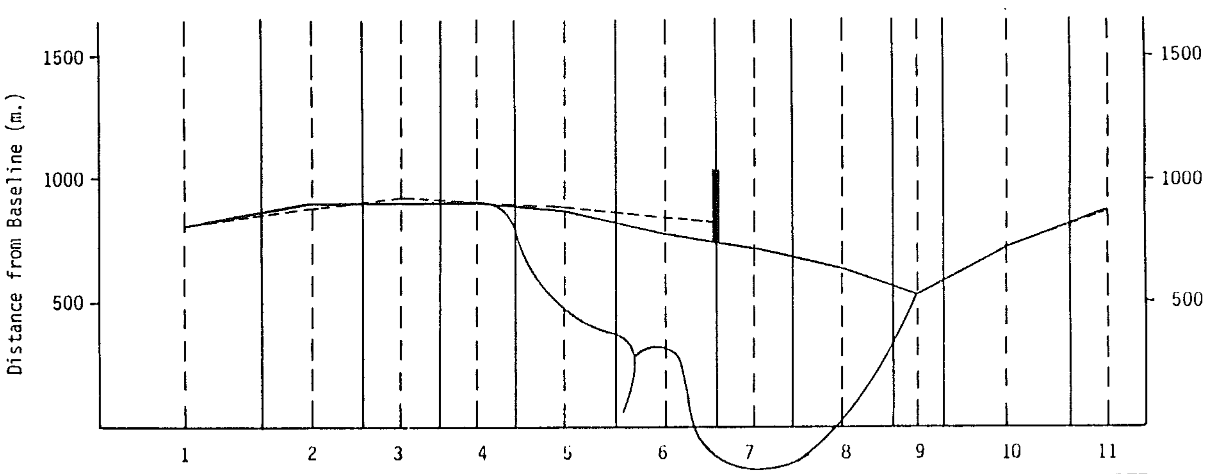
2b
1970



Shoreline Change	-2.4	-3.9	4.8	-3.4	-1.9	8.9	-0.2	-0.3	1.2	0.2	0.3
Cumulative Change	-2.4	-3.9	4.8	-3.4	-1.9	8.9	-0.2	-0.3	1.2	0.2	0.3

Net Drift	0.5	8.3	16.1	8.9	14.1	17.8	0.0	0.2	0.8	-2.7	-4.2	-5.6

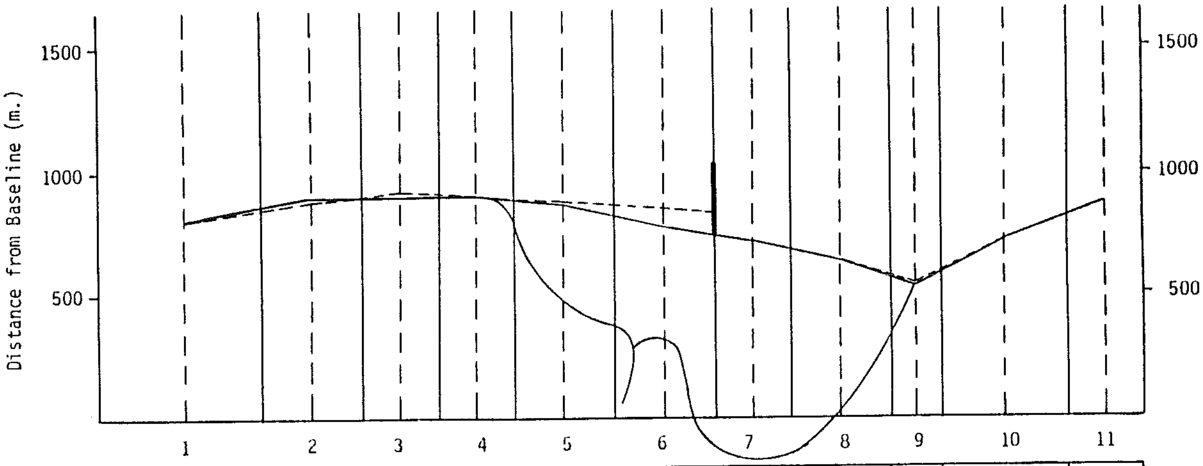
2c
1971



Shoreline Change	-4.1	-6.6	12.7	3.6	12.4	57.8	-0.5	-0.5	1.1	-2.2	-3.7
Cumulative Change	-6.5	-10.5	17.5	0.2	10.5	66.7	-0.7	-0.8	2.3	-2.0	-3.4

Net Drift	138.4	151.7	164.9	145.7	140.3	115.5	0.0	0.8	1.7	-1.7	14.9	31.4

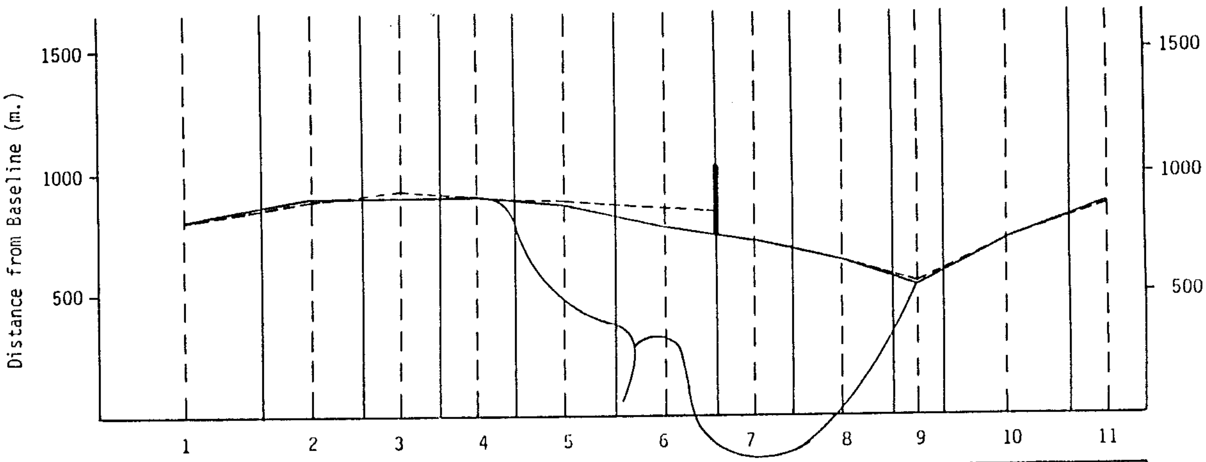
2d
1972



Shoreline Change	0.8	1.3	1.7	-0.7	-0.6	3.9	-0.4	-0.5	2.3	-0.3	-0.6
Cumulative Change	-5.7	-9.2	19.2	-0.5	9.9	70.6	-1.1	-1.2	4.7	-2.4	-3.9

Net Drift	13.5	10.8	8.2	5.6	6.7	7.9	0.0	0.6	1.5	-5.5	-3.0	-0.4

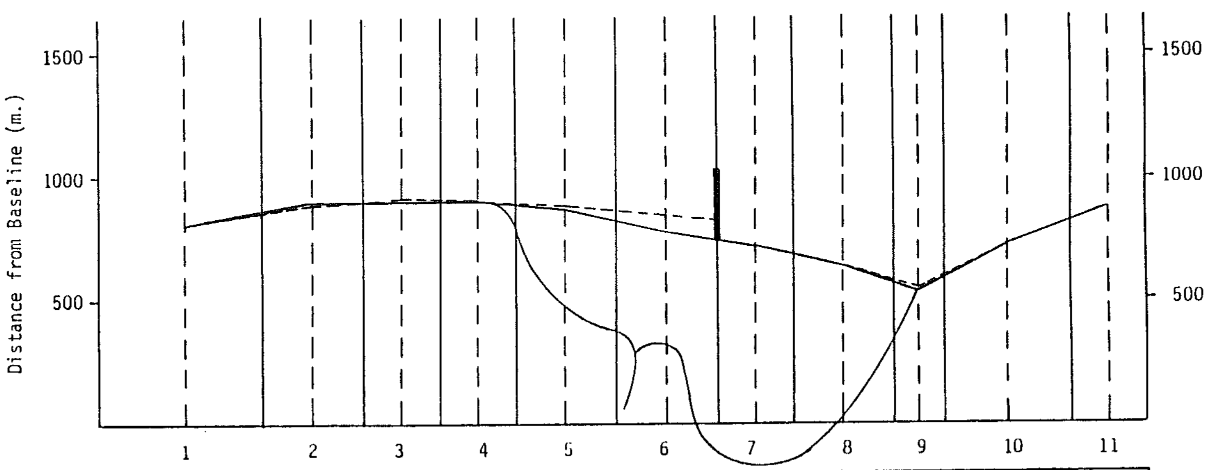
2e
1973



Shoreline Change	0.0	0.0	-0.2	0.0	0.1	2.6	-0.4	-0.2	0.9	0.0	0.0
Cumulative Change	-5.7	-9.3	19.4	-0.5	10.1	73.2	-1.4	-1.4	5.6	-2.3	-3.9

Net Drift	5.4	5.5	5.7	5.4	5.4	5.1	0.0	0.5	0.9	-1.9	-2.3	-2.6

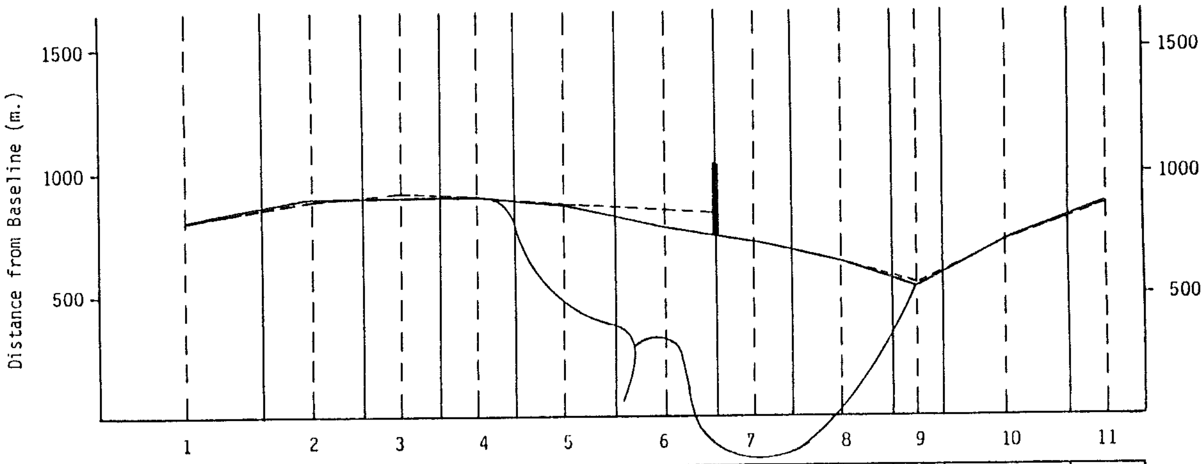
2f
1974



Shoreline Change	-0.3	-0.5	-4.0	-1.3	-2.1	-2.2	-0.6	-0.3	2.2	0.3	0.4
Cumulative Change	-5.3	-8.8	15.4	-1.8	8.0	70.9	-2.0	-1.7	7.8	-2.1	-3.4

Net Drift	-14.6	-15.6	-16.6	-10.6	-8.7	-4.5	0.0	0.8	1.3	-5.3	-7.2	-9.1

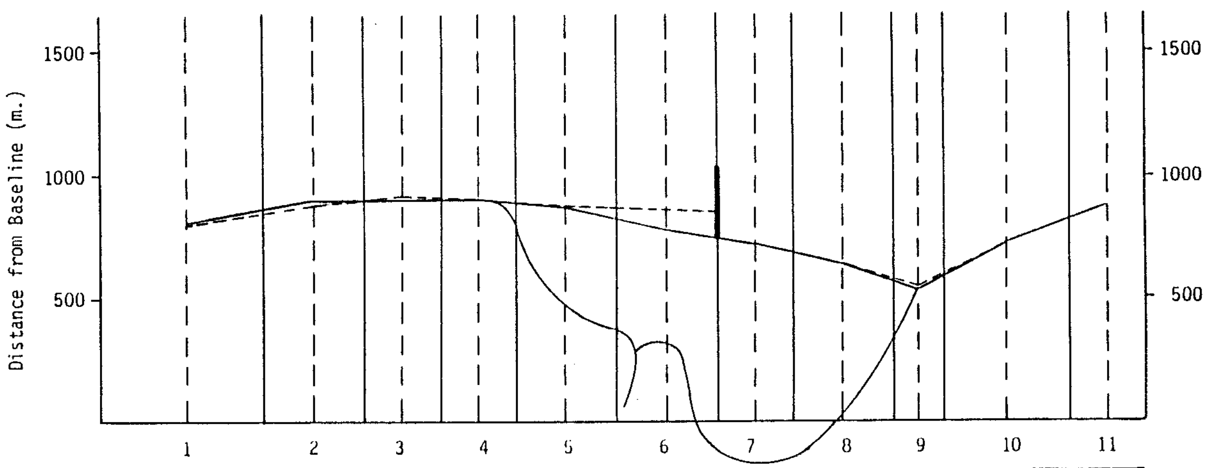
2g
1975



Shoreline Change	-0.6	-0.9	-1.9	-0.5	-0.2	1.7	-0.6	-0.2	1.2	0.2	0.3
Cumulative Change	-5.9	-9.7	13.6	-2.3	7.8	72.6	-2.6	-1.8	9.0	-1.9	-3.1

Net Drift	-4.3	-2.5	-0.7	2.1	2.9	3.3	0.0	1.0	1.3	-2.3	-3.5	-4.8

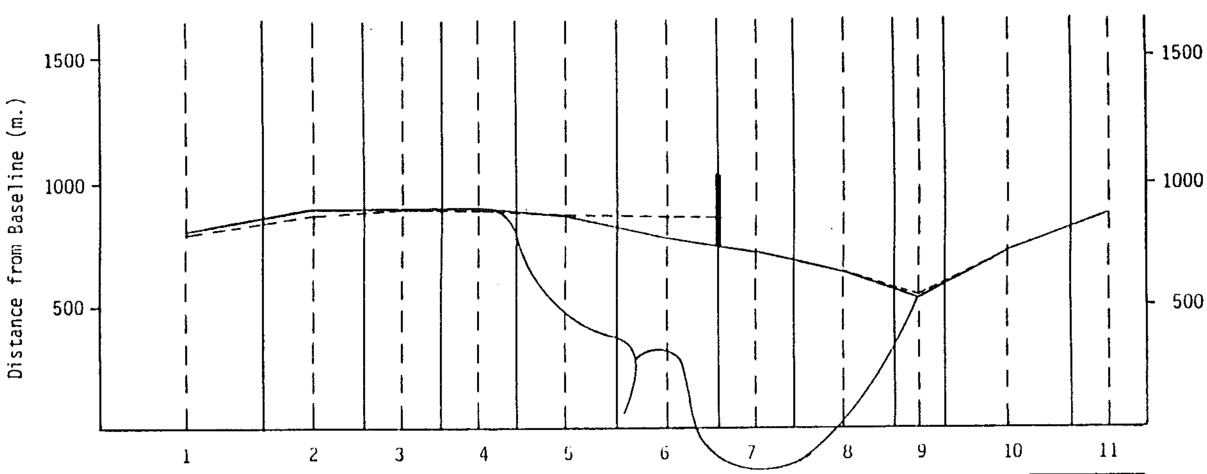
2h
1976



Shoreline Change	-1.3	-2.1	-3.1	-1.7	-0.2	5.7	0.3	-0.1	1.0	0.7	1.2
Cumulative Change	-7.3	-11.8	10.4	-4.0	7.6	78.3	-2.3	-1.9	10.0	-1.2	-2.0

Net Drift	-4.9	-0.6	3.7	8.3	10.9	11.3	0.0	-0.5	-0.2	-3.2	-8.4	-13.7

2i
1977



Shoreline Change	-3.8	-6.2	-9.1	-5.3	-1.6	6.3	-0.5	-0.3	3.4	2.3	3.8
Cumulative Change	-11.1	-18.0	1.4	-9.3	5.9	84.6	-2.8	-2.3	13.4	1.1	1.8

Net Drift	-37.0	-24.6	-12.2	1.4	9.3	12.5	0.0	0.7	1.4	-8.9	-26.1	-43.2