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EXPERIMENTS WITH THE UKMO MESOSCALE MODEL
ON THE 12TH JANUARY 1983 CASE

N A Machin

Met O 11 (Forecasting Research Branch),
Meteorological Office
London Road,
Bracknell,
Berkshire,
RG12 2SZ

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1. Introduction

Although the mesoscale model suite of programs has reached a stage where case studies are being run regularly, the forecast model itself has recently undergone several important changes. In particular, the horizontal grid spacing has been increased, a penetrative convective parametrization has been introduced, and horizontal diffusion (of momentum and heat) has been simplified to a linear formulation. An opportunity has therefore been taken to examine the effects of these changes on one of the cases studied. Section 2 outlines the changes in more detail. The last two changes in particular have only recently been incorporated into the model. Thus the results presented in section 4 must be considered preliminary. Indeed the purpose of this empirical approach is to identify deficiencies which require further research. Section 3 describes the chosen case.

2. Changes to the Model

a. Horizontal Grid Spacing

The forecast model domain has been extended from an experimental version covering England and Wales, to cover the British Isles. To retain the ability to store all model data within the present central memory capacity of the Cyber 205 computer it has been necessary to reduce the precision of data representation from 64 to 32-bit and, more importantly, increase the horizontal grid spacing from 10 to 15 km.

b. Convective Parametrization

With no parametrization of convection in the model, when diffusion of heat acts too slowly to maintain stability, the model performs its own dynamic mixing on the grid scale. Although this process is handled stably by the non-hydrostatic formulation and existing stratiform condensation parametrization, the results cannot be realistic. Thus a penetrative convection scheme designed specifically for the mesoscale has been included (Golding, 1982).

c. Horizontal Diffusion

Horizontal diffusion of (horizontal) momentum and heat uses a $K \nabla_H^2$ formulation. Until recently the coefficient K, was set proportional (X0.5) to the (horizontal) deformation. This has been used, apparently successfully, since the original formulation of the model. However, Parrett and Cullen (1983) have shown that, in the presence of a forced discontinuity such as a front, high order diffusion may, by damping only selected modes, distort the development. Low order linear diffusion damps a wider range of wavelengths and thus gives a better solution in these circumstances. It is also computationally much cheaper. Thus K is now assigned a constant value.

3. The Case

At 18 GMT on 12th January 1983 a cold front lying from Newcastle to Rosslare was accompanied by an area of mainly light rain ($\leqslant 1 mmhr^{-1}$) from just ahead of the front to 150 km behind, with only a small area around $3mmhr^{-1}$ off the Lancashire coast. A strong southwesterly flow with surface temperatures around 9°C became a lighter northwesterly at around 3°C almost immediately behind the narrow surface front. The front intensified and moved southeastwards, though only slowly in the north. By 00 GMT on 13th the radar network (Fig. 1) showed that line convection had developed with rainfall rates (meaned over 5 km grid squares) between 8 and 16 $mmhr^{-1}$ in a narrow band between Manchester and Penzance, and moderate rain falling up to 60 km further behind. Note that mesocale forecasts are now run on a 15 km grid so that a more useful interpretation of Figure 1 is that on the front, grid scale rainfall is around 4mmhr^{-1}, with convection adding a further 4 to 12 mmhr^{-1} over about one third of the grid square. During the period a series of rain areas with rates up to 4mmhr^{-1} formed in the warm, moist 'conveyor belt' well ahead of the front and moved east northeastwards parallel to the front.

A trough west of the Hebrides at 18 GMT weakened as it swept southeastwards giving light to moderate rain and showers over W Scotland by 00 GMT.

4. The Experiments

A fine mesh forecast (horizontal grid spacing approximately 75 km) was run from 12 GMT on 12th and interpolated to the mesoscale grid (Purser, 1982) at 18, 21 and 00 GMT. Mesoscale analyses of surface observations of wind, temperature, cloud and rainfall (Higgins and Wardle, 1983) were inserted into the 18 GMT interpolation to produce initial data for the mesoscale model. The remaining interpolations were simply used to extract data with which to update variables at the boundaries of the mesoscale domain during the forecasts. Obviously then for a useful mesoscale forecast it is essential that the fine mesh forecast is broadly correct.

The fine mesh model is unable to resolve the narrowness of the cold front, and although at 18 GMT it gives a good representation of the rain area, with maximum rates around 3mmhr^{-1}, the area, especially of moderate rain, is rather too extensive. There is some indication of rain falling ahead of the front in the southwest, though it is too light and there is no indication of any east northeastward movement during the forecast. Surface temperatures drop only gradually in the cold air, not falling to 3°C until 150 km behind the front, compared to almost immediately in reality. After

18 GMT the fine mesh forecast badly smoothes out the front so that by 00 GMT light rain is falling over all of the British Isles except East Anglia, with only some patches heavier than 1mmhr^{-1} along the front. Although the position of the trough over Scotland is well forecast during the period, its associated rainfall area is so extensive as to be of no practical use.

Several mesoscale forecasts have been run from the interpolated/analysed data to test some of the changes described earlier. All follow the forecast by the fine mesh model and move the cold front broadly correctly, though useful detail has been added. In particular the veer of surface wind on the front is narrowed to less than 30 km, and the rain area is now more realistic in extent and rates. Accumulated rainfall amounts are still too small in all the mesoscale forecasts though. All forecasts fail to reproduce the observed sharp drop in surface temperature behind the front. It seems that air in the boundary layer is unrealistically retarded by surface friction and by orography, allowing the front at higher levels to slide over it. Although this effect is sometimes observed in the atmosphere, it is incorrect in this case, and the splitting of the front, evident in all the mesoscale forecasts, is probably the main reason for the underprediction of rainfall. As Golding (1983) points out, the problem may be helped by the inclusion of vertical momentum transport in the convection scheme since this would result in air with higher momentum being brought down to the surface behind the front. Boundary conditions seem unable to pass cloud into the model domain, in the warm southwesterly flow ahead of the front, without setting off convective instability. Unfortunately this contaminates any 'conveyor belt' rain areas developing in the southwest.

Each of the mesoscale forecasts is now examined in detail.

a. <u>10 km grid, non-linear diffusion, no convection</u>

Since the 10 km grid covers only England and Wales, much of the cold front is initially outside the mesoscale domain. The introduction of 18 GMT observations has had some success in narrowing the surface wind veer, temperature drop and frontal rain area from the fine mesh forecast, within the grid. The mesoscale model soon develops a much narrower surface wind veer, so that by 21 GMT strong ascent on the front has developed thick cloud and correctly increased the maximum rainfall rate from 3 to $8mmhr^{-1}$ in Liverpool Bay. A second maximum of $7mmhr^{-1}$ is also well forecast in Cardigan Bay. There are already signs that the front is beginning to split and in the west by 00 GMT there is a second band of cloud and rain parallel to, and 80 km ahead of, the first (Fig. 2). Rainfall rates in each of the bands are generally $2mmhr^{-1}$ with maxima $6mmhr^{-1}$. These are perhaps not surprisingly only half those observed by the radar network in the single band. The clearance of rain behind the front is well forecast but is probably due to not being able to pass cloud information through the boundaries correctly from the still raining fine mesh forecast.

b. <u>15 km grid, non-linear diffusion, no convection scheme</u>

The forecast on the extended 15km grid is very similar to that on the 10km grid, with no marked degradation. Slight reductions in maximum rainfall rates on the front to $7mmhr^{-1}$ at 21 GMT and $4^1/_2mmhr^{-1}$ at 00 GMT (Fig 3) simply reflect that grid point values now reprsent an average over more than twice the area than in the 10km version. Rainfall rates over Devon and Cornwall are much improved, probably due to the proximity of the western boundary of the old grid. There is now no proper clearance of rain between the cold front and the trough, reinforcing the comment on boundary problems under a. The position of the trough over Scotland is well forecast and, because of the absence of the convection scheme from this run, produces rainfall on the grid scale which would otherwise be essentially convective. Rainfall rates are not unrealistic though. Grid point storms in the convectively unstable air behind the trough cause some unrealistic convergence patterns in the surface wind there.

c. <u>15 km grid, non-linear diffusion, including convection scheme</u>

The most striking difference from forecast b. (without the convection scheme) is that although there is still the same tendency for the cold air aloft to overrun sluggish warm air in the boundary layer, only a weak forward feature develops ahead of the surface front, at least on the grid scale. It seems that convective instability generated by this process is efficiently removed by the convection scheme. Thus grid scale ascent, cloud and rain do not develop (Fig 4) as they do in the forecasts without the scheme, where the instability is released more slowly by grid scale mixing. Although local convective rainfall rates ahead of the surface front of 3 to 7mmhr^{-1} are well forecast (Fig 5), few grid squares have convective precipitation over more than one tenth of their area, whereas the radar observations show this proportion to be nearer one third on the front for a 15 km grid. Thus although the net position of the moderate rainfall new compares more favourably with reality, the problem is simply disguised.

We can suppose that had sub-grid scale vertical momentum transport been included in the model then the front would have moved on more quickly at the surface and slower aloft, as observed, so that splitting would not have occcurred. Grid scale rainfall rates would have perhaps been doubled from 2mmhr^{-1} to the observed rates at 00 GMT, and convective instability would have taken place above, rather than well ahead of, the surface convergence line. The hypothesis remains to be tested.

Grid scale rainfall on the trough is now light with local convection rates at 00 GMT of 3 to 5 mmhr^{-1}, again over around one tenth of the 15 km grid square. This compares well with surface observations. There is evidence at a single grid point here that the convection scheme is not quite removing all grid scale instability.

The grid point storms behind the trough and their associated unrealistic surface wind patterns are removed from the forecast by the convection scheme.

d. <u>15 km grid, linear diffusion, including convection scheme</u>

Forecasts with linear diffusion show a surprisingly high sensitivity to the coefficient used. A value of 2 x 10^{4}ms^{-1} was insufficient to keep the model stable and the forecast 'blew-up' soon after 3 hours. Increasing the value to 5 x 10^{4}ms^{-1} so reduced the frontal wind shear and associated convergence that rainfall rates were generally reduced by 25% compared with the same run with non-linear diffusion, c. However setting the value to 4 x 10^{4}ms^{-1} produced encouragingly good results and it is this run which is compared with the previous forecasts.

Considering that the forecast with linear diffusion took more than 15% less computing time than the forecast with the original diffusion formulation, it is encouraging that the results are very similar. Indeed there seem to be a number of improvements. Away from the cold front two gridlength roughnesses are smoothed. The cold front itself, where strong deformation effectively gave a large coefficient with the original diffusion, is now sharper with stronger ascent and maximum grid-scale rainfall rates increased to $5^1/_2$ $mmhr^{-1}$ at 21 GMT and $3mmhr^{-1}$ at 00 GMT. Apart from the maxima the rainfall is otherwise virtually unchanged from Figs 4 and 5. Another pleasing feature is that windward coasts, in particular W Scotland now seem to present less of an obstacle to the strong northwesterly flow at the surface. Retardation, from around $10ms^{-1}$ over the sea to $1ms^{-1}$ within 30 km of the coast, is now reduced, with an apparently more realistic value of $3ms^{-1}$ inland.

5. Summary

All mesoscale forecasts were similar and moved the cold front broadly correctly, though a probable deficiency in the sub-grid scale dynamics has been identified. The modifications introduced gave differences in the forecasts which were virtually independent of each other and in this case could be quantified thus:

a. Increasing the horizontal grid spacing from 10 to 15 km gave no marked degradation in the forecast detail. A reduction in maximum grid scale rainfall rates by $1mmhr^{-1}$ could be attributed to the more than doubling of the area represented by each grid point.

b. Introduction of the penetrative convection scheme removed unrealistic grid scale mixing and gave realistic partitioning of 'dynamic' and 'convective' rainfall. Grid scale rainfall rates were reduced, probably correctly, by $2^1/_2mmhr^{-1}$ but although local convective rates were correctly forecast, convective precipitation fell over too small a proportion of each grid square so that grid mean rainfall rates were too light.

c. The model was found to be very sensitive to the value of the diffusion coefficient. Setting a constant value of $4 \times 10^4 ms^{-1}$ increased maximum rainfall rates by $1mmhr^{-1}$ comapred to the forecast using non-linear diffusion, though the forecasts were very similar in all other respects. The change to linear diffusion gave at least a 15% saving in computing time, (approximately 8 minutes for a 12 hour forecast).

6. References

Golding, B W	1982	A penetrative convection scheme for the mesoscale model. Met O 11 Work Pap No 46.
	1983	Impact of convection schemes in mesoscale models. Met O 11 Tech Note No 179.
Higgins, A G and Wardle, P R W	1983	Analyses of moisture and convective activity from cloud, visibility and present weather reports. Met Mag 112, 189-199.
Parrett, C A and Cullen, M J P	1983	Simulation of atmospheric hydrolic jumps in the presence of rotation and mountains. Met O 11 Tech Note No 165.
Purser, R J	1982	An algorithm for the accurate interpolation of 15-level model data to the mesoscale model grid. Met O 11 Work Pap No 42.

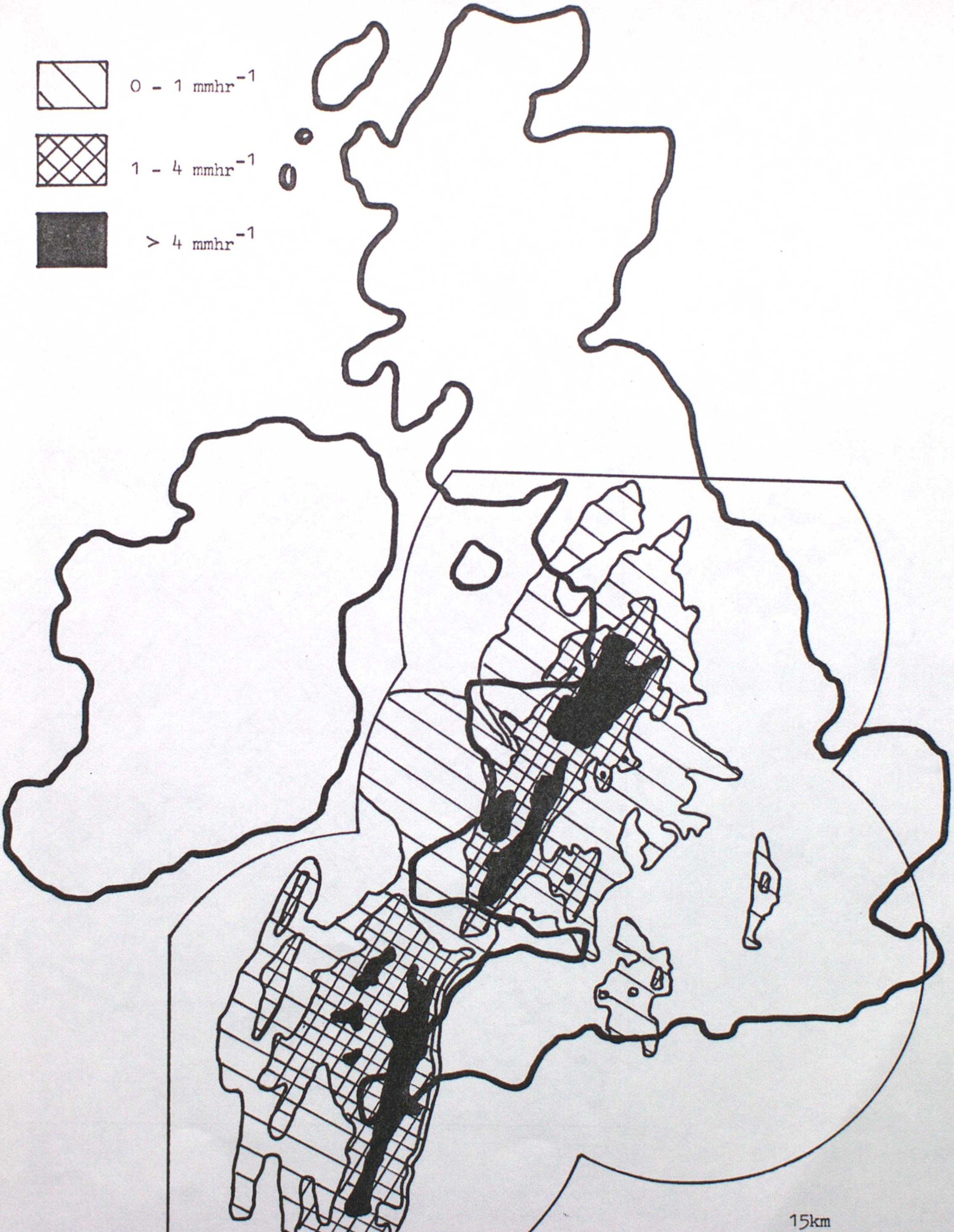

Figure 1. Rate of rain at 00GMT 13/1/83 observed by the radar network

Rates are meaned over 5km grid square

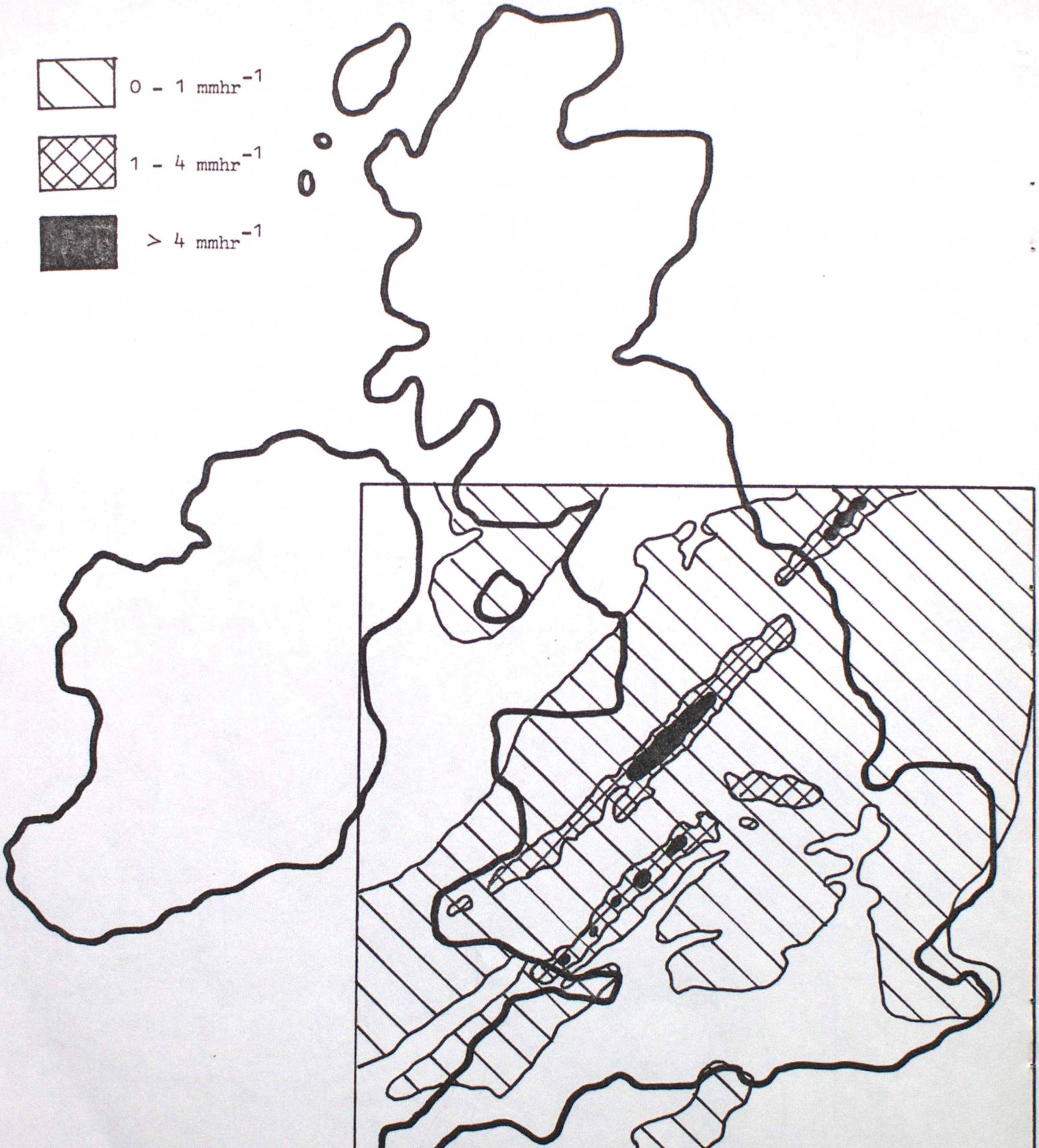

Figure 2. 6 hour forecast of grid-scale rain for 00GMT 13/1/83 with 10km grid, non-linear diffusion and no convection scheme.

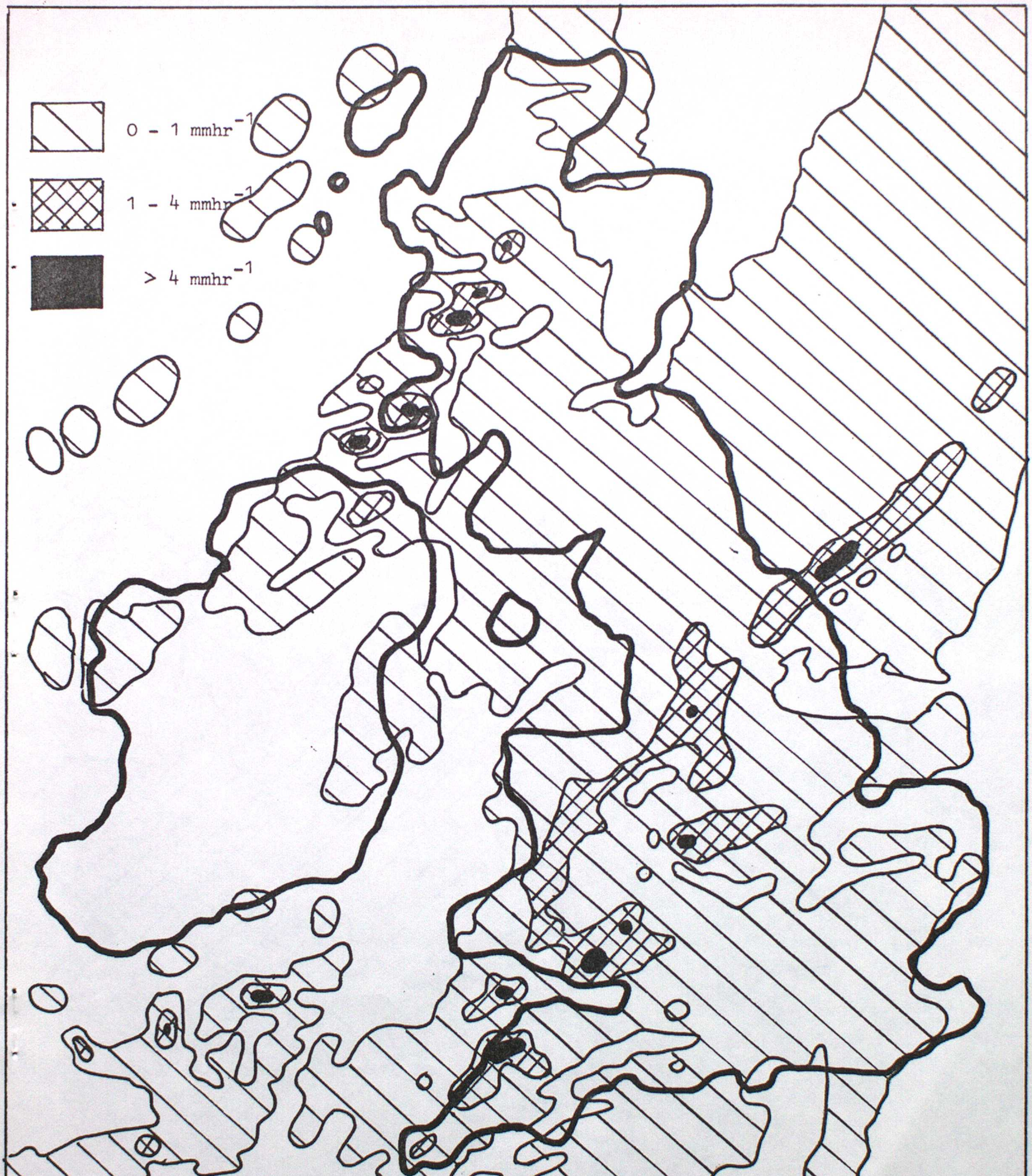

Figure 3. 6 hour forecast of grid-scale rain for 00GMT 13/1/83 with 15km grid, non-linear diffusion and no convection scheme.

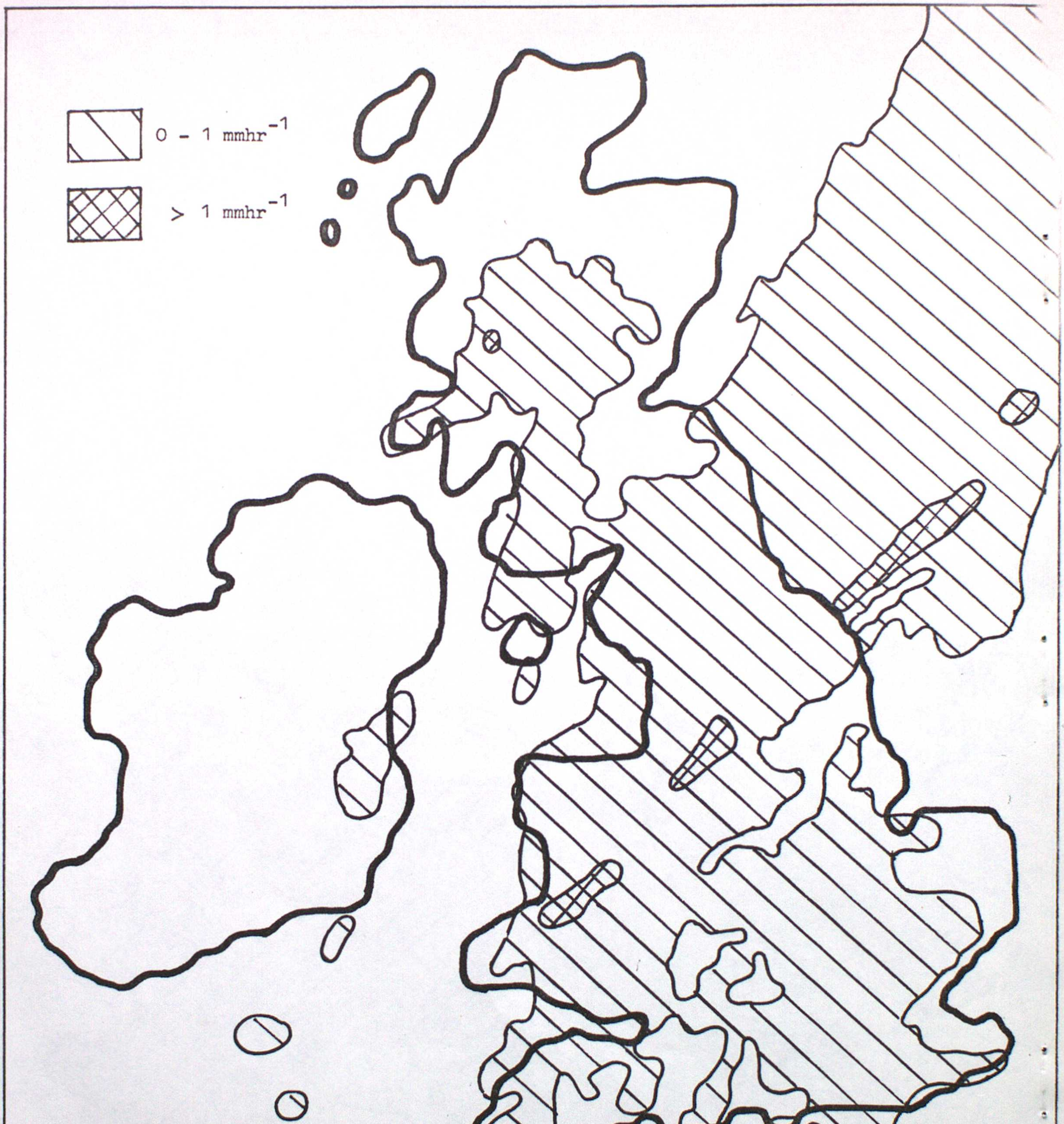

Figure 4. 6 hour forecast of grid-scale rain for 00GMT 13/1/83 with 15km grid, non-linear diffusion and convection scheme.

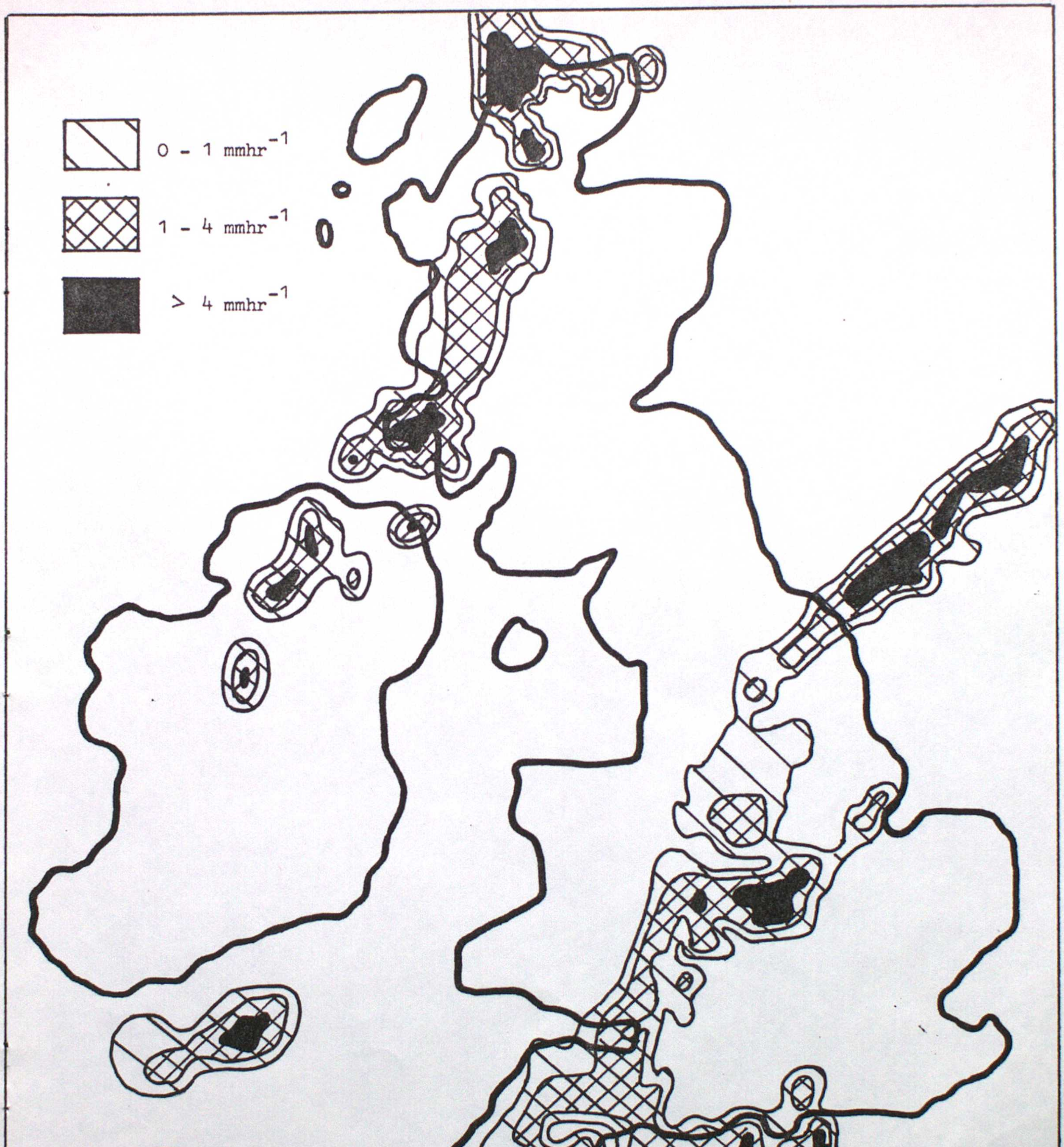

Figure 5. 6 hour forecast of local convective rain for 00GMT 13/1/83 with 15km grid, non-linear diffusion and convection scheme.