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EXTREME WIND CONDITIONS IN DIGERNESSUNDET, STORD.

FINAL REPORT

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The extreme wind conditions at the mooring site in Digernessundet are found for all directions and return periods from 2 to 100 years. The analyses is based on extreme wind analyses of Utsira, local wind measurements around Digernessundet and weather map studies of strong wind situations.

UNDERSKRIFT

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CONTENTS OF FINAL REPORT

EXTREME WIND CONDITIONS IN DIGERNESSUNDET

FINAL REPORT

1 *INTRODUCTION*

The Norwegian Meteorological Institute (DNMI) has in cooperation with the Norwegian Research, Institute of Electricity Supply A/S performed an analyses of extreme wind conditions in Digernessundet, south of the island of Stord. The purpose of this project was to update the design wind criteria for the mooring area, on the basis of a correlation between local wind measurements and long time series of wind recordings from meteorological stations.

There are three reasons to believe that the results of this project are of higher reliability than earlier wind studies of the area:

1. A directional extreme wind analysis of 23 years of homogenized wind recordings from Utsira lighthouse.

2. A relatively simple local topography around the area, together with some sets of local measurements, provided a good description of local conditions.

3. A method based on a weather map study of 120 cases of strong wind conditions was used to establish "transfer coefficients" for high wind speeds and different directions between Utsira and Stord.

Because of the general interest in an examination of the Utsira data, this analysis has been written separately and is included as Appendix 1 of this report. However, the main conclusions are referred to in chapter 3.

The weather map study of a number of strong wind situations from all main directions has mainly been performed by Alv Sunde at the DNMI division Western Norway.

A preliminary report was issued in November 1985 (DNMI report 47/85), and an updated version by Alv Sunde in January 1986. Those reports are replaced by the present one.

The project was funded by Aker Stord A/S, who have also taken care of the type writing and prepared many of the figures in the report.

2 METHOD

The analysis was carried out according to the following steps:

A. Periods when there were strong winds in Digernessundet were found from nearly 2 years of wind recordings, taken near to or at Digernessundet.

B. The above recordings are compared with records from the regular weather station Utsira lighthouse, and reduction factors are calculated for different sectors. Directional deviations are found as well.

C. 23 years of wind recordings from Utsira lighthouse are examined and seasonal extremes for 10 min. mean wind and 3-5s gust wind speeds are found for 8 directions and 2 seasons: September-April and May-August. The months September and April were included in the winter season since the relatively high probability of strong winds in those months would otherwise cause the summer analysis to be dominated by results for those two months.

   A detailed homogeneity study is performed on the Utsira recordings to ensure that the data is homogeneous.

D. The "all-direction" - extremes are calculated according to Gumbel's 1. distribution of extremes.

E. The directional distribution of extreme values with different return periods are determined as follows:

   Return period 2 and 5 years:

   The 50 and 20 percentiles of the recorded maxima of each sector are used.

   Return periods of 10 years or more:

   The "all direction" values are fixed for the most exposed sector(s) and weighted for the 5 highest values recorded for each sector.

F. The extreme values thus found for Utsira are reduced to Digernessundet by means of the functions found under B.

3 WIND EXTREMES AT UTSIRA

The study of wind extremes at Utsira lighthouse has a general interest beyond this project. It is therefore presented as a separate paper included in this report as appendix 1. From the wind recordings of both 10 min. mean wind and gusts, yearly and seasonal extremes are found for 8 main directions: N, NE, E, SE, S, SW, W and NW. The time series of the wind data are listed in tables 4.2 and 4.3 in appendix 1, while the calculated extremes for mean winds and gusts are shown in table 4.6.

The main conclusions of the Utsira-study are in other respects:

- The records of mean wind were nearly homogeneous for the period 1 September 1962 -31 August 1985. Only minor adjustments were made.

- The wind gusts recorded by a pressure-tube anemometer had to be adjusted in agreement with the cup anemometer.

- The results found by methods D and E (chapter 2) seem very reasonable compared with the general knowledge of the area.

- The results are representative within 5-10% for the near coastal waters from Obrestad to Sogn. The representativity varies both with wind direction and the distance from Utsira.

It should be noted that the "all direction" extremes are somewhat higher than the highest value for each sector for the return periods 2 and 5 years. This is correct since for short return periods the seasonal extremes may occur from several directions. The "all-direction" value must therefore represent a longer return period for each of these sectors alone.

Longer return periods (10 years or more) give higher wind speeds and it is reasonable that these strong winds are restricted to one or two sectors. However, the directional extremes for long return periods are probably on the conservative side (higher wind values). Due to high standard deviations of the recorded directional maxima, the Gumbel distribution gave unrealistic values when applied to each sector separately. Therefore a different method was used which weighted the "all-direction value" relative to the mean of the 5 highest (recorded) values in each sector.

The high summer extremes for long return periods should be mentioned. Light winds prevail during summer time, illustrated by low values for the short return periods. However, a strong storm may blow up, but has a long return period. This happened, for example on May 21, 1979, when the maximum 10 min. mean speed at Utsira, was 31 m/s, and the estimated value at Stord was 24 m/s.

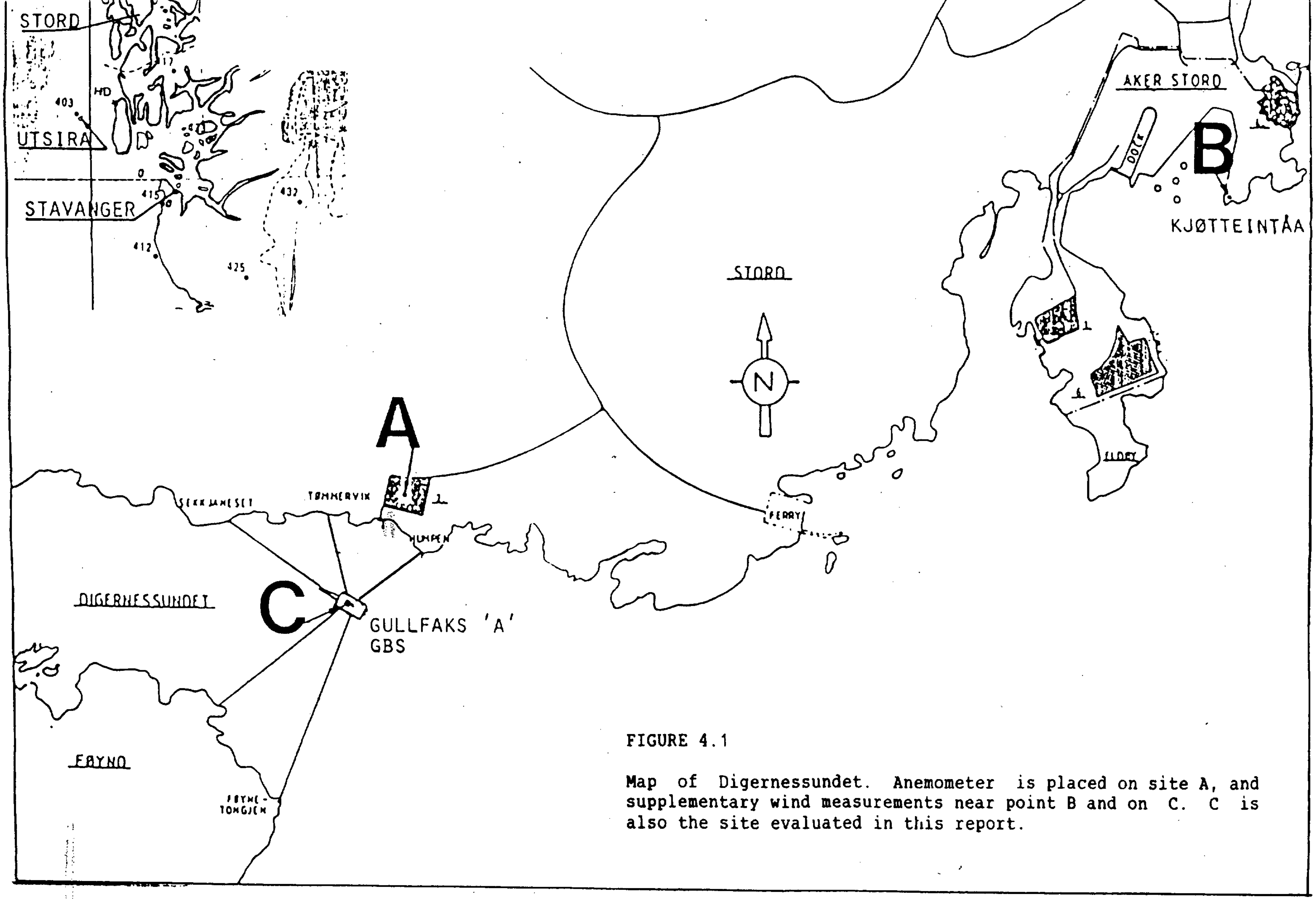
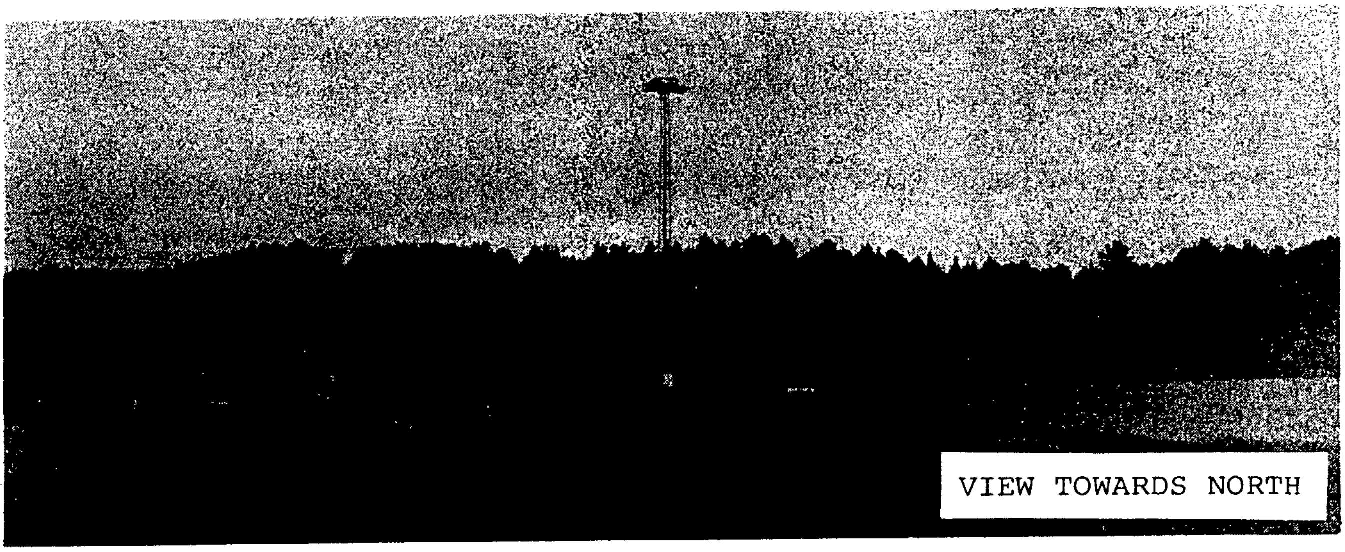


FIGURE 4.1

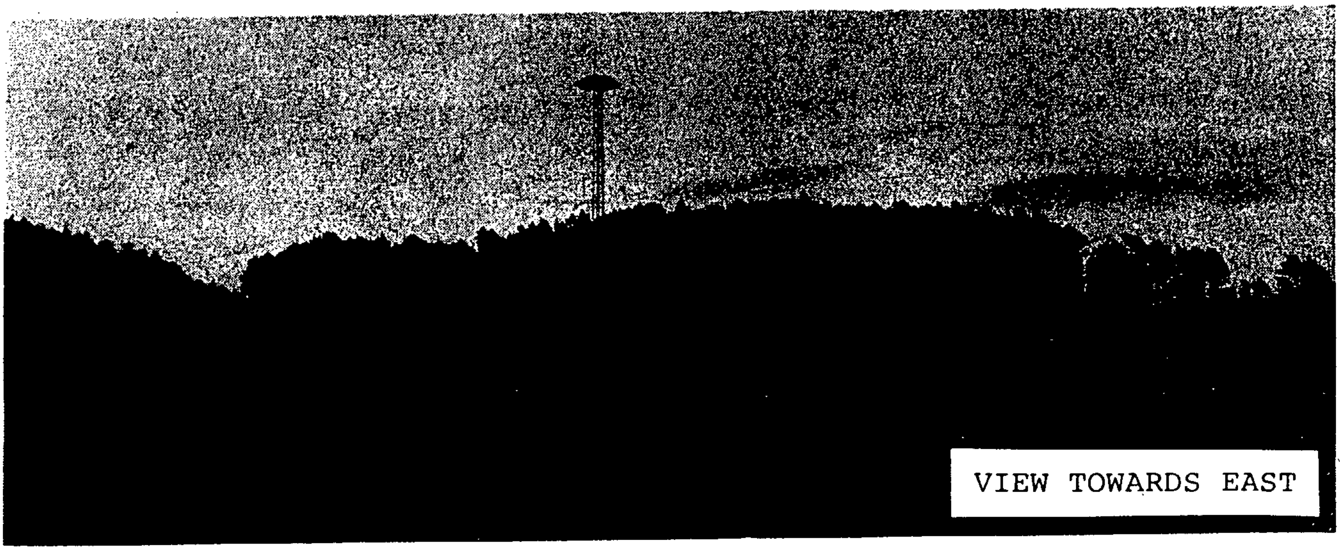
Map of Digernessundet. Anemometer is placed on site A, and supplementary wind measurements near point B and on C. C is also the site evaluated in this report.

FIGURE 4.2

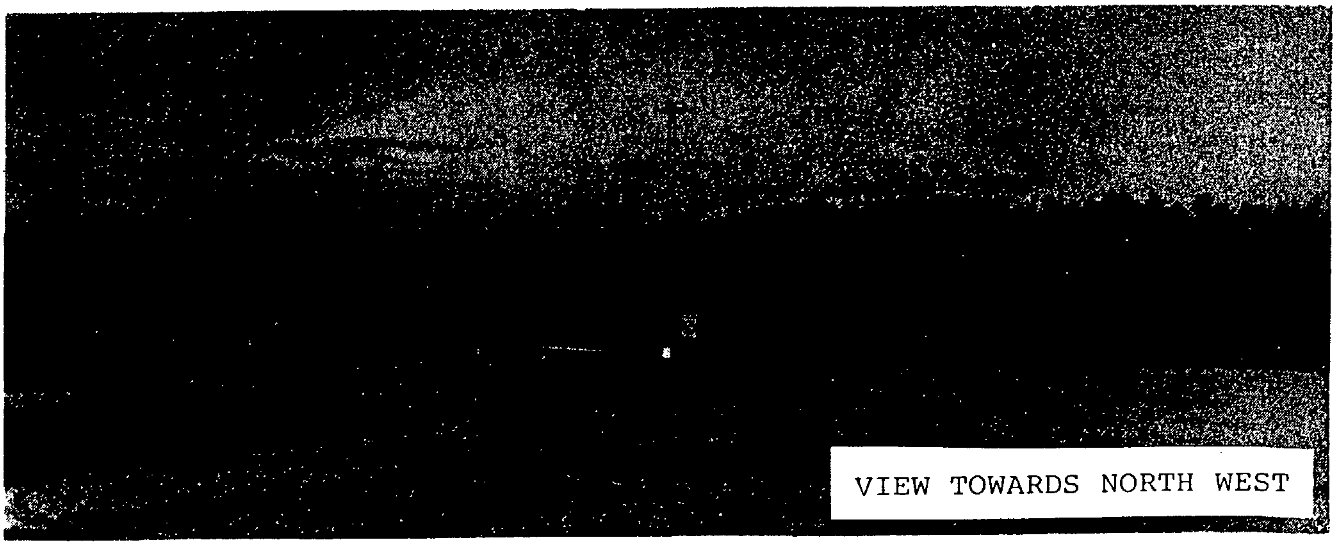
The anemometer at site A (Tømmervika) is placed on the top of the 26 m high mast. Anemometer level: 38 meter above sea level.



VIEW TOWARDS NORTH



VIEW TOWARDS EAST



VIEW TOWARDS NORTH WEST

4 *DIGERNESSUNDET. SITE DESCRIPTION AND LOCAL WIND MEASUREMENTS*

A map of the area is shown in figure 4.1 and figure 4.2 shows the surroundings of the anemometer on the car park site at "Tømmervika", site A on the map.

4.1 INSTRUMENTS AND EXPOSURE

Aanderaa wind recorders have been in operation on three sites in the Digernessund area:

4.1.1 Tømmervika car park, position A on fig. 4.1.

The anemometer is situated on a 26 m high mast approximately 200 m from the shore. The height above sea level is 38 m, see photo. A continuous recording of 10 minutes mean wind and highest gusts are available for more than 2 years (November 1983 - January 1986).

The exposure is good for winds from the southern sector 130^0 - 240^0 and the data are recognized to be representative for Digernessundet for those directions as no obstacles shelter the anemometer.

When winds are blowing from the northern sector between W and E, the air flow is hampered due to flowing over uneven ground covered by high trees. Northerly winds over the area are also diverted and channelled on both sides of Stord island.

The obvious sheltering effect is evident from the recordings, and the same sheltering occurs to some extent in Digernessundet, especially when the wind direction is straight northerly.

When wind directions are northwest or southeast, or the wind is blowing parallel to the sound, the representativity of the recordings is poor. The wind recordings from these directions are influenced by the land friction, and the real wind over the sea is most likely increased by funnelling up the sound.

4.1.2 Kjøtteintåa, position B on fig. 4.1.

Data from an anemometer situated at Kjøtteintåa (B on the map) are available for the period August 1983 - June 1984. The measure was completely exposed to easterly wind, and the data are recognized to be representative for wind blowing through the sound from easterly directions. The measure also had a good exposure to south and south-easterly winds.

4.1.3 Gullfaks A (GBS), position C on fig. 4.1.

In November 1985 an anemometer was erected on the Gullfaks 'A' GBS shafts, one metre below the top and 101 m above sea level (C on the map).

The anemometer had a good exposure towards west and north west and also towards east.

December 1985 and the early days of January 1986 was a windy period and gave some very good records of strong winds from all directions. This data allows for some valuable corrections of the estimates done on the basis of the data from the sites A and B.

On the basis of the data from these three sites, transfer coefficients Utsira - Digernessundet have been established.

5 COMPARING DATA UTSIRA - STORD (DIGERNESSUNDET).

The wind measure at Utsira has a good exposure to winds from all directions, and the recordings are representative for the open sea, to within 5-10%.

The land and fjord area in Western Norway is greatly influenced by large scale modification of the air flow, due to the mountains inland. Furthermore, local deviations have to be considered.

In order to compare representative wind data from Utsira and Stord, the following procedure has been used:

1. Typical weather situations representing strong wind over the whole area Utsira - Stord have been selected.

2. Wind directions, 10 min. mean wind speeds and gusts, during periods with strong wind, have been plotted for Utsira together with the data available in the Stord area.

3. The maximum wind speeds and corresponding wind directions at Utsira and Stord have been picked out for each situation. Usually the maximum speed occurs 1-2 hours later at Stord than at Utsira due to the eastward movement of air pressure systems.

Alltogether 120 sets of corresponding data representing typical pressure patterns over the Utsira - Stord area, have been examined. The conclusions of this weather map study are given in appendix 2..

When selecting the data representing Digernessundet, the representativity of the different sites A, B and C have been considered.

In order to reduce intercorrelation, only one pair of wind values of each direction have been chosen from each weather situation, i.e. the same front or low approaching the area.

A more comprehensive discussion of these topics with some examples are shown in appendix 2.

There are some important features to notice:

- When comparing the wind directions they always show that the wind at Stord has backed (turned counterclockwise), as compared to Utsira.

- The wind speed at Stord is weaker than at Utsira for every direction.

- Transfer coefficients for the wind speeds have been estimated by postulating that some correlation exists:

  Wind Speed Stord = K x(Wind Speed Utsira)

Such coefficients, K, have been calculated for different wind directions by statistical methods, see appendix 2.

There are no significant difference between coefficients for winter and summer.

The calculations have been based mainly on the recordings from the site A, but the temporary recordings from site B and C have been of great value for adjusting the coefficients for easterly and westerly winds. Attention has also been paid to topographical influences. See tables 5.1 and 5.2.

These coefficients have been used on the Utsira extreme mean wind values given in appendix 1, table 4.6 to obtain the values for Digernessundet in table 6.1.

Fig. 6.1 displays values of some return periods and directions, and table 6.1 gives the complete list of extreme values.

Table 5.1 TRANSFER COEFFICIENTS UTSIRA - STORD
(Wind speed Stord)/(Wind speed Utsira)

Direction Utsira Direction Stord	N N-NW	NE N-NE	E NE	SE E	S SE-S	SW S-SW	W SW	NW W
10 min. mean Wind Speed	0.4	0.5	0.7	0.7	0.8	0.8	0.8	0.6
Gusts	0.8	0.6	0.7	0.8	0.8	0.9	0.8	0.7
Correlation Coef.	0.0	0.0	0.7	0.6	0.9	0.9	0.7	0.5

Table 5.2 CHANGE OF WIND DIRECTION (BACKING)
(Wind direction Utsira)-(Wind direction Stord)

Change of wind direction (backing)

Utsira	N	NE	E	SE	S	SW	W	NW
Stord	54^0	25	33	45	21	28	40	35
Standard dev.	34	20	14	30	9	14	22	22

6 *EXTREME VALUES FOR DIGERNESSUNDET*

6.1 10 MINUTES MEAN WIND SPEED

The transfer coefficients in table 5.1 for 10 minutes mean winds are applied on the calculated extremes for the 8 directions at Utsira. In some cases two values were obtained for the same direction since the sector limits for the transfer coefficients did not always match with the sector limits for the Utsira extremes. As a rule the conservative value has been chosen, but attention was also paid to the topography so that sector limits reflects the horizontal panorama as seen from the mooring site (position C fig. 4.1).

These sector limits do not therefore necessarily coincide with the sector chosen for the site A in Appendix 2.

The extreme wind speeds calculated according to the above procedure are listed in table 6.1 for return periods 2, 5, 10, 50 and 100 years, summer and winter season. A selection of the same data is also shown in figure 6.1.

The all-direction values are set equal to the highest wind speed for each sector for return periods, 10 years or more.

It should be noted that the sectors given in table 6.1 are chosen conservatively. That means that no "scaling down" is necessary of a high wind speed into the sector of the lower speed.

It should also be stressed that the values are restricted to the specific mooring site (position C on fig. 4.1) only.

6.2 GUST SPEED AND 1 MIN. MEAN

The extremes for short periodic wind gusts (3-5s) have been calculated from local gust ratioes measured at Tømmervika, however somewhat adjusted with respect to the differences in the local surroundings especially for easterly winds in Digernessundet. For this sector the gust ratio at Tømmervika was measured to 2.2 in strong wind situations, while 1.8 was found more correct for Digernessundet.

The gust ratioes thus obtained are compared with ratioes valid for different averaging times and roughness categories given in (2), and adequate ratioes are chosen for each sector to calculate 1 minute means.

6.3 HEIGHT VARIATIONS

From the generally accepted "power law":

$$V(Z) = V(10) \times (Z/10)^{\alpha}$$

The wind speed Vz at height z can be found when the wind speed at 10m level (V_{10}) and the exponent α is known. According to the DnV-specifications α =0.113 should be used for 1 min means in open waters. It is assumed that this value can be used for the sector 060^0 - 320^0, while for the northern sector, 320^0 - 060^0, α = 0.25 is recommended due to a much rougher topography upstream. These values are also indicated by the measurements from the top of the Gullfaks A GBS (101 masl.).

Table 6.1 EXTREME WIND SPEEDS FOR ALL DIRECTIONS AND 2 SEASONS FOR THE MOORING SITE IN DIGERNESSUNDET FOR VARIOUS RETURN PERIODS.

Unit: m/s.

	SEPTEMBER - APRIL Return per. (years)					MAY -AUGUST Return per. (years)				
	2	5	10	50	100	2	5	10	50	100
a) <u>10 min. means</u>: Sector (degrees)										
355-025	9	10	11	12	13	4	6	9	10	11
025-060	13	15	16	18	19	8	11	14	17	18
060-085	18	20	22	24	25	11	13	16	19	20
085-190	20	22	23	25	26	14	17	21	24	26
190-260	21	23	25	27	29	12	15	20	23	26
260-320	16	19	20	22	23	11	13	15	17	19
320-355	10	12	13	14	15	7	8	10	12	13
All:	23	24	25	27	29	16	18	21	24	26
b) <u>1 min. means</u>										
355-025	13	14	16	17	18	6	9	13	14	16
025-060	17	20	21	24	25	11	15	19	23	24
060-085	24	27	28	31	32	17	21	26	29	32
085-190	23	26	27	29	30	16	20	25	28	30
190-260	26	29	32	34	37	15	19	25	29	33
260-320	21	25	27	29	31	15	17	20	23	25
320-355	14	17	18	19	21	10	11	14	17	18
All:	28	30	32	34	37	19	22	26	29	33
c) <u>3 s gust speeds</u>										
355-025	18	20	22	24	26	8	12	18	20	22
025-060	23	27	29	32	34	14	20	25	31	32
060-085	32	36	40	43	45	20	23	29	34	36
085-190	30	33	35	38	39	21	26	32	36	39
190-260	34	37	40	43	46	19	24	32	37	42
260-320	29	34	36	40	41	20	23	20	31	34
320-355	19	23	25	27	29	13	15	14	23	25
All:	37	38	40	43	46	24	27	32	38	42

EXTREME WIND IN DIGERNESSUNDET SEPTEMBER - APRIL

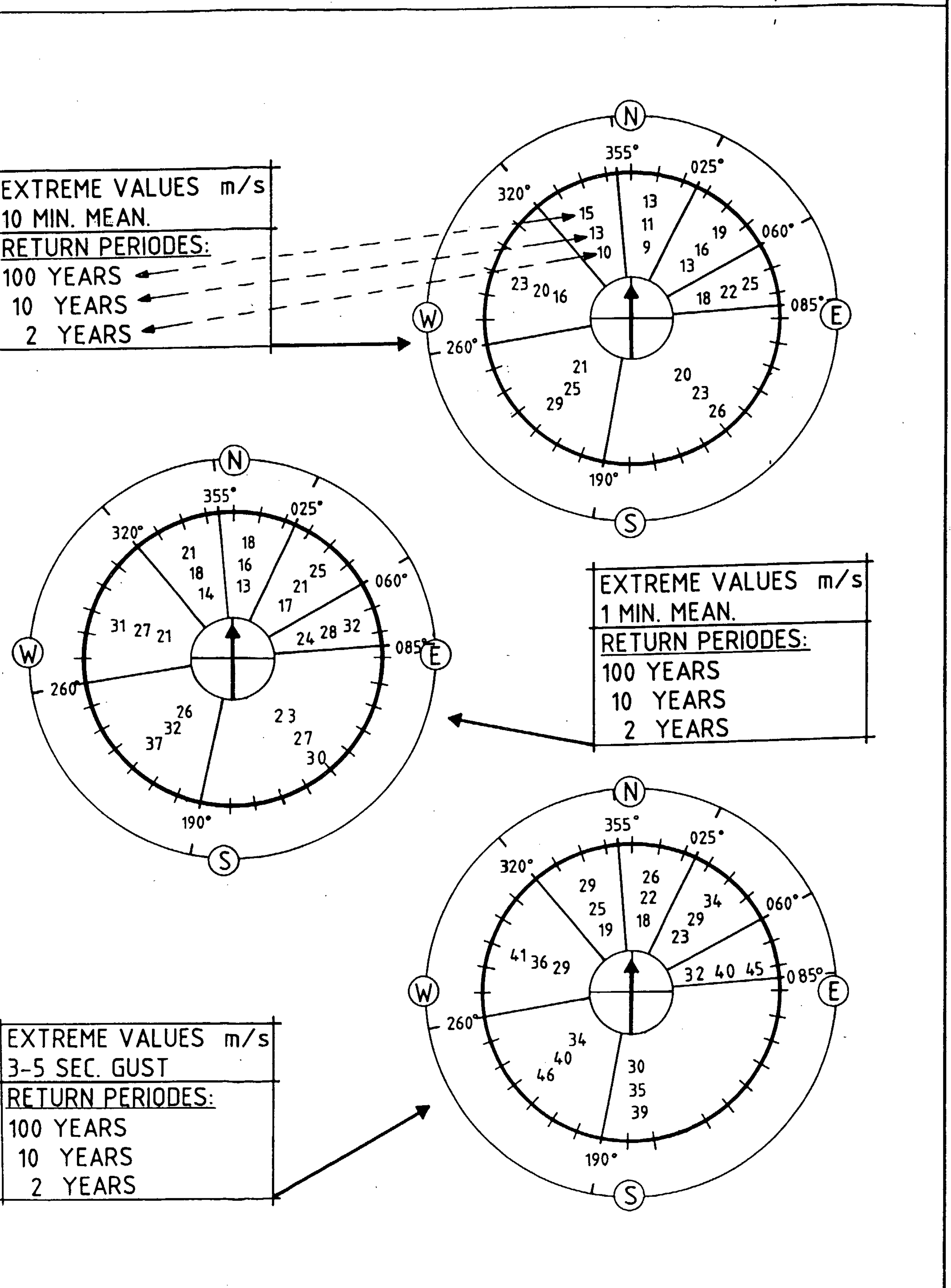


FIGURE 6.1: Wind roses for extreme values for 10 min. means (above), 1 min. means (center) and gusts (below). Ratioes of 1 min. means to 10 min. means are given in the outer ring of the center rose.

7 EXTREME WIND SPEEDS FOR THE DOCK AREA.

Table 7.1 and figure 7.1 are estimated from an analysis of the locality of the dock area relative to Digernessundet. From the Stord topograhical conditions it seems that north-northeasterly wind should be much stronger at the dock area. Northeasterly wind in general, also has a long wooded upstream surface at Digernessundet. The wind speed of the dock area is some higher east of 50° than north of 50° due to a land surface then to cross.

Southerly and southeasterly wind seems to be of equal strength at the two sites due to identical exposition to open areas. However, at 220° - 230° the wind is some more reduced at the dock due to more wooded upstream area.

Wind from the west (240° - 320°) must be weaker at the dock area. This wind has to cross the wooded land surface and also feels shading effects behind the local hill west to northwest of the harbour.

Wind from the sector 330° - 10° seems to be of equal strength at the two sites, and is much reduced because of equal shading effects by the mountains and considerable wooded land upstream of both sites.

TABLE 7.1 EXTREMES FOR 10 MIN. MEAN SPEEDS (IN M/S) FOR THE DOCK AREA

	RETURN PERIOD	
SECTOR (degrees)	10 YEARS	100 YEARS
10 - 50	16	19
50 - 190	23	26
190 - 230	25	29
230 - 250	20	23
250 - 300	15	17
300 - 10	10	12

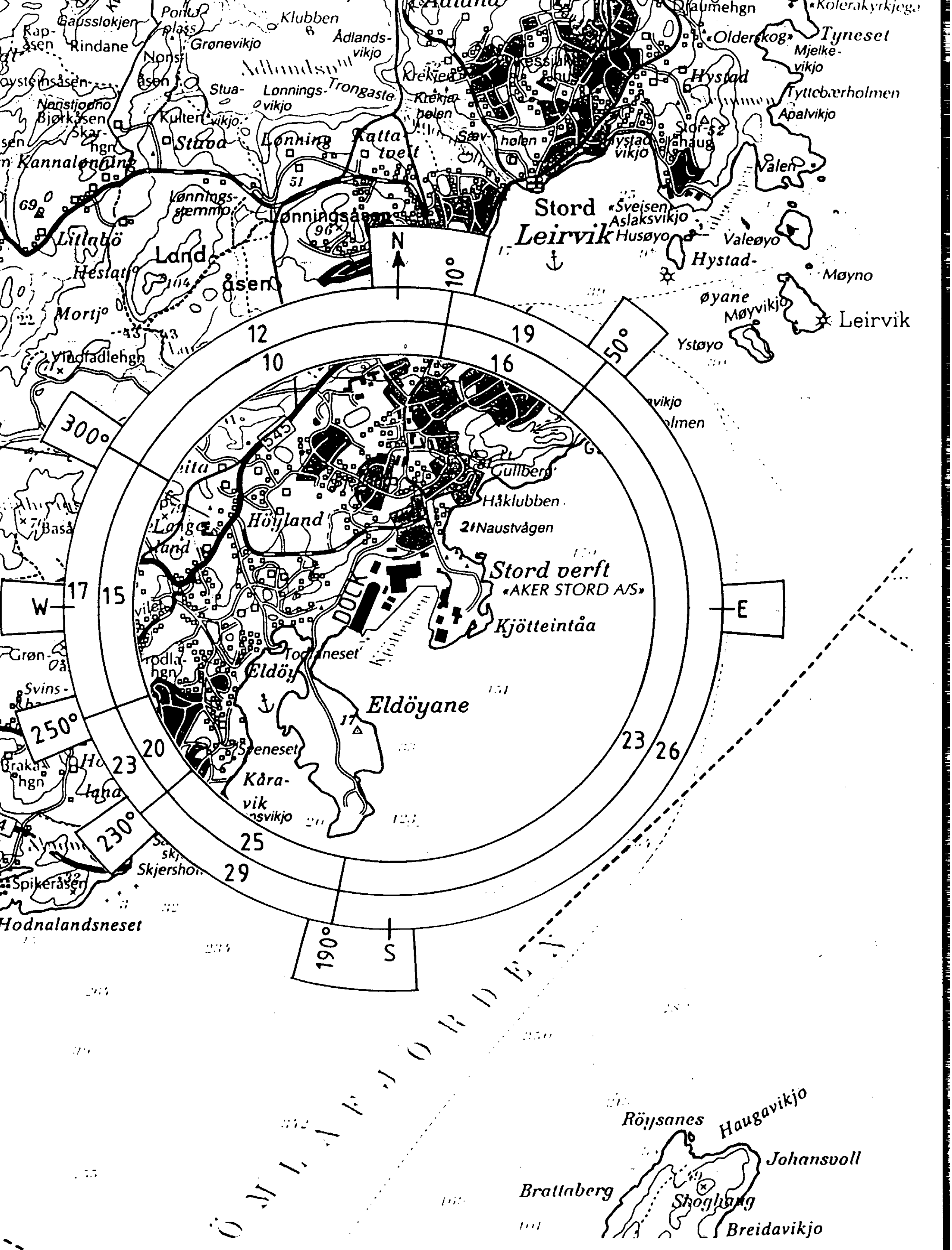


FIGURE 7.1 EXTREMES FOR 10 MIN. MEAN SPEEDS (IN M/S) FOR THE DOCK AREA.

Inner circle : 10 years return period.
Outer circle : 100 years return period.

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APPENDIX 1

EXTREME WIND ANALYSES

FOR UTSIRA LIGHTHOUSE

BY

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APPENDIX 1 EXTREME WIND ANALYSES FOR UTSIRA LIGHTHOUSE

1 INTRODUCTION

The background for this analysis of extreme gust and mean wind speeds at Utsira lighthouse was a request from Aker Stord A/S concerning more precise estimates of extreme wind conditions in Digernessundet, Stord. Even small variations in the expected extreme wind speeds are of increasing economic importance in e.g. the construction, mooring, coupling and towing of the oil platforms in this area, as the constructions are getting even bigger.

Although local measurements can be made, all such extreme value analyses must be based on the long records of wind data from a representative weather station. It is reason to believe that the free exposure of Utsira makes the station representative for a larger area along the coast of Southwestern Norway. Results from the extreme value analysis for this station are therefore of general interest, for instance for special studies of the fjords inside the coast line. The seasonal and directional variations of extreme wind conditions found in this study, and the development work behind the presentation may be of general interest.

As long wind records from other stations are, or will be analysed in a similar manner in connection with other studies at The Norwegian Meteorological Institute, a more detailed description of extreme wind conditions for different directions and seasons will be available for the major part of the Norwegian coast. The well exposed weather station Utsira lighthouse is of great importance in this respect.

2 PLACE AND TOPOGRAPHY

2.1 LOCAL TOPOGRAPHY AND REPRESENTATIVITY

Utsira is a detached island, approximately 3 x 3 km (figure 2.1). The island is relatively flat with highest ground level at ca 50-60 m above sea level.

Most of the island consists of bare rock and areas with grass and heather.

The anemometer 40 is placed 11 m above ground on a hill 70 m above sea level which is orientated mainly southwest-northeast.

The settlement on the island is situated down in a valley which turns north-south in the northern part. East and northeast from the instrument, on the other side of the valley, the hills are approximately as high as the hill where the anemometer is situated.

Wind in the sector west to north, which is coming undisturbed from the ocean, will probably gain a certain strengthening when passing the hill where the anemometer is placed ("hill effect"). It is difficult to estimate this strengthening, due to the cause of the three-dimensional structure of the island. The roughness is higher at the island than at the sea and affects the general "hill effect". An increase of 5-10% of the wind speed valid at 10 m above free sea level is a probable effect.

Southeasterly winds are likely to obtain a corresponding strengthening. This wind flows over 1-2 km land surface before reaching the instrument, but here the land surface is a lower canal zone laying between two hills.

Southerly winds will separate over the southern hill, while southwesterly winds decrease due to the lighthouse standing southwest of the instrument. Southerly and southwesterly winds will probably be measured lower than if measured 10 m above free sea level.

Wind flow in this sector will probably be more turbulent than southeasterly and northeasterly wind flows.

Northeasterly and easterly winds have to cross the hills at the east side of the island in this sector. This decreases the average wind flow, but a more turbulent wind flow will be recorded.

The probable effects are summarized in table 2.1.

2.2 REGIONAL TOPOGRAPHY AND REPRESENTATIVITY

Utsira is located 15 km west of Karmøy (figure 2.1). Off the island there are free waters in the sector south through west to north.

Towards northeast and to some extent east, lies the mainland with high mountains of great horizontal extent.

Towards southeast the range of mountains is considerably lower, and towards south-southeast the mountains slope downwards to Skagerak and the southern North Sea.

The influence of the distant mountains of the region affects the representativity of the station. Northeasterly and to some extent easterly wind flows will surely be underrepresented and weakened because Utsira is lying in a typical sheltered zone for wind flow from these directions. Easterly wind flow are somewhat more shielded north than south of Utsira.

Southeasterly winds are strengthened by deflection around the mountains. The effect of such a "beam" decreases further north, but probably increases further south.

Southerly winds have a typical strengthening due to leading effects of the land/sea distribution. That kind of strengthening with inland and high mountains to the right of the flow direction results in an acceleration towards lower pressure. This effect will of course increase further north and decrease further south.

Southwesterly and westerly wind flow are retarded towards the mountains. Such a decline may lead to a southerly turn, but anyway it leads to reduced frequency of strong southwesterly and westerly wind flows. (For unstable or near neutral air masses, strong winds will be less retarded than for stable air masses).

Owing to the shape of the range of mountains, the southerly wind flows increase further north while the westerly wind flows increase further south.

Northwesterly wind flow is strongest at the southern part of the area due to retardation of the wind field in the northern area.

Northerly wind flows have a small strengthening along the coast from Obrestad to Sogn. The pressure pattern does not favour strong leading effects in these cases.

2.3 SUMMARY OF ESTIMATED REPRESENTATIVITY (Mean Wind Flow)

The recordings/estimated extreme wind flows at Utsira are representative of the conditions 10m above free sea level close to Utsira. The representativity to the coast line Obrestad-Sogn is considered to be good. There are, however, some pattern in the deviations, see table 2.1.

Wind flow in the sector west to north as well as southeast recorded at Utsira is slightly overestimated compared to the wind flow recorded 10m above free sea level nearby.

Northeasterly to easterly wind flows are on the contrary slightly underestimated. The deviation is probably within 5-10%.

Wind flow over free water close to Utsira in the northeasterly sector will mostly not be strong. The conditions are nearly the same along the coast line Obrestad-Sogn. Easterly, southeasterly, westerly and northwesterly wind flows are somewhat stronger south of Utsira, while southerly and southwesterly wind flows are somewhat stronger further north.

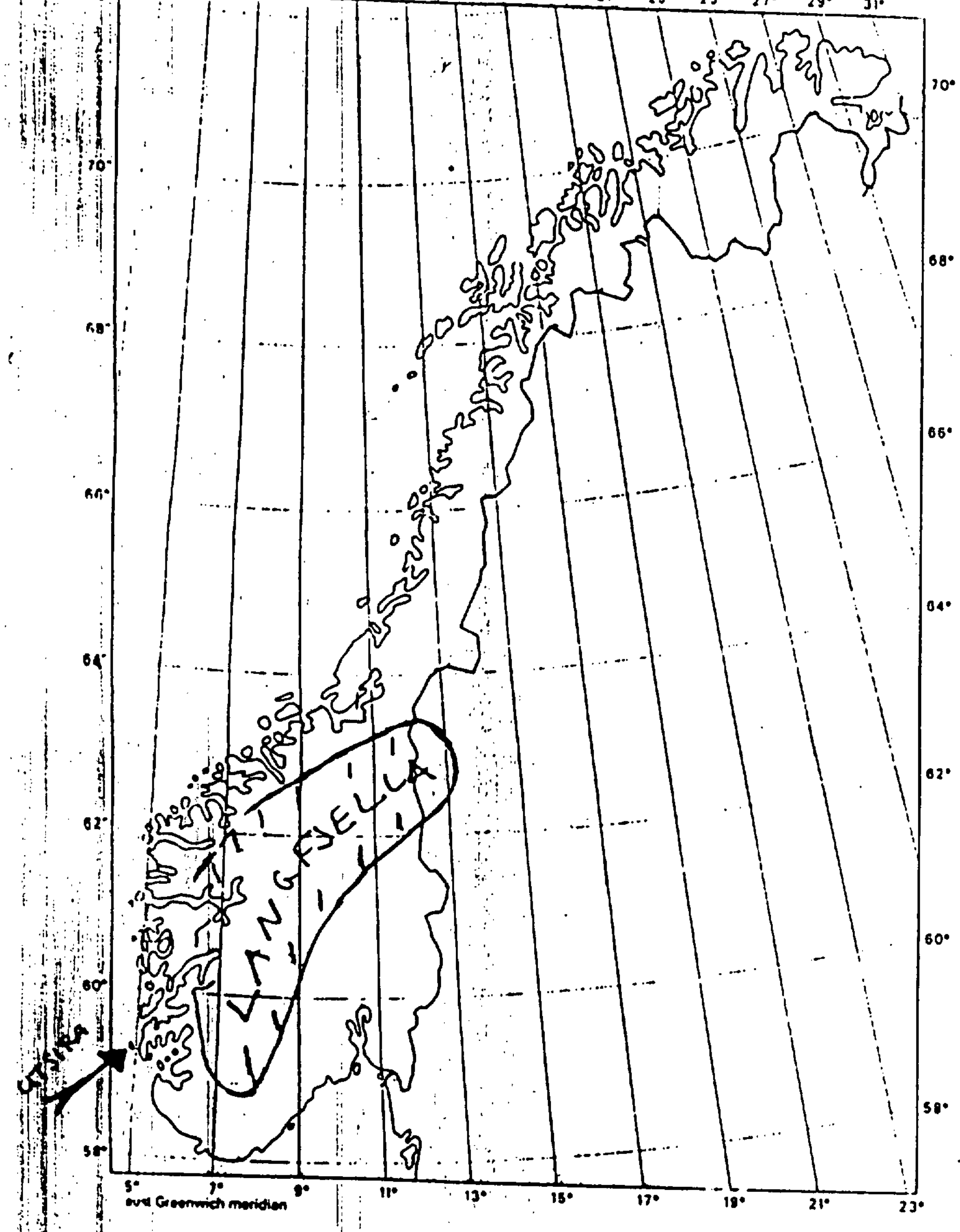
Since southeasterly, westerly and northwesterly wind flows are somewhat strengthened at Utsira compared to the free sea conditions, and southerly to southwesterly wind flow are correspondingly weakened, this indicates that the representativity is good for the coast line Obrestad-Sogn. The southeasterly, westerly and northwesterly wind flows at the coast line Utsira-Sogn are some weaker than recorded/estimated at Utsira, while southerly to southwesterly wind flows are stronger. Wind flows from north to northeast at Utsira are estimated as approximately representative for the coast line (north; slightly overestimated, south; slightly underestimated).

The wind gusts are supposed to have the same strength at Utsira as over free sea surrounding Utsira, with the exception of a certain strengthening of southeasterly, westerly and northwesterly wind gusts. These wind gusts are most representative for the southern part of the coast line.

Table 2.1

Estimated representativity of 10 min. mean wind flows recorded at Utsira. Under the column "Local Scale" the effects of Utsira in terms of strengthening (+) or weakening (-) are stated. The representative area in the last column concerns wind flows 10m above free sea level in approximately same distance offshore as Utsira.

	Local Scale	Regional Scale	Representative area for wind flows recorded at Utsira
N	+	Constant (strong)	Obrestad-Sogn (some strengthened)
NE	-	" (weak)	Obrestad-Sogn (some too weak)
E	-	Some increase south	Utsira-Sogn
SE	+	Some increase south	Obrestad-Sogn
S	-	Some increase north	Obrestad-Sogn
SW	-	Some increase north	Obrestad-Sogn
W	+	Some increase south	Obrestad-Sogn
NW	+	Some increase south	Obrestad-Sogn



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NASJONALATLAS FOR NORGE
HOVEDTEMA 1: KARTGRUNNLAG OG OVERSIKTSKART
EMNE 1.1: BASISKARTEKSEMPLER

BASE MAP NORWAY 1:10 000 000

NATIONAL ATLAS OF NORWAY
CATEGORY 1: BASE MAP AND BASIC INFORMATION
SECTION 1.1: BASE MAP EXAMPLES

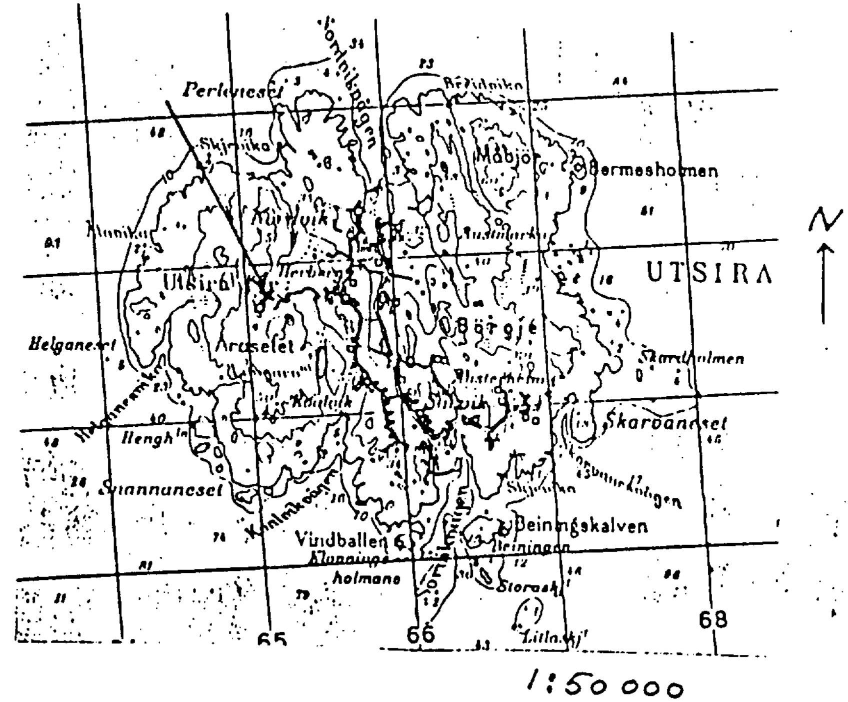

Fig. 2.1. Map of Utsira.

3 DATA BASIS

At Utsira there has been continuous wind records since 1924, except from a shorter period during World War II. These paper diagrams are not conventionally prepared for EDB use. Our data storage on EDB basis contains data from Utsira at the hours 01, 07, 13 and 19 (local time) back to 1951. Between the hours of observation there are values of maximum wind force.

Due to defects in the anemometer system wind data before 1962 are of small use for extreme value analysis.

From July 8, 1962 until August 31, 1978 the instantaneous wind has been recorded by means of a pressure tube anemometer and the mean wind speed by an integrating exit from a cup anemometer (Fuess 82a). The wind direction is recorded by means of a wind vane. See figure 3.1.

From August 31, 1978 until present the weather station at Utsira has been equipped with Fuess 90z, which shows the instantaneous wind speed (3-5 sec. gust wind) and 10 minutes mean wind speed on an easy readable form. This instrument also shows instantaneous values of the wind direction. See figure 3.2.

In the data storage there was a change in the wind data at the end of 1981. From January 1, 1982 the maximum 10 minutes mean wind speed values are stored as knots as distinct from the previously Beaufort-values. Maximum wind gusts (in knots) are stored from the same point of time.

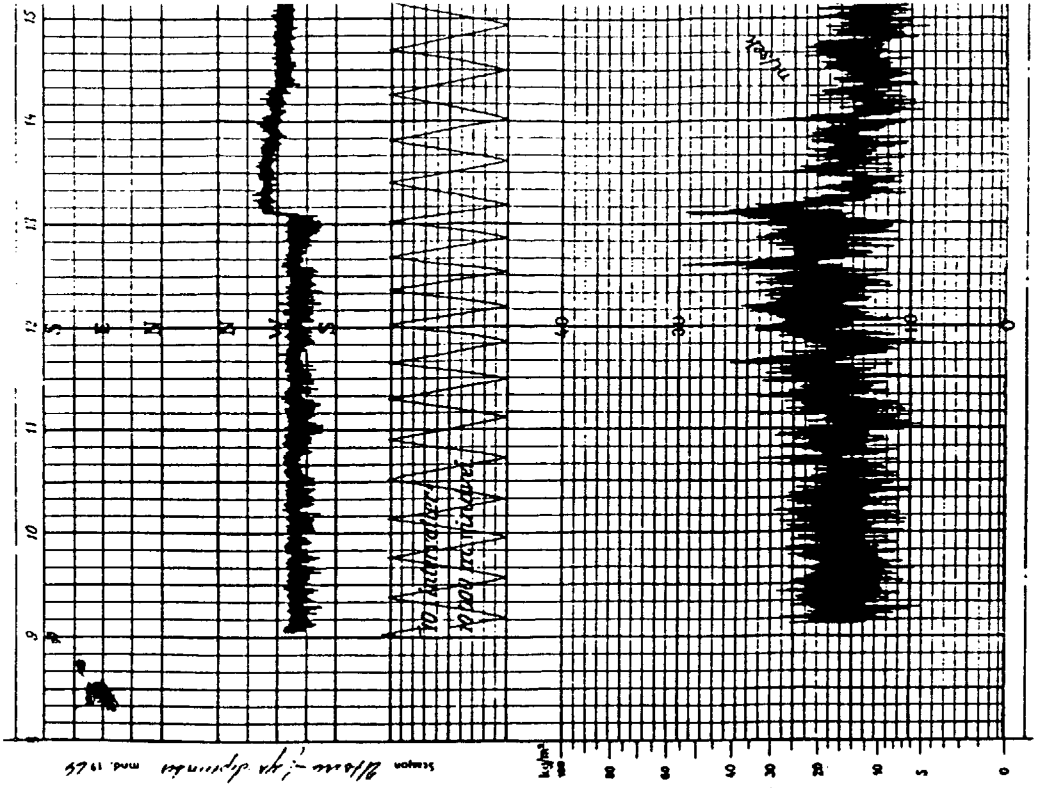

Figure 3.1. Type of anemogram used at Utsira before 1978.

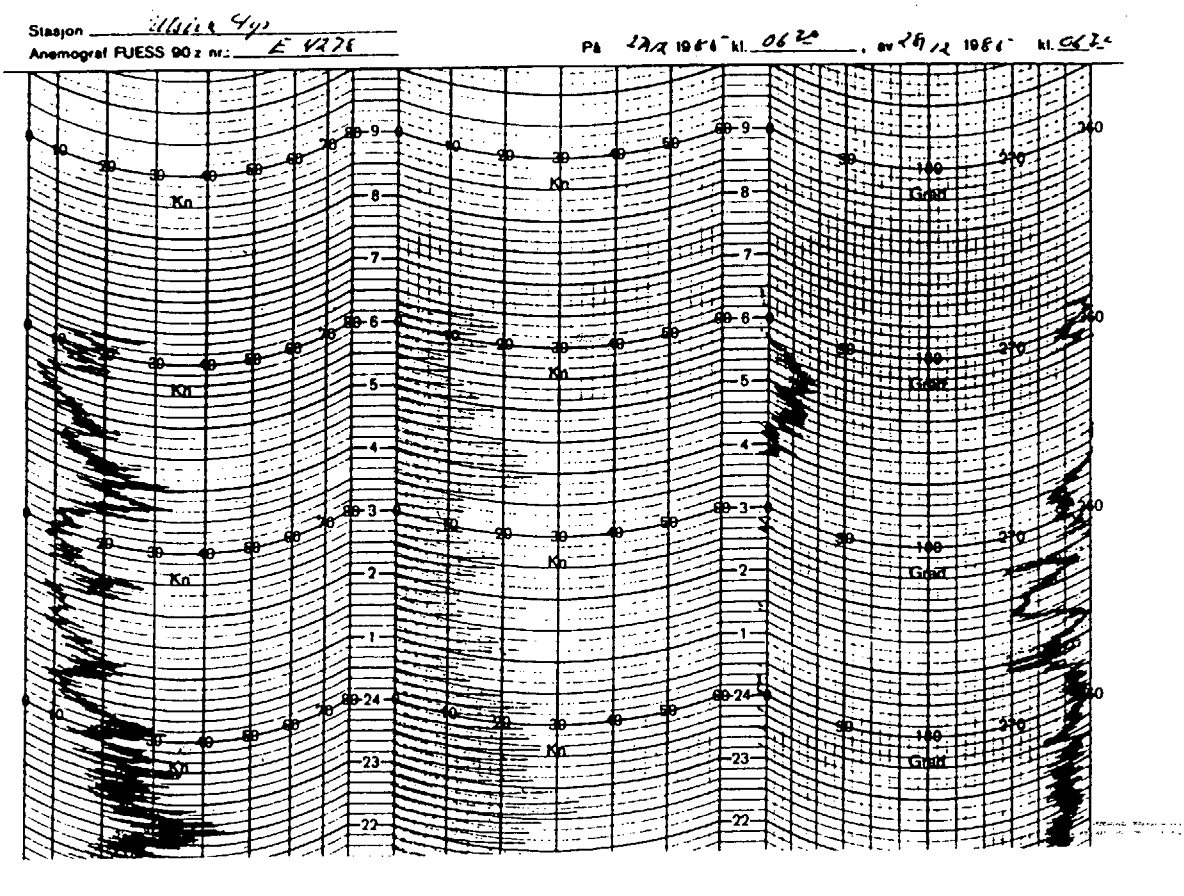

Figure 3.2. Type of air anemogram used at Utsira from 1978 on.

3.1 HOMOGENEITY CONSIDERATIONS OF THE DATASERIES

It is important that the data set which is used for extreme value computations, is homogeneous. At least 20 years of data records are necessary to give statements of extreme winds with return periods up to 50 years. If some break in the homogeneity or a gradually change of the values has occured (assumed unchanged climate), this will affect the results negatively.

Considering homogeneity we use graphic representation of the monthly or annual mean wind force for the period 1957-1985. The station which is considered, is compared with a reference station (with approximately homogeneous data series).

Concerning stations with wind instruments Sola and Flesland are nearest Utsira, and therefore selected as possible reference stations. Both stations have had the same type of instrument (Fuess 90z) since 1958 and 1956 respectively. The anemometer at Sola has not been moved since 1952, except a minor movement in 1969 (10-12 m). At Flesland the anemometer was moved 1500 m towards NNE, September 4, 1979, from the west side of the runway to the east side of its nothern end.

Utsira lies between Sola and Flesland (nearest Sola), but outside the coast line. The wind conditions at Sola and Flesland in the summer season are affected by the sea-breeze circulation, as distinct to Utsira. In the winter season the pressure gradients are relatively strong (the distance between the isobars is relatively small), the winds are stronger and there is no influence of a local circulation system caused by radiation. That is the reason for letting December/January represent the stations in the considerations of homogeneity.

Figure 3.3 gives a graphical view of the mean wind force for December/January from 1957 to 1985 for Utsira, Sola and Flesland. In addition we have used Bergen-Florida, which probably has homogeneous data for the whole period (same type of instruments, no movements).

Perhaps apart from 1962/63 - 1963/64 the mean wind force at Sola and Flesland correspond very well in the period 1957/58 - 1968/69. From 1969/70 up to the present the Flesland values are a little below the values of Sola, particularly after 1978/79.

The values from Bergen-Florida correspond to the Flesland values up to 1978/79 (except 71/72 - 73/74 - 77/78), but then there is a change. The difference between the two stations in the region of Bergen then decreases. This is caused by the movement of the wind instruments at Flesland. The new site in the northern part of the runway area is obviously less exposed than the previous site. This is reasonable, looking at the distribution of the wind directions at Flesland, compared with the terrain conditions.

Sola then clearly points out to be chosen as the reference station when considering the Utsira data.

3.2 GENERAL CONSIDERATION OF THE MEAN WIND DATA FROM UTSIRA

Figure 3.3 shows that the main break in the data series of Utsira is between January and December 1962. The other monthly data (not shown here) indicate that the break in the data set occours at the same time as the change of anemometer in July 1962. Before that Utsira has had a "wind climate" comparable with that of Sola. After the change of instrument the wind values was adjusted to a apparent reasonable level.

There was a new change of anemometer August 31, 1978, which led to a similar break in the data set. The difference between Utsira and Sola became greater than before.

On the average we can assume that Utsira has had about 2 Beaufort too weak winds before the break in 1962 and 0.5-1 Beaufort too weak winds up to the break in 1978.

The cause of the last break is not due to the change of instrument only. As mentioned earlier the anemometer before 1978 was Fuess 82a. This shows the instantaneous wind by means of the pressure-tube principle, while the mean wind speed is recorded by means of a cup anemometer. We often see that the mean instantaneous wind speed after a while shows lower value than the mean wind record itself. Practically, the mean wind speed was not taken from the mean wind record. Rather it was an estimate based on a look at the instantaneous wind speed indicator. This will always be an uncertain value of the mean wind speed.

We must, however, assume that the main cause that too low mean wind speeds are observed at Utsira is due to the use of the pressure-tube anemometer in observation of the mean wind speed. Because of the lower values from this instrument the break in 1978 will lessen, perhaps disappear, if we use the values from the cup anemometer records for the period 1962-78.

After 1978 there has not been any problems concerning 10 minutes wind speed, as a Fuess 90z has a much simpler diagram to read (fig. 3.2).

4 *METHOD FOR CALCULATION OF EXTREME WIND SPEEDS*

To make a reliable extreme wind analysis we must have homogeneous data. As shown, this is not the case as far as the stored data of Utsira are concerned. More accurate values than given by the Beaufort values are also required. By reading the maximum 10 minutes wind speed from the anemograms we obtain the data required.

4.1 PROCEDURE FOR READING THE ANEMOGRAMS

We have chosen to divide the year into two parts, the winter season (Sept.-Apr.) and the summer season (May-Aug.). This unequal way of dividing the year is due to the quick change of the frequency of storms from August to September and correspondingly from April to May . If September and April should be counted for in the summer season, the wind extremes would by preference represent September and April, not the summer months.

Further the extreme values are placed into 8 sectors: N, NE, E, SE, S, SW, W and NW. We have used the data storage to locate the weather situations with strong winds and then examined the anemograms.

The maximum 10 minutes mean is read from the integrating wind speed anemogram (cup anemometer) by counting the number of kilometres or halfkilometres during 10 minutes. The corresponding (same 10 minutes interval) mean wind speed is estimated from the instantaneous wind speed anemogram (pressure-tube anemometer). Then the maximum gust speed and the corresponding mean wind speed are read from the last mentioned anemogram.

The first season with this type of instrument is September 1962- April 1963, and the last is May-August 1978. Since September 1978 Utsira has had Fuess 90z - anemograms (see figure 3.3). From these diagrams are read directly the maximum 10-minutes mean wind (to the nearest knot) and the gust speed (and the corresponding mean wind speed from the mean wind part of the diagram).

For some years a maximum wind speed as strong as 10 m/s has not been found in some sectors. This is of no practical importance.

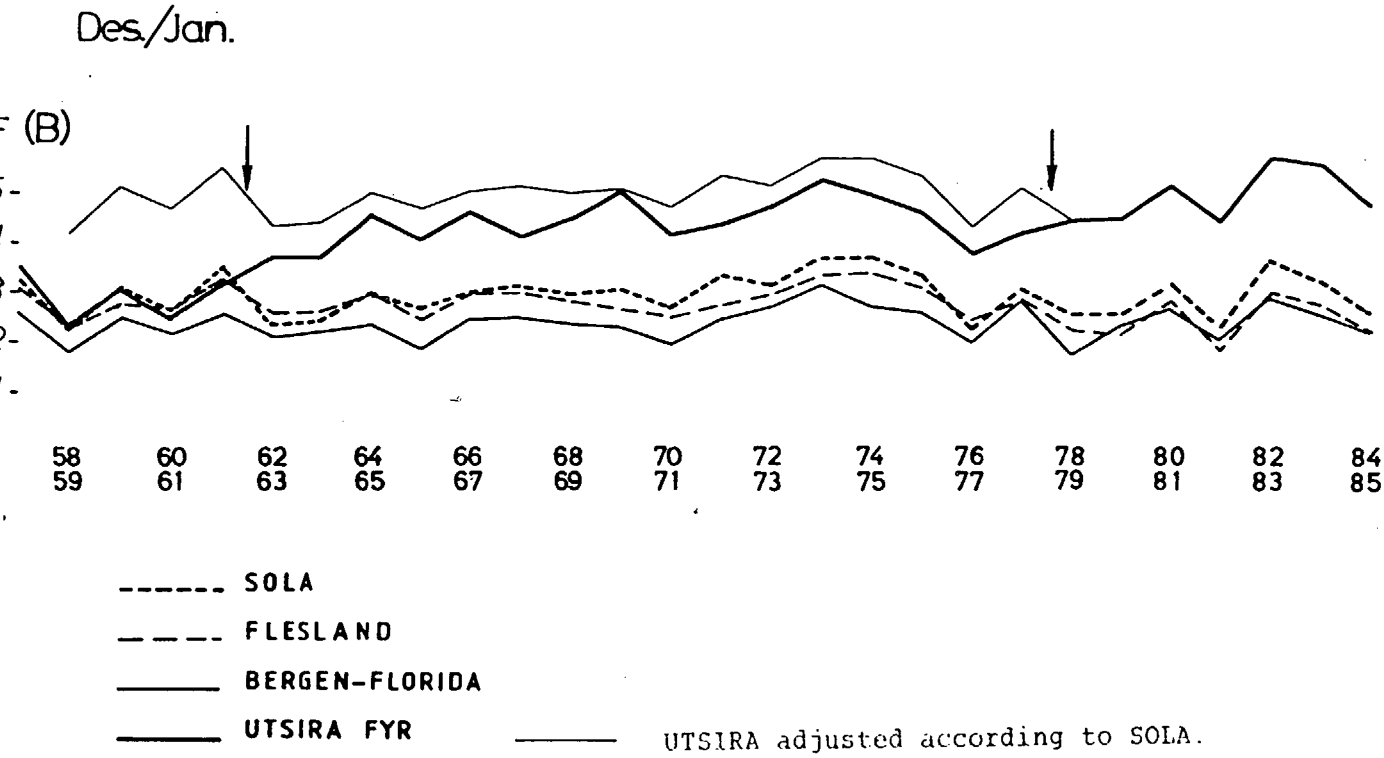

FIGURE 3.3 Variations of the mean wind force (Beaufort) for selected stations in December/January, year by year in the period 1957-85. The upper thin solid line is a corrected Utsira-value, based on a 2.0 Beaufort value difference between Utsira and Sola.

4.2 THE MEAN WIND EXTREMES

By comparing the 10 minutes mean from the cup and pressure-tube anemometer, it appears that the cup anemometer during long periods shows higher values than the pressure-tube anemometer. This is not surprising, because the Instrument Division of the NMI has experienced that the fluid level in the pressure-tube system is difficult to maintain stable for a longer time. The two recording systems have opposite sign in the period Sept. 1968 - Apr. 1970, which is possibly due to wrong calibration of the pressure-tube anemometer. Otherwise everything indicates that the cup anemometer values are correct for the whole period, and that the pressure-tube values have to be corrected.

Computations of extreme mean wind speeds are based on the read values from the cup anemometer diagrams. The two summer seasons when the cup anemometer has been out of function (1968 and 1972) the values are corrected by means of the regression equations given in table 4.1.

4.3 CORRECTIONS OF THE GUST SPEED EXTREMES

Extensive corrections have to be made for computation of gust speed extremes, because the instantaneous wind speeds are read from the pressure-tube diagram.

We have chosen to divide the period Sept. 1962 - Aug. 1985 into 8 groups. This is done roughly by examination of the read values previously mentioned. For each period a scattering diagram is made for the mean wind values from the pressure-tube and cup anemometer respectively. Regression lines are drawn in the diagram. The result is a displacement of origo, which is due to a change in the fluid level of the pressure-tube system.

By means of the regression equations based on the mean wind data, the necessary corrections of gust speeds are made. The regression equations used are shown in table 4.1.

I	Sept. 62 - Aug. 68	y = x + 1.0	N = 81
II	" 68 - " 70	y = x - 1.5	N = 24
III	May 70 - " 74	y = x + 1.5	N = 60
IV	Sept. 74 - " 75	y = x + 2.0	N = 14
V	" 75 - " 77	y = x + 3.0	N = 26
VI	" 77 - Apr. 78	y = x + 4.0	N = 8
VII	May 78 - Aug. 78	y = x + 6.5	N = 4
VIII	Sept. 78 -	No correction necessary	

TABLE 4.1 Regression equations based on largest value in 8 sectors and 2 seasons every year in the period (summer: May - Aug., winter: Sept. - Apr.). Y and X are the values from the cup and pressure tube anemometer respectively. N is the number of observations in each period.

The equations above show that there has been a displacement in the instantaneous wind speed since the change of instrument in Sept. 1968. The pressure-tube anemometer was perhaps calibrated too high, because one was aware of the low stability of the instrument. (There was also a change of instrument in Oct. 1972, but it does not look like anything was done with the pressure-system, except for the anemometer).

From September 1978, as mentioned, there is only used cup anemometers at Utsira, with another type of anemogram. Some spot tests taken proved accordance between mean wind and instantaneous wind. Corrections are not found necessary in this period.

With the corrections mentioned above, the data records of gust speed extremes are assumed nearly homogeneous.

4.4 THE DATA SET

The homogenized time series for mean wind and gust are listed in table 4.2 and 4.3 for the period September 1, 1962 - August 31, 1985. Hence we have 23 years data of the highest wind speed for 8 directions for both the winter season and the following summer.

The highest values regardless direction are listed in the last two columns for the winter and summer seasons respectively. Note that the value 0.0 in the tables means that the 10 min. mean wind did not exceed 10 m/s for that season. As the number of cases which have to be controlled increases rapidly with lower wind speeds, the reduced importance of these values did not justify the great amount of work.

On the May 21, 1979 there was recorded one case with stronger mean wind than the preceeding winter season. For the rest, all winter extremes are higher than the summer extremes.

The tables 4.4 and 4.5 show the same data sets sorted in decreasing order.

4.5 CALCULATION OF EXTREMES

Gumbel's 1. distribution of the extremes (3) is the most recognized method for calculation of the extreme probability with long return periods. Any mathematical method should hardly be used for longer return periods than twice the length of the data set, but in the absence of better alternatives the distribution is used up to 100 years, or four times the length of the data sets.

The probability P (Vo) that the wind speed some arbitrary year should be less than or equal to Vo, is given by the expression:

$$P(Vo) = \exp(-\exp(-\alpha(Vo-\mu))) \quad (1)$$

Where α and μ are the standard deviation and the mean value, respectively, of the theoretical probability distribution and are functions of the length of the time series, as well as the statistical properties of the data.

The probability that the value should be exceeded some arbitrary year is then 1 - P (Vo) and the average return period T for the exceedance is the inverse value

$$T = \frac{1}{1-P(Vo)} \quad (2)$$

This method is used to calculate the winter and summer extremes regardless direction for return periods of 10 years or more.

The Gumbel extreme value distribution is relative sensitive to scattering in the dataset. For instance, two data sets with the same mean value, the set with the higher standard deviation will obtain the largest extreme value for long return periods. This is logical and correct, but if the method is applied on too limited subsets of the data, for instance the data from one single wind sector, higher 50 years values for this sector alone than the "all direction" value may be found. This is not logical, and hence the method should not be used for sectors where the wind speeds generally are low but occasionally are relatively high.

To find the extremes of each direction, a weighting method based on the mean value of the five highest values within each sector is chosen. These mean values are divided by the mean value of the "strongest" sector. The quotients thus obtained are then used as reduction factors and applied on the "all direction" values. Hence, the "all direction" value is connected with the sector which has the strongest winds.

The mean values and the reduction factors are stated in the tables 4.4 and 4.5.

The extreme values for the 2 and 5 year return period are for all cases indentical with the 50 and 20 percentiles of the data set.

The extreme values which are found by these methods, are listed in tables 4.6 and 4.7.

The tables show that the all-direction extremes are somewhat higher than the highest of each sector value for 2 and 5 years return period. This is logical as it is likely that the seasonal extremes in these cases may occur from more than one sector. The value of the season's extreme then represent a longer return period for each of these sectors alone.

The high summer extreme values for long return periods are caused by the fact that the summer extreme values have a high standard deviation. As a rule the winds will be weak during these months, which is reflected in the short return periods. Some rare cases with strong winds (as in 1979) contribute to high longtime extremes.

5 SUMMARY AND CONCLUSION

An analysis of extreme wind speeds at Utsira is carried out, based on 23 years of registrations of 10 min. mean wind speeds and wind gusts. A homogeneity examination has shown that the mean wind speeds are approximately homogeneous in this period while wind gusts up to 1978 are adjusted in accordance to the difference in the two sensor systems: Cup anemometer (mean wind speed) and pressure-tube (wind gust). It is assumed that the corrected wind gusts then are approximately homogeneous and that the data sets are the best obtainable for this station.

The extreme values for 8 main directions for the winter season September - April and the summer season May - August are registrated.

The extreme values with return period 2 - 5 years are set equal to the 50 - and 20 percentiles respectively, in the data sets.

For longer return periods Gumbel's 1. distribution is used for the all-direction season extremes, while the directional extremes are weighted relatively to the strongest sector.

The calculated extremes for mean wind speeds and wind gusts are acknowledged as reasonable, compared to other calculations and compared to the general knowledge of wind conditions in the actual area.

The results are also acknowledged as reasonably representative to the sea close to the coast line Obrestad - Sogn.

The representativity varies somewhat depending on the direction of the wind and the distance from Utsira.

Table 4.2.
10 min. mean wind extremes for 8 directions and 2 seasons at Utsira.

	SEPTEMBER - APRIL								MAY - AUGUST									
YR1-YR2	N	NE	E	SE	S	SW	W	NW	N	NE	E	SE	S	SW	W	NW	MAX-WINT	MAX-SUMM
1962-1963	21.0	16.5	15.8	25.8	24.5	25.5	26.7	19.0	13.3	11.0	0.0	21.0	21.0	11.0	16.0	18.7	26.7	21.0
1963-1964	25.0	19.3	18.5	20.3	25.5	28.5	27.5	23.5	15.0	0.0	14.0	17.5	16.5	21.0	22.5	21.5	28.5	22.5
1964-1965	29.0	13.3	14.5	28.3	26.0	19.0	29.5	15.0	16.7	16.7	18.3	17.0	16.0	15.5	14.0	17.5	29.5	18.3
1965-1966	23.3	18.5	20.0	22.5	20.0	20.0	26.0	23.0	19.0	10.0	18.3	18.3	21.0	13.3	0.0	23.0	26.0	23.0
1966-1967	19.5	22.5	16.0	25.0	27.5	25.0	22.5	22.5	15.5	0.0	15.8	16.0	17.5	21.5	15.5	14.0	27.5	21.5
1967-1968	31.0	18.5	14.0	25.0	23.0	19.0	26.7	27.0	16.0	0.0	11.5	14.5	19.0	13.5	15.0	13.5	31.0	19.0
1968-1969	23.3	13.0	17.0	23.5	23.5	20.5	20.5	19.5	20.0	9.5	11.5	16.0	17.5	13.3	14.5	17.5	23.5	20.0
1969-1970	30.0	20.0	20.0	25.0	25.5	22.5	30.0	33.0	20.0	0.0	18.3	16.5	19.3	15.0	18.3	22.5	33.0	22.5
1970-1971	26.7	12.5	22.5	27.5	22.0	23.3	24.0	26.7	16.7	13.0	14.5	15.0	16.7	15.5	14.0	21.0	27.5	21.0
1971-1972	17.5	16.7	22.5	26.7	21.7	27.0	29.0	23.5	16.5	0.0	0.0	16.5	14.0	0.0	0.0	0.0	29.0	16.5
1972-1973	21.7	15.0	11.7	19.0	26.0	25.0	29.0	21.0	19.0	0.0	11.7	15.7	22.5	26.0	27.5	17.8	29.0	27.5
1973-1974	31.5	17.5	19.0	30.0	23.3	21.0	22.5	27.5	17.0	0.0	0.0	15.0	20.0	13.5	14.0	13.0	31.5	20.0
1974-1975	23.3	14.0	12.5	25.0	26.7	23.3	25.0	30.0	22.0	0.0	0.0	13.3	16.5	14.0	12.5	21.0	30.0	22.0
1975-1976	29.0	17.5	13.0	23.3	24.0	23.5	26.5	30.0	19.0	0.0	0.0	15.0	18.3	0.0	19.0	20.0	30.0	20.0
1976-1977	23.5	17.0	18.3	31.5	23.3	16.7	20.0	20.0	21.0	14.0	0.0	13.0	14.0	0.0	0.0	14.5	31.5	21.0
1977-1978	20.0	17.0	19.0	24.5	23.0	19.0	26.0	28.3	18.3	0.0	0.0	0.0	16.5	0.0	16.0	16.0	28.3	18.3
1978-1979	21.6	17.0	15.4	19.3	25.5	25.7	28.0	24.4	20.1	0.0	12.6	21.6	30.9	18.5	16.5	16.7	28.0	30.9
1979-1980	24.4	11.1	21.1	27.8	28.6	25.2	21.9	31.6	24.2	0.0	15.9	11.8	18.5	11.1	18.5	18.3	31.6	24.2
1980-1981	27.5	16.2	15.9	20.6	26.8	19.5	29.3	31.9	18.5	0.0	16.5	15.4	17.7	12.3	19.3	12.9	31.9	19.3
1981-1982	28.6	12.9	19.5	27.8	26.5	19.3	21.6	32.4	16.7	18.8	15.2	21.3	17.2	21.6	22.9	18.0	32.4	22.9
1982-1983	14.1	22.1	24.4	27.3	27.3	27.0	23.9	28.6	16.2	0.0	15.9	18.3	14.4	14.1	11.3	14.1	28.6	18.3
1983-1984	23.7	18.8	19.5	30.6	24.7	27.3	30.9	27.8	21.1	0.0	0.0	0.0	11.1	0.0	0.0	15.2	30.9	21.1
1984-1985	25.7	18.5	12.3	22.6	23.7	23.7	21.6	20.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.7	0.0
NUMBER OF YEARS :	23	23	23	23	23	23	23	23	22	7	14	20	22	17	18	21	23	22
MEAN :	24.4	16.7	17.5	25.2	24.7	22.9	25.6	25.5	18.3	13.3	15.0	16.4	18.0	15.9	17.1	17.5	29.2	21.4
STANDARD DEVIATION:	4.43	2.95	3.55	3.48	2.11	3.31	3.31	4.96	2.58	3.49	2.47	2.66	3.89	4.27	4.08	3.18	2.39	3.18

Table 4.3.
3-5 s wind gust extremes for 8 directions and 2 seasons at Utsira.

	SEPTEMBER - APRIL								MAY - AUGUST									
YR1-YR2	N	NE	E	SE	S	SW	W	NW	N	NE	E	SE	S	SW	W	NW	MAX-WINT	MAX-SUMM
1962-1963	30.2	22.8	21.4	39.1	34.0	33.2	37.5	29.0	18.3	15.7	0.0	32.8	28.0	16.2	24.2	25.0	39.1	32.8
1963-1964	41.5	24.2	27.8	31.4	37.2	41.5	39.1	35.6	19.7	0.0	20.2	26.0	23.5	29.9	31.0	28.0	41.5	31.0
1964-1965	35.1	18.9	20.0	40.0	36.3	28.0	37.3	21.9	23.0	18.6	21.5	24.2	21.7	21.5	23.1	26.8	40.0	26.8
1965-1966	33.8	30.0	29.4	36.0	27.5	28.0	38.0	32.3	26.4	14.7	24.5	26.5	30.9	17.3	0.0	30.8	38.0	30.9
1966-1967	31.6	33.9	24.0	35.9	40.4	34.6	36.9	34.3	20.1	0.0	22.0	24.0	24.6	29.3	23.0	19.5	40.4	29.3
1967-1968	41.5	25.2	21.1	36.0	32.8	24.1	40.5	36.9	22.0	0.0	15.7	20.1	27.7	18.6	19.5	19.7	41.5	27.7
1968-1969	37.2	18.5	26.5	35.8	36.5	30.4	30.1	27.5	24.5	11.8	17.0	19.3	23.1	20.4	15.8	24.4	37.2	24.5
1969-1970	39.8	29.8	27.7	37.7	35.6	31.0	42.5	45.5	28.9	0.0	23.1	25.8	29.3	22.9	26.7	33.2	45.5	33.2
1970-1971	35.7	17.7	31.7	39.0	30.0	32.2	34.5	37.7	19.9	15.3	18.8	19.6	20.9	19.5	18.7	27.8	39.0	27.8
1971-1972	27.5	24.3	33.2	34.5	26.5	39.8	35.5	30.0	21.6	0.0	0.0	24.2	20.0	0.0	0.0	0.0	39.8	24.2
1972-1973	32.7	20.5	17.0	30.7	35.2	35.0	41.5	28.4	24.7	0.0	15.3	17.2	34.5	36.9	33.2	23.2	41.5	36.9
1973-1974	41.1	21.5	27.2	41.5	30.5	30.5	33.9	38.8	22.4	0.0	0.0	17.9	28.4	18.0	19.4	17.7	41.5	28.4
1974-1975	32.5	18.0	16.0	36.0	35.7	30.5	36.0	43.3	28.0	0.0	0.0	18.4	23.0	17.0	15.5	26.0	43.3	28.0
1975-1976	43.1	23.1	18.9	34.2	32.9	31.3	36.6	39.3	25.5	0.0	0.0	20.5	25.8	0.0	25.4	28.3	43.1	28.3
1976-1977	33.0	21.5	25.3	37.1	36.4	23.0	29.3	35.0	24.4	17.9	0.0	18.5	19.1	0.0	0.0	18.7	37.1	24.4
1977-1978	26.3	22.0	27.4	35.0	33.1	24.2	34.8	36.1	22.8	0.0	0.0	0.0	21.7	0.0	21.5	23.7	36.1	23.7
1978-1979	26.5	19.3	19.3	27.5	32.7	32.4	35.5	29.8	24.7	0.0	13.9	29.3	30.9	24.4	20.8	20.8	35.5	30.9
1979-1980	31.4	12.6	28.3	37.0	35.5	30.9	31.6	39.1	26.8	0.0	19.3	15.2	23.7	14.7	24.2	24.2	39.1	26.8
1980-1981	34.2	19.5	21.1	28.3	30.9	23.4	36.8	39.1	23.2	0.0	21.1	19.5	22.4	13.4	23.9	14.1	39.1	23.9
1981-1982	33.2	14.4	24.4	33.7	32.4	25.0	27.3	42.2	20.1	16.5	20.6	29.3	22.6	26.5	28.8	25.2	42.2	29.3
1982-1983	17.7	30.9	31.9	36.0	38.1	35.0	32.4	35.0	21.1	0.0	22.4	24.4	18.0	16.7	20.6	16.5	38.1	24.4
1983-1984	34.2	22.9	25.2	31.4	32.4	35.0	38.6	33.4	25.5	0.0	0.0	0.0	13.4	0.0	0.0	19.3	38.6	25.5
1984-1985	30.4	24.7	14.5	30.9	29.8	29.8	28.3	26.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.9	0.0
NUMBER OF YEARS :	23	23	23	23	23	23	23	23	22	7	14	20	22	17	18	21	23	22
MEAN :	33.5	22.4	24.4	35.0	33.6	30.8	35.4	34.7	23.3	15.8	19.7	22.6	24.2	21.4	23.1	23.5	39.5	28.1
STANDARD DEVIATION:	5.86	5.18	5.08	3.61	3.40	4.90	4.08	5.82	2.86	2.24	3.17	4.71	4.88	6.23	4.79	4.91	3.06	3.49

Table 4.4.
10 min. mean wind extremes for 8 directions and 2 seasons at Utsira.
sorted in decreasing order.

	SEPTEMBER - APRIL								MAY - AUGUST									
	N	NE	E	SE	S	SW	W	NW	N	NE	E	SE	S	SW	W	NW	MAX-WINT	MAX-SUMM
1	31.5	22.5	24.4	31.5	28.6	28.5	30.9	33.0	24.2	18.8	18.3	21.6	30.9	26.0	27.5	23.0	33.0	30.9
2	31.0	22.1	22.5	30.6	27.5	27.3	30.0	32.4	22.0	16.7	18.3	21.3	22.5	21.6	22.9	22.5	32.4	27.5
3	30.0	20.0	22.5	30.0	27.3	27.0	29.5	31.9	21.1	14.0	18.3	21.0	21.0	21.5	22.5	21.5	31.9	24.2
4	29.0	18.8	21.1	28.3	26.8	27.0	29.3	31.6	21.0	13.0	16.5	18.3	21.0	21.0	19.3	21.0	31.6	23.0
5	29.0	18.5	20.0	27.8	26.7	25.7	29.0	30.0	20.1	11.0	15.9	18.3	20.0	18.5	19.0	21.0	31.5	22.9
6	28.6	18.5	20.0	27.8	26.5	25.5	29.0	30.0	20.0	10.0	15.9	17.5	19.3	15.5	18.5	20.0	31.5	22.5
7	27.5	18.5	19.5	27.5	26.0	25.2	28.0	28.6	20.0	9.5	15.8	17.0	19.0	15.5	18.3	18.7	31.0	22.5
8	26.7	18.3	19.5	27.3	26.0	25.0	27.5	28.3	19.0	0.0	15.2	16.5	18.5	15.0	16.5	18.3	30.9	22.0
9	25.7	17.5	19.0	26.7	25.5	25.0	26.7	27.8	19.0	0.0	14.5	16.5	18.3	14.1	16.0	18.0	30.0	21.5
10	25.0	17.5	19.0	25.8	25.5	23.7	26.7	27.5	19.0	0.0	14.0	16.0	17.7	14.0	16.0	17.8	30.0	21.1
11	24.4	17.0	18.5	25.0	25.5	23.5	26.5	27.0	18.5	0.0	12.6	16.0	17.5	13.5	15.5	17.5	29.5	21.0
12	23.7	17.0	18.3	25.0	24.7	23.3	26.0	26.7	18.3	0.0	11.7	15.7	17.5	13.5	15.0	17.5	29.0	21.0
13	23.5	17.0	17.0	25.0	24.5	23.3	26.0	24.4	17.0	0.0	11.5	15.4	17.2	13.3	14.5	16.7	29.0	21.0
14	23.3	16.7	16.0	25.0	24.0	22.5	25.0	23.5	16.7	0.0	11.5	15.0	16.7	13.3	14.0	16.0	28.6	20.0
15	23.3	16.5	15.9	24.5	23.7	21.0	24.0	23.5	16.7	0.0	0.0	15.0	16.5	12.3	14.0	15.2	28.5	20.0
16	23.3	16.2	15.8	23.5	23.5	20.5	23.9	23.0	16.7	0.0	0.0	15.0	16.5	11.1	14.0	14.5	28.3	20.0
17	21.7	15.0	15.4	23.3	23.3	20.0	22.5	22.5	16.5	0.0	0.0	14.5	16.5	11.0	12.5	14.1	28.0	19.3
18	21.6	14.0	14.5	22.6	23.3	19.5	22.5	21.0	16.2	0.0	0.0	13.3	16.0	0.0	11.3	14.0	27.5	19.0
19	21.0	13.3	14.0	22.5	23.0	19.3	21.9	20.6	16.0	0.0	0.0	13.0	14.4	0.0	0.0	13.5	27.5	18.3
20	20.0	13.0	13.0	20.6	23.0	19.0	21.6	20.0	15.5	0.0	0.0	11.8	14.0	0.0	0.0	13.0	26.7	18.3
21	19.5	12.9	12.5	20.3	22.0	19.0	21.6	19.5	15.0	0.0	0.0	0.0	14.0	0.0	0.0	12.9	26.0	18.3
22	17.5	12.5	12.3	19.3	21.7	19.0	20.5	19.0	13.3	0.0	0.0	0.0	11.1	0.0	0.0	0.0	25.7	16.5
23	14.1	11.1	11.7	19.0	20.0	16.7	20.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.5	0.0

MEAN OF THE 5 HIGHEST VALUES :

30.1 20.4 22.1 29.6 27.4 27.1 29.7 31.8   21.7 14.7 17.5 20.1 23.1 21.7 22.2 21.8

IN RELATION TO STRONGEST SECTOR :

0.95 0.64 0.70 0.93 0.86 0.85 0.94 1.00   0.94 0.64 0.76 0.87 1.00 0.94 0.96 0.94

Table 4.5.
3-5 s wind gust extremes for 8 directions and 2 seasons at Utsira, sorted in decreasing order.

	SEPTEMBER - APRIL								MAY - AUGUST									
	N	NE	E	SE	S	SW	W	NW	N	NE	E	SE	S	SW	W	NW	MAX-WINT	MAX-SUMM
1	43.1	33.9	33.2	41.5	40.4	41.5	42.5	45.5	28.9	18.6	24.5	32.8	34.5	36.9	33.2	33.2	45.5	36.9
2	41.5	30.9	31.9	40.0	38.1	39.8	41.5	43.3	28.0	17.9	23.1	29.3	30.9	29.9	31.0	30.8	43.3	33.2
3	41.5	30.0	31.7	39.1	37.2	35.0	40.5	42.2	26.8	16.5	22.4	29.3	30.9	29.3	28.8	28.3	43.1	32.8
4	41.1	29.8	29.4	39.0	36.5	35.0	39.1	39.3	26.4	15.7	22.0	26.5	29.3	26.5	26.7	28.0	42.2	31.0
5	39.8	25.2	28.3	37.7	36.4	35.0	38.6	39.1	25.5	15.3	21.5	26.0	28.4	24.4	25.4	27.8	41.5	30.9
6	37.2	24.7	27.8	37.1	36.3	34.6	38.0	39.1	25.5	14.7	21.1	25.8	28.0	22.9	24.2	26.8	41.5	30.9
7	35.7	24.3	27.7	37.0	35.7	33.2	37.5	38.8	24.7	11.8	20.6	24.4	27.7	21.5	24.2	26.0	41.5	29.3
8	35.1	24.2	27.4	36.0	35.6	32.4	37.3	37.7	24.7	0.0	20.2	24.2	25.8	20.4	23.9	25.2	41.5	29.3
9	34.2	23.1	27.2	36.0	35.5	32.2	36.9	36.9	24.5	0.0	19.3	24.2	24.6	19.5	23.1	25.0	40.4	28.4
10	34.2	22.9	26.5	36.0	35.2	31.3	36.8	36.1	24.4	0.0	18.8	24.0	23.7	18.6	23.0	24.4	40.0	28.3
11	33.8	22.8	25.3	36.0	34.0	31.0	36.6	35.6	23.2	0.0	17.0	20.5	23.5	18.0	21.5	24.2	39.8	28.0
12	33.2	22.0	25.2	35.9	33.1	30.9	36.0	35.0	23.0	0.0	15.7	20.1	23.1	17.3	20.8	23.7	39.1	27.8
13	33.0	21.5	24.4	35.8	32.9	30.5	35.5	35.0	22.8	0.0	15.3	19.6	23.0	17.0	20.6	23.2	39.1	27.7
14	32.7	21.5	24.0	35.0	32.8	30.5	35.5	34.3	22.4	0.0	13.9	19.5	22.6	16.7	19.5	20.8	39.1	26.8
15	32.5	20.5	21.4	34.5	32.7	30.4	34.8	33.4	22.0	0.0	0.0	19.3	22.4	16.2	19.4	19.7	39.0	26.8
16	31.6	19.5	21.1	34.2	32.4	29.8	34.5	32.3	21.6	0.0	0.0	18.5	21.7	14.7	18.7	19.5	38.6	25.5
17	31.4	19.3	21.1	33.7	32.4	28.0	33.9	30.0	21.1	0.0	0.0	18.4	21.7	13.4	15.8	19.3	38.1	24.5
18	30.4	18.9	20.0	31.4	30.9	28.0	32.4	29.8	20.1	0.0	0.0	17.9	20.9	0.0	15.5	18.7	38.0	24.4
19	30.2	18.5	19.3	31.4	30.5	25.0	31.6	29.0	20.1	0.0	0.0	17.2	20.0	0.0	0.0	17.7	37.2	24.4
20	27.5	18.0	18.9	30.9	30.0	24.2	30.1	28.4	19.9	0.0	0.0	15.2	19.1	0.0	0.0	16.5	37.1	24.2
21	26.5	17.7	17.0	30.7	29.8	24.1	29.3	27.5	19.7	0.0	0.0	0.0	18.0	0.0	0.0	14.1	36.1	23.9
22	26.3	14.4	16.5	28.3	27.5	23.4	28.3	26.8	18.3	0.0	0.0	0.0	13.4	0.0	0.0	0.0	35.5	23.7
23	17.7	12.6	16.0	27.5	26.5	23.0	27.3	21.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.9	0.0

MEAN OF THE 5 HIGHEST VALUES :

41.4 30.0 30.9 39.5 37.7 37.3 40.4 41.9 27.1 16.8 22.7 28.8 30.8 29.4 29.0 29.6

IN RELATION TO STRONGEST SECTOR :

0.99 0.72 0.74 0.94 0.90 0.89 0.97 1.00 0.88 0.55 0.74 0.93 1.00 0.95 0.94 0.96

Table 4.6.

Extreme wind speeds for Utsira lighthouse.

The extremes for the 8 different sectors are calculated according to the following procedure:

Return period 2 and 5 years - 50 and 20 percentiles of 23 years of data.
Return periods 10 years or more - the extreme value for all directions calculated according to Gumbels 1. distributions of extremes are fixed to the most wind exposed sector. For the other sectors, this value are weighted after the average of the 5 highest recorded speeds of each sector.

Unit: m/s.

Return periode (years)	SEPTEMBER - APRIL N	NE	E	SE	S	SW	W	NW	MAY - AUGUST N	NE	E	SE	S	SW	W	NW	All directions Winter	Summer
10 MIN. MEAN WINDSPEEDS																		
2	24	17	18	25	25	23	26	27	18	8	12	16	18	14	15	18	29	21
5	29	19	21	28	27	26	29	31	21	12	16	18	21	20	19	21	32	23
10	31	21	23	31	28	28	31	33	25	17	20	23	26	25	25	25	33	26
50	34	23	26	34	31	31	34	37	29	20	24	27	31	29	30	29	37	31
100	36	24	27	36	33	32	36	38	31	21	25	29	33	31	32	31	38	33
3 - 5 s GUSTWIND SPEEDS																		
2	33	22	25	36	33	31	36	35	23	10	16	20	23	17	21	24	39	28
5	41	28	29	38	36	35	39	39	26	15	22	26	29	25	26	28	42	31
10	44	32	33	42	40	40	43	44	30	19	25	31	34	32	32	32	44	34
50	49	35	36	46	44	44	48	49	34	22	29	36	39	37	37	37	49	39
100	50	37	38	48	46	45	49	51	36	23	31	38	41	39	39	39	51	41

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(2) Ghiocel, D. and D. Lungu: Wind, Snow and Temperature Effects on Structures Based on Probability. Abacus Press, 1975

A P P E N D I X 2

CONCLUSIONS FROM THE

CASE STUDIES OF WEATHER MAPS

COMMENTS AND CONCLUSIONS

BY

ALV SUNDE

CASE_STUDY_OF_WEATHER_MAPS
COMMENTS_AND_CONCLUSIONS

The calculated extreme winds for Utsira have been transferred to Stord (Site C fig. 4.1) by means of transfer coefficients estimated on basis of a number of selected weather situations 1983-1986.

These weather situations have been carefully examined to assure that the development of the local isobaric patterns and the corresponding wind fields over the Utsira - Stord area, are only depending on topographical effects, i.e. friction and local and broad scale deviations due to fjords and mountains.

The selected weather situations represent cases with strong winds from all directions, the maximum wind speed at Utsira exceeding 15 m/sec. in most cases, depending on the wind direction.

Only maximum wind speeds of every direction have been selected from each situation. All together 120 pairs of data have been compared, distributed as follows for different sectors:

Sector 135^0 - 260^0 : 64 pairs of data
Sector 260^0 - 320^0 : 15 pairs of data
Sector 320^0 - 360^0 : 10 pairs of data
Sector 360^0 - 090^0 : 12 pairs of data
Sector 090^0 - 135^0 : 19 pairs of data

The sector limits are chosen in order to reflect both the overall wind patterns and special topographical effects.

The transfer functions in tables 5.1 and 5.2 in the main report have been calculated by means of statistical methods. For the southern sector (south of East-West) the correlation between the two stations are good, and the transfer coefficients have been calculated by means of a simple regression equation.

For the northern sector the correlation is poor, and the quotients:

$$\frac{\text{wind speed Stord}}{\text{wind speed Utsira}}$$

have been calculated seperately for each case.

Even if the number of cases is low for these sectors, the data are considered to be sufficient to justify estimates of reliable transfer coefficients.

The mean value of the quotients + one standard deviation has been chosen to be an acceptable approximation.

Nevertheless, to be on the safe side, the figures presented in the tables 5.1 and 5.2 in the main report, have been evaluated considering both the scattering and the local topography. In case of doubt, a conservative value has been chosen.

Examples of typical weather situations selected for this study, are shown in the succeeding pages. They illustrate how topographical influence modify the isobaric pattern, and how the wind speeds and the directions respond.

Some examples of the quotients Stord-Utsira are shown for the different cases.

The term "Wind Stord" in the calculations of the quotients refers to site A fig. 4.1 in the main report.

South East Wind Direction at Utsira and Easterly Wind at Stord. Fig. 1 and 2.

The pressure pattern over Southern Norway is deflected due to topographical influence when the air is flowing over or around the high mountains. The pressure gradient is concentrated over the West-Norwegian inland and correspondingly strong easterly winds occur in the vallies and inner fjords. The strong SE wind over the sea south of Stavanger is touching Utsira, and may even be stronger due to a corner effect. Over the Stord area the pressure gradient and corresponding easterly wind are weaker (sheltering effect).

The weather maps fig. 1 and 2 are typical examples of such situations.

Examples of quotients Utsira - Stord:

1.1.84: $\frac{\text{10 min. mean wind Stord}}{\text{10 min. mean wind Utsira}} = 0.48$

4.3.85: $\frac{\text{10 min. mean wind Stord}}{\text{10 min. mean wind Utsira}} = 0.34$

The wind marked "Stord" on the graphs refers to Site A, which has a rather poor exposure to easterly wind. That has been confirmed by the recordings from Site B and C and has been considered when estimating the transfer coefficients.

Site A, B and C figure 4.1.

South at Utsira, South East at Stord. Figures 3 and 4

When the pressure field turns south or south west, the pattern becomes more homogeneous. The corresponding wind direction is at Utsira S, and at Stord SE.

The weather maps Fig. 3 and 4 show examples.

Examples of quotients Utsira - Stord

12.1.84: $\frac{\text{10 min. mean wind Stord}}{\text{10 min. mean wind Utsira}} = 0.75$

27.11.84: $\frac{\text{10 min. mean wind Stord}}{\text{10 min. mean wind Utsira}} = 0.78$

Apperently there is a rather sharp limit of the deflection effect when the wind flow over the coast changes from approximately 170^0 to 190^0, and the direction over Stord becomes SE.

NW air flow over West Norway. Fig. 5

This example shows a strong NW wind penetrating the whole Western Norway. Exposed places, even in the inner fjords, report strong wind.

The maximum 10 min. mean wind was NW 56, gusting 76 knots, at Utsira, while the maximum at Stord was W 27 knots, gusting 51 knots. These extreme values correspond fairly well with the estimated transfer coefficients,when allowance has been made for land friction.

$$\frac{\text{10 min. mean wind Stord}}{\text{10 min. mean wind Utsira}} = 0.48$$

NE flow over West Norway. Fig. 6 and 7

The pressure pattern is deflected due to easterly air flow over the mountains creating a "trough" just inside the coast.

Max. mean wind Utsira NE 33 knots, gust 44,and Stord NE 13 knots,gust 26.

$$\frac{\text{10 min. mean wind Stord}}{\text{10 min. mean wind Utsira}} = 0.39$$

Such situations with rather strong NE wind over the area are rather rare.

A transfer coefficient Utsira - Digernessundet for NE wind based on Site A is obviously too low due to the long "land-fetch" towards this direction. The estimate is corrected considering the records from Site B and C.

Fig. 7 shows the position of the low and the high in this situation. The low is passing south of Norway from west towards east.

Westerly air flow over South West Norway. Fig.8

The weather map shows a typical strong westerly wind over the North Sea penetrating the Utsira - Stord area and further over the whole South Norway. This is a frequent situation occuring fairly often during autumn and winter. The max. 10 min. mean wind was at Utsira W 50 knots, gusting 63. The max. 10 min. mean wind at Stord was SW 27 knots, gusting 43 knots.

$$\frac{\text{Mean wind Stord}}{\text{Mean wind Utsira}} = 0.5$$

COMMENTS TO THE GBS - DATA

1.12.85 fig. 9.

This weather map shows a typical example of pressure pattern causing easterly wind in Digernessundet. This day the wind recorder at the Gullfaks "A" GBS (Site C) was in operation, giving excellent data for adjusting or approval of the transfer coefficients based on the data from Tømmervika (Site A) and Kjøtteintåa (Site B).

The data from the GBS show clearly that the easterly wind out through the sound is substantially stronger than recorded on the Tømmervik recorder (Site A).

13.12.85 fig. 10, 11, and 12:

The GBS data show that the northwesterly wind on Site A is too weak to be representative for the sound, but the height of the recorder (GBS 101 meter above sea level) has to be kept in mind.

Great importance has been attached to these data when evaluating the estimated transfer coefficients.

FIGURE 1

THE WEATHER MAP SHOWS THE PRESSURE GRADIENT 11 JANUARY 1984 18 GMT. A TYPICAL SITUATION CAUSING EASTERLY WIND OVER THE UTSIRA-STORD AREA. THE FRAMED GRAPHS SHOW THE CORRESPONDING 10 MIN. MEAN WIND AND GUSTS AT UTSIRA AND STORD (SITE A) 11 JANUARY 15-24 GMT.

THE NUMBERS ALONG THE GRAPHS ARE WIND DIRECTIONS IN DEGREES.

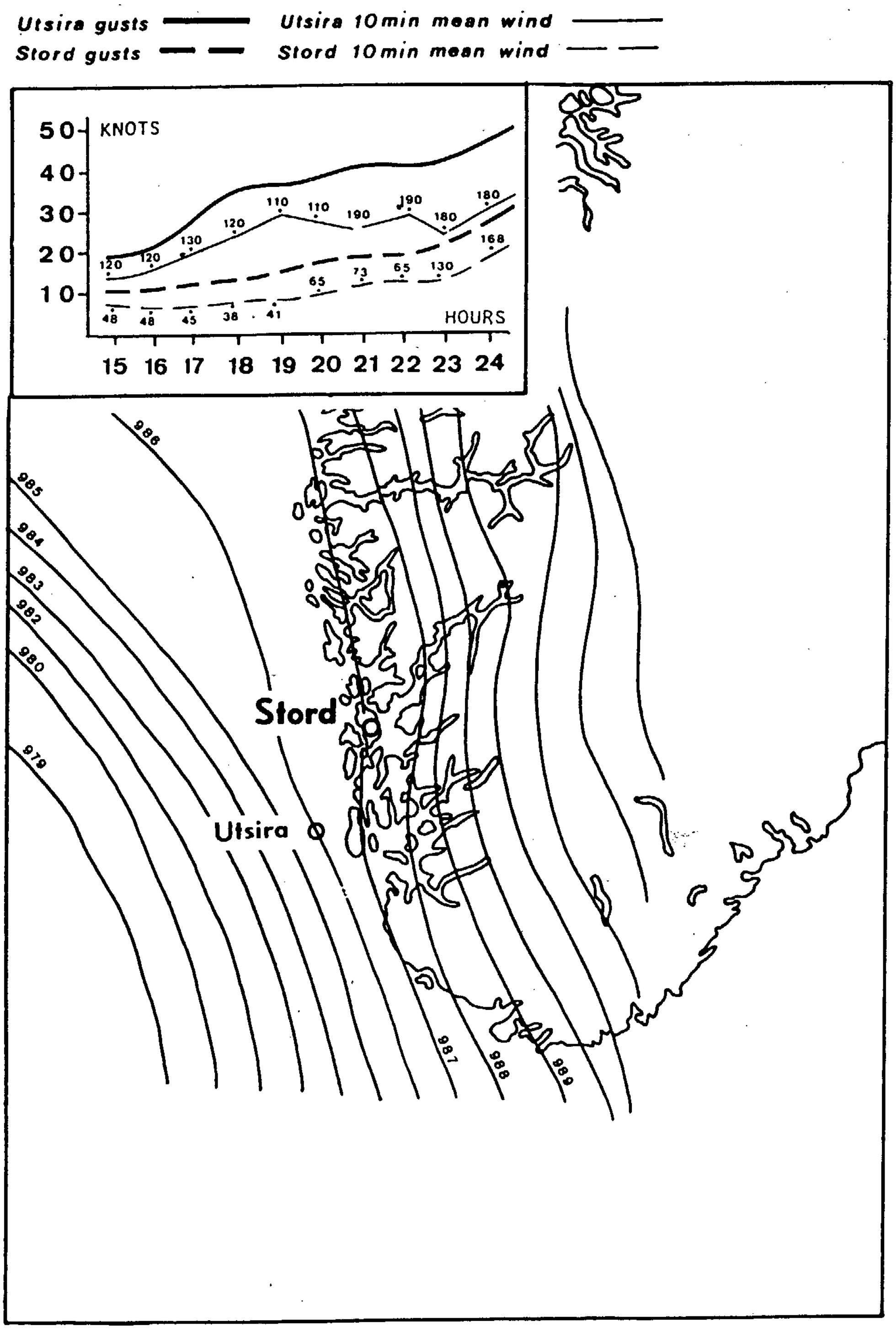

FIGURE 2

THE WEATHER MAP 4 MARCH 1985. 18 GMT SHOWS A SIMILAR PRESSURE PATTERN AS THE WEATHER MAP FIG. 1 AND THE CORRESPONDING WINDS AT UTSIRA AND STORD (SITE A).

THE NUMBERS ALONG THE GRAPHS ARE WIND DIRECTIONS IN DEGREES.

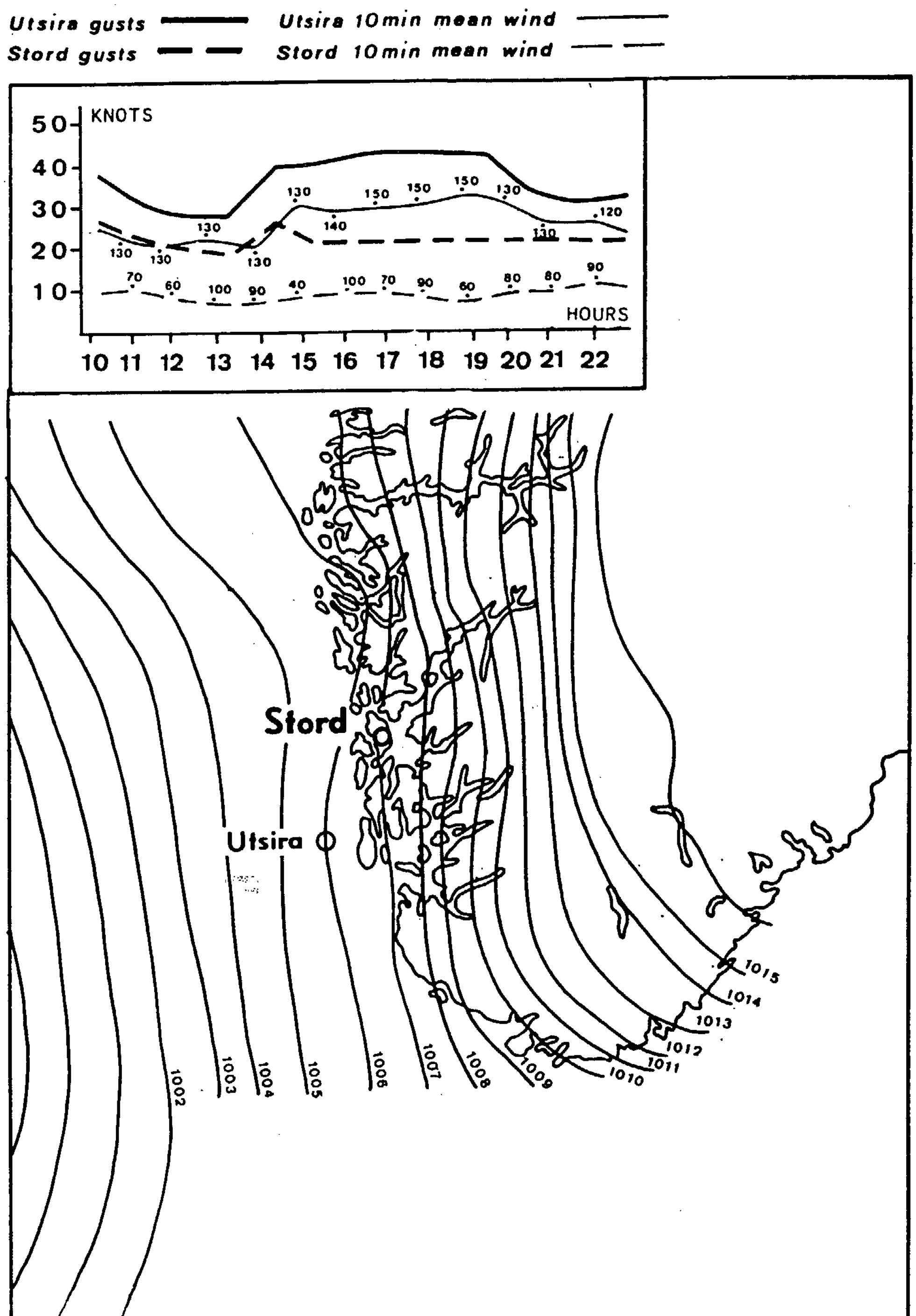

FIGURE 3

THE WEATHER MAP SHOWS THE SITUATION 12 JANUARY 1984 06 GMT. THE FRAMED GRAPHS SHOW 10 MIN. MEAN WIND AND GUSTS AT UTSIRA AND STORD (TØMMERVIKA SITE A) 12 JANUARY 01 GMT-13 GMT.

THE NUMBERS ALONG THE GRAPHS ARE WIND DIRECTIONS IN DEGREES.

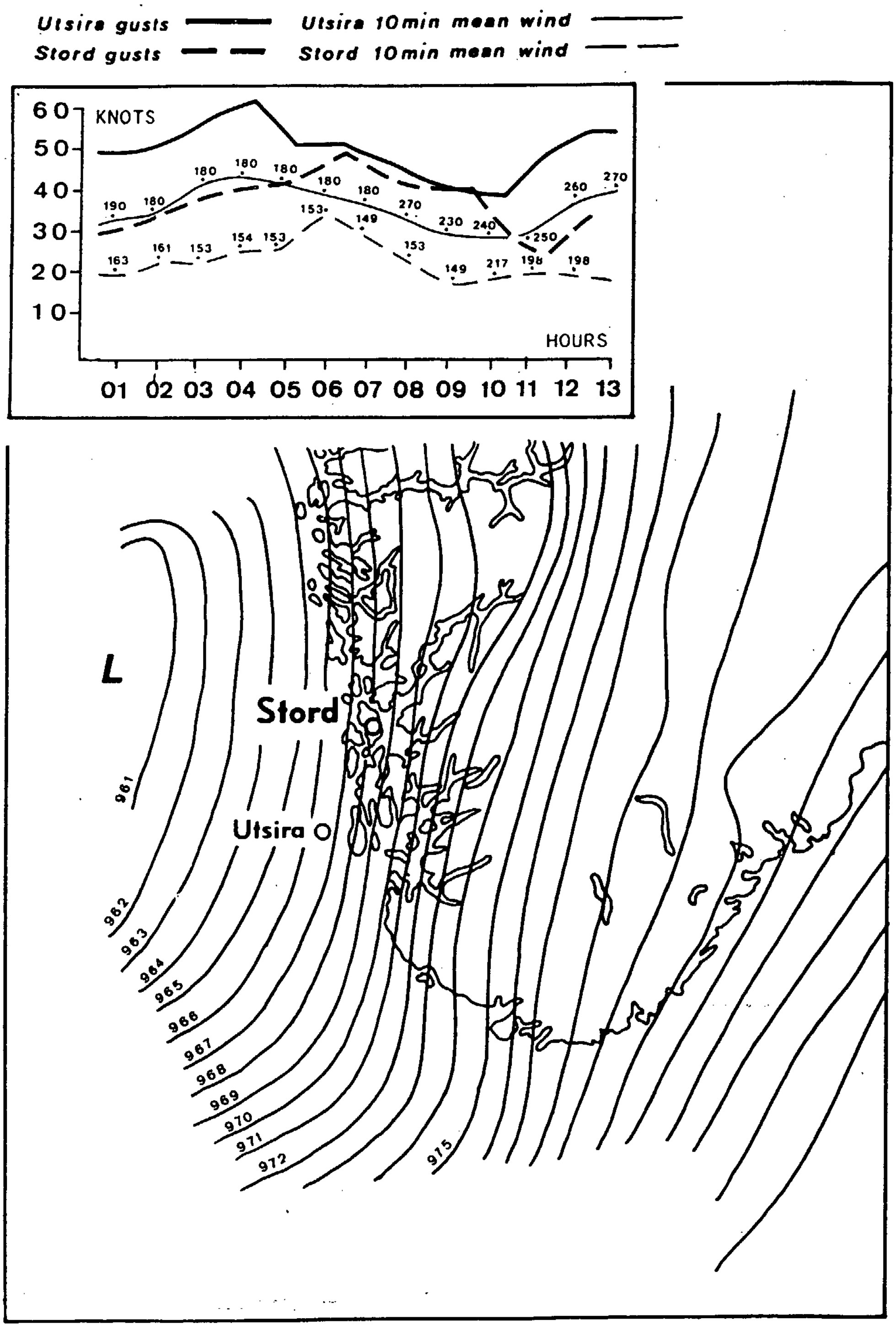

FIGURE 4

THE WEATHER MAP SHOWS THE SITUATION 27 NOVEMBER 1984 18 GMT. THE FRAMED GRAPHS SHOW 10 MIN. MEAN WIND AND GUSTS AT UTSIRA AND STORD (TØMMERVIKA SITE A) 27 NOVEMBER 1984 05 GMT-22 GMT.

THE NUMBERS ALONG THE GRAPHS ARE WIND DIRECTIONS IN DEGREES.

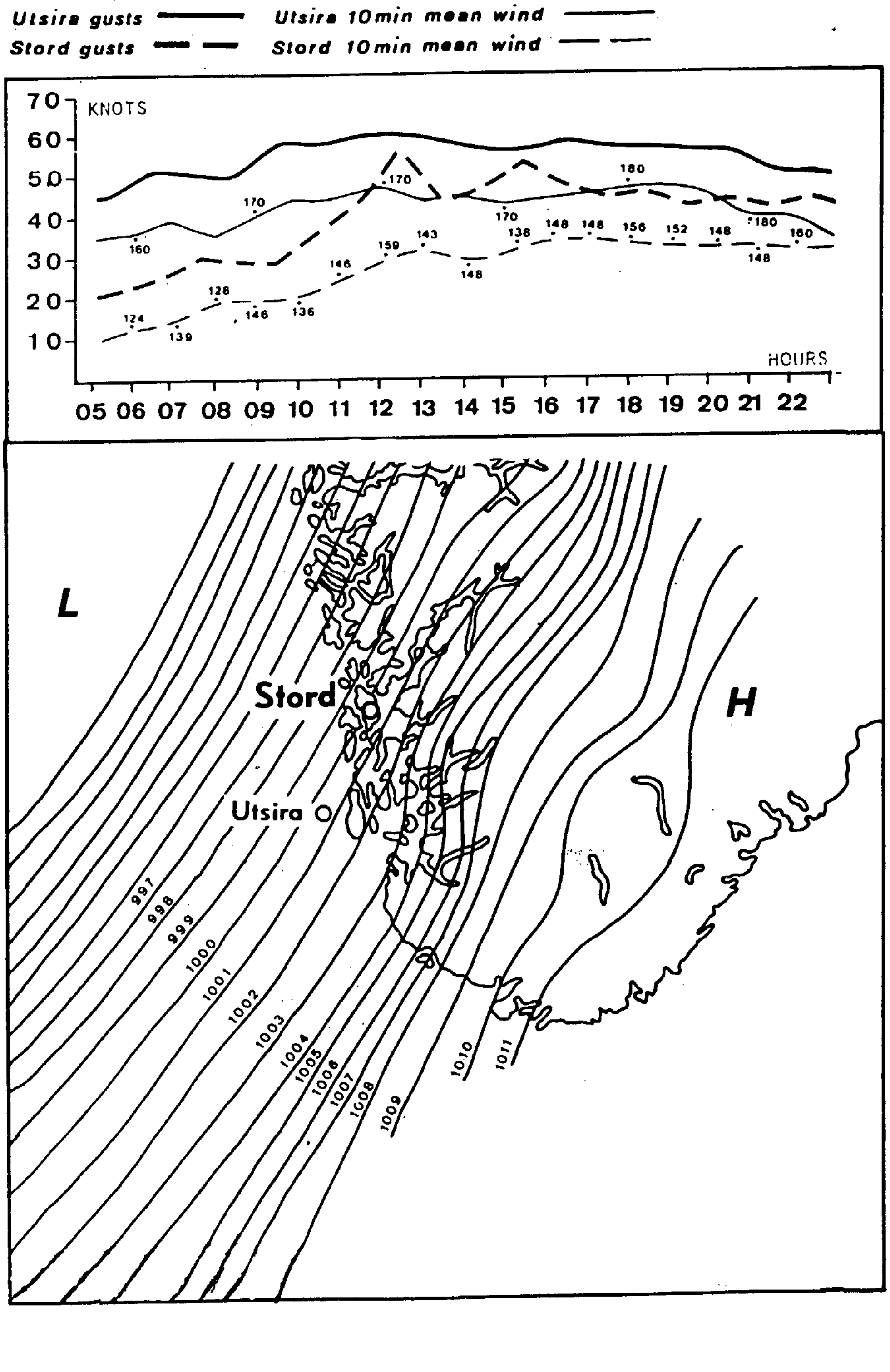

FIGURE 5

THE WEATHER MAP 11 OCTOBER 1985 18 GMT SHOWS A TYPICAL SITUATION WHEN A STRONG NW WIND IS BLOWING OVER THE UTSIRA-STORD AREA. THE FRAMED GRAPHS SHOW THE CORRESPONDING WIND AT UTSIRA AND STORD (SITE A) 11 OCTOBER 1985 13-22 GMT.

THE NUMBERS ALONG THE GRAPHS ARE WIND DIRECTIONS IN DEGREES.

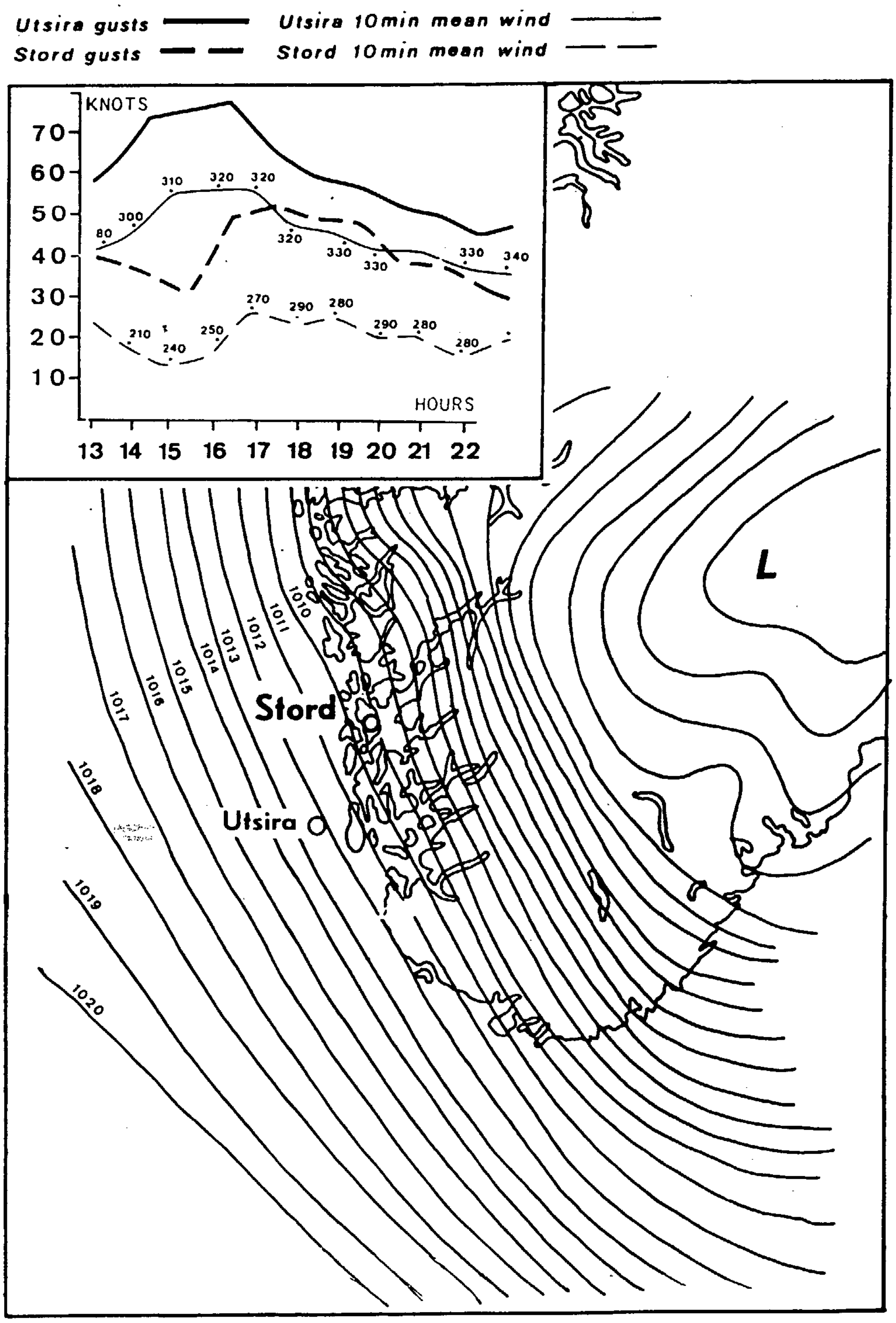

FIGURE 6

THE WEATHER MAP 16 JANUARY 1984 06 GMT SHOWS A TYPICAL EASTERLY WIND FLOW OVER SOUTH NORWAY CREATING A THROUGH ALONG THE COAST OF WEST NORWAY. THE WIND DIRECTION OVER THE UTSIRA-STORD AREA BECOMES NORTH EASTERLY. THE FRAMED GRAPHS SHOW THE CORRESPONDING WINDS AT UTSIRA AND STORD (SITE A) 16 JANUARY 17 GMT - 17 JANUARY 1984 10 GMT.

THE NUMBERS ALONG THE GRAPHS ARE WIND DIRECTIONS IN DEGREES.

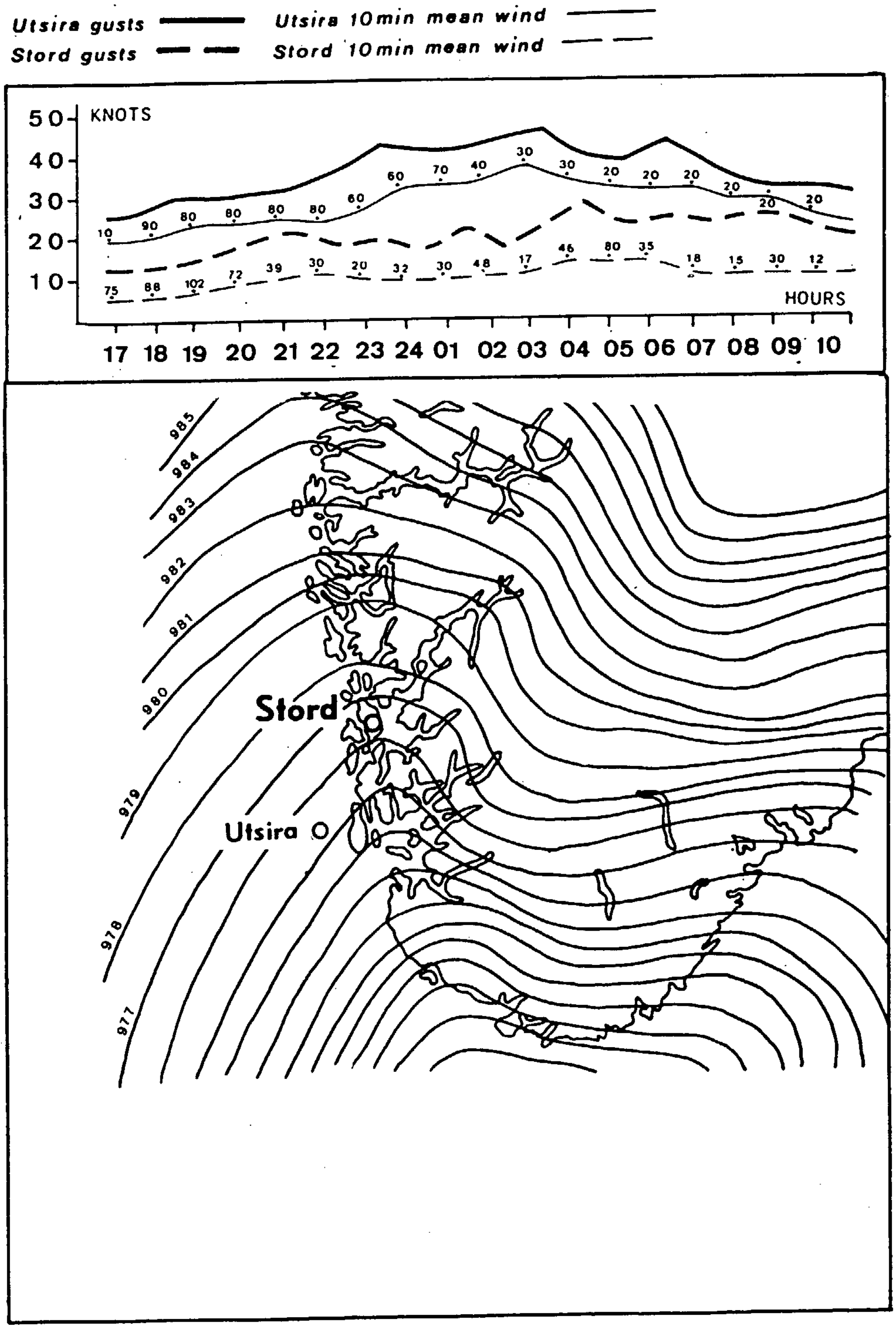

FIGURE 7

THIS WEATHER MAP SHOWS THE SAME SITUATION AS FIG. 6. THE POSITION OF THE LOW IS 17 JANUARY 1984 00 GMT. AND THE TRACK IS FROM WEST TOWARDS EAST. THE LOW IS PASSING SOUTH OF NORWAY.

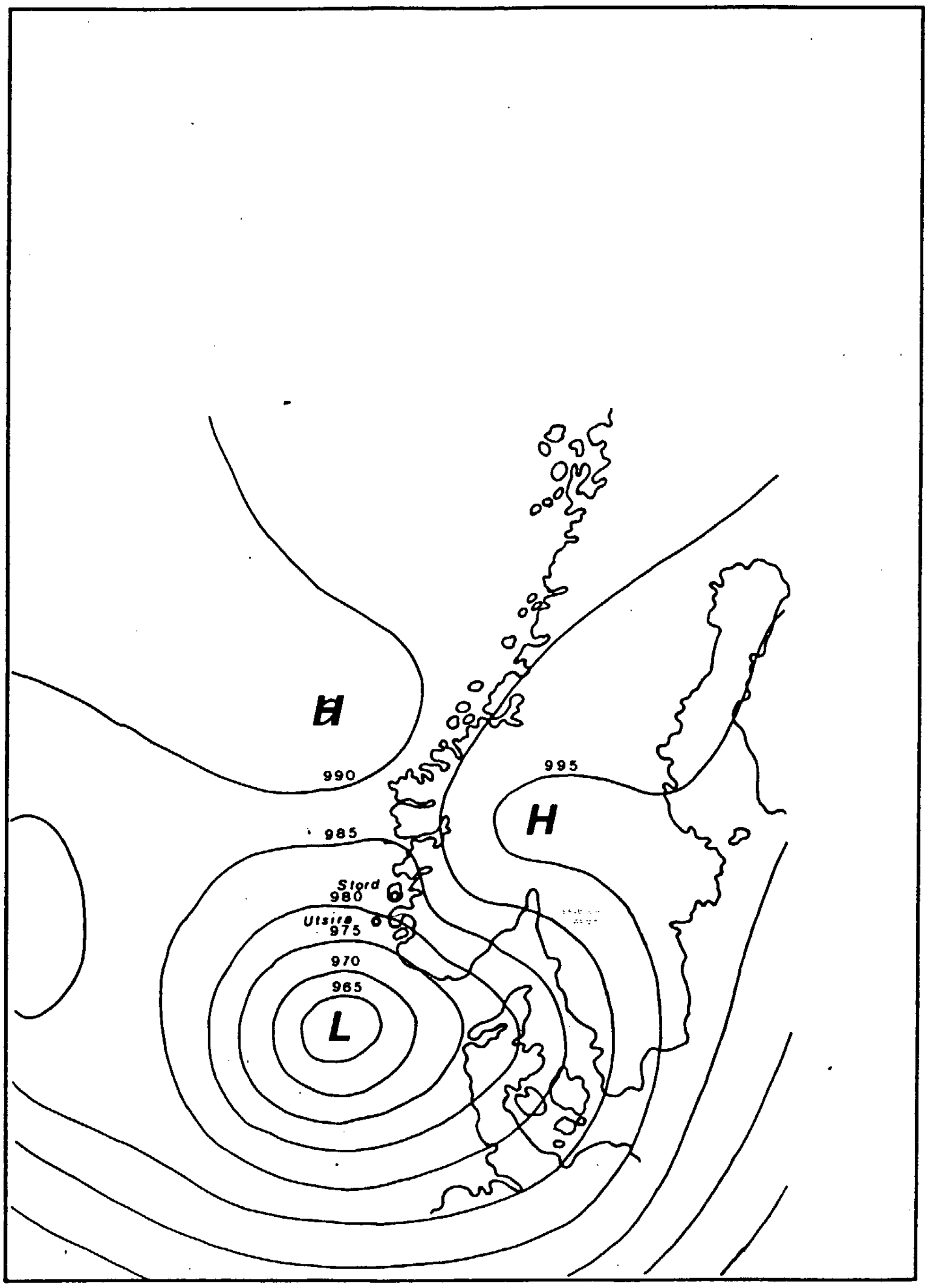

FIGURE 8

THE WEATHER MAP SHOWS THE PRESSURE PATTERN 11 OCTOBER 1985 12 GMT CAUSING A STRONG SOUTH WESTERLY WIND OVER THE UTSIRA-STORD AREA. LATER VEERING WESTERLY.

THE NUMBERS ALONG THE GRAPHS ARE WIND DIRECTIONS IN DEGREES.

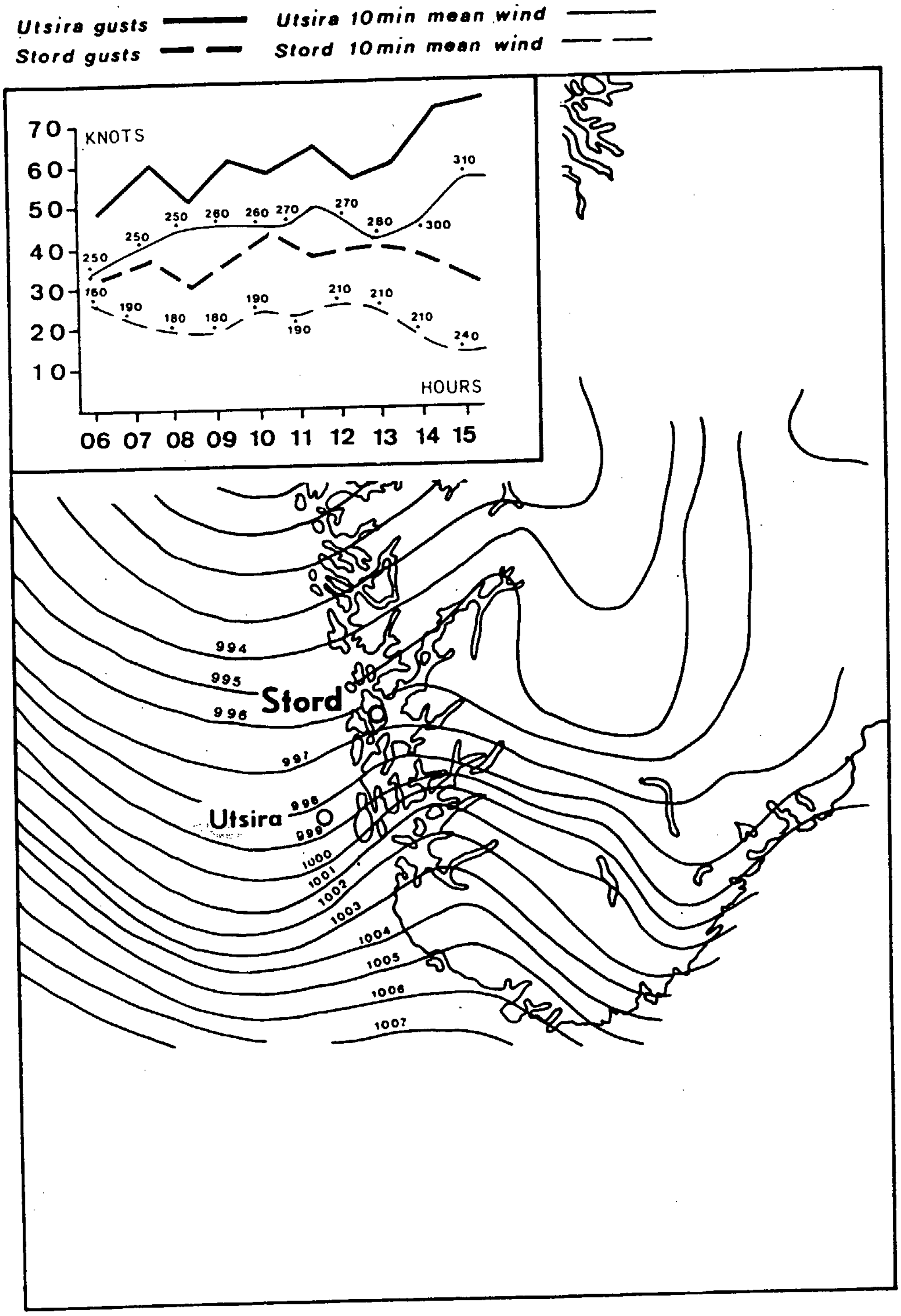

FIGURE 9

THE WEATHER MAP SHOWS THE SITUATION 1 DECEMBER 1985 18 GMT. THE FRAMED GRAPHS SHOW UTSIRA 10 MIN. MEAN WIND AND GUSTS. GBS (SITE C) 10 MIN. MEAN WIND AND GUSTS AND TØMMERVIKA 10 MIN. MEANO WIND. 1 DECEMBER 1985 01-19 GMT.

THE NUMBERS ALONG THE GRAPHS ARE WIND DIRECTIONS IN DEGREES.

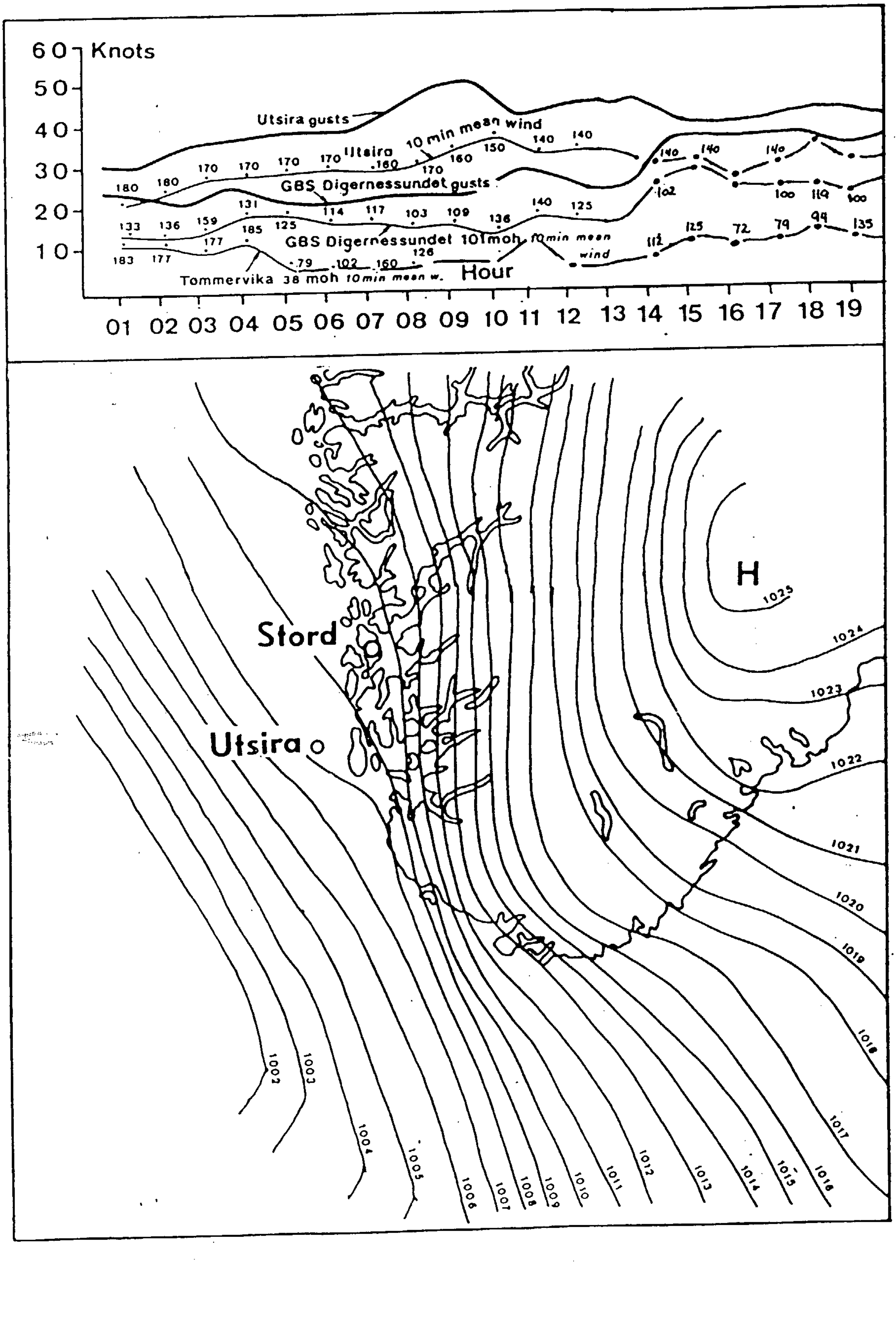

FIGURE 10

THE WEATHER MAP SHOWS THE SITUATION 13 DECEMBER 1985 06 GMT. THE FRAMED GRAPHS SHOW UTSIRA 10 MIN. MEAN WIND AND GUSTS, GBS (SITE C) 10 MIN. MEAN WIND AND GUSTS AND TØMMERVIKA (SITE A) 10 MIN. MEAN WIND 13 DECEMBER 1985 10-24 GMT.

THE NUMBERS ALONG THE GRAPHS ARE WIND DIRECTIONS IN DEGREES.

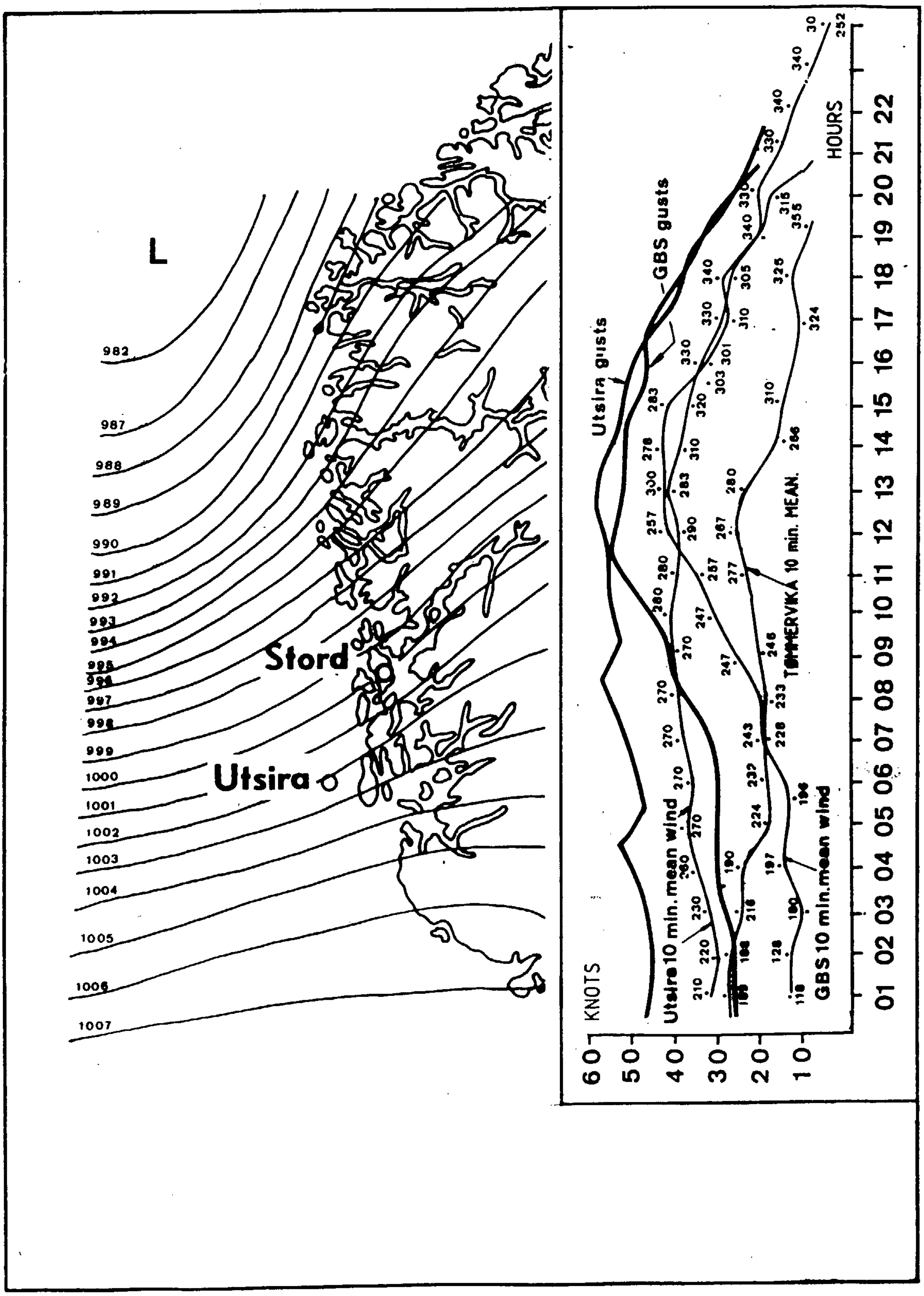

FIGURE 11

13 DEC. 1985 12 GMT.
THE WEATHER MAP SHOWS THE CHANGE SINCE 06 GMT. THE WIND HAS BECOME WESTERLY (SEE GRAPHS FIG. 10).

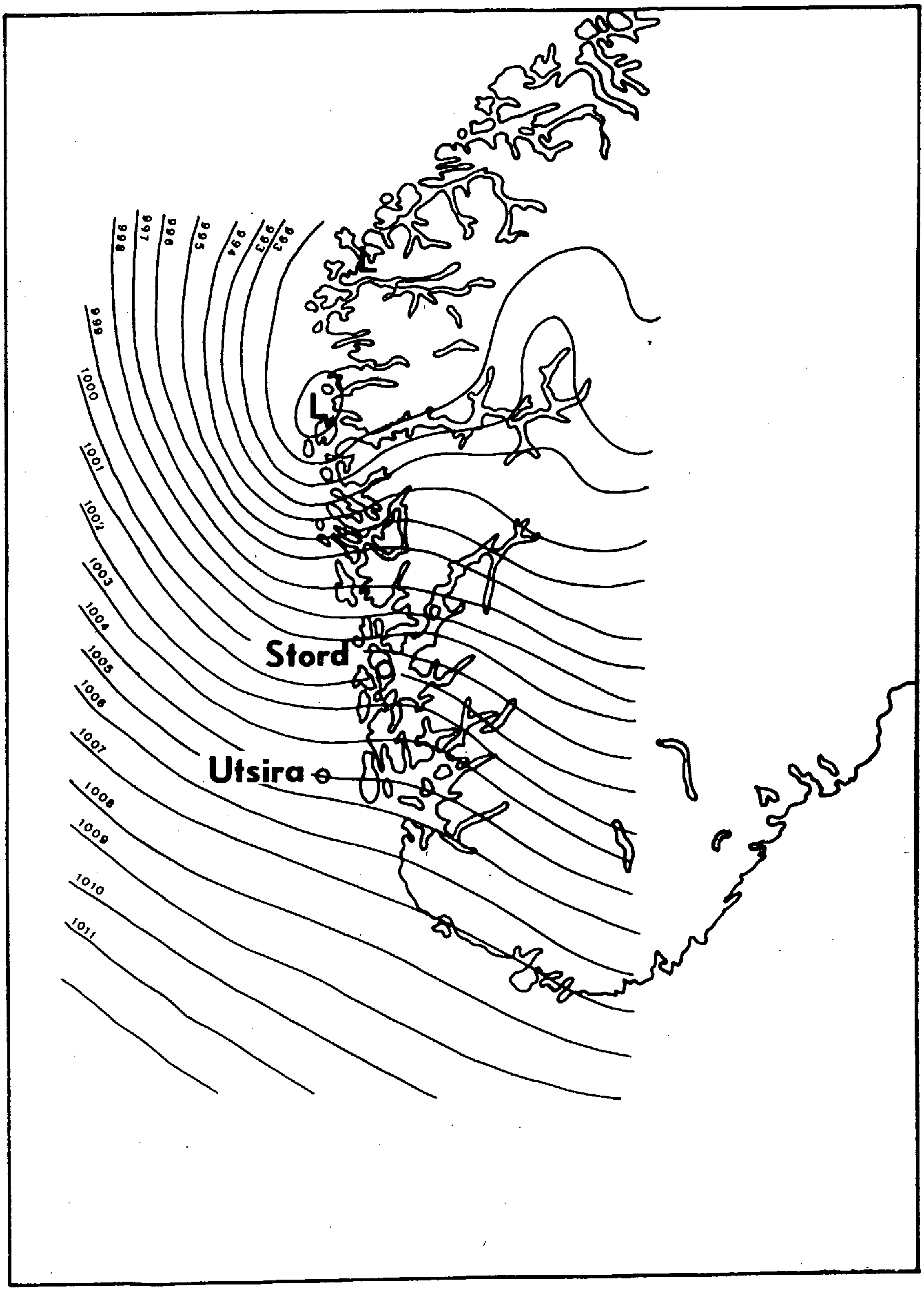

FIGURE 12

13 DEC. 1985 15 GMT.
BY THIS TIME THE WIND HAS VEERED NORTH WESTERLY (SEE GRAPHS FIG. 10).