Air Pollution Forecasting: A UK Particulate Episode from 7th May to 12th May 2006

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SUMMARY

Over the period Sunday 7th May to Friday 12th May 2006 seven sites in the UK Automatic Urban and Rural monitoring network (AURN) measured levels of PM_{10} particulate matter at air pollution index 6 (MODERATE) or above, and four of these sites also went on to record HIGH pollution at index 7 or more. Over the same period a further twelve monitoring sites recorded MODERATE PM_{10} air pollution at index 4 or 5.

The cause of this PM_{10} particulate episode was very likely to have been agricultural fires in western Russia, possibly combined with some secondary particulate pollution associated with the easterly air trajectories from Europe. Pollen counts were also reported as high at the time but the particles are likely to have been too large to be recorded in a PM_{10} instrument which was later verified by optical analysis of samples collected over that period.

Of the seven sites measuring PM_{10} at index 6 or above, three were located in Scotland, three in the north east of England and one in the central north of England. The increase in pollution was first detected at Aberdeen and then moved south across the UK.

A number of these sites measured MODERATE or HIGH levels as a result of local pollution sources combined with the additional long-range transport component. However, of the nineteen sites measuring PM_{10} air pollution in the MODERATE or HIGH bands, we believe that 13 of these were predominantly due to the particulates transported to the UK on the easterly air currents. Eight of these sites were urban, two urban industrial, two roadside and one suburban.

The Netcen air quality forecasting team identified the potential of the smoke from the Russian fires to affect the UK several days before the episode. On Friday 5th May an email from the duty forecaster alerted Defra, the Devolved Administrations and other UK air quality experts to the situation.

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 and subsequently.
  - results of an analysis of samples collected over that period using x-ray fluorescence spectroscopy, optical microscopy and scanning electron microscopy / energy dispersive x-ray analysis.
- Track and understand how the pollution spread across the UK by examination of satellite images 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.

Figures 1a and 1b show hourly-averaged PM_{10} measurements from a selection of northern and southern UK sites. Figure 1 shows that the episode was first detected in Aberdeen on the 7^{th} and then progressed southwards.

Site name	Site designation	Site location	Significant local pollution contribution?	Maximum Air Pollution Index on each day					
				Sun 7th	Mon 8th	Tue 9th	Wed 10th	Thu 11th	Fri 12th
Aberdeen	Urban background	Scotland	No	6	6	4	-	-	-
Edinburgh St Leonards	Urban background	Scotland	No	-	5	5	-	-	-
Grangemouth	Urban industrial	Scotland	No	-	6	5	-	-	-
Glasgow Kerbside	Roadside	Scotland	Yes	-	7	7	4	-	4
Glasgow Centre	Urban centre	Scotland	No	-	5	4	-	-	-
Stockton on Tees	Roadside	NE	No	-	6	5	-	-	-
Scunthorpe Town	Urban industrial	NE	Yes	-	9	9	-	-	-
Middlesborough	Urban industrial	NE	No	-	7	7	4	-	-
Redcar	Suburban	NE	No	-	5	5	-	-	-
Newcastle Centre	Urban centre	NE	No	-	5	4	-	-	-
Hull Freetown	Urban centre	NE	No	-	5	5	-	-	-
Bradford Centre	Urban centre	C North	Yes	-	7	7	-	-	4
Sheffield Centre	Urban centre	C North	No	-	5	4	-	-	-
Leeds Centre	Urban centre	C North	No	-	4	4	-	-	-
Liverpool Speke	Urban background	NW	Yes	-	-	5	5	-	-
Bury Roadside	Roadside	NW	No	-	4	5	-	-	-
Manchester Piccadilly	Urban centre	NW	No	-	4	4	4	-	-
Wigan Centre	Urban background	NW	No	-	4	4	-	-	-
Port Talbot	Urban background	Wales	Yes	-	-	-	4	5	4
Lon. Marylebone Road	Roadside	London	Yes	-	-	-	-	-	4

Table 1: The May 2006 PM_{10} episode Quantified

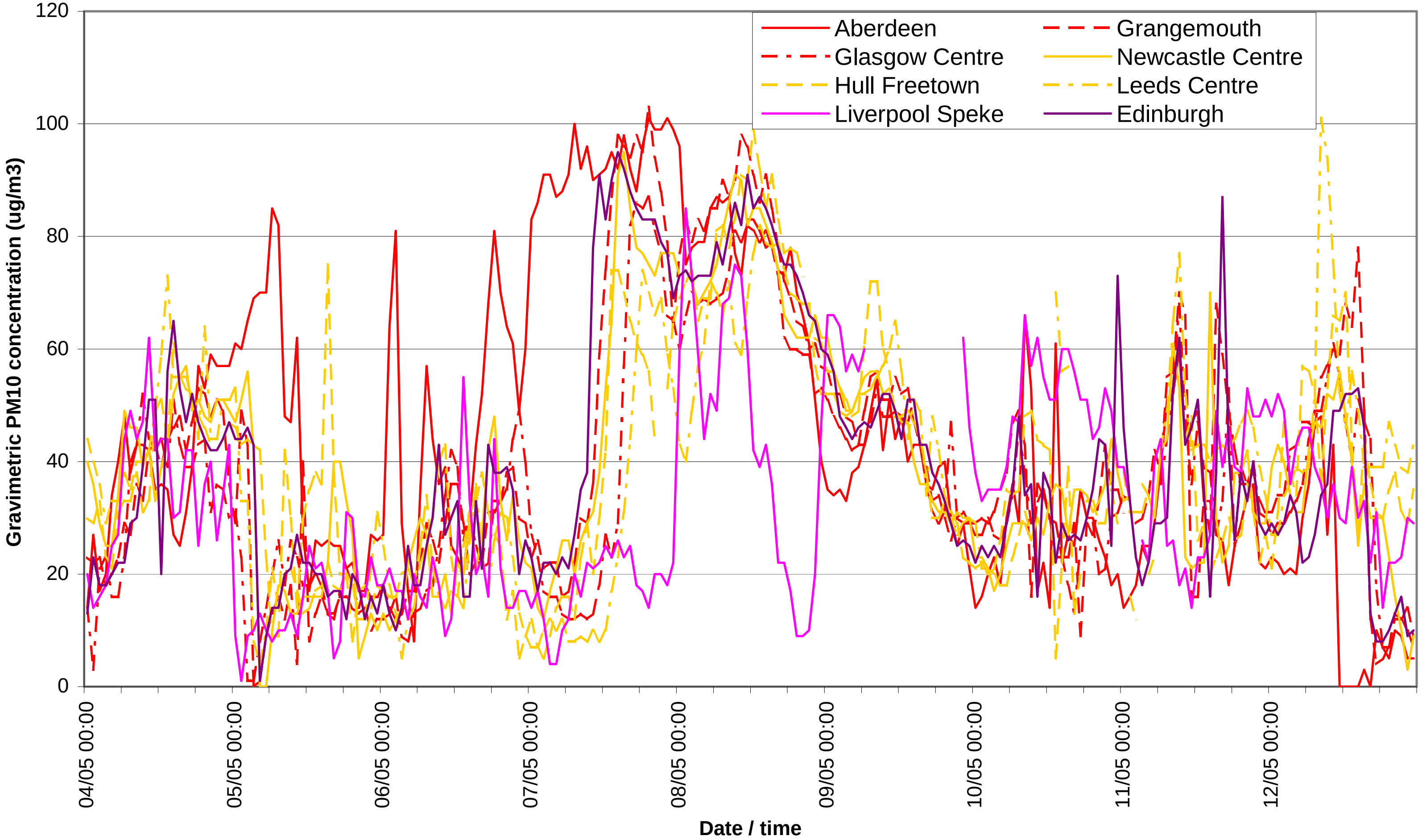


Figure 1a: Hourly mean PM_{10} measurements at selected northern sites in the UK, May 4th to 12th 2006

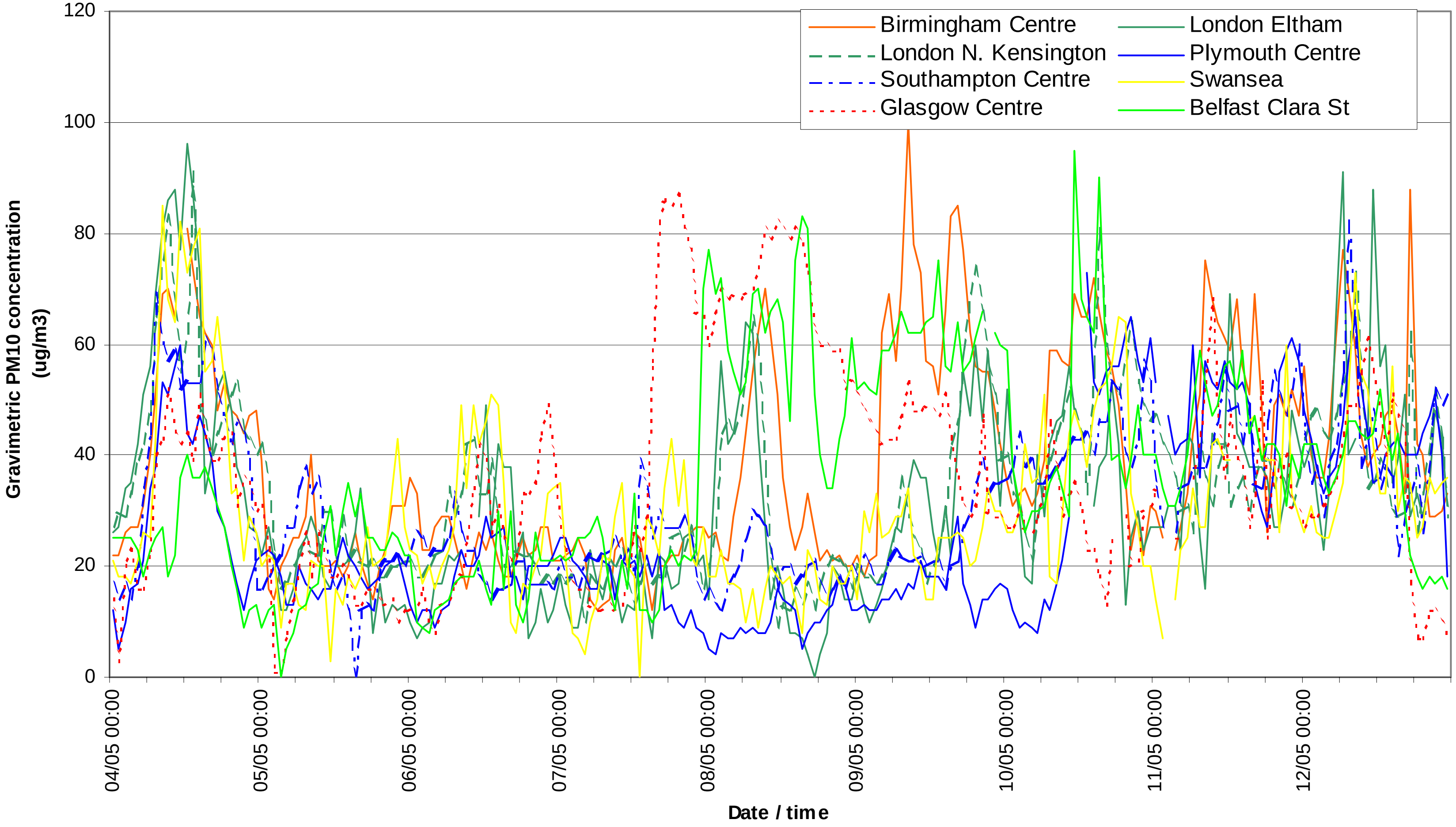


Figure 1b: Hourly mean PM_{10} measurements at selected southern sites (with Glasgow and Belfast for comparison) for May 4th to 12th 2006

Figures 2a to 2c show the additional daily averaged contributions of particulate PM_{10} above an estimated UK background over the period 6th to 12th May at Edinburgh, Belfast and Newcastle. A UK background level was estimated by Netcen on these days using data from reference sites unaffected by the particulate episode (Plymouth centre from the 6th to the 10th at midday and Aberdeen from the 10th at midday to the 12th). The reference sites were then scaled to each modelled site individually, using a ratio based on the average of the first five days in May 2006 for both the reference and modelled sites. Unavoidable inaccuracies are seen using this model, for example additional contributions have been calculated on the 11th and 12th at Newcastle, after the effect of the plume was considered to have passed from the north of the UK. Other sources for the additional contribution on these two days cannot be discounted. Particulate levels are inherently difficult to model due to the many and varied sources of particulates in the environment. The model does show however that at the height of the plume's effect, towards the north of the UK on the 8th, an estimated 80 % of the particulate PM_{10} contributions measured at Newcastle centre and Edinburgh St Leonards were due to the particulate cloud and around a 70 % contribution for the 7th and 9th. Similar contributions were calculated for Belfast Clara Street on the 8th and 9th with very little effect on the 7th, as could be expected.

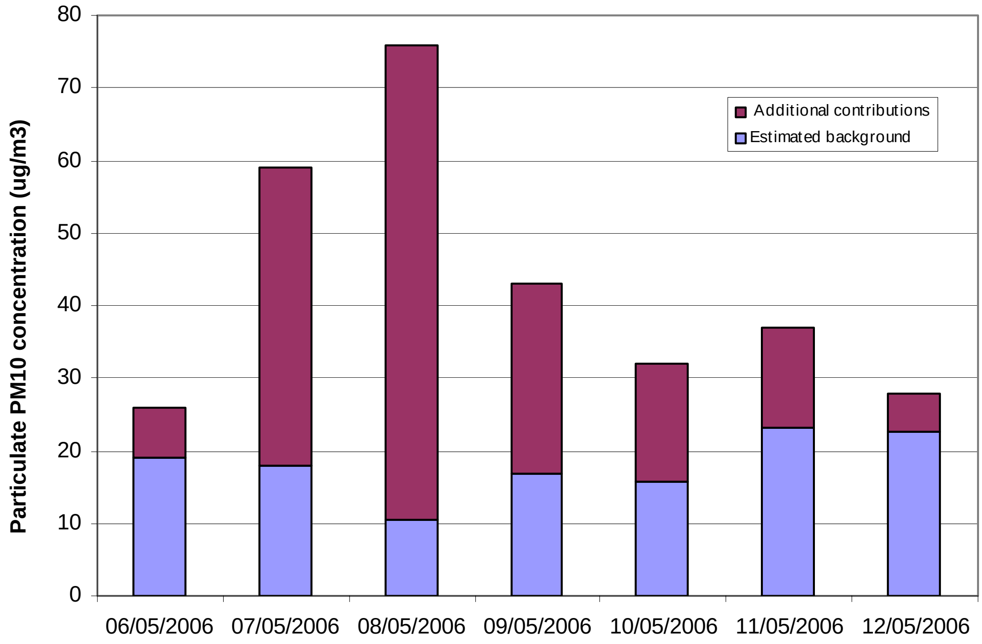


Figure 2a: Estimated additional contributions of particulate PM_{10} at Edinburgh St Leonards.

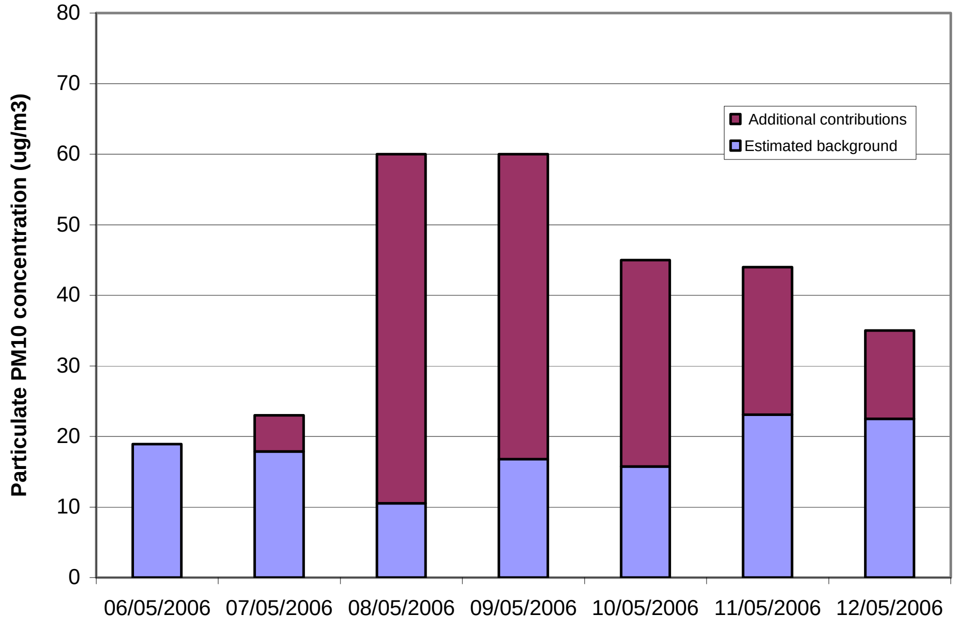


Figure 2b: Estimated additional contributions of particulate PM_{10} at Belfast Clara Street.

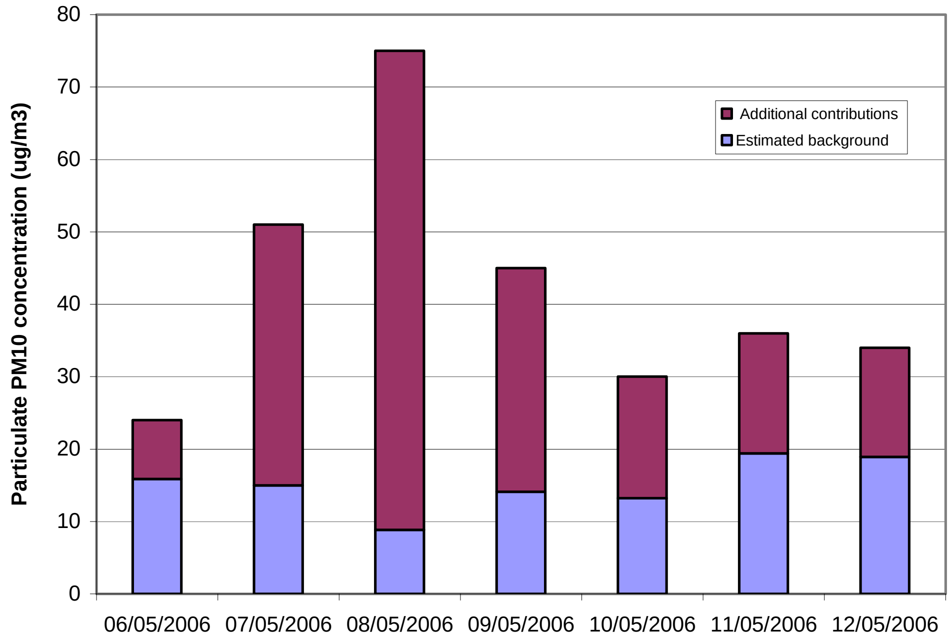


Figure 2c: Estimated additional contributions of particulate PM_{10} at Newcastle Centre.

Daily partisol measurements taken at Auchencorth Moss, located 10 miles south of Edinburgh, for particulate fractions PM_{10} and $PM_{2.5}$ indicate that the ground-level composition of the cloud was approximately 80 % of the finer fraction $PM_{2.5}$ by mass-volume when directly compared to the PM_{10} fraction. $PM_{2.5}$ is a particle size normally associated with the accumulation mode of particle formation, primarily the result of combustion sources or cloud processing effects on particles and not with natural sources such as mechanically generated particles from wind blown suspended soils or non-combusted plant debris. Figure 2d shows the provisional daily partisol $PM_{2.5}$ and PM_{10} measurements which were supplied by Bureau Veritas, London.

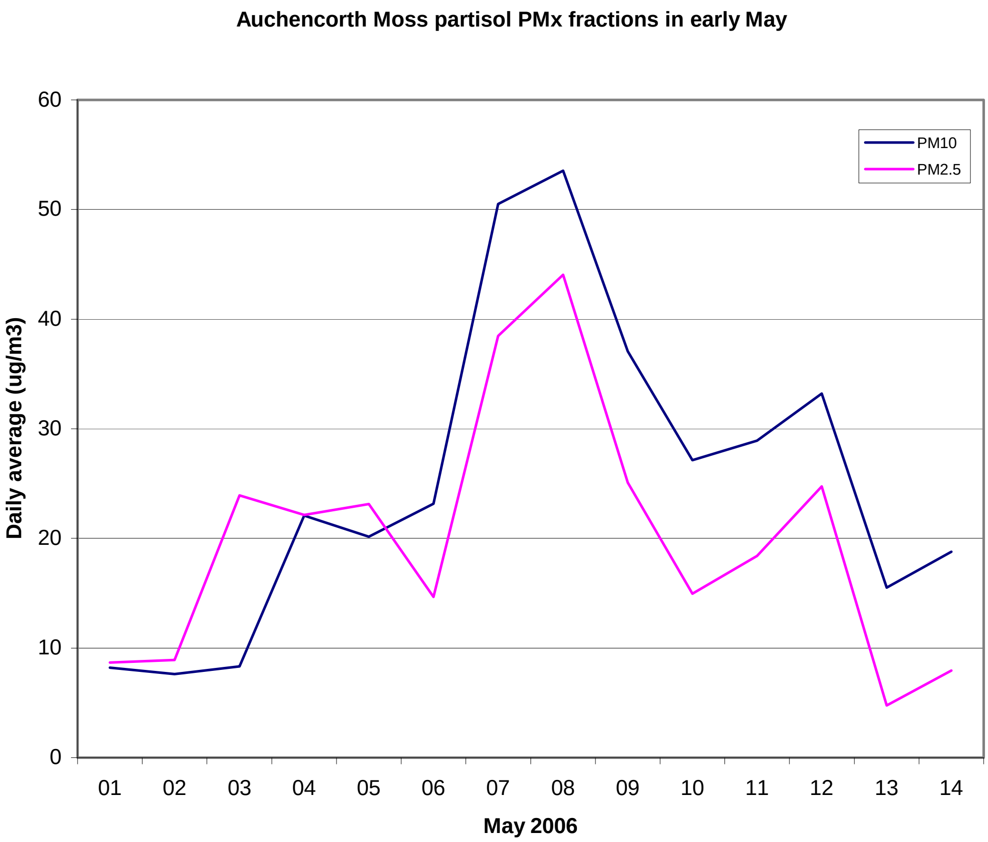


Figure 2d: Provisional daily partisol measurements taken at Auchencorth Moss, Scotland in early May.

LIKELY SOURCES OF THE POLLUTION

Simple 1000mB 96-hour forecast air mass back-trajectory data are provided by the Met Office to the Netcen air pollution forecasting team each day. These data illustrated that the air arriving in Scotland and the north east of England on the first day of the episode (7th May) had traveled from western Russia and over northern Europe (figure 3a). Figures 3b to 3d show a similar pattern on subsequent days for many other areas of the UK, although the south-west of England was in a clean Atlantic air flow for much of the time.

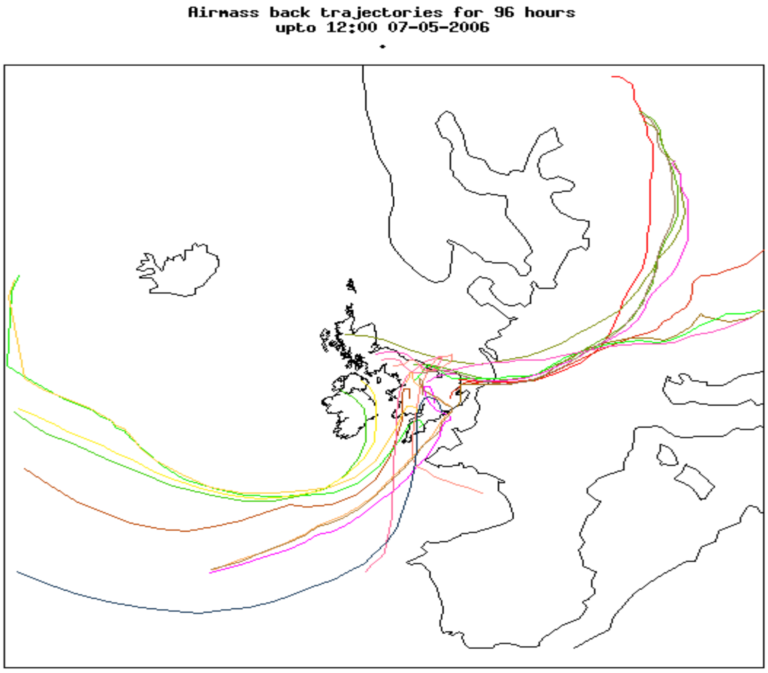


Figure 3a: Air mass back-trajectories for 7th May

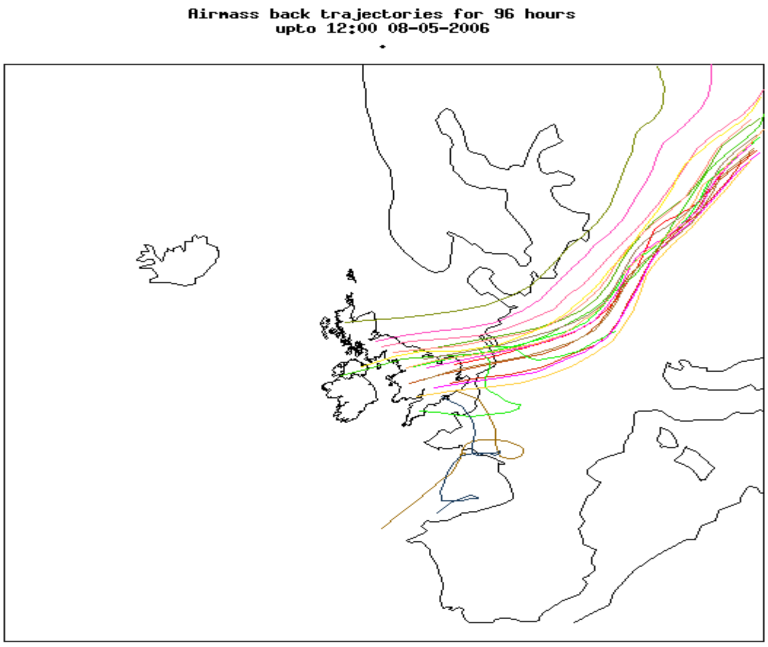


Figure 3b: Air mass back-trajectories for 8th May

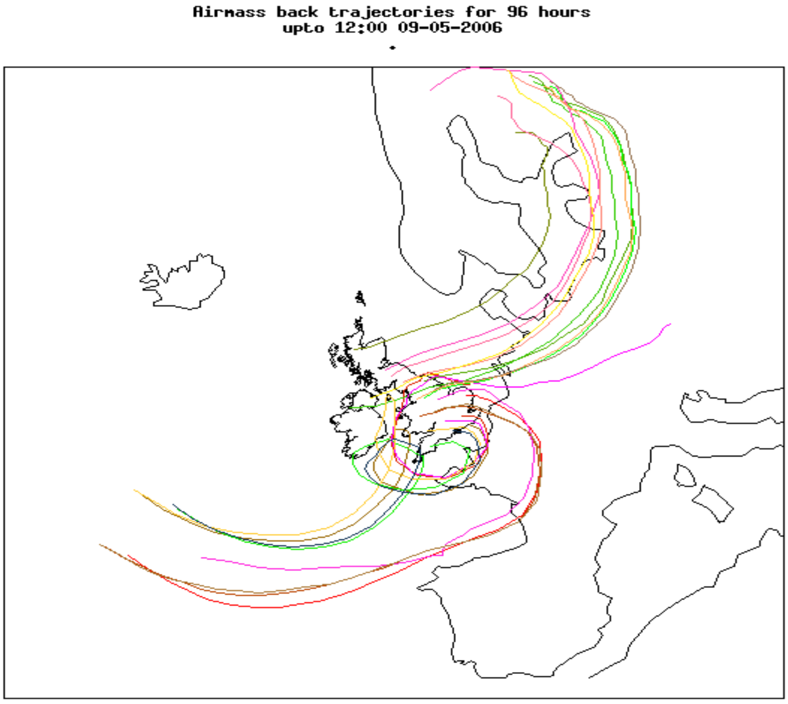


Figure 3c: Air mass back-trajectories for 9th May

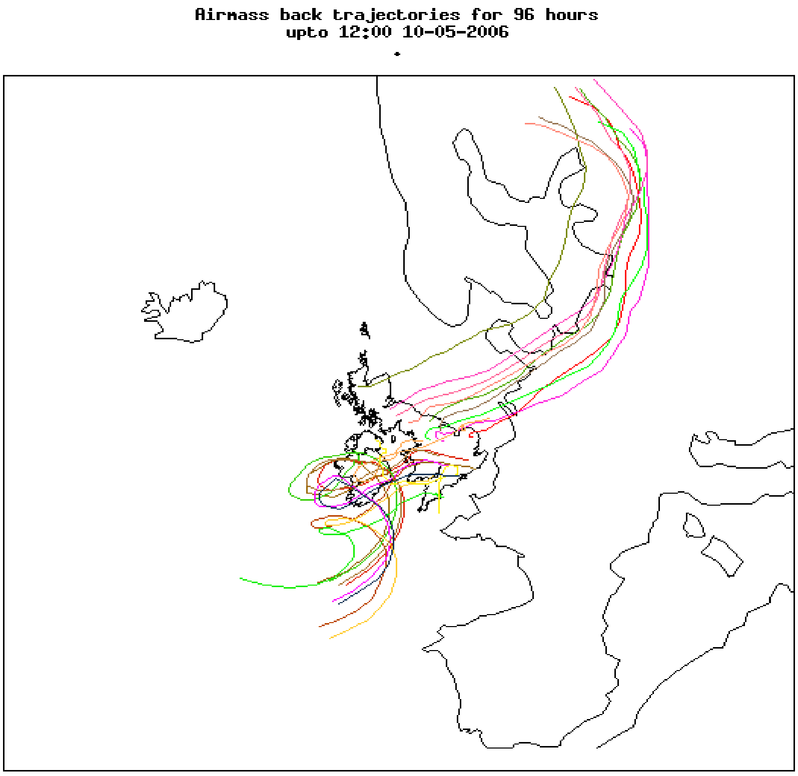


Figure 3d: Air mass back-trajectories for 10th May

Netcen and the Met Office considered three hypotheses for the pollution source:

1) Russian fires
2) Pollen from Northern Europe
3) European pollution

Agricultural fires in western Russia were observed by MODIS (Moderate Resolution Imaging Spectroradiometer, housed onboard a NASA satellite) at the end of April and start of May 2006 (figure 4a) and smoke from these fires was observed to be travelling north-west over the Gulf of Finland (see figure 4b for the position of the Volga River in relation to Europe). A plume of particulates observed to the north of Scandinavia on 30th April (figure 5) was hypothesised to be smoke from these fires.

Figure 4a: Fires in western Russia (indicated by red dots) on 3rd May, smoke travelling north-westwards

Figure 4b: Approximate position of the Volga River in Western Russia (indicated by blue cross).

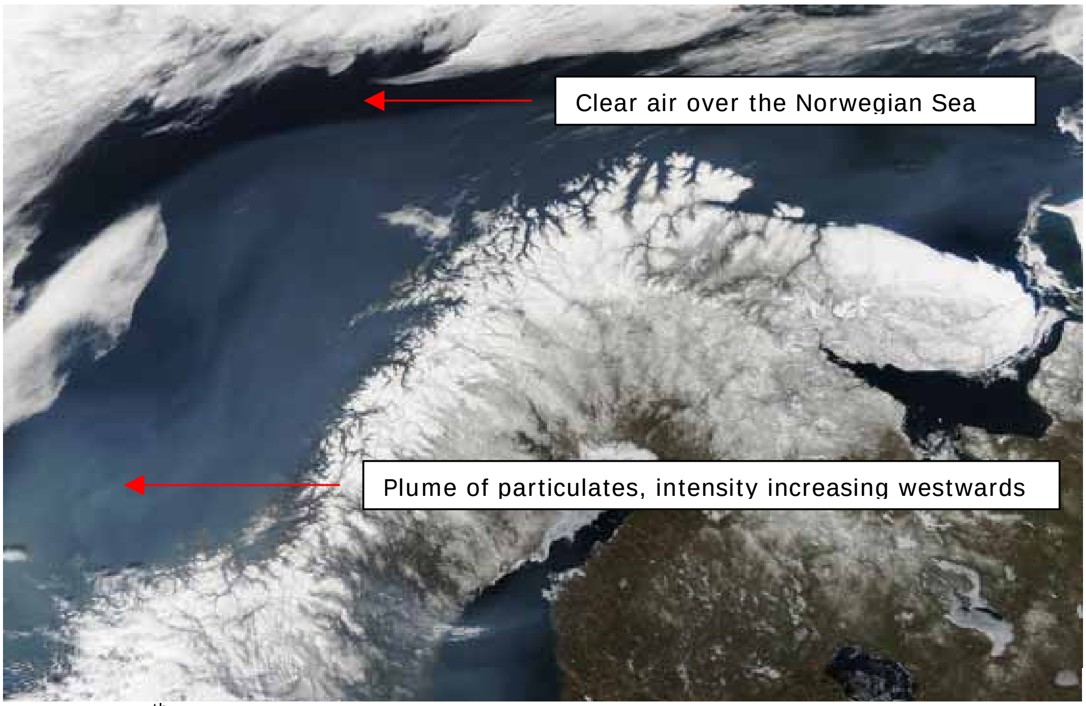


Figure 5: 30th April – A plume of particulates was detected to the north of Scandinavia, its intensity appeared to be highest to the west

The Met Office NAME atmospheric dispersion model was run backwards for a selection of sites in the northern UK to determine the origin of the air masses reaching this region at the time of the increased PM_{10} . The resultant air origin maps show that on the 8th May – the day with the highest PM_{10} indices – the air mass had travelled over the Russian fire region (figure 6a). On the following day – when indices were somewhat lower – the air source was more widespread (figure 6b).

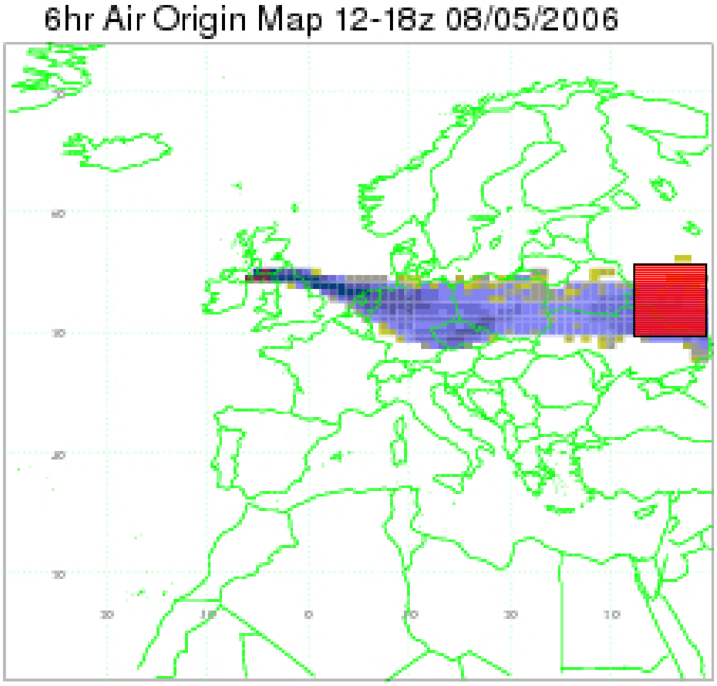
NAME was also run forward from the fire area (see squares in figure 6) from the 1st May. The modelled peaks in PM_{10} concentration at Edinburgh (evening of the 7th and morning of the 8th) illustrated in figure 7, match the observed dual peak in PM_{10} also shown in the same figure. The dip between the two peaks (early morning of the 8th) also matches. Observed NO_2 did not follow the same pattern as the PM_{10} which implies that long-range transport of general pollution from Europe was not the cause of the PM_{10} peak. The air reaching the UK on the 9th -11th originated to the north of the fire area, implying a low PM_{10} component from the fires and this corresponds to a decrease in the modelled and observed PM_{10} concentrations.

During the period of the incident some members of the public on the east coast of the UK reported yellow dust deposited on vehicles and windows. It is likely that this was pollen either released locally or that had been transported from northern Europe (in particular Denmark) where counts were reported as exceptionally high. Birch pollen particles, which are the most common species seen during this part of the year, are reported to have a diameter of around 20 microns and are therefore unlikely to be measured by a PM_{10} instrument. The PM_{10} instrument head has a 50 % cut off at the 10 micron fraction (i.e. higher diameter particles can be measured but in decreasing amounts with increasing diameters above 10 microns).

Denmark was consistently upwind of Scotland from 8th – 11th May, but the PM_{10} observations were not consistently high during this period, which suggests that the Danish pollen was not the source of the increased PM_{10}.

Climatology (1995-2004 inclusive) indicates that it is not uncommon for air to pass over this region en route to the UK in April and May. It would be a rare year if there was no transport to the UK in this period and given that this type of pollution incident is not seen frequently from year-to-year it is unlikely that pollen releases from Denmark and the rest of Europe were the main source of the pollution.

(a)



(b)

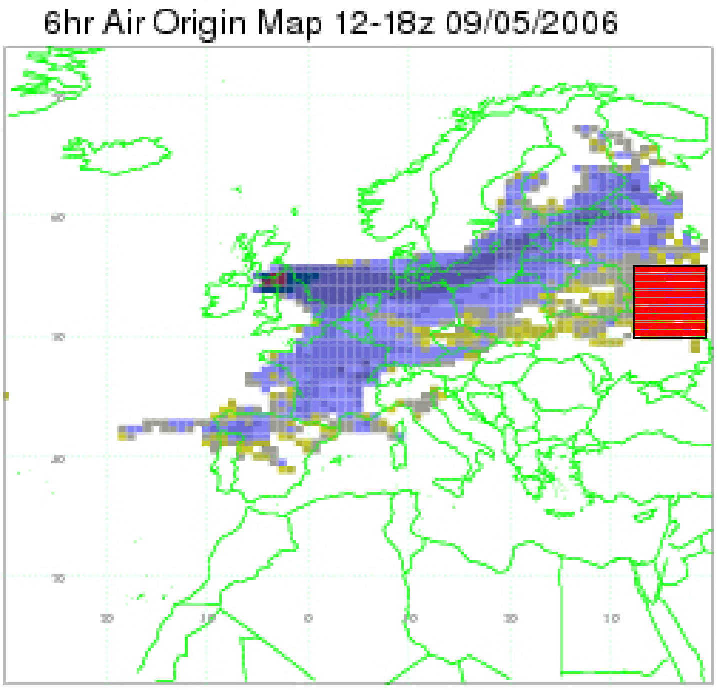


Figure 6: NAME air origin maps for Edinburgh for (a) 8th and (b) 9th May - Red squares indicate the approximate modelled fire area for the forward runs

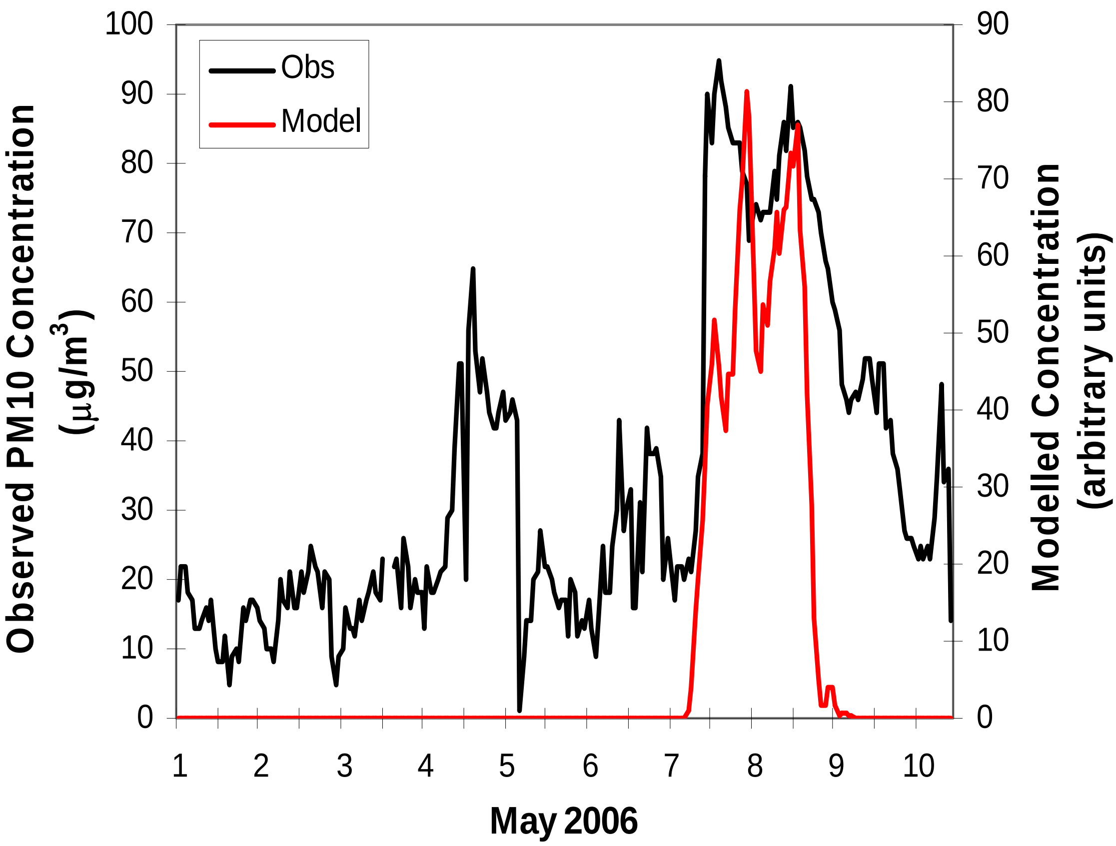


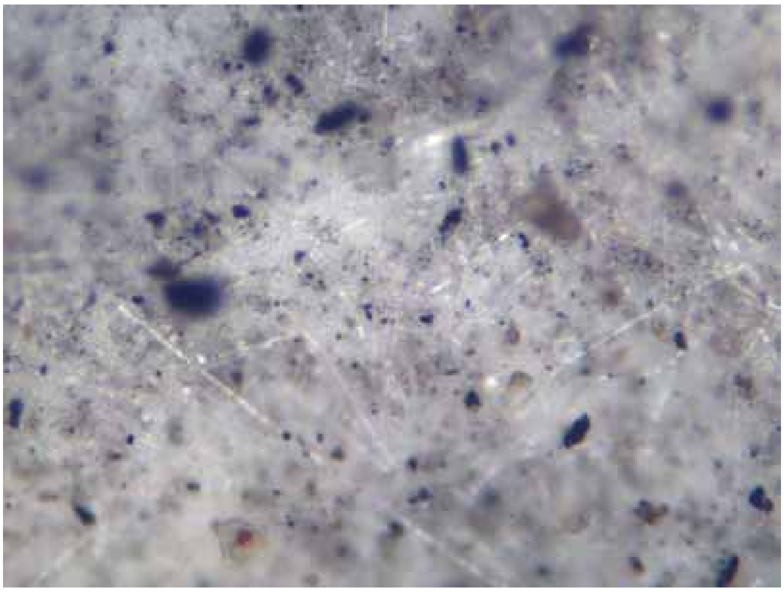
Figure 7: Observed and modelled levels of PM_{10} at Edinburgh for May 1st to 11th 2006. Note the modelled values have been scaled to display on this graph so the units for these data are arbitrary.

Following a period of extensive enquiries a series of daily collected (partisol) particulate samples from a central site in Forfar, Scotland, which had been donated by Angus Council, were analysed using microscopy and x-ray analysis techniques.

An optical analysis at a magnification of x 200 revealed many blue coloured particles and some red in colour, as shown in figure 8.

Figure 8
Optical micrograph of typical area of particles on filter dated 8/5/06

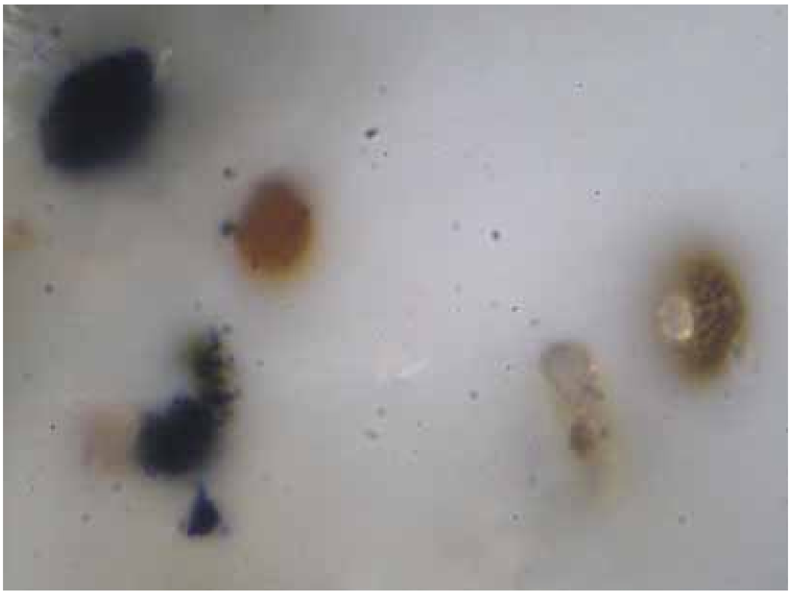
Magnification x 200



With increasing magnification the particles were identified as black, carbonaceous particles and red "rust" grain. Some organic and pollen particles were also found on the filter, although very few in number. Figure 9 shows the micrograph at magnification x 500.

Figure 9
Higher magnification optical micrograph of black particle, red "rust" grain and organic material on filter dated 8/5/06.

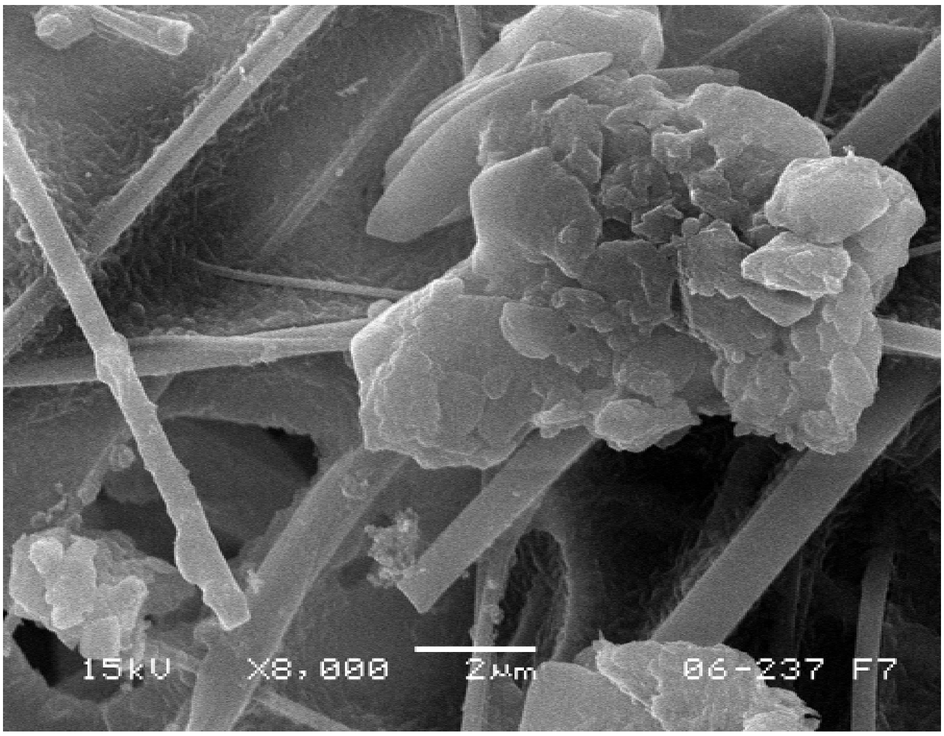
Magnification x 500



At magnifications of x 8000 a scanning electron microscope identified many crystalline, non-organic particles caught on the fibre of the filter. The particle shown in figure 10 has a diameter of approximately 8 microns.

Figure 10
SEM micrograph of particles on filter

X 8,000 mag



The report concluded that most of the particles observed by microscopy appeared to be inorganic carbonaceous materials, for example soots and black particulate matter. There were also some angular grains found, thought to have been possibly quartz. A proportion of the particles were red in colour, thought to have been iron rust. A few pollen grains were also present, although low in number.

X-ray fluorescence spectroscopy showed no significant changes in the composition of approximately 15 metals such as magnesium, zinc and lead on the series of partisol filters supplied, dated from 2nd to 15th May. Levels of elemental iron were found to have increased by around 20 % above the 14 day period average on the most significant day of the particulate cloud (i.e. the 8th) and the following day (9th). Figure 11 shows this.

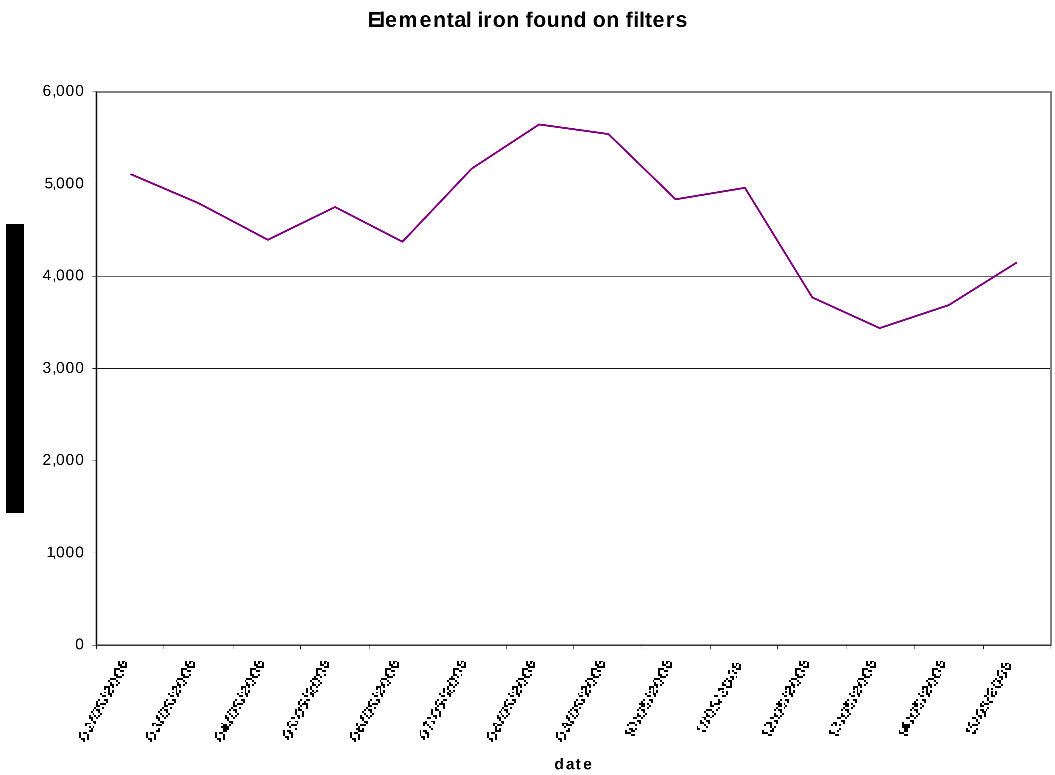


Figure 11: Elemental iron found on filter series 2nd to 15th May.

The increased levels of elemental iron found on the 8th are likely to be related to the red rust particles found on the filters by microscopy. This could be an indication that wind-bourn iron particles, possibly as a result of debris from a combustion process, have been rusted by atmospheric water vapour prior to deposition on land.

From the evidence above it was concluded that the most likely cause of the particulate pollution event was the fires in western Russia, which were initially identified through satellite imagery. In the following section of this paper we use satellite images to track how the air pollution episode progressed across the UK.

TRACKING THE EPISODE FROM SATELLITE IMAGES

Please note that many of the high resolution colour images which follow have been sourced from a MODIS satellite, black and white images were mainly sourced from an advanced very high resolution radiometer (AVHRR), onboard a U.S. civilian meteorological satellite.

On Thursday 4th May England and Wales were free of cloud cover whilst a band of cloud covered Scotland and Northern Ireland. A general haze could be seen over the North Atlantic, as well as the Baltic Sea. There was some light cloud over northern France (figure 12) and an area of low pressure was moving towards the UK from the west.

Figure 12: 4th May at mid-day

By mid-day on Friday 5th May, this low pressure centre was located to the north-west of the UK and the cold front associated with it was to the east of the UK (figure 13). Haze had built up to the west of Scandinavia and to the east of the UK around a large area of high pressure centred over Scandinavia.

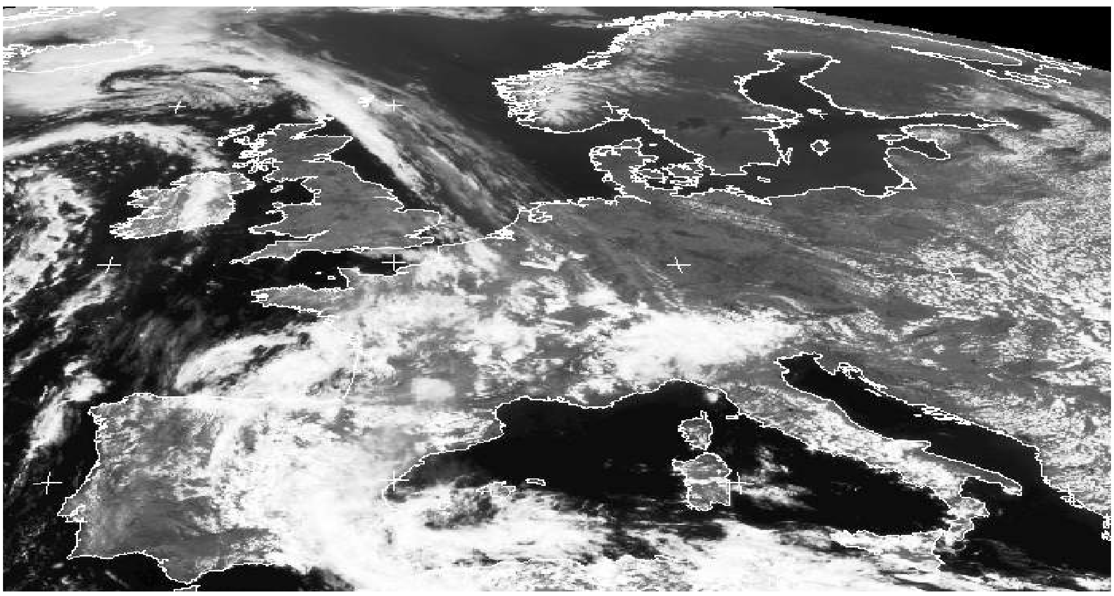


Figure 13: Friday 5th May at mid-day

On Saturday 6th May, the south of England was enveloped by cloud that had moved northwards from France (figure 14). To the east of the UK, the spiral arm of cloud identifying the frontal system formed a continuous barrier sweeping north-eastwards over the north Atlantic. The high pressure system remained to the east of this front, whilst a new low pressure centre developed to the west of Ireland. A further build up of a haze to the east the frontal system was apparent over the North Sea.

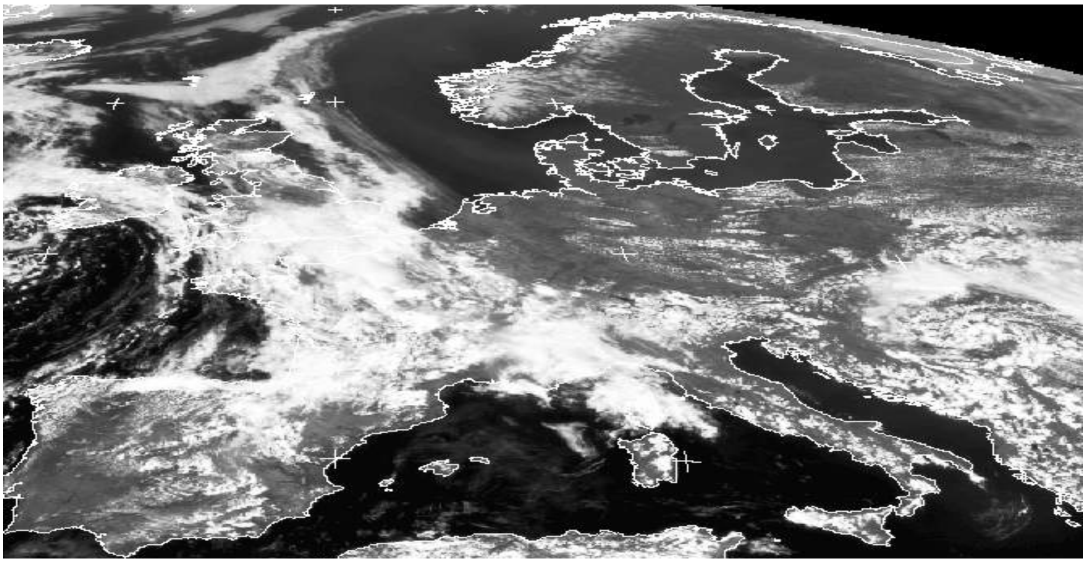


Figure 14: Saturday 6th May at mid-day

A high resolution satellite image for Saturday 6th May, centred on Europe (figure 15), shows that the particulate cloud had passed over Denmark and Germany before building up behind the frontal system. The image also clearly shows a further possible cloud of particulates issuing eastwards from western Russia.

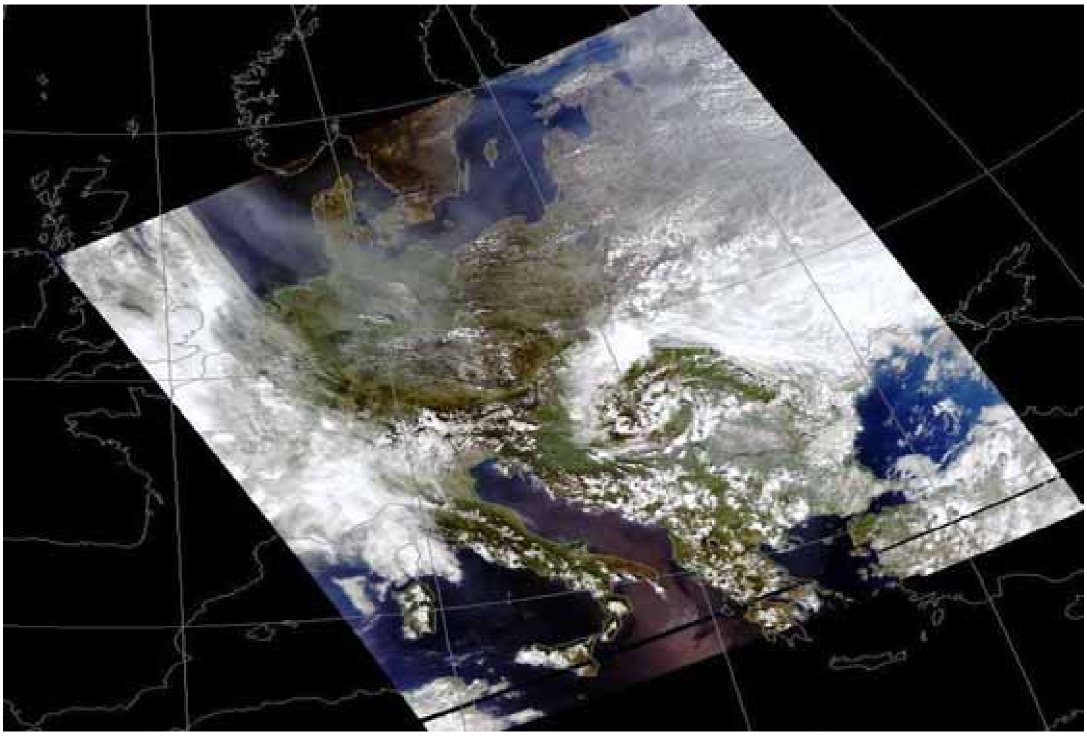


Figure 15: Saturday 6th May (high resolution image centred on Europe)

By 9 pm on Saturday evening, cloud from the south had enveloped the UK completely and the build up of dust behind the band of cloud directly to the east of the UK could be seen (figure 16). At this stage, no AURN AQM site in the UK had measured an elevated level of particulates.

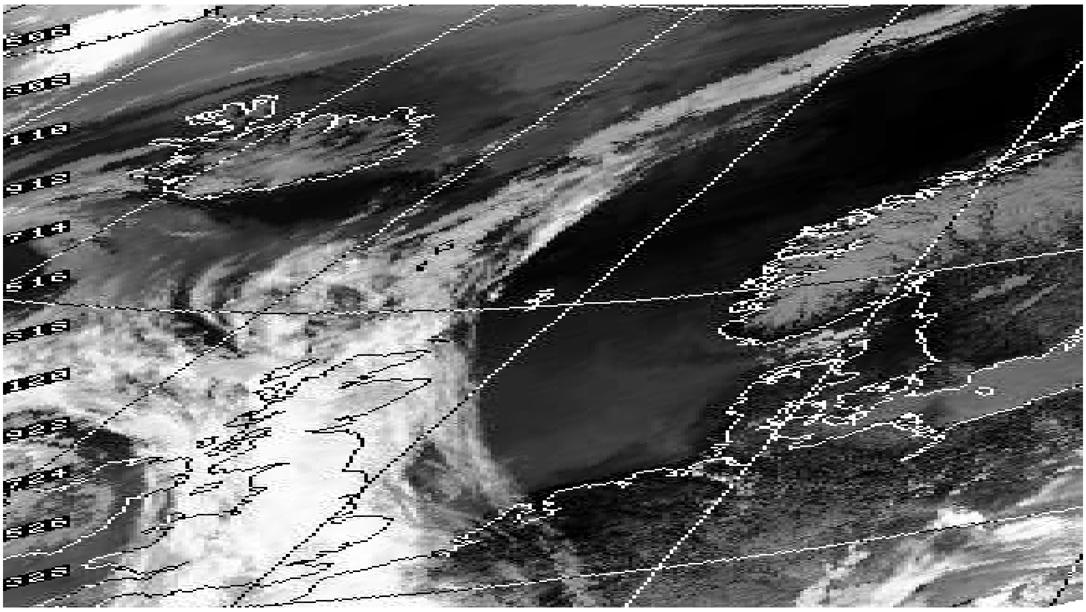


Figure 16: Saturday 6th May at 21:00

On the morning of Sunday 7th May, the frontal system to the east of the UK moved westwards and areas of Scotland began to be exposed to the dust particles present in the easterly air mass. By this time, the cloud of dust covered most of the North Sea and areas of Scandinavia (figure 17). Only the AQM site in Aberdeen (north-west Scotland) measured elevated particulate levels at this stage (see figure 1a).

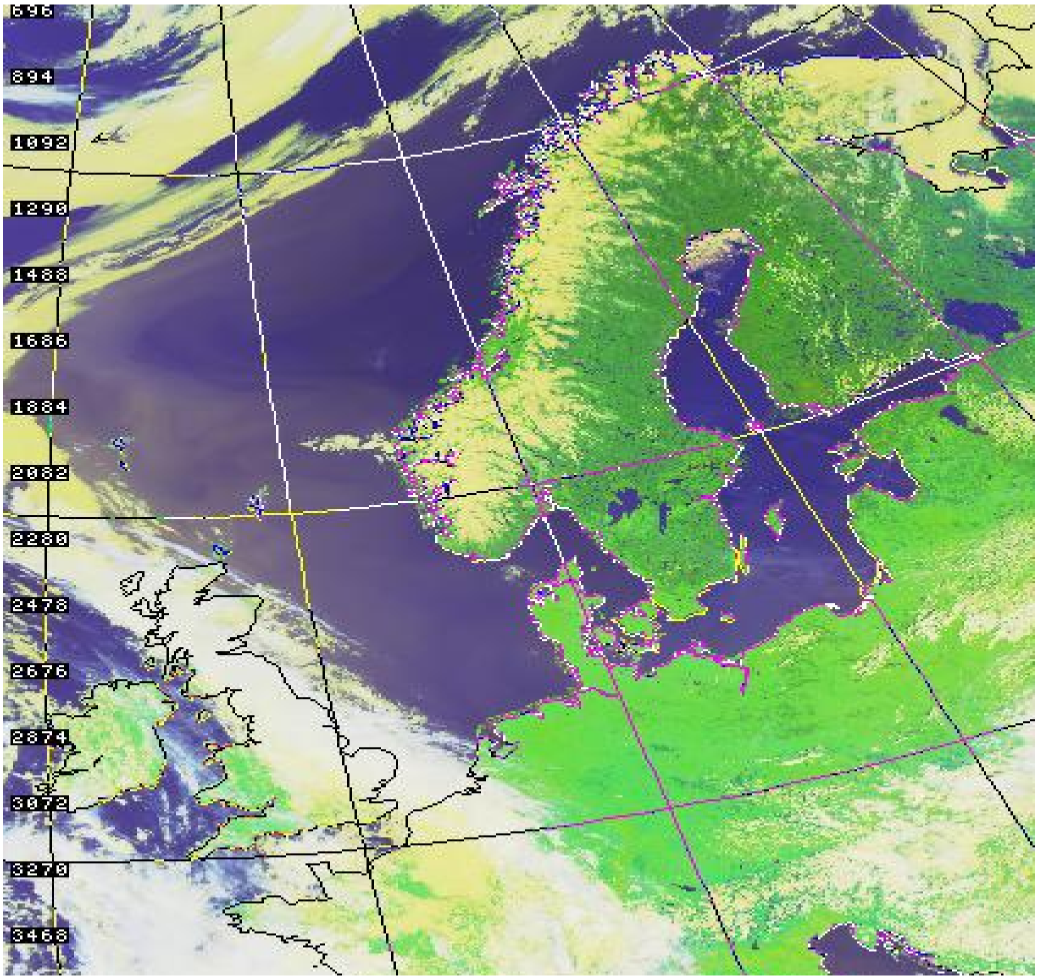


Figure 17: Sunday 7th May at 10:00 (Pseudo colour image)

By mid-day on Sunday 7th May, more of Scotland had been exposed to the dust cloud as the frontal system continued to move slowly westwards. Particulate levels had begun to rise in central areas of Scotland and in the north east of England by this time, as shown in figure 1a. Figure 18 shows that the northern edge of Scotland and the Scottish Islands were below the dust cloud. The figure also shows that the air to the west of the frontal system was much cleaner than that to the east.

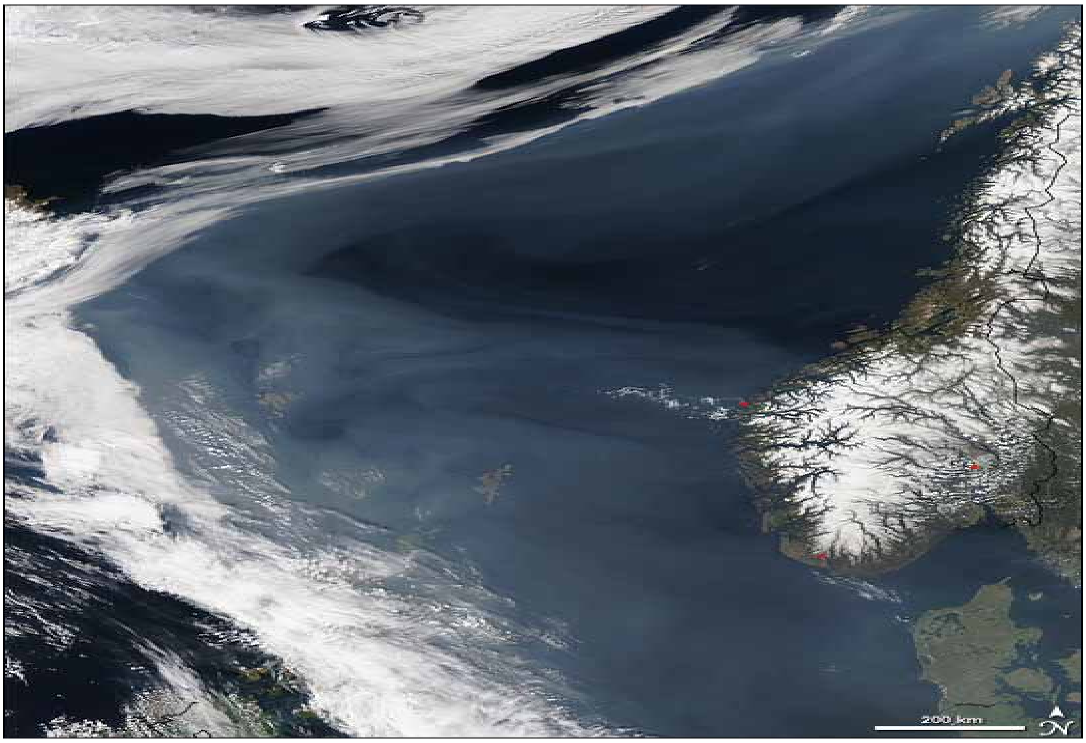


Figure 18: Sunday 7th May at mid-day (high resolution image)

By the evening of Sunday 7th May, much of the north of Scotland was under the dust cloud. Denmark and Norway also appeared to be under the dust cloud in satellite images. Figure 19 shows the position of the atmospheric pressure centres at the time. The dust cloud was transported in the air mass between the weather fronts located across northern England and Scotland and across Iceland.

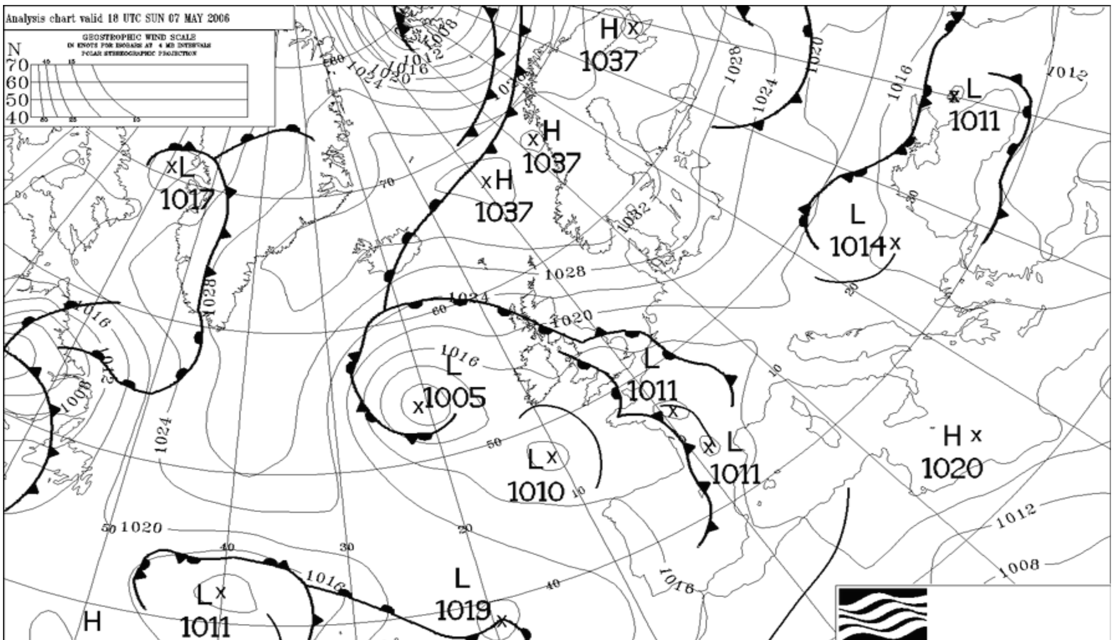


Figure 19: Sunday 7th May at 18:00

On the morning of Monday 8th May the rest of Scotland was increasingly exposed to the dust cloud as shown in figure 20.

Figure 20: Monday 8th May at 06:00 (Please note the intensity of light displayed is higher in the morning and the evening than at mid-day)

By mid-day on Monday 8th May, Scotland and the north east of England were completely covered by the dust cloud, which also could be seen to the north of the UK in satellite images. Clearer patches could be seen in the North Sea, as the dust was transported to the west. Figure 21 shows the synoptic situation at the time; the dust plume remained bounded by the frontal system which lay across England and Northern Ireland.

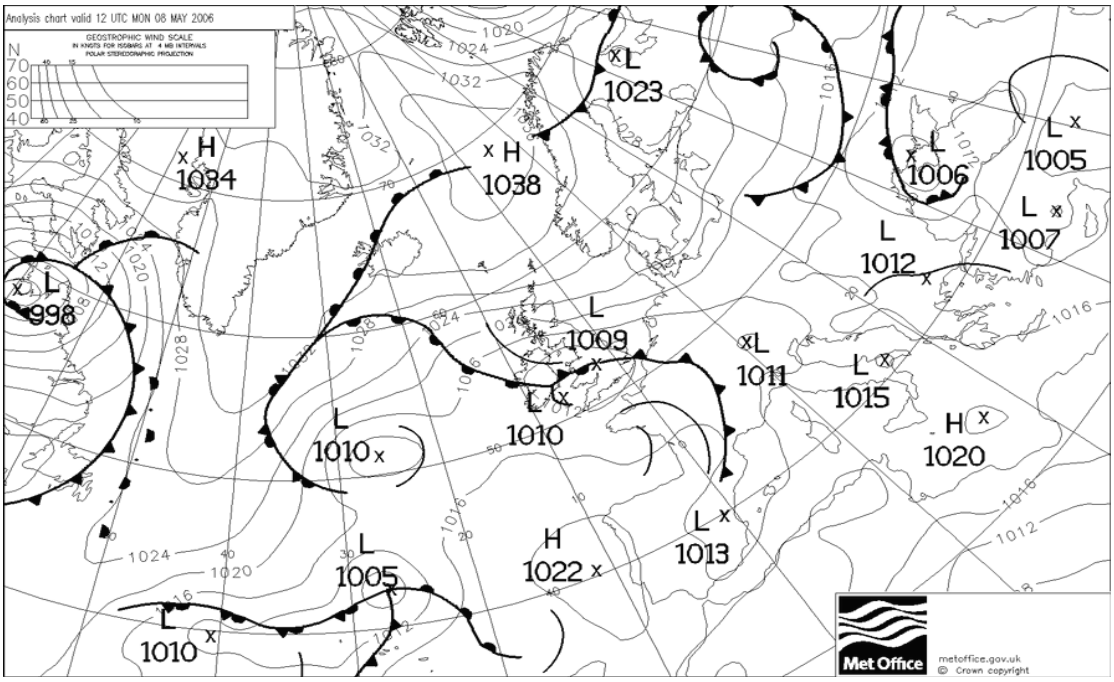


Figure 21: Monday 8th May at mid-day

In the evening of Monday 8th May, Northern Ireland began to be exposed to the dust cloud as it dispersed further westwards. Air quality measurements show a sudden rise in particulate levels in Northern Ireland on the morning of the 8th (figure 1b), indicating that the edge of the dust cloud resided within the cloud cover associated with the frontal system. Swirls of newly arriving dust can be seen emanating from Scandinavia and Northern Europe in figure 22.

Figure 22: Monday 8th May at 18:00 (Please note the intensity of light displayed is higher in the morning and the evening than at mid-day)

By the morning of Tuesday 9th May the frontal system over the UK had weakened and the band of cloud was starting to break up over Ireland. By mid-day, this band of cloud was positioned over Wales and Northern Ireland (figure 23). Clearer air was in evidence over southern Ireland and the south-west of England, as these areas remained to the west of the front. Most of the rest of the UK was covered by the plume, although Scotland appeared to be in clearer air, confirmed by the gradual fall in measurements for Scotland. Measurements in most areas of England had begun to rise by this stage, although the magnitude was lower than the initial impact when the smoke plume first reached Scotland. Most of the UK was still covered by the (now dispersed) smoke plume in the evening. An intense plume of dust can also be seen to the west of Norway in figure 23.

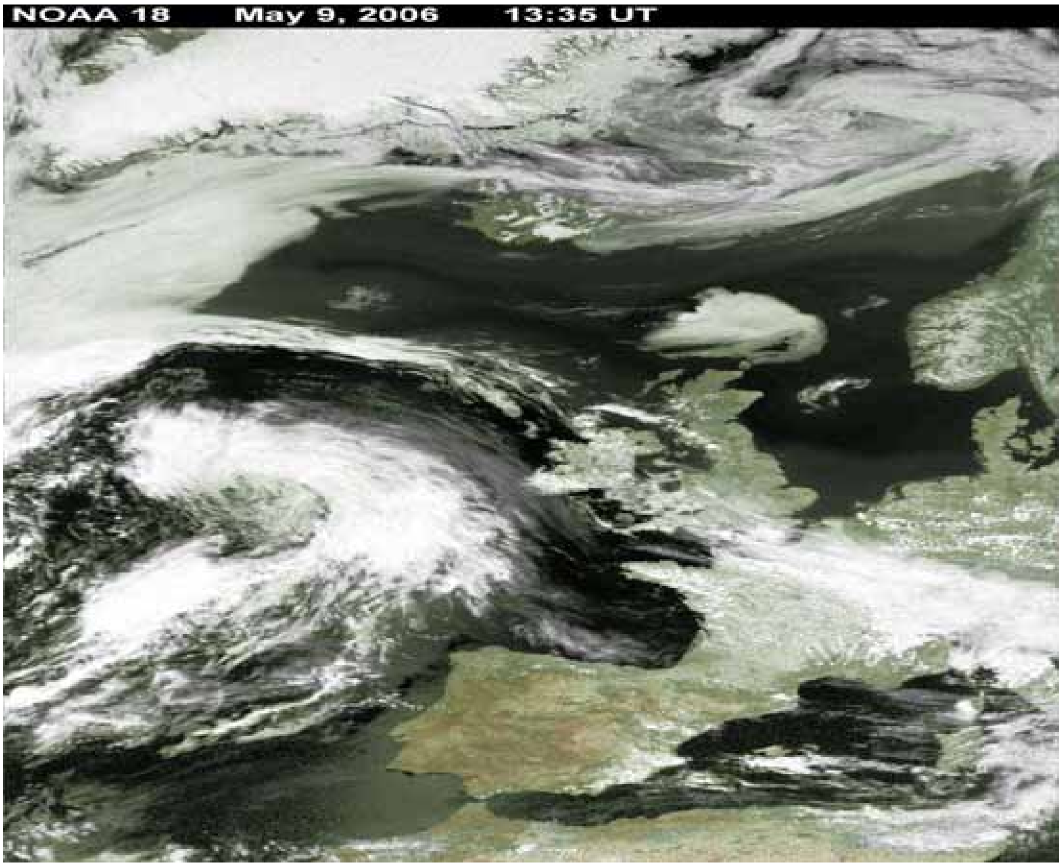


Figure 23: Tuesday 9th May at around mid-day (high resolution image)

The plume continued to be transported westwards during Wednesday 10th May and satellite images from the morning show a general haze over the south of England and Wales. Scotland and the North Sea appeared to be clearing slightly, although haze seemed to continue to reach the UK from France and Scandinavia. By mid-day, the majority of the haze had been transported past Northern Ireland to the north-west, over the Atlantic. No new sources of the plume were observed to the east in satellite images. Figure 24 shows that a portion of the particulate plume remained dispersed over Ireland, Wales and the south of England, but that other areas were clear. In the evening, the particulate plume appears to have remained intensified to the west, although further haze is evident in the vicinity of Scandinavia (figure 25). The haze observed in these final images could also be attributed to low-lying cloud.

Figure 24: Wednesday 10th May at mid-day (high resolution image)

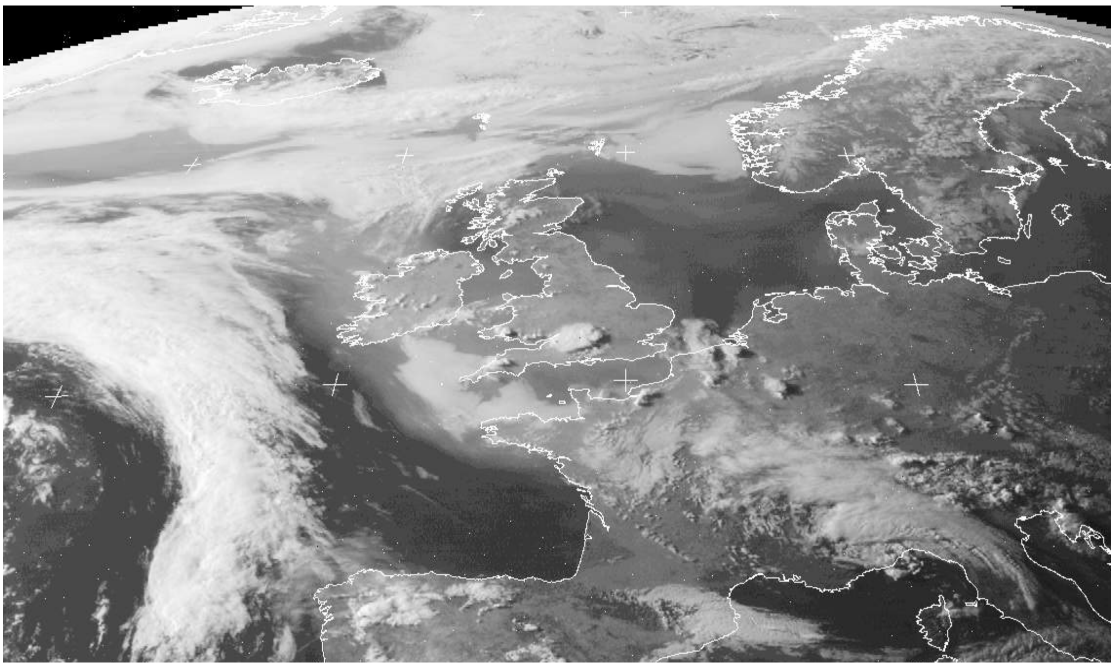


Figure 25: Wednesday 10th May at 18:00 (Please note the intensity of light displayed is higher in the morning and the evening than at mid-day)

By mid-day on Thursday 11th May, most of the plume had cleared from the UK out to the west, as seen in figure 26, and a drop in particulate levels in England and Northern Ireland was observed (Table 1).

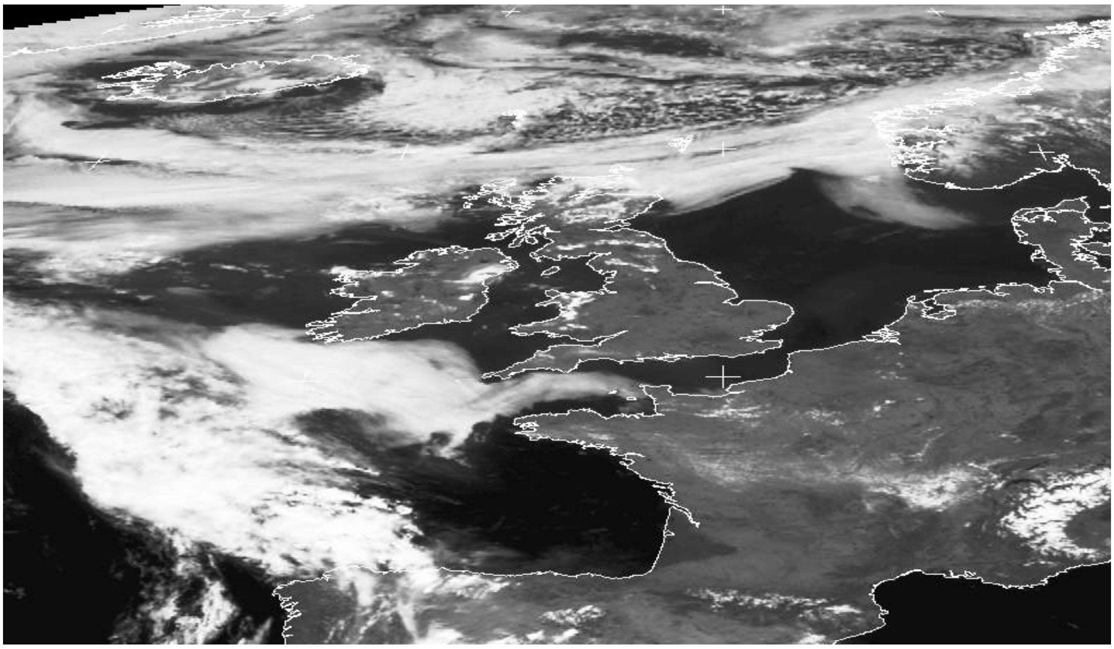


Figure 26: Thursday 11th May at mid-day

CONCLUSIONS

The main features of the early May 2006 particulate episode may be summarised as follows:

Air sourced from western Russia and passing over northern Europe contained a cloud of particulates for at least several days, between approximately 6th May and 10th May.

The transport and detection of the particulate plume was strongly influenced by the synoptic meteorological situation at the time. The cold front over the UK initially kept the plume to the east, but as the front moved south-west increased levels of particulates were measured as ground-level PM_{10} pollution in Scotland and the north east of England for several days. The problem then spread to England and Northern Ireland at reduced levels for several days, after the cold front had broken up.

No analytical measurements were initially made of the composition of the particulate cloud. The following people were contacted by Netcen in an exhaustive attempt to locate a suitably integral sample of ground-level particulates collected over the episode period in early May or particulate analysis results already performed by an independent body:

Professor Neil Cape, CEH, Edinburgh Research Station, Penicuik.
Mathew Heal, local authority contact, Edinburgh.
Helen Lawrence, Acid Rain section of AEAT Environment.
Patricia Bowe, Bureau Veritas, London.
David Butterfield, NPL.
Ian Beverland, Strathclyde University.
Tom Brydone, Perth and Kinross Council, Perth.
Danny Johnston, Angus Council, Forfar.

Professor Neil Cape indicated that the steam jet aerosol collector (EMEP MARGA instrument) at Auchencorth Moss, Scotland, was not commissioned until June 2006, after the episode had occurred. No other suitable particulate samples were readily identified by CEH, Edinburgh. Particulates collected on particulate filters used in the analysis of acid rain samples (AEAT Environment) had been previously destructively tested. Patricia Bowe of Bureau Veritas supplied partisol PM_{10}/$PM_{2.5}$ datasets taken from a site in Auchencorth Moss, Scotland, which have been used in this report. The other contacts mentioned were unable to supply any useful data or suitable samples, except Danny Johnston at Angus Council who has stored samples taken from three review and assessment partisol sites (Carnoustie, Glenisla and Forfar).

An optical and x-ray analysis was eventually performed on a series of daily partisol filters taken from the urban Forfar site and the results concluded that the majority of particles present were carbonaceous, inorganic and resembled soot. Red rust-like particles were also found which could have been the result of wind-bourn iron particles rusted by atmospheric water vapour, possibly linked to a large scale combustion process. Pollen and organic particles were also found but were low in abundance.

The particulate cloud is therefore suspected to have been the result of long range transport from fires in Russia, combined with a contribution of European secondary PM_{10} pollution and a small contribution from local and European pollen.

Acknowledgements

Thanks to the Met Office for supplying weather charts to cover the period of the pollution episode, to Dundee University and NASA/GSFC MODIS Rapid Response for allowing publication of the satellite images shown in this report and to Angus Council for supplying the partisol samples.

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	≥ 360 μgm^{-3}	≥ 180 ppb	≥ 764 μgm^{-3}	≥ 400 ppb	≥1064 μgm^{-3}	≥ 400 ppb	≥ 23.2 mgm^{-3}	≥ 20 ppm	≥ 130 μgm^{-3}