B. Interpretation of surface wind direction and speed

1. Introduction

I shall start with showing you the results of a verification test carried out in Sweden and concerning the errors in forecasts of surface wind speed. Fig. B1 shows along with the verification diagram the position of those coastal stations to which the verification applies, Vinga, Falsterbo, S. Öland and Östergarn. Although this test was based on a fairly small material, namely two forecasts a day during a single month (December 1967), the general trends in the diagram can nevertheless form the basis for useful discussions. Here I compare numerical interpretation forecast with forecasts issued by the duty forecaster just before he received the computer products. Such was the arrangement. Also compared in the same diagram are persistency forecasts and pure climatological forecasts, which in this case means always saying 8 m/s irrespectively of the current weather situation.

Thus, in the verification diagram these fixed climatological forecasts have constant R.M.S. error, amounting to slightly less than 5 m/s. As to the time axis I must indicate that zero here stands for the time of issuing the forecasts. The last available observation was made 2 hours earlier, which means that at t=-2 the error in persistency forecasts was equal to zero. The error of persistency increases rapidly. Already 8 hours after observation the persistency forecast was less reliable than the climatological forecast.

Looking now at the forecasts made by the duty forecaster, they prove to be much better than persistency - but even these forecasts loose their value as compared with the simple climatological forecast after a certain time. During the test period this happened after 19 hours. This should not be considered as a figure which applies in all cases. But I think it is true that after about 24 hours, forecasters are not able to give detailed wind speed forecasts.

The straight line starting at t=-7 represents automatic interpretation of numerical forecast maps with the relatively simple method now used in Sweden. At t=-7 the RMS error equals 2.6 m/s. This is the error in the interpretation method applied on the analysis map on which the numerical forecasts are based. From 12 hours after the issue these forecasts were more correct than those of the forecaster. Curve (a) indicates the improvement of these forecasts achieved by simply speeding up the computer work; (b) shows the possible effect of improving the numerical technique and (c) the additional improvement which would probably be achieved by improving the interpretation technique by including persistency and by other refinements.

I am aware that detailed interpretation of the surface wind is not very interesting when dealing with the 5-10 day forecast products from the Centre. Nevertheless I shall go on discussing this problem. As I see it; the difficulties, the shortcomings and the objections of principle that we meet in wind interpretation have their implication also in other types of interpretation, although maybe to a lesser degree.

2. Experiencies from a pilot project dealing with surface wind conditions around Norrköping

Let me bother you again with Swedish geography. Fig. B2 shows the area around Norrköping situated in southeastern Sweden. Places shown on the map are those synoptic stations which measure atmospheric pressure.

The pressure gradient over this area has been determined within each one of the 7 triangles indicated on the map. It was shown, particularly by studying situations with light winds, that the pressure observations at two of the stations had to be corrected by 0.5 and 0.6 mb, respectively in the whole material. Even after this correction had been made there could at times appear considerable differences in the gradients found over the seven triangles. As an alternative, the pressure gradient over the area was determined in a way corresponding to measuring it over a grid distance equal to 180 km.

The pilot study dealt with a small sample, being a special selection of data, altogether32 days, comprising 2 strong gale situations, 2 near gale situations and 4 light wind situations, and with all wind directions represented. I would like to concentrate here in my presentation on one day when strong gale to storm occurred at the coastal station Landsort, (4-5 April 1973). During this period triangles A, B and C had most features in common. So had D,E and F but they were different from those of the first three triangles, whereas the variations of the pressure gradient measured over G was quite different (Fig. B3).

When the gradient was measured over a grid cross (Landsort, Västervik, Västerås and a combination of Karlsborg and Örebro) a smother time-variation-curve was obtained, approximately averaging the values obtained over the triangles.

I have mentioned this to stress that the pressure gradient might in cases be far from uniform even over such a small area as this, and even if it is, the gradient cannot be established adequately over too small test areas. The idea was also to stress the type of disturbancies in the statistical material which can be created by systematic observational errors, and that those errors should, if ever possible, be deleted before the final investigation starts.

Next step is to investigate how the actually reported surface wind varied during the same period at stations within the area. The stations are shown on

Fig. B4 .Some of the stations are well situated for wind observations, others are not. Most of the stations are equiped with anemometers. For the further discussion, note in particular the position of Landsort, Harstena and Norrköping. Figure B 5 compares the average of the geostrophic wind computations - the upper curve - with the reported wind speed at those 3 stations. The only place where strong gale (>21 m/s) and storm (>24 m/s) was reported was at the coastal station Landsort. You see that compared with the geostrophic wind there seems to be a time-lag between gradient and wind of about 3 hours. The same holds for the other coastal station, Harstena, where, though, due to its location in a small archipelago, the place is less exposed to the wind. At Norrköping - and I don't know why, the wind culminates before the maximum gradient is established.

In discussing interpretation of forecast maps, I think it is generally agreed that wind speed and wind direction should be the parameters most easy to interpret. You only have to find the ratio between observed and geostrophic wind speed and the typical angle between the wind and the isobar. And of course, possibly, how these factors vary from one sector to another.

By this detailed discussion of the wind conditions in one particular gale situation I have tried to show that there are complications in finding the characteristics of various wind stations.

The following items are the main results of this pilot study:

- The gradients determined over the 180 km grid are in general more closely related to observed winds than are gradients determined over the small triangles. If uncorrected pressure observations are used, the correlation is bad.

- Winds observed at the hour H are equally well correlated to the gradients observed at H and at H + 3 hours, but much less correlated to gradients at H+6 hours.

- There are clear indications that the conditions are different in different sectors and that the individual stations differ in this respect due to their particular location. However, the very limited sample used in the pilot study is not sufficient for establishing these characteristics in detail.

- There is a marked diurnal variation in the wind speed. In fig. B4 the relative amplitude of this effect is shown at each station. It very much depends on the topographic location of the station. Västerås, Eskilstuna, Örebro, Nyköping, Norrköping, Karlsborg and Linköping are airports. Falerum has a very complicated topography. The diurnal variation is most clearly seen under flat gradient conditions but it is distinguishable also in gale situations and could be allotted the same amount in m/s in all situations. By first correcting observed winds by adding for the diurnal effect, a better correlation is achieved between wind and gradient.

- With the limited data available it was not possible to establish any significant effect of land and sea breeze. That can probably only be done by data specially selected for that purpose.

Fig. B6 shows the form of the curve for the diurnal corrections. The figures obtained from the diagram should be multiplied with the amplitude factors shown in Fig B4.

I shall conclude the presentation of this pilot study by a verification diagram.

The formula used for computing the wind speed reads as follows

$$v = A + B \cdot G + F(G) + k \cdot \Delta_d$$

where G is the geostrophic wind, F(G) is the typical correction which varies with the weather type (that is with the direction of the gradient) and Δd is the diurnal correction. For Landsort, A=4, B=0.68, and k=0.9. F(G) is not used in this case,

Fig. B7 presents the observed wind at Landsort during the four day period 4-8 April 1973, as compared with the wind determined from the actual pressure gradient. The period includes the day of strong gale, earlier discussed.

This is an example of the best possible interpretation of the wind speed that can be achieved in a particular case. When the interpretation is applied to forecast maps, the result, of course, cannot be quite as good due to errors in the numerical products and the smothing involved in interpolation between grid-point values.

3. Background to the operational system used in Sweden

Now, I should like to leave the pilot study and go back to the interpretation climatology used operationally in Sweden for the surface wind.

This will allow me to discuss how the wind characteristics vary with the direction of the geostrophic wind. To study this, the statistical material - that is the "historical data" - must be divided into distinct groups which could be called "weather types". That can be done by distinguishing between various predictors and by dividing the values of these predictors into classes. I have often used the average west component and south component of the geostrophic wind over the area, and then dividing both of them in four classes in such a way that each class contains the same number of historical cases. By doing so I obtain 16 "types" and if the two predictors are not too strongly correlated I shall approximately obtain the same number of cases in each one of the 16 boxes.

Fig. B8 demonstrates such a type-classification over Southwestern Sweden. The data used concern December over the years 1949-1964.

The isobars drawn show the average pressure distribution in each "type" and the wind arrows show the corresponding interpreted wind at three coastal stations, Väderöbod, Vinga and Varberg, and two inland stations, Lurö and Jönköping at the great Swedish lakes. Already from this figure it is clear that the different stations do not react in the same way, as to wind and direction, for the same pressure gradient.

Fig. B9 demonstrates this more clearly as far as the wind direction is concerned. First, the stations have got different average angles between the wind and the isobar, amounting from 15°at Väderöbod to 50° at Jönköping. To this adds the deviations from this average which are typical for the 16 "types". It is easily seen from the figure that the stations have got their station characteristics. The similarity from month to month is much higher than from station to station.

The same holds for how sensitive is the wind speed at the station to a given gradient. In Fig. B10 the comparison is made using that pressure gradient 16.3 mb/500 km which on an average would give a surface wind equal to 14 m/s, which is the limit for gale warnings used in Sweden. As I just said, even here each station has its "typical signature".

What forms these signatures, applicable to both wind direction and speed? No doubt, part of it depends on the general geographic position, for instance for the coastal stations that they are located on a west coast; the response to a given gradient being highest for winds parallel to the coast line. Another part of the signature is an effect of the more local topography. There are, undoubtably, also effects of the very nearby topography, and - unfortunately - of the exposure of the anemometer.

This poses a problem of principle - maybe it could even be classified as a moral question concerning the ethics of forecasting.

- Should the forecaster try to forecast as accurately as possible what will be reported by the observer and read on his instruments, thus obtaining a high verification mark, or should he try to filter out the very local effects, including the observational errors, and present as his forecast a value of a more general applicability? The same question holds for all kinds of statistical interpretation. Should it try to grasp all the pecularities in the observational material or rather try to smoth out features of little significance? I think - really - the answer is given. And the way to do it may be to combine data from nearby stations;a form of smothing. That is, to try to find by statistical methods interpretations that hold for areas rather than for particular stations. Then the verification must of course be adjusted to this fact.

4. Verification of the operational system

So far I have discussed the complications in finding reliable interpretation methods for the surface wind. Maybe you have got the impression that the task is rather hopeless, due to difficulties in establishing the true geostrophic wind, the time-lag between gradient and wind in rapidly changing situations, local topographic disturbancies and bad exposure of the anemometer.

Nevertheless, the operational wind interpretation has proven to be fairly successful. Fig. B11 shows a sample of operational forecasts at Landsort. From this sample it looks that even the 48 hours forecast are fairly good. Unfortunately the shortcomings show up mainly in the important gale and storm situations. Here work has to be done to further improve the interpretation technique, and I would suggest that it be done by studying, in particular, periods of high wind and not least cases with rapid increases in the pressure gradient.

In conclusion, let me show some daily figures from one Winter month, December 1977, and one Summer month, July 1978 - taken from our operational verification work. The test concerns 24 hour forecasts at 5 coastal stations; persistency is compared with the duty forecaster and automatic interpretation.It should be noted that in this case the forecaster is aware of the interpretations and can use them as a tool when issuing his forecasts. In the table, 10 is given when the forecast is correct, within certain limits, at all stations. The mark 8 indicates that the forecast is correct at 80% of the stations, and so on. The tolerance interval is ±2 m/s up to 13 m/s, ±3 m/s from 14 to 24 m/s, and ±4 m/s for winds above 24 m/s.

The high quality of the interpretation is evident and if we just compare the first 3 columns in each month, it is seen that the meteorologist's forecast are also rather good, although he could have relied more on interpretation as a forecasting tool. Remembering, however, from Fig. B1 the relative success of simple climatology for 24 h forecasts, attention should be given also to the fourth column. In December the standing forecast is 8 m/s, in July 6 m/s. Note that in July the forecaster is not very much better than that.

Thus far for wind interpretation. As I started before I hope that this has given you useful ideas on the difficulties, complications and matters of principle that turn up in statistical work for interpretation purposes.

Day	December 1977				July 1978			
	Per-sist.	Fore-caster	Inter-pret.	Clim.	Per-sist.	Fore-caster	Inter-pret.	Clim.
1	6	6	10	6	10	10	8	8
2	8	10	8	8	8	10	10	10
3	8	10	10	4	6	10	10	10
4	10	10	8	4	4	8	10	10
5	6	6	10	6	10	8	10	10
6	0	8	8	6	6	6	8	8
7	8	8	8	8	6	10	10	10
8	6	6	6	2	8	10	10	10
9	8	6	4	4	4	2	10	2
10	6	6	8	4	4	8	6	6
11	10	10	8	0	6	10	10	8
12	10	8	8	4	8	10	10	8
13	0	10	10	10	4	8	8	10
14	6	4	8	4	10	10	10	8
15	6	10	8	8	8	10	4	10
16	8	8	8	8	6	10	8	10
17	4	4	6	8	10	6	10	8
18	2	10	8	8	8	10	10	8
19	8	10	6	2	4	6	8	8
20	8	8	10	4	10	10	10	6
21	6	10	6	8	10	10	10	10
22	6	8	10	4	8	6	10	10
23	6	8	4	8	10	10	10	10
24	6	8	10	6	6	4	8	8
25	4	4	4	10	6	6	10	10
26	4	6	8	10	4	10	10	8
27	8	8	10	10	8	8	8	8
28	6	6	10	6	8	8	8	6
29	6	4	3	8	8	4	6	4
30	2	8	10	6	10	10	10	2
31	8	6	8	10	8	10	10	10
Average	6.1	7.5	7.8	6.3	7.3	8.3	9.0	8.2

Table 10

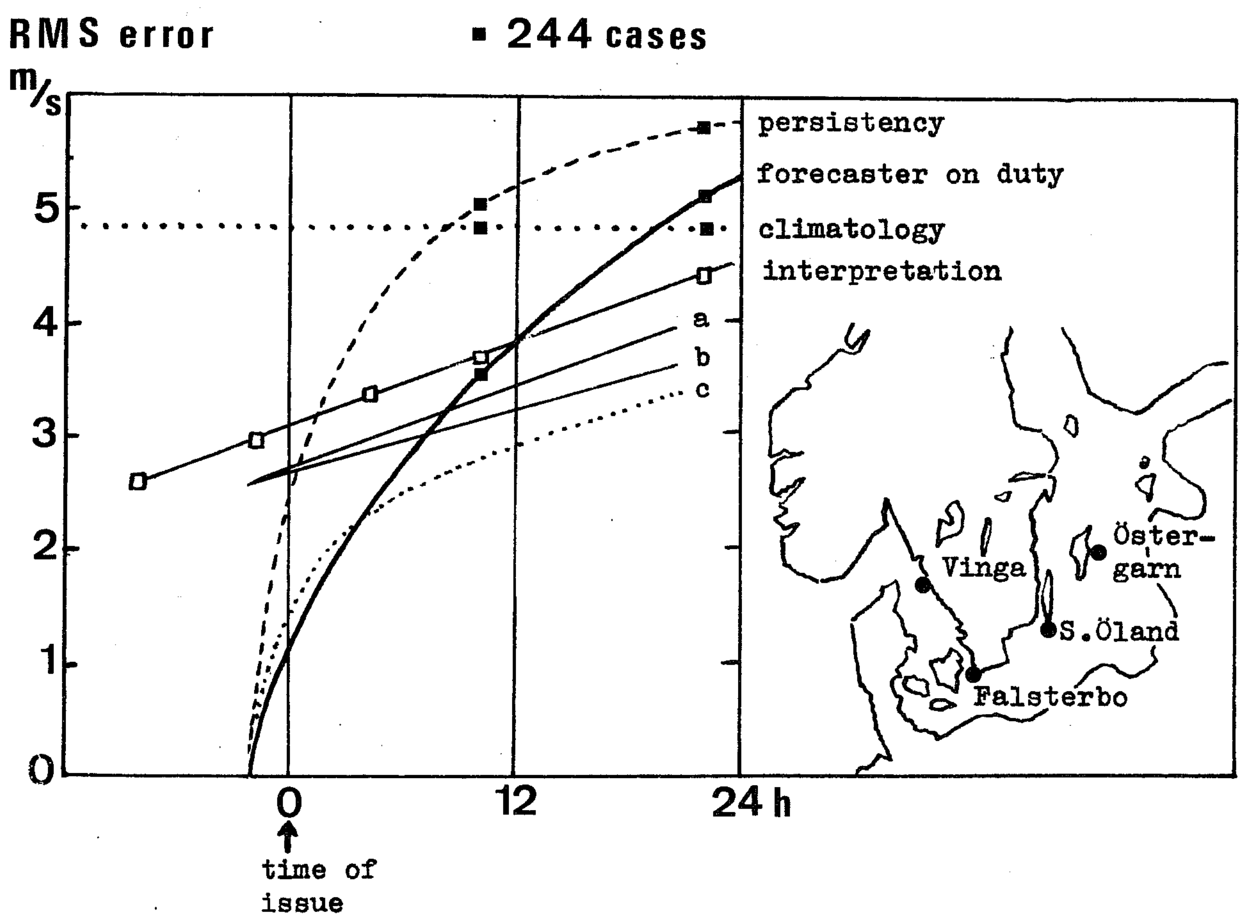

Fig. B1 : Verification of wind velocity forecasts, showing RMS errors as a function of time after issue. Each dot represents 244 forecasts at Swedish coastal stations, December 1967. Curves a, b and c indicate speculated improvements of the interpretation.

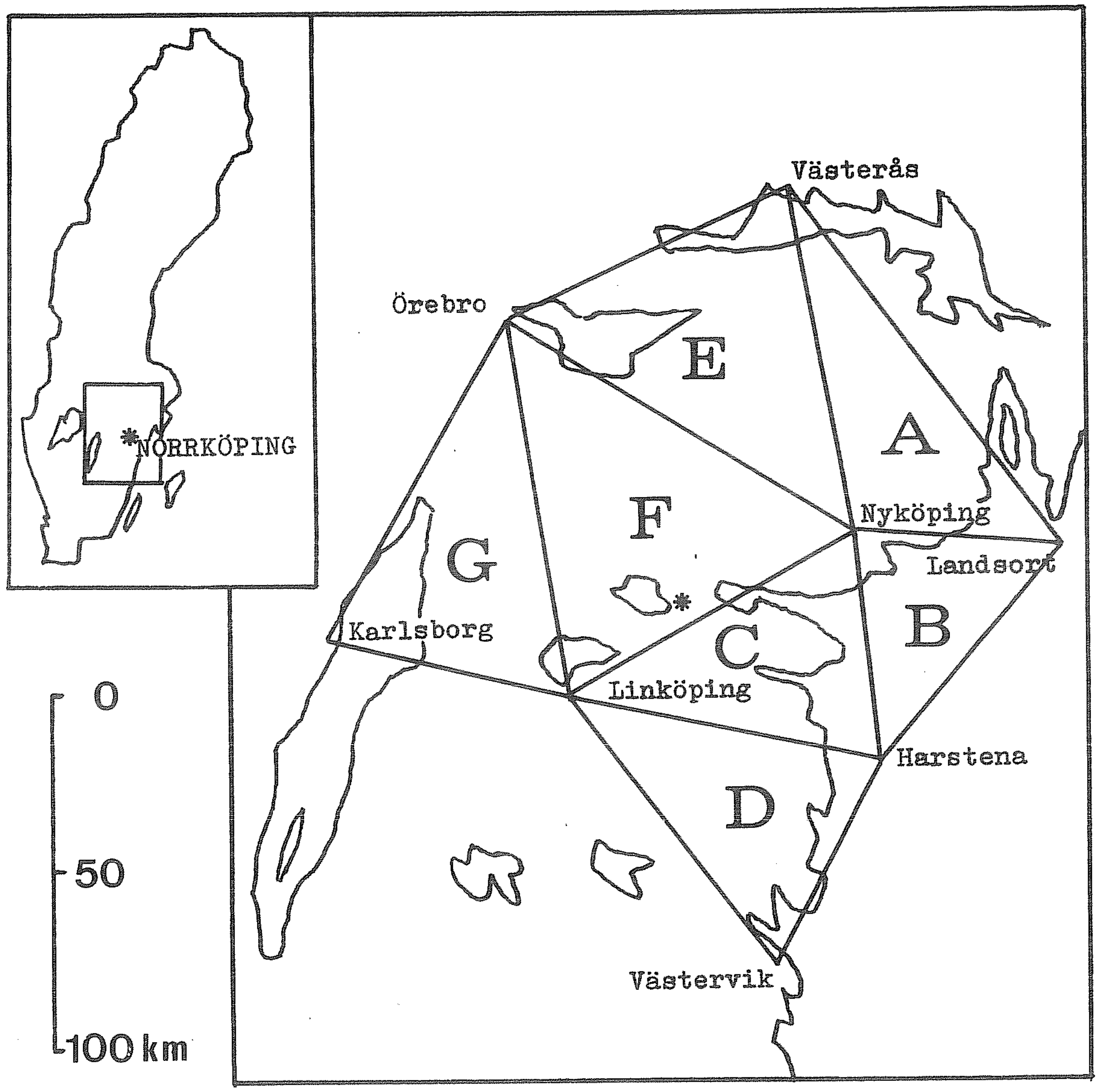

Figure B 2

Pressure observing stations and triangular areas (A through G) used in the surface-wind pilot study in the Norrköping area. Selected sample 1972-1973.

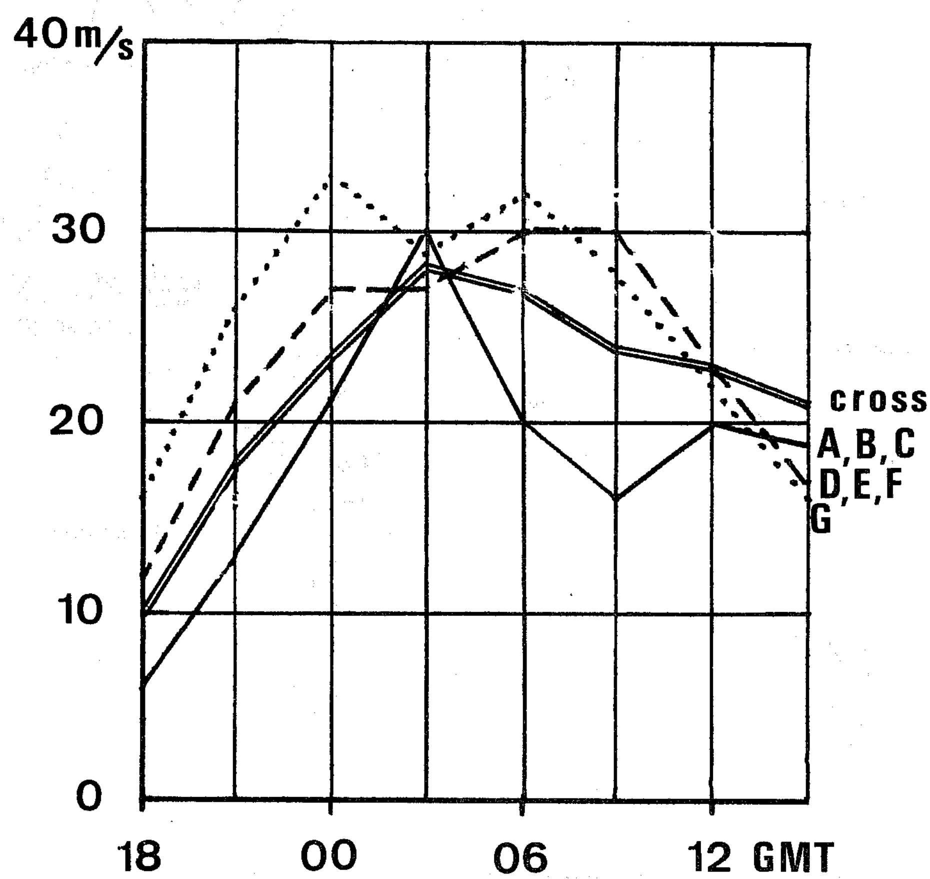

Figure B 3

Geostrophic winds computed over various areas (see Fig. B2), 4-5 April 1973. Curve indicated by "cross" represents computations made over a somewhat larger distance (about 180 km).

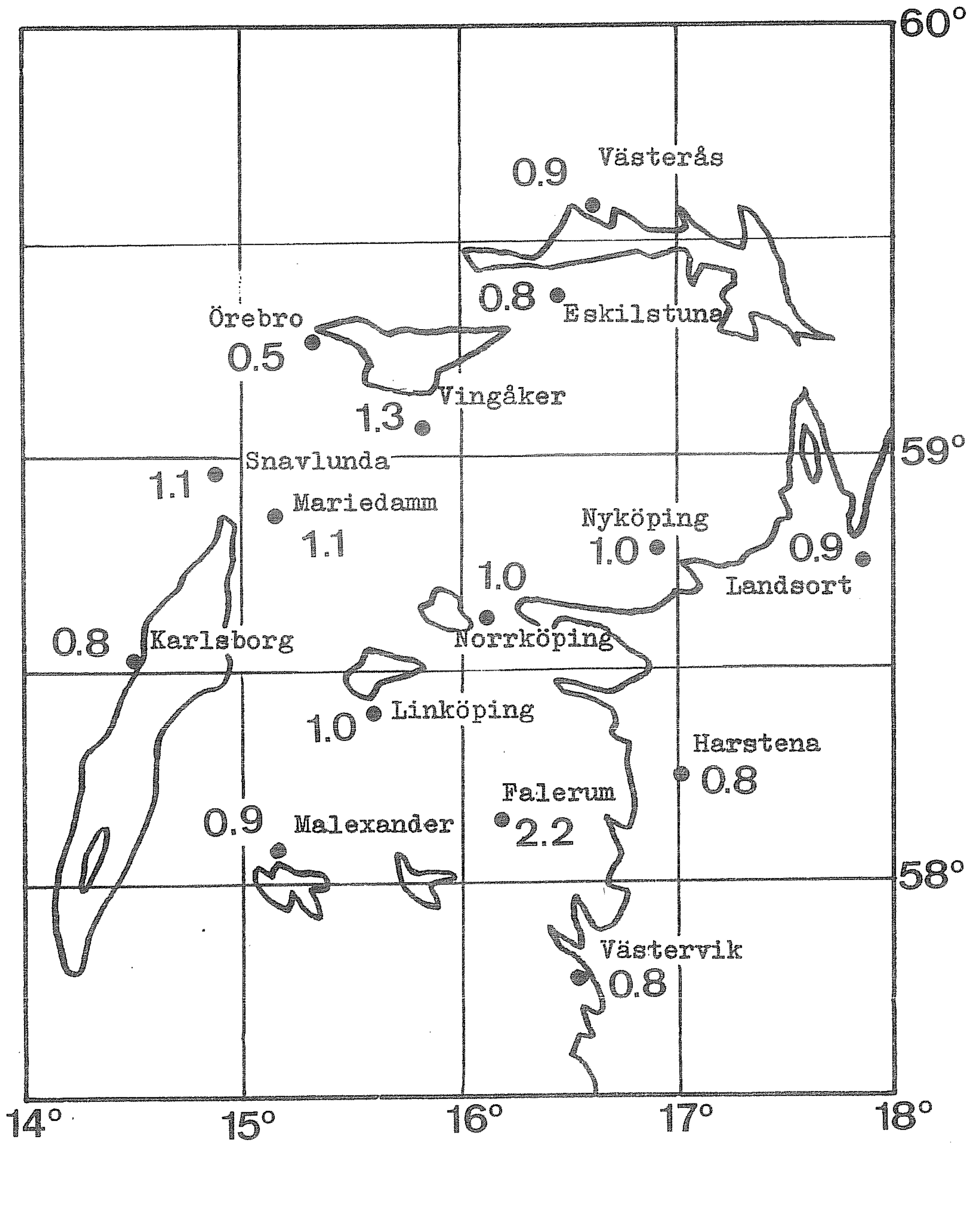

Figure B 4

Wind observing stations used in the pilot study. Figures indicate the amplitude of the diurnal correction shown in Fig. B6.

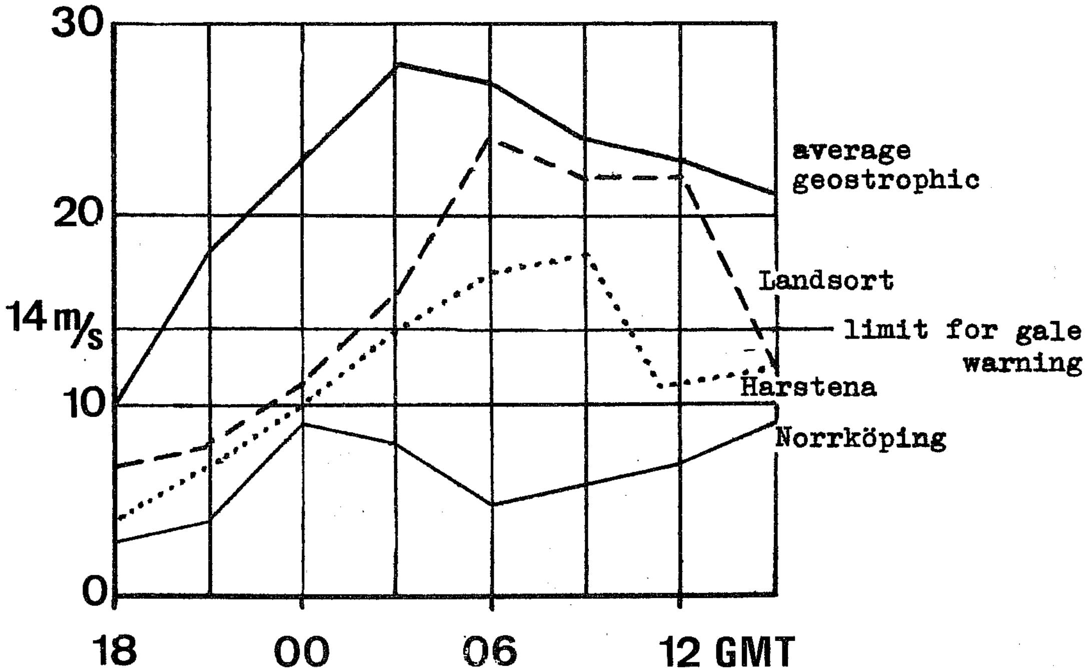

Fig. B5 : Variations of the observed wind, 4-5 April 1973, at certain stations, compared with the average geostrophic wind.

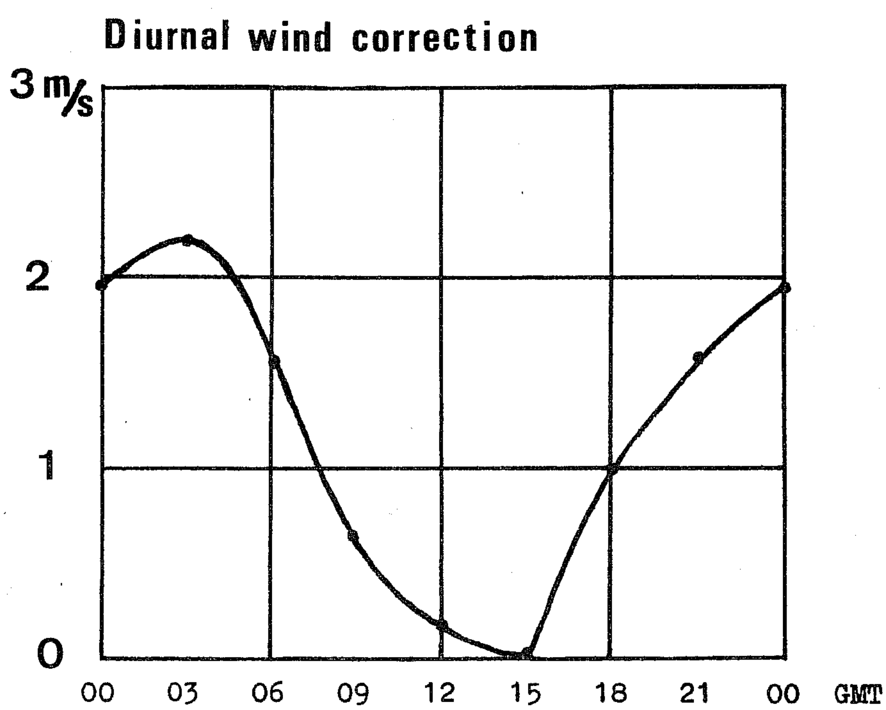

Fig. B6: Diurnal wind correction applicable throughout the pilot study.

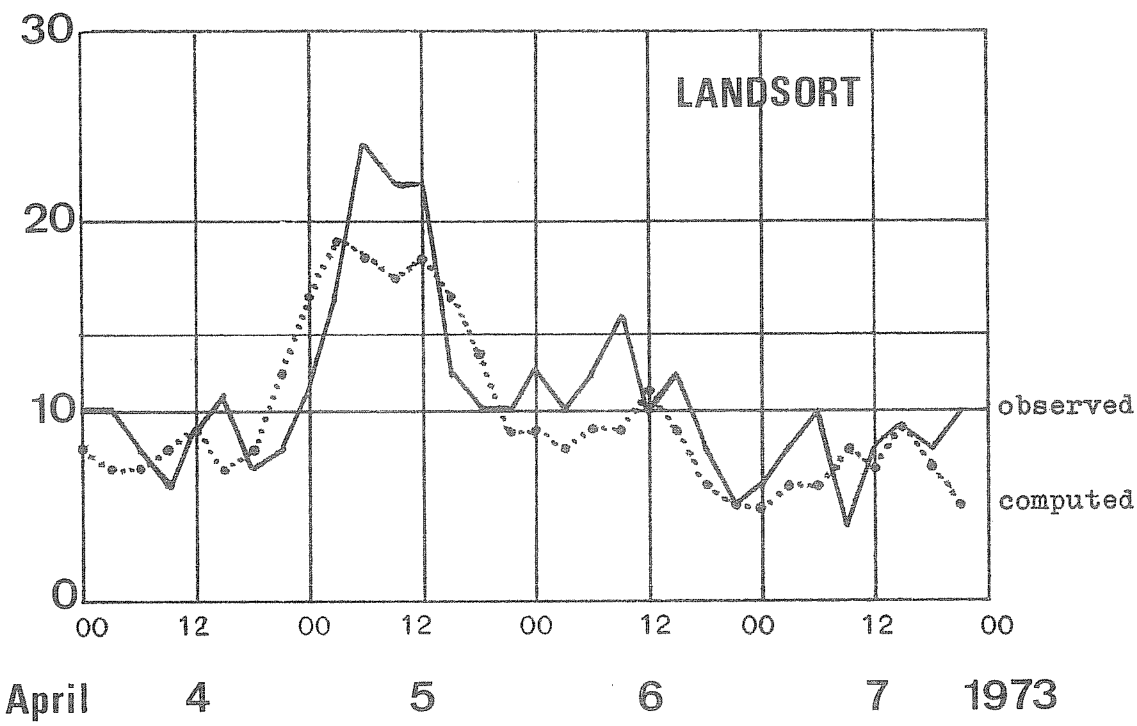

Fig. B7 : Observed surface wind speed at Landsort, 4 - 7 April 1973, compared with interpretation derived from actual geostrophic wind.

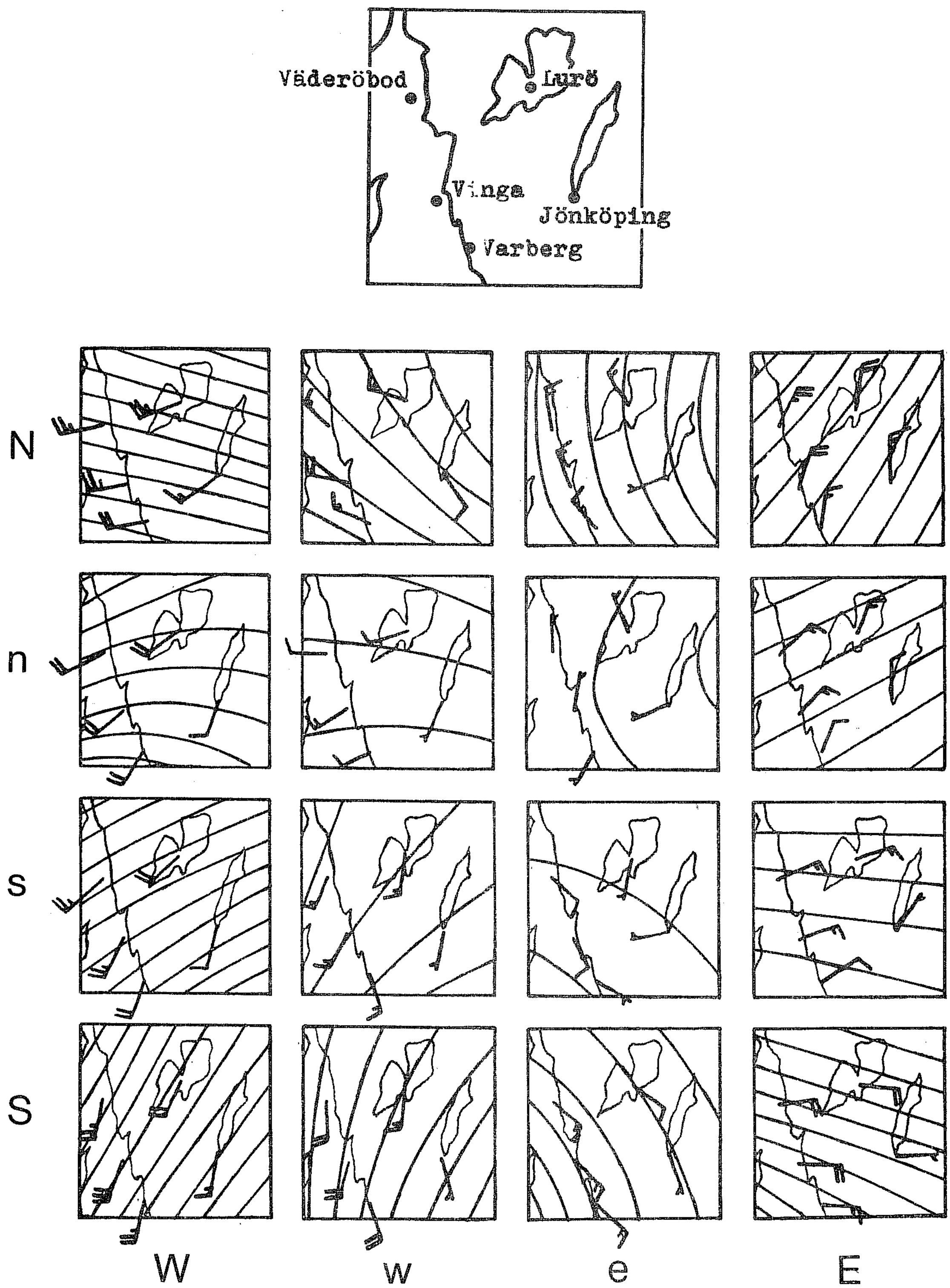

Fig. B8 : Average surface pressure distribution and winds near the Swedish West Coast for each type in a 16-type classification, December 1949 - 1964.

STATION	MEAN VALUE	DEVIATIONS FROM THE MEAN IN DECEMBER	DEVIATIONS FROM THE MEAN IN JANUARY

VÄDERÖBOD 15°

December:

N	0	-20	-30	-10
	0	-20	-20	10
	0	0	0	10
S	10	10	10	10
	W			E

January:

0	-10	-20	-10
0	0	-10	-10
0	0	0	20
10	10	10	20

VINGA 20°

December:

0	0	-20	0
10	10	-20	0
10	0	-10	0
0	-10	0	0

January:

10	0	-10	0
10	20	-20	0
10	10	-20	0
10	-10	0	0

VARBERG 30°

December:

-10	-20	-20	0
10	0	-20	10
10	20	0	0
0	10	0	-10

January:

-10	-20	-10	0
10	-10	-30	10
10	30	-10	0
20	10	0	0

JÖNKÖPING 50°

December:

0	10	40	0
10	20	60	20
0	-10	-150	0
-10	-20	-50	-20

January:

0	0	0	0
20	20	30	0
-10	-30	-180	0
-20	-10	-40	10

Fig. B9: Mean values of the cross-isobar angle of surface wind and deviations from the mean value at 4 Swedish stations using a 16-type classification (see Fig. B8).

STATION — GALE-GRADIENT WIND SPEED

VÄDERÖBOD

IN DECEMBER

	W			E
N	13	15	21	16
	14	—	—	15
	15	—	—	12
S	15	18	12	13

IN JANUARY

12	15	22	21
13	—	—	16
16	—	—	14
16	14	14	12

VINGA

IN DECEMBER

13	18	21	13
12	—	—	13
14	—	—	12
18	18	16	12

IN JANUARY

13	18	20	17
12	—	—	15
15	—	—	14
20	18	13	12

Figure B 10

Wind speeds in m/s at two Swedish stations corresponding to the "gale gradient", 16.3mb/500 km, using a 16-type classification

(see Fib. B8).

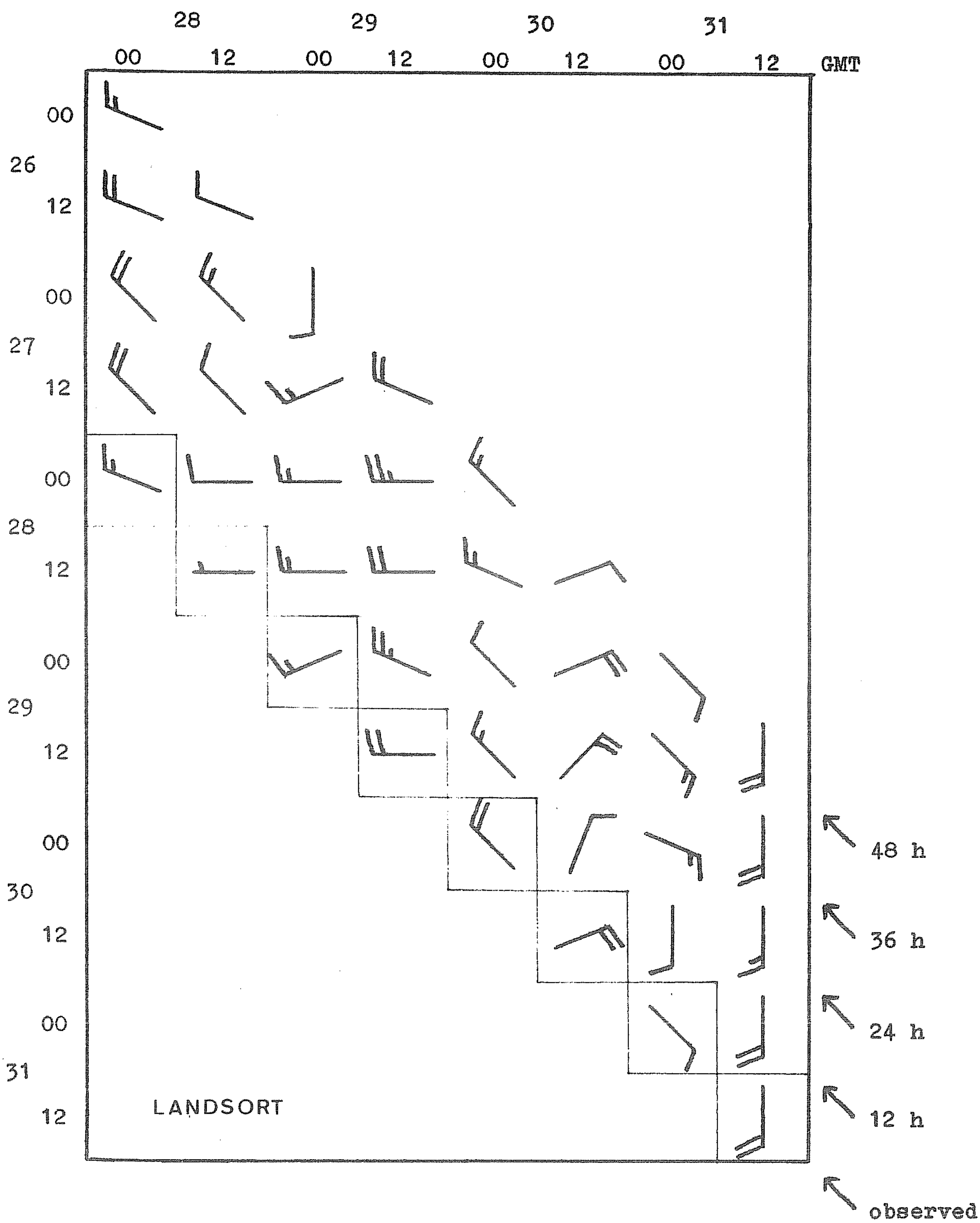

Fig. B11 : Extract from verification of operational wind forecasts (Landsort).