# LONG RANGE FORECASTING IN THE METEOROLOGICAL OFFICE: PART II

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## 1. INTRODUCTION

In this lecture I shall be dealing with the use of dynamical methods in long range forecasting. As indicated at the beginning of the first lecture, the central problem is how to forecast, or possibly what can be forecast, beyond what is generally taken to be 'the limit of deterministic predictability'. For shorter periods, the technique of integrating forward from a specific realization of the atmospheric state at a particular moment is clearly appropriate. Beyond the 'limit', however, the irreducible inaccuracies in the specification of the initial state have grown to overwhelm the true solution of the problem. Two qualifications have to be recognised and they may have considerable practical importance:

(i) predictability is a function of the scales of the motions being considered and, in general, the large scales are more predictable than shorter scales. There may therefore be some extension of the 'limit of predictability' if only the largest scales are considered, or if the forecast results are averaged in time.

(ii) there is considerable evidence that predictability is a function of the initial state of the atmosphere. There may be particularly stable states for which the atmosphere, viewed on the large scale, remains predictable to a useful extent well beyond the normal 'limit of deterministic predictability'.

It is unlikely however that either of these qualifications is sufficient to change the essential nature of the problem. Viewed from the perspective of the first lecture, the crucial question for long range forecasting is whether they alter our ability to predict the length of time for which a spell, just initiated, will last. This is a significantly more difficult problem than that of indicating that in the next few days there will be a change of type which will be persistent. Numerical models have been successful in some instances of this more limited achievement, but strictly, forecasting a change of type in this way falls within the ambit of short to medium range forecasting. On the other hand information about the persistence of a spell is only of practical significance if it adds to the knowledge of similar spells which can be deduced from the meteorological historical record.

Taking time averages of the results from numerical integrations can be useful in removing some of the short-period variability but it is clear that short and long scales are not distinct and independent. On many occasions even the largest features in the atmospheric flow are affected within a fairly short time by non-linear feedback from the active baroclinic developments. Indeed this is the normal process by which the large-scale flow is altered. Gilchrist (1977, Figure 6 ) has shown examples of the error values with different averaging periods and different initial conditions. While temporal averaging may mitigate some aspects of the general problem it is at best a minor aid in the process of long range forecasting. It should be noted also that some of the apparent gain in predictability is illusory, because the process of interpreting the results in terms of variables of interest to the user is made considerably more difficult.

In view of the formidable difficulties, it is sometimes concluded that numerical integrations from given atmospheric conditions are not an appropriate way of tackling the problem of long range forecasting. The alternative view, to which I subscribe, is that, although it is by no means proven that this approach will be successful, it is nevertheless the only one which has any real hope of more than marginal success, at least for areas like the British Isles and Western Europe which, being in the westerlies, experience a great deal of variability simply because of minor variations in the normal depression tracks. It is possible that for areas whose climate is more continental or which are in different latitudes, statistical methods still hold significant promise.

Broadly, in extended range forecasting, we may distinguish two aspects; namely, the extent to which the atmospheric developments which occur in the time period of interest are dependent on (i) the initial atmospheric state and (ii) forcing by external factors such as conditions at the earth's surface, variations in solar radiation etc. It must be recognised of course that the two aspects are not wholly independent as sea-surface temperatures and land surface conditions of temperature and moisture availability are affected by atmospheric developments. For integrations of a few days, there is little doubt that the initial conditions have an overwhelming influence, and it is only at much longer ranges that the effects of forcing functions begin to be important. Presumably at some point it is possible to say that the problem has ceased to be sensitive to the initial atmospheric state and the motions in the atmosphere may be considered to have arisen solely from the action of the forcing functions which have been acting since the initial time.

For the forecast periods being considered here, both the initial state and the forcing functions are important and both need to be taken into account. This provides a compelling argument to justify the use of numerical integrations of suitable model equations in the long range forecasting problem. Only by this technique can all the important factors be included and given adequate representation. Gilchrist (1977) shows results from integrations which differed only in the initial specification of sea-surface temperatures, or, alternatively, only in the atmospheric initial state, chosen to represent conditions 24-hours apart. They indicate that a significant influence of realistic sea-surface temperature anomalies on the atmospheric flow is evident after 10 days or so, and the differences have become major by about 20 days. The effects of starting from successive days with the same sea-surface temperatures was much more substantial. While these results may be affected by the particular model used in the experiment (the same model has produced most of the results described later in this lecture), it is believed that they are representative of integrations using even the most complex available models.

It appears from experiments carried out in the Dynamical Climatology Branch of the Meteorological Office that the response time for realistic anomalies of surface conditions is, in general, probably about the same as that for sea-surface temperatures. This has been found in experiments to test the sensitivity of the atmosphere to large-scale anomalies of surface albedo and soil moisture. However, one experiment, concerning the effect of soil moisture conditions over West Africa, indicated a substantial effect on the 700 mb flow in a significantly shorter time. This is not inconsistent with the general proviso made elsewhere in these lectures that the response of tropical flow to surface conditions may be more rapid and significant than elsewhere. It should of course be noted that we are concerned here with the sensitivity of the atmospheric flow to the anomalies; it is clear that effects on more local features such as rainfall or surface temperatures can be much more rapid.

That the influence of the initial atmospheric state is important well beyond the 'limit of deterministic predictability' is supported not only by investigations using numerical models, but by more empirical studies concerning the lengths of spells, as indicated in my first lecture, and by searches among historical data for analogues. It is sometimes implied that monthly forecasts may be possible from the sea-surface temperatures alone, ignoring the atmospheric state (Opsteegh and Van den Dool, 1980) by assuming that the influence of the forcing reaches its asymptotic value. It is not easy however to reconcile this with the evidence from experiments with numerical models or from the observed association (or comparative lack of it) between time-averaged sea-surface temperatures and the atmospheric state.

The view-point of this lecture therefore is we have to pursue the possibility of using time integrations of numerical models of the atmospheric system, including interactions with 'external' forcing mechanisms. The aims are first of all to clarify the problems and possibilities which exist and then to use models in the practice of long range forecasting in some way not as yet clear in detail but about which there are a number of ideas to be followed up.

Accepting this general approach there are, as a broad generalization, two standpoints from which to proceed. The first may be characterized as that of the shorter range forecaster. The emphasis is on improving the performance of medium range forecasting models, by improving the physical representations within them, improving the resolution used in the computations and so on. The primary purpose is to exploit the proportion of occasions on which the atmosphere may be considered to have longer than normal predictability.

I shall not be talking about this way of proceeding here. It is already covered by research at a number of centres. Although it is an essential adjunct to long range forecasting it cannot of itself provide an acceptable solution, because it fails to optimize the method of dealing with the central problem of long range forecasting; namely, how to proceed for periods beyond the limit of deterministic prediction, when even the most complete model has lost detailed resemblence to the atmospheric state.

The second standpoint may be characterized as that of the conventional long range forecaster. Lengths of spells, deviations from climatological averages, analogues from the historical record of meteorological events - these and similar quantities are his stock-in-trade and his interest in using models is essentially whether or not they can help make good the deficiences of historical data, which, at least as far as quantitative measurements are concerned, cover such a small part of the past that they lack adequate representation of many possible atmospheric evolutions. For the long range forecaster, the concept of the atmospheric evolution involving a range of possible solutions is an inherent part of his thinking, even if his forecasts are not always stated explicitly in terms of probabilities.

This lecture is conceived in that general line of thought, and it will therefore be concerned, not with the use of models to describe the detailed development of the atmospheric system, but as a possible means of extending and complementing the information that the long range forecaster already has at his disposal.

## 2. THE METEOROLOGICAL OFFICE EXPERIMENT

An experiment to begin to explore, in a systematic way, the possibility of using numerical models in long range forecasting and to look at methodologies for their practical application to the problem, was initiated about two years ago. The more immediate aims were

(i) to determine model climatologies, not only for each month and season, but for selective quantities such as the ability to reproduce statistics of spells etc.

(ii) to identify if possible, the impact of specific anomalies of surface conditions on the evolution of the atmosphere. It has of course been the practice of those in the long range forecasting group to try to take account of the presence of marked anomalies of this kind, but the arguments used have been qualitative and what numerical models did was to provide the means of making them quantitative, at least in some measure.

(iii) to examine in detail those instances in which the numerical integrations had some success in indicating developments on time-scales beyond a week or so to see if they were associated with identifiable characteristics - the time of year, blocking patterns in the upper flow, initial synoptic type, features of the model climatology etc.

For the experiment, the Meteorological Office's 5-layer model (Corby et al 1977) has been used. It is perhaps not ideal for the purpose. However, we do not yet know which are the most important features of a numerical model to be used for long range forecasting. For shorter ranges there have been a number of investigations to determine the sensitivity to resolution, variations in physical parametrizations etc, but for longer ranges the difficulties of selecting an appropriate model have hardly been explored. Most crucially, it is not clear how a model's performance in a shorter range forecasting role should be weighted vis-a-vis its performance in reproducing the observed climatology; also, as the aim in long range forecasting must be to specify the probability of various alternative developments as realistically as possible the balance to be struck between a small number of highly accurate integrations as opposed to a larger number of less accurate integrations, is one of the most important areas to be investigated; so far, it has barely been looked at.

The advantages of the 5-level model were that many of its climatological features were already known and a substantial body of knowledge existed concerning its response to various kinds of forcing. In order to allow a reasonable flow of integrations, it was used in hemispheric form, the integration time on the IBM 360/195 computer being then 4-5 minutes per day. Integrations were normally started twice per month from atmospheric situations chosen from real conditions near the beginning and middle of each month and they were continued for 50 days of simulated time. For integrations of this length, there is convincing evidence that, in general, the two hemispheres interact substantially, and therefore it is logical to use a global model. However, for the intended purposes, it is by no means clear that the use of a hemispheric model is more restrictive on the interpretation of the results than other assumptions implicit in the construction of the model. The option of having two hemispheric integrations from good initial analyses was preferable to that of one global integration for which an acceptable southern hemisphere could not be provided.

Taking into account the substantial number of integrations carried out in the period of two years or so, there is a useful body of information on which to base a study of the model's behaviour. In the following section, some aspects of the model results which have emerged from these integrations are described.

## 3. SYSTEMATIC MODEL DEVIATIONS FROM OBSERVED CLIMATOLOGY

The January and July climatologies for the model used in the long range forecasting experiment are quite fully documented in GARP Publication No. 22 (1979), where standard deviations are reproduced as well as mean quantities. They were of course derived from long integrations using a fixed solar zenith angle, and are not therefore strictly comparable with the observed climatologies for these months. It is indeed found that model climatologies created from month-long episodes embedded in integrations which include a variable zenith angle differ systematically from those shown. Similarly, for the forecasting experiment, in which the model was always integrated forward from observed northern hemisphere flows, there are systematic changes not only with time of year, but with the length of time into the forecast.

This is illustrated in Figures 1 and 2. Figure 1, which refers to winter conditions, shows model variables and actuals computed for the same periods and illustrates the changes taking place through a 50-day integration. (a), (b) and (c), for 500 mb between 40 and 60°N, show that the zonal mean wind speed gradually increases. At the same time, the standard deviation of the value from day to day tends to decrease whereas it was observed to increase slightly. There is a rapid fall in the average meridional wind during the first 7 days or so, and recovery towards realistic values is slow and certainly not complete in 50 days.

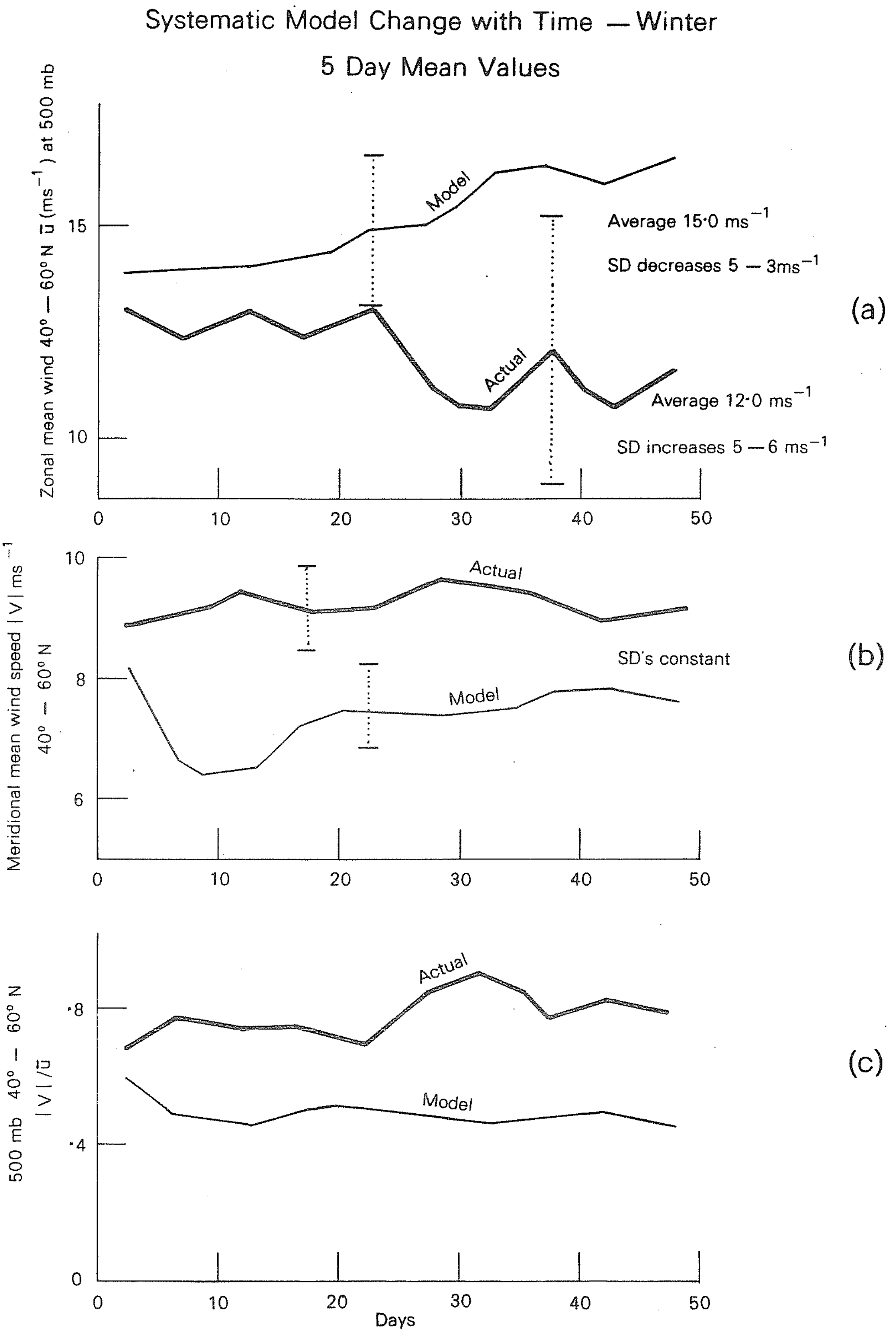


Fig. 1 Average variation of model and atmospheric variables during 50-day integrations from real data in winter.

(a) mean zonal wind $\bar{u}$ at 500 mb, $40^{o}$ - $60^{o}$N, 5-day average.

(b) mean meridional wind $|\bar{v}|$ at 500 mb, $40^{o}$ - $60^{o}$N, 5-day average.

(c) ratio $|\bar{v}|/\bar{u}$, 500 mb, $40^{o}$ - $60^{o}$N, 5-day average.

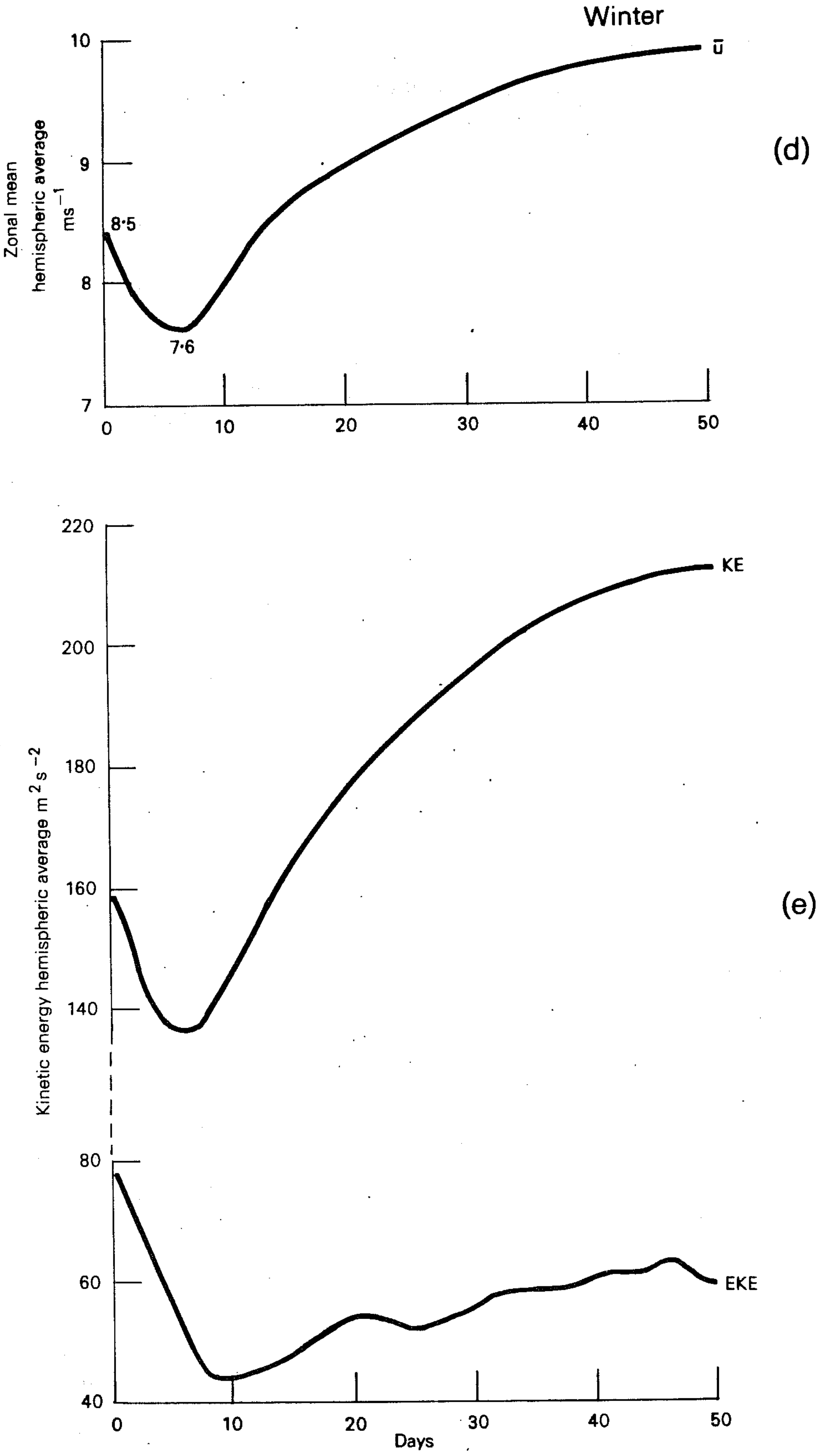


Fig. 1 (contd.) (d) mean zonal wind, $\bar{u}$, all levels, hemisphere.

(e) (i) kinetic energy, all levels, hemisphere (KE).

(ii) eddy kinetic energy, all levels, hemisphere (EKE).

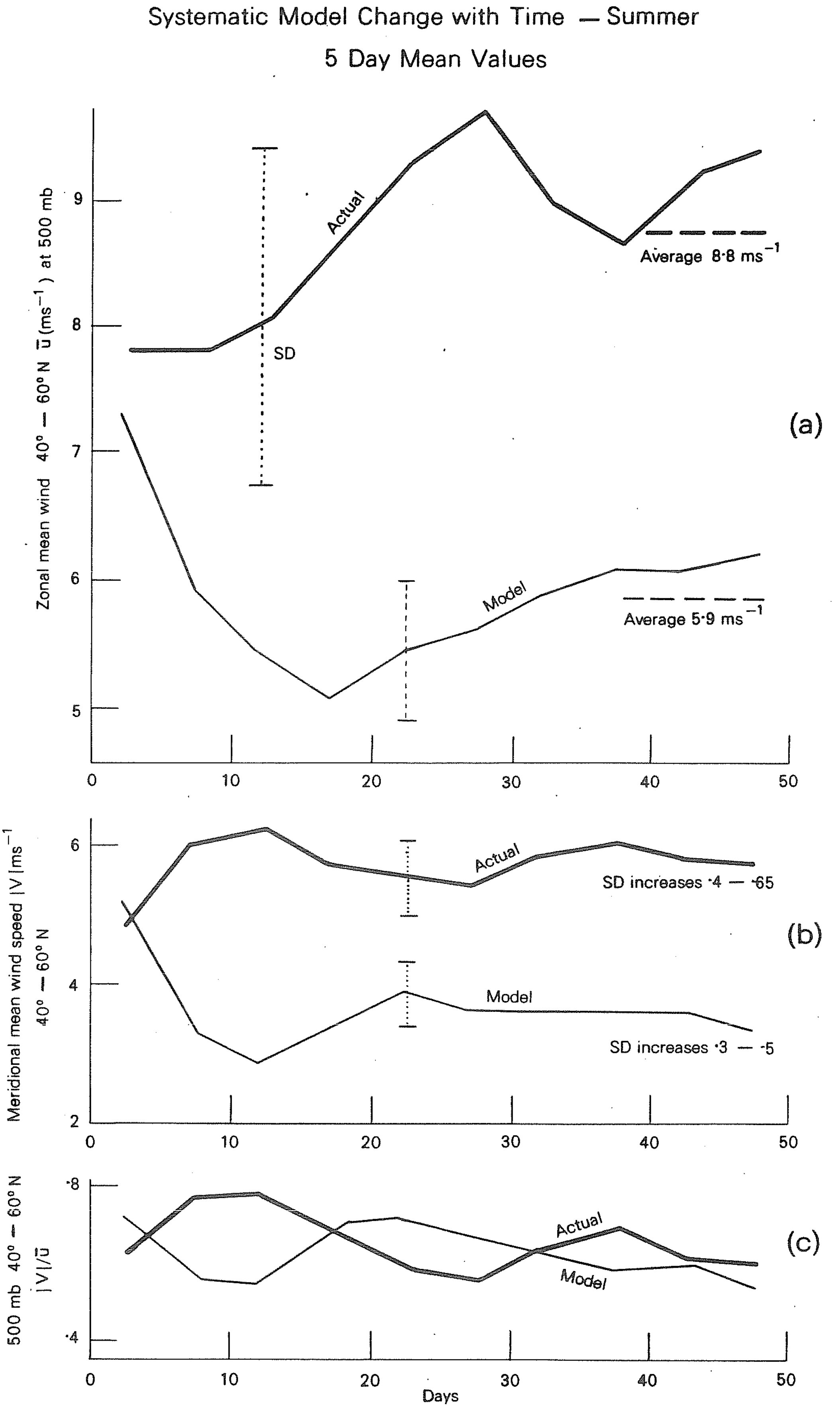


Fig. 2 Average variation of model and atmospheric variables during 50-day integrations from real data in summer.

(a) mean zonal wind $\bar{u}$ at 500 mb, $40^{o}$-$60^{o}$N, 5-day average.

(b) mean meridional wind $|\bar{v}|$ at 500 mb, $40^{o}$-$60^{o}$N, 5-day average.

(c) ratio $|\bar{v}|/\bar{u}$, 5-day average.

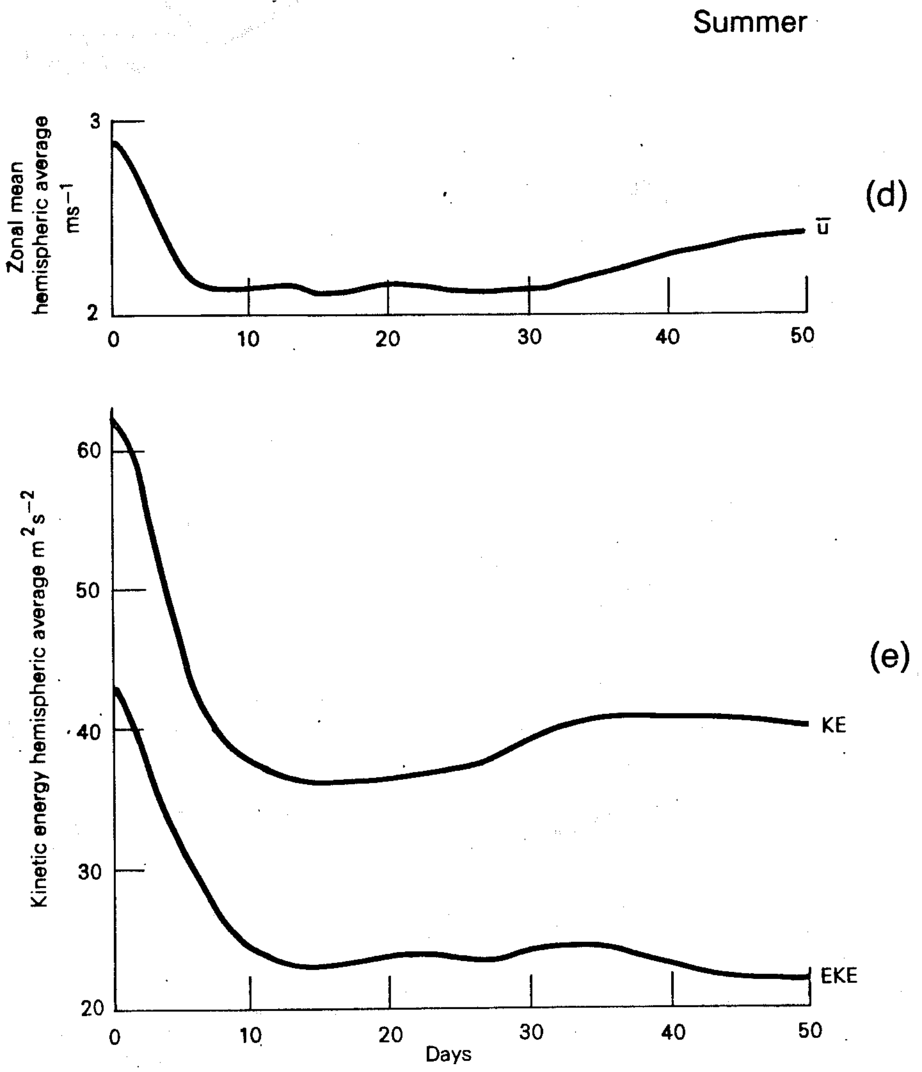


Fig. 2 (contd.) (d) mean zonal wind, $\bar{u}$, all levels, hemisphere.

(e) (i) kinetic energy, all levels, hemisphere (KE).

(ii) eddy kinetic energy, all levels, hemisphere (EKE).

Both these effects tend to produce a lower ratio of meridional to zonal mean wind in the model than actually occurs.

Considering hemispheric mean values for all levels, (Figures 1(d) and (e)) there is a fall in the zonal mean wind during the first 7 days but thereafter it recovers rapidly and at 50 days is about 15 percent above the observed value. As expected, the kinetic energy follows a similar evolution, the final value being about 30 percent greater than observed. The eddy kinetic energy falls very substantially in the initial period and gradually recovers but has not reached observed values at the end of 50 days. These very obvious variations with time are probably due in substantial measure to the fairly coarse horizontal and vertical resolution of the model (330 km and 200 mb). In particular, the kinetic energy is affected by very strong flow at the top level, 100 mb, which must be partly attributed to the lack of a resolved stratosphere.

The equivalent summer diagrams are shown in Figure 2. At this time, the model flow is systematically too weak, and baroclinic systems are considerably underdeveloped. The flow recovers only to a minor degree from the low values attained between days 10 and 20. Presumably this is because the radiation fields, which in winter drive the atmosphere towards stronger zonal flow, have very weak gradients between pole and equator, and the model fails to reproduce the strength of flow necessary for it to create substantial cyclonic activity in the westerlies. The deviations from observation are more serious in summer than in winter, and indeed it is observed that any successes the model achieves in its simulation of the detailed atmospheric evolution are mostly in the winter. Thus, the model's summer climatology, considered only as a reproduction of the average summer values is misleading to an extent that is far greater than its winter climatology.

The derivation of climatologies is essential for long range forecasting experiments such as those considered here, for it is essential to judge the model's behaviour relative to its own climatology. This is a requirement which will probably not disappear entirely as models more suited to the role of long range forecasting are used.

Obviously some aspects of model behaviour described in this section must be improved before we can realistically expect the probability of atmospheric developments to be estimated reasonably well. In particular, the initial variation in time of global averages needs to be substantially reduced, as otherwise there is a large, and almost certainly unacceptable loss of information during the first 7-8 days of an integration. This however was appreciated before the experiment began, and one of the main aims was to define more precisely where improvements were most essential. We have tried to achieve this by examining a range of atmospheric situations in order to avoid the obvious dangers of optimizing the model response for a particular set of atmospheric circumstances.

## 4. BLOCKING SITUATIONS IN THE MODEL

An important aspect of the long range forecasting experiment is the determination of the characteristics of spell types and durations within the model. As 'atmospheric blocking situations' are one of the main causes of observed persistent spells, an examination of simulated blocks was an essential part of the process.

Both from its earlier simulations and from examples which occurred during the experiment, it has been evident that the model is capable of producing blocking situations, of varying intensities and widely different geographical positions but which are on the whole fairly realistic both as regards mode of occurrence and time-scale for development. An early example, taken from an integration initiated from atmospheric data for September 1978, is illustrated in Figures 3(a) to (h). It is by no means the best which has occurred in the experiment but it was an early example, and therefore one of which particular note was taken.

The figures show charts for particular days between the 14th and 26th of the integration. They are for 900 mb($\sigma$ =.9) is the lowest level) and for 300 mb. The former, which show winds in addition to contours, are preferred to surface pressure charts; the model's deep boundary layer ($\sim$ 200 mb) in which the only temperature available is at $\sigma = .9$, tends to exaggerate a real tendency to have a too high pressure in polar regions. In assessing model performance it is probably better to consider the lowest level at which both wind and mass fields are available.

A trough, approaching from the west on day 14 (Figure 3(a)) is succeeded by a substantial ridge, which by about day 16 has settled over the British Isles. Thereafter it remains in this position with only minor variations for about 10 days. On day 26 (Figure 3(d)) however, a trough from the west sweeps the high away, and brings the blocking episode to an end. To the south of the high over the British Isles, there is relatively low pressure throughout the period. At upper levels a split flow develops, most markedly at days 21-24 (Figure 3(g)). An interesting point about this blocking situation is that it did not develop in a similar integration which differed from the first only in having a slightly different radiation parametrization. Charts for day 23 of this integration are at Figure 4.

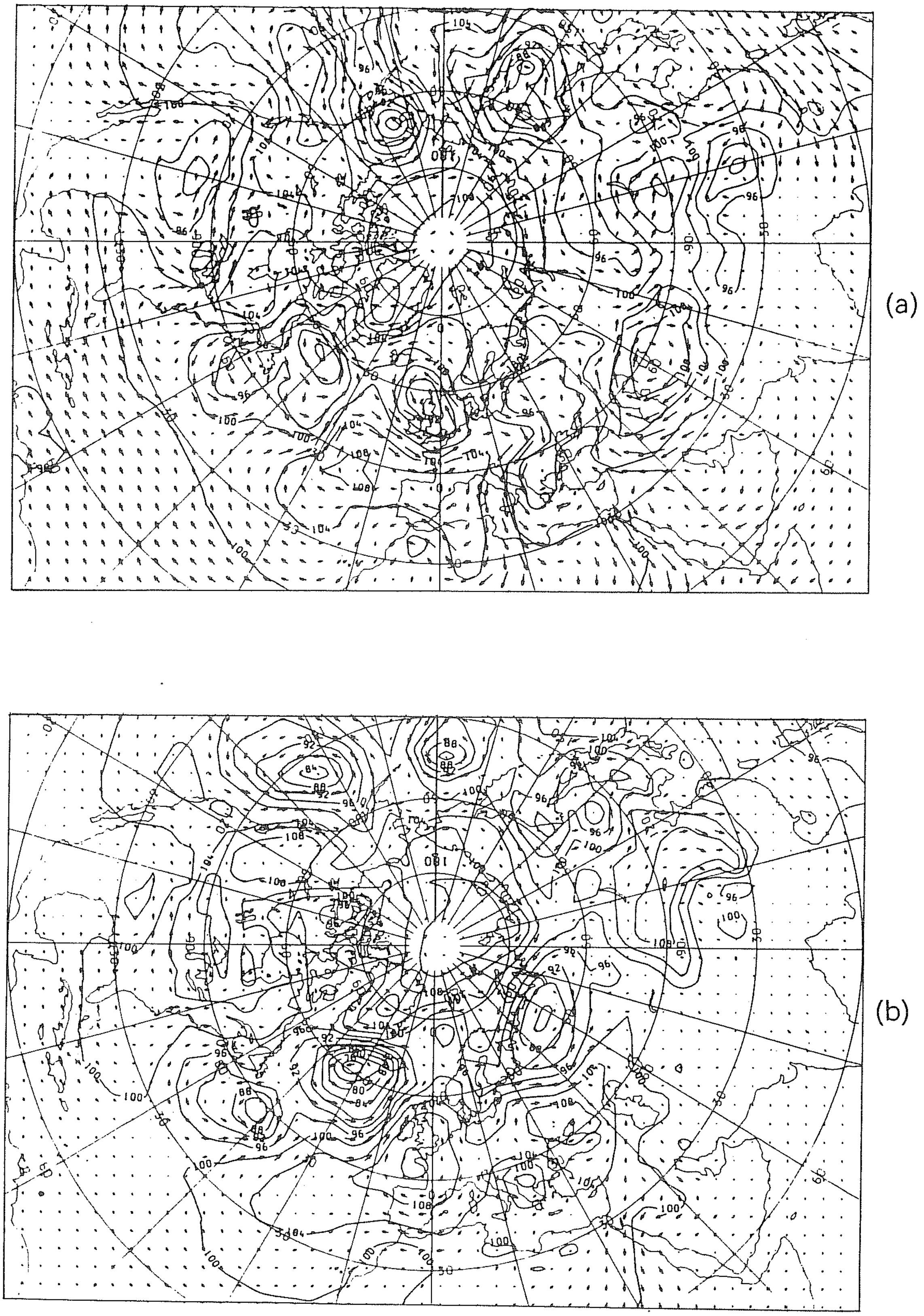


Fig. 3 Formation of an east Atlantic block in a model intergration.
Integration from real data from day in mid-September 1978.
(a), (b) - 900 mb contour heights and winds for days 14, 19.
Contour interval 4 dam

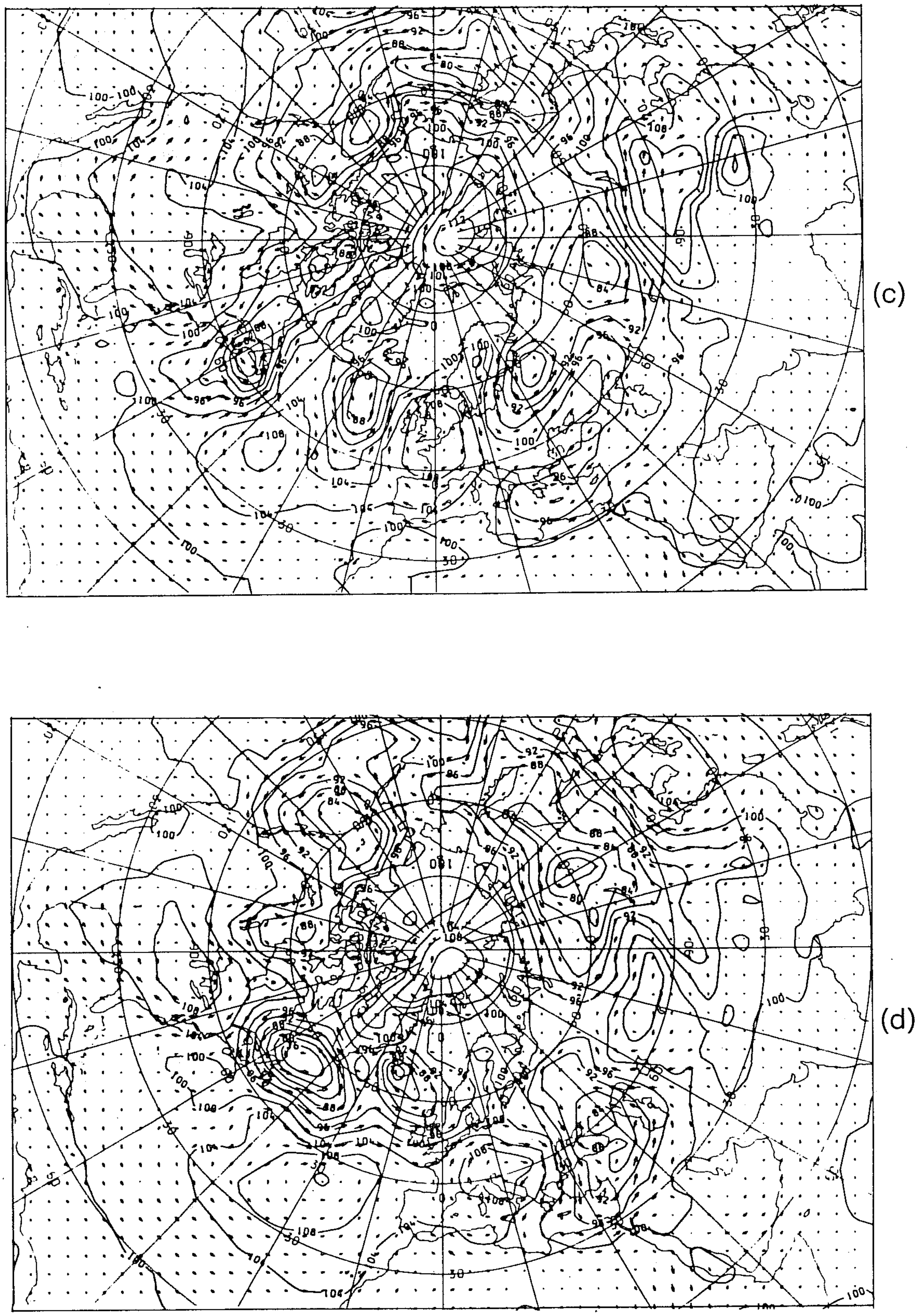
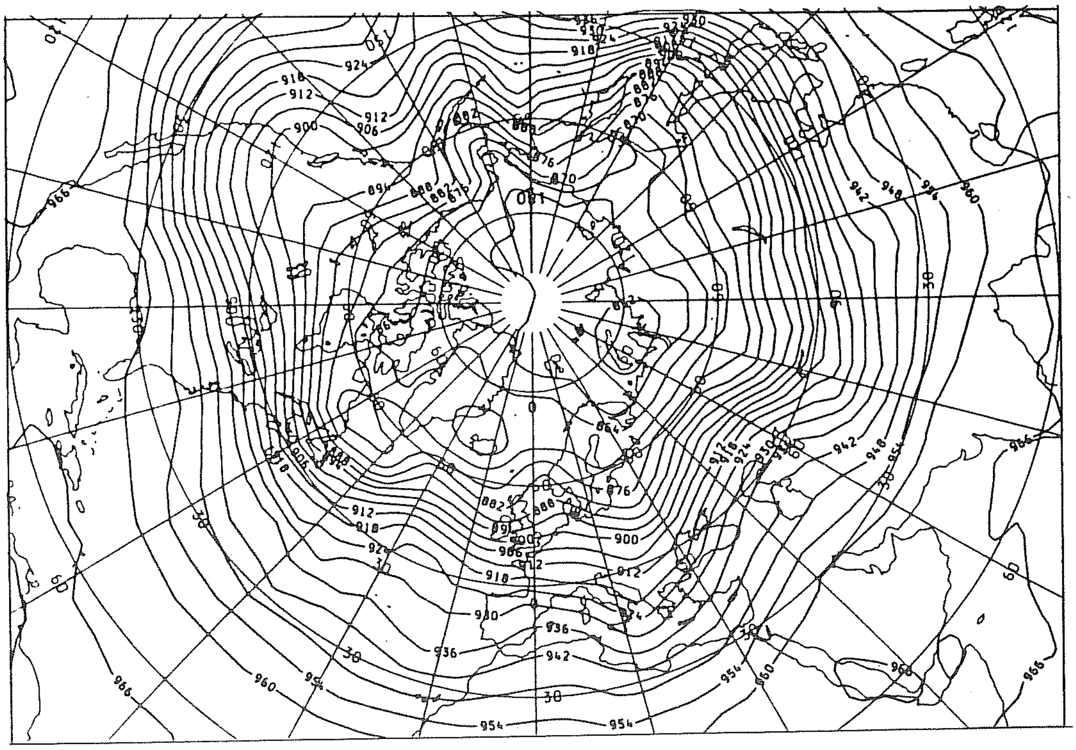
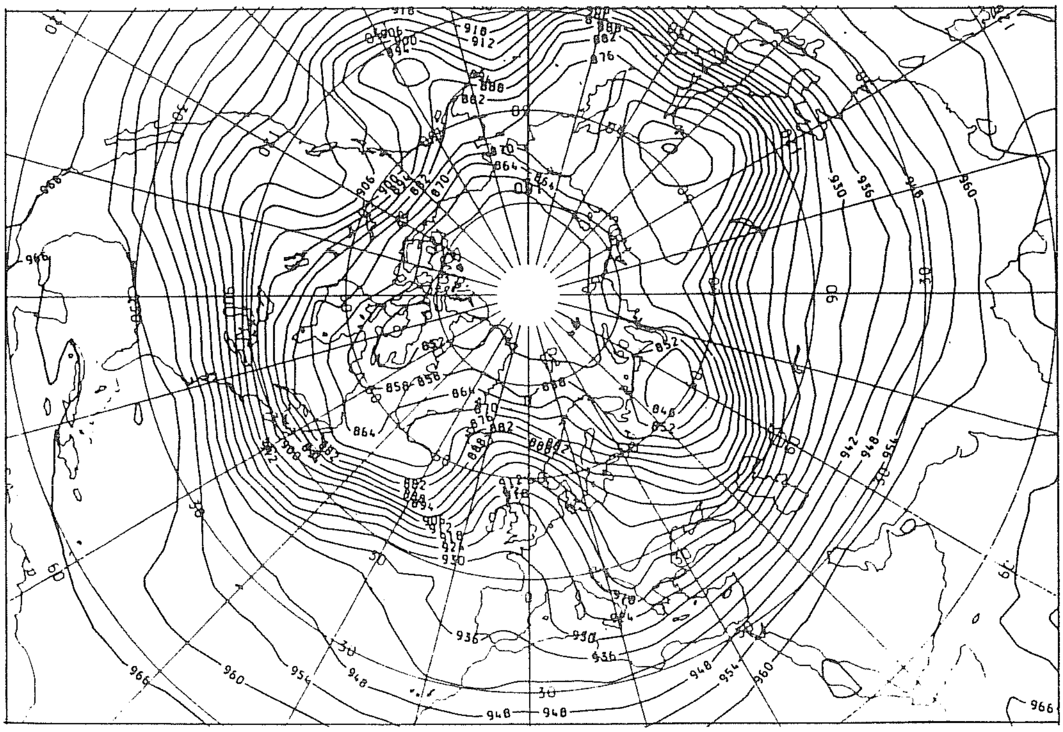


Fig. 3 (contd.) (c) (d) - 900 mb contour heights and winds for days 22, 26. Contour interval 4 dam



(e)



(f)

Fig. 3 (contd.) (e) (f) - 300 mb contour heights for days 14, 19.
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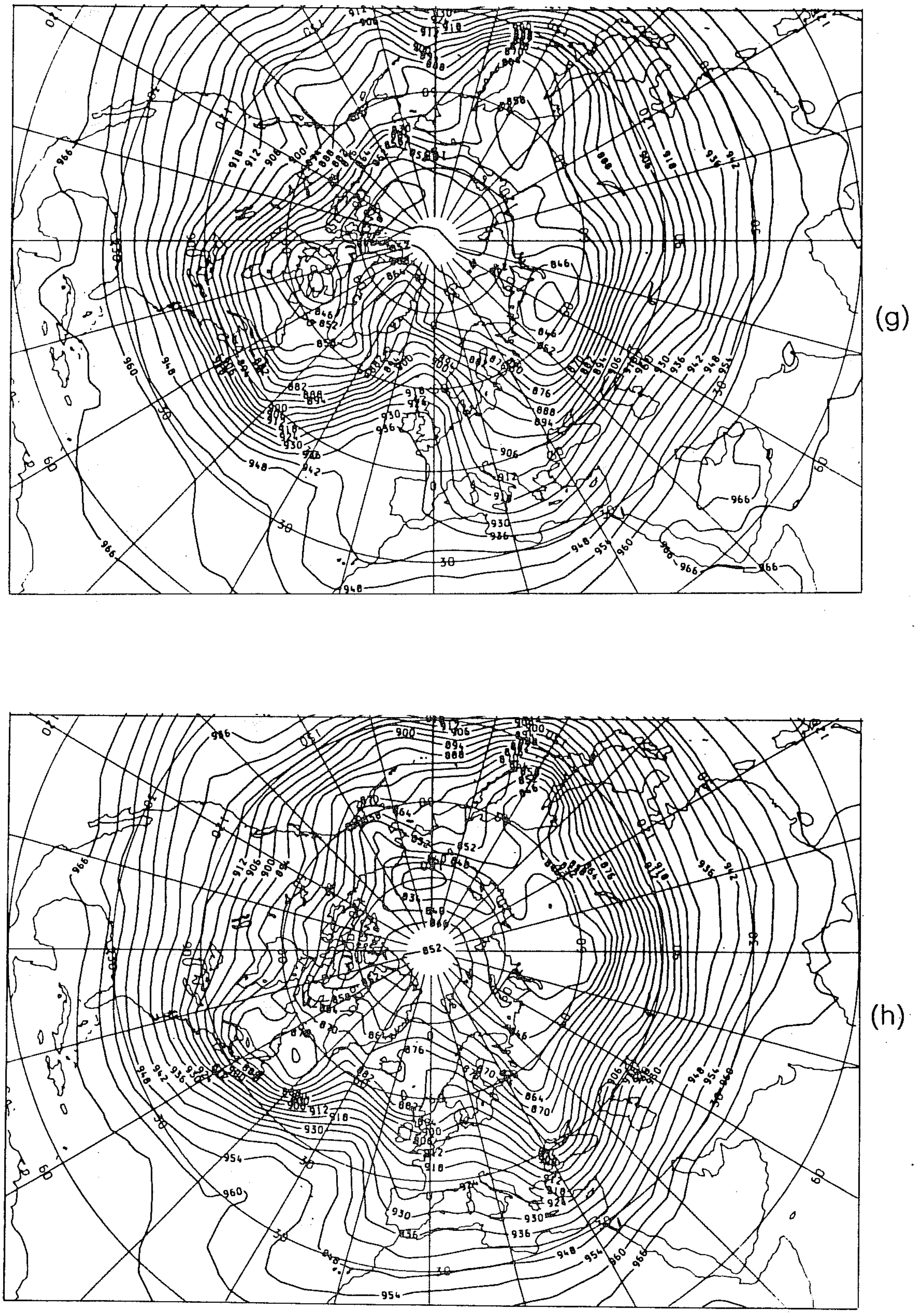


Fig. 3 (contd.) (g) (h) - 300 mb contour heights for days 22, 26. Contour interval 4 dam

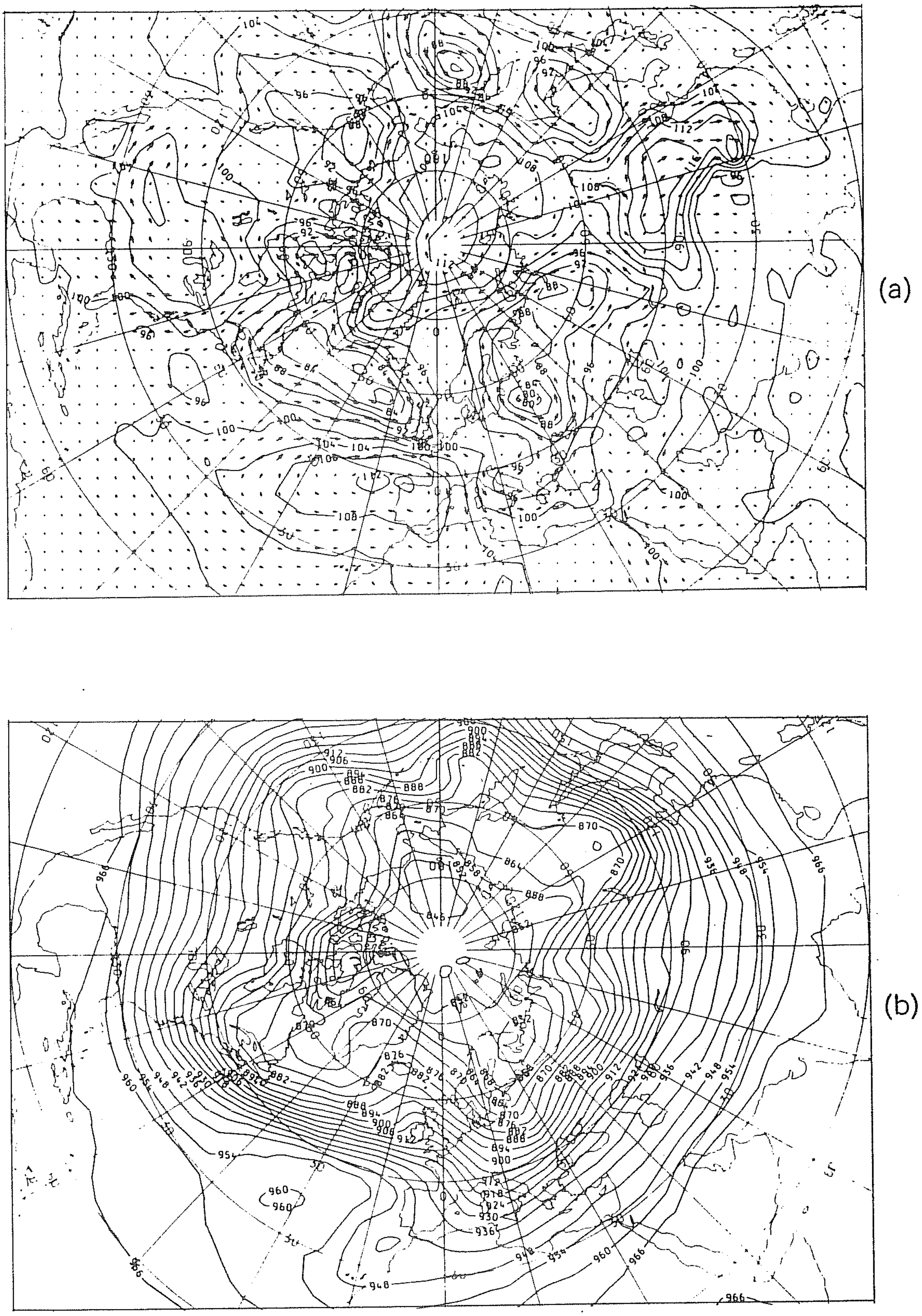


Fig. 4 Integration similar to that shown in Fig. 3, except that radiation constants were slightly different. No block formed.

(a) - 900mb contour heights and winds, day 23.

(b) - 300mb contour heights, day 23.

To examine the climatology of blocks (Mansfield (1981)), the requirement that the component of westerly flow be zero or negative over any 15°N latitude band within 40°N to 60°N was applied to the model and actual 500 mb 5-day mean charts for the periods for which integrations were available. The occasions so chosen were then examined. Figure 5(a) shows the duration of blocks in terms of pentads, and Figure 5(b) shows the variation of frequency through the year. Fewer blocking situations develop in the model than in the atmosphere and therefore for forecasting purposes it would probably be realistic to apply a more stringent criterion to the latter than the former; equivalently, one has to be prepared to take comparatively weak indications of blocking in an integration as probably indicating a much stronger development. Despite the fact that the total number of blocks is deficient, the distribution of lengths and the distribution of numbers through the year are rather realistic. In particular, the latter shows a very strong spring maximum and a weaker autumnal maximum. Probably the least convincing feature of Figure 5(b) is the very small number of blocks which occur in the integrations during January and February. It is to be noted however that there is probably considerable variation in this quantity in the real atmosphere from one period to another. Thus Painting (1977), considering blocks near the British Isles, found a very large variation between 1965-69 and 1970-74; for the former the number of blocked days per month was 14-15 and for the latter period it was 5-6. It is possible therefore that a larger selection of model integrations would depart less from the real atmosphere's statistics.

The distribution of blocks with longitude and the distribution in the two halves of the year are shown in Figures 5(c), 5(d) and 5(e) respectively. In each instance the model's distribution is close to the observed.

During recent years there has been a number of theoretical studies aimed at clarifying the nature and characteristics of blocking. Few if any of them however have examined the questions considered here; namely, the variation with time through the year and the variation of incidence with longitude. It is interesting to speculate on whether any of the proposed mechanisms would reproduce the spring maximum and the concentration of blocking near 0° - 30°W and 120-150°W. These are perhaps useful tests against which to test theoretical results.

The examination of blocks in the model also seems to bring into question the concept of blocks as a highly specific type of atmospheric flow. Rather it appears to support the view point that a complete range of blocking or quasi-blocking situations is possible, varying from substantial ridges with no split flow to circumstances in which the high and low to the south are isolated from

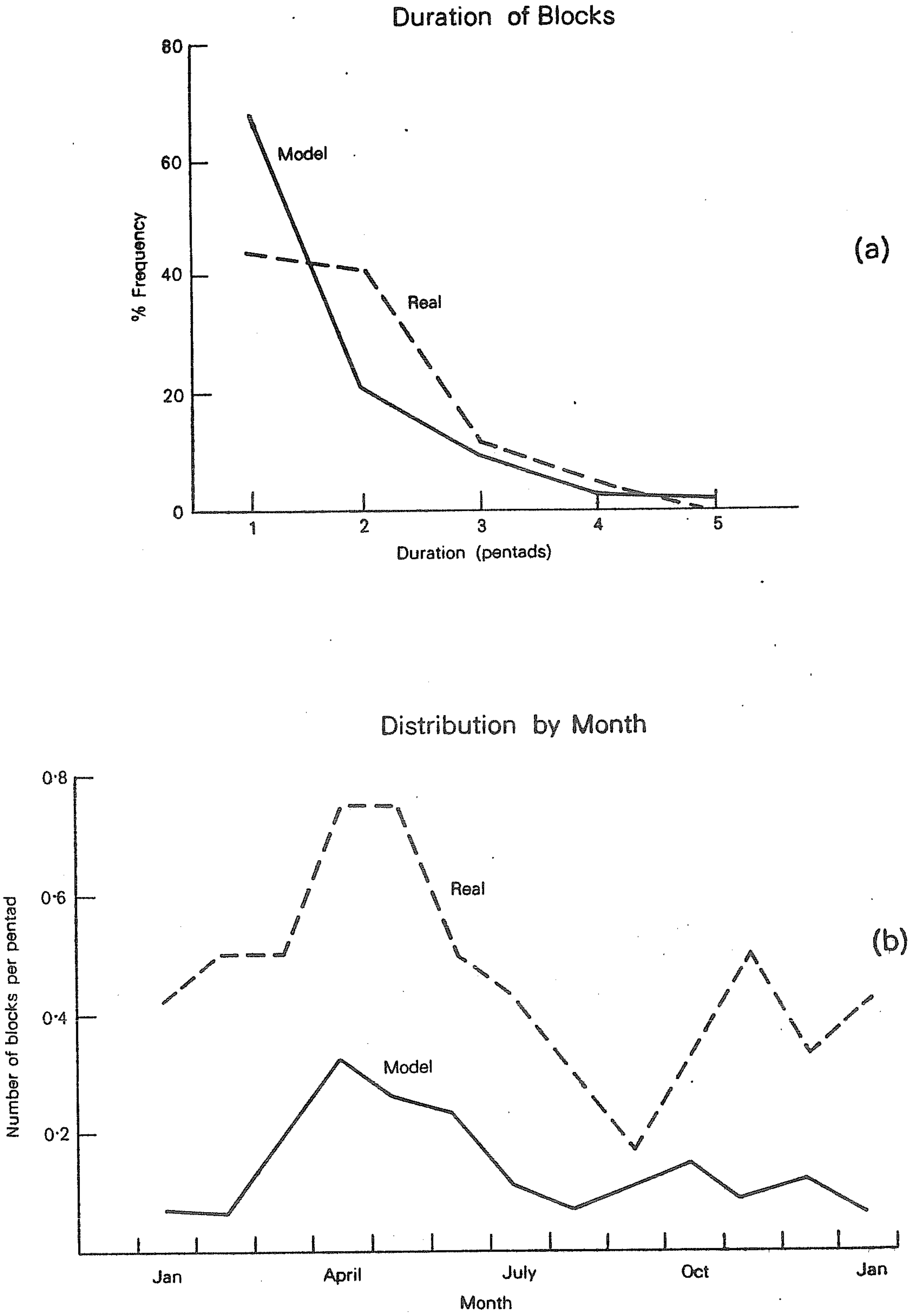


Fig. 5 Statistics of blocks which formed during model integrations compared with statistics for the real atmosphere for the periods of the integrations.

(a) percentage frequency of block durations in pentads.

(b) variation of frequency through the year. Number of blocks per pentad for model and atmosphere (using same definition of a block) for each month.

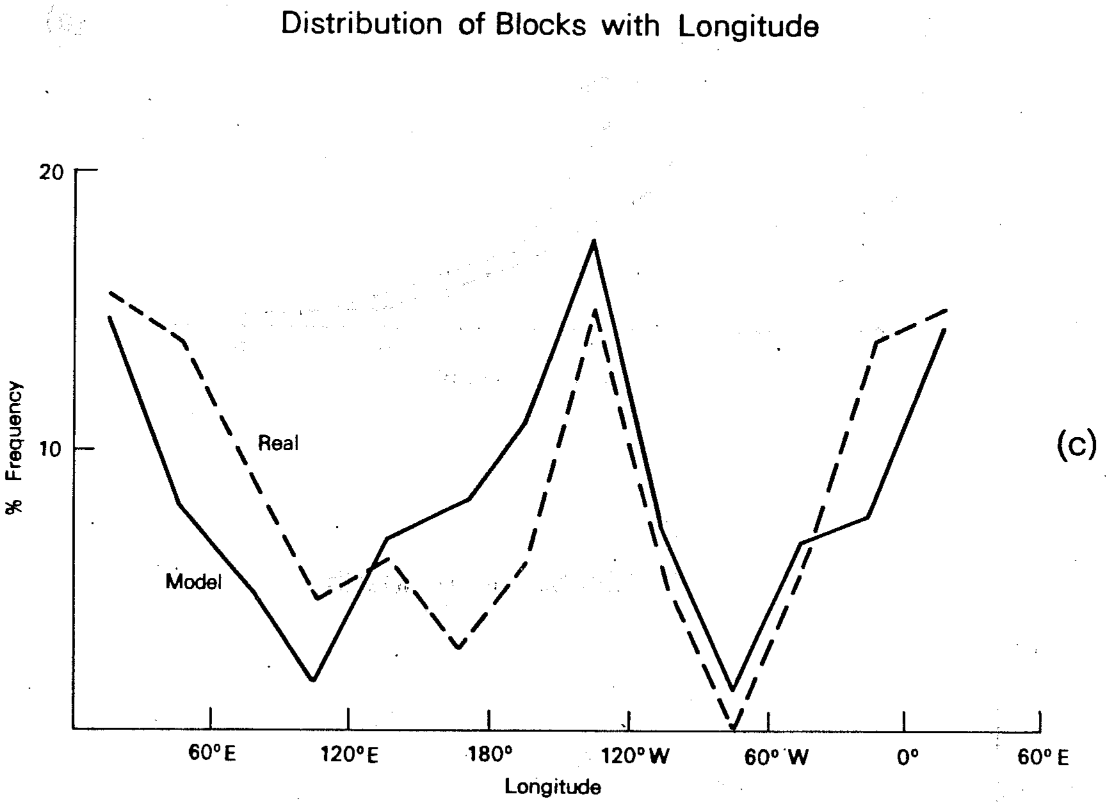


Fig. 5 (contd.) (c) distribution of blocks by longitude. Percentage frequency, using all integrations.

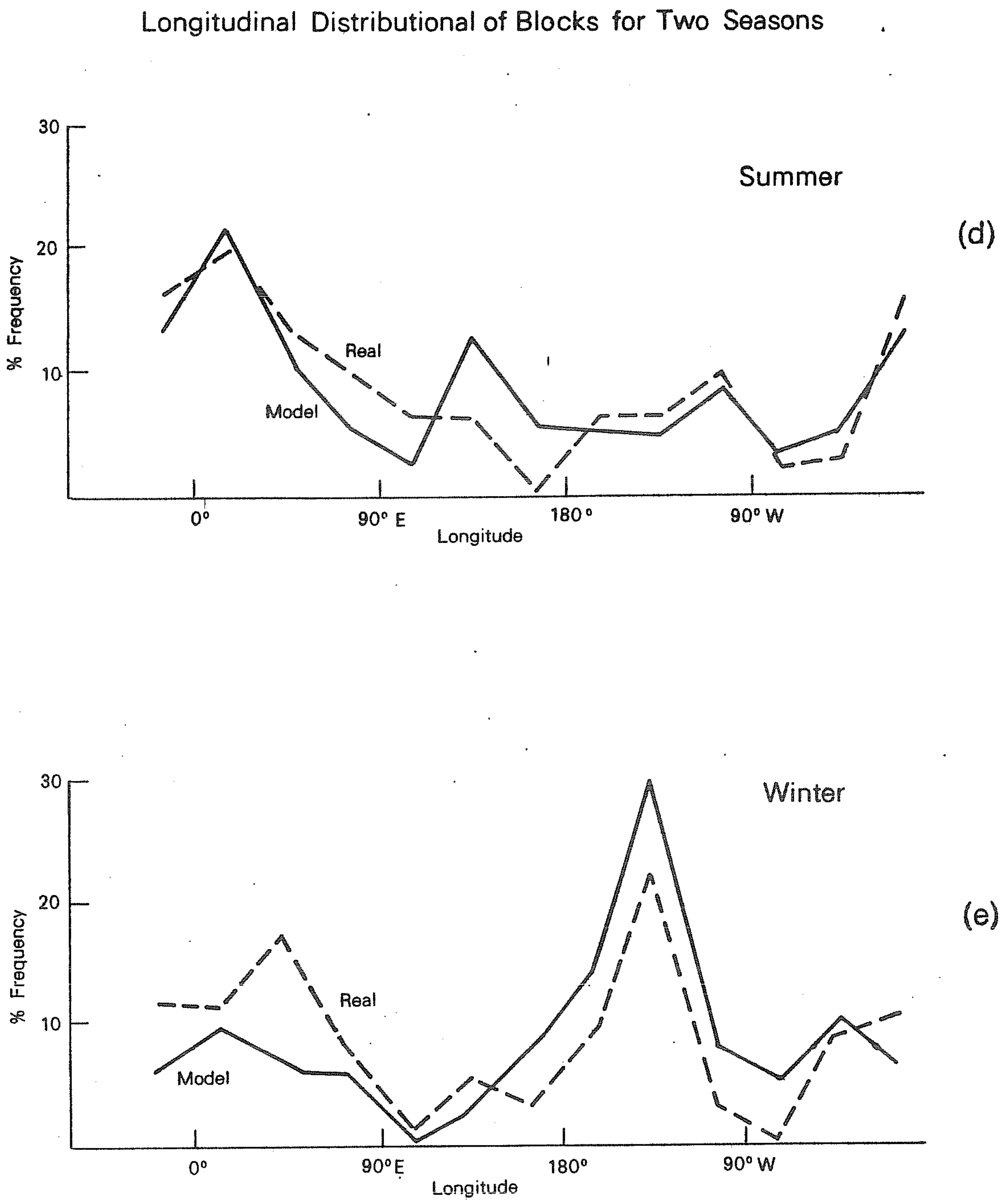


Fig. 5 (contd.) (d) distribution of blocks by longitude. Percentage frequency, using summer integrations.

(e) As (d), but using winter integrations.

the rest of the flow by jetstreams passing to the north and to the south, and that the spatial characteristics of the block cannot readily be related to the period for which it will last.

## 5. LENGTHS OF TEMPERATURE ANOMALY SPELLS

In order to compare the model's simulations of temperature spells with data such as have been presented in the first lecture, the temperatures at daily intervals have been extracted from a 3-year run of the model (it was not part of the long range forecasting experiment) at $\sigma = .9$ for a grid point over eastern England, and they were then treated in a similar fashion to the Central England temperatures already discussed. The 5-day running mean values for two complete annual cycles are shown in Figure 6(a). It is to be noted that there are substantial differences between one year and the next. A two harmonic approximation to the annual cycle has been derived separately for the two years, and shows up the generally higher temperatures in the second winter. However, the severest cold spell occurred in March of that year, with values more than $10^{\circ}$C below the estimated normal.

The result of subjecting the daily temperatures to spectrum analysis is shown in Figure 6(b). The analysis determines dominant periods in the temperature variation that are not dissimilar from those found for Central England temperatures. There is ample evidence that the model variables contain a substantial proportion of their variance in periods between 10 and 100 days.

## 6. AN EXAMPLE OF A LONG RANGE FORECAST SHOWING APPARENT SKILL

As is to be expected, some of the integrations in the long range forecasting experiment show little skill beyond the first few days. This is the general behaviour to be expected from the comparatively simple model that was used, and from current ideas on the limited range of deterministic prediction. However, on occasions the integrations maintain a useful resemblance to the atmosphere for much longer periods; they deserve special study to determine the circumstances and to derive if possible some rationale to explain the variations in forecasting skill.

Here, I present a particular forecast which verified well against the large scale features of the atmosphere for at least 20 days. It was the best forecast in the first full year of the experiment 1979-80, and as may be expected from earlier discussion of the model integrations, it applied to a winter situation.

The initial data referred to 18 January 1980, and the integration was carried on for 50 days until 8 March. Hovmuller diagrams for the latitude $45-55^{\circ}$N for waves 1-5 of the 500 mb contour charts are shown in Figure 7. Figures 7(a) and (b)

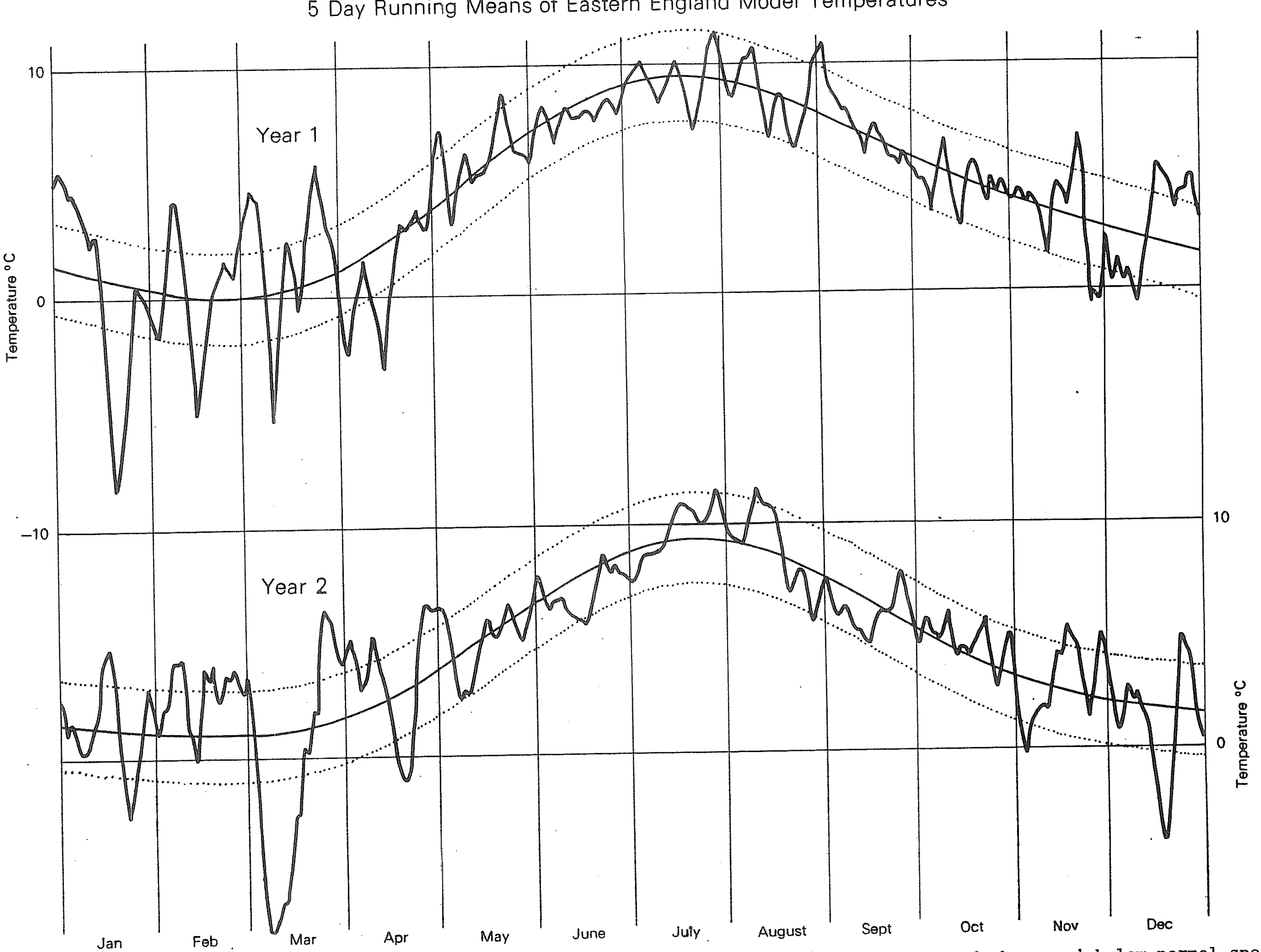
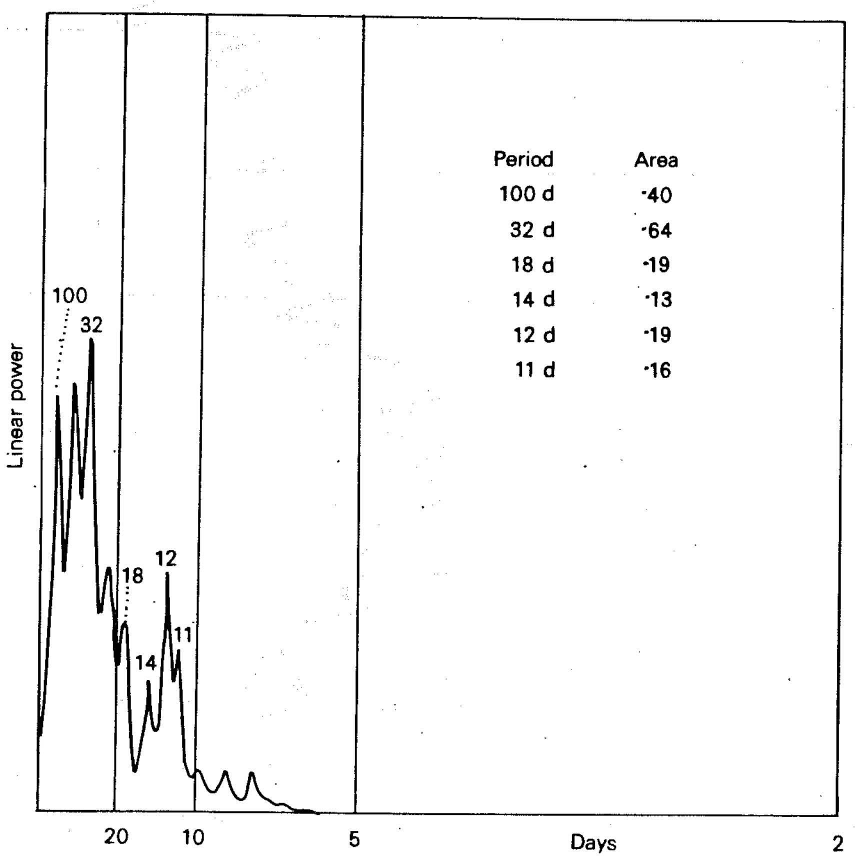


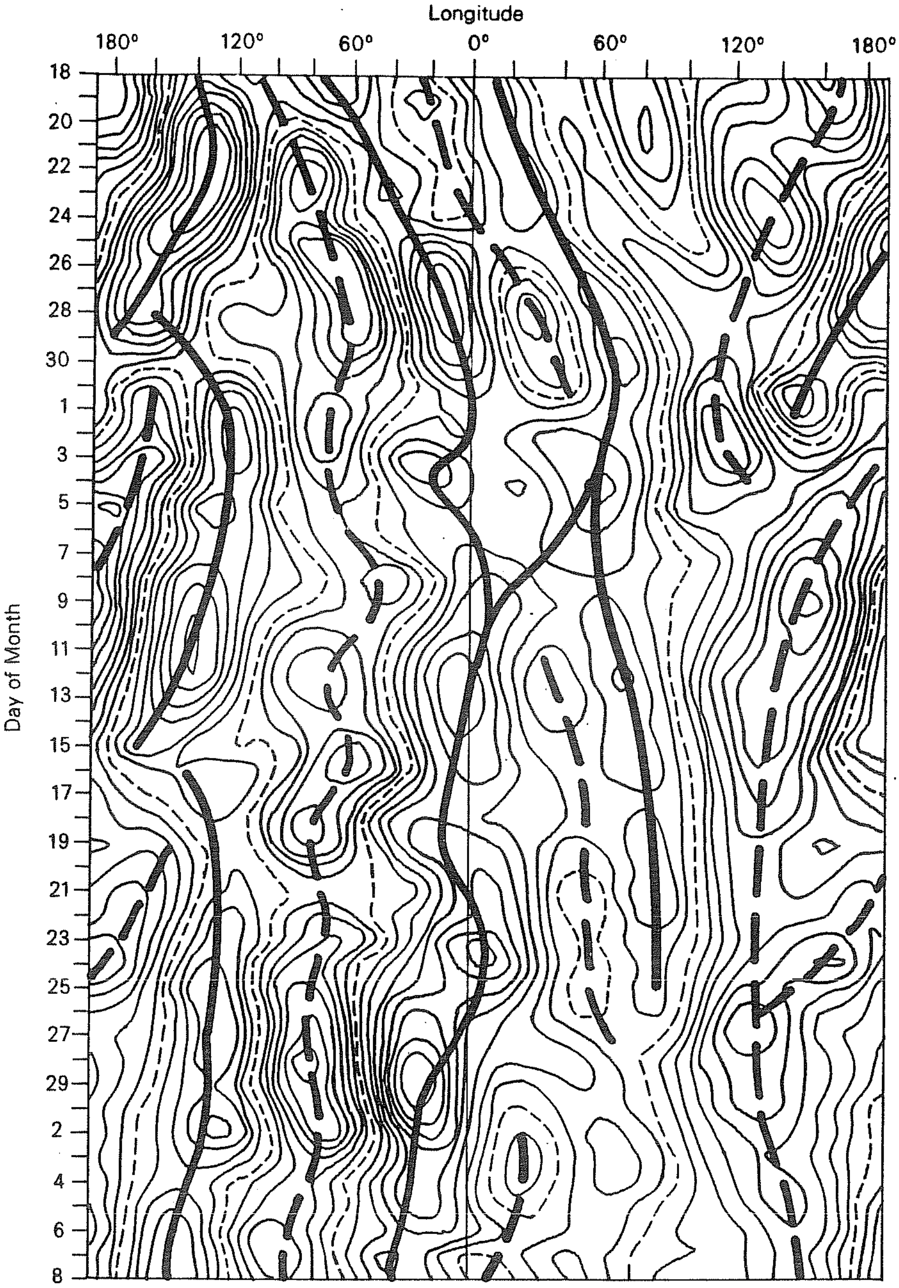
Fig. 6 Variation of $\sigma = .9$ temperature at a grid-point in Eastern England to illustrate length of above and below normal spells.
(a) 5-day average temperatures from 2 complete years of a 3-year integration. Thinner smooth line shows a 2-term harmonic fitted to the individual years.

# 5 Day Running Means of Daily Eastern England Model Temperatures



| Period | Area |
|---|---|
| 100 d | ·40 |
| 32 d | ·64 |
| 18 d | ·19 |
| 14 d | ·13 |
| 12 d | ·19 |
| 11 d | ·16 |

Fig.6 (contd.) (b) spectral analysis of departures of temperature from normal (based on average 2-term harmonic fit).



Hövmuller diagram 500 mb Waves 1 – 5

January 18 1980 – March 8 1980

(Real data)

Fig. 7 Integration from real data for 18 January 1980 compared with actual. Hovmüller diagrams $45^{o}-55^{o}N$, 500 mb, waves 1-5.

(a) atmospheric data, January 18-March 8, 1980.

Hövmuller diagram 500 mb Waves 1 — 5

January 18 1980 — March 8 1980

(Model Forecast)

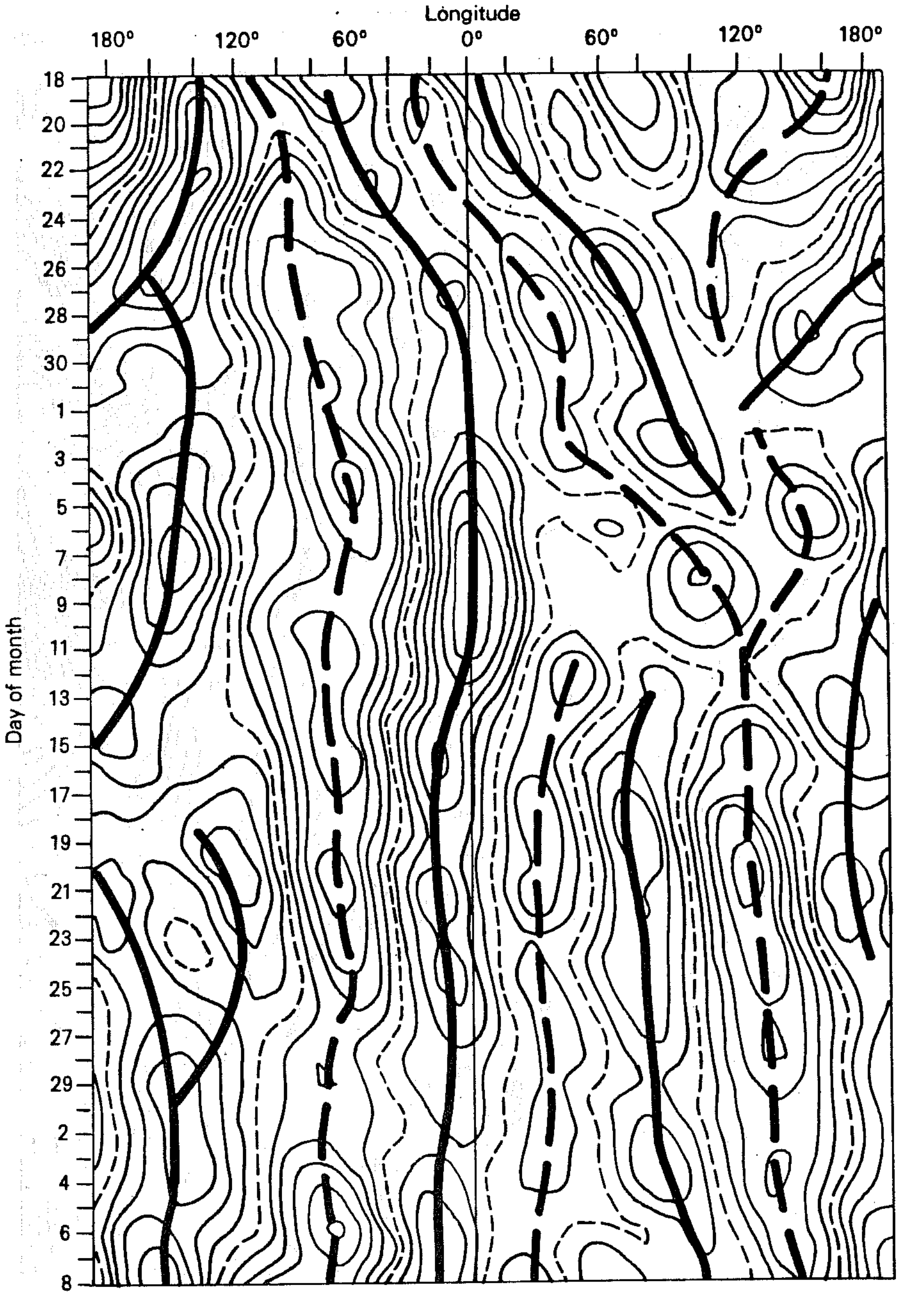


Fig. 7 (contd.) (b) model data, January 18-March 8, 1980.
Zero indicated by light dashed line. Ridges indicated by heavy full line; troughs heavy dashed line. Contour interval - 5 dam.

show the real data and model results respectively. Although the amplitudes of the waves are deficient in the model simulation, the movement of most of the main troughs and ridges has been reproduced with reasonable accuracy. Notably one may cite:

(i) the ridge initially near 140°W. After slight progression, it retrogresses and declines in intensity to reach 160°E by the end of January. It reforms in early February and again retrogresses, becoming weak in mid-February. Later it again reforms. All these variations have a counterpart in the model simulation.

(ii) the initially weak trough at about 110°W. The trough moves east as it intensifies to reach 70°W towards the end of January. It then remains around this position, with substantial variations in intensity from time to time. The integration captures the initial movement and intensification, though it is somewhat slow on both counts and reaches its maximum intensity only in early February. Thereafter its position changes little.

(iii) the ridge, initially at about 80°W. The ridge moves to the longitude of the British Isles by the end of January, is then quasi-stationary for most of February and finally tends to retrogress to about 30°W. The model similarly moves this ridge to 0°W by the end of January, though its intensity is underestimated. It stays in this position until mid-February and then moves to about 20°W.

On the whole the features of the eastern hemisphere are less well handled, though there are certainly some aspects which accord with reality. They can be seen in the diagrams and will not be further elaborated here.

To see how the situation at the surface was handled, Figure 8(a) - (l) show the mean sea-level pressure charts for the 6 pentads from 21 January to 19 February, actuals and model simulations. For the first pentad (days 3-7 of the forecast), there is a good correspondence between the positions of features even if the intensities are significantly wrong (Figures 8(a) and (b)). We note for example the lows near the British Isles, over Newfoundland, over northern Siberia at about 80°E, over the Pacific at about 160°E; and the ridges over western America and northern Siberia at about 140°E. In the next pentad (Figures 8(c) and (d)), the Atlantic is dominated by a single large cyclone, and the high over America has moved towards the centre of the continent. The low which was over the British Isles has moved east, allowing a ridge to build near the Greenwich meridian. The Siberian anticyclone has intensified and the main

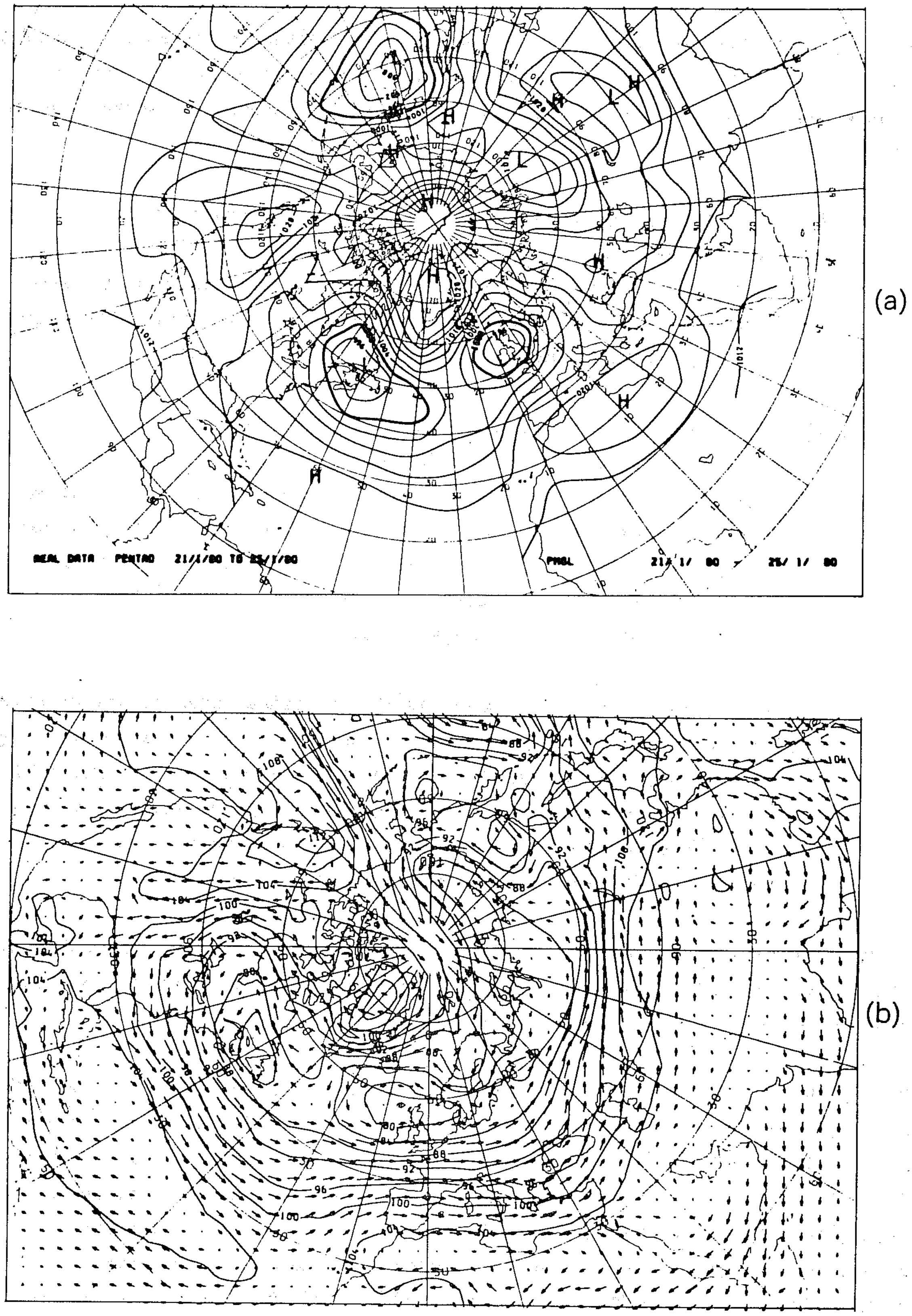


Fig. 8 Integration from real data for 18 January 1980. Pentad mean values of atmospheric and normal data; actual PMSL charts (top) and model 900 mb contours and winds (bottom) on following pages for successive pentads.

(a),(b) 21-25 January 1980.

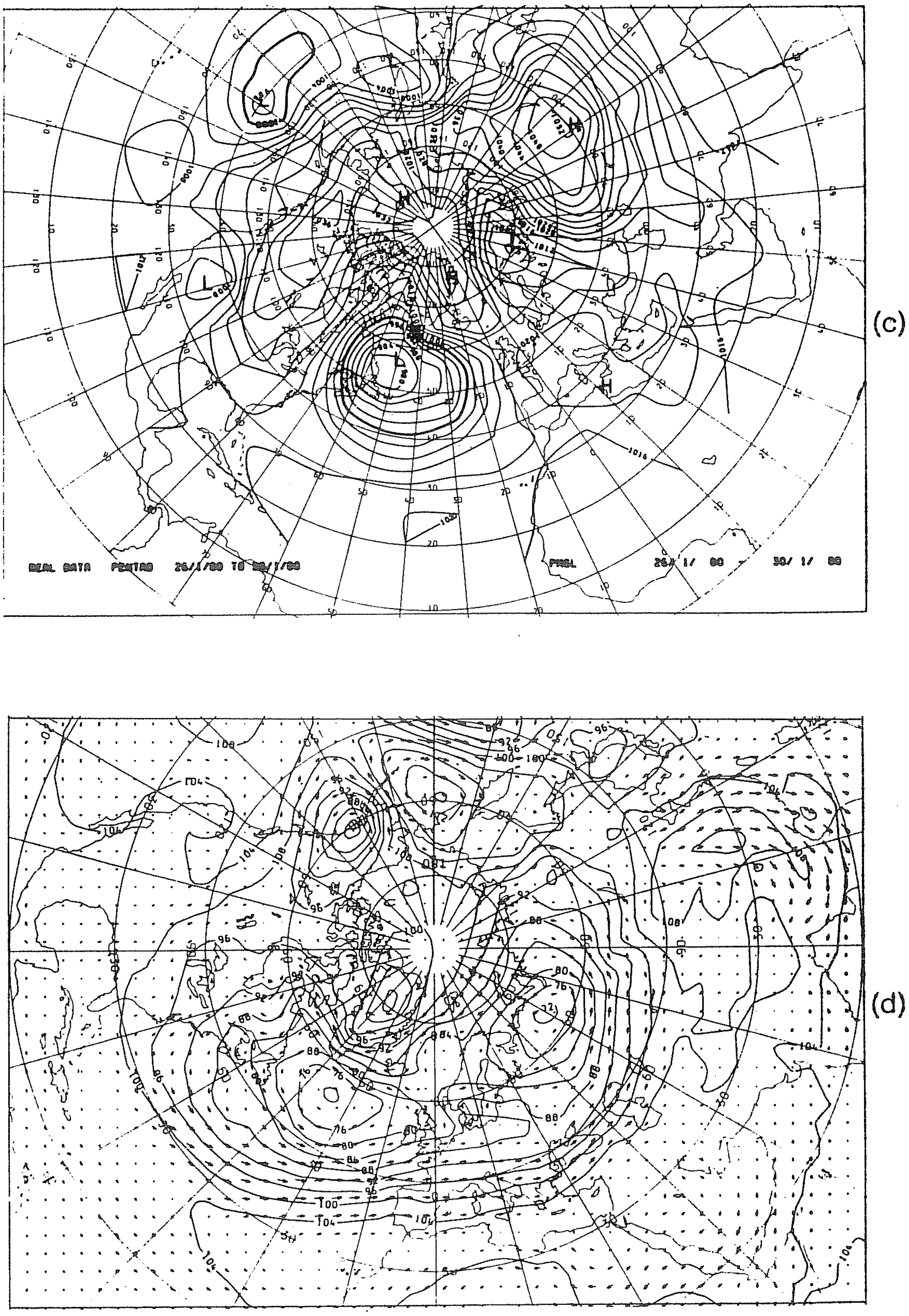


Fig. 8 (contd.) (c),(d) 26-30 January 1980.

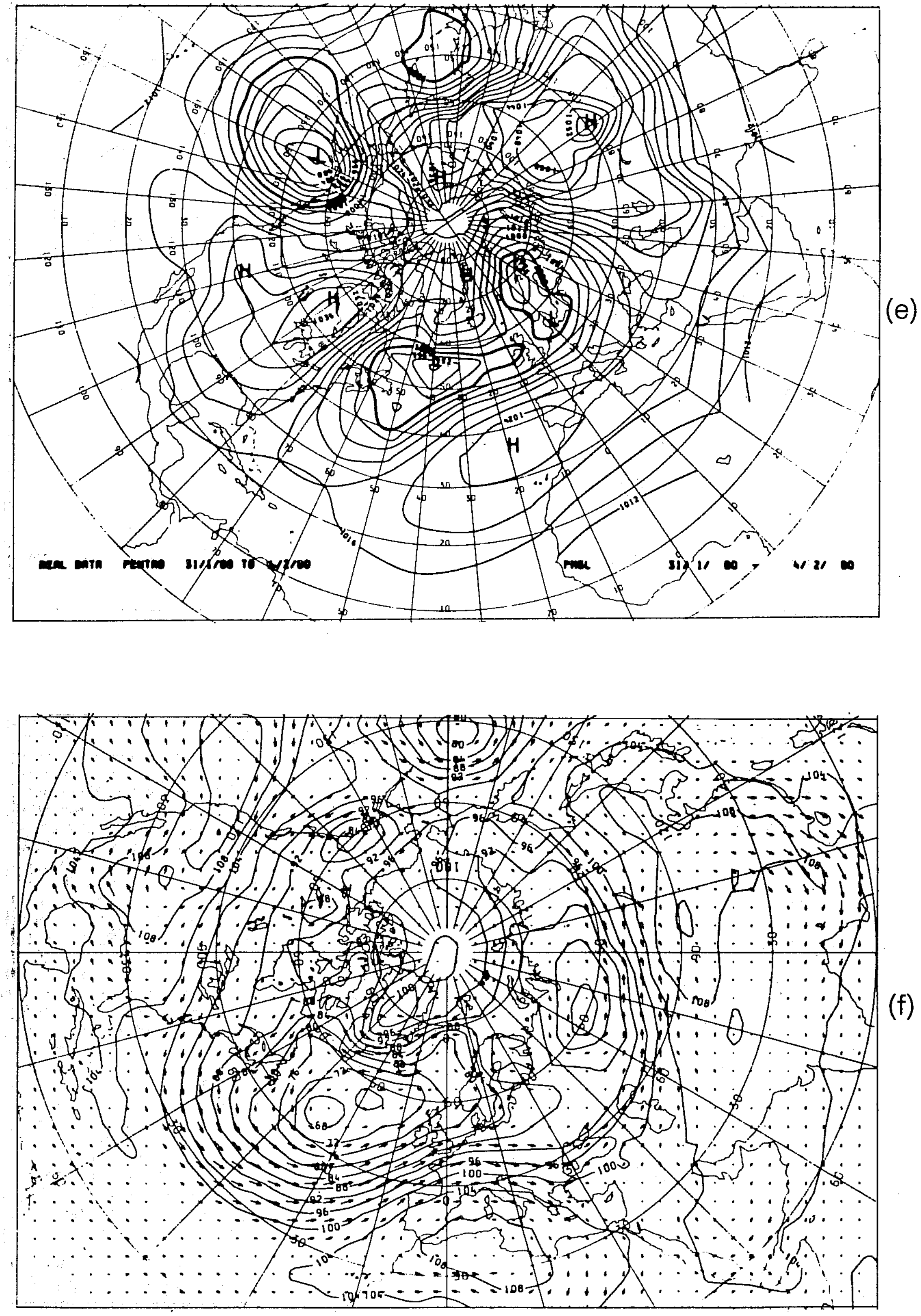


Fig. 8 (contd.) (e),(f) 31 January - 4 February 1980.

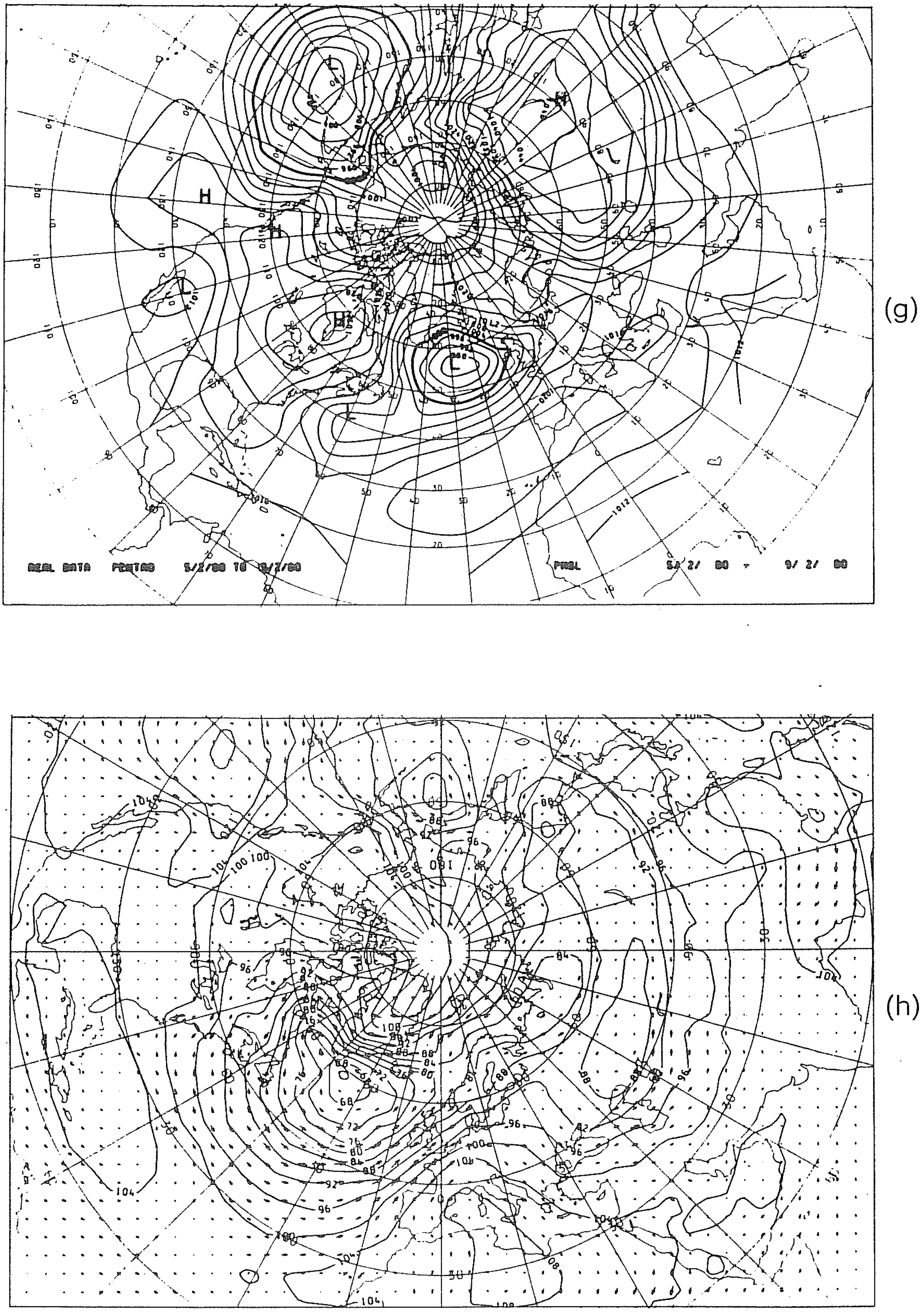


Fig. 8 (contd.) (g),(h) 5-9 February 1980.

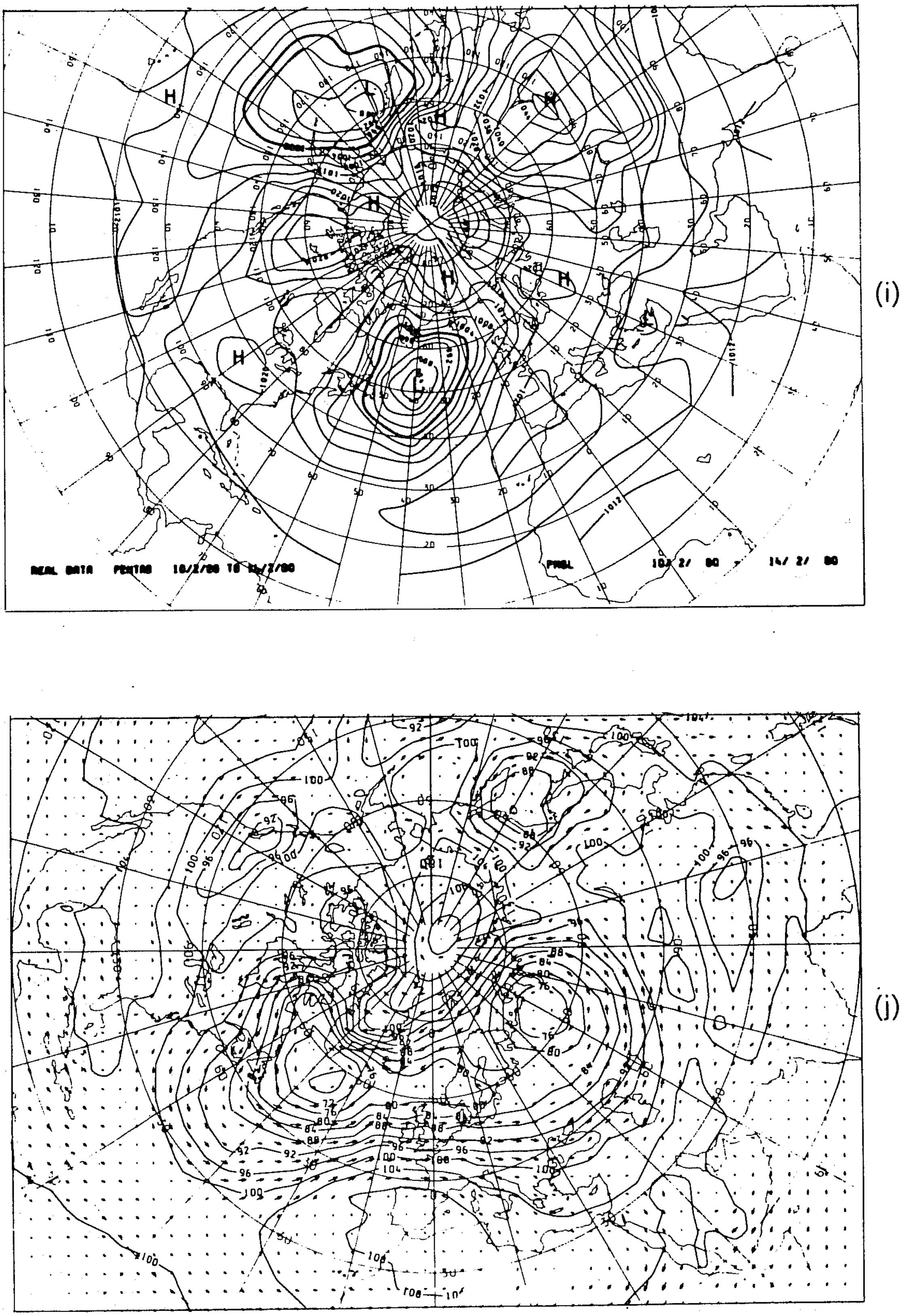


Fig. 8 (contd.) (i),(j) 10-14 February 1980.

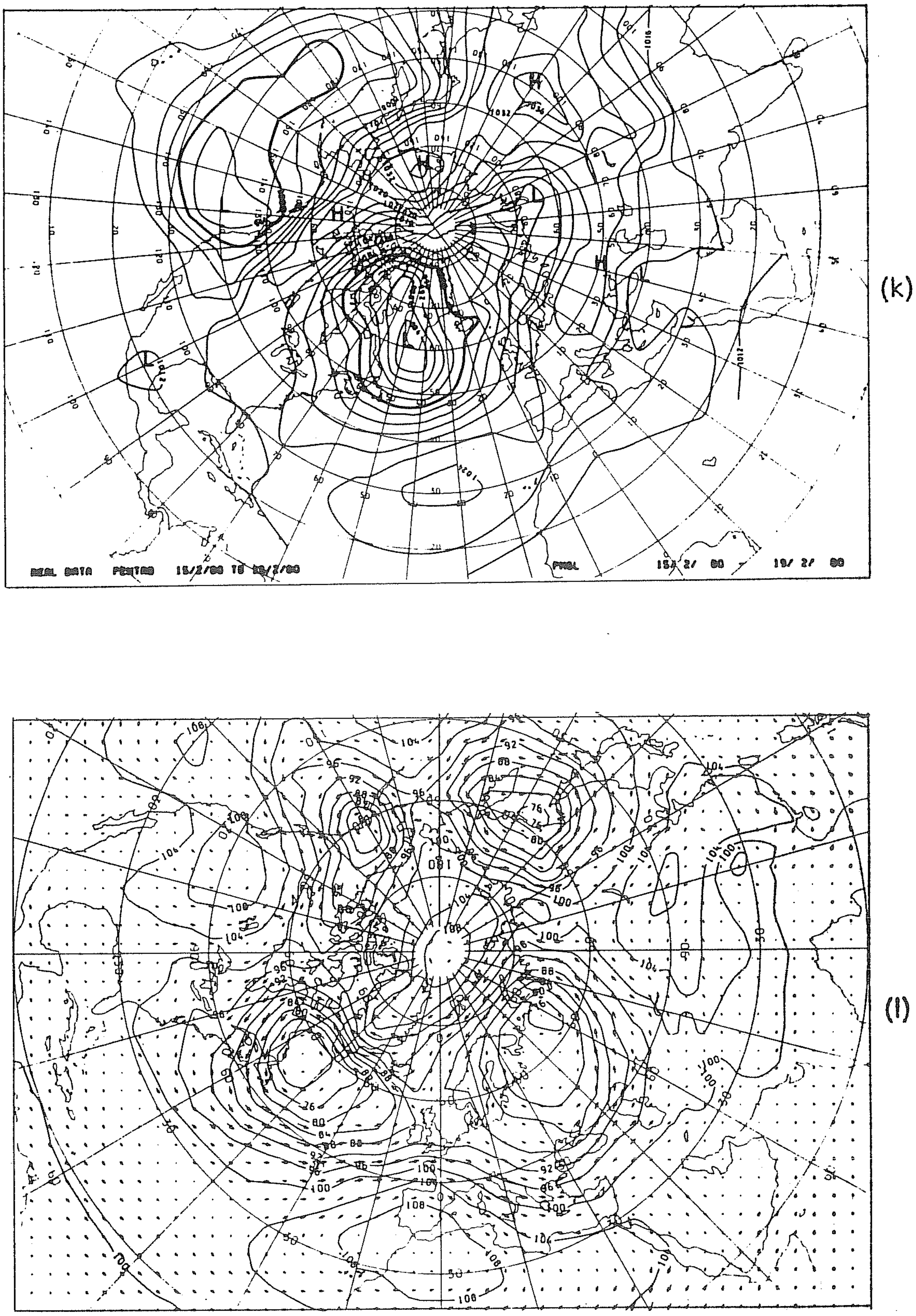


Fig. 8 (contd.) (k),(l) 15-19 February 1980.

Pacific low has moved to east of the 180 meridian. In the simulation, the Atlantic low is too far east, as is the ridge which is at 20°E rather than at 0°, but the developments have clearly occurred in the correct way. By the third pentad (Figures 8(e) and (f)) the high over America is on the eastern side of the continent and low pressure has extended across the British Isles and Scandinavia from the Atlantic; in the Pacific the main low centre is in the Gulf of Alaska. The model's simulation departs very substantially from the actual in the Pacific, with pressure too high over Japan and neighbouring oceanic areas, but elsewhere the developments generally can still be seen to correspond in some measure with actuality. During the fourth pentad (Figures 8(g) and (h)) the predominantly wave-2 pattern is clear on both charts. In the fifth (Figures (i) and (j)), there is a high pressure ridge stretching from the Atlantic across the whole of Euro-Asia, and the centre of high pressure over America has been re-established west of its previous position. In the last pentad shown, (Figures 8(k) and (l)) the Atlantic low has retrogressed to about 50°W both in reality and in the simulation. In the model this has allowed a ridge to develop over the British Isles, a development which in reality occurred in the next pentad (Feb. 20-24). The tendency for low pressure to penetrate into the American continent is reproduced to some extent.

Forecasts which are able to follow general developments in the atmosphere for long periods $\sim$ 20-30 days, even although the detailed features show large errors, probably involve a 'chance' element in their success; that is, one must expect that other integrations starting from a closely related atmospheric situation would develop differently after the initial period. However, it seems inconceivable that results such as those shown here occur purely by chance. On this occasion fairly coherent large scale changes with a time span of several pentads can be discerned, and the model has apparently some skill in reproducing them. It is clearly of the utmost importance for long range forecasting that we seek further understanding of this capability in models.

## 7. CONCLUSIONS

The experiment reported here on the introduction of numerical general circulation models into long range forecasting has so far been exploratory in nature. Our view is that, for the foreseeable future, model integrations must be regarded as providing an additional piece of evidence which, in the hands of 'conventional' long range forecasters, is capable of supplementing the methods and knowledge already available to them. This parallels the way in which numerical methods were introduced to forecasting for shorter ranges. In that case progress was slow and it took about two decades before the numerical product was considered sufficiently good to weaken substantially the forecasters reliance on subjective methods. Progress in long range forecasting may be even slower because the problems are more difficult and only the most hopeful can see cause for expecting sudden changes in the level of forecasting skill.

The most obvious way in which numerical models might be used in the first instance is to improve the forecasting of lengths of spells. At present, the concept of spells or weather types underlies, either explicitly or implicitly, the practice of long range forecasting, and the information available to forecasters is deduced from the historical data on similar spells. Model integrations could be used either to supplement the data base on which deductions have to be made or to select from the observational data base those occasions which are most relevant to the spell type being considered.

The longer term aim of the experiment is to devise an optimum strategy for the use of numerical models in long range forecasting, but an essential prerequisite is a greater knowledge and appreciation of the characteristics of general circulation models. By studying results appropriate to a wide variety of initial conditions and presenting them to long range forecasters, as well as to the dynamical meteorologists who were initially responsible for creating the models, the necessary knowledge is being extended and spread to those who need to know. I have tried to show some of the results achieved in this process, concentrating on the positive aspects rather than belabouring, once again, the problems and difficulties. Although the latter are daunting, and many integrations seem to provide little immediately useful guidance to the long range forecaster, there are surprising successes and an adequate number of hopeful indications to convince me that the general approach is right and should be pursued as vigorously as possible.

It is clear from some of the results that I have shown that the general circulation model used in the experiments so far is not ideal for the purpose. The immediate task in hand is to select and implement a more adequate model which it will be possible to accommodate on the Meteorological Office's CYBER 205 computer. We may expect that a future report will document the extent of its success in providing what the long range forecaster requires.

## 8. ACKNOWLEDGMENTS

In preparing these lectures I have drawn freely on the work and advice of scientists in the Synoptic and Dynamical Climatology branches of the Meteorological Office. The work is theirs and I have merely used it to present some personal views largely based on the results.

## 9. REFERENCES

Corby, G.A., Rowntree, P.R., Gilchrist, A., 1977, United Kingdom Meteorological Office five-level general circulation model. Methods in Comp. Physics, 17, 67-110. Academic Press.

Gilchrist, A., 1977, An experiment in extended range prediction using a general circulation model and including the influence of sea-surface temperature anomalies. Beitr. Phys. Atmos. 50, 25-40.

Gilchrist, A., 1979, The Meteorological Office 5-layer general circulation model. GARP Publication Series, No. 22, Vol. 1, WMO, Geneva, 254-295.

Mansfield, D.A., 1981, The incidence of blocking in the Meteorological Office's 5-level model. Met O 13 Branch Memorandum No. 99. Obtainable from the Meteorological Office, AD Met O(SC), London Road, Bracknell, Berks.

Opsteegh, J.D. and Van den Dool, H.M., 1980, Seasonal differences in the stationary response of a linearised primitive equation model: prospects for long-range weather forecasting? J. Atmos. Sci., 37, 2169-2185.

Painting, D.J., 1977, A study of some aspects of the climate of the northern hemisphere in recent years. Meteorological Office Scientific Paper No. 35, H.M.S.O.