Forecasting Research

Forecasting Research Division
Technical Report No. 166

The Spring Mesoscale Model upgrade part II - focus on data assimilation

by

A J Maycock

May 1995

Meteorological Office
London Road
Bracknell
Berkshire
RG12 2SZ
United Kingdom

Forecasting Research Division
Technical Report No. 166

The Spring Mesoscale Model upgrade part II - focus on data assimilation.

by A.J.Maycock

May 1995

Forecasting Research Division
Meteorological Office
London Road
Bracknell
Berkshire, England

The Spring 1995 Mesoscale Model upgrade part II - focus on data assimilation

The spring of 1995 saw the implementation of a package of changes in the mesoscale configuration of the Unified Model. The package as a whole has been described in a companion technical report. Included in this package were changes to the assimilation of MOPS data, 10m wind data, and upper air data. This technical report describes in more depth the work leading up to these changes and shows some results from impact studies.

1. Introduction

An upgrade to the mesoscale version of the Unified Model (Cullen 1991) was made on the 11th April 1995. This included a number of changes, some of which were aimed at improving the way in which data is assimilated. Details of other model changes that were made are not described here, but can be found in Clark et al (1995).

The most significant of the data assimilation changes was a change to the MOPS cloud analysis (Wright 1993), which addressed the problem of spurious precipitation frequently seen in cases where the model displayed mid-level instability. This is described in some detail, along with changes to the assimilation of 10m wind and radiosonde temperature data.

2. Changes to the MOPS analysis

a) Motivation

Throughout the summer and autumn of 1994, examples of the mesoscale model producing large areas of spurious precipitation were observed. These occurred both at analysis time and throughout the forecast. One notable example of this occurred in the 00Z and 06Z runs on the 23rd November 1994. Figure 1 shows the analysis and T+6 forecast from the 00Z run. Comparison with the radar imagery shows the area of rain to the South of Ireland at 00Z, which moved north-eastwards, was spurious.

It was cases such as these that provided the motivation for work to determine the cause and propose a solution.

b) Investigation work

It was strongly suspected that the MOPS analysis was largely responsible for the problems seen. This was confirmed by re-running the 00Z forecast from the 23/11/94 case without MOPS data. Figure 2 shows the analysis and T+6 precipitation forecast from this run, showing that the spurious rain problem has been eliminated. Based on this finding, more detailed investigations into this case were carried out to determine which component of the MOPS analysis was instrumental in the addition of the precipitation.

The 23rd November case was used to look in detail at the formation of the spurious rain. The first guess precipitation field (a 3 hour forecast from the previous model analysis) was examined to determine how much of the rain was present prior to the MOPS analysis (figure 3). Although this did have some rain present, it was much less than that seen after the MOPS analysis had been assimilated.

The MOPS analysis blends information from radar imagery, Meteosat Infrared satellite imagery, and surface observations of precipitation and cloud with this first guess field. A quick look at the radar imagery and surface observations for the time of the MOPS analysis revealed that these could not be responsible for the spurious rain. Suspicions that the spurious rain was produced as a result of the use of the satellite imagery in this case were confirmed by rerunning the 00Z forecast with MOPS data that **did not include satellite imagery** in the analysis (figure 4). The satellite image for the analysis time (figure 5) was examined in the region of the spurious rain. Looking to the south of Ireland, the satellite image shows what appears to be patches of low to mid-level cloud (i.e. with a brightness lower than you would associate with a band of cirrus). The actual cloud top temperatures derived from the image backed this up. Should such cloud be introduced to the model via the MOPS analysis, it could well lead to mid-level convective precipitation.

Further indications as to the source of the problem were gained by looking at the model cloud profiles before and after the MOPS analysis. The model first guess cloud profile and the MOPS analysis cloud profile (both at the same point in the area of spurious precipitation) are shown in figure 6. The first guess profile shows a high layer of full cloud cover (at about 30000 ft.) and a less dense layer at about 11000 ft. The model analysis, which has had the MOPS analysis data introduced via the assimilation, has a fairly dense layer at about 8000 ft., and a dense lower layer at about 1000 ft. Obviously, the role of the satellite image in this case has been to lower what was a layer of cirrus in the first guess cloud field, to a layer of quite heavily precipitating cloud.

We might normally suspect that the layer of cloud in the first guess field is wrongly placed, but in this case the satellite data appears to be having a detrimental effect. After studying frontal analyses and an animation of the satellite imagery up until 00Z, it was considered that what we are seeing on the satellite image might not in fact be low or medium level cloud, but very thin cirrus. If this was the case, an infrared image will be 'seeing' the warmer surface through the thin high cloud, and so the pixel brightness will be some sort of average. The MOPS analysis could be assuming mid-level cloud, whose cloud top temperature corresponds to this average. Once introduced into the model, this spurious mid-level cloud could lead to the development of spurious precipitation.

A scheme to test this theory was tested in the MOPS analysis. We wish to identify areas where thin high cloud over a warmer surface might possibly be mis-interpreted as lower level cloud. The scheme uses the model first guess cloud field to 'quality control' the satellite imagery. At gridpoints where the first guess field has any cloud present above

5500m, a flag is raised to indicate that data from the satellite image should not be used to modify the vertical structure of the model cloud.

This scheme was tested with the 23/11/94 case. The precipitation analysis and T+6 forecast from the 06Z run are shown in figure 7. It is clear that the spurious rain problem has been eliminated by using the model background high cloud information to identify areas where thin high cloud could be mis-identified in the satellite imagery. Figure 8 shows the areas that were affected by the scheme in this case. Points indicated by an 'F' are those where high cloud was present and hence the satellite data was not used to modify the model cloud profiles.

c) Further testing

The success of the new MOPS scheme in this case led to further testing with other spurious rain cases. Some cases were also chosen to check that the scheme did not lead to degradation of a good precipitation forecast. The cases are briefly described here, along with selected charts showing the impact of the scheme.

13th July 1994.

At analysis time in this case (00Z) the operational forecast had severely overdone the precipitation over the S coast of England as well as in several areas inland. As the forecast progressed a spurious band of rain developed behind the (real) main band over E Anglia. This was most noticeable at about T+8.

With the new MOPS scheme included, the precipitation forecast was improved in both of these aspects. In the early part of the forecast, some of the spurious rain over the S coast was removed, along with some of the inland showers. However, by no means all of the over-forecast rain was removed - the resulting rain band was still too wide and too far west. The improvements in the early part of the forecast led to complete elimination of the spurious secondary band 6 to 9 hours into the forecast. After about T+12 the test and control runs had no noticeable differences. See figure 9 for charts showing the impact of the change.

28th July 1994.

Operationally, the 00Z run had slightly too much precipitation over SE England and the Midlands, whereas in reality a band of rain clipped only Kent. A small band of rain stretching roughly from Humberside to the Bristol Channel was also slightly overdone, although the model signal was generally good. A rerun with no MOPS data tended to remove too much of the real precipitation as well as removing some of the spurious.

The effect of the MOPS change was small. At analysis time there was probably slightly more spurious rain but as the forecast evolved there were only small differences between the two runs. This is a case where the MOPS changes have not really improved what was already a fairly good forecast. [NB This case was chosen because the operational run from the time was far worse in terms of spurious rain. The autumn package (a package of changes implemented operationally in the autumn of 1994) had corrected much of the precipitation spin-up problem seen in this case.]. See figure 10.

10th August 1994.

In the 06Z run, there were again problems with spurious rain. The model had a band of rain over NE England which developed early in the forecast, and persisted throughout the forecast leading to some very high accumulations in that area.

The use of the new MOPS scheme led to a vast improvement. The band was not present at analysis time at all, and, although it did develop later on, the intensities were nowhere near as high as those seen operationally. See figure 11.

17th June 1994.

This was another 06Z case where the model produced spurious precipitation. At analysis time, the model had areas of rain over S Ireland, S Wales and showers in Wales and NW England - none of which were backed up by radar imagery. As the forecast developed these areas intensified leading to widespread rain, covering an area north of a line from the Thames estuary to Liverpool by T+9. A spurious band was also present off the NE coast of England at this time.

The MOPS change again had a positive impact in this case. The analysis was greatly improved, having none of the spurious areas mentioned above. The subsequent evolution of the forecast was consequently better, with the rain over land and the band off the NE coast at T+9 almost completely gone. See figure 12.

18th August 1994.

The operational analysis in this case was good in terms of precipitation, but as the forecast developed a band of rain formed from the (real) area of rain over N Ireland. This then moved north-eastwards and developed; by T+12 it was over the coast from the Wash northwards. Spurious light rain was also present over land later in the forecast.

In this case the MOPS change did not have a large impact, but it did lead to some reduction in spurious precipitation. The most noticeable impact was around the T+12 period when it made a reasonable attempt at removing the spurious band over the East coast. See figure 13.

29th April 1994.

This case is similar to the 23rd November case in that a large spurious area of rain was present off the S Irish coast at analysis time; moving NE throughout the forecast to give some heavy precipitation. The radar showed that the only rain was over the NW tip of Scotland, with a band reaching W Ireland later on.

As seen in the November case, the large area of precipitation was completely removed with the MOPS changes, with only a spurious shower manifesting itself during the forecast. See figure 14.

23rd August 1994.

At analysis time, a cold front moving in a easterly direction was situated roughly over the Irish Sea. Ahead of this, the model incorrectly produced widespread showers over mainland UK, and these were present throughout.

The use of the new MOPS scheme in this case had very little impact. It is probably true to say that in each frame, there was less spurious rain, but certainly not all of it had been removed. See figure 15.

d) Recent developments

Since the operational implementation of the new MOPS formulation, another spurious rain case was highlighted by forecasters in CFO. This was investigated in order to determine how the precipitation was introduced.

The 00Z operational mesoscale model run on the 2nd May 1995 had precipitation over Southern Ireland, whilst the radar indicated no rain at all in this area. The first sign of any precipitation was in the 18Z 01/05/95 analysis. The cloud profiles in the area of the rain showed a fairly substantial layer of mid-level cloud at this time. Investigations showed that this spurious cloud was first observed in the model after the 15Z 01/05/95 MOPS analysis. The 12Z MOPS cloud analysis looked much more realistic, yet the 12Z *model* analysis was deficient in high cloud. This appeared to be as a result of the LAM boundary conditions feeding in clear air at high levels. The effect of this was to degrade the distribution of high cloud in the mesoscale model and provide poor quality control for the 15Z satellite imagery. This allowed the high cloud to be incorrectly assigned as mid-level cloud as we found in so many cases before.

This case serves to show that the new MOPS quality control scheme relies on a good first guess distribution of high cloud. Any errors introduced to this distribution, such as from the LAM, will reduce the effectiveness of the change. However, it must be stressed that the problems encountered with this case were not as a result of the new MOPS scheme (they would have occurred with the old scheme), but of an external error which limited the effectiveness of the new scheme.

e) Summary and conclusions

The problems often observed with spurious rain in the mesoscale model, and the subsequent investigations carried out on such a case, have highlighted the problem that the MOPS analysis can encounter in dealing with thin high cloud when present in the satellite image. A scheme has been designed and tested, which uses the model first guess high cloud to 'quality control' the satellite image by identifying and flagging areas where the imagery data should not be used to modify the distribution of cloud layers in the model.

The nature of the scheme means that satellite data will also be 'rejected' in areas where high cloud would have been correctly identified. This, however, is probably unlikely to lead to disastrous impacts on the forecasts, as in such areas both the model first guess and the satellite image are in agreement, and consequently the cloud profiles are likely to be only slightly modified.

In eight cases used for testing, the MOPS changes have proved to be either very beneficial or slightly beneficial. No negative impacts have been observed. The performance is better when the forecast had large (organised) areas of spurious rain. Spurious showers tend to be reduced but not completely removed. The benefits obtained have been found to last well into the forecast.

Finding the perfect way to address the whole question of utilising satellite imagery correctly in a system such as MOPS is no easy task. Plans for the future should go a long way to solving some of the difficulties. As we found in the 01/05/95 case, a solution relying on a good model background distribution of cloud may at times be undesirable. Ultimately, a more thorough solution to the height mis-assignment problem must be found that does not depend on the model background. This may include the use of methods for the generation of cloud motion winds from Meteosat IR imagery (Schmetz et al 1993), which include a semi-transparency correction for the height assignment of high cloud. This would also require simultaneous water vapour imagery and radiation model calculations based on temperature and humidity profiles from an NWP model.

3. Changes to the 10m wind assimilation

Since the assimilation of 10m wind data (over land only) was introduced to the mesoscale model, little work has been done in tuning the associated assimilation parameters. The spring upgrade package provided an opportunity to do so.

The parameters we wished to tune were the forecast error correlation scales (both in the horizontal and vertical), and the degree of non-divergence of the 10m wind increments. This tuning can be done by studying archived statistics of (observation - model background) differences (taken from the Observation Processing Database (OPD)). This uses a similar method to that of previous tuning experiments (Clark et al 1994), but differ slightly when dealing with the correlation of vector quantities in the horizontal.

In dealing with scalar quantities, we simply calculate a best fit curve to a plot of (o-b) correlation as a function of observation separation. In the case of a vector, we first need to calculate the longitudinal and transverse components (components along and perpendicular to a line joining the observations) of (o-b). We can then separately plot these as a function of observation separation. A best fit curve was plotted through each of these, the form of the curves being:

$$\mu_{LL}=\mu_{LL_0}\, e^{-\frac{R}{S}} \qquad \text{(longitudinal)}$$

$$\mu_{TT}=\mu_{TT_0}\left(1-\gamma\frac{R}{S}\right) e^{-\frac{R}{S}} \qquad \text{(transverse)}$$

where μ represents a correlation, R is the distance between observations, S is the horizontal correlation scale. The degree of non-divergence parameter (γ) has a value in the range 0 to 1, where a value of 1 implies that the 10m wind increments are assumed to be totally non-divergent. Details of the above equations can be found in Bell et al (1993)

For both the longitudinal and transverse data, the correlation data was averaged into bins of station separation - the width of the bins being 30km. The longitudinal data was fitted first to obtain a best fit value for S - the correlation scale. This value was then used when fitting the transverse component data, to obtain a best fit value for γ - the non-divergence parameter. An example of the bin averaged correlation data for the various between-observation components is shown in figure 16. It can be seen that the longitudinal and transverse components are almost identically correlated at all observation separations. As one would expect to see, there is no significant correlation between the longitudinal component of one observation increment and the transverse component of another (and vice versa). Figure 17 shows the best fit curve through the data.

The OPD data study also enables better estimates of the observation and background errors (E_o and E_b) to be made. The method is again similar to that described in Clark et al (1994). With knowledge of the correlation value extrapolated to zero station separation, and the mean squared (observation - model) differences, revised estimates of the observation and background errors were made.

The revision of the correlation scale in the vertical is carried out in the same way as has been done previously for such variables as screen level relative humidities and temperatures. The correlation between the 10m wind (o-b) and the lowest few levels of collocated radiosonde wind (o-b) was calculated as a function of pressure ratio, and a curve of the form

$$\mu_V=\mu_{V_0} e^{-b^2 \ln^2 \frac{P_L}{P_M}}$$

was fitted to obtain the best fit value of b - the vertical correlation scale. (P_L / P_M is the ratio of pressures at which the observations are made).

Figure 18 shows the correlation data and the best fit curve through it. It indicates that the assumed functional form of the correlations is not well suited, and possibly should be changed at a future date.

A summary of the revised assimilation parameters, along with their pre-upgrade values, is given in Table 1. The horizontal correlation scales have been considerably reduced - the original parameters were based purely on those used in the Limited Area Model. The new vertical scale also suggests that the correlations decrease with height more rapidly than had been assumed previously, although a more realistic form of the vertical correlation function would lead to an increase in the value of 'b'. It is interesting to note that the non-divergence parameter best fit was found to be 0.0. This is quite a change from the previous operational value (0.8), which implied the wind increments were nearly non-divergent.

The new 10m wind assimilation parameters were tested on two cases chosen from those used in the spring upgrade trials. The cases were chosen based on the impact seen on the 10m wind scores with the whole package included. We wished to test how much of the impact was due to the changes to the 10m wind assimilation only. The cases (organised convection case 06Z 15/02/95 and clear winter night case 00Z 22/02/95) were rerun with the only difference from the trial control run being the change to the 10m wind assimilation parameters. Despite some very impressive reductions in RMS vector 10m wind errors seen in the trial (typically 0.2 ms^{-1} out to T+15), the results from the experiments showed that very little of this impact came from the assimilation changes. About half the impact at analysis time could be attributed to the assimilation changes, whereas beyond this the effect of the assimilation changes alone was negligible. Further experiments showed that the impact obtained from the new 10m wind assimilation parameters was almost entirely due to the changes made to the correlation scales; the change to the non-divergence parameter having a negligible effect even at analysis time. Figure 19 shows the impact obtained with one of the cases.

4. Changes to upper air temperature assimilation

A similar study to that described above has been carried out with a view to revising the correlation scales for radiosonde temperatures. OPD data covering a large period of time were analysed, with the correlation of (o-b) calculated separately for bands of levels in the atmosphere. (these were in fact the boundary layer, and above the boundary layer). The functional form of the assumed correlation-distance relationship was:

$$\mu=\mu_0\left(1+\frac{R}{S}\right)e^{-\frac{R}{S}}$$

The result of the study was to reduce the error correlation scale from 150 km. to 100 km.

REFERENCES

Bell, R.S., Lorenc, A.C., Macpherson, B., Swinbank, R. and Andrews, P. 1993: The Analysis Correction Data Assimilation Scheme. UK Meteorological Office, Unified Model Documentation Paper No. 30.

Clark, P.A., Jackson, S.D., Macpherson, B., Maycock, A.J., Robinson, R.W., Smith, R.N.B., Woltering, S.A. and Wright, B.J., 1994: Developments of the mesoscale model during 1993. UK Meteorological Office, Forecasting Research Division, Technical Report No. 91.

Clark, P.A., Jackson, S.D., Maycock, A.J., Macpherson, B., Smith, R.N.B. and Woltering, S.A. 1995: The Spring 1995 Mesoscale Model Upgrade. UK Meteorological Office, Forecasting Research Division, Technical Report No. 160.

Cullen, M.J.P., 1991: The Unified Forecast/Climate Model. UK Meteorological Office, Short-range Forecasting Research Division Scientific Paper No. 1.

Schmetz, J., Holmlund, K., Hoffman, J., Strauss, B., Mason B., Gaertner, V., Koch, A. and Van de Berg, L. 1993: Operational cloud-motion winds from Meteosat infrared images. *J. Appl. Meteorol.*, **32**, 1206-1225.

Wright, B.J., : The Moisture Observation Pre-processing System (MOPS). UK Meteorological Office, Forecasting Research Division, Technical Report No. 38.

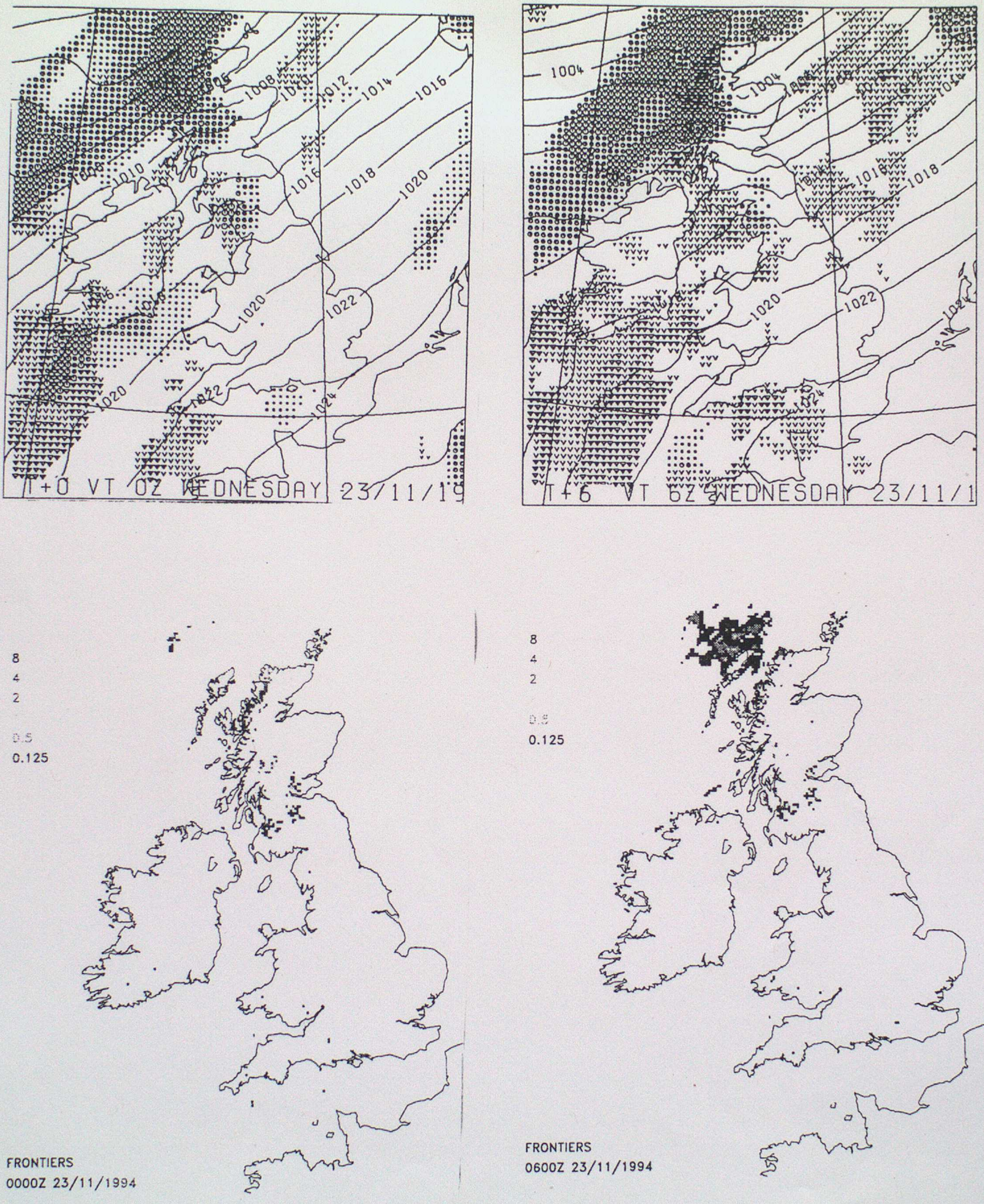


Figure 1. Analysis and T+6 precipitation forecast from an operational rerun of the 00Z run 23/11/94. Radar frames are shown for verification.

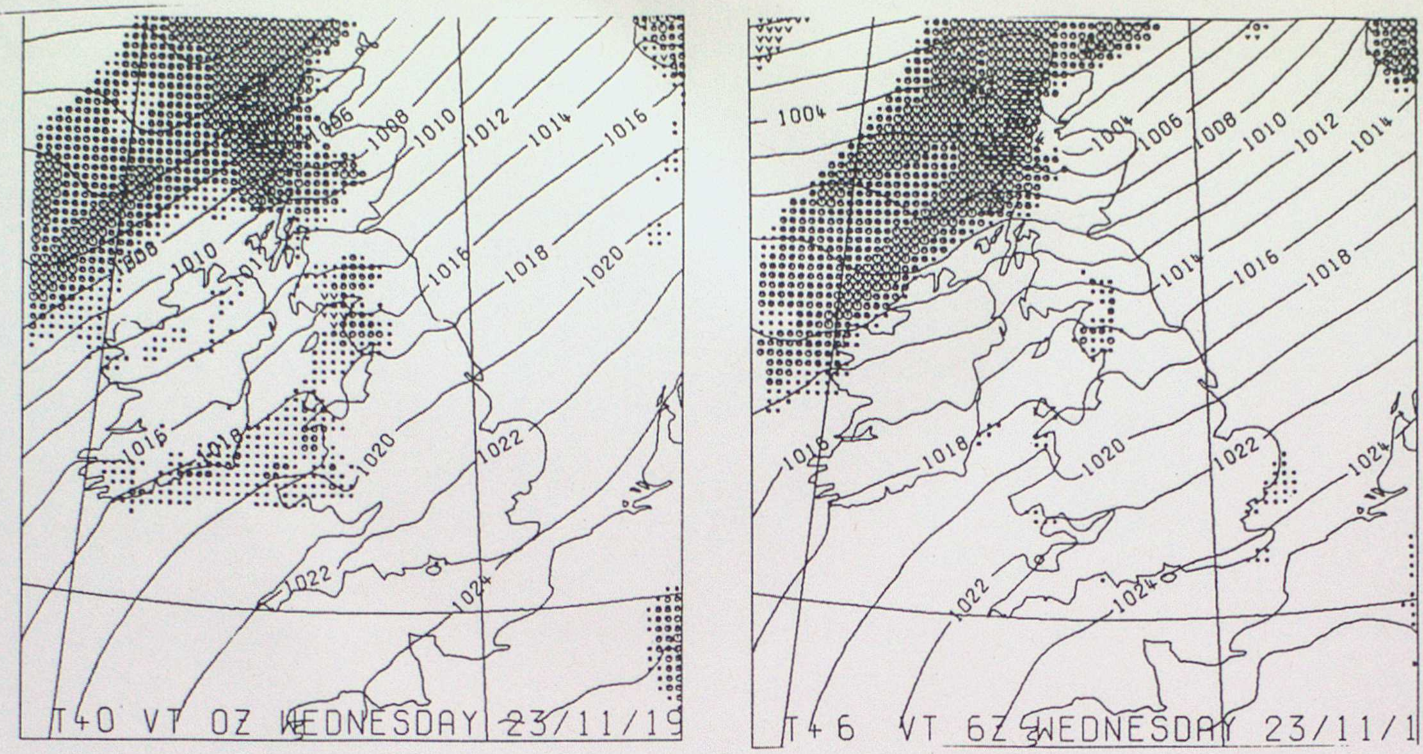


Figure 2. Analysis and T+6 precipitation forecast from a rerun of the 00Z 23/11/94 run with MOPS data removed. See figure 1 for radar verification frames.

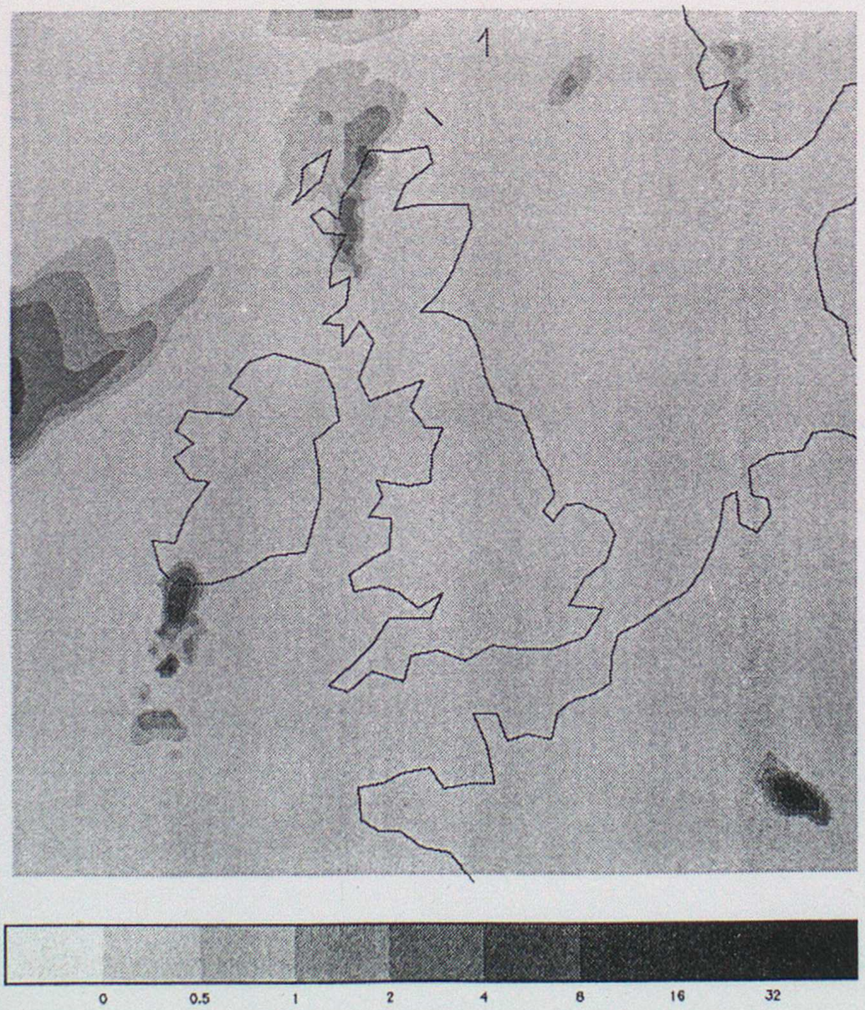


Figure 3. Model first guess precipitation field valid at 00Z 23/11/94.

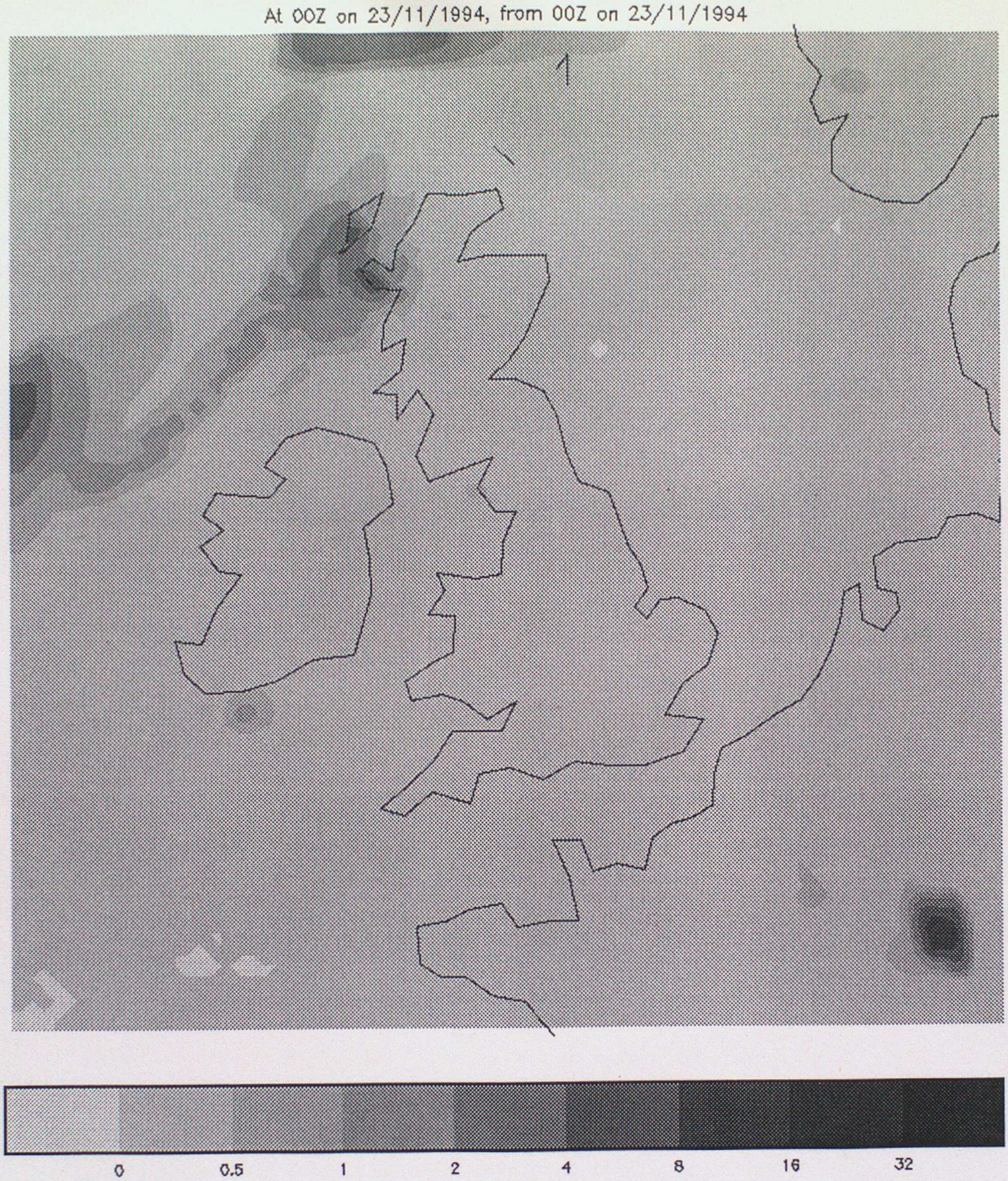


Figure 4. Precipitation analysis valid at 00Z 23/11/94 from a rerun where satellite data was not used in the MOPS analysis.

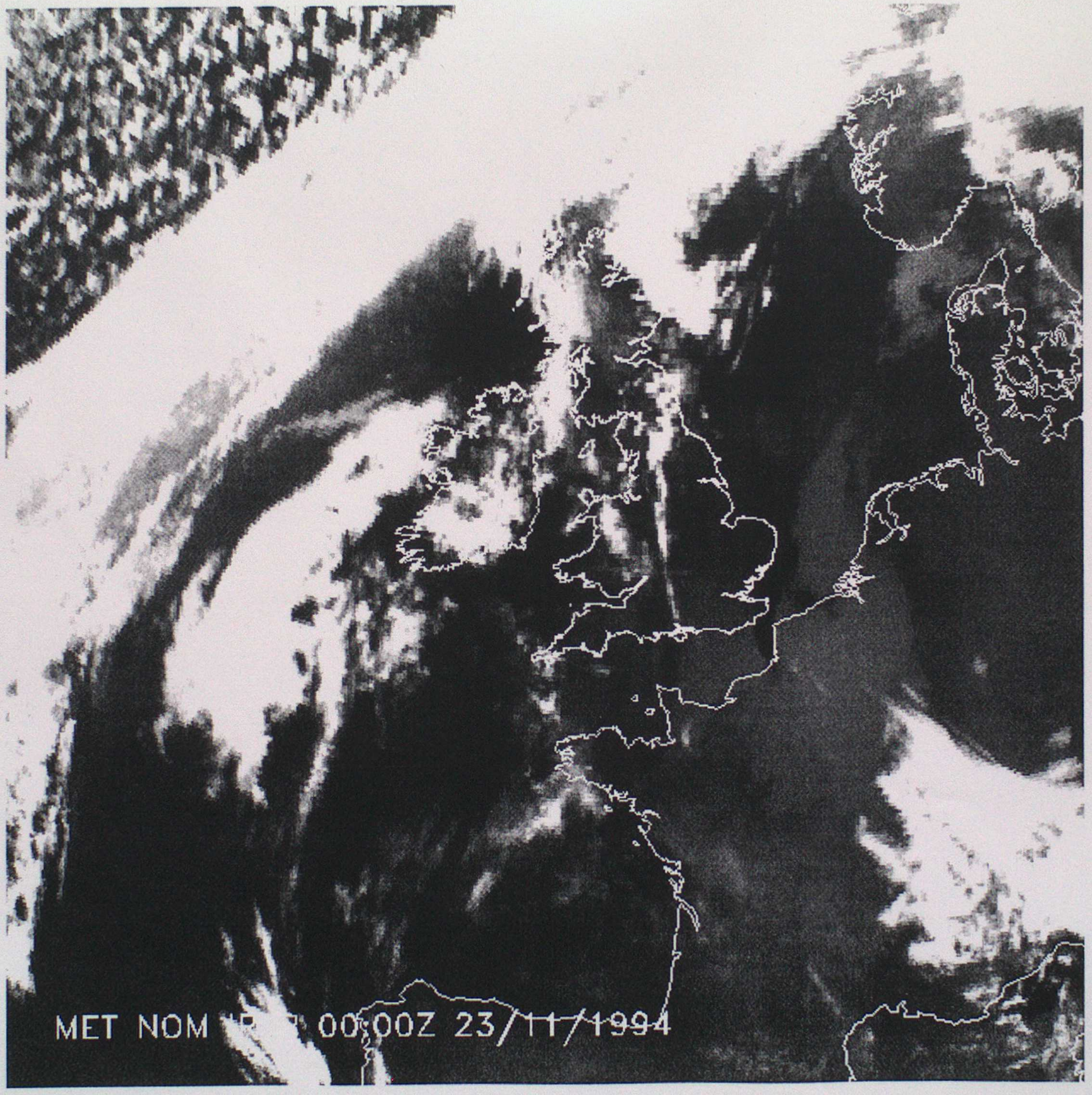


Figure 5. Meteosat IR image from 00Z 23/11/94.

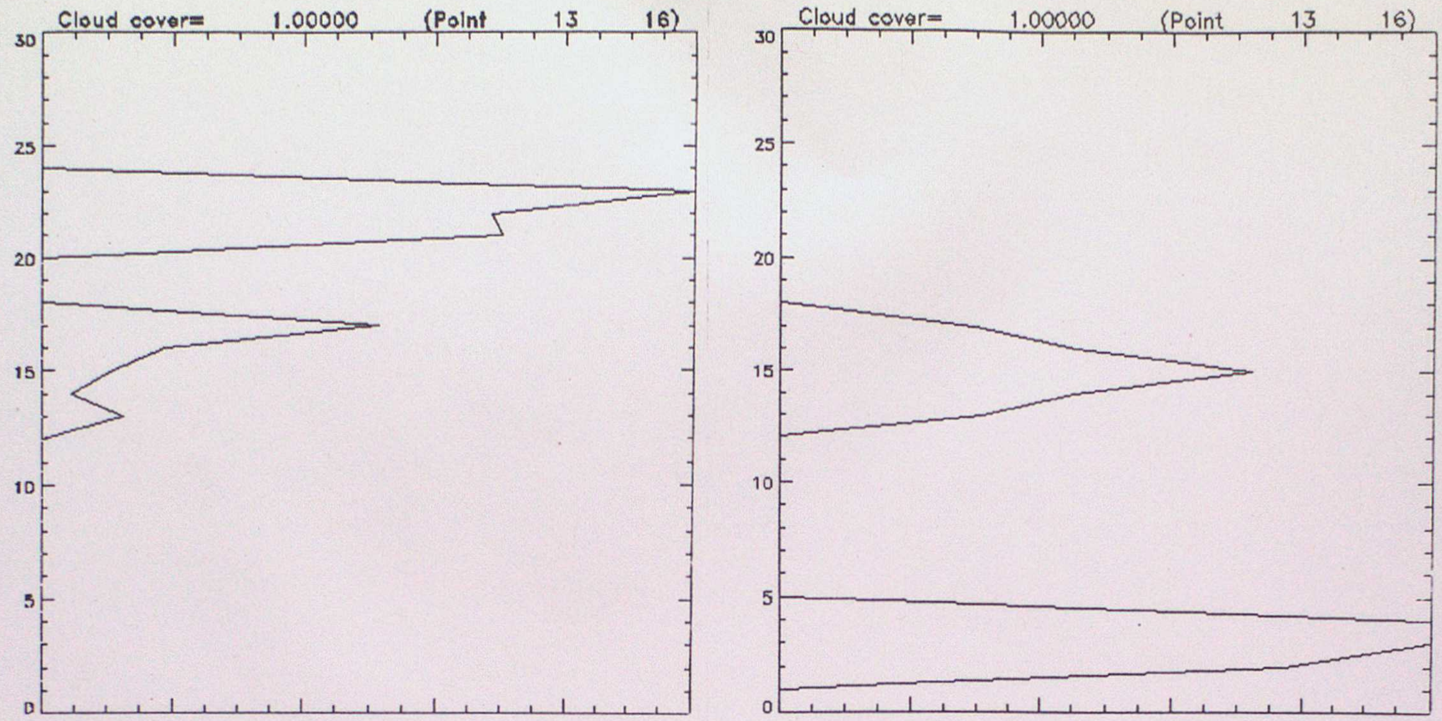


Figure 6. Model cloud profiles valid at 00Z 23/11/94. The left-hand frame is from the first guess field, and the right-hand frame is from the MOPS analysis. Both profiles are taken from a point in the area of spurious precipitation.

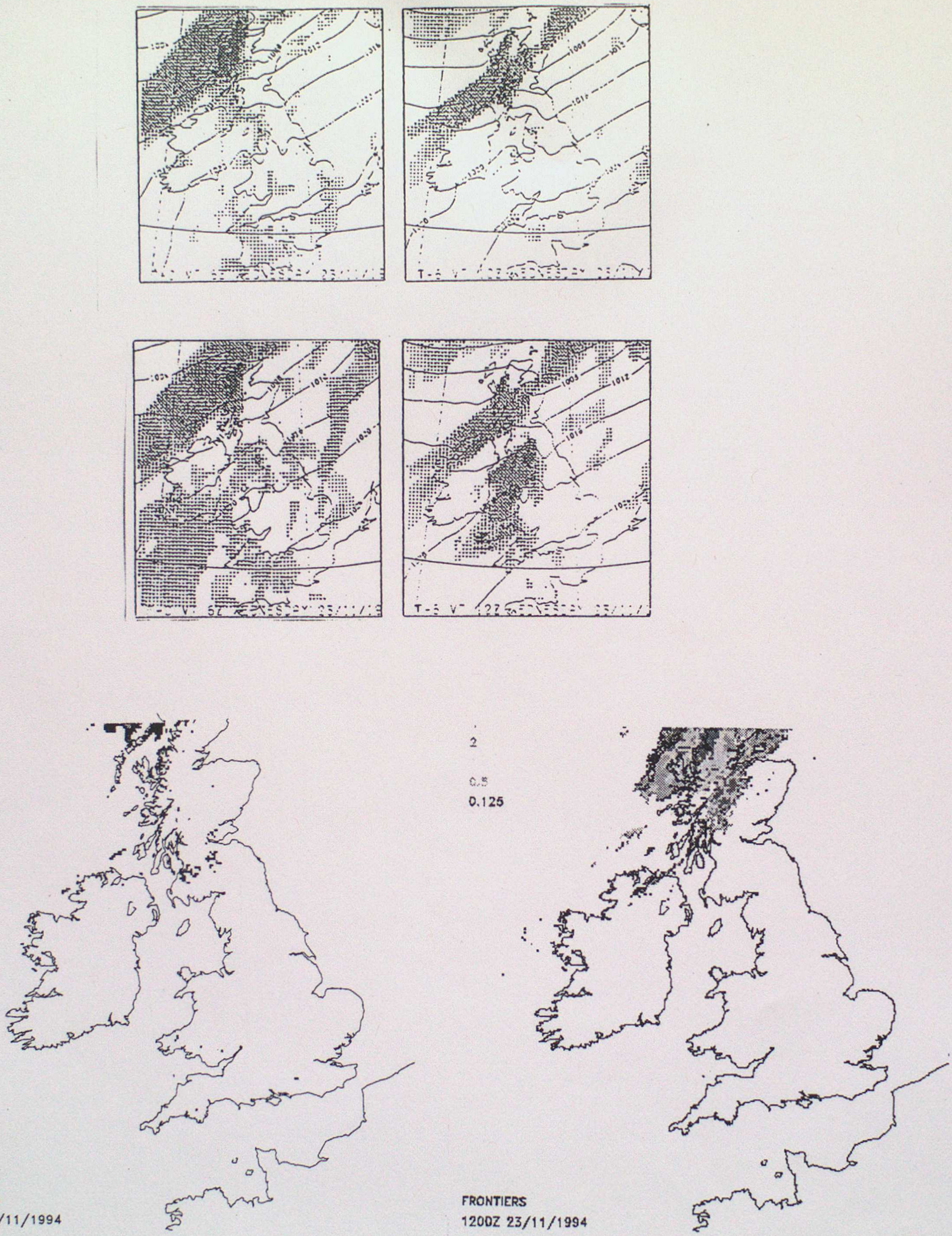


Figure 7. Analysis and T+6 precipitation forecast from the 06Z 23/11/94 run with the MOPS 'quality control' change included (top) and from a control run (bottom). Radar frames are shown for verification.

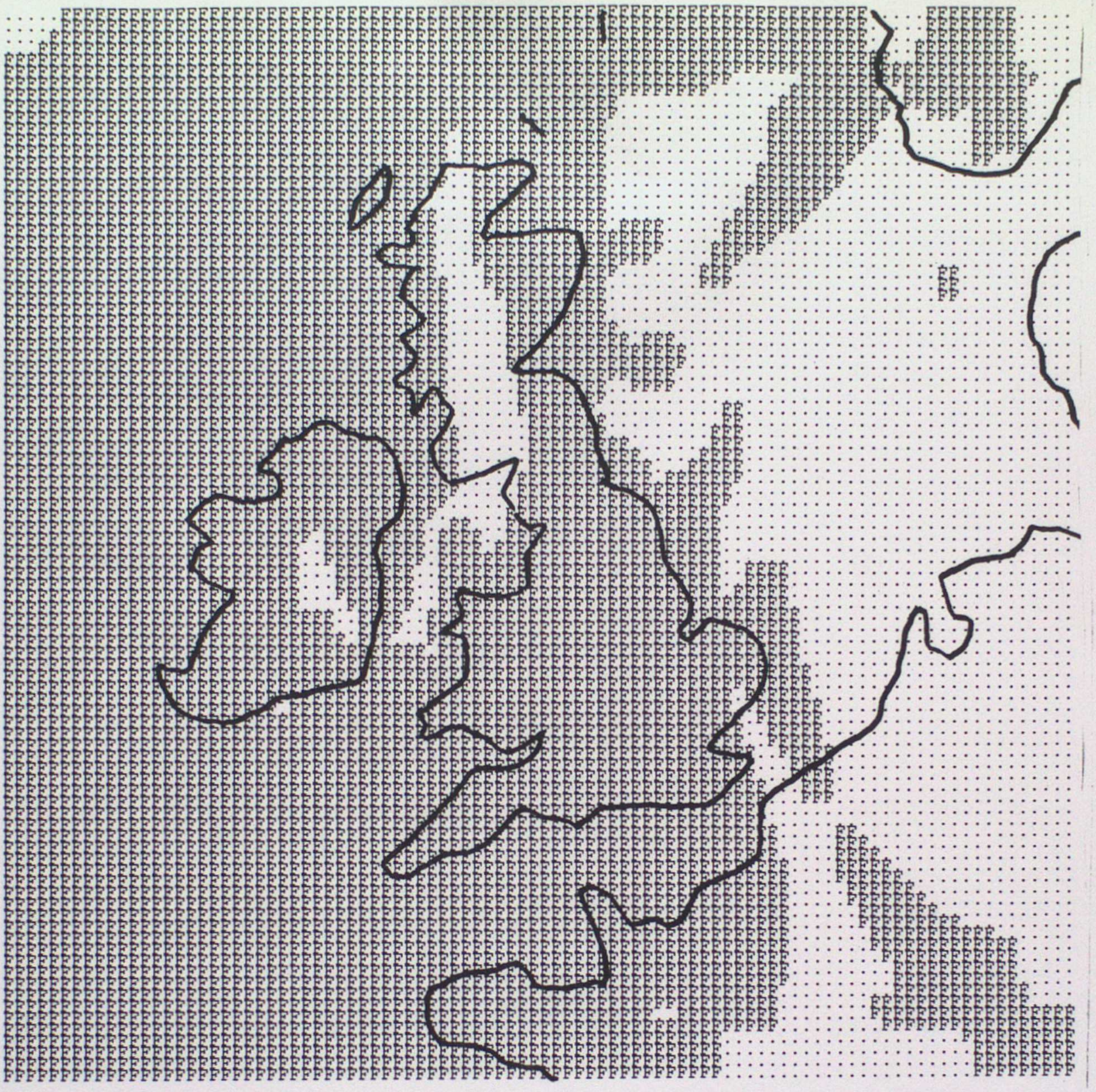
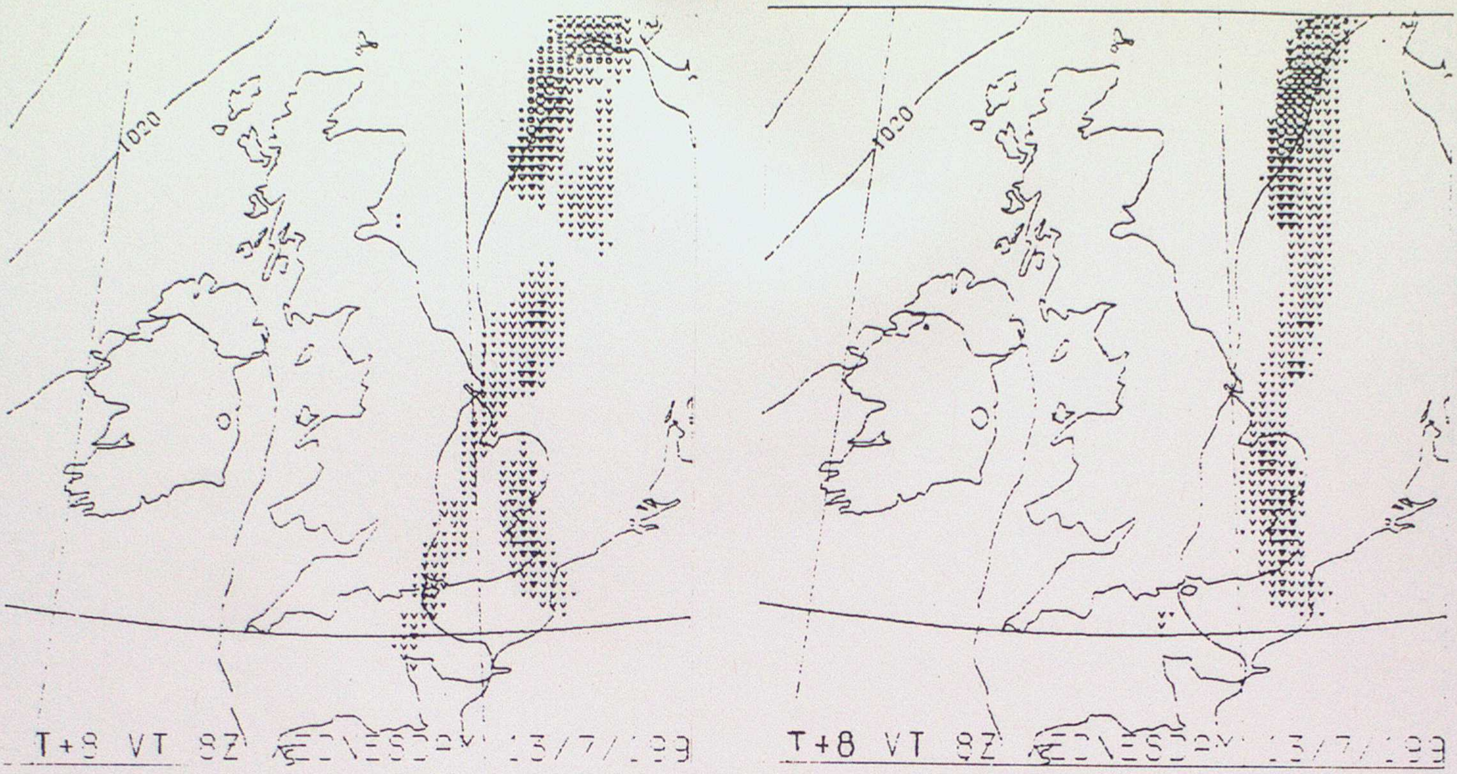


Figure 8. Areas at 00Z 23/11/94 affected by the MOPS 'quality control' change. An 'F' indicates a gridpoint where the change was having an effect.



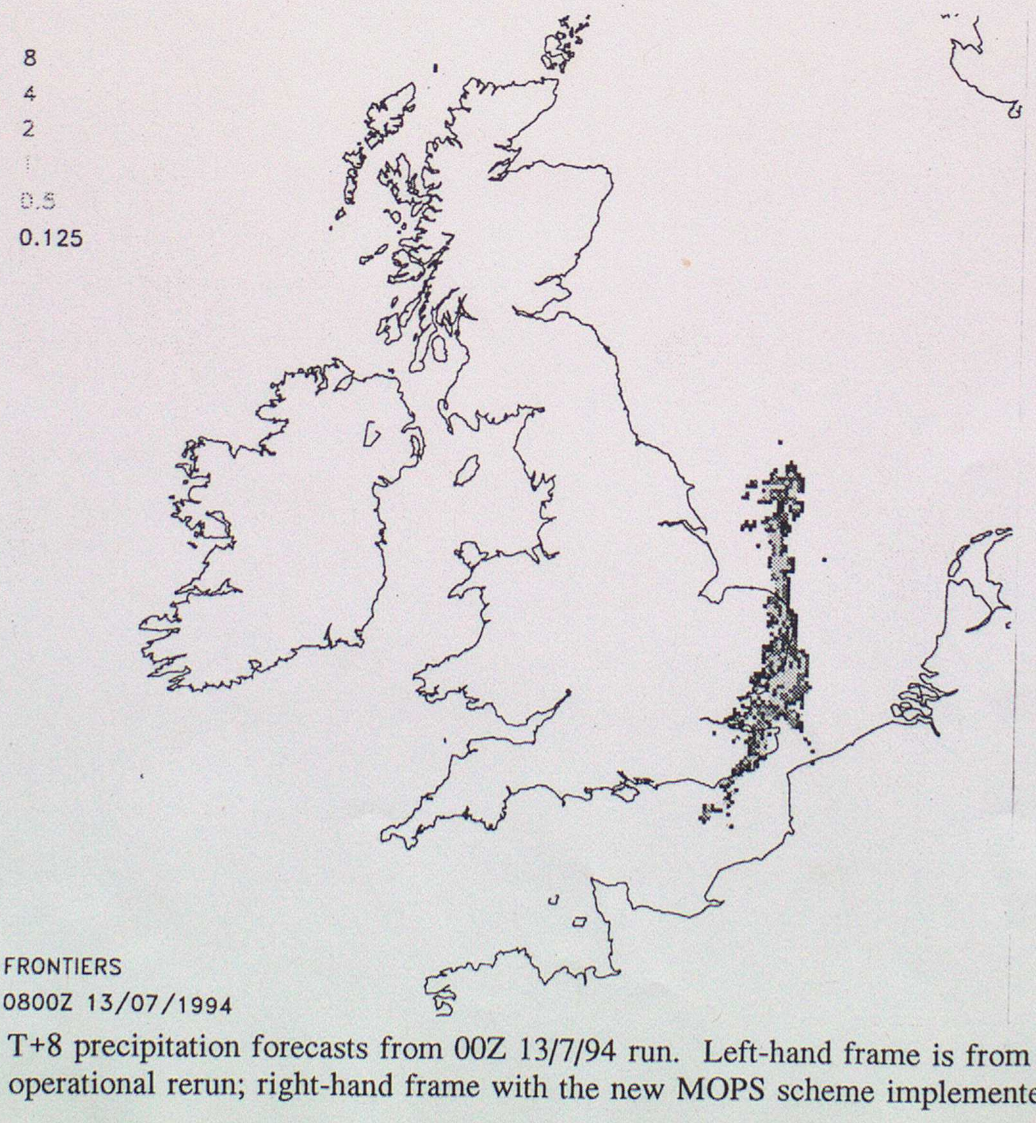


Figure 9. T+8 precipitation forecasts from 00Z 13/7/94 run. Left-hand frame is from the operational rerun; right-hand frame with the new MOPS scheme implemented.

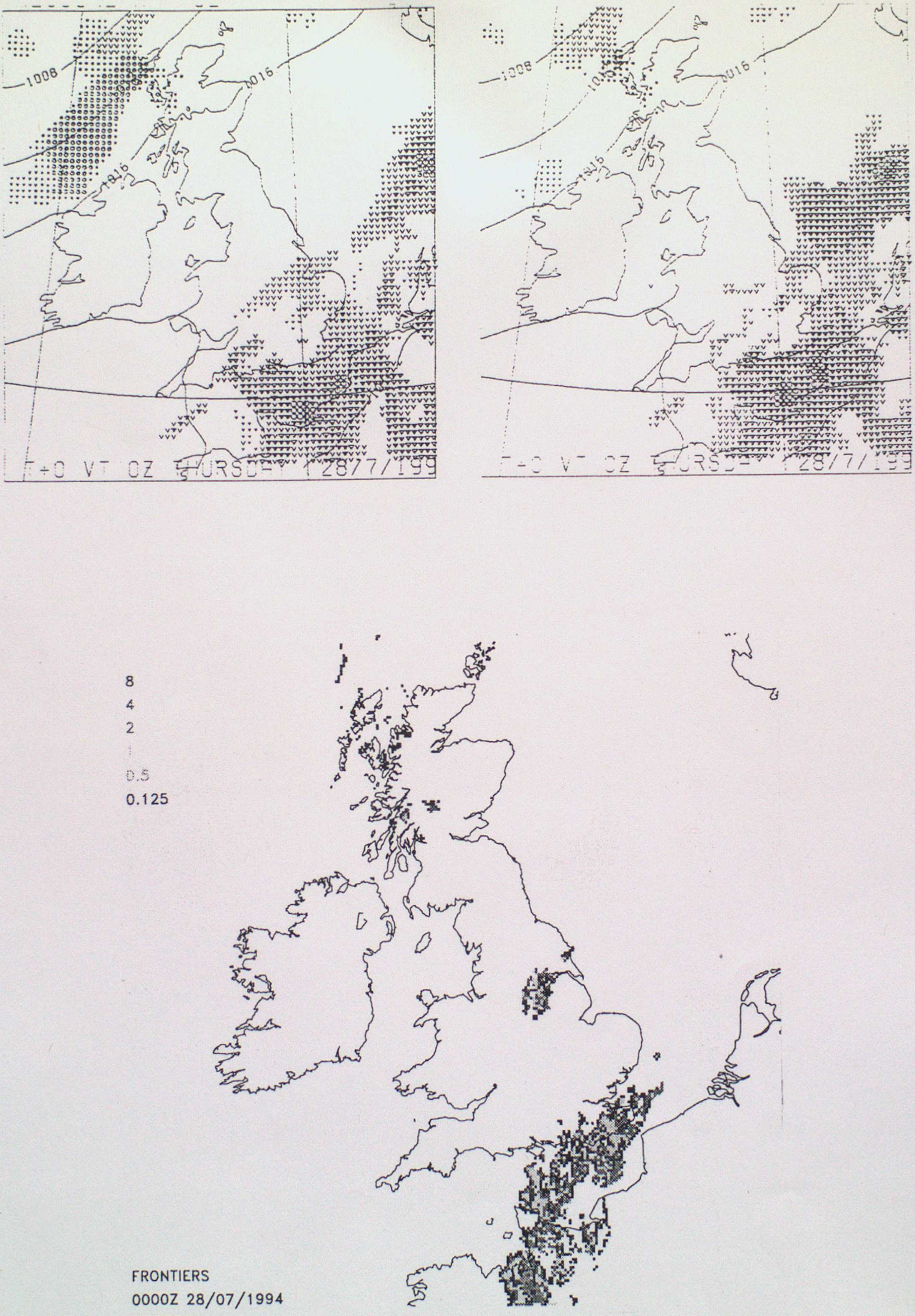
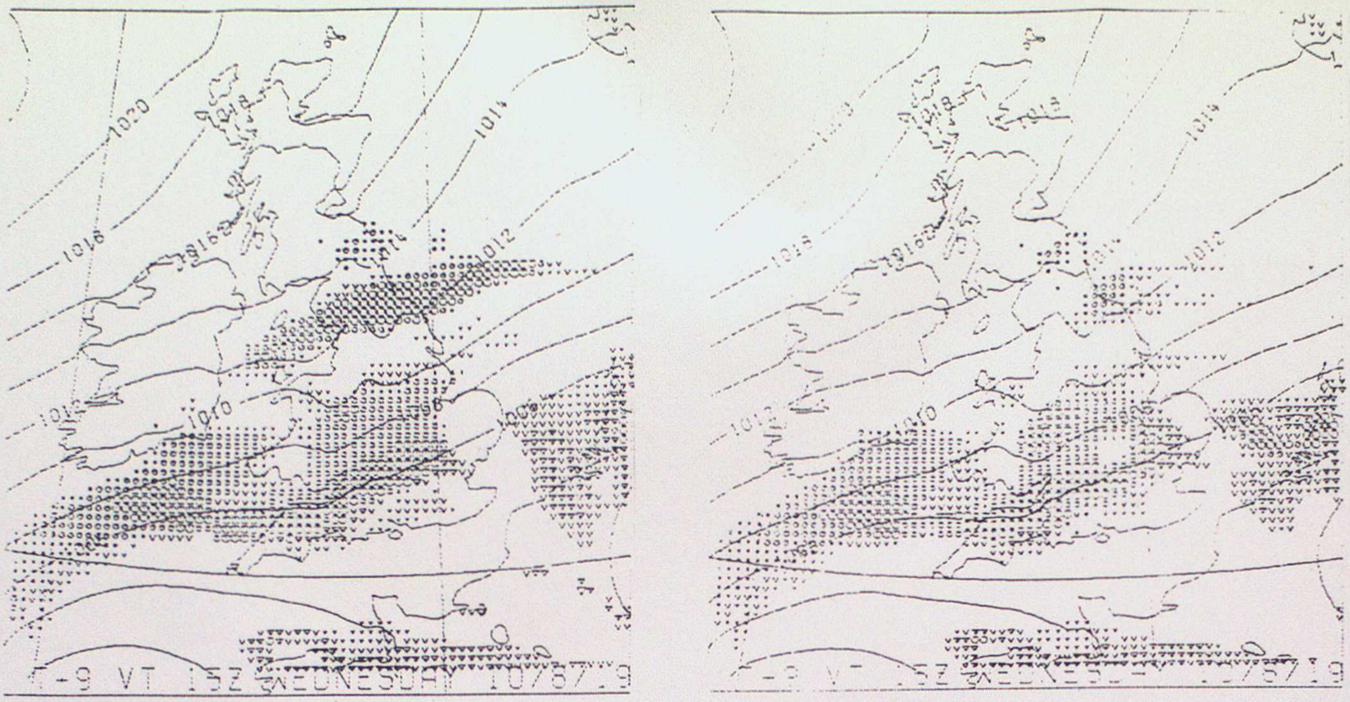


Figure 10. Precipitation analyses from 00Z 28/7/94 run. Left-hand frame is from the operational rerun; right-hand frame with the new MOPS scheme implemented.



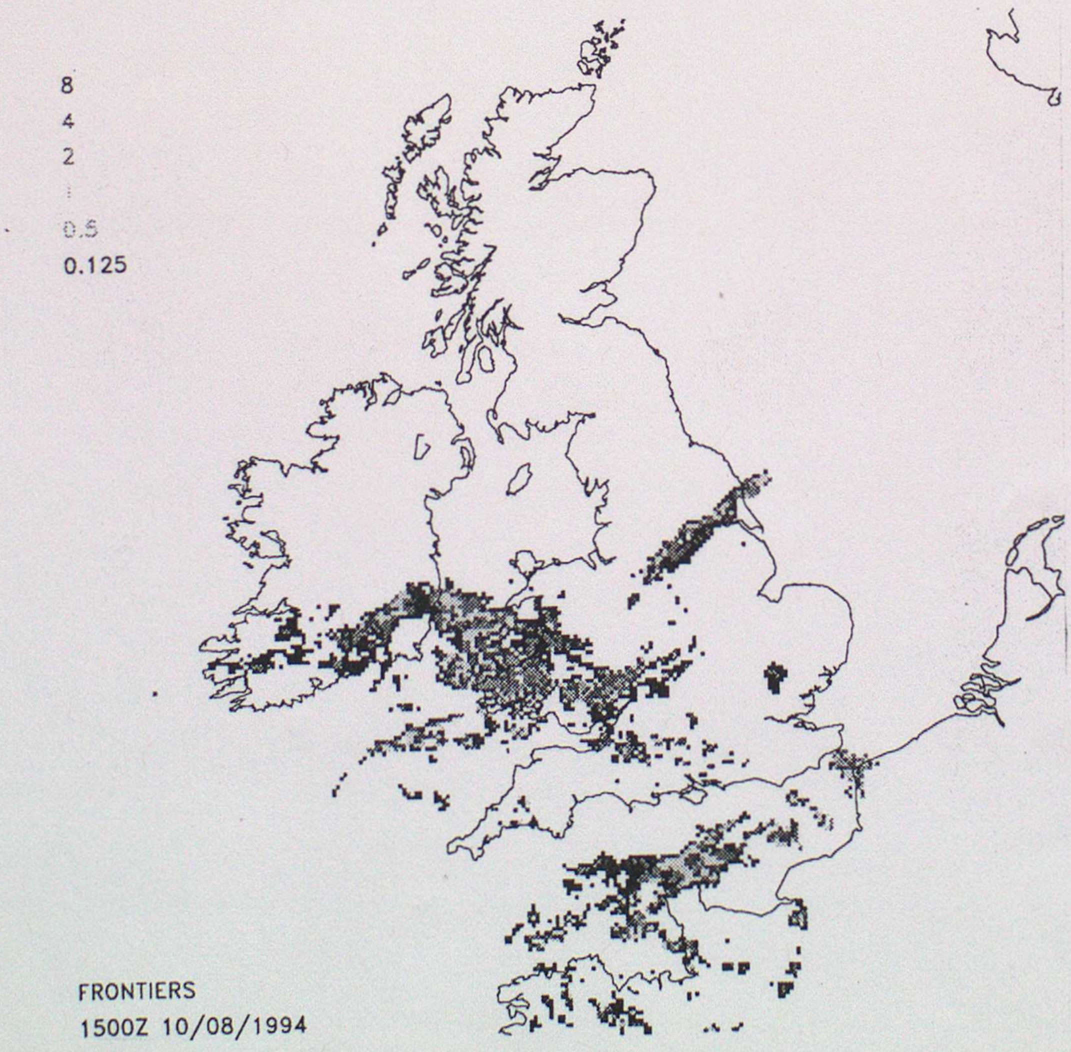


Figure 11. T+9 precipitation forecasts from 06Z 10/8/94 run. Left-hand frame is from the operational rerun; right-hand frame with the new MOPS scheme implemented.

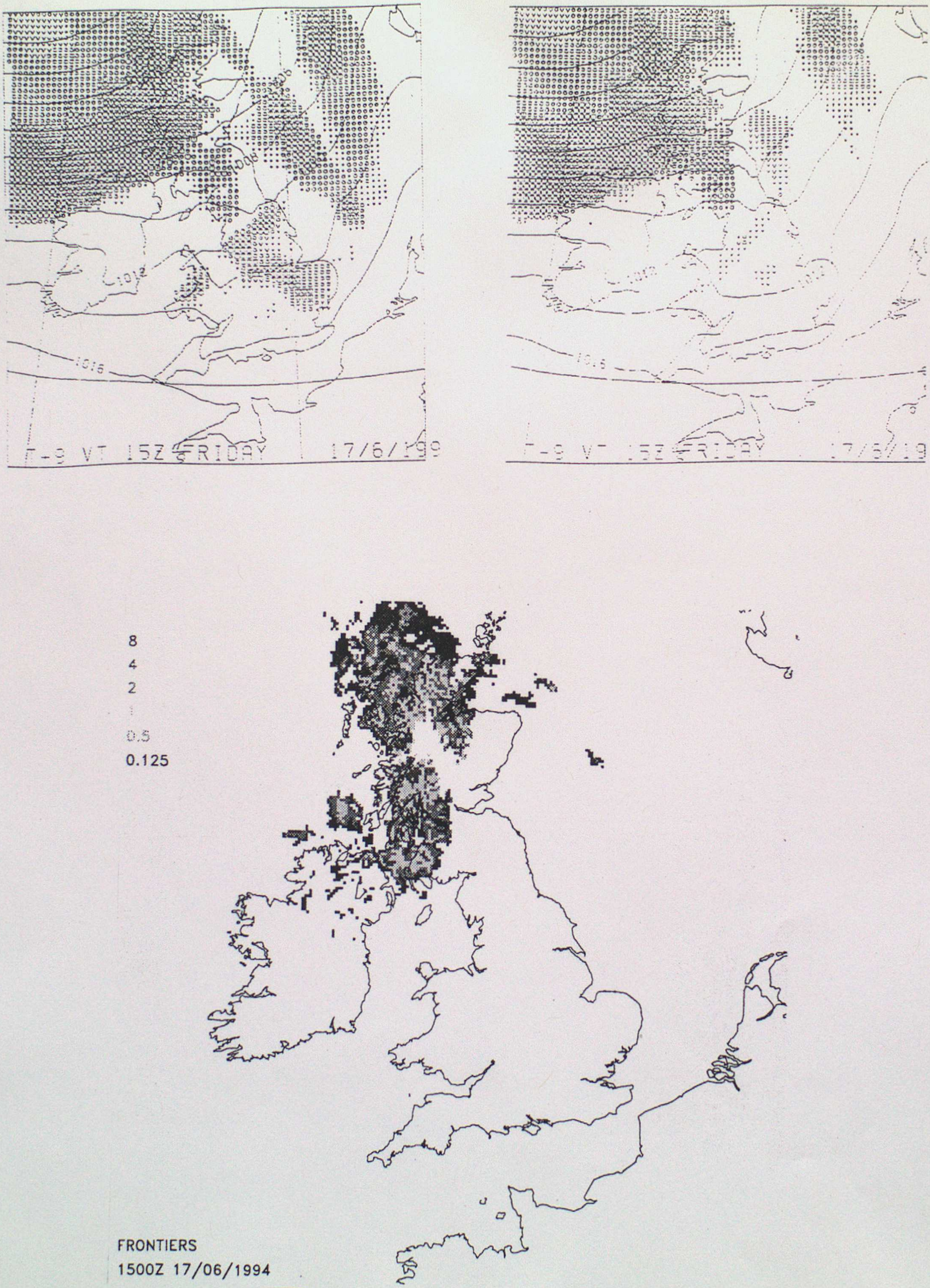


Figure 12. T+9 precipitation forecasts from 06Z 17/6/94 run. Left-hand frame is from the operational rerun; right-hand frame with the new MOPS scheme implemented.

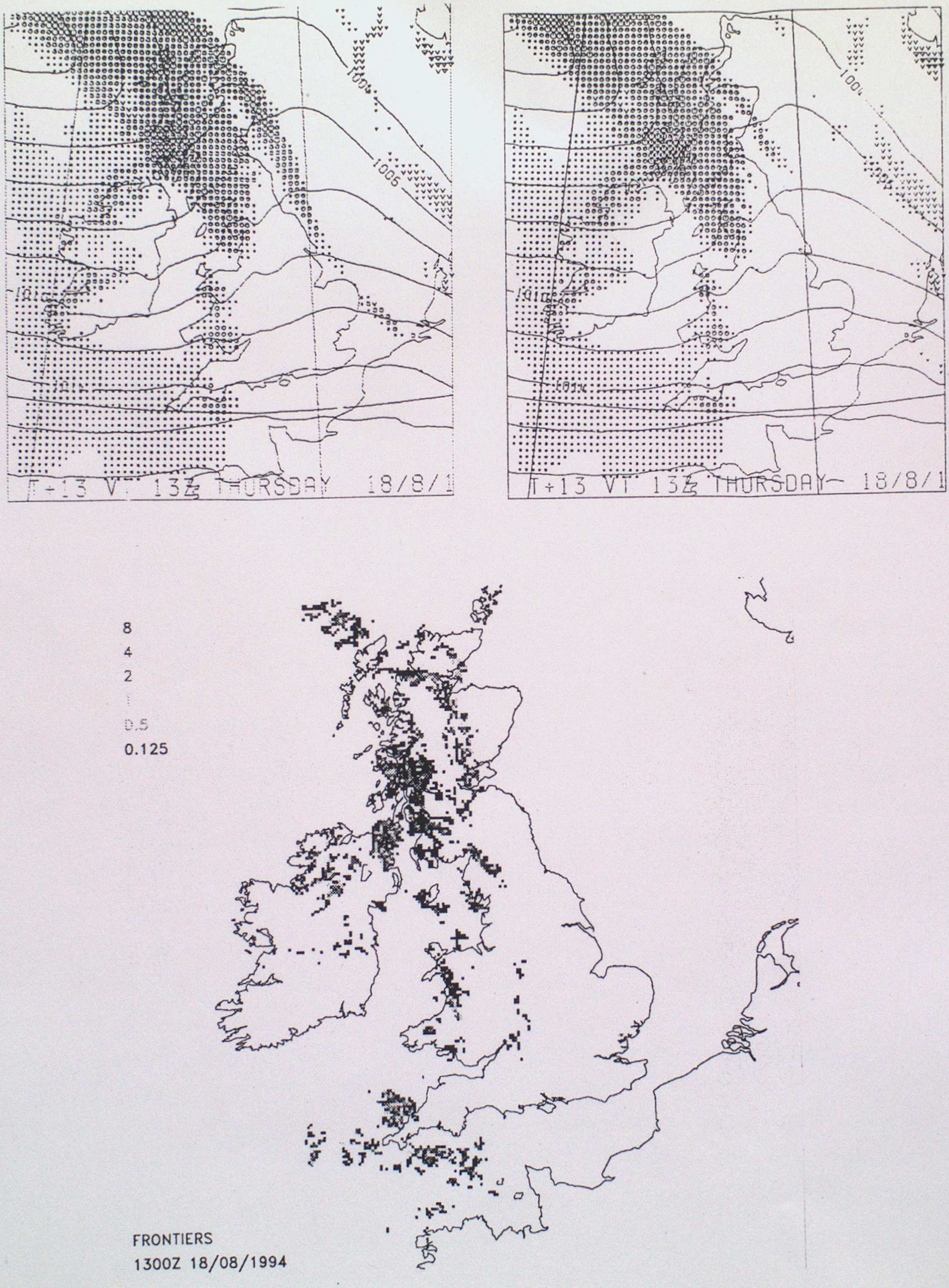


Figure 13. T+13 precipitation forecasts from 00Z 18/8/94 run. Left-hand frame is from the operational rerun; right-hand frame with the new MOPS scheme implemented.

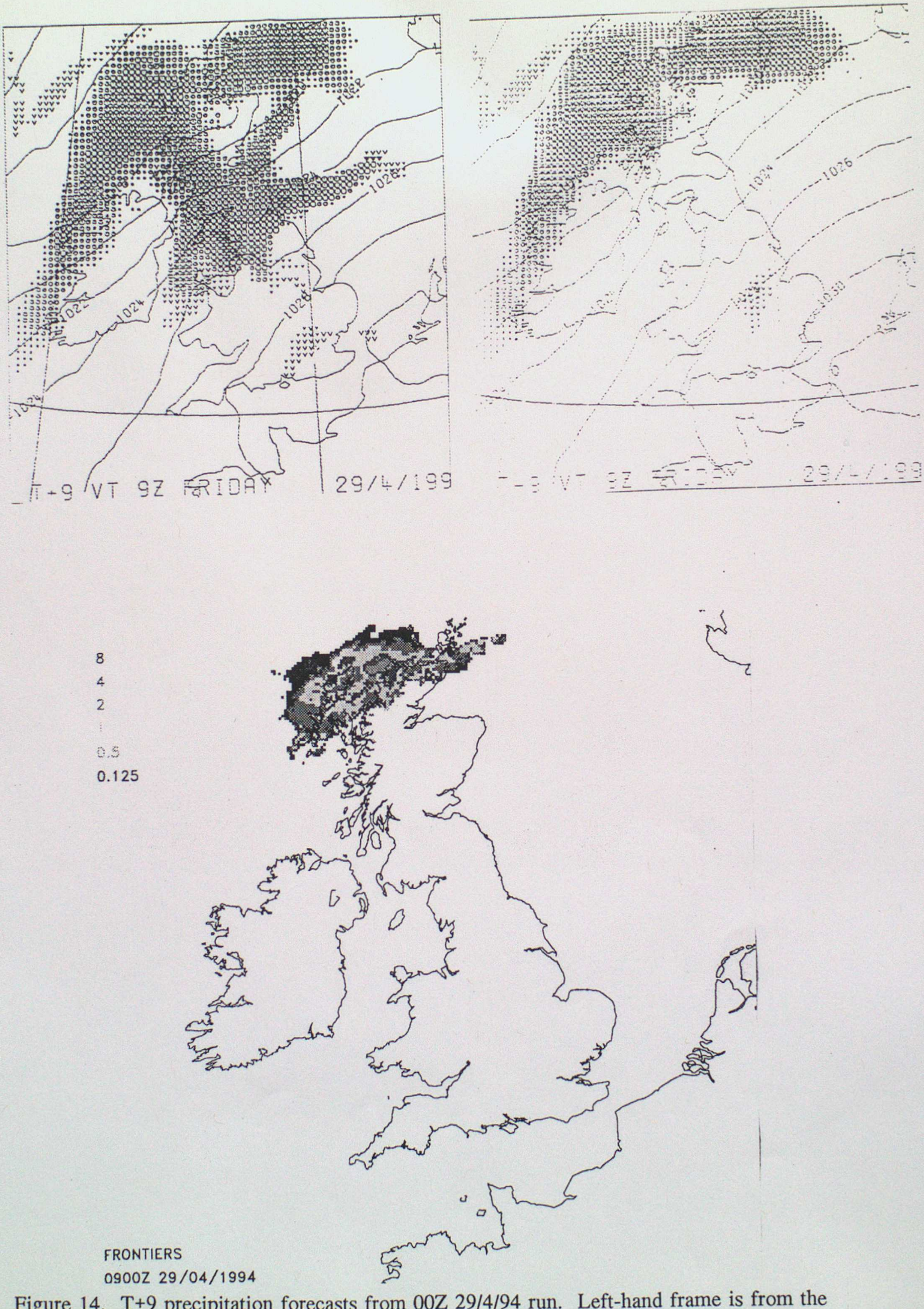


Figure 14. T+9 precipitation forecasts from 00Z 29/4/94 run. Left-hand frame is from the operational rerun; right-hand frame with the new MOPS scheme implemented.

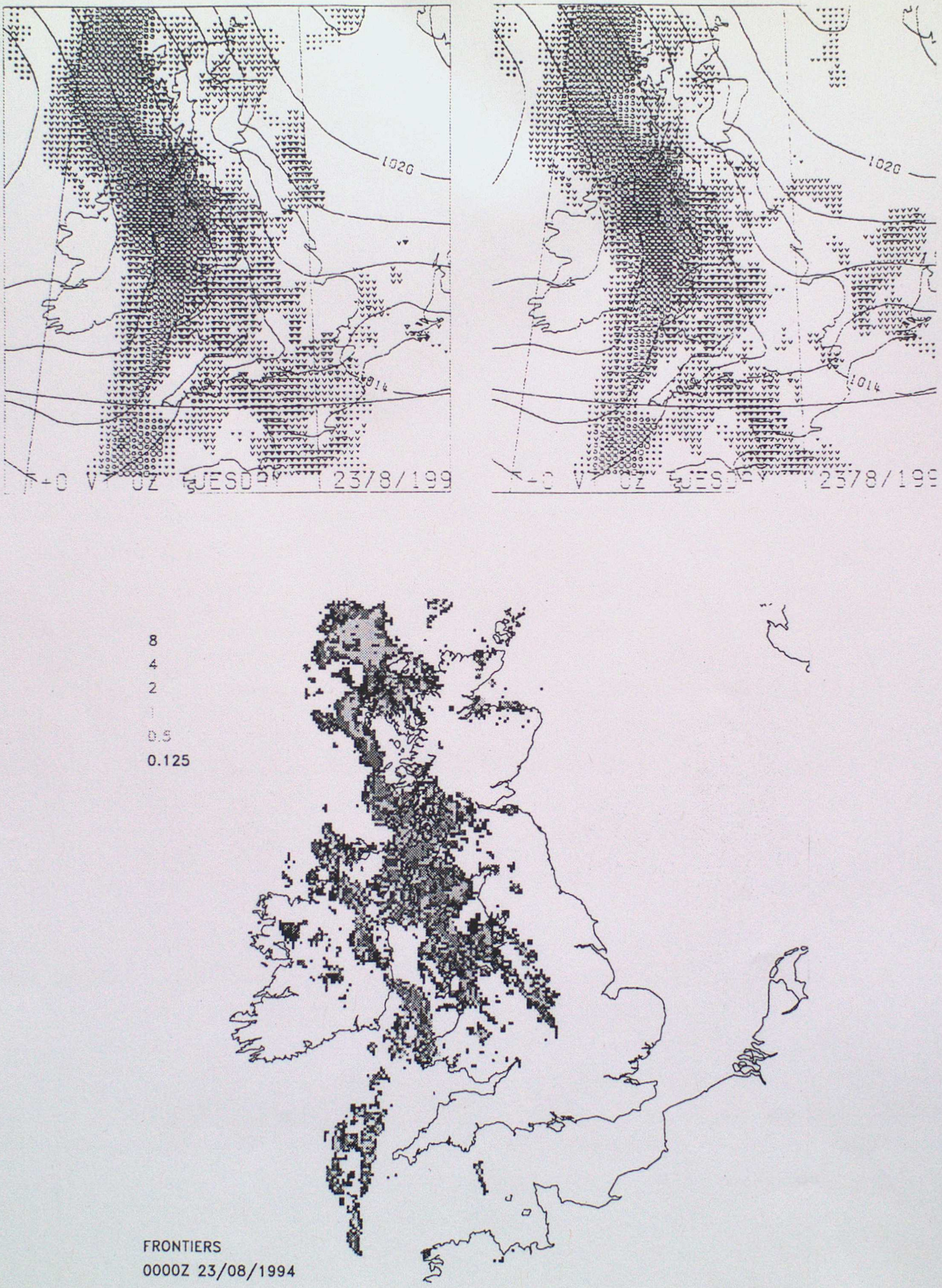


Figure 15. Precipitation analyses from 00Z 23/8/94 run. Left-hand frame is from the operational rerun; right-hand frame with the new MOPS scheme implemented.

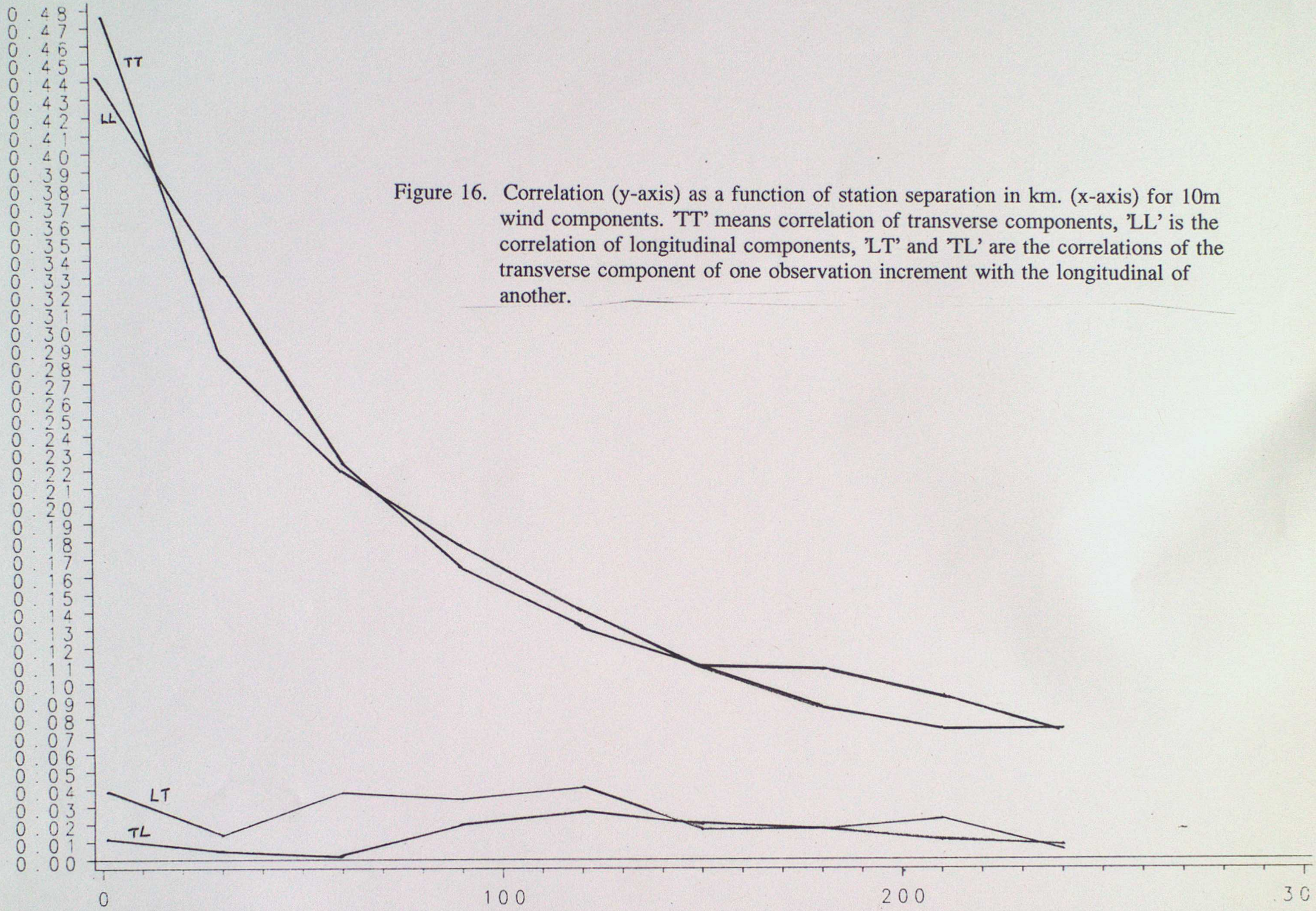


Figure 16. Correlation (y-axis) as a function of station separation in km. (x-axis) for 10m wind components. 'TT' means correlation of transverse components, 'LL' is the correlation of longitudinal components, 'LT' and 'TL' are the correlations of the transverse component of one observation increment with the longitudinal of another.

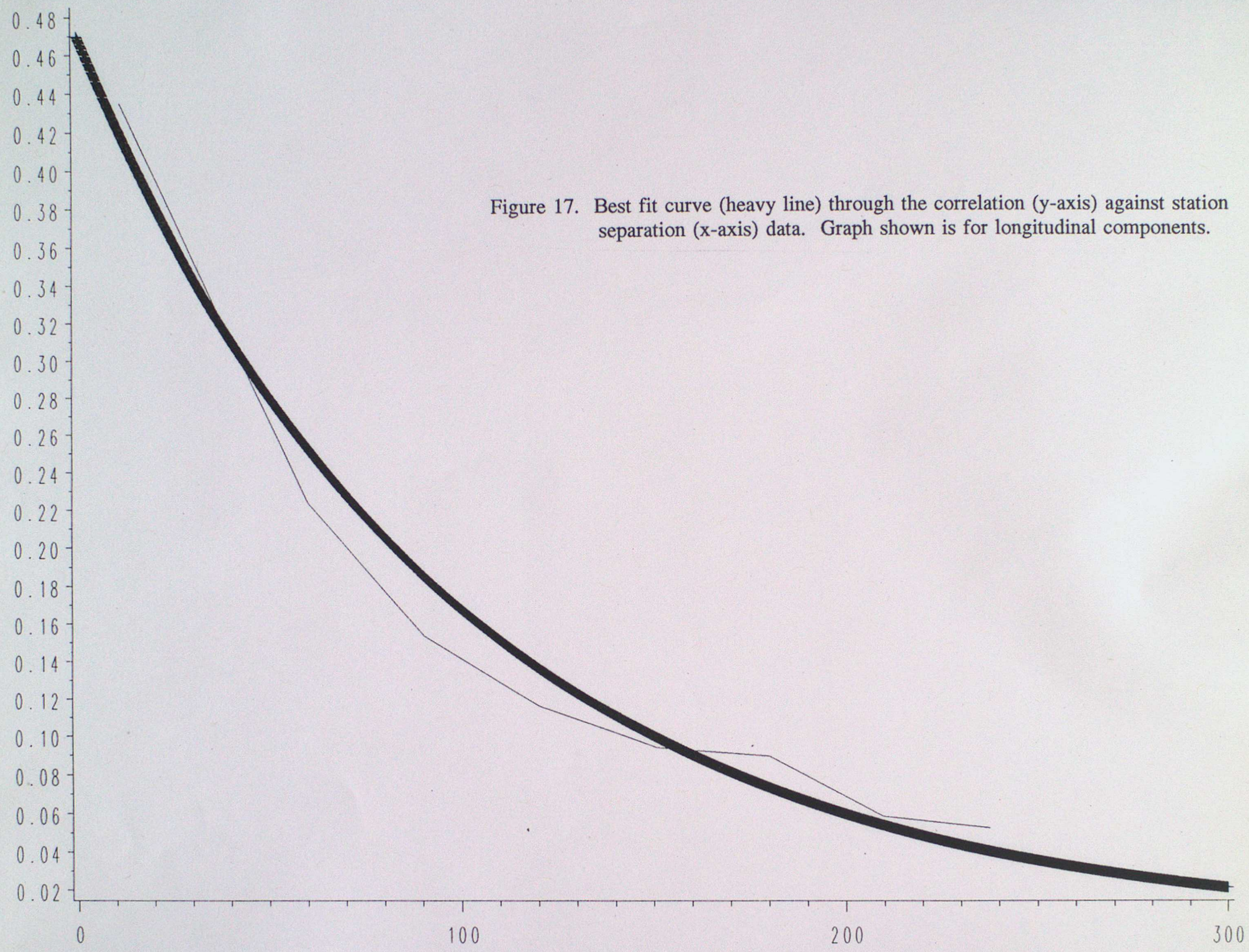


Figure 17. Best fit curve (heavy line) through the correlation (y-axis) against station separation (x-axis) data. Graph shown is for longitudinal components.

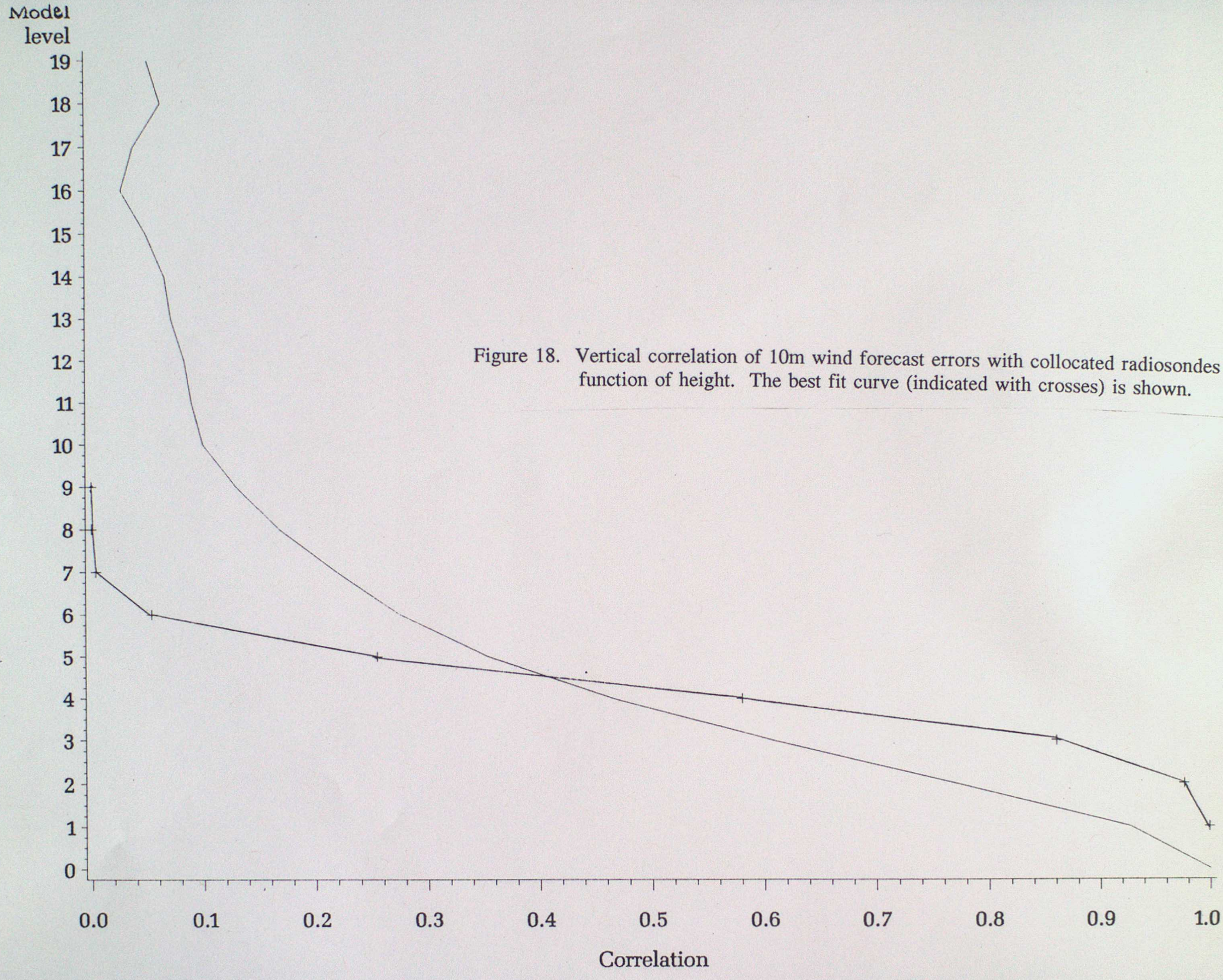


Figure 18. Vertical correlation of 10m wind forecast errors with collocated radiosondes as a function of height. The best fit curve (indicated with crosses) is shown.

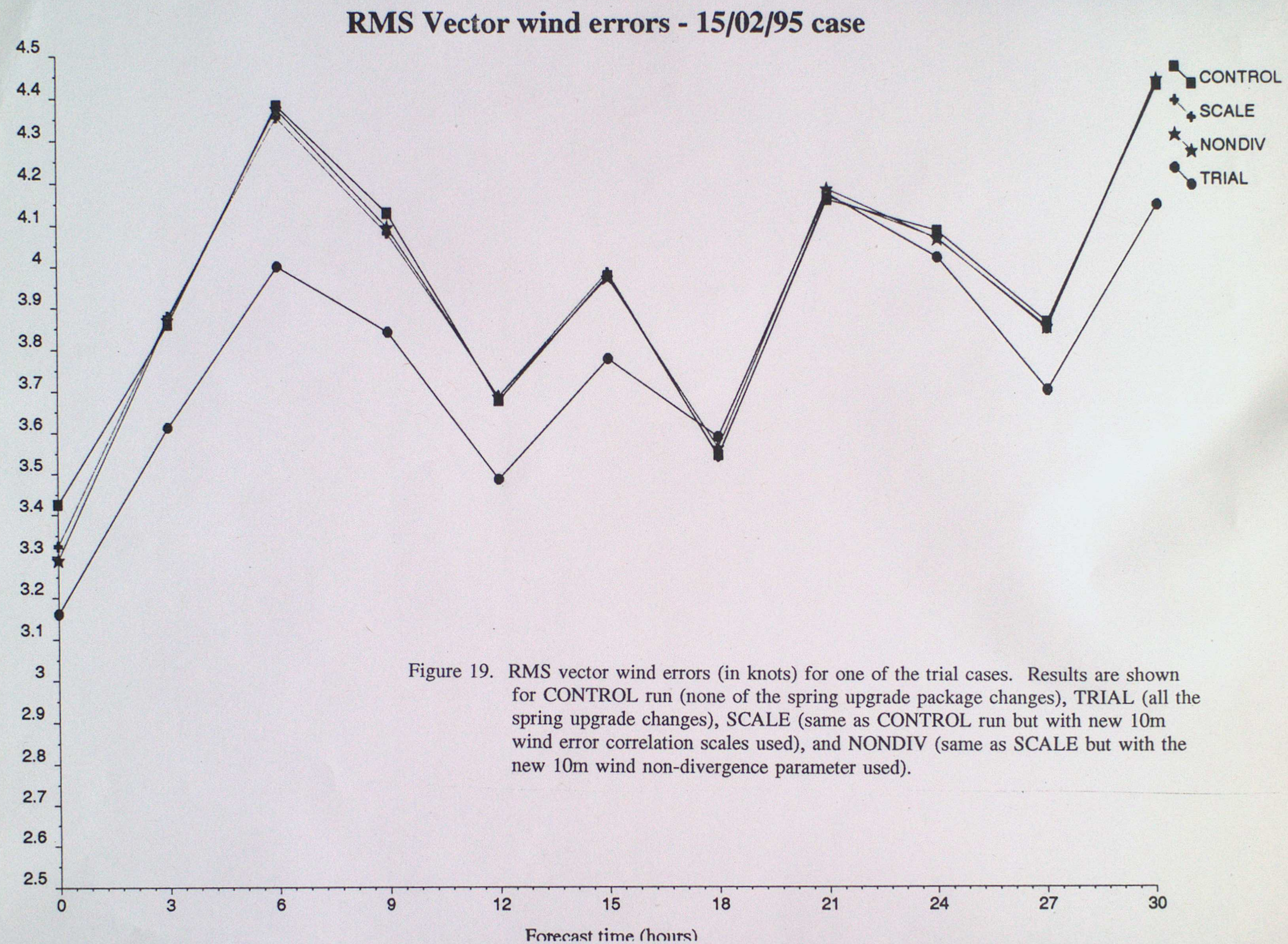


Figure 19. RMS vector wind errors (in knots) for one of the trial cases. Results are shown for CONTROL run (none of the spring upgrade package changes), TRIAL (all the spring upgrade changes), SCALE (same as CONTROL run but with new 10m wind error correlation scales used), and NONDIV (same as SCALE but with the new 10m wind non-divergence parameter used).

Parameter	Old value	New value
S	150 km.	75 km.
γ	0.8	0.0
E_o	2.0 ms^{-1}	1.5 ms^{-1}
E_b	approx 3.0 ms^{-1}	1.5 ms^{-1}

Table 1. Old and new assimilation parameters for 10m wind data. N.B. New observation and background errors have not yet been implemented operationally.