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The severe weather during 31 May and 1 June 1983 — a case study using a numerical model

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Summary

An account is given of the severe weather that occurred over England and Wales during the evening of 31 May and the morning of 1 June 1983. A forecast from the Meteorological Office numerical weather prediction model on a fine mesh, extending over this period, is presented and the results are discussed. Two experiments with the model, both of which give improved forecasts, are then described. In one of the experiments, the response of the model to an improved specification of topography over the Alps and Pyrenees is examined.

1. Introduction

The weather over the British Isles during May and early June 1983 was unsettled and often thundery. The period from 1800 GMT on 31 May to 1200 GMT on 1 June was particularly severe with thunderstorms and associated heavy rain occurring over large areas of England and Wales. This paper describes in some detail in Section 2 the synoptic evolution and weather during this period. A 36-hour forecast by the Meteorological Office numerical weather prediction model on a fine mesh (Gilchrist and White 1982), extending over this period from initial data at 0000 GMT on 31 May, is presented in Section 3. Section 4 of the paper then describes two experimental changes that were made to the model, and their effect on the forecast (particularly of rainfall) is examined.

2. Synoptic evolution

The analyses of the 500 mb constant pressure surfaces at 0000 GMT on 31 May and 1200 GMT on 1 June are shown in Fig. 1. The main features are a vortex (Fig. 1(a)) centred at 45 °N, 17 °W and a trough extending south from the centre of the vortex along longitude 15 °W. By 0000 GMT on 1 June the trough had sharpened and had moved east with the main portion lying from just west of Corunna to just west of Gibraltar. The vortex by this time had moved north and filled slightly. By 1200 GMT on 1 June (Fig. 1(b)) the trough had moved north-east and was lying west–east along the English Channel with the vortex centred at 50 °N, 10 °W. The associated mean-sea-level pressure patterns and developments are illustrated in Figs 2(a) and 2(b). The most significant feature that affected the weather over the British Isles was

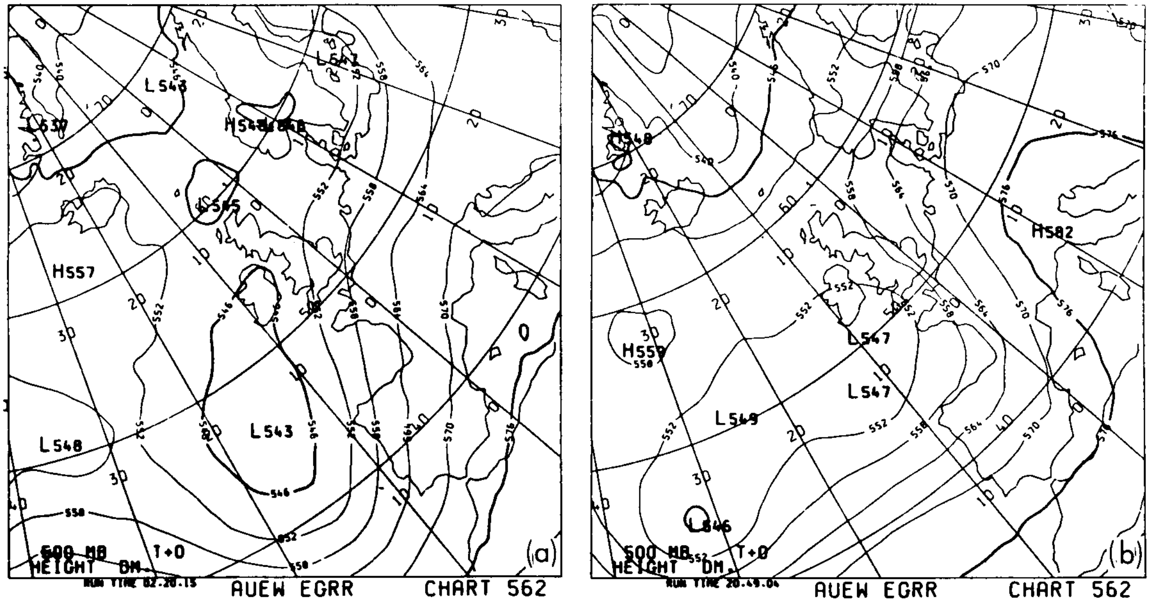

Figure 1. Analysis of the 500 mb constant pressure surface (in standard decageopotential metres) for (a) 0000 GMT on 31 May 1983 and (b) 1200 GMT on 1 June 1983.

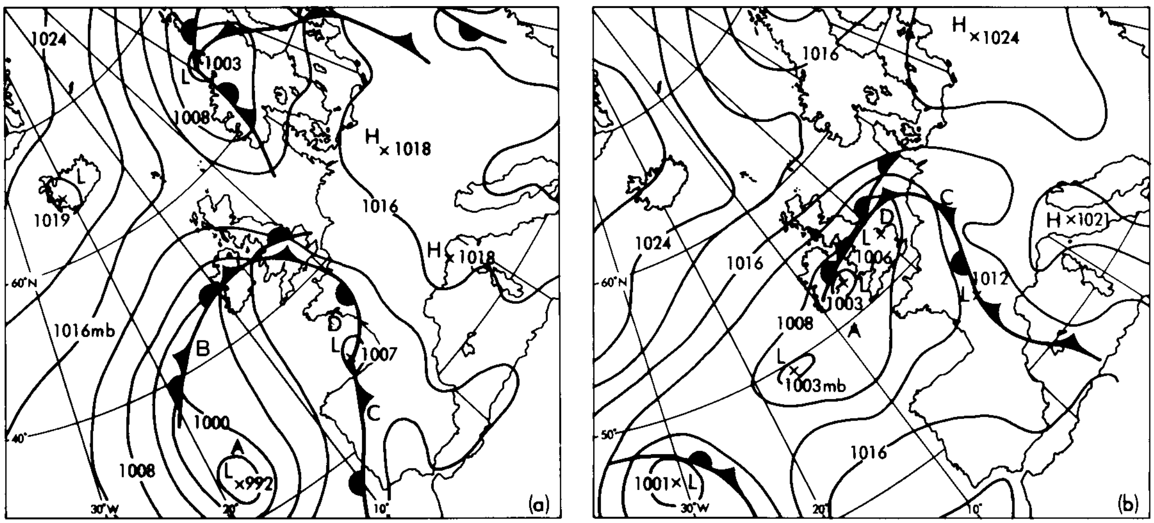

Figure 2. Hand-analysed mean-sea-level pressure pattern for (a) 0000 GMT on 31 May 1983 and (b) 1200 GMT on 1 June 1983.

depression A which moved slowly north-east from 42 °N, 18 °W at 0000 GMT on 31 May to become a complex feature to the south of Ireland by 1200 GMT on 1 June. Occlusion B moved slowly north during 31 May and became a weak decaying front over northern Scotland by 0600 GMT on 1 June. Cold front C moved steadily east over Spain and into the Mediterranean Sea during the 36 hours to 1200 GMT on 1 June. Further north, over the Bay of Biscay and north-west France, the eastward progress of the front was slow and erratic as waves developed and moved north along the front. One such wave that is shown as low D in Figs 2(a) and 2(b) and which was at 44 °N, 4 °W at 0000 GMT on 31 May, moved north into central southern England shortly after midnight on 1 June.

By dawn the wave had moved north-east to become a more pronounced feature with a much broader circulation over the eastern Midland counties. As the wave continued to move north-east into the North Sea during the morning of 1 June, very cold air at low levels was injected into the circulation of the wave by the strong easterly winds north of the warm front. Consequently a very active front was generated over northern England by midday on 1 June.

2.1 *Significant weather*

The weather associated with occlusion B at midnight on 31 May consisted of a narrow band of mainly light rain extending from northern England west into northern Ireland. By 0600 this rain area had moved north into Scotland with only scattered remnants remaining at midday. The afternoon of 31 May was dry over most of the British Isles with only slight rain in parts of Scotland and eastern England at first. Over France and Spain there were scattered showers and thunderstorms. At 1800 GMT outbreaks of thundery rain were being reported over south-west England, and by midnight over central southern England there was a large area of thunderstorms which extended south into the Channel Islands and northern France (see Fig. 3). During the early morning of 1 June, the rain and thunderstorms moved

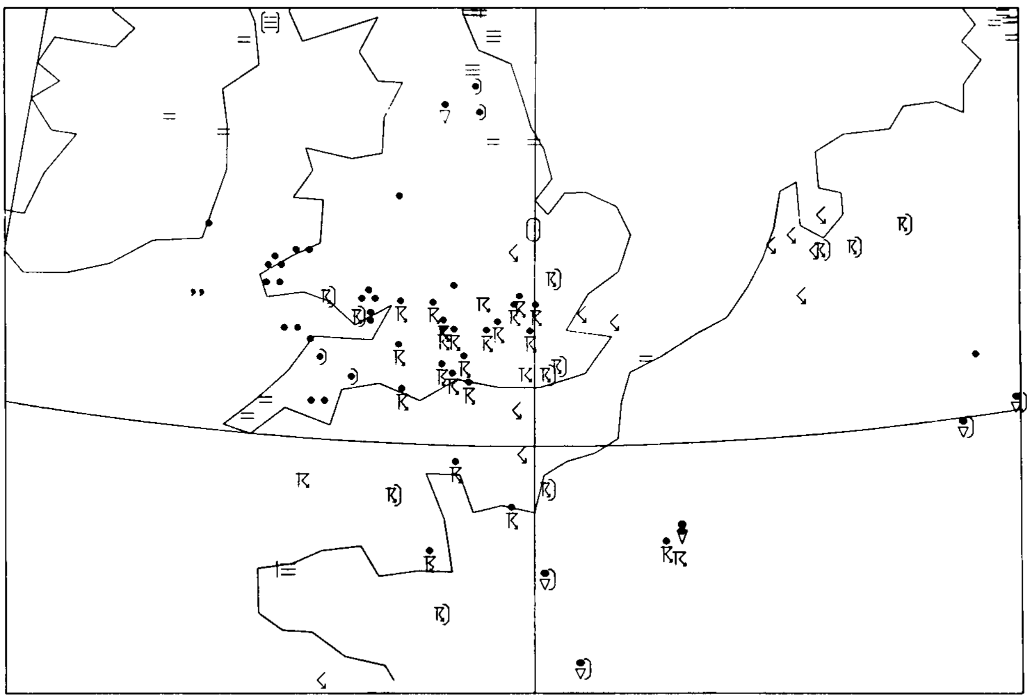

Figure 3. Significant weather at 0000 GMT on 1 June 1983.

north-east, and by 0600 GMT they were over east Yorkshire, Humberside, Lincolnshire and Norfolk, except the coast of Norfolk which was still dry. By this time, Wales, the Midland counties, central southern and south-west England had become dry. Rainfall accumulations were typically 10–15 mm over a six-hour period with a small region in the range 20–25 mm. The observed rainfall for the six hours from 0000 to 0600 GMT on 1 June is shown in Fig. 4. The map shows that the heaviest rainfall in this period occurred in a narrow band extending from the Isle of Wight in the south towards Lincolnshire further north. In contrast, the south-east part of Suffolk and the extreme east of Kent received much less rain and the coastal strip of Norfolk remained dry. By midday all the thundery activity had died out, but there remained a wide band of heavy frontal rain over northern England that extended west into Northern Ireland then south-west into Eire (see Fig. 13). The remainder of the British Isles was dry apart from some slight drizzle in Wales and a few showers on the south coast of England.

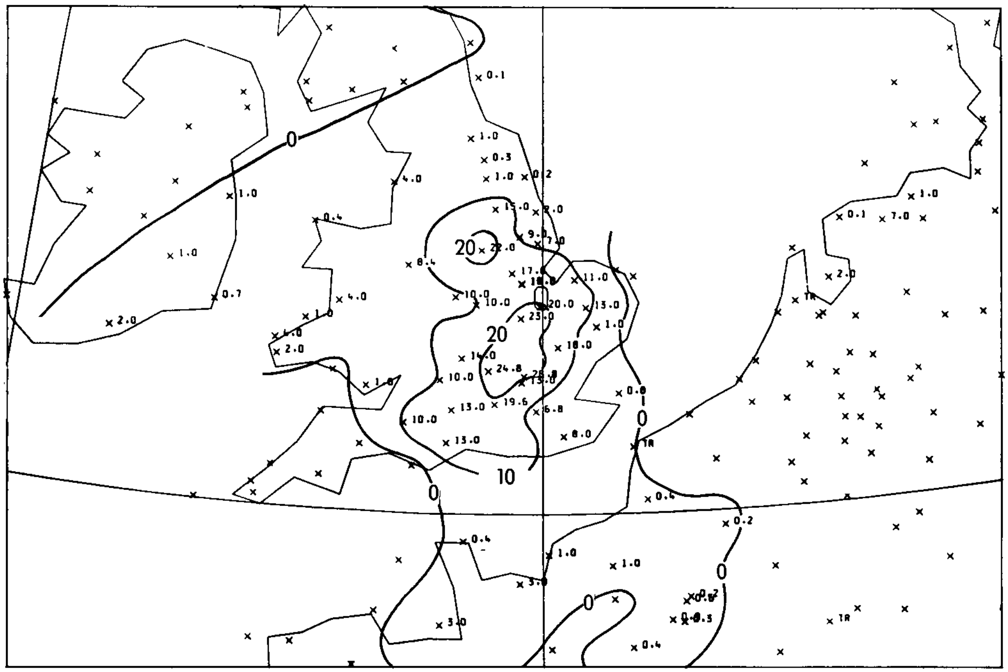

Figure 4. Observed rainfall in millimetres between 0000 GMT and 0600 GMT on 1 June 1983. Isohyets are at 10 mm intervals.

2.2 *Discussion*

The heavy rain and thunderstorms were undoubtedly associated with the frontal wave that moved north from the Bay of Biscay during the afternoon of 31 May. The air to the east of the wave was potentially unstable between 1000 mb and 650 mb. This fact is illustrated in the upper-air sounding from Trappes (Paris) made at 1200 GMT on 31 May (Fig. 5). The ascent shows a steady decrease in wet-bulb potential temperature from 16 °C at 1000 mb to 13 °C at 650 mb. The development of the thunderstorms can best be seen in Figs 6, 7 and 8 which display a sequence of infra-red satellite pictures from Meteosat taken at 1755, 2055 and 2355 GMT on 31 May over north-west Europe. The sequence shows a dramatic increase in the area of cloud just to the south of the British Isles between 1755 and 2055 GMT. This increase in cloud area can be attributed to a release of energy in the potentially unstable area to the east of the waving cold front. The mechanism for the release of energy at that time of day was partly provided by dynamical lifting associated with the frontal wave as it moved north. The situation was further complicated, however, by a trough in the wind flow at 700 mb. The 700 mb wind at Trappes at 1800 GMT was 205 °, 20 knots, but by midnight it had backed by 55 ° to 150 °, 20 knots indicating a trough approaching from the south. By 0600 GMT on 1 June the trough had passed through Trappes and had become a sharpening feature between Shoeburyness and Hemsby that extended east-south-eastwards into Holland and Belgium (see Fig. 9). The presence and subsequent development of the trough to the south of Trappes during the evening of 31 May probably provided another trigger for the release of energy in the area to the east of the cold front. After the release of energy, organized convection started. The trough then became self maintaining, developing as it moved north-east. The origin of the trough is

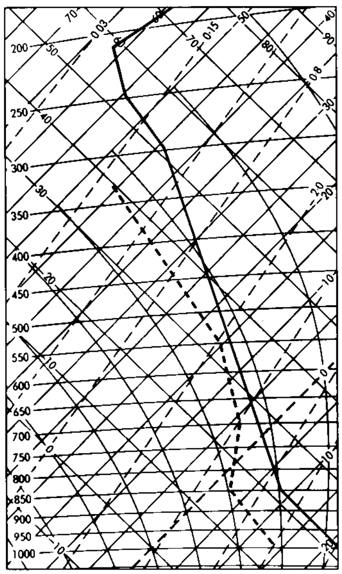

Figure 5. Upper-air sounding from Trappes (Paris) for 1200 GMT on 31 May 1983.

not entirely clear, but it seems likely that it was orographically induced by the Pyrenees. To a south-south-westerly airflow, the Pyrenees are effectively a 3000-metre-high solid barrier. Evidence of wave motion can be found in the satellite picture for1755 GMT on 31 May that is shown in Fig. 6. The strong south-south-westerly flow extends from north Africa, where a discontinuity in the cloud cover over the Atlas mountains is visible, to another discontinuity that can be seen further north in the lee of the Pyrenees. In fact this discontinuity of cloud cover in the Pyrenees and Alps region can be seen throughout the picture sequence shown in Figs 6–8. The discontinuities show up as clear areas in the satellite pictures, and are probably caused by moist air descending and drying out on the leeward sides of the mountains.

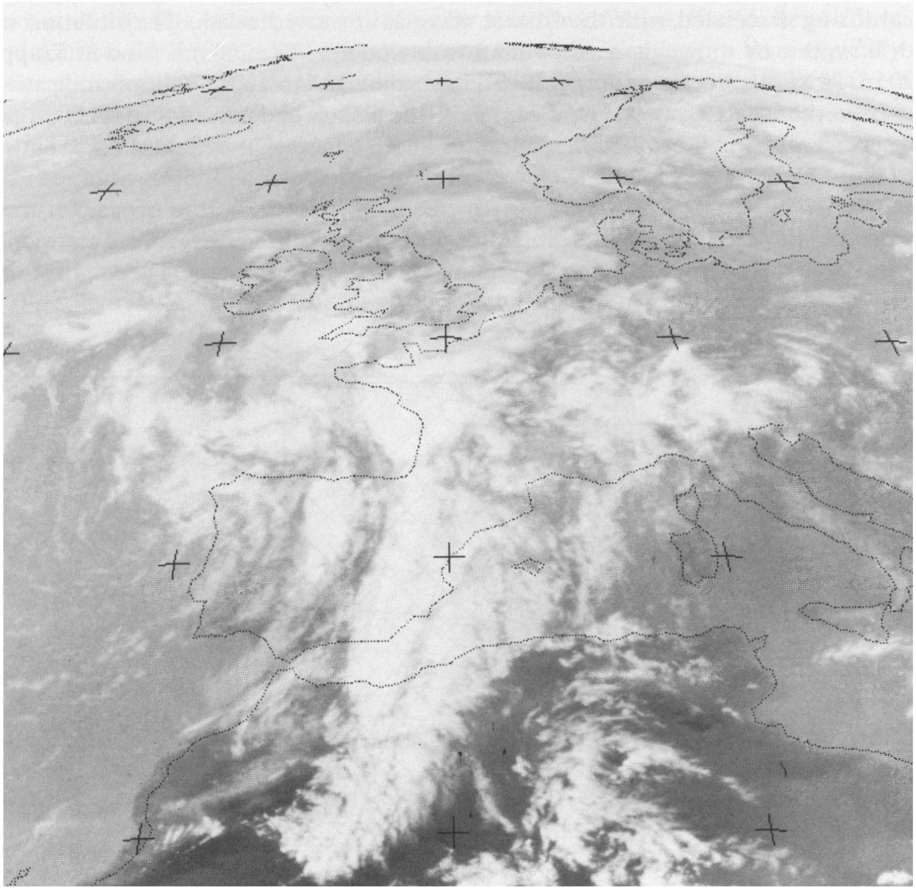

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Figure 6. Meteosat infra-red picture of north-west Europe and part of north Africa at 1755 GMT on 31 May 1983.

3. The fine-mesh forecast

3.1 *Brief description of the model*

The fine-mesh version of the Meteorological Office weather prediction model uses a grid which is defined by lines of latitude and longitude and has a grid-length of 0.9375 degrees in the east–west direction and 0.75 degrees in the north–south direction. The geographical area covered by the grid extends from 79½ °N to 30 °N and from approximately 80 °W to 39 °E. This area includes most of the North Atlantic and Europe and the eastern part of America. In the vertical, the sigma co-ordinate is used which is defined as p/p_* where p = pressure and p_* = pressure at the earth's surface. The successive levels of

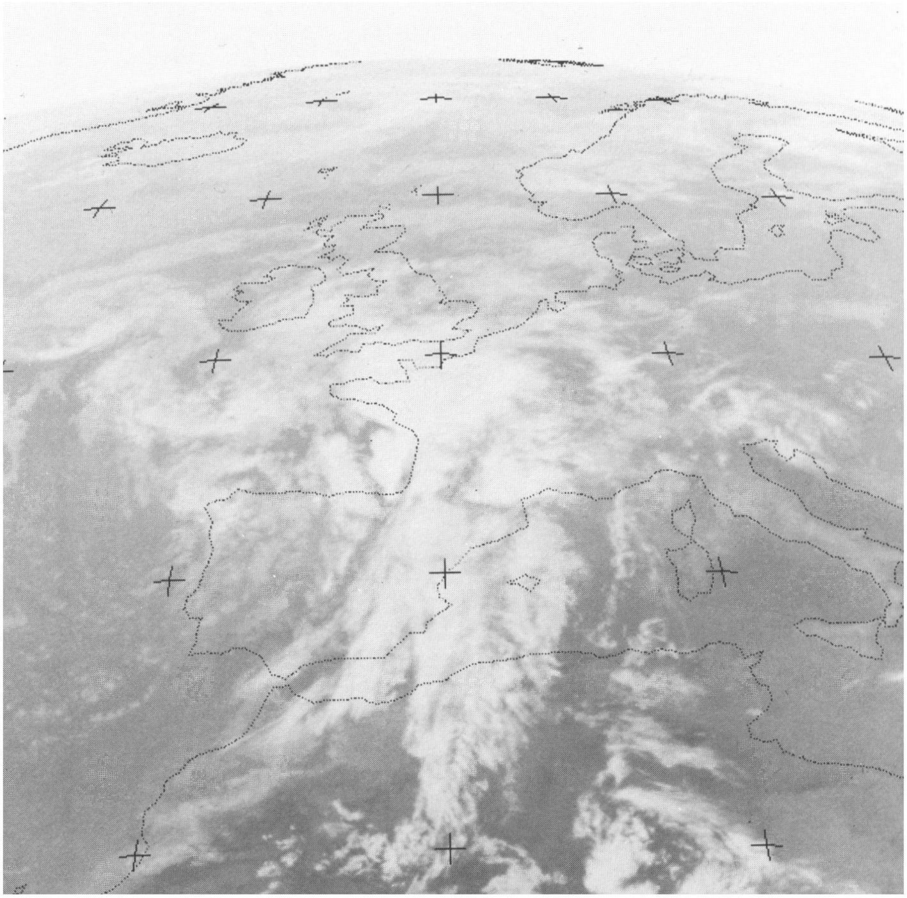

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Figure 7. Meteosat infra-red picture of north-west Europe and part of north Africa at 2055 GMT on 31 May 1983.

the model thus lie parallel to the contours of the earth's surface that are defined by the topography used in the model. The model has 15 levels in the vertical with greater concentrations in the boundary layer and near the usual jet-stream levels. Rain can be produced by the model from two processes; dynamical and convective. Dynamic rain is produced when there is mass ascent of moist air on scales larger than the grid used in the model. Convective rain, which occurs on a scale smaller than that of the model grid, is produced using a convective parametrization scheme described elsewhere (Meteorological Office 1979). In the version of the scheme that was used by the model, when a level of the model becomes supersaturated, after moist air has been lifted, the excess moisture is allowed to fall into the level below. Evaporation then occurs at this level but any remaining moisture left after evaporation has been completed is then

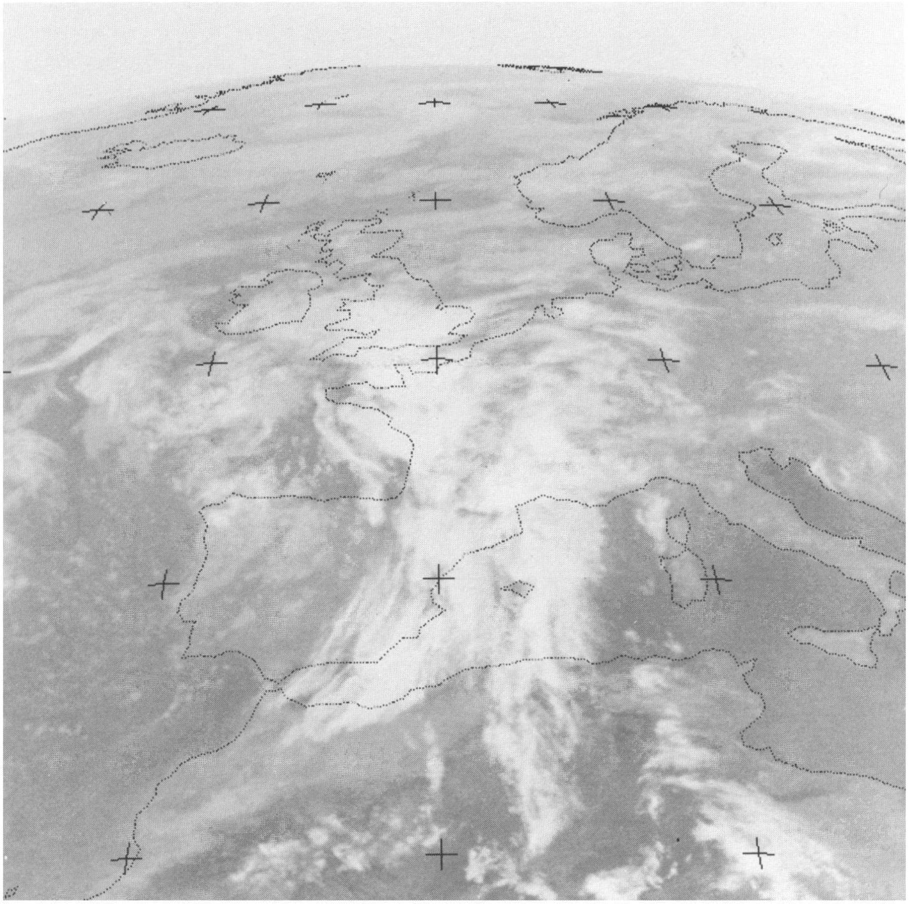

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Figure 8. Meteosat infra-red picture of north-west Europe and part of north Africa at 2355 GMT on 31 May 1983.

allowed to fall to the surface as rain. Clearly this process is not altogether realistic and can generate spurious rainfall, since in the real atmosphere moisture would be evaporated at all levels to the surface.

3.2 *The initial data*

The forecast was run to 36 hours from data valid at 0000 GMT on 31 May. The initial data fields for the forecast were in reasonable agreement with observations, except for the mean-sea-level pressure field close to the centre of depression A and near to wave D. The mean-sea-level pressure initial field is shown in Fig. 10. By comparing this field with the observed field shown in Fig. 2(a), one can see that the centre of depression A in the initial field is 5 mb too high and that the position of wave D is slightly too far south. These differences are not considered to be serious in this case since by T+6 the discrepancies

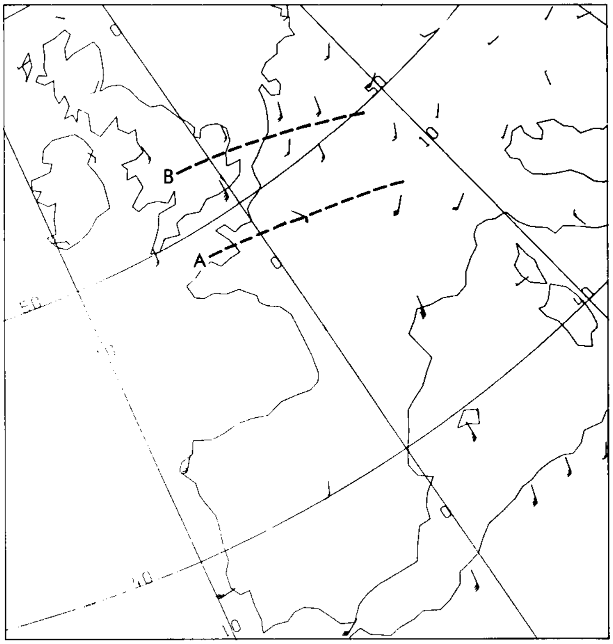

Figure 9. Observed 700 mb wind in knots at 0000 GMT on 1 June 1983. Line A indicates estimated position of trough at 0000 GMT on 1 June. Line B indicates estimated position of trough at 0600 GMT on 1 June.

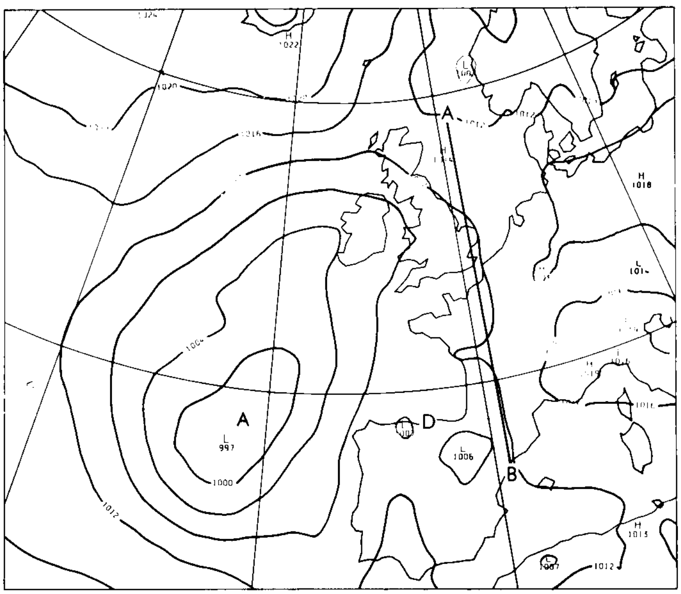

Figure 10. Mean-sea-level pressure at 0000 GMT on 31 May 1983 derived from fine-mesh initial data. The line AB denotes the cross-section shown in Figs 21 and 22.

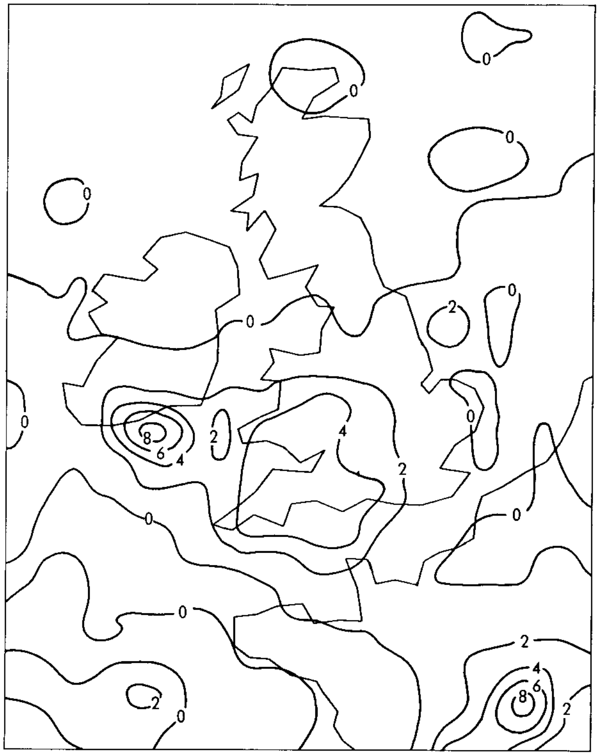

Figure 11. Total rainfall accumulations produced by forecast A for the period 0000 GMT to 0600 GMT on 1 June 1983. Isohyets are at 2 mm intervals.

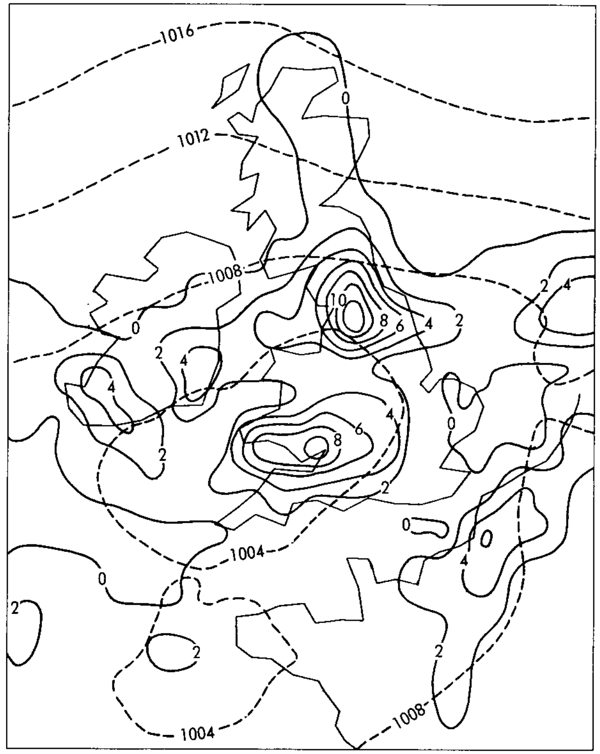

Figure 12. Total rainfall accumulations produced by forecast A for the period 0600 GMT to 1200 GMT on 1 June 1983. Isohyets are at 2 mm intervals. The forecast mean-sea-level pressure field for 1200 GMT on 1 June is shown by pecked lines with isobars at 4 mb intervals.

mostly vanish. This suggests that the differences between the mean-sea-level pressure analyses may have been due to an inconsistency between the pressure and wind analyses so that a properly initialized field would have been correct.

3.3 *The rainfall forecast*

The standard forecast will be referred to in the rest of this paper as forecast A. Although no charts are shown here, the main criticism of the rainfall forecast during the first 18 hours was that a large number of showers were predicted by the model over England and Wales in the period 1200–1800 GMT on 31 May, which was in fact a mainly dry period. There was also some spurious convective rainfall over Holland and Belgium. The onset of the thundery rain over south-west England at around 1800 GMT was quite well predicted, but the subsequent movement and development of the rain was badly forecast. Fig. 11 shows the total accumulated rainfall, that is convective and dynamic added together, produced by the model in the period 0000 to 0600 GMT on 1 June. Comparing this chart with the observed rainfall field shown in Fig. 4, one can see that the rain area in the model was too broad and that the heaviest rain did not move quickly enough north-eastwards, although the coastal strip of Norfolk was correctly predicted to remain dry. During this period south-west England was also dry, whereas in the model forecast there was still some rainfall. The total rainfall accumulations produced by the model were much too small, the largest values, 6–8 mm, covered an area over the sea just to the south of Ireland. Over England and Wales the highest totals were only 4–6 mm which does not compare favourably with the large area of rainfall in excess of 10 mm that occurred in reality. The reluctance of the model to move the thundery rain north-east shows up in the rainfall accumulations predicted for the period 0600 to 1200 GMT on 1 June which are shown in Fig. 12. The corresponding observed accumulations are shown in Fig. 13. From

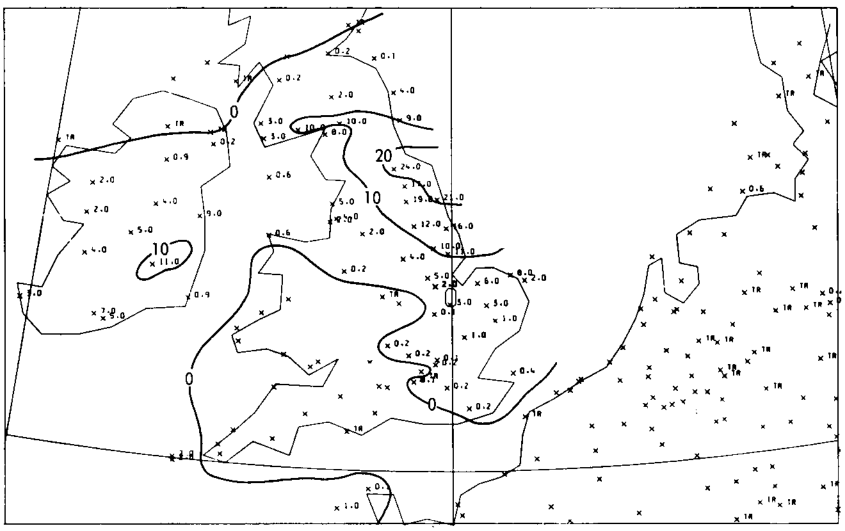

Figure 13. Observed rainfall between 0600 GMT and 1200 GMT on 1 June 1983. Isohyets are at 10 mm intervals.

these charts it can be seen that the frontal rain over northern England and Northern Ireland, with the remnants of the thundery activity over the eastern half of northern England, was not predicted accurately. The model has the area of maximum rainfall too far west and, again, the amount of rainfall was much too small in places. The highest accumulation predicted by the model was 12mm but in reality there was an area over north-east England in excess of 20 mm. The major error in the rainfall forecast at this time, however, was over South Wales, the west Midland counties and south-west England. Over these regions the model retained a separate area of quite heavy rainfall which was entirely erroneous, since the weather in this area was mostly dry throughout this period. Most of the rain predicted by the model during this forecast was convective, although the model did produce some dynamic rain after 1800 GMT on 31 May. The forecast frontal rainfall over northern England at midday on 1 June was a mixture of both dynamic and convective origin, but the erroneous area of rainfall further south was entirely convective. To summarize, we can say that the main errors of the forecast were that the model produced too much convective rainfall on the afternoon of 31 May, and that the movement and intensity of the thunderstorms and rain on 1 June were poorly forecast.

4. Experiments with the model

4.1 *Discussion*

After some investigation, it was found that the most likely cause of the spurious convective rainfall produced early in the forecast was in the formulation of the convective parametrization scheme used in the model, which was briefly described in Section 3.1. A very simple experimental change that can be made to this scheme is to change the constant that governs the rate of evaporation allowed. The change that was made in the experiment described in the next subsection was to increase the rate of evaporation substantially. By doing this it was expected that most of the spurious convective rain produced by the model early in the forecast would be removed by evaporation. This means that there would be more moisture available to the model later in the forecast and the model could then conceivably produce greater amounts of rainfall in the last twelve hours of the forecast when convection was more vigorous.

4.2 *The fine-mesh forecast with increased evaporation*

This forecast will subsequently be referred to as forecast B. Increasing the amount of evaporation did remove most of the spurious convective rain early in the forecast. This allowed the model to retain more moisture in the early stages of forecast B than it did in forecast A. This difference in moisture retention is well illustrated in Figs 14 and 15. Fig. 14 shows the forecast 700 mb relative humidity field for 1800 GMT on 31 May produced from forecast A. Fig. 15 shows the same field produced from forecast B. The area of relative humidity greater than 80% is much larger in forecast B than in forecast A, especially over the English Channel and southern England. The same effect was also seen at 850 mb and 500 mb. This added moisture retention did enable the model to produce increased rainfall amounts after T+18, particularly over England and Wales. For example, at 0000 GMT on 1 June (not shown), forecast A produced a maximum six-hour 1800 to 0000 GMT total rainfall accumulation of 10 mm over south-west England, whereas forecast B produced two maxima of 14 mm over south-west England and Brittany, which were more realistic. The differences in accumulated rainfall totals between forecasts A and B were more apparent in the period 0000–0600 GMT on 1 June. These six-hour accumulations are shown in Figs 11 and 16 respectively. The amount of rainfall over South Wales and south-west England produced by forecast B is about 4 mm higher than that produced by forecast A, although the areal extent of the rainfall is still incorrect. During the six hours between 0600 and 1200 GMT on 1 June there was an average increase of 2 mm in the frontal rainfall over northern England and the Irish Sea, and a decrease of 1 mm in the erroneous accumulated rainfall over South Wales and the west Midland counties. The differences between other forecast fields such as mean-sea-level pressure, geopotential and wind were negligible throughout the forecast.

Figure 14. Forecast A 700 mb relative humidity, with areas greater than 80% shaded, for 1800 GMT on 31 May 1983.

Figure 15. Forecast B 700 mb relative humidity, with areas greater than 80% shaded, for 1800 GMT on 31 May 1983.

Figure 16. Total rainfall accumulations produced by forecast B for the period 0000 GMT to 0600 GMT on 1 June 1983. Isohyets are at 2 mm intervals.

4.3 *Discussion*

Although changing the evaporation rate gave some improvement in rainfall amounts, the accumulations were still too small compared with observations after 0000 GMT on 1 June. Moreover, the distribution of the rainfall was still incorrect. Examination of the wind fields at 700 mb from forecasts A and B revealed that the trough, which was approaching Trappes at 0000 GMT on 1 June, was not predicted. Section 2.2 presented evidence that suggested this trough was probably an important factor in the development of the thunderstorms and heavy rain, and that it may have been initially orographically forced by the Pyrenees. The topography over Spain and part of France that was used in both forecasts A and B is shown in Fig..17. The shaded area shows actual high ground greater than 1500 metres in the region of the Pyrenees. Clearly, the Pyrenees are not correctly represented by the fine-mesh topography. Moreover, the western slopes of the Alps are too gentle, and the Massif Central and the Rhône Valley are not modelled at all. Almost certainly this lack of detail in the topography specification for these areas would cause inaccuracies and deficiences in the forecast wind and rainfall over the Alps and Pyrenees. The effect downstream, particularly upon the trajectories of the air reaching the British Isles, is not clear, although the failure to predict the trough at 700 mb correctly could be attributed to this poor representation of the Pyrenees in the model. This possibly had a detrimental effect on the rainfall forecast over the British Isles. Consequently, it was felt that the rainfall forecast might be further improved, especially later in the forecast, by giving the model a more realistic topography over the Alps and Pyrenees.

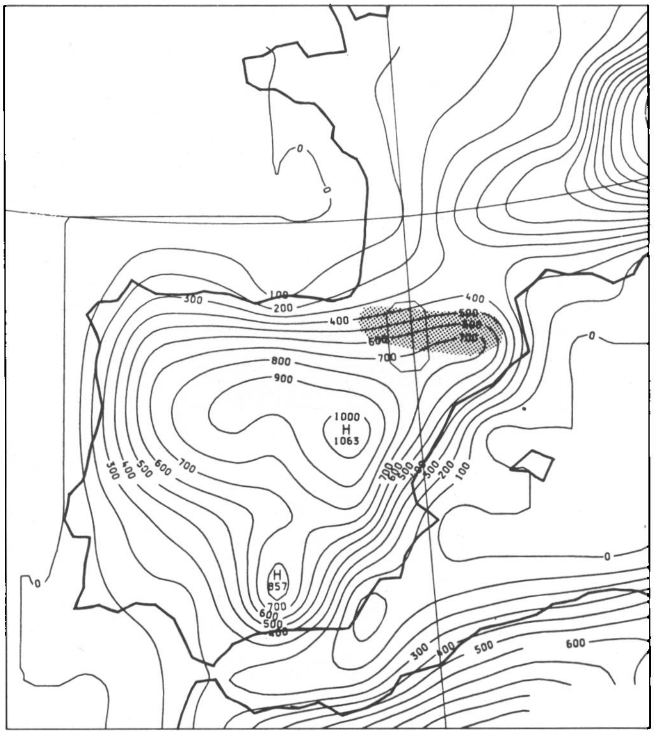

Figure 17. Topography over the Alps and Pyrenees used in forecasts A and B. Contours are at 100 m intervals. The stippled area shows actual high ground above 1500 m in the region of the Pyrenees.

4.4 *The fine-mesh forecast with an improved specification of topography over the Alps and Pyrenees*

This forecast will subsequently be referred to as forecast C. The topography over the Alps and Pyrenees that was used for this experiment is shown in Fig. 18. This new topography clearly gives an improved representation of the Alps and Pyrenees; also, the Massif and Rhône valley are now represented. Before the forecast could be re-run, the initial data had to be adjusted to correspond to the new topography. No attempt was made to balance the initial fields after adjustment; therefore, the model was given a shock at the start of the forecast. This shock generated gravity waves early in the forecast which dispersed within 6 hours. The amount of evaporation allowed in the convective parametrization scheme was set to the same value as that used in forecast A. The quantity of spurious convective rainfall over England and Wales that was produced by forecast A between 1200 and 1800 GMT on 31 May, which is not shown here, was less in forecast C. The reason for this effect was not clear but could possibly be attributed to gravity-wave propagation. Apart from increased rainfall over the Alps and Pyrenees, and the decrease of spurious convective rainfall, mainly over the British Isles, the rainfall forecast up to 0000 GMT on 1 June was similar to that in forecast A.

After midnight, however, large differences occurred between forecasts A and C. The total accumulated precipitation between 0000 and 0600 GMT on 1 June from forecast C is shown in Fig. 19. By comparing this chart with the equivalent chart from forecast A shown in Fig. 11 one can see that the forecast rainfall amounts over South Wales and the Midlands have increased by about 2 mm. More important, however, is that forecast C did extend an area of rainfall of 2–4 mm north-east from the

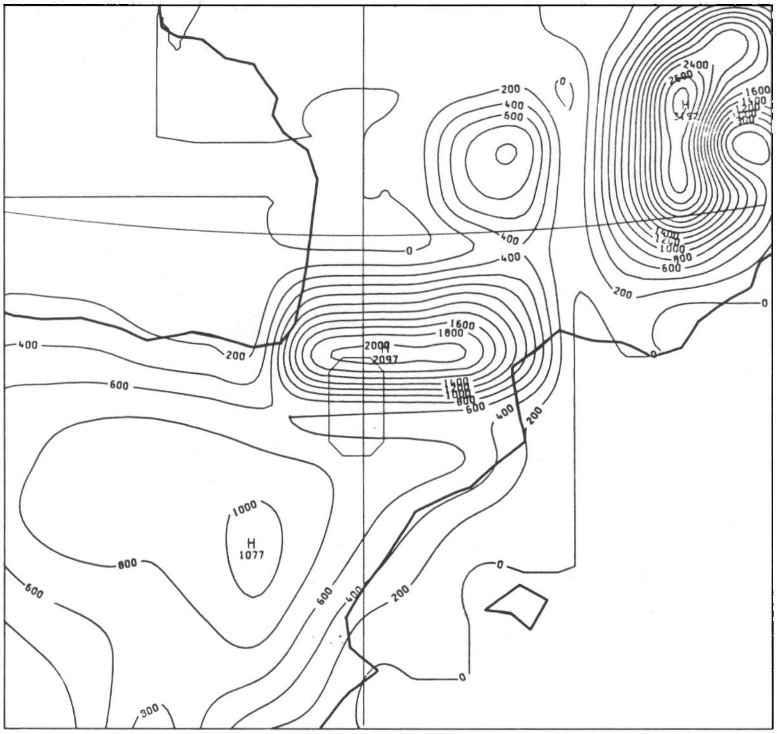

Figure 18. Topography over the Alps and Pyrenees used in forecast C. Contours are at 200 m intervals.

Midlands into Lincolnshire and East Anglia, which was a similar movement to that which actually occurred (see Fig. 4), although the rainfall totals were still much too low and the dry coastal part of Norfolk was now wet. Neither of forecasts A and B showed this movement, so in this respect forecast C was an improvement over the other two. There was a greater improvement in the rainfall forecast during the period 0600 to 1200 GMT on 1 June. The total accumulated precipitation from forecast C for this period is shown in Fig. 20; this is to be compared with the accumulated rainfall from forecast A shown in Fig. 12 and the observed rainfall shown in Fig. 13. The immediate noticeable difference is that forecast C did not produce the erroneous separate area of heavy rainfall over South Wales; also it did correctly predict a dry area over the extreme south and south-west of England. However, over northern England forecast C was worse than forecast A, since the area of heaviest rainfall in forecast C was further west, over the Irish Sea, than it was in forecast A and in reality. Also the maximum amount of rainfall in forecast C was 2 mm less than that in forecast A. However, the frontal nature of the rainfall during this period was best portrayed by forecast C, since the rainfall pattern appears to be banded rather than cellular as in the previous forecasts.

In all the forecasts a large proportion of predicted rainfall during this period was of dynamic origin within the model, and the forecast using the new topography increased dynamic rates by 1 mm per hour compared with the other two forecasts at 1200 GMT on 1 June. The highest rainfall rates obtained from forecast C were 2 mm per hour, which compares favourably with the continuous moderate rain that was reported over northern England at this time. These rainfall rates are not shown in this paper. Related to

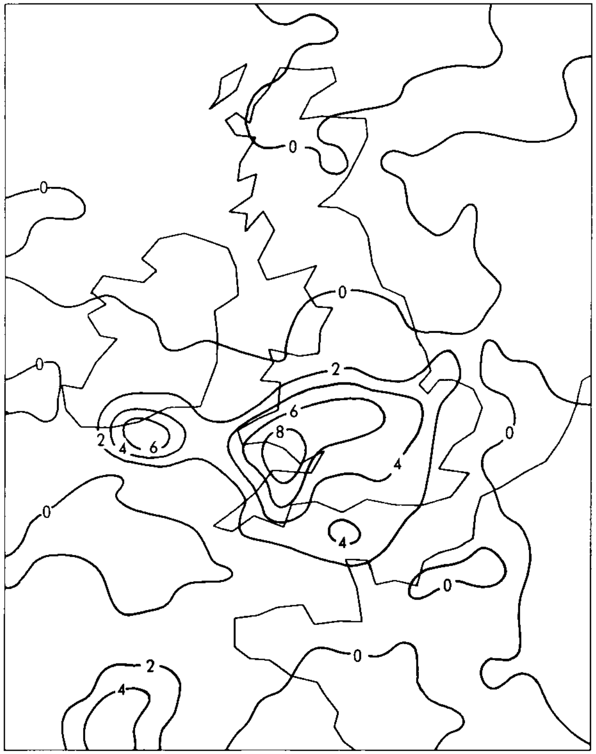

Figure 19. Total rainfall accumulations produced by forecast C for the period 0000 GMT to 0600 GMT on 1 June 1983. Isohyets are at 2 mm intervals.

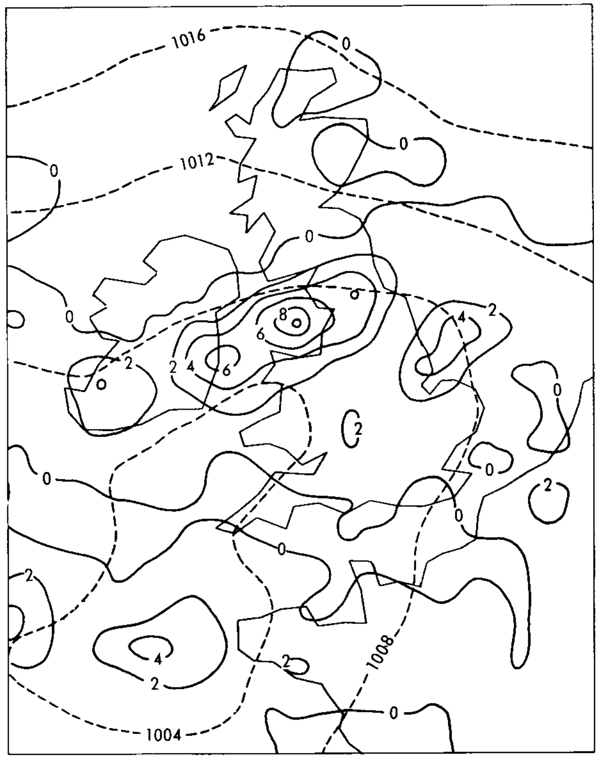

Figure 20. Total rainfall accumulations produced by forecast C for the period 0600 GMT to 1200 GMT on 1 June 1983. Isohyets are at 2 mm intervals. The forecast mean-sea-level pressure field for 1200 GMT on 1 June is shown by pecked lines with isobars at 4 mb intervals.

the improved rainfall prediction by forecast C, was an improvement in the predicted mean-sea-level pressure field at T+36. This field is shown in Fig. 20 superimposed over the forecast rainfall field. By comparing this field with the same field from forecast A which is shown in Fig. 12 and the analysed pressure field that is shown in Fig. 2(b), one can see that the pressure over the Midlands is higher in forecast C than it is in forecast A and was very close to the observed pressure shown in Fig. 2(b). Also the strong east-north-easterly pressure gradient, north of the occlusion over the Irish Sea is better predicted by forecast C than by forecast A. The trough in the 700 mb wind flow, which became evident at Trappes at 0000 GMT on 1 June, was not correctly modelled by forecast C. However, this forecast, unlike forecasts A and B, did produce to the lee of the Pyrenees a number of minor troughs which subsequently moved north-north-east into Belgium and Holland.

4.5 *Discussion*

The fact that forecast C did not correctly predict the trough near Trappes, given the improved topography over the Alps and Pyrenees, suggests either that the effect of the Alps and Pyrenees on the wind flow was still not correctly modelled, or that the trough may not have been entirely due to orographic forcing. However, the new topography did have some effect upon the wind flow. Since the trough near Trappes was not formed correctly, it is not surprising that forecast C was still incorrect; although it was an improvement over forecasts A and B, especially regarding the movement of rain after T + 18. It is not clear therefore what the reason for the improvement was.

4.6 *Investigation*

As a first step it was thought useful to compare the distribution of moisture between forecasts A and C. Figs 21 and 22 show two vertical cross-sections of relative humidity at 0600 GMT on 1 June along longitude 0.9375 °E, from 58.5 °N to 41.25 °N from forecasts A and C respectively. The line of the cross-sections is shown in Fig. 10 as line AB. The topography in each section is shown as a solid black line close to the x-axis. The difference in topography between the two sections south of 47 °N is very large. The very steep topography in forecast C causes some spurious local wave effects that can be seen in Fig. 22. Further north, the largest difference between the forecast cross-sections was found between latitudes 52.5 °N and 50.5 °N below 3000 metres (which was the height of the Pyrenees used in forecast C). In forecast A a large part of this area of the cross-section had values of relative humidity less than 80%, and in part less than 70%, whereas in forecast C, almost all this area had values greater than 80%. This effect coincides very well with the greater amount of rainfall produced by forecast C along longitude 0.9375°E between 52.5 °N and 50.5 °N in the period 0000–0600 GMT on 1 June. Although the chart is not shown here, at 51 °N, 0 °E at 0600 GMT on 1 June, forecast C had a convective rainfall rate of 0.7 mm h^{-1} which compares more favourably with the moderate rain observed at 0600 GMT than the zero dynamic and convective rates that were produced by forecast A. Above 3000 metres and north of 48 °N there are only small differences in relative humidity between forecasts A and C. The fact that there is an appreciable difference in relative humidity between forecasts A and C at heights that are greater than the topographic height over the Pyrenees used in forecast A but less than the topographic height used in forecast C, suggests that increasing the topographic height of the model over the Pyrenees had most impact on the humidity distribution below 3000 metres. This conclusion is verified by the relative humidity fields at 850 mb and 900 mb from forecasts A and C. These fields are not shown here but there were large differences in the fields between forecasts A and C, especially at 900 mb (approximately 1000 metres), throughout the forecast period. The fields derived from forecast C more closely followed the observed rainfall distributions than did those from forecast A. This seems to suggest that introducing enhanced topography over the Alps and Pyrenees enabled the model to distribute its

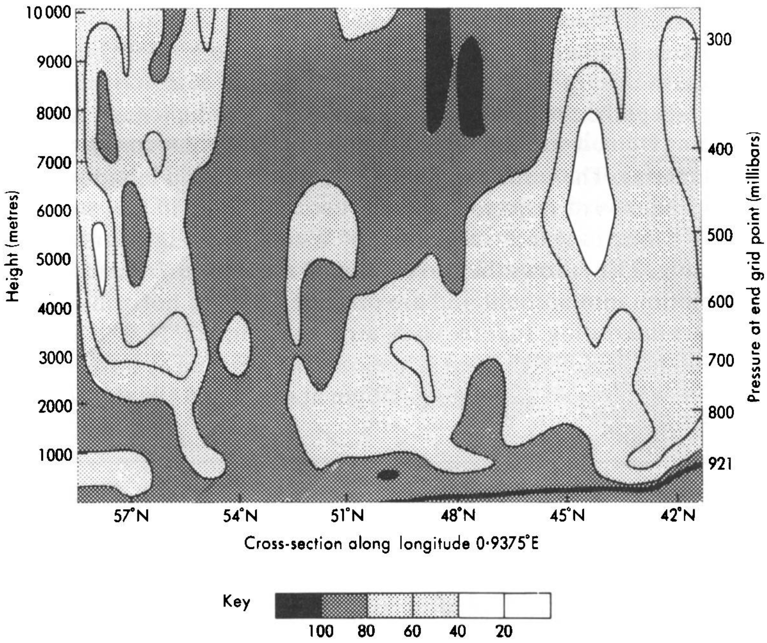

Figure 21. Cross-section of relative humidity along longitude 0.9375 °E from forecast A. Isopleths are at 20% intervals.

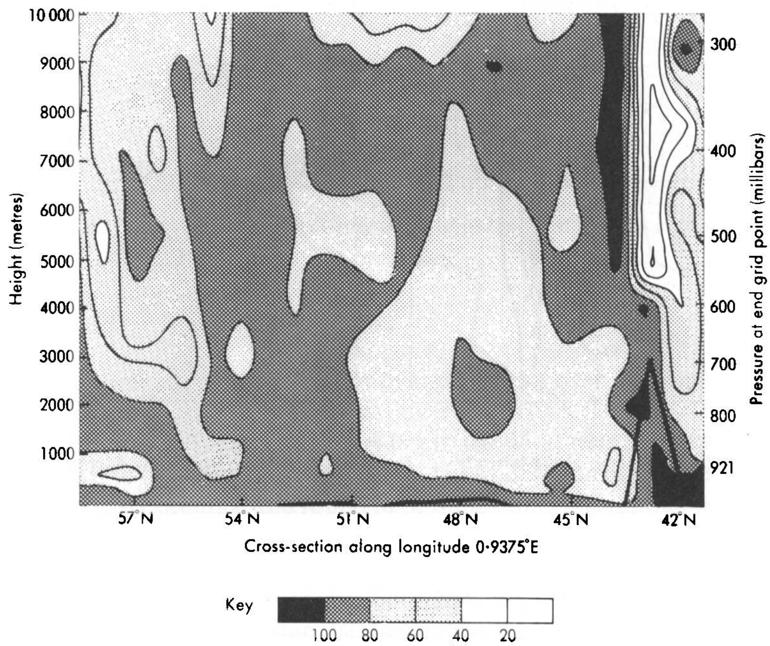

Figure 22. Cross-section of relative humidity along longitude 0.9375 °E from forecast C. Isopleths are at 20% intervals.

moisture in the lower levels in forecast C in a different manner to that in forecasts A and B, and that it was this low-level moisture redistribution that was partly responsible for the improvement in rainfall movement in the forecast.

In order to ascertain where the extra moisture, (and therefore the increased rainfall) between latitudes 52.5 °N and 50.5 °N came from, it was thought useful to calculate some trajectories backward in time of air parcels below 3000 metres. The results of these calculations at 850 mb are shown in Figs 23(a) and 23(b). Fig. 23(a) shows backward trajectories from forecast A at 850 mb, starting at 0600 GMT on 1 June, from points at 1 ° longitude intervals from 10 °W to 5 °E along latitude 52 °N, and finishing at 0000 GMT on 31 May. Fig. 23(b) shows the corresponding trajectories from forecast C. The trajectories only take horizontal motion into account and are projected on to a horizontal plane. The differences between the two maps are interesting. In forecast A, air at the point 52 °N, 0 °E at 0600 GMT would have been at 43 °N, 2 °E at 0000 GMT on 31 May if it had only been moved by horizontal advection, whereas in forecast C air at 52 °N, 0 °E would have had its origin at 45 °N, 0.5 °W at 0000 GMT on 31 May. The

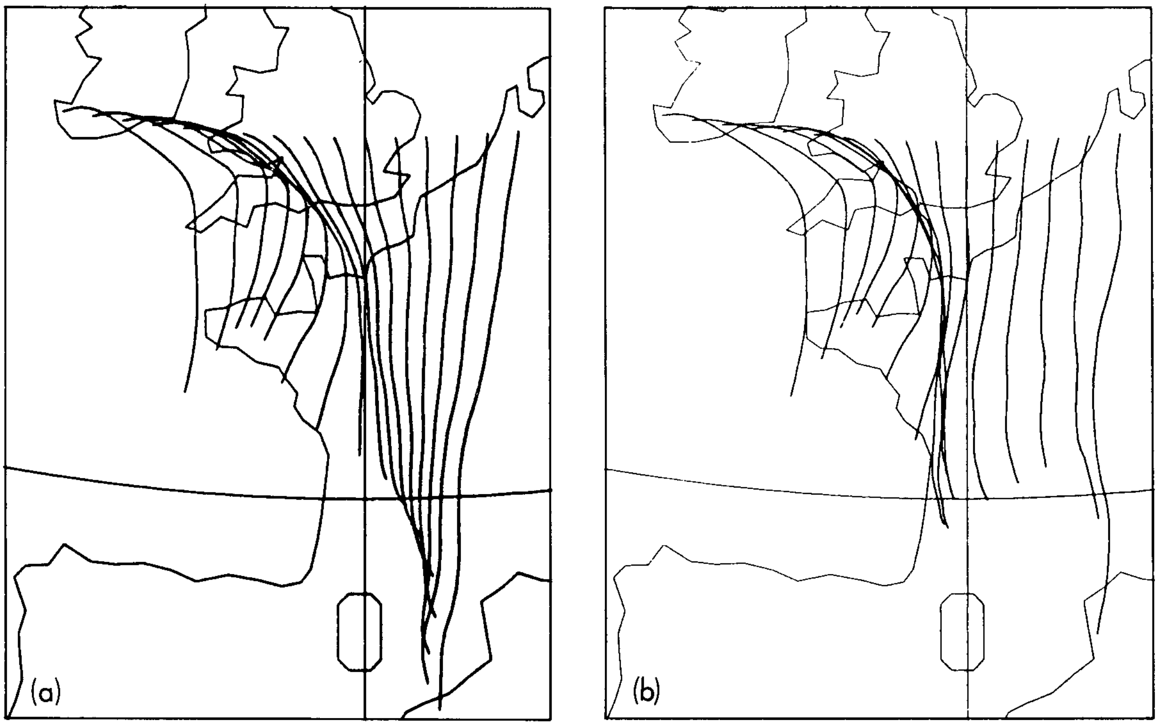

Figure 23. Thirty-hour backward trajectories at 850 mb for parcels of air initiated at 0600 GMT on 1 June 1983 from points at 1 ° longitude intervals from 10 °W to 5 °E along latitude 52 °N, (a) in forecast A, and (b) in forecast C.

two sources of the air at 52 °N, 0 °E from forecasts A and C are shown on the relative humidity initial field at 850 mb for 0000 GMT on 31 May as points A and C respectively in Fig. 24. Fig. 24 in fact shows the initial relative humidity field at 850 mb used for forecast A, but since the initial values of relative humidity at point C for forecasts A and C were identical, only one map is shown. It is clear from Fig. 24 that the origin of air that reached 52 °N, 0 °E is moister in forecast C than in forecast A. Or, alternatively, in forecast A, air that originated at point C was carried into Wales, whereas in forecast C this patch of moist air was advected towards East Anglia. The restriction of taking only horizontal motion into account when calculating the trajectories does mean that the results must be interpreted carefully since the effect of the vertical advection of humidity may be important. Nevertheless, the differences between the tracks of the air from forecasts A and C indicates the effect of the new topography on the wind fields. The introduction of the enhanced topography into forecast C had most impact on the fields at levels below 3000 metres. The main effect was to produce a number of minor troughs north of the Pyrenees and to decrease the wind speeds. Dry air to the south of the Pyrenees below 3000 metres was effectively blocked and this allowed initially moister air to the north of the Pyrenees to be advected into the eastern half of England thereby increasing the rainfall in that area.

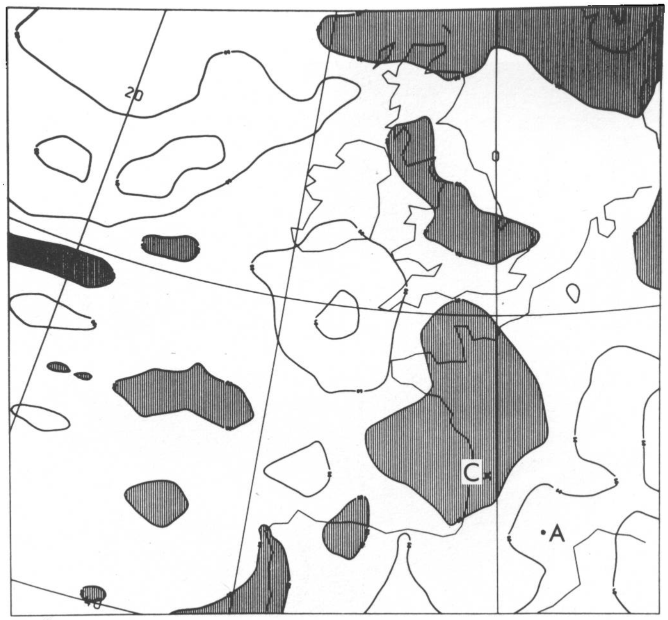

Figure 24. Initial relative humidity field at 850 mb used in forecast A. Isopleths are at 20% intervals with values greater than 80% shaded.

4.7 *Conclusions*

The introduction of an improved specification of topography over the Alps and Pyrenees into the model led to an improvement in the rainfall forecast over the British Isles. It seems that the effect of the Pyrenees upon the model was to introduce troughing in the wind fields at and below 700 mb, and to provide a barrier to the air to the south of the Pyrenees. The interaction of these effects with the moisture fields in the model have been examined and found to be important. The rainfall prediction from forecast C was the best but still incorrect, and part of the reason for this may be because the 700 mb trough near Trappes was not accurately predicted. The experiment has shown that this trough may not have been entirely orographically forced and it is likely that the initial data used for the forecast were not sufficiently accurate to develop it. Increasing the evaporation rate in the convective parametrization scheme produced some improvement in forecast rainfall amounts, but very little improvement in movement and development of the main rain areas. Probably one of the most interesting conclusions that can be made from this case study is that the effect of the Pyrenees on the wind flow may be an important factor in the development and movement of thunderstorms over England and Wales when there is a large-amplitude upper trough to the west of the British Isles. It seems that in these types of potentially thundery situations, numerical models could benefit from a realistic topography over the Alpine and Pyrenean regions.

Acknowledgements

The author would like to express his thanks to Mr M. D. Gange and Mr D. Robinson, both from the Meteorological Office at Bracknell, for their computer programming assistance in producing some of the charts shown in this paper.

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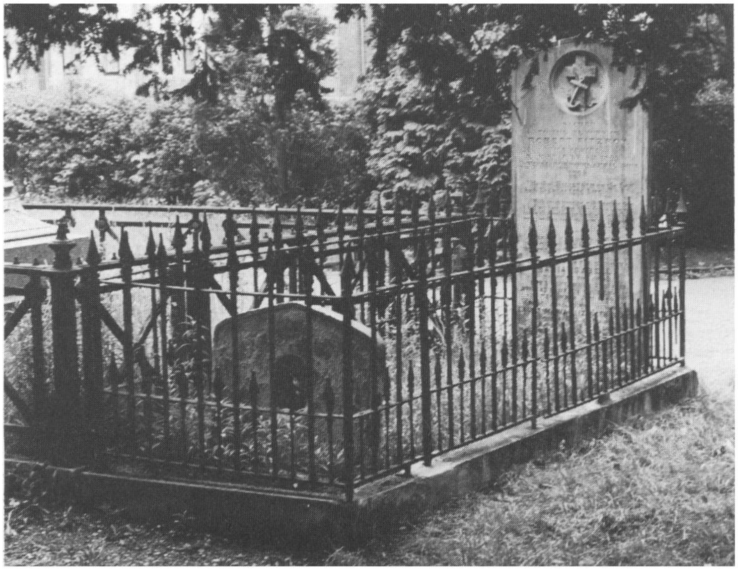
551.5:718:92

The grave of Admiral FitzRoy

By R. P. W. Lewis

(Meteorological Office, Bracknell)

About three years ago work was undertaken to renovate the grave of Admiral Robert FitzRoy, FRS — the first head of the Meteorological Office — including replacement of the footstone which had deteriorated very badly; see Figs 1 and 2.



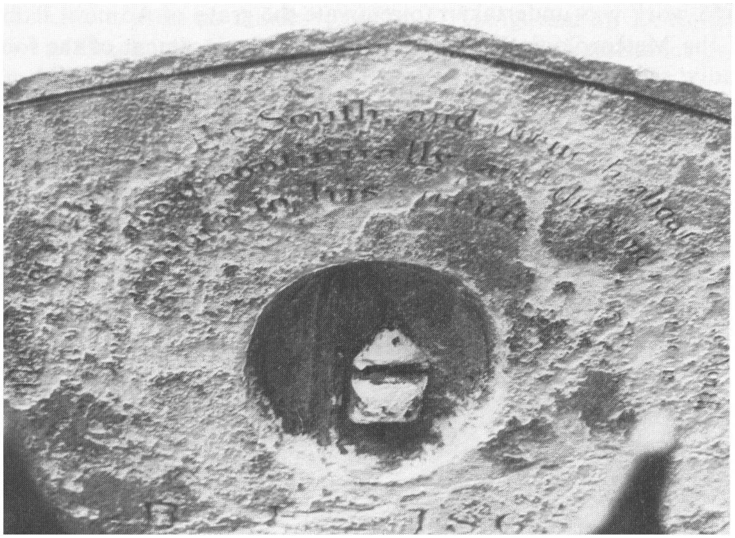
Photograph by courtesy of Mr D. Stanbury

Figure 1. Grave of Admiral FitzRoy before its renovation.

Miss R. Davis of Dulwich, a parishioner of All Saints, Upper Norwood, in the churchyard of which is the grave, reported to the Society for the Protection of Ancient Buildings in 1979 that the stones were in poor condition. On 19 February 1980 the Duke of Grafton, as the senior member of the FitzRoy family, wrote to the Director-General of the Meteorological Office asking whether the Office could have the footstone repaired.

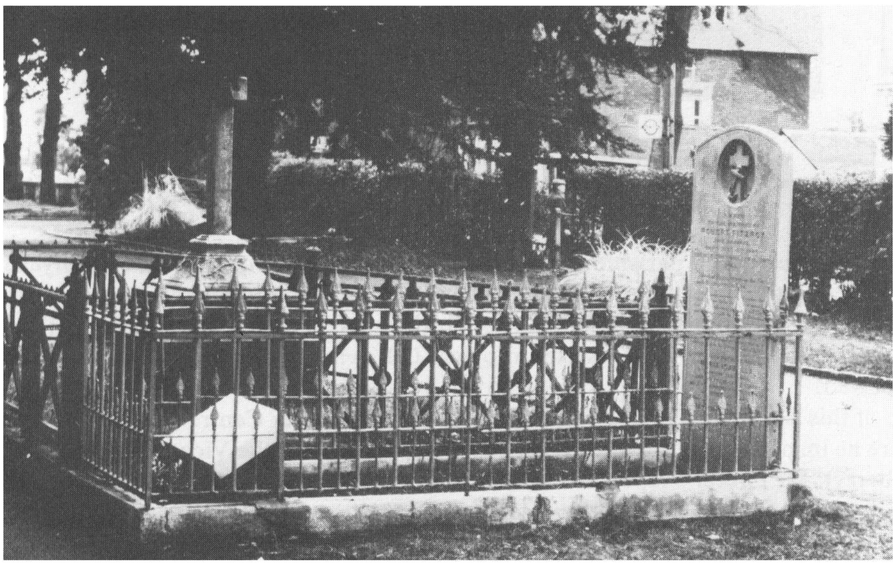
As a result of this letter, Mr G. H. Parker of the London Weather Centre visited Upper Norwood on 20 April where he inspected the grave and met both Miss Davis and the Vicar of All Saints (the Revd R. St. L. Broadberry). Mr Parker's report led to efforts by the Administrative Division of the Office to see who could execute the work and whether the necessary finance could be found from official funds. These efforts soon met with success, and it was decided that the Commonwealth War Graves Commission would design a new footstone (the old one being beyond repair) and have it made and fixed, the cost being met from Defence Votes.

The drawing up of a design and the obtaining of necessary permission from the ecclesiastical authorities both took a good deal of time — the matter had, in fact, to be referred to the Diocesan Registrar at Canterbury — and it was not until 22 October 1981 that the old footstone was removed and the new one fixed in its place. The design of the new stone differs in certain respects from the old, but all the essential components of the latter are retained, including the pictorial representation of a North Cone and Drum, part of FitzRoy's original system of storm-warnings (see Figs 3–5).



Photograph by courtesy of Mr D. Stanbury

Figure 2. The original footstone.



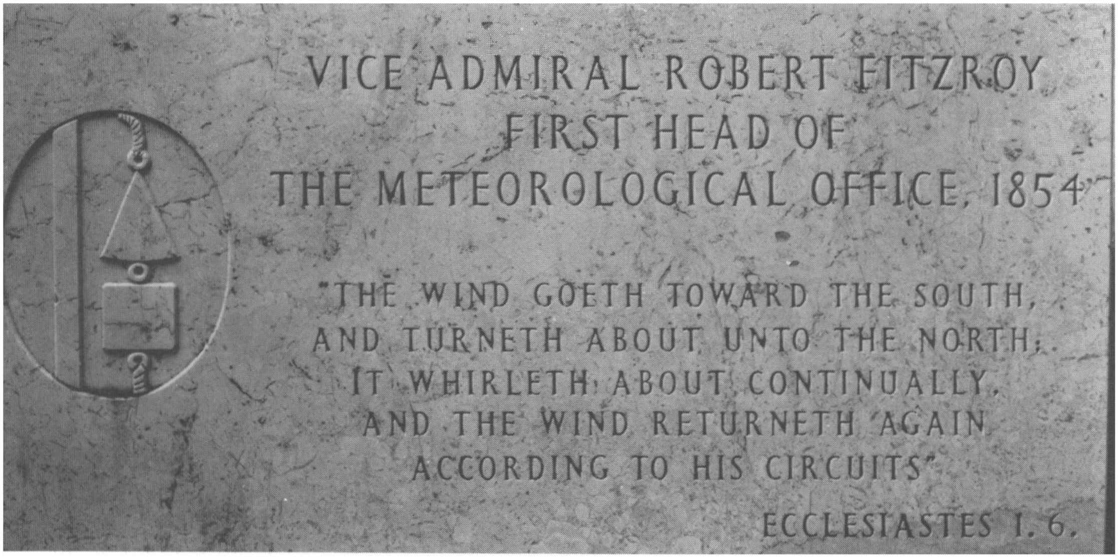
Photograph by courtesy of Mr R. P. W. Lewis

Figure 3. The grave after renovation.

Photograph by courtesy of Mr R.P.W. Lewis

Figure 4. The original headstone after renovation.

The grave of Admiral FitzRoy is now, we hope, in a state worthy of the remarkable and accomplished man who was our first Chief.



Photograph by courtesy of Mr R. P. W. Lewis

Figure 5. The new footstone.

Reviews

Lightning, auroras, nocturnal lights, and related luminous phenomena: A catalog of geophysical anomalies, **compiled by William R. Corliss. 260 mm × 180 mm, pp. v + 242, *illus*. The Sourcebook Project, Glen Arm, MD 21057, USA, 1982. Price US $11.95.**

Natural phenomena that defy explanation by established physical laws have long engaged the curiosity of both scientists and laymen, and have invited frequent speculation on the validity and mechanisms of the reported events. This book deals with anomalies associated with luminous behaviour, adding one volume to a series which attempts to identify and describe a wide range of unexplained observations in a systematic fashion. The anomalies are listed in the form of a catalogue with each entry containing a brief description, a possible explanation, and numerous references, including extracts from many of the eye-witness accounts. The author gives a subjective assessment of the quality of the data supporting the anomalies and the extent of the departure from known laws implied by their existence.

For those with a casual interest in unusual and unexplained phenomena, this book offers entertaining glimpses of the strange effects that have been reported, such as 'auroral pillars' and 'underwater lightning', and reveals a wide range of novel observations. The sets of references provide a useful, though not exhaustive, initial source for research and the copious indexing should satisfy most enquirers. However, many readers are likely to seek a deeper treatment of specific anomalies and will be disappointed with the brevity of background information, with the absence of material indicating the points of conflict with known laws and with the uncritical acceptance of unsupported evidence.

A distinction should be drawn between: those phenomena which appear to contradict established physical laws; those phenomena which are unexplained, owing to the complexity of the system (as, for example, in many aspects of weather); and those events which cannot be assigned to a specific cause, owing to the inadequacy of the data. My main complaint with this work is the inclusion of too many cases within the third category where anomalies are based on fragmentary evidence — sometimes a single report — 'hot-air blasts following lightning strokes' and 'black auroras', for instance, at the expense of better documented problems. A number of rare lightning anomalies is described, yet no mention is made of the basic difficulty in understanding the generation of lightning, which is still incompletely resolved after much research.

In brief, this book gives colourful, abbreviated accounts of a class of anomalies with luminous characteristics and offers an opportunity for an interesting browse through reports of unusual phenomena. However, the more sceptical student is poorly served by the shallow treatment of unexplained observations.

F. Rawlins

Acid deposition. Proceedings of the CEC workshop organized as part of the concerted action 'Physico-chemical behaviour of atmospheric pollutants' held in Berlin, 9 September 1982, edited by S. Beilke and A. J. Elshout. 160 mm × 235 mm, pp. X × 235, *illus.* D. Reidel Publishing Company, Dordrecht, Boston, Lancaster, 1983. Price US $32.50.

The reader attracted by the main title of this book should note that it is the result of only a one-day workshop, whose geographic remit was Europe. Nevertheless, and at the risk of mixing metaphors, one is impressed by the amount of ground covered by 'Acid deposition'.

I have a mental image of a workshop: castings ready for machining and assembly, tools ranged on the wall, cuttings on the floor, while craftsmen fashion articles of order and symmetry out of seeming chaos. How does this scientific workshop compare with such an image? First, the rough edges of a product fresh from the mould are obvious. There is no index, and apparently little editorial intervention; each paper appears in its own particular typeface, the standard of graphs is variable, and spelling errors numerous. However, such shortcomings represent the acceptable compromise between aesthetics and the prompt appearance of these proceedings on the bookshelves of scientists concerned with acid deposition.

The range of tools on the wall, in the form of scientific disciplines represented, is restricted, with only one paper concerned directly with biological aspects. Biologists and ecologists will find it a useful review of current European work on the chemistry and meteorology of acid deposition, though they may wish to take issue with the proceedings' focus on the uncertainty of trends and background levels which, somehow, manages to leave the reader with the impression that acid rain is not as serious a problem as he thought. Nevertheless, most scientists interested in the problem, even on the fringe, would be pleasantly surprised by the highly readable reviews in what could have been a very specialized and esoteric book.

The introductory review on the present situation in Europe is clear and comprehensive, and contains a list of the major questions yet to be answered. The rest of the book is a mixture of reviews and reports of individual research, and it is the former which contribute most to the book's value. Thorough resumés are presented of the acidity of background precipitation (Delmas and Gravenhorst) and on the formation of atmospheric acidity (Cox and Penkett). Delmas and Gravenhorst arrive at tentative conclusions for background precipitation pH for continental and maritime regions, and also background pH and so-called reference pH (no anthropogenic contribution) for polar regions. Showing commendable restraint in the amount of chemical notation, Cox and Penkett discuss progress in understanding oxidation occurring via homogeneous and liquid-phase reactions, and on the surface of aerosols. They draw attention to the fact that the decline of the black smoke emissions from the 1950s onwards has been accompanied by a steady increase in vehicle emissions, and call for more investigation into the role of vehicle pollutants in acid deposition. As well as reviewing and assessing existing ideas on atmospheric chemistry they introduce some new ideas on the promotion of sulphur dioxide oxidation by chlorine nitrate, or its inhibition by formaldehyde.

Trends in acidity of precipitation receive attention in three papers; all, in different ways, challenge the commonly-held view that in Europe the amount of acid precipitation has shown a steady increase with time and in geographical extent. There are two papers each on heavy metal deposition associated with acid precipitation, cloud chemistry, and surface fluxes; to express disappointment that only one paper deals with source-receptor modelling would be to expect too much from a one-day session. The editors furnish a concise 'Workshop Conclusions' to end the volume.

In my imaginary workshop I expect to see sparks fly, but this book suggests that little scientific heat was generated during discussions. To push the analogy, it seemed to be more of an assembly shop where the program ensured that various components fitted together without conflict. However, more extensive reporting of discussions would have been welcome. This lack is most evident in the section on trends: Kallend's guarded and slightly enigmatic conclusions about the changes in the geographical extent of acid rain serve to undermine existing views that accord well with 'common sense', without replacing them with an alternative theory.

Finally, what items of order and symmetry were fashioned out of the frustratingly complex mass of acid deposition data? Insofar as the perspective afforded by the reviews adds shape to the subject, then the publication of these proceedings succeeds in chipping a fresh contour from the acid rain monolith, but it is clear from the editors' conclusions that the floor of many more workshops will be littered with chippings before the final shape of acid deposition emerges.

B. A. Callander

North Sea dynamics. Proceedings of an International Symposium held in Hamburg, West Germany, 31 August - 4 September 1981, edited by J. Sündermann and W. Lenz. 170 mm × 247 mm, pp. xvii + 693 *illus.* Springer-Verlag, Berlin, Heidelberg, New York, 1983. Price DM 98.

This large volume contains no fewer than 45 papers arranged in 4 main sections: Currents and water balance; Wind waves and storm surges; Transport of momentum, energy and matter; and Ecosystems. The overlap in subject matter between the first three sections is such that in practice there are 32 papers dealing with many aspects of the modelling and measurement of dynamical processes in the sea. The subject matter is very uneven, there being just one paper on surface wave modelling, and only two directly on measurement techniques. The 12 papers in the final section reveal how the complex ecosystems in the North Sea are directly related to such dynamical processes as water exchange, mixing, etc. which affect temperature and salinity levels. The opening review article of the book successfully illustrates how the development of physical and biological oceanography, centred on the North Sea, has been led into a rewarding synthesis under the guidance of the International Council for the Exploration of the Sea.

The majority of the papers to be found in the earlier sections of the book are concerned in one form or another with mathematical modelling of either 2- or 3-dimensional systems. The equations concerned are very familiar to a meteorologist but are simplified by the incompressibility of water and the finite depth of the region of integration. Another common element in the material presented is the requirement for a good quality network of observations, preferably in real time! The problems of a synoptic meteorologist are dwarfed by the lack of data which confronts the dynamical oceanographer. The few papers that are concerned with measurement techniques are illustrative of the growing interest in remote sensing in dynamical oceanography; both radio-wave and acoustic systems are discussed.

Three papers that particularly interested the reviewer were those by I. D. James (A three dimensional model of shallow-sea fronts), G. Kullenberg (Mixing processes in the North Sea and aspects of their modelling) and J. C. J. Nihoul (Interactions between tidal residuals and 'synoptic' eddies in the North Sea). The latter two papers were more 'complete' in themselves than most of the others in the volume and gave more background and scientific justification for the solutions adopted. The paper by James was a fascinating restatement of the 'universality' of both fluid flow (air or water) phenomena and the techniques used to model them.

An interesting point to arise from many of the papers was the simplistic approach adopted when a meteorological input was required. It is to be hoped that the synthesis between dynamical and biological oceanography, highlighted in this volume, is succeeded by a similar blending with meteorology.

As is usual with this kind of book there are a greater number of misnumbered and mislabelled equations and diagrams than would be found in a conventional textbook, although this is not too much of a draw-back since the individual papers are self contained and hence the potential confusion is limited. The subject index at the end of the book is very comprehensive and adds significantly to its value as a 'state of the art' reference source. The fact of a significant delay between the ending of the symposium and the publication of the proceedings is to be regretted, but the contents of the book truly reflect the recent significant advances in dynamical oceanography.

P. E. Francis

Climate and energy systems: a review of their interactions, by Jill Jäger. 155 mm × 235 mm, pp. ix + 231, *illus.* John Wiley & Sons, Chichester, New York, Brisbane, Toronto, Singapore, 1983. Price £19.95.

This book opens with two questions: could the large-scale and widespread use of fossil fuel, and nuclear and solar energy sources cause changes in climate and, if so, might these changes constrain the future development of energy systems? As regards the first the author presents an overview by assembling the present scattered knowledge and relevant studies. Since no confident and definitive statements on the probable climatic changes can truthfully be made, we are, quite properly, spared from speculative predictions on the second question. The book is a result of the author's participation in the Energy Systems Program of the International Institute for Applied Systems Analysis (IIASA). (An unfortunate by-product is the proliferation of the jargon word 'system' throughout the text.) The author uses the projections of energy use over the next 50 years made by IIASA in 1981 as the basis for examining the impact of energy production on climate. Consideration is mainly given to two projections: in the first, the global annual energy use rises from the present 8 TW years (1 TW = 10^{12}W) to 22 TW years in 2030 and in the second it rises to 36 TW years; in both, fossil fuel is assumed to supply over 60% of the total. The world population in assumed to double to 8000 million by year 2030 with energy consumption per head per year rising from 2 kW years to 3 or 5 kW years.

After an introductory chapter summarizing the main findings of the Energy Systems Program relevant to the aim of the book there is a concise and readable account of the physical basis of climate intended for non-climatologists. Methods of assessing the influence of human activities are described including past analogues and the use of numerical models; the shortcomings of atmospheric general circulation models such as absence of an interactive ocean model, poor treatment of clouds and hydrological processes and sub-grid-scale processes are noted here and are usually recalled later when describing the results of particular studies that have used such models. The chapter concludes with a brief review of observational and model investigations of the effect of sea surface temperature anomalies on climate to illustrate the nature of the interactions between major components of the climate system; I found this rather out of place here.

The next four chapters form the core of the book and examine respectively the CO_2 question, the effect of waste heat, other pollutants besides carbon dioxide, and the potential climatic consequences of large-scale use of renewable energy sources. Given the large consumption of fossil fuels assumed in the projections (above) of energy use, the increase in atmospheric CO_2 is taken to be the most serious climate issue and is the one treated most fully. The observed increase of atmospheric concentration, the carbon cycle and the box models of it are covered briefly whilst more attention is given to speculations on future atmospheric concentrations of CO_2. Given the evident difficulties of economic forecasting, it is not surprising that divergent projections result from different workers. Indeed the assumptions of the IIASA study are all questionable and neglect unforseeable events such as wars, sudden oil price increases or technological advances in transport. The treatment of the effect on climate of increased CO_2 is largely confined to equilibrium surface temperature increases given by radiative convective models and atmospheric general circulation models in studies up to 1981, though the role of oceans, the transient response and the feasibility of detecting a CO_2 signal above the natural 'noise' are all briefly mentioned. The uncertainties about response of the biosphere and possible control strategies are also examined.

I found the chapter on waste heat and the effects of solar energy systems interesting and informative. The local increase in summer cloudiness in a mesoscale model of southern Spain, which included a large array of solar reflectors, causes doubt whether the exploitation of benign energy sources is relatively straightforward. The interesting question of possible climatic perturbations caused by other gaseous pollutants and particles is only briefly treated and I found my appetite whetted and requiring further information.

The penultimate chapter reverses the standpoint and considers the effect of climate on energy supply and demand (a familiar exercise to temperature forecasters for gas and electricity industries!). This is mostly serious and sensible stuff but one hopes that the proposed intentional climate modification schemes such as damming the Gulf Stream remain forever science fiction.

The concluding chapter summarizes the topics covered and the conclusions reached on present knowledge. In general the review is well balanced and fairly presents many viewpoints and results. The diagrams are well reproduced and clearly labelled and abundant references are provided at the end of each chapter. Inevitably the treatment of complicated and controversial questions has been shortened to keep the book a manageable size. The book might have benefited, however, if the author had more often stated her own judgement on conflicting results.

C. A. Wilson

Books received

The urban climate, by Helmut E. Lansberg (New York and London, Academic Press Inc., 1981. £29.50) is volume 28 in the *International geophysics series* and it is hoped that it will be found useful by city planners and developers, and human ecologists as well as boundary layer meteorologists. The book attempts to summarize knowledge of the physical relations that create the climate differences of urbanized areas gained from studies made over the last quarter of a century since the last monographic review about urban climates was published.

Dynamic meteorology: data assimilation methods, edited by L. Bengtsson, M. Ghil and E. Kallen (New York, Heidelberg and Berlin, Springer-Verlag, 1981. DM 44) is volume 36 in the series *Applied mathematical sciences.* The book contains selected lectures from the 1980 seminar devoted to data assimilation methods held at the European Centre for Medium Range Weather Forecasts. It attempts to give a review of the fundamental progress made in defining atmospheric states and of issuing forecasts from the states so defined using new observing systems, in particular polar-orbiting and geostationary satellites.

Food – climate interactions, edited by Wilfred Bach, Jurgen Pankrath and Stephen H. Schneider (Dordrecht, Boston and London, D. Reidel Publishing Co., 1981. Dfl 135 cloth, Dfl 65 paper) is an account of the *Proceedings of an International Workshop* held in Berlin in December 1980 which was the third in a series of international conferences carried out under the project 'Impacts of air pollution on climate'. The problems of supplying the increasing world population with food while the production of agricultural products is decreasing are difficult enough even without the climatic changes caused by man's activities. This book contains Working Groups' reports and recommendations, 'Climate as a hazard' and 'Climate as a resource'.

The earth's problem climates, by Glenn T. Trewartha (Madison and London, The University of Wisconsin Press, 1981) is the second edition of this book first published in 1961. This new edition is extensively revised and updated from the former edition which received a favourable review in this magazine. The revisions affect particularly the sections on Pacific Colombia, the Chilean-Peruvian desert, the drought region of north-east Brazil, the dry region of the southern Caribbean, the dry-subhumid belt of the eastern and central parts of the equatorial Pacific, equatorial East Africa, the Indian subcontinent, East Asia and western Anglo-America.

The weather of Britain, by Robin Stirling (London, Faber and Faber Ltd, 1982. £12.50) sets out to analyse and describe systematically the patterns and the aberrations, to be discerned through the haze of statistics over the past 100 years. The book contains information about every conceivable aspect of the weather over Britain with fully documented sources of information. It is suggested that we may easily be lulled into thinking that because our climate is temperate, the weather will be mostly benign, if variable.

Correction

Meteorological Magazine, April 1984, p. 91, tenth line from bottom of page. For 50 m read 500 m.

THE METEOROLOGICAL MAGAZINE

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CONTENTS

NOTICES

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