Air Pollution Forecasting: A UK Particulate Episode from 23rd to 24th January 2008

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SUMMARY

Over the period Wednesday 23rd to Thursday 24th January 2008 eight sites in the UK Automatic Urban and Rural monitoring network (AURN) measured levels of PM_{10} particulate matter at air pollution index 7 (HIGH) or above, and two of these sites also went on to record VERY HIGH pollution at index 10. Over the same period a further eighteen monitoring sites recorded MODERATE PM_{10} air pollution at index 4 to 6.

The cause of this PM_{10} particulate episode was observed to have been long range transport of dust as a result of sandstorms in Africa with a possible but unlikely contribution from forest fires, also in Africa.

Of the eight sites measuring PM_{10} at index 7 or above, three were located in London, two in the South East and three in South Wales. In additional to three roadside sites reaching the HIGH band, index 7 or above was measured at one remote site in Wales, one urban centre and one rural site in the south of England and an urban centre site in London.

The increase in particulate levels was first detected along the south coast of England during the early hours of Wednesday 23rd and then moved northwards across the UK during the course of the day. No significant increase in airborne particulate matter was recorded across Scotland or Northern Ireland over the duration of the episode, the most northerly site measuring a MODERATE band exceedence was located in Norwich.

Some of these sites may have measured MODERATE or HIGH levels as a result of local pollution sources combined with the additional long-range transport component. However, the twenty seven sites measuring PM_{10} air pollution in the MODERATE or HIGH bands were all considered to have been primarily affected by the long range transport of particulate matter.

The AEA air quality forecasting team did not successfully predict this episode. There was no early detection of the dust cloud on the NASA Natural Hazards website, or other satellite image-based forecasting services.

INTRODUCTION

Within this short paper we will attempt to:

- Quantify the magnitude of the episode by analysing automatic air pollution monitoring data.

- Identify the source of the pollution by examining:
  - simple air mass back-trajectory analyses available to the forecasters in real-time during the event,
  - more sophisticated NAME model runs carried out as the episode progressed.

- Track and understand how the pollution spread across the UK by examination of satellite images and particulate maps produced from worldwide dust model forecasting systems over the period of interest.

MONITORING RESULTS

Table 1 attempts to quantify the magnitude of the episode in terms of air pollution index values (see Appendix) recorded in affected areas on each day. Only days and locations where PM_{10} air pollution was measured above index 3 are listed in the table.

Figure 1 shows hourly-averaged gravimetric equivalent PM_{10} measurements from a selection of sites across the UK. Figure 1 shows that the episode was first detected in areas to the south west before spreading over England and Wales.

Site name	Site designation / (FDMS or TEOM)	Site location	Significant local contribution?	Maximum Air Pollution Index on each day *			
				Tue 22nd	Wed 23rd	Thur 24th	Fri 25th
Norwich Centre	Urban centre (T)	Eastern	no	-	-	6 (4)	-
Southend-on-Sea	Urban background (F)	Eastern	No	-	-	4	-
Stanford-le-Hope Roadside	Roadside (T)	Eastern	Traffic sources	-	4 (3)	6 (4)	-
Thurrock	Urban background (T)	Eastern	No	-	-	5 (4)	-
Camden Kerbside	Kerbside (T)	London	Traffic sources	-	5 (4)	7 (5)	-
London Bloomsbury	Urban centre (T)	London	No	-	5 (3)	7 (5)	-
London Marylebone Road	Kerbside (T)	London	Traffic sources	-	8 (5)	9 (7)	5 (3)
Haringey Roadside	Roadside (T)	London	Traffic sources	-	4 (3)	6 (4)	-
London Bexley	Suburban (T)	London	No	-	4 (3)	6 (4)	-
London Harlington	Airport (T)	London	No	-	5 (3)	6 (4)	-
London N. Kensington	Urban background (T)	London	No	-	4 (3)	6 (4)	-
Leamington Spa	Urban background (T)	Midlands	No	-	5 (3)	5 (3)	-
Northampton	Urban background (T)	Midlands	No	-	5 (3)	6 (4)	-
Portsmouth	Urban background (T)	South	No	-	7 (5)	10 (7)	4 (3)
Southampton Centre	Urban centre (F)	South	No	-	4	5	-
Harwell	Rural (T)	SE	No	-	6 (4)	7 (5)	-
Oxford St Ebbes	Urban background (T)	SE	No	-	5 (3)	6 (4)	-
Reading New Town	Urban background (F)	SE	No	-	-	5	-
Rochester Stoke	Rural (T)	SE	No	-	-	6 (4)	-
Chepstow A48	Roadside (T)	S Wales	Traffic sources	-	8 (5)	8 (6)	-
Narberth	Remote (T)	S Wales	No	-	8 (6)	7 (6)	-
Port Talbot Margam	Urban industrial (F)	S Wales	not observed	-	9	10	-
Cardiff Centre	Urban centre (F)	S Wales	No	-	4	4	-
Swansea Roadside	Roadside (F)	S Wales	Traffic sources	-	5	6	-
Bristol St Paul's	Urban background (F)	SW	No	-	5	6	-

* (x) indicates the maximum index which would have been reached for TEOMs if the factor of 1.3, normally used for conversion to gravimetric equivalent units, hadn't been applied

Table 1: The January 2008 PM_{10} episode Quantified

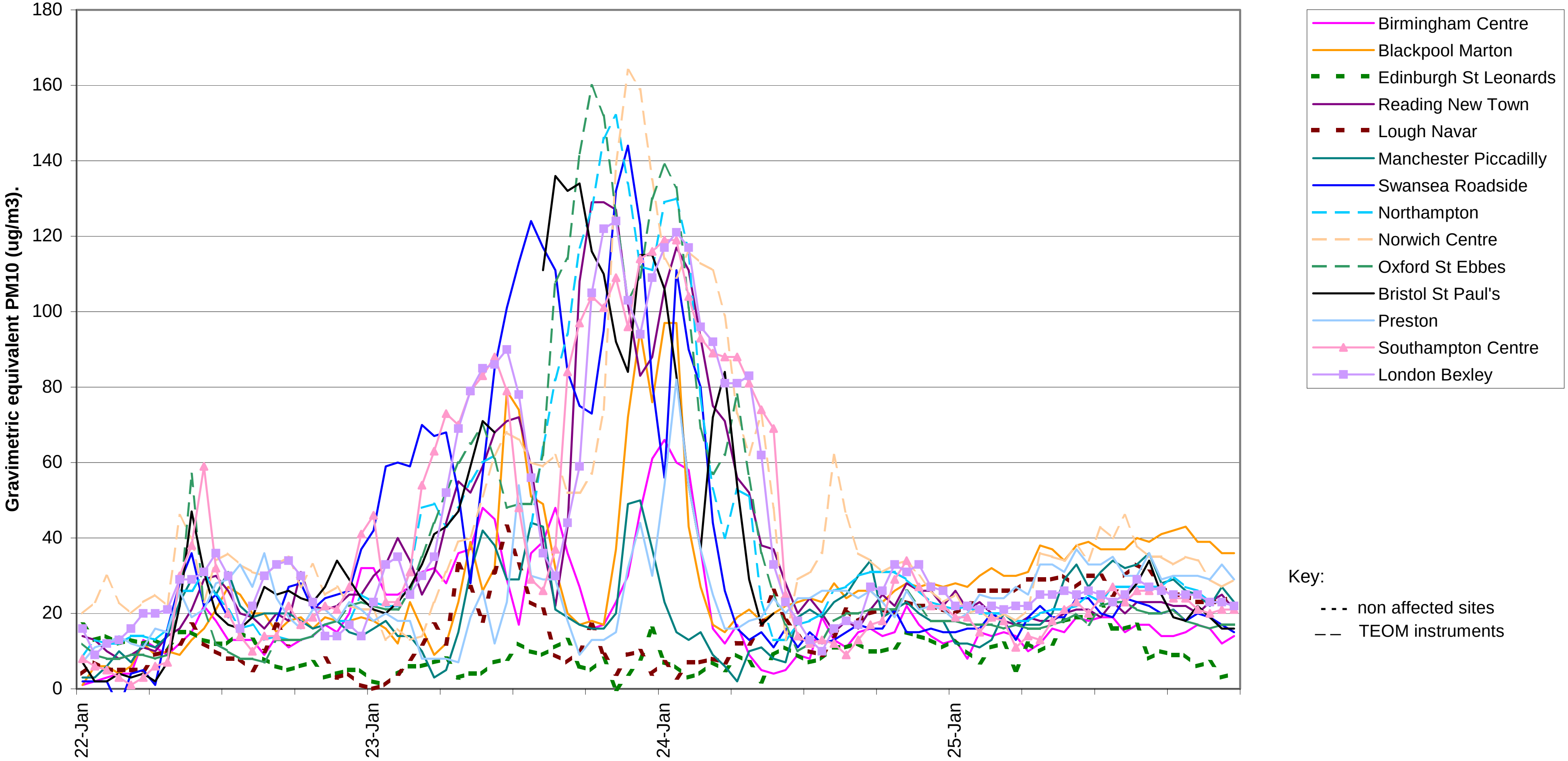


Figure 1: Hourly mean PM_{10} measurements at selected sites in the UK, January 22nd to 25th 2008

Figures 2a to 2c show the additional daily averaged contributions of particulate PM_{10} above an estimated background for each site over the period 23rd – 24th January.

The backgrounds were estimated by taking an average of measurements over the periods 13th to 21st and 25th to 27th January for the relevant site. The measurements made at London Bloomsbury have not been converted to gravimetric equivalent units (ie a factor of 1.3 was not applied) for the purpose of this analysis due to the low volatile fraction of the particles measured throughout the episode by FDMS instruments in the network.

The additional contribution on the 23rd January was about 3 times normal background level at these sites and a factor of 1 to 1.5 normal background level on the 24th January.

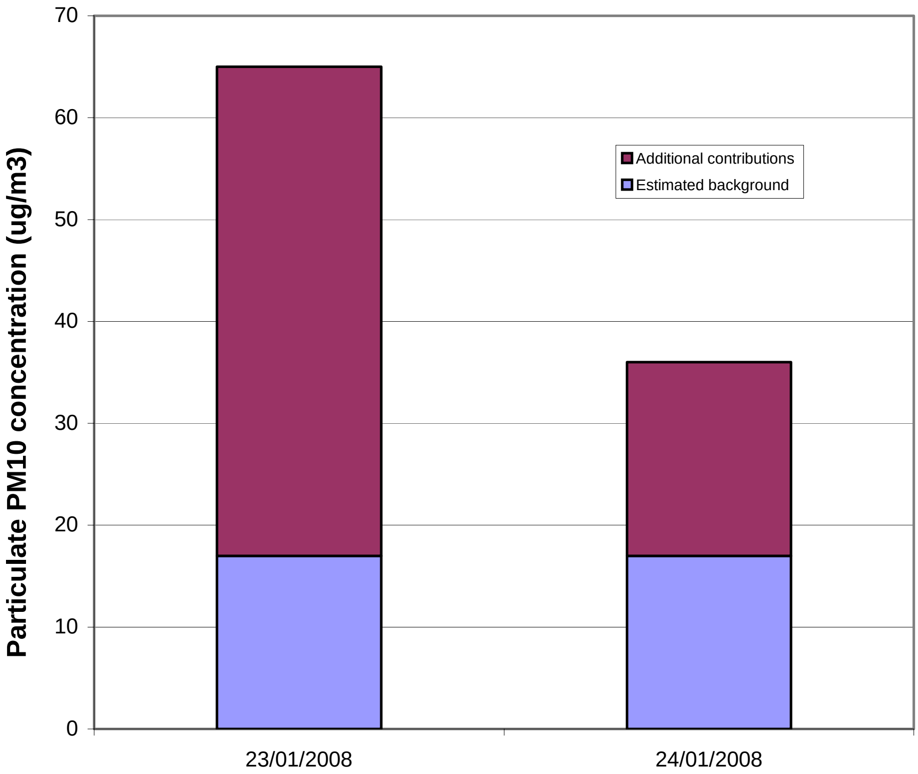


Figure 2a: Estimated additional contributions of particulate PM_{10} at Cardiff Centre.

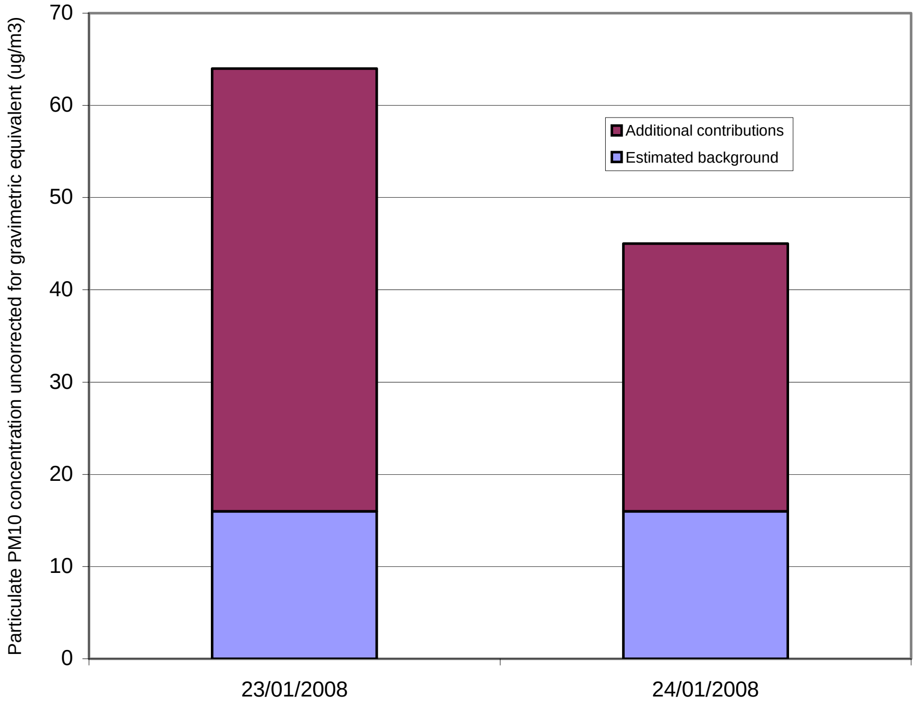


Figure 2b: Estimated additional contributions of particulate PM_{10} at London Bloomsbury.

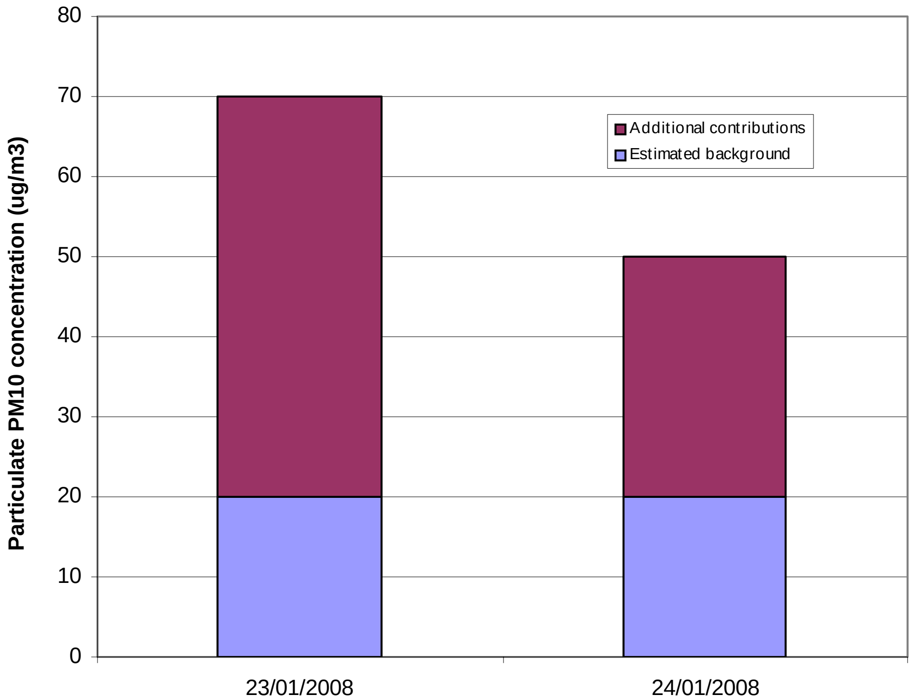


Figure 2c: Estimated additional contributions of particulate PM_{10} at Southampton Centre.

Figure 2d shows the provisional $PM_{2.5}$ and PM_{10} hourly averaged measurements made at the Harwell AURN site over the period 21st to 25th January in gravimetric equivalent units. The $PM_{2.5}$ fraction measured compared to the PM_{10} fraction indicates that the episodic particles were predominantly coarse (i.e. were composed of predominantly larger diameter particles).

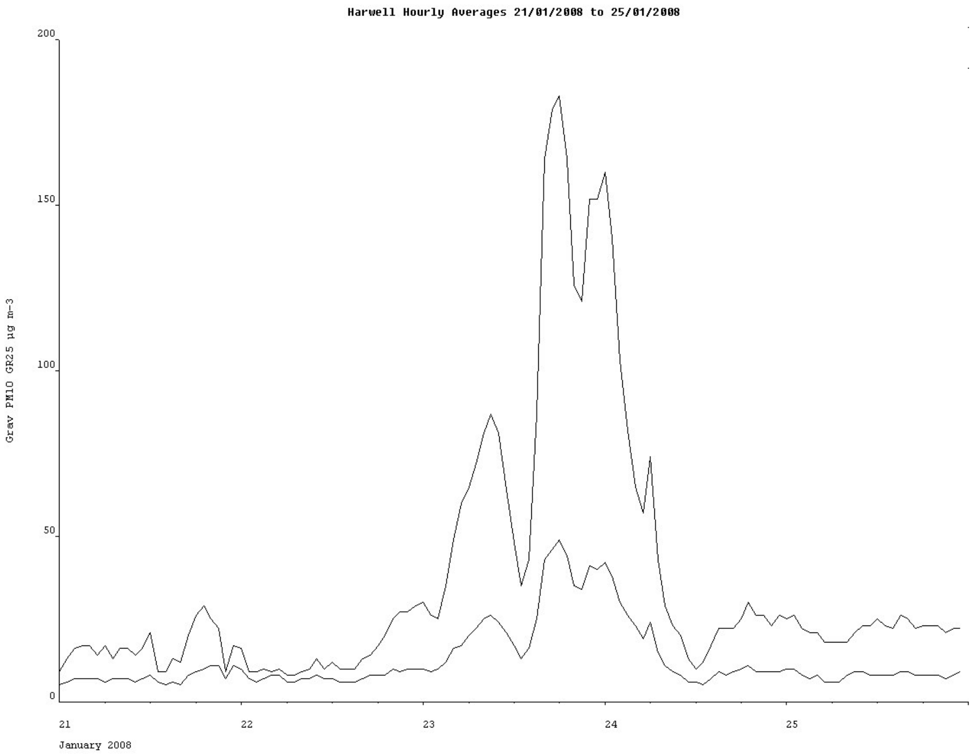


Figure 2d: Provisional measurements taken at Harwell AURN site

Measurements made by the “Osiris” instrument at Slough Colnbrook (non-AURN) site were used to determine the particle size fraction ratio experienced during the days of the episode. The Osiris particulate measurement instrument uses an optical laser technique for “indicative” measurements of particulate matter in the UK. The instrument’s measurement range is from 0.5 to 20 microns particle diameter. This instrument can monitor PM_1 , $PM_{2.5}$, PM_{10} and total suspended particulates (where TSP = PM_1 to PM_{20}) simultaneously.

Typical particle size ratios for PM_{fine} to PM_{coarse} were estimated using reference data found in the book “Atmospheric Chemistry and Physics” (by Seinfeld / Pandis, ISBN-13: 978-0471720188) for various environment types. The following particle diameter fractions were used to represent the coarse and fine PM fractions: $PM_{fine} = PM_{2.5}$ and $PM_{coarse} = PM_{10} - PM_{2.5}$.

Further research data was found in Schütz et al in 1981 (“Saharan dust transport over the North Atlantic Ocean: model calculations and measurements”. Geological Society of America Special Paper, 186, p 87–100), in which the particle size distribution of Saharan dust was measured at various long-range distances from the source. Schütz et al analysed the size distribution of seven particle size fractions up to the 10 micron diameter range, four of which were used in this analysis.

The particle size ratios, as calculated by AEA, for PM_{fine} to PM_{coarse} corresponding to various distances of travel over the North Atlantic are tabulated below:

Saharan dust at source (no travel)	0.11
Saharan dust after 2k km of travel	0.13
Saharan dust after 5k km of travel	0.38

Hourly averaged PM_{fine} : PM_{coarse} ratios were plotted using data from “Osiris” particulate monitor located at Slough Colnbrook, as shown in figure 2e. This figure shows that the particle fraction ratios measured entered the range of ratios expected for the long range transport of Saharan dust in the morning of the 23rd and remained within the band of expected ratios until the end of the episode in the late morning of the 24th. By examining the modelled air-mass trajectory path from North East Africa to the UK, the actual distance of travel for the Saharan dust reaching the UK on January 23rd was estimated to have been in the range of 3500-5000 km. After the episode has finished the ratios measured returned to those typical of an urban environment.

Various assumptions have to be made for this analysis to be valid, which include:

- The particulates measured during the episode were exclusively caused by long range transport, or that localised pollution did not significantly contribute to the levels measured.
- The density of the particles was the same at all particle diameters.
- The particle size distribution of Saharan dust arriving in the UK from long range transport over the North Atlantic Ocean was similar to that measured by Schütz et al for long range transport over the Atlantic to the USA.

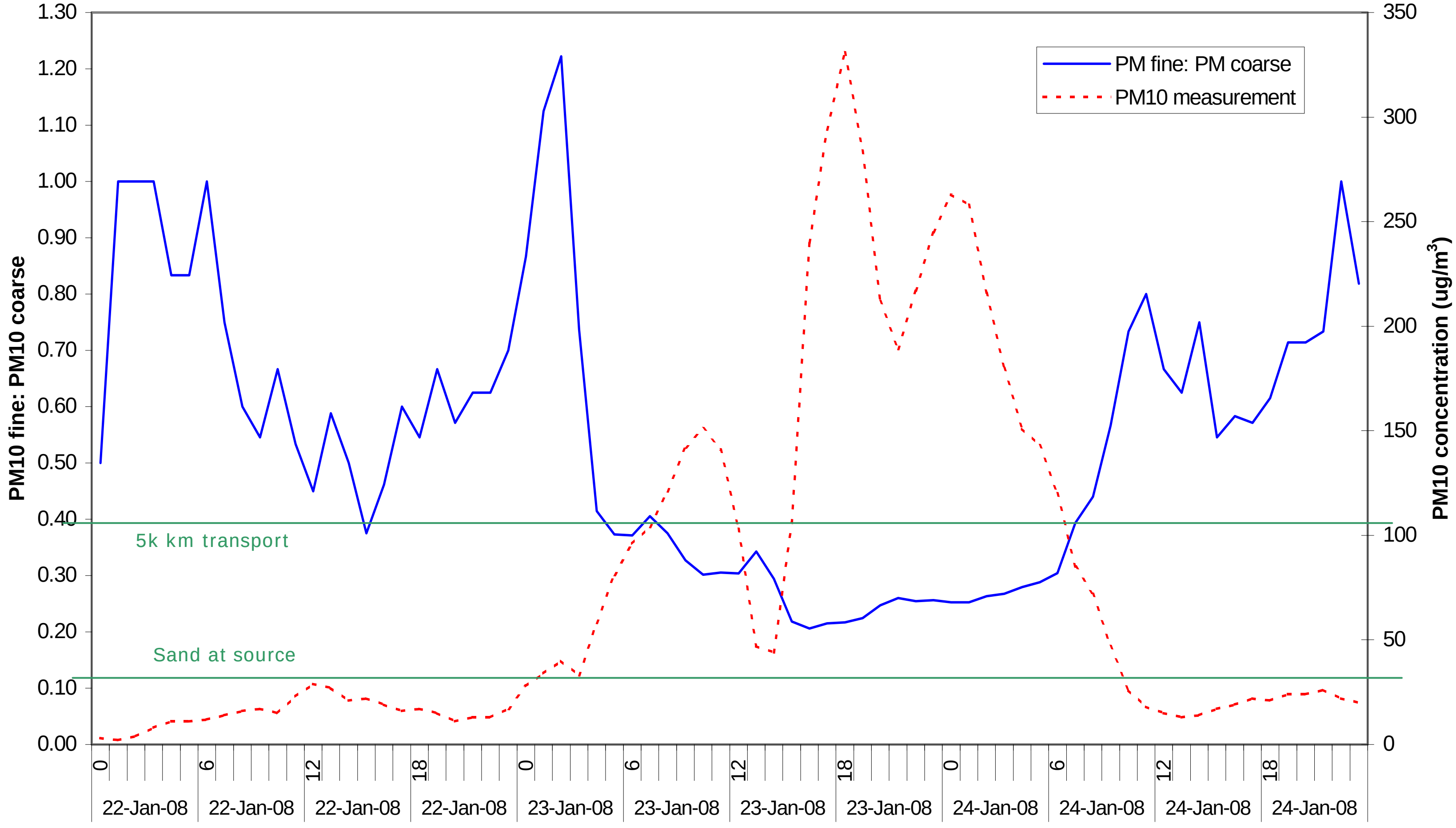


Figure 2e: Particle size fraction ratios calculated using measurements from the Osiris instrument at Slough Colnbrook.

Measurements made by the FDMS instrument at Reading New Town in the south east of England show that the volatile fraction associated with the episodic particulates arriving in the UK was very low, which is consistent with the air having passed over no significant areas of pollution, as shown in figure 2f.

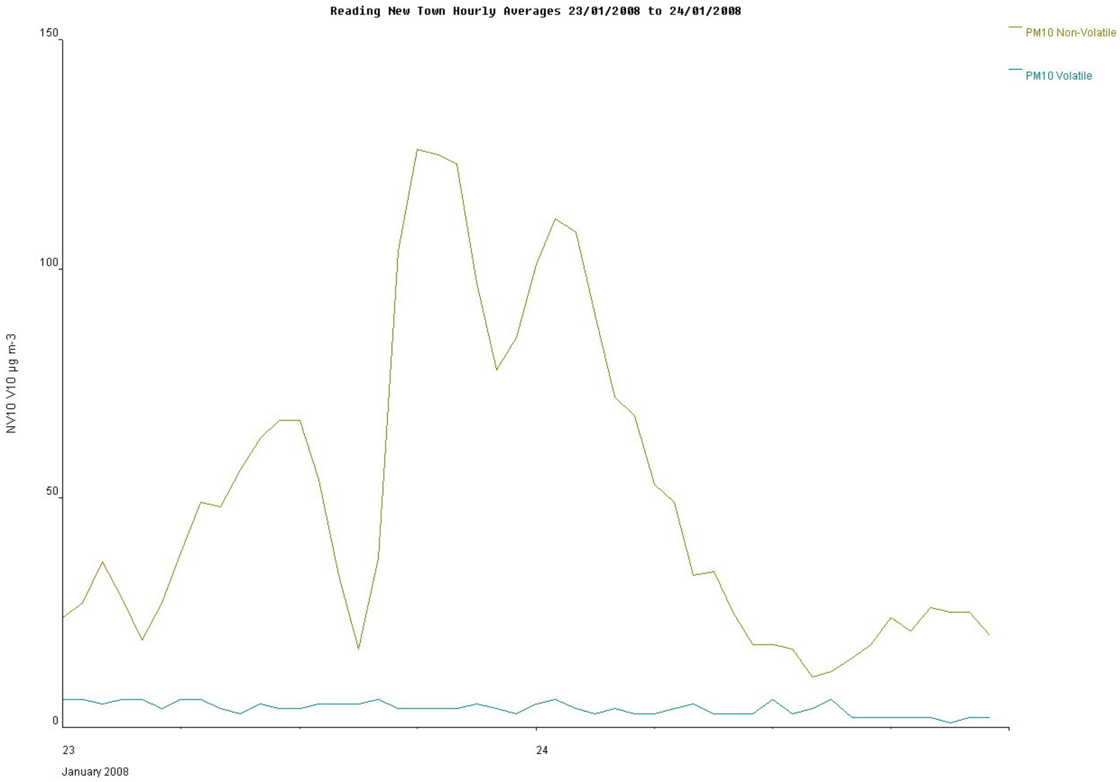


Figure 2f: Hourly averaged PM_{10} volatile and non-volatile fractions measured by the FDMS instrument at Reading New Town on the 23rd and 24th January.

LIKELY SOURCES OF THE POLLUTION

Simple 1000mB 96-hour forecast air mass back-trajectory data are provided by the Met Office to the AEA air pollution forecasting team each day. These data illustrated that the air arriving in England and Wales on the 23rd January had been sourced from the west coast of Africa and had traveled exclusively over the Atlantic, as shown in figure 3c. Figure 3c also modeled the arrival of air transported from North America to Scotland and Northern Ireland on the 23rd. Figures 3a and 3b indicate that air masses arriving on the days leading up to the episode were predominantly from the west, however the direction of travel varied from south-westerly to north westerly on these two days. Figures 3d and 3e show that the air masses arriving on the 24th and 25th had reached all areas of the UK from North America.

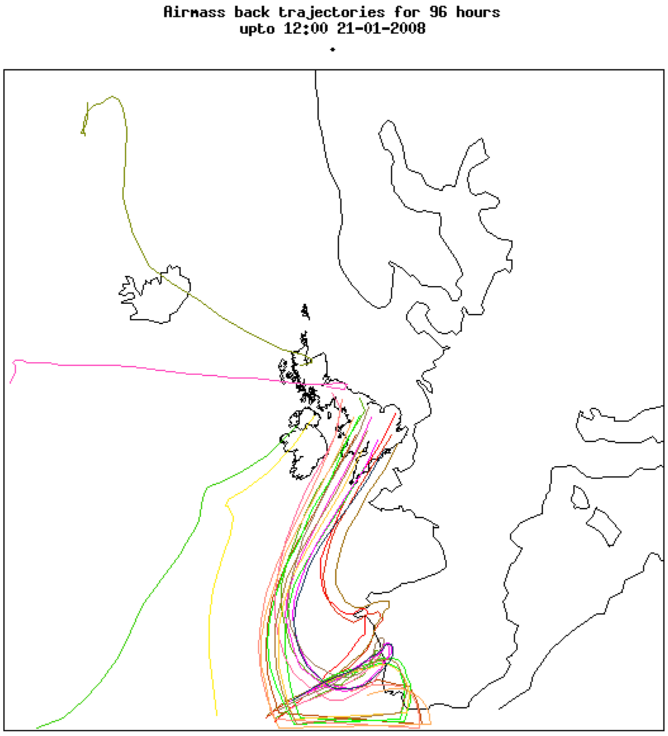


Figure 3a: Air mass back-trajectories for 21st January

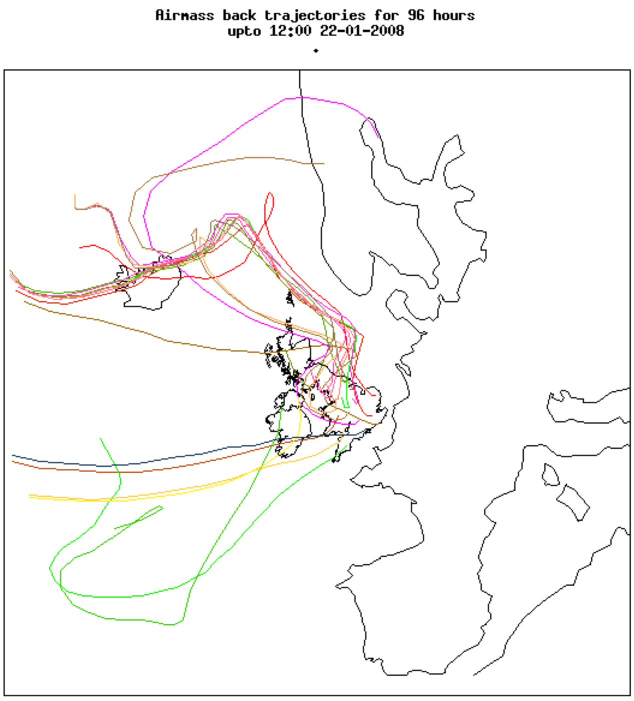


Figure 3b: Air mass back-trajectories for 22nd January

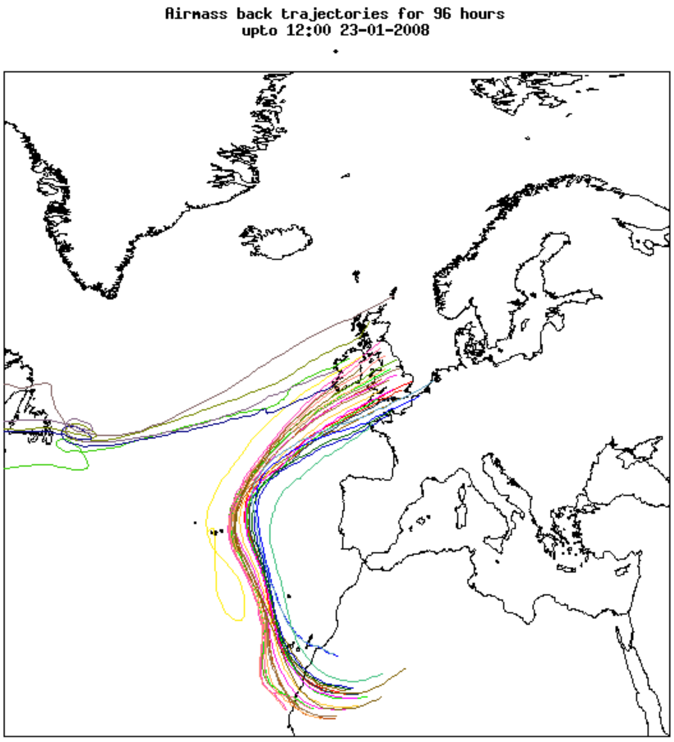


Figure 3c: Air mass back-trajectories for 23rd January

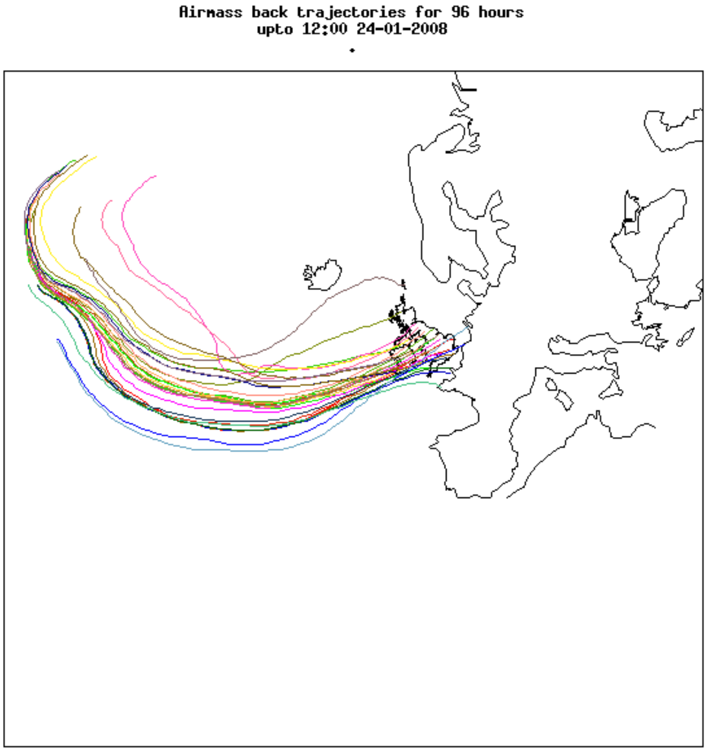


Figure 3d: Air mass back-trajectories for 24th January

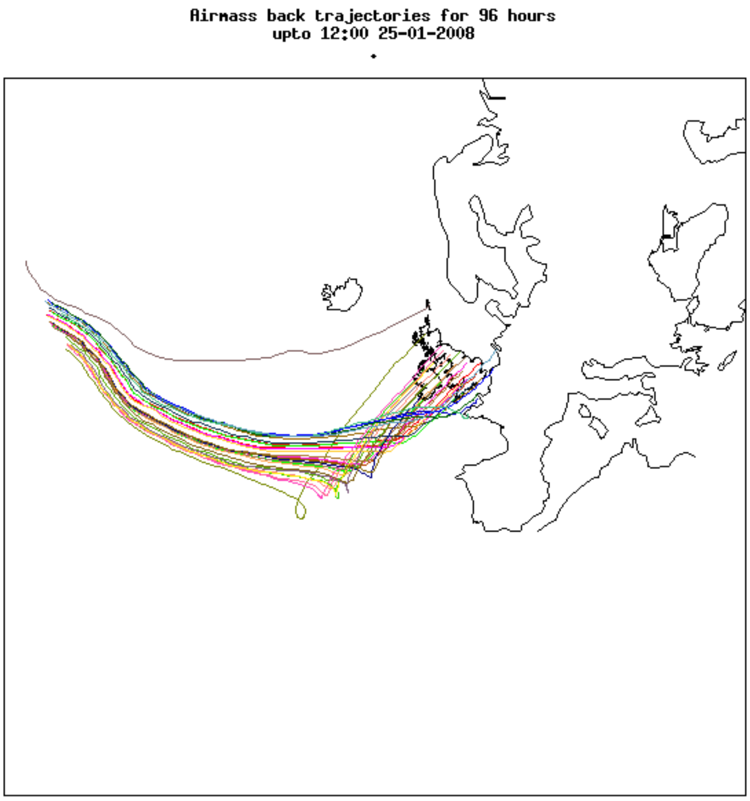


Figure 3e: Air mass back-trajectories for 25th January

AEA and the Met Office considered two hypotheses for the pollution source:

1) Sandstorms across Africa
2) Smoke from forest fires in Africa

Dust from sandstorms in western Africa had been observed by MODIS (Moderate Resolution Imaging Spectroradiometer, housed onboard a NASA satellite) on the 20th January, as shown in figure 4a.

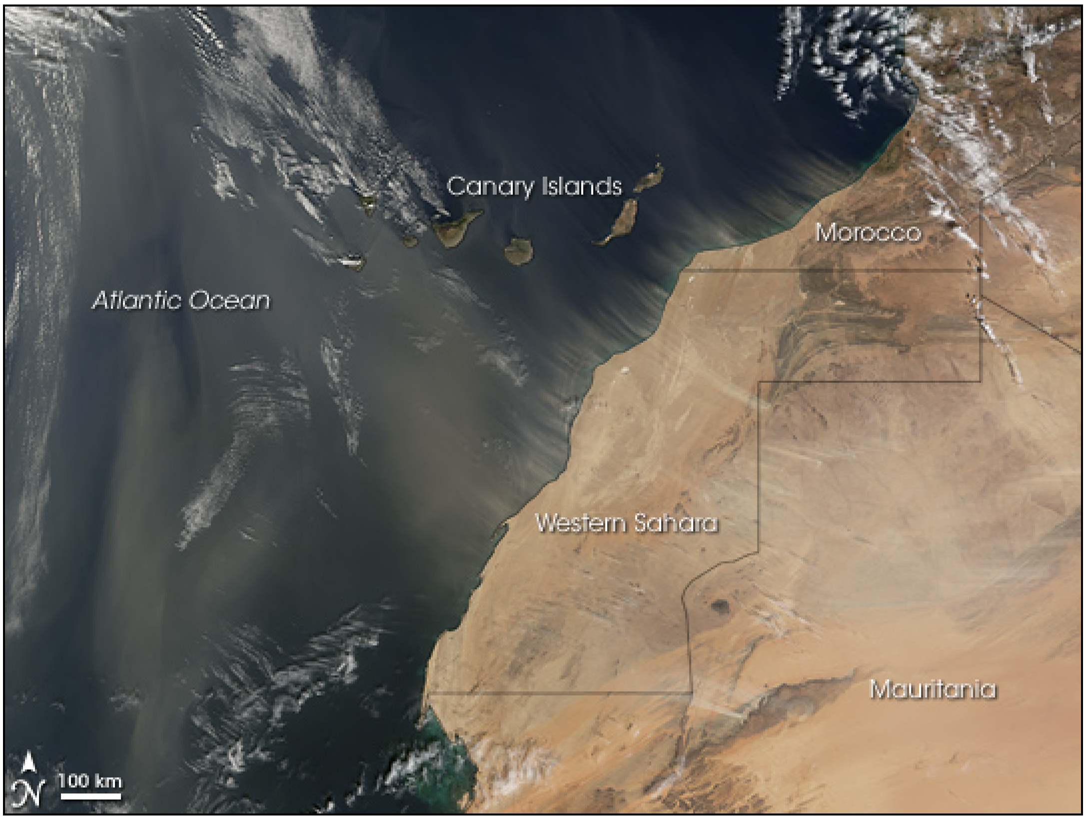


Figure 4a: Particulates over the Atlantic Ocean on 20th January and more issuing from the Western Sahara.

Fires were identified, again by MODIS, on the 21st January in the area of Guinea and the Ivory Coast, as shown in figure 4b. These fires were thought to have been likely the result of Agricultural fires during the dry season.

Figure 4c shows the relative global positions of the two events.

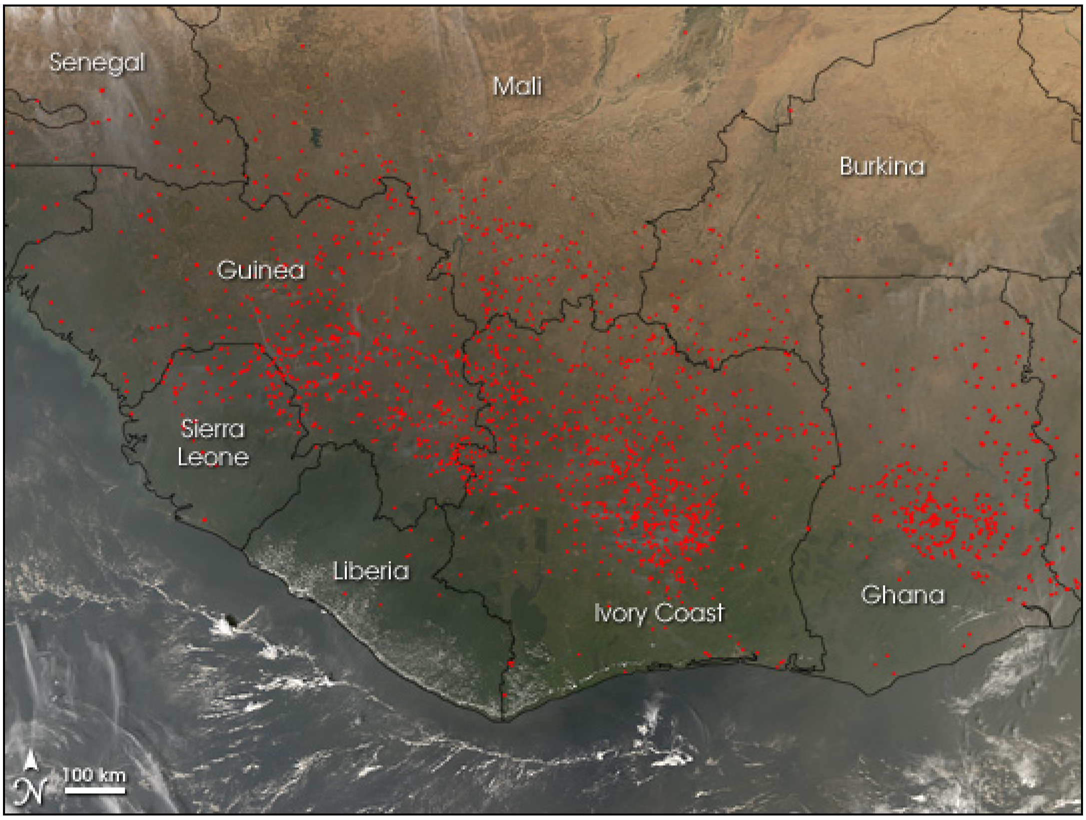


Figure 4b: Fires in western Africa on the 21st January (indicated by the red dots).

Figure 4c: Approximate position of the fires and sandstorms in Africa (indicated by blue cross for the sandstorm region and a red cross for the fire region).

The Met Office NAME atmospheric dispersion model was run forwards assuming a multiple source release on the 18th January. Figures 4d to 4j show the modelled dust concentration in the air both arriving and over the UK and Europe over the period 00 UTC on the 23rd January to 18 UTC on the 24th January.

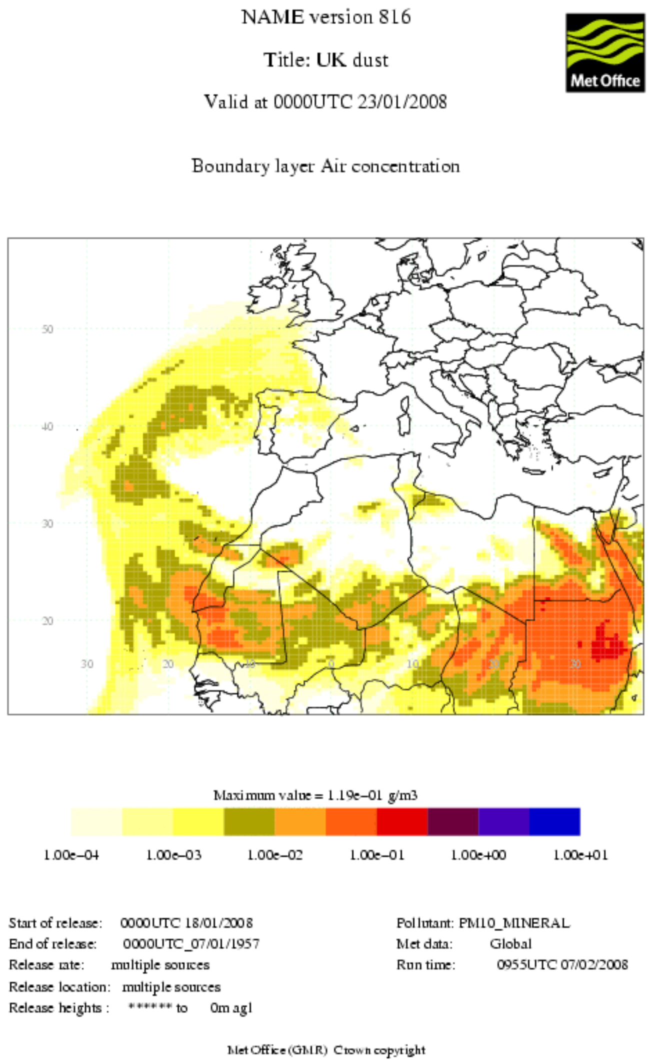


Figure 4d: Modelled dust composition of air arriving in the UK on 23rd January at 00 UTC.

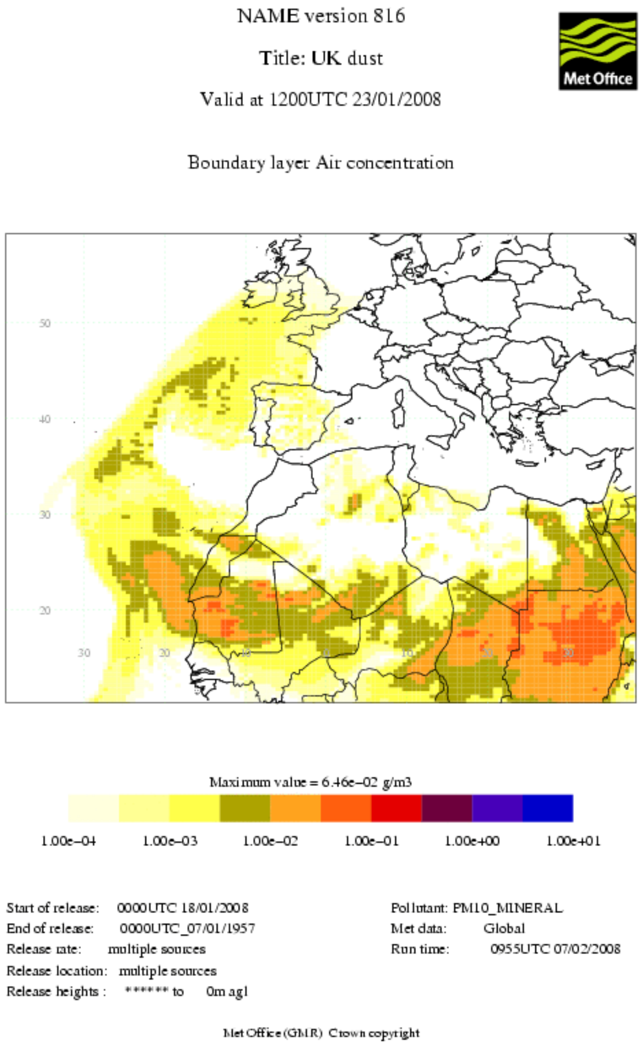


Figure 4e: Modelled dust composition of air arriving in the UK on 23rd January at 12 UTC.

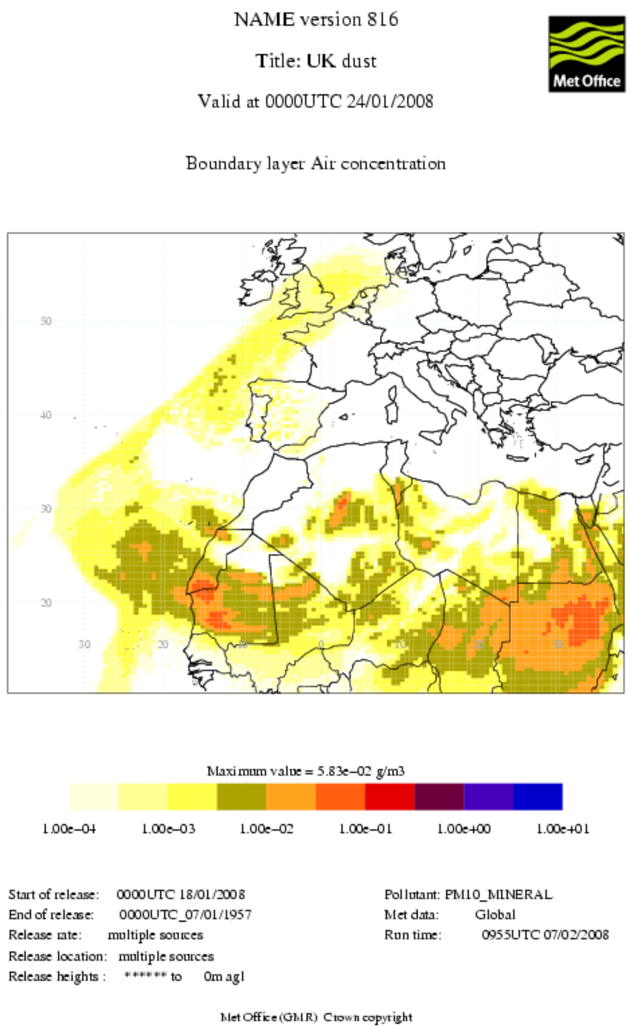


Figure 4f: Modelled dust composition of air arriving in the UK on 24th January at 00 UTC.

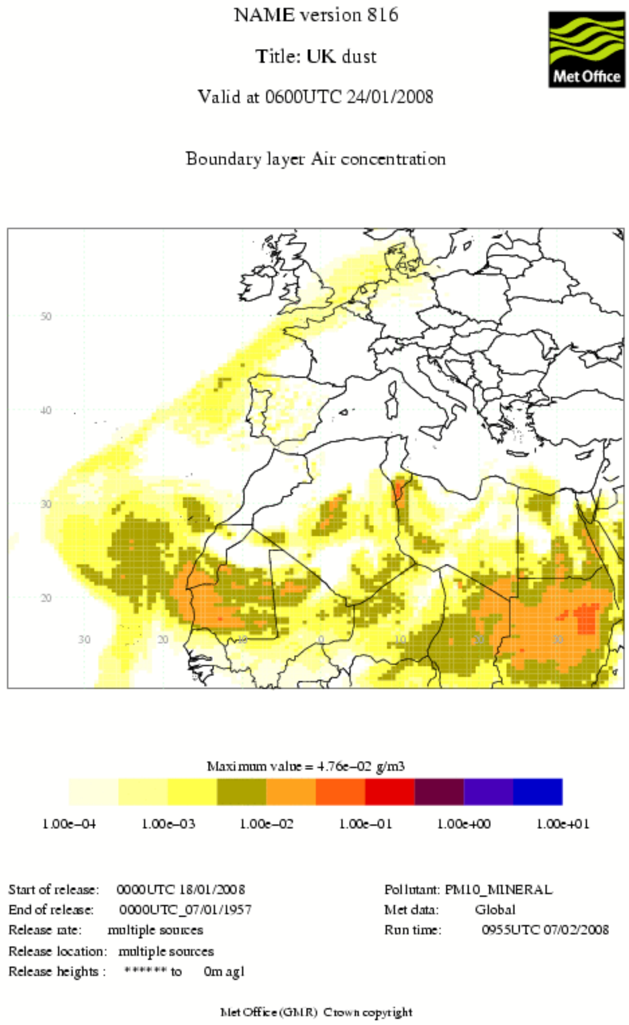


Figure 4g: Modelled dust composition of air arriving in the UK on 24th January at 06 UTC.

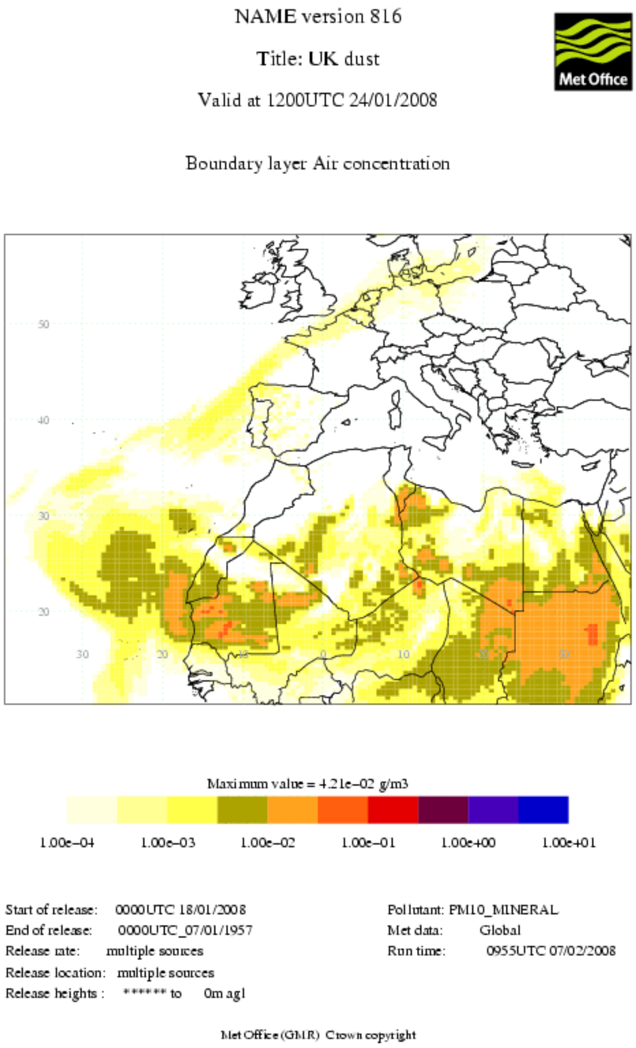


Figure 4h: Modelled dust composition of air arriving in the UK on 24th January at 12 UTC.

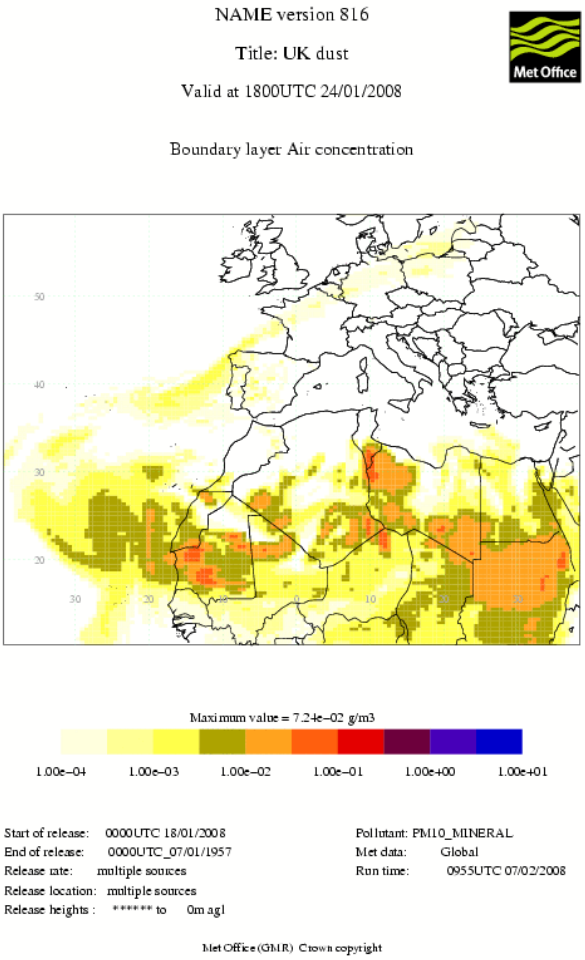


Figure 4j: Modelled dust composition of air arriving in the UK on 24th January at 18 UTC.

The results of the modelling studies agreed with the hypothesis that the particulates measured at ground level in the UK during the episode had issued from Western Africa. The model also indicated that the particulate laden air had passed to the south of the UK and over continental Europe after midday on the 24th January and that both Scotland and Northern Ireland hadn't been significantly affected by the dust.

TRACKING THE EPISODE FROM SATELLITE IMAGES AND ATMOSPHERIC PRESSURE CHARTS

Please note that many of the high resolution colour images which follow have been sourced from a MODIS (Moderate Resolution Imaging Spectroradiometer) sensor onboard a U.S. civilian meteorological satellite and others have been sourced from pictures taken by a geo-stationary orbiting satellite (i.e. one which remains in a fixed position relative to a point on the Earth), which have been interpolated and processed by Dundee university.

On the 20th January, the day of the reported sandstorms in the Western Sahara, atmospheric pressure charts show high pressure air over the Atlantic, to the west of Spain, with a series of low pressure areas over the Mediterranean and near the UK, as shown in figure 5a.

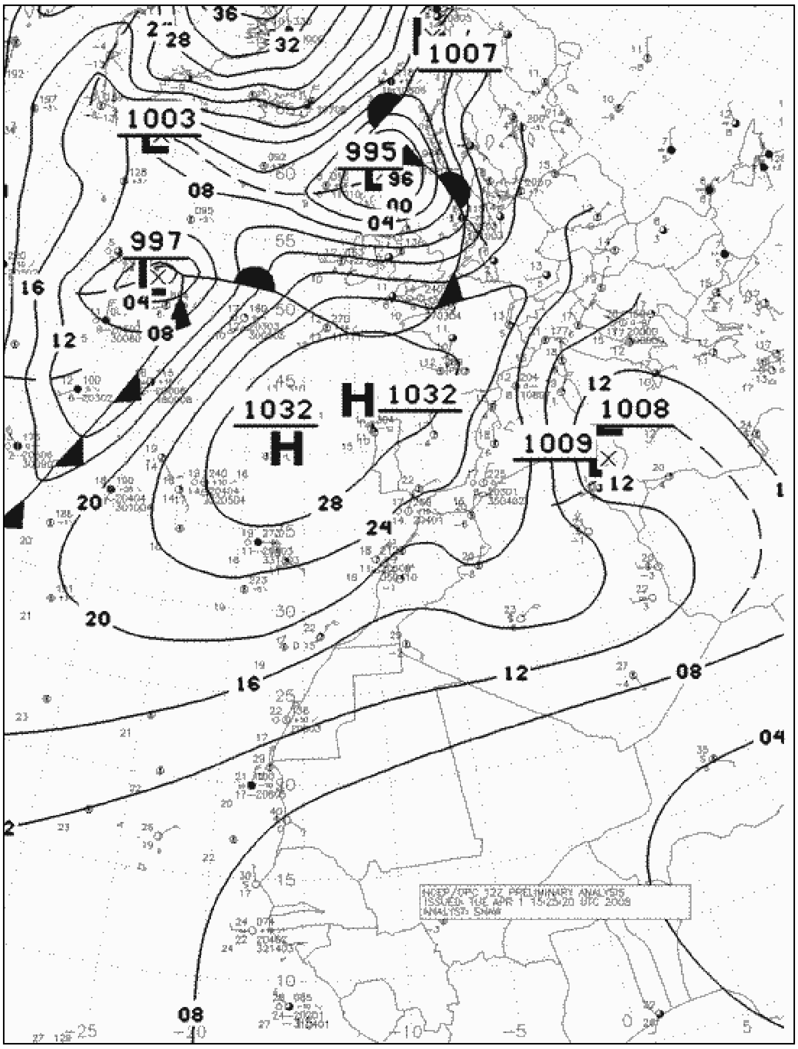


Figure 5a: Atmospheric pressure chart for the 20th January

By the evening of the 20th January a centre of low pressure over the Atlantic, to the west of southern Spain, appears to have drawn sand from the Western Sahara northwards towards the line of an advancing cold front extending out from the low pressure's centre. The plume of sand and the advancing cold front are marked on figures 5b and 5c.

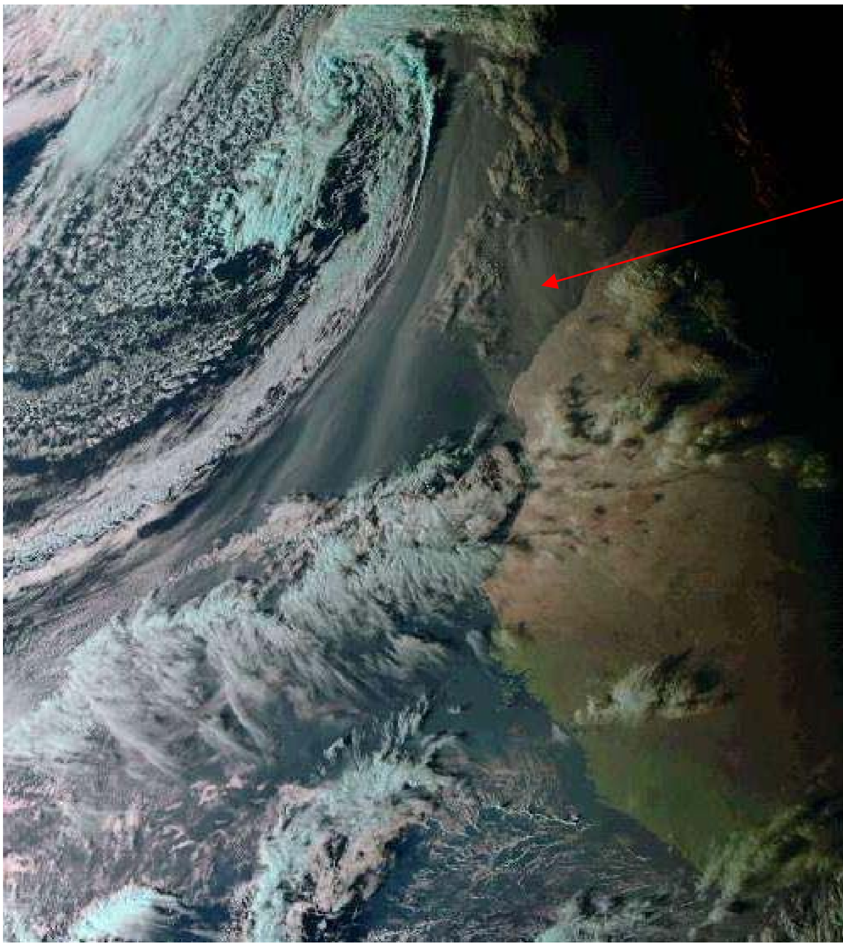


Figure 5b: Interpolated high resolution satellite image taken on the 20th January at 18 UTC

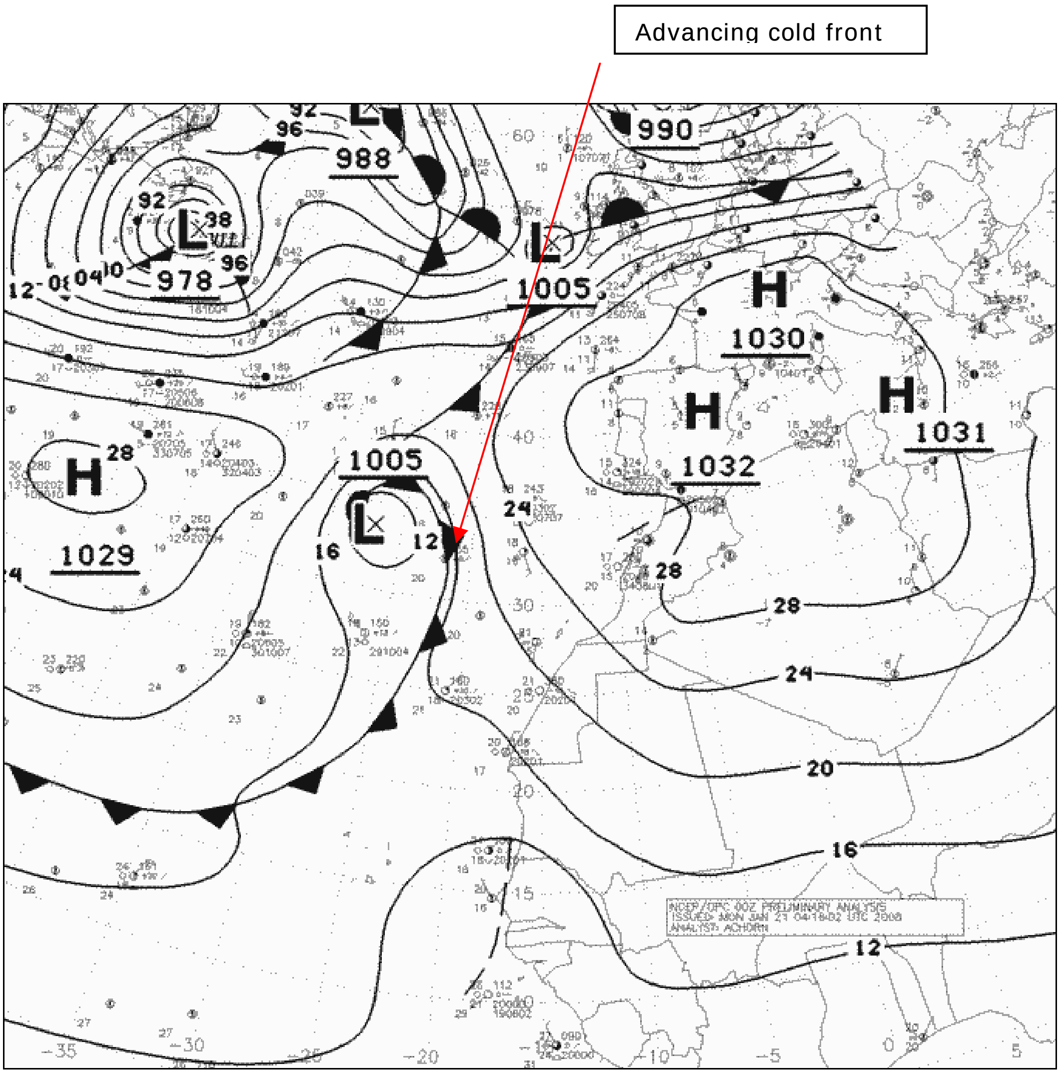
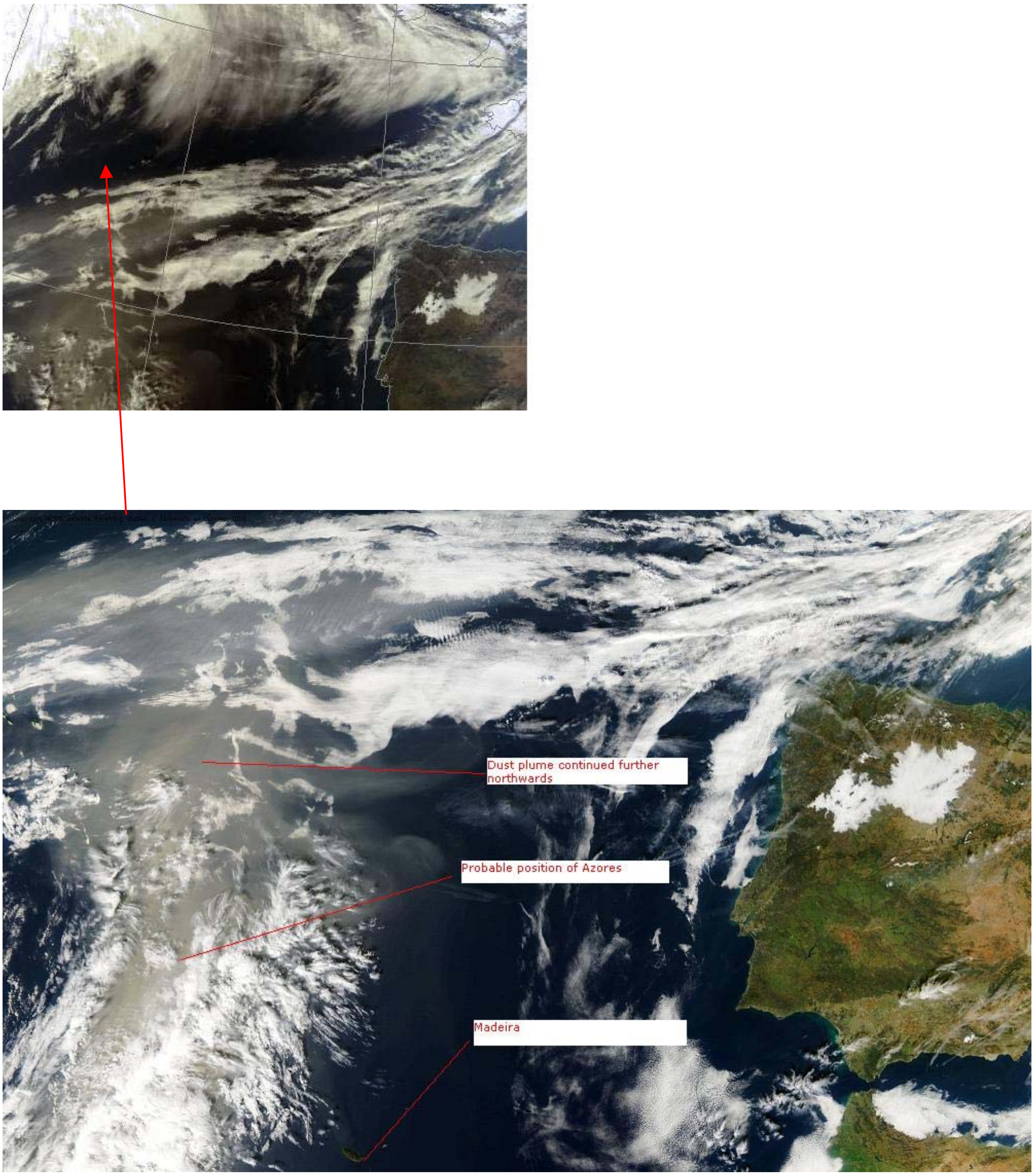


Figure 5c: Atmospheric pressure chart for the 21st January.

On the 22nd January high pressure air over Spain and an area of low pressure over the Atlantic, to the west of the UK, caused the sand laden air to travel northwards over the Azores and begin spreading eastwards on fronts associated with an area of particularly low pressure which was situated higher up in the Atlantic, to the north west of the UK. Figures 5d and 5e show the sand laden air moving northwards over the Azores and other islands located to the west of Spain. The plume appears to have begun to spread laterally at that stage. Figure 5f shows the synoptic situation on the 22nd January.



Figures 5d and 5e: high resolution satellite images taken on the 21st January.

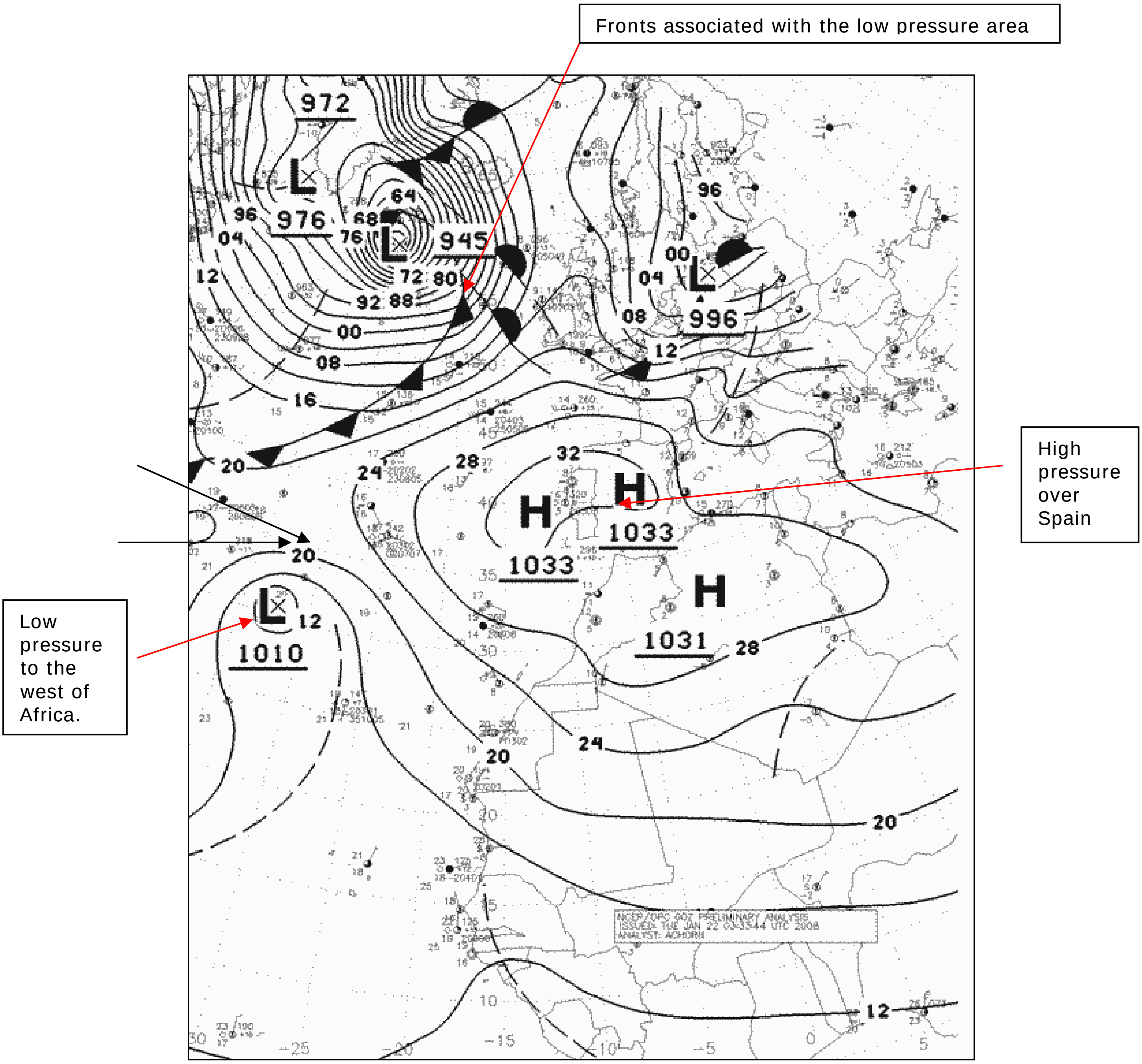


Figure 5f: Atmospheric pressure chart for the 22nd January.

Smoke drifting out over the Atlantic from fires in Guinea and the Ivory Coast were reported on the 21st January. The smoke from these fires is likely to have been drawn towards an area of low pressure over the Atlantic, to the west of Africa as labelled in figure 5f. The smoke may also depicted in figure 5g. Figure 5h shows a significant build up of cloud over the Atlantic to the south west of the UK on the 22nd January, therefore the sand laden air was under cloud cover leading up to the episode in the UK.

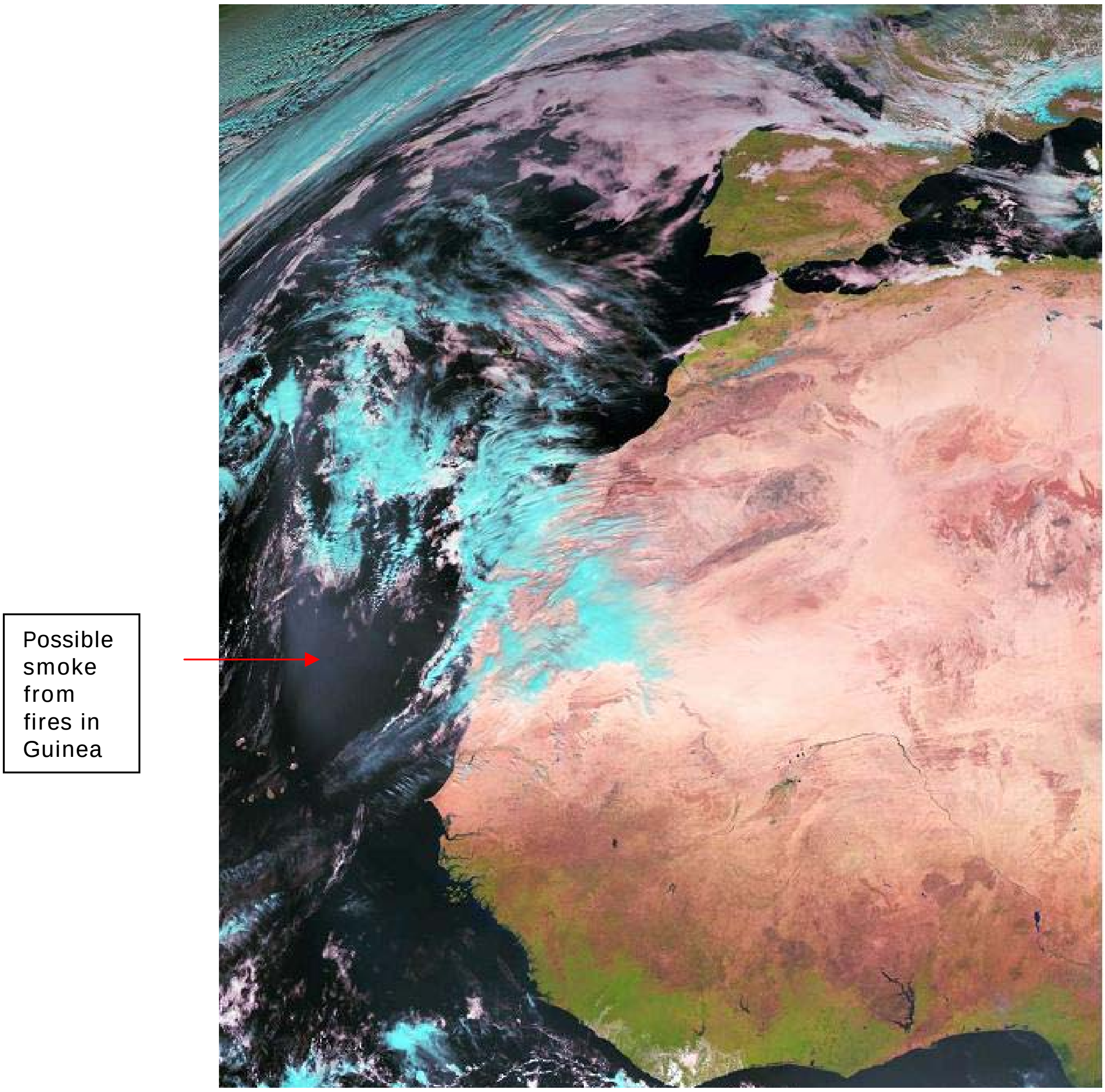


Figure 5g: Interpolated geostationary satellite image taken on 22nd January at 12 UTC

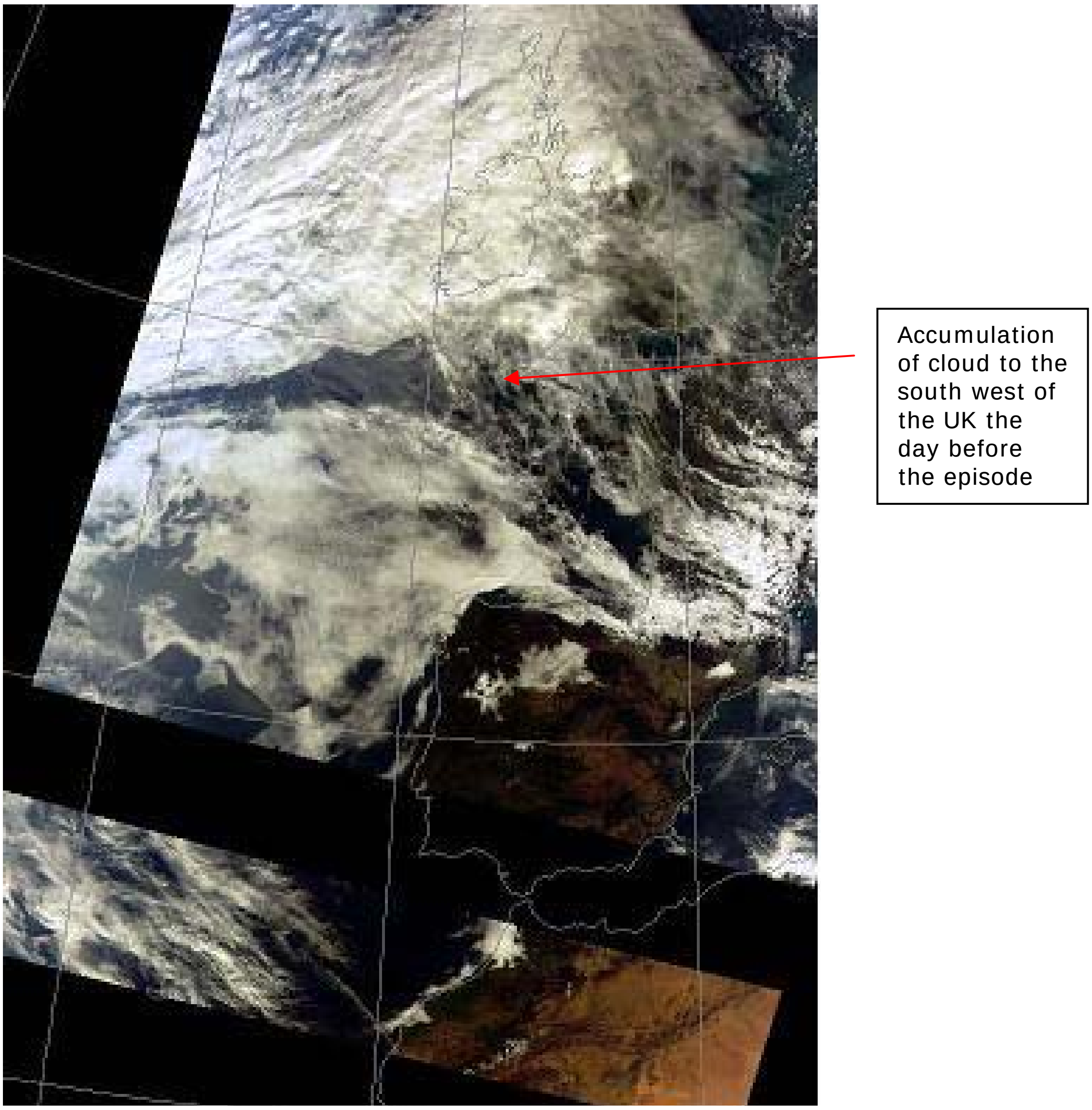


Figure 5h: High resolution satellite image taken on the 22nd January.

Figure 5j shows the synoptic situation on the first day of the UK episode. A series of fronts associated with an area of low pressure centred over the Atlantic, to the north west of the UK, were in the process of passing over. The pressure charts indicate that the sand laden air was prevented from propagation across Scotland and the north of Ireland by a cold front and was instead swept eastwards across the UK. Figure 5k shows a high resolution satellite image taken on the first day of the episode. By midday elevated PM_{10} measurements had been made at sites in the south of England and South Wales. Figure 5k shows that the UK was covered in a blanket of cloud on the 23rd January. Figure 5L shows an interpolated satellite image taken from a geo-stationary satellite at the same time on the same day. This image suggests that some of the residue from the fires in Guinea may have continued to drift further northwards and was over the Atlantic, to the east of Africa at this stage.

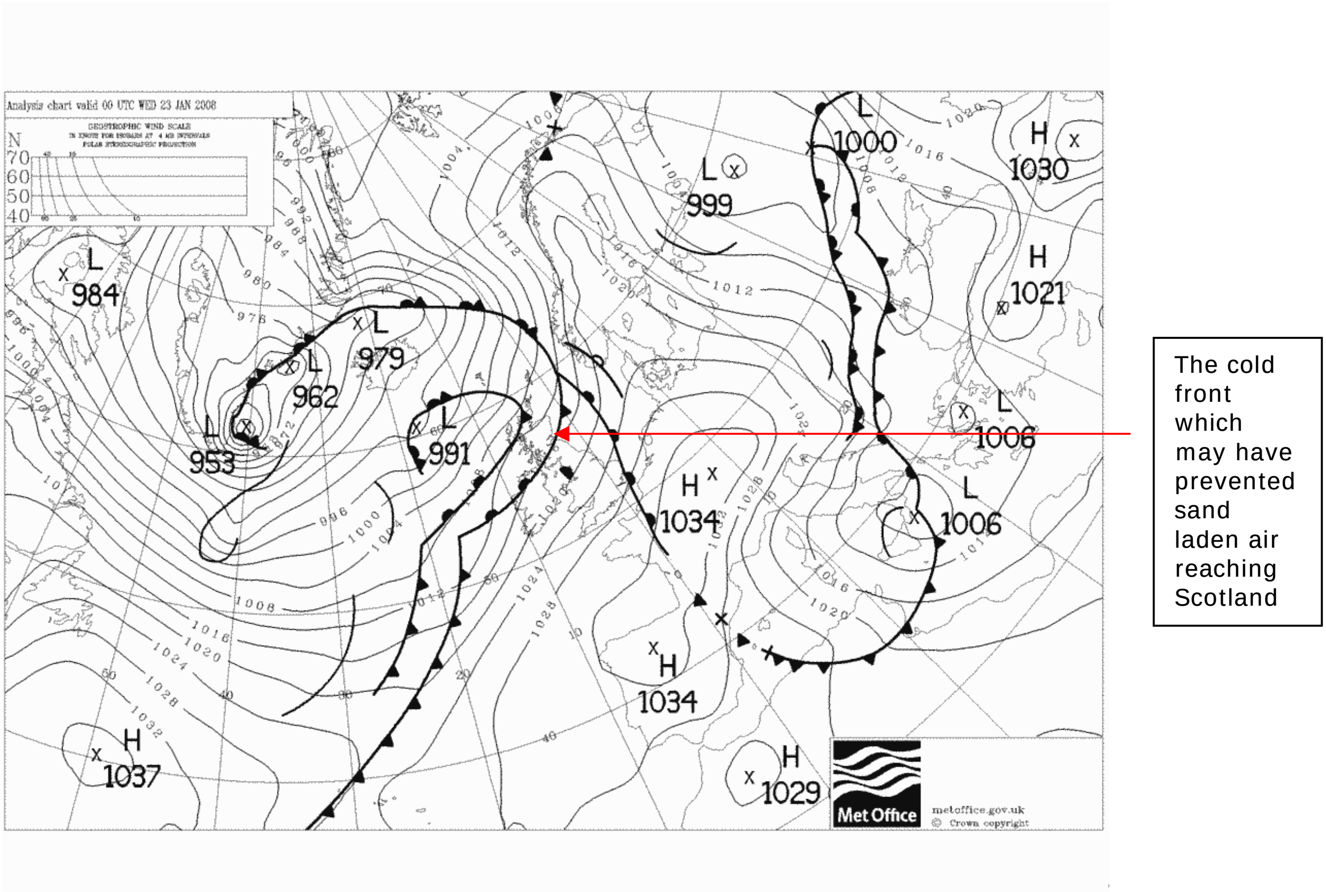


Figure 5j: Atmospheric pressure chart for the 23rd January.

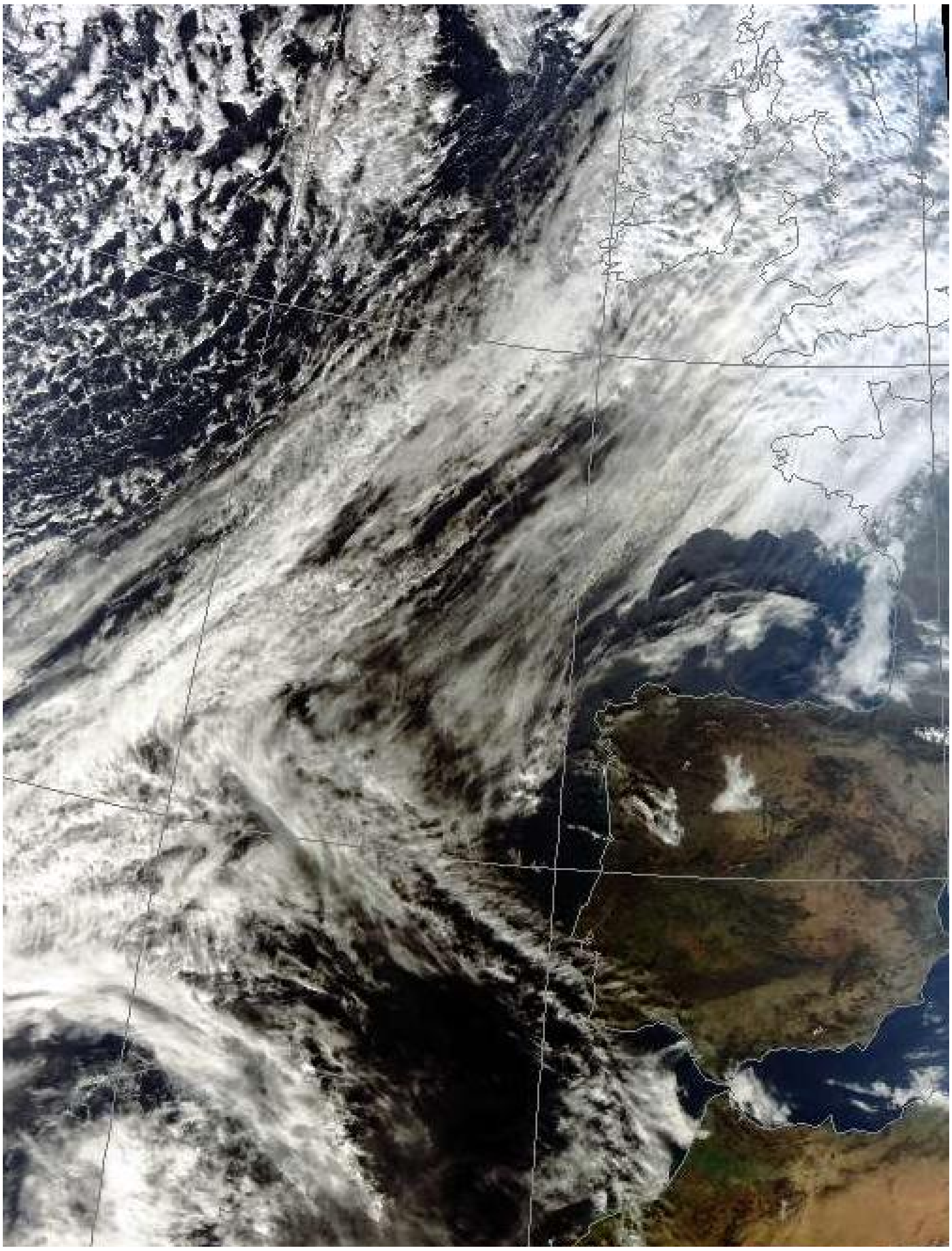


Figure 5k: High resolution satellite image taken on the 23rd January at 12 UTC.

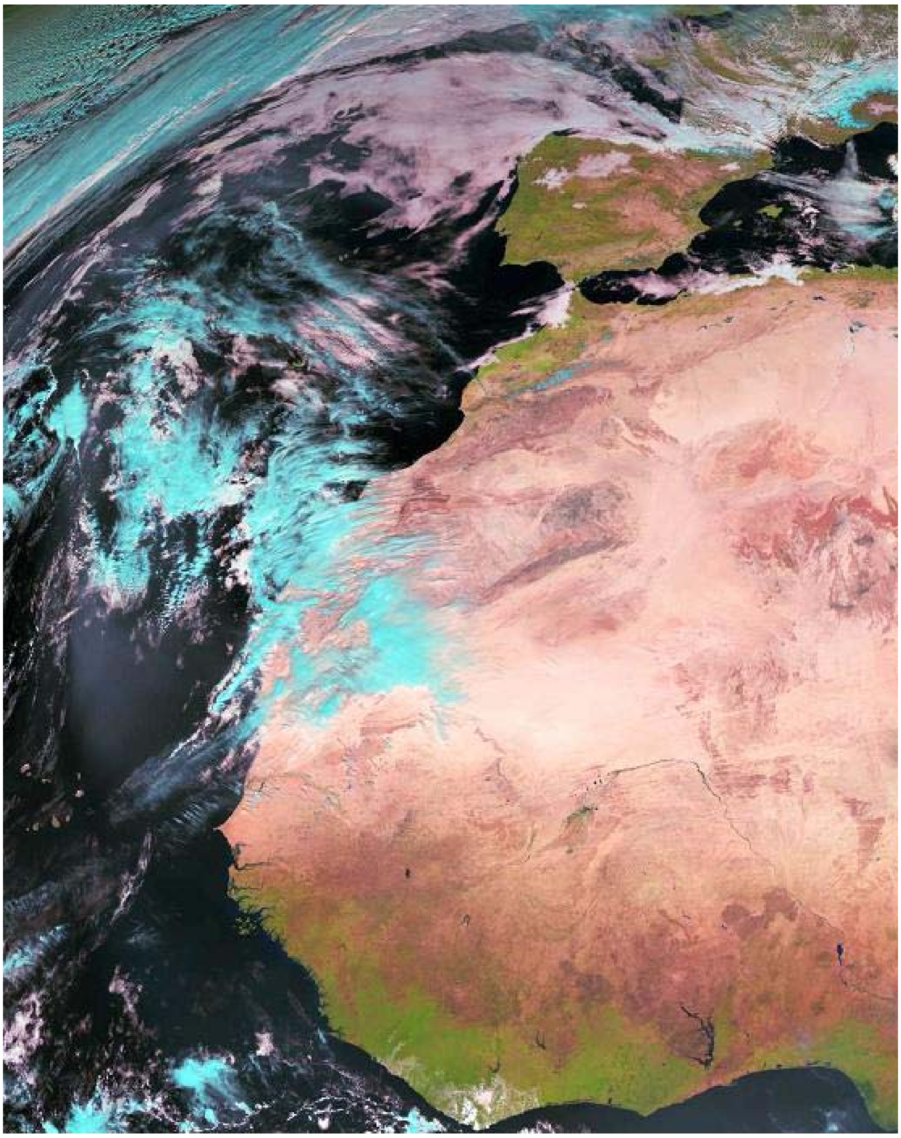


Figure 5L: Interpolated geostationary satellite image taken on 23rd January at 12 UTC

Figures 5m and 5n show that by midday on the 24th January the cold front had moved to a position encompassing mainly the south east of England. The plot shown in figure 1 confirms that the sand laden air had cleared from the UK during the morning. The air mass containing the sand then moved further eastwards and over parts of Europe.

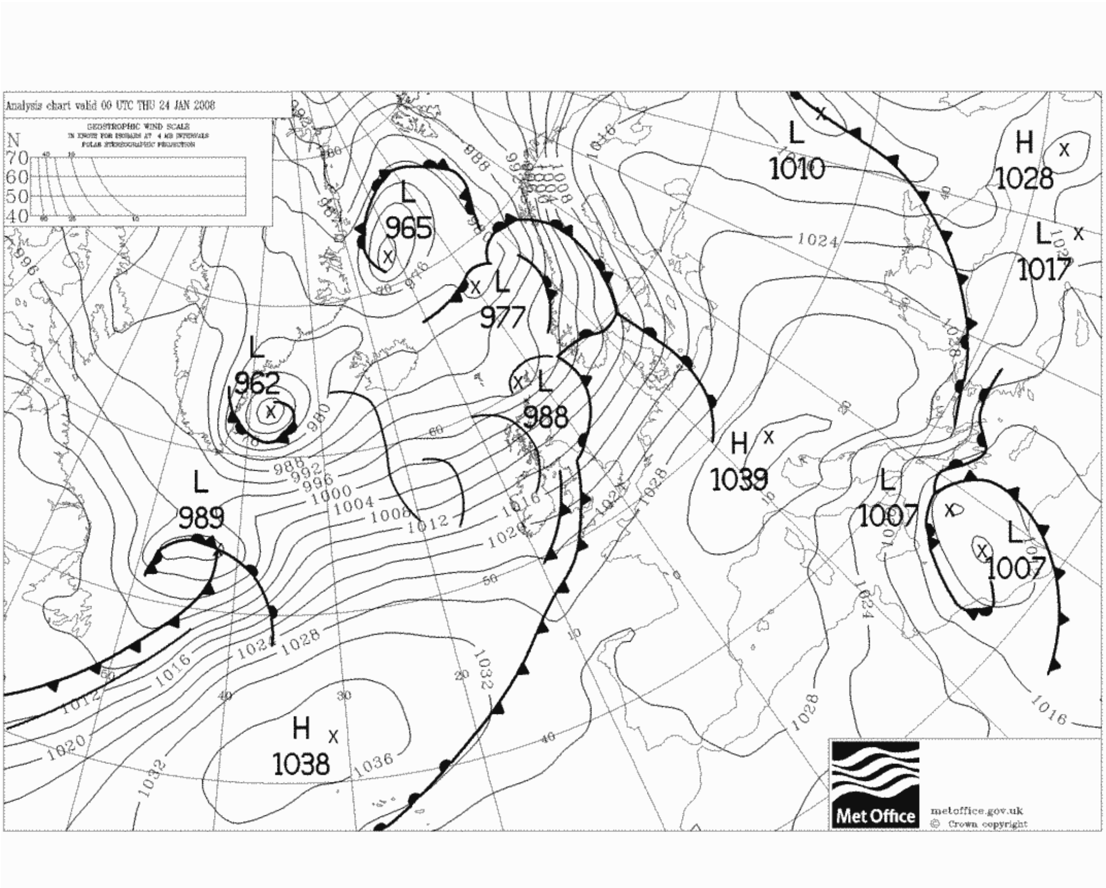


Figure 5m: Atmospheric pressure chart for the 24th January.

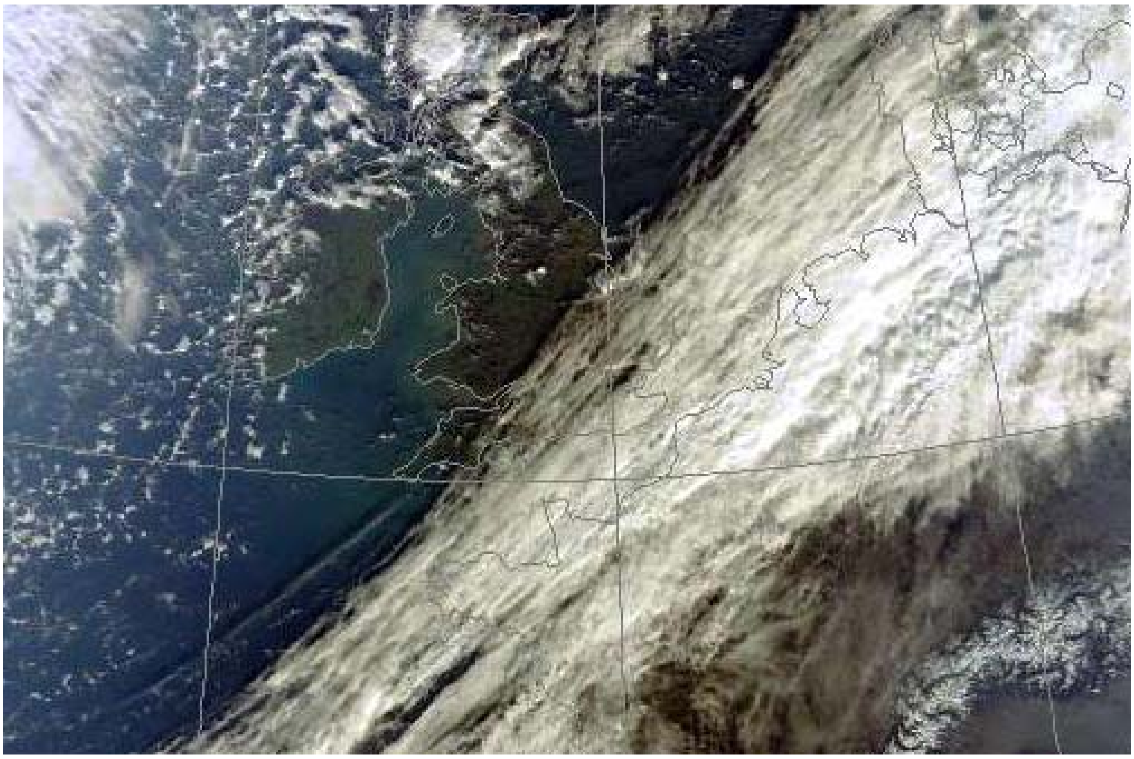


Figure 5n: High resolution satellite image taken on the 24th January.

European and worldwide particulate forecast models

The following section shows a daily account, including the figures that follow the text, of the output from two particulate models (named “NAAPS” and “Skiron”) with the result from the French “PREV'AIR” model also shown for the 24th January. A global view of the NAAPS model is shown for some of the days on the build up to the episode in the UK, from the 19th to the 21st January.

The NAAPS (Navy Aerosol Analysis and Prediction System) Global Aerosol Model is delivered by the Naval Research Laboratory in California, USA. This model is outputted in terms of the optical depth in the atmosphere of various “species” of airbourne dust. In the following figures the NAAPS forecast is broken down into suspended soils and sand (bottom left), smoke emissions (bottom right), sulphate particles as a result of long range transport of secondary pollution (top right) and the total of all these species (top left). The intensity of the species measured is mapped using colours from blue (effectively representing low concentrations of dust) to red (high concentrations).

The Skiron Dust Forecast is issued daily by the University of Athens and has been developed by their Meteorology, Atmospheric Modelling and Weather Forecasting Group. This model is “non-speciated” and shows forecasted levels of airbourne particulates at ground level over Europe and North Africa. The red/brown colours mapped effectively indicate where the dust from Africa had transported to. The Skiron Dust Forecast may have been slightly out of synchronisation, by up to 12 hours, with the NAAPS forecast.

Links to the “NAAPS” and “Skiron” forecasts can be found at:
http://wija.ija.csic.es/gt/geoamb/matpart/

The PREV'AIR system was implemented in 2003 upon an initiative by the French Ministry for Ecology and Sustainable Development (MEDD) with the aim of generating and publishing daily air quality forecasts and maps of numerical simulations on different spatial scales. This system also supplies observation maps based on measurements carried out in the French network. Particulate maps, showing reanalysed forecast concentrations with assimilated observations made in France, are shown for the 24th January and were obtained from the open access PREV'AIR website (www.prevair.org). As with the NAAPS model the intensity of the forecasted concentrations range from blue (lowest) to red (highest).

The following text refers to the figures, which have been labelled by date, that follow:

On the 19th January, the day before the report of sand issuing from the Western Sahara, both the NAAPS and Skiron forecasts showed traces of sand over the Atlantic emanating from that particular area of Africa. Interestingly the NAAPS forecast also showed smoke in the area of the reported fires in Guinea, some of which had begun to drift out over the Atlantic.

By the 20th January the concentration of airbourne sand over the Western Sahara was its greatest intensity seen leading up to the episode in the UK, as shown in the NAAPS forecast. Some of the sand laden air appears to have begun to drift out north westwards over the Atlantic at this stage. Smoke from the fires in Guinea were modelled to have not dispersed significantly from the previous day.

Two days before the UK episode, the 21st January, further northerly propagation of the sand laden air occurred, with the highest intensity of particles measured over the Atlantic, just to the north of the West Saharan coast. Again the smoke from the fires to the south had remained relatively stationary according to the models. Later NAAPS forecasts for the smoke from the fires, although not shown pictorially in this report, indicated that the majority of the smoke did not drift significantly from its origin up to the end of the UK episode.

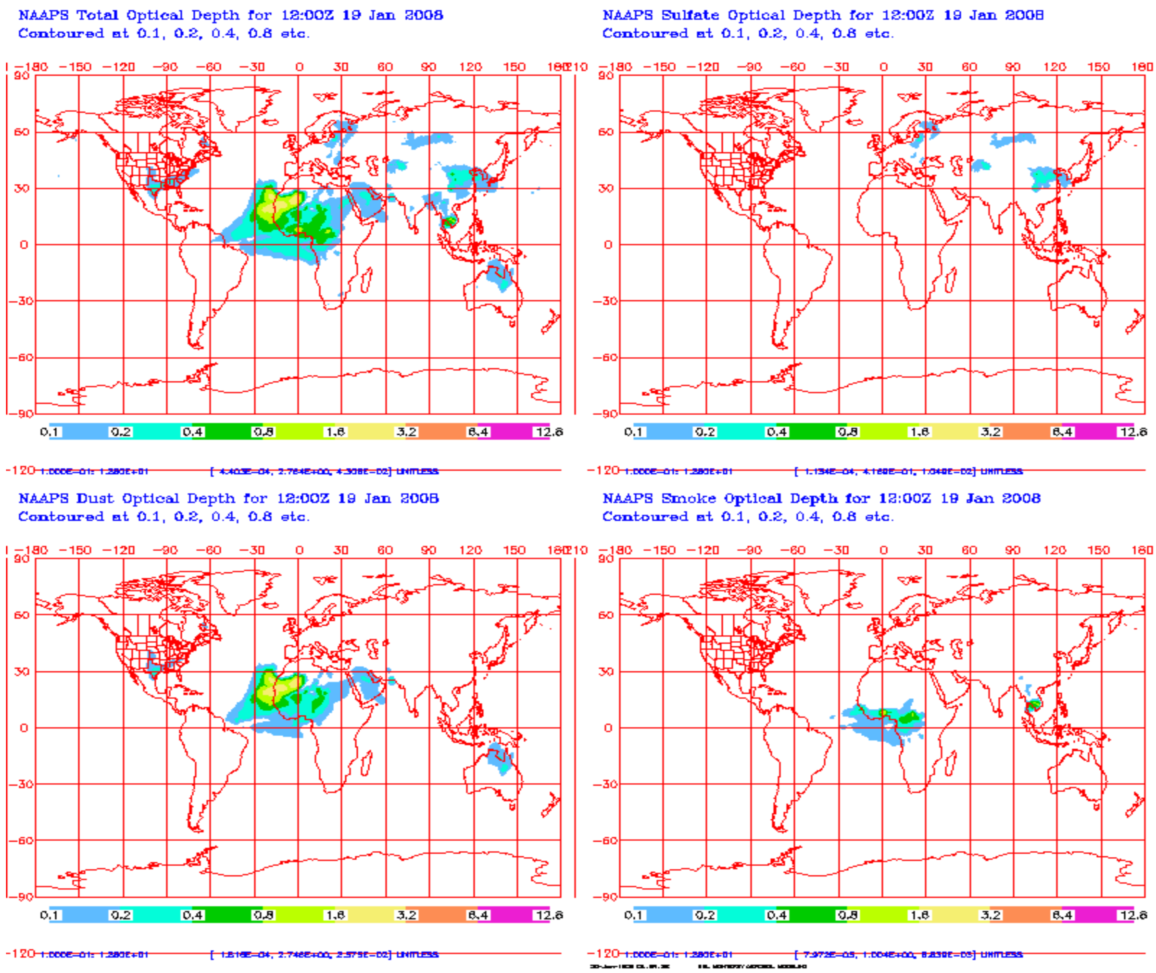
On the 22nd January, the day before the onset of the UK episode, both the Skiron and NAAPS models showed the sand laden air moving north eastwards towards the UK. The Skiron model forecasted ground level concentrations of particles at about 30 ug/m^3 at the head of the air stream.

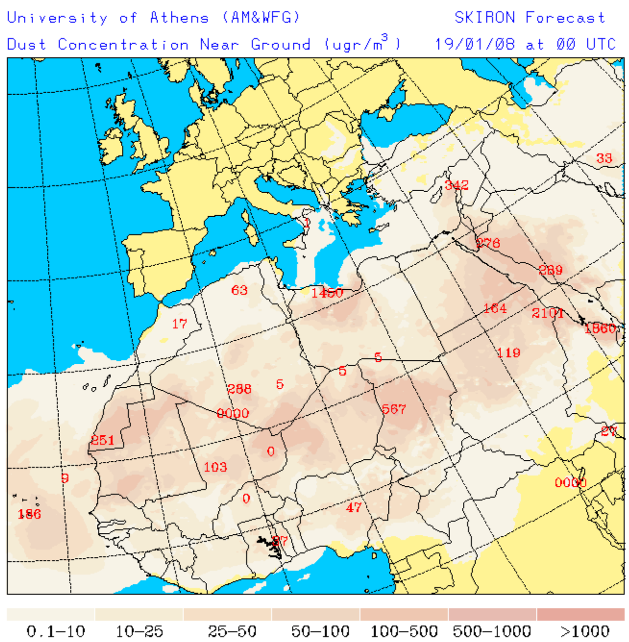
For the first day of the UK episode, the 23rd January, both models had successfully predicted the Saharan sand reaching the UK. The regional distribution of the sand laden air over the UK was forecasted with a fair degree of accuracy by the NAAPS model. The Skiron model, which may have been 12 hours out of phase with the other models, had accurately forecasted the areas of the UK which had been affected, at 0 UTC on the 24th. The NAAPS model result for the area of Africa on the 23rd January indicated that the smoke and debris from the fires in Guinea had remained along and just off the west coast of Africa, below the latitude of the Western Sahara.

The clearance of the sand laden air in a south–easterly direction was again forecasted by the NAAPS model for the second and last day of the episode. The PREV'AIR model also indicated that MODERATE or HIGH levels of PM_{10} would continue to be measured in the UK on the 24th January.

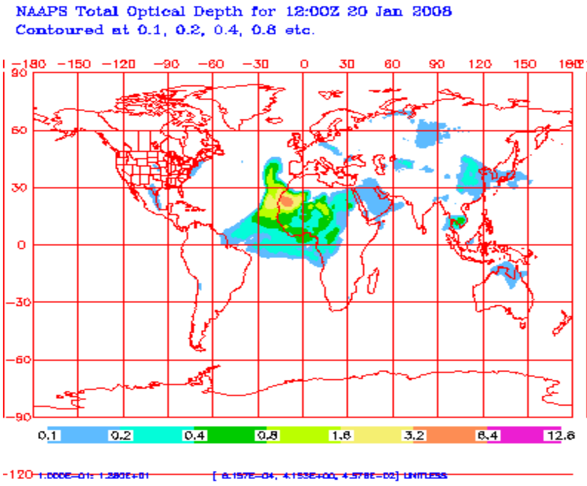
The models agreed that, on the 25th January, the sand laden air stream had moved away from the UK and had subsequently propagated across Spain and continental Europe in a north easterly orientation.

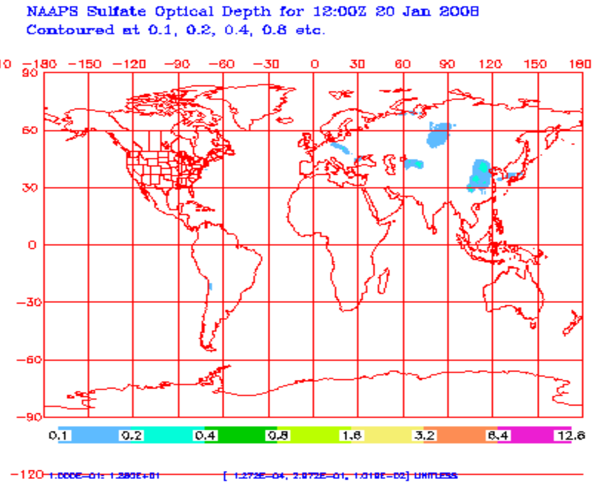
Dust model forecasts for the 19th January 2008.

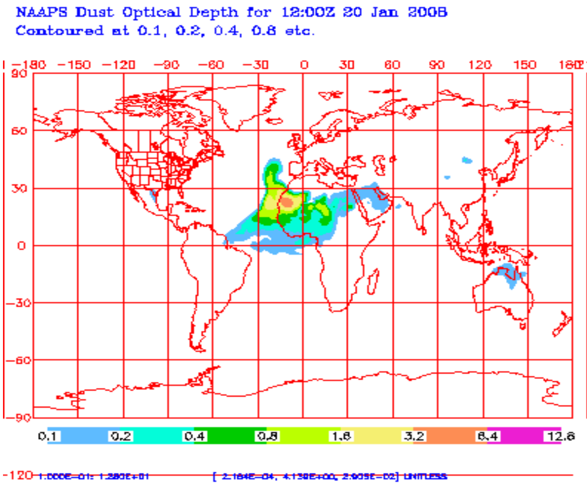


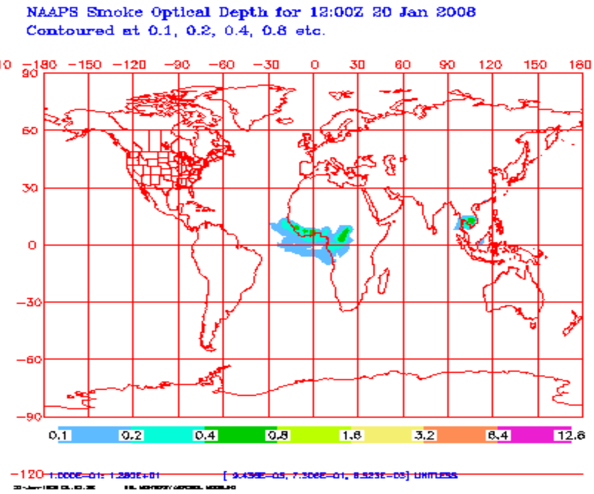


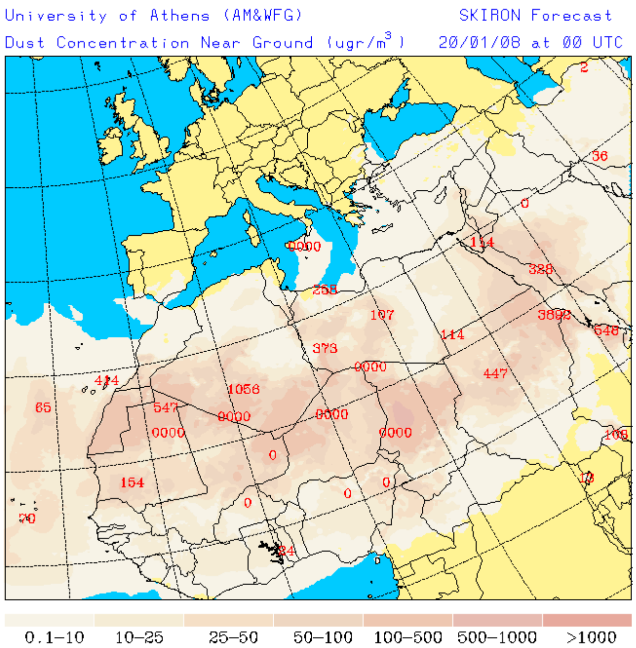
Dust model forecasts for the 20th January 2008.



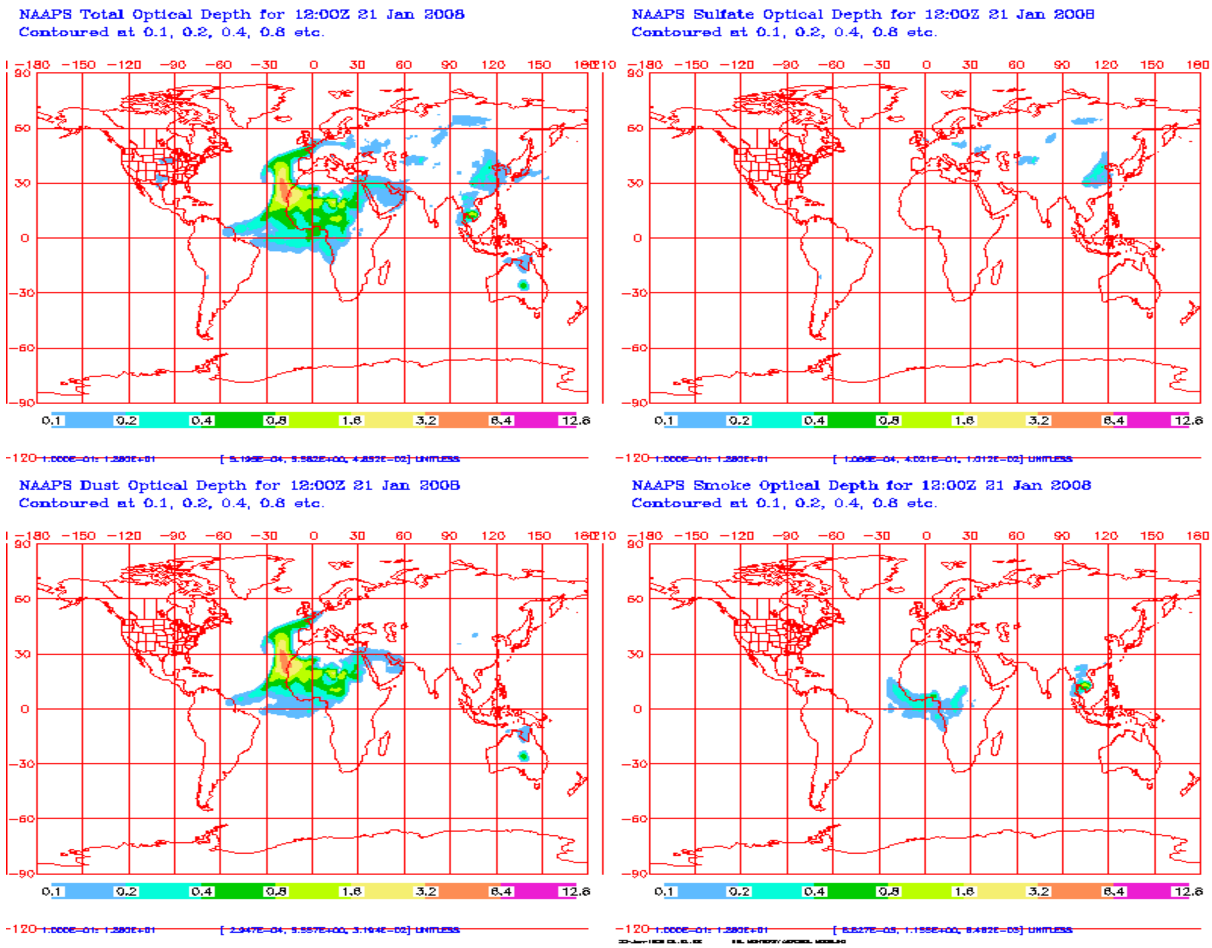


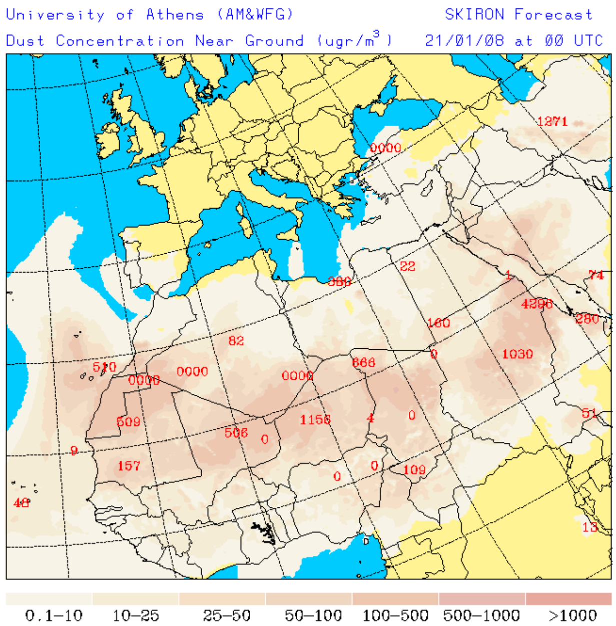




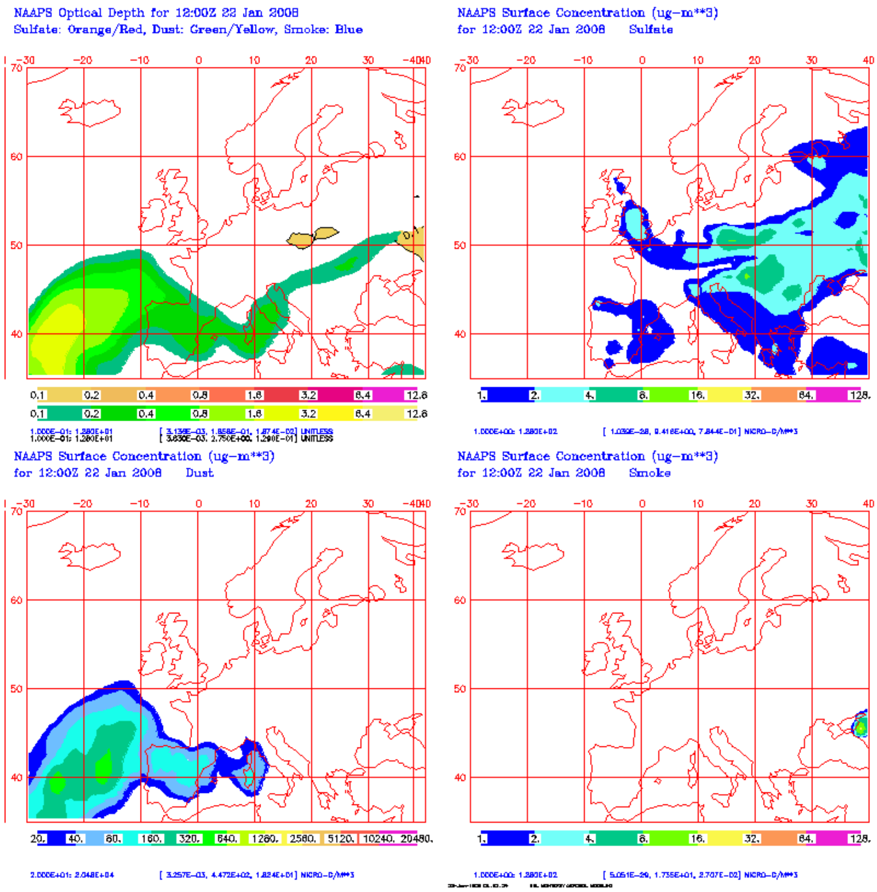


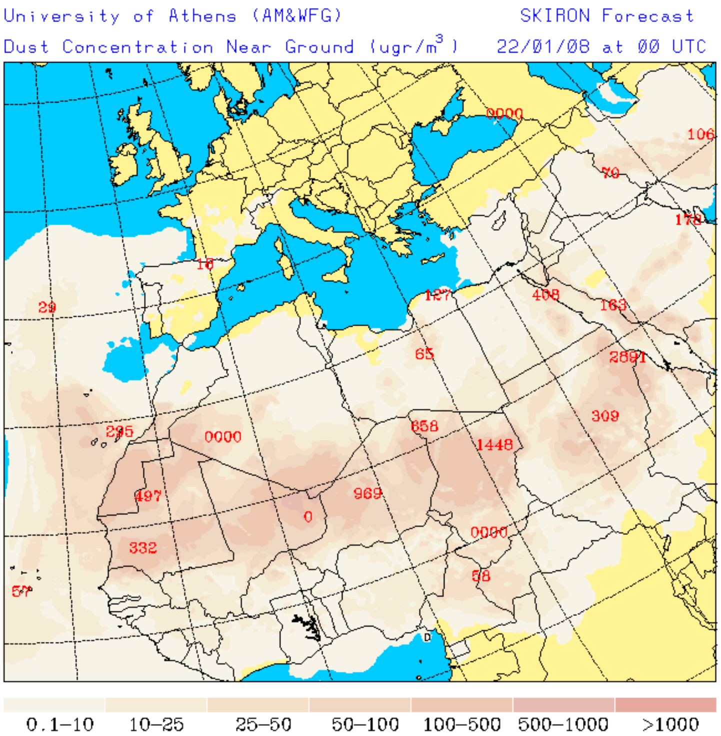
Dust model forecasts for the 21st January 2008.



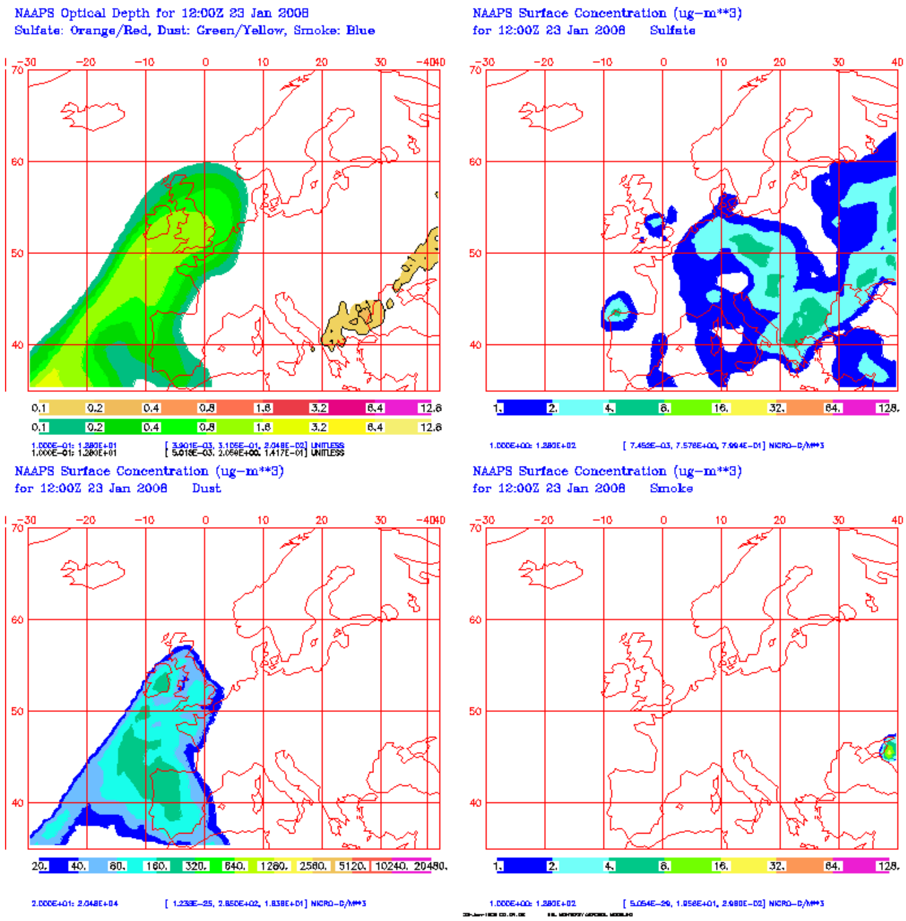


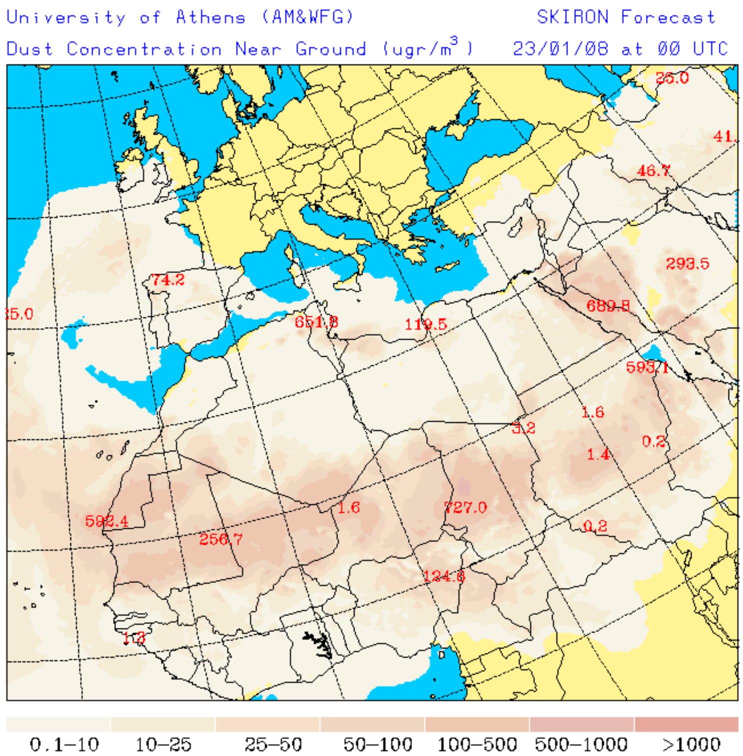
Dust model forecasts for the 22nd January 2008.



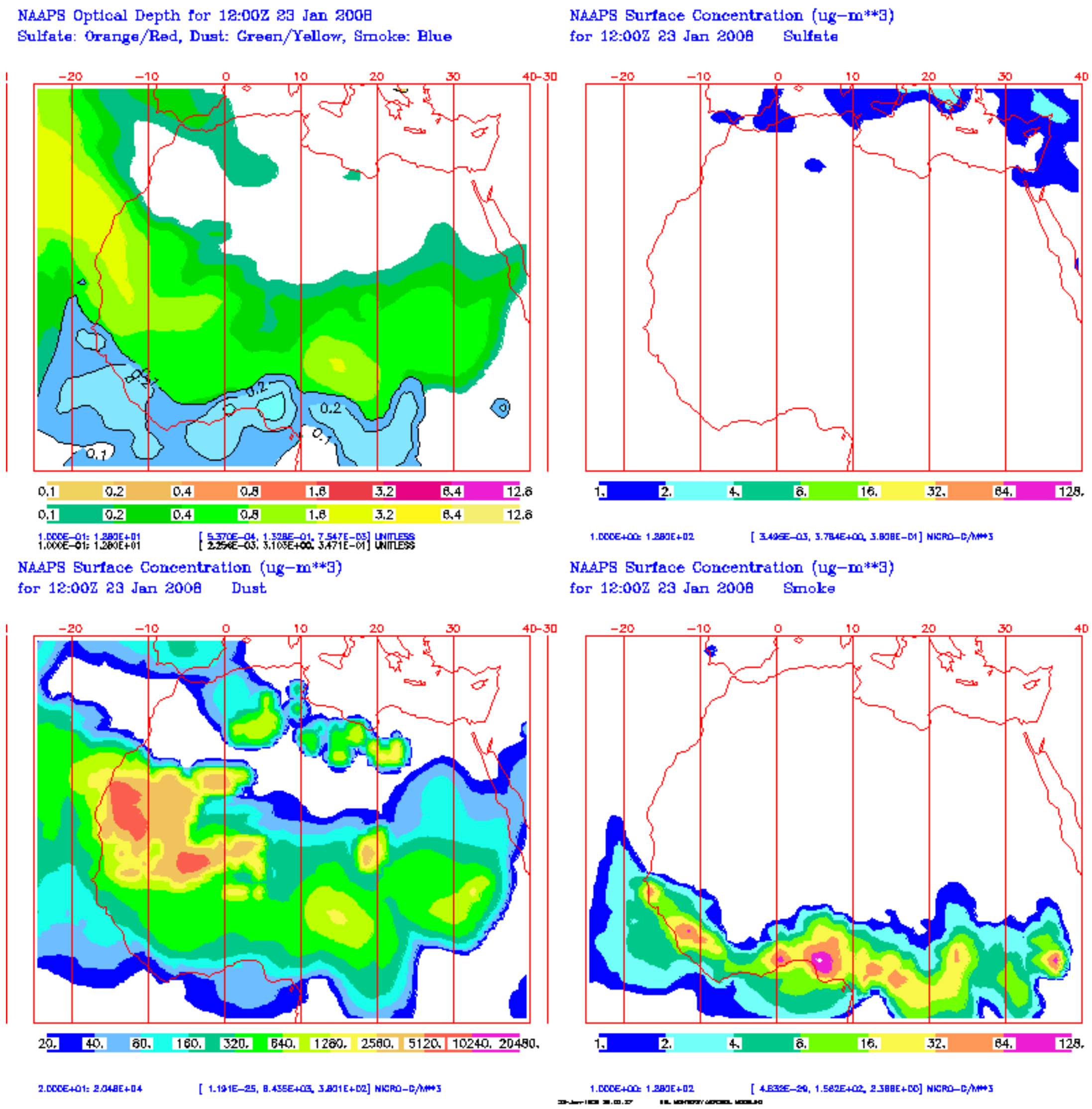


Dust model forecasts for the 23rd January 2008.

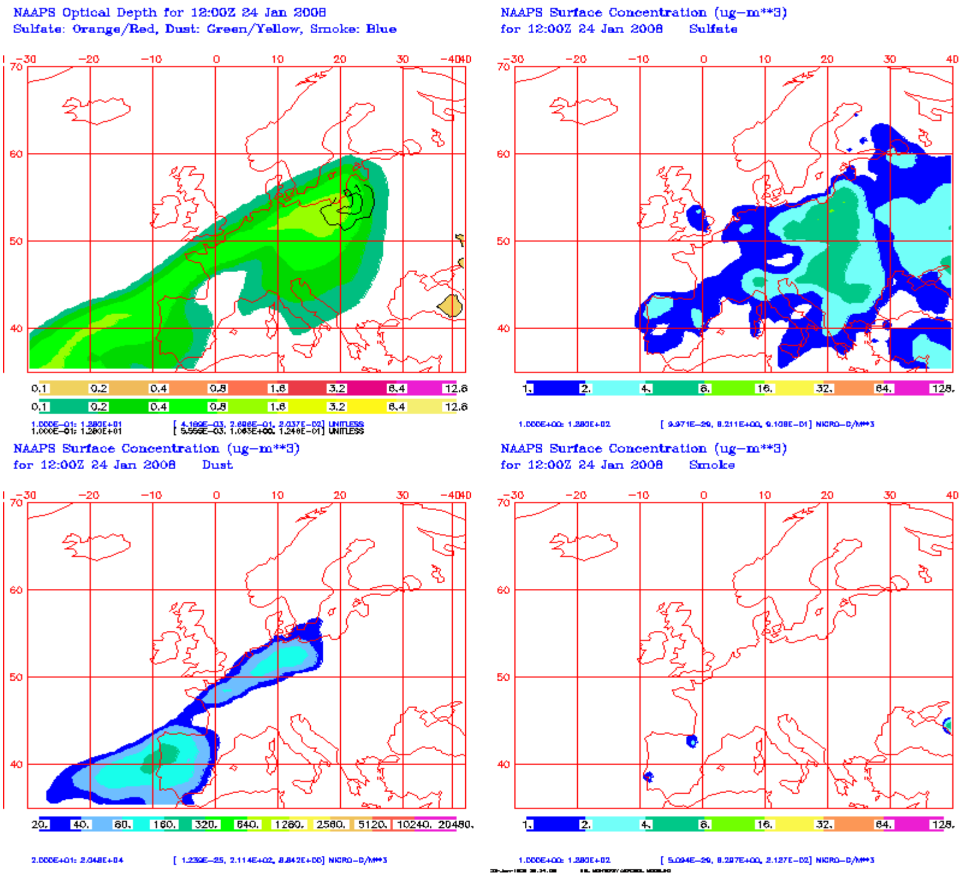


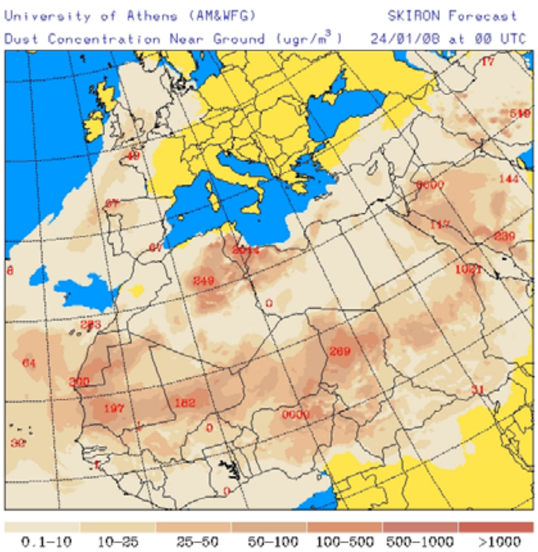


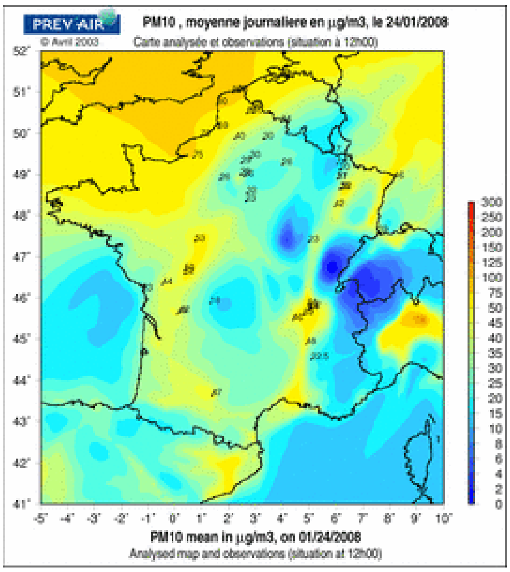
Dust model forecasts around Africa for the 23rd January 2008.



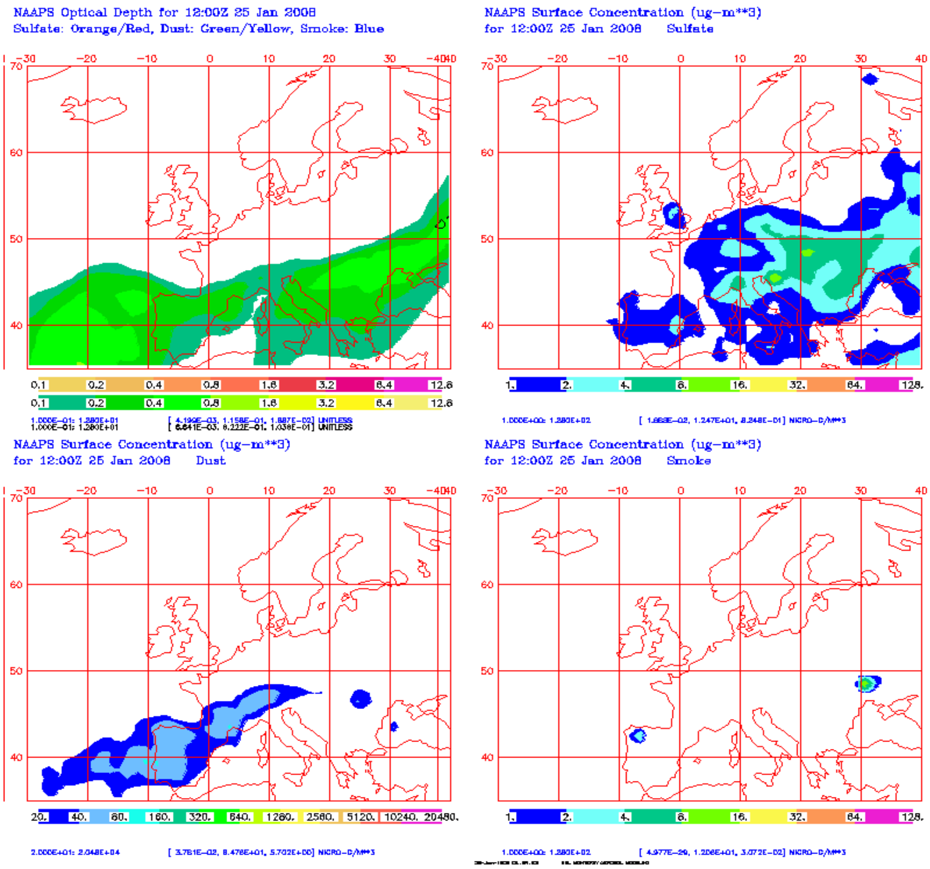
Dust model forecasts for the 24th January 2008.

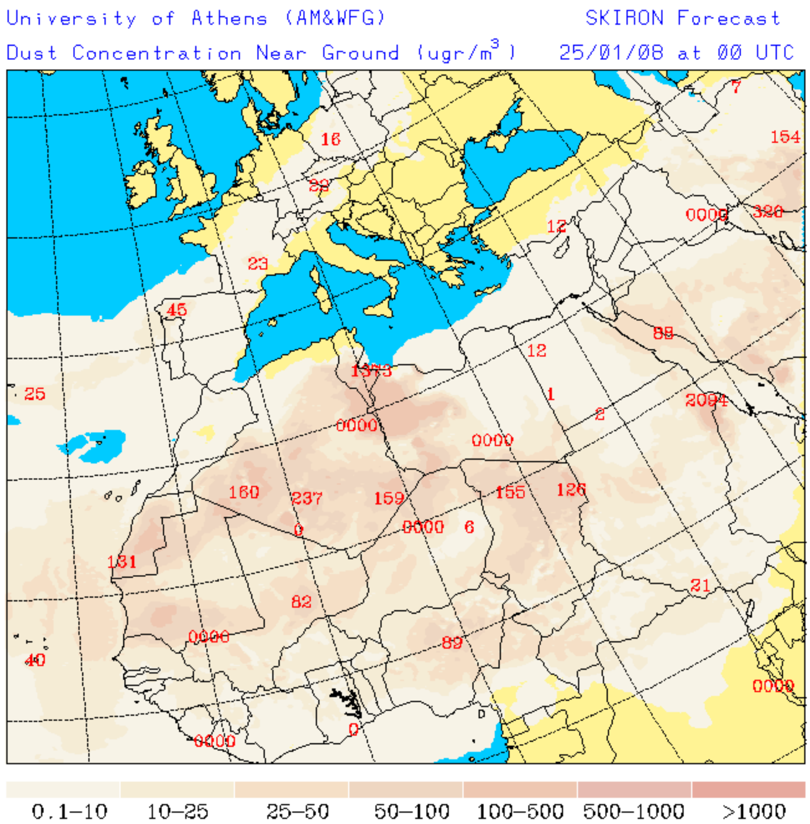






Dust model forecasts for the 25th January 2008.





CONCLUSIONS

The main features of the early January 2008 particulate episode may be summarised as follows:

- Dust which had lifted from the Western Sahara desert was transported out over the Atlantic, and eventually reached the UK on air currents between the 23rd and 24th January 2008 causing MODERATE or HIGH levels of PM_{10} to be measured at many sites across the south of England and South Wales.

- Scotland and Northern Ireland were not significantly affected by the episode due to the position of a cold front associated with an area of low pressure air which had spread over the UK from the north west.

- Following the two day episode in the UK much of continental Europe received the dust laden air stream.

Acknowledgements

Thanks to the Met Office for supplying weather charts to cover the period of the pollution episode. Thanks to NEODAAS/University of Dundee in Scotland (http://www.sat.dundee.ac.uk) and NASA/GSFC MODIS Rapid Response (http://modis.gsfc.nasa.gov), for allowing publication of the satellite images shown in this report. Thanks to the PREV'AIR system (http://www.prevair.org/en/index.php) for allowing publication of the particulate maps found in this report and to wikipedia.org for allowing the use of a copyright-free image available on their website. Thanks to the CSIC Database (http://wija.ija.csic.es/gt/geoamb/matpart/) for allowing publication of particulate maps generated from the NAAPS and SKIRON models which have been compiled on their website. For the NAAPS model acknowledgements go to the Naval Research Laboratory from the Marine Meteorology Division, Monterey, Ca.. For the SKIRON model acknowledgements go to the Atmospheric Modeling and Weather Forecasting Group (AM&WFG) from the division of Applied Physics, School of Physics of the University of Athens.
Thanks also to Slough Borough Council for allowing the use of their air quality monitoring data used for the particulate size ratio analysis within this report.

APPENDIX – UK AIR POLLUTION INDEX

Old Banding	Index	Ozone 8-hourly / Hourly mean		Nitrogen Dioxide Hourly Mean		Sulphur Dioxide 15-Minute Mean		Carbon Monoxide 8-Hour Mean		PM_{10} Particles 24-Hour Mean
		μgm^{-3}	ppb	μgm^{-3}	ppb	μgm^{-3}	ppb	mgm^{-3}	ppm	gravimetric μgm^{-3}
LOW										
	1	0-32	0-16	0-95	0-49	0-88	0-32	0-3.8	0.0-3.2	0-21
	2	33-66	17-32	96-190	50-99	89-176	33-66	3.9-7.6	3.3-6.6	22-42
	3	67-99	33-49	191-286	100-149	177-265	67-99	7.7-11.5	6.7-9.9	43-64
MODERATE										
	4	100-126	50-62	287-381	150-199	266-354	100-132	11.6-13.4	10.0-11.5	65-74
	5	127-152	63-76	382–477	200-249	355-442	133-166	13.5-15.4	11.6-13.2	75-86
	6	153-179	77-89	478-572	250-299	443-531	167-199	15.5-17.3	13.3-14.9	87-96
HIGH										
	7	180-239	90-119	573-635	300-332	532-708	200-266	17.4-19.2	15.0-16.5	97-107
	8	240-299	120-149	636-700	333-366	709-886	267-332	19.3-21.2	16.6-18.2	108-118
	9	300-359	150-179	701-763	367-399	887-1063	333-399	21.3-23.1	18.3-19.9	119-129
VERY HIGH										
	10	$\geq$ 360 μgm^{-3}	$\geq$ 180 ppb	$\geq$ 764 μgm^{-3}	$\geq$ 400 ppb	$\geq$1064 μgm^{-3}	$\geq$ 400 ppb	$\geq$ 23.2 mgm^{-3}	$\geq$ 20 ppm	$\geq$ 130 μgm^{-3}