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THE USE OF EMPIRICAL METHODS FOR MESOSCALE PRESSURE FORECASTS

by

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ABSTRACT

Empirical formulas are suggested to simulate the impact exerted by mountains and local thermal phenomena on the mean sea level pressure. These formulas are then used to modify and interpret large-scale numerical pressure forecasts, both in the large scale and mesoscale region. A test of 8 cases with 24-hour forecasts in August 1980 showed a considerable improvement of the forecasted pressure distribution in Iceland. Furthermore, an empirical method is suggested to extrapolate surface pressure tendencies, in order to update mean sea level pressure forecasts every 3 hours. In these forecasts, the empirical mountain and thermal formulas are also used as a modifying factor. This extrapolation model was tested on eight 12-hour mean sea level pressure forecasts in January 1979, using as a measure the correlation between forecasted and observed pressure at Icelandic weather stations. The mean correlation coefficient was 0.77, while the operational ECMWF model gave 0.85 for the same cases. On the other hand, the mean pressure gradient over Iceland seemed to be better forecasted with the extrapolation model in these few cases. Using a detailed analysis, the extrapolation model gave a successful forecast of a sudden and severe storm over north-east Iceland on 15 January 1979 when subjective methods had not been satisfactory.

1. INTRODUCTION

In recent years, some discussion has been going on concerning the role of the national weather services in numerical weather forecasting. It is the opinion of the author that the general large-scale forecasts should be computed by large and well-equipped institutes. Every national centre would be able to obtain these forecasts quickly after their computation twice a day, and it seems to be both needless and uneconomic to duplicate this activity in every country. Instead, the national centres should concentrate on local interpretation of the large-scale weather forecasts and on detailed short-range forecasts based on the numerous 3-hourly synoptic observations, but with a due regard to the numerical forecasts. This report is intended to be a certain contribution to the discussion of this national activity, with particular reference to Iceland.

The results presented in this report were to a considerable degree obtained during a six months visit to the European Centre for Medium Range Weather Forecasts during the summer 1980.

2. AN EMPIRICAL SIMULATION OF MOUNTAIN PRESSURE ANOMALY

2.1 The mountain pressure formula

As a synoptician for over 30 years, the author has among other things been dealing with the surface pressure anomaly observed over and near mountains. The main features of the experience gained in this period are the following.

A relatively high pressure (negative Laplacian of pressure) is observed over the windward sides of mountains, both on large scale and the mesoscale. The pressure anomalies seem to be the greater, the greater the mountains, both in height and horizontal extension. Over the lee side there is a corresponding negative anomaly of pressure (positive Laplacian). It is the low level wind that almost entirely determines this pressure distribution, while the upper wind seems to be relatively unimportant, e.g. the 500 mb wind. This pressure anomaly, both on the windward and lee side, is relatively strong in statically stable air, weaker in unstable air.

Fig. 1 shows this effect on a large scale over Greenland, on a mean map for the month of February 1979. On Fig. 2 the same thing is demonstrated over Iceland, even on the relatively small scale of Vestfirdir, the peninsula in north-west Iceland.

Intuitively, the author suggested in 1973 that this phenomenon could be simulated by the simple equation:

$$\nabla^2(PM) = - CT \cdot J(P,H) \qquad (1)$$

where ∇^2 is the Laplacian operator, PM is the mountain pressure anomaly, CT is an empirical coefficient, J is the Jacobian operator, P is the mean sea level pressure and H is the elevation of the orography over sea level.

Some computations made in Reykjavik in 1974, in cooperation with Dr. Sven Sigurdsson of Reykjavik University, indicated that the empirical equation would be able to simulate reasonably well the mountain pressure anomaly, both on large and small scale, using in all cases the same coefficient CT. In many cases, the coefficient seemed to be about 0.004 m^{-1}, but probably lower in unstable air. Experiments made by the author at ECMWF in 1980 indicated that the mountain height should not be represented by the <u>mean</u> height of the country, but rather by an <u>effective</u> height, generally representing the ridges that the wind would have to pass in each area. This will on the whole be greater than the mountain height, and consequently the coefficient CT will be lower, close to 0.002 m^{-1} according to the 1980 experiments.

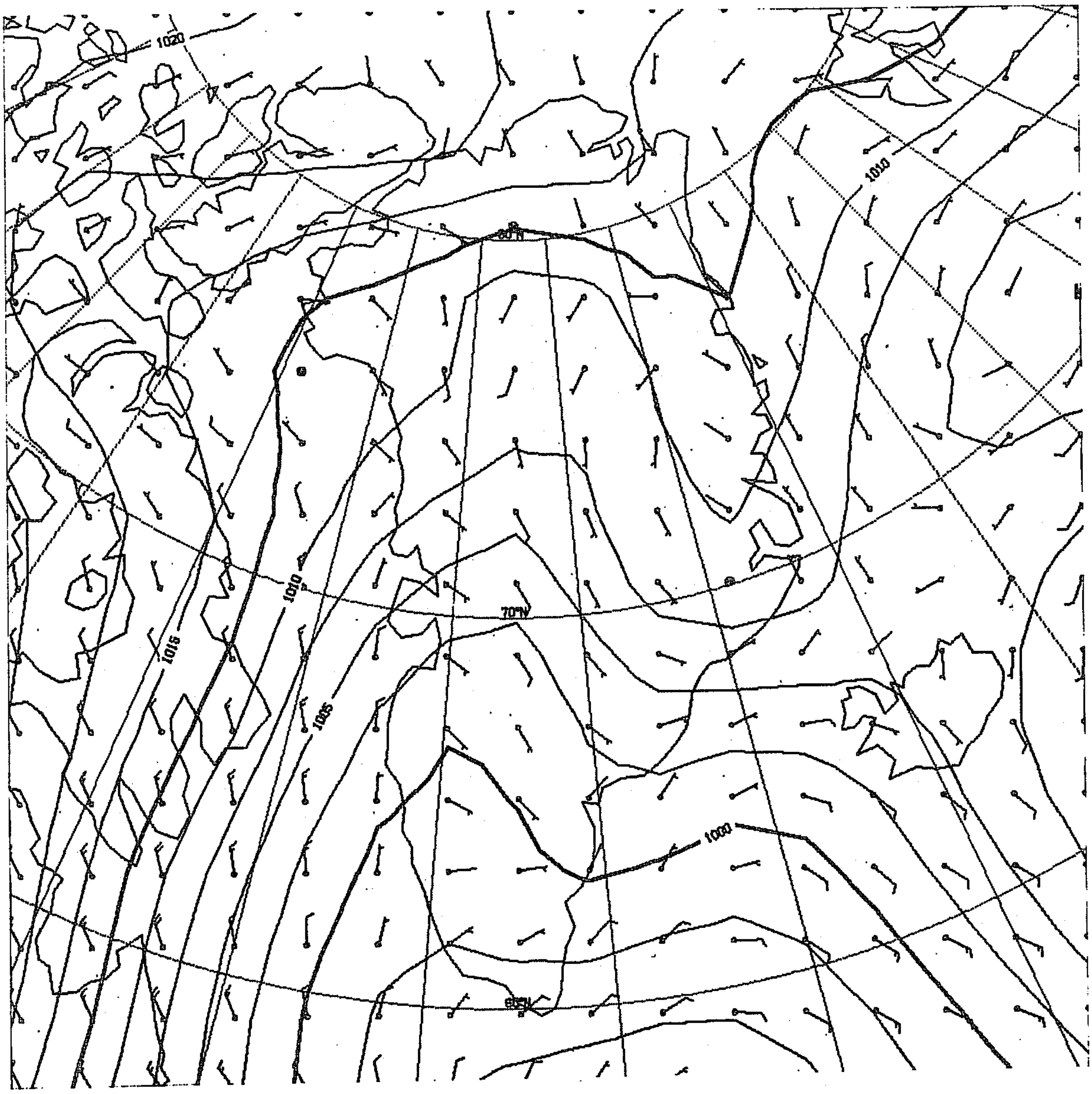

Fig. 1 **The average mean sea level pressure of February 1979, showing the pressure ridge over the windward side of Greenland and the lee trough over the western slopes. (cf. effective height, Fig. 3).**

This simulation of the mountain pressure anomaly can in several ways be useful. It should be an aid in the interpolation of pressure between distant stations in mountainous areas, i.e. in objective analysis. Having obtained the large-scale pressure distribution in a forecast, the simulation should indicate the local deviation in pressure and wind, insofar as the modern numerical forecasts do not manage to show these details. As discussed in another part of this report, this simulation seems also to be useful in simple short-range forecasts based on 3-hourly synoptic observations.

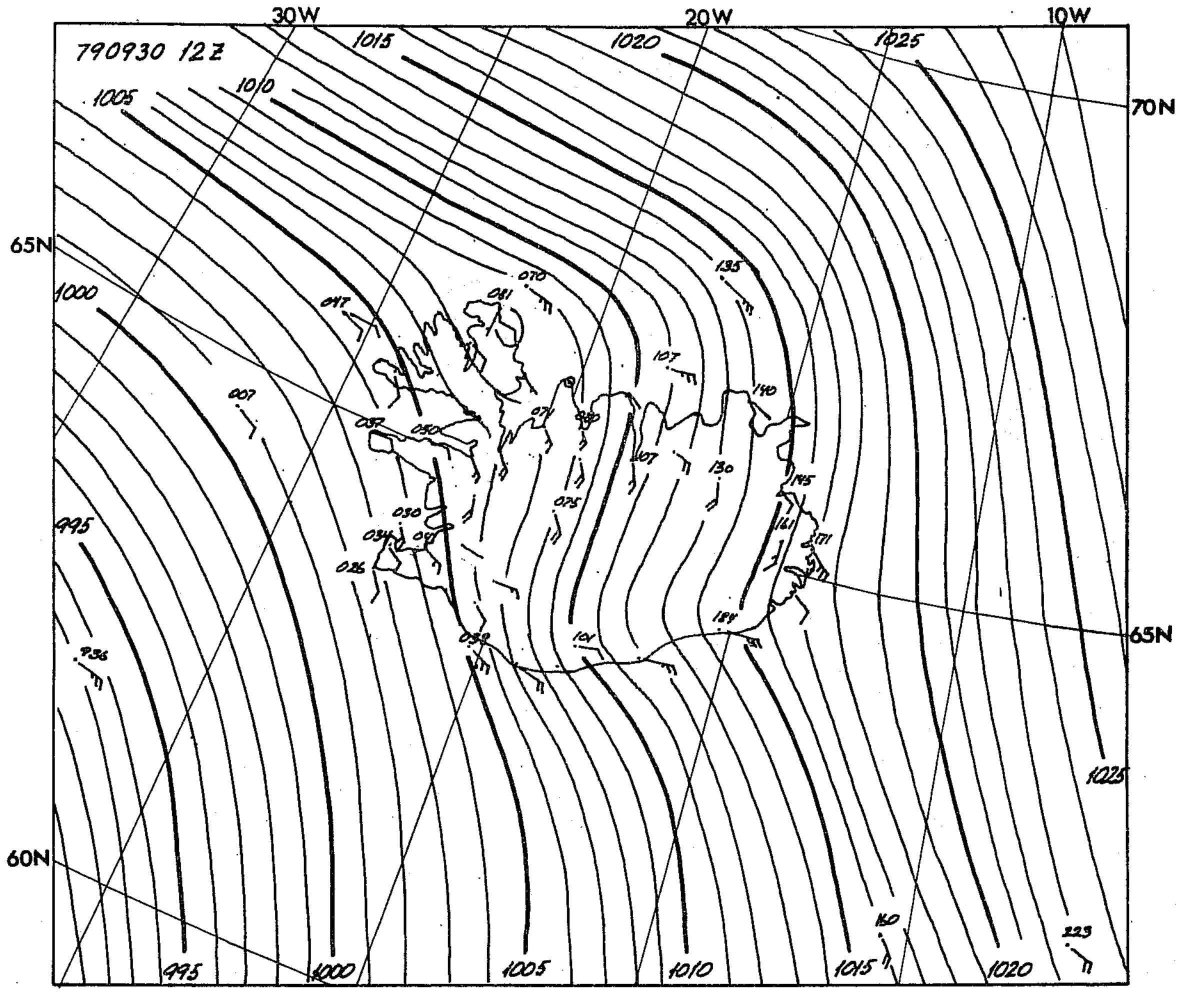

Fig. 2 Mean sea level pressure over Iceland at 12Z on 30 September 1979, showing the pressure distribution in connection with mountains. (cf. effective height, Fig. 4).

A more general form of the simulation formula is the following:

$$\nabla^2 (PM) = - CT \cdot J(PB + PM, HE) \qquad (2)$$

where PB denotes the mean sea level pressure as it is supposed to be without mountains. We call it the basic pressure. HE is here the effective height of the orography, discussed later in the report. This equation can be numerically solved for PB if we know PB + PM = P, where P is the actual mean sea level pressure, and it can also be solved for P if we know PB.

2.2 The choice of the effective height

In the experiments at ECMWF, the effective height of the orography was obtained from a general survey supplied on a tape from the U.S. Navy, where information is given on the orography of every 10 by 10 minutes square. In order to make the resolution approximately the same for the E-W as for the N-S direction, we determined by interpolation the mean height of every square 18.75 by 18.75 km on a polar stereographic map, the scale being true at 60°N. On a polar stereographic map, where the mesh size was (N · 18.75) km at 60°N, the effective height of every square was now determined as follows.

For every row of small squares (18.75 by 18.75 km) in the x-direction across a grid square, we determined the small square with the greatest mean height. The mean of the N heights obtained in this manner, one for each row, was then defined as the effective height looking in the x-direction for the grid square.

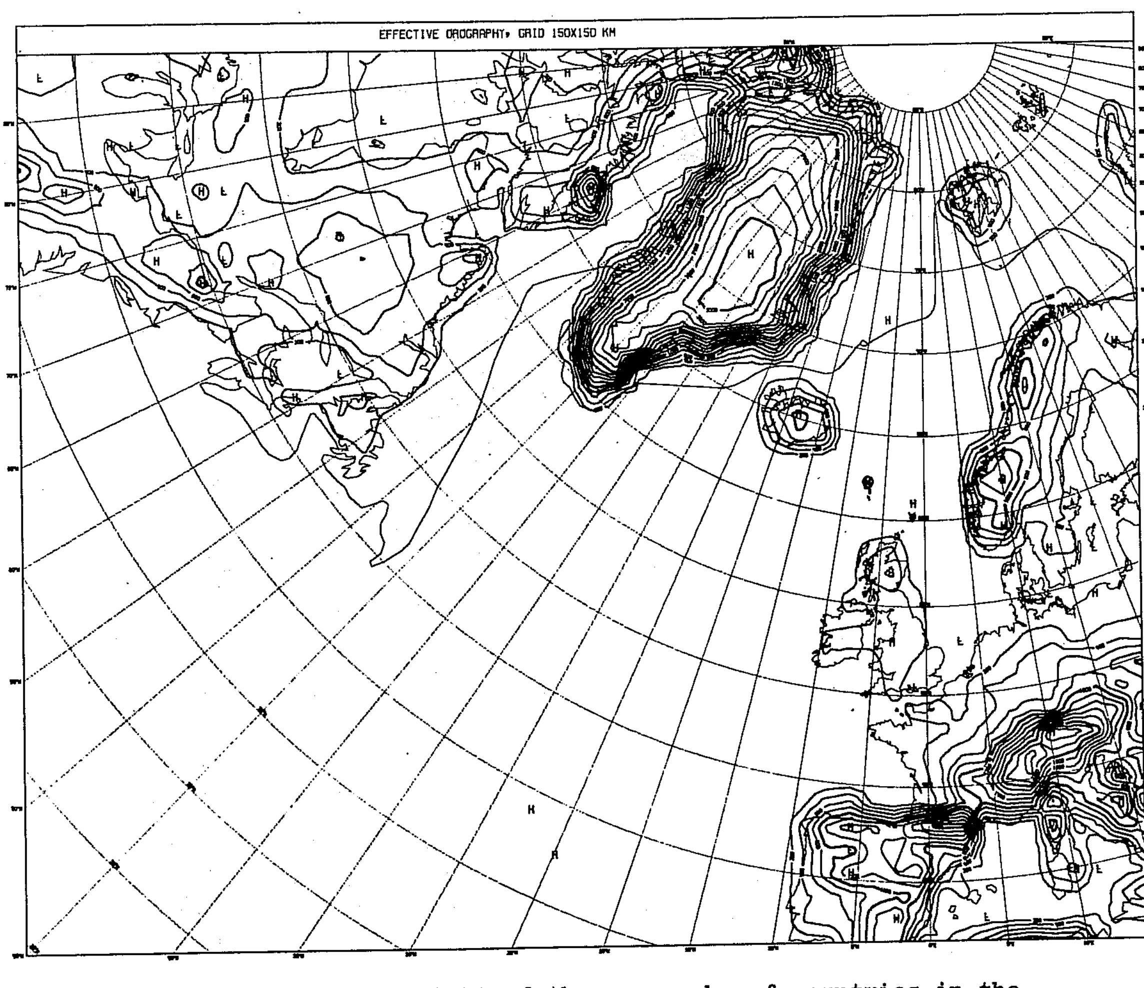

Fig. 3 The effective height of the orography of countries in the North Atlantic area, using a grid size of 150 km. Contours are drawn for every 200 meters. The solid line across the Labrador basin and off the east coast of Greenland is the approximate sea ice limit in Spring.

In a corresponding manner we found the effective height looking in the y-direction, and the mean of these two effective heights was then defined as the effective height of the grid square. It would be logical to compute a separate effective height for every wind direction, but it was not thought to be worthwhile, since the increased accuracy obtained by such a procedure could also be obtained by increasing the resolution.

Fig. 3 shows isolines of the effective height for an area in the North Atlantic, with a grid size of 150 by 150 km at 60^{O}N on a polar stereographic map. Fig. 4 gives the effective height for an area around Iceland, using a grid of 37.5 by 37.5 km at 60^{O}N on a polar stereographic map. This mesoscale distribution of the orography will be used in determining the mesoscale pressure distribution.

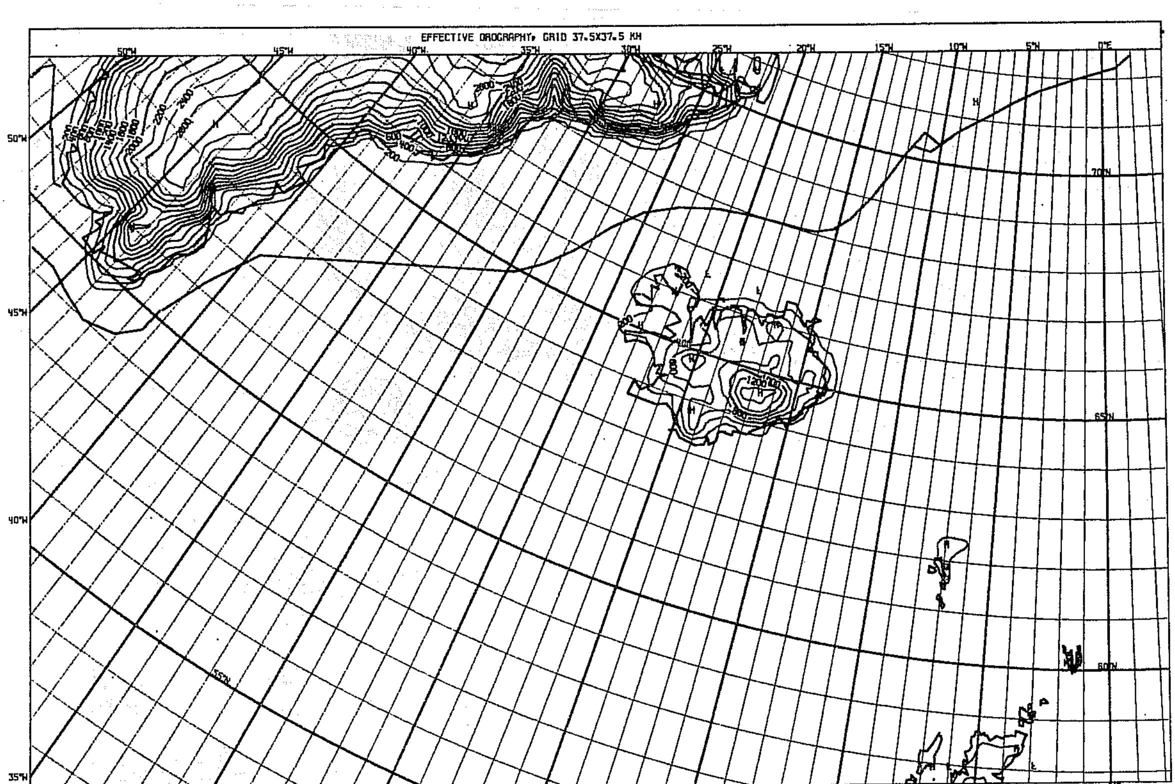

Fig. 4 The effective height of the Iceland area, using a grid of 37.5 km. Contours are drawn for every 100 meters. The solid line off the Greenland coast is the approximate sea ice limit in Spring.

2.3 Some problems of the mountain pressure anomaly

We have found by observation that in an area of ascending air motion near mountains there is a tendency for high pressure, while low pressure will be dominating on the lee side. It is interesting to note in this connection that the so called Ekman pumping, an air transport between the planetary layer and the free atmosphere, will therefore tend to compensate for the mountain-induced ascending motion at the top of the planetary layer, at least to the order of magnitude. In the free atmosphere above mountain slopes, this will greatly reduce the mountain-induced vertical velocity. This may be a partial explanation of the fact that the mountain pressure anomaly shows very little correlation with the 500 mb flow, as mentioned before. According to this, the vertical shrinking and stretching of air masses passing mountains is mainly confined to the friction layer, where the corresponding variation in relative vorticity is to a high degree destroyed by the friction. This tends to prevent the formation of anticyclones over extensive mountain areas and consequently it will also considerably modify the formation of the corresponding planetary waves in an air flow in the lee of a mountain range.

The main problem in the analysis of the mountain pressure anomaly is the lack of observations in many mountain areas. Another difficulty is the fact that in mountainous areas the mean sea level pressure has to be obtained by extrapolation of the pressure from the surface to the sea level.

3. AN EMPIRICAL SIMULATION OF THERMAL PRESSURE ANOMALY

Local heating or cooling has a noticeable impact on the mean sea level pressure, as shown by heat lows over large islands on a warm day, as well as the strong cold high over Siberia during the winter months. In many cases, it may be desirable to analyse these thermal anomalies separately on the pressure maps. Knowing the large-scale pressure distribution, e.g. from a numerical forecast where the heat effect has been partly or wholly neglected, it may be desirable to add the pressure anomaly due to the local thermal effect. Even a simple simulation of this impact can be useful for this purpose.

To simulate this thermal pressure anomaly in a country like Iceland (some 300 by 500 km) it is possible to use as a first approximation the following empirical expression:

$$CP = .4 \cdot (SIN(3.14/6 \cdot (MAN - 3)) + 1)/2 \cdot SIN(3.14/12 \cdot (STUND - 9)) + .4 \cdot SIN(3.14/6 \cdot (MAN - 3)) - .10 \quad (3)$$

where CP denotes an anomaly in the Laplacian of the mean sea level pressure, using the grid 37.5 by 37.5 km on a polar stereographic map. MAN is the month of the year and STUND is the hour of the day, Greenwich time. The anomaly of the Laplacian is to be applied only to grid points over land, and furthermore only if the wind according to the basic pressure distribution is blowing downslope. This condition will place the thermal pressure anomaly mainly in the lee of the mountains, where clouds are preferably dissolved and inward and outward radiation reaches a maximum. To avoid any general raising or lowering of the pressure on the whole map, the sum of the thermal pressure Laplacians over land may be evenly distributed with a negative sign on all grid points of the map.

Even a very rough method like this seems to express reasonably well the thermal pressure anomalies in Iceland. It has not been investigated whether this kind of simulation can be used for other countries as well, and in any case a latitudinal and longitudinal variation would then have to be introduced.

In Fig. 5 and Fig. 6 we show a simulation of the pressure in Iceland on a summer day and a winter night, assuming the basic pressure gradient on the polar stereographic map to be easterly and constant. The thermal pressure anomaly is only applied to Iceland, while the mountains are assumed to affect the pressure in all the map.

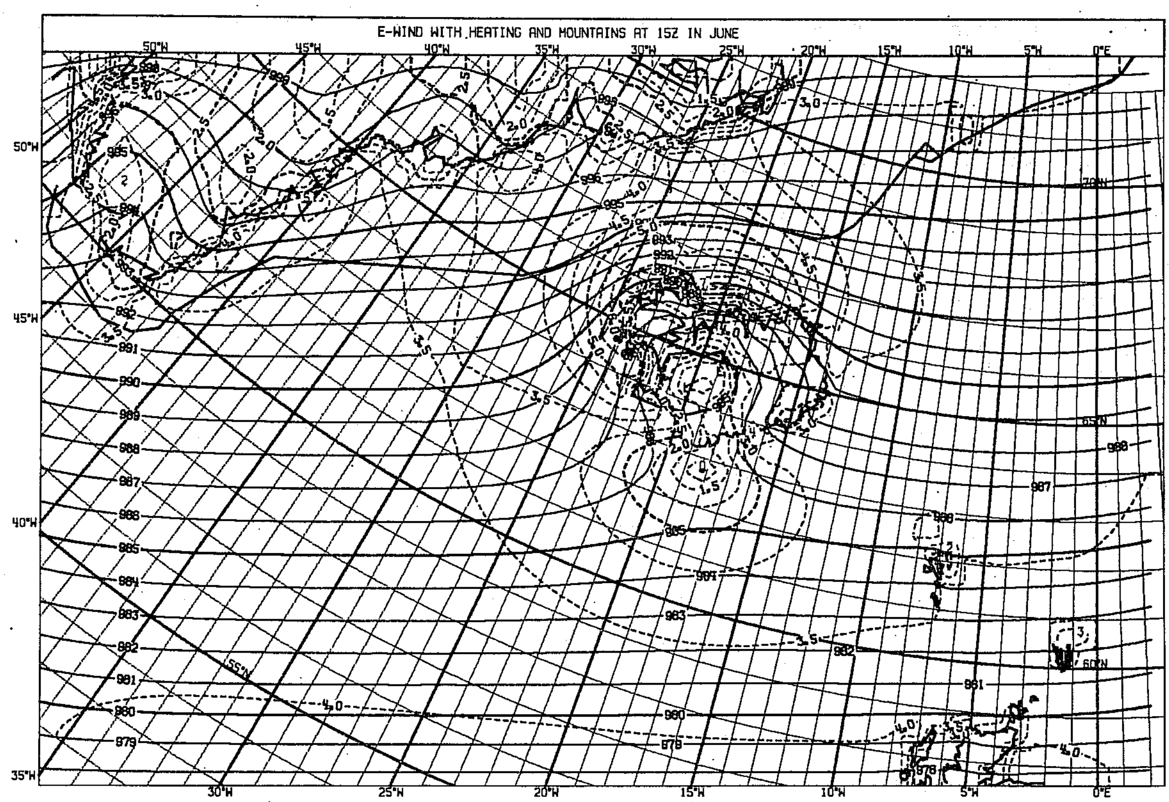

Fig. 5 **The computed modification of the mean sea level pressure by mountains and thermal conditions in Iceland at 15Z in June assuming initially equidistant isobars to be running parallel on the map, with higher pressure to the north.**

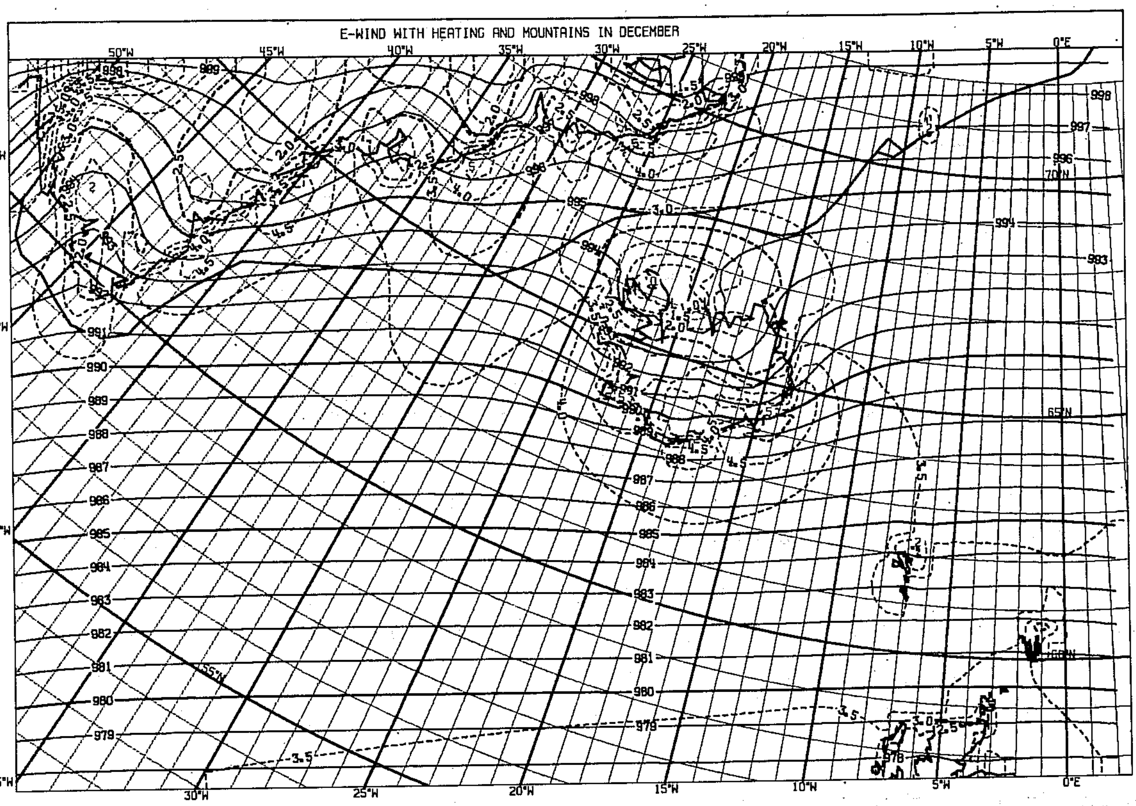

Fig. 6 The computed modification of the mean sea level pressure by mountains and thermal conditions in Iceland in December, assuming initially equidistant isobars to be running parallel on the map, with higher pressure to the north.

4. LOCAL INTERPRETATION OF MEAN SEA LEVEL PRESSURE FORECASTS

4.1 Forecast adjustment to mountains and thermal conditions

In this part of the report we discuss a method for the local interpretation of numerical mean sea level pressure forecasts issued by the ECMWF. The interpretation consists of two steps:

a) A post-processing of the mean sea level pressure forecasts, as they appear on a polar stereographic map with mesh-length 150 km at 60^{O}N, covering the North Atlantic area and adjoining countries. In this post-processing it is attempted to take into account the mountain effect on the pressure (Section 2), insofar as it is not already contained in the forecast.

b) A further mesoscale interpretation for the Iceland area, using both the mountain formula discussed in Section 2 and the thermal formula described in Section 3. The mesh-length used in this case in 37.5 km at 60^{O}N for a polar stereographic map.

If the ECMWF model were using an orography as detailed as the grid-size permits (1.875^{O} lat, 1.875^{O} long) it is conceivable that the forecasts would show the corresponding pressure details in connection with the mountains. This is however not the case. The orography of the model used hitherto is very smoothed and in many cases heavily reduced. (A new and more detailed version will, however, soon be introduced, but for computational reasons it will not show all the details permitted by the gridlength). Several experiments performed by the author indicate that the mountain pressure anomaly PM can be approximately expressed by the mountain formula described in Section 3, using CT = 0.002 and putting the height HE equal to the model's orography. Subtracting from a forecast the pressure anomaly calculated in this way, we obtain the basic pressure PB of the forecast. Thereafter we can compute a new and more detailed mountain pressure anomaly by using the mesoscale effective orography described in Section 2. Here again, the coefficient CT = 0.002 is used.

Having obtained the basic pressure of the large-scale map, in our case covering the North Atlantic area, it is fairly easy to transfer the basic pressure by interpolation onto a mesoscale map of the forecast areas, in our case around Iceland. For this purpose we use a polar stereographic map of 45 by 69 grid-points, with a mesh size 37.5 km at 60^{O}N, four times as high resolution as in the Atlantic map. This interpolation of the basic pressure is thought to be sufficiently detailed, since the basic pressure is by its nature rather smooth in comparison with the mountain and thermal pressure anomaly. For this interpolation of the basic pressure we first interpolated the Laplacian of the basic pressure onto the mesoscale map, linearly. To this Laplacian we then added the thermal Laplacian (Section 3). Knowing this sum of the two Laplacians we can find the corresponding pressure by relaxation methods, provided that we also know this pressure along the boundaries of the mesoscale map. These boundary values can be obtained by a linear interpolation of PB from the Atlantic map. The resulting basic + thermal pressure which corresponds to PB in Eq. (2), Section 2, can now be used to find PM + PB in the same equation, in this case the mesoscale pressure in the Iceland map, modified by mountains and thermal conditions. To complete the map and make it more useful for forecasting purposes, we furthermore draw isolines of the computed wind force according to the Beaufort scale. Over sea, it is assumed that the surface wind velocity is 2/3 of the geostrophic velocity. Over Iceland, this velocity ratio is assumed to be a linear function of the thermal Laplacian (Section 3), becoming 2/3 on a midsummer day and 1/3 on a winter night.

4.2 Results of the experiment

In August 1980, eight ECMWF 1000 mb forecasts (24 hours) were modified using the mountain simulation formula. The mesoscale forecasts for Iceland and the surrounding seas were furthermore modified with the thermal simulation formula.

As an example, we show the modified 24 hour forecast for August 21, at 12Z, as compared with the original forecast, Fig. 7 and Fig. 8. As a partial verification, we give the manual analysis of W-Europe (Fig. 9). The main modification occurs over southern Scandinavia and Iceland, in both cases improving the forecast. The slight mountain effect of Scotland is also indicated on the modified map.

The main purpose of the modification is however to find the mesoscale pressure distribution in a limited area, in our case Iceland and the surrounding waters. As an example we show the mesoscale map for August 21, 12Z, Fig. 10. The pressure gradient over and around the country is evidently rather reasonable, making it possible to distinguish between different regions and fishing banks in the wind forecast.

The 21 Iceland pressure observations available at 12Z were used to verify the forecasts. Correlations with the pressure forecasted at the stations are shown in the following table.

24-hr forecast valid at 1200Z	Modified pressure	Unmodified pressure
80-08-14	0.70	0.93
80-08-17	0.76	0.31
80-08-18	0.79	0.43
80-08-19	0.86	0.96
80-08-20	0.83	0.47
80-08-21	0.91	0.67
80-08-22	0.83	0.61
80-08-23	0.17	-0.16
Mean	0.73	0.53

The experiment is, of course, too short to be conclusive, but it is notable that the correlation of the modified forecasts is much more stable, in most cases varying from 0.70 to 0.90, while the unmodified forecasts show in the same cases a considerable scatter, from 0.30 to 0.95. The last forecast, showing no skill with both methods, was, however, not bad, since both forecasts gave a very light gradient, which was quite true, according to observations.

This result indicates that experiments of this type should be continued.

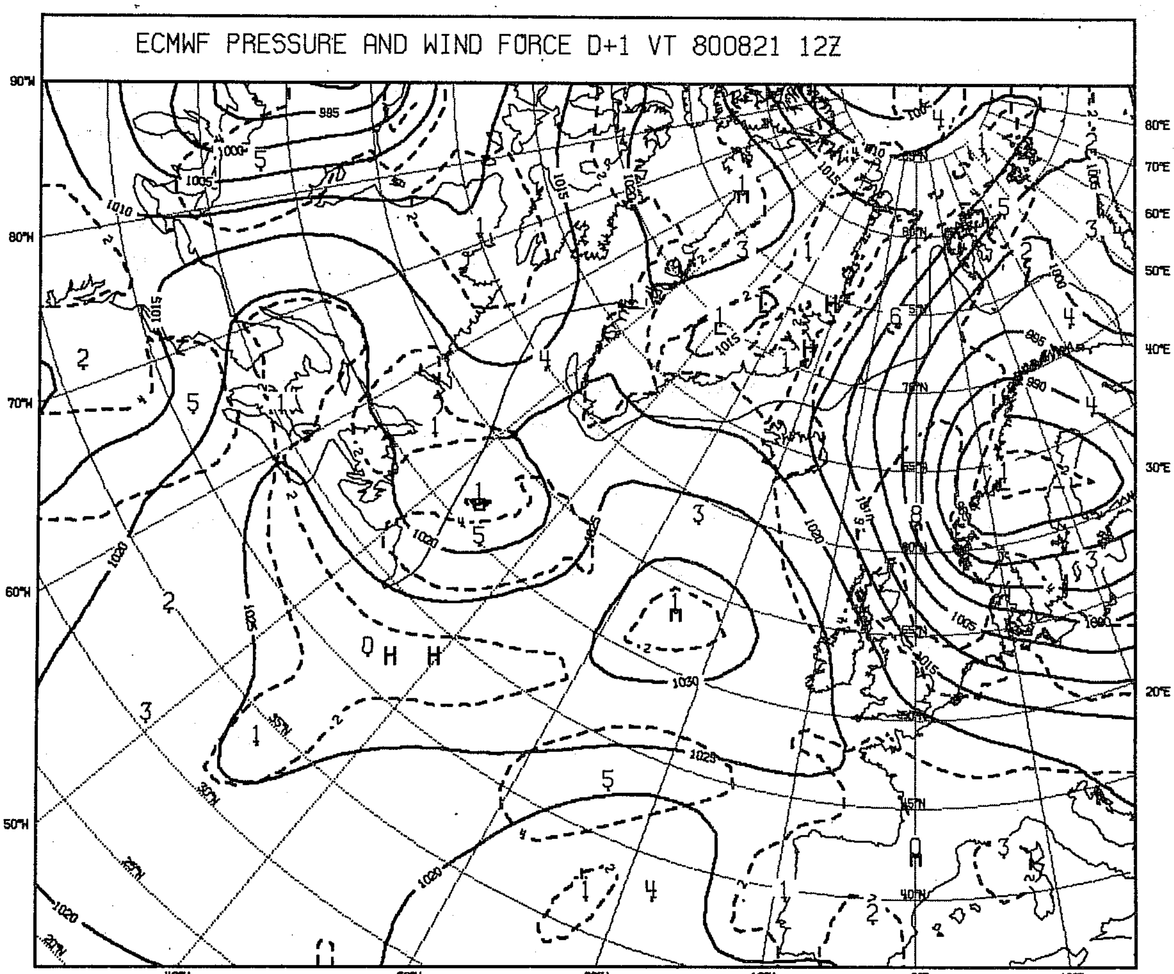

Fig. 7 An unmodified 24 hour m.s.l. pressure forecast computed with the ECMWF model. Stipled lines: Wind force in Beaufort computed from m.s.l. pressure (4.1). Valid time 800821 12Z.

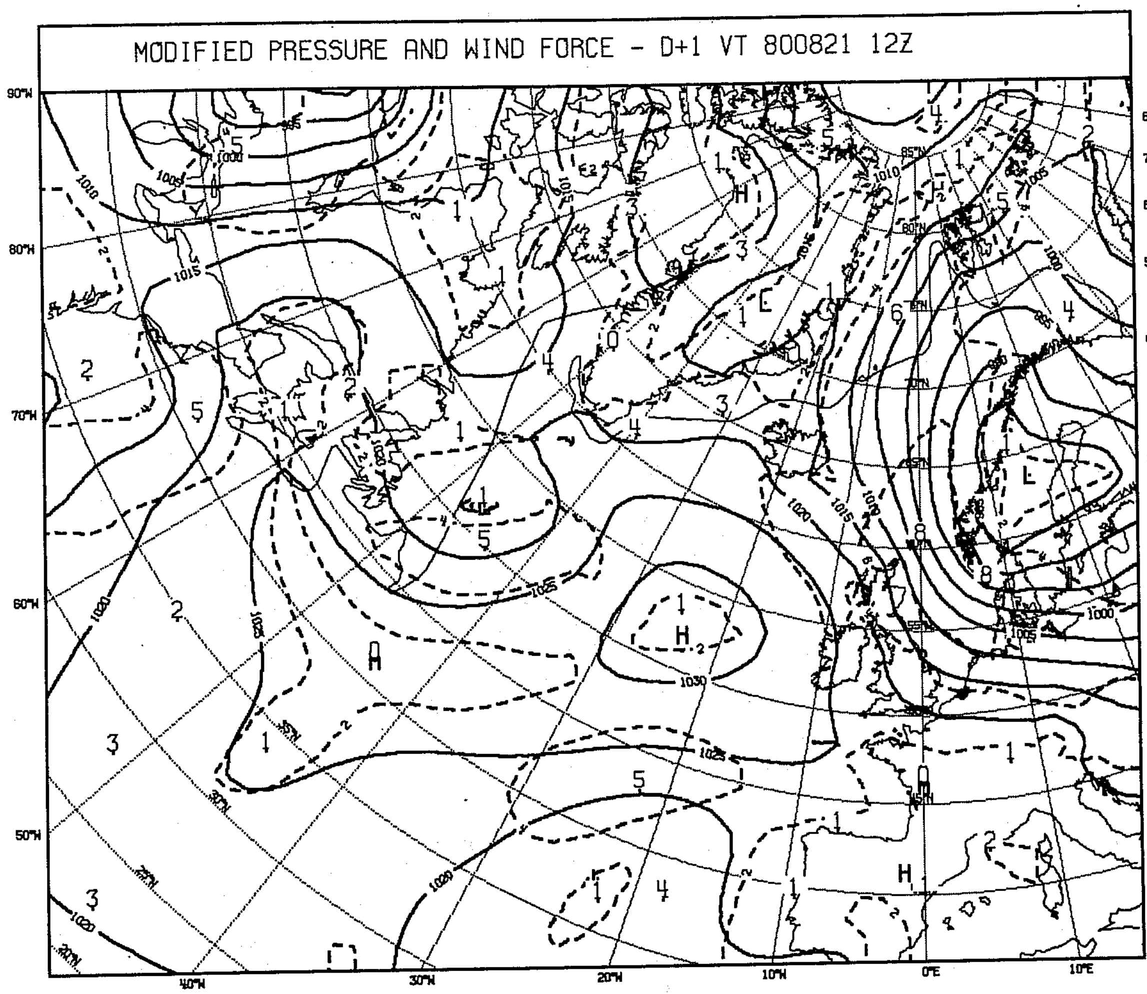

Fig. 8 A 24 hour m.s.l. pressure forecast computed with the ECMWF model and modified by the mountain pressure formula. Stipled lines: Wind force in Beaufort computed from m.s.l. pressure (4.1). Valid time 800821 12Z.

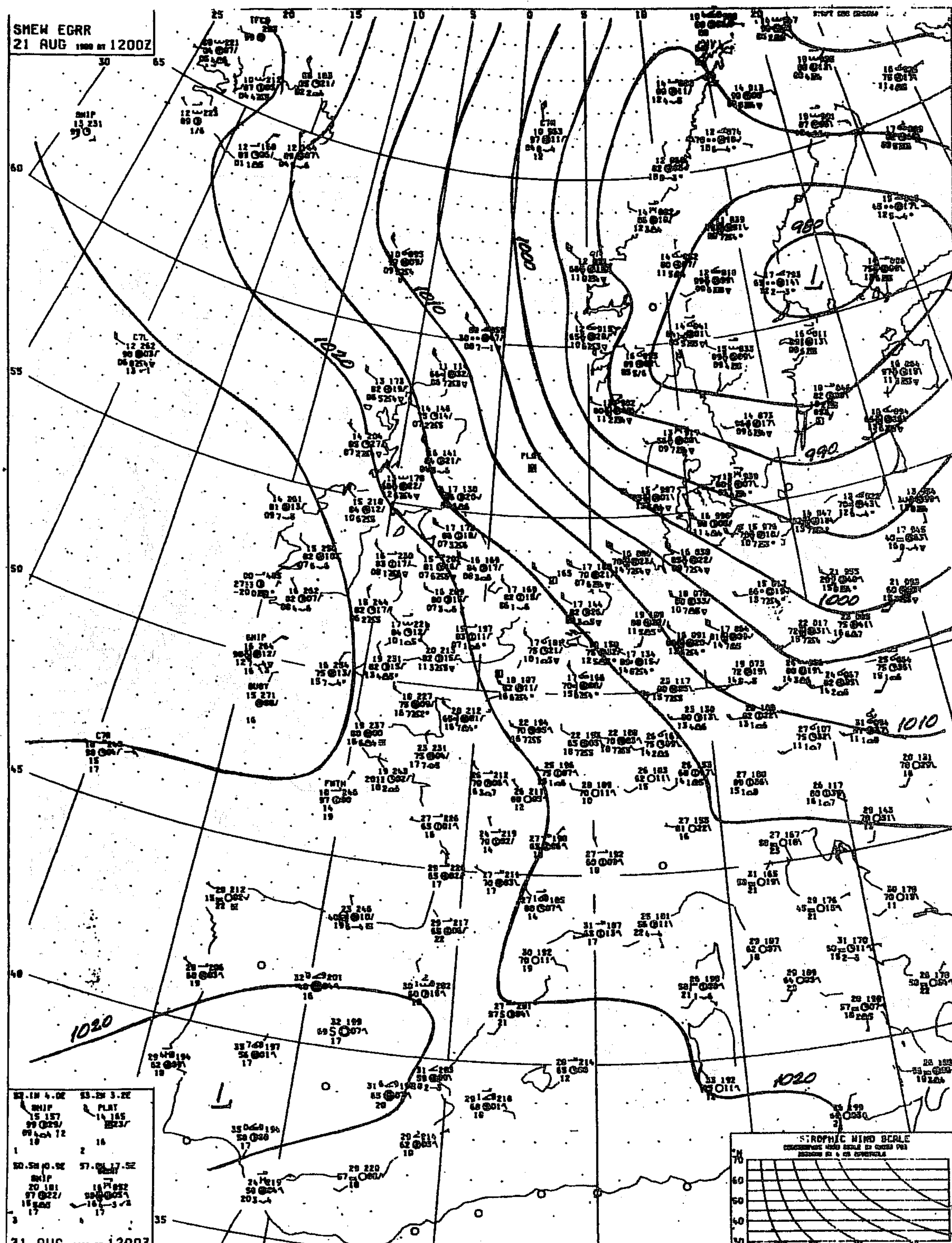

Fig. 9 Mean sea level pressure at 800821 12Z, manual analysis

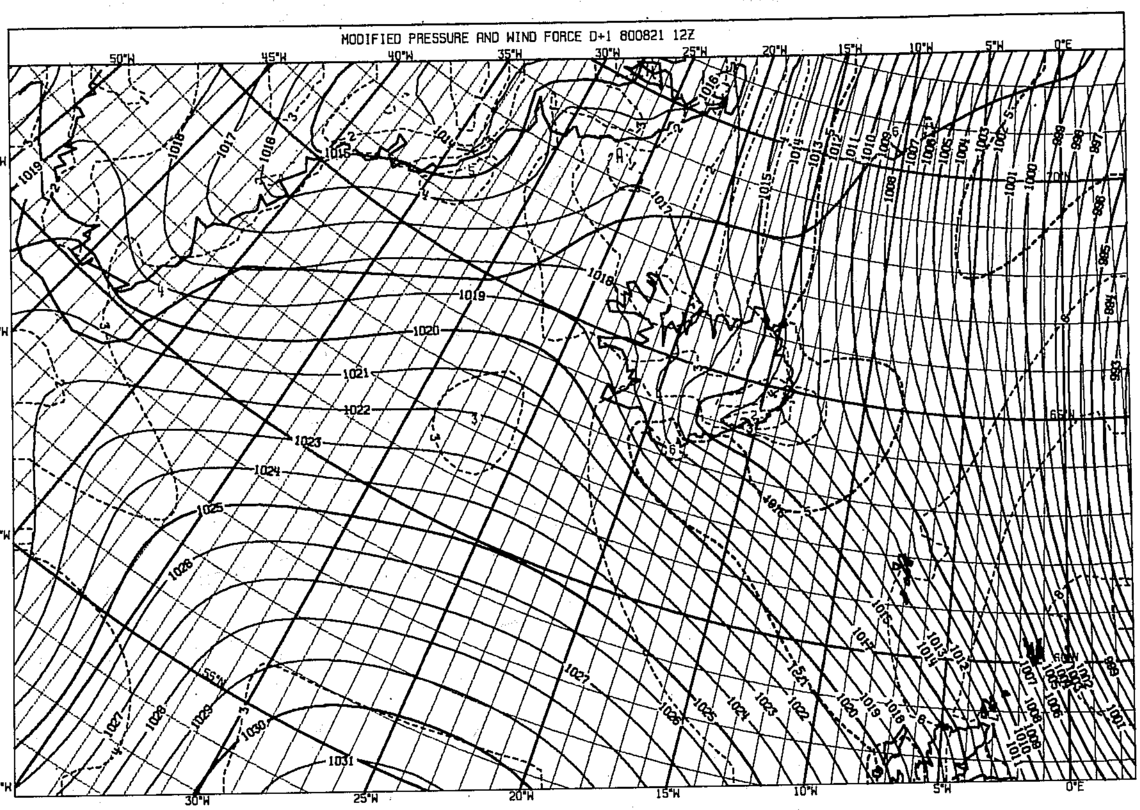

Fig. 10 A 24 hour mesoscale m.s.l. pressure forecast computed with the ECMWF model and modified by the mountain pressure formula in all the area, and by the thermal pressure formula in Iceland, using a grid size of 37.5 km. Stipled lines: Wind force in Beaufort computed from m.s.l. pressure (4.1). Valid time 800821 12Z.

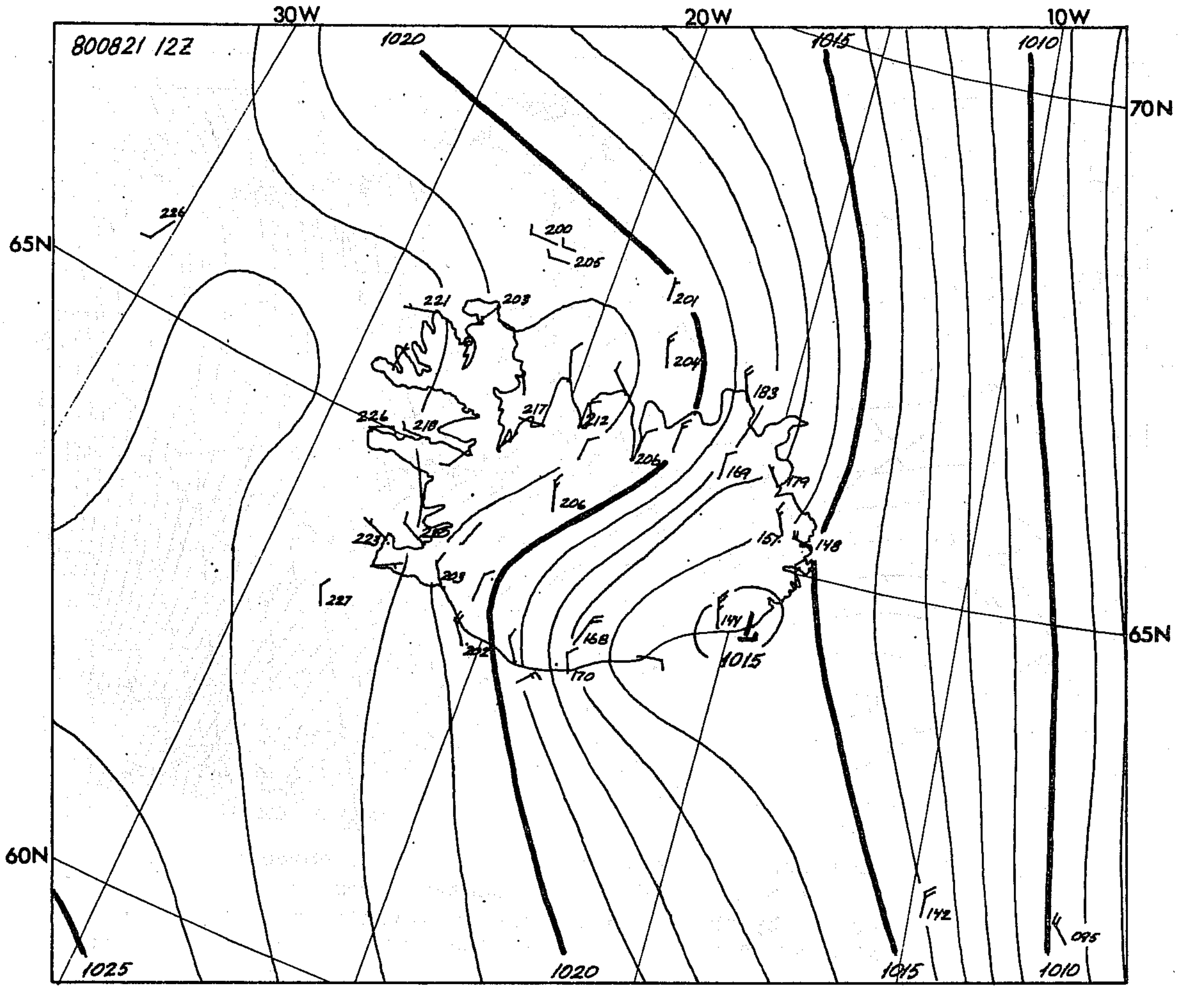

Fig. 11 Mean sea level pressure at 800821 12Z, manual analysis

5. SHORT TERM EXTRAPOLATION FORECASTS BASED ON 3-HOURLY SURFACE OBSERVATIONS

5.1 General comments

A common problem of all national forecasting centres is the short term interpretation of 12-hourly numerical large-scale forecasts in the light of the 3-hourly synoptic surface observations. This problem is accentuated by the fact that usually there is a considerable time lag between the hour of the upper air observations and the dissemination of the corresponding numerical forecasts. This problem is also of great concern for the numerical forecasting centres. In this interpretation the numerical forecasts should not be violated to an unnecessary degree while new observational evidence must of course be appropriately taken into account.

The conventional solution is that the forecaster on duty in the national forecasting centre subjectively estimates to what a degree the disseminated forecast must deviate from the large-scale numerical forecast.

It is the opinion of the author that this problem should be approached in a more objective manner. The methods of the forecasters, theoretical as well as empirical, should in other words be objectively computerized as far as possible. The following is a very preliminary attempt to computerize the author's experience of this kind of work in a simple manner. The principles of this method are the following.

For the period immediately after a synoptic surface observation time the latest pressure tendency is considered to be the main clue to the pressure forecast. It is however clear that a straightforward local extrapolation of pressure tendencies will often fail as time goes on. An important feature is here to take into account the displacement and development of the tendency field. It is furthermore the author's opinion that regarding this observed tendency one should distinguish between "expected" and "unexpected" pressure tendencies, on one hand tendencies due to a reasonable development of pressure characteristics such as highs or lows, and on the other hand tendencies due to "unexpected" deepening or filling. The initial "expected" tendency may be computed with the aid of some forecast model. The rest of the initial observed tendency is then the unexpected part, and it can be assumed to be a rather short-lived phenomenon. It can even change its sign within 12-24 hours. This unexpected tendency should therefore be treated separately and not be considered to be conservative during the forecast period.

In order to split the pressure tendency into the two different components discussed above, the following method is suggested. From a mean sea level pressure map 6 hours before the actual start of the forecast, a forecast is run, using a simple forecast model, generally assuming certain characteristics of the mean sea level pressure to be displaced with the forecasted tropospheric winds. The forecasted pressure distribution at the start of the forecast is then compared with the actual map at the same hour. The pressure deviation is assumed to be the result of an unforeseen deepening or filling, i.e. a certain unexpected change of the pressure, or an error of the model. Then the actual forecast is run. The expected tendencies according to the model are fully taken into account in every timestep of the forecast, but the hourly unexpected pressure changes computed in the beginning undergo a certain decay, determined by empirical methods.

In the above considerations, we have only split the pressure tendency in two parts, expected and unexpected. Besides, it should be recognized that there may be further deviations not taken into account in the model, such as pressure anomalies due to mountains and local thermal effects. This can be taken into account, using the ideas discussed in Section 2 above.

It is essential that the pressure variations at the boundaries of this limited forecast area be determined according to the latest large scale numerical forecast. Furthermore, this preliminary forecast for any area should also be empirically weighted against the numerical forecast for the corresponding hour of the forecast period. This is important in order not to extend these local or national forecasts beyond the point when the numerical forecast has become the optimal solution.

The choice of the simple forecast model for this purpose is not as crucial as might be thought. This is because the unexpected part of the pressure tendency will in any case compensate for the model error in the very beginning of the forecast, but of course this compensation will gradually lose its value in the course of the forecast.

5.2 A simple numerical model used in the pressure extrapolation

In the pressure extrapolation it is suggested to use a certain simple forecast model in order to find that part of the observed pressure tendencies which we call the "expected" pressure tendencies, while the remaining part is called the "unexpected" tendency. For this purpose it has been attempted to apply a simplification of the Fjørtoft model proposed for graphical prediction of the 500 mb height Z5 and of the thickness h between 1000 and 500 mb.

According to Fjørtoft, and neglecting the contribution of the Coriolis parameter to the absolute vorticity, the properties

$$Z5 - \overline{Z5} \tag{4}$$

and

$$h - \overline{h/2} \tag{5}$$

are approximately conserved in the smoothed 500 mb flow, represented by $\overline{Z5}$ where the bar denotes a certain space mean, obtained as the mean height of four gridpoints surrounding every point. The space mean suitable for 0-24 hours displacement of these properties can be obtained using a grid size of some 600 km. This smoothing will effectively exclude the frequent travelling pressure disturbances with wavelength 2400 km, thus giving a space mean which will stay fairly constant for some time. Fjørtoft however points out that disturbances with only half this wavelength will after such a smoothing appear with the same amplitude as before, but shifted completely out of phase. It is easy to prevent this with the aid of numerical computations, by first applying a smoothing with the grid size 150 km, then with 300 km, and finally 600 km. As a 500 mb map it is natural to use the latest available large-scale numerical forecast, valid for the centre of the forecast period. In this case it seems even possible to use only the smoothing of 300 km, at least for a 12-hour forecast.

By subtraction of (5) from (4), one can derive with a good approximation that the property

$$p - \overline{p/2} \tag{6}$$

should also be conserved in the smoothed 500 mb flow. Here, p denotes the pressure at the mean sea level.

Following Fjørtoft's reasoning, one should thus be able to find the future distribution of the property $p - \overline{p/2}$, simply by advecting it in the stationary smoothed 500 mb flow, during any period up to say 24 hours.

Having thus predicted the distribution of this conservative property, the problem arises to find the corresponding p at the same time. This is quite simple, applying numerical relaxation methods, which converge very quickly in this case. For this relaxation it is, however, necessary to know the forecasted pressure at the boundaries of the map, and here it is natural to use the latest available large-scale numerical forecast. Failing this information, it is possible to keep the pressure at the boundaries constant during the forecast period, but in that case a larger map is necessary.

This simplified forecast can be computed every 3 hours, following the synoptic observations. But, as pointed out before, this is a simple model, liable to considerable errors. To compensate for this, we are going to use a tool which has been generally neglected in numerical forecasting hitherto, the latest pressure tendencies.

5.3 The use of the latest pressure tendencies

Since we are dealing with a short term forecast, it is likely that any deepening or filling that the model does not manage to forecast at a certain moment, will be persistent for at least a part of the forecast period. To make use of this fact, we have applied the following procedure.

To initiate a pressure forecast we use two successive maps, with a 6 hours difference in time. This gives a better defined difference than if only 3 hours elapse between the maps, but a longer interval between the maps does, on the other hand, not give as fresh an information for the start of the forecast. On the previous map we form the property $p - \overline{p/2}$ and advect it in the $\overline{Z5}$-field for 6 hours. If this forecast of the conservative property is perfect, it should match exactly with the corresponding property on the latter map. If it does not, the deviation represents a certain individual variation in the property $p - \overline{p/2}$, not being obtained by the model. This deviation is due to the "unexpected" tendency, as mentioned before.

It will be noted that the hourly difference between the forecasted and observed property $p - \overline{p/2}$ should generally be centered on the map at the average hour of the two maps. In order to find the instantaneous location of this deviation at the beginning of the real forecast, this hourly correction has to be advected for 3 hours forward in the smoothed 500 mb field, or even half an hour more, if it is to be suitably located for the first time step, which in our case is one hour.

Now the real forecast begins. Instead of advecting only the property $p-\overline{p/2}$ as it is in the beginning, we now add to it an hourly correction. For this purpose we use the computed hourly "unexpected" $p-\overline{p/2}$ which is constantly being displaced in the smoothed field, along with the conservative property itself. However, we can hardly expect this correction to remain unchanged during the succeeding 12 or 24 hours. Statistically, it will gradually deteriorate as an approximation, in the course of the forecast. To account for this, we only use the correction with its full weight in the very beginning of the forecast. The weight w of the correction can, e.g. be approximated by the following function of time T:

$$w = 1/(1 + A \cdot T^2) \quad (7)$$

where T is the time in hours elapsed since the beginning of the forecast. The coefficient A = 1/100 has tentatively been used, the weight thus being halved in the first 10 hours.

For the advection of the property $p-\overline{p/2}$ in the smoothed Z5-field, the so-called upstream difference has been applied, following the advice of Dr. D. Burridge at ECMWF. This will ensure a good stability in the computations, but possibly it tends to smooth out partly the contrasts in the pressure distribution. It has at least in most experiments proved useful to apply an over-advection of some 20%. In this manner, a reasonable displacement of the pressure systems has been obtained.

5.4 The effect of local pressure anomalies

In our model, the advection of the property $p-\overline{p/2}$ and its gradual variation by deepening and filling is the fundamental principle. But this rule does not take into account stationary pressure anomalies, which are mainly connected with mountains and local thermal effects. The anomalous $p-\overline{p/2}$ of a cold local high over Iceland on a winter night should for example stay where it is and not be displaced with the upper winds to the surrounding fishing banks. And an anomalous $p-\overline{p/2}$ of a local high pressure ridge over east Greenland together with a lee trough over the west coast, should not either be displaced with the smoothed 500 mb flow.

The local pressure effects of mountains and heating were discussed in Section 2. Empirical methods are developed to compute these local anomalies, and in the preceding chapter on modification of numerical forecasts the use of these empirical methods is described. Shortly, we start the forecast by subtracting the mountain pressure anomaly from the mean sea level pressure in both the initial maps, at the time of the beginning of the forecast, and 6 hours earlier. The forecast is then run as described above. At the end of the forecast we compute the mountain pressure anomaly and then the final forecast for the large-scale map is ready.

5.5 High resolution computations for a limited forecast area

The previous discussion applies to a grid extending over a considerable area, sufficiently large for a 24 hour forecast to be made within the area. The grid size of 150 km has been used for this purpose. This resolution is, however, not high enough for local forecasts. As in the case of modification of large-scale numerical forecasts, we have therefore in these short-range forecasts transferred the final result onto a mesoscale map of Iceland and its surroundings. The method of this transfer is analogous and needs no further description.

5.6 The extrapolation forecast experiments

In order to test the extrapolation forecast model, the period from 15 to 18 January 1979 was selected. This period falls within the international FGGE-year which is now being analysed at ECMWF. Furthermore, this was thought to be a severe test of the model, since a very sudden storm occurred in the north east part of Iceland on the first day of this period. After that, the wind backed gradually to a southerly direction, becoming fairly strong, but rather stable.

In this experiment, the 500 mb wind at the beginning of the forecast was used, smoothed over a gridlength of 150 km and then 300 km. The pressure at the boundaries of the map was kept constant during the forecast.

To verify the pressure forecasts for Iceland we used the 5 pressure stations which are inherent in the FGGE-analyses. The correlation between the forecasted and observed pressure may be considered to indicate how correct the isobar direction is in the forecast. But when such a small area is under consideration, a high correlation can occur even if the general gradient is either far too weak or far too strong. Therefore, we have furthermore used the regression coefficient to test mainly the pressure gradient. This coefficient should, for a perfect forecast, be equal to unity, and it can become higher than 1.0, but for low correlation it will generally also be low.

5.6.1 Comparison of the extrapolation model and the ECMWF-model

It is evident that the extrapolation model can only be used for very short term forecasts, particularly when the latest available numerical forecast is beginning to deviate from observations, which on the other hand can be used as a basis for the extrapolation. Even then, the extrapolation forecast should be properly weighted against the numerical forecast according to statistical information. To justify the use of this simple method, it seems then desirable that for say 12 hour forecast, the extrapolation model shows a skill comparable with a rather sophisticated numerical model.

For verification of the eight extrapolation forecasts in January 1979, we therefore used the ECMWF-model to run the same forecasts. The result of the verification for Iceland was the following, using in both cases the initial analyses of FGGE:

Forecast starting at	Extrapolation model		ECMWF-model	
	Correl.coeff.	Regr.coeff.	Correl.coeff.	Regr.coeff.
1979-01-15-00Z	.07	.02	.54	.17
15-06Z	.57	.16	.90	.46
15-12Z	.94	.66	.95	.61
16-00Z	.77	1.09	.75	.83
16-12Z	.89	1.02	.97	.85
17-00Z	.99	1.44	.91	.96
17-12Z	.97	1.11	.92	.62
18-00Z	.95	1.27	.89	.84
Mean	.77	.85	.85	.67

Starting from the same analyses, the ECMWF forecasts give a higher mean correlation for the 8 cases, 0.85, against 0.77 for the extrapolation model. The regression coefficient of the extrapolation model is, however, closer to that of a perfect forecast, 0.85, against 0.67 for the ECMWF model. The sample is far too small to be conclusive, but this comparison still gives some hope that the wind forecasts made with this extrapolation can be as valuable as the much more sophisticated ECMWF forecasts, particularly concerning the strength of the pressure gradient. The main advantage is of course that the extrapolation forecast can be run every 3 hours, and that can justify its use, even if the results are not quite comparable with genuine numerical forecasts starting from the same hour. And, as will be shown in Section 5.6.2 by using a more refined initial analysis, the score of the short range model can probably be raised. Figs. 12 to 16 illustrate the extrapolation forecast for 790115 18Z.

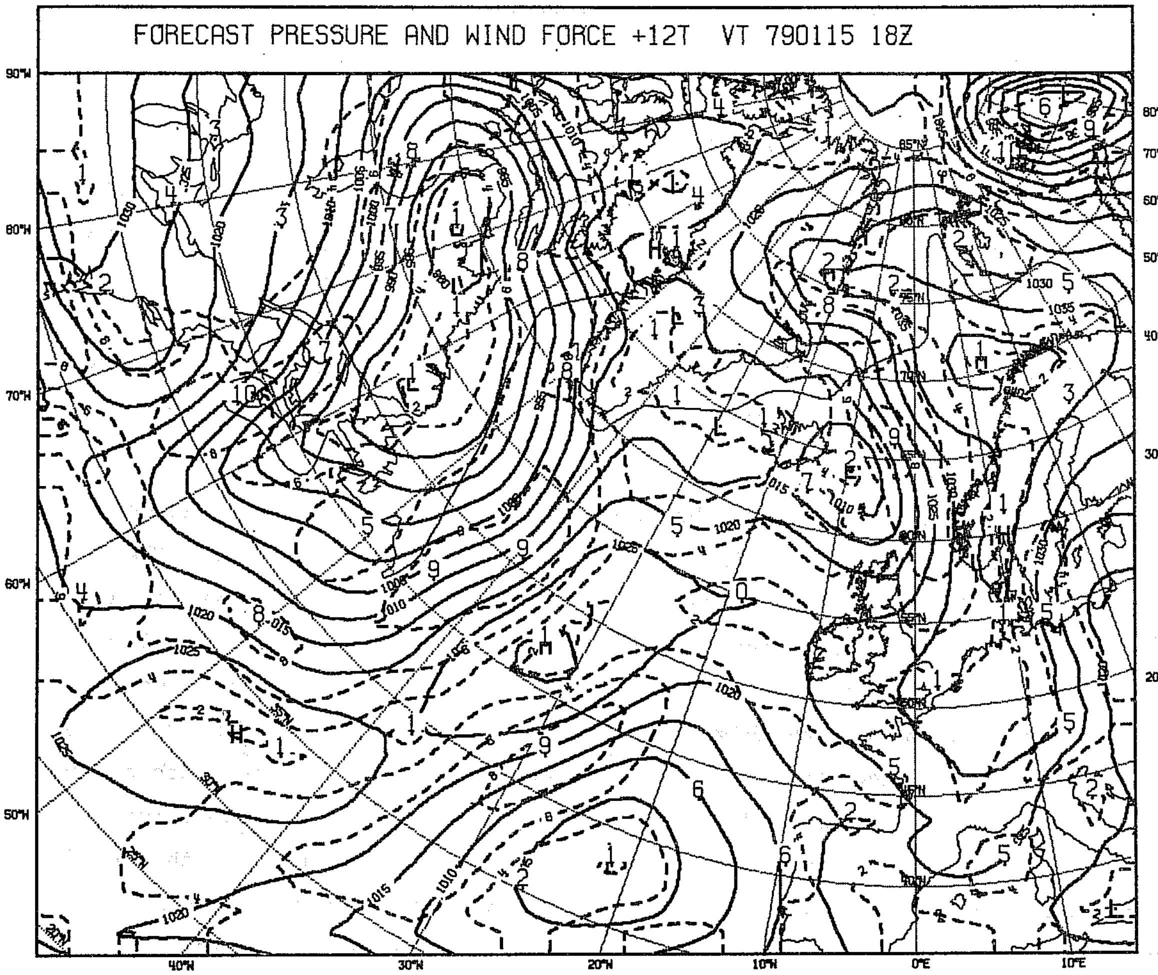

Fig. 12 A 12 hour m.s.l. pressure forecast computed with the extrapolation model, valid at 790115 18Z. Stipled lines: Wind force in Beaufort, computed from m.s.l. pressure (4.1).

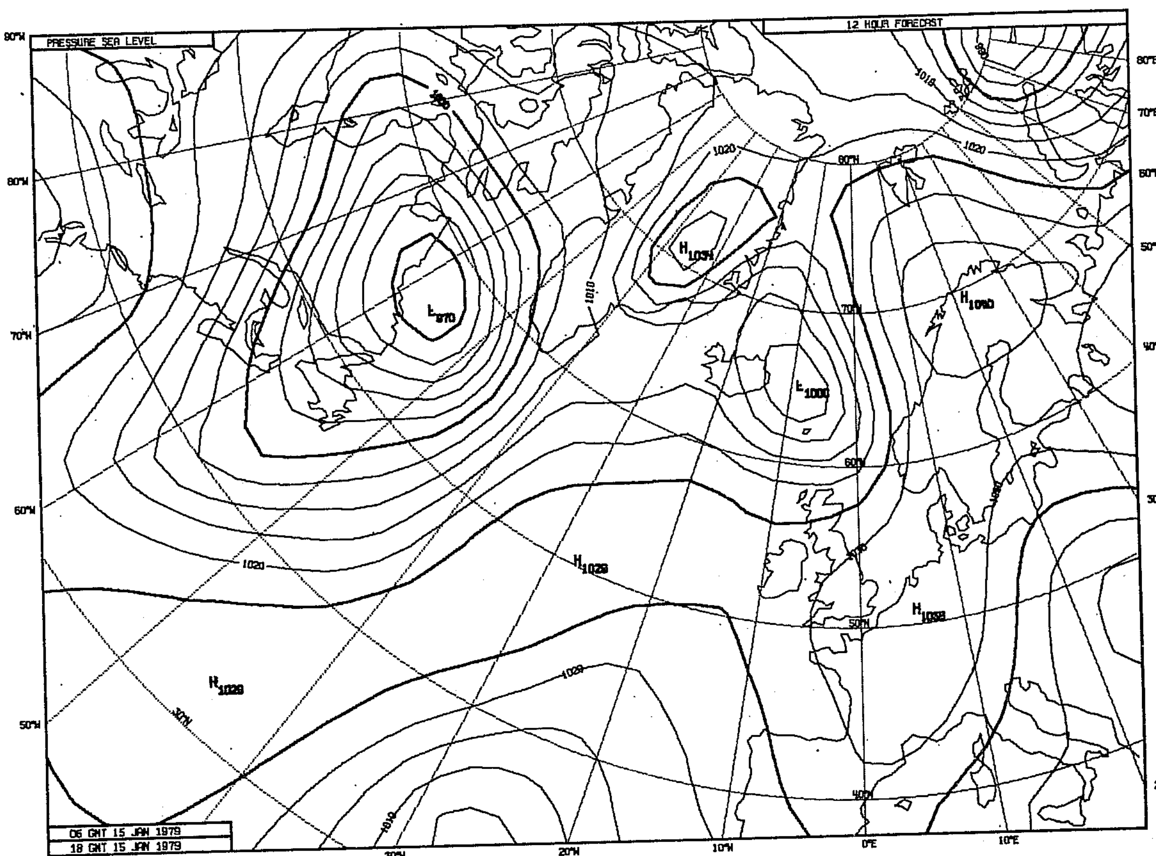

Fig. 13 A 12 hour m.s.l. pressure forecast computed with the ECMWF model, valid at 790115 18Z.

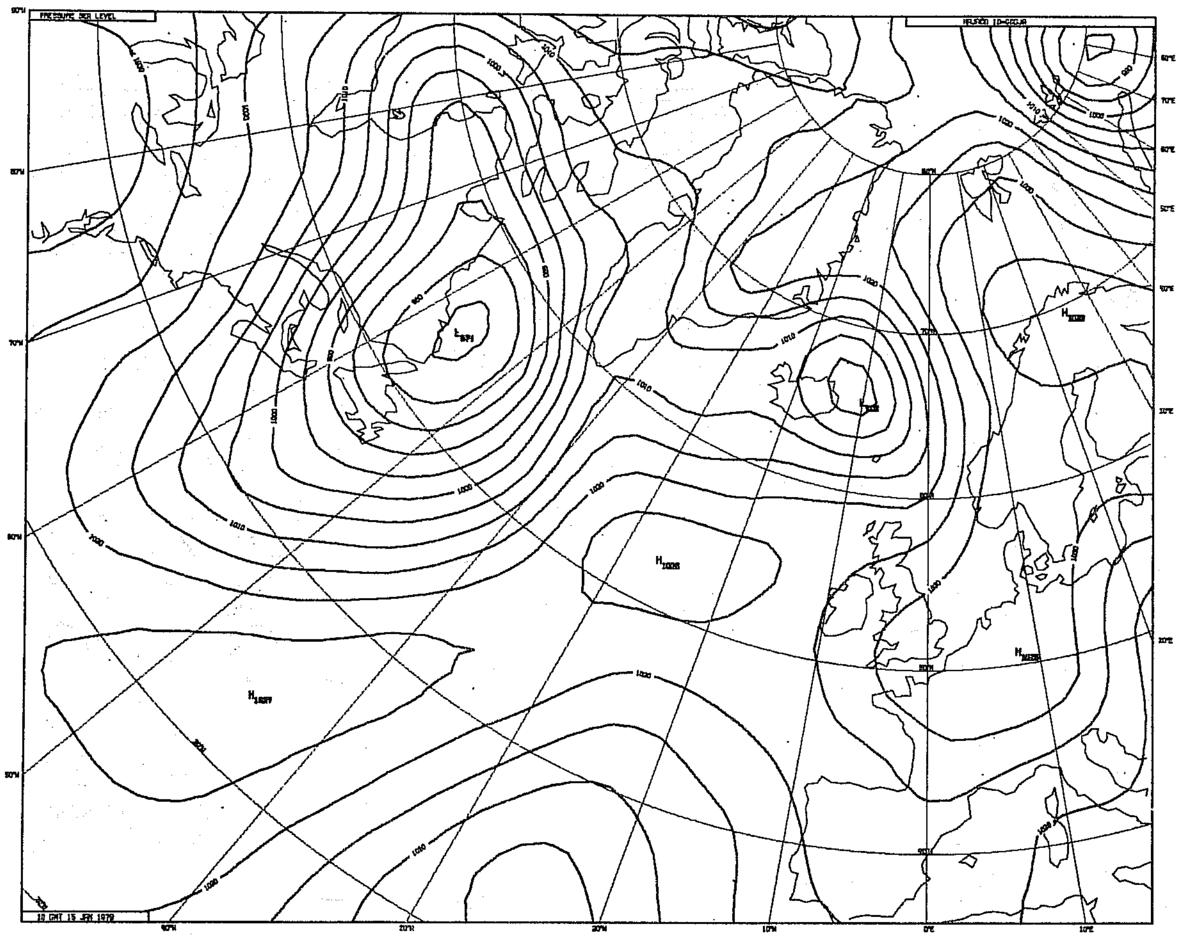

Fig. 14 A FGGE m.s.l. pressure analysis for 790115 18Z.

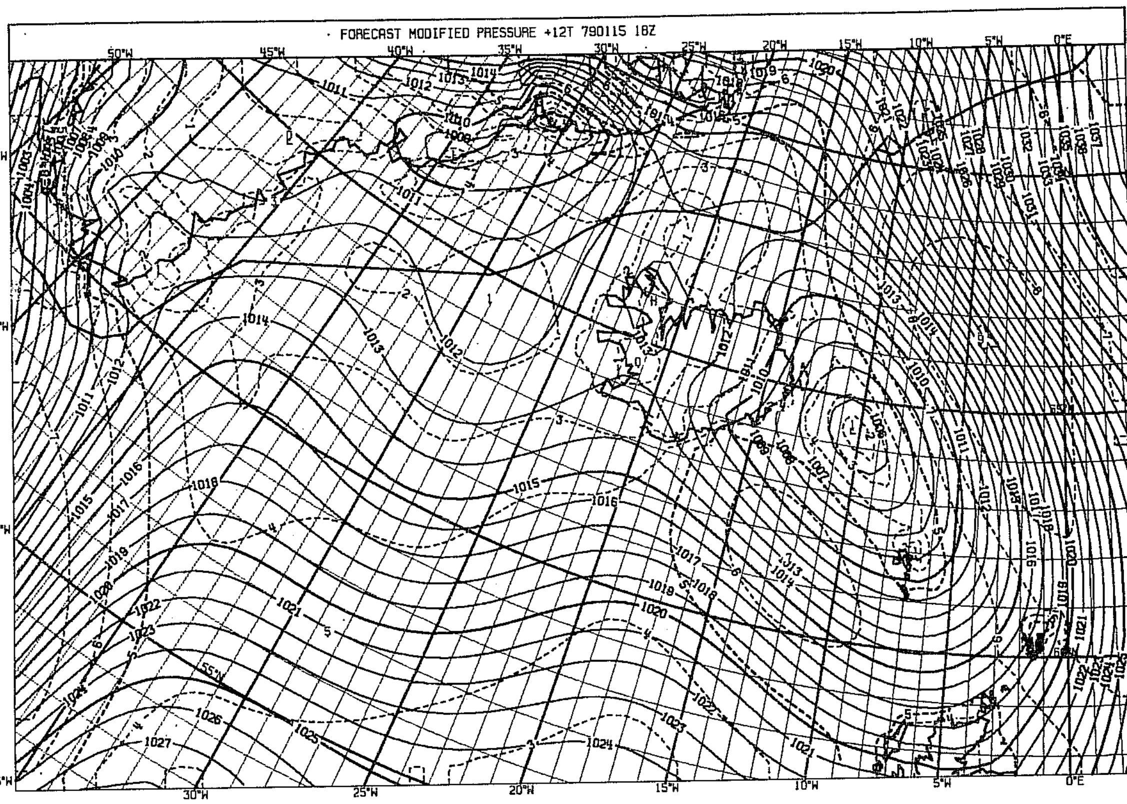

Fig. 15 A mesoscale 12 hour m.s.l. pressure forecast computed with the extrapolation model, valid at 790115 18Z. Grid size 37.5 km. Stipled lines: Wind force in Beaufort, computed from m.s.l. pressure (4.1).

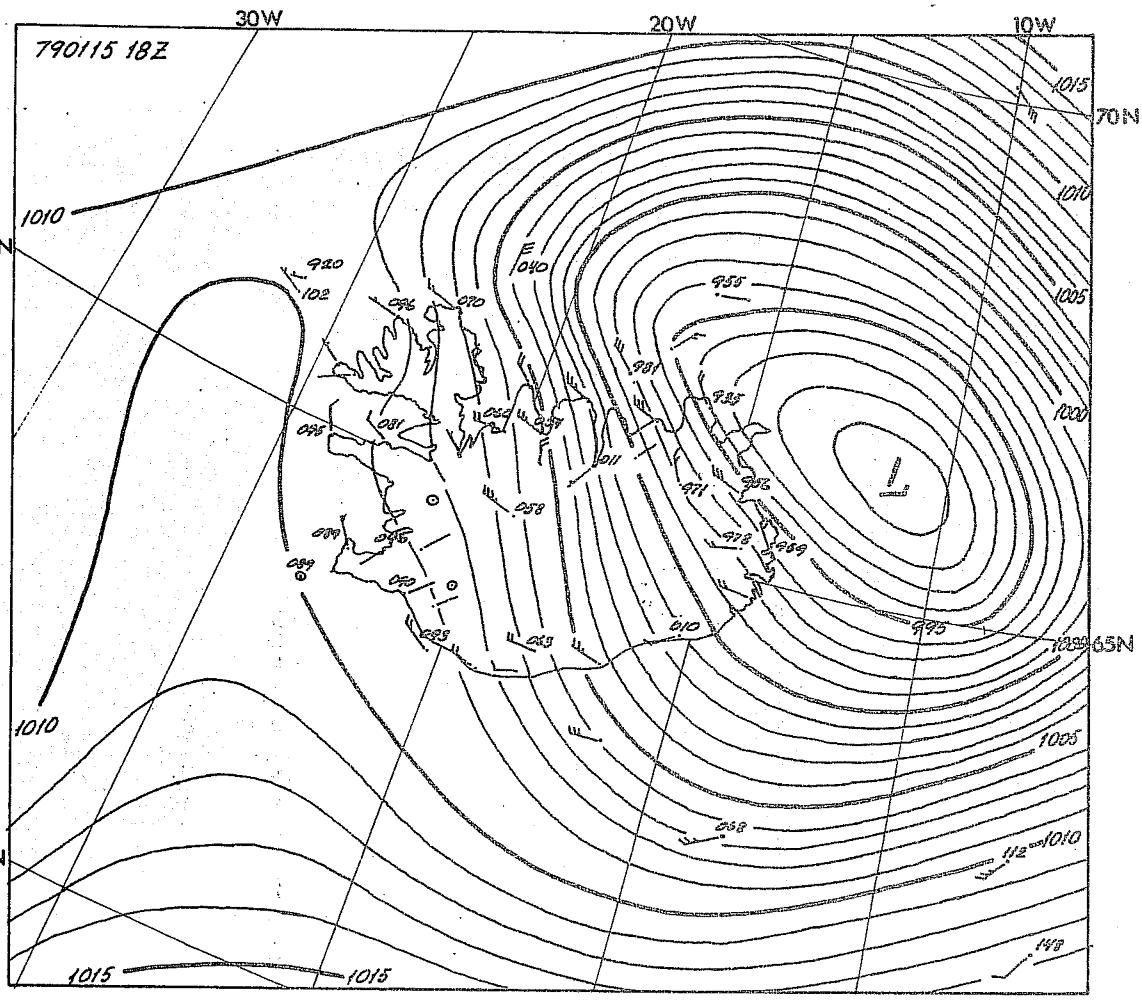

Fig. 16 A manual m.s.l. pressure analysis valid at 790115 18Z

5.6.2 Extrapolation forecasts based on corrected analyses

In the analysis scheme used in ECMWF, small and intense cyclones tend to be smoothed out considerably. They are not considered to be very important for the long-term forecasts which are the main purpose at the Centre, and this smoothing is also a means of excluding the effect of erroneous observations. In our case it is on the contrary essential to catch any small and intense cyclones, such as the one that passed east Iceland on 15 January 1979. It was therefore decided to correct roughly the pressure in the centre of this low to bring it as close as possible to a reasonable manual analysis. This was done for the forecasts starting at 06Z and 12Z, but only for the extrapolation model. Then the forecasts

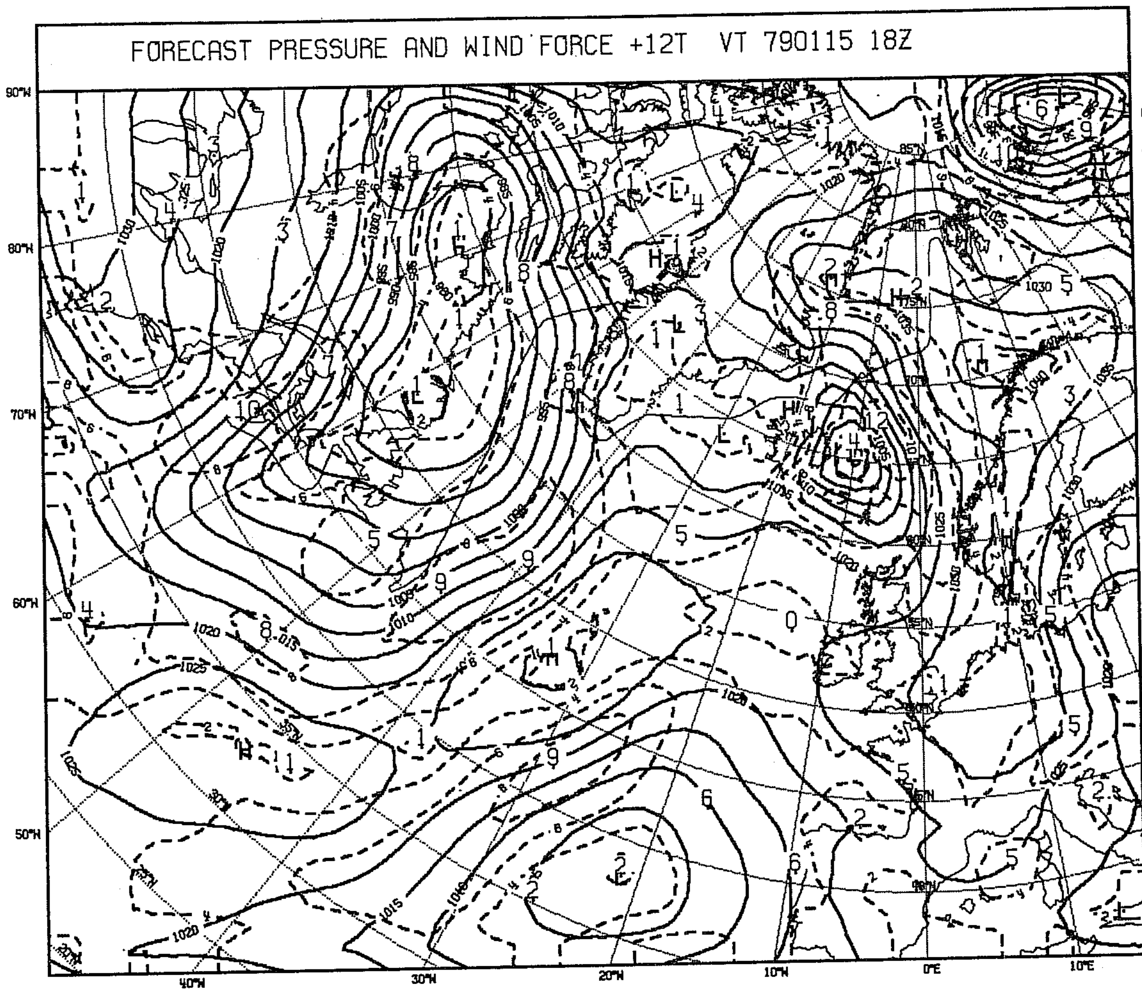

Fig. 17 A 12 hour m.s.l. pressure forecast computed with the extrapolation model and based on corrected analyses. Valid at 790115 18Z. Stipled lines: Wind force in Beaufort, computed from m.s.l. pressure (4.1).

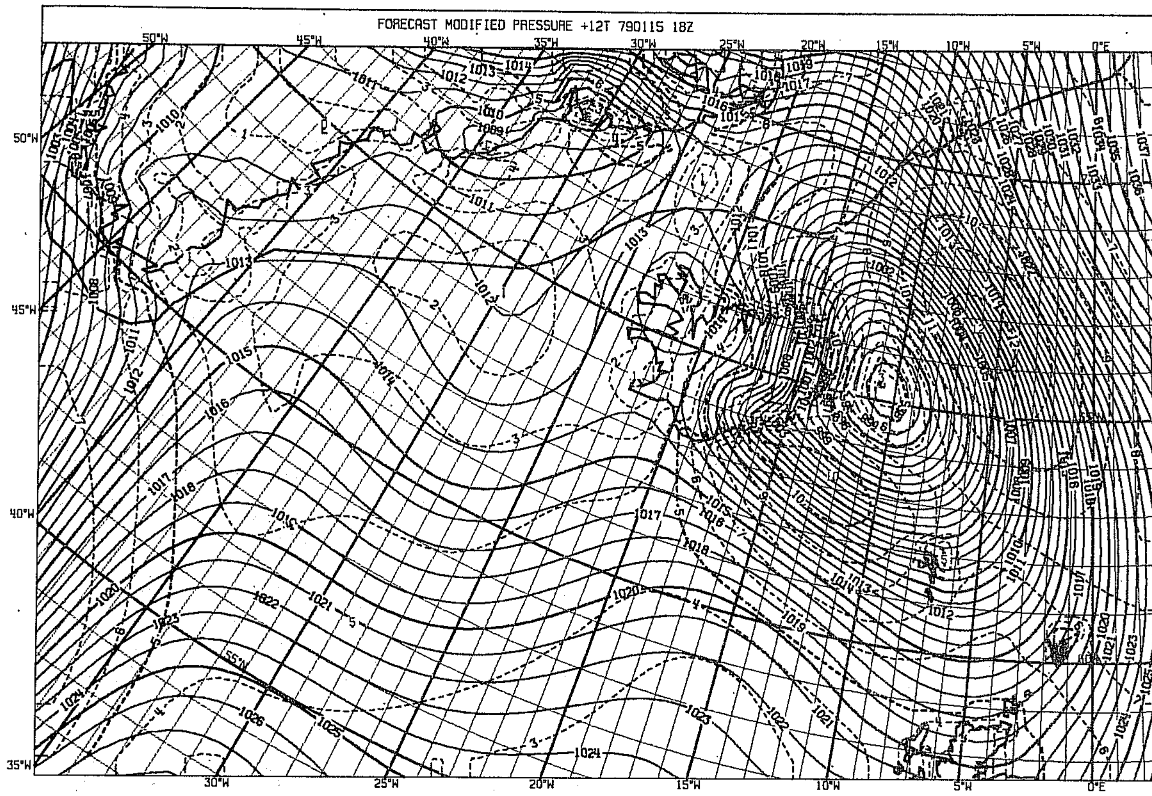

Fig. 18 A 12 hour mesoscale m.s.l. pressure forecast computed with the extrapolation model and based on corrected analyses, valid at 790115 18Z. Grid size 37.5 km. Stipled lines: Wind force in Beaufort, computed from m.s.l. pressure (4.1). (cf. Fig. 16)

were rerun. For this purpose the analyses from Iceland, Great Britain and West Germany were consulted. The maximum correction and its location was determined, and then a certain weight function was used to give the corrections in the surrounding gridpoints. These weights were so selected as to be 0.5 at the distance of 225 km from the correction centre, and 0.2 at the distance of 450 km. The maximum corrections and their positions were the following:

Analysis	Lat.	Long.	Correction
1979-01-15-00Z	57°N	12°W	-6 mb
1979-01-15-06Z	64°N	12°W	-10 mb
1979-01-15-12Z	65°N	12°W	-10 mb

The verification of the forecasts gave the following results

Forecast starting at	Corr.coeff.		Regr.coeff.	
	without correction	with correction	without correction	with correction
1979-01-15-06Z	.57	.69	.16	.59
1979-01-15-12Z	.94	.97	.66	1.14

These two forecasts, particularly the first one, (Figs. 17 and 18) were the most important forecasts in the whole series, since a sudden and unexpected storm occurred at the north-east coast in the early afternoon. Both the extrapolation model and the ECMWF-model failed to forecast this strong wind when an uncorrected analysis was used, (Figs. 7 to 11) while already the extrapolation forecast based on the corrected analysis at 06Z gave a wind force of 10 Beaufort in east-Iceland, and of approximately the right direction. Even if the storm was too extensive in the forecast, this computed forecast would have been valuable for the forecaster on duty and possibly prevented the loss of lives that accompanied this storm. The forecast of the extrapolation model based on a corrected analysis at 12Z was also very successful, even if it exaggerated somewhat the storm.

It must be stressed that this is a very limited test of the extrapolation model, but the result obtained indicates that further experiments along these lines are desirable.

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