C. Interpretation of surface temperature and precipitation

1. Introduction

In my first lecture I showed you a 4-dimensional crossword puzzle which I used for demonstrating both temperature and precipitation conditions near the Swedish West Coast. It was obvious from the slides I showed that the atmospheric pressure and the direction and strength of its horizontal gradient explain quite a portion of the variance of temperature and precipitation.

To give you some figures to start with, it would seem that pressure and its gradients explains about 30% of the variance of precipitation and around 40% of the variance of surface temperature.

Further reductions of the variance is achieved in the present operational system by using vertical velocity for precipitation and by using the latest observed temperature and the forecast thickness for obtaining the future temperature.

A recent pilot study has shown that the predictors mentioned so far are by no means the only possible ones for temperature and precipitation interpretation.

I refer here to a small study that I have undertaken, using data from Sundsvall, situated at the coast of Sea of Bothnia, in September, October and November 1971-1975. (Fig. C1).

Before giving you the detailed figures I would like to stress that most of the predictors in that study are closely correlated.

The following table shows the correlations (multiplied by 100) between such parameters.

Table 1

		W	S	ω	q	p	dp	H	dH
W-component	W	100	0	32	0	17	-13	24	-6
S-component	S		100	-55	35	-14	-55	18	-33
vertical veloc.	ω			100	-32	25	55	0	44
specific humid.	q				100	-11	-16	43	-24
pressure	p					100	0	75	25
pressure change	dp						100	-18	59
thickness	H							100	0
thickness change	dH								100

Worth mentioning in particular is the specific humidity q at 850 mb (used in the study as an approximation for the precipitable water). It is for obvious reasons positively correlated with the thickness H (1000-500 mb) and negatively with the pressure p. That is the reason why it comes out as the best predictor in formulas where one would have expected that p and H would have played a major role.

The next table demonstrates the variance reduction, in percent, achieved by an optimum combination of predictors. In each case the first best predictors are listed in the order they come out of the regression process, and for each predictor the figures given in parenthesis indicate the additional contribution to the variance reduction obtained by adding that predictor.

Table 2

Predictand		Best predictors (variance reduction)				Total reduction
Temperature	no persist.	+q (57)	$+T_N$ (14)	-dH (1)	+dp (1)	(77)
	24 h persist.	+q (57)	$+T_{-24}$(16)	$+T_N$ (3)	-dH (0)	(77)
	6 h persist.	$+T_{-6}$(84)	+q (4)	$-\omega$ (0)	$-T_N$ (0)	(88)
Same with q exluded (estimate)	no persist.	-p (42)	+H (17)	$+T_N$ (14)	-W (3)	(77)
	24 h persist.	-p (39)	+H (16)	$+T_{-24}$(16)	$+T_N$ (3)	(77)
	6 h persist.	$+T_{-6}$(84)	-p (5)	+H (1)	-W (0)	(88)
Precip./clouds	Formula 1	$-\omega$ (35)	-p (6)	+q (6)	-W (4)	(52)
Continuous precip./clouds	Formula 2	$-\omega$ (37)	-p (6)	+q (4)	-W (5)	(53)
Convective precip./clouds	Formula 3	+q (3)	-S (0)	-dH (0)	+dp (0)	(3)

The reason why normal temperature T_N enters is that it accounts for the seasonal trend during the autumn.

The enormous effect of persistency on very short temperature forecasts is clearly demonstrated. An attempt has been made to estimate how the effect of p and H increases when q is excluded.

For precipitation, three different predictands have been studied. They are all of the PCF-type as defined in an earlier lecture. That means that on the positive side it is the logarithm of the amount, whereas on the negative side it is a function of cloud conditions. The first function deals with precipitation in the conventional way. The second, though, deals only with continuous precipitation, which means that in cases with showers the amount is put equal to zero. In both formulas the negative side is a linear function of the amount of clouds in octas.

In the third formula, however, it is the continuous precipitation that is put equal to zero, and on the negative side I have used a combination of cloud type and cloud amount, so that cases with 8 octas of cumulunimbus comes very close to zero, whereas the less convective the clouds, the negative value increases. In cases when both continuous rain and showers are reported during a 12 h period, the amount should be divided accordingly. For a proper treatment one has to go to the daily notes made by the observer.

Unfortunately, the period and place chosen were quite bad for establishing the latter formula. There were very few convective cases, which shows up in the large similarity between Formula 1 and 2. Nevertheless, I think I am right in stating that the convective cases must be described in a quite specific way and that it is probabely much more difficult to reduce the variance in those cases.

In spite of the low variance reduction one cah infer from Formula 3, that showers and convective clouds occur in low pressure areas behind cold fronts and with northerly winds. High temperature increases the amount.

Fig. C 2 shows an example of precipitation/cloudiness interpretation taken from the pilot study. It is a fairly good agreement between computed and observed values.

2. Temperature

The interpretation technique now used operationally in Sweden for surface temperature has it weaknesses. That is obvious from the pilot study just referred to. Nevertheless, it works fairly well. Since it can be used to demonstrate how temperature interpretation can be handled, I shall describe it in some details.

One problem is how to handle the very important diurnal variation of the temperature. One possible way could have been to deal with data from each synoptic hour quite separately, that is to use different interpretation climatology for H = 00, 06, 12 and 18 GMT. I have preferred instead to interpret the maximum and minimum temperature to be expected under the actual conditions and then from those results infer the most likely temperature depending on the hour of the day. This gives an additional advantage if some customer asks for the extremes rather than the temperature at given hours. Fig. C3 demonstrates this technique.

The diurnal interpolation is based on a thorough investigation based on hourly observations at all the so-called hourly observing station in Sweden. These stations proved to have such similar features in this respect, that one and the same interpolation scheme could be used for all of them (Fig. C4). Note that the interpolation curves do not touch the minimum value (0.00), nor the maximum value (1.00), especially not in winter. The reason is that part of the diurnal amplitude is really not depending of the time of the day. In winter it is only slightly more likely that the temperature minimum occurs at night and not in the daytime. That holds not only for the northernmost stations.

I have tried two different techniques, Method 1 and 2, for temperature interpretation. The results of both methods are presented operationally.

To explain the difference between these techniques, let us forget about the complication introduced by the diurnal variation. Both methods are based on the fact that the interpretation climatology provides, for each time step, forecast values of the typical temperature anomaly, A, and the typical 24 h change in temperature, dT.

Let us start from the very simple assumption that you have to make a temperature forecast, knowing only the climatological normal T_N at the actual time of the year, and the last observed temperature T_0.

Your forecast should then be

$$T = (\alpha-1)T_N + \alpha T_0 \tag{1}$$

Here $\alpha=1$ at $t=0$. Experience shows that α comes close to zero already after 24 hours. Let us simply assume that α varies linearly so that $\alpha=0.25$ at $t=6$ hours.

Let us further assume that equ.(1) still holds when we add the forecast anomaly A_F to T_N and the forecast 24 h temperature change dT_F to T_0. Then we obtain

$$\left.\begin{aligned} T_{+6} &= 0.25\ (T_N+A_{F_1})+0.75(T_0+0.25dT_{F_1}) \\ T_{+12} &= 0.50\ (T_N+A_{F_2})+0.50(T_0+0.50dT_{F_2}) \\ T_{+18} &= 0.75\ (T_N+A_{F_3})+0.25(T_0+0.75dT_{F_3}) \\ T_{+24} &= T_N+A_{F_4} \end{aligned}\right\} \tag{2}$$

The index F_1 indicates forecasts at time step 1, etc.

Equations (2) constitute Method 1.

In Method 2 the 6 hour prediction technique is applied anew at each time step, so that T_{+6} replaces T_0 when computing T_{+12}, and so on.

We obtain the following equations:

$$\left.\begin{aligned} T_{+6} &= 0.25\ (T_N+A_{F_1})+0.75(T_0+0.25dT_{F_1}) \\ T_{+12} &= 0.25\ (T_N+A_{F_2})+0.75(T_{+6}+0.25dT_{F_2}) \end{aligned}\right\} \tag{3}$$

etc.

Experience has shown that the two methods give at times quite different results. In the long run Methods 2 seems to give more reliable results than Method 1 (seven months out of ten). I have not yet worked out any compromise method.

Before leaving temperature, I think I should show you one example of the interpretation climatology. Fig. C5 demonstrates the minimum temperature conditions in January in the whole of Sweden. Maps to the left refer to low pressure situations; those to the right to high pressure. The nine charts on each side apply to different directions of the geostrophic wind.

The values given at stations show that part of the anomaly which is not explained by thickness H. Thus

$$\Delta A = A - A(H) \tag{4}$$

If we look at Haparanda at the northern end of the Gulf of Bothnia, we see that $\Delta A=+5$ for low pressure and easterly winds, whereas $\Delta A=-6$ for high pressure and westerly winds.

The following table shows schematically the magnitude of those effects on the temperature which are incorporated in the interpretation methods.

	Effect	Positive	Negative
Day of the year	$\pm 10^{\circ}$	July	January
Hour	$\pm 6^{\circ}$	Afternoon	Sunrise
Thickness	$\pm 5^{\circ}$	Warm air	Cold air
Pressure distrib.	$\pm 5^{\circ}$	NW	Flat
Pressure	$\pm 5^{\circ}$	High	High!
Totally	$\pm 31^{\circ}C$		

3. Precipitation

As I mentioned before, the South and West Components of the geostrophic wind measured over a distance of about 500 km are together fairly good predictors for the precipitation. To this one should add the effects of pressure and vertical velocity. I shall deal with those effects at a later stage.

As to the effect of the geostrophic wind on precipitation, Sweden can be divided into three typical areas. (Fig C6) The western side of the mountains in Northern Sweden is the first area. Here precipitation mainly occurs with northwesterly winds. The second area is the Swedish West Coast were precipitation mostly is coupled with south-westerly winds. The third area covers a large portion of Sweden, in particular the eastern and central parts of Northern Sweden. Here SE situations give most precipitation.

Fig.C6 shows the interpretation statistics for three stations, Riksgränsen, Strömstad and Härnösand; places where these three quite different conditions are most extremely pronounced.

The 4-by-4 squares indicate that both components of the geostrophic wind have been divided into 4 equal classes, thus defining 16 weather types. The numbers given in the boxes are values of the "relative precipitation" R_{24}, that is the ratio between precipitation fallen during 24 hours and the normal 30-day amount for the month in question according to climatological normals.

To help to understand the parameter "relative precipitation", let me say that if during a normal month the precipitation were the same all days, then $R_{24}=3$. Figures lower than 3 gives a deficit; the number 14 as it appears in the SW box at Strömstad on the other hand, means that after 7 days with that particular type, the normal monthly amount is already reached.

Fig. C7 exemplifies what I have just said in another way. For each station included in the investigation I have tried to determine the direction of the geostrophic wind at which maximum precipitation occurs. Analysing this map with isolines, the division into three different areas shows up clearly with a certain transition zone between the SW and SE-types but a very narrow boundary to the NW-type. If it were possible to analyse that boundary in detail it would certainly bend and wriggle in a complicated way following the topography.

A map of this type is very useful if you have to make interpretations for stations not included in the study and for places were observations are lacking.

You might ask yourself whether the features just presented are about the same through all seasons. Therefore I will illustrate this with a figure (Fig.C8) showing the geographical distribution of the relative precipitation in January, April, July and October, in the case of southwesterly geostrophic wind. That is the box where the West Coast gets its maximum amounts. As you see, the maps are all fairly similar, but there are interesting differences as to the intensity of the maximum round Strömstad and of the minimum in Southeastern Sweden. The secondary maximum round Stockholm in January is also worth mentioning.

Fig. C9 demonstrates how the relative precipitation varies with atmospheric pressure - a calibration curve for antique barometers.

Fig. C10 demonstrates the variation due to the mean vertical velocity in the layer 1000-500 mb. Note that the same vertical velocity gives relatively more precipitation in Summer than in Winter.

Up to recently I have used a much too complicated technique for combining the three effects; gradient wind, pressure and vertical velocity. I see no reason to describe it here. In the programmes rewritten for our new computer, I simply use the product of the R found from the studies of the effect of the geostrophic wind and normalized values of R(p) and R(w).

Verification

Like for the surface wind the success of the temperature and precipitation forecasts are verified operationally. In the table the figures for December 1977 are given. In the case of precipitation the verification compares percistency, a numerical physical model introduced by Bengtsson, the forecast issued by the duty forecaster and the best interpretation forecast.

Day	Temperature			Precipitation			
	Per- sist.	Fore- caster	Inter- pret.	Per- sist.	Physical method	Fore- caster	Inter- pret.
1	6	6	7	10	9	10	9
2	6	6	8	9	10	9	10
3	5	7	8	10	10	10	10
4	8	8	5	10	10	10	10
5	6	5	6	10	10	10	9
6	6	7	6	3	3	3	4
7	6	10	7	6	7	8	5
8	3	8	6	5	10	4	7
9	10	8	8	10	9	10	10
10	5	5	7	10	10	10	10
11	10	10	9	10	10	10	9
12	5	9	7	5	2	3	3 ***
13	4	10	6	2	7	7	9
14	7	10	7	9	9	10	9
15	9	9	5	8	7	8	7
16	6	7	8	8	10	10	9
17	8	9	8	8	6	8	10
18	4	6	4	8	10	9	10
19	9	9	8	9	9	10	10
20	5	2	8 *	10	9	9	9
21	4	5	8	9	6	5	5
22	5	7	7	8	8	7	10
23	5	7	6	7	7	7	7
24	5	7	8	4	6	8	8
25	1	8	7 **	2	9	8	9 **
26	8	9	8	8	6	8	8
27	4	8	5	6	7	8	4
28	3	7	5	7	7	5	8
29	5	7	8	6	4	2	4 ***
30	3	7	9	7	5	5	4
31	6	5	7	2	8	8	8
Average	5.7	7.4	7.0	7.3	7.7	7.7	7.9

The figures in the table can be looked upon in various ways. Note for instance one case when a good interpretation has not at all influenced the official forecast (*). Also note that it happens that persistency is really a bad forecast (**), but also that persistency gives the best forecast (***). It is of special interest to judge if the forecaster has succeeded in using his two tools, the physical method and the interpretation, in an optimum way. There are 7 cases when both tools give a better forecast than that of the forecaster; on the other hand the forecaster is more successfull than both tools in 5 cases.

It should be mentioned that these verification figures are currently shown to the forecasters, and they study them with great interest. That should be a guarantee for that they gradually adapt their forecasts to the true quality of the forecasting tools.

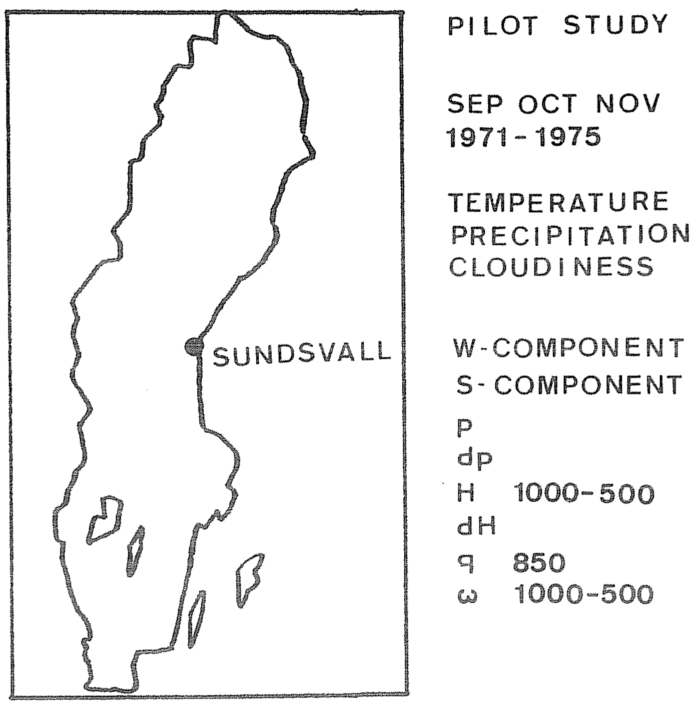

Fig. C1: A pilot study concerning temperature, precipitation and cloudiness at Sundsvall in September, October, November, 1971 - 1975.

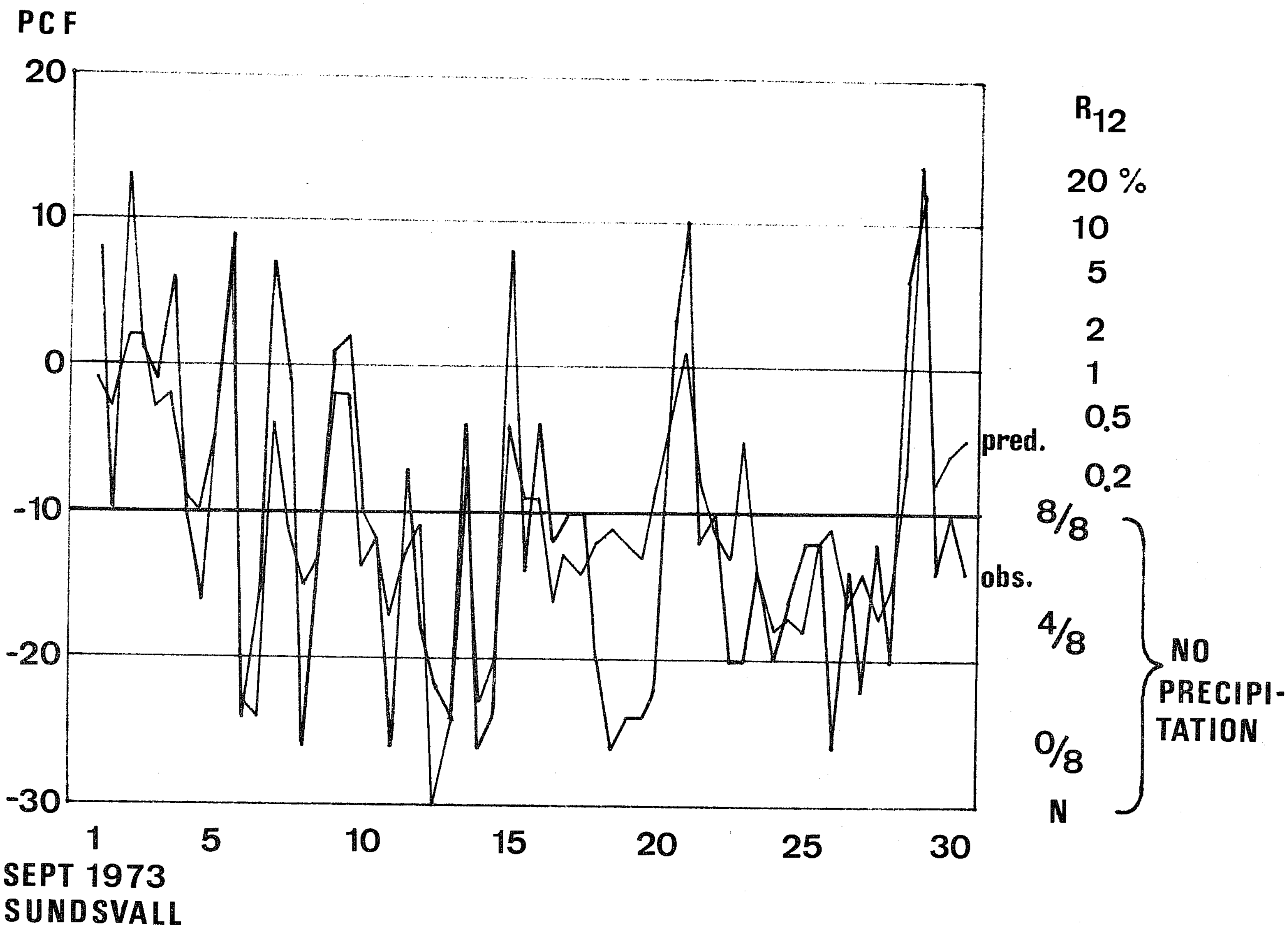

Fig. C2 : Example of precipitation/cloudiness interpretation taken from the pilot study presented in Fig. C 1.

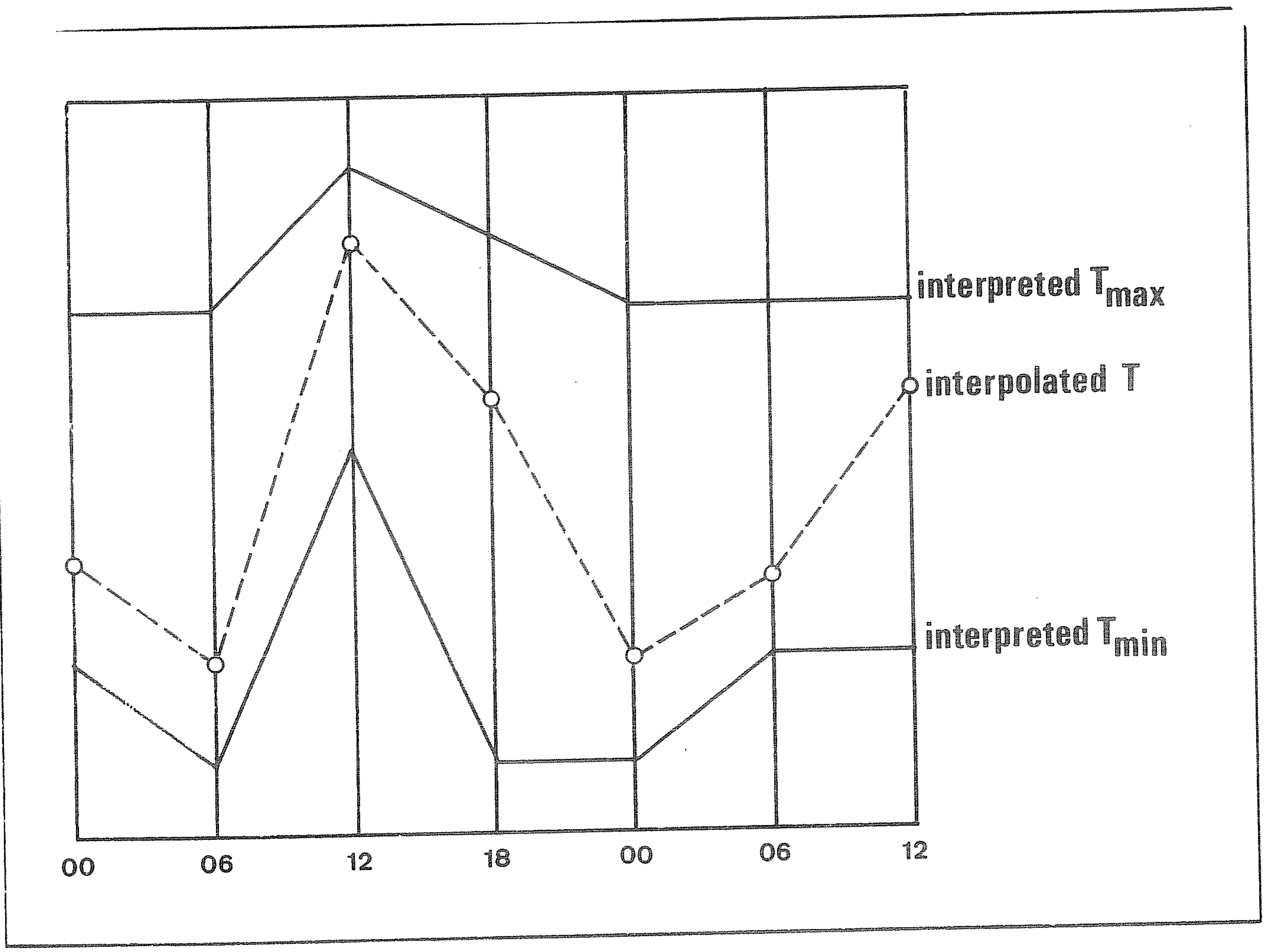

Fig. C3: Interpolation scheme used operationally in Sweden and demonstrated in Fig. C3.

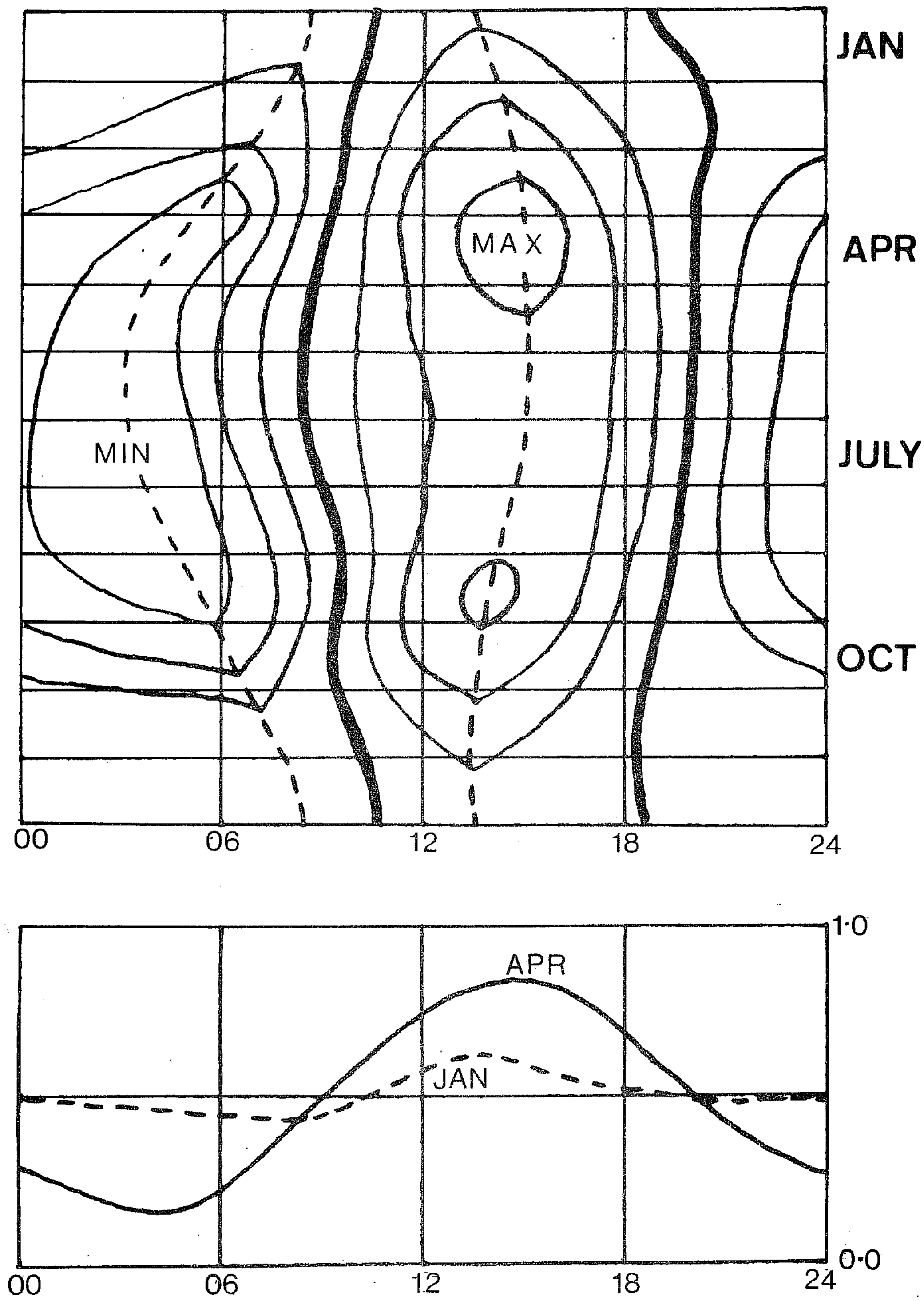

Fig. C4 : Interpolation scheme used operationally in Sweden and demonstrated in Fig. C3.

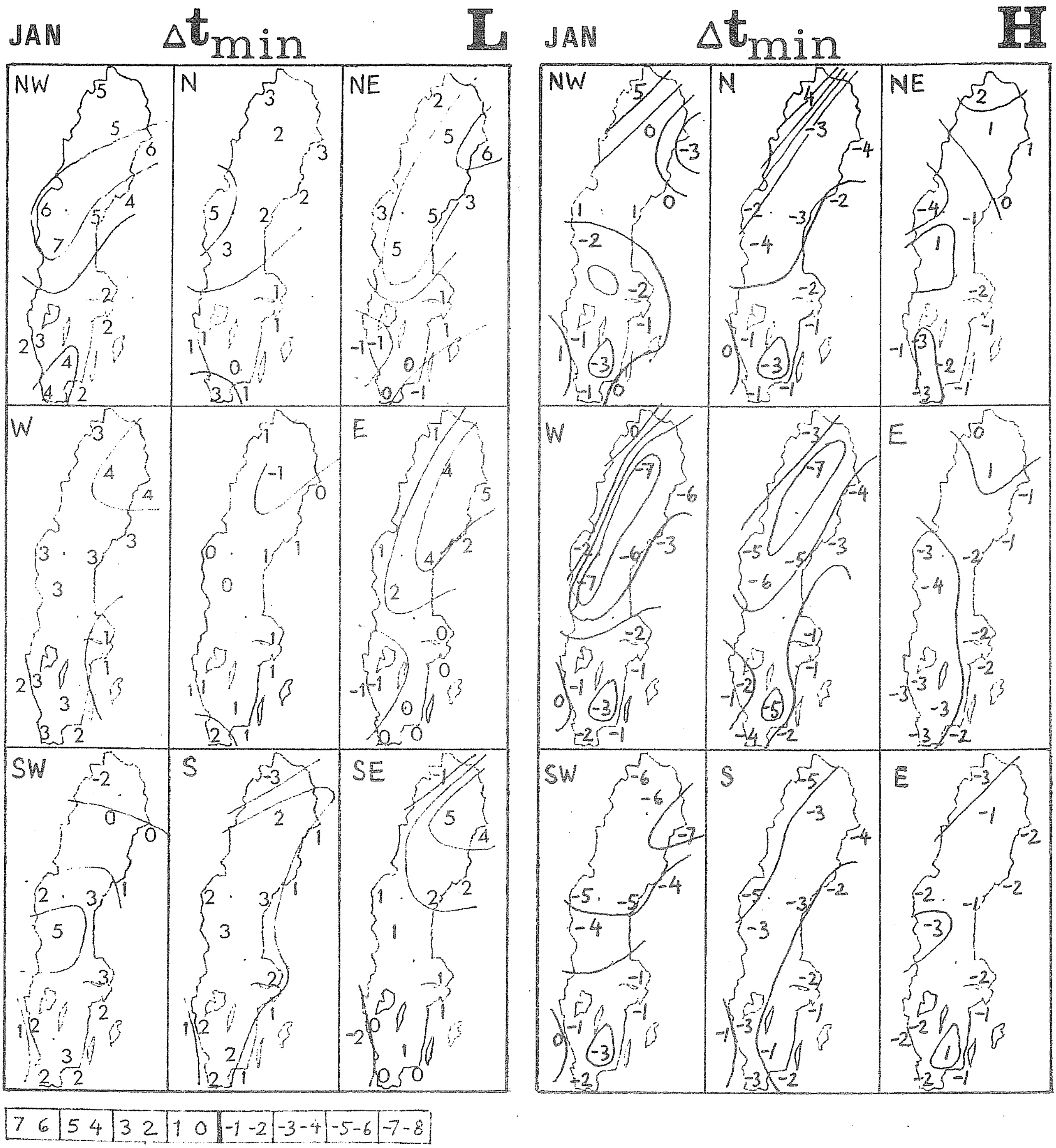

Fig. C5: Example of interpretation climatology for minimum temperature in January. Low pressure conditions to the left, high pressure to the right. A 9-type classification is used for the geostrophic wind.

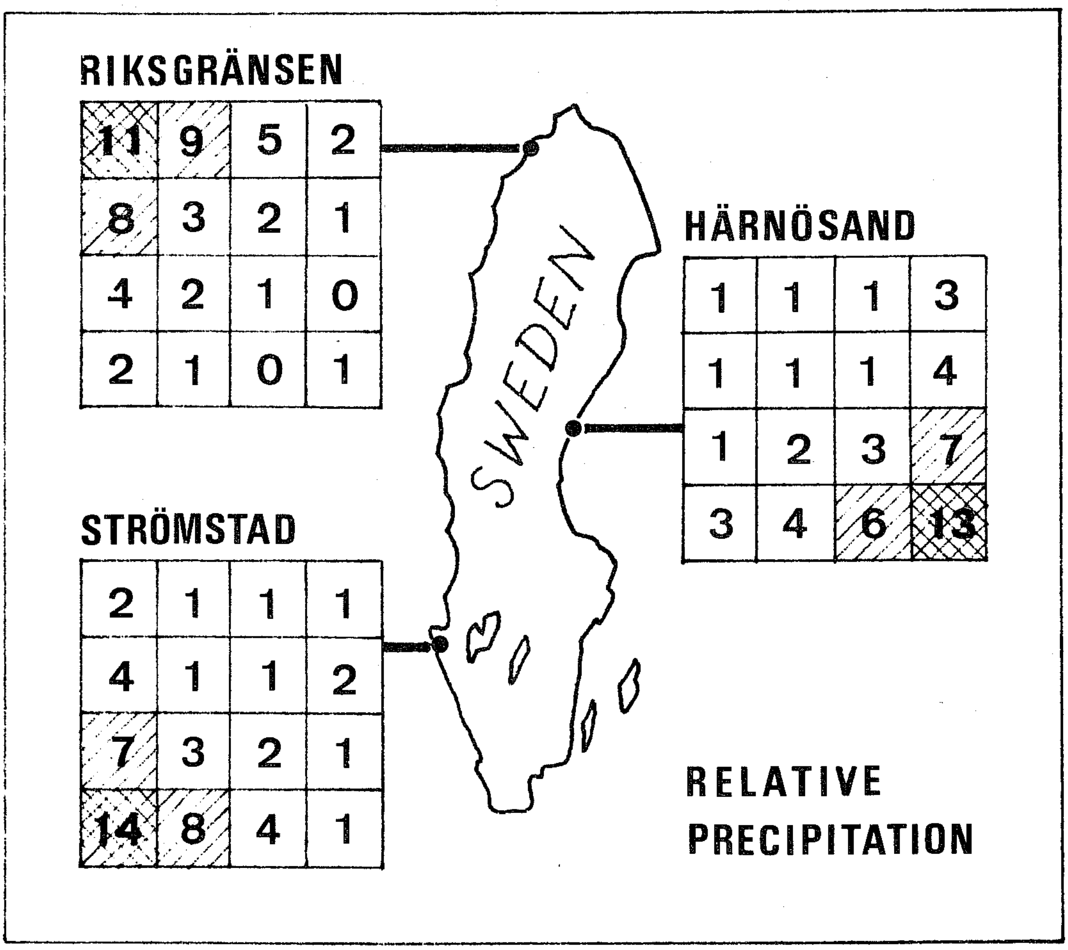

Fig. C6 : Relative precipitation amounts according to a 16-type classification of the geostrophic wind at three stations representing three different precipitation conditions in Sweden. Annual means.

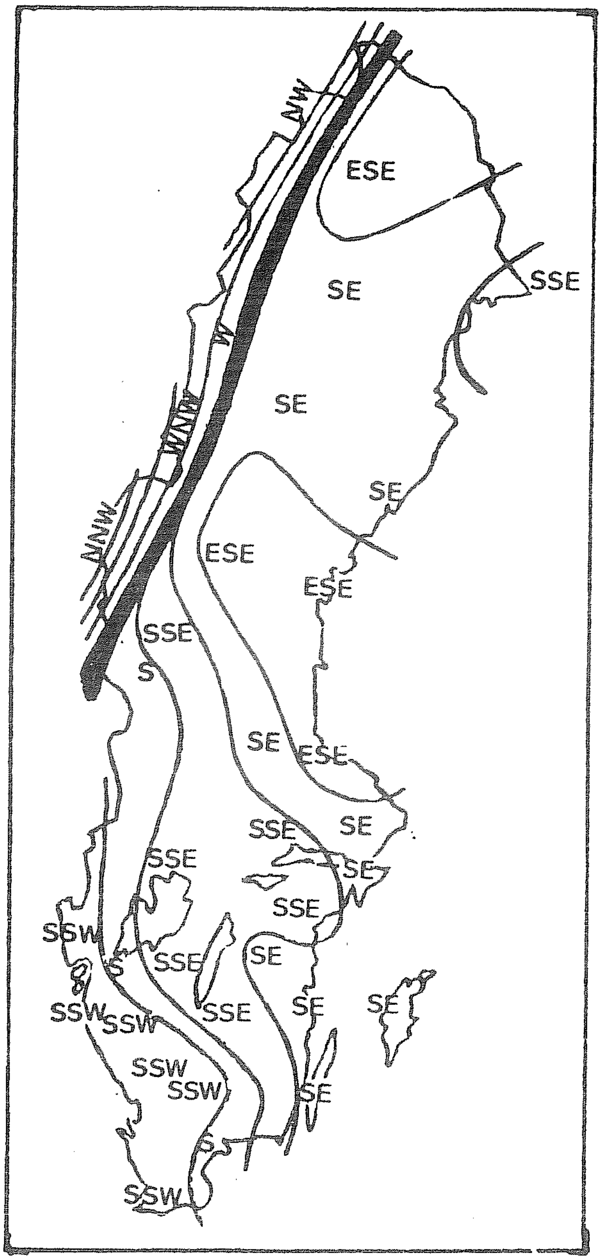

Fig. C7 : Geostrophic wind direction at which precipitation has its maximum in Sweden.

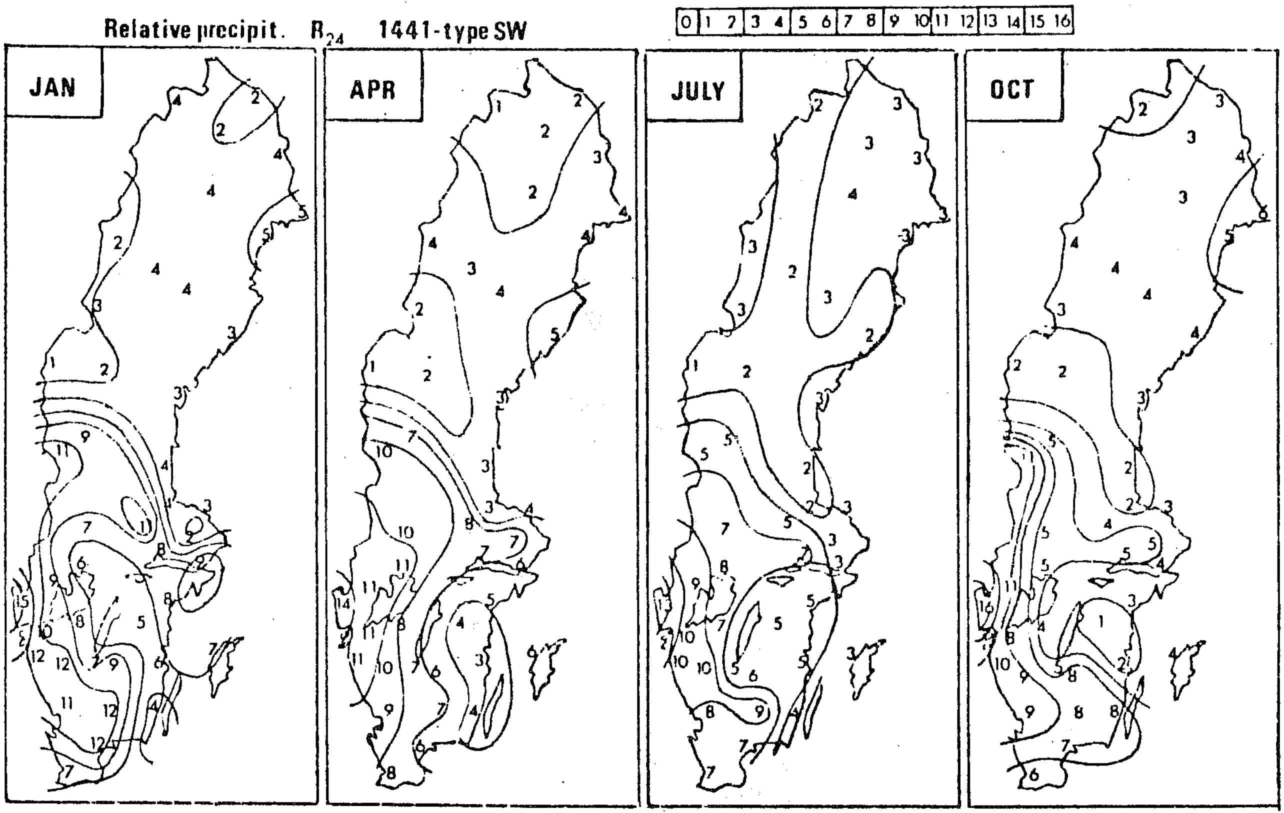

Fig. C8 : A comparison between January, April, July and October, showing the relative precipitation at Swedish stations in the SW-type according to the 16-type classification exemplified in Fig. C6.

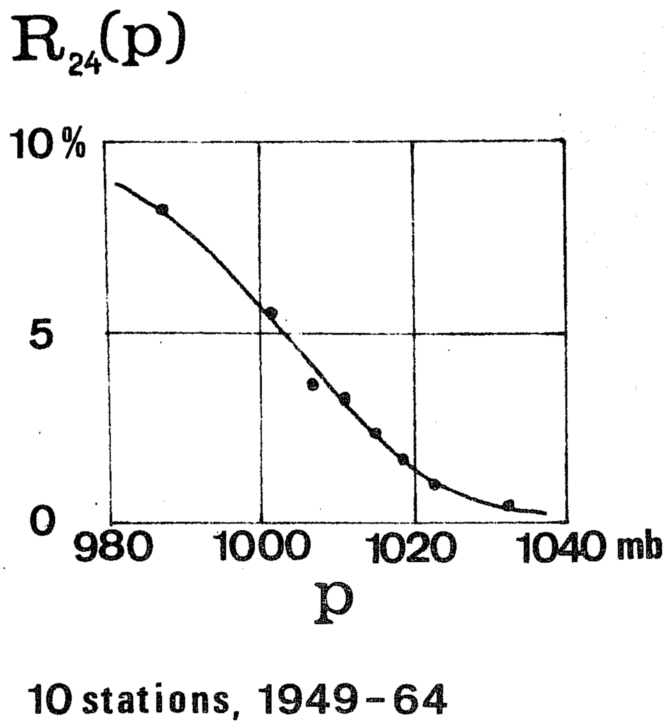

Fig. C9 : Relative precipitation as a function of atmospheric pressure.

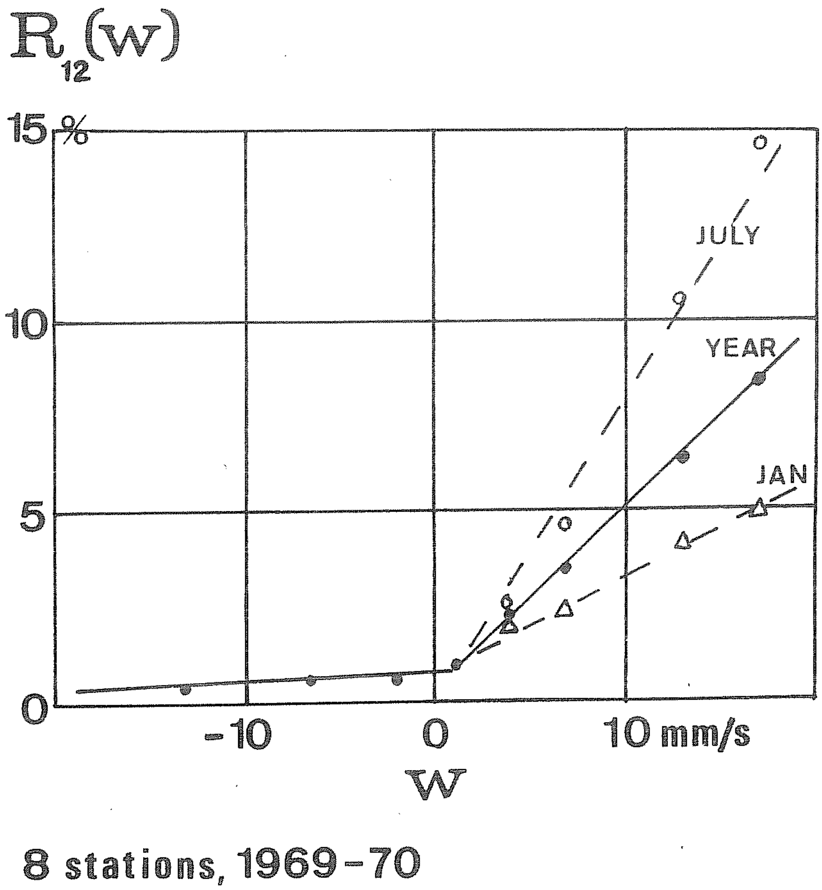

Fig. C 10: Relative precipitation as a function of vertical velocity.