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THE SPECIFICATION OF WIND AND PRESSURE FIELDS OVER THE NORTH SEA AND SOME AREAS OF THE NORTH ATLANTIC DURING 42 GALES FROM THE PERIOD 1966 to 1976

J HARDING and A A BINDING

The work described in this report was supported financially by the Departments of Energy and Industry

REPORT No. 55

1978

NATURAL ENVIRONMENT RESEARCH COUNCIL

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1.0 ABSTRACT

Surface wind and atmospheric pressure fields associated with 42 gales in the North Sea were prepared and wind and pressure evaluated and tabulated for a network of grid points. The analysis area was extended northwards to $70^{\circ}N$ for a selection of gales when the associated winds contributed to wave conditions in the North Sea, and for some gales the analysis was extended to cover part of the North Atlantic. The method of analysis is described and accuracy of results discussed. The severe gale of early January 1976 is described in detail.

2.0 INTRODUCTION

The work to be described in this report was undertaken primarily to provide data for use with a numerical North Sea Wave Model (NORSWAM) whose development took place concurrently with it. The work was however formally separate from the NORSWAM project, and it is hoped that the results will find wide application in studies of storm surges, residual current circulations and other oceanographic phenomena for which meteorological forces are the most important inputs.

Since the work was closely linked with the development of the NORSWAM wave model it is of interest to give some background information to that study.

There is a need to provide accurate wave information for operators engaged in fossil fuel extraction from the sea bed of the UK Continental Shelf, and in particular of the North Sea. The information they require is broadly speaking of two types:

(1) Accurate wave forecasts so that they can conduct their day to day operations as efficiently and safely as possible.

(2) Statistical information on waves for planning purposes and for use in the engineering design of offshore installations.

The situation with regard to both of these was unsatisfactory: in the case of operational forecasts the methods which have been used for calculating the wave field from a given wind field do not use the considerable recent advances in this field, while in the case of wave statistics it is impracticable to obtain data of adequate geographic coverage, or of the duration which is desirable for reliable statistics.

The North Sea Numerical Wave Model, which was formulated by the NORSWAM group of European scientists and jointly supported by the United Kingdom Offshore Operators Association Oceanographic Committee and the Departments of Industry and Energy, was developed in response to these problems, to which it gives at least a partial solution.

The wave model uses the knowledge gained in recent theoretical and empirical studies and will eventually make an important contribution to operational forecasting. However for a number of reasons the model is being used first in the so-called 'hindcast' mode as will now be described.

The best estimates of the wind fields which occurred during a past storm event are fed into the model, and the corresponding wave fields are calculated. If the worst storms over a number of years are selected according to a suitable criterion, then the wave data which the model calculates can be used to make an estimate of the distribution of extreme waves over the same period, and this can be extrapolated to the longer periods for which extreme wave estimates are required.

The central advantage of the method is that it allows one to produce a wave data set whose extent both in terms of time and space is much greater than can be produced by instrumental measurement.

The implementation of the NORSWAM model was carried out at the Hydraulics Research Station at Wallingford (HYDRAULICS RESEARCH STATION, 1977).

2.1 The sample decade

The work started in 1974 and the previous 10 years were chosen as the period from which the sample was selected.

The choice of this period was dictated by the availability of adequate meteorological data, since it was found that prior to 1965 there were very few observations from the North Sea. With the increase in offshore activities from then on came a considerable increase in the quantity of meteorological data available from this area.

The work occupied two years and since the meteorological and wave data for this period were greatly superior to that for the mid-sixties, it was decided latterly to analyse several more recent storms (see Section 4.0).

3.0 CLASSIFICATION OF DEPRESSIONS

The decade 1965 to 1974 inclusive was initially chosen as the period for investigation. An examination of the Daily Weather Reports of the Meteorological Office for this period produced a list of more than 200 occurrences of gales in the North Sea. At this stage it was appreciated that gales should be classified according to the prevailing weather patterns. This had significance from the viewpoint of fetch and therefore for choice of area for wind analysis. Moreover, it facilitated the choice of a reasonable representation of the various weather patterns in the list of gales chosen for analysis.

Seven classes of depression were identified and the principles governing the classification are given below.

Class A - Depressions from the north-west and north

Sub-class a - Depressions which moved from Iceland to South Norway and the South Baltic

Sub-class b - Depressions which moved from Iceland to the Shetland area and Denmark

Sub-class c - Depressions which moved south along the Norwegian coast to South Norway and Denmark

Sub-class d - Depressions which moved south-south-east or south-east from the vicinity of ocean station M (66^{o}N,2^{o}E)

In general, associated gales in the North Sea were between west and north. There were occasional south to south-west gales, usually associated with depressions on the more westerly tracks.

Class B - Depressions which moved east between 60^{o} and 70^{o} north

Sub-class a - Depressions and waves which moved east to the south of Iceland but north of the British mainland

Sub-class b - Depressions which moved east from Iceland to Norway

Sub-class c - Polar depressions which moved east or east-south-east from north of Iceland to Norway

Gales were predominantly west to north-west. Wind directions sometimes veered as far round as north, whether or not this happened often depended on the history of the depression after reaching the Norwegian coast; for example, some might develop south-eastwards or even southwards rather than eastwards, with north-west to north gales in the North Sea. Sometimes a polar depression developed behind the main depression and moved south along the Norwegian coast. From time to time a development of this type produced a major gale in the North Sea.

Class C - North-eastward-moving depression in the North Atlantic

Gales in the North Sea were most frequently produced by this type. Broadly speaking they were north-eastward-moving depressions or waves over the North Atlantic, moving between Iceland and Scotland, but some which moved north-east through the Denmark Strait also led to gales in the North Sea.

A few of these depressions turned east while still well to the west of Britain while others did not turn east until they reached a point to the north.

A few swung south-eastwards into the North Sea and across Denmark, or south-eastwards across south Norway. Some became quasi-stationary near Iceland.

Gales in the North Sea associated with these depressions predominantly followed the direction sequence south-south-east to south-west to west to north-west. Depressions swinging south-eastwards into the North Sea might result in gales as far round as north.

Class D - Depressions or waves over or west of Britain which moved north or north-north-east

Usually there was an anticyclone over the continent, either with depressions west of Britain moving north, or deep depressions from the south-west turning north towards Iceland. Waves moving north over Britain between a continental anticyclone and an Atlantic depression would on occasions tighten the North Sea gradients sufficiently to produce gales.

Associated gales were mainly south to south-east and included some prolonged periods of gales or near gales, eg on 3 - 13 January 1974.

Class E - Ridge of high pressure to the north; depressions to the south.

Associated gales were mainly between east and north-east.

Class F - Depressions which crossed the North Sea, but excluding Class A and C depressions

Class F gales were a good second to Class C gales in frequency. They may be roughly sub-classified as follows:

Sub-class a - Depressions from Scotland and north-east England. Those which moved north or north-north-east were mainly associated with gales between south and west.

Those which moved north-east were mainly associated with gales having a south-west to west to north-west sequence of directions.

Those which moved in directions between east-north-east and east-south-east were mainly associated with gales having a south to west to north sequence.

Only two out of 34 depressions in this sub-class moved south-east or south-south-east, one with west veering north-west gales and the other with north-west and north-east to east gales.

Sub-class b - Depressions from east and south-east England

These depressions moved in directions between east and north-east.

Gale directions were predominantly south-east backing east backing north-east, and south-west veering west veering north.

Sub-class c - Others

One depression moved northwards from the continent, with gales between north-east and north.

Two moved south-west and then south from Denmark, with northerly gales.

Class G - Depression over Germany

There was one occasion of northerly gales over the central and southern North Sea associated with a depression over Germany. This depression had come from the south-east, deepening. It then moved away eastwards, filling.

4.0 SELECTION OF GALES FOR ANALYSIS

A total of 215 North Sea gales were identified in the 10 year period 1965 - 1974, and from these a sub-set had to be selected which adequately represented the main features of the most severe gales in that period. For reasons of cost and time it was realised that the number of gales which could be analysed by a subjective method would be limited to about 50; and with such a comparatively small sample the task of selection would need to be approached with great care.

As a first step the original total was reduced by about 50% by deleting the less noteworthy gales. This left 113 gales which again required reduction by more than half. An approach was made to A F Jenkinson of the Meteorological Office for advice on the best method of making this selection. Jenkinson has made an objective classification of weather types around the British Isles and has allocated an index of severity to gales in the area since 1881 (JENKINSON and COLLINSON (1977)). Maintaining the same proportions of gales when classified by type and distribution (both monthly and annual) he selected 58 gale periods from the set of 113, with two periods overlapping, leaving 56 analysis periods. At a later date 1965 was deleted from the investigational period and 1975 added, and, again using Jenkinson's gale catalogue, a selection of less vigorous gales was deleted. Furthermore, two gales in January 1976 with high severity indices were included, as these would contribute to extreme value analysis. The final list of gales, covering the period 1966 to January 1976 appears at Appendix A.

While this selection procedure was made as objective as possible, there was inevitably a considerable element of judgment involved. The criteria used were primarily meteorological, and would be somewhat different for specific oceanographic effects in specific places.

However, the storms selected will almost certainly include those giving the most severe effects for any particular phenomenon.

This final change in the list of storms led to the following changes in the year to year frequencies (Table 4.1):

	1965	66	67	68	69	70	71	72	73	74	75	76(Jan)	No of analysis periods
Original	2	4	5	3	6	4	5	7	10	10			56
Final		3	2	1	3	3	3	5	5	11	4	2	42

This forward shift in the period under investigation and the reduction of the number of gales to be analysed, involving the elimination of the less severe gales, has highlighted 1974 as the stormy year of the decade.

The change in the list of gales led to the following changes in the number of gales in each class (Table 4.2):

Class	A	B	C	D	E	F	G	Number of gales
Original	6	5	22	9	1	14	1	58
Final	4	7	12	5	1	12	1	42

This represented a proportionate increase in the number of Class F gales and an actual increase in the number of Class B. These increases occurred at the expense of Class C and D gales. In fact, of the six gales in 1975 and January 1976 three were in class B and three in class F.

The distribution of gale classes by months was now (Table 4.3):

Jan	BBB	DDD	FFF		9
Feb	CCCC	F			5
Mar	B	D	E		3
Apr	F				1
May	F				1
Jun					
Jul					
Aug					
Sep	F				1
Oct	A	B	C	G	4
Nov	AA	BB	CCCC	FFFF	12
Dec	A	CCC	D	F	6

The change in the monthly distribution of analysis periods (Table 4.4):

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	No of analysis periods
Original	7	5	5	2	3	1			4	5	14	10	56
Final	9	5	3	1	1				1	4	12	6	42

The proportion of gales occurring in January, February and November rose at the expense of those in May, June and September, as might be expected in the elimination of the less severe gales in a period, and there was a small proportionate fall in December gales.

5.0 SPECIFICATION OF ANALYSIS AREAS

The windfields for the selected gales were specified at 3-hour intervals, using the grid used in numerical forecasting by the Meteorological Office - BURRIDGE et al (1977). Having in mind the importance of fetch the analysis areas varied from storm to storm. The areas were (Table 5.1):

N	-	The North Sea
NN	-	The North Sea and northward extension to 70°N
NNA	-	The North Sea and northward extension to 70°N plus a selected area of the North Atlantic

Appendix B shows the North Sea area and the northward extension to 70°N. The analysis area over the North Atlantic is also indicated but this varied from storm to storm and usually extended westwards to 50°W for at least part of the analysis period. The 100 km grid shown was used in the North Sea and the 300 km grid elsewhere. The analysis period over the North Sea was determined by the duration of gales there, beginning 24 hours before the onset of a gale and ending 24 hours after its cessation. The same analysis period was covered when analysis was required over the northward extension to 70°N. When North Atlantic gales could be expected to contribute directly to heavy seas in the area around the Shetland Isles, requiring wind analysis over the Atlantic, the analysis period usually differed from that of the North Sea, beginning earlier than the North Sea's period and ending before its cessation.

Surface wind direction and speed and atmospheric pressure were read from the specially prepared synoptic charts (see below) using transparent overlays of the grid point systems. The information was then recorded on sheets specially designed for ease of data entry - examples are shown at appendices C and D.

6.0 METHOD OF ANALYSIS

Synoptic weather charts produced routinely within the Meteorological Office were used in the analysis work.

The North Sea analyses were based on the charts which are used for the routine analysis of hourly surface data at the London Weather Centre, where they are subsequently stored. These charts are used to monitor weather developments over the British Isles and the North Sea and in addition cover adjacent areas of Continental Europe. With a scale of $1 : 3 \times 10^6$ they are ideally suited for wind analysis on a 100 km grid.

The analyses for areas outside the North Sea for the period up to mid-1971 were based on Atlantic charts which are held in Meteorological Office archives at Bracknell. These charts have a scale of $1 : 15 \times 10^6$. However, in mid-1971 charts with scale $1 : 20 \times 10^6$ were adopted by the Meteorological Office for the routine analysis of North Atlantic data and this scale was found to be inadequate for the detailed analysis of the wind field. In view of this it was necessary to replot the observations on charts of scale $1 : 7.5 \times 10^6$. Towards the end of the investigational period this need for the preparation of new charts disappeared, as similar charts were available from the Meteorological Office at London (Heathrow) Airport.

During the preparation of all these charts additional observations, eg ships' observations from climatological data banks and returns of oil-rig observations not available on an operational basis when the charts were first prepared were plotted. The charts were then re-analysed with a view to getting as accurate a presentation of the sea-level pressure fields as possible over the analysis areas. This historical re-analysis had of course the benefit of having subsequent developments available to help in the interpretation of a particular synoptic situation.

Wind and pressure fields had to be specified every three hours throughout an analysis period. The magnitude of the task demanded a ready means of estimating the surface wind at a sufficient number of points throughout the analysis area to permit an accurate presentation of the surface windfield.

The surface windfield was derived primarily from a consideration of the surface pressure field. For offshore areas this approach was both necessary and practicable. It was necessary because of the sparseness of surface wind observations in offshore areas, and it was practicable because the aerodynamic smoothness of the sea surface and the freedom from marked diurnal effects meant that surface winds could be derived from the pressure field with some certainty, as will now be described.

On the basis of the "geostrophic approximation" it can be shown that the velocity of an air particle which is part of a steady rectilinear flow is inversely proportional to and normal to the horizontal pressure gradient. Thus for isobars drawn at standard pressure intervals (and for a given latitude), the flow speed is inversely proportional to the isobar spacing, and it is standard practice to use a transparent overlay scale to read this "geostrophic wind" from the synoptic chart.

The next step was therefore to prepare a table for the ready conversion of geostrophic winds to surface winds.

FINDLATER et al (1966) studied the ratio of the surface wind speed to the speed of the wind at the 900 mb surface and the angle by which the surface wind was backed from the 900 mb wind at, amongst other locations, the ocean weather stations I (59°N, 19°W) and J (52°30'N, 20°W) in the Atlantic. These relationships are very dependent upon the degree of stability in the friction layer and the authors produced a table of the relationships in terms of ranges of wind speeds at 900 mb and classes of lapse rate of temperature between the surface and 900 mb. Before applying their reduction factors to geostrophic winds in order to produce a table of surface winds corresponding to the various ranges of wind speed at 900 mb and classes of lapse rate of temperature between the surface and 900 mb it was necessary to consider the relationship between the geostrophic and 900 mb winds and in particular make distinctions between straight and markedly cyclonic flow. The difference between the 900 mb and the geostrophic wind is negligible at low wind speeds but increases with increasing wind speed, and is especially significant when the flow is markedly cyclonic. The reduction factors were applied to the corrected geostrophic values and the resulting table is shown at appendix E. Amplification of the table is necessary on two points. Firstly, a subjective assessment of the degree of curvature was used, and the maximum reduction of the geostrophic wind which was applied near the centre of the depression was gradually eased with distance from the centre and the reduction applicable to straight flow was made where nearly straight flow was reached. Secondly, the Findlater paper is inconclusive in respect of lapse rates equal to or less than -0.4°C/300m and data for these lapse rates are not included in the table at appendix E. However, there was evidence of the occurrence of surface winds in these conditions that were more typical of unstable than stable air. Some examples of this, supported by observations, were found during the 10-year study where air over land with a strong surface inversion moved over warm sea.

The table proved to be a very useful working tool. However, it must be remembered that it is based on averages of wind relationships measured in a variety of synoptic situations and there were occasions when the table produced results that differed markedly from actual reported surface winds. A decision had to be taken as to whether the table or the reported wind was at fault. There were occasions when the table was understandably in error, for example when the pressure gradient was varying rapidly in time and space. On such occasions reported winds were particularly important.

Once the analysis of the pressure field was complete the windfield could be determined, and the technique of isotach analysis proved valuable at this stage. (An isotach is a line joining points having equal wind speed).

Isotach analysis involved the measurement by scale of geostrophic winds and their conversion to surface winds using the prepared table at a sufficient number of points over an analysis region to ensure that the subsequent drawing of isotachs was accomplished accurately. For example, in active synoptic situations a denser distribution of such points was required than in relatively quiet situations.

Isotachs were particularly useful in strong winds and where observations were sparse, for maxima could be followed from chart to chart very much as depression centres were tracked. The isotachs were also essential in reading off wind speeds at grid points. Finally, the tabulated speeds and directions were examined for continuity, and smoothed if necessary, after further examination of the synoptic charts.

7.0 ACCURACY

Fundamental to the accuracy of the derived surface winds was that of the synoptic charts whose accuracy in turn depended largely on the density of observations. It was for this reason that additional observations from climatological data banks and other records were plotted on the charts, which were then re-analysed. An added advantage of analysing charts well after the event lay in a knowledge of the subsequent history of pressure systems. By back-tracking it was often possible to improve accuracy in both position and central pressure.

There was a marked increase in the density of observations over the North Sea during the investigational period, thanks largely to the development of the oil industry, but even in 1976 there were considerable areas where observations were conspicuous by their absence on many charts. The situation worsened northwards towards 70°N, with observations confined largely to coastal stations in Norway and Iceland, Thorshavn, the ocean weather station 'M' (66°N, 2°E) and shipping near the Norwegian and Icelandic coasts. Observations from 'M' were invaluable. Many reports from ships were available over the North Atlantic but their density fell off in the north. The withdrawal of certain ocean weather stations towards the end of the investigational period added to the difficulty of analysis.

Accuracy of chart construction also depended upon that of reported pressures. Gross pressure errors in reported and archival ships' observations were not uncommon; these were not misleading in chart construction, they were merely useless. Suspected smaller errors were more of a problem. Such errors were particularly troublesome in the earlier days of the investigation in respect of reports from oil-rigs in the North Sea. However, through careful consideration of the spatial and temporal continuity of the pressure fields it was often possible to detect systematic instrumental errors and then a correction could be applied to the reported pressures. As time went on the problem was greatly eased by the inspection visits to oil-rigs by Meteorological Office personnel. Reported winds were also useful in chart construction, but here again accuracy and reliability were all-important. Gross errors in ships' reports for the North Sea were not uncommon during the investigational period. A particular problem with winds reported from oil-rigs was that the anemometer was sometimes badly exposed in certain wind directions or was perhaps installed at a height considerably in excess of the standard height. Our confidence in our ability to make allowance for these difficulties increased as time went on. As with the pressures, the situation improved greatly later in the sample decade with the instigation of Meteorological Office inspections.

Sparseness of observations over the North Sea has long been a problem for meteorological services and the marked improvement with the increase in oil exploration is very welcome. It is good to know that the Meteorological Office, with the co-operation of the oil industry (United Kingdom Offshore Operators' Association) is actively engaged in the extension of the UK meteorological observing and reporting network on the fixed North Sea platforms. Another welcome development in the elimination of errors in reported observations in general is the increasing use of computer-based quality control.

Added to possible errors in chart construction were those inherent in the analysis method used in the investigation. However, there were compensations in the use of reliable wind observations and isotach analysis. Isotach centres intensify, weaken and move very much as to pressure centre. The tracking of isotach centres proved to be invaluable throughout the investigational period, especially on occasions of relatively strong winds and sparse observations.

It is not possible to quantify analysis errors comprehensively. It is probably fair to say that many derived wind speeds are accurate to within ± 10%, although the lighter winds would not be so accurate.

However, higher errors must be expected at some grid points at times, for example when winds were strong and isotach gradients steep. Wind directions are often correct to within 10°, but greater errors must be expected locally when there were vigorous changes in the pressure field. The greatest accuracies were probably attained in strong straight flow in unsable air.

8.0 THE GALES OF EARLY JANUARY 1976

The gales of early January 1976 were amongst the most severe to affect the British Isles and North Sea this century and have been chosen to illustrate the methods used in the work detailed in this report. SHAW et al (1976) have written in considerable detail on the gales over the United Kingdom itself, where damage was widespread. A study in detail of developments over the North Sea during these gales was only possible by making full use of the experience and facilities built up during the course of the project.

Additional reports were obtained from various sources; knowledge and experience of the reliability of the observations was used to make interpretive judgements and correct systematic errors in the wind and pressure reports; tracking techniques were used to determine the most probable intermediate situations between those that had been adequately documented.

The eight synoptic charts for 3 January are illustrated at Appendix F. Figure 1 to 8 and the tracks of the parent and secondary depressions are at Figure 9 of the Appendix. Developments in the windfield are readily followed by reference to the isotachs on the synoptic charts.

Having moved east-north-east from the Atlantic to a position over the western Highlands of Scotland by 1800 on 2 January, a small but vigorous and deepening frontal depression continued on the same track for another 3 hours, then turned east and later southeast. The centre deepened to its lowest pressure estimated at 963 mb at 0300 on 3rd and slowly filled thereafter. By 1800 on 2nd the northerlies behind the deepening low had gained strength and fetch causing severe troughing southward from the centre and as this process intensified a new depression centre formed in the trough soon after it crossed the east coast of Scotland, becoming evident by 2100. This centre moved almost due east deepening to a minimum central pressure of 964 mb also at 0300 on 3rd. Turning north-east after 0600 it had coalesced over north-west Denmark with the original centre by 0900 and the combined centre continued then in a south-easterly direction with the central pressure staying close to 967 mb, and later turned east-southeast.

The north-westerly gales associated with the depressions had already reached the western North Sea by 0001 on the 3rd with a maximum mean wind exceeding 50kn along the east coast of England. This increased to more than 60kn as it moved very quickly east broadly retaining its position relative to the centres of depression, then between 0300 and 0600 extended downwind towards north-west Germany. Notable gusts at heights somewhat above 30m reported from North Sea installations included 90 kn near $56\frac{1}{4}^{O}$ $2\frac{1}{2}^{O}$E at 0500 and 95 kn near 57^{O}N 2^{O}E at 0600. The maximum wind then transferred downwind as pressure rose strongly behind the centre weakening the pressure gradient there, and between 1200 and 1500 passed into north-west Germany and the Danish border, where coastal gusts of 85 and 88kn were recorded, LOADER (1976).

Meanwhile between 0000 and 0300 on the 3rd a well-marked trough developed off the Norwegian coast between about 60 and 65^{O}N, due at least in part to orographic influence in the easterlies north of the depression, while a ridge of high pressure was moving east over the eastern North Atlantic. Pressure rose gradually in the trough which moved little during the next 12 hours, but as the ridge continued its eastward movement towards the British Isles a big rise of pressure began between 0300 and 0600 to the north-north-west of Scotland increasing the pressure gradient between 0^{O} and 5^{O}W north of 60^{O}N, and this process continued as the ridge continued to approach the almost stationary trough off Norway. The pressure gradient continued to increase and its maximum moved south and developed gradually eastwards, giving rise by 1200 to a belt of northerly winds with a maximum of over 60kn just east of the Greenwich meridian between 59 and 60^{O}N. This maximum wind belt moved slightly east of downwind with little change in intensity until 1800. It then decreased while progressing south-south-east, the ridge approaching from the west having collapsed over the British Isles and the trough off south-west Norway having quickly moved south and filled. This rapid collapse of the trough occurred as the easterlies over southern Norway died away, the causal depression having continued filling and moving away east-south-eastwards. Notable gusts in this second burst of storm force winds from the north were 90 kn at 0900 and 82 kn at 1200 in the extreme north of the Shetland Isles, 88 kn near $61\frac{1}{4}^{\circ}$N $1\frac{1}{4}^{\circ}$E at 1200, 85 kn near 57°N 2°E at 1800 and 84 kn near $59\frac{1}{2}^{\circ}$N $1\frac{1}{2}^{\circ}$E at 1500, the last three quoted being for heights above 30m from North Sea installations. It is also interesting that at an installation near 61°N 2°E the wind speed increased from 16 to 60 kn in the 10 minutes preceding 0900, at a time and place where a very steep isotach gradient existed.

It has been a natural reaction in any study of this gale to recall that of 31 January/1 February 1953 over the United Kingdom and North Sea. DOUGLAS (1953) reported on the latter. SHAW et al (1976) refer to it when comparing the associated tidal surges in the North Sea on the two occasions. LOADER (1976) draws comparisons between them both synoptically and in respect of tidal surges in the North Sea. Inspection of the 1953 charts reveals an almost complete absence of observations over the North Sea with the exception of light-vessel reports near coasts. It would be impossible to carry out a wind analysis with the same confidence as that of the period from 1966. However, conclusions can be drawn from the charts from which comparisons can be made with the 1976 gales.

The 1953 depression originated on the warm front of a depression which was moving towards the Azores from the north-west. It moved north-eastwards and then eastwards to a position between Scotland and Thorshavn and then south-eastwards between Scotland and the Shetlands and across the North Sea and Heligoland Bight. An outstanding feature of this depression was the intense northerly flow over Scotland just behind the depression. DOUGLAS (1953) estimated that the geostrophic wind reached 150 kn in a belt over 100 miles wide and that there was a long belt with a geostrophic wind averaging about 120 kn over the whole of the western and central parts of the North Sea as the depression moved south-east towards the Heligoland Bight.

The 1976 depression had a somewhat similar origin, breaking away from an area of low pressure to the west of the Azores and moving north-eastwards to Scotland. It subsequently moved east and south-east across the North Sea and Denmark - see Appendix F, fig 9. SHAW et al (1976) studied in detail the low-level winds over the United Kingdom. They found evidence of geostrophic winds of between 150 and 160 kn over Lancashire and the Sheffield area.

The tracks of the two depressions were significantly different with corresponding major differences in the distribution, fetch and direction of the gales in the North Sea. There were also significant differences in the development of the two depressions. As described earlier in this section a secondary depression formed in the severe troughing behind the 1976 depression and the two depressions coalesced over Denmark as illustrated in Fig 9 of appendix F. There was well-defined troughing behind the cold front of the 1953 depression but there is no evidence to suggest that a secondary depression existed at any time in this trough. Any secondary developments were weak and associated with the frontal system to the east of the depression. This is also an interpretation of Mr J Sanders of the Koninklijk Nederlands Meteorologisch Institut who kindly supplied his synoptic reconstruction of the 1953 gales. The isotach maximum moved south-eastwards from North Scotland to the Netherlands more or less parallel to the track of the depression. Herein lie the major differences between the 1953 and 1976 gales. The synoptic charts at Appendix F, Figure 1 - 8 clearly illustrate the existence of two isotach maxima both of which exceeded 60 kn at peak development. The first was closely associated with the depression itself and its secondary, whilst the second and more unusual maximum was associated with the interplay between the advancing Atlantic high pressure ridge and the trough off the Norwegian coast. It is this secondary maximum that has made the 1976 gales of especial meteorological interest.

9.0 AVAILABILITY OF DATA

Copies of the wind and pressure data for the 42 gales are available from the Marine Information and Advisory Service, Institute of Oceanographic Sciences, Brook Road, Wormley, Godalming, Surrey, GU8 5UB.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the co-operation of the Director-General of the Meteorological Office for the use of office accommodation throughout the investigation, access to synoptic charts and data, and the ready support and advice of various branches and ancillary services. Thanks are due also to IMCOS Marine Limited for the supply of data from North Sea structures.

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APPENDIX A

STORMS SELECTED FOR ANALYSIS

Year	Month	Class	Analysis period (DDHH)	Analysis area
1966	MAY	F	2200 - 2506	NN
	NOV/DEC	A	2818 - 0206	NN
	DEC	C	0700 - 0918	N
1967	FEB/MAR	C	2612 - 0215	NNA
	DEC	C	0206 - 0506	NNA
1968	MAR	B	1512 - 1912	NNA
1969	MAR	E	1206 - 1918	N
	NOV	A	2612 - 3012	NN
	DEC	D	1812 - 2300	N
1970	JAN/FEB	C	3112 - 0418	N
	FEB	F	1818 - 2200	N
	OCT	B	1612 - 2200	NNA
1971	OCT	C	2100 - 2400	NN
	NOV	B	1500 - 1818	NNA
	NOV	F	2000 - 2321	N
1972	JAN	F	2600 - 2906	NN
	MAR	D	0206 - 0506	N
	NOV	C	0806 - 1212	NNA
	NOV	F	1200 - 1412	NN
	NOV	C	1718 - 2106	N
1973	FEB	C	1012 - 1306	NNA
	APR	F	0106 - 0406	NN
	NOV	B	1106 - 1418	NNA
	NOV	C	1706 - 2106	NN
	DEC	A	1118 - 1518	NNA

Year	Month	Class	Analysis period (DDHH)	Analysis area
1974	JAN	D	0318 - 0621	NN
	JAN	D	1100 - 1403	NN
	JAN	F	1518 - 1812	NNA
	JAN	D	2700 - 3006	NN
	FEB	C	0912 - 1306	N
	SEPT	F	0606 - 0921	NN
	OCT	G	2112 - 2412	N
	OCT	A	2612 - 3018	NNA
	NOV	C	1000 - 1312	N
	NOV	F	2318 - 2706	N
	DEC	C	1612 - 1918	NN
1975	JAN	B	0406 - 0718	NNA
	JAN	B	2106 - 2512	NNA
	NOV	F	2606 - 2906	NN
	NOV/DEC	F	3012 - 0412	NN
1976	JAN	F	0112 - 0500	NN
	JAN	B	1815 - 2306	NNA

Note: DD - Day of month

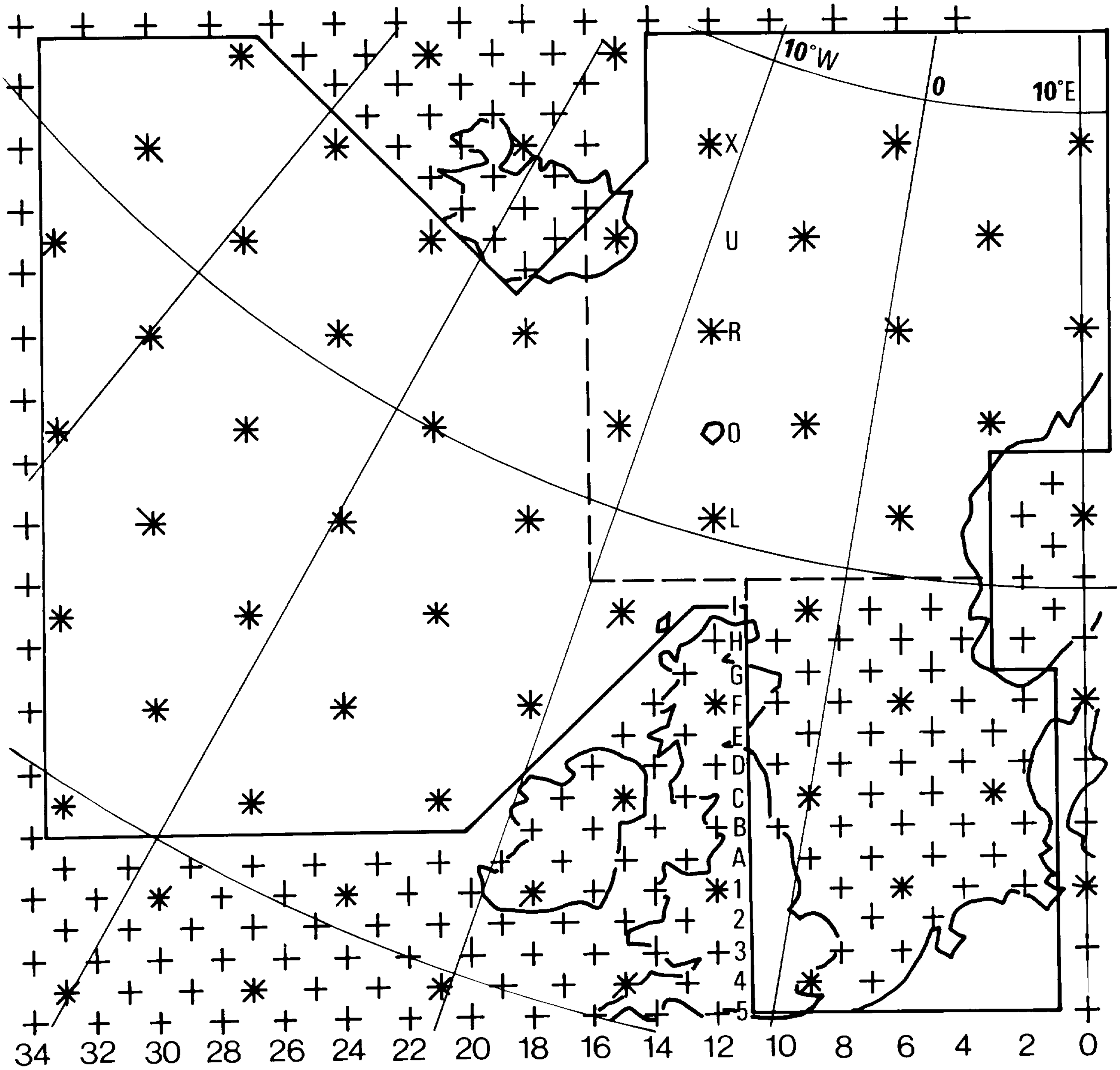
HH - Hour of synoptic chart

Analysis periods refer to the North Sea and, when analysed, to the northward extension to 70°N. Periods of Atlantic analyses usually differ from those of the North Sea.

N = North Sea

NN = North Sea and northward extension to 70°N

NNA - North Sea and northward extension to 70°N plus a selected area of the North Atlantic


10°W
0
10°E
X
U
R
O
L
I
H
G
F
E
D
C
B
A
1
2
3
4
5
34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0

NUMBER

WIND FIELD DATA

SHEET A - NS2

	STATION NO.	DAY	MONTH	YEAR	SURFACE WIND DIRECTION (deg.) AND SPEED (knots) 00h. D D D V V	03h. D D D V V	06h. D D D V V	09h. D D D V V	12h. D D D V V	15h. D D D V V	18h. D D D V V	21h. D D D V V
1	D 1 0											
2	D 0 8											
3	D 0 6											
4	D 0 4											
5	D 0 2											
6	C 0 9											
7	C 0 7											
8	C 0 5											
9	C 0 3											
10	B 1 0											
11	B 0 8											
12	B 0 6											
13	B 0 4											
14	B 0 2											
15	A 0 9											
16	A 0 7											
17	A 0 5											
18	A 0 3											
19												
20												

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57

NUMBER

SURFACE PRESSURE DATA SHEET B-NS2

	STATION NO.	DAY	MONTH	YEAR	SURFACE PRESSURE (mb.) 00h. PPPP	03h. PPPP	06h. PPPP	09h. PPPP	12h. PPPP	15h. PPPP	18h. PPPP	21h. PPPP
1	D10											
2	D08											
3	D06											
4	D04											
5	D02											
6	C09											
7	C07											
8	C05											
9	C03											
10	B10											
11	B08											
12	B06											
13	B04											
14	B02											
15	A09											
16	A07											
17	A05											
18	A03											
19												
20												
	1 2 3	4 5	6 7	8 9	10 11 12 13	14 15 16 17	18 19 20 21	22 23 24 25	26 27 28 29	30 31 32 33	34 35 36 37	38 39 40 41 42 43 44 45 46 47 48 49

REDUCTION OF GEOSTROPHIC TO SURFACE WINDS

Geostrophic Wind (kn) Cyclonic flow / Straight flow	10 / 10	15 / 15	20 / 20	25 / 25	30 / 30	40 / 35	50 / 40	60 / 50	70 and above / 60	70 and above / 70	70 and above / 80	70 and above / 90	70 and above / 100
Lapse (°C/300 m)	Surface wind and angle of backing from geostrophic wind direction: Speed / Angle								50-70°N	50-70°N	50-70°N	50-70°N	50-70°N
⩾3.1	10 / 0	15 / 0	18 / 0	23 / 0	25 / 0	30 / 0	32 / 0	36 / 0	40-43	45-50	50-55	55-60	60-67
3.0-2.2	9 / 5	13 / 5	17 / 5	20 / 5	25 / 5	28 / 5	30 / 5	34 / 5	37-40	43-47	47-52	52-57	57-64
21.-1.4	9 / 10	13 / 10	15 / 12	20 / 12	20 / 15	25 / 15	27 / 12	30 / 10	32-35	37-41	41-45	45-49	49-55
1.3-0.6	8 / 17	12 / 17	15 / 20	18 / 20	20 / 20	23 / 20	25 / 22	27 / 20	30-33	34-38	38-41	41-45	45-51
0.5-0.3	7 / 15	11 / 15	13 / 18	17 / 18	20 / 20	22 / 20	25 / 20	26 / 25	27-30	31-35	35-38	38-42	42-46
									(Angles as in previous column)				

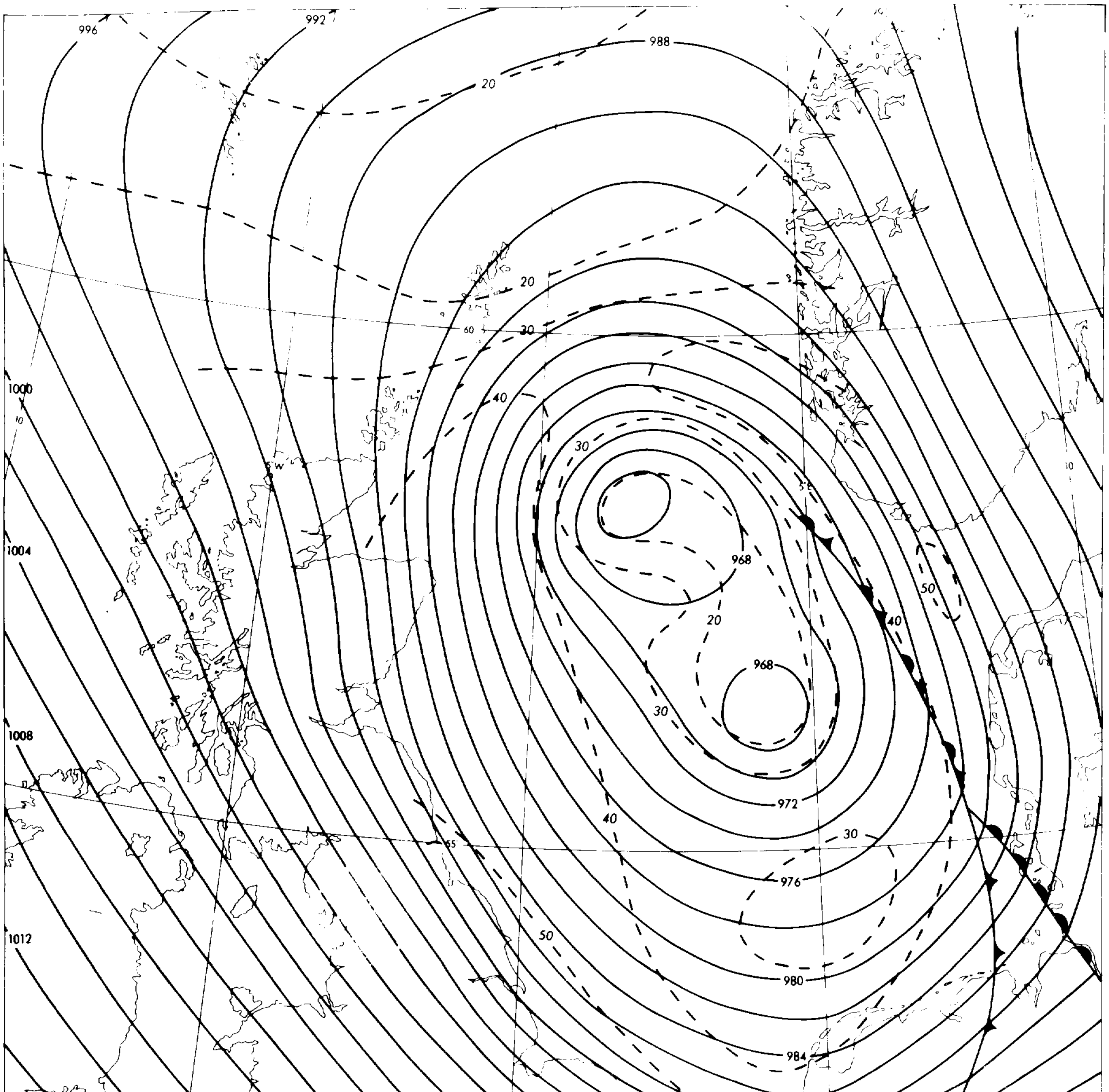


Figure 1 Synoptic Chart 0000 3rd January, 1976 Isobar (mb) ——— Isotach (kt) — — —

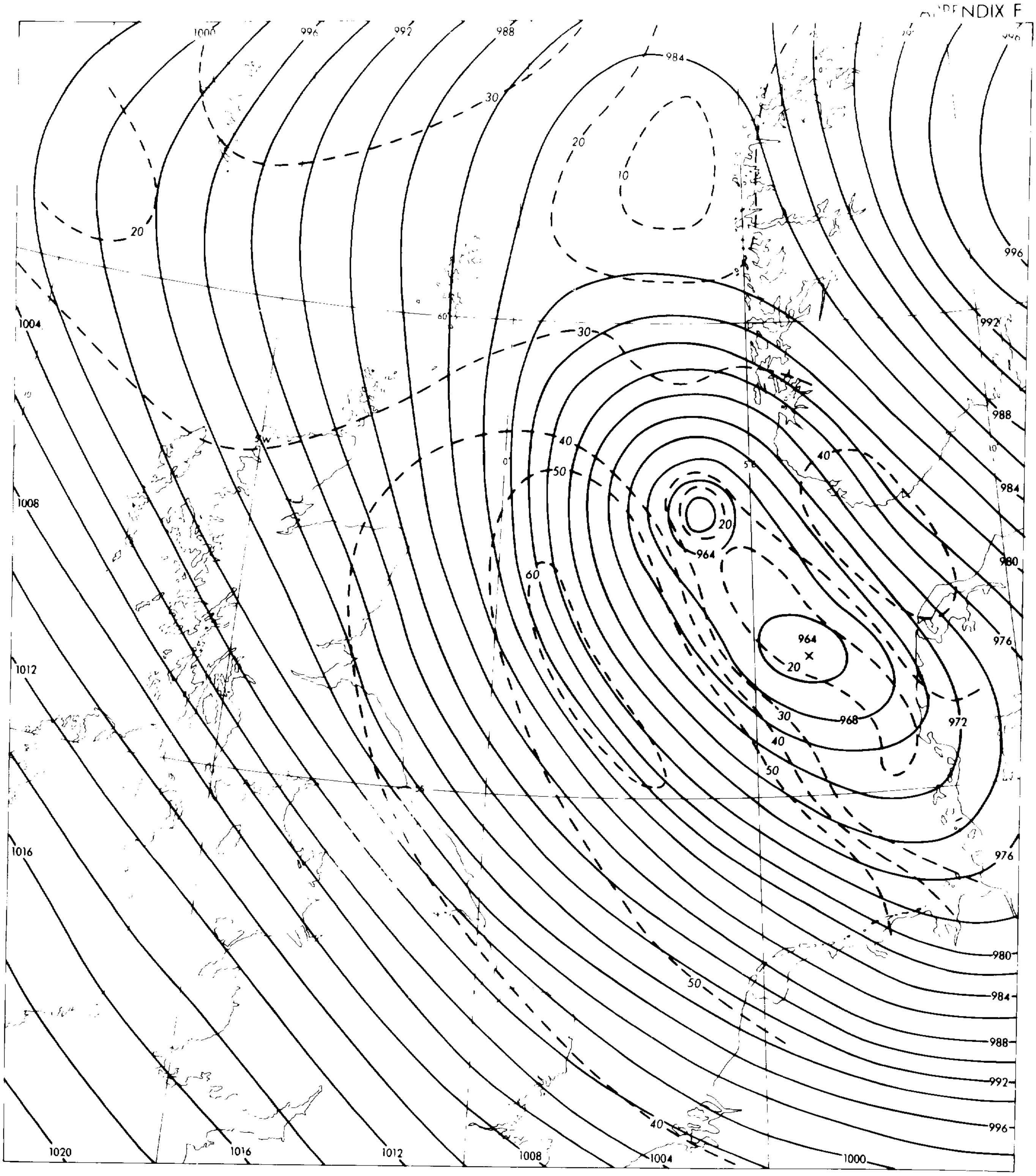


Figure 2 Synoptic Chart 0300 3rd January, 1976 Isobar (mb) ——— Isotach (kt) — — —

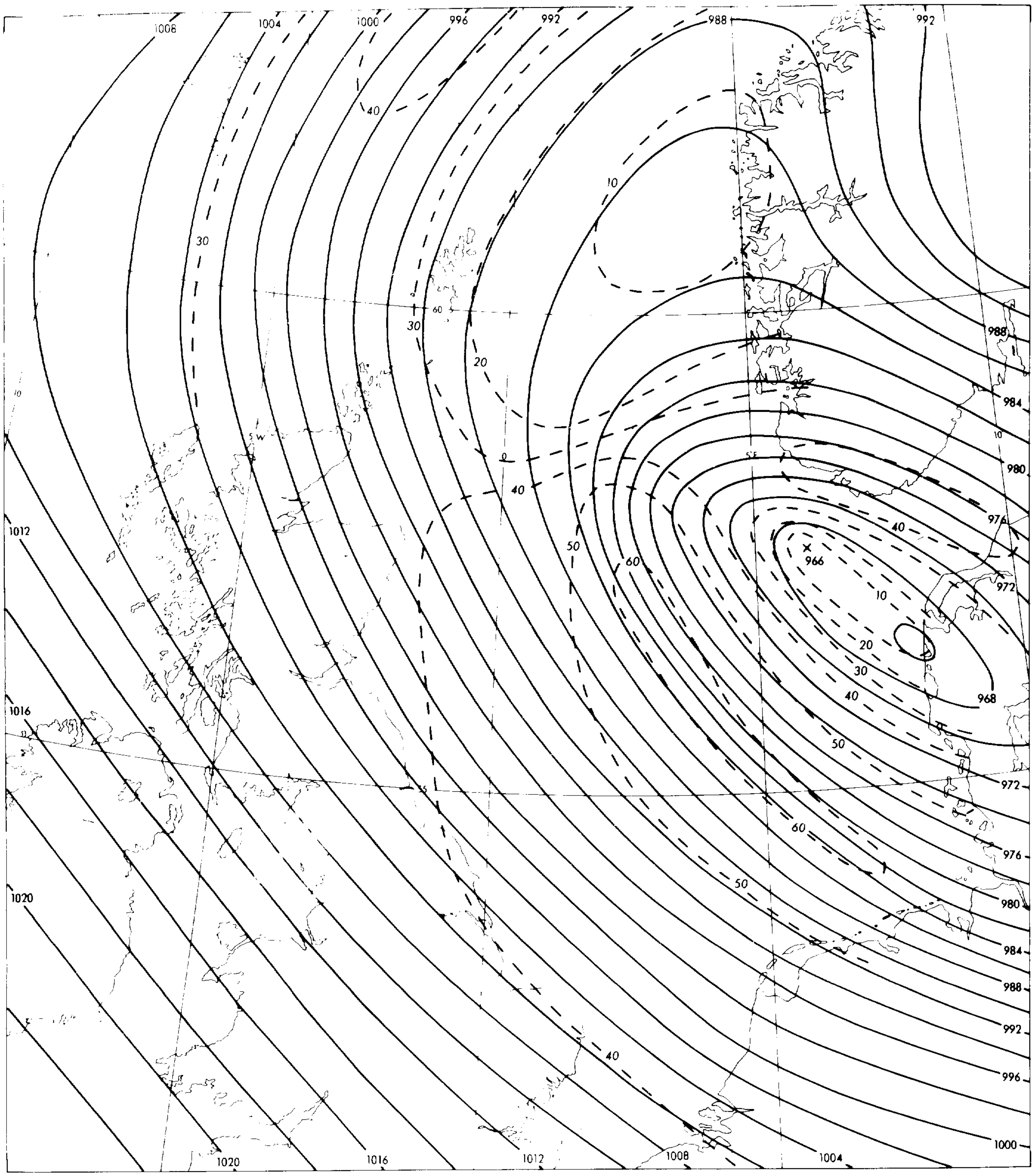


Figure 3 Synoptic Chart 0600 3rd January, 1976 Isobar (mb) ——— Isotach (kt) – – –

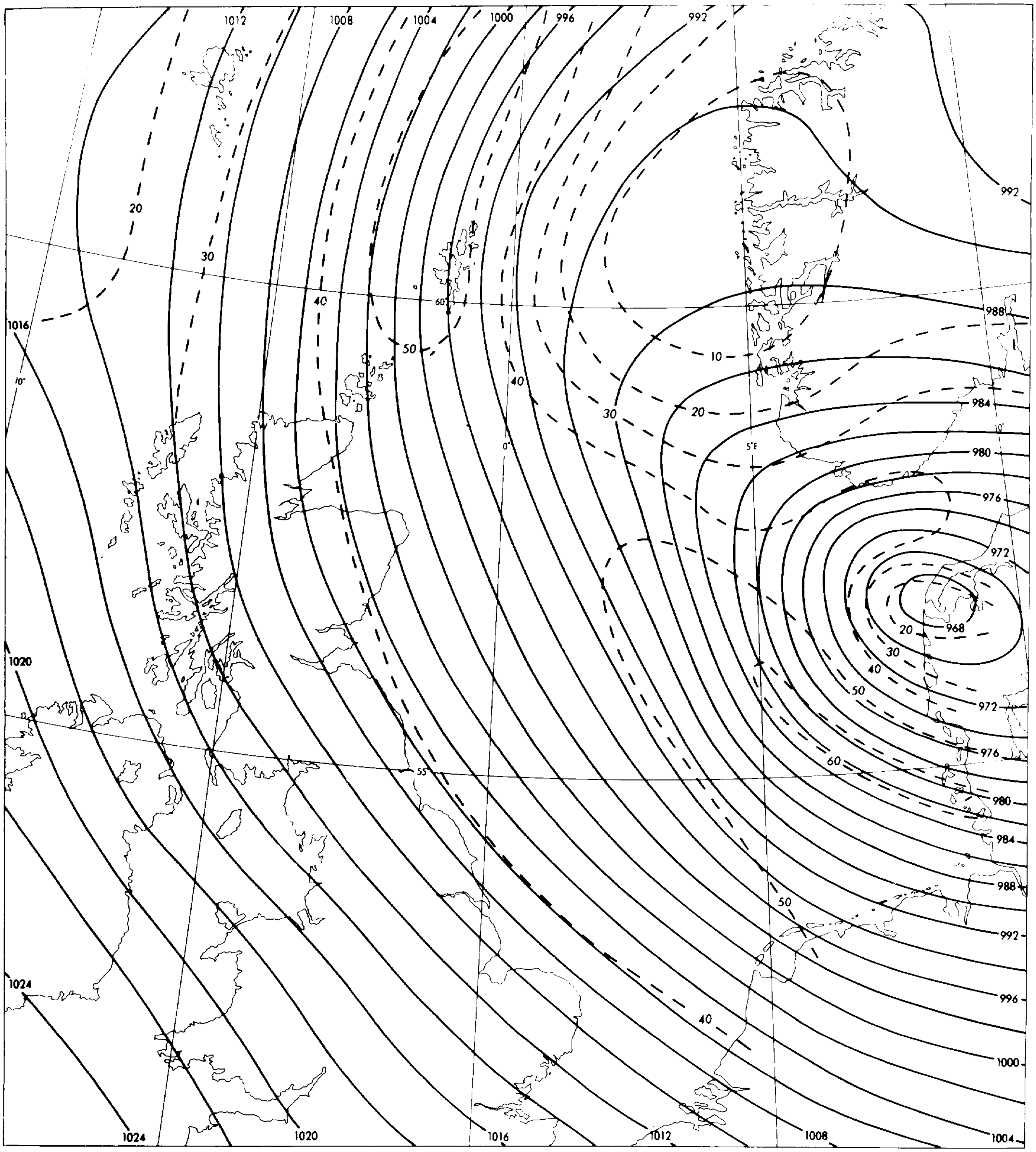


Figure 4 Synoptic Chart 0900 3rd January, 1976 Isobar (mb) ——— Isotach (kt) — — —

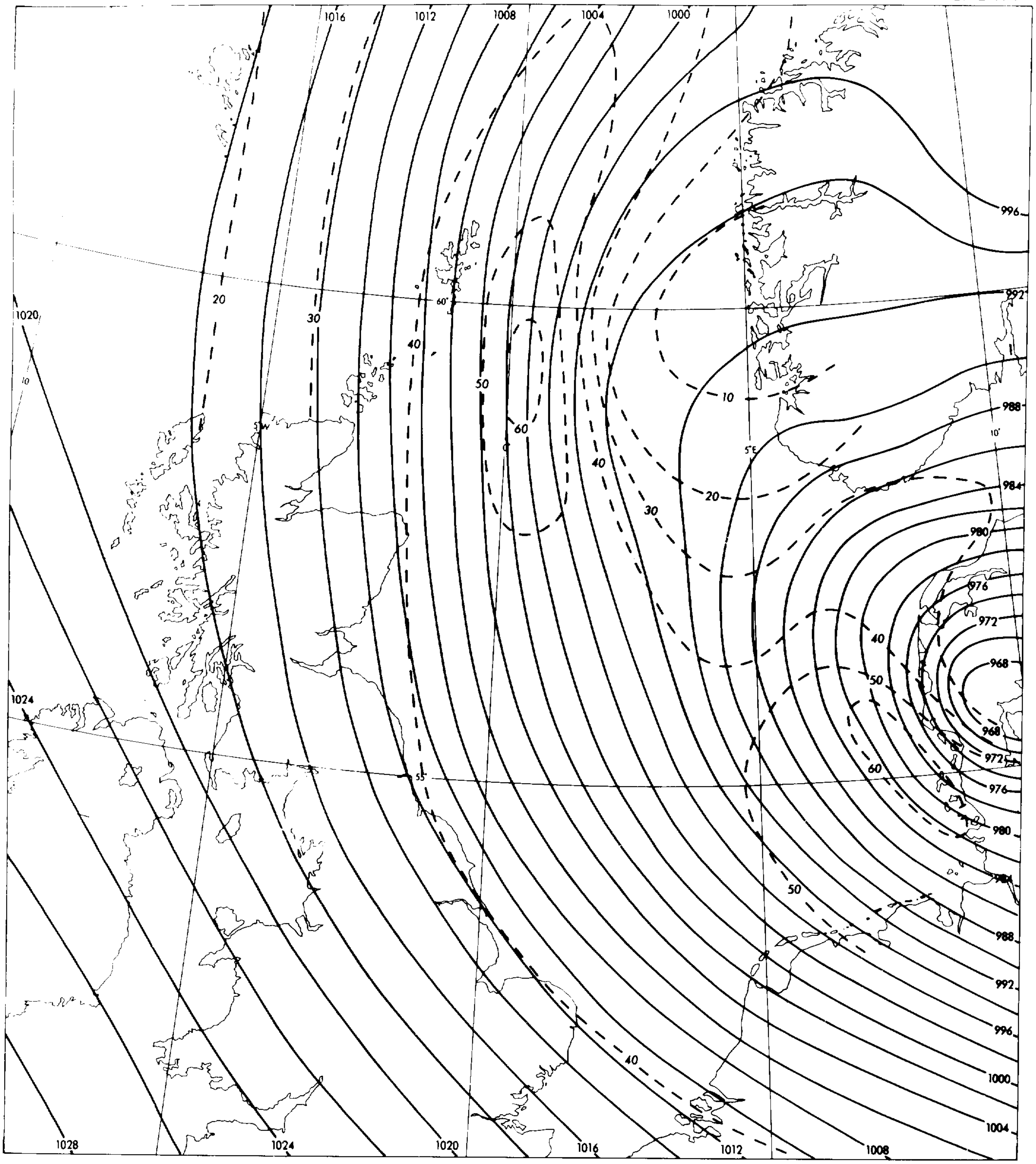


Figure 5 Synoptic Chart 1200 3rd January, 1976 Isobar (mb) ——— Isotach (kt) – – –

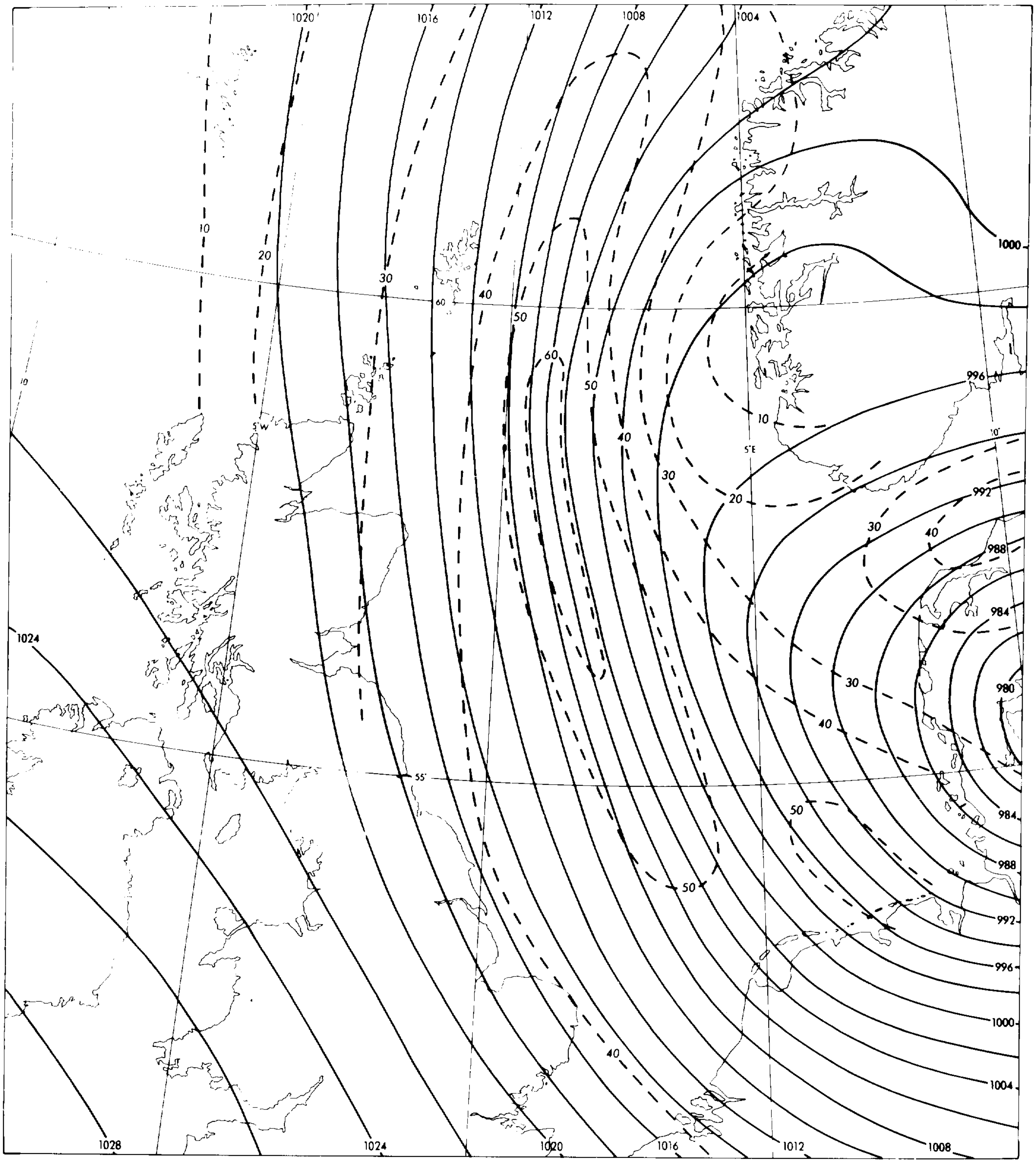


Figure 6 Synoptic Chart 1500 3rd January, 1976 Isobar (mb) ——— Isotach (kt) – – –

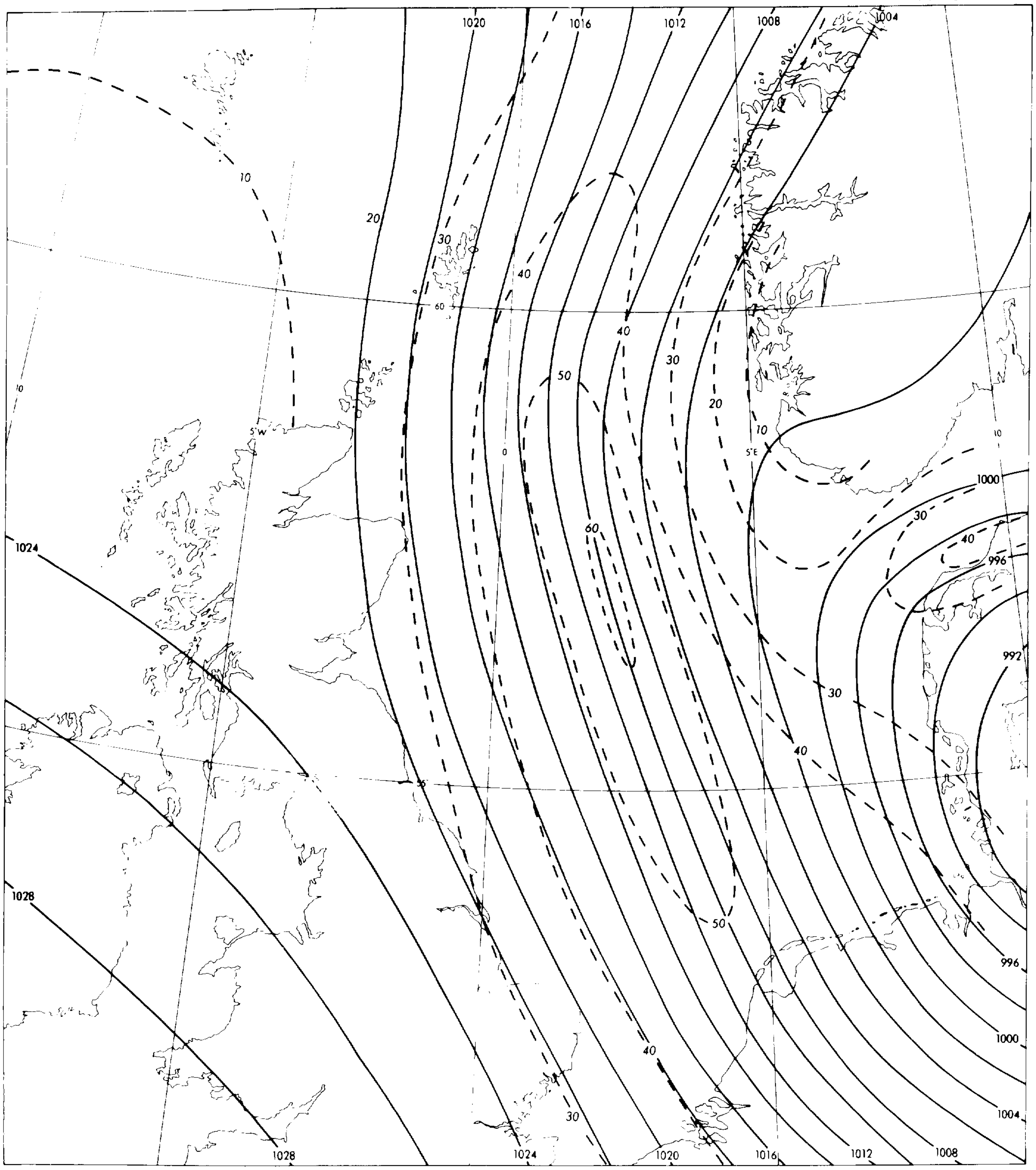


Figure 7 Synoptic Chart 1800 3rd January, 1976 Isobar (mb) ——— Isotach (kt) — — —

Page 29 : Appendix F, Figure No 7.

20 kt isotach, to the west of Shetland, has been omitted

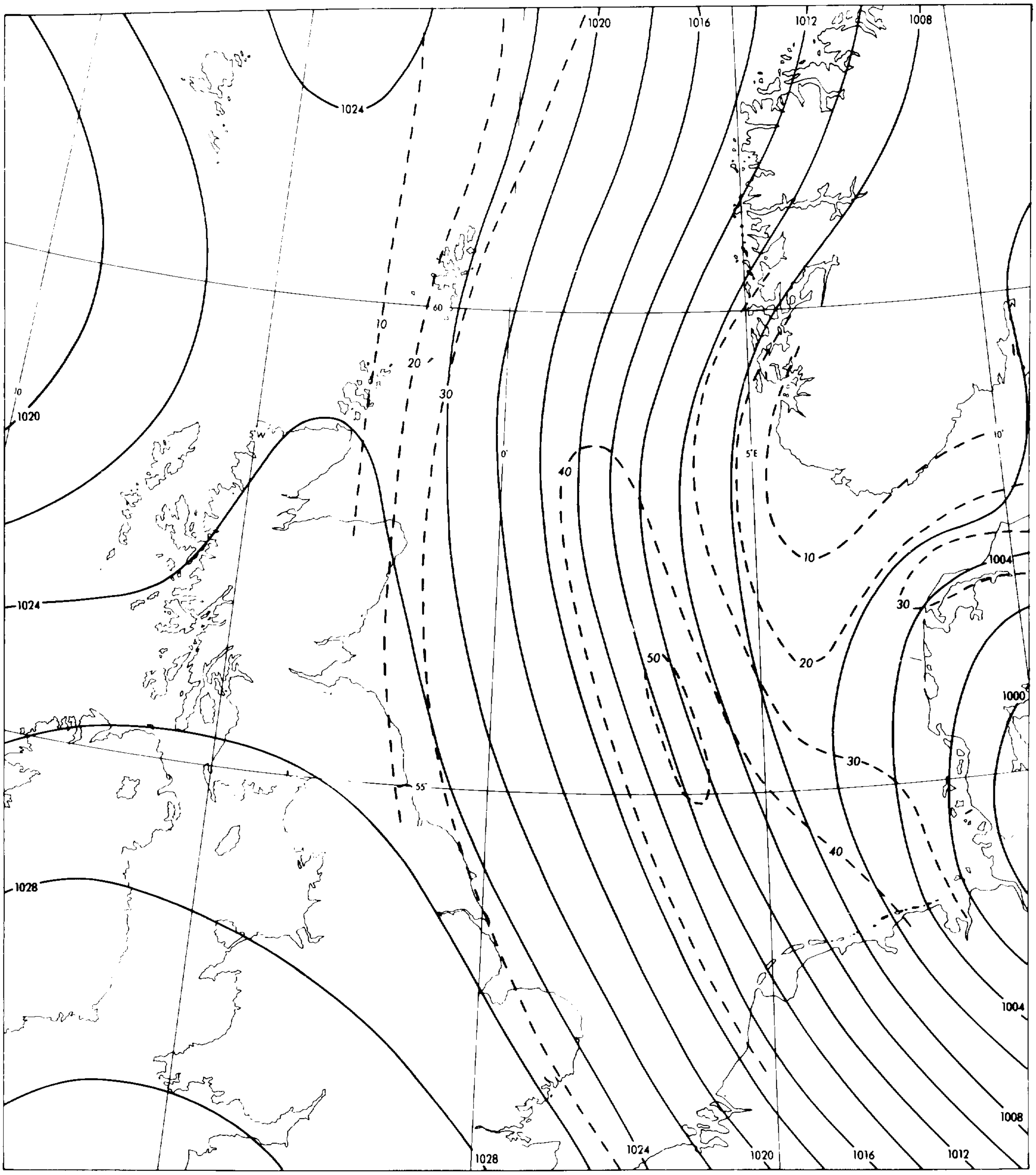


Figure 8 Synoptic Chart 2100 3rd January, 1976 Isobar (mb) ——— Isotach (kt) – – –

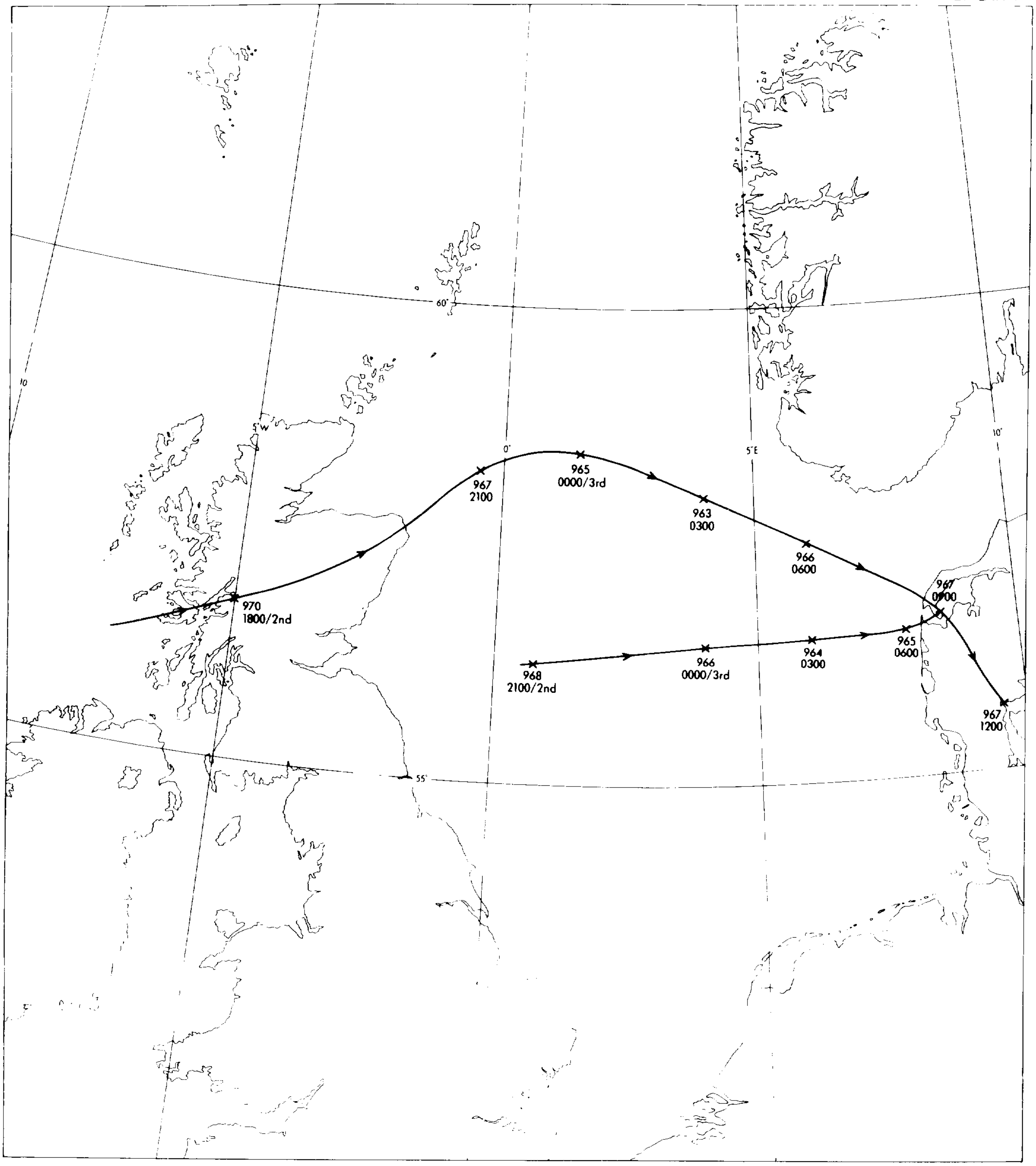


Figure 9 Tracks of depressions with central pressures and times