# MET O 11 TECHNICAL NOTE NO 146

## SUBJECTIVE ASSESSMENTS OF MEDIUM-RANGE FORECASTS PRODUCED BY ECMWF AND METEOROLOGICAL OFFICE OPERATIONAL NUMERICAL MODELS

by

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## 1. Introduction

The European Centre for Medium-range Weather Forecasts (ECMWF) has issued forecasts for up to seven days ahead since August 1979; the forecasts are produced daily, but prior to August 1980, were not issued on Fridays and Saturdays, and are based on data (analysis) time of 1200 GMT. Charts of the 1000 mb and 500 mb contour prognoses have been available at the Meteorological Office in Bracknell, where the medium-range forecasters in the Central Forecast Office (CFO) are able to make use of them.

Starting in September 1979, Met O 11 have made detailed subjective assessments of the guidance value of the ECMWF product and that of the Meteorological Office's own operational 10-level (Octagon) model. These assessments are carried out for two areas, one covering eastern USA, the North Atlantic and Europe (a sector north of $30^{\circ}$N, from $90^{\circ}$W to $40^{\circ}$E) and the other, a small subset of the first, covering the United Kingdom and Republic of Ireland ($49^{\circ}$-$61^{\circ}$N, $13^{\circ}$W-$4^{\circ}$E). Findlater (1980) and Jones and Findlater (1980) have already described the main results arising out of the first six months (September 1979-February 1980) of the assessments; this note attempts to update those reports by presenting the results of the first complete year of the project (September 1979-August 1980).

In the meantime, the assessments are continuing over the autumn and winter 1980-81.

## 2. The numerical models

The ECMWF model is global with a regular latitude-longitude grid having a grid-length of $1.875^{\circ}$ (approximately 210 km x 180 km at $60^{\circ}$N); it has 15 $\sigma$-coordinate levels in the vertical ($0.996\,\sigma$ to $0.025\,\sigma$) and uses a semi-implicit time integration scheme based on a 15-min time-step. The adiabatic formulation of the model is described by Burridge and Haseler (1977) and the physical parameterization schemes ('physics') by Tiedtke et al (1979); some modifications have been incorporated into the model during the period of subjective assessments.

The UK Meteorological Office operational (Octagon) model covers an octagonal area of the northern hemisphere north of 15°N, centred on the North Pole. The regular square grid (on a polar stereographic map projection) within this area has a grid spacing of 300 km at 60°N. In the vertical, there are ten equally spaced levels with pressure as the vertical coordinate (1000 mb-100 mb), and a split explicit time integration scheme, as described by Gadd (1978), is used with a time-step of 30 mins. The basic model was described by Burridge and Gadd (1977) although some of the details have gradually been modified.

## 3. Model products

Although EMCWF produced global analyses and forecasts, for up to ten days ahead, from data time 1200 GMT on Sundays to Thursdays inclusive, the forecast charts received at Bracknell covered only a sector including eastern USA, the North Atlantic and Europe (north of 30°N, 90°W-40°E roughly) and for up to seven days ahead.

In the Central Forecast Office at Bracknell the fields of surface pressure, 1000-500 mb thickness, and by implication the 500 mb contours, are forecast five days ahead for general operational forecasting purposes. These subjectively drawn charts are based mainly on the Octagon model output but the confidence ratings of the forecasts, and the forecast fields themselves, are influenced by consideration of numerical forecasts from the United States, West Germany and ECMWF. If the ECMWF forecast agrees with the German and/or United States forecast, and is significantly different from the Octagon forecast, the latter may be modified accordingly, but the forecaster also has to take into account the known characteristics/defects of the various models.

The ECMWF forecasts are not used directly for forecasting rainfall, temperature or wind for specific days, but for assisting with the general synoptic-scale evolution. The scheduling of these products is such that they are received after the main distribution of Meteorological Office products, but they are considered in conjunction with Octagon model forecasts based 12 hours later (at the following midnight). The Octagon model produces forecasts up to six days ahead; in addition, since 14 January 1980, the Octagon 7-day forecast based on 1200 GMT every Monday has been available.

## 4. Characteristics of the models

All numerical weather prediction models exhibit tendencies or biases, and these may be particularly evident in certain synoptic situations or may often be associated with well defined fixed geographical features. Throughout this project of subjective assessments, attempts are made to identify any such idiosynchrasies of the respective models, particularly in the case of the relatively novel ECMWF model. To a certain extent, several years of regular operational experience with Octagon products has helped to establish a well-founded knowledge of the characteristic behaviour of that model in a wide range of synoptic situations.

Many of the impressions of model behaviour gained during the first six months of the project remain unaltered since that period included the autumn and winter seasons, with the northern hemisphere circulation in its most active phase of the annual cycle. For the sake of completeness and ease of reference, the main characteristics described by Jones and Findlater (1980) based on the first six months are re-iterated below, with some elaboration, qualification and additions stemming out of the experience with the models during the second six-month period (spring and summer 1980). Various examples of the behaviour of the ECMWF model, alluded to in this section, are presented in the Appendix together with brief descriptions of the main features of interest. Since, as already pointed out, the characteristics of the Octagon model are reasonably well known, it is considered unnecessary in this note to dwell on similar examples of forecast sequences from that model.

A particular characteristic which has emerged during the assessments has been the capability of both models to follow individual features such as fronts (particularly cold fronts) or troughs on many occasions from the analysis through to day 6 or 7, and to predict their development is a realistic fashion. This feature of the forecasts has been noted with sufficient regularity to demonstrate the capability of both models to deal with synoptic-scale features provided that the analysed fields (D + 0) are adequate. In addition, up to day 3 or 4 the development of new depressions in areas of frontogenesis is often well indicated, but, on the other hand, if substantial developments occur (in reality) at or after day 4, it is often the case that these developments are poorly modelled or missed altogether.

The ECMWF model is generally very active, maintaining well the strength of the main upper flows, both zonal and meridional components, whereas the Octagon has a distinct tendency to weaken them with time, particularly their meridional components. The ECMWF model's development of new depressions from shallow wave features moving into regions of frontogenesis, such as that along the eastern coast of USA in winter, often appears convincingly realistic; more often than not the rate of deepening and phase speed of new depressions in the early stages of development is quite well predicted, particularly when this occurs before day 4 (D + 4) in the forecast sequence (see, for example, Fig A1 in the Appendix), although, as with most numerical models, there is frequently a tendency for the phase and development of such features to lag behind the real atmospheric evolution (Fig A2). However, during the first six-month period (autumn and winter 1979-80) the ECMWF model occasionally exhibited a tendency to overdevelop depressions in forecasts for D + 3 and later (eg D + 3 in Fig A3 and D + 5 onwards in Fig A1), and sometimes incorrectly forecast them to become large slow-moving features near Iceland by D + 5 to D + 7, dominating much of the eastern Atlantic and northern Europe (Fig A1). It is worth pointing out that this defect has not been particularly prevalent in the second six-month period covering the spring and summer seasons, nor has it been a particular problem in the three months (September-November 1980) that have elapsed since the end of the one-year period considered in this note. During the period examined, modifications to the ECMWF model have been introduced from time to time (eg modifications to the representation of surface exchanges - see ECMWF (1979)), and it is possible that the defect which was responsible for the occasional overdevelopment of depressions has been eliminated. An associated problem which arose during the winter season was that in isolated cases two large depressions were forecast to co-exist in close proximity (Fig A4); this seldom occurs in the real atmosphere.

Although the early stages of the development of new depressions were often adequately predicted by the ECMWF model, there was ample evidence that, in the case of mature depressions the model frequently failed to turn them to the left of their original tracks (Figs A4 and A5), as frequently happens in the real atmosphere; in fact the tracks of major depressions and anticyclones were often predicted to be further south than the actual tracks. This is associated with the tendency for the ECMWF model's jet stream axes to be too far south.

In contrast the Octagon has a distinct bias towards zonal flow; meridional developments tend to be underforecast with the typical result than central pressures of surface depressions, particularly those in the developing stage, are not predicted low enough. However, in spite of this, the timing of events and the positions of the main synoptic systems were often good, and changes of synoptic type were often quite well predicted by the Octagon. On the evidence of the second six-month period examined, the ECMWF model appears to be about as good as or better than the Octagon at indicating changes of type, although, as reported by Jones and Findlater (1980), during the first six-month period the Octagon held the advantage in this respect. Nevertheless, the ECMWF model's ability to predict changes of type during the winter months was occasionally in evidence (Fig A6). Although both models usually provide good indications of secondary developments such as triple-point depressions and secondary depressions on cold fronts, they both tend to mis-time the development of these short-wave features and to underestimate their phase speed.

Both models are capable of producing reasonable predictions of the disruption of upper troughs and the subsequent formation of cut-off vortices, the ECMWF model more frequently being the superior in this respect (Fig A7), particularly, it seems, when the cut-off vortex forms south of about 40°N, in the Mediterranean for example. (This is not inconsistent with the ECMWF model's propensity for meridional developments). However, the process of disruption usually occurs a lot more rapidly than predicted by either model with the typical consequence that the low-latitude axis of the disrupting trough is carried too far east in the forecast.

Developments in the Mediterranean were not particularly well predicted by either model, although the Octagon performed better than the ECMWF model during the first six months and incursions of cold air into the area were quite well timed up to D + 4; there is also evidence to suggest that, once formed, the movement of upper vortices across the Mediterranean and Black Sea areas was better handled by the ECMWF model.

During the first six months both models tended to predict 850 mb temperatures too low south of 40°N in the Atlantic, Iberia and N African regions; in particular the Octagon model typically forecast 850 mb temperatures to be 4-8 deg C too low in these areas by D + 6. Insufficient allowance for warming by subsidence and convection, especially that due to the release of latent heat in the convection process, appeared to be the cause. Over the second six-month period this tendency has persisted with the Octagon, particularly in association with the Azores anticyclone, but has not been so much in evidence in the ECMWF 850 mb temperature fields.

A peculiarity of the Octagon model which does not seem to be shared by the ECMWF model is a tendency for the 850 mb temperatures to be too high in frontal troughs and too low in mobile ridges. Indeed, a noticeable feature is that the axis of a cold trough in the forecast 850 mb isotherms was usually coincident with the surface ridge axis and remained so during the forecast period; the normal process of the thermal trough moving to the east of the surface ridge axis was not usually reproduced.

During the first six-month period, it was noted that the ECMWF model occasionally produced 500 mb contour and temperature fields around depressions which appeared to be inconsistent with the predicted subsequent movement of the depression; this tendency was not noticed during the second six-month period.

The characteristics of the two models are summarised in Table 1.

## 5. Assessment scheme

The main aim of the project is to assess the information content of the numerical model forecasts (D + 1 to D + 7) and hence their value as guidance to forecasters. In an attempt to overcome the many difficulties, noted by Findlater (1980), associated with subjective assessment, a very simple and general scheme for the assessment of the forecasts was adopted; it is based on a scheme used in the Central Forecast Office for the subjective assessment of forecasts (by experienced forecasters). There are three "guidance value" categories used:-

A - Good guidance

B - Did not lead to any major error

C - Misleading in some important respect

For each weekly sequence of forecasts, the charts for D + 1 to D + 7 at 500 mb and surface/1000 mb were individually assessed by a meteorologist with good experience of synoptic forecasting. Separate assessments are made for the two areas:-

(i) "WHOLE AREA" - Covering a sector north of 30°N, from 90°W-40°E.

(ii) "UK AREA" - 49°-61°N, 13°W-4°E.

The assessment attempts to take account of the various constituent elements of the weather, as inferred from the predicted pressure distribution; qualitative impressions of temperature, wind (speed and direction), general weather type (including likelihood of precipitation) can all be inferred. In addition the sequence of events indicated by the forecast is taken into account. Within the scheme adopted, the guidance value frequently depends to some extent on the forecast period; for instance a moderate displacement of a particular feature from its actual position at D + 1 or D + 2 is generally regarded as a more serious error than the same displacement at D + 5 or D + 6, when the forecast should be taken to give only a general indication of the positions and tracks of synoptic-scale systems.

Apart from the subjective assessment described above, actual and predicted zonal and meridional indices at 500 mb for the UK area were logged for each of the weekly sequences. The zonal index was measured from 50°N to 60°N at 5°W, and the meridional index from 13°W to 4°E at 55°N. Some results of the analysis of these data are shown in section 6.

In his preliminary report on the first six months Findlater pointed out that an element of personal bias may inevitably be inherent in the assessment scheme, and he attempted to illustrate the point, highlighting particularly the degree of subjectivity involved in attaching particular elements of weather to the forecast contour pattern. In this context, it is important to note that, for the first six months, all the assessments were carried out by J Findlater, while one of the co-authors of this note, B A Hall, took over the task for the second half of the year. Caution should therefore be exercised in the interpretation of the statistics arising out of the first six months as compared with those from the second six-month period, although it is considered that the performances of the models relative to each other are not significantly affected by the change of assessor.

## 6. Results

In this section the content of the Tables and Figures which present the main results in various alternative formats will first be described, followed by a discussion of the main points arising.

The overall performance of the two models in terms of the guidance value classifications (A, B, C) is summarised in Figures 1-6. Figures 1 and 2 show the distributions of A, B and C classifications for D + 1 to D + 7 for the first six-month period (Fig 1) and the second six-month period (Fig 2), hereinafter referred to as periods I and II respectively, while the results for the year as a whole appear in Fig 3. Within each figure the results for each area (WHOLE AREA and UK AREA) and level (SURFACE/1000 mb and 500 mb) are presented separately*. Figures 4 (period I), 5 (period II) and 6 (whole year) present the same results, expressed in percentages (A and C classifications only), in graphical format,

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* Note that during the first six-month period only 7 Octagon sequences were assessed (14/1/80-25/2/80) while in the second six-month period 25 were assessed (D + 7 forecast for 4/8/80 was not available).

from which it is easier to appreciate the relative performances of the models, (the Octagon figures for D + 7 for period I have not been plotted as there were only 7 cases assessed).

Tables 2-4 attempt to answer some specific questions about the performances of the two models. These questions are:-

(i) At D + N in the forecast sequence, how often was the ECMWF forecast better than the Octagon (by at least one category), and vice versa?

This question relates solely to the relative performance of the two models; Table 2 provides the answers. The main figures here are for the whole year (52 sequences for days 1-6, 32 sequences for day 7), while the figures in parentheses are for period I (upper figure) and period II (lower figure) separately.

(ii) How often did the forecast sequence provide reasonable guidance (ie no "C" marks) up to and including D + N?

Table 3 and Figures 7 (period I), 8 (II) and 9 (whole year) provide the answers to this question which is the corollary of another that is also answered in this Table; this is:-

(iii) How often did the first "C" marking within the forecast sequence occur at D + N?

(The results for D + 7 are not included in Table 3 and Figures 7-9). A further question concerning the relative performance of ECMWF and Octagon forecast sequences follows on naturally from question (ii); this is:-

(iv) Within the sequences assessed, how often did the ECMWF model retain A/B marks longer than the Octagon, and vice versa?

Table 4 provides the answers to this question (only the sequences from D + 1 to D + 6 have been considered).

To a certain extent many of the Figures and Tables referred to above speak for themselves, but it is worth highlighting several points arising.

The overriding impressions gained from examination of Figures 1-2 and 4-5 are that:-

(a) Over the first six-month period (I) there was little significant difference between the two models, with the possible exception that at 500 mb for days 3-6, the ECMWF model achieved a greater percentage of "A" marks than the Octagon (for example, 46% versus 34% at D + 4 for the UK area).

(b) By contrast, over the second six-month period (II), there is clear evidence that, for the whole area, the ECMWF model performed a lot better than the Octagon at days 3 and 4, and, to a lesser extent, at day 5 (based on percentages of "C" classifications). For the UK area no such distinction between the models is apparent, with the exception that at day 3 the ECMWF model is better.

Separate brief appraisals of the results for each area/level, with particular reference to Tables 2, 3 and 4 and Figures 7-9, are probably worthwhile.

WHOLE AREA, SURFACE

At days 2, 3 and 4 the ECMWF model shows marked superiority; at day 4, for instance, the ECMWF product was at least one category better than the Octagon product in 19 (out of 52) cases (Table 2a), while the Octagon proved at least one category better than the ECMWF model in only 7 cases. A similar result shows up (Table 2a) at day 3 for which, during period I, the ECMWF model was better on 5 occasions and the Octagon better on a further 5 occasions, while, rather remarkably during period II, the ECMWF model proved superior in 10 (out of 26) cases and the Octagon failed to better the ECMWF product in any of the (D + 3) forecasts assessed. At days 5 and 6 the Octagon had the better overall record, due mainly to its much better relative performance in period I; by day 7 there is little to choose between the models. Table 3a and Fig 9 reveal a similar relative performance of the models; for instance 37 (71%) of the ECMWF forecast sequences provided reasonable guidance (ie no "C" marks) up to and including day 4, while the corresponding figure for the Octagon was 26 (50%). Table 4 (surface/1000 mb, whole area) shows that although neither model exhibited any monopoly in scoring over the other (14-12), the Octagon proved more reliable in period I (8-3), while the ECMWF model was much the better in period II (11-4).

WHOLE AREA, 500 mb

In Table 2b the results are broadly similar to those in Table 2a, except that the ECMWF model's overall superiority at days 3 and 4 is carried through to day 5 and, to a lesser extent, to days 6 and 7. The great improvement in the relative performance of the ECMWF forecasts after the first few months is again strikingly obvious for days 3-6, but most particularly at day 4. Table 3b and Fig 9 shows that the ECMWF model provided reasonable guidance to day 4 on 38 occasions (73%) and to day 5 on 28 occasions (54%), while the corresponding figures for the Octagon were 31 (60%) and 20 (38%). Table 4 confirms the superiority of the ECMWF model at 500 mb for the whole area (21-11 in favour of ECMWF), but note that in period I there was nothing to choose between the models (8-8), while in period II the ECMWF forecast sequence proved superior much more often than the Octagon (13-3).

UK AREA, SURFACE

Here again (Table 2c) the ECMWF model appears marginally superior at days 3 and 4, although the superiority is not as marked as in Tables 2a and 2b; at days 5 and 6 however the Octagon forecast was better. Indeed, in Table 3c and Fig 9 the only significant difference in performance between the two models is for days 5 and 6 where the Octagon achieved more success, providing reasonable guidance to day 5 in 24 cases (46%) and to day 6 in 22 cases (42%); the corresponding figures for the ECMWF model were 18 (35%) and 13 (25%). Table 4 shows that the ECMWF sequence scored over the Octagon about as frequently as the Octagon scored over ECMWF (18-20). Again, some improvement in the performance of the ECMWF model relative to the Octagon is evident in period II as compared to period I.

UK AREA, 500 mb

The indications from Table 2d are that, for days 3-7, the ECMWF model scored over the Octagon more frequently than the Octagon scored over the ECMWF model (most obviously at days 3 and 5), due mainly to the improved performance of the ECMWF model in period II. However this superiority does not show up at all in Table 3d and Fig 9 where the performances of the two models are virtually indistinguishable, implying that, in most cases where the ECMWF model scored over the Octagon by only one category (see Table 2d), the difference in the marking was A-B rather than B-C. Table 4 indicates that, as at the surface for the UK area, there is little to choose between the performances of the models.

An interesting general point which arises out of examination of many of the Figures and Tables is that, if the percentage frequencies of "C" marks for the surface/1000 mb forecasts are considered, there appears to be a tendency for the relative performance of the two models to reverse at or after day 5, so that, at days 5, 6 and 7 the Octagon suffers a smaller percentage of "C" marks than the ECMWF model, (this is not apparent at the 500 mb level). This tendency can probably be explained partly in terms of the relative characteristics of the models, already discussed in section 4. In the large majority of cases when the ECMWF model became misleading at, say, day 4 or earlier (perhaps due to the overdevelopment of a depression), the model had become so fully "committed" to a particular train of atmospheric evolution, carrying it through to day 7 in a positive and active (and often convincingly realistic) fashion, that the guidance value of model fields deteriorated very quickly as they diverged increasingly from the truth. This comment is particularly relevant to the forecast 1000 mb fields where poor marks at day 4 and after were frequently attributable (in period I) to the overdevelopment of depressions. This characteristic behaviour of the ECMWF model contrasts strongly with that of the Octagon for which the forecast fields often become less well-defined with time as, typically, depressions are not developed sufficiently and a general tendency towards reduced meridionality is common. This general characteristic of the Octagon was often seen to be beneficial to the quality of the forecast in that even when it became misleading ("C" mark) at day 3 or 4, the Octagon managed to regain "B" marks later in the sequences (at days 5, 6 or 7) on a significant number of occasions, this usually being achieved in situations when the real atmosphere, for the area in question, was losing kinetic energy and major synoptic systems were in a state of decline. Note that in Figures 7-9 the forecast is effectively regarded as having broken down irretrievably on the day when the first "C" mark occurs; no credit is given when "A" or "B" marks are regained after the first "C" occurred.

The mean errors (forecast minus actual) at day 5 in zonal and meridional indices for the UK area are shown in Figures 10a and 10b respectively; the errors have been categorised according to actual zonal (westerly component positive) or meridional (southerly component positive) index. Fig 10a confirms the commonly observed tendency of most numerical models to overforecast zonality in weak zonal flow and to underforecast it in strong zonal flow; from this point of view the ECMWF model appears to have performed slightly better than the Octagon. Fig 10b shows that the strength of meridional components tends to be underestimated in the forecasts; again, the ECMWF model on this evidence is the more accurate of the two models, but note that there is a suggestion that it models southerly flows better than northerly flows (no such discrimination is apparent for the Octagon model).

## 7. Concluding remarks

This programme of subjective assessment of ECMWF and Meteorological Office operational numerical model forecasts has shown that:

(a) Over the first six months (3/9/79-25/2/80) neither model proved to be superior to the other in any consistent fashion.

(b) Over the second six-month period (3/3/80-25/8/80) a marked improvement in the performance of the ECMWF model relative to the Octagon is undeniable, and this improvement is particularly noticeable at days 3 and 4 *if* the assessments for the whole area are taken into account.

(c) Over the complete year, considering only surface pressure (or 1000 mb contour) forecasts for the <u>whole area</u>, the ECMWF model's forecast sequence provided reasonable guidance (no "C" marks) up to and including days 3, 4, 5 and 6 on 90%, 71%, 40% and 25% of occasions respectively; the corresponding figures for the Octagon were 81%, 50%, 40% and 33%. At the surface for the UK area, the corresponding figures were 81%, 62%, 35% and 25% for the ECMWF model and 77%, 58%, 46% and 43% for the Octagon.

It is uncertain to what extent the documented improvement in the ECMWF model's forecasts is due to seasonal influences, and to what extent it can be attributed to improvements to the model. The programme of subjective assessments is continuing over the autumn/winter 1980-81 in order to help resolve this uncertainty. Throughout the year the characteristic vigour of the ECMWF model has contrasted strongly with the relatively subdued behaviour of the Octagon, especially in forecasts for day 3 and later. During the first six months the occasional overdevelopment of depressions by the ECMWF model was undoubtedly a cause for concern; however, it should be said that, in the opinion of the authors, this problem has not been particularly prevalent during the second six months, nor indeed in the 3 months (September-November 1980) that have elapsed since the end of the period reported on.

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TABLE 1 - A summary of the characteristics of the Octagon and ECMWF medium-range forecasts

| | Model | |
|---|---|---|
| | Octagon | ECMWF |
| Very small features handled well . . . . . . . . . . . | NO | NO |
| 500 mb flow becomes too zonal . . . . . . . . . . . | YES | NO |
| " " " " " meridional . . . . . . . . . | NO | YES* |
| " " " " " weak . . . . . . . . . . . . | YES | NO |
| " " " " " strong . . . . . . . . . . . | NO | NO |
| Central pressure of lows not deep enough . . . . . | YES | NO |
| " " " " too deep . . . . . . . . . | NO | YES* |
| Developing lows fail to turn left . . . . . . . . . | YES | YES |
| Good with trough distuption . . . . . . . . . . . . | YES | YES |
| Good with changes of type . . . . . . . . . . . . . | YES | YES |
| Fills old lows too quickly . . . . . . . . . . . . | YES | NO |
| Weakens old highs too quickly . . . . . . . . . . . | YES | - |
| Often runs 1 day slow by Day 6 . . . . . . . . . . . | YES | - |
| 850 mb temperatures too low south of 40°N . . . . | YES | YES* |
| 500 mb contours too low south of 40°N . . . . . . . | YES | YES |
| 850 mb temperatures too high in troughs . . . . . | YES | - |
| Ridge axes too cold at 850 mb . . . . . . . . . . . | YES | NO |
| New lows off US deepen quickly enough . . . . . . . | NO | YES |
| New lows in Atlantic absorbed by parent low . . . | YES | NO |
| Parent low absorbed by new lows . . . . . . . . . . | NO | YES |
| Low circulations too small . . . . . . . . . . . . . | YES | NO |
| " " " large . . . . . . . . . . . . . . | NO | YES* |
| Tracks of systems too far south . . . . . . . . . . | - | YES |
| 500 mb jet often too far south . . . . . . . . . . . | - | YES |
| Mediterranean depressions handled well . . . . . . . | YES* | NO* |
| Cold air incursions into Mediterranean well timed. | - | YES |
| Occasional inconsistent surface and upper patterns | NO | YES* |
| Handles cut-off lows well . . . . . . . . . . . . . | NO | YES |

* Judgement based mainly on period I (autumn/winter) - see text.

TABLE 2. Comparative performance of ECMWF (EC) and Met.Office (MO) models.

(a) SURFACE/1000mb — WHOLE AREA

(upper figure in parentheses is for first 6-month period, lower figure for last 6-month period)

| | DAY (N) | | | | | | |
|---|---|---|---|---|---|---|---|
| | N=1 | 2 | 3 | 4 | 5 | 6 | 7 |
| EC two categories better | — | — | 3 (1 / 2)* | 5 (2 / 3) | 2 (1 / 1) | 1 (1 / 0) | 1 (0 / 1) |
| EC one category better | — | 8 (3 / 5) | 12 (4 / 8) | 14 (5 / 9) | 7 (2 / 5) | 5 (3 / 2) | 3 (0 / 3) |
| same category for both models | 51 (26 / 25) | 42 (23 / 19) | 32 (16 / 16) | 26 (15 / 11) | 27 (11 / 16) | 35 (15 / 21) | 23 (6 / 17) |
| MO one category better | 1 (0 / 1) | 2 (0 / 2) | 5 (5 / 0) | 5 (2 / 3) | 14 (10 / 4) | 9 (6 / 3) | 4 (0 / 4) |
| MO two categories better | — | — | — | 2 (2 / 0) | 2 (2 / 0) | 2 (1 / 1) | 1 (1 / 0) |

(b) 500mb — WHOLE AREA

| | DAY (N) | | | | | | |
|---|---|---|---|---|---|---|---|
| | N=1 | 2 | 3 | 4 | 5 | 6 | 7 |
| EC two categories better | — | — | 2 (1 / 1) | 4 (3 / 1) | 5 (4 / 1) | 5 (5 / 0) | 2 (1 / 1) |
| EC one category better | — | 3 (2 / 1) | 12 (5 / 7) | 16 (3 / 13) | 11 (3 / 8) | 9 (2 / 7) | 4 (0 / 4) |
| same category for both models | 52 (26 / 26) | 49 (24 / 25) | 34 (16 / 18) | 25 (14 / 11) | 28 (14 / 14) | 28 (12 / 16) | 23 (5 / 18) |
| MO one category better | — | — | 4 (4 / 0) | 5 (4 / 1) | 7 (5 / 2) | 8 (6 / 2) | 3 (1 / 2) |
| MO two categories better | — | — | — | 2 (2 / 0) | 1 (0 / 1) | 2 (1 / 1) | — |

TABLE 2. Comparative performance of ECMWF (EC) and Met.Office (MO) models.

(c) SURFACE/1000mb U.K. AREA

| | DAY (N) | | | | | | |
|---|---|---|---|---|---|---|---|
| | N=1 | 2 | 3 | 4 | 5 | 6 | 7 |
| EC two categories better | — | 1 (0, 1) | 4 (1, 3) | 5 (4, 1) | 2 (1, 1) | 1 (1, 0) | 2 (1, 1) |
| EC one category better | — | 6 (4, 2) | 11 (5, 6) | 10 (3, 7) | 8 (3, 5) | 7 (5, 2) | 7 (3, 4) |
| same category for both models | 52 (26, 26) | 41 (22, 19) | 29 (15, 14) | 25 (14, 12) | 21 (9, 10) | 29 (12, 17) | 17 (19, 16) |
| MO one category better | — | 4 (0, 4) | 6 (4, 2) | 11 (5, 6) | 15 (8, 7) | 10 (6, 4) | 3 (0, 3) |
| MO two categories better | — | — | 2 (1, 1) | 1 (1, 0) | 6 (3, 3) | 5 (2, 3) | 3 (1, 2) |

(d) 500mb U.K. AREA

| | DAY (N) | | | | | | |
|---|---|---|---|---|---|---|---|
| | N=1 | 2 | 3 | 4 | 5 | 6 | 7 |
| EC two categories better | — | — | 1 (0, 1) | 4 (3, 1) | 4 (2, 2) | 4 (1, 3) | 3 (1, 2) |
| EC one category better | 1 (0, 1) | 3 (2, 1) | 12 (6, 6) | 9 (3, 6) | 15 (4, 11) | 14 (8, 6) | 6 (1, 5) |
| same category for both models | 51 (26, 25) | 48 (23, 25) | 34 (16, 18) | 29 (15, 14) | 23 (13, 10) | 19 (8, 11) | 18 (3, 15) |
| MO one category better | — | 1 (1, 0) | 5 (4, 1) | 6 (3, 3) | 9 (7, 2) | 11 (5, 6) | 2 (1, 1) |
| MO two categories better | — | — | — | 4 (2, 2) | 1 (0, 1) | 4 (4, 0) | 3 (1, 2) |

TABLE 3. Number of occasions A/B marks retained up to Day N.

(a) SURFACE/1000mb    WHOLE AREA

| | | DAY (N) N=1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| No. of occasions when A/B marks retained up to and including day N | EC | 52 (26/26)* | 51 (25/26) | 47 (24/23) | 37 (19/18) | 21 (13/8) | 13 (10/3) |
| | MO | 52 (26/26) | 51 (25/26) | 42 (23/19) | 26 (16/10) | 21 (16/5) | 17 (12/5) |
| No. of occasions when first C marking occurred at day N | EC | — | 1 (1/0) | 4 (1/3) | 10 (5/5) | 16 (6/10) | 8 (3/5) |
| | MO | — | 1 (1/0) | 9 (2/7) | 16 (7/9) | 5 (10/5) | 4 (4/0) |

(b) 500mb    WHOLE AREA

| | | DAY (N) N=1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| No. of occasions when A/B marks retained up to and including day N | EC | 52 (26/26) | 52 (26/26) | 47 (24/23) | 38 (17/21) | 28 (16/12) | 13 (9/4) |
| | MO | 52 (26/26) | 51 (25/26) | 46 (24/22) | 31 (18/13) | 20 (14/6) | 14 (10/4) |
| No. of occasions when first C marking occurred at day N | EC | — | — | 5 (2/3) | 9 (7/2) | 10 (1/9) | 15 (7/8) |
| | MO | — | 1 (1/0) | 5 (1/4) | 15 (6/9) | 11 (4/7) | 6 (4/2) |

* within the parentheses, the upper figure refers to the first 6-month period, while the lower figure refers to the last 6-month period.

TABLE 3. Number of occasions A/B marks retained up to Day N.

(c) SURFACE/1000mb U.K. AREA

| | | DAY (N) | | | | | |
|---|---|---|---|---|---|---|---|
| | | N=1 | 2 | 3 | 4 | 5 | 6 |
| No. of occasions when A/B marks retained up to and including day N | EC | $52\binom{26}{26}$ | $51\binom{25}{26}$ | $42\binom{20}{22}$ | $32\binom{16}{16}$ | $18\binom{12}{6}$ | $13\binom{8}{5}$ |
| | MO | $52\binom{26}{26}$ | $49\binom{25}{24}$ | $40\binom{21}{19}$ | $30\binom{16}{14}$ | $24\binom{13}{11}$ | $22\binom{12}{10}$ |
| No. of occasions when <u>first</u> C marking occurred at day N | EC | — | $1\binom{1}{0}$ | $9\binom{5}{4}$ | $10\binom{4}{6}$ | $14\binom{4}{10}$ | $5\binom{4}{1}$ |
| | MO | — | $3\binom{1}{2}$ | $9\binom{4}{5}$ | $10\binom{5}{5}$ | $6\binom{3}{3}$ | $2\binom{1}{1}$ |

(d) 500mb U.K. AREA

| | | DAY (N) | | | | | |
|---|---|---|---|---|---|---|---|
| | | N=1 | 2 | 3 | 4 | 5 | 6 |
| No. of occasions when A/B marks retained up to and including day N | EC | $52\binom{26}{26}$ | $52\binom{26}{26}$ | $47\binom{24}{23}$ | $36\binom{18}{18}$ | $30\binom{17}{13}$ | $18\binom{9}{9}$ |
| | MO | $52\binom{26}{26}$ | $51\binom{25}{26}$ | $48\binom{25}{23}$ | $35\binom{19}{16}$ | $30\binom{18}{12}$ | $18\binom{12}{6}$ |
| No. of occasions when <u>first</u> C marking occurred at day N | EC | — | — | $5\binom{2}{3}$ | $11\binom{6}{5}$ | $6\binom{1}{5}$ | $12\binom{8}{4}$ |
| | MO | — | $1\binom{1}{0}$ | $3\binom{0}{3}$ | $13\binom{6}{7}$ | $5\binom{1}{4}$ | $12\binom{6}{6}$ |

E.R.

TABLE 4. Number of occasions when the ECMWF (EC) model retained A/B marks longer than the Octagon (MO), and vice versa.

| | SURFACE/1000mb | | 500 mb | |
|---|---|---|---|---|
| | WHOLE AREA | U.K. AREA | WHOLE AREA | U.K. AREA |
| No. of occasions when EC retains A/B marks longer than MO | 14 (3 / 11)* | 18 (7 / 11) | 21 (8 / 13) | 15 (6 / 8) |
| No. of occasions when A/B marks retained to same day by both models | 26 (15 / 11) | 14 (9 / 5) | 20 (10 / 10) | 25 (13 / 12) |
| No. of occasions when MO retains A/B marks longer than EC. | 12 (8 / 4) | 20 (10 / 10) | 11 (8 / 3) | 13 (7 / 6) |

* within the parentheses, the upper figure refers to the first 6-month period, while the lower figure refers to the last 6-month period.

## WHOLE AREA

### SURFACE

DAY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 25/25 | 25/22 | 14/13 | 9/9 | 3/6 | 4/4 | 4/(2) |
| B | 1/1 | –/3 | 10/11 | 10/7 | 11/15 | 9/12 | 3/(1) |
| C | –/– | 1/1 | 2/2 | 7/10 | 12/5 | 13/10 | 19/(4) |

## U.K. AREA

### SURFACE

DAY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 26/26 | 25/22 | 15/13 | 10/7 | 3/9 | 7/4 | 6/(1) |
| B | –/– | –/3 | 5/10 | 10/12 | 10/9 | 4/14 | 4/(2) |
| C | –/– | 1/1 | 6/3 | 6/7 | 13/8 | 15/8 | 16/(4) |

EC/MO

EC - ECMWF model
MO - Met.Office model

## WHOLE AREA — 500 MB

DAY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 26/26 | 25/24 | 15/11 | 12/10 | 7/3 | 6/1 | 4/(1) |
| B | –/– | 1/1 | 9/14 | 6/9 | 11/13 | 5/11 | 6/(1) |
| C | –/– | –/1 | 2/1 | 8/7 | 8/10 | 15/14 | 16/(5) |

## U.K. AREA — 500 MB

DAY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 26/26 | 24/24 | 16/12 | 12/9 | 7/6 | 5/4 | 7/(2) |
| B | –/– | 2/1 | 8/14 | 6/11 | 12/14 | 8/11 | 3/(3) |
| C | –/– | –/1 | 2/0 | 8/6 | 7/6 | 13/11 | 16/(2) |

Fig. 1. Classification of ECMWF and Meteorological Office (Octagon) forecasts for the period 3/9/79 to 25/2/80. (26 forecast sequences).

## WHOLE AREA

### SURFACE

DAY (cell entries: EC / MO)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 25 / 25 | 21 / 18 | 14 / 6 | 8 / 4 | 1 / – | – / 1 | 1 / 1 |
| B | 1 / 1 | 5 / 8 | 9 / 13 | 10 / 6 | 7 / 6 | 3 / 4 | 4 / 5 |
| C | – / – | – / – | 3 / 7 | 8 / 16 | 18 / 20 | 23 / 21 | 21 / 19 |

### 500 MB

DAY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 26 / 26 | 26 / 25 | 19 / 11 | 9 / 4 | 2 / 2 | 1 / 1 | 1 / – |
| B | – / – | – / 1 | 4 / 11 | 13 / 9 | 11 / 5 | 7 / 5 | 5 / 3 |
| C | – / – | – / – | 3 / 4 | 4 / 13 | 13 / 19 | 18 / 20 | 20 / 22 |

## U.K. AREA

### SURFACE

DAY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 25 / 25 | 17 / 19 | 13 / 8 | 6 / 6 | 3 / 4 | 2 / 6 | 2 / 3 |
| B | 1 / 1 | 9 / 5 | 9 / 11 | 11 / 8 | 6 / 10 | 7 / 8 | 7 / 5 |
| C | – / – | – / 2 | 4 / 7 | 9 / 12 | 17 / 12 | 17 / 12 | 17 / 17 |

### 500 MB

DAY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 25 / 24 | 23 / 22 | 20 / 13 | 9 / 10 | 10 / 2 | 5 / 4 | 4 / 2 |
| B | 1 / 2 | 3 / 4 | 3 / 10 | 9 / 7 | 8 / 13 | 9 / 5 | 6 / 6 |
| C | – / – | – / – | 3 / 3 | 8 / 9 | 8 / 11 | 12 / 17 | 16 / 17 |

EC / MO

EC – ECMWF model
MO – Met.Office model

Fig. 2. Classification of ECMWF and Meteorological Office (Octagon) forecasts for the period 3/3/80 to 25/8/80. ( 26 forecast sequences).

## WHOLE AREA

### SURFACE

DAY (cells: EC / MO)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 50/50 | 46/40 | 28/19 | 17/13 | 4/6 | 4/5 | 5/(3) |
| B | 2/2 | 5/11 | 19/24 | 20/13 | 18/21 | 12/16 | 7/(6) |
| C | –/– | 1/1 | 5/9 | 15/26 | 30/25 | 36/31 | 40/(23) |

### 500 MB

DAY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 52/52 | 51/49 | 34/22 | 21/14 | 9/5 | 7/2 | 5/(1) |
| B | –/– | 1/2 | 13/25 | 19/18 | 22/18 | 12/16 | 11/(4) |
| C | –/– | –/1 | 5/5 | 12/20 | 21/29 | 33/34 | 36/(27) |

## U.K. AREA

### SURFACE

DAY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 51/51 | 42/41 | 28/21 | 16/13 | 6/13 | 9/10 | 8/(4) |
| B | 1/1 | 9/8 | 14/21 | 21/20 | 16/19 | 11/22 | 11/(7) |
| C | –/– | 1/3 | 10/10 | 15/19 | 30/20 | 32/20 | 33/(21) |

### 500 MB

DAY

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| A | 51/50 | 47/46 | 36/25 | 21/19 | 17/8 | 10/8 | 11/(4) |
| B | 1/2 | 5/5 | 11/24 | 15/18 | 20/27 | 17/16 | 9/(9) |
| C | –/– | –/1 | 5/3 | 16/15 | 15/17 | 25/28 | 32/(19) |

EC/MO:
EC – ECMWF model
MO – Met.Office model

Fig. 3. Classification of ECMWF and Meteorological Office (Octagon) forecasts for the period 3/9/79 to 25/8/80. ( 52 forecast sequences).

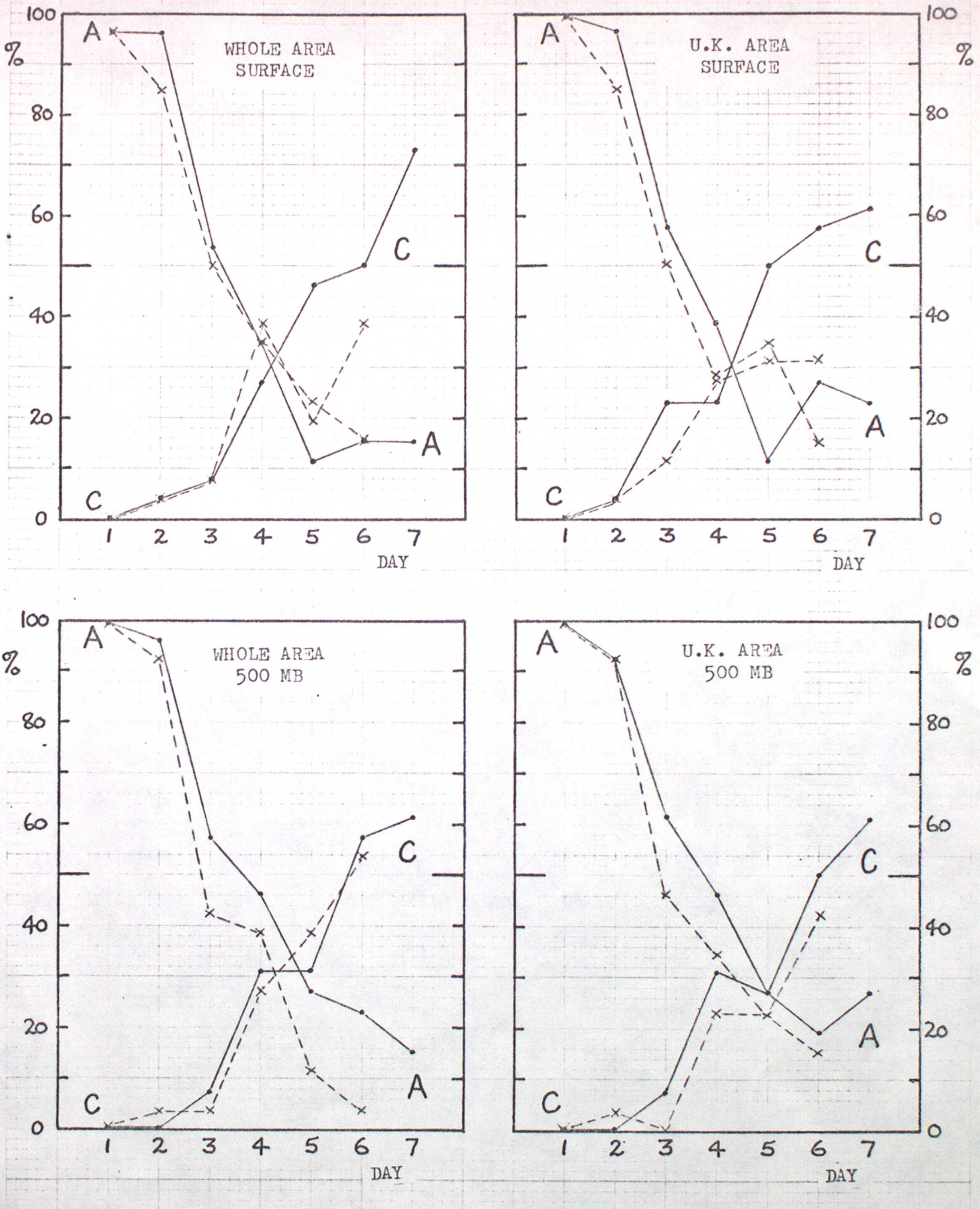



Fig. 4. Percentage of A and C classifications. 3/9/79 to 25/2/80.

•——• ECMWF model

×----× Met O model (day 7 omitted - only 7 cases)

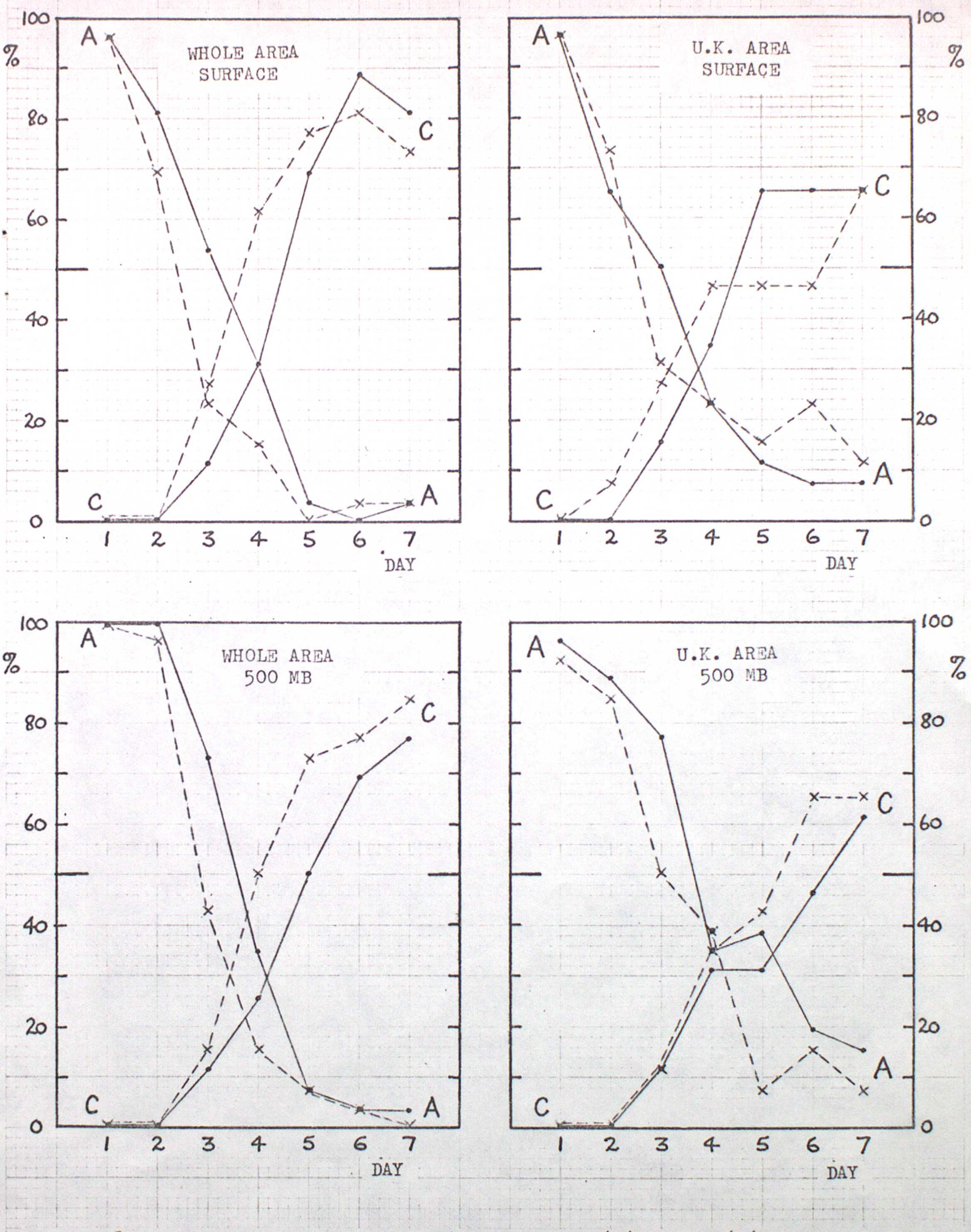



Fig. 5. Percentage of A and C classifications. 3/3/80 to 25/8/80.

•——• ECMWF model

×---× Met O model

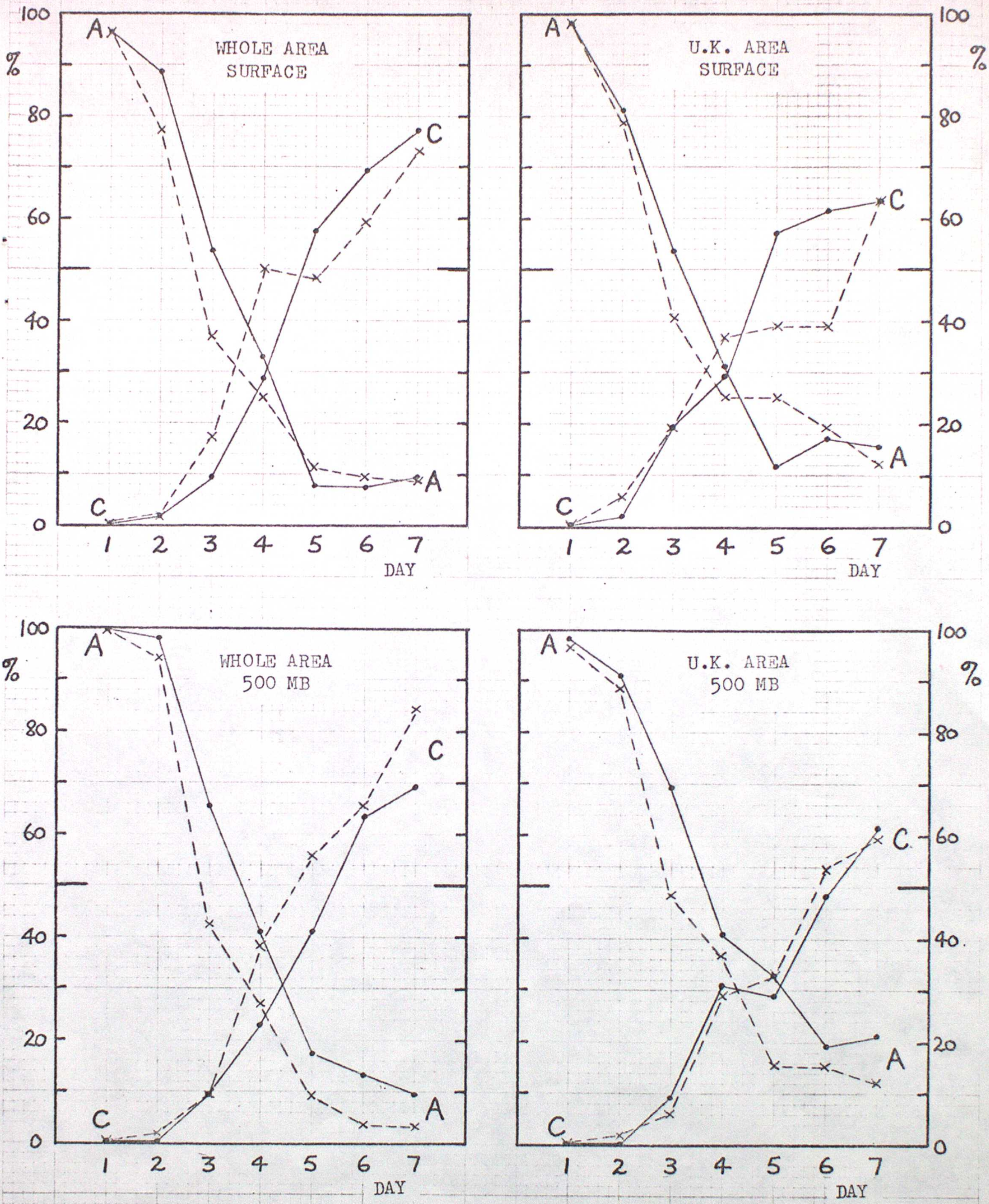



Fig. 6. Percentage of A and C classifications. 3/9/79 to 25/8/80 (whole year).

•——• ECMWF model

×----× Met O model (32 cases at day 7)

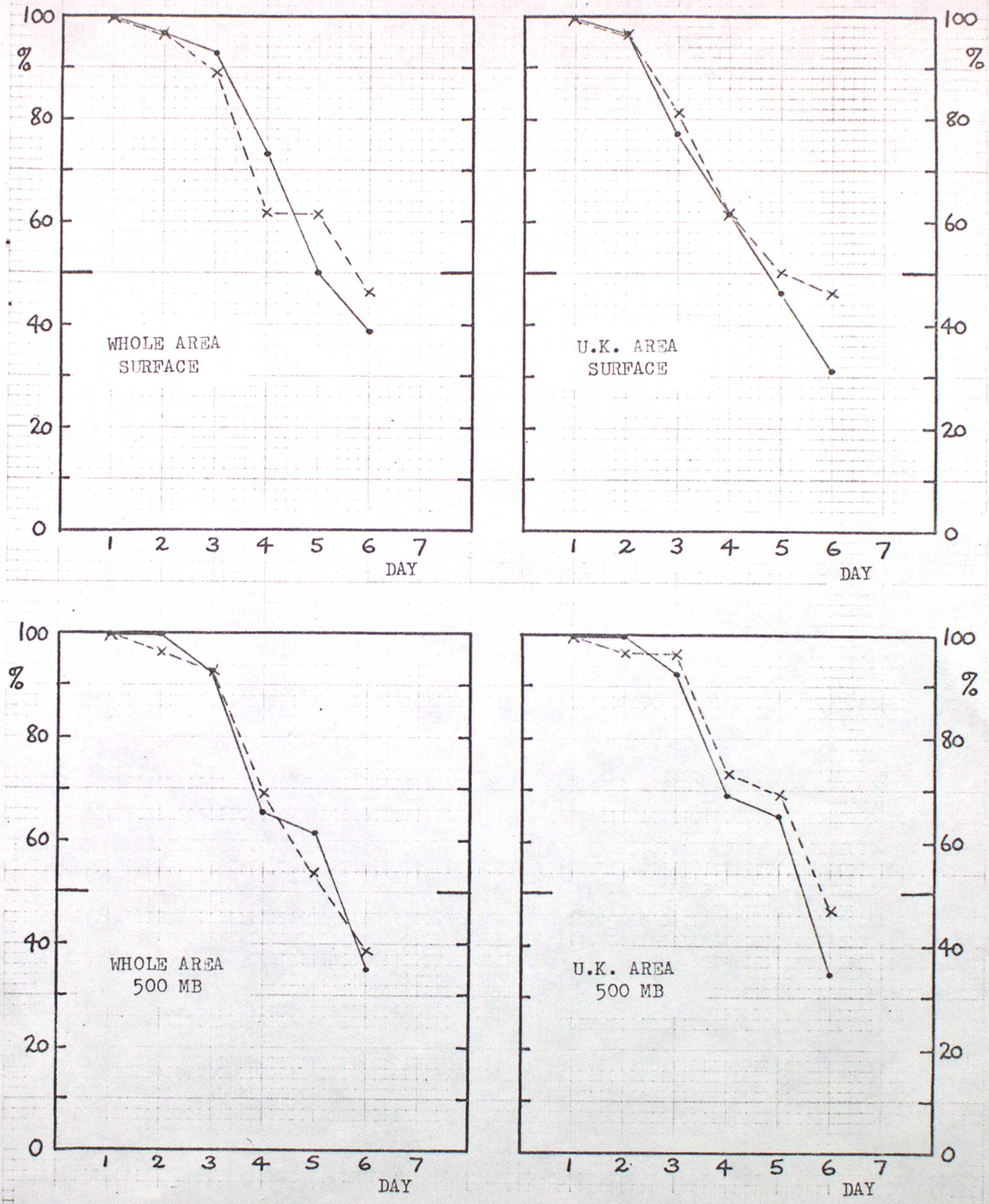



Fig. 7. Percentage of occasions when A/B marks were retained up to and including day N, for the period 3/9/79 to 25/2/80.

•———• ECMWF model
×----× Met O model

E.R.

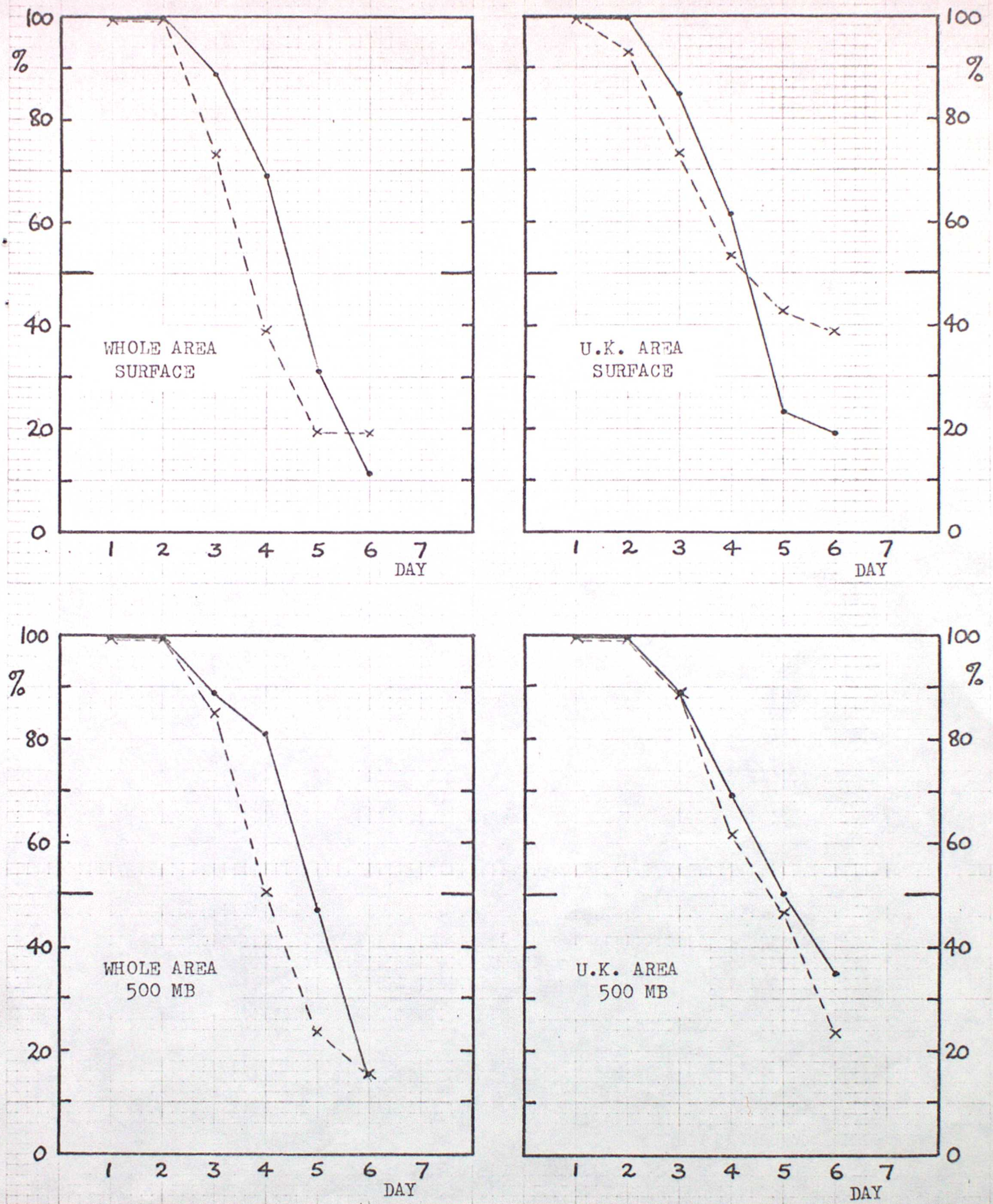



Fig. 8. Percentage of occasions when A/B marks were retained up to and including day N, for the period 3/3/80 to 25/8/80 .

●———● ECMWF model
×- - - -× Met O model

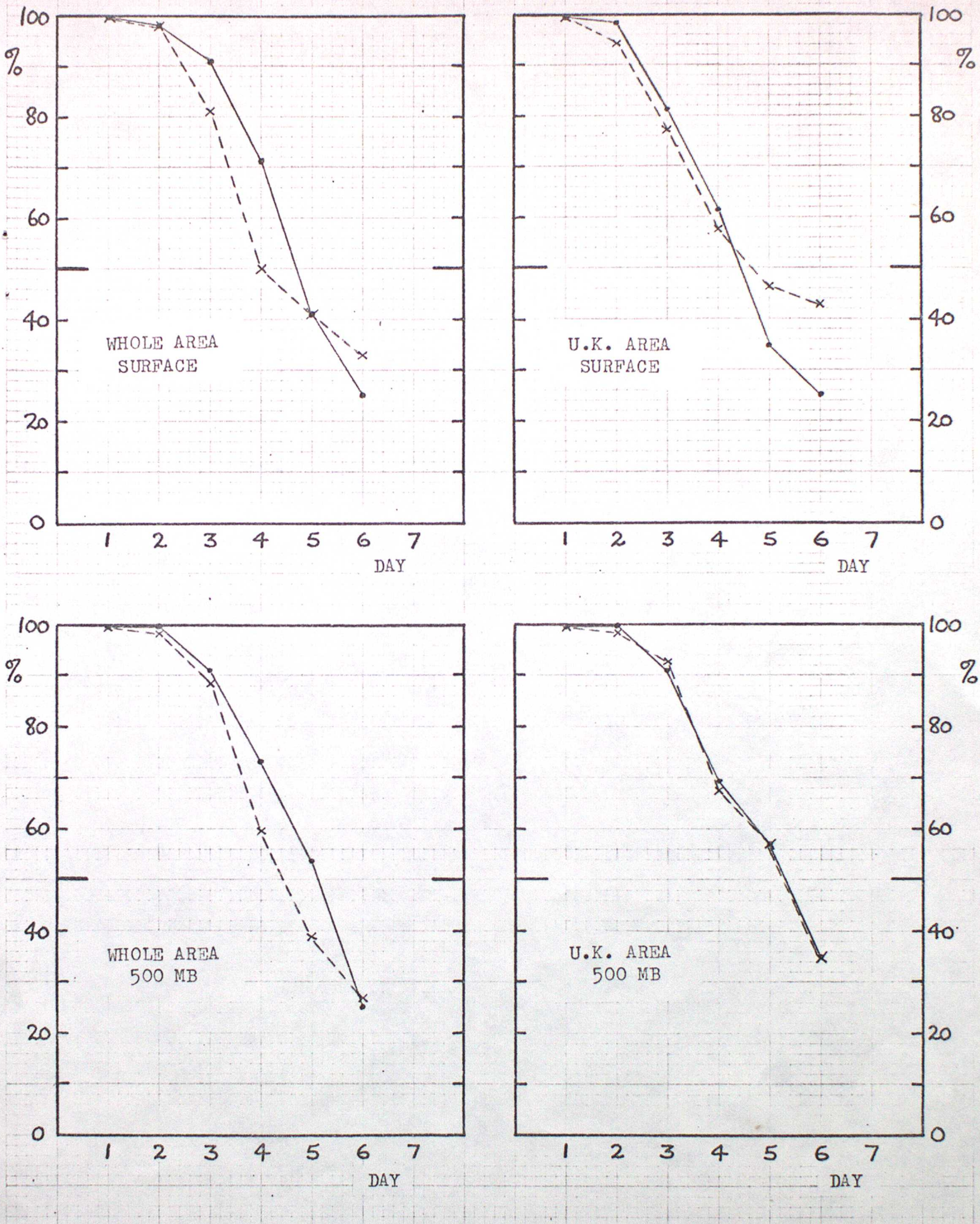
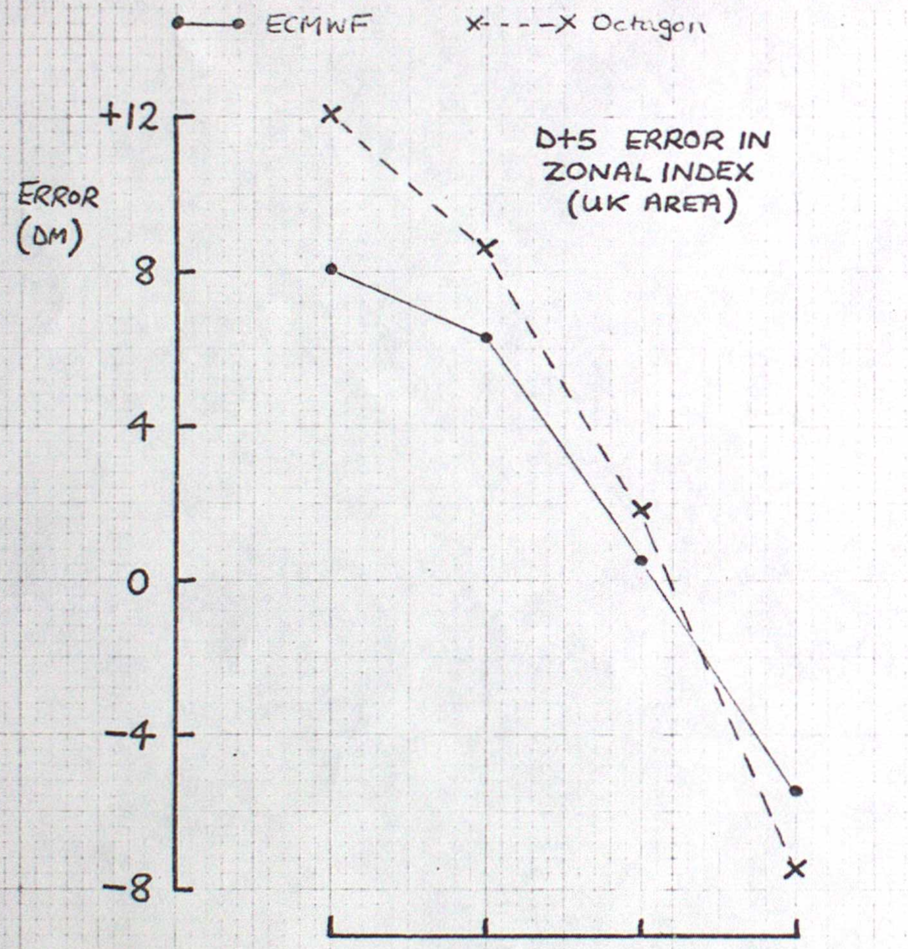



Fig. 9. Percentage of occasions when A/B marks were retained up to and including day N, for the period 3/9/79 to 25/8/80 (whole year).

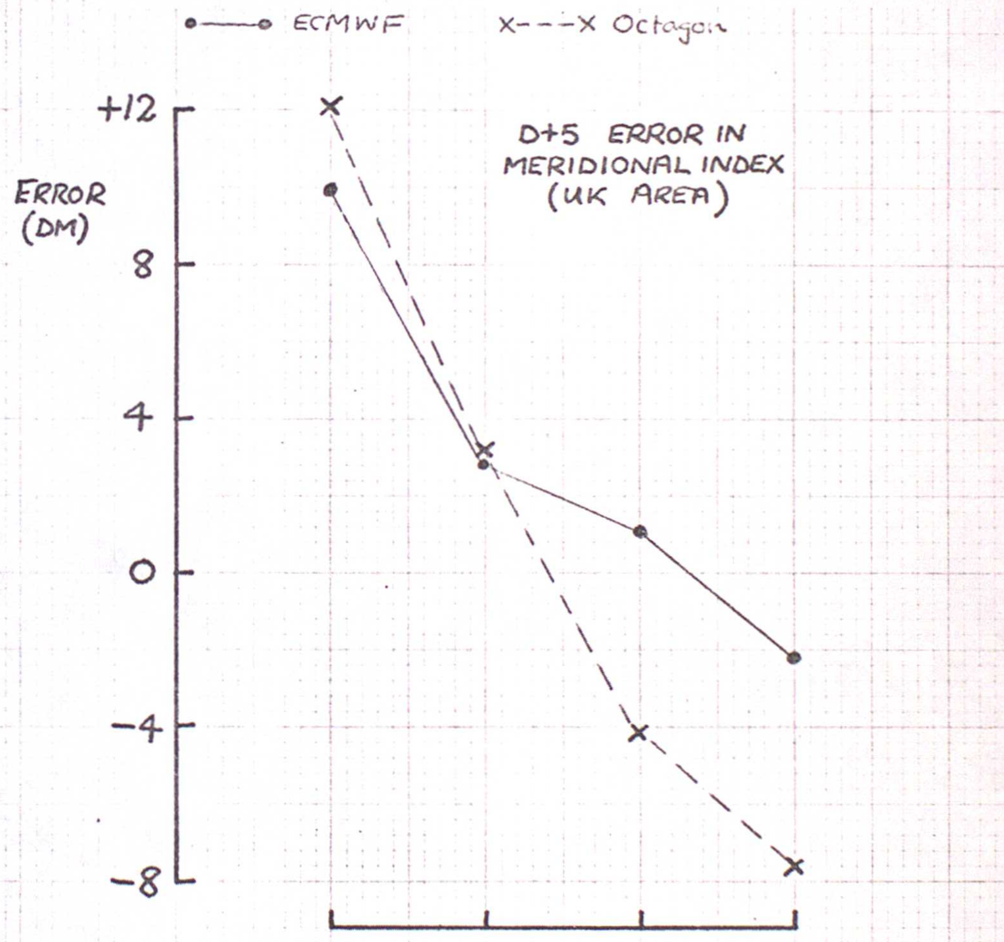
•———• ECMWF model
×- - - -× Met O model

Fig. 10a. D+5 mean errors (forecast — actual) in 500mb Zonal Index (50°-60°N at 5°W)




| ZI (actual) class | 0 | 0-9 | 10-19 | ≥20 DM |
|---|---|---|---|---|
| class mean ZI | -8.8 | +3.9 | +13.5 | +26.1 DM |
| sample size | 6 | 19 | 12 | 15 |

Fig. 10b. D+5 mean errors (forecast — actual) in 500mb Meridional Index (13°W-4°E at 55°N)




| MI (actual) class | ≤-10 | -9-0 | 1-9 | ≥10 DM |
|---|---|---|---|---|
| class mean MI | -17.3 | -2.3 | +4.3 | +16.6 DM |
| sample size | 15 | 12 | 11 | 14 |

# APPENDIX

## Examples of forecast sequences produced by the ECMWF model

The examples included here (Figures A1-A7) are intended to illustrate various facets of the model's behaviour alluded to in section 4 of this note. All the analysed ("ANAL") and forecast ("D + N") fields relate to 1200 GMT on the indicated date. On 1000 mb charts, the 1000 mb contour intervals are 4 dm and 850 mb isotherms are at 5 K intervals, while on 500 mb charts, the contour and isotherm intervals are 8 dm and 5 K respectively. Analyses verifying the forecasts appear on the right-hand side of each Figure.

### 14/11/79 (Fig A1)

The development and phase speed of new depressions moving out into the Atlantic from the USA was handled well up to D + 4, apart from slight over-development at D + 2. From D + 4 onwards however, the major Atlantic depression was moved east-north-east and overdeveloped to become an overdominant feature between Iceland and Scandinavia at D + 7. In reality this depression transferred slowly from a position north of Newfoundland towards Iceland, filling slowly, over the period D + 4 to D + 6. A relatively settled dry spell over the UK late in the forecast period was not indicated; the forecast showed continuing mobility with strong westerlies across the UK.

### 22/2/80 (Fig A2)

This sequence illustrates the tendency, present in most numerical models, for the predicted evolution of major depressions to lag behind the real atmospheric evolution. The analysis for 22/2/80 (1200 GMT) is compared with the D + 1, 2, 3, and 4 forecasts verifying at that time. The correct central pressure and location of the major Atlantic low was gradually approached as the period of the forecast reduced from 4 days to 1 day.

### 23/12/79 (Fig A3)

From D + 1 to D + 2 a shallow depression near 40°N, 55°W was predicted to move too quickly east-north-eastwards, with some development. Subsequently the predicted enhancement of baroclinicity to the north of the low at D + 2 favours further rapid (erroneous) development and it was transferred quickly north-east towards the UK (D + 3), and then northward to become the major depression near Iceland at D + 5. In reality this depression moved slowly eastwards, with no development, from D + 1 to D + 3; thereafter a new depression developed in a baroclinic region to the south-west of the UK and moved quickly north-east following a path predicted, a day early, by the model for its own (spurious) depression. The next depression moving out from eastern USA was better handled.

### 26/11/79 (Fig A4)

The model's predicted sequence for the Atlantic was generally good up to and including D + 4, but thereafter the track of the developing Atlantic depression was predicted too far south, moving eastward to cross the UK at D + 6 and D + 7; in reality this low began to turn north-eastwards at D + 4, absorbing its parent depression and, following further deepending up to D + 5, continued north-eastwards. Note also that the relatively close proximity of the two major lows on the D + 5 forecast chart appears unrealistic; the depression over northern Europe, overdeveloped at D + 4, was not filled quickly enough.

10/12/79 (Fig A5)

The depression in the western Atlantic at D + 1 developed quickly, moving north-east then north (following occlusion) over D + 2 to D + 3, to become slow-moving near Iceland at D + 4. The rapid deepening of this system was well indicated in the forecast at D + 1 and D + 2 but it was moved (too slowly in the early stages) almost directly eastwards to be centred over UK at D + 4.

16/12/79 (Fig A6)

A change from a mobile westerly type across the Atlantic (50-60°N) and north-west Europe to a more settled type early in the forecast period was well predicted, although the forecast deteriorated towards the end of the period (D + 5, 6), with the overdevelopment of a depression to the east of Greenland and the poor handling of events in the western Mediterranean.

11/3/80 (Fig A7)

The disruption of a major Atlantic trough near the UK (D + 2), the formation of a cut-off vortex (D + 3) and its subsequent movement into and across the Mediterranean (D + 4, 5, 6) were well predicted. The upstream trough then disrupted in two stages, one cut-off vortex forming near 42°N, 21°W (the model predicted this, but too far east), and another, more significant, vortex forming over the UK at D + 6; it is extremely unlikely that any operational numerical model would have been able to predict the development of this latter vortex six days ahead.

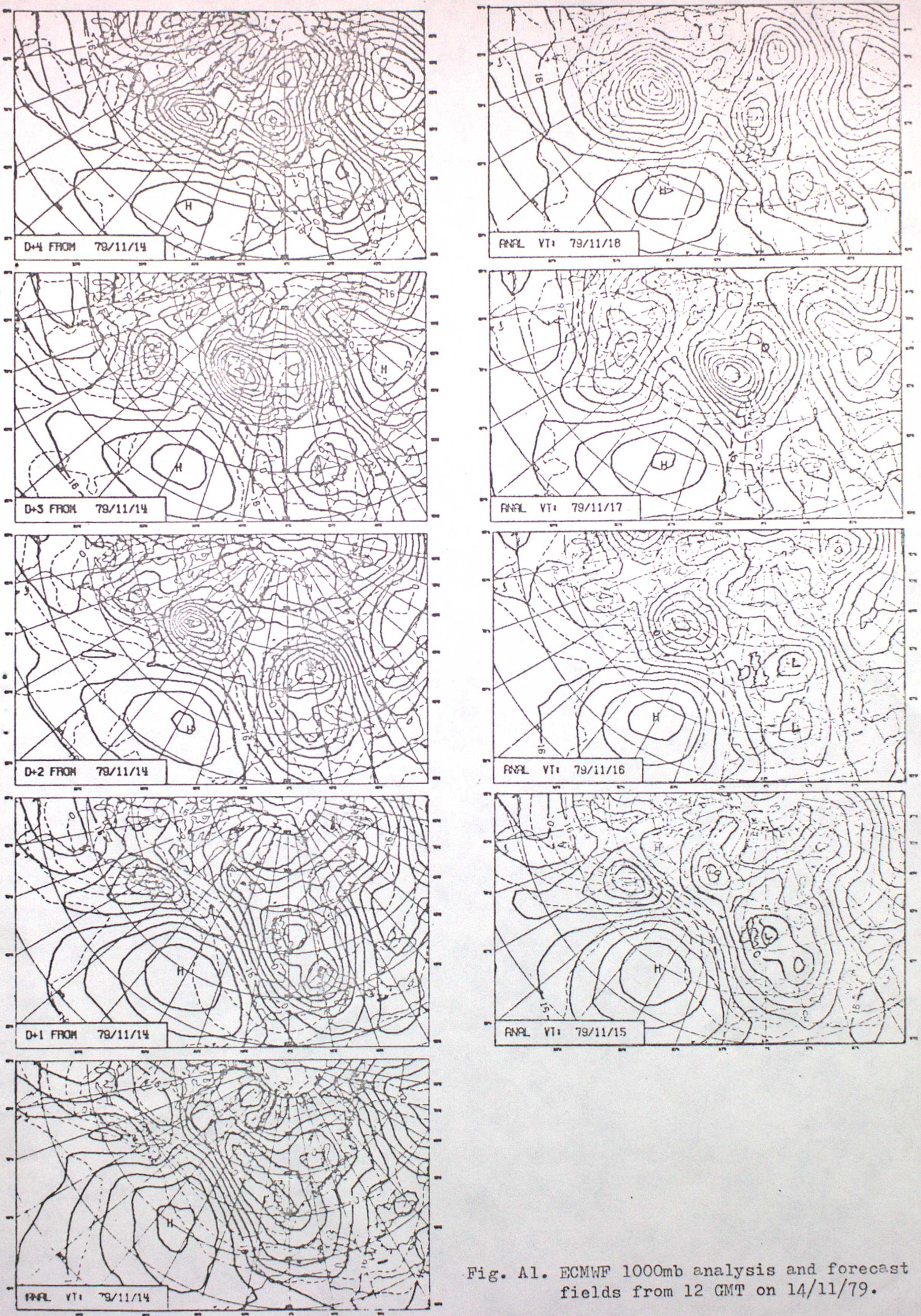



Fig. A1. ECMWF 1000mb analysis and forecast fields from 12 GMT on 14/11/79.

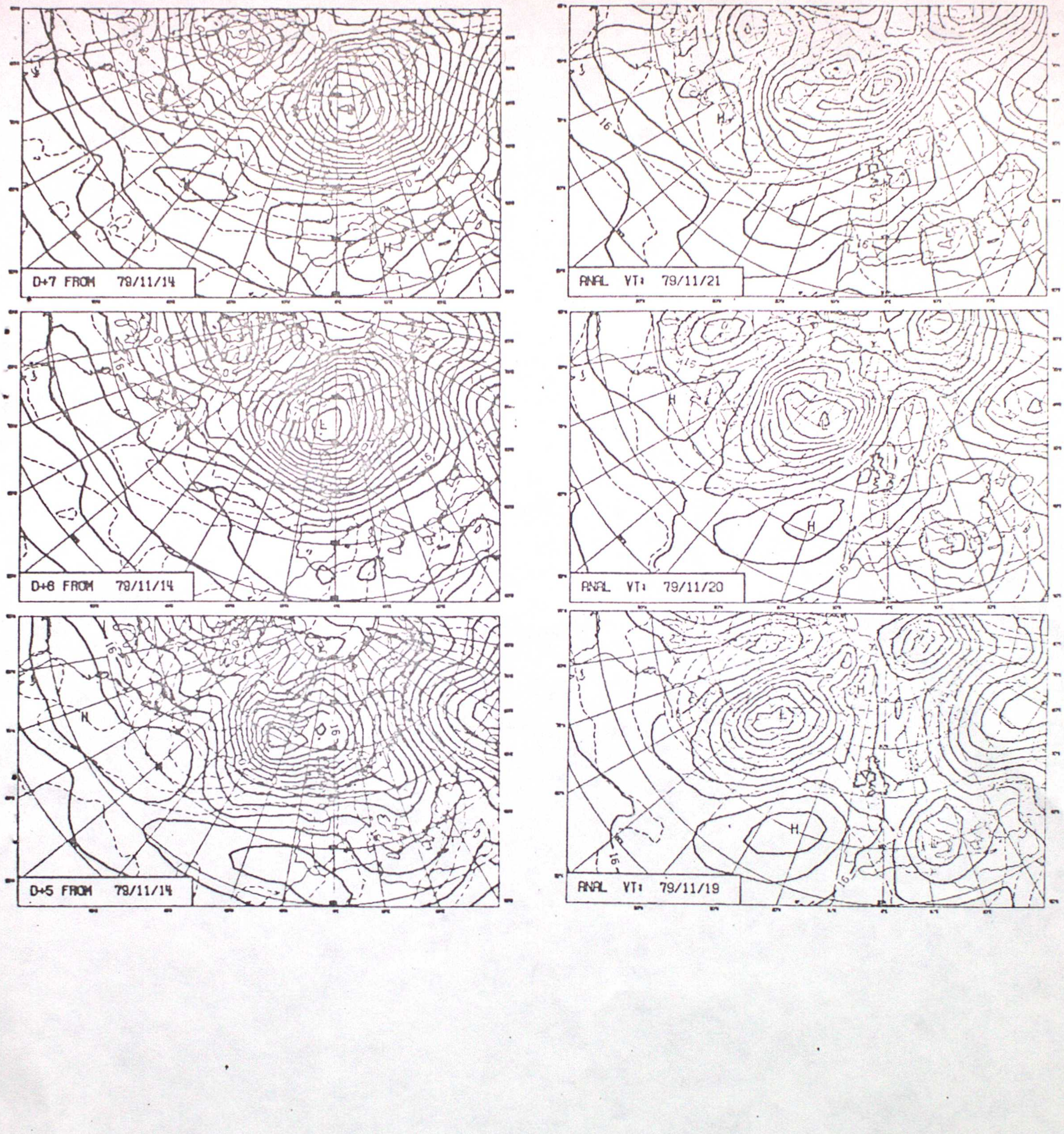



Fig. A1. (continued)

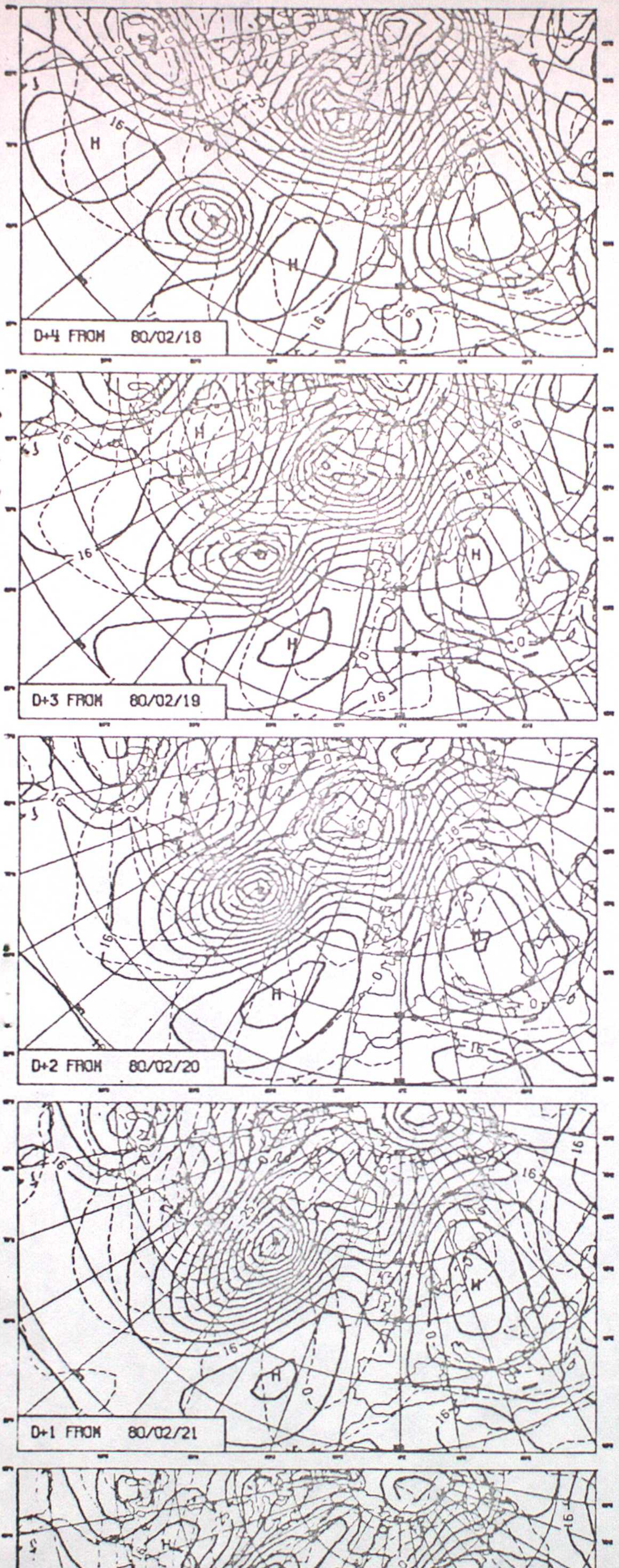



Fig. A2. ECMWF 1000mb analysis for 12 GMT on 22/2/80, and forecast fields verifying at that time.

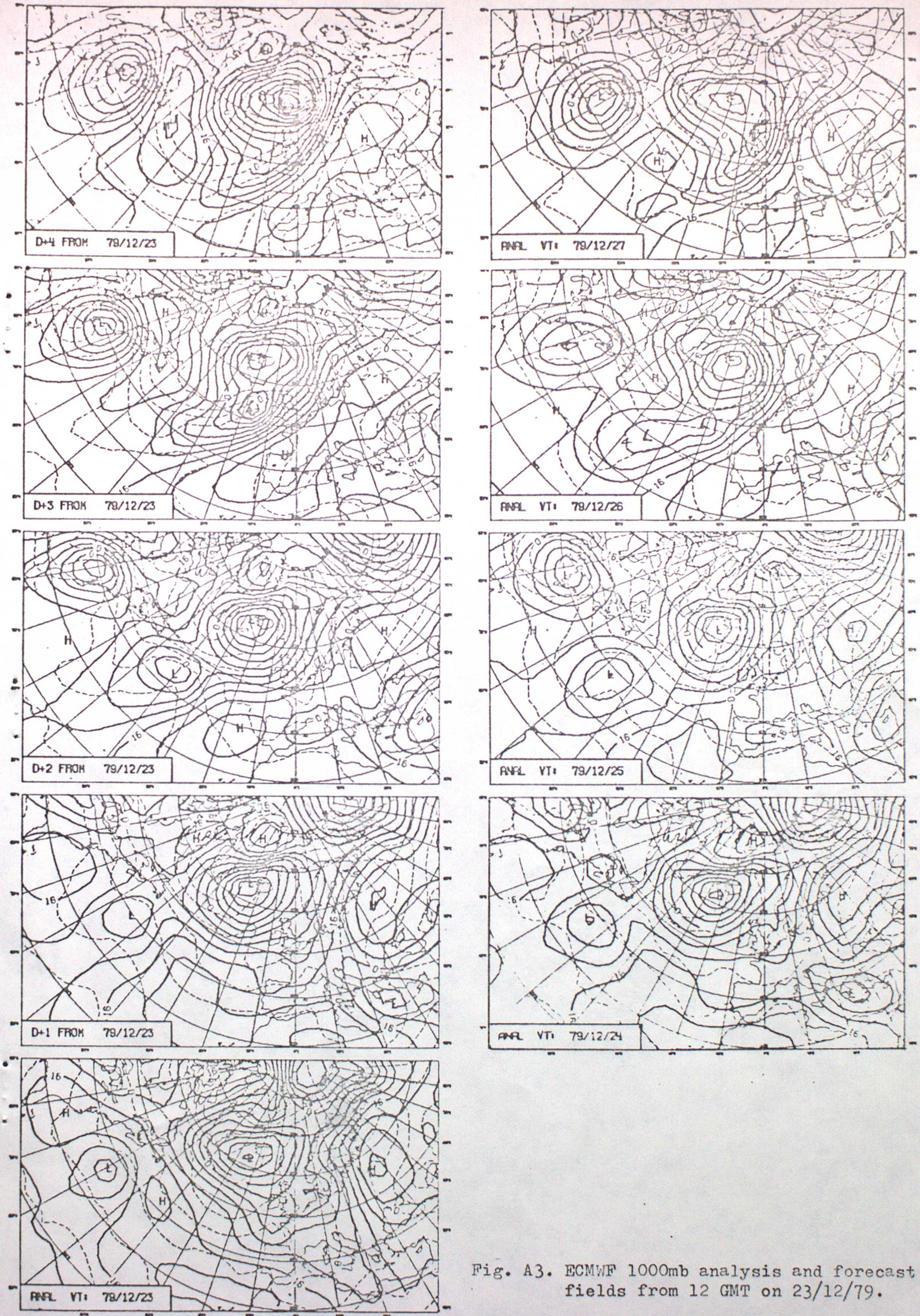
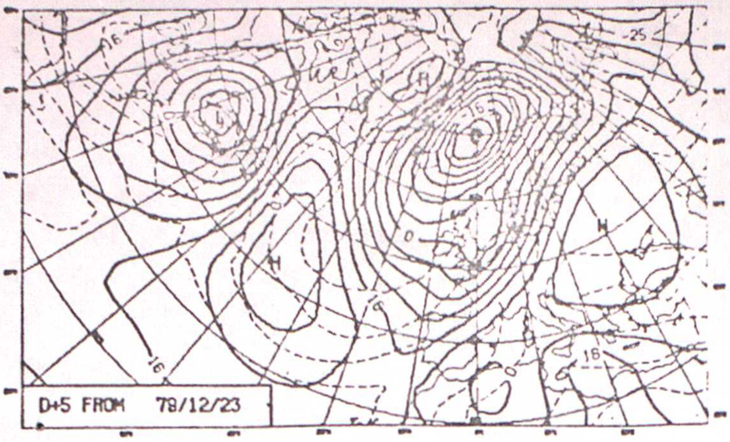



Fig. A3. ECMWF 1000mb analysis and forecast fields from 12 GMT on 23/12/79.



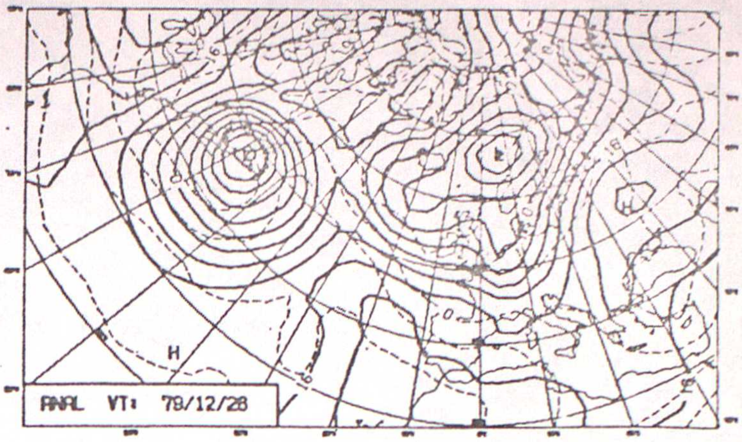




Fig. A3. (continued)

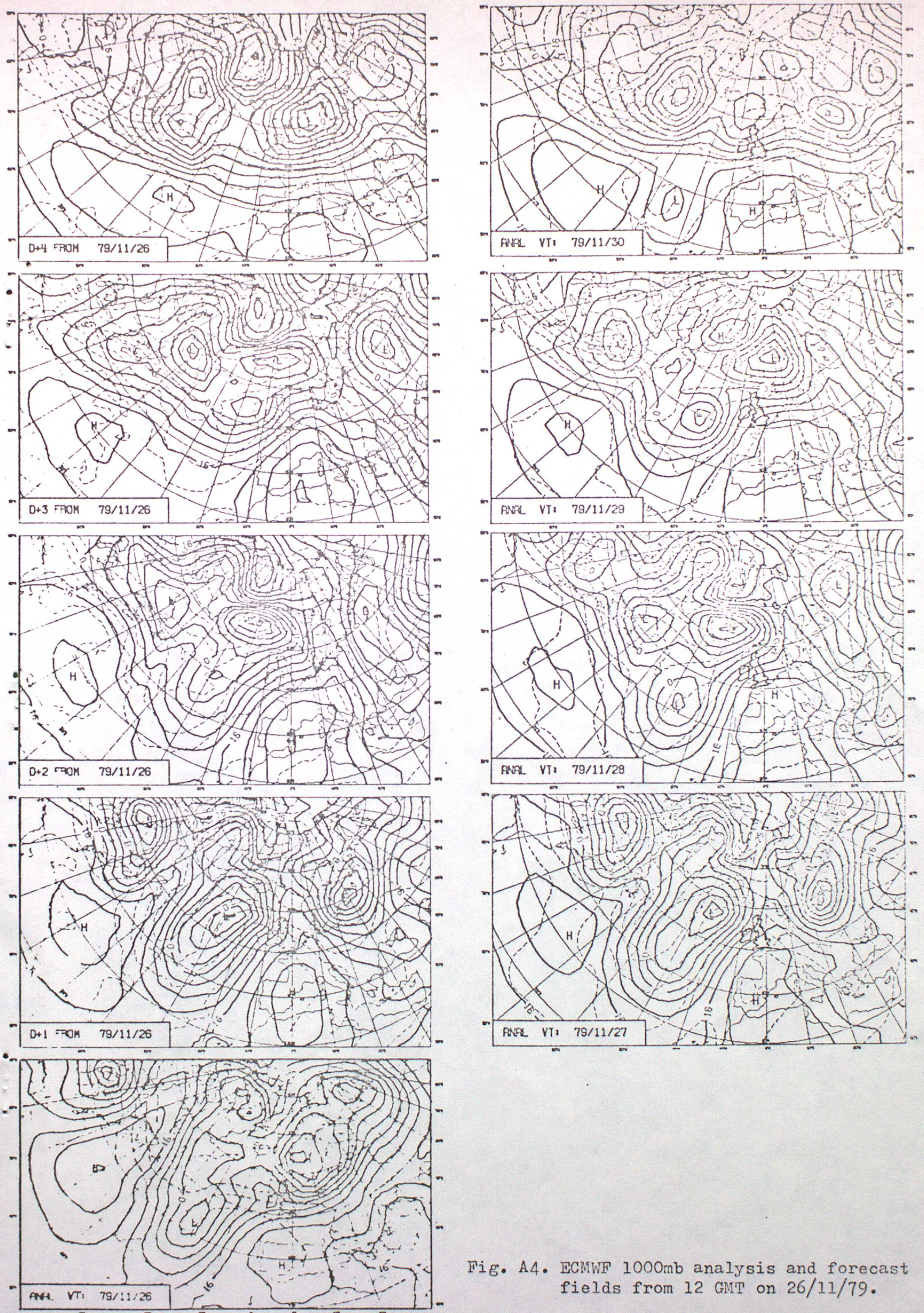



Fig. A4. ECMWF 1000mb analysis and forecast fields from 12 GMT on 26/11/79.

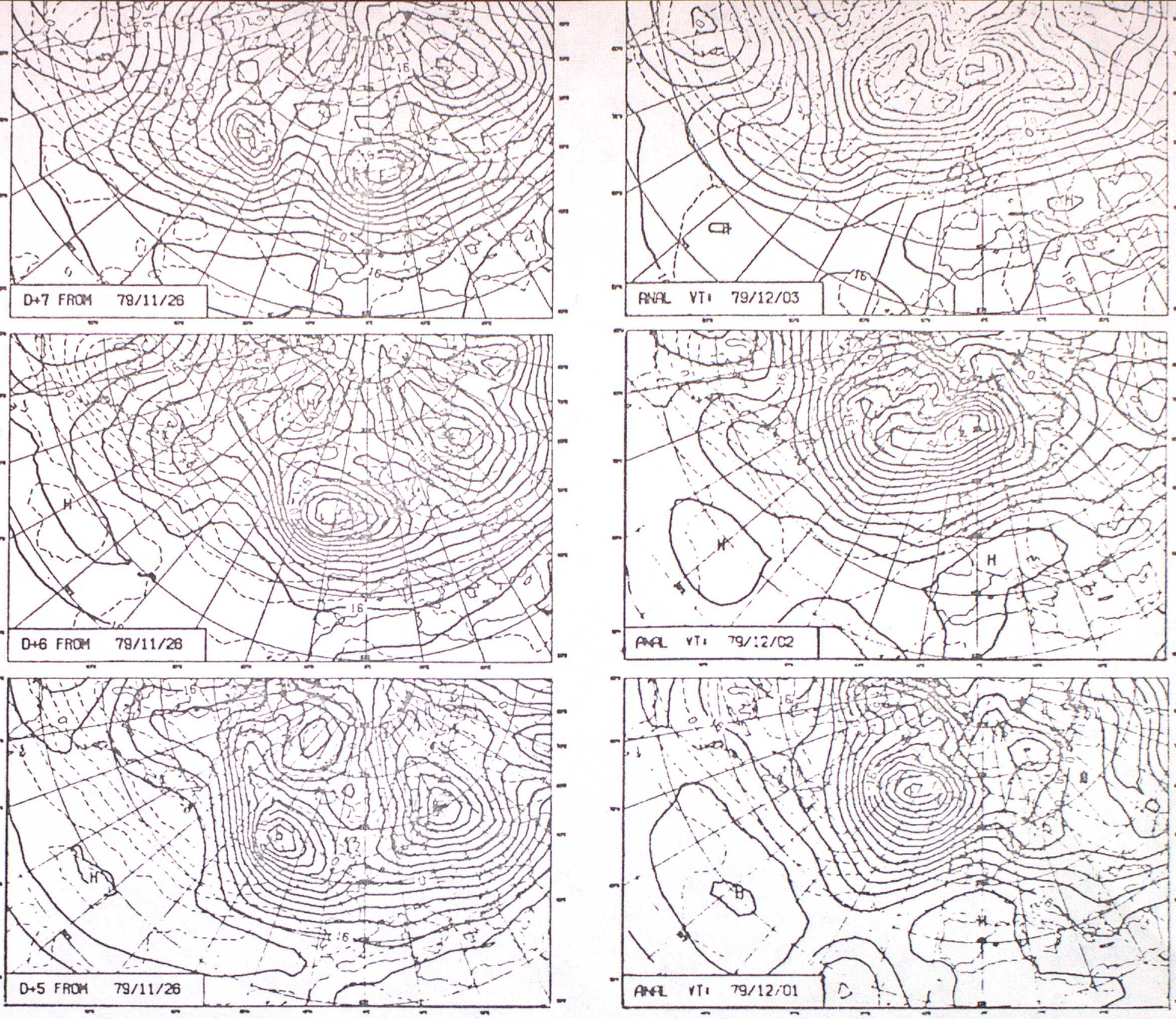



Fig. A4. (continued)

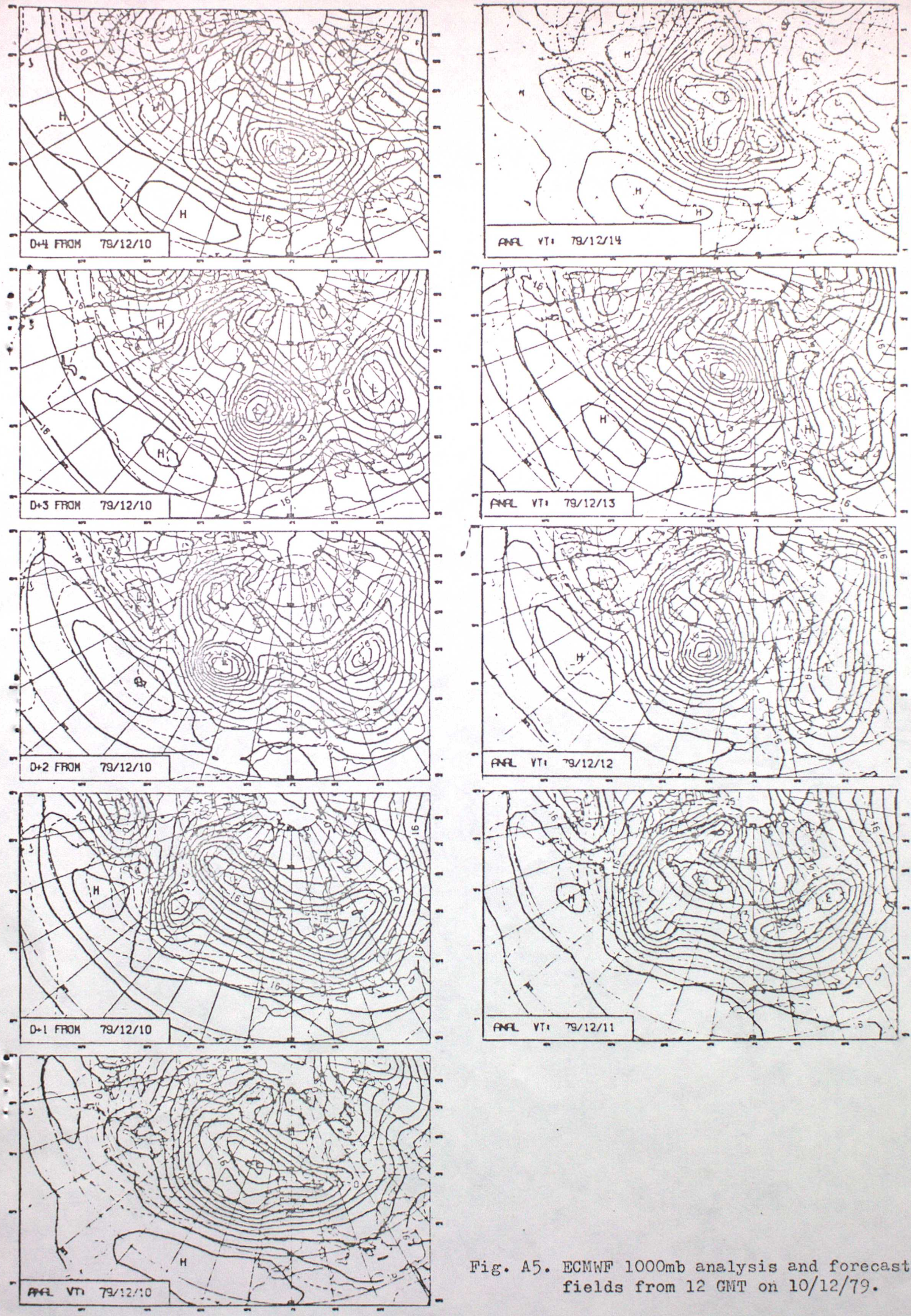
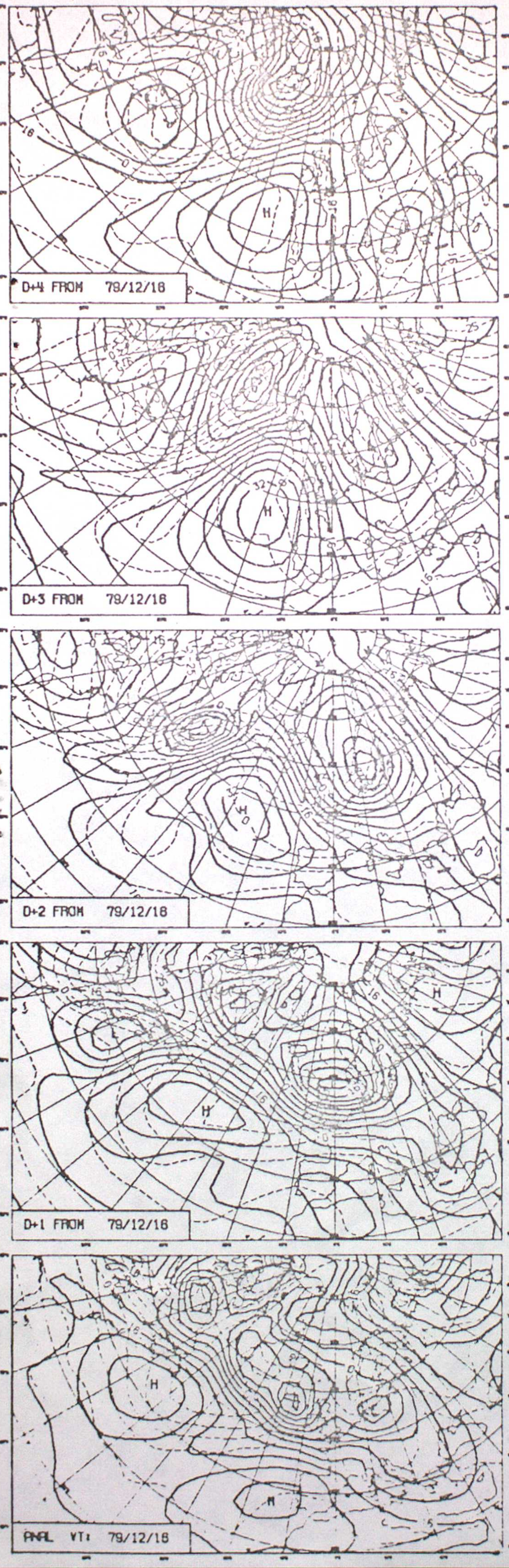



Fig. A5. ECMWF 1000mb analysis and forecast fields from 12 GMT on 10/12/79.



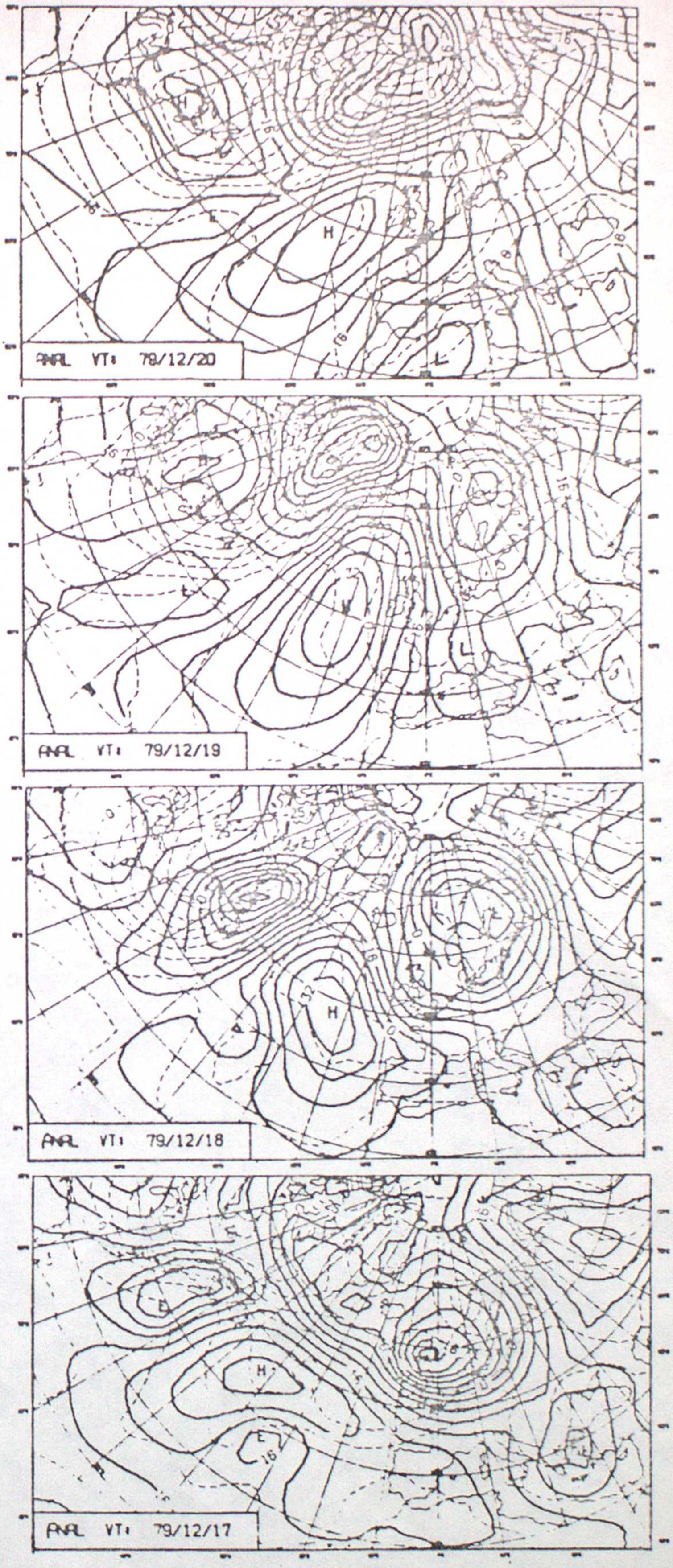




Fig. A6. ECMWF 1000mb analysis and forecast fields from 12 GMT on 16/12/79.

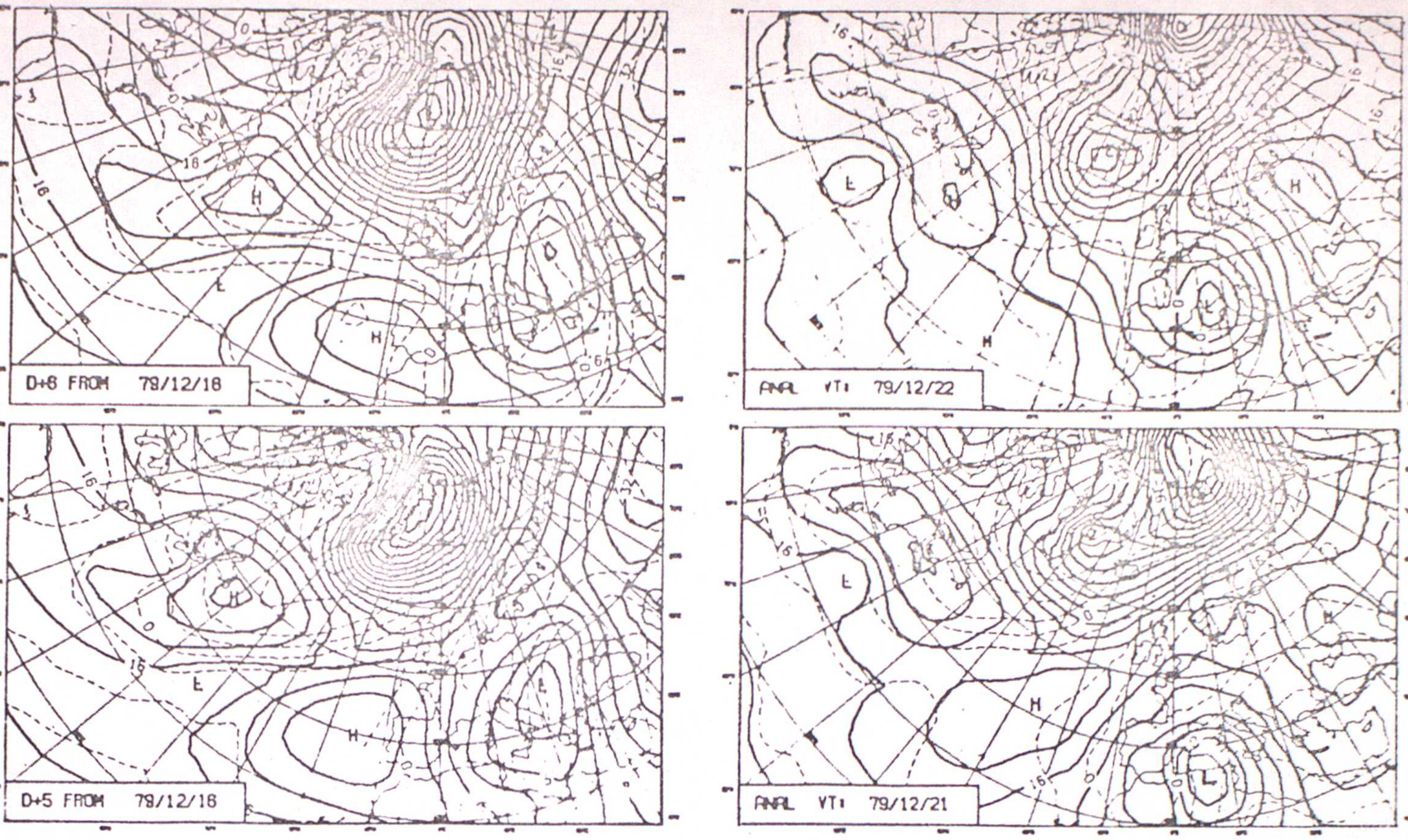



Fig. A6. (continued)

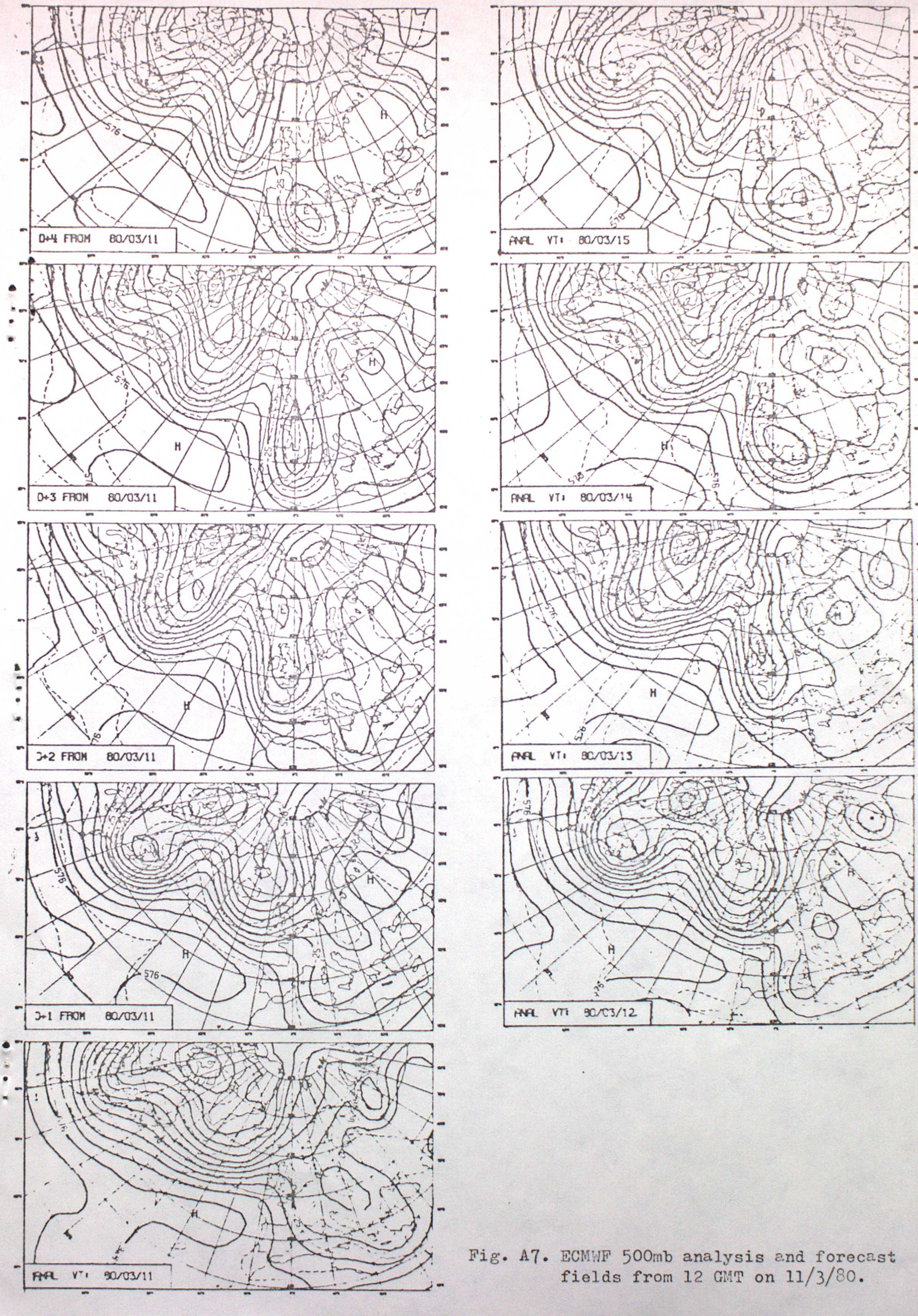



Fig. A7. ECMWF 500mb analysis and forecast fields from 12 GMT on 11/3/80.

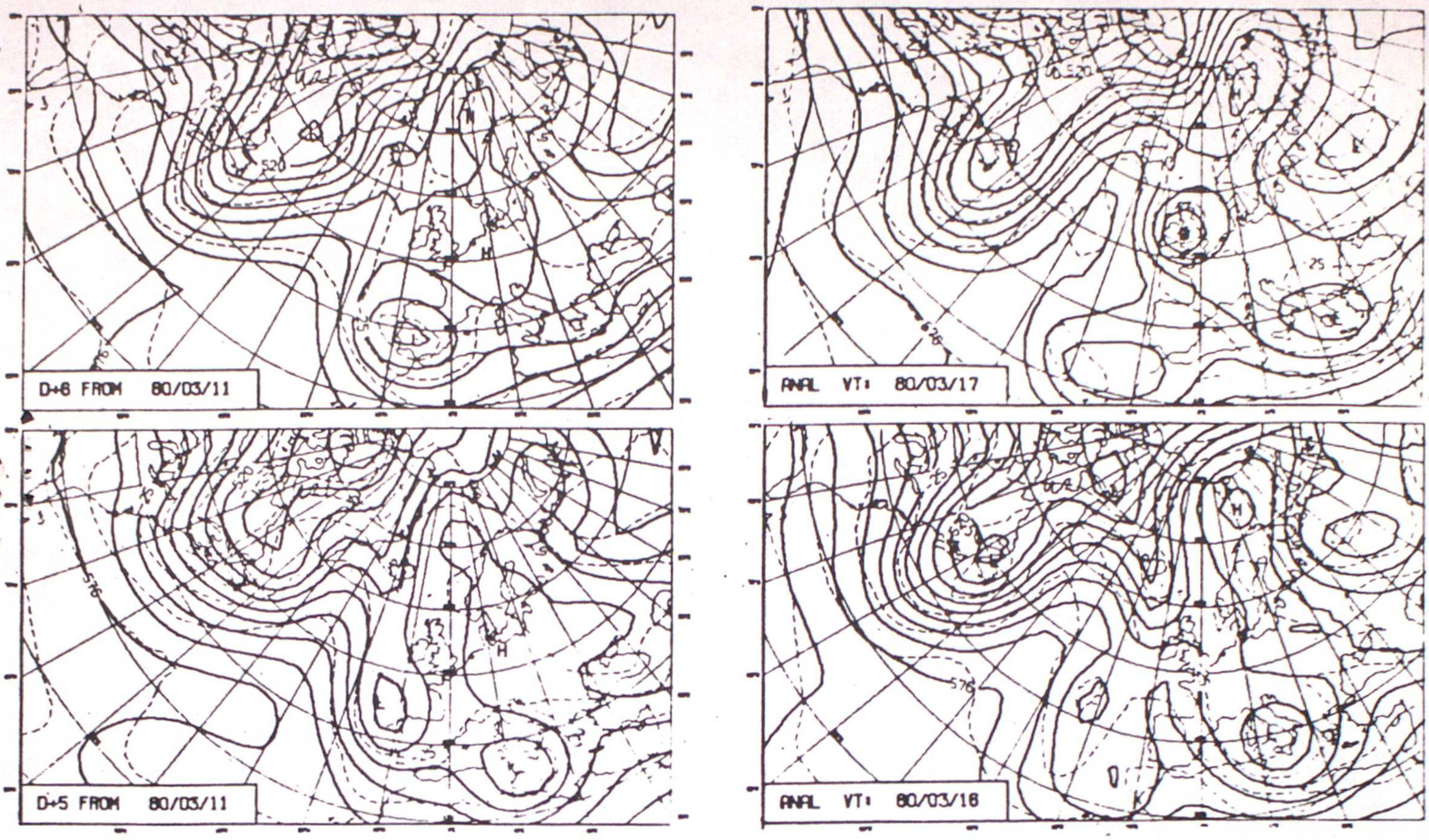



Fig. A7. (continued)