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TITTEL

PROBABILITIES FOR PERIODS WITH LOW WIND SPEED IN GANDSFJORDEN

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OPPDRAGSGIVER

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SAMMENDRAG

The report contains a probability analysis based on data from the weather station Sola, 1957 - 1986. The probability for periods of 1 - 4 days which have a maximum mean wind speed within a given upper limit (3,4 or 6 Beaufort) are calculated for the months May and June.

We have also looked at diurnal variations of such probabilities due to the active sea-breeze effect at Sola in May and June. The problem of waiting for a suitable day is also discussed.

The results are presumed to be valid also for Gandsfjorden.

UNDERSKRIFT

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S U M M A R Y

This report contains a probability analysis based on wind data from the weather station Sola, 1957 - 1986, the months being May and June. The probability for a period of n days that have a maximum 10 minute wind speed, FX, not exceeding X Beaufort the first day and not exceeding Y Beaufort the following n-1 days, is determined. We also have calculated the conditional probabilities for FX $\leq$ Y Beaufort in n-1 days, the condition being FX $\leq$ X the day before.

It is argued that the wind climate in Gandsfjorden is similar to Sola, or perhaps even milder. The results from Sola should therefore be representative (or slightly conservative) for most of the operational area. For the outermost part of the fjord, however, the winds may be even slightly stronger than at Sola, and the probability for periods with light winds correspondingly smaller.

SOLA 1957-1986

Probabilities, P	May	June	Conditional P	May	June
P(3)	0.12	0.15	P(3)3	0.30	0.36
P(4)	0.52	0.54	P(33)3	0.09	0.13
P(6)	0.95	0.98	P(333)3	0.03	0.05
P(33)	0.03	0.06	P(4)3	0.81	0.77
P(44)	0.37	0.36	P(44)3	0.59	0.51
P(66)	0.92	0.97	P(444)3	0.42	0.33
P(333)	0.02	0.02	P(6)3	0.99	0.99
P(444)	0.27	0.24	P(66)3	0.96	0.98
P(666)	0.89	0.95	P(666)3	0.93	0.96
P(3333)	0.003	0.007	P(4)4	0.72	0.66
P(4444)	0.20	0.16	P(44)4	0.52	0.44
P(6666)	0.86	0.93	P(444)4	0.38	0.29
P(34)	0.09	0.12	P(6)4	0.99	0.99
P(344)	0.07	0.08	P(66)4	0.95	0.98
P(3444)	0.05	0.05	P(666)4	0.93	0.96
P(36)	0.11	0.15	P(6)6	0.97	0.98
P(366)	0.11	0.15	P(66)6	0.93	0.97
P(3666)	0.11	0.14	P(666)6	0.90	0.95
P(46)	0.50	0.54			
P(466)	0.49	0.53			
P(4666)	0.48	0.52			

The probability for having one day of FX ≤ 3 Beaufort in the first day and FX ≤ 6 Beaufort in the following three days, P(3666) = 0.10 in May and 0.14 in June. Correspondingly, P(3444) = 0.05 in both months, and P(3333) < 0.01 in both months.

The conditional probability for having FX ≤ 4 Beaufort in 2. - 4. day, the condition being FX ≤ 3 Beaufort in day 1, P(444)3 = 0.42 in May and 0.33 in June. Correspondingly, the probability of having FX > 6 Beaufort in 2., 3., or 4. day, the condition being FX ≤ 3 Beaufort in day 1, 1.00 - P(666)3 = 0.07 in May and 0.04 in June.

The probability of having FX≤ 4 Beaufort in 4 days, P(4444) = 0.20 and 0.16, correspondingly P(6666) = 0.86 and 0.93 in the two months.

Due to the long data series, 30 years, the results was found to be significant, and the inaccuracies rather small.

We also have looked upon the diurnal variations. The probability of getting a six hour period with FX ≤ 3 Beaufort is 0.62 (May) and 0.65 (June) from 01 - 07, while it is 0.25 (both months) from 13 - 19 (Norwegian Normal Time). This clearly shows that the sea breeze effect (late fornoon and in the afternoon) spoils the chances of getting periods with FX ≤ 3 Beaufort.

We have studied six days with a distinct sea breeze effect. At Sola, a rapid increase of the wind speed takes place from 10 - 11 local time, while the wind speed maximum is found at 15 o'clock. From 19 - 21 we have the most distinct drop of the wind speed.

The persistence is also studied in a different way. For how long time do we have to wait before the wind speed obey the criterion FX ≤ 3 Beaufort if we decide to start somewhere in the period May 18 - June 1? We find that after 6.0 days we have the probability, p=0.50 of getting such a 24 hour period (19 - 19), and after 14.3 days p=0.90. The longest time we had to wait in the 30 year period was 29 days. If we restrict ourselves to the period 01 - 07 we have p=0.50 after 0 days, p=0.90 after 2.7 days and 9 days is the longest period of waiting.

It is also shown that days with maximum wind speed, FX ≥ 7 Beaufort (B) are rare in May (6.2 %) and June (3.5%), and that 8B (highest occured wind speed in the two months) occurred in < 1 % of the days. Further on, the risk of having FX = 7B within 3 days when FX ≤ 3B the day before is very low (<1%), and that 8B has not occurred at day 1, 2 or 3 after a day with FX ≤ 3B, within the last 30 years.

1. INTRODUCTION.

The background for this report is a request from Norwegian Contractors concerning operational criteria at Hinnavågen, Gandsfjorden. At this place a platform operation is planned on May 25, 1987. The operation cannot be carried out unless the 10 min wind speed obey certain criteria. The criteria are as follows: The wind speed cannot exceed 3 Beaufort the first day (strictly spoken 4 hours), and 6 Beaufort the three following days. The main request from the operator then is to get probabilities for such a four day period in May and June. Probabilities for other criteria is wanted, too, some of them defined through discussions with representants for the operator.

Our institute have earlier made a report concerning weather windows in Digernessundet (1). The weather stations Sola and Flesland was used in that report. Sola is the only reference station to be used in this examination. Since the operation is planned in May, it is also necessary to look at diurnal variations, especially for periods with an upper limit of 3 Beaufort.

We will also draw attention to some other publications concerning wind conditions in the area. That is the general frequency tables (2), and extreme wind analysis at Sola transferred to Gandsfjorden (3) and Nedstrandsfjorden (4).

2. SITE DESCRIPTION AND DATA BASIS.

2.1. Localities. Topographical description and representativity of recorded wind data.

Gandsfjorden (Fig.1) is situated in Western Norway in Rogaland county, straight to the east and southeast of Stavanger. The fjord is running north - south, and become gradually narrower towards the fjord bottom near Sandnes, 6 km south of Stavanger. The locality Hinnavågen is lying at the western side of the fjord.

The fjord gradually mixes into a larger basin north of Stavanger.

The mountains is running up to 300 m at the eastern side of the fjord. At the western side the landscape is rather flat, partly covered with wood, groups of buildings and farm land. The weather station Sola airport, is situated at this flat area, 7 km west of the fjord. The area at Sola is covered only of a few buildings, and grass and stones with only a very few groups of trees. 1-3 km further west there is open sea.

The strongest and most frequent winds in the area (Sola airport) in late spring and early summer is comming from west to north (270^0 - 360^0) and southeast to south (120 - 200^0). The sea breeze easily blow up as a northwesterly to northerly wind in the afternoon, and this effect may change a weak northerly wind to a strong breeze (6 B).

In the fjord area, it is supposed that the wind is even more channelled along the direction of the fjord (N - S).

In Gandsfjorden the wind speed conditions probably are equal to Sola. The afternoon sea breeze, however, is not believed to be quite as strong. Hinnavågen seems to be more sheltered than the fjord. At this place, winds from south to north probably are weaker than at Sola, while south-easterly winds should be as strong as at Sola. Due to no measurements, however, we find it risky to recommend a reduction of the wind speed from Sola to this fjord area.

At the outermost part of the fjord, northerly wind travel through a long fetch of open water. Northerly wind including sea breeze may there be even slightly stronger than at Sola.

2.2. Wind instruments and data quality.

Sola is equipped with the anemometer type Fuess 90z. The anemograph is recording the instantaneous wind speed and wind direction and give in addition 10 minute mean wind speed. The anemometer height is 11 m above the ground.

Sola has data series from 1957. In our data storage we have 4 wind observations each day : 01,07,13 and 19 o'clock local time. The data consist of 10 minute mean wind speed and direction at the hours of observation and the 10 minute maximum wind speed between the hours of observation. At Sola the anemometer position is unchanged through the period, apart from a minor moving in 1969 (10-12 m). The data are found homogeneous for the period 1957-1985.

3. RESULTS.

3.1. Results for periods of 1 - 4 days.

Our task is to find the probability for a period of n days that have a maximum wind force, FX, not exceeding X Beaufort (B) the first day and not exceeding Y B during the following n-1 days. Here a day means the 24 hours period from 19 to 19 o'clock local time. The probability for such a period is here denoted P(X(1)Y(2)...Y(n)). The conditional probability, the condition being that the maximum wind force $\leq$ X beaufort the first day, is defined by

$$P(Y(2)...Y(n))X(1) = P(X(1)Y(2)...Y(n))/P(X(1)) \quad \text{(Eq. 3.1)}$$

At first we will find the relative frequency, f(E), of the occurrence of an event, E, by counting the number of successes and then divide with the total possibility for successes.

Example : The total number of successes for a 4 days period in one month are 3 less than the total number of days of that month. Suppose a period is looking like : 2373343323557. The numbers represent the daily maximum wind forces (Beaufort). Here the number of cases of 3666 are 5. Further on, we suppose that the total number of cases during a period of 30 years is 83 in May. Then the relative frequency is f(3666)=83/[(31-3)x30]=0.10. If the number of days with FX ≤ 3B that month is 90, the conditional relative frequency f(666)3 is 83/90=0.92. The result are given in Table 1. Details concerning the countings are given in Appendix 1.

SOLA 1957-1986

Probabilities, P		May	June	Conditional P		May	June
P(3)	f	0.12	0.15	P(3)3	f	0.30	0.36
P(4)	f	0.52	0.54	P(33)3	M	0.09	0.13
P(6)	f	0.95	0.98	P(333)3	M	0.03	0.05
P(33)	f	0.03	0.06	P(4)3	f	0.81	0.77
P(44)	f	0.37	0.36	P(44)3	M	0.59	0.51
P(66)	f	0.92	0.97	P(444)3	M	0.42	0.33
P(333)	M	0.02	0.02	P(6)3	f	0.99	0.99
P(444)	M	0.27	0.24	P(66)3	M	0.96	0.98
P(666)	M	0.89	0.95	P(666)3	M	0.93	0.96
P(3333)	M	0.003	0.007	P(4)4	f	0.72	0.66
P(4444)	M	0.20	0.16	P(44)4	M	0.52	0.44
P(6666)	M	0.86	0.93	P(444)4	M	0.38	0.29
P(34)	f	0.09	0.12	P(6)4	f	0.99	0.99
P(344)	M	0.07	0.08	P(66)4	M	0.95	0.98
P(3444)	M	0.05	0.05	P(666)4	M	0.93	0.96
P(36)	f	0.11	0.15	P(6)6	f	0.97	0.98
P(366)	M	0.11	0.15	P(66)6	M	0.93	0.97
P(3666)	M	0.11	0.14	P(666)6	M	0.90	0.95
P(46)	f	0.50	0.54				
P(466)	M	0.49	0.53				
P(4666)	M	0.48	0.52				

Table 1. Probabilities for events (see below), partly interpreted as relative frequencies,f, and partly given as Markov chain estimates,M (see Appendix 1). The data from 1957-86 at Sola are used in the analysis. FX is the maximum 10 minute wind speed.

P(X(1)..X(n)): The probability for n days with FX ≤ X Beaufort.

P(X(1)Y(2)..Y(n)): The probability for n days with FX ≤ X Beaufort the first day and FX ≤ Y Beaufort the remaining n-1 days.

P(Y(2)..Y(n))X(1): The conditional probability for n-1 days with FX ≤ Y Beaufort when FX ≤ X Beaufort the day before.

Some striking points should be mentioned. At first, the probability of getting a day with FX ≤ 3 Beaufort is only 0.10 - 0.15 in May - June. This probability drops to < 0.01 for a 4 - days period. As we later shall see, it is the see breeze effect which destroys this chance.

The chances of having days with FX ≤ 4 Beaufort are better, 0.5 for 1 day and 0.15 - 0.20 for 4 days. There is a high probability of having FX ≤ 6 Beaufort, 0.95 in May and 0.98 in June for 1 day, dropping only to 0.86 and 0.93 for 4 days. Periods with strong wind are not frequent at that time of the year. This also means that probabilities of events defined by FX ≤ 3 or 4 Beaufort are only slightly modified if we also require that FX ≤ 6 the following day(s). Further on, the conditional probabilities P(6(2)..6(n))X(1) ≈ P(6(1)..6(n-1)), which means that the high probabilities are only slightly enhanced if we have a condition of low wind speed of the day before.

The probability of getting 1 day of FX ≤ 3 Beaufort, 0.10 - 0.15 moves up to 0.30 - 0.35 when we also have the condition FX ≤ 3 Beaufort the day before. Correspondingly, the probability of 1 day of FX ≤ 4 Beaufort, 0.5, moves up to 0.8. This clearly illustrate the persistence of periods with low wind speed.

The wind speed of the two months May and June show a very related behaviour, though there also seems to be some deviations which may be significant. Significance of the results are discussed in Appendix 2.

3.2. Results for 6 hours periods.

Owing to the fact that the operator needs only 4 hours with low wind speed the first day, we are requested to give probabilities for different 6 hours periods that day, to find the best suitable time of the day to start the operation. Table 2 shows the actual probabilities.

SOLA 1957-1986

Probabilities	P	May	June
01-07	P(3)	0.62	0.65
	p(3)3	0.73	0.73
07-13	P(3)	0.32	0.36
	P(3)3	0.45	0.46
13-19	P(3)	0.22	0.25
	P(3)3	0.29	0.37
19-01	P(3)	0.47	0.50
	P(3)3	0.60	0.61

Table 2. Probabilities for having FX ≤ 3 Beaufort in different 6 hours periods, during a day. FX is the maximum 10 minute wind speed.

The finest partition of the day we are able to do for data within our data storage is four 6 hours periods : 01-07, 07-13, 13-19 and 19-01 (local time). The chances of having FX ≤ 3 B in such a period are best at night, between 01 and 07, and then getting worse and worse during the following two periods. From 19 to 01 the chances again improve. The chances are not significantly different in May and June.

The probabilities for having FX ≤ 3 in a 6 hours period increases with 0.07 - 0.13, if FX in the same period of the day before satisfy the criterion. This fact indicates a relatively small persistence from day to day when only given parts of each day is concerned.

Diurnal variability.

As we have seen in the preceding chapter the probability for having FX ≤ 3 B varies very much during the different 6 hours periods of a day, in May and June. How is this variability for the other months of the year? Fig. 2 shows that in the winter season, November- February, the mentioned probability varies very little during a day, on the average. From March to May the variability increases, due to the more and more pronounced sea breeze effect, and it is high through the summer. In September the variability has a rapid decrease, due to a weakening of the sea breeze effect and the beginning of the autumn storms.

Example.

In Fig. 3 we have chosen 6 days in 1986 to illustrate the daily variation in the wind speed on days with sea breeze. On 26.06 - 28.06 the background fiels is rather weak, while it is a considerable northerly background field on the days 11.07 - 13.07, see weather maps, Fig. 4 - 5, and wind record from Sola, Fig. 6 - 7. In Fig. 3 we have drawn this 6 days mean of the maximum 10 min wind speed of each hour at daytime. From the figure we find that the wind speed have a rapid increase at 10 - 11 local time (09-10GMT), while the maximum of the day is found at 15. From 19 -21 we have the most distinct drop in the wind speed.

3.3. Risk of delay.

When planning an operation like the present one, many questions come up. For example : If the operation is planned to start at May 25, what is the risk then that it will be postponed ? And for how long time may the delay last ? We have calculated this delay with different levels of probability (i.e. relative frequencies interpreted as probabilities). Because of the great variability from day to day in this aspect, we look upon possible starting points in the period May 18 to June 1, or within one week before and after May 25. This will reduce the variabilities and thus improve the reliability of the results. The results from this investigation are presented in Table 3.

01-07

SOLA 57-86	P	50 %	75 %	90 %	95 %	99 %
18/5	0.33	0	2	3	5	5
19/5	0.47	0	1	2	4	9
20/5	0.30	0	1	3	3	8
21/5	0.43	0	2	4	6	7
22/5	0.43	0	2	3	5	6
23/5	0.43	0	2	3	4	5
24/5	0.40	0	1	2	4	5
25/5	0.37	0	1	3	4	4
26/5	0.27	0	1	2	3	3
27/5	0.30	0	1	1	2	3
28/5	0.30	0	1	1	2	2
29/5	0.37	0	1	2	2	4
30/5	0.30	0	1	1	3	3
31/5	0.23	0	0	2	2	4
1/6	0.37	0	1	2	3	4
MEAN	0.35	0.0	1.2	2.3	3.5	4.8
SD	0.07	0.0	0.6	0.9	1.2	2.0
START DAY		1.	2.	3.	5.	6.

07-13

P	50 %	75 %	90 %	95 %	99 %
0.67	1	4	7	11	11
0.70	1	4	8	10	10
0.63	1	4	7	9	9
0.67	2	4	8	8	8
0.80	1	5	7	7	11
0.63	2	6	6	8	10
0.73	3	5	6	7	9
0.63	2	4	5	6	8
0.73	2	3	5	7	13
0.60	1	2	5	6	12
0.73	1	3	5	5	11
0.60	1	4	5	10	15
0.60	1	3	6	9	14
0.57	1	3	5	8	13
0.70	1	4	5	11	12
0.67	1.4	3.9	6.0	8.1	11.1
0.07	0.6	1.0	1.1	1.8	2.1
	2.	5.	7.	9.	12.

Table 3a. Probability, P for a delay in the two 6 hours periods, 01-07 and 07-13, in the last part of May, and the duration of the delay (in days) with different probability levels (%). Mean and standard deviation (SD) are also presented.

This investigation indicates a risk of delay of 35 % and 67 % in the time intervals 01-07 and 07-13, respectively. If we have a delay, we will interpret the mean as the average delay at May 25, with different probability levels. The delays with probability levels higher than 95 % are rather uncertain, because of the few independent data in thus intervals.

We see that it is a chance of 90 % to have FX ≤ 3 B in the time intervals 01-07 and 07-13, within a period of 3 and 7 days, respectively, assuming that the operation starts at May 25. One should be fairly sure to have satisfying wind conditions within 1 week or 2 weeks, respectively.

If we require that FX ≤ 3 B for 24 hours (19-19), it is a risk of delay of 87 %. It is a probability of 0.90 to satisfy the criterion within two weeks, and one should be fairly sure within 4 weeks. See Table 3b.

19-19

SOLA 57-86	P	50 %	75 %	90 %	95 %	99 %
18/5	0.80	9	15	19	22	23
19/5	0.97	10	14	18	21	22
20/5	0.87	9	13	17	20	21
21/5	0.93	8	13	17	20	29
22/5	0.90	7	12	16	19	28
23/5	0.90	7	12	15	18	27
24/5	0.93	6	11	14	17	26
25/5	0.77	5	10	13	16	25
26/5	0.93	5	10	14	18	24
27/5	0.83	4	9	13	17	23
28/5	0.90	5	9	12	16	22
29/5	0.80	4	8	11	15	21
30/5	0.77	4	8	11	20	22
31/5	0.87	4	7	13	19	21
1/6	0.83	3	8	12	18	20
MEAN	0.87	6.0	10.6	14.3	18.4	23.6
SD	0.06	2.2	2.5	2.6	2.0	2.8
START DAY		7.	12.	15.	19.	25.

Table 3b. Probability, P for a delay in a 24 hours period in the last part of May, and the duration of the delay (in days) with different probability levels (%). Mean and standard deviation (SD) are also presented.

4. EXTREME WIND CONDITIONS.

The maximum 10 min wind speed recorded at Sola in May and June 1957 -1986, is 18.5 m/s (8 Beaufort), occurred at 01.05.73. The 10 year summer storm (June - August) calculated is 17 m/s (3). S. Fikke also have calculated the spring storm (March - May) to 21 m/s. We think that the summer storm 17 m/s is valid also from May 25, while 19 m/s should be used for the first half of the month.

It is of interest to see the actual occurence of FX ≥ 7B and FX = 8B.

SOLA 1957 - 86

EVENT	MAY 01 - 15	MAY 16 - 31	JUNE 01 - 15	JUNE 16 - 30	TOTAL MAY+JUNE
FX≥7B	28 (6.2%)	17 (3.5%)	5 (1.1%)	6 (1.3%)	56 (3.1%)
FX=8B	4 (0.9%)	1 (0.2%)	0	0	5 (0.3%)
1.D:FX≤3B 2.,3.,OR 4.D:FX=7B	5 (1.1%)	1 (0.2%)	2 (0.4%)	2 (0.4%)	10 (0.6%)
1.D:FX≤3B 2.,3.,OR 4.D:FX=8B	0	0	0	0	0

Table 4. Number of cases and percental occurence of strong wind events in May and June at Sola 1957 - 1986. FX is the maximum wind speed of a 24 hour period (19 - 19 o'clock local time).
Symbols: D: day
B: Beaufort

From the table it is seen that days with maximum 10 minute wind speed, FX = 8B are very rare in May and June (<1% of the days). It is also seen that the risk of FX = 7B within 3 days when FX ≤ 3B the day before is very low (<1%), and that 8B has not occurred at day 1, 2 or 3 after a day with FX ≤ 3B, within the last 30 years.

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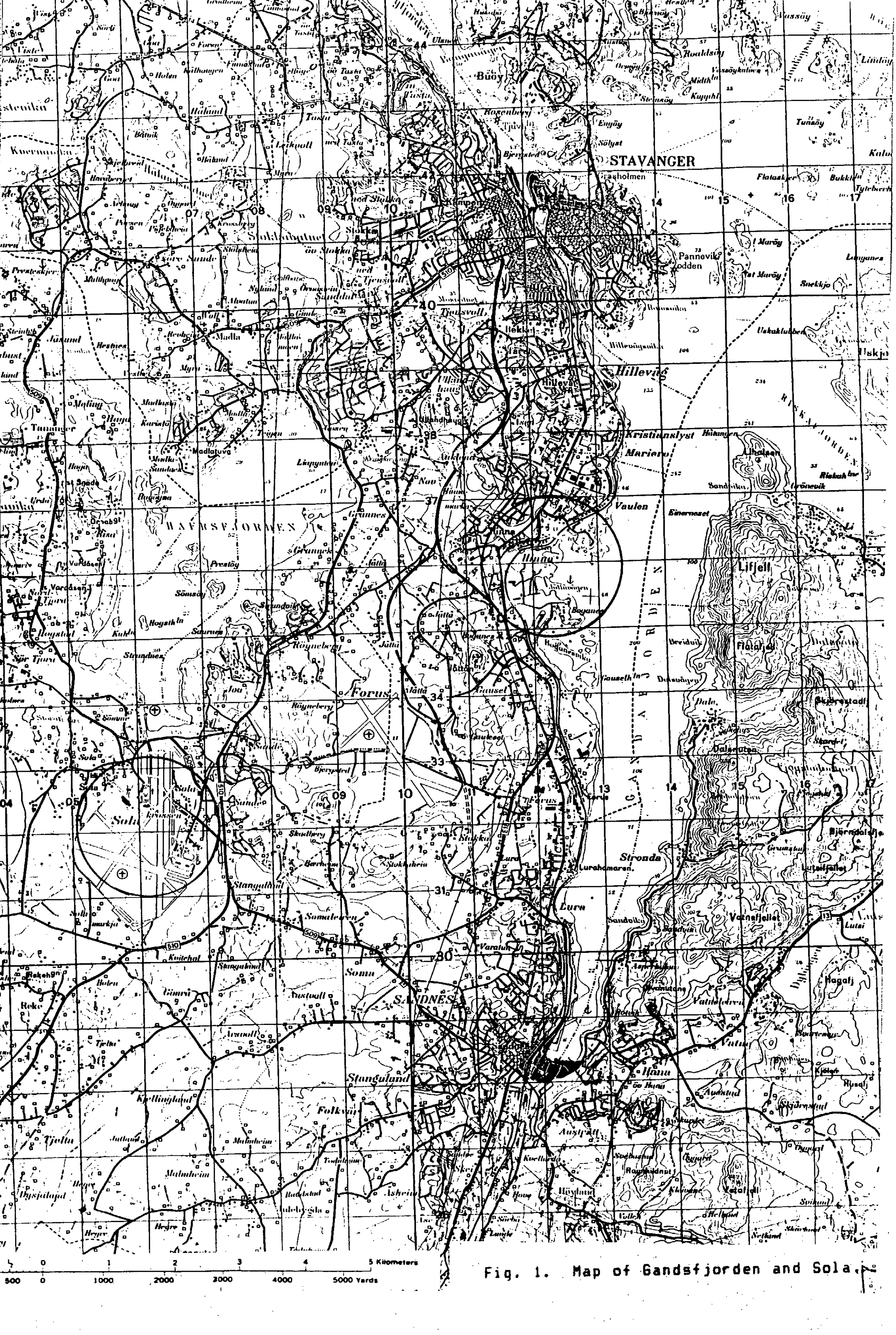


Fig. 1. Map of Gandsfjorden and Sola.

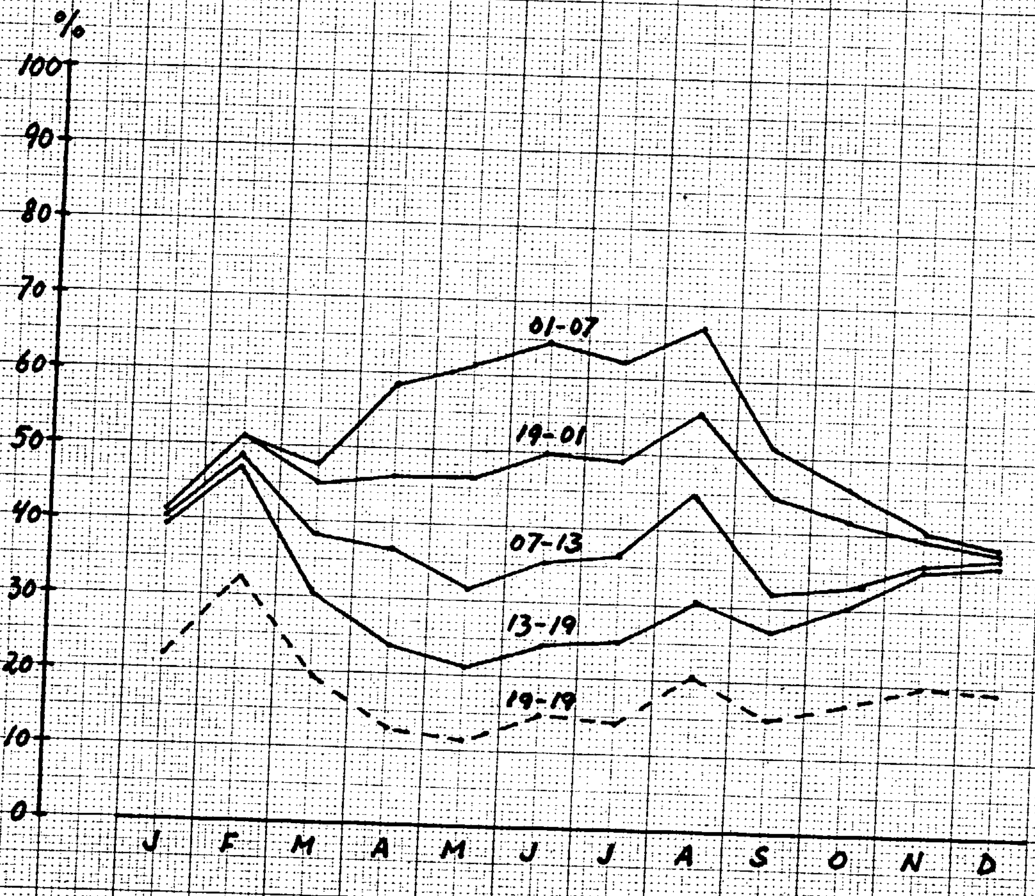
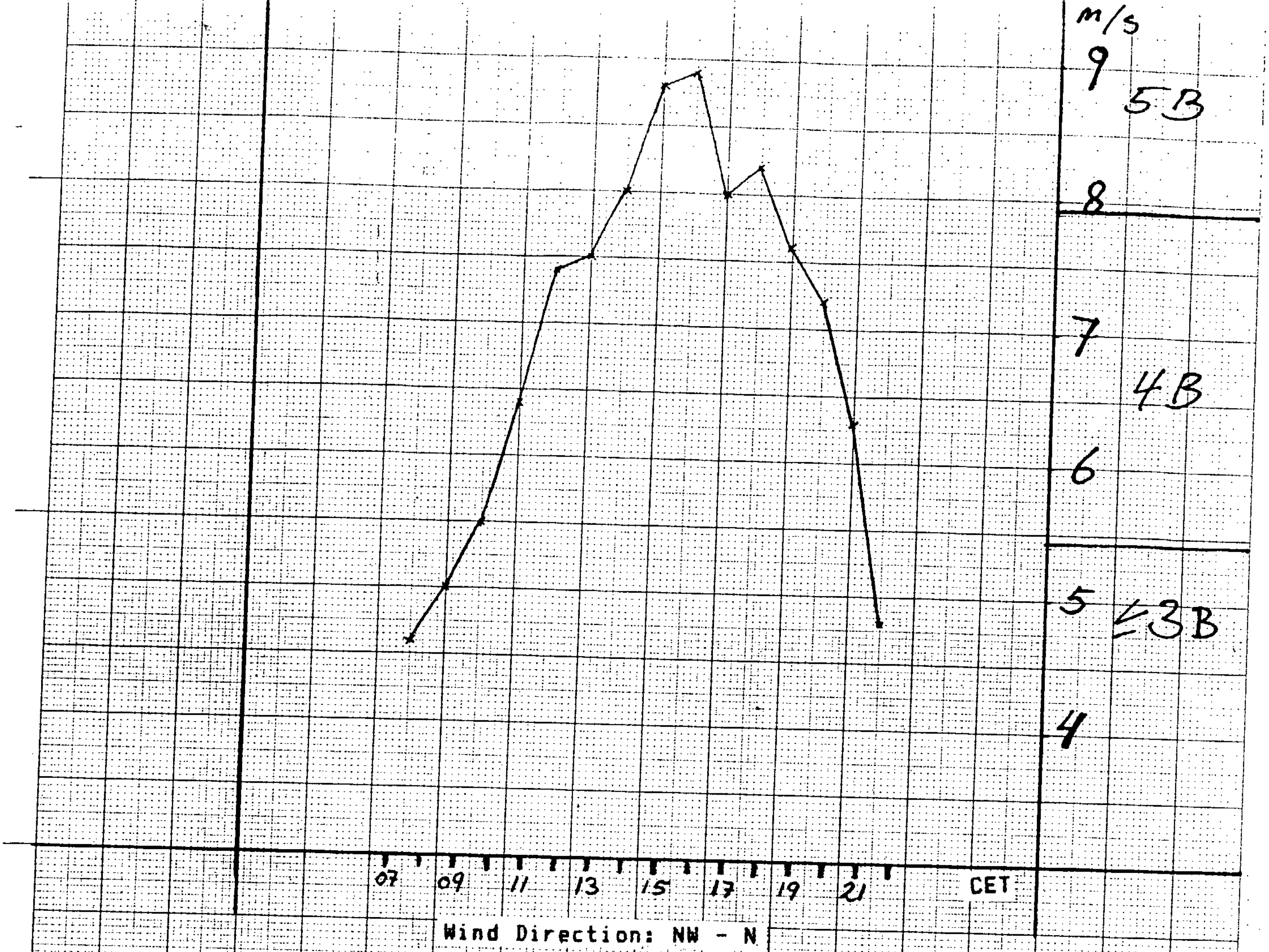


Figure 2. Diurnal variability of the probability for having FX ≤ 3B during a year.



Time	June 1986 26.	27.	28.	July 1986 11.	12.	13.	Mean FX kts	m/s
	FX (kts)							
07-08	1	6	6	14	14	13	9.0	4.6
08-09	2	8	5	14	17	12	9.7	5.0
09-10	3	9	8	16	16	12	10.7	5.5
10-11	5	10	9	17	20	14	12.5	6.4
11-12	8	10	13	19	22	14	14.3	7.4
12-13	8	10	13	18	24	14	14.5	7.5
13-14	8	11	16	19	24	15	15.5	8.0
14-15	10	12	14	23	26	18	17.2	8.8
15-16	11	12	13	23	27	18	17.3	8.9
16-17	8	11	12	20	25	17	15.5	8.0
17-18	6	10	15	23	26	16	16.0	8.2
18-19	6	10	13	23	22	14	14.7	7.6
19-20	6	9	14	22	20	13	14.0	7.2
20-21	6	7	10	20	18	13	12.3	6.3
21-22	5	4	9	15	13	10	9.3	4.8

Fig. 3. Daily variation of the wind speed at Sola during 6 days of sea breeze, summer 1986.

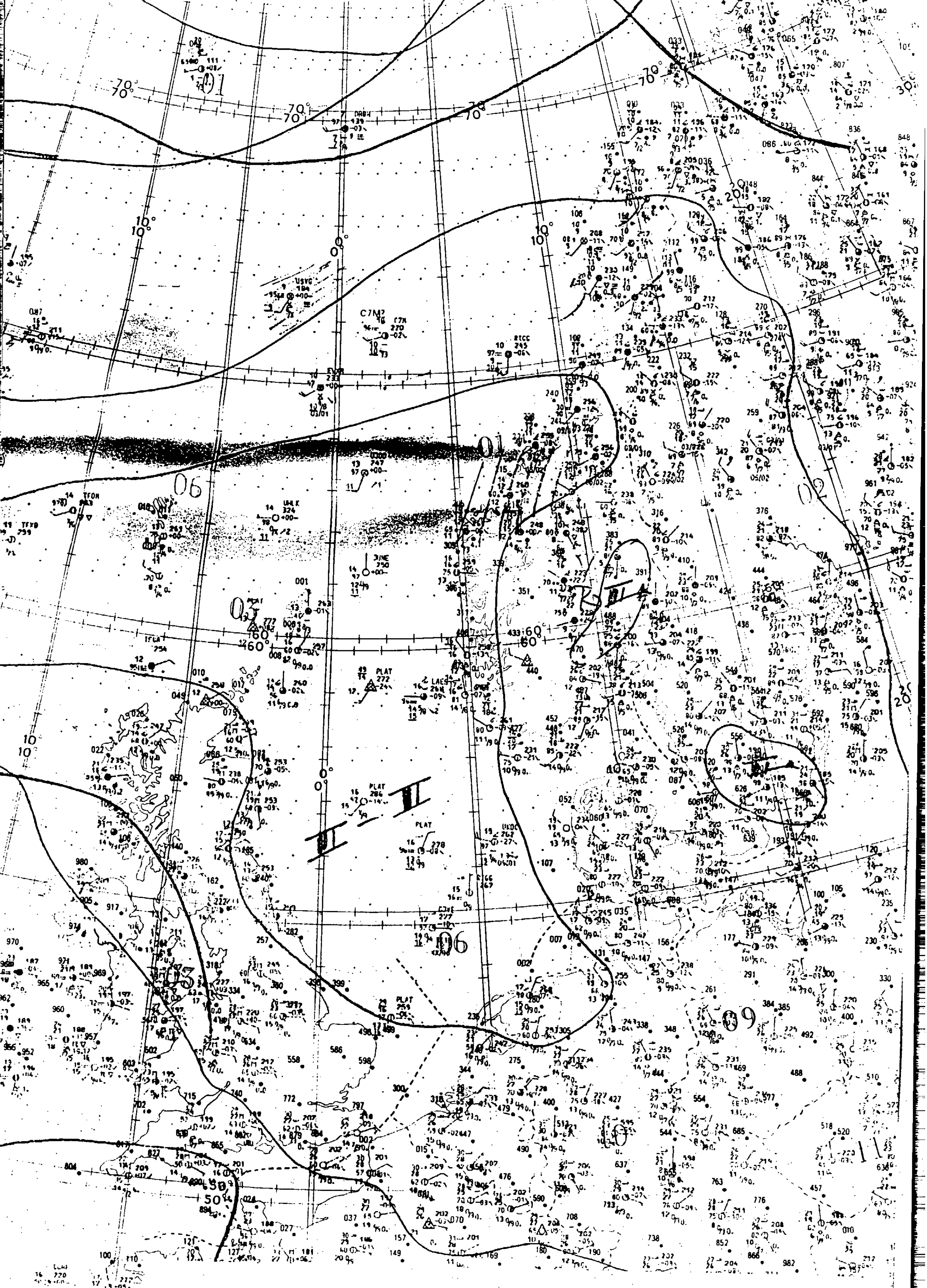


Figure 4. Weather map for June 27 at 18 GMT.

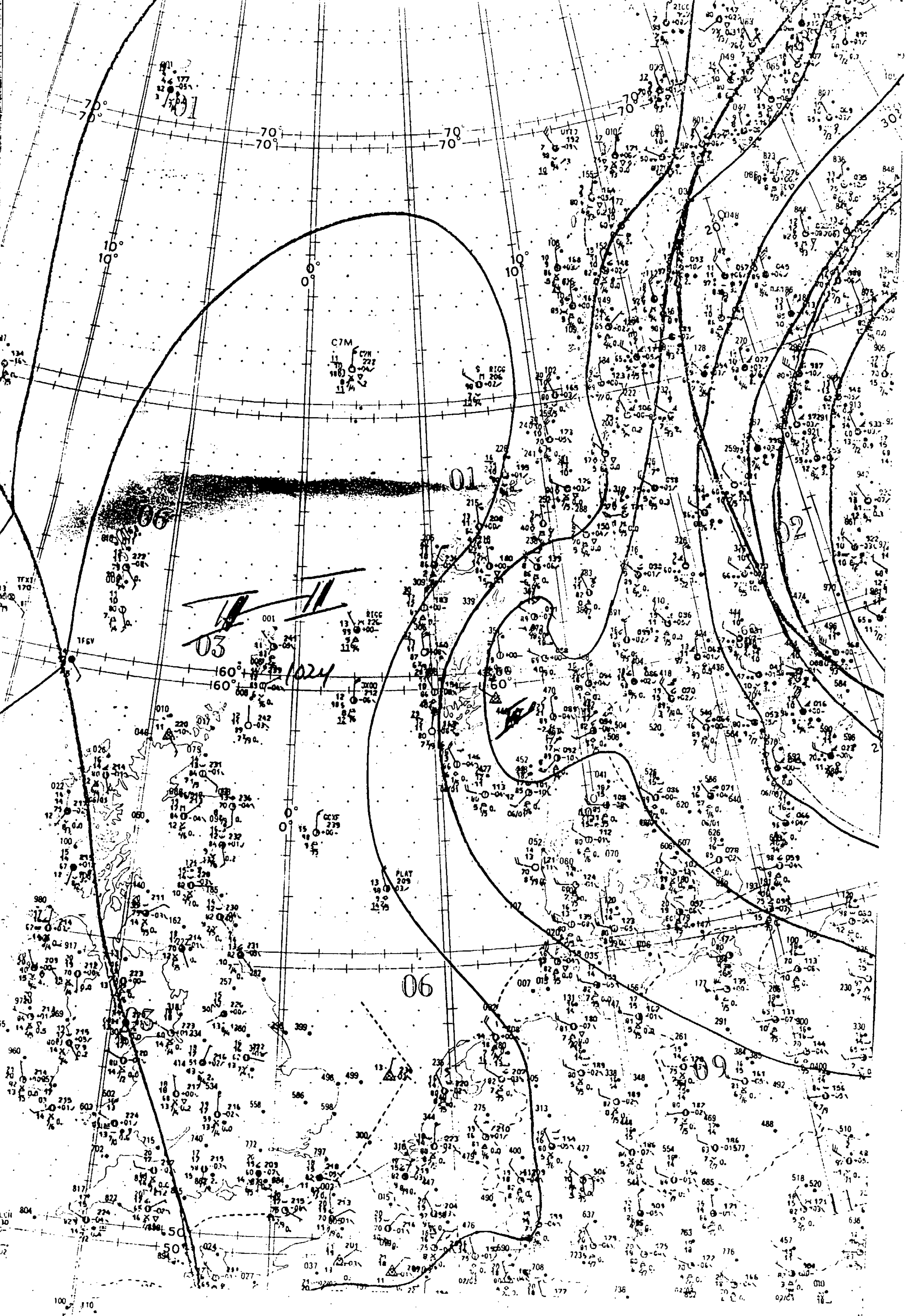


Figure 5. Weather map for July 12 at 18 GMT.

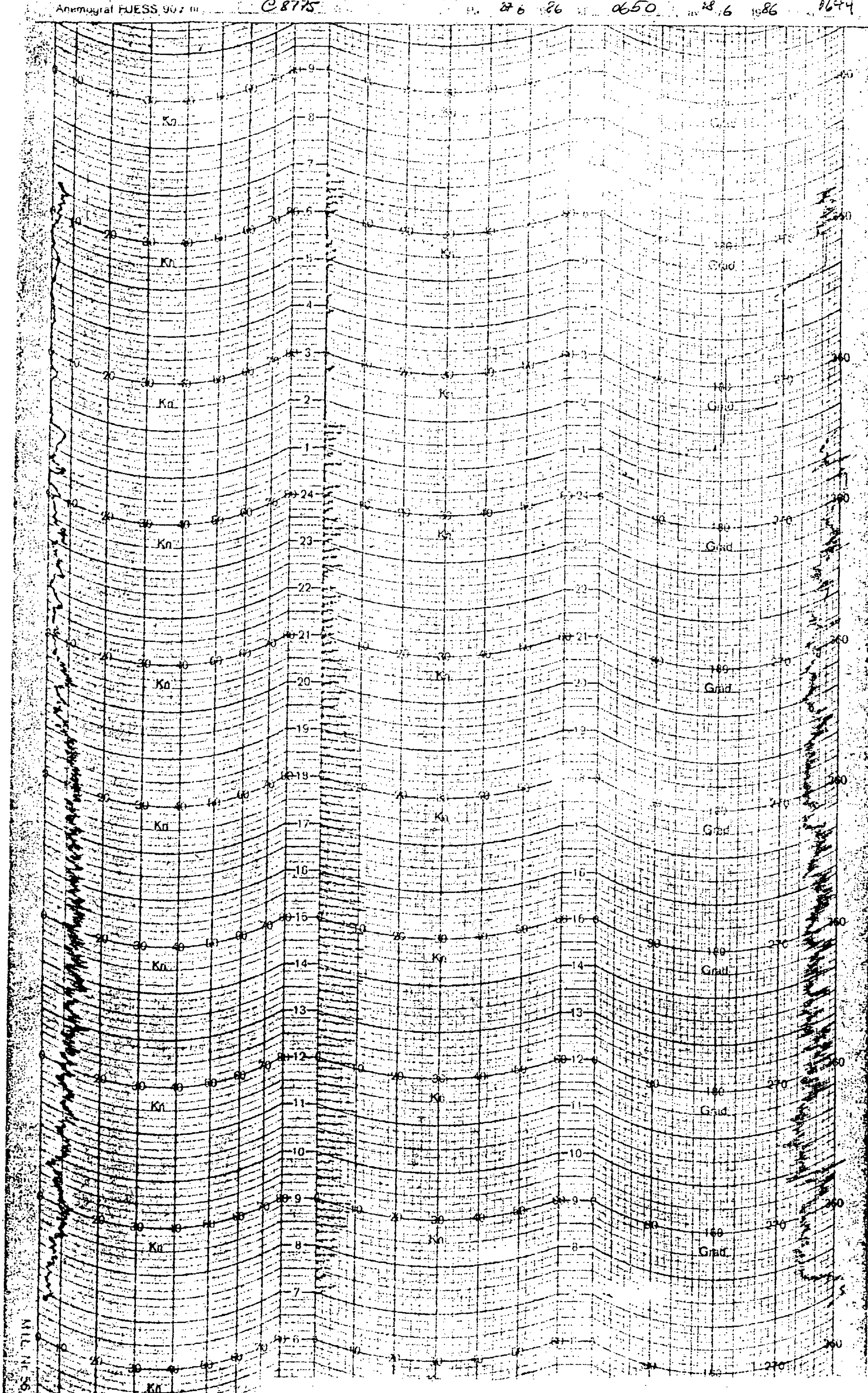


Fig. 6. Wind record from Sola at June 27, 1986.

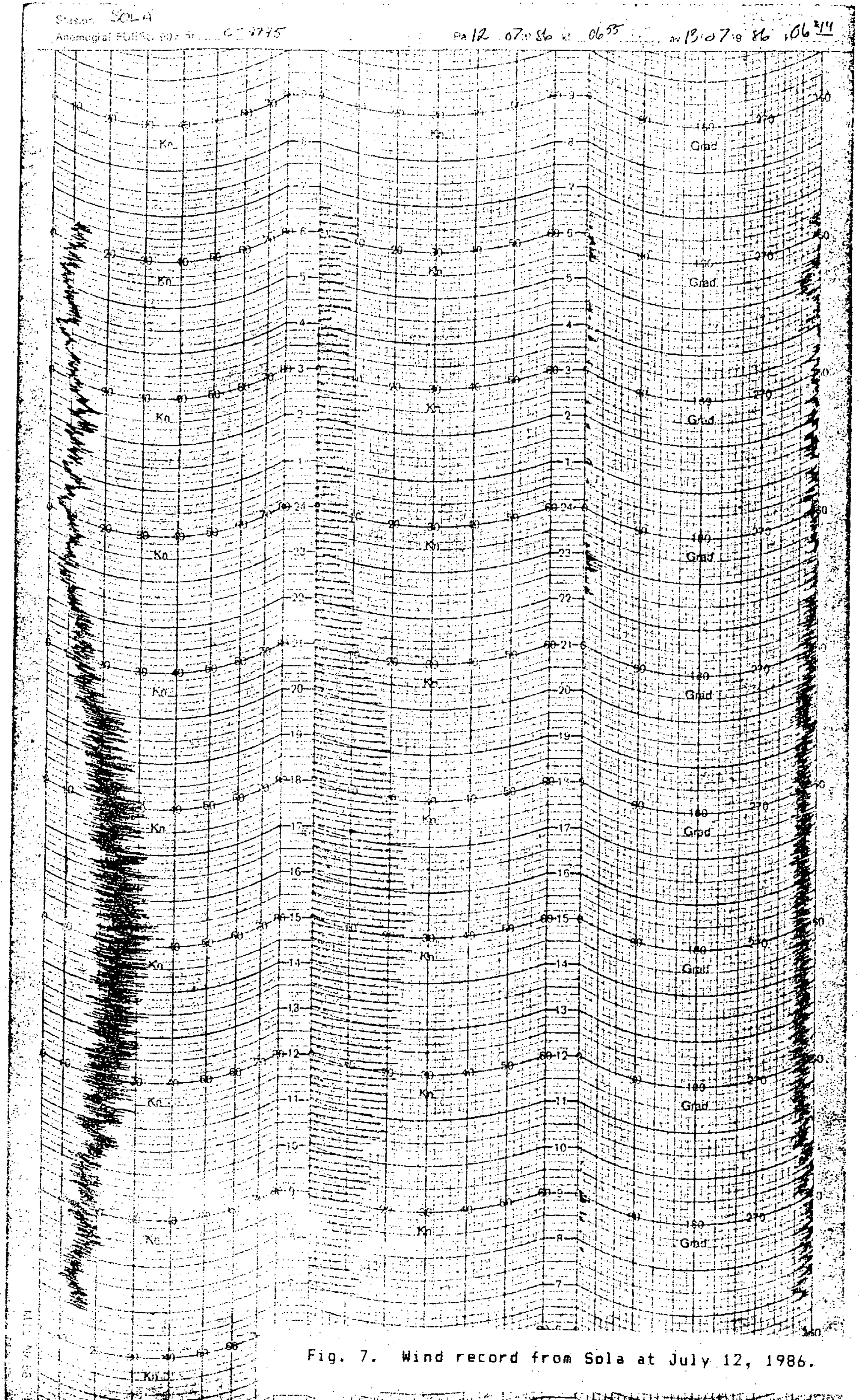


Fig. 7. Wind record from Sola at July 12, 1986.

APPENDIX 1.

Method of countings and application of Markov chains.

We have used a data programme that makes the countings described in Chapt. 3.1 (unfortunately for only the same event for the period concerned), where the result day by day is listed in a table and summed for 1, 2 and 3 consecutive days. To count sequences of 3666, for example, we had to use two tables with the events 3 and 6 Beaufort respectively. As a result we got the relative frequency of the event 3666 for each month.

As known from the statistical theory the probability of an event is taken as the relative frequency of occurrence of that event when the number of observations is very large. We have noticed that there may be large variations in number of cases from year to year. These variations has a random nature and the choice of data series may have great influence on the computations of relative frequency. That means that even data series as long as 30 years may be rather short, when we shall interpret the relative frequency as a probability. However, we have given an evaluation of the reliability of the results by applying a Student T-test.

Here it is interesting to look upon periods of 2, 3 ,and 4 days with the criteria mentioned above. To avoid too many manually countings, we will use the transition probabilities in the Markov chains, see f.ex. (5). This theory states that the probability for an outcome (i.e. $B \leq 6$ or $B > 6$) in a sequence of events depends upon the outcome of the immediately preceding event. We then have:

$$P(X(1)Y(2)...Y(n)) \approx P(X).P(Y)X.[P(Y)Y]^{n-2} ,$$

which also may be put into the general formula for conditional probability (Eq. 3.1), to calculate the actual probabilities.

To find the 2, 3 and 4 days periods mentioned above we then only have to count: f(34), f(36) and f(46) in addition to those already counted by the computer (f(3), f(4), f(6), f(33), f(44) and f(66)).

For May we have compared some countings (f) with the corresponding calculations based on the transition probabilities (M) :

P(3333)=0.008(f)	P(3666)=0.10(f)	P(4666)=0.47(f)	P(66)4=0.96(f)
P(3333)=0.003(M)	P(3666)=0.11(M)	P(4666)=0.48(M)	P(66)4=0.95(M)

From these tests we conclude that applications of Markov chains give satisfactory results.

APPENDIX 2.

Significance of the results.

We now look to the problem of significance of the results in Chapt. 3.1. To get closer to such a problem, we have carried out a T - test of the f(X) values. We then presume that the $f_1, f_2, \ldots\ldots, f_{30}$ are independent relative frequencies, of the event FX $\leq$ X Beaufort for one single month in each of the 30 years. f is the measured average value. We also presume that these frequencies have an approximated normaly distribution $N(\mu, \sigma)$, where μ is the mean value and σ is the standard deviation. The test parameter,

$$T_0 = \frac{(f - \mu)\sqrt{n}\sqrt{(n-1)}}{\sqrt{\Sigma(f_i - f)^2}}$$

then is T - distributed (n-1), n=30.

We now postulate the null - hypothesis : $\mu = \mu_0$, and let μ_0 deviate from f such that $|T_0|$ increases. When $|T_0|$ is large, we will get a low probability for a correct null hypothesis, which means that f most probably deviates significantly from μ_0. The probability for a correct null hypothesis is called the significance level of the test. We then are able to find which values of μ_0 that corresponds to established significance levels.

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EVENT	f,P	SD(f)	$f-\mu_0$		
			$\|T_0\|=1.31$ $\alpha=10\%$	$\|T_0\|=1.70$ $\alpha=5\%$	$\|T_0\|=2.04$ $\alpha=1\%$
f(3) MAY	0.12	0.11	0.03	0.03	0.05
f(3) JUNE	0.15	0.08	0.02	0.02	0.03
f(4) MAY	0.52	0.17	0.04	0.05	0.08
f(4) JUNE	0.54	0.13	0.03	0.04	0.06
f(6) MAY	0.95	0.06	0.01	0.02	0.03
f(6) JUNE	0.98	0.02	0.005	0.007	0.01
THEORET. BINOMINAL DIST. n=30	0.50	0.09	0.021	0.028	0.040
	0.10 / 0.90	0.05	0.013	0.016	0.024
	0.01 / 0.99	0.02	0.004	0.006	0.008

Table A. Results from a T - test performed on the f(X) data from Sola. The f - μ_0 numbers (see text) are given for different levels of the test. For example, for f(4), that is FX $\leq$ 4 Beaufort, in May, we have f - μ_0 = 0.08 at 1 % level. We are then 99 % sure that P(4) < 0.60, or correspondingly, > 0.44. Also significance levels for a theoretical, binominal distribution for n=30 is shown. The standard deviation of the monthly frequencies, SD(f) is also given.

From the table we find that the actual frequencies (interpreted as probabilities) are somewhat less accurate than the theoretical values from a binominal distribution, approximated to normality. Here SD(f) = $(1/M)\sqrt{np(1-p)}$, where M is the number of days in the month. This, of course, is to be expected. The variations, however, are related. This tells us that the reliability of other events most probably follows the same pattern. That is, for probabilities of 0.50, the 10 % level is found for a deviation of 0.03 - 0.04, and the 1 % level for 0.06 - 0.08. For 0.99 and 0.01 the corresponding numbers are <0.01 and 0.01. A conclusion from this discussion is that the closer the probability to 1 or 0, the more accurate is the result (although the relative accuracy is low near 0). The probabilities of 0.9 - 0.99 therefore are very accurate determined.

When comparing different events in Table 1 , we can, by using Table A, get a good idea of to what extent the difference of the probabilities are reliable. For example, we may compare corresponding events in May and June. If we find no overlapping when adding the number of Table A under a given significance level, to the lowest probability of the two months, and subtracting it from the highest, we can be quite sure that the signinificance level is valid. Some overlapping may be tolerated, too, but not much since the two monts are correlated. For example, P(3) + 0.03 = 0.15 in May, and P(3) - 0.02 = 0.13 in June for the signinficance level, α = 10 %. The difference therefore is not significant. Correspondingly, P(6) + 0.02 = 0.97 in May and P(6) - 0.007 ≈ 0.97 in June for α = 5 %. This difference is significant at a 5 % level.

When doing comparisons as above for all events, we find that most of the differences which include the event FX ≲ 6 Beaufort in one or several days, with or without a condition of low wind speed the day before, are significant lower in May than in June, the significance level being 5 - 10 %. This is not unexpected since strong wind fields are more common in spring than in summer. We think that the first part of May month mostly contributes to this difference.

Another type of event also shows significant differences of 5 - 10 %. The probability of having FX ≲ 4 Beaufort in two or three days, presuming that FX ≲ 3 or 4 Beaufort the day before is higher in May than in June. The wind blow more easily up to 5 - 6 Beaufort in a calm period in June. We will not follow this point further on, only suggest that the reason may be shorter situations of high pressure system over land, or stronger sea breeze effects.

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Our ref.: TAH/ibj Your ref.: 343.2/496/87 BA/MB 1320 Stabekk, 9. februar 1987

Vær- og operasjonskriteria for Hinnavågen. Beregning av sannsynligheter

Det vises til telefonisk henvendelse av 29. januar 1987 til Dem, samt Deres brev av 3. februar 1987 med referanse 343.2/496/87 BA/MB.

Videre vil vi referere til telefonsamtale med Deres herr Knut ~~Heistad~~ Harstveit 3. februar 1987.

Følgende oppdrag ønskes bekreftet utført:

Sannsynlighetsberegninger for 4-døgns perioder hvor vindhastigheten ikke overstiger:

a) 3 Beaufort første døgn,
6 Beaufort andre til fjerde døgn.

b) 3 Beaufort første døgn,
4 Beaufort andre til fjerde døgn.

c) 3 Beaufort første til fjerde døgn.

For disse 3 eksemplene vil kriteriet på Beaufort 3 den første dagen utgjøre en faktor som i stor grad vil påvirke beregningene.

Det er derfor ønskelig å gjøre bildet noe mer komplett for å kunne trekke noen slutninger av beregningene. Vi ber Dem derfor utføre følgende beregninger i tillegg:

Sannsynligheten for følgende vindhastigheter når en tar i betraktning at vi allerede har fått vind på Beaufort 3 eller mindre første dag:

d) 4 Beaufort andre til fjerde døgn.

e) Mer enn Beaufort 6 andre til fjerde døgn.

Videre sannsynligheten for følgende maksimum vindhastigheter:

f) 4 Beaufort første til fjerde døgn.

g) 6 Beaufort første til fjerde døgn.

Samtlige analyser ønskes utført for Hinnavågen, Gandsfjorden for månedene mai og juni.

For den videre planlegging i prosjektet er det av særlig stor betydning at vi kan få presentert de beregninger som er blitt utført snarest mulig.

Vi bekrefter derfor avtalen av 9. februar 1987 om en presentasjon på Stabekk torsdag 12. februar 1987 kl. 09.00.

Med vennlig hilsen,
for NORWEGIAN CONTRACTORS

G. Kure
Engineering & Contract Manager

Tor A. Hauer

Tor A. Hauer
Discipline Supervisor
Nautical Arrangements