IMPACT OF CONVECTION SCHEMES IN MESOSCALE MODELS

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1. INTRODUCTION

The availability of rapidly increasing computer power has led, over the last decade, to the development of very fine mesh numerical forecast models which can simulate mesoscale weather systems. The gridlength required to simulate such features is typically 20 Kms or less. One such model has been developed at the UK Meteorological Office (Tapp and White (1976), Carpenter (1979), Bailey et al (1981), Carpenter and Lowther (1982)). It currently has a 15 Km grid mesh covering the British Isles (Fig. 1). The non-hydrostatic, compressible equations of motion are used and a comprehensive suite of sub-grid scale parametrizations is under development. The penetrative convection scheme is based on that described by Fritsch and Chappell (1980a, b), hereafter denoted FC. It has been modified to take account of the differences between the continental supercell convection modelled in their study and the normal maritime air mass convection found over the British Isles. The remaining sections of this paper contain a brief description of the parametrization scheme, some results obtained with it, deficiencies that have been identified, and some implications for larger scale models.

2. CONVECTION SCHEME

The small gridlength used in mesoscale models changes the approach to convective parametrization in two important ways. Firstly, the grid scale dynamics can be assumed to deal with the mesoscale organisation of cloud cells into clusters, squall lines, hurricanes etc. This simplifies the problem found in large scale models so that the parametrization need model only the cloud cells themselves. Secondly, the size of individual cloud cells will typically be a substantial fraction of a grid square. In this situation, assumptions of statistical homogeneity must be dropped and the parametrization becomes effectively a representation of sub-grid scale features diagnosed deterministically from the grid scale fields. This also has implications for the time domain since a deterministic cloud representation implies a life-cycle for its effects much greater than a model timestep. The scheme used in the UK Meteorological Office Mesoscale Model can, like FC, be described in five parts:- location of convection, updraught, downdraught, rainfall, grid scale effects (Fig. 2). In the following description, major differences from FC are noted.

2.1 Location of convection

In FC, convection was diagnosed by lifting model layers to their Lifting Condensation Level and there testing for upward buoyancy. In the present model, it has been found that the turbulent diffusion parametrization adequately deals with dry convection and so only cloudy layers are tested for buoyancy. Clouds are assumed to last for an hour once formed. However each point is tested for instability every 15 minutes and a new cloud is allowed to replace a pre-existing one if it is larger.

2.2 Updraught

An unstable parcel is lifted, with entrainment at each model level, until it has risen above the level of neutral buoyancy far enough so that the vertical momentum has reduced to zero. At the highest model level below this, the updraught air detrains into the environment. Entrainment is computed so as to double the updraught mass flux between cloud base and top. The cloud base mass flux is determined so that the environment (see 2.5) will warm to the updraught temperature profile in one hour if all other processes are ignored. This is a similar but not identical condition to that used in FC. The total mass flux is not allowed to exceed the mass of air in the grid square beneath cloud base.

2.3 Downdraught

In FC, an entraining parcel formulation is used for the downdraught. This was successfully used in simulating continental supercell storms. However, attempts to use a similar formulation on profiles from UK radiosonde ascents produced unrealistic results. A much cruder approach was therefore adopted in which a downdraught with constant mass flux starts at the mid-level of the cloud and detrains at the ground. Cooling by evaporation of rain occurs only below cloud base.

2.4 Rainfall

Rainfall at cloud base is computed by applying an empirical efficiency factor to the total condensed moisture in the updraught. The moisture not precipitated is assumed to pass into the environment by detrainment during the cloud's lifetime, or when it dissipates. An empirical profile for this detrainment is specified. The efficiency is much smaller for typical UK showers than for the supercell storms considered in FC. Thus the peak is 0.5 in the absence of shear, decreasing to zero for a shear of $10^{-2}\ s^{-1}$. Below cloud base, evaporation occurs depending on the humidity, which is taken as a weighted average of the environment and an assumed steady state value for the downdraught (80%).

2.5 Grid scale effects

The detrainment of updraught and downdraught air at cloud top and at the ground have already been mentioned as has the detrainment of un-precipitated cloud water. Remaining effects are due to the environmental subsidence required to balance the net upward mass flux in the cloud. This can only occur in the cloud free part of the grid square. In addition there is detrainment of cloud air at all levels representing principally the dissipation stage of the cloud's life. The balance of these effects is to warm and dry much of the atmosphere and hence to stabilise it relative to the ground. The influence of the cloud on the momentum field was incorporated in FC but is not included in the present scheme yet.

3. RESULTS

The convection scheme has only recently been incorporated into the mesoscale model so the results obtained so far must be considered preliminary. They do, however, indicate some deficiencies which will require further research. Two cases will be briefly described in the sections below. The first is a winter cold front and the second a summer air mass case. First, however, a brief reference should be made to the results presented in FC. In part II, a mesoscale model incorporating their convection parametrization was tested in idealised conditions to simulate the development of a mesoscale convective complex. They showed that cold downdraughts from individual storms can combine to form meso-highs while subsidence warming at middle levels can lead in some circumstances to generation of meso-lows. In their simulation, the downdraughts produced substantial surface cooling of 5-10°C in addition to cooling relative to the surroundings by radiative effects of the cloud. The meso-high was situated over this cool area, and at middle levels of the troposphere was overlain by a substantial cell of rising air.

3.1 Cold front line convection

On 13th January 1983 a cold front crossed England and Wales from the northwest. Although initially accompanied by a weak band of rain, it developed a squall line along its forward edge, in which rainfall rates of 8-16 mm/hr were recorded by the radar (Fig. 3). The forecast was initialised at 1800 GMT 12th January from a 6 hour forecast of the 75 Km gridlength regional model. Mesoscale analyses of boundary layer and cloud variables were also inserted. The forecast moved the front correctly both with and without convection. Also, in both cases, accumulated rainfall was too light. In the run with convection, the grid scale rainfall rates (Fig.4) declined to under 2 mm/hr by midnight with convective rates (Fig. 5) over one tenth of each grid square, of 3-6 mm/hr correctly located on the forward edge. Without convection, the rainfall was mostly less than 5 mm/hr (Fig.6). Both forecasts predict a strong wind shear at the front and both fail to produce the observed sharp drop in surface temperature. The run with convection removes the unrealistic convergence patterns shown by the surface winds in the run without convection. Both runs were contaminated near the southern boundary where the boundary conditions were unable to pass cloudy air into the model without setting off convective instability. The failure of this moist air to become involved in the front is probably part of the reason for the underprediction of rainfall rates. The absence of the observed temperature drop indicates a more complex problem which may be related to the sub-grid scale dynamics of a front. In reality surface air is forced to rise at a front and is replaced by the air mass behind the front. However, both the convection scheme and the vertical diffusion respond to the grid scale vertical stability and do not react directly to the horizontal gradients which force the local frontal dynamics. Friction then retards the surface air and allows the front to slide over it. The problem may be helped by the inclusion of momentum transport in the convection scheme since this would result in air with higher momentum being brought down to the surface behind the front.

3.2 Summer air mass convection

On 24th July 1983 a weak complex of low pressure affected much of the British Isles. At 0600 GMT there was an area of rain over central England and isolated showers, mostly over the sea, were recorded by the radar. During the morning, the rain in the south intensified and moved north (Fig.7). A circulation formed over the south midlands, and warm air was advected northwards producing an east-west belt of thundery showers which continued northward(Fig.10). It dissipated in the evening after reaching the Humber estuary. Meanwhile further showers had developed ahead of it, especially to the west of the Pennines, and over Wales. There was also a line of showers marking cold advection by the circulation. This extended from the midlands to Cornwall. The forecast was initialised, as before, using interpolated data with enhanced detail in the boundary layer and cloud fields. An early feature of the forecast was that the convection scheme erroneously mixed, and cleared the widespread stratocumulus cloud put in by the analysis. At the same time, the rain area over southern England developed strong convection with local rates of 20 mm/hr (Fig. 8). These are consistent with observations. Although it correctly spread north in this time, convection continued on the south coast until afternoon. It correctly cleared quicker without the convection scheme (Fig.9). In both runs a circulation formed, the position being better in the one with convection. At about noon, the restrictions on mass flux in the convection scheme allowed grid scale convection to develop and this continued throughout the afternoon producing too much rain and over-intensifying the low (Fig.11). This resulted in insufficient northward movement of the main rainbelt. For the same reason, the run without convection kept its pressure centre even further south and even deeper. The other deficiency of both forecasts was the absence of showers in northwest England and north Wales. Some outbreaks of light rain were predicted but no instability. The reason for this is not clear since surface temperatures were well predicted and there was obviously moisture present to give the grid scale rain. The reason probably lies in the initial data specification. However, another possibility is that the showers were triggered by waves initiated in the system further south.

4. DEFICIENCES

A number of faults of the scheme have been identified above. However, some more fundamental difficulties should be considered first. The basic flaw in a parametrization of this type is that the circulation created by a large cloud cannot be assumed to be contained in a single grid square. The presently imposed limit forces a grid scale circulation when the time-integrated mass flux exceeds the mass below cloud base. However, the second case study indicates that the response may still be unrealistic, and in any case, the upper boundary condition of the model is not adequate for simulating grid scale convection through the full troposphere. A possible, though untried, approach is to parametrize only the cloud scale updraught and downdraught and to allow the model to perform the necessary mass redistribution at the grid scale. An alternative may be to cluster groups of unstable grid squares. However, this reintroduces the problem of parametrizing the mesoscale.

Another theoretical fault arises from the deterministic nature of the scheme since convection is initiated by turbulent eddies which are normally considered random. This is not a serious problem if it can be shown that the convection responds strongly to features in the grid scale fields.

Other faults noted in the case studies were the lack of momentum transport and the erroneous clearance of stratocumulus. The latter arises because any cloud with a lapse rate less stable than a saturated adiabat above it will be considered unstable regardless of whether means are available for it to be lifted above its present position. This problem could be avoided if the grid scale vertical velocity was included in the vertical momentum calculation.

5. IMPLICATIONS FOR LARGE SCALE MODELS

The primary conclusion for this section is that a convective parametrization in a mesoscale model is representing different features from one in a large scale model. In the latter, it is the mesoscale that must be parametrized and if the convection is organised this may be quite different from simply an ensemble of clouds. If the convection is organised, the statistical problem noted for mesoscale models will also exist for the large scale model since the assumed mesoscale organisation will have to be deterministic. In such situations it may still be an error to assume that the whole (mesoscale) circulation occurs in a grid square, although this problem is certainly less acute for the large scale model. Similarly, the time evolution of the mesoscale system may be an important feature of its parametrization. The case studies showed some skill in simulating mesoscale development. However, there are several problems remaining to be solved before such studies could form the basis of a parametrization in a large scale model.

6. REFERENCES

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Carpenter, K.M. 1979 An experimental forecast using a non-hydrostatic mesoscale model. Quart. J.R.Met.S., 105, 629-655.

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Fritsch, J.M. and Chappell, C.F. 1980a Numerical prediction of convectively driven mesoscale pressure systems. Part I: Convective parametrization. J.Atmos.Sci., 37, 1722-1733.

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Tapp, M.C. and White, P.W. 1976 A non-hydrostatic mesoscale model. Quart. J.R.Met.S., 102, 277-296.

Fig. 1 Domain and orography currently used for mesoscale forecasts. The contour interval is 100 m and the gridlength is 15 km.

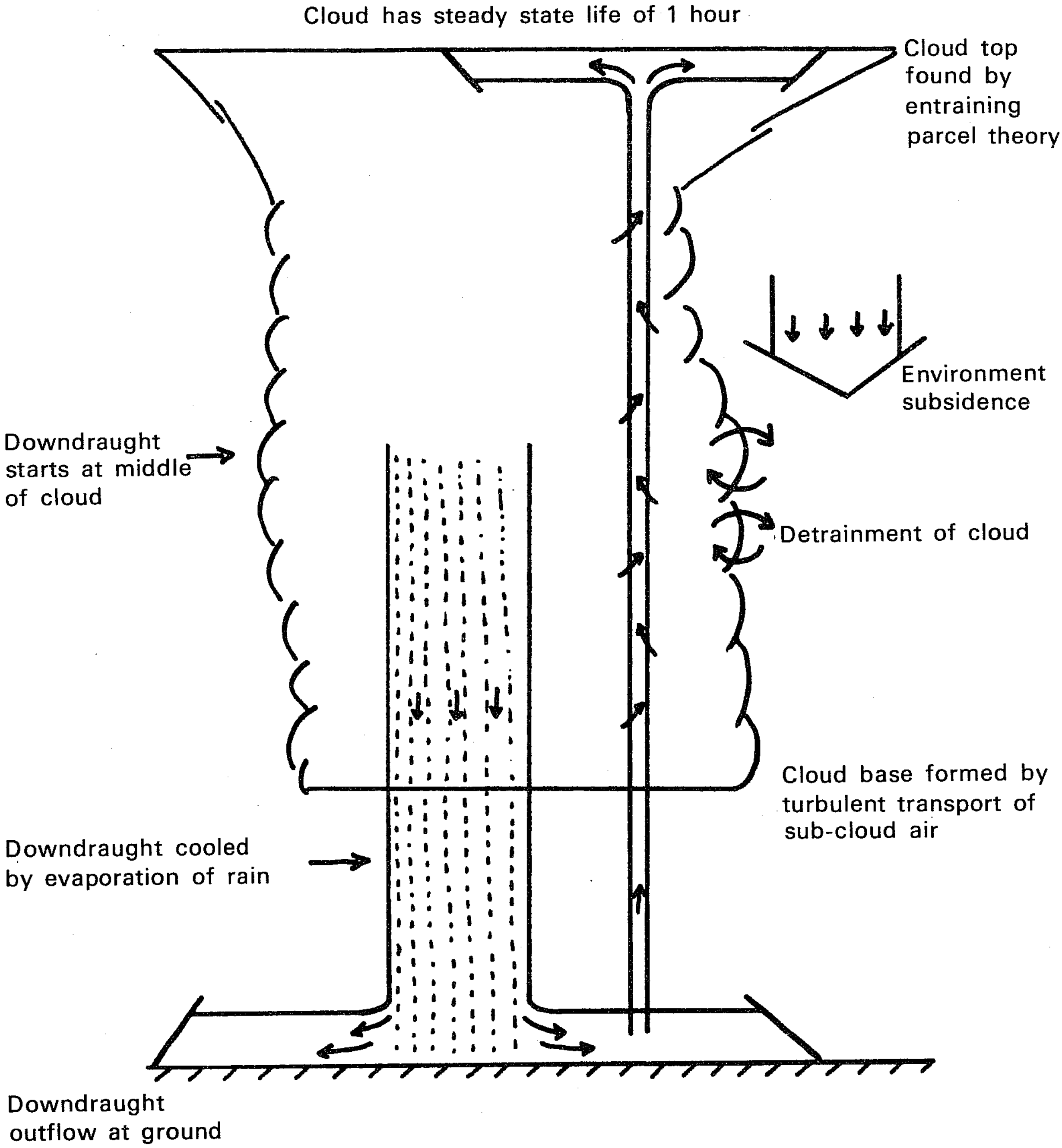

Fig. 2 Schematic diagram showing the main features of the deep convection parametrization.

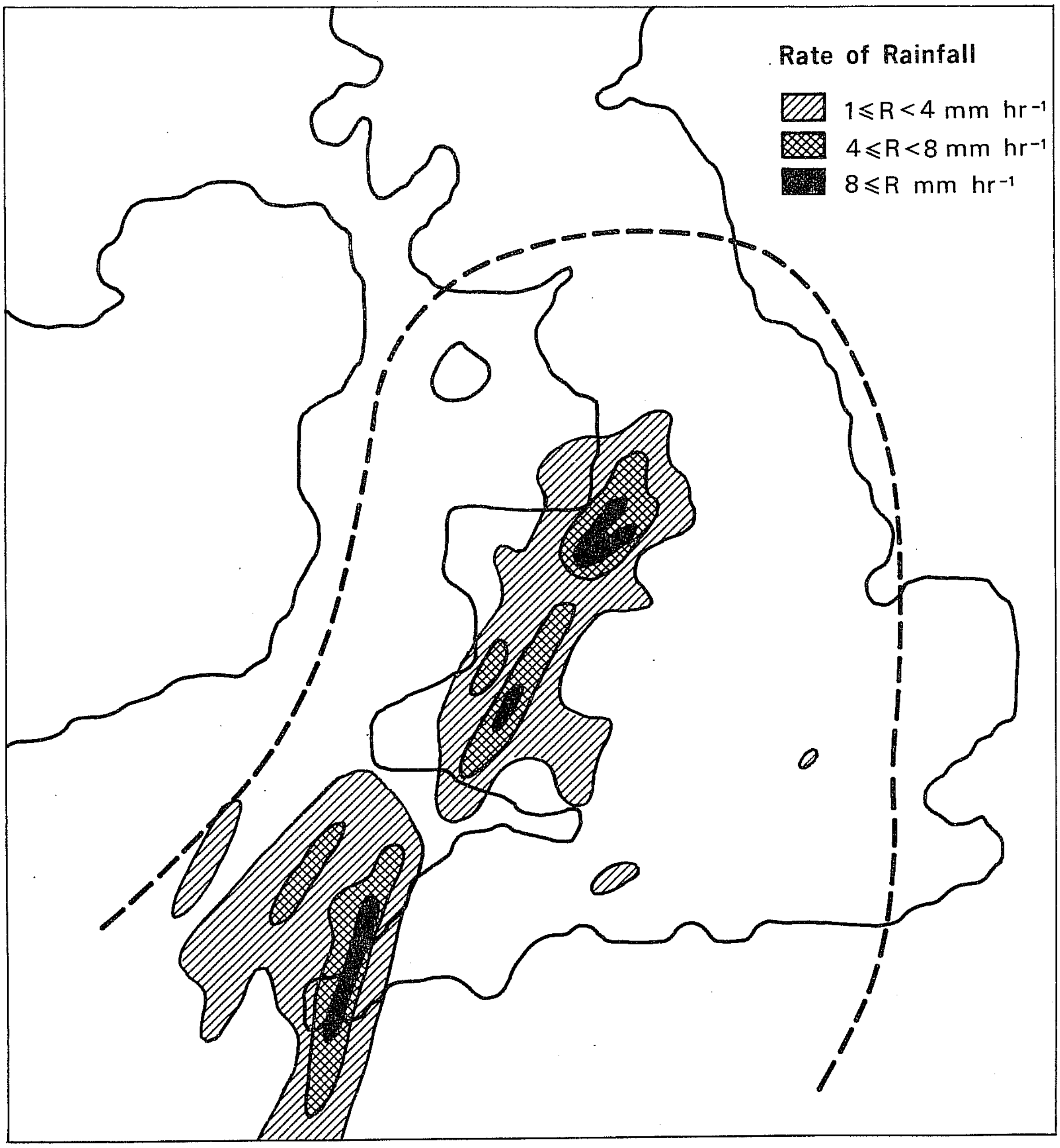

Fig. 3 Rate of rain at 0000 GMT 13.1.1983 from the radar network. Dashed line indicates approximate limit of data. An extensive area of light rain surrounding the rain belt is not shown.

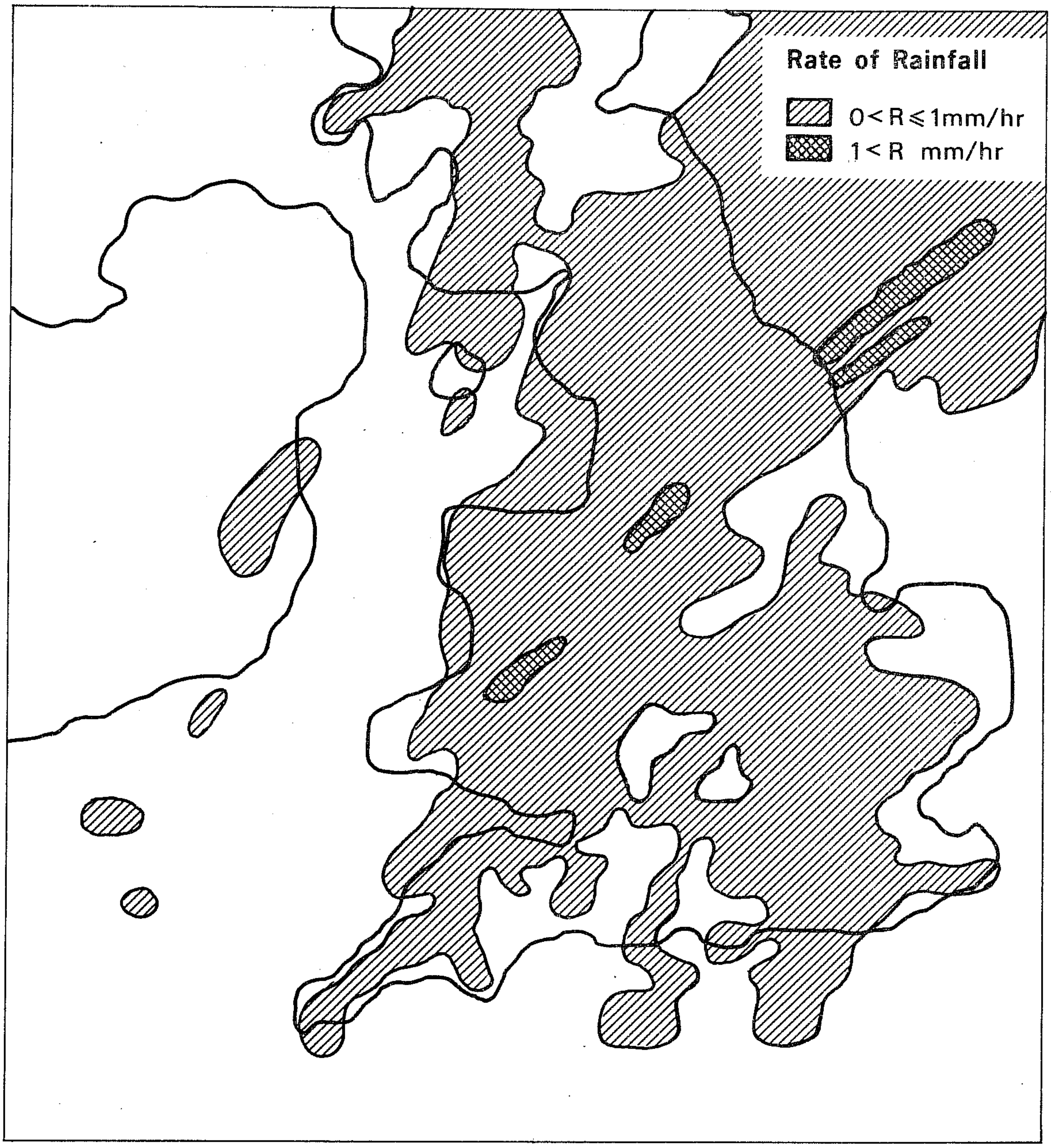

Fig. 4 6 hour forecast of grid scale rainfall for 0000 GMT 13.1.1983 using full model.

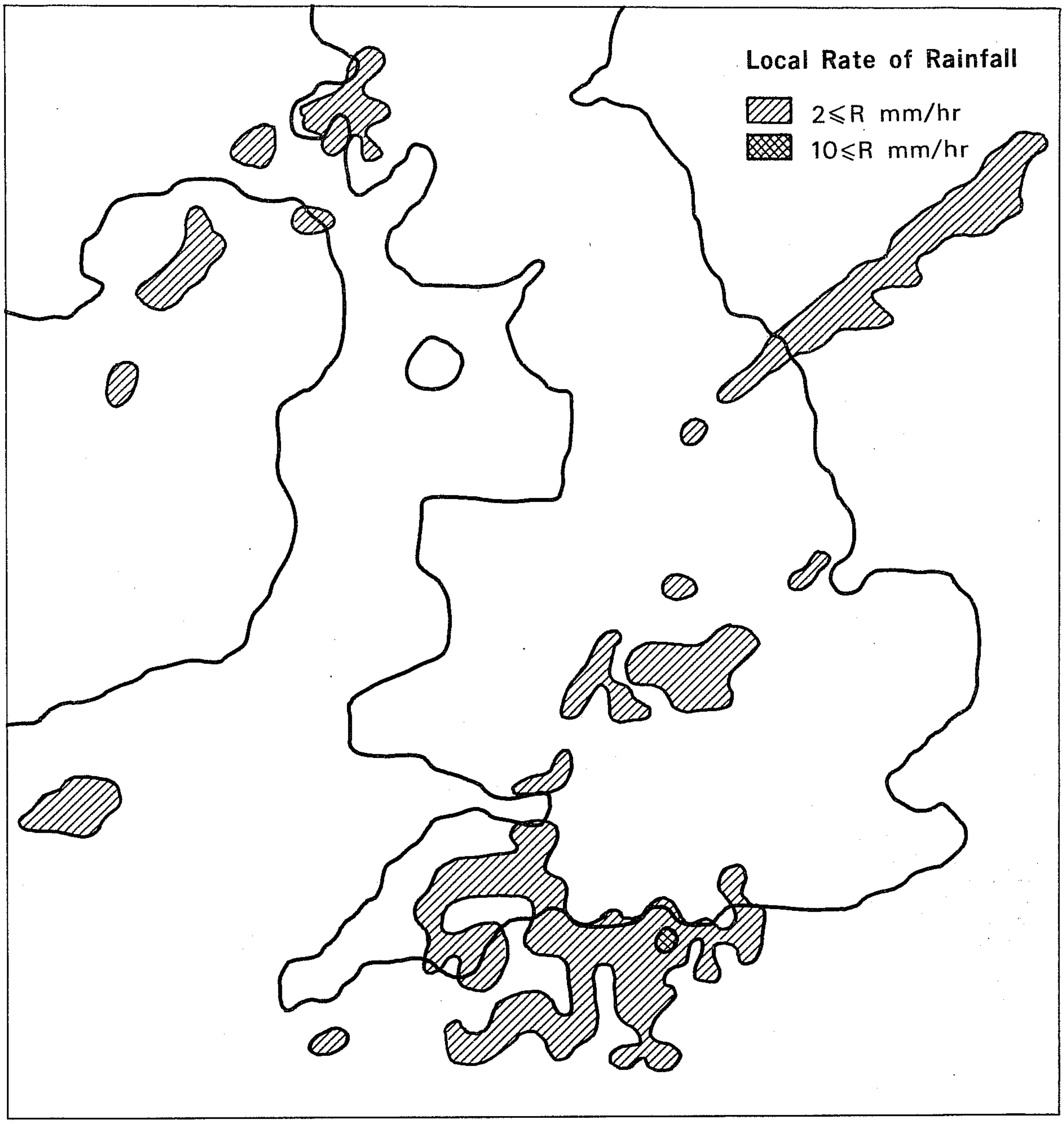

Fig. 5 6 hour forecast of convective rainfall for 0000 GMT 13.1.1983. Average rates of rain over whole grid squares are roughly one tenth of these local rates.

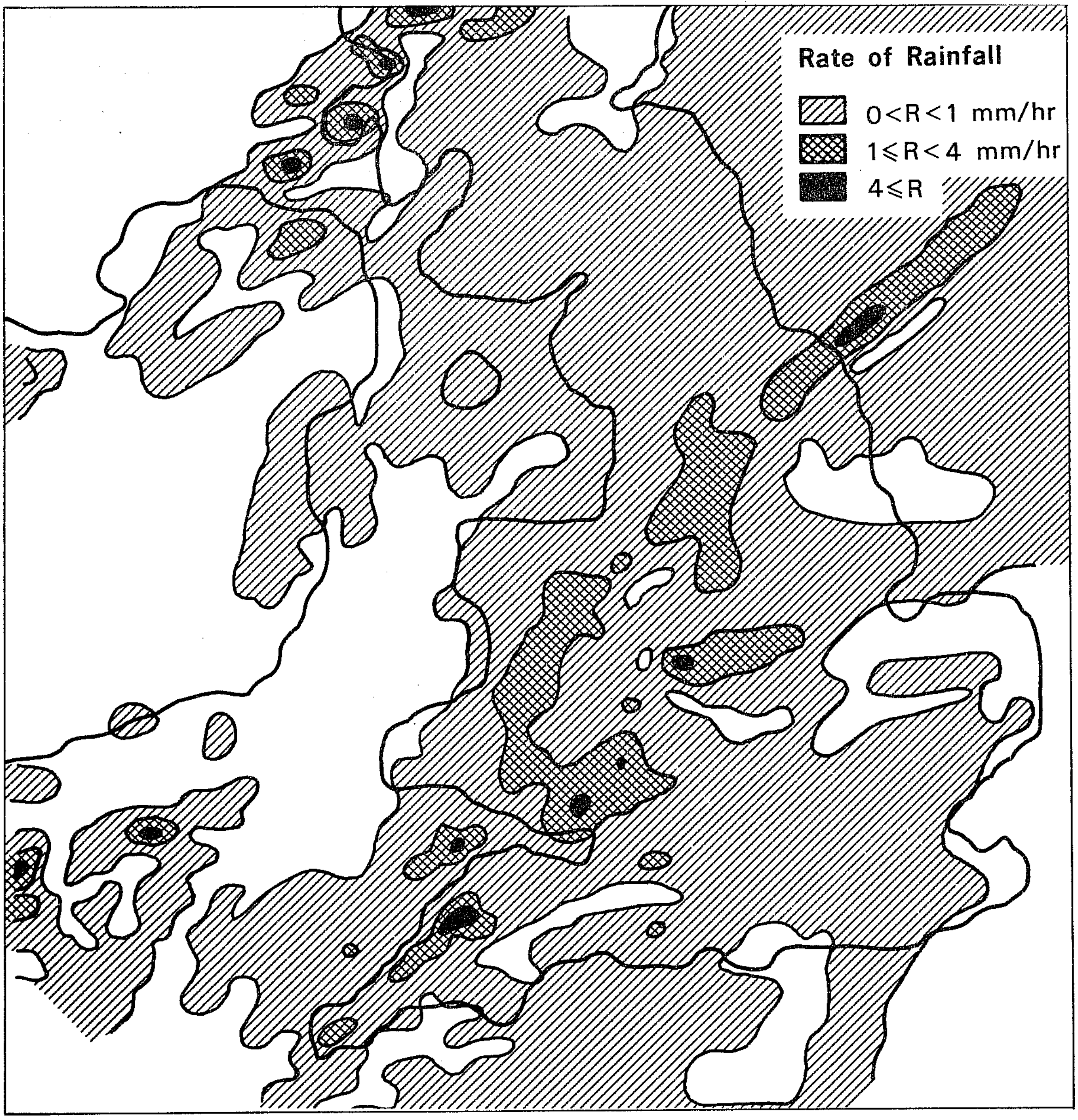

Fig. 6 6 hour forecast of grid scale rainfall for 0000 GMT 13.1.1983 using model without convection scheme.

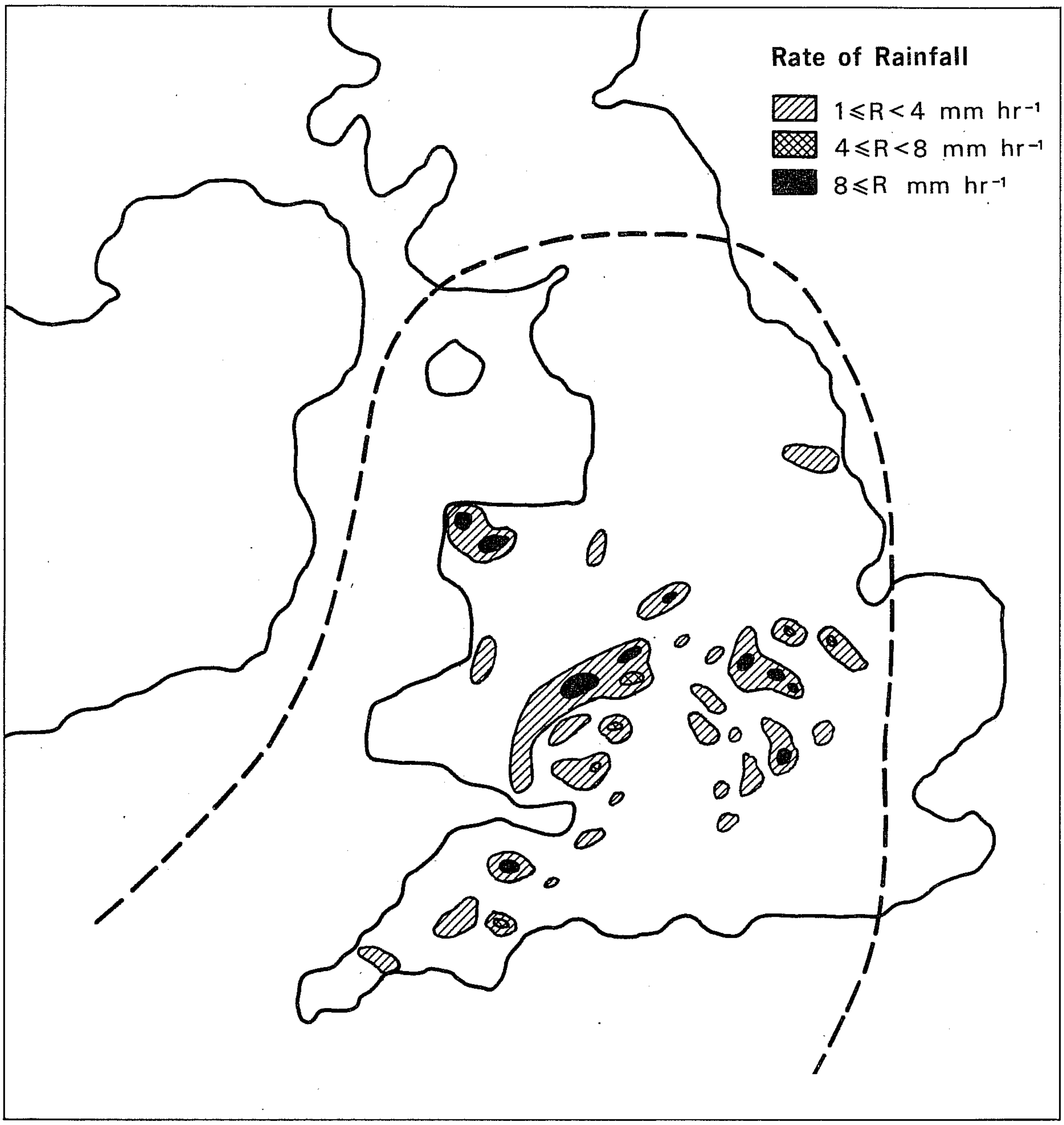

Fig. 7 Rate of rain at 1200 GMT 24.7.1983 from the radar network. Dashed line indicates approximate limit of data.

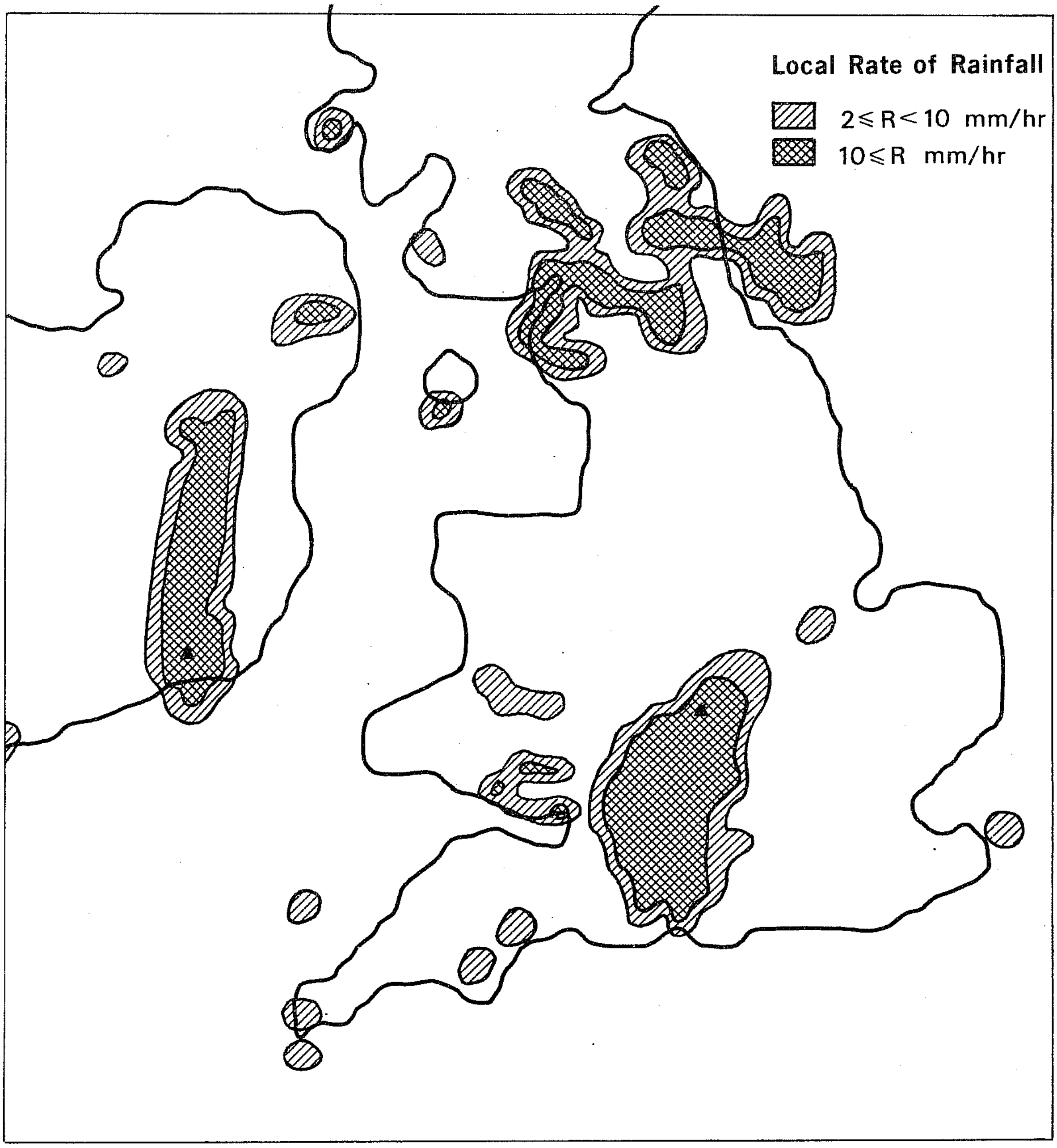

Fig. 8 6 hour forcast for 1200 GMT 24.7.1983 using full model.
Triangles ▲ indicate locations of grid scale convection. Elsewhere, grid scale rain amounts were small and have been included in the 2-10 mm/hr category of local rate of rain.

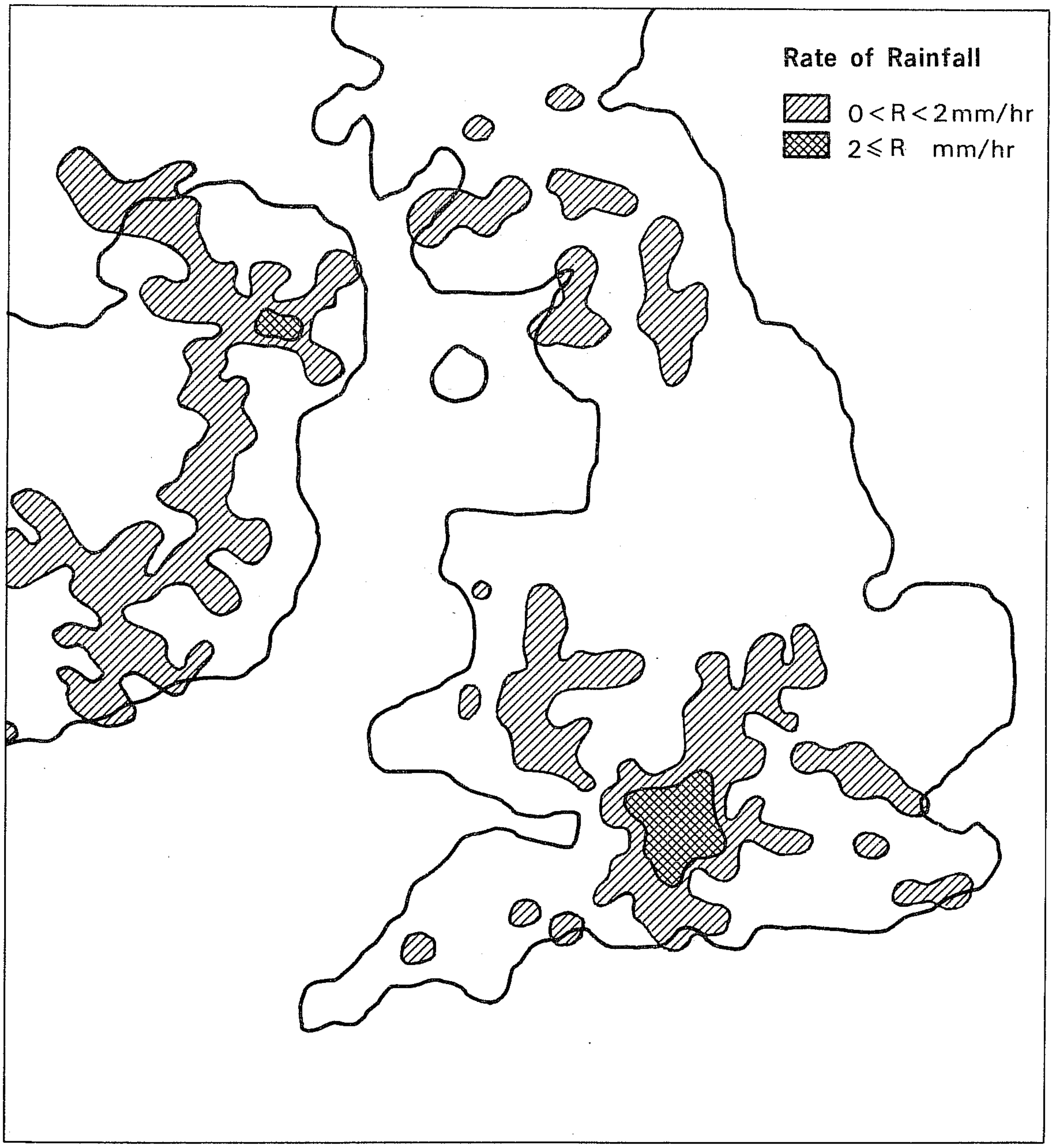

Fig. 9 6 hour forecast for 1200 GMT 24.7.1983 using model without convection scheme. In order to relate rainfall rates to those in figure 8 it has been assumed that the local rate of rain is approximately 5 times the grid scale rate. This is consistent with the diagnosed rainfall areas in the run with convection scheme.

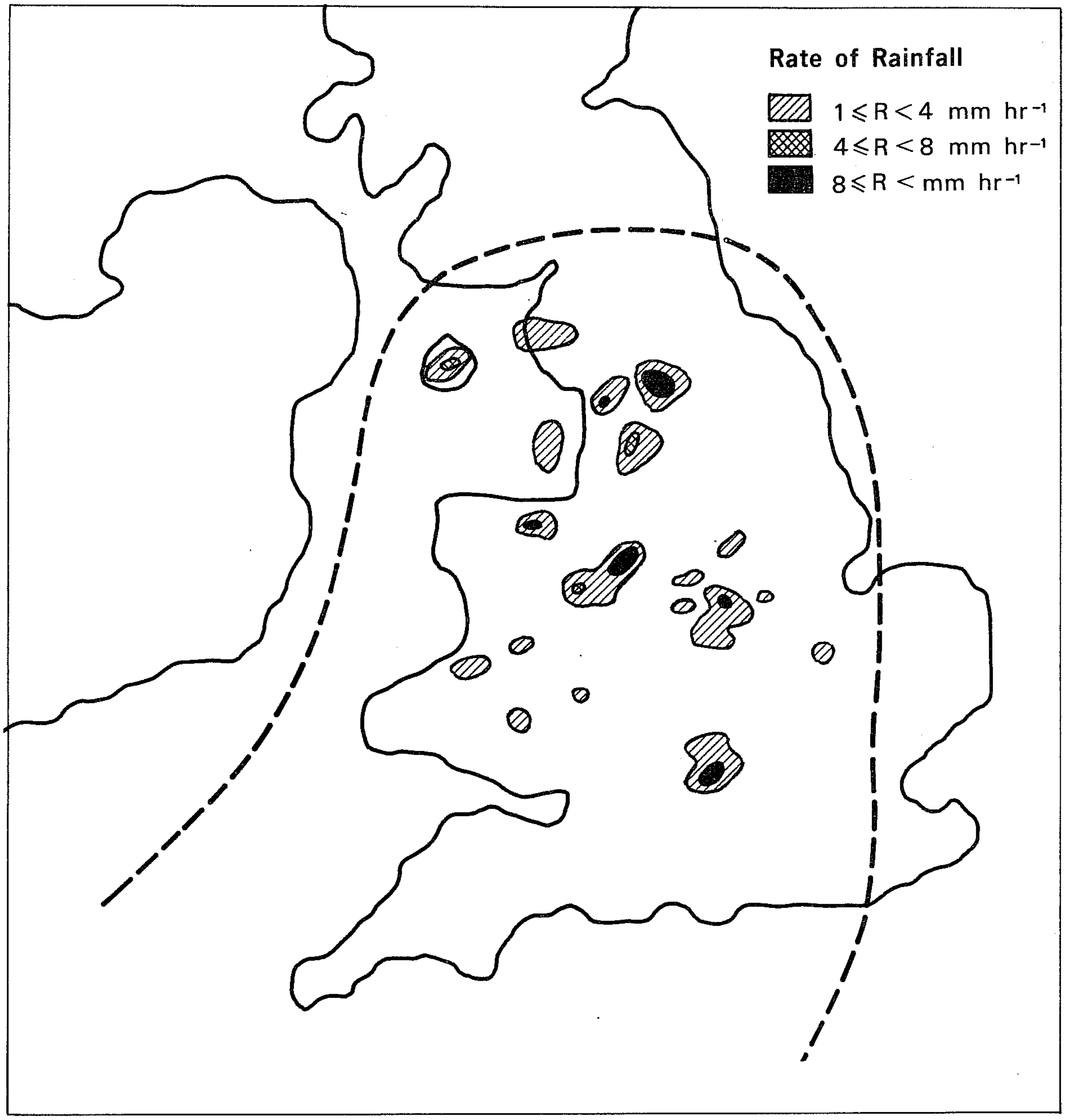

Fig. 10 Rate of rain 1800 GMT 24.7.1983 from the radar network. Dashed line indicates approximate limit of data.

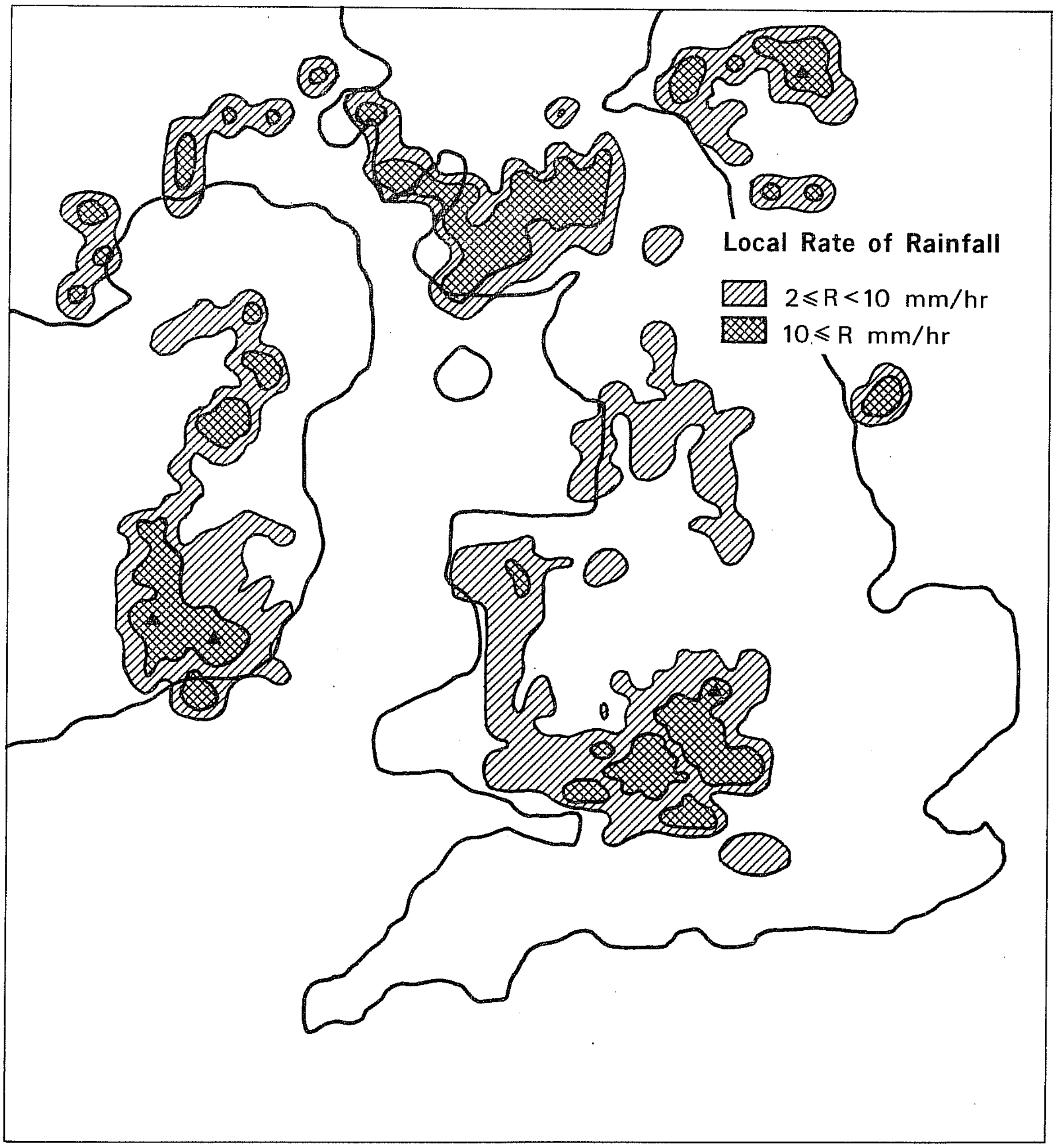

Fig. 11 12 hour forecast for 1800 GMT 24.7.1983 using full model. Triangles Triangles ▲ indicate locations of grid scale convection. Elsewhere, grid scale rain amounts were small and have been included in the 2-10 mm/hr category of local rain.