Met O (PMSR) Turbulence and Diffusion Note No. 256

COMPARISONS OF THE NAME DISPERSION MODEL WITH VAAC AND RTMOD MODELS

by

R.H. Maryon

April 1999

Met O (APR) (Public Met Services Research)
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Comparisons of the NAME Dispersion Model with VAAC and RTMOD models

TDN 256

Introductory Note: As part of the Products Development Programme for 1998/99 the Atmospheric Dispersion Group was required to carry out intercomparisons between NAME and the VAFTAD volcanic ash model run by the Washington Volcanic Ash Advisory Centre (VAAC). This was to establish NAME's credentials as the operational volcanic ash model for Bracknell VAAC. Output from other VAACs was, in the event, included in the intercomparison. An interim report was also required, under the Core Research Programme for the same year, on progress in the international RTMOD project for the intercomparison of long range transport models---a later phase of the EC/WMO/IAEA ETEX model validation project. This also involved intercomparisons, this time using the statistical package of the EC Joint Research Centre at Ispra.

These studies were considered to be of sufficient interest for a permanent record to be kept, and it was decided to bind them together in a single Turbulence and Diffusion Note.

RTMOD: INTERIM REPORT TO 28TH FEB 1999.

R H Maryon, Atmospheric dispersion group, PMSR

March 1999

1. Introduction. RTMOD constitutes the third phase of a sequence of projects designed to compare and validate long range dispersion models. The work was planned jointly by the WMO, IAEA and EC, and the day to day organization handled by the EC Joint Research Centre at Ispra in Italy. Long range transport and dispersion modellers from many European countries and some further afield participated, including organizations with operational responsibilities in the event of a major nuclear accident. The UK Met Office, which has a role as WMO Regional Specialist Met Centre (RSMC) handling nuclear or toxic releases for Region VI (and initially much wider areas) has participated from the beginning using the NAME model (Ryall & Maryon 1996).

The earlier phases of the project were ATMES, based upon the Chernobyl disaster (Klug et al 1992), and ETEX, the European Tracer Experiment (Girardi et al, 1998, Graziani et al 1998a, 1998b, Ryall & Maryon, 1998). ETEX was particularly important, as the source terms were precisely known and air concentrations of tracer measured across much of Europe using uniform instrumentation. For all phases the main experiment was preceded by real-time 'dry runs' to test operational response and communications. At the conclusion of ETEX it was widely felt that the collaborative momentum should not be lost and, although no further tracer experiments were envisaged for the time being, a programme of model intercomparisons should be continued, and eventually extended to consider wet and dry deposition as well as air concentration. This project was given the title RTMOD---a not-quite acronym for Real-time Atmospheric Long-range Models Intercomparison.

2. The RTMOD agreement. RTMOD was organized a little differently from the earlier studies, a formal contract (Concerted Action) being drawn up between CEC DG XII and the Risoe National Laboratory, Denmark, for the administration and much of the general organization of the project. Subsidiary agreements provided for the reimbursement of travel and subsistence to participants for attendance at three workshops during the 20 months from Jan 1998. The major objectives were defined:

- to maintain contact with a restricted number of key ETEX participants, who will continue real-time model intercomparisons for meteorological scenarios likely to produce hazardous situations for EU populations;
- to quantify discrepancies between model results in different meteorological scenarios with the aim of understanding and reducing them;
- to improve the links between meteorological and dispersion models;
- to arrive at consensus measurement criteria for model performance;
- to improve links between mesoscale and long range dispersion models;
- to analyse the effect of concentration assimilation techniques on model performance.

With no firm validation available intercomparisons could, of course, only be between different dispersion models. Interpreted literally this was an ambitious programme for a heterogeneous group of 20 or 30 modelling organizations over a period of 20 months, and in the event progress is fairly slow and starting to concentrate on more concrete objectives such as the treatment of wet and dry deposition. In the writer's view the important thing at present is to maintain the unique collaboration of the world's foremost long range dispersion modellers together with the communications links, transmission protocols and personal contacts which have been established. More tracer experiments are needed, and the 'team' will be thoroughly prepared and ready to participate when one can be organized. Personal contact, over what is now a long period, with the major 'players' overseas has proved to be of immense value---for example, ready consultation in time of emergency, exchange of papers and reports of investigations, sharing of ideas on the operation of parametrizations, and so on.

3. The Exercises of Spring and Summer 1998. Planning for the first two RTMOD intercomparisons was carried out at a workshop at Risoe, Roskilde, Denmark, in January 1998. Notional releases were to be notified to all the participants by JRC Ispra for an easterly and a westerly type over Europe. Immediate forecast runs were to be made, followed up by hindcasts at a later date. Air concentrations calculated at a lat/long grid of points over Europe were to be computed and transmitted to Ispra following a specified format. Wet and dry deposition were to be postponed pending the development of a suitable analysis package by Ispra. A major advance was introduced at this point---the set-up of a web site by JRC Ispra to which data could be transmitted and at which the statistical analysis of the results could be accessed. It would also constitute a forum for the posting and exchange of messages and ideas. The page has been well-designed and functions very well, although---as far as the UK is concerned---only limited data analysis seems to have been carried out by Ispra (i.e. forecast not hindcast concentrations).

The statistics are as developed for the earlier phases such as ETEX, and are now handled by the 'RTMOD statistical module'. It is well known that it is difficult to quantify the goodness of fit even of two-dimensional patterns, let alone a four-dimensional structure such as a plume. No single statistic would be adequate, so that Ispra developed an array of measures, arranged in three groups:

- *Time analysis,* where the concentrations at a fixed location are considered for the whole duration of the simulation, i.e. the evolution of plume concentration can be studied at specific localities.
- *Space analysis*, where the concentrations at a fixed time are considered all over the domain. A typical example is the Figure of Merit in Space (FMS), the ratio of the intersection to the union of two plumes (one of which ideally should be a validation).
- *Global analysis*, where all the concentration values at any time and location are considered. There are many values involved, which can be arranged as scatter plots, etc.

Some examples will be shown later, although space is limited here. A list of the 28 participants with identifying model number is given in Table 1.

The first notional release (10g/s of 'inert non-depositing tracer') took place 09-15UTC 28th

April 1998 from Chernobyl, in a situation with low pressure over W Europe and high pressure over Russia, so that material was expected to be carried NW from the source. It was also in part to commemorate the 12th Anniversary of that event! There were no problems running the model at Bracknell, but as a result of stringent security at UKMO, the results could not be transmitted to an external web site. In a very short time a means of transmission by ftp was put in place, but this did result in some delay in Ispra's analysis of the UK data. The second notional release was from 53N00E near Boston, Lincs, on 9th July 1998 to exploit a W to NW'ly airstream over Europe; otherwise the release details were as for 28th April. Some of the organizers insisted on calling this the London release! The Bracknell forecast and hindcast products for the Chernobyl and Boston runs are shown in figs. 1 and 2 respectively. The forecasts are seen to be moderately good but with shortcomings. The Chernobyl plume was roughly elliptical, and was carried too far north in the forecast. The Boston emission was subject to much elongation which was under-represented in the forecast.

Obviously Ispra's statistical comparisons for all the models and all the analysis sites for the two experiments cannot be presented here, and indeed there is no requirement given the lack of validation. However, sample output showing the standard intercomparisons from the Boston run is given in figs. 3 to 6, and for the Chernobyl run in figs. 7 to 12. *As pointed out above, only analyses for the forecast runs are available.* Fig. 3 is a sample comparison with the Meteo-France model---the time profile shows similar maximum concentrations, somewhat surprisingly as the French model clearly adopts a much stronger diffusion than NAME. This is the case with many models: NAME's outstanding correlation statistics for the ETEX experiment suggest its diffusion is by no means too small, while its RMS error could only be improved at the expense of reducing the correlation. The treatment of vertical motions including convective venting from the boundary layer may be the keys to the question: we are content for the moment to maintain what seems to be a realistic diffusion. The scatter plot between the French and UK models (fig. 3b) is moderately good---the line of zero values along the vertical axis is indicative of the extra diffusion in the French model. Fig. 4 shows a respectable correspondence between the UK and Russian models at the quoted locality, apart from a detached patch of material arriving ahead of the main plume in the Russian version. Fig. 5 shows some 'figures of merit in space' at T+48, although no real merit can be allocated without validation. Fig. 5a is a reasonable overlap of NAME and a model at LLNL (Lawrence Livermore); fig. 5b a partial overlap for the UK and German (DWD) models and fig. 5c a case of considerable disparity between NAME and the Canadian model. Figs. 6 illustrate 'confidence in contamination level' (CCL) plots---each cell is coded to show the percentage of models that predict concentrations above a chosen threshold value. This constitutes the limited progress made in RTMOD towards the assessment of reliability.

Turning to the runs for Chernobyl, fig. 7 shows a good correspondence between the UK and Danish time-sequences at the quoted location, the NAME plume evidently slightly in advance of the Danish. The underpinning NWP models, of course, control the rate and direction of advection of a plume. Fig. 8 shows a sample CCL plot at T+36hr. Another good correspondence was between the UK and Austrian models even (fig. 9a) for one of the more remote locations from source. The corresponding scatterplot (fig. 9b) illustrates one of the highest global correlations, 0.64. A series of FMS plots are given (figs. 10, 11). Fig. 10 shows T+24 overlaps, one quite good with the French model (10a), one distinctly poor with the model from Bulgaria (10b). For T+48 we reproduce overlaps with the Canadian (11a) and DWD (11b) models, the German product exhibiting a great deal of diffusion. Finally, figs. 12, a set of global scatter plots for the UK against Germany (12a)---quite good apart from the evidences of extra diffusion in the DWD product along the vertical axis (correlation 0.54); Norway (12b) showing even distribution across the 45deg line (this is quantified in the FOEX statistic quoted), correlation 0.58, and a poor correspondence with the Czech dispersion model (12c), correlation 0.10.

4. Future Plans. A second workshop was held in Ispra in September 1998 to plan for the remaining time available for the concerted action, and tentatively for the longer term. A number of suggestions were made by the modelling community, many (or most) of which it will not be possible to implement in the present framework. The ideas include

--- The inclusion of wet and dry deposition and the extension of the statistical package to these results. Dry deposition alone was not worth analysis, as it was closely linked to the integrated air concentration.

--- On the web, tables of model characteristics with identification. Many minor improvements to the web facility were proposed!

--- Access to the results of other modellers, with downloadable output files. At present it is only possible to access statistics specific to one's own model, although, based on intercomparisons, these do involve some insights into the performance of others.

--- Dynamical clustering of models for creating a 'reference' model (I pointed out the danger in this procedure if a disproportionate number of the dispersion models were to be underpinned by a single NWP model).

--- Comparison of vertical profiles of air concentration.

--- Application of the statistical package to compare the forecast and hindcast products of individual models.

--- Using distributions of notional monitored data, rather than source details, as the notification of an incident requiring determination of the source and future development of the plume. A model could be chosen to carry out an integration to provide bogus 'monitored' measurements.

Looking three to four years ahead an idea was introduced by the organizers and some Russian scientists (A Jourtchak and A Korenev from SPA Typhoon) for a release from Obninsk, in Russia, about 100km SW of Moscow. Obninsk has a 315m meteorological tower and other facilities, and the proposal is to use super-light chaff (at least in the initial stages) for tracing with 3D radar. Smoke might also be emitted for use with lidar. As the chaff apparently has a deposition velocity of 5-10cm/s it will be a near-source facility (although it was alleged that it might be airborne for 50km in the right conditions!), but the exercise would be complementary to a long range experiment with conventional tracer launched at the same time. There was a certain feel of 'hard sell', and I wonder whether there were some political overtones to these proposals.

An important part of the business concerned the arrangements for the remaining months of the action. A release of radioactivity had occurred in Algeciras, Spain (near Gibralter) on 30th May 1998, and a number of modellers had attempted to reconstruct the source details from measurements in France and Switzerland. It was estimated between 50 and 100Ci had been released between 00 and 03UTC. The general consensus in the workshop was that this would form a good case for a model intercomparison, although Ispra's technical specification would require some revision. It was planned that there would be exercises involving wet and dry deposition in the winter of 98/99 and the spring of 1999 (the latter using Obninsk as source), plus the Algeciras incident. In the event Technical Specification Documents have been issued (1st March 99) for an Algeciras run and for an unspecified spring run.

RTMOD will conclude with a 3rd and final workshop, most likely in September 1999.

References:

Girardi F and co-workers, JRC Environment Institute, 1998: ETEX. The European Tracer Experiment. EC EUR 18143 EN.

Graziani G, Klug W and S Mosca, 1998a: Real-time long-range dispersion model evaluation of the ETEX first release. EC EUR 17754 EN.

Graziani G, Galmarini S, Grippa G and W Klug, 1998b: Real-time long-range dispersion model evaluation of the ETEX second release. EC EUR 17755 EN

Klug W, Graziani G, Grippa G, Pierce D and C Tassone (Eds.), 1992: Evaluation of long range atmospheric transport models using environmental radioactivity from the Chernobyl accident. CEC, Elsevier Applied Science.

Ryall D B and R H Maryon, 1996: The NAME 2 dispersion model: a scientific overview. UK Met Office, Turbulence & Diffusion Note 217b.

Ryall D B and R H Maryon, 1998: Validation of the UK Met Office's NAME model against the ETEX dataset, *Atmospheric Environment*, **32, 24,** 4265-4276.

Figure captions:

Note: (i) All the statistical analyses relate to forecast products, as no hindcast equivalents were made available; (ii) The UK dispersion model, NAME, is identified as mod 13.

Fig. 1: NAME dispersion model runs for the notional release from Chernobyl, 09-15UTC 28th April 1998. (a) forecast concentration (i) at T+24hr, (ii) at T+48hr, after release. (b) Similar, for the hindcast. Note: the hindcast was rerun at time of writing, as the original was no longer readily available.

Fig. 2: As fig. 1 for the notional release from Boston, Lincs, 09-15UTC, 9th July 1998.

Fig. 3: Boston release. Time analysis for 52N7E, (a), and global scatterplot, (b): comparisons with the Meteo-France forecast product.

Fig. 4: Boston release. Time analysis for 52N7E: comparison with the Russian forecast product.

Fig. 5: Sample 'figures of merit in space' (FMS) for the Boston release---in fact illustrating the overlaps of the forecast concentration field at T+48 with (a) the Lawrence Livermore, (b) the German (DWD), and (c) Canadian, forecast products. Note the FMS percentages ranging from 49% to 8%.

Fig. 6: Confidence in Contamination Level: sample CCL charts for Boston forecasts for (a) T+24, (b) T+48hr. See text for description. Note only 19 of the 28 models had produced results in time for this calculation.

Fig. 7: Notional Chernobyl release: Time analysis for 58N24E---comparison with the Danish forecast product.

Fig. 8: Sample CCL chart for Chernobyl forecast at T+36hr. Again data for 19 models were used.

Fig. 9: Chernobyl release. Time analysis for 60N22E, (a), and global scatterplot, (b): comparisons with the Austrian product. A high correlation, and good match towards the end of the forecast period.

Fig. 10: Sample FMS plots for the Chernobyl release---illustrating the overlaps of the forecast concentration field at T+24hr with (a) the Meteo-France, and (b) the Bulgarian forecast products. Note the FMS percentages of 63% and 5%.

Fig. 11: Sample FMS plots for the Chernobyl release---illustrating the overlaps of the forecast concentration field at T+48hr with (a) the Canadian, and (b) DWD products. Note the very moderate FMS percentages at this time.

Fig. 12: A few more global scatterplots for the Chernobyl forecast---(a) DWD, correlation 0.54, (b) Norway, correlation 0.58 and (c) Czech Republic, correlation 0.10.

Model No	Country	Organization	Representative
1	Denmark	Risoe Nat. Lab.	T Mikkelsen
2	France	Meteo-France	F Bompay
3	Italy	ANPA	F Desiato
4	US	Westinghouse	D Griggs
5	Japan	Atomic Energy Res.	H Yamazawa
6	Canada	CMC Montreal	R D'Amours
7	Czech Re.	Hydromet Inst.	J Macoun
8	US	Lawrence Livermore	M Bradley
9	Netherlands	KNMI	G Geertsema
10	Germany	DWD	H Glaab
11	Poland	Inst. Atomic Energy	R Zelazny
12	Sweden	SMHI	J Langner
13	UK	Met Office	R Maryon
14	France	CEA-IPSN	M Monfort
15	Denmark	DMI	J Sorensen
16	Romania	Inst. Met & Hydro.	I Sandu
17	Norway	DNMI	J Saltbones
18	Switzerland	Inst. de Met.	D Schneiter
19	Russia	SPA Typhoon	V Shershakov
20	Slovakia	Hydromet Inst.	S Skulec
21	US	NOAA	R Draxler
22	Bulgaria	Inst. Met & Hydro.	D Syrakov
23	Netherlands	National Inst. Neth.	T Hantke
24	Belgium	Inst. Roy. Met.	L van der Auwera
25	Finland	FMI	I Valkama
26	Austria	Inst. Met & Geodyn.	U Pechinger
27	US	Lawrence Livermore	C Foster
28	Denmark	Nat. Env. Research	J Brandt

Table 1. Participants in the RTMOD project 1998/99, showing the Model identification.

UKMO NAME MODEL

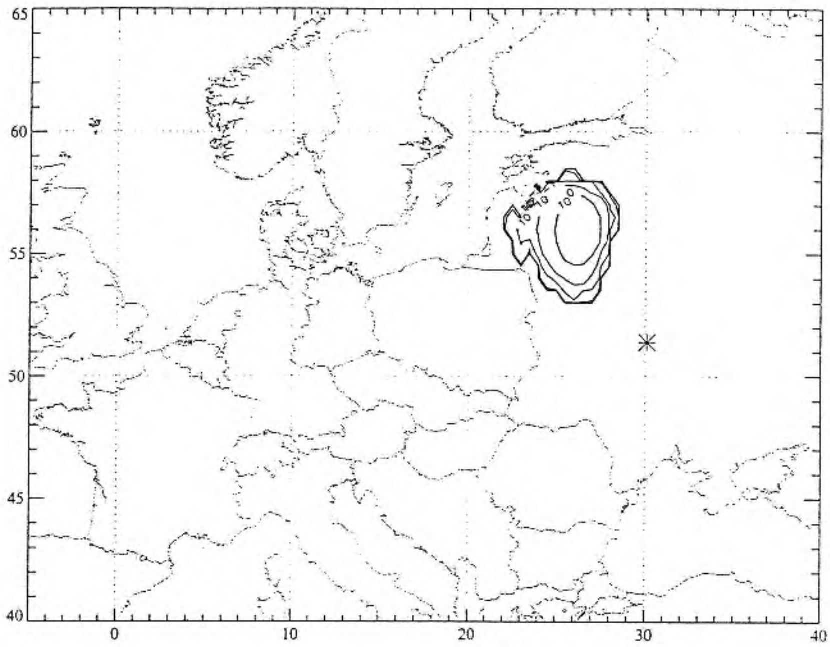
Surface Air Concentration

Valid at 0900UTC/29/04/1998 (T+ 24H)

Maximum: 1.41E+01 ngm^{-3}

Contours at 1.0E-06 1.0E-05 1.0E-04 1.0E-03 1.0E-02 1.0E-01 1.0E+00 ngm^{-3}

(i)



Valid at 0900UTC/30/04/1998 (T+ 48H)

Maximum: 4.66E+00 ngm^{-3}

Contours at 1.0E-07 1.0E-06 1.0E-05 1.0E-04 1.0E-03 1.0E-02 1.0E-01 ngm^{-3}

(ii)

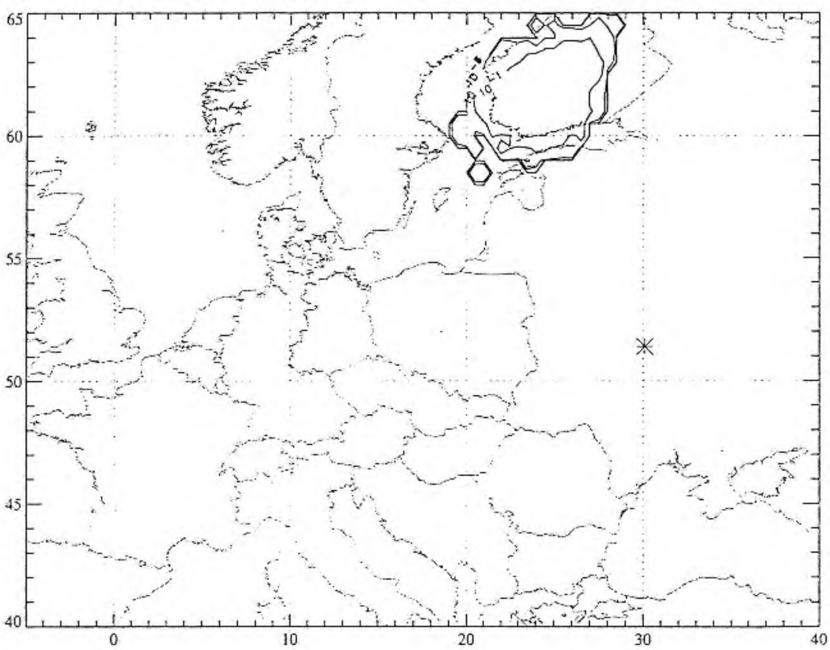


Fig. 1a

Simulation Description

Pollutant: INERT-TRACER
Start of Release: 0900UTC 28/04/1998
End of Release: 1500UTC 28/04/1998
Release rate: 3.60e+13$nghr^{-1}$
Source Location: 51.4000N 030.1000E
Release Height: 0 to 50m agl
Run Time: 0808UTC 28/04/1998

Met data: Global Regional
Analysis on Custom1

UK Meteorological Office Bracknell (APR)

UKMO NAME MODEL

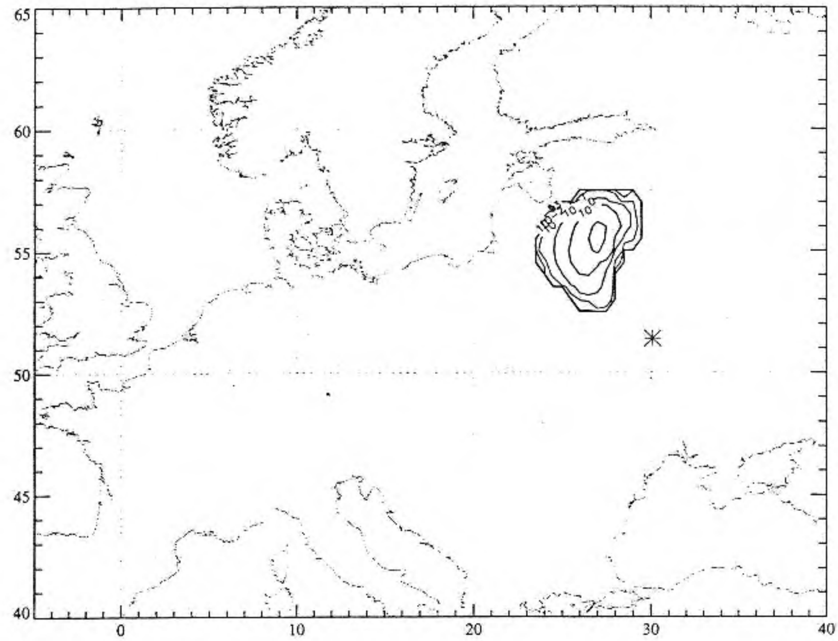
Surface Air Concentration

Valid at 0900UTC/29/04/1998 (T+ 24H)

Maximum: 1.89E+01 ngm^{-3}

Contours at 1.0E-05 1.0E-04 1.0E-03 1.0E-02 1.0E-01 1.0E+00 1.0E+01 ngm^{-3}

(i)



Valid at 0900UTC/30/04/1998 (T+ 48H)

Maximum: 5.65E+00 ngm^{-3}

Contours at 1.0E-06 1.0E-05 1.0E-04 1.0E-03 1.0E-02 1.0E-01 1.0E+00 ngm^{-3}

(ii)

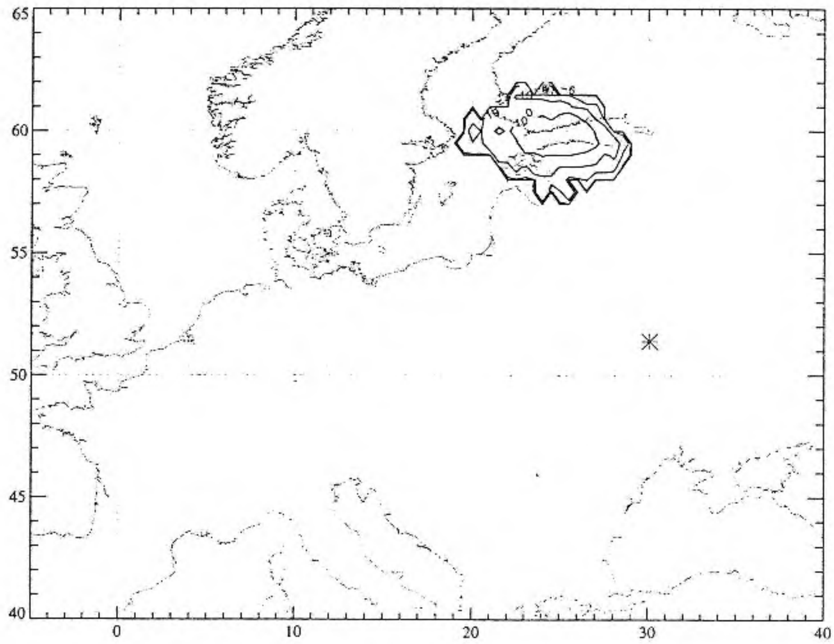


Fig. 1b

Simulation Description

Pollutant: INERT-TRACER
Start of Release: 0900UTC 28/04/1998
End of Release: 1500UTC 28/04/1998
Release rate: 3.60e+13$nghr^{-1}$
Source Location: 51.4000N 030.1000E
Release Height: 0 to 50m agl
Run Time: 09:38:43 8-Mar-99

Met data: Regional
Analysis on Custom1

UK Meteorological Office Bracknell (APR)

UKMO NAME MODEL

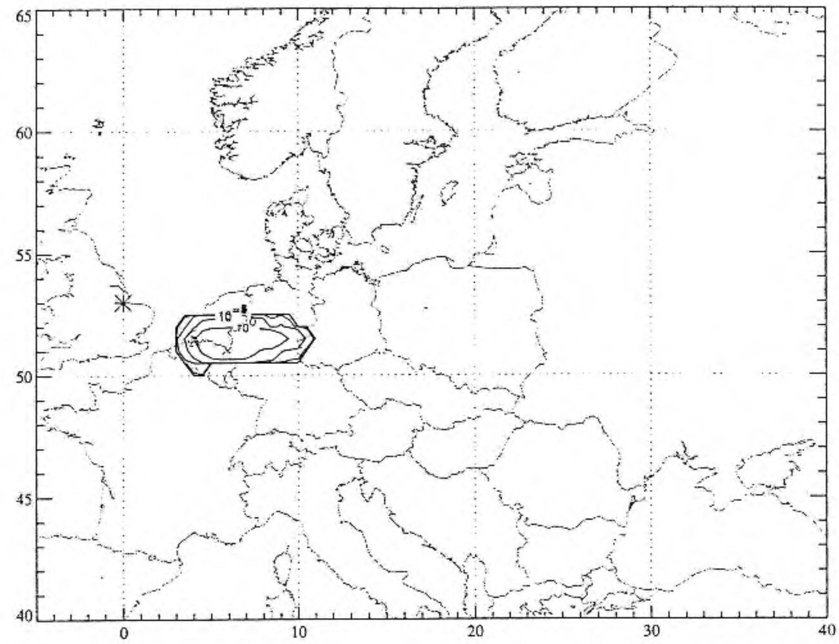
Surface Air Concentration

Valid at 0900UTC/10/07/1998 (T+ 24H)

Maximum: 8.02E+00 ngm^{-3}

Contours at 1.0E-06 1.0E-05 1.0E-04 1.0E-03 1.0E-02 1.0E-01 1.0E+00 ngm^{-3}

(i)



Valid at 0900UTC/11/07/1998 (T+ 48H)

Maximum: 2.60E+00 ngm^{-3}

Contours at 1.0E-06 1.0E-05 1.0E-04 1.0E-03 1.0E-02 1.0E-01 1.0E+00 ngm^{-3}

(ii)

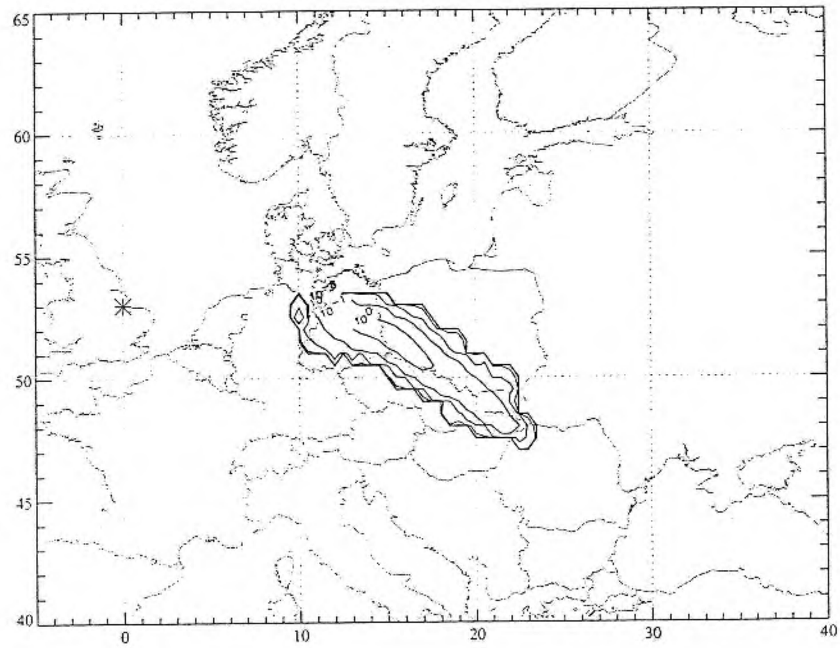


Fig. 2a

Simulation Description

Pollutant: INERT-TRACER
Start of Release: 0900UTC 09/07/1998
End of Release: 1500UTC 09/07/1998
Release rate: $3.60e+13nghr^{-1}$
Source Location: 53.0000N 000.0000E
Release Height: 0 to 50m agl
Run Time: 0919UTC 09/07/1998

Met data: Global Regional Analysis on Custom1

UK Meteorological Office Bracknell (APR)

UKMO NAME MODEL

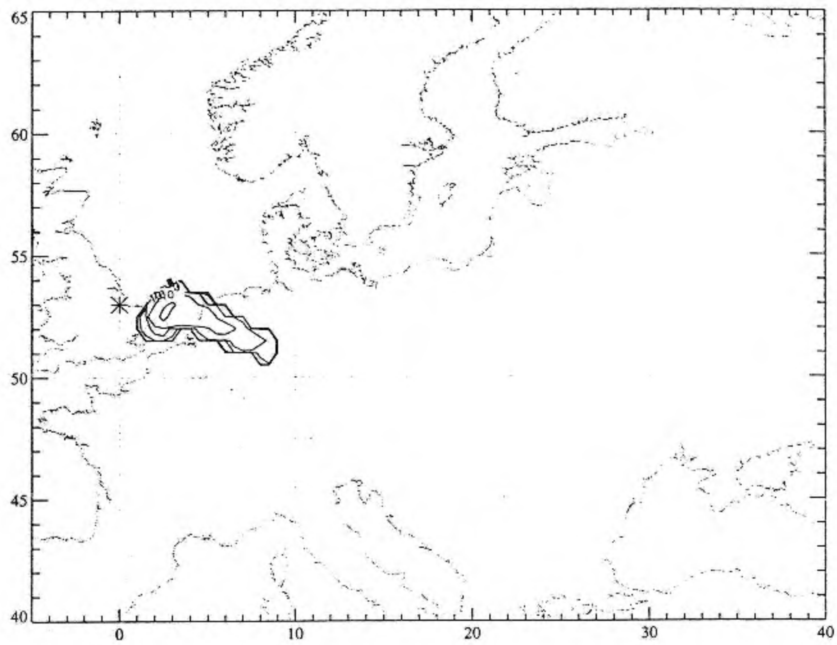
Surface Air Concentration

Valid at 0900UTC/10/07/1998 (T+ 24H)

Maximum: 1.49E+01 ngm^{-3}

Contours at 1.0E-05 1.0E-04 1.0E-03 1.0E-02 1.0E-01 1.0E+00 1.0E+01 ngm^{-3}

(i)



Valid at 0900UTC/11/07/1998 (T+ 48H)

Maximum: 3.88E+00 ngm^{-3}

Contours at 1.0E-06 1.0E-05 1.0E-04 1.0E-03 1.0E-02 1.0E-01 1.0E+00 ngm^{-3}

(ii)

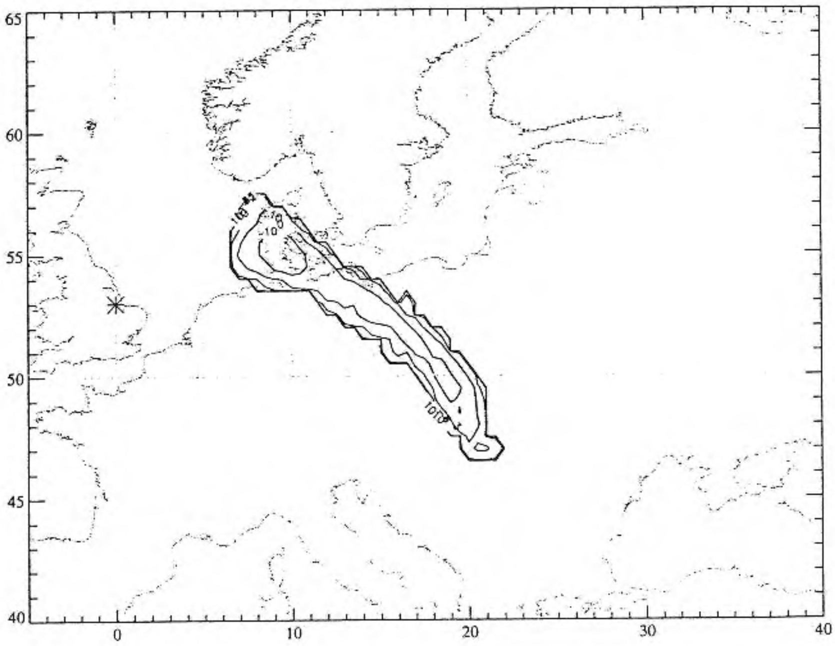


Fig. 2b

Simulation Description

Pollutant: INERT-TRACER
Start of Release: 0900UTC 09/07/1998
End of Release: 1500UTC 09/07/1998
Release rate: 3.60e+13nghr^{-1}
Source Location: 53.0000N 000.0000E
Release Height: 0 to 50m agl
Run Time: 08:30:35 8-Mar-99

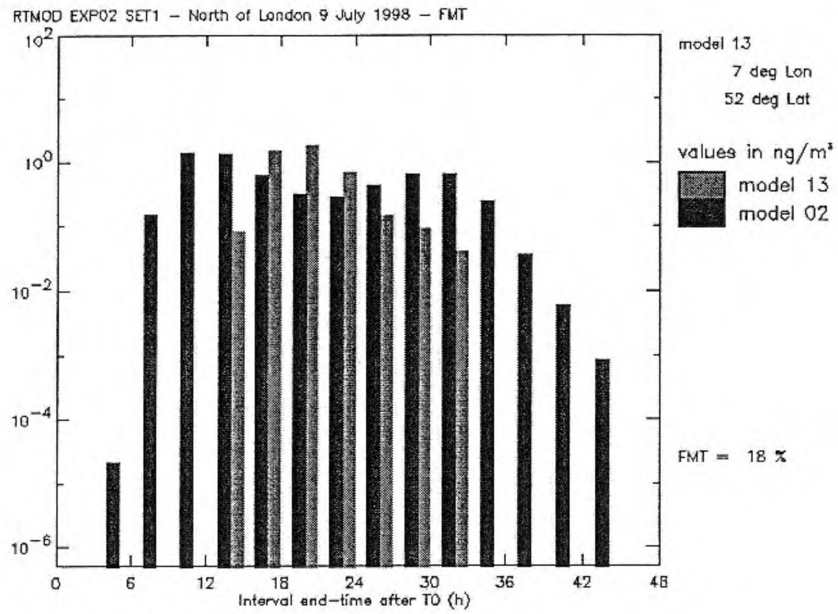
Met data: Regional
Analysis on Custom1

UK Meteorological Office Bracknell (APR)

RTMOD - FMT for concentration

Back to preview
Back to Model 13 results

(a)



Archive

RTMOD - Scatter diagram for concentration : Model 13 vs Model 02

Back to preview
Back to Model 13 results

(b)

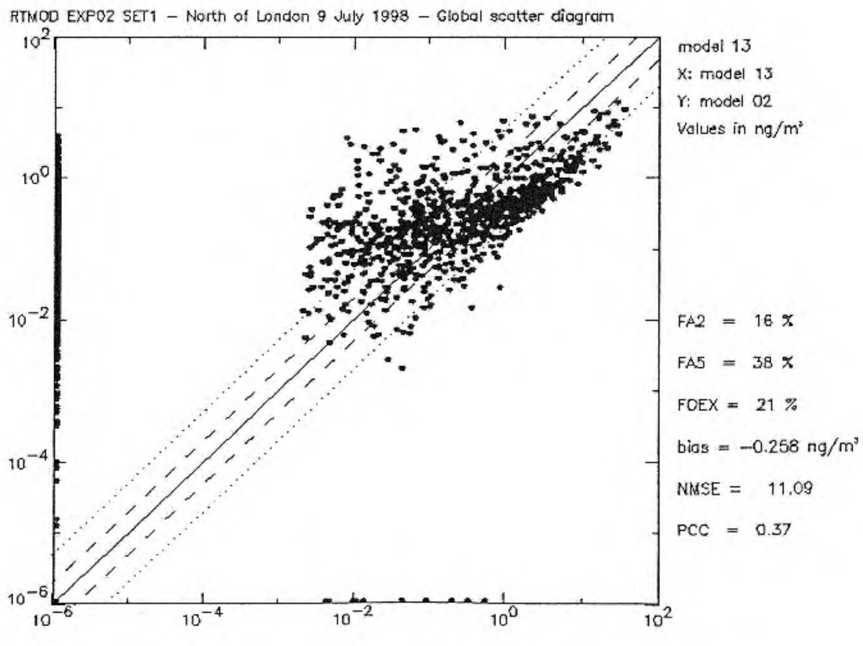


Fig. 3

Archive

RTMOD - FMT for concentration

Back to preview

Forum

Back to Model 13 results

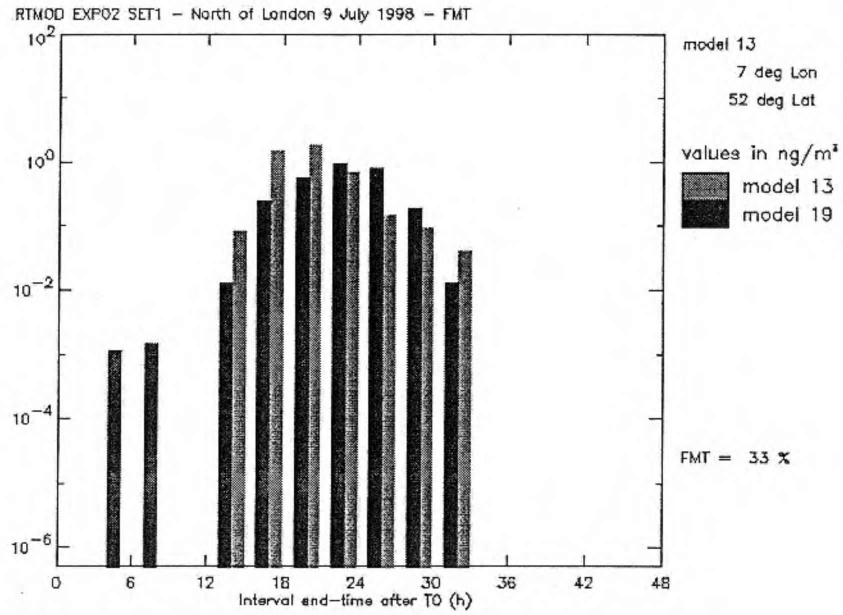


Fig. 4

Archive

RTMOD - FMS for concentration

Back to preview

Send data

Back to Model 13 results

(a)

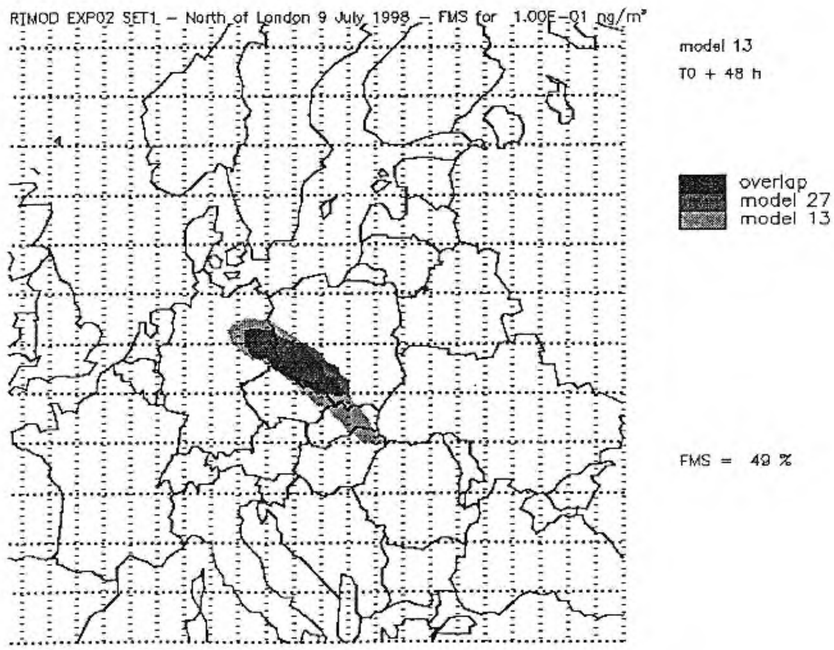


Fig. 5

Archive

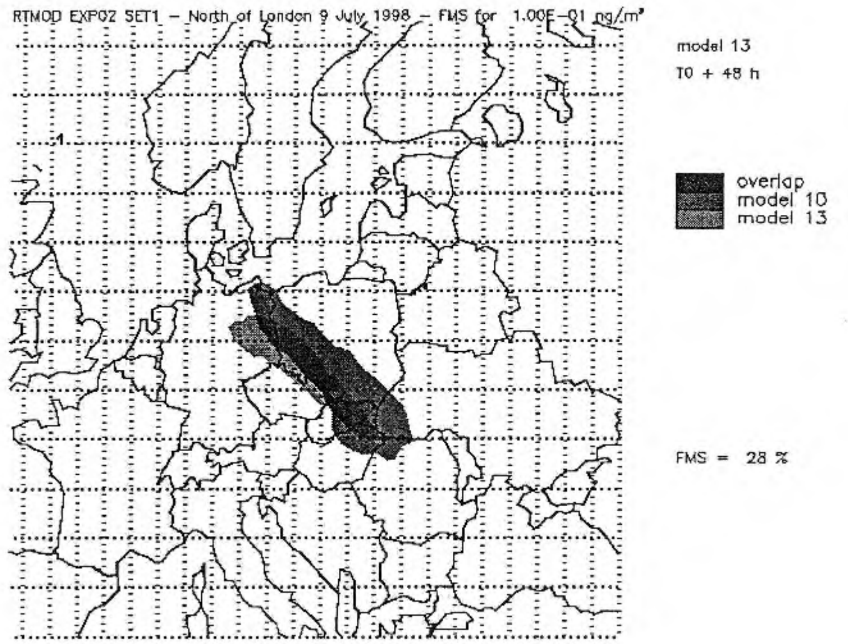
RTMOD - FMS for concentration

View results

Back to preview

Back to Model 13 results

(b)



Archive

RTMOD - FMS for concentration

Send data

Back to preview

Back to Model 13 results

(c)

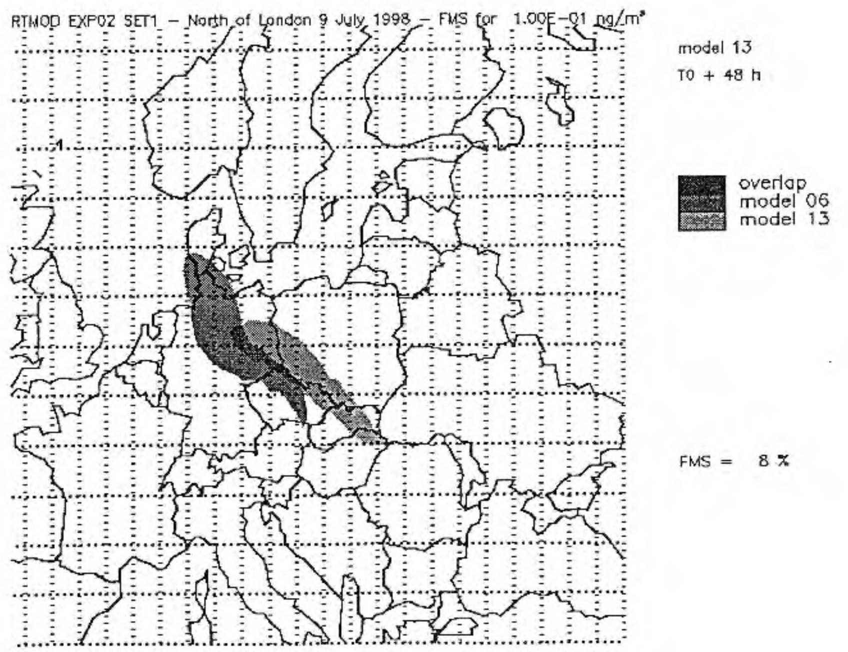
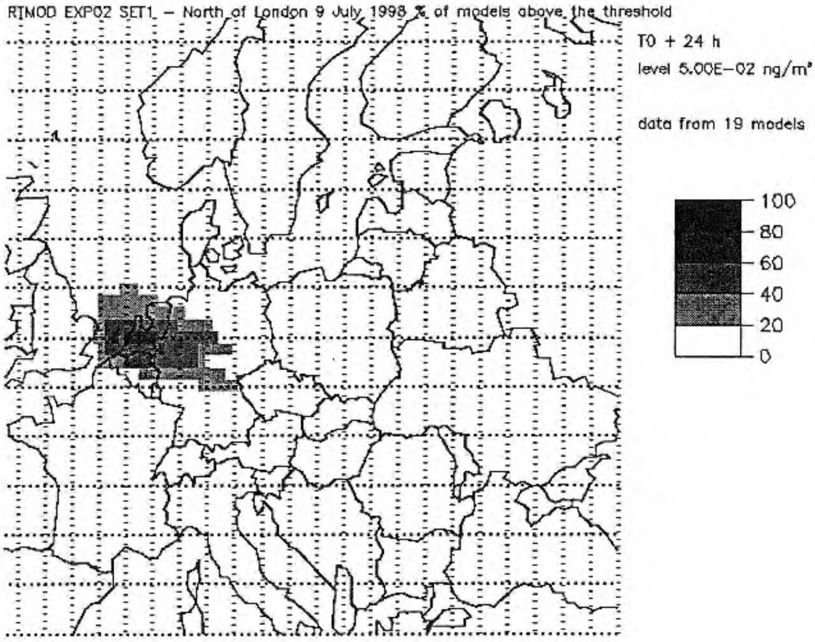


Fig. 5

RTMOD - CCL for concentration

Back to preview

(a)



Archive

RTMOD - CCL for concentration

Back to preview

(b)

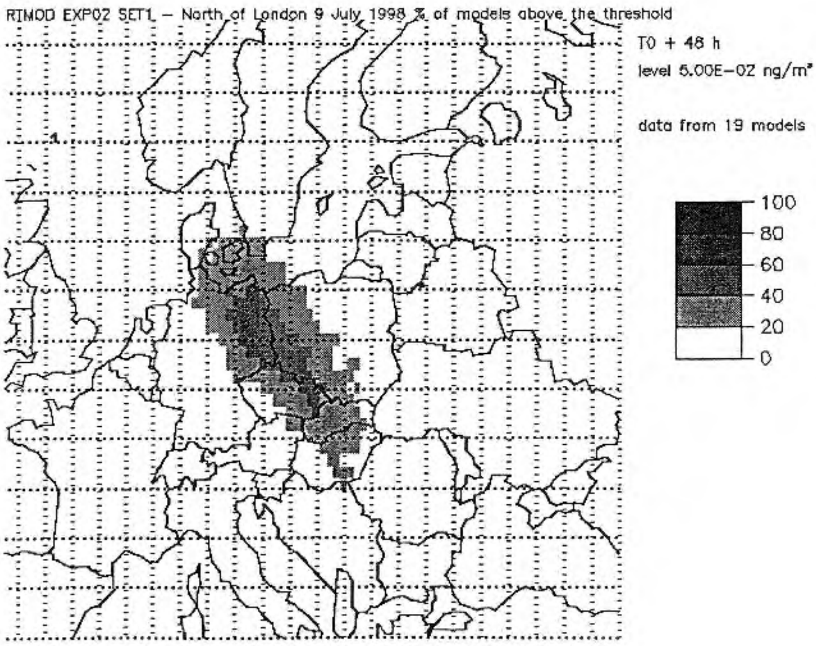


Fig. 6

Archive

RTMOD - FMT for concentration

Participants

Back to preview

Back to Model 13 results

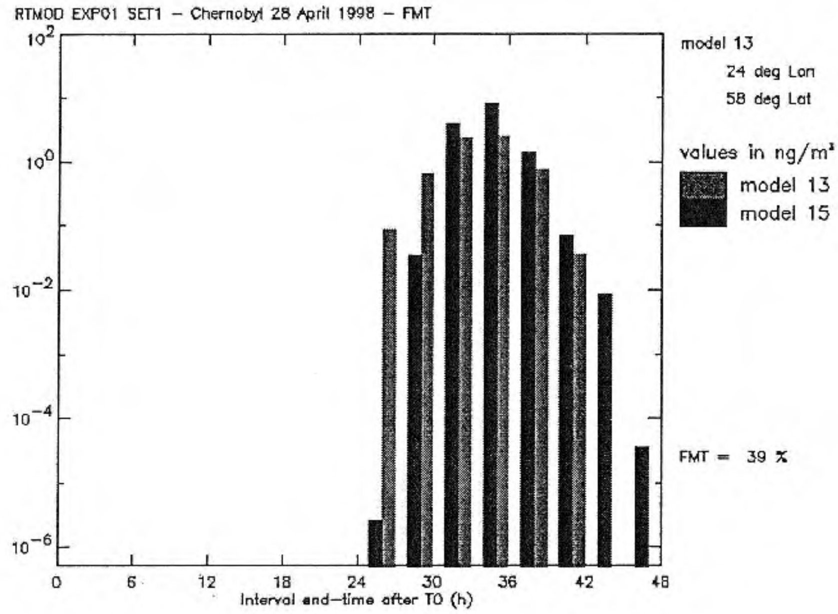


Fig. 7

Archive

RTMOD - CCL for concentration

Participants

Forum

Back to preview

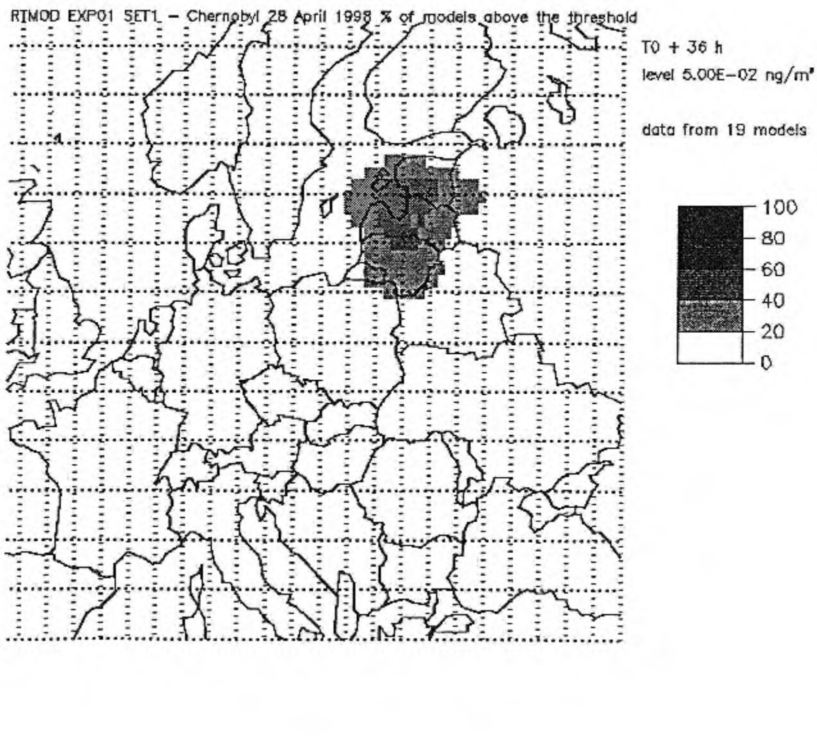


Fig. 8

Archive

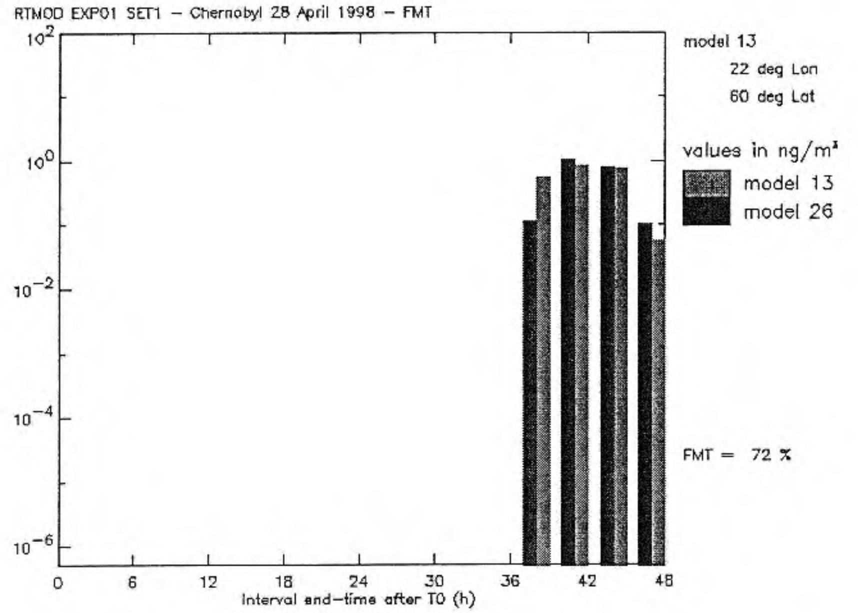
RTMOD - FMT for concentration

Back to preview

Participants

Back to Model 13 results

(a)



Archive

RTMOD - Scatter diagram for concentration : Model 13 vs Model 2

Back to preview

Meetings

Back to Model 13 results

(b)

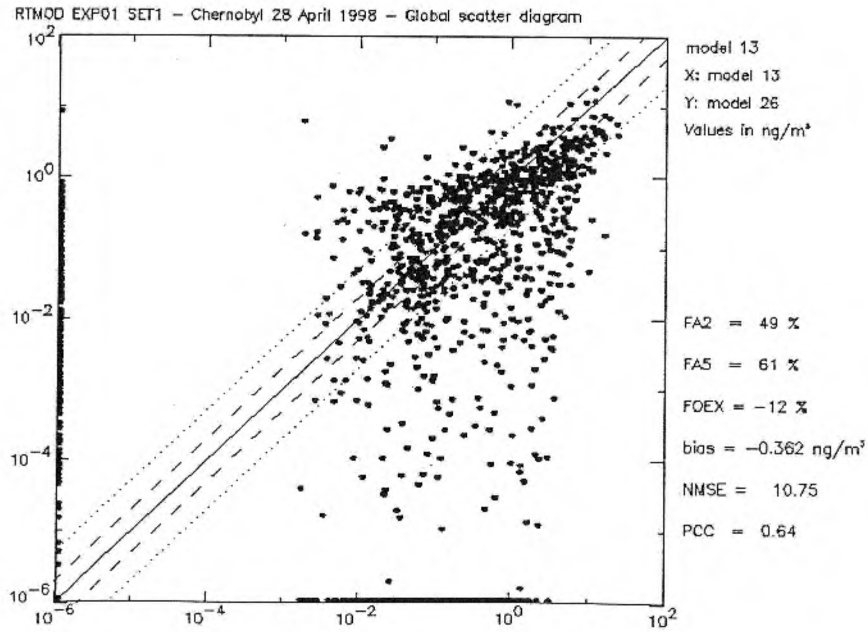
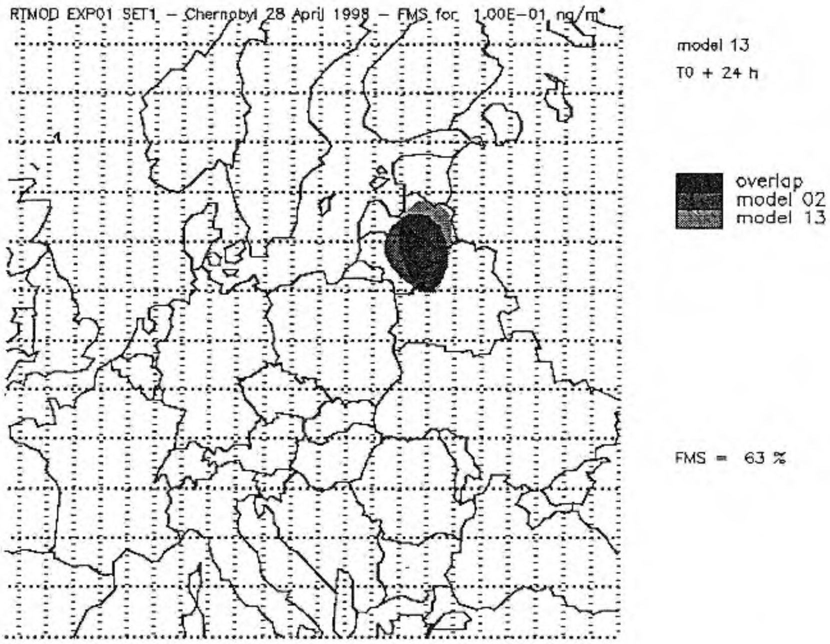


Fig. 9

RTMOD - FMS for concentration

Back to preview
Back to Model 13 results

(a)



Archive

RTMOD - FMS for concentration

Back to preview
Back to Model 13 results

(b)

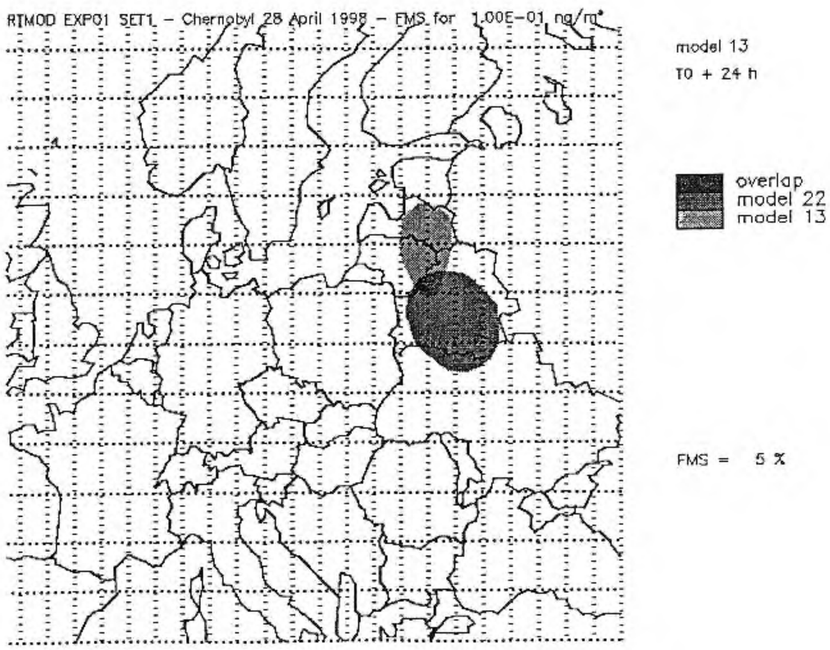


Fig. 10

Archive

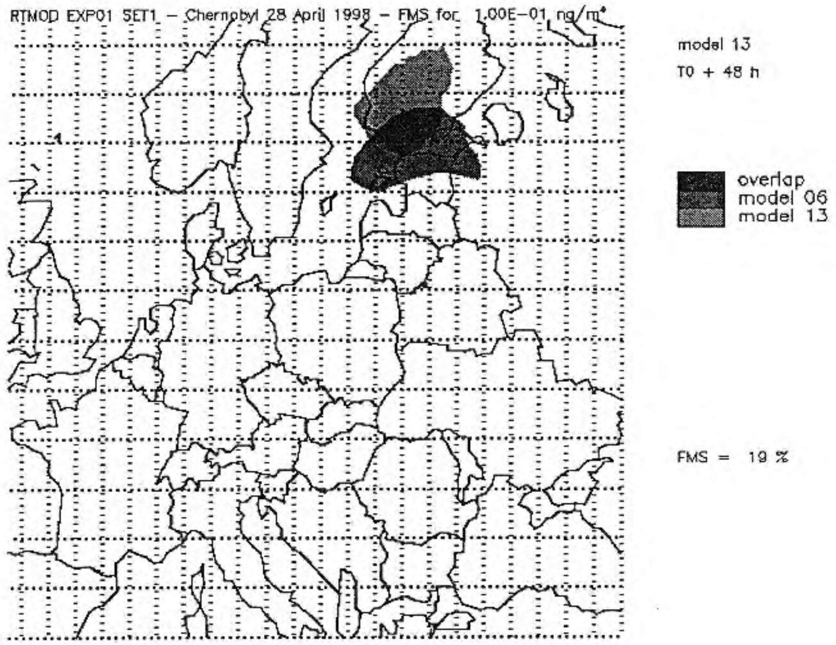
RTMOD - FMS for concentration

Back to preview

Back to Model 13 results

Meetings

(a)



Archive

RTMOD - FMS for concentration

Back to preview

Back to Model 13 results

Send data

(b)

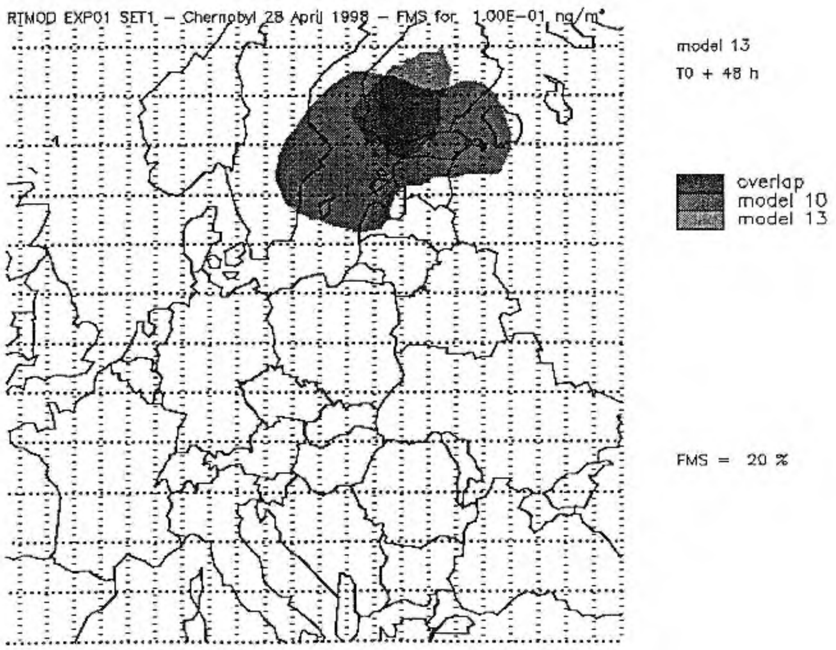
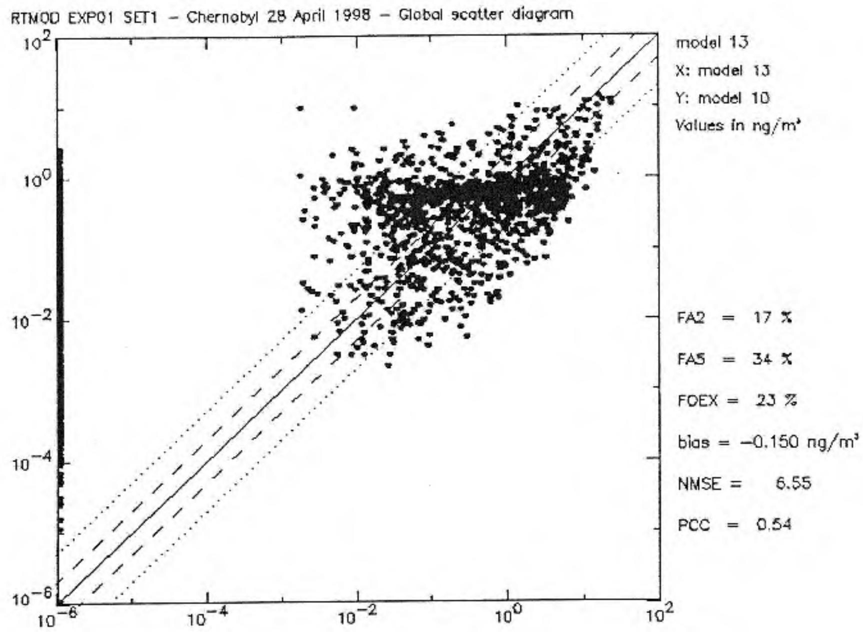


Fig. 11

RTMOD - Scatter diagram for concentration : Model 13 vs Model :

(a)



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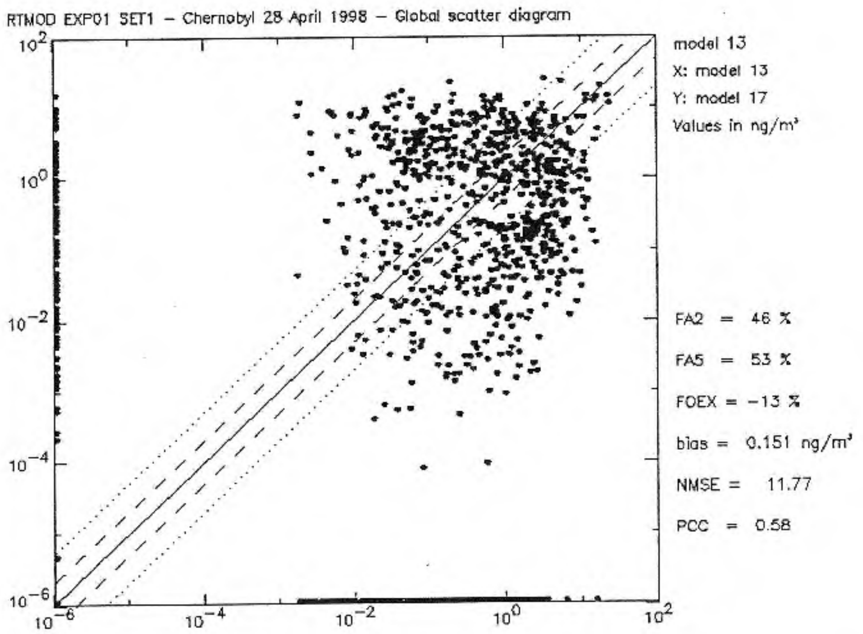

(c)

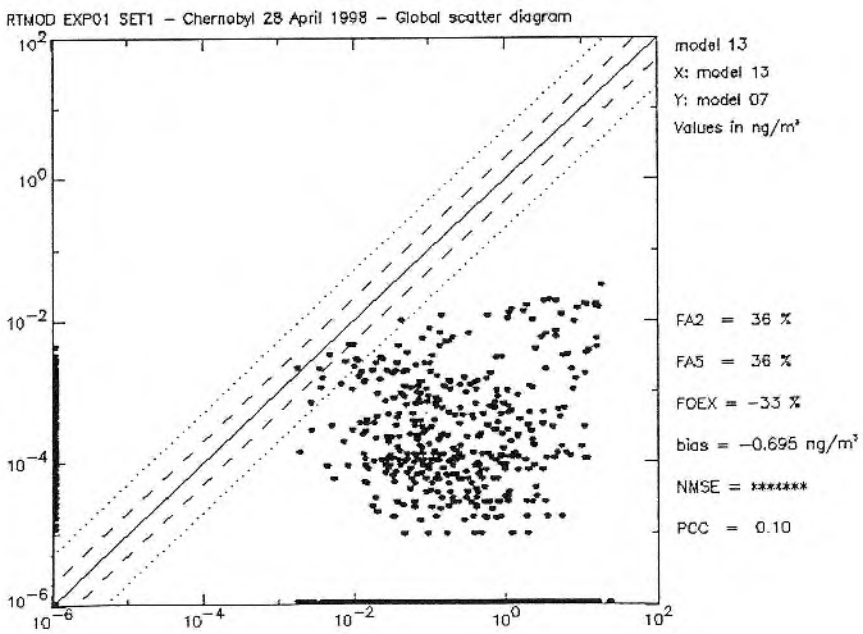

Fig.12

A COMPARISON OF THE NAME DISPERSION MODEL WITH VAFTAD AND OTHER VAAC MODELS

R H Maryon
Atmospheric Dispersion Group, PMSR

Feb 1999.

Introduction. The spread of volcanic ash in the upper atmosphere constitutes a very real danger to civil aviation. Bracknell is one of seven WMO-designated VAACs (Volcanic Ash Advisory Centres), and recently took over the modelling aspects of the dispersion of volcanic ejecta for the UK area of responsibility. Previously the NOAA-based VAFTAD operation in Washington was relied upon for this purpose. A comparison of the NAME (Ryall & Maryon, 1998) and VAFTAD (Heffter & Stunder, 1993) models for predicting the dispersal of volcanic ash was included as part of the Volcanic Ash project of the Product Development Programme for 1998/99. To meet this requirement a number of model intercomparisons are brought together here---NAME is compared both with the VAFTAD model and with those used by other VAACs.

The comparison of long range transport and dispersion models is known to be a difficult undertaking. Dispersion on large scales is controlled by the major wind systems, which are changing in time and space: the dynamics are deterministic but chaotic. A chaotic system, by definition, is extremely sensitive even to slight differences in initial conditions. NWP models thus diverge, and the divergence can become serious after a few days. Using forecast meteorology accordingly imposes additional error on the dispersion models. The forecast element is, however, very important for providing warnings to the aviation authorities. Models can, of course, be run using only analysed data, but even the analyses will vary among the different underpinning NWP models. The dispersion models themselves will have different assumptions and techniques for representing diffusion, diagnosing boundary layer depth, etc: probably the diffusion allowed constitutes one of the largest causes of difference between models, although it will be seen that NAME and VAFTAD appear to be fairly consistent in this respect. The Toulouse and Darwin VAAC models, on the other hand, tend to exhibit much greater dispersion than NAME.

Despite all these inherent difficulties, there is often a gratifying level of consistency among dispersion model products; there are also situations with disappointing differences. Of course, unless validating data are available, there is no indication as to which model is closest to the 'truth'. Such validation was the aim of the EC/WMO/IAEA ETEX project, in which tracer was released from a site in Brittany and concentrations recorded across the breadth of Europe (Graziani et al, 1998). NAME ranked very highly among the many international models used to simulate the tracer spread.

In this study a number of situations, both forecast and analysed, will be examined and illustrated and conclusions drawn on the consistency of the NAME and (in particular)

VAFTAD products as far as possible at the present time. Both global and regional versions of NAME were used, but differences in performance of the different NAME resolutions is not addressed here. A further source of variation arose from the different attenuations made to the plotted output of most of the VAACs included here to approximate and delineate the 'visible plume'---this is discussed in the Conclusions. The VAACs are largely concerned with predicting dispersion not, at this stage, concentrations in air, and no material is available for comparing modelled concentrations. The following cases are available and will be examined in sequence:

A. A set of five forecasts, February 1999, between NAME and VAFTAD.

B. The Icelandic Vatnajokull eruption of Dec 1998: comparisons between NAME, VAFTAD and the Montreal model.

C. A comparison of hindcasts made by 6 VAACs, July 1998.

D. The Mt Etna eruption, Feb 1999: a comparison with the Toulouse model.

In the following discussions the following short-hand will be adopted:

T+n	n hours into a forecast
R+n	n hours after the start of the eruption (real or notional).

The standard VAAC output format shows the spread of the plume in three deep layers: from the surface to FL200, FL200 to FL350, and from FL350 to FL550. In addition a composite plot shows the spread of the entire ash plume from the surface to FL550. Plots of this kind were not always received complete, and on one or two occasions non-standard output will be used in the following studies. Even standard output has in most cases been cut up and reassembled to allow direct and easy comparisons between different models at specific times.

A: NAME and VAFTAD forecast comparisons, Feb 1999.

The illustrations for these 48hr forecasts for notional releases from Vatnajokull in Iceland show the spread of the plume for the standard layers, surface to FL200, FL200 to FL350, and from FL350 to FL550. The 'eruptions' were assumed to last for one hour.

1. 00UTC 16th February. There was a slight difference in initial conditions in this case as VAFTAD took the ash column to be 10000-35000ft, NAME 5600-33000ft, but in view of the large depths of the analysis layers this was unlikely to influence the appearance of the plumes to any marked extent. Figs 1a, 1b show that the correspondence was very poor indeed. Other than the fact that both plumes drifted east (at different speeds), the shapes and locations showed no similarity at all. This was perhaps the worst case among all those reviewed, and it is difficult to account for such disparate forecasts.

2. 00UTC 17th February. The depth of the ash columns differed as for A1. A very different

case (figs 2a, 2b) with excellent correspondence even at 48hr into the forecast. Note in particular, at T+48, the line of the plume north of Iceland - southern Norway - Germany - Italy below FL200 in both products. There are some differences, however---at low levels over E Europe while NAME has more material reaching higher levels. VAFTAD most likely has rather more attenuation to delineate the 'visible ash cloud', which may account for some of the differences.

3. 00UTC 18th February. The ash columns are now brought into line (5000 - 30000ft). An outstandingly good result considering we have independent 48hr forecasts (figs 3a, 3b). The difference in the map projections should be taken into account in comparing these plumes. Again VAFTAD loses more material at high levels, probably due to attenuation as in A2.

4. 00UTC 19th February. Identical release scenarios (figs 4a, 4b). Again if the differences in map projection are allowed for these are seen to be very similar forecasts, NAME once more having rather more material at high levels. The developing 'whorl' N of Scotland and W of Norway at T+48 compares excellently in position and shape.

5. 00UTC 23rd February. Identical release scenarios (figs 5a ,5b). The 24hr forecast is close to perfection, the plume skirting northern Iceland and running through Scotland, E England to SE France in both. VAFTAD has lost its material above FL200, no doubt due to its attenuation option. By T+48 the comparison is still very good, although not perfect---note the cusp in the plume near Brittany and the whorl NW of Iceland.

Of course we have a small sample, here, but the results (four good out of five) do suggest that in many cases NAME and VAFTAD provide very comparable plumes, even at 48hr into a forecast. There will also be cases where they diverge strongly, but the indications are that this is due to differences in the forecast, in particular, rather than the dispersion sub-model. Given identical meteorology one gets the impression that the two models have the capability of providing consistent information---at least for the deep ash clouds and analysis layers compared in this study. It should be observed, however, that at typical flight levels VAFTAD on this evidence 'loses' more of the ejecta, evidently due to their attenuation procedures.

B: Iceland---the real eruption of Vatnajokull, Dec 1998.

Under the pressure of events where VAACs become involved operationally, there are bound to be differences in initial conditions, and some mix of forecast and hindcast products. The model products are still useful for intercomparison, however. Vatnajokull erupted on 18th Dec, with some material ejected to around 30000ft. The eruption continued intermittently for about 10 days, the ash cloud gradually reducing in height.

1. 09UTC 18th December. Three runs are available, here---VAFTAD and NAME hindcasts and a NAME forecast (figs 6a, 6b and 6c respectively). The VAFTAD and NAME hindcasts had near-identical ash columns, FL56 - FL330 and assumed emissions ran from 09 to 15UTC; the NAME forecast, made at the first notification, had used a column extending from the surface to FL450 and made the standard assumption of a 1hr eruption from 09UTC. Only the

'composite' plume plot over the complete depth (surface to FL550) was produced by Washington VAAC, for 12, 24 and 36hr after release (fig 6a).

Comparing the composite plots of figs 6a and 6b (the VAFTAD and NAME hindcasts) we find very creditable levels of similarity. Notice in particular the plume over and east of Scotland at 36hr after release. There are difference from R+24, but the two runs are telling essentially the same story. The same can be said for VAFTAD and the forecast (fig 6c), which was quite a good match despite the short release duration. At R+24 the NAME forecast is closer to VAFTAD than the hindcast, although by R+36 it is showing excessive eastward spread---probably the comparisons at both times simply reflect the deep ash column released. Altogether a good 3-way intercomparison.

2. 24th/25th December. With a long-continued eruption different VAACs had adopted different release strategies by 24th, and it is difficult to find operational NAME plots directly comparable with the only other runs available, from Montreal VAAC (the CANERM model). Two runs are available from CANERM, one operational NAME run, and a NAME hindcast has been made. There is considerable overlap of the period covered by these runs, but for the sake of simplicity the operational NAME product will be compared with one of the CANERM runs, (a) below, the NAME hindcast with the other, with which it has an identical release time and emission duration ((b) below).

(a) A CANERM release at 10UTC 25th, ash cloud to 10000m (about FL330), release duration 6hr; the run may have been hindcast to 18UTC, but this is uncertain. The operational NAME run was from 00UTC 25th Dec, ash cloud to FL300, release duration a full 24hr; the first 12hr may have been hindcast---again, this is uncertain as the run was submitted at about the time the met fieldsfiles were updated. On this occasion the NAME model was given a strong attenuation for visible plume. No composite plots (full depth of ash cloud) were sent by Montreal. Comparisons are possible at 00 and 12UTC on 26th and 00UTC on 27th (figs 7a, 7b). The comparisons are reasonable, with the general positions of the plumes similar although the relative spread and shape had shortcomings. NAME produced no material above FL350, perhaps due to the attenuation imposed. By 12UTC on 26th the similarities below FL 350 are quite strong, especially at the lowest level, and by 00UTC on 27th the NAME attenuation seems to account for most of the difference. This comparison is perhaps as good as could be expected given the different start times and assumptions.

(b) A CANERM release at 12UTC 24th Dec, the ash cloud apparently only up to 4000m (about FL130). This is surprising, as a well-defined plume is plotted above FL200 by 18UTC. The run was hindcast to 00UTC on 25th. There is no information on release duration, but the charts suggest it was 6 or 12hr. This is compared with a recent NAME hindcast, same release time, ash cloud FL20 to FL250, 12hr duration. The NAME output is plotted using contours rather than the standard VAAC format, to bring it more into line with the CANERM product. Comparisons are possible at 00 and 12UTC on 25th and 26th Dec (figs 8a, 8b(i)-(iii)). Note that fig 8b(i) plots the evolution of the surface - FL200 cloud; (ii) and (iii) show similar information for the two upper layers. Thus each of figs 8b is comparable with a row of fig 8a.

At 00UTC on 25th we are comparing two hindcasts. The correspondence is excellent. Moving on into the CANERM forecast period the similarity remains very good at 12UTC on 25th up to FL350, particularly if the very diffuse sections of the NAME plume are ignored (there is no attenuation in the contour charts). The patchy high level material differs, especially in the NAME tendril E into Sweden. At 00UTC on 26th the low level plumes again correspond excellently if the very diffuse part of the NAME plume is disregarded. Above FL200 both plumes now have the tendril extending E through N Finland into NW Russia, although NAME keeps more material close to the source. The upper level plumes correspond reasonably over Greenland, but CANERM does not lift the tendril above FL350. By 12UTC on 26th the CANERM run is 36hr into its forecast. In contrast to NAME it has lost all ejecta above FL350; below that level the correspondence is moderately good, particularly in the FL200 - FL350 layer, both models handling the denser material extending W from S Greenland, and the eastward tendril, in very similar fashion. Evidently the CANERM forecast was quite a good one, and, as before, the comparisons generally good except at the highest level.

In short, the conclusions from the handling of the eruption at Vatnajokull reinforce those of the February 1999 forecasts.

C. A comparison of hindcasts from six VAACs, July 1998.

Nick Heffter of Washington VAAC organized an intercomparison of six VAACs using hindcast runs. The test eruption was at the Icelandic volcano Hekla, the ash column extending from FL15 to FL120. The eruption was to last for 1hr from 00UTC, 3rd July 1998. Fig 9a shows Heffter's analysis of all the models in the layer FL200 - FL350 at R+24 (no other levels were made available). All the models compare quite well, with Bracknell, Washington, Anchorage and Montreal quite similar, although Montreal throws a lobe E over the S Baltic Sea. The Darwin plume is similarly situated, although it has greater diffusion. The Toulouse model tells a somewhat different story to the others on this occasion. By R+48 (fig 9b) the model plumes are generally assuming different shapes---the effect of chaotic advection---although positionally there is still a great deal of consistency. All the models have material reaching S central Europe. Bracknell, Washington and Anchorage all have a tendril extending to or towards southern Sweden, although the rump of the plume lies W of the tendril according to Bracknell, E according to Anchorage, and both sides for VAFTAD! Montreal replaces the tendril with a patch of material over W Germany, and still throws a lobe towards the east. It also has a lobe extending NW into N Italy, resembling similar features in the Bracknell and VAFTAD products. Darwin resembles a highly diffused VAFTAD plume, whereas Toulouse continues on its own way with widely dispersed material over Norway, Scotland and the N Atlantic.

Some encouragement can be taken from these comparisons although (from the Bracknell point of view) one or two of the other VAACs need to cut down on diffusion. This raises the old dilemma of how cautious one should be in setting plume limits against the cost (severe for aviation) of false alarms.

D. The Mt Etna eruption of 2nd Feb 1999.

This appears to have been a relatively minor event, as little was heard about it on the media. A VAAC response was made by Toulouse, with a release 06 to 07UTC on 2nd Feb (fig 10a), with the ash column surface to 3000m (about FL100). This must be a forecast run in its entirety, although information was provided only out to 00UTC on 3rd. NAME was run in forecast mode later on 2nd, the ash cloud surface to FL200, otherwise release details similar (fig 10b). NAME was given a strong attenuation to delineate the 'visible plume' on this occasion. The case is of little interest, as the plume did no more than drift slowly ESE, without deformation, during the few hours of the forecast. By 00UTC on 3rd Toulouse had a broadly oval plume situated between Sicily and the Ionian Sea. NAME exhibited a smaller feature which could be largely contained in the western half of the Toulouse plume. No conclusions can be drawn from this---Toulouse products generally seem more diffuse than NAME, and NAME was strongly attenuated here.

There is something of a sting in the tail, however: a hindcast run with NAME, this time without attenuation, showed an oval, near-stationary plume over Sicily at 00UTC on 3rd---if anything with a very slight WSW'ly drift (fig 10c). At later times the modelled plume was deformed, and stretched SW into Africa.

Conclusions.

1. The above studies indicate that NAME and Washington's VAFTAD are highly comparable models, with perhaps more similarities than any other pairing of the six VAAC models examined. Even taking into account a level of uncertainty due to different plume attenuation assumptions the overall diffusion of the two models seems very similar.

2. One would expect the two models to diverge more strongly in forecast mode, but except on one occasion the respective 48hr forecast products were by no means greatly inferior to the hindcasts available. The story would be different for longer range forecasts of course. The dispersion sub-models are entirely dependent on the underpinning NWP models, so that strong divergence would be unavoidable as the length of a forecast increases.

3. The area of least consistency was above FL350: these levels are above the initial ash column, and the appearance of material in the top layer reflects what are sure to be different vertical motions diagnosed by the two models. The dispersion sub-models may in addition be more crudely discretized at high level. Yet another cause of variation lies in the attenuation assumptions.

4. Following work in Canada and the United States there is a generally agreed factor for attenuating the model plumes to derive a visible plume; this attenuation is (no doubt correctly) quite stringent. There seems to be a tendency among modellers, both as a matter of common caution and because they like the warm feeling of seeing the full results of their integrations, to use less than recommended attenuation. As this adjustment is accordingly somewhat arbitrary, it increases the variation in model outputs, particularly where the plume

is diffuse (e.g. above FL350 in these cases). Where the plume is reasonably dense and well-delineated, the attenuation (on the periphery) is usually of little significance. Further work is needed in this area.

5. Before closing mention should be made of the excellent performance of the NAME model in the ETEX tracer exercise. For the hindcast part of the 1st release for example, in a set of twenty tabulated statistics involving correlation, mean square error and figure of merit in space, among others, for various times out to R+60 NAME obtained seven firsts, six seconds and two thirds out of 28 models from around the world. It was, of course, a long way short of perfect, being relatively weak on the normalized mean square error. This could only be improved at the expense of correlation, most easily by increasing the diffusion one suspects.

It may safely be concluded that NAME's credentials, demonstrated performance and consistency with VAFTAD place it in the first rank of dispersion models, and eminently suitable for application in Bracknell VAAC to simulate the dispersal of volcanic ash.

References:

Graziani, G., Klug, W. and S. Mosca, 1998: Real-time long range dispersion model evaluation of the ETEX first release. Joint Research Centre Ispra, European Commission.

Heffter, J. L. & B. J. B. Stunder, 1993: 'Volcanic Ash Forecast Transport and Dispersion (VAFTAD) Model', *Computer Techniques,* **8,** 533-541.

Ryall, D.B. & R. H. Maryon, 1998: 'Validation of the UK Met Office's NAME model against the ETEX dataset', *Atmospheric Environment*, **32, 24,** 4265-4276.

Figure captions. Note that full details of the start conditions for the integrations can be found in the messages accompanying the figures and/or in the text.

Fig. 1: VAFTAD (a) and NAME (b) 48hr forecast commencing 00UTC 16th Feb 1999.

Fig. 2: VAFTAD (a) and NAME (b) 48hr forecast commencing 00UTC 17th Feb 1999.

Fig. 3: VAFTAD (a) and NAME (b) 48hr forecast commencing 00UTC 18th Feb 1999.

Fig. 4: VAFTAD (a) and NAME (b) 48hr forecast commencing 00UTC 19th Feb 1999.

Fig. 5: VAFTAD (a) and NAME (b) 48hr forecast commencing 00UTC 23rd Feb 1999.

Fig. 6: VAFTAD hindcast (a), NAME hindcast (b) and NAME operational (forecast) (c) for the Vatnajokull eruption, Iceland, 09UTC 18th Dec 1998.

Fig. 7: CANERM (a) and NAME (b) operational runs for Vatnajokull 25th Dec 1998.

Fig. 8: CANERM operational run (a) and NAME hindcast (b) for Vatnajokull, 12UTC 24th Dec 1998. 8b(i), (ii), and (iii) show the evolving ash cloud at FL000-FL200, FL200-FL350 and FL350-FL550 respectively.

Fig. 9: Ash cloud comparisons for 6 VAAC model hindcast runs, Hekla, 00UTC 3rd July 1998. (a) 24hr after release, (b) 48hr after release. Outlining of 'visible clouds' by Washington VAAC.

Fig. 10: Toulouse (a) and NAME (b) operational (forecast) runs and NAME hindcast run (c) for the Mt Etna eruption, Sicily, 06UTC 2nd Feb 1999.

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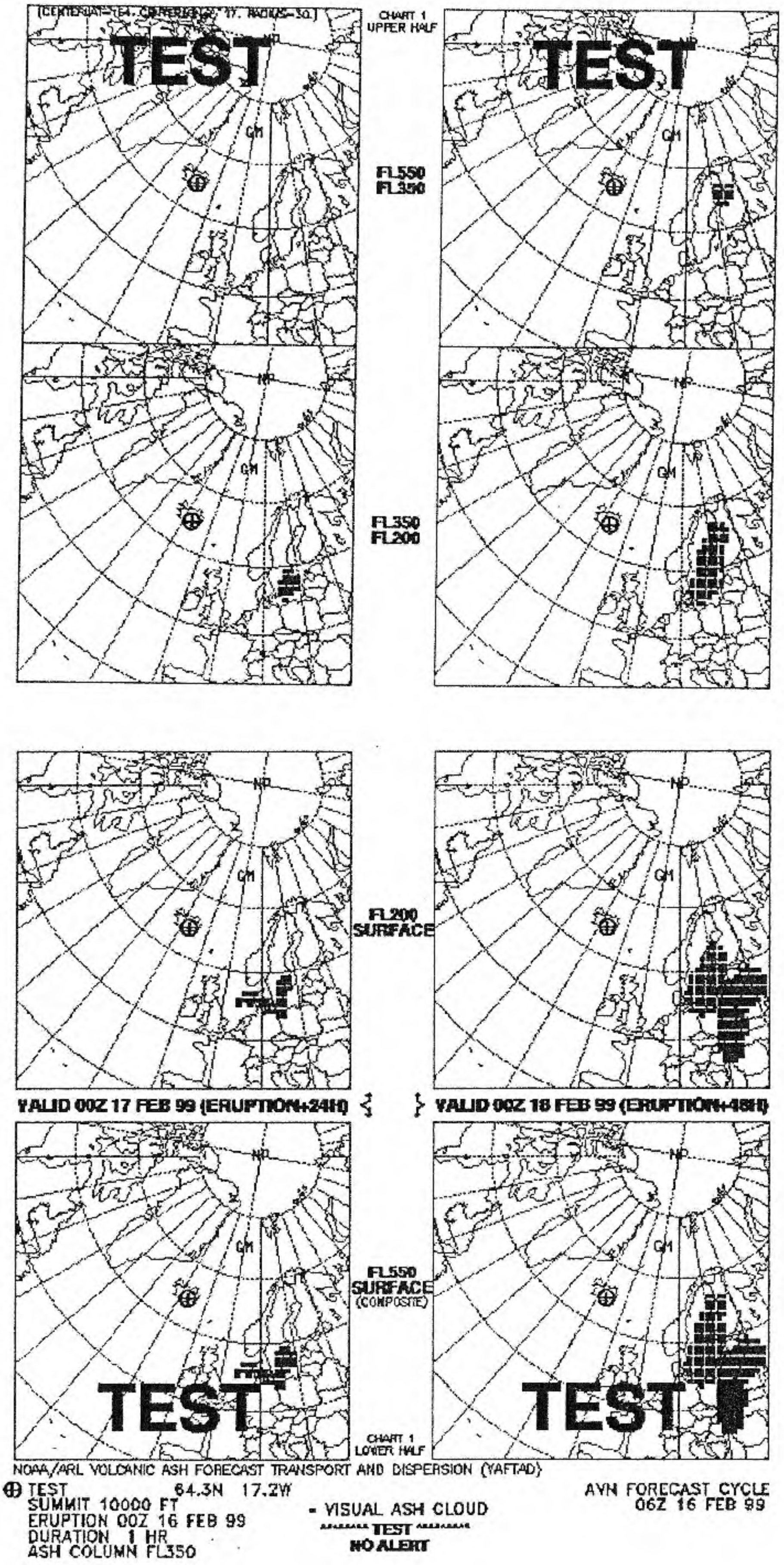
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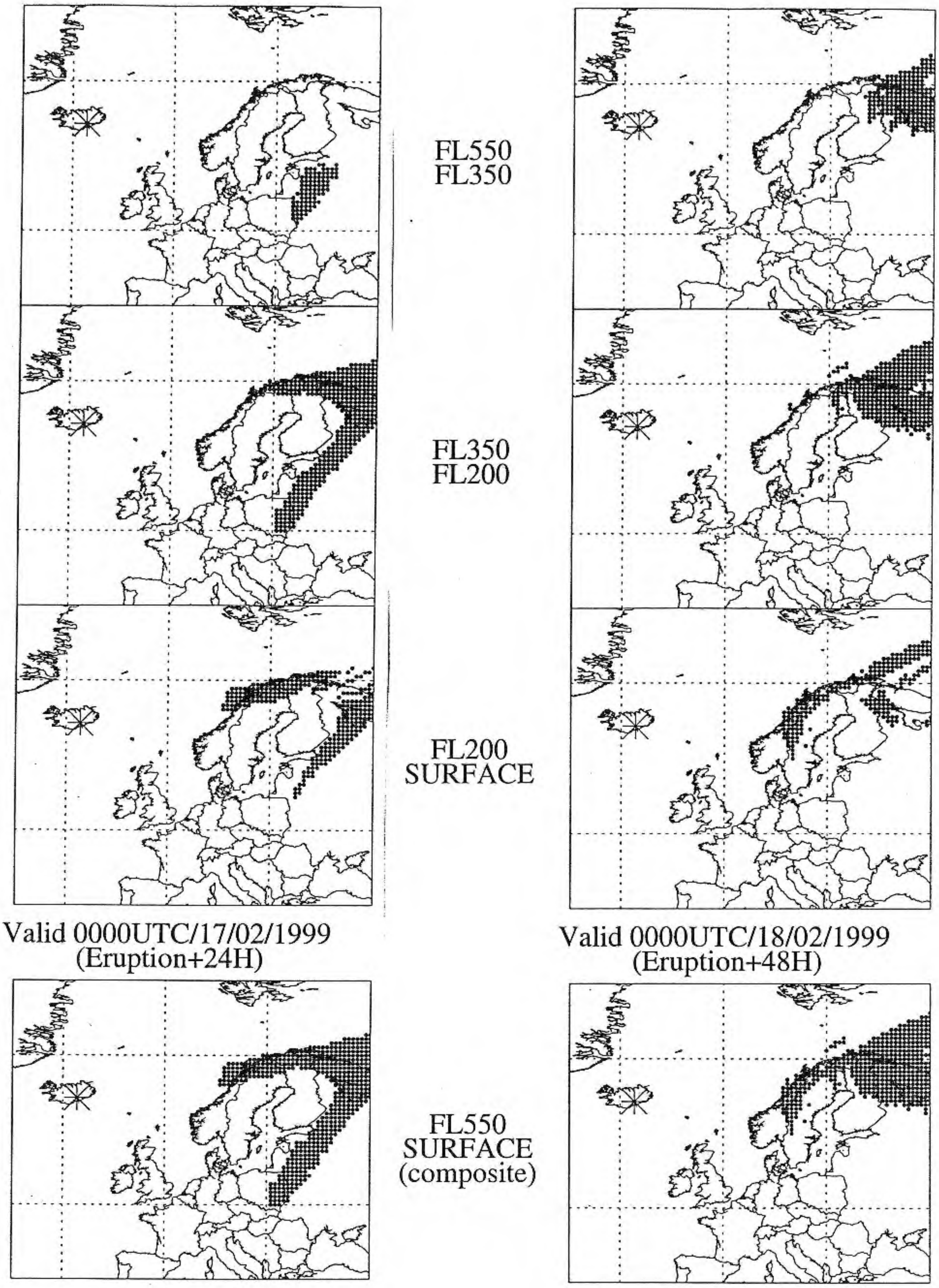
UPPER HALF
TEST
TEST
NP
GM
FL550
FL350
FL350
FL200
FL200
SURFACE
VALID 00Z 17 FEB 99 (ERUPTION+24H)
VALID 00Z 18 FEB 99 (ERUPTION+48H)
FL550
SURFACE
(COMPOSITE)
TEST
TEST
CHART 1
LOWER HALF
NOAA/ARL VOLCANIC ASH FORECAST TRANSPORT AND DISPERSION (VAFTAD)
TEST 64.3N 17.2W
SUMMIT 10000 FT
ERUPTION 00Z 16 FEB 99
DURATION 1 HR
ASH COLUMN FL350
VISUAL ASH CLOUD
TEST
NO ALERT
AVN FORECAST CYCLE
06Z 16 FEB 99

Fig. 1a



UKMO NAME Model (PMSR)
Location: 64.3000N 017.2000W
Eruption start: 0000UTC 16/02/1999
Eruption End: 0100UTC 16/02/1999
Ash Column: FL056 to FL330

Met data: Global
Analysis on Global
Run Time: 16:23:21 16-Feb-99
Release Rate: 1.00e+00g/hr
Threshold conc: 1.00e-20g/m^3

Fig. 1b

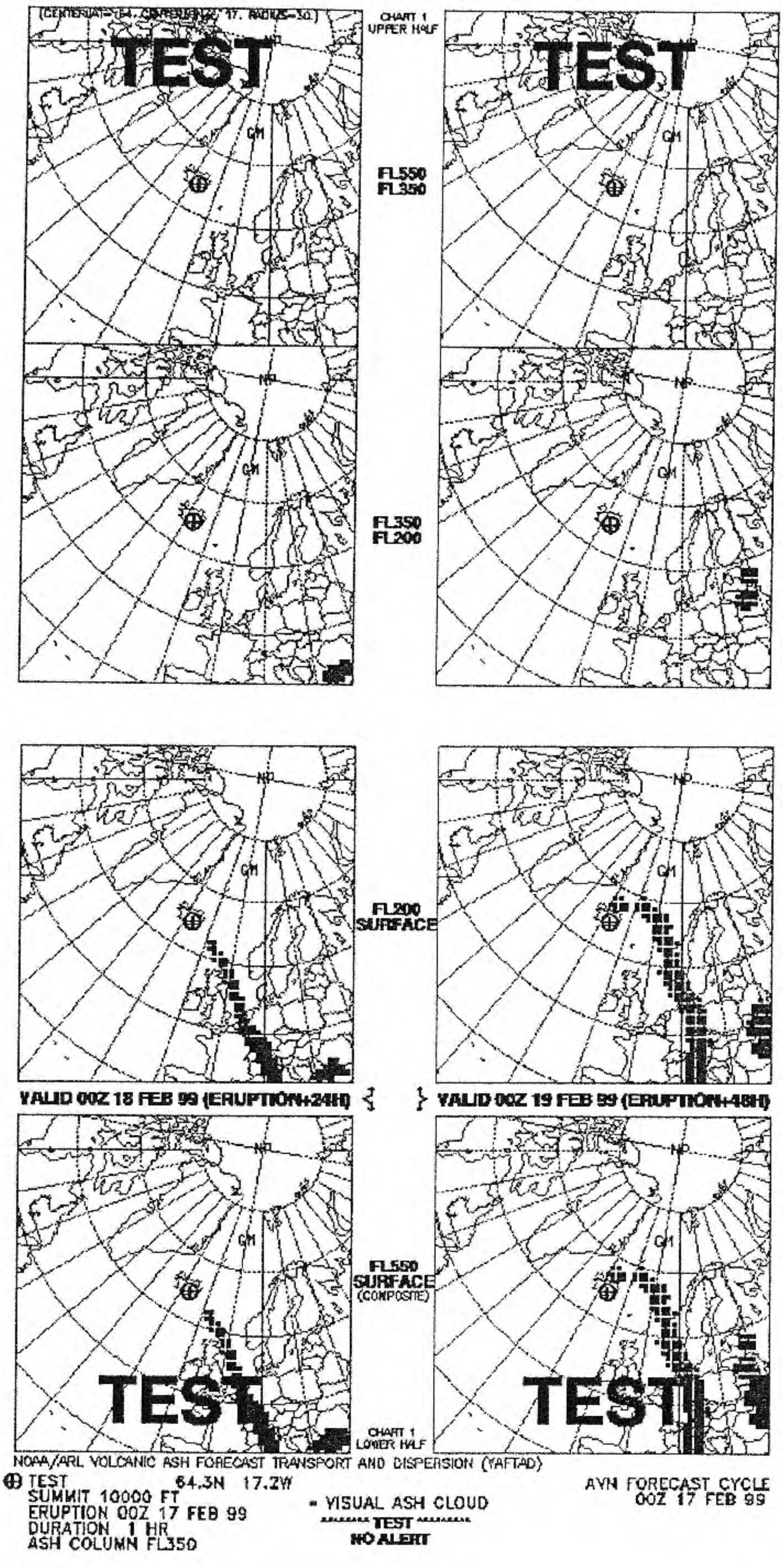
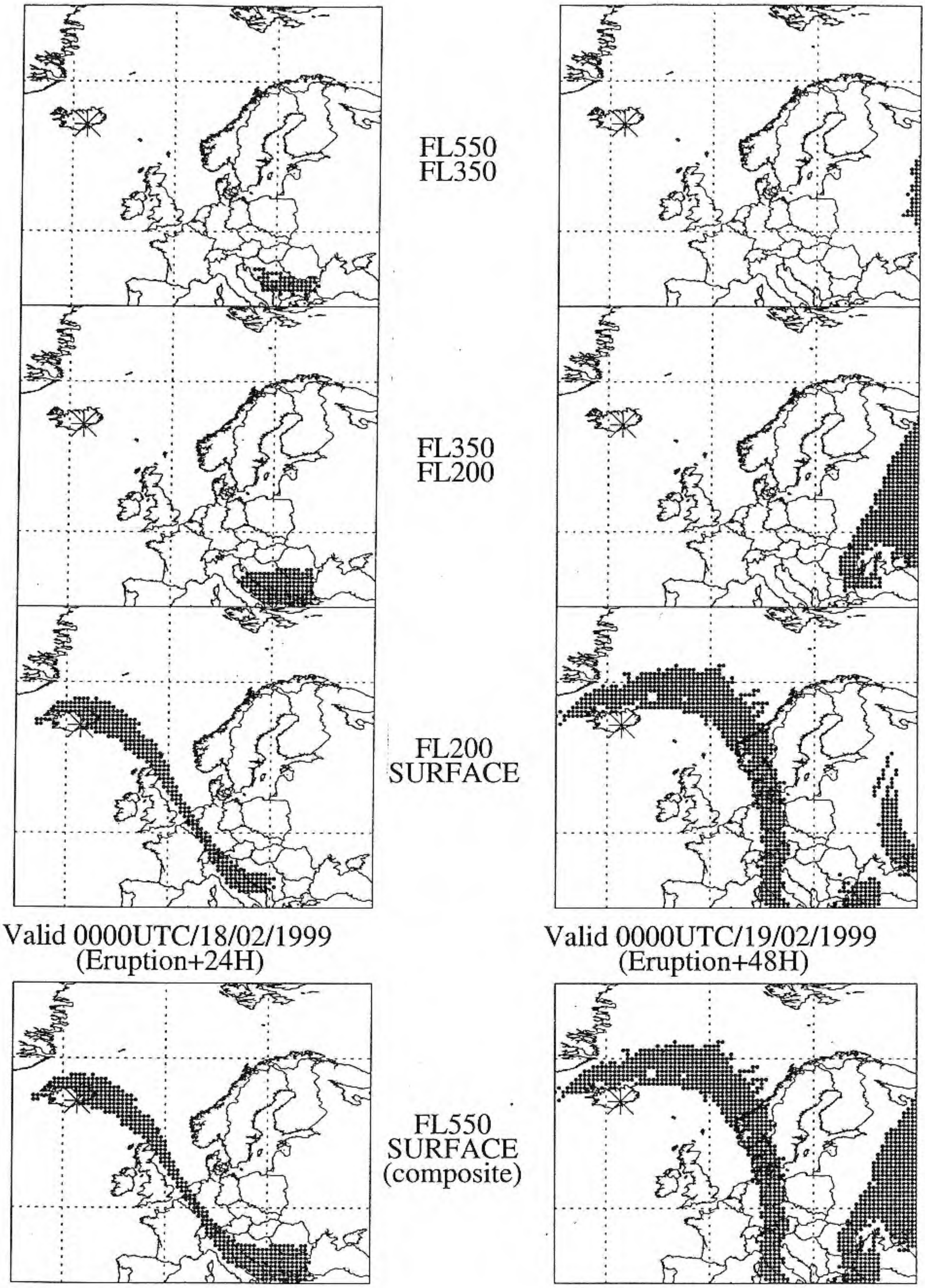


CHART 1
UPPER HALF
TEST
TEST
FL550
FL350
FL350
FL200
FL200
SURFACE
VALID 00Z 18 FEB 99 (ERUPTION+24H)
VALID 00Z 19 FEB 99 (ERUPTION+48H)
FL550
SURFACE
(COMPOSITE)
TEST
TEST
CHART 1
LOWER HALF
NOAA/ARL VOLCANIC ASH FORECAST TRANSPORT AND DISPERSION (VAFTAD)
TEST 64.3N 17.2W
SUMMIT 10000 FT
ERUPTION 00Z 17 FEB 99
DURATION 1 HR
ASH COLUMN FL350
= VISUAL ASH CLOUD
TEST
NO ALERT
AVN FORECAST CYCLE
00Z 17 FEB 99

Fig. 2a



UKMO NAME Model (PMSR)
Location: 64.3000N 017.2000W
Eruption start: 0000UTC 17/02/1999
Eruption End: 0100UTC 17/02/1999
Ash Column: FL056 to FL330

Met data: Global
Analysis on Global
Run Time: 08:08:14 17-Feb-99
Release Rate: 1.00e+00g/hr
Threshold conc: 1.00e-20g/m^3

Fig. 2b

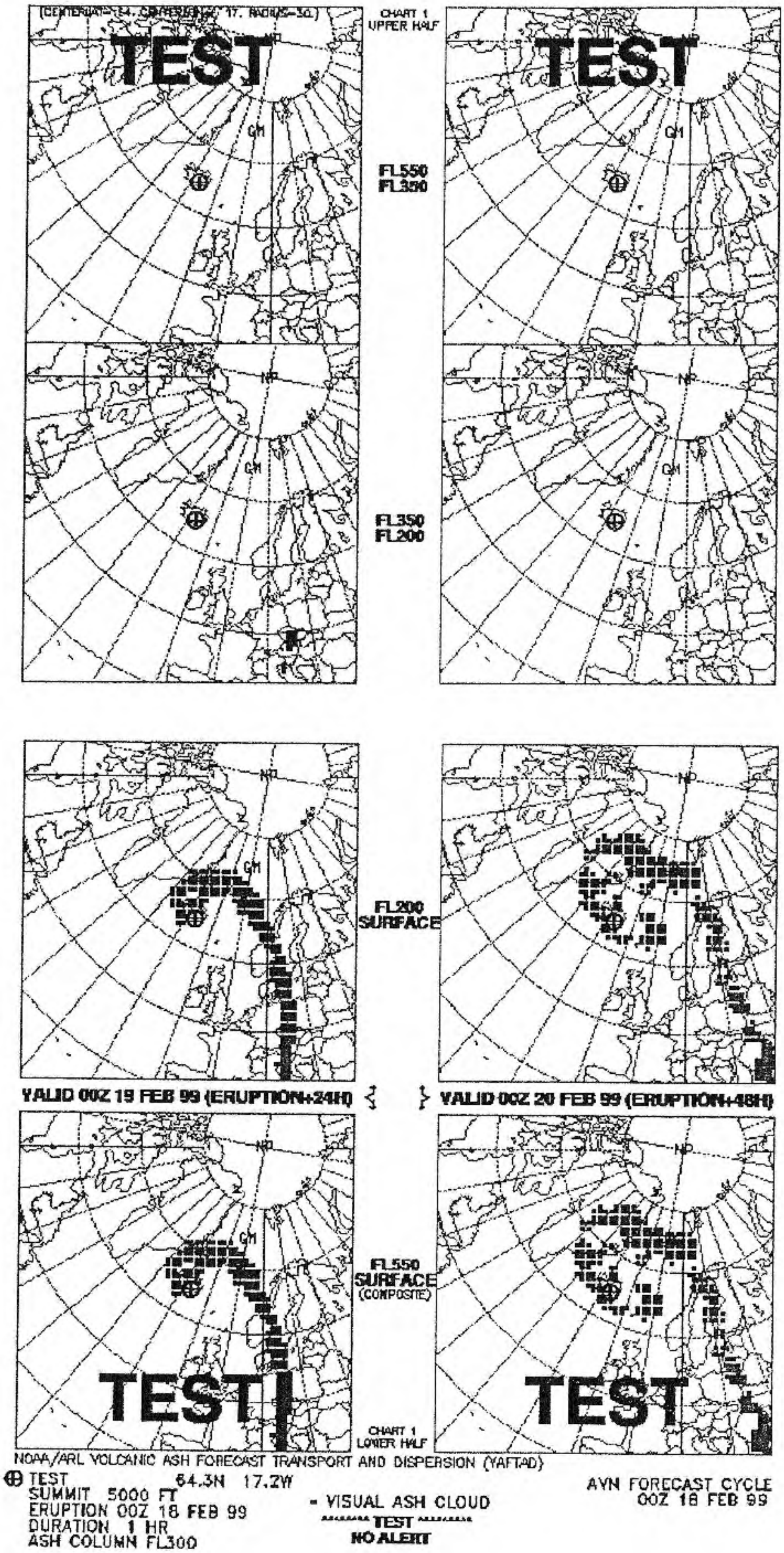
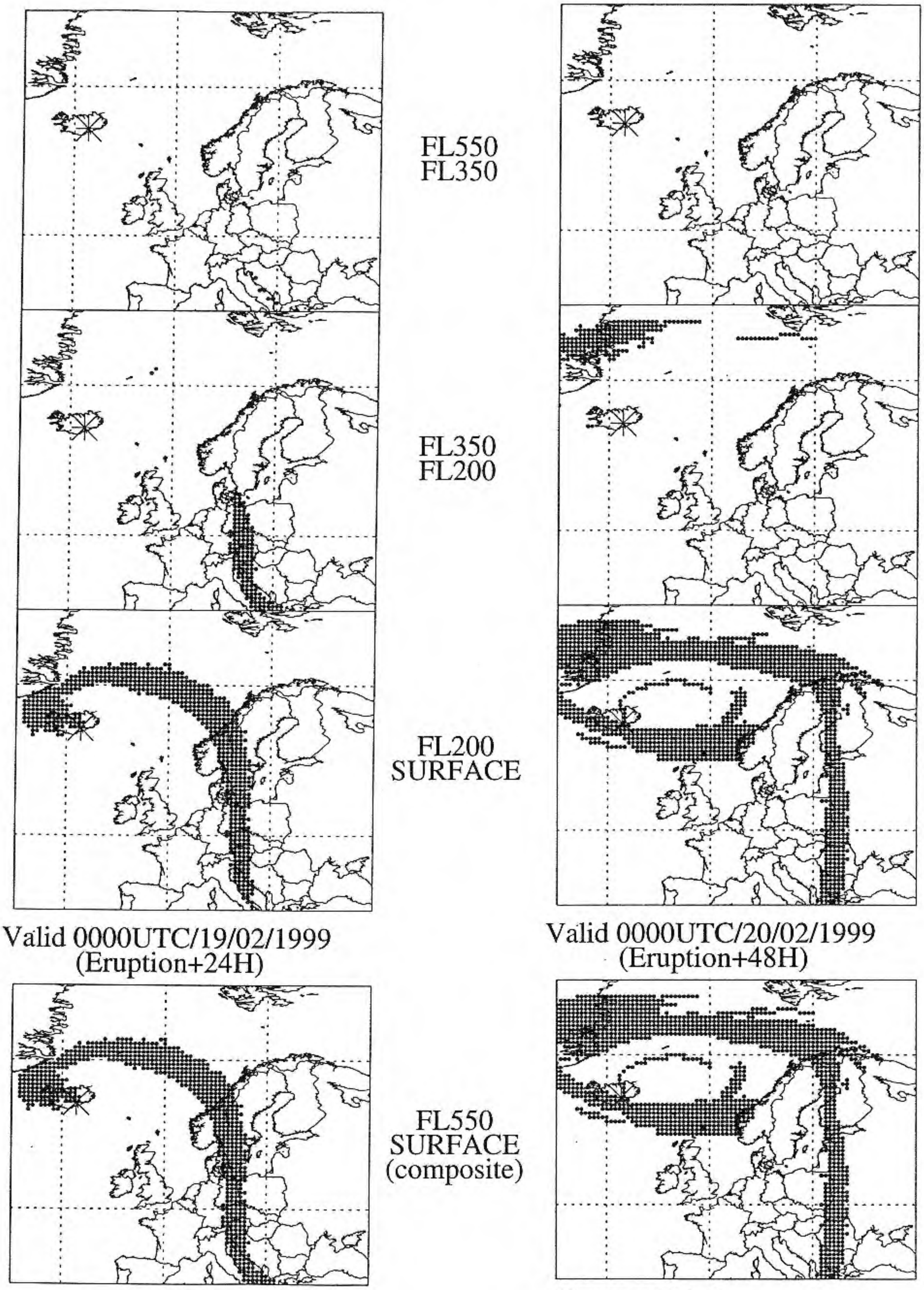


CHART 1
UPPER HALF
TEST
TEST
FL550
FL350
FL350
FL200
FL200
SURFACE
VALID 00Z 19 FEB 99 (ERUPTION+24H)
VALID 00Z 20 FEB 99 (ERUPTION+48H)
FL550
SURFACE
(COMPOSITE)
TEST
TEST
CHART 1
LOWER HALF
NOAA/ARL VOLCANIC ASH FORECAST TRANSPORT AND DISPERSION (VAFTAD)
TEST 64.3N 17.2W
SUMMIT 5000 FT
ERUPTION 00Z 18 FEB 99
DURATION 1 HR
ASH COLUMN FL300
- VISUAL ASH CLOUD
TEST
NO ALERT
AVN FORECAST CYCLE
00Z 18 FEB 99

Fig. 3a



UKMO NAME Model (PMSR)
Location: 64.3000N 017.2000W
Eruption start: 0000UTC 18/02/1999
Eruption End: 0100UTC 18/02/1999
Ash Column: FL050 to FL300

Met data: Global
Analysis on Global
Run Time: 08:59:11 18-Feb-99
Release Rate: 1.00e+00g/hr
Threshold conc: 1.00e-30g/m^3

Fig. 3b

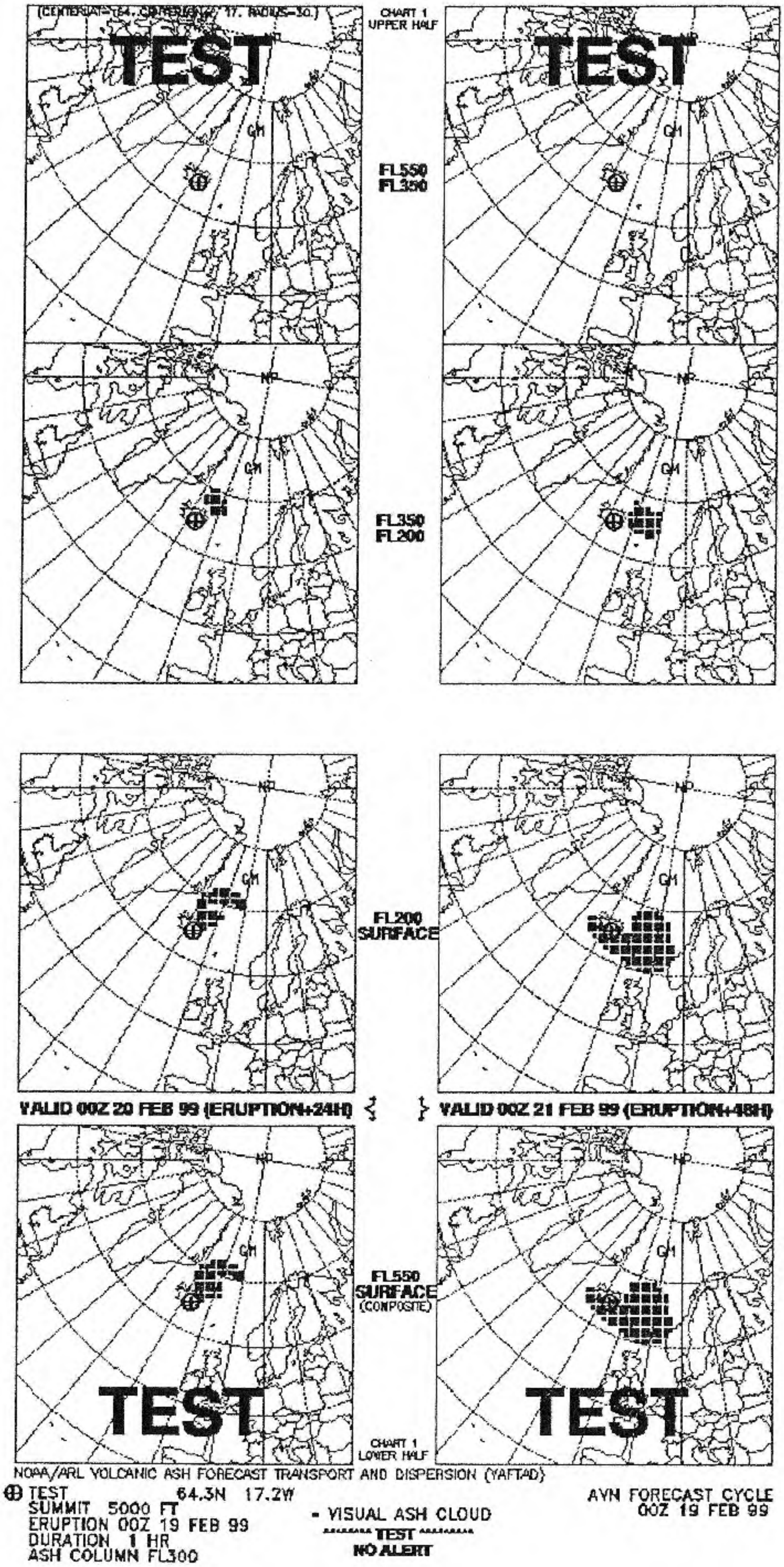
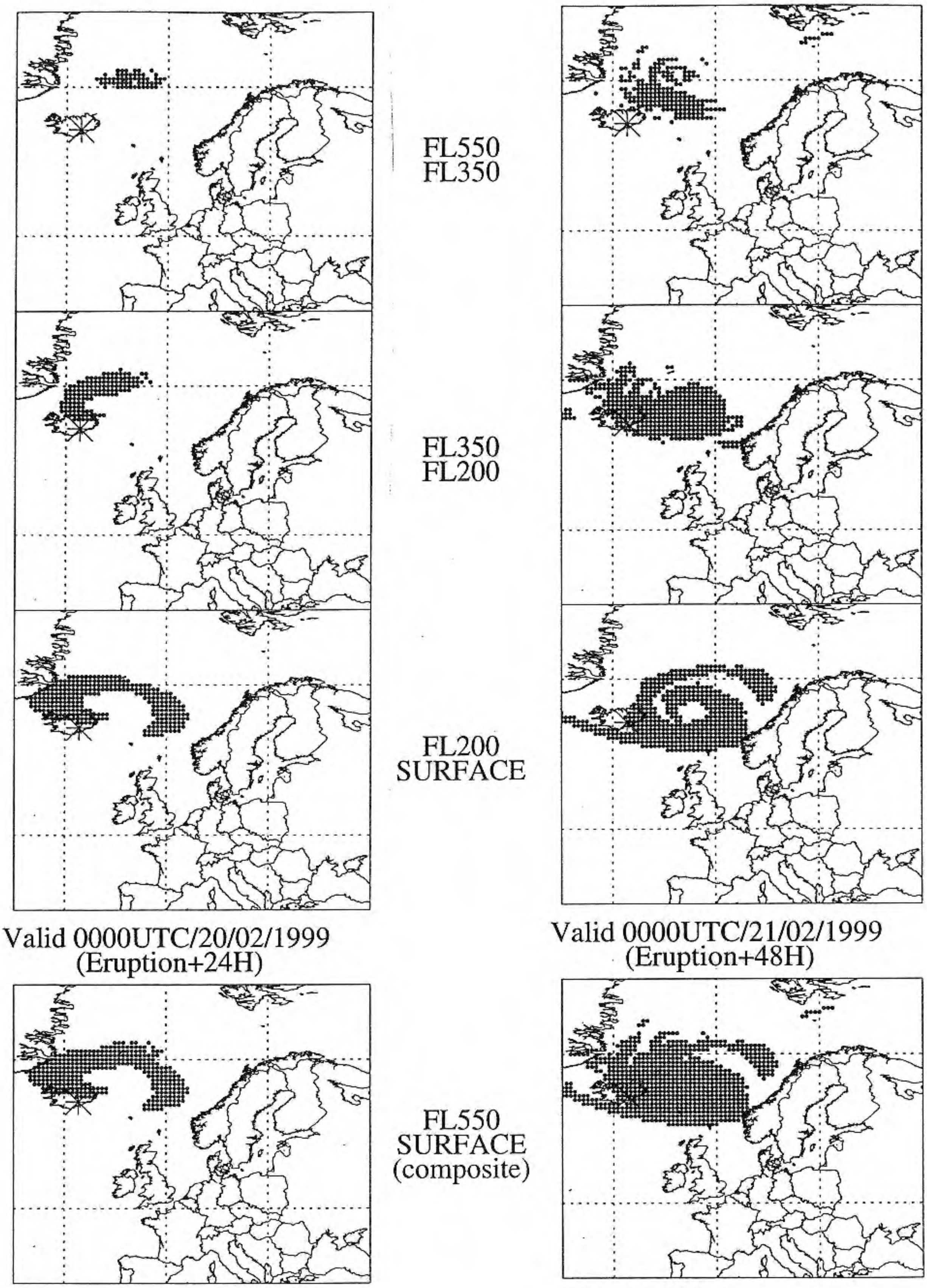


CHART 1
UPPER HALF
TEST
TEST
FL550
FL350
FL350
FL200
FL200
SURFACE
VALID 00Z 20 FEB 99 (ERUPTION+24H)
VALID 00Z 21 FEB 99 (ERUPTION+48H)
FL550
SURFACE
(COMPOSITE)
TEST
TEST
CHART 1
LOWER HALF
NOAA/ARL VOLCANIC ASH FORECAST TRANSPORT AND DISPERSION (VAFTAD)
TEST 64.3N 17.2W
SUMMIT 5000 FT
ERUPTION 00Z 19 FEB 99
DURATION 1 HR
ASH COLUMN FL300
- VISUAL ASH CLOUD
TEST
NO ALERT
AVN FORECAST CYCLE
00Z 19 FEB 99

Fig. 4a



UKMO NAME Model (PMSR)
Location: 64.3000N 017.2000W
Eruption start: 0000UTC 19/02/1999
Eruption End: 0100UTC 19/02/1999
Ash Column: FL050 to FL300

Met data: Global
Analysis on Global
Run Time: 08:04:29 19-Feb-99
Release Rate: 1.00e+00g/hr
Threshold conc: 1.00e-30g/m^3

Fig. 4b

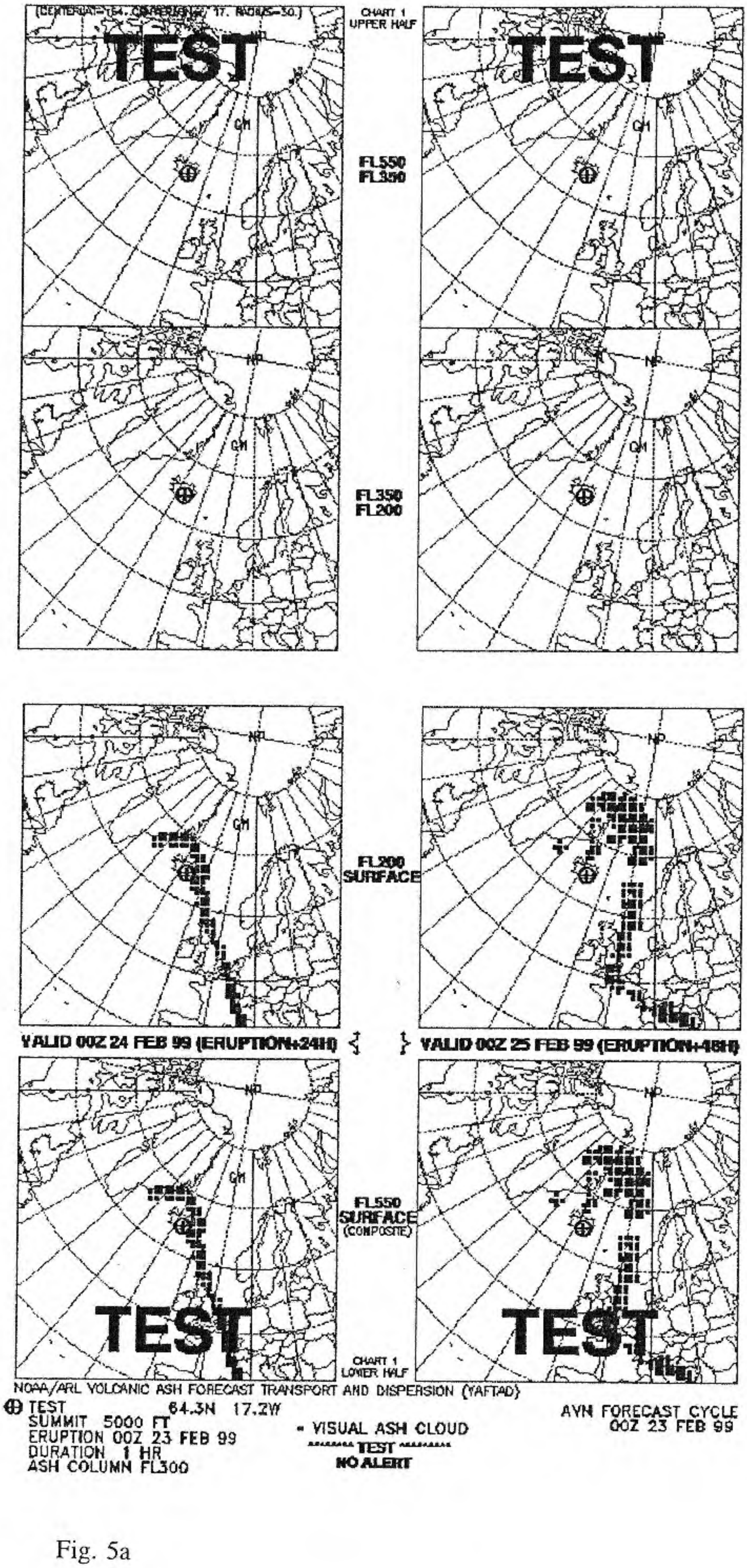
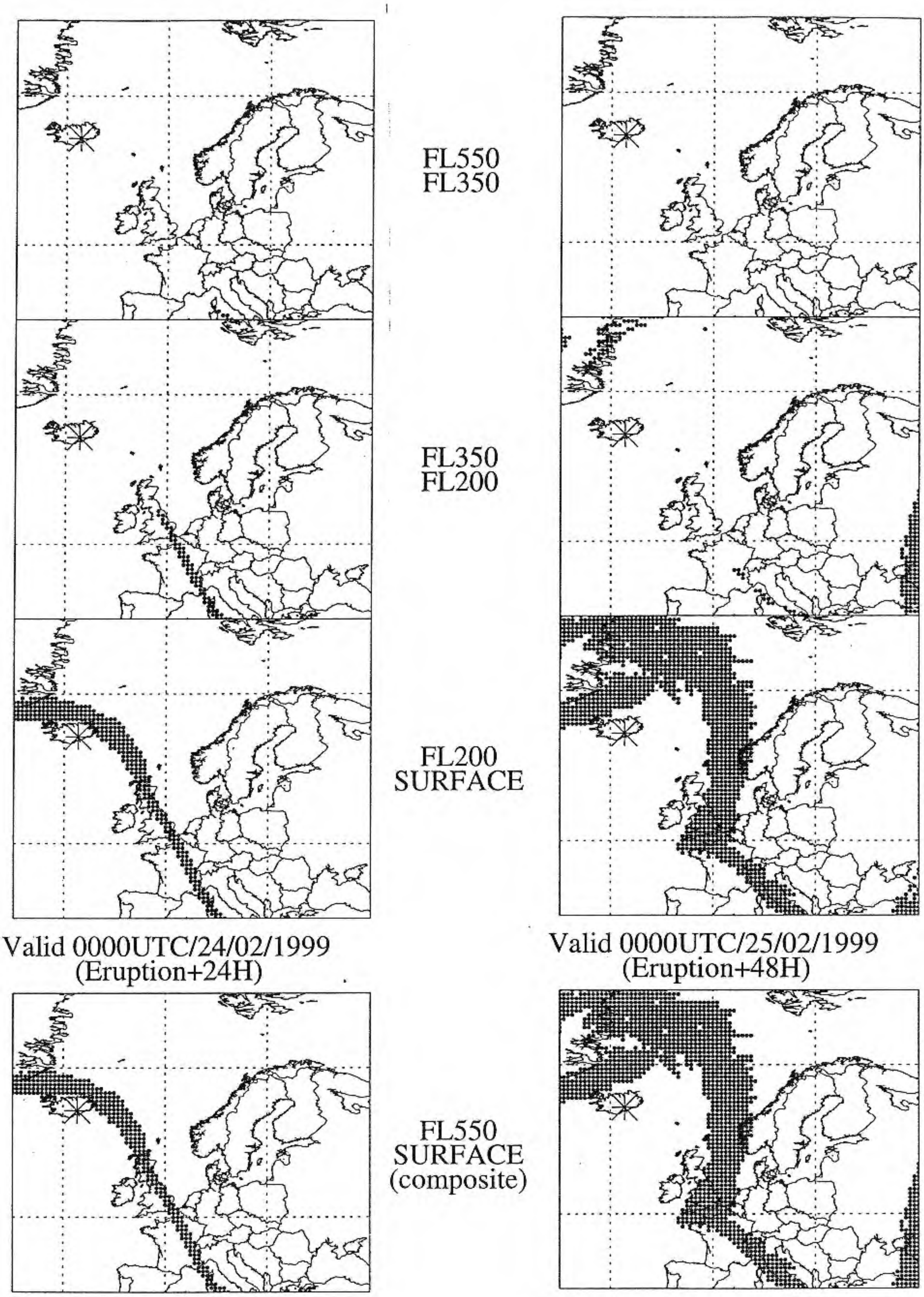


CHART 1
UPPER HALF
TEST
TEST
FL550
FL350
FL350
FL200
FL200
SURFACE
VALID 00Z 24 FEB 99 (ERUPTION+24H)
VALID 00Z 25 FEB 99 (ERUPTION+48H)
FL550
SURFACE
(COMPOSITE)
TEST
TEST
CHART 1
LOWER HALF
NOAA/ARL VOLCANIC ASH FORECAST TRANSPORT AND DISPERSION (VAFTAD)
TEST 64.3N 17.2W
SUMMIT 5000 FT
ERUPTION 00Z 23 FEB 99
DURATION 1 HR
ASH COLUMN FL300
• VISUAL ASH CLOUD
TEST
NO ALERT
AVN FORECAST CYCLE
00Z 23 FEB 99

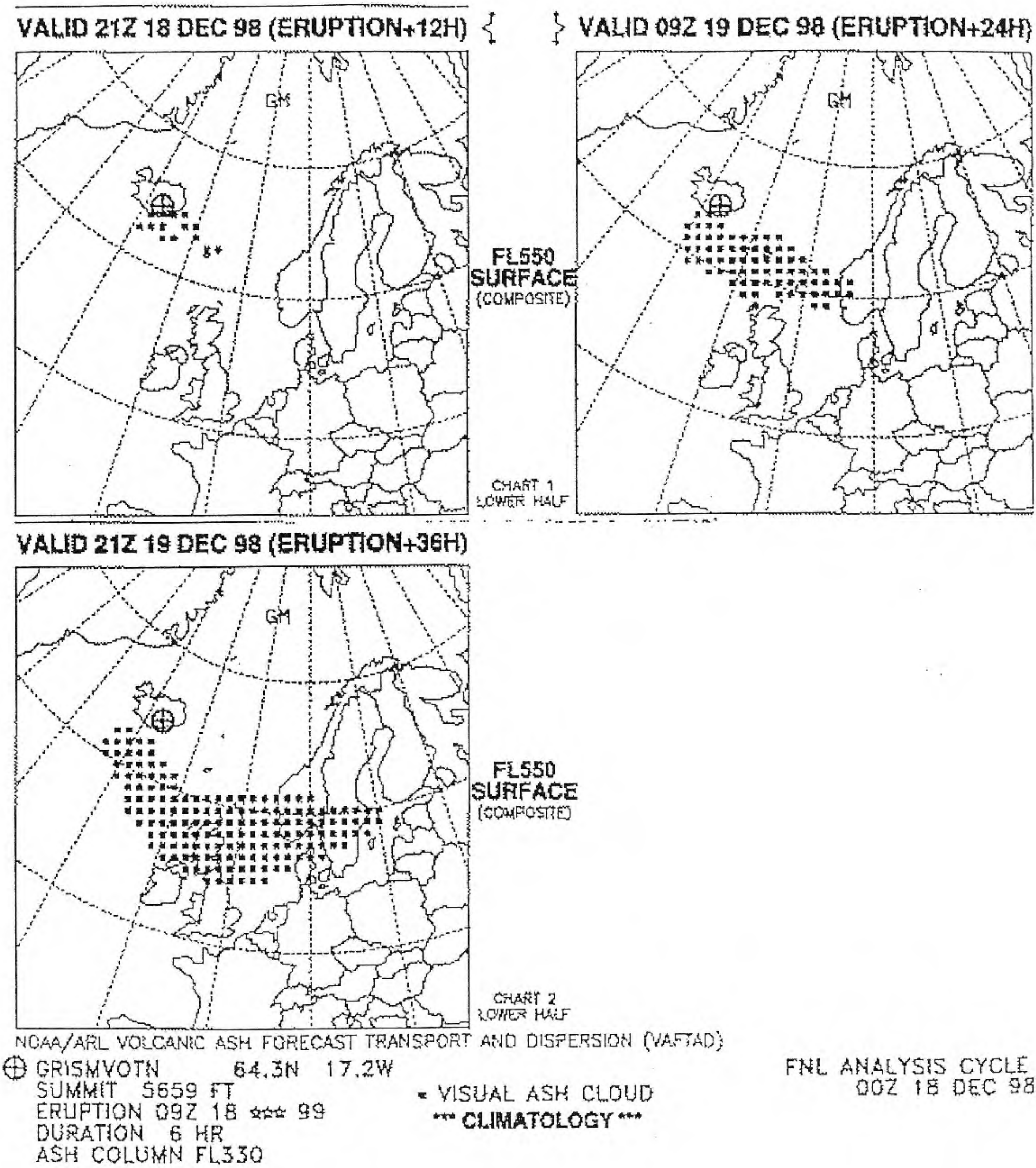
Fig. 5a



UKMO NAME Model (PMSR)
Location: 64.3000N 017.2000W
Eruption start: 0000UTC 23/02/1999
Eruption End: 0100UTC 23/02/1999
Ash Column: FL050 to FL300

Met data: Global
Analysis on Global
Run Time: 08:11:36 23-Feb-99
Release Rate: 1.00e+00g/hr
Threshold conc: 1.00e-30g/m^3

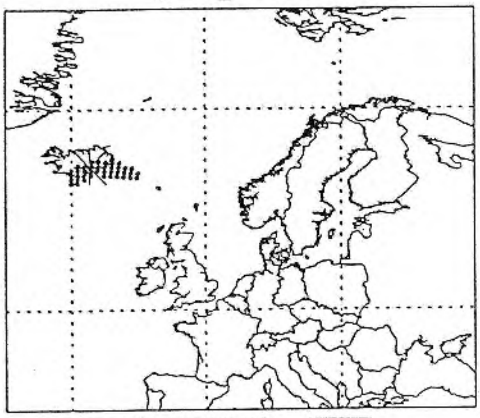
Fig. 5b



VALID 21Z 18 DEC 98 (ERUPTION+12H)
VALID 09Z 19 DEC 98 (ERUPTION+24H)
VALID 21Z 19 DEC 98 (ERUPTION+36H)
GM
FL550
SURFACE
(COMPOSITE)
CHART 1
LOWER HALF
CHART 2
LOWER HALF
NOAA/ARL VOLCANIC ASH FORECAST TRANSPORT AND DISPERSION (VAFTAD)
GRISMVOTN 64.3N 17.2W
SUMMIT 5659 FT
ERUPTION 09Z 18 *** 99
DURATION 6 HR
ASH COLUMN FL330
* VISUAL ASH CLOUD
*** CLIMATOLOGY ***
FNL ANALYSIS CYCLE
00Z 18 DEC 98

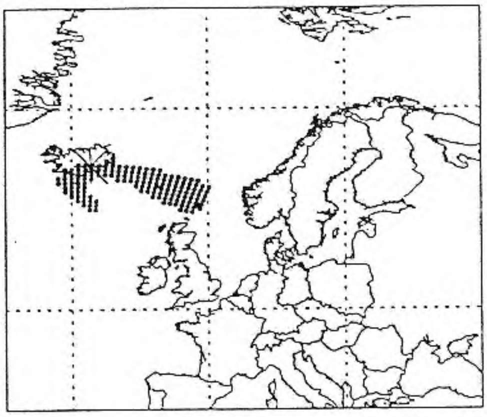
Fig. 6a

Valid 2100UTC/18/12/1998
(Eruption+12H)

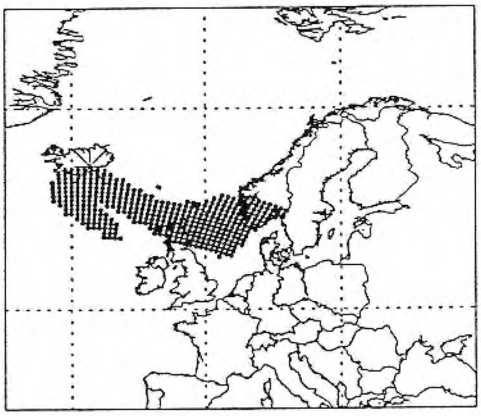


FL550
SURFACE
(composite)

Valid 0900UTC/19/12/1998
(Eruption+24H)



Valid 2100UTC/19/12/1998
(Eruption+36H)



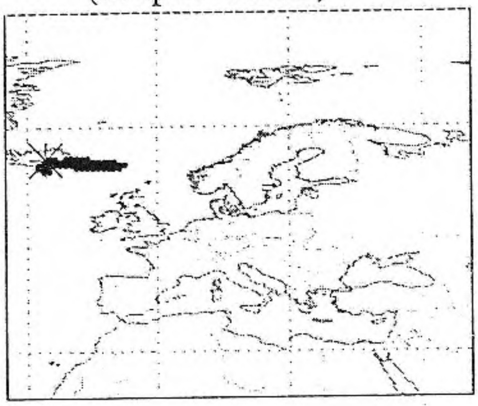
FL550
SURFACE
(composite)

UKMO NAME Model (PMSR)
Location: 64.3000N 017.2000W
Eruption start: 0900UTC 18/12/1998
Eruption End: 1500UTC 18/12/1998
Ash Column: FL056 to FL330

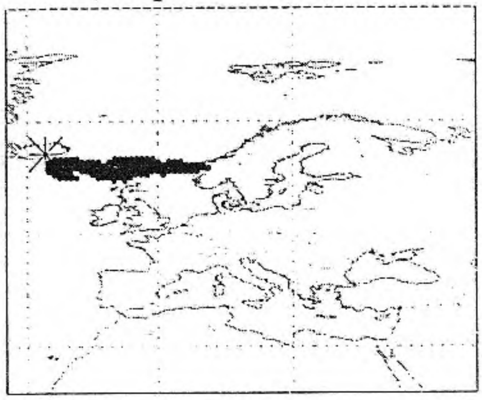
Met data: Regional
Analysis on Regional
Run Time: 15:03:50 16-Feb-99
Release Rate: 1.00e+00g/hr
Threshold conc: 1.00e-38g/m^3

Fig. 6b

Valid 2100UTC/18/12/1998
(Eruption+12H)

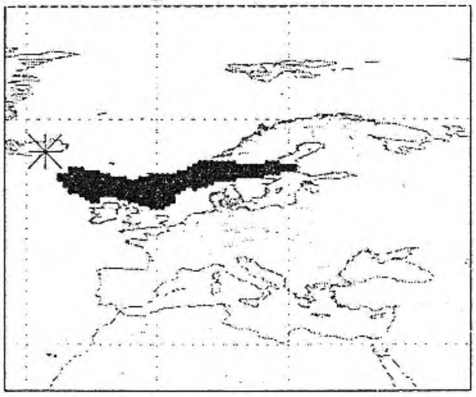


Valid 0900UTC/19/12/1998
(Eruption+24H)



FL550
SURFACE
(composite)

Valid 2100UTC/19/12/1998
(Eruption+36H)



FL550
SURFACE
(composite)

UKMO NAME Model (PMSR)
Location: 64.2900N 017.2300W
Eruption start: 0900UTC 18/12/1998
Eruption End: 1000UTC 18/12/1998
Ash Column: FL000 to FL450

Met data: Global
Analysis on Global
Run Time: 10:52:07 18-Dec-98

Fig. 6c

INTENTIONALLY BLANK

A: GRIMSVOTN
ERUPTION:FRI-VEN 25 DEC-DEC 98, 1000Z
LATITUDE:64.44N
LONGITUDE:17.24W
CYCLE:(10000-0,18,6)

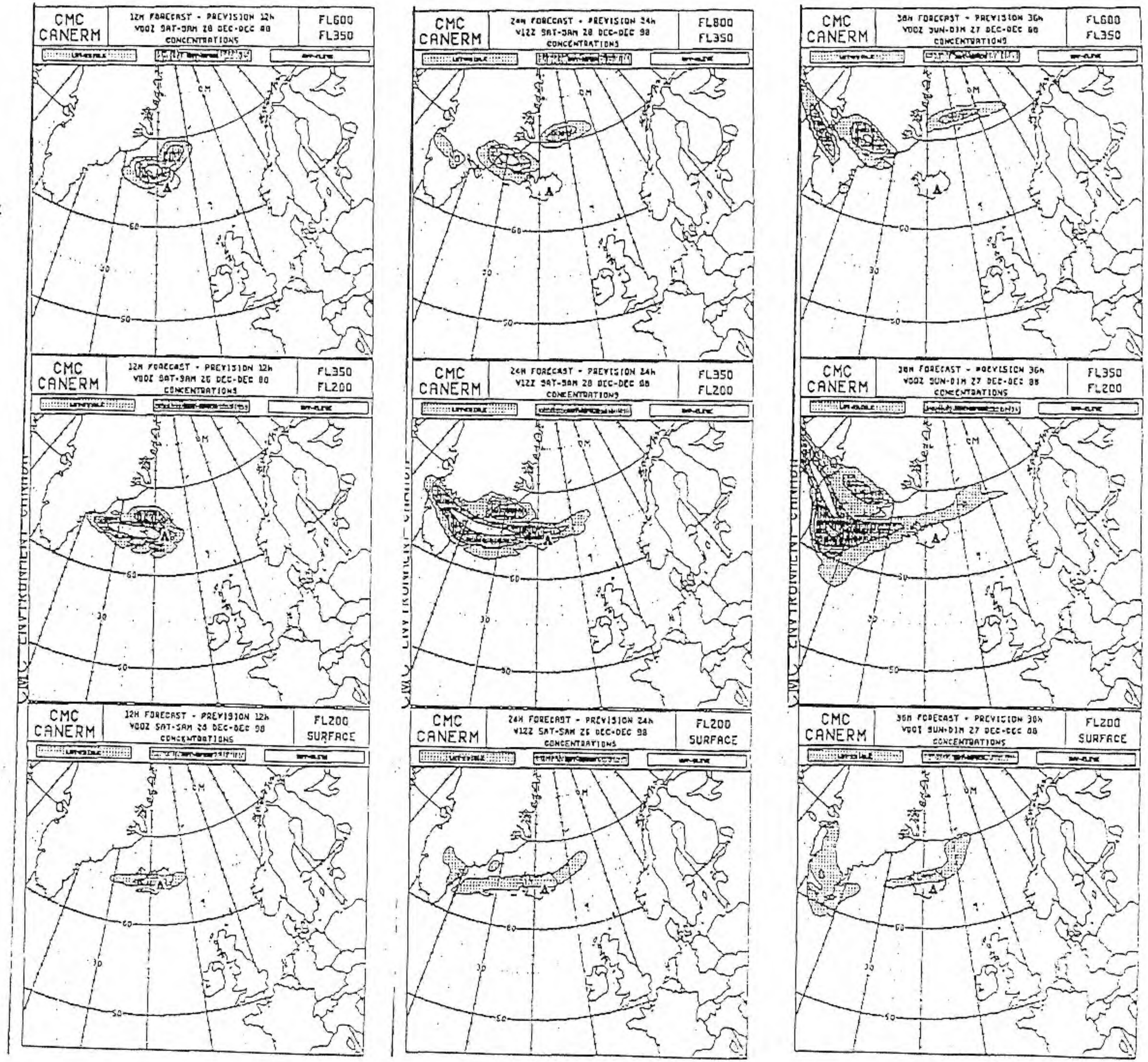
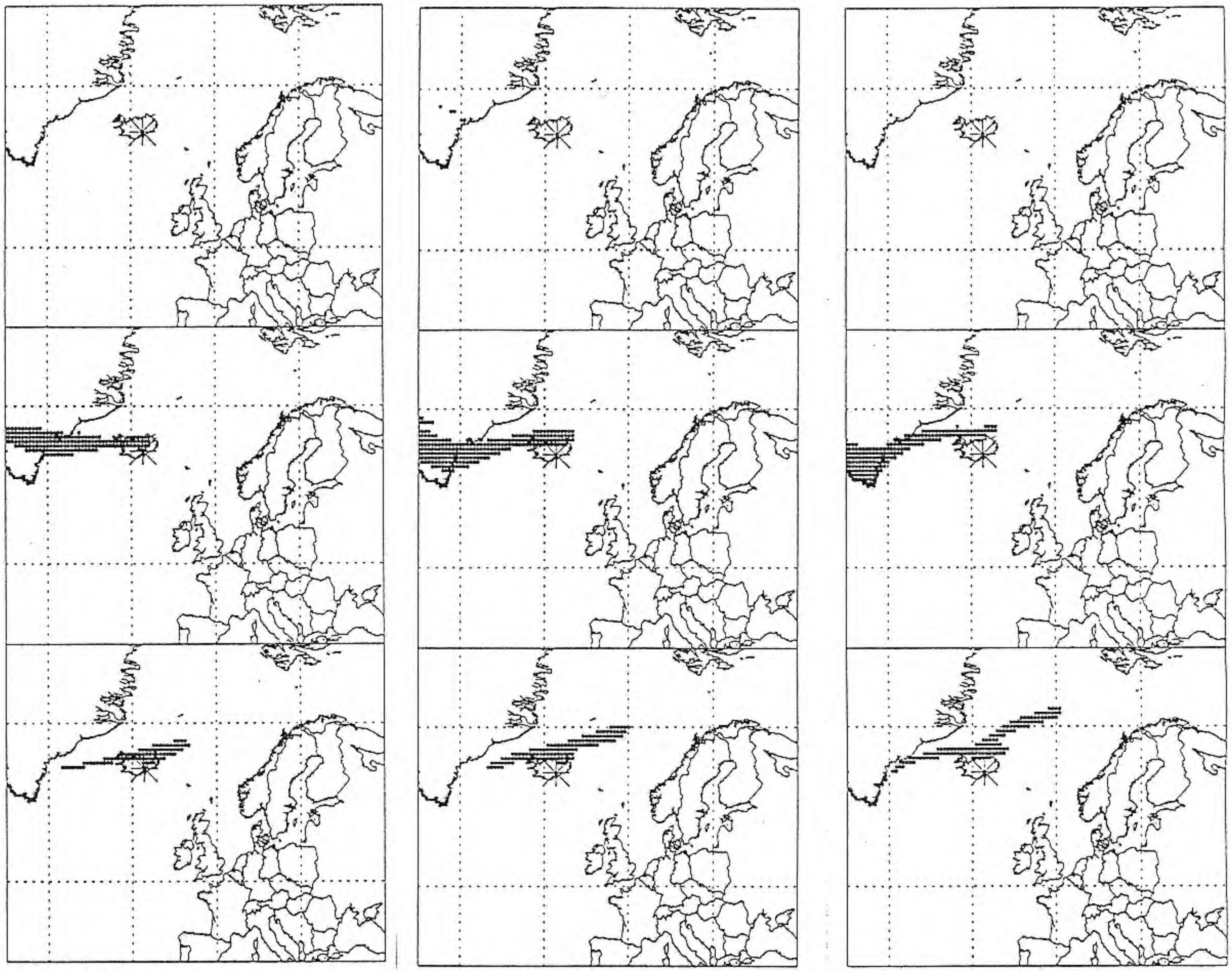


Fig. 7a

UKMO NAME Model (PMSR)
Location: 64.2900N 017.2300W
Eruption start: 0000UTC 25/12/1998
Eruption End: 0000UTC 26/12/1998
Ash Column: FL000 to FL300

Met data: Global
Analysis on Global
Run Time: 17:52:31 25-Dec-98
Release Rate: 1.00e+00g/hr
Threshold conc: 1.00e-16g/m^3



FL550
FL350

FL350
FL200

FL200
SURFACE

Valid 0000UTC/26/12/1998
(Eruption+24H)

Valid 1200UTC/26/12/1998
(Eruption+36H)

Valid 0000UTC/27/12/1998
(Eruption+48H)

Fig. 7b

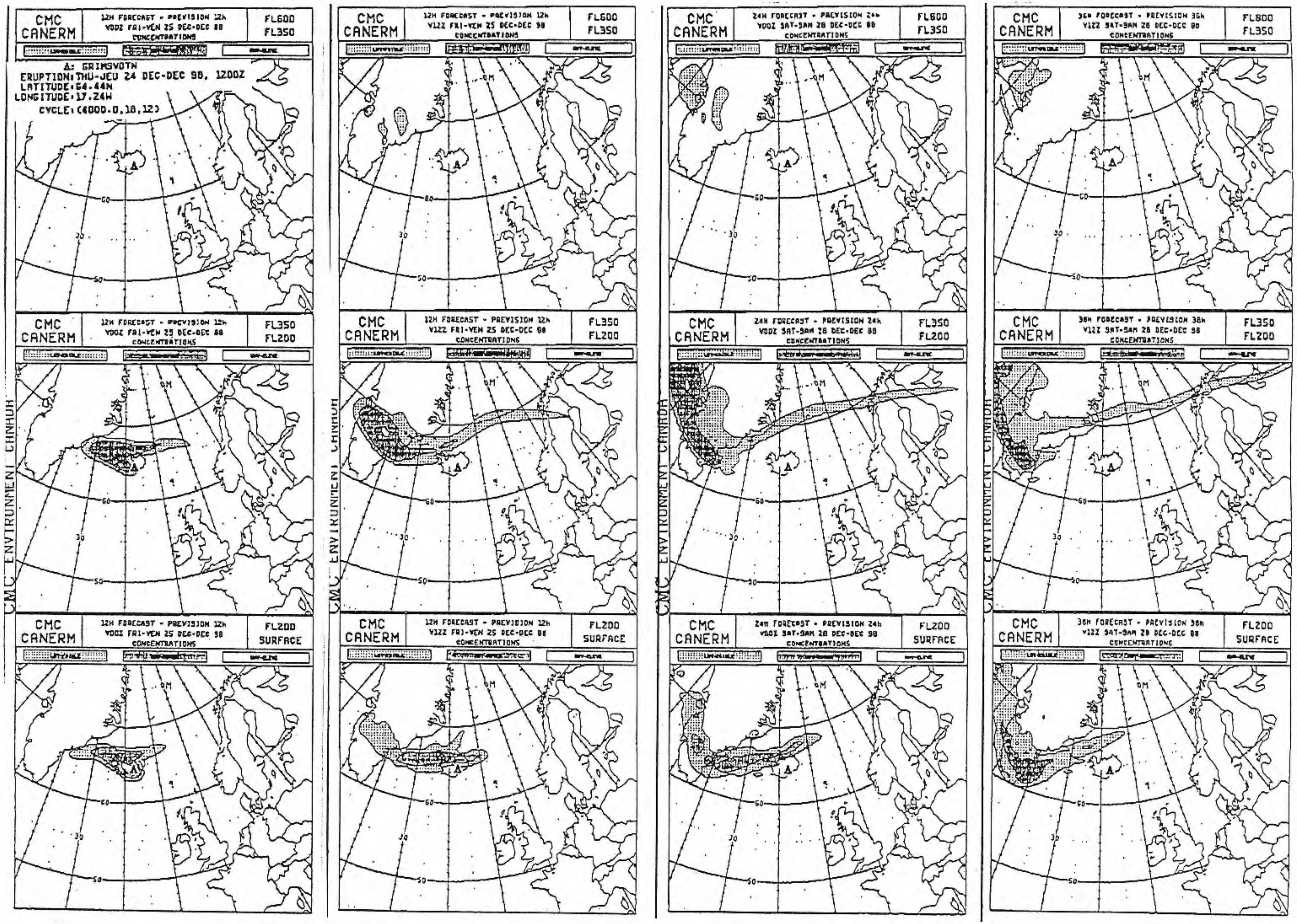

CMC CANERM
12H FORECAST - PREVISION 12h
V00Z FRI-VEN 25 DEC-DEC 98
CONCENTRATIONS
FL600 FL350
A: GRIMSVOTN
ERUPTION: THU-JEU 24 DEC-DEC 98, 1200Z
LATITUDE: 64.44N
LONGITUDE: 17.24W
CYCLE: (4000.0,18,12)
FL350 FL200
FL200 SURFACE
V12Z FRI-VEN 25 DEC-DEC 98
24H FORECAST - PREVISION 24h
V00Z SAT-SAM 26 DEC-DEC 98
36H FORECAST - PREVISION 36h
V12Z SAT-SAM 26 DEC-DEC 98
CMC ENVIRONMENT CANADA
60
50
30
0M

Fig. 8a

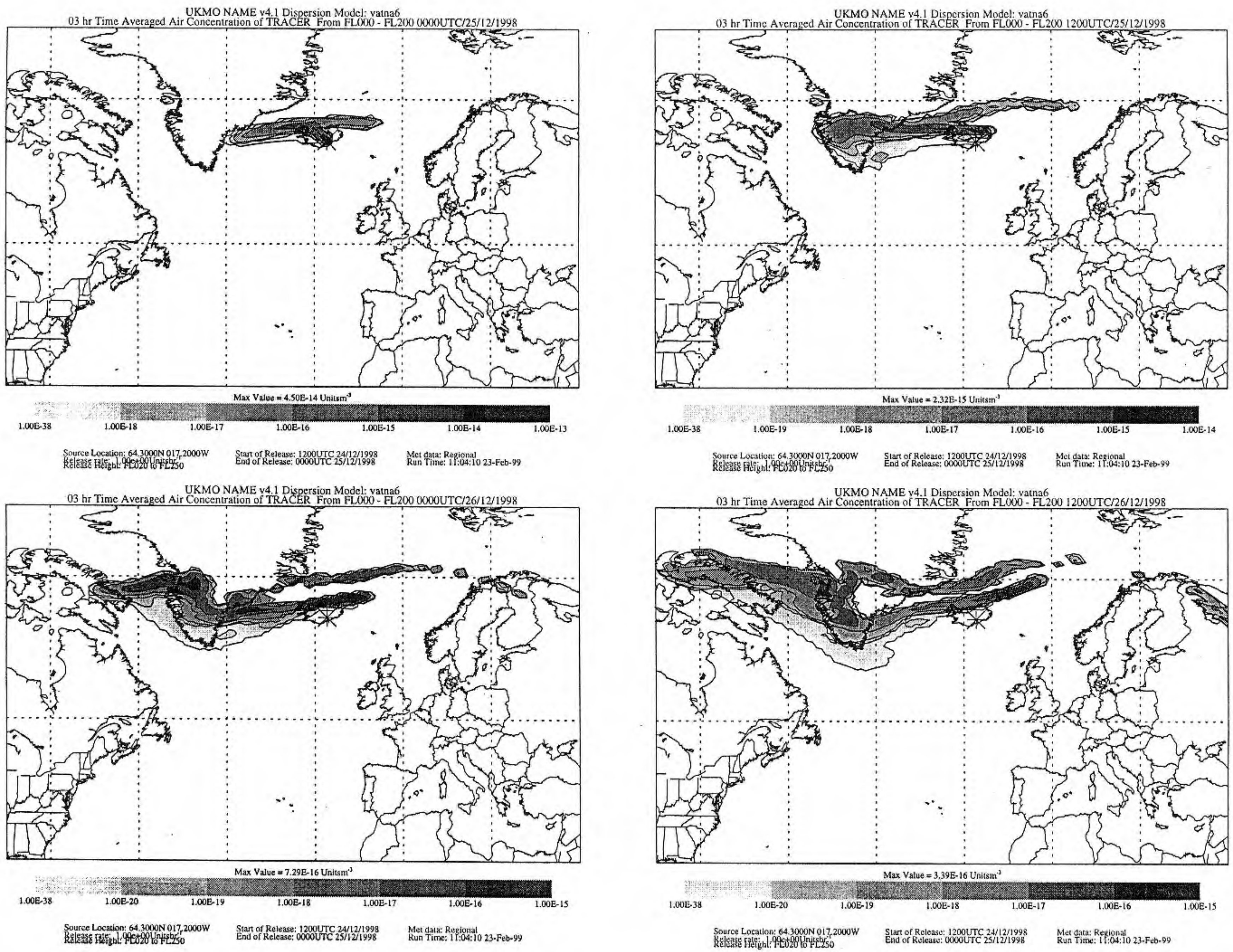

UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL000 - FL200 0000UTC/25/12/1998
Max Value = 4.50E-14 Units m^-3
1.00E-38 1.00E-18 1.00E-17 1.00E-16 1.00E-15 1.00E-14 1.00E-13
Source Location: 64.3000N 017.2000W
Release Height: FL020 to FL250
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99
UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL000 - FL200 1200UTC/25/12/1998
Max Value = 2.32E-15 Units m^-3
1.00E-38 1.00E-19 1.00E-18 1.00E-17 1.00E-16 1.00E-15 1.00E-14
Source Location: 64.3000N 017.2000W
Release Height: FL020 to FL250
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99
UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL000 - FL200 0000UTC/26/12/1998
Max Value = 7.29E-16 Units m^-3
1.00E-38 1.00E-20 1.00E-19 1.00E-18 1.00E-17 1.00E-16 1.00E-15
Source Location: 64.3000N 017.2000W
Release Height: FL020 to FL250
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99
UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL000 - FL200 1200UTC/26/12/1998
Max Value = 3.39E-16 Units m^-3
1.00E-38 1.00E-20 1.00E-19 1.00E-18 1.00E-17 1.00E-16 1.00E-15
Source Location: 64.3000N 017.2000W
Release Height: FL020 to FL250
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99

Fig. 8b(i)

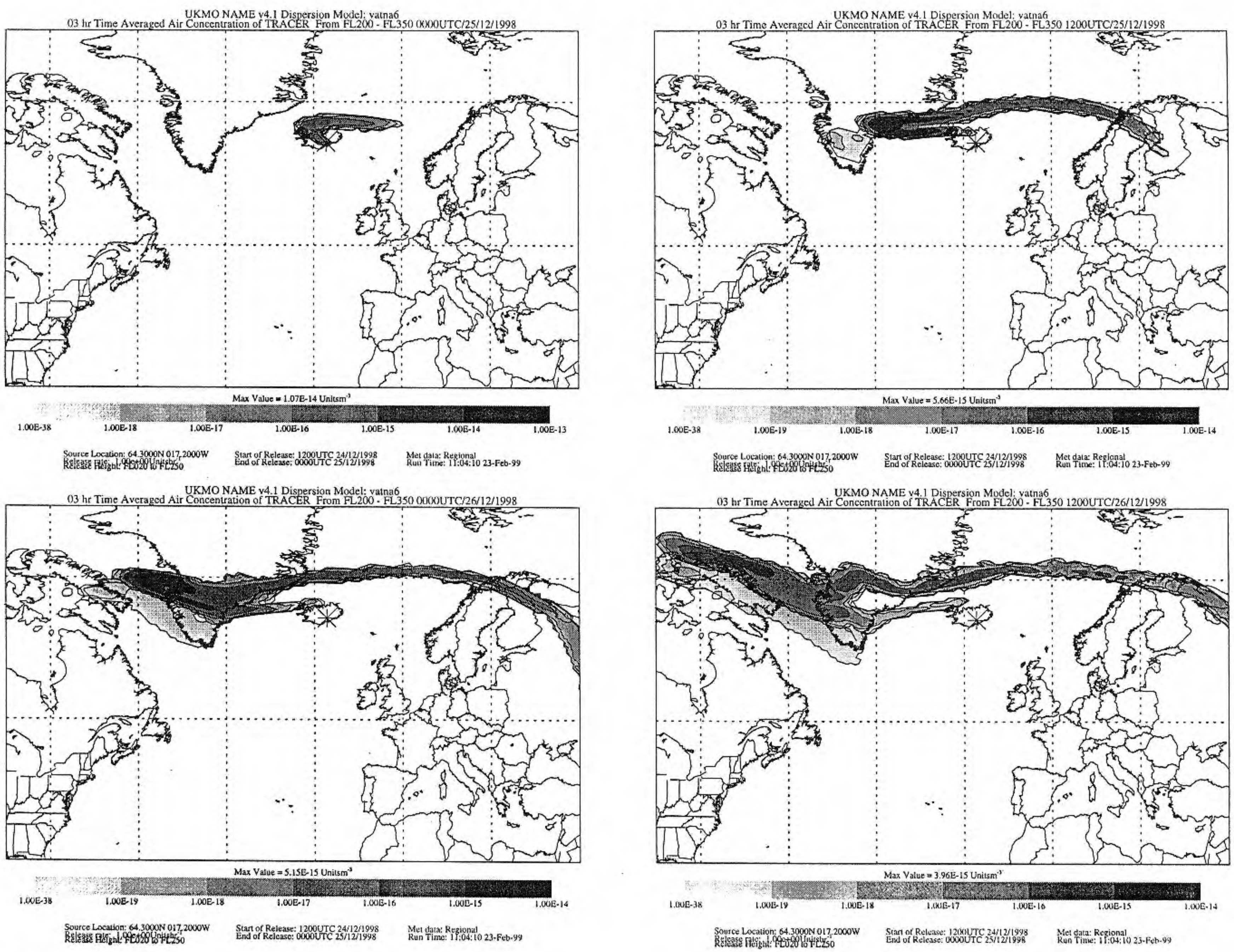

UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL200 - FL350 0000UTC/25/12/1998
Max Value = 1.07E-14 Units m⁻³
1.00E-38
1.00E-18
1.00E-17
1.00E-16
1.00E-15
1.00E-14
1.00E-13
Source Location: 64.3000N 017.2000W
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99
UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL200 - FL350 1200UTC/25/12/1998
Max Value = 5.66E-15 Units m⁻³
1.00E-38
1.00E-19
1.00E-18
1.00E-17
1.00E-16
1.00E-15
1.00E-14
Source Location: 64.3000N 017.2000W
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99
UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL200 - FL350 0000UTC/26/12/1998
Max Value = 5.15E-15 Units m⁻³
1.00E-38
1.00E-19
1.00E-18
1.00E-17
1.00E-16
1.00E-15
1.00E-14
Source Location: 64.3000N 017.2000W
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99
UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL200 - FL350 1200UTC/26/12/1998
Max Value = 3.96E-15 Units m⁻³
1.00E-38
1.00E-19
1.00E-18
1.00E-17
1.00E-16
1.00E-15
1.00E-14
Source Location: 64.3000N 017.2000W
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99

Fig. 8b(ii)

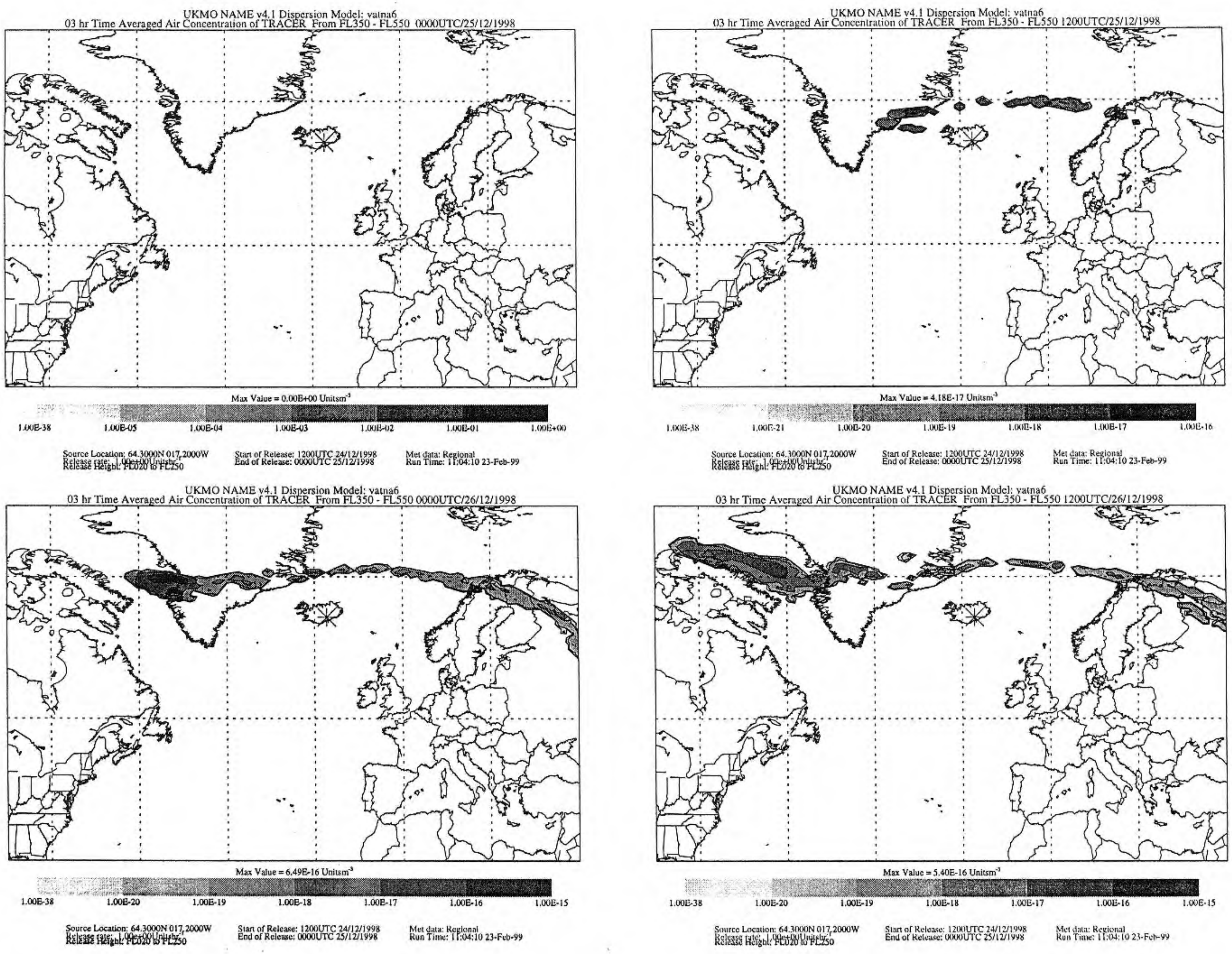
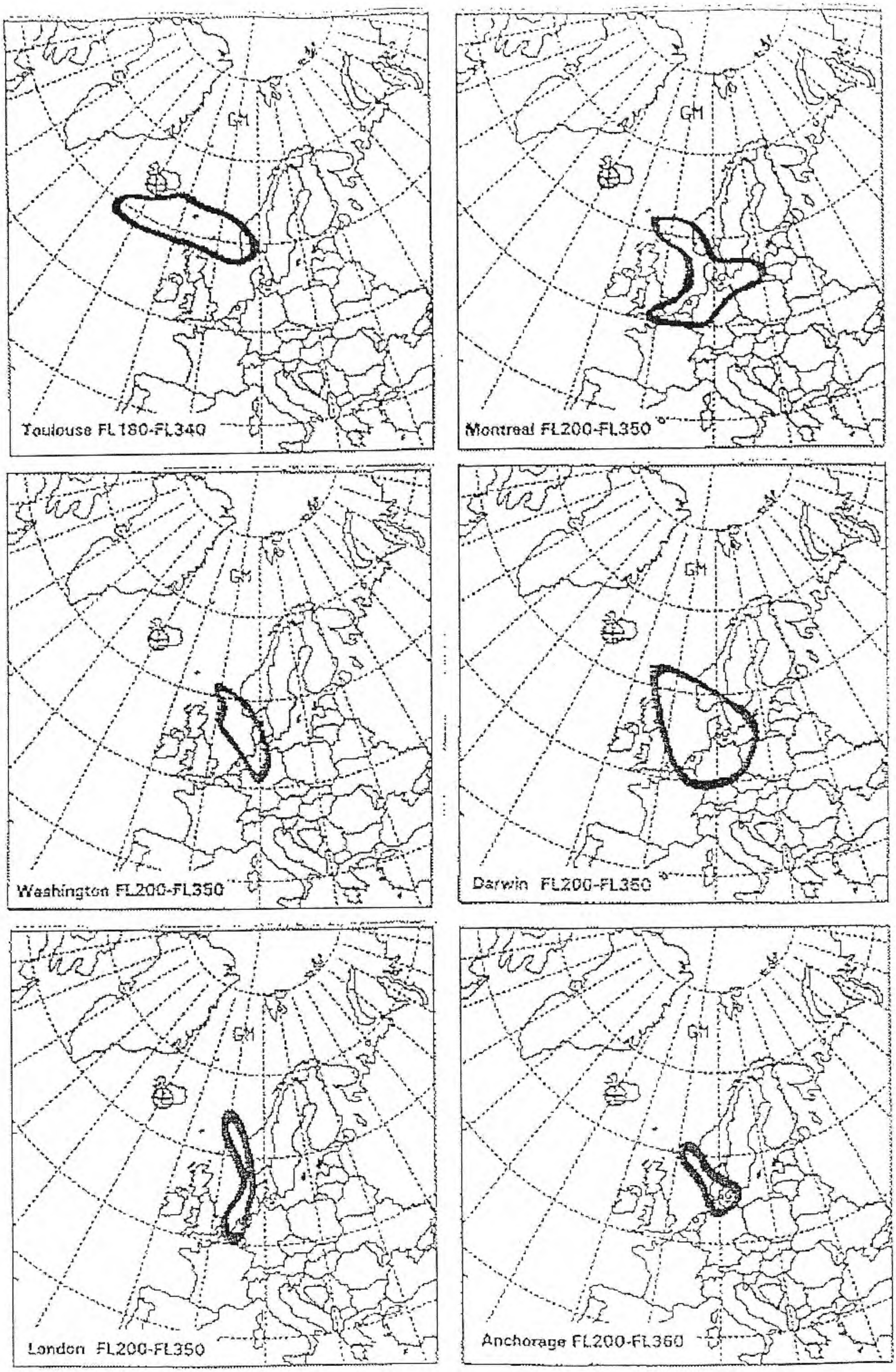
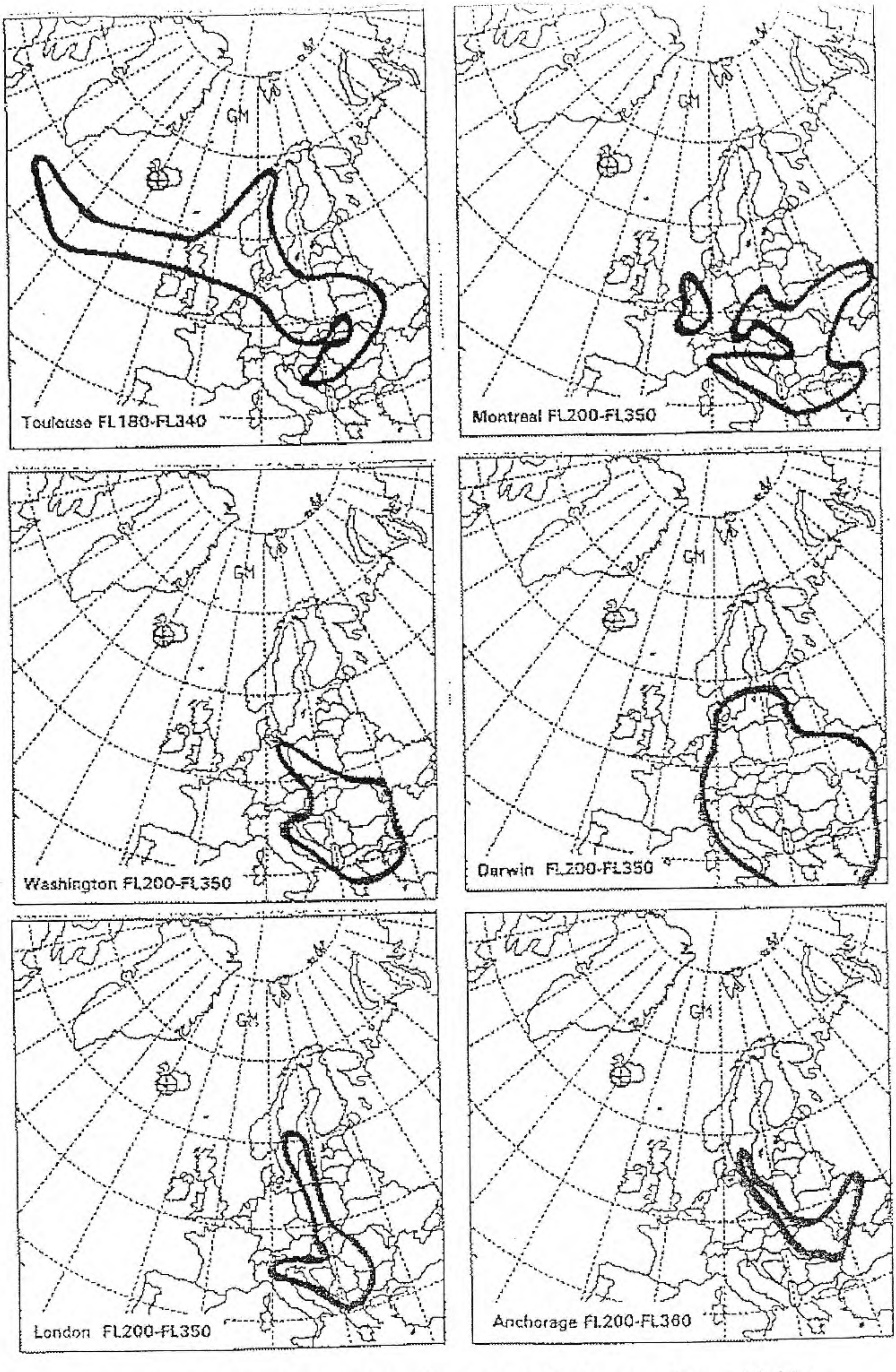

UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL350 - FL550 0000UTC/25/12/1998
Max Value = 0.00E+00 Units m^{-3}
1.00E-38 1.00E-05 1.00E-04 1.00E-03 1.00E-02 1.00E-01 1.00E+00
Source Location: 64.3000N 017.2000W
Release Height: FL020 to FL250
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99
UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL350 - FL550 1200UTC/25/12/1998
Max Value = 4.18E-17 Units m^{-3}
1.00E-38 1.00E-21 1.00E-20 1.00E-19 1.00E-18 1.00E-17 1.00E-16
Source Location: 64.3000N 017.2000W
Release Height: FL020 to FL250
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99
UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL350 - FL550 0000UTC/26/12/1998
Max Value = 6.49E-16 Units m^{-3}
1.00E-38 1.00E-20 1.00E-19 1.00E-18 1.00E-17 1.00E-16 1.00E-15
Source Location: 64.3000N 017.2000W
Release Height: FL020 to FL250
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99
UKMO NAME v4.1 Dispersion Model: vatna6
03 hr Time Averaged Air Concentration of TRACER From FL350 - FL550 1200UTC/26/12/1998
Max Value = 5.40E-16 Units m^{-3}
1.00E-38 1.00E-20 1.00E-19 1.00E-18 1.00E-17 1.00E-16 1.00E-15
Source Location: 64.3000N 017.2000W
Release Height: FL020 to FL250
Start of Release: 1200UTC 24/12/1998
End of Release: 0000UTC 25/12/1998
Met data: Regional
Run Time: 11:04:10 23-Feb-99

Fig. 8b(iii)



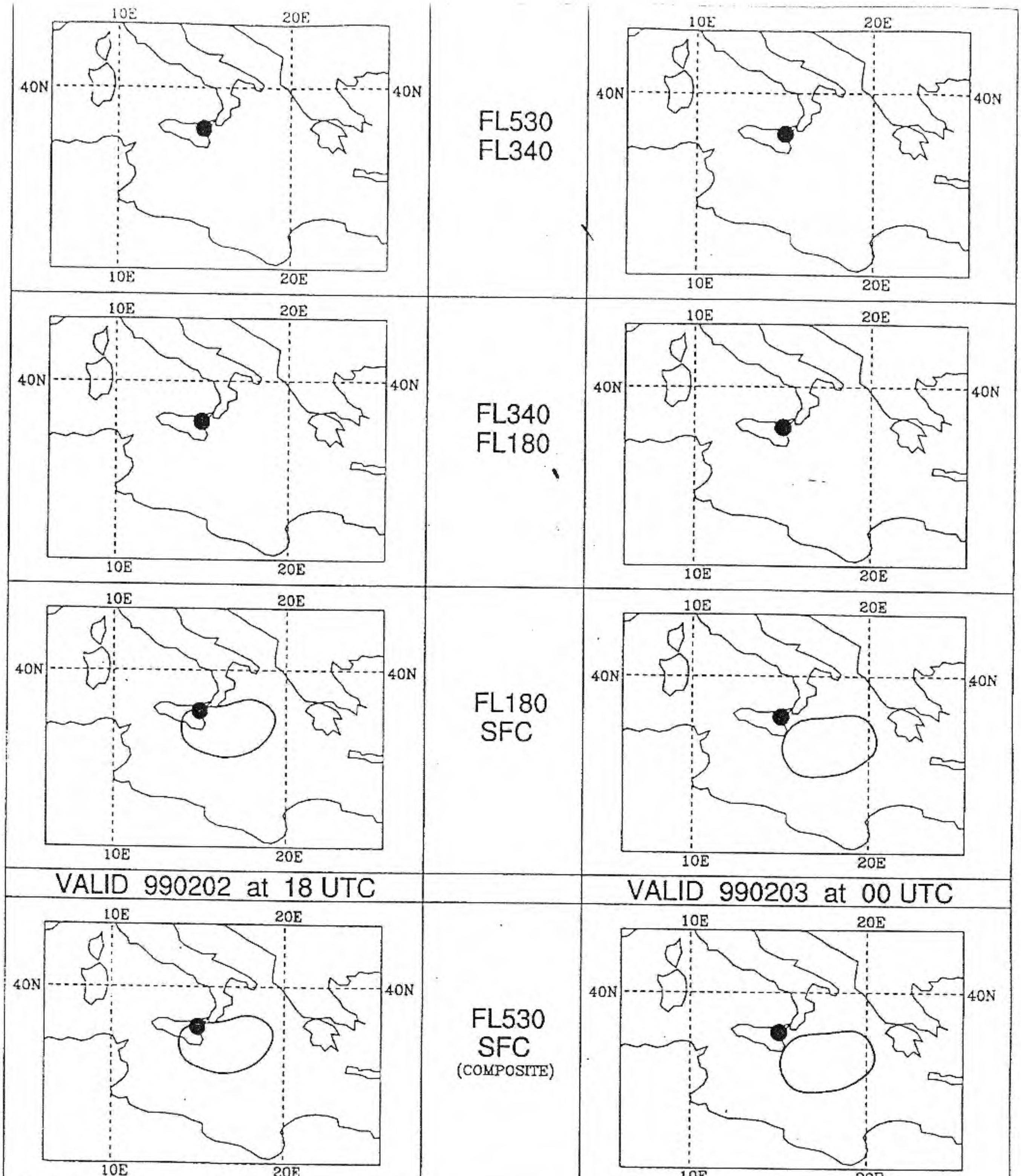
VAAC ash cloud model comparisons for 24 hours after a Hekla test eruption at 0000 UTC 3 July 1998

Fig. 9a



VAAC ash cloud model comparisons for 48 hours after a Hekla test eruption at 0000 UTC 3 July 1998

Fig. 9b



Pollutant released : VOLCANIC ASH
Name of volcano : ETNA
Start of the emission : 990202 at 6.00 UTC
End of the emission : 990202 at 7.00 UTC

Latitude : 37.73 N
Longitude : 15.00 E
Top of ash column : 3000. m – AGSL
Base of ash column : 0. m – AGSL

Remarks : ISOLINE DELINEATING VISIBLE ASH CLOUD AS COMPUTED BY MODEL
SAT IMAGERY SHOWS A VISIBLE ASH CLOUD MORE CONCENTRATED NEAR THE ETNA'S CRATERE

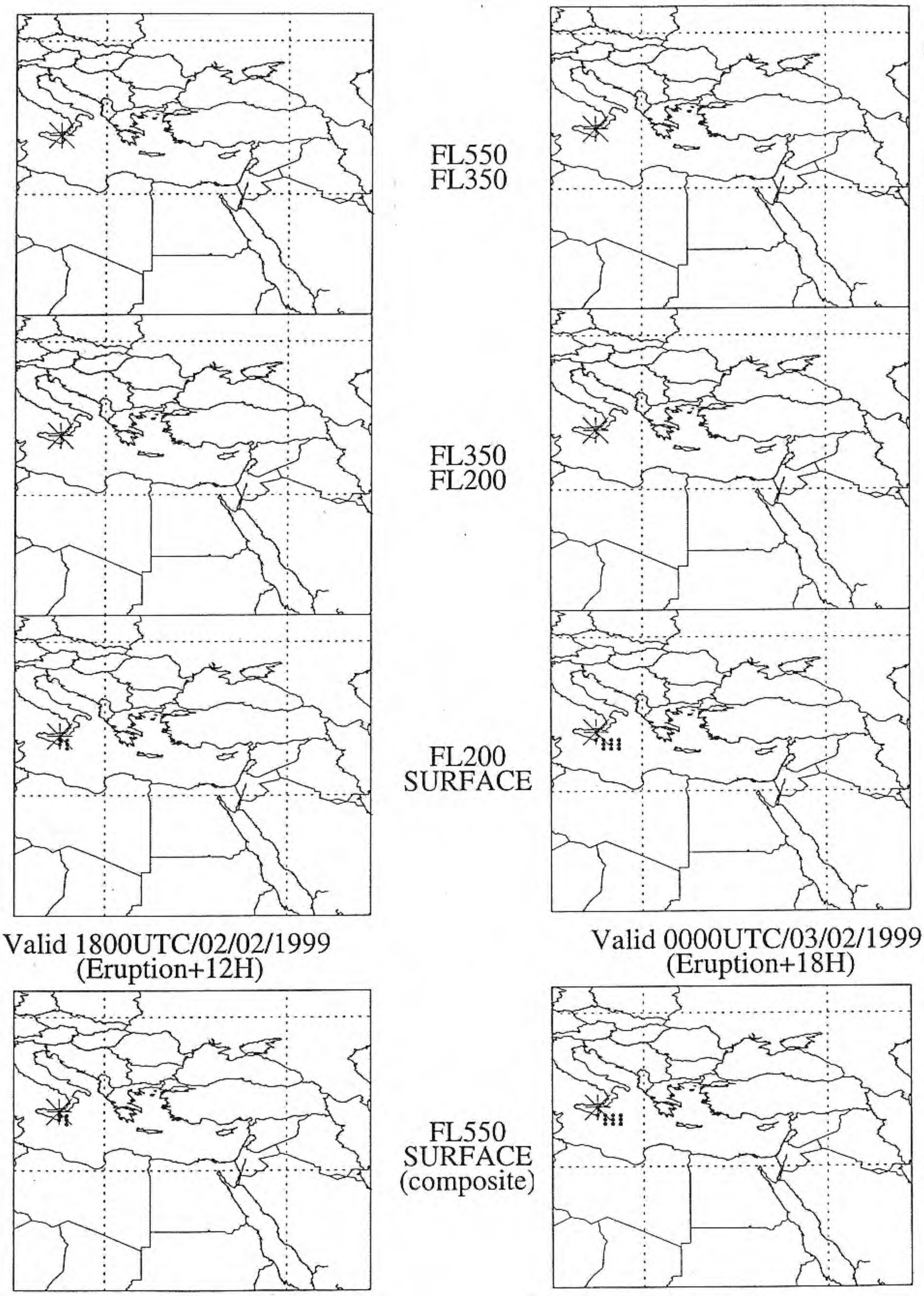
METEO FRANCE
VAAC TOULOUSE

VOLCANIC ASH ADVISORY INFORMATION IN GRAPHICAL FORMAT

8039

Fig. 10a

VOLCANIC ASH ADVISORY STATEMENT

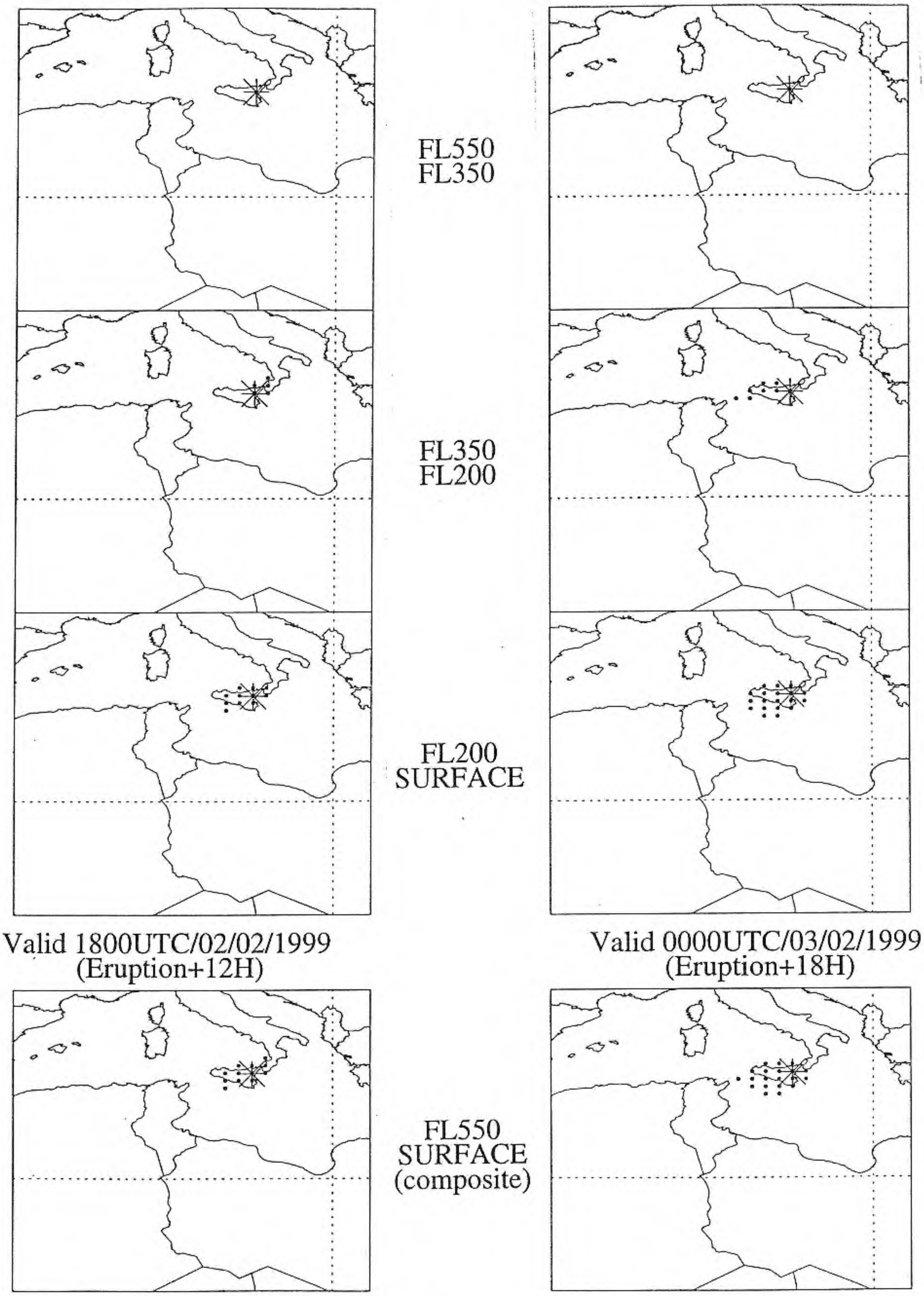


UKMO NAME Model (PMSR)
Location: 37.7300N 015.0000E
Eruption start: 0600UTC 02/02/1999
Eruption End: 0700UTC 02/02/1999
Ash Column: FL000 to FL200

Met data: Global
Analysis on Global
Run Time: 16:34:06 2-Feb-99
Release Rate: 1.00e+00g/hr
Threshold conc: 1.00e-16g/m^3

Fig. 10b

VOLCANIC ASH ADVISORY STATEMENT



UKMO NAME Model (PMSR)
Location: 37.7300N 015.0000E
Eruption start: 0600UTC 02/02/1999
Eruption End: 0700UTC 02/02/1999
Ash Column: FL000 to FL200

Met data: Global
Analysis on Global
Run Time: 13:17:01 19-Feb-99
Release Rate: 1.00e+00g/hr
Threshold conc: 0.00e+00g/m^3

Fig. 10c