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THE METEOROLOGICAL OFFICE MESOSCALE MODEL: AN OVERVIEW

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by

B.W. Golding

Met O 11 (Forecasting Research Branch)
Meteorological Office,
London Road,
Bracknell,
Berkshire,
England.

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THE METEOROLOGICAL OFFICE MESOSCALE MODEL: ITS CURRENT STATUS

By B W Golding

(Meteorological Office, Bracknell)

Summary

A numerical forecast model with very fine resolution, is being developed as a short period forecast tool to give detailed guidance on local weather up to a day ahead. The processes represented in the model have been specially developed to take account of the scales represented. Surface synoptic reports are incorporated into the initial data to give mesoscale detail on boundary layer and cloud variables. Trials of the system have shown considerable skill in surface temperature and wind forecasts. The precipitation forecasts are superior to previous numerical models and show a realistic orographic enhancement. Cloud and fog forecasts are still of rather poor quality although recent improvements in the cloud results are very encouraging.

1. Introduction

Numerical models in current operational use give valuable guidance to forecasters on the broad scale atmospheric structure. A gridlength of about 150 km is used for global predictions and half that for the regional model covering the North Atlantic and Europe. However, even this latter model cannot represent the topographic differences between parts of the United Kingdom which are important for short period forecasting. A mesoscale numerical forecast model with very fine resolution is being developed to tackle this problem with the aim of providing guidance to forecasters on the local variations of weather in the period up to a day ahead. This model will be closely tied to the regional model through its boundary conditions so it must be seen as a sophisticated tool for adding detail to the predictions of the coarser models. In particular it will not be able to correct timing errors in systems that are passed through the boundaries. On the other hand, in slow moving situations the topographically induced effects should be well forecast and should be of considerable help to the outstation forecaster. It is widely recognised that model predictions of mesoscale systems that are not forced by topography will be difficult. However the errors will often be in timing or location in the same way that regional scale models predict realistic cyclogenesis but often at the wrong time or place. It may also be that much of the mesoscale variation in weather from larger scale systems is actually induced by topographic variations, perhaps through the surface temperature or moisture. in these cases the added detail will be of considerable value provided that the regional model has correctly predicted the large scale evolution. In these situations an important task to be performed after the forecast will be to apply gross timing or development corrections which have become apparent through consideration of other observations and forecasts. This will involve the sort of techniques discussed in Browning and Golding (1984). In the present paper, the remaining sections will describe the model formulation, the methods currently used for preparing the initial data, and some recent results.

2. The forecast model

The model presently has a 15 km gridlength and covers the British isles except for the Northern Isles (see Fig. 1). With this resolution, a reasonably faithful representation of the orography can be given, and the coastline, indicated by the zero contour in Fig. 1, has a realistic shape. The mountain ranges are still somewhat lower than reality, eg the Cairngorms reach 750 m rather than the observed 1200 m. Also, the valleys which dissect them are not represented and so their local effects on the weather of cities like Sheffield, for instance, cannot be accounted for. These will have to be added to the model guidance by the forecaster.

The basic dynamical equations used by the model have been described in Tapp and White (1976) and Carpenter (1979). In most respects they are the same as those used in the lower resolution operational models. An important difference, however, is in the vertical co-ordinate which is height above the land surface rather than a pressure based co-ordinate. The vertical structure of the model is shown in Fig. 2 for the current version with 16 levels. The lowest level is at 10 m and the spacing increases linearly from 100 m to 1500 m at the top. The highest level at 12010 m is in the stratosphere. This arrangement gives 5 levels in the lowest kilometre, and when expressed in terms of the standard atmosphere, an almost constant spacing of 60 mb from there up to the tropopause.

As in larger scale models, many of the important weather producing processes occur at scales too small for the model to resolve. These processes must be parametrized in terms of scales that are represented. In the following sections, descriptions of these parametrizations are given under the headings of boundary layer, layer cloud, and convective cloud processes.

a. Boundary Layer Processes

The processes involved are illustrated schematically in Fig. 3. They may be divided into three groups: radiation, turbulent diffusion in the atmosphere and conduction in the ground. All three are controlled by the characteristics of the ground, eg its wetness, reflectivity, conductivity and porosity, and the vegetation present. At present the soil conductivity is specified as fixed over all land areas. However, the albedo, the roughness length (z_o) and the surface resistance to evaporation, can be varied. Over the sea, the latter is zero and roughness is related to wind speed through Charnock's formula (Charnock 1955).

$$z_o = \frac{k u_*^2}{g}$$

with k = 0.0185 after Wu (1982)

and u_* calculated from $\underline{u}_{10}$ using the previous timestep's drag coefficient. Over land, roughness length is prescribed using the drag coefficient map of Smith and Carson (1977) with an upper limit of 1 m in highland regions. Over Ireland and France a fixed value of 0.1 m is used. The distribution of resistance to evaporation is derived from the weekly estimates of soil moisture deficit in MORECS (Thompson et al 1981) assuming a grass surface. Over Ireland and France the value is fixed at 100 s m^{-1}. At night the resistance is trebled to model the effects of darkness on the transpiration of plants, but it is set to zero if dew is forming. A surface water balance accumulates rain and dew and removes evaporated water. If the surface is wet, the resistance to evaporation is calculated for saturated ground regardless of the prior specification. Run-off limits the water depth to 1 mm unless the surface is frozen in which case accumulations over 1 mm represent snow cover and the albedo is then increased from its normal value of 0.2 to 0.6.

Most of the heat gain at the surface comes from solar radiation. This is strongly affected by the presence of clouds in the atmosphere and is modelled by applying a transmission function (T) which depends on the integrated density of forecast cloud through a column of the atmosphere. The function has been fitted to data obtained from the radiation scheme of Slingo and Schrecker (1982) and has the form

$$T = \exp \{-7.9 \, W^{0.5}/(1.84 + \cos^2 \alpha)\}$$

where W is the total liquid water path in kg m^{-2} and α is the solar zenith angle. Clouds also emit long wave radiation and it is the balance between this and the radiation emitted by the ground which determines the surface temperature in overcast conditions. The cloud emission (L) is again dependent on the total liquid wter path W and is based on a scheme of Lind and Katsaros (1982) giving

$$L = \sigma \, (1 - \exp \, (-70 \, W))T_c^{\,4}$$

where σ is the Stefan-Boltzmann constant and T_c is the cloud base temperature.

Heat conduction in the ground is crudely modelled by predicting the temperature of a single level below the ground. This varies slowly depending on its difference from the surface temperature.

The final component of heat balance at the surface is the turbulent diffusion through the lowest layers of the atmosphere. In the model, transport between the surface and first level at 10 m is modelled using Monin-Obukhov similarity theory to calculate the mixing coefficient. A full description of the formulation is given in Carpenter (1979). The surface resistance to evaporation, defined above, is important here in determining the relative transports of sensible heat and of moisture. Above the 10 m level, the mixing coefficients are determined from a forecast parameter, the turbulent kinetic energy (TKE), and a diagnosed one, the mixing length. The latter increases above the ground until it reaches an empirically defined fraction of the boundary layer depth. The TKE is generated by shear and buoyancy and can also be transported. In particular, it can be diffused upwards from where it is generated near the ground to the boundary layer top, where the resultant entrainment of air from above is an important factor in the boundary layer evolution. The formulation uses variables which are conservative in condensation processes so that turbulence is not suppressed by latent heat release. This couples the cloud layer to the mixed layer beneath and is important in the prediction of stratus and stratocumulus cloud.

b. Layer cloud processes

The processes involved in the layer cloud parametrization are depicted in Fig. 4 for a region of orographically induced cloud. When the humidity reaches a critical value, depending on the grid volume and the turbulent intensity, cloud is diagnosed. The amount increases as the mean humidity approaches saturation. The diagnosed cloud is stored in the model and may be advected and evaporated. The resulting precipitation is calculated taking account of whether ice cloud or water cloud is present as shown in Fig. 5. All cloud below -15°C is considered to be snow, together with any cloud below 0°C which is being seeded with snow. Snow falls at 1 ms^{-1} until it reaches the melting level where it is turned to rain (cooling the air at this level) and falls immediately to the ground (unless the melting level is below 1000 feet in which case it falls immediately to the ground as snow). Water clouds produce precipitation, P, locally according to the formula.

$$\frac{dp}{dz} = C_L \left(1 - \exp\left(-\left({}^{m}/_{C_m}\right)^2\right)\right)m$$

where m is the cloud water mixing ratio and C_L, C_m are empirical constants. The exponential term ensures that for low cloud water densities no rainfall is produced and above a critical value dependent on C_m the precipitation is linearly dependent on m. In addition, if rain is falling through a cloud layer it accretes water according to the formula.

$$\frac{dP}{dz} = C_A\, Pm$$

where P is the precipitation rate and C_A is an empirical constant. Thus the efficiency of rainfall production from cloud may be effected by rain accretion as shown in Fig. 4 or by snow seeding as shown in Fig. 5.

Below cloud base, precipitation is evaporated as it falls to the ground. In the case of snow the evaporation is total if cloud base is above 1000 feet.

c. Convective cloud processes

In large scale models, cumulonimbus clouds are modelled by parametrizing the mean effect of a large number scattered throughout a general area of instability. This approach is inappropriate for a model with a grid length of the same order as the largest clouds and much smaller than a typical spacing between clouds in an area of instability. It is therefore necessary to model the processes in an individual cloud rather more carefully. The scheme used in the model attempts to do this but is still capable of considerable improvement. It is based on that described by Fritsch and Chappell (1980). Figure 6 shows a schematic of the 'typical' cumulonimbus cloud used in the parametrization. An important departure from schemes used in large scale models is that the cloud has a specified lifetime, much larger than the model timestep. The cloud can move during its life but the details of the cloud's life cycle are not modelled. Its growth, maturity and dissipation are all averaged out over its lifetime. A major problem for all cumulonimbus parametrizations is to determine the amount of cloud, or more specifically, the mass flux of air through the cloud(s). In the present case this is determined by the maximum deviation of the pseudoadiabat of a parcel lifted from cloud base from the environment temperature sounding. For a given depth of cloud, a standard mass flux is defined taking account of the observation that the aspect ratio of depth to area is of limited variability. If the temperature criterion would give a very tall, thin cloud, the aspect ratio criterion overrides this. Another difficulty in formulating a parametrization is to determine under what conditions a cloud will form. This is sensitive to the formulation of the boundary layer scheme and in the present model is determined by testing the stability to lifting of layers that already have at least 1 okta of cloud, normally produced by upward turbulent transport of moisture.

Other details of the scheme are illustrated in Fig. 6. The updraught is modelled as an entraining plume with inflow below cloud base and outflow where the buoyancy is reduced to zero. The downdraught is forced by precipitation drag and cools by evaporation below cloud base before spreading out in the lowest three layers ie 460 m, of the model. The net mass fluxes from the updraught and downdraught are fed into the model and result in grid scale subsidence. Finally, air from the updraught and downdraught is mixed into the environment to simulate the dissipation process. Rainfall is determined as a proportion of the total moisture condensed in the updraught, the proportion having an empirical dependence on mean shear and humidity. The remaining condensate is mixed into the environment with 60% from the 'anvil' and 40% from the lower layers of the cloud. An empirical formula is also used to relate the rain area to the mass flux and mean shear of the cloud so that local rainfall intensity can be diagnosed.

3. Initialisation

The representation of the initial state of the atmosphere is of critical importance to the quality of forecast that can be expected from the model. As with large scale models, the constraints of near-geostrophy must be satisfied if a stable forecast evolution is to be obtained. However, a short range forecast model must also be correctly initialised with cloud if the temperature and precipitation are to be realistically forecast. Indeed, the atmosphere 'remembers' much of its initial state over a 12 hour period on many occasions and this contributes to the accuracy of subjective forecasts based on modified extrapolation procedures.

Three sources of data are curently used to initialise each forecast. They are an interpolation of the latest fine mesh forecast (a 6 hour forecast), a 3 hour mesoscale forecast and the surface synoptic observations. It is hoped to include radar rainfall rates and satellite cloud top heights soon. The initialisation for the short 3 hour mesoscale forecast is made in the same way but with a 3 hour fine mesh forecast and a 9 hour mesoscale forecast, thus permitting a continuous passing forward of mesoscale forecast data where observations are not available. The interpolation from the fine mesh model is a complex process since the models are based on different map projections, have a different vertical co-ordinate and different orography as well as the mesoscale model having finer resolution. The interpolated fine mesh data are used to replace the large scale component of the mesoscale forecast above the boundary layer. The moisture distribution, all variables in the boundary layer, and short wavelength detail at all levels is retained from the mesoscale forecast. The resulting 'hybrid' forecast data are then corrected by the use of surface synoptic observations. At present the techniques used are purely objective but interactive facilities are being developed and it is intended that the human analyst will be able to influence the process at all stages (Browning and Golding 1984). The modifications are made in two stages. First, surface variables and then cloud variables are analysed and incorporated.

The use of surface variables is illustrated in Fig. 7. Temperature, humidity and wind observations are first used to correct the interpolated 10 m values of these variables. When a well mixed boundary layer is present in the atmsophere, it can be assumed that information about the surface quickly reaches the boundary layer top. The corrections at 10 m are therefore applied with decreasing weight at higher levels up to a diagnosed boundary layer top. A minimum of three levels is affected.

Surface observations are also used to analyse the cloud amount at each model level and the precipitation rate using the mesoscale forecast as a first guess. The model's precipitation scheme is then used to define the cloud water mixing ratio which, with the analysed cloud depth, will give the analysed rainfall rate. At the 10 m level, fog observations are used to provide cloud water values.

Some comparison runs have indicated that the forecast is quite sensitive to the enhancement of initial conditions described above and, in particular, to the cloud data and surface temperature.

4. The Operational Trial

After a weekly trial of the forecast system in the first part of 1984, a Working Group was set up to manage the operational trials. The first phase ran from October 1984-January 1985 in which a single 12 hour forecast was run each day from 0600 GMT. The forecasts were assessed at about 30 selected stations using both objective and subjective techniques. The results were sufficiently encouraging for a second extended trial to be started in April 1985. Meanwhile, enhancement of the Cyber main store enabled the efficiency of the forecast to be improved by more than a factor of two. Further improvements mean that the forecast now takes about 1 min per hour of forecast time and that a forecast can be disseminated within an hour of the data time. The early part of this trial was interrupted by a serious hardware fault in the Cyber 205 computer but was resumed in June with an improved version of the turbulence scheme using the conservative variables. Major improvements since then have been the revised ice phase precipitation scheme at the end of September and a change to the boundary conditions at the end of November which has reduced the failure rate from over 10% to virtually zero. The system for carrying information forward from one forecast to the next was also implemented in November.

The objective assessment of this trial has been carried out at all observing stations for most observed variables and permits great flexibility in the comparisons that can be made. It has been supplemented by various subjective assessment techniques including comparison with the

Local Area Forecast for Bracknell each day. Since December 1985, comparison of temperatures with those forecast by Weather Centres for the gas boards has started.

In general, the development predicted by the mesoscale model differs little from the fine mesh model, as intended. It does not generally improve on timing and development errors and does not consistently forecast mesoscale dynamical developments such as rainbands with accuracy. At its present stage of development it should therefore be seen as a detailed diagnostic tool which enables the effects of topographic variation to be taken into account and, by using more sophisticated physical parametrizations, enables the variables required by forecast users to be predicted directly. Its ability to forecast these variables is now considered.

(i) Surface Temperature

The lowest mesoscale model level is at 10 m which enables it to be more responsive to the surface than the fine mesh (first level at about 25 m) but still leaves a problem of how to diagnose a temperature for comparison with surface observations. At present, the average of the surface soil temperature and the 10 m temperature is used. The results are generally good except when there is a serious error in the cloud forecast, this having most effect at night. Table 1 shows percentages of max/min forecasts within given tolerances for each month through autumn 1985. All observing stations are verified including those which fall in the model sea. Most of the maximum temperature errors greater than 4° can be attributed to such topographical differences. The frequency of occurrence of such large errors at 15 GMT and 06 GMT is shown for each station for January in Figs. 8, 9. As can be seen, many of these errors occur at coastal and highland stations. A more detailed assessment of surface temperature forecasts for a few individual stations has been carried out in comparison with those prepared subjectively for issue to gas boards. Table 2 shows the results for January expressed as percentages within given tolerances. The afternoon forecasts were issued by the forecaster at the same time as the model results were available and show tht the model produces forecasts of very similar quality for both 15 GMT and 17 GMT. The overnight forecast for 09 GMT shows that the model is superior when the 2° tolerance is considered but it is slightly worse in its extreme errors. However the forecaster did not issue his forecasts until 5 hours after the model results were available in this case.

Table 1 Percentages of maximum and minimum temperature errors within specified limits for each month from August 1985-January 1986

Month	Max ≤1°	Max ≤2°	Max ≤4°	Min ≤1°	Min ≤2°	Min ≤4°
August	45	77	98	47	79	98
September	45	75	97	44	73	94
October	53	82	98	40	68	93
November	53	85	98	38	63	88
December	58	85	97	43	70	93
January	58	88	99	45	74	95

Table 2 Percentages of errors for model (MES) and forecaster (FCR) within specified limits at 6 locations in January 1986. Forecasts for 15 GMT and 17 GMT are issued at 07 GMT for both model and forecaster. Forecasts for 09 GMT are issued at 19 GMT from the model and 00 GMT for the forecaster.

		SOUTHAMPTON		LWC		WATNALL		MANCHESTER		NEWCASTLE		GLASGOW	
	Tolerance	FCR	MES	FCR	MES	FCR	MES	FCR	MES	FCR	MES	FCR	MES
	1°	68	83	83	76	91	73	67	80	77	70	80	70
	2°	96	100	90	97	100	97	97	93	93	90	100	93
15 GMT	3°	100		97	100		100	100	100	93	97		100
	4°			100						100	100		
	1°	74	70	77	68	83	83	74	84	77	77	68	65
	2°	96	89	97	94	92	92	97	94	87	94	81	90
17 GMT	3°	96	96	100	100	96	100	100	100	97	100	97	100
	4°	100	100			100				100		97	
	5°									100		100	
	1°	67	67			71	52	57	69	64	71	61	79
	2°	96	92			95	81	82	85	79	86	82	89
09 GMT	3°	100	100			95	95	100	96	89	89	96	93
	4°					100	100		100	100	96	100	96
	5°										100		100

(ii) Humidity

There is a similar problem in defining the screen level humidity to that for temperature. At present it is set equal to the 10 m value. The objective verification shows that the surface humidity is about 5% too high on average. This is rather worse than the bias in the fine mesh model 25 m values. However, the mesoscale model shows a much lower incidence of large errors. This humidity bias is almost certainly connected with the cloud base bias noted below.

(iii) Wind

The placement of the lowest level at 10 m gives a clear advantage to the mesoscale model when comparing with observations over land. This is borne out by objective verification of the wind speed. Fig. 12 shows the RMS wind speed errors in the 12 hour forecast for each station in December. Most stations have an RMS error of under 5 knots. Table 3 shows the frequency of prediction of each Beaufort Force compared to that observed and to the fine mesh predictions, again for December. The mesoscale model is generally closer to the observations than the fine mesh but there remains a lack of calms and force 1's. There is also a slight shortage at high wind speeds but many of these occurrences are due to unrepresentative coastal observing stations.

Table 3 Percentage occurrence of wind speeds by Beaufort force in 12 hour mesoscale and fine mesh predictions and observations for 1800 GMT in December 1985

	Beaufort Force								
	≤1	2	3	4	5	6	7	8	9
MES	3	13	25	35	16	7	2	0	0
OBS	17	16	22	25	12	5	2	1	0
FM	2	10	27	26	16	11	5	2	1

(iv) Cloud

This is very difficult to verify since it is essentially a 3-D variable which is normally described by a small number of 2-D ones. Up to now, the verification has been of just cloud base and cloud cover but it must be recognised that a forecast of 1 okta at 2000' will be assessed as a correct cloud base if 8 oktas at 2000' was observed and a wrong cloud base if no cloud was observed. Similarly 8 oktas of cirrus forecast will be assessed as a correct amount if 8 oktas stratus was observed but a wrong amount if 4 oktas of cirrus was observed.

A number of persistent faults have been identified in the cloud forecasts since the trial started and some have been corrected. A general underforecasting of cloud amounts has been largely corrected as has much of the tendency once noted to give either no cloud or full cover. Table 4 is a contingency table of observed and predicted cloud cover. it shows that there is still some tendency to underforecast the amount. However 46% of forecasts were in the correct category and 89% within one category, which should normally provide a useful forecast. Cloud base has proved a more difficult problem although some headway has been made. There is a remaining tendency for cloud base to be too low. This is closely related to the problem of overforecasting surface humidity. Table 5 shows the contingency table of cloud base for 1800 GMT in January 1986. While the observations are dominated by cloud at about 2000 feet, the model produces its highest frequency in the under 600 feet category. Nevertheless closer inspection shows that the model has some skill in forecasting the trend of cloud base, with a mean error of about 1 model level. Investigation of some cases suggests that the practice of assuming cloud is spread through the full depth of a model layer may be producing much of this error and that a substantially improved vertical resolution is the main requirement for improving the cloud base prediction.

Another known problem with the cloud predictions is spurious decrease of stratocumulus cloud. This is believed to be due to the absence of radiative cooling at cloud top, a process which will soon be included in the model.

Table 4 Contingency table for cloud cover in 12 hour forecasts for 1800 GMT during January 1986

		Observed			
		Clear	Mostly clear	Mostly cloudy	Cloudy
PREDICTED	Clear	2	7	3	1
	Mostly clear	1	6	7	4
	Mostly cloudy	0	5	10	9
	Cloudy	0	4	14	28

Correct forecasts are between the diagonal lines and total 46% of occasions. 89% lie between the dashed lines and would give useful guidance in many circumstances.

Table 5 Contingency table for cloud base heights in 12 hour forecasts for 1800 GMT during January 1986

		Observed					
		<600'	600-1500'	1500-2600'	2600-4100'	4100-5900'	>5900'
PREDICTED	< 600'	5	9	7	3	1	3
	600'-1500'	2	7	9	3	1	5
	1500'-2600'	0	3	6	2	0	2
	2600'-4100'	0	1	2	1	0	1
	4100'-5900'	0	0	0	0	0	0
	> 5900'	0	3	9	4	1	8

Correct forecasts are between the diagonal lines and total only 27% of occasions. However 55% lie between the dashed lines and have an error of only 1 model level.

Visibility

At present this is the least promising model prediction. In general, fog is overpredicted for the same reasons as low cloud and surface humidity. However, there are also strong indications that a 15 km resolution description of the topography is inadequate for producing even general predictions of fog. In suitable conditions, the model regularly predicts fog in the large valleys of the Thames, Severn, Mersey etc, often spilling out into their associated estuaries, but it is unable to form radiation fog in locations such as Gatwick or parts of East Anglia where the relevant topographic variations are on too small a scale. As noted before, the model is also poor at forecasting sufficiently light winds for a physically correct description of fog formation. Another major difficulty is that much of the variability of visibility in fogs is due, not to the water content, but to the pollution contained in it. It is clear therefore that for some time the model will be unable to rival subjective techniques of fog prediction.

Precipitation

The precipitation pattern closely follows that of the fine mesh model. However, the mesoscale model has a much better representation of orographic enhancement and rain shadow. A comparison between forecast and observed 12 hour accumulations, summed for December 1985 is shown in Fig. 11, 12. The general pattern is in excellent agreement contrasting with the fine mesh model where the totals were less than half the actuals over the western hills. The major fault in the mesoscale forecasts at present is a tendency to forecast small amounts too often. On some occasions this is worse than the fine mesh model which may be excused because of its coarser grid length.

Solid precipitation is distinguished at present if the level 3 (~ 1000 feet) temperature is below freezing. Figs. 13, 14 compare a 12 hour prediction of rain and snow areas with the verifying observations for a case in January 1986. A belt of precipitation spread into the country ahead of a frontal system in the SW approaches which became slow moving and ultimately relaxed away eastwards. The precipitation turned to snow as it moved northeastwards and a quasi-stationary dividing line between rain and snow became established as shown in Fig. 13. This line is well reproduced in the 12 hour forecast shown in Fig. 14 including the indication of an area of rain to the east of the snow near the Thames estuary. The forecast overpredicted the intensity of both rain and snow as shown by the larger areas of moderate precipitation in Fig. 14. It also predicted some light precipitation over high ground in the northeast of England which was not observed. Other cases suggest that the indicator used for distinguishing snow from rain here is generally useful but there are improvements that should be made in specific circumstances.

5. Conclusions

A short range, fine scale forecast model has been developed for forecasting for the British Isles. Many of the physical parametrizations have been specially written to take account of the scales represented by the model. A sophisticated scheme for analysis of surface synoptic reports has been developed for preparing fine scale initial data of the boundary layer and cloud fields. The complete system has been under regular test since the beginning of 1984 and has produced some encouraging results. However, further development and testing are required before it can be used for operational guidance. In particular the format in which the output will be presented to forecasters must be determined. This is a much more complicated task for a model which predicts variables such as cloud, rain and visibility than for one whose main prediction is a pressure pattern. In addition, facilities must be developed for checking the forecast and making any necessary modications. On the broad scale this may be done centrally but detailed processing for specific requirements will have to be done at the outstation where the guidance is used.

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Figure Legends

Fig. 1. Model domain and orography. The grid points have a 15 km spacing and the contour interval is 50 m. The bold contour is at zero metres and indicates the model coastline.

Fig. 2. Vertical structure of the model. The vertical co-ordinate is height above ground (η) and there are 16 levels from 10 m to 12010 m. Wind, pressure, temperature, humidity and cloud are carried at the main levels indicated by solid lines. Vertical velocity and turbulent kinetic energy are carried at intermediate levels.

Fig. 3. Schematic diagrams of processes involved in the surface heat balance of the model.

Fig. 4. Schematic diagram of processes involved in the layer cloud parametrization. The wind is assumed to be blowing from left to right at all levels.

Fig. 5. Schematic diagram of the representation of snow and rain in the precipitation scheme.

Fig. 6. Schematic diagram of the cloud model used in the convection parametrization.

Fig. 7. Schematic diagram of the method of incorporating surface observations into the model initialisation.

Fig. 8. Map of occurrences of errors greater than 4° in 9 hour predictions of screen temperature for 1500 GMT in January 1986. Zero occurrences are marked by small crosses.

Fig. 9. As in Fig. 8 but 12 hour predictions for 0600 GMT.

Fig. 10. Map of root-mean-square wind speed errors in knots in 12 hour predictions for 1800 GMT in December 1985. A contour is drawn at 5 knots.

Fig. 11. Sum of the 12 hour rainfall totals for each forecast in December 1985, plotted at each observing station in millimetres and contoured at 50, 100, 200, 300 mm.

Fig. 12. Observed monthly rainfall map for December 1985 compiled by Met O 3.

Fig. 13. Observed precipitation distribution at 18Z 7/1/1985.

Fig. 14. 12 hour prediction of the precipitation distribution for 18Z 7/1/1985.

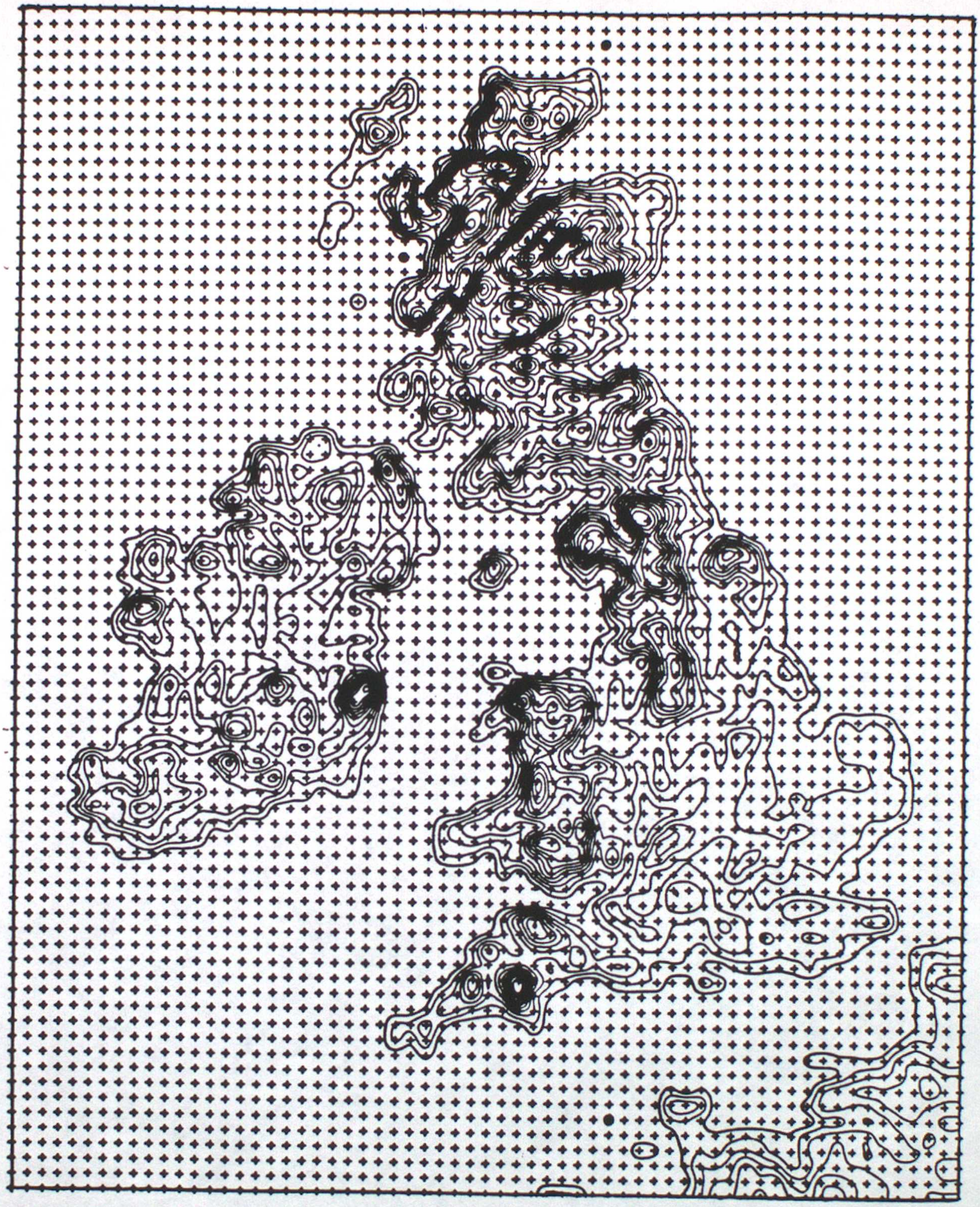

Fig. 1

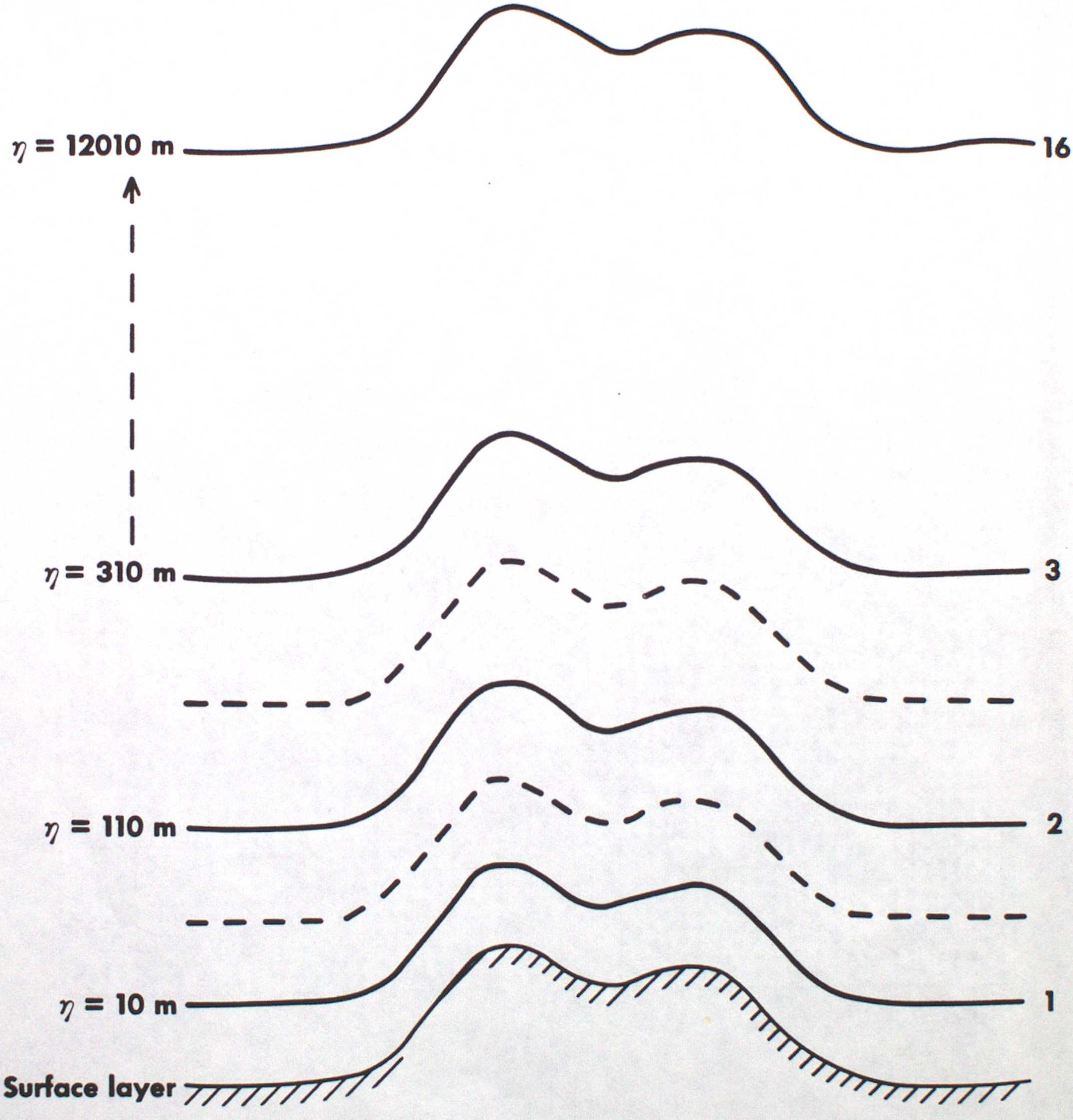

Fig. 2

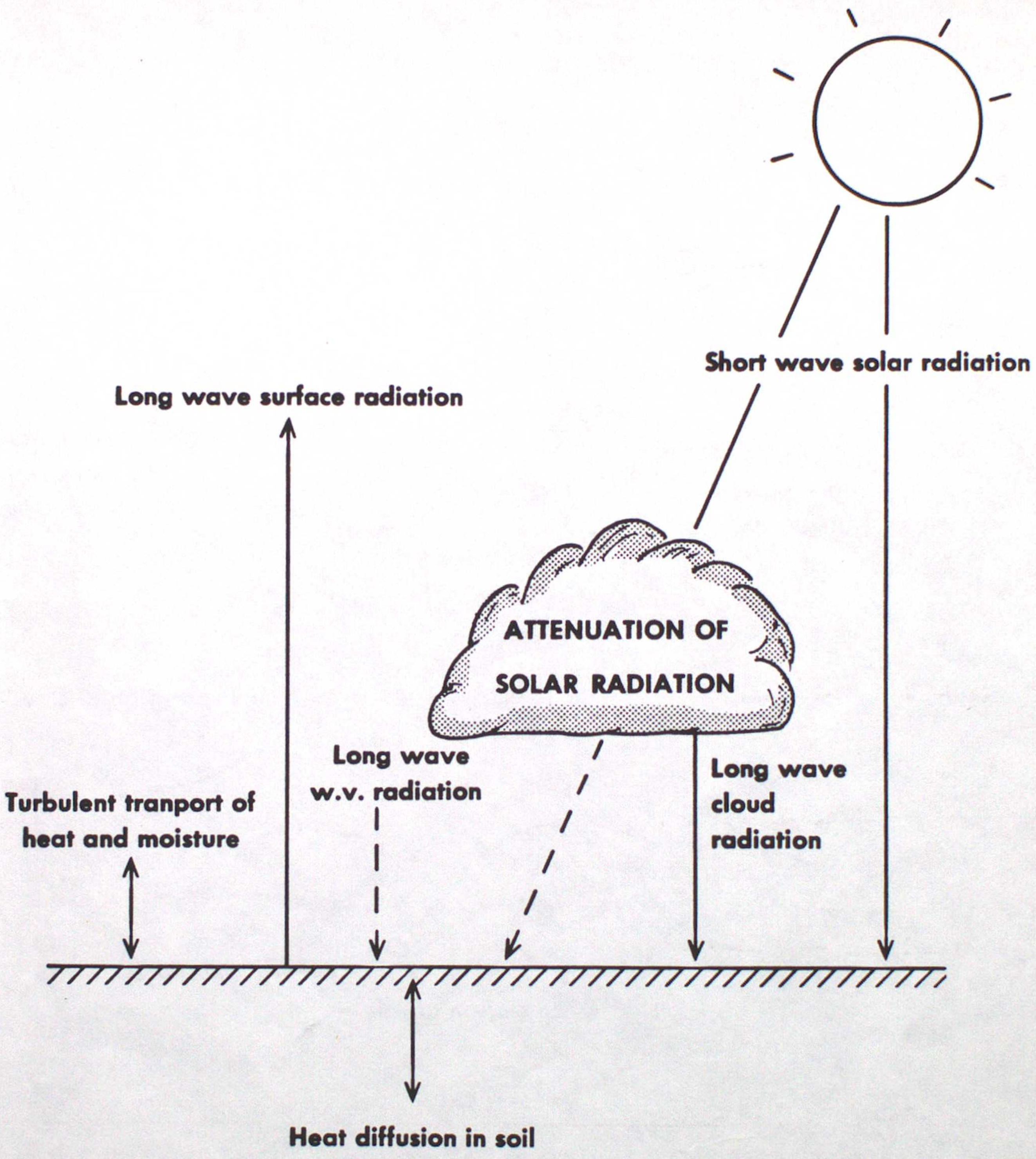
Short wave solar radiation
Long wave surface radiation
ATTENUATION OF
SOLAR RADIATION
Long wave
w.v. radiation
Long wave
cloud
radiation
Turbulent tranport of
heat and moisture
Heat diffusion in soil

Fig. 3

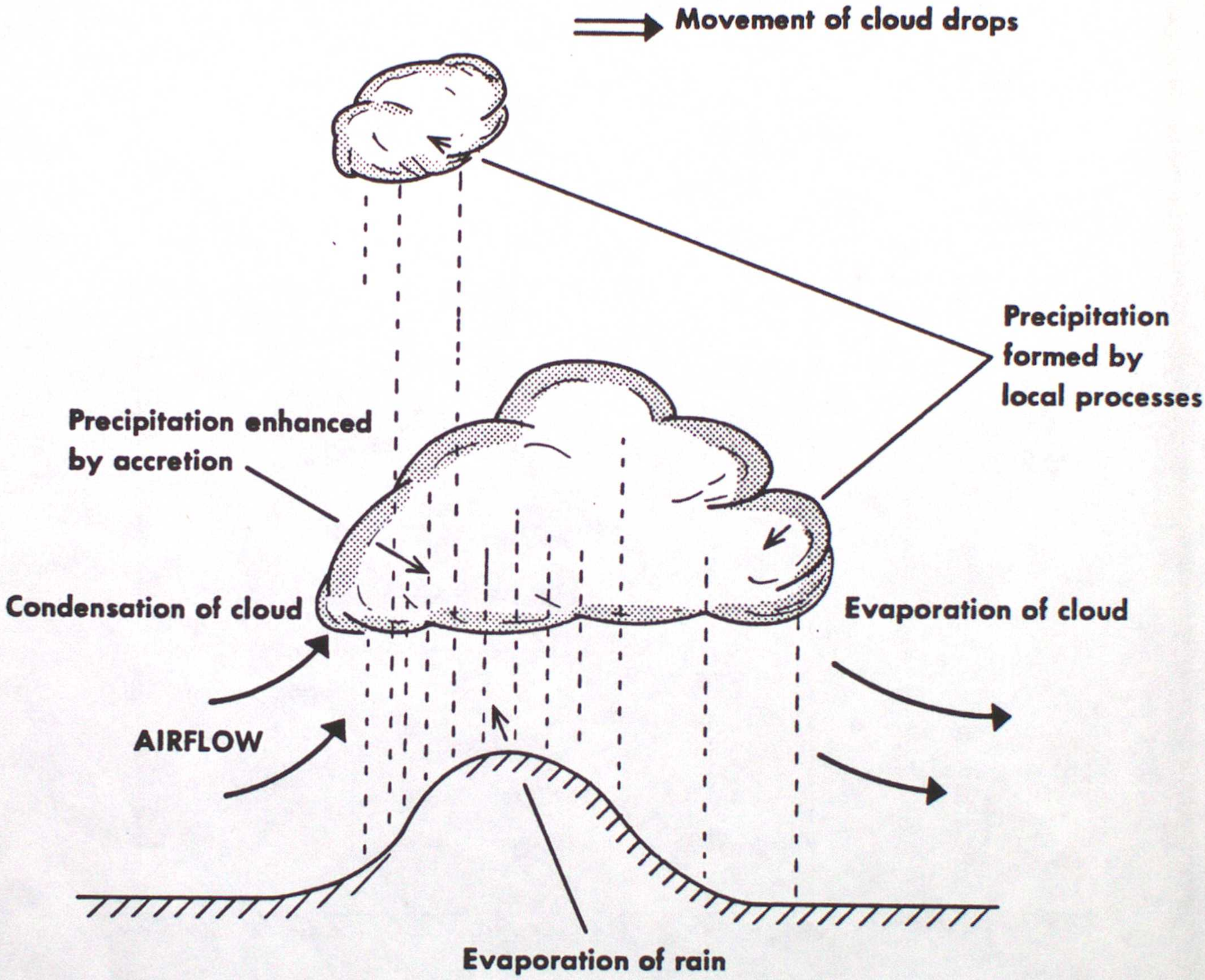
Movement of cloud drops
Precipitation formed by local processes
Precipitation enhanced by accretion
Condensation of cloud
Evaporation of cloud
AIRFLOW
Evaporation of rain

Figure 4

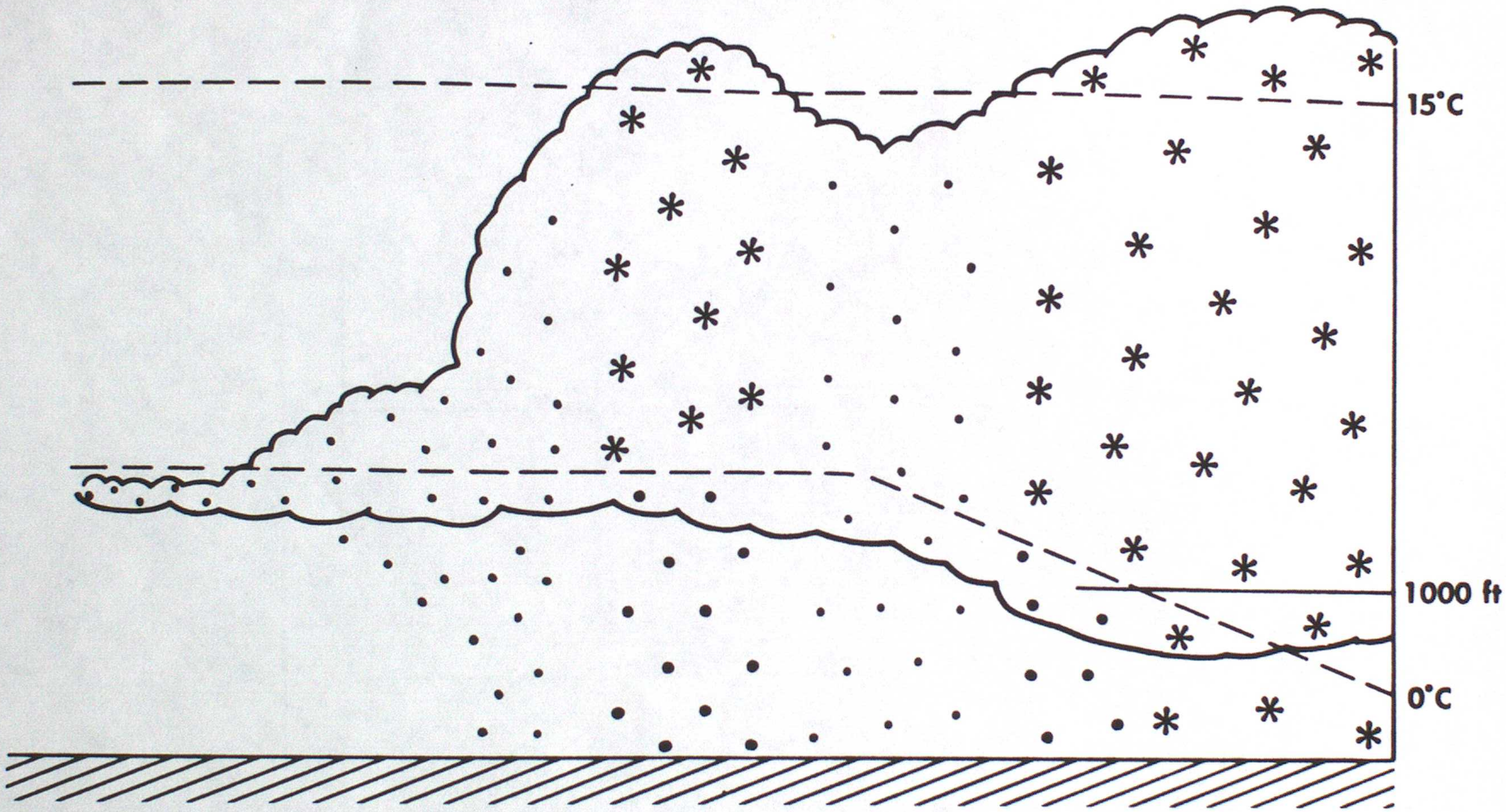

Figure 5

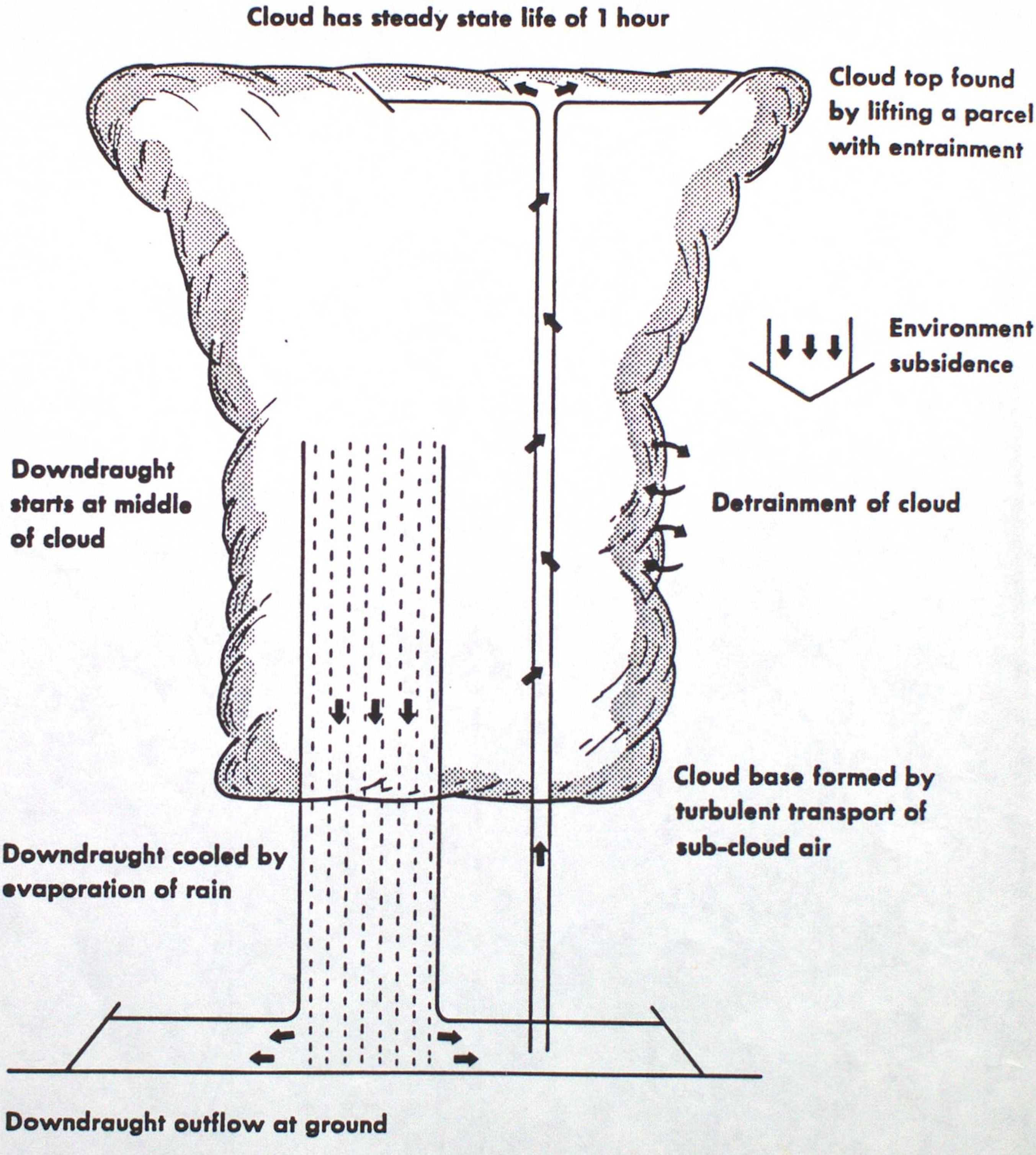
Cloud has steady state life of 1 hour
Cloud top found by lifting a parcel with entrainment
Environment subsidence
Downdraught starts at middle of cloud
Detrainment of cloud
Cloud base formed by turbulent transport of sub-cloud air
Downdraught cooled by evaporation of rain
Downdraught outflow at ground

Figure 6

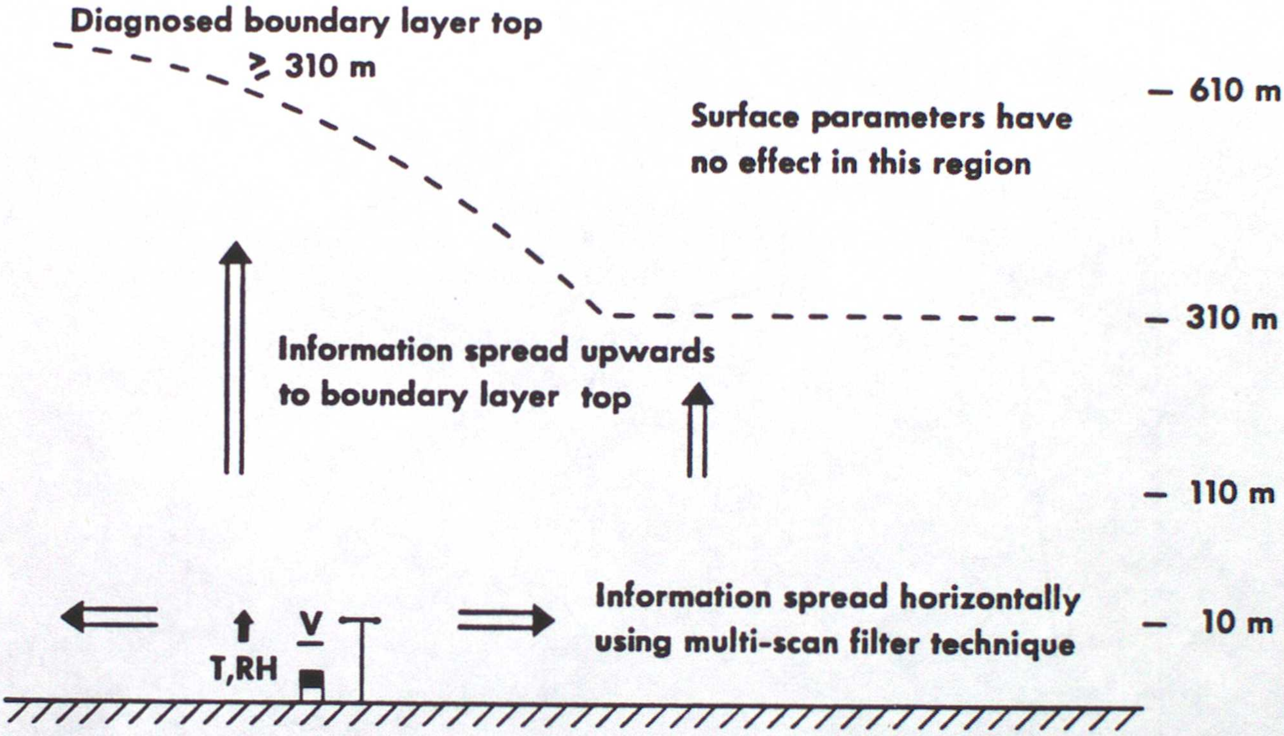
Diagnosed boundary layer top
≥ 310 m
— 610 m
Surface parameters have
no effect in this region
— 310 m
Information spread upwards
to boundary layer top
— 110 m
Information spread horizontally
using multi-scan filter technique
— 10 m
T,RH
V

Figure 7

Figure 8

Figure 9

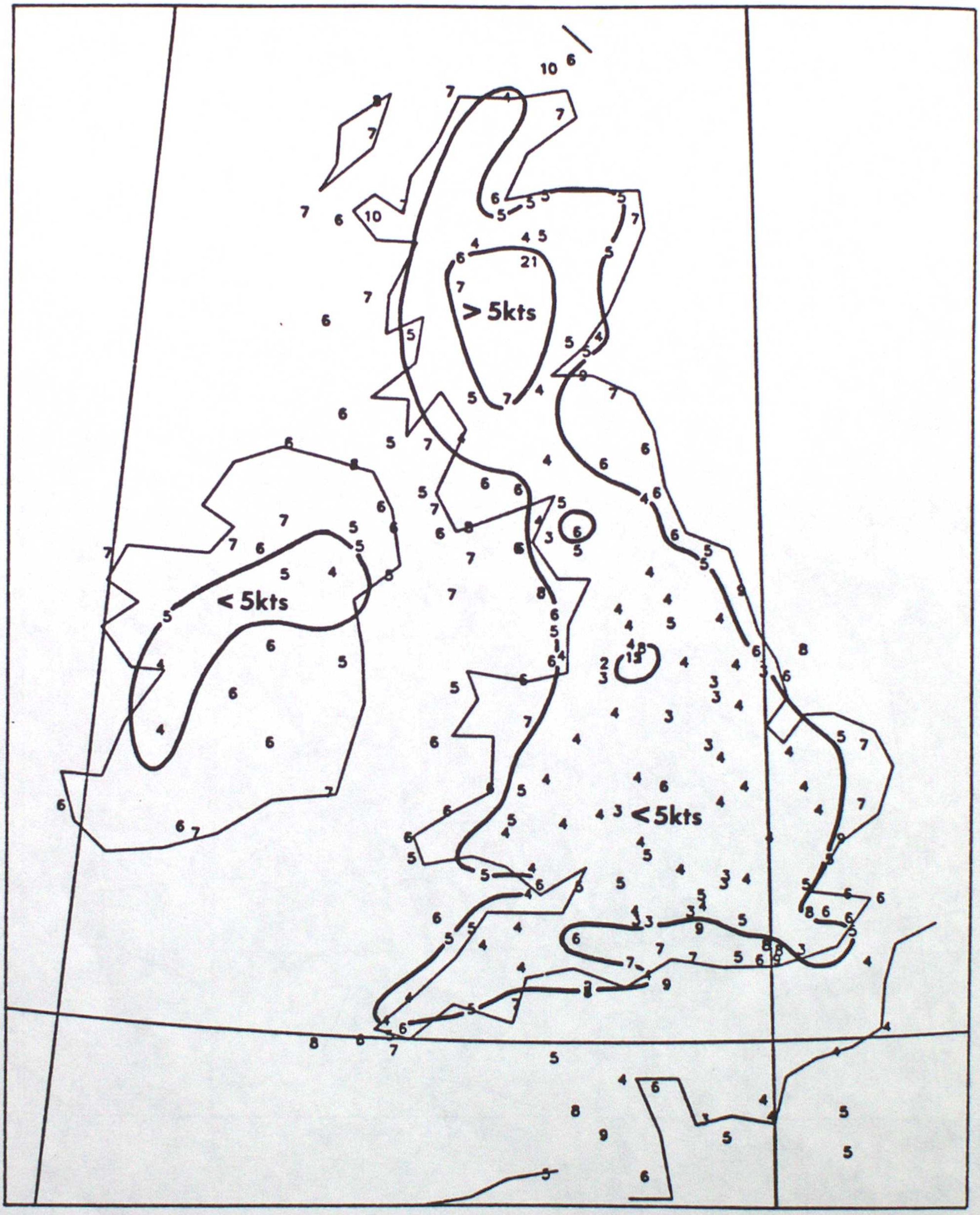

Figure 10

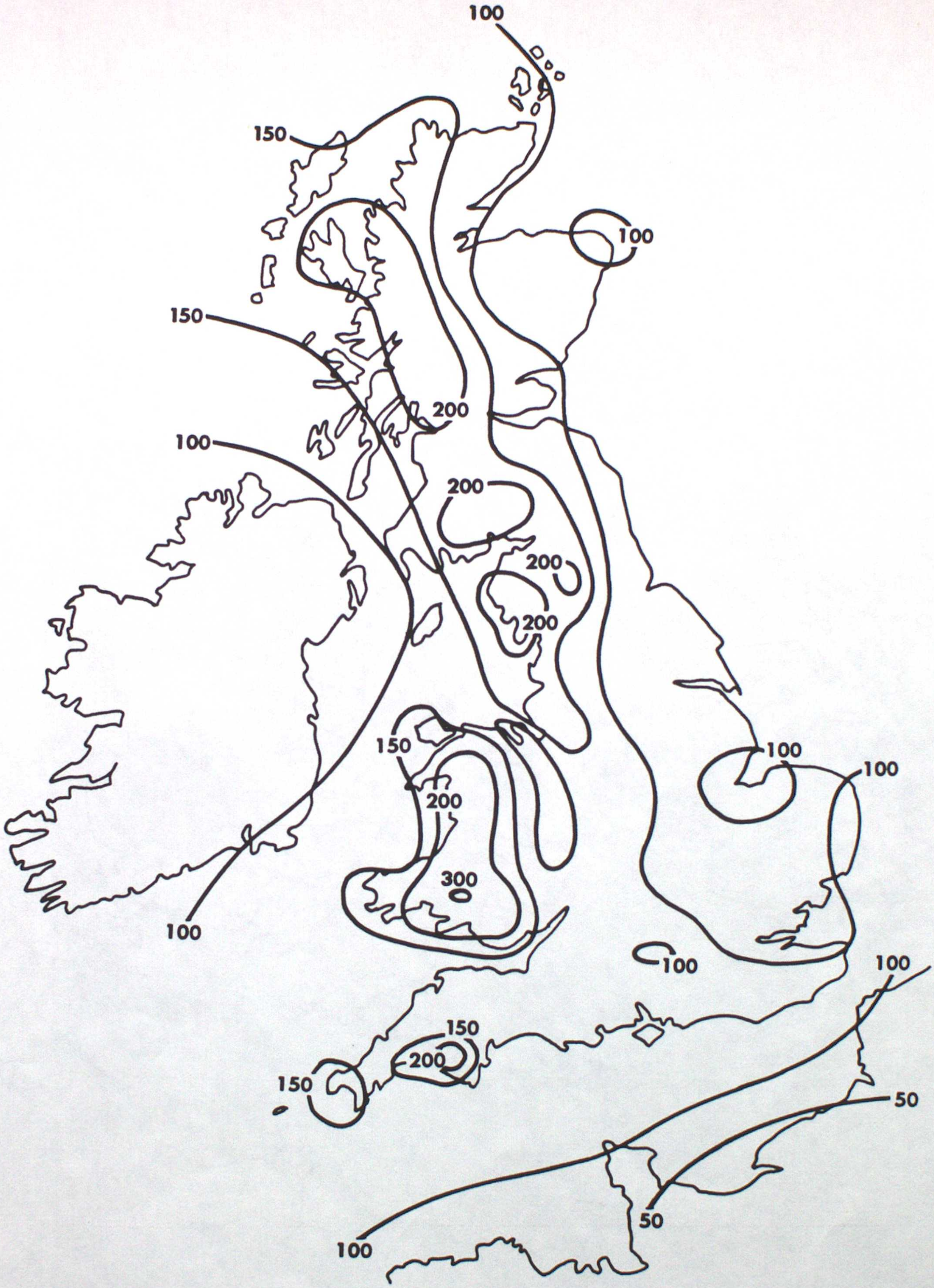
100
150
100
150
200
100
200
200
200
150
200
300
100
100
100
100
100
150
200
150
50
50
100

Figure 11

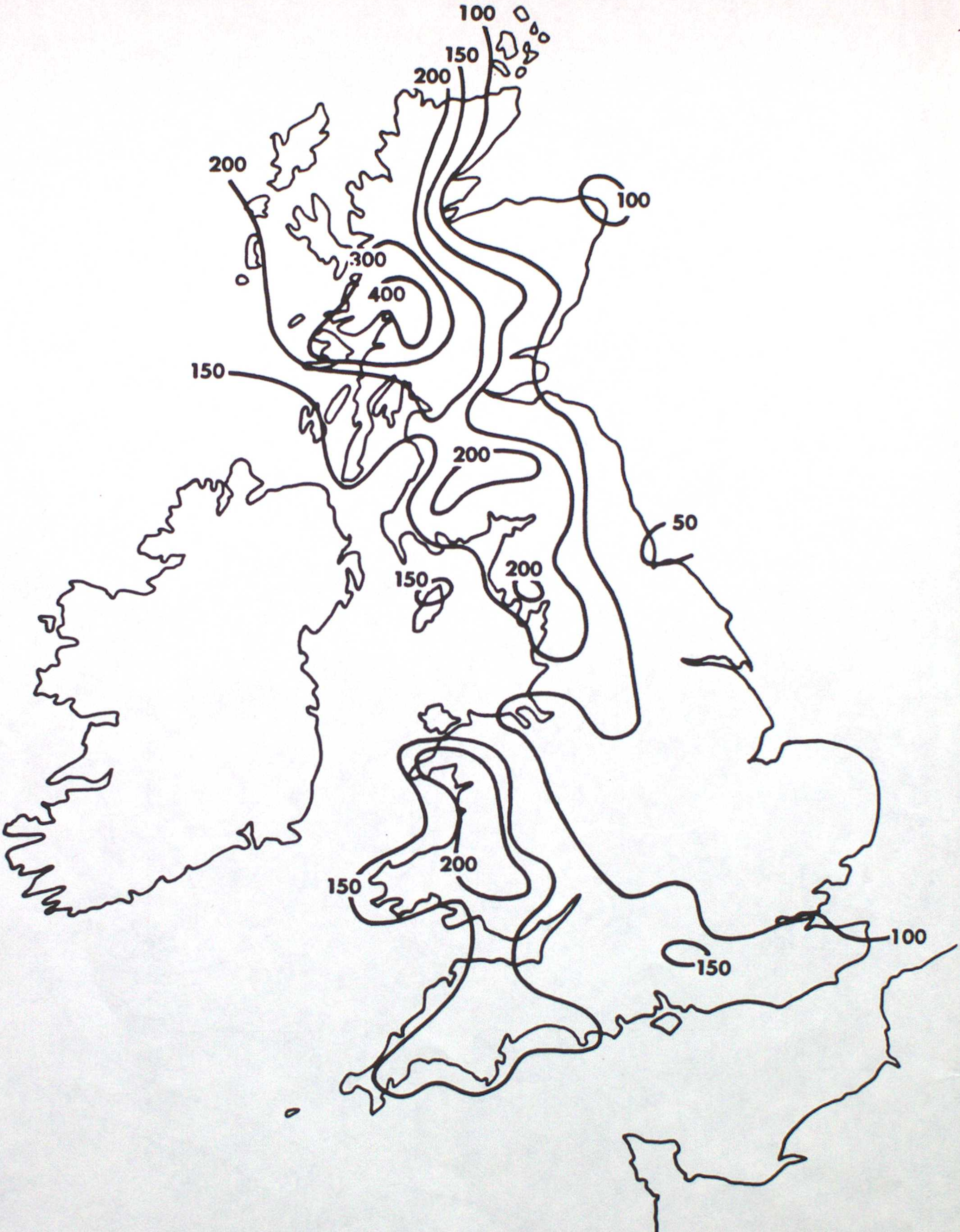

Figure 12

Key • Light rain • Moderate rain • * Sleet

* Light snow * Moderate snow

Figure 13

Key • Light rain • Moderate rain
* Light snow * Moderate snow

Figure 14