Gibraltar PM_{10} TEN: source attribution analysis

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Executive summary

Concentrations of particulate matter (PM_{10}) have been measured in Gibraltar and reported to the European Commission since 2005, in accordance with European Air Quality Directives. After relatively low measured concentrations in 2005, the Gibraltar Air Quality Monitoring Network has since recorded exceedences of Limit Values (LVs) prescribed in the Directives. Given the scale of exceedences across Europe, the Commission have encouraged Member States to provide a Time Extension Notification (TEN) in order to delay the application of these LVs until the end of the time extension period (2011 for PM_{10}). The TEN application process provides scope to clarify and quantify the nature of the measured exceedences and to present the policy measures put in place to address them, by doing so demonstrating how the Member State intends to achieve compliance with the LVs at the end of the time extension period.

The purpose of this report is to present analysis of PM_{10} (and associated pollutants) in support of a formal application by the Government of Gibraltar for a time extension (TEN) to the PM_{10} Limit Values (LVs) imposed under the Air Quality Directive. The analysis presented in this document is a component part of a wider programme of work designed to:

1. identify and quantify sources of particulate matter in Gibraltar highlighting the significance of each source;
2. present policy measures being implemented to abate these sources;
3. demonstrate the effectiveness of these policy measures in achieving the LVs at the end of the time extension period in 2011.

The modelling estimates that the most significant source affecting measured PM_{10} concentrations at the Rosia Road air quality monitoring station is the local area of unmade land and associated bulk handling operations. The model estimates that this constitutes almost a quarter of the total PM_{10} measured. Other significant contributions were estimated from transboundary sources, resuspended road dust and exhaust emissions (particularly from 2-stroke vehicles that are prevalent in Gibraltar). African dust is quantatively accounted for each year and is known to make a significant contribution to total PM_{10} concentration. The other significant natural source affecting Gibraltar is sea salt. No formal quantification of sea salt has yet been possible despite attempted laboratory analysis. It is recommended that the Government of Gibraltar formally approach the Spanish authorities with a request for daily speciated sea salt data from the nearby La Linea monitoring station. The importance of obtaining these data may be signifianct as quantifying this natural source is likely to affect the exceedence status of Gibraltar,it may even remove the need to pursue a formal application for a time extension.

Despite the lack of evidence or quantification for contribution to PM_{10} from construction dusts, it is recommended that authorities in Gibraltar treat this as a significant potential source and formally implement appropriate legislative abatement strategies which are policed and enforced by the Gibraltar Environmental Agency.

Given the potential financial penalties of infraction under the European Air Quality Directives, it is recommended that the Government of Gibraltar explore the implications of UK infraction for Gibraltar and the legal mechanisms relating to it.

It is advisable that Gibraltar adopts air pollution mitigation strategies designed to achieve a more stringent annual mean concentration target than the minimum estimated annual mean concentration of 37.1 $\mu g\ m^{-3}$ developed through our analysis as necessary to achieve daily mean compliance with the Directive. Given the uncertainties involved in the modelling tasks, aiming for higher abatement than minimum required provides more ‘headroom’ should some mitigation strategies not be as effective as anticipated.

Despite the potential for achieving compliance through abatement of more easily controllable sources, it is recommended that more challenging abatement measures are at least considered to ensure that these can be implemented quickly if simpler strategies are not as effective as envisaged. It is recommended that a wide range of sources are targeted to maximise the chances of success and that the implementation of these strategies is considered within a wider, holistic policy setting so that complimentary policy areas such as planning and transport can be given due consideration to ensure maximum success.

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1 Introduction

Concentrations of particulate matter (PM_{10}) have been measured in Gibraltar and reported to the European Commission since 2005, in accordance with European Directives[1,2,3]. After relatively low measured concentrations in 2005, the Gibraltar Air Quality Monitoring Network has since recorded exceedences of Limit Values (LVs) prescribed in the Directives (summarised in Table 1-1).

Table 1-1 Limit Values for PM_{10},set down in the First Daughter Directive

Metric	Limit Value
Daily mean LV	50 µg m^{-3} (not to be exceeded more than 35 times per calendar year)
Annual mean LV	40 µg m^{-3}

The LVs for PM_{10} came into force in 2005 and many Member States (including the UK) have struggled to achieve these stringent values. Exceedences and concentrations measured in Gibraltar from the inception of the monitoring network are summarised in Table 1-2 which illustrates the rise since 2005. The concentrations presented have not been corrected for natural contributions. Natural contributions to measured PM concentrations in Gibraltar are generally quite high. For example, in 2006 the stated value of 60 daily exceedences was reduced to 32 daily exceedences[4] when contributions from natural African dust were quantified and deducted – this was the difference between compliance with the LV and exceedence.

Table 1-2 Summarised PM_{10} concentrations* in Gibraltar

Rosia Road	2005	2006	2007	2008
Number of exceedences of daily LV	16	60	109	63
Maximum daily concentration (µg m^{-3})	82	92	250	179
Annual mean concentration (µg m^{-3})	36	40	45	41

*** concentrations presented have not been corrected for contributions from natural sources and are for Rosia Road Partisol data only (i.e. the highest concentrations in the network reported to the Commission)**

Given the scale of exceedence across Europe, the Commission have encouraged Member States to provide a Time Extension Notification (TEN) in order to delay the application of these LVs until the end of the time extension period (2011 for PM_{10}). The provision for these and associated guidance has been developed in parallel with the new EU Air Quality Directive and the mechanism for applying for a time extension has been modelled on Plans and Programmes reporting submissions that were in place in the run up to the LVs coming into force. The TEN applicatiojn process provides scope to clarify and quantify the nature of the measured exceedences and to present the policy measures put in place to address them, by doing so demonstrating how the Member State intends to achieve compliance with the LVs at the end of the time extension period.

The purpose of this report is to present analysis of PM_{10} (and associated pollutants) in support of a formal application by the Government of Gibraltar for a time extension (TEN) to the Limit Values (LVs) imposed under the First Daughter Directive and subsequent updated EU Air Quality Directive of 2008. The analysis presented in this document is a component part of a wider programme of work designed to:

1. identify and quantify sources of particulate matter in Gibraltar highlighting the significance of each source;
2. present policy measures being implemented to abate these sources;
3. demonstrate the effectiveness of these policy measures in achieving the LVs at the end of the extension period in 2011.

[1] Directive 96/62/EC on Ambient Air Quality Assessment and Management (The Framework Directive)
[2] Directive 1999/30/EC (the first Daughter Directive)
[3] Directive 2008/50/EC (The EU Air Quality Directive)
[4] http://www.gibraltarairquality.gi/documents/Gib_natural_quantification_2006_v2.pdf

Other tasks in this programme of work include

- **Modelling of contributions to measured PM_{10} concentrations from the OESCO and MOD power stations**[5]

- **Modelling of contributions to measured PM_{10} concentrations from transboundary sources**[6]
  including primary and secondary particulate matter split and including emissions sources from Europe and Africa.

- **Modelling of contributions to measured PM_{10} concentrations from shipping**[7]
  Including split of contributions between the Bay of Gibraltar, the nearby Spanish port of Algeciras and traffic passing through the Straits of Gibraltar.

These tasks have been presented in detail in separate reports but are summarised briefly in Chapters 7-0 of this report and presented in the table in Chapter 16.

Additional relevant analysis in the core programme of work for Gibraltar includes quantification of African dust contributions to measured PM_{10} concentrations[8] which is provided for 2006 to 2008 in short reports on the Gibraltar Air Quality website (http://www.gibraltarairquality.gi). The results of these analyses are summarised in Chapter 10 and presented in the table in Chapter 16.

It should be noted that Gibraltar's application for a time extension is based on a reference year of 2007. However, the wide range of comprehensive data needed to support such an application does not exist for this year, additionally monitoring implemented to facilitate these various analyses cover periods in 2008 and into 2009. As a result, the supporting data, to provide the most robust practicable assessment of source characterisation and contribution to measured concentrations, is often based on more recent monitoring data than the reference year.

[5] Abbott, J (2009) Dispersion modelling of MOD and OESCO power station PM_{10} discharges (AEA Report to Gibraltar Environmental Agency: AEA/ED43072/R2835 Issue 1)
[6] Abbott, J (2009) Transboundary particulate matter pollution on Gibraltar (AEA Report to Gibraltar Environmental Agency: AEA/ED43072/R2834 Issue 1)
[7] Abbott, J (2009) Contribution from shipping emissions to PM_{10} and nickel contents on Gibraltar (AEA Report to Gibraltar Environmental Agency: AEA/ED43072/R2833 Issue 1)
[8] Kent, A J (2008) Measured PM_{10} concentrations in Gibraltar in 2006 removal of the natural component http://www.gibraltarairquality.gi/documents/Gib_natural_quantification_2006_v2.pdf;
Kent, A J (2009) Measured PM_{10} concentrations in Gibraltar in 2007 removal of the natural component http://www.gibraltarairquality.gi/documents/Gib_natural_quantification_2007_v1.pdf;
Kent, A J (2009) Measured PM_{10} concentrations in Gibraltar in 2008 removal of the natural component http://www.gibraltarairquality.gi/documents/Gib_natural_quantification_2008_v1.pdf

2 The Openair toolset

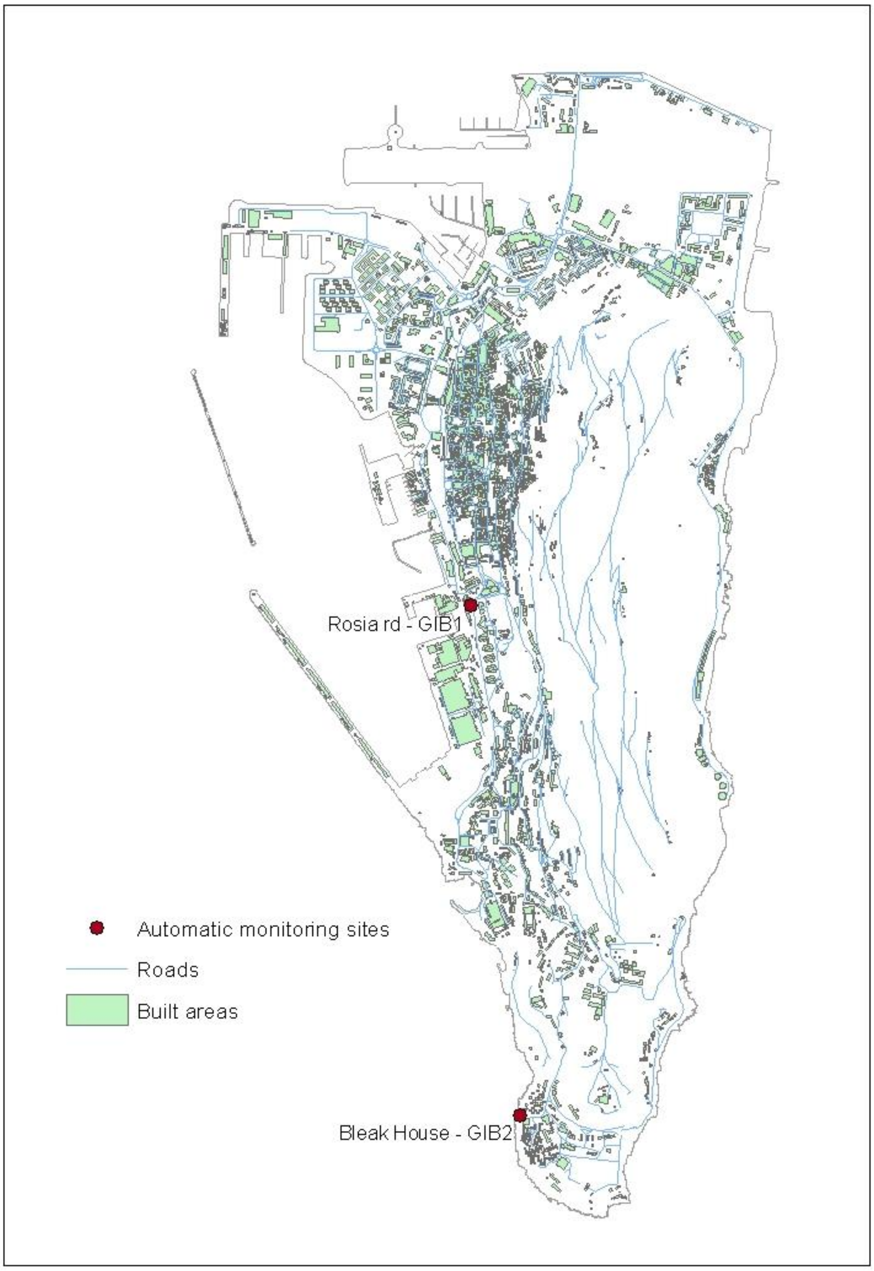
A key feature of the analysis presented in this report has been the application of powerful new statistical and visualisation capabilities that have become available in the UK. The toolset used, known as 'Openair', are being developed by the Institute of Transport Studies (ITS) at Leeds University under a 3 year NERC grant ending in 2011. The toolset and guidance are freely available at http://www.openair-project.org/

The toolset is specifically intended for interrogation of air quality monitoring data sets and allows powerful analyses of concentrations between different pollutant species and how they vary with each other and with meteorological variables without the need to purchase expensive proprietary software.

3 The Gibraltar Air Quality Monitoring Network

The Gibraltar Air Quality Network has been operational since 2005 and in 2009 consisted of 3 automatic monitoring stations measuring NO_X, NO_2, O_3, PM_{10}, $PM_{2.5}$, CO, SO_2, heavy metals and PAH and 28 passive samplers (diffusion tubes) measuring NO_2, benzene, toluene and xylene. For the purposes of this study, the passive samplers measuring low temporal resolution concentrations not specifically related to PM have been omitted. The automatic monitoring stations are displayed in Figure 3-1 showing their locations in Gibraltar. A summary of site details for the automatic sites used in this study are provided in Table 3-1 and includes the site classification (background or roadside), specifics on the PM instrumentation and list the other pollutant species measured by automatic analysers.

Figure 3-1 Location of the Gibraltar automatic monitoring sites



PM_{10} is measured at two automatic monitoring stations in Gibraltar – Rosia Road and Bleak House. These sites both use Partisol instruments measuring daily concentrations have been in operation since the network commenced in order to satisfy the requirements of the European Directives. The Rosia Road site also measures $PM_{2.5}$ by Partisol.

An FDMS instrument measuring hourly concentrations of PM_{10} was later added to the Rosia Road site to fulfil requirements for public information provision in near real-time. The OSIRIS analyser was installed at Rosia Road specifically to aid this programme of work by providing high temporal resolution (1 minute) PM concentrations across several different particle size fractions. In order to compare with this high temporal resolution PM data the loggers for the existing instruments have been altered to provide corresponding 1 minute data for the other channels.

The advantage of the FDMS and OSIRIS data is that the temporal resolution that they operate at allows analysis of the data across a day so diurnal patterns can be observed relating to traffic movements, industrial processes etc.

Table 3-1 Summary table of Gibraltar automatic monitoring sites.

Site	Type	PM Instrument	Other pollutants
Rosia Road	Roadside	• Partisol (2005 to present) PM_{10}, $PM_{2.5}$ • FDMS (May 2008 to present) PM_{10} • OSIRIS (June 2009 to present) PM_{10}, $PM_{2.5}$, PM_1, TSP	• NO_X • NO_2 • CO • SO_2 • PAH • Heavy metals
Bleak House	Background	• Partisol (June 2008 to present) PM_{10}	• Ozone • NO_X • NO_2

4 Meteorological data

Three met data sets have been compiled by AEA to assist in the investigation of air pollution in Gibraltar. Consideration of such data is essential in determining the contributing sources to measured levels (particularly wind direction) and in determining the effectiveness of dispersion at particular locations (particularly wind speed). Two of these data sets have been derived from meteorological monitoring equipment at the air quality monitoring sites themselves (Rosia Road, Bleak House). These two data sets have the advantage of corresponding directly to the air pollution concentrations measured as the met data is co-located .

A met data set has been purchased from the UK Met Office which refers to the met conditions at the Gibraltar Airport (location labelled in Figure 3-1) between 2002 and 2006. Although this data does not include 2007 (the reference year for PM_{10} for the TEN application), the 5 year met history from the airport is enough to help provide a more regional context for the met conditions measured at the two monitoring stations.

4.1 QA/QC of met data

Unlike pollution data in Gibraltar (which is ratified to the same standard as the UK National Networks), there are no formal quality control procedures in place for met data measured at the Rosia Road or Bleak House monitoring stations. Data for the airport is assumed to be of high quality with appropriate checking and QA procedures since it is a commercial product of the UK Met Office.

The met data has undergone a pre-process of quality control to ensure that any idiosyncrasies are understood and explained and, where necessary, that these are corrected or removed. This has been undertaken using the Openair suite of tools and consideration has been given to negative wind speeds, excessive wind speeds and unrealistic distribution of wind directions. Negative wind speeds have been removed from the data. Excessive wind speeds have been arbitrarily capped at 20 ms^{-1}.

4.2 Wind rose and polar frequency analysis

Using the Openair toolset, the available met data was interrogated using wind rose plots (Figure 4-1) and polar frequency plots (Figure 4-2). Initially the met data was examined as a complete record and so Figure 4-1 and Figure 4-2 show data over a number of years for which the measurements exist rather than examining it on an annual, monthly, daily or diurnal basis. The wind rose plots show wind direction (in degrees about the plot origin), the wind speed (divided into specific ‘bins’ and represented by the paddle width) and the percentage of time for each direction/wind speed bin (distance from the plot origin). Figure 4-1 therefore shows that winds at Rosia Road are generally from the SW/SSW between 20% and 25% of the time and that wind speeds for any direction are rarely above 2 ms^{-1}. This is in contrast to measured met parameters at Bleak House and Gibraltar airport where wind speeds are generally much higher and more varied in terms of direction.

The interesting topography of Gibraltar is immediately apparent in these plots. Rosia Road is affected by the Rock itself providing shelter from winds from the east whereas the open sea to the south west results in winds from this direction for the majority of the time. A feature of the topography’s effect on met data is a ‘rotor effect’ that occurs when regional winds are easterly, blowing over the Rock and then rotating over the rock and then reaching Gibraltar from the opposite direction. Wind speeds measured at Rosia Road are significantly lower than the regional trend (represented by the airport location) and this is a contributory feature of the measured exceedences at the site. The average wind speed measured at Rosia Road when the measured wind direction is from the road (easterly) is 1.4 ms^{-1}, resulting in poor dispersion of road traffic emissions in close proximity to the monitoring site.

Bleak House is situated on a cliff above the water south of the Rock and is less affected by air mass blocking by the topography. Instead there is a more prevalent easterly or westerly wind directions that result from winds being funnelled through the Straits of Gibraltar. Wind speeds are higher here due to the open aspect and the height of the station. Gibraltar airport is located to the north of the Rock and so gets strong winds from the east and west (both directions are dominated by open runway and then open sea).

The polar frequency plots show the trends in an alternative way, binning the data by wind speed and direction and then representing the number of records in each bin using a colour scale. On these plots the wind direction remains represented by degrees about the plot origin but wind speed is now represented by the distance from the origin in ms^{-1}. From these plots it is easier to see the most commonly occurring wind directions and speeds.

4.3 Met data used for modelling

It has been noted in Section 1 that the data analysis used to support Gibraltar's application for a time extension is often based on data that is not directly associated with the reference year (2007 for PM_{10}) for the application. In the case of the modelling studies carried out for shipping, transboundary and power station contributions to measured PM_{10}, the met data used was from Gibraltar airport for 2006. The Gibraltar airport location was selected for use rather than the met data gathered from the individual monitoring sites because the met mast is situated in a wide, open unobstructed space and does not experience the same topographically related met effects caused by the Rock as the other data sets. The 2006 met data was the available data at the time of the analysis. In order to demonstrate that the met conditions measured at this location do not significantly vary between years (particularly between the year used and the reference year), the variation in wind speed and direction was plotted over successive years from 2002 onwards, as shown in Figure 4-3. This illustrates that from 2003 onwards the met data has been very similar and so modelled concentrations for 2006 are likely to be representative of the reference year (no known emissions source changes are believed to have taken place for each of the modelled components from 2006 to 2007).

Figure 4-1 Wind rose plots for air quality monitoring stations and Gibraltar airport

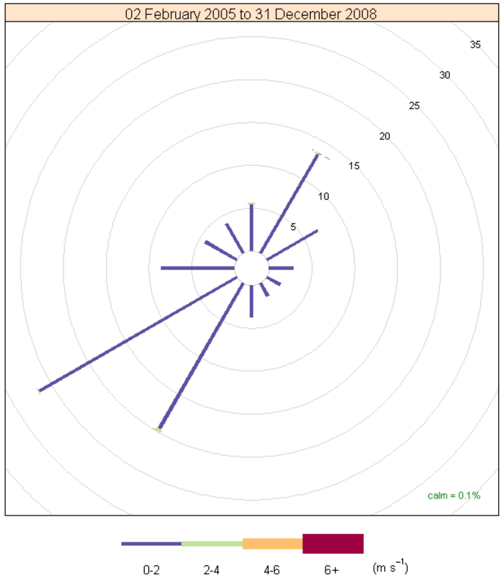
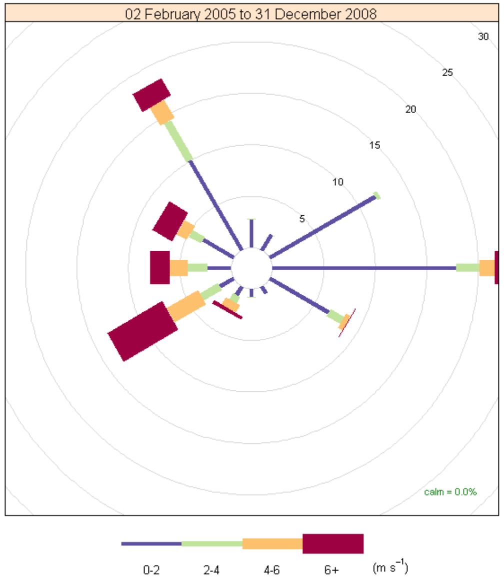
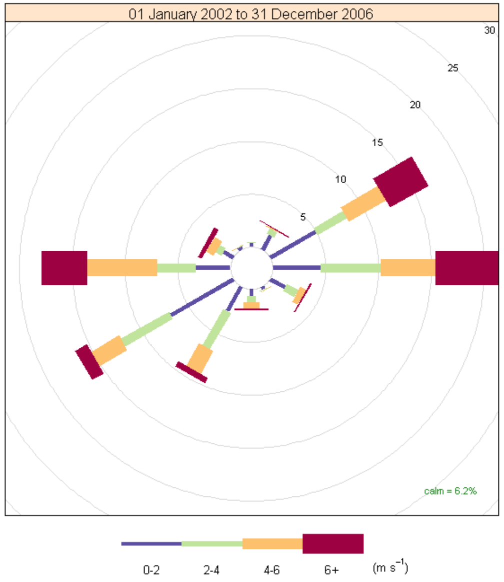
Rosia Road	Bleak House	Gibraltar airport
		

Figure 4-2 Polar frequency plots for air quality monitoring stations and Gibraltar airport

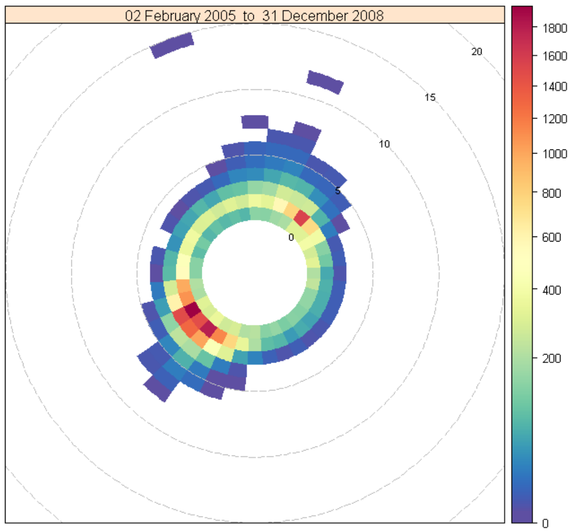
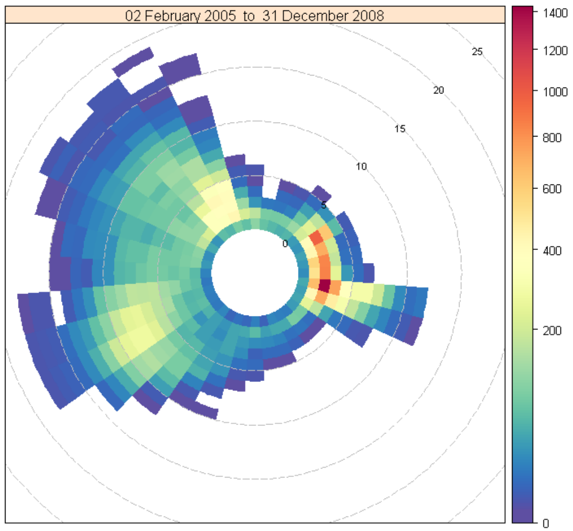
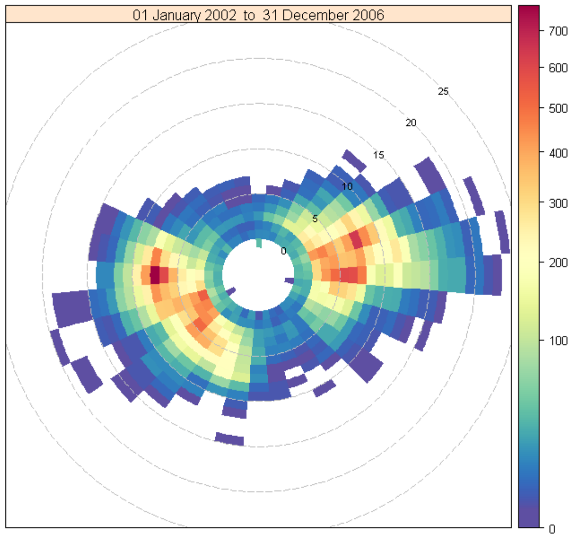
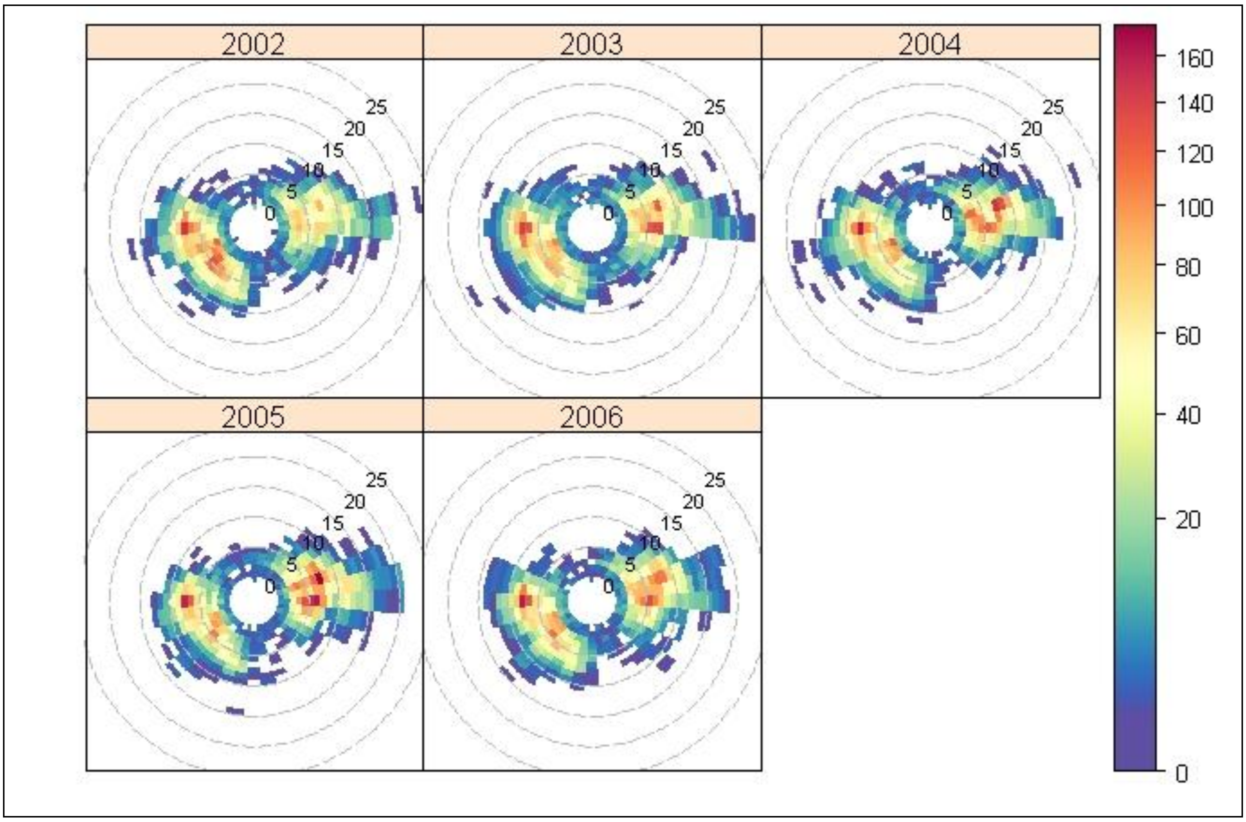
Rosia Road	Bleak House	Gibraltar airport
		

Figure 4-3 Variation in met data at Gibraltar airport 2002-2006

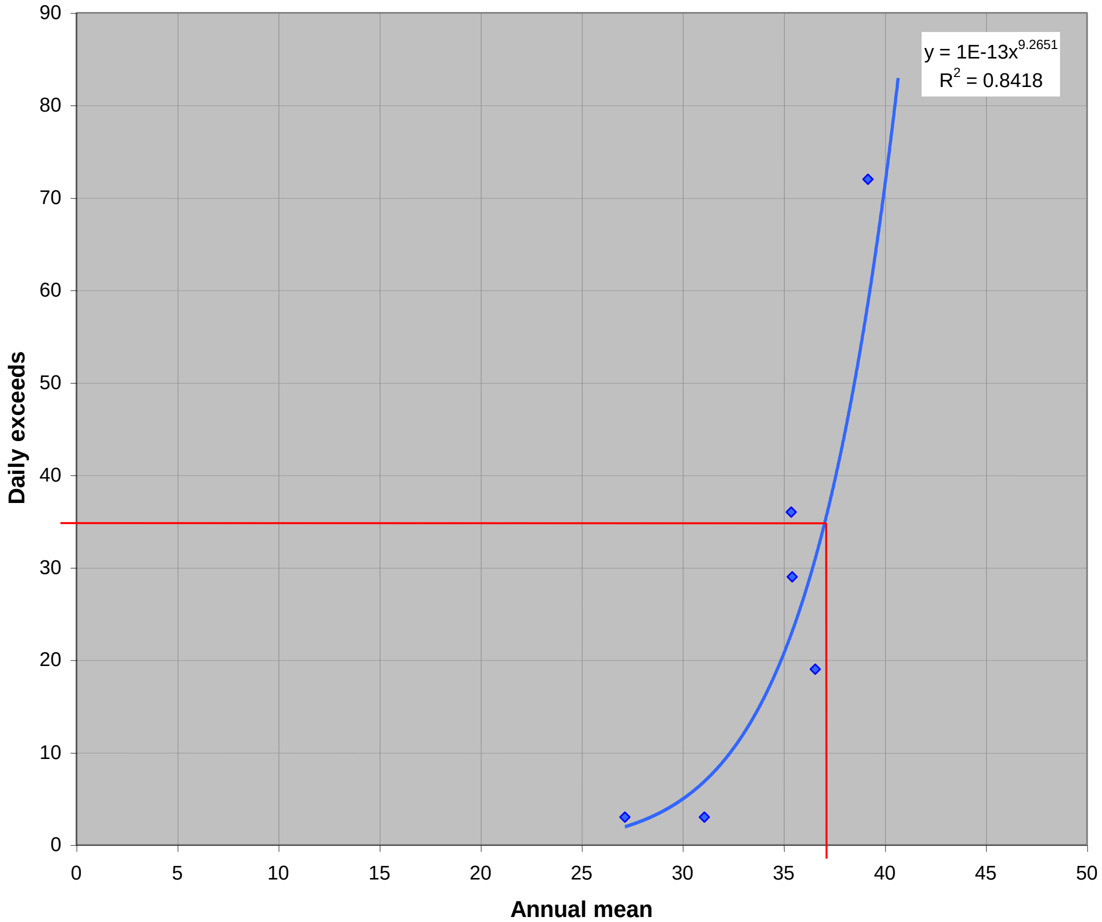


5 Relating annual means to daily exceedences

The PM_{10} daily LV is the exceedence metric of concern in Gibraltar. Every possible attempt has been made to quantify the impact of different sources to measured concentrations on a daily basis (e.g. natural African dust correction) though this is rarely possible. Some models, such as the EMEP model used to estimate contributions from transboundary sources, are only capable of producing an annual mean. The standard output of dispersion models (typically from the ADMS dispersion model) is an annual mean metric. The ADMS model is capable of producing a 90th percentile but this metric cannot be related to specific days in the measured data set. In other cases the source related data, such as road traffic counts, are not available for each specific day and so representative samples must be used and generalisations across the year must be made.

As a result of these complexities, it has been necessary to produce a relationship between the annual mean concentration and the number of exceedences of the daily LV in Gibraltar. This has been achieved using annual statistics from the monitoring campaign between 2005 and 2008 which have undergone the daily correction for natural African dust. PM_{10} data from Bleak House and Rosia Road FDMS in 2008 were added to the Partisol data at Rosia Road from 2005 to 2008. The relationship is presented in Figure 5-1. The relationship demonstrates that an annual mean of 37.1 µg m^{-3} or below is necessary to suggest compliance with the daily LV.

Figure 5-1 Relationship between annual mean concentration (µg m^{-3}) and number of exceedences of daily LV



6 Directional analysis

The Openair toolset has been used to interrogate data from the Gibraltar air quality monitoring network. Figure 6-1 shows directional analysis of PM_{10} concentrations at the Rosia Road monitoring site. These are daily data gathered from the Partisol instrument and used in conjunction with hourly met data from the station that has been vector averaged up to daily wind speed and direction. The distance around the origin (º) represents the polar direction while the distance from the plot origin outwards represents the wind speed (1 ms^{-1} tick marks). The averaging of the hourly met data to daily values is the reason why wind speeds are relatively lower in these plots than in successive plots based on hourly met data. Note that the plots have been set to omit data for bins where less than 2 observations occur so that the plotted surface is not unduly influenced by individual high observations. Different particle size fractions (PM_{10} and $PM_{2.5}$) are both measured by the Partisol instruments. $PM_{2.5}$ is a subset of PM_{10} has been subtracted from corresponding PM_{10} measurements to give an indication of the coarse particle fraction (PM_{coarse}). PM_{10} is shown in Figure 6-1 (a), $PM_{2.5}$ in (b) and PM_{coarse} in (c).

The plot for PM_{10} shows a distinct wind direction and speed 'hotspot' to the west of the monitoring site suggesting a source in this direction. $PM_{2.5}$ also displays this area as a possible source but for this size fraction it is a lot weaker. The major hotspot for $PM_{2.5}$ occurs at low wind speeds (typically less than 1 ms^{-1}) with no strong directional signature. This is suggesting that the road running adjacent to the monitoring site is the cause, specifically poorly dispersed road traffic exhaust emissions. The coarse particle fraction strongly mirrors PM_{10}, indicating that the source to the west is predominantly coarse material. There is no evidence of elevated PM_{coarse} at low wind speeds which suggests that resuspended road dust is not a significant contributor (note that modelling of this component is attempted in Section 12.4.2).

The directional evidence for PM_{10} sources demonstrated above is in contrast to initial expectations that the MOD and OESCO power stations to the south would be the dominant contributor to measured concentrations. This assertion had been based on the fact that the modelled contribution to measured NO_X concentrations were high and the plant uses relatively old technology and has no contemporary stacks but rather uses open cowls in the roof approximately 3 storeys up. This is a very low emissions height for such a potentially large source. A comparison against polar plots for NO_X (a) and NO_2 (b) in Figure 6-2 shows that PM_{10} has a much stronger westerly directional signature than NO_X which is much more southerly. In this case the NO_X hotspots suggest the nearby power stations as the dominant contributor and this evidence is reinforced by modelling work previously provided to the Gibraltar Environmental Agency[9] which also identified significant contributions of NO_X from the power station. Dispersion modelling of PM_{10} emissions from the power stations has been undertaken using ADMS4.1 using similar methodology as that used for the NO_X modelling study and has been presented in a separate report[10] to the Gibraltar Environmental Agency. The findings of that report were that both power stations together contributed approximately 0.6 µg m^{-3} to annual mean PM_{10} concentrations and 3.1 µg m^{-3} to p.90 daily mean concentrations (equivalent to 35 permissible exceedences of 50 µg m^{-3}) in 2006. As described in Section 4.3, 2006 was the most recent year for which model-ready meteorological data was obtained for ADMS but meteorological trends across 2006 and 2007 (Figure 4-3) show that it is reasonable to assume the model results are representative of the reference year in 2007. The model results for the period 2002 to 2006 were relatively stable and the operational parameters of the power station have not changed significantly (if at all) between 2006 and 2007.

In the absence of a strong contribution from the power station, the westerly signature of PM_{coarse} is likely to originate from the harbour area, either over the water (within the South Mole or slightly beyond) or the area immediately west of the monitoring station between it and the water's edge. Natural contributions from sea salt can likely be ruled out because the signatures shown in the plots are so specific in direction and wind speed (2.5 to 3.0 ms^{-1}). A sea salt contribution would be greater at higher wind speeds and would not be limited to such a small upper and lower wind speed range. Similarly, a sea salt contribution would likely extend to a broad direction range from around 200º to

[9] Abbott, J (2007) Dispersion modelling of MOD and OESCO power station discharges (AEA Report to Gibraltar Environmental Agency: AEA/ED48335/R2455 Issue 1)
[10] Abbott, J (2009) Dispersion modelling of MOD and OESCO power station PM_{10} discharges (AEA Report to Gibraltar Environmental Agency: AEA/ED43072/R2835 Issue 1)

340º. There will be a sea salt contribution to Rosia Road (noted in Section 15.1) but these plots suggest that the sea salt contribution is not directly associated with the defined signatures evident in Figure 6-1. A further possibility is that emissions from shipping (particularly from bunkering operations in the Port of Gibraltar) are contributing to concentrations associated with this wind direction. The contribution from shipping has been modelled explicitly and is presented in a separate report to the Gibraltar Environmental Agency[11]. This modelling concluded that shipping from the Port of Gibraltar contributed 1.1 µg m^{-3} to annual mean concentrations – this is a notable contribution but not enough to account for the directional signature evident in Figure 6-1.

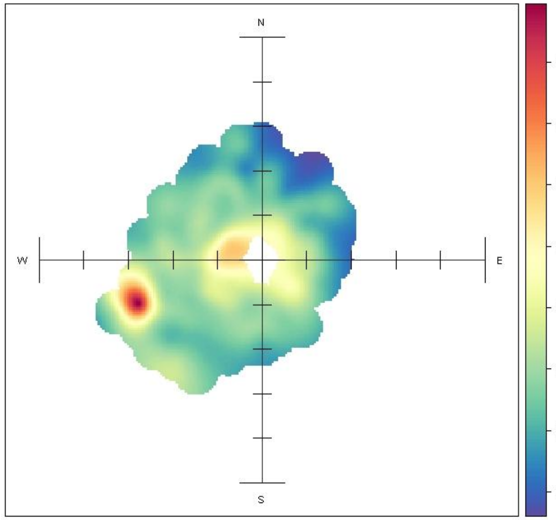
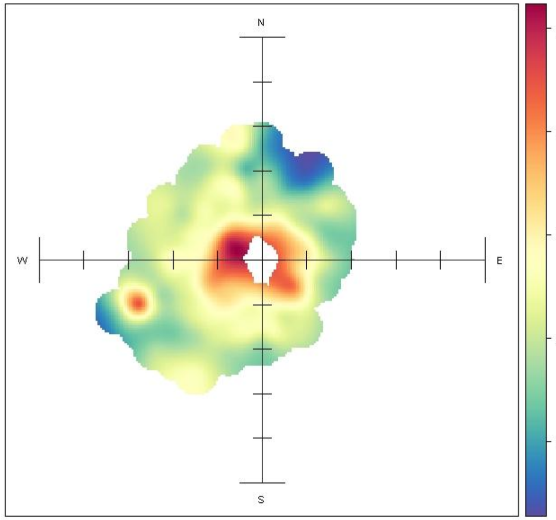
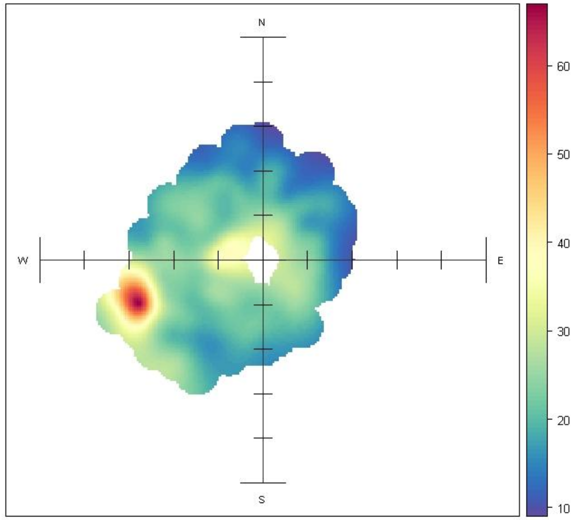
The most obvious alternative source of particles from this direction from the monitoring site is an area of unmade land between the monitoring site and the harbour's edge. This is overlaid by loose material providing a fugitive source of wind blown dust. It has also been used for bulk handling operations of construction materials in recent years which would compound its role as a potential source. Anecdotal evidence from the Gibraltar Environmental Agency suggests that bulk handling and storage activities from this area peaked in 2007 and was then more tightly controlled for air quality purposes during 2008 which may help to explain the decline in exceedences between 2007 and 2008. As a result of this directional analysis and evidence from the Gibraltar Environmental Agency, this area was explicitly modelled and the results are presented in Section 13.

Figure 6-3 shows directional analysis in another polar plot – in this case hourly PM_{10} data from Rosia Road (from the FDMS instrument) is shown. This dataset covers a significantly short (but recent) period compared with the daily Partisol data but also picks out specific source to the south west of the monitoring site. In this example, the wind speeds are more interesting because, unlike the daily Partisol analysis in Figure 6-1, averaging these hourly met observations to daily means has not been necessary. As a result, the influence of wind speeds on the measured concentrations from the south west is more evident. The high wind speeds at which the maximum concentrations occur further reinforces the evidence that these are coarse particles that are providing the dominant contribution in this direction, strengthening the evidence that the source is related to fugitive emissions from the area unmade ground. Hourly FDMS data at Rosia Road is only available for PM_{10} so a calculation of the coarse fraction by subtracting $PM_{2.5}$ is not possible on an hourly basis. However the influence of wind speed shown by the hourly FDMS data coupled with the PM_{coarse} polar plot using the daily data together indicate coarse particles of wind blown dust picked up at reasonably high wind speeds by prevailing winds towards the monitoring station. Plotting the directional data of PM_{coarse} for different years at Rosia Road (Figure 6-4) demonstrates the significant increase in the reference year (2007) from this source compared with other years, however the source from this direction is evident in 2005 and 2008 also, though at lower concentrations. The plot for 2008 also suggests higher concentrations of PM_{coarse} at low wind speeds (typically 1 ms^{-1}) from all directions. This may be evidence of an increase in poorly dispersed resuspended road dust from traffic passing the monitoring site.

Speciated data from individual filters presented in Section 15 are used to help characterise the nature of different contributing sources and may help to confirm the influence of both sea salt and construction dusts or stockpiled dusty construction materials from this direction.

[11] Abbott, J (2009) Contribution from shipping emissions to PM_{10} and nickel contents on Gibraltar (AEA Report to Gibraltar Environmental Agency: AEA/ED43072/R2833 Issue 1)

Figure 6-1 Polar plots showing variation of particulate matter concentrations with wind speed and direction* from daily measurements (Partisol instrument) at Rosia Road, 2005 to 2008

(a) PM_{10}	(b) $PM_{2.5}$	(c) PM_{coarse}
		

* associated meteorological data vector averaged to daily from hourly observations at monitoring site – note that the wind speeds on these axes are in the range 0-5 ms^{-1} which is lower than hourly data because it has been averaged to daily values.

Figure 6-2 Polar plots showing variation of NO_X and NO_2 concentrations with wind speed and direction from hourly measurements at Rosia Road

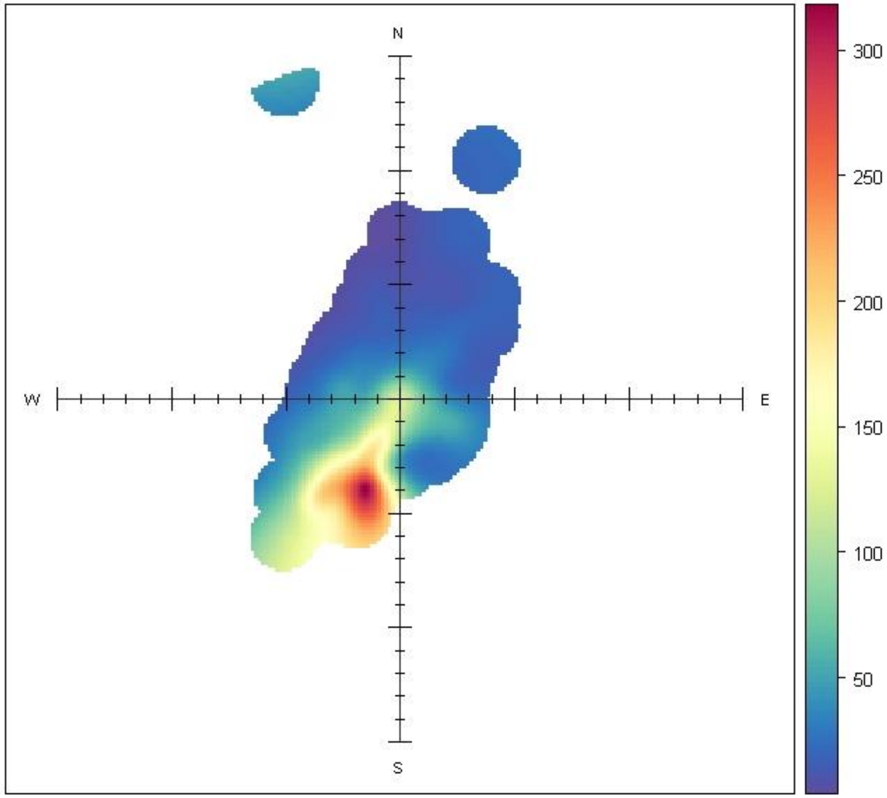
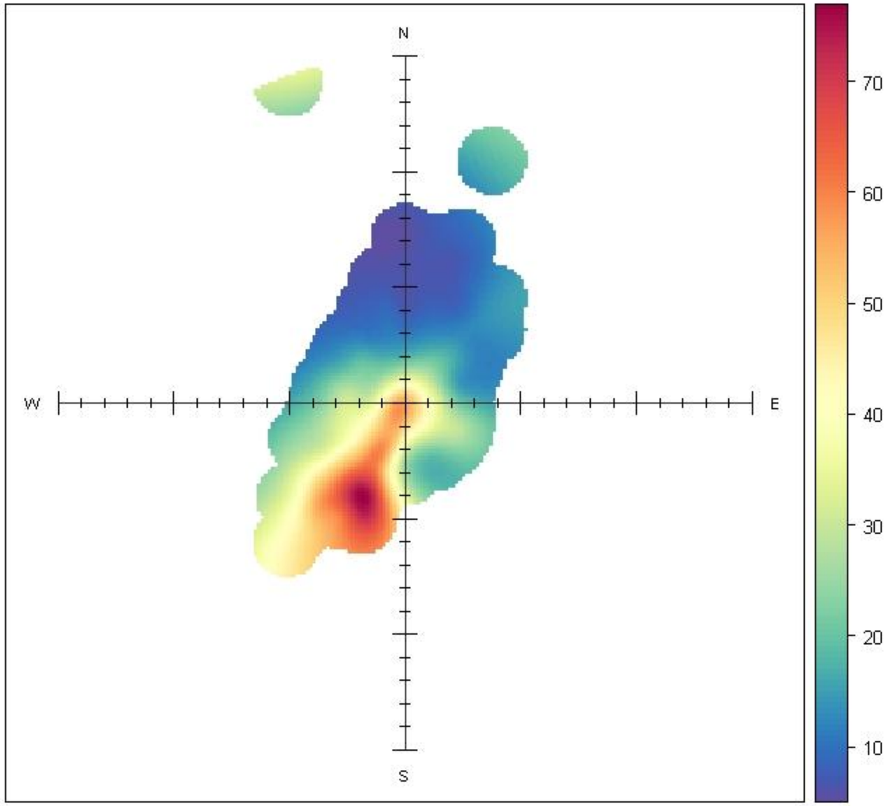
<table>
<tr><th>(a) NO_X</th><th>(b) NO₂</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Figure 6-3 Polar plot showing variation of PM_{10} concentrations with wind speed and direction from hourly measurements (FDMS instrument) at Rosia Road

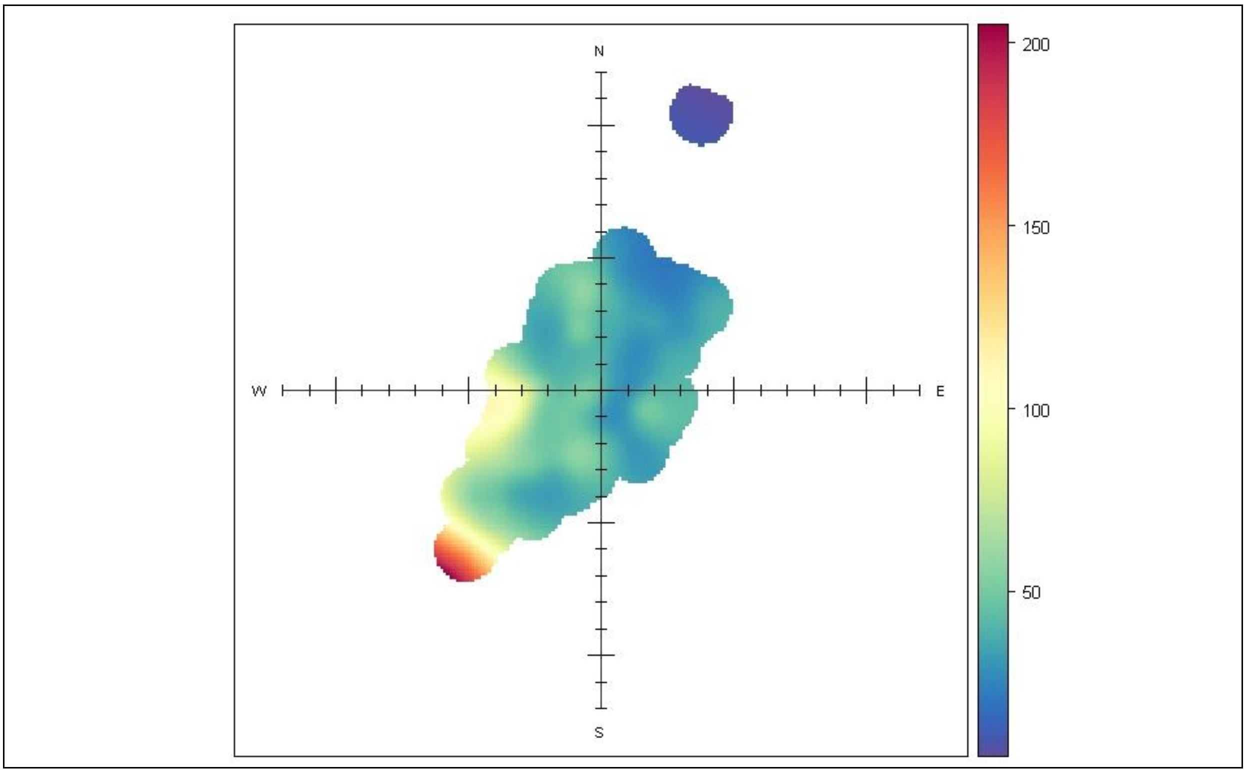
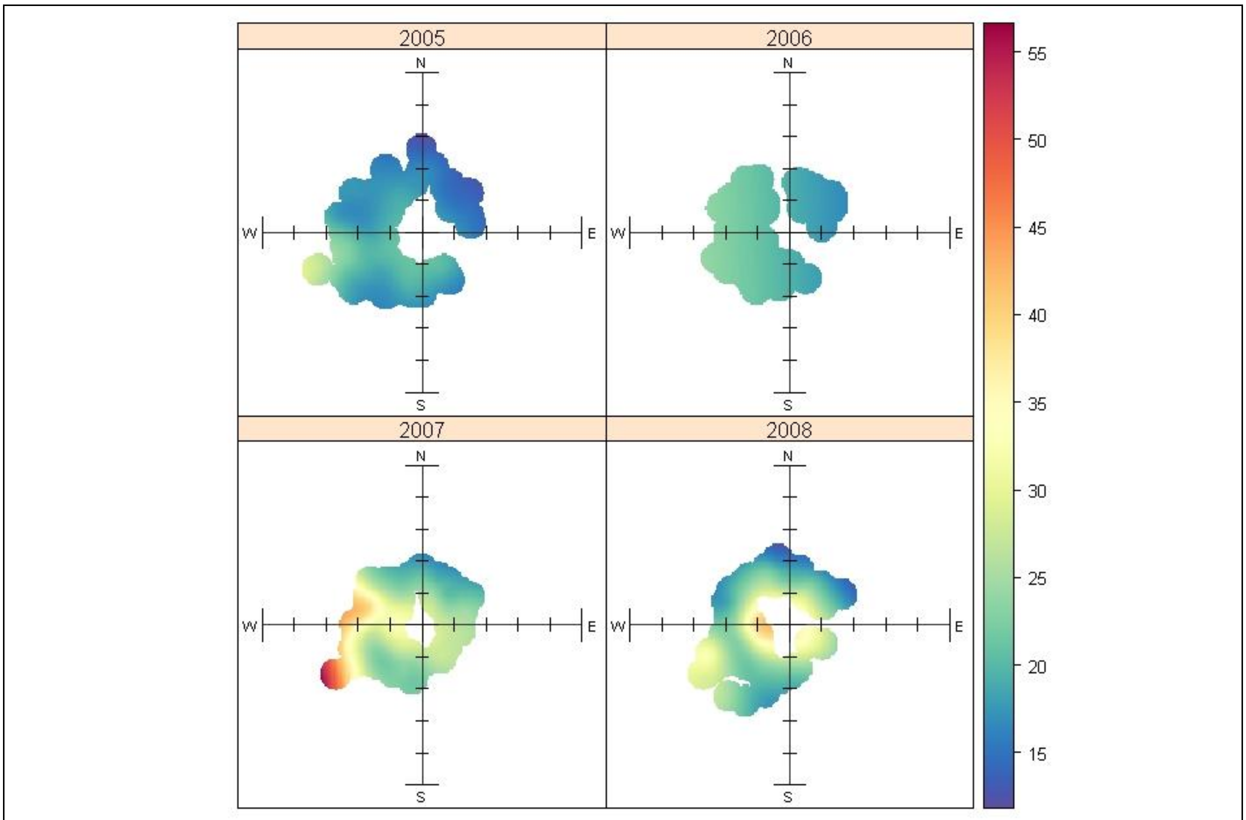


Figure 6-4 Polar plots showing variation of PM_{coarse} concentrations with wind speed and direction from daily measurements (Partisol instrument) by year, 2005-2008 at Rosia Road



7 OESCO and MOD power stations

Some discussion regarding the modelled contribution from the power stations has been included in Chapter 6. This chapter summarises results from the modelling studies undertaken and explains which of these values will be used to support the TEN application (presented in Table 7-1 below and Table 16-1 in the concluding chapter of this report). The authoritative explanation of the modelling process and methodology for the Gibraltar power stations has been included in a separate technical report[12].

Additional modelling work undertaken by Air Quality Consultants (AQC) on behalf of Environmental Gain (ENGAIN) and included in the Environmental Statement[13] for the proposed power station at Lathbury Barracks estimated the annual mean contribution from the *existing* power station to Rosia Road to be approximately 17 $\mu g\ m^{-3}$ to annual mean concentrations (ENGAIN environmental statement - technical reports, Volume 2: Air Quality, p.35). Modelling by AEA on behalf of the Gibraltar Environmental Agency estimated this to be significantly lower at 0.6 $\mu g\ m^{-3}$. The AQC modelling has been reviewed by AEA and the difference between the model results has been attributed to the higher production capacity of the power stations that AQC assumed in their modelling scenario compared with the AEA assumption. It has been decided that a conservative approach to these modelling results should be adopted, therefore the AEA model result has been used to represent contributions associated with the power stations in 2007 (i.e. 0.6 $\mu g\ m^{-3}$). If this proves to be significantly lower than the contribution from the power stations in reality, then a greater improvement in air quality will result from the decommissioning of the existing power stations and replacement with the proposed new power station.

AQC modelled annual mean contributions from the new power station at Lathbury Barracks in 2011 were 0.3 $\mu g\ m^{-3}$ (ENGAIN environmental statement - technical reports, Volume 2: Air Quality, p.42), similar to the AEA model results for 2007. This represents a slight decline in contribution resulting from new power station technology and standards, a location further from the main centre of population and a higher stack. Central to applicability of this analysis in supporting the TEN application is the proposed decommissioning of the existing 3 power stations (ENGAIN environmental statement - technical reports, Volume 2: Air Quality, p.42).

Table 7-1 Modelled contribution from power stations to annual mean concentration at Rosia Road ($\mu g\ m^{-3}$)

2007 (AEA model result)	2011 (AQC model result)
0.6	0.3

[12] Abbott, J (2009) Dispersion modelling of MOD and OESCO power station PM_{10} discharges (AEA Report to Gibraltar Environmental Agency: AEA/ED43072/R2835 Issue 1)
[13] Proposed new power station, Lathbury Barracks, Gibraltar: Environmental Statement (Volume 2: technical reports; Chapter 1 (Air Quality) and appendices AQ1-AQ5

8 Shipping

As noted in Chapter 1, modelled contributions to measured annual mean concentrations in Gibraltar from shipping have been presented in a separate technical report detailing the methodology and results[14]. The summary of that modelling is presented in this Table 8-1, below and in Table 16-1 in the concluding chapter of this report.

Three individual shipping sources affecting Gibraltar have been identified and these have been modelled explicitly so providing a breakdown of individual contributions to best aid authorities in Gibraltar in their assessment of possible measures to abate these sources.

The modelling confirms a total contribution to measured annual mean concentrations of 1.98 $\mu g\ m^{-3}$, the majority of which is attributed to nearby fuel bunkering operations in the Port of Gibraltar to the south west of the Rosia Road monitoring site. A contribution of 0.88 $\mu g\ m^{-3}$ is estimated from shipping sources outside the control of the Gibraltarian authorities.

Table 8-1 Modelled contribution from shipping to annual mean concentration at Rosia Road ($\mu g\ m^{-3}$)

Shipping source	2007
Port of Gibraltar	1.1
Algeciras Port	0.6
Straits of Gibraltar	0.28
Total	1.98

[14] Abbott, J (2009) Contribution from shipping emissions to PM_{10} and nickel contents on Gibraltar (AEA Report to Gibraltar Environmental Agency: AEA/ED43072/R2833 Issue 1)

9 Contributions from outside Gibraltar

Transboundary contributions are significant in Gibraltar. Unlike natural contributions which can be quantified and removed from measured concentrations, transboundary contributions are outside the direct control of the Member State. As noted in Chapter 1, modelled contributions to measured annual mean concentrations in Gibraltar from sources originating beyond their borders have been presented in a separate technical report[15]. The summary of that modelling is presented in Table 9-1, below and in Table 16-1 in the concluding chapter of this report. The modelling suggests an estimated total contribution to annual mean concentrations of 8.2 µg m^{-3} in Gibraltar from transboundary sources.

Table 9-1 Modelled transboundary contribution to annual mean concentration at Rosia Road (µg m^{-3})

Transboundary source type	2007
Primary PM_{10}	2.8
Secondary PM_{10}	5.4

[15] Abbott, J (2009) Transboundary particulate matter pollution on Gibraltar (AEA Report to Gibraltar Environmental Agency: AEA/ED43072/R2834 Issue 1)

10 Natural sources

Two natural sources of PM_{10} affect measured ambient air in Gibraltar. These are

- wind blown dusts from Africa
- sea salt

Natural African dust has been quantified for years 2005 - 2008 using a methodology developed and used by Spain. The method was discussed at the workshop 'Contribution of natural sources to PM levels in Europe' organized by the JRC in Ispra in October 2006 and has been reviewed in the subsequent workshop report (Marelli, 2007[16]). The adoption of this method by Gibraltar therefore has the additional advantage of being consistent with neighbouring Member States. Separate technical reports are available from the Gibraltar Air Quality Website for 2006[17], 2007[18] and 2008[19]. Data from 2005 has also been corrected but has not been presented in a specific report as measured concentrations during 2005 did not exceed the annual or daily LVs. Results of this quantification are summarised here in Table 10-1.

Table 10-1 Quantification and adjustment of measured concentrations of natural African dust, 2005-2008

YEAR	Annual mean (µg m^{-3})		African dust contribution to annual mean (µg m^{-3})	Daily exceedences	
	Uncorrected	Corrected		Uncorrected	Corrected
2005	35.9	31.1	4.8	16	3
2006	39.9	35.4	4.5	60	29
2007	45.0	39.2	5.9	109	72
2008	40.5	35.4	5.1	63	36

Estimated contributions to annual mean from African dust have remained reasonably consistent across several years at approximately 5 µg m^{-3}. In 2005, the first year of monitoring in Gibraltar, both the annual mean and daily LVs were met prior to any correction for natural sources as allowed by the Directive. In 2006 the annual mean LV was met but the daily LV was exceeded until correction for natural African dust reduced the number of exceedences to below the permissible 35. Original analysis (in the report for 2006) calculated this as 32 but after a methodological change in 2007 (see report for 2007) this was amended to 29. In 2007 both the annual mean and daily LV were exceeded. By accounting for the African dust the annual mean was reduced to below the LV but the number of daily exceedences remained above 35 – hence this year has been selected as the reference year for thePM_{10} TEN application. The annual mean and daily LVs were also exceeded in 2008. The African dust correction resulted in the annual mean LV being met and the daily LV being a single exceedence above the permissible number. Although the daily LV was exceeded after correction, this represents a significant improvement in air quality from the previous year. It is likely that this improvement is related to ad-hoc intervention by the Gibraltar Environmental Agency to bulk handling operations on unmade land near the Rosia Road monitoring site (see Chapter 13).

Given the coastal location of Gibraltar, sea salt is potentially a significant natural contributor to measured PM_{10} concentrations, particularly in light of the 'rotor effect' on the meteorology (see Chapter 4.2) which results in winds affecting Rosia Road from across the water for the majority of the time. Efforts to quantify the contribution from sea salt are ongoing. Anecdotal evidence from Spanish researchers suggests approximately 5 µg m^{-3} PM_{10} from sea salt at the nearby La Linea monitoring site (a short distance from Gibraltar's northern frontier with Spain). Although this would be a significant contribution, this is not sufficiently defensible evidence to apply to a further correction for natural sources for policy purposes. Further information on sea salt analysis has been presented in Chapter 15.1 which discusses efforts to use filters for speciated analysis, including sea salt apportionment.

[16] Marelli, L (2007) Contribution of natural sources to air pollution levels in the EU - a technical basis for the development of guidance for the Member States (post workshop report from 'Contribution of natural sources to PM levels in Europe' workshop organized by JRC, Ispra, October 2006. EUR 22779 EN)
[17] Kent, A J (2008) Measured PM_{10} concentrations in Gibraltar in 2006 removal of the natural component http://www.gibraltarairquality.gi/documents/Gib_natural_quantification_2006_v2.pdf
[18] Kent, A J (2009) Measured PM_{10} concentrations in Gibraltar in 2007 removal of the natural component http://www.gibraltarairquality.gi/documents/Gib_natural_quantification_2007_v1.pdf
[19] Kent, A J (2009) Measured PM_{10} concentrations in Gibraltar in 2008 removal of the natural component http://www.gibraltarairquality.gi/documents/Gib_natural_quantification_2008_v1.pdf

11 Construction dusts

Although there were no data available with which to characterise and quantify these multiple sources, Gibraltar has experienced (and continues to experience) significant construction activity across much of the peninsula including several large-scale developments over a long period of time.

Given the small geographical area of Gibraltar, and the concentration of urban development into the northern and western areas by the topography, several concurrent construction projects are capable of influencing air quality across a relatively large urban area.

Therefore, despite the absence of a construction dust category in this formal quantification, it is recommended that authorities in Gibraltar do implement legislative abatement strategies to control emissions from these processes and police compliance with this legislation.

12 Road traffic emissions

Road traffic sources are also expected to have a strong contribution to measured PM_{10} in Gibraltar although no formal attempt to quantify this has previously been undertaken. Rosia Road is classified as a roadside site and the sample inlet is located approximately 4m from the kerb. As a result, poor dispersion conditions or winds from anywhere between 0-170º will result in a road traffic component in the measured data. The impact of poor dispersion on measured concentrations is demonstrated in Figure 6-1b which shows elevated concentrations at wind speeds of 1 ms^{-1} or lower from a localised source hence no strong directional signature.

12.1 Roadside increment

The influence of road traffic on ambient concentrations can be quantified as the roadside increment. The roadside increment is typically calculated using a concentration from the roadside site (Rosia Road) and corresponding background site (Bleak House) to represent concentrations in the absence of the road traffic source. In Gibraltar, monitoring of PM_{10} at the background location (Bleak House) commenced in June 2008 and so there is limited daily data with which to undertake this calculation. The assumption when using this method is that the additional concentration measured at roadside, over and above that at the background site, is associated purely with emissions related to the presence of the road (i.e. road traffic exhaust emissions and resuspended roadside dust). However, the industrial complexity of Gibraltar means that this is not so and the Rosia Road site may also be affected by several non-road sources such as power station emissions and wind blown dust from nearby unmade land and bulk handling operations, all of which would affect the calculation of the roadside increment.

In order to resolve this problem, daily PM_{10} data from Rosia Road and from Bleak House monitoring stations were analysed with met data that was vector averaged from hourly to daily data from each station. The data was filtered so that only observations during wind directions from 0°-170° (the easterly direction of the adjacent road relative to the monitoring site) when both sites had valid concentrations were used. The intention was to remove the influence of the power station, approximately 500m to the south-south-west. This provided a roadside increment for 21 of the available 195 days (11%). The ‘rotor’ effect of the Rock discussed in Section 4 is such that there is a relatively small subset of data available at Rosia Road to examine concentrations when the wind is from the direction of the road. With this small amount of data the result is an average roadside increment of 14 µg m^{-3}.

An alternative method to calculate the roadside increment is proposed by the European Environment Agency[20] and relies on hourly data from the roadside site only. Hourly PM_{10} data is available from Rosia Road from May 2008 and was examined from this date through to the end of June 2009, using the minimum concentration in the first 4 hours of each day to represent the background concentration at Rosia Road. Once again, in order to capture the influence of road traffic isolation and remove the contribution from the power station, only observations with a wind direction of 0º-170º were used. The average background concentration for these observations was 26 µg m^{-3}, compared with an average roadside concentration of 32 µg m^{-3} when the wind direction was easterly. The result is a calculated roadside increment of 6µg m^{-3}. The hourly FDMS data has significant advantages over the available Partisol data for this exercise because the hourly resolution and longer operational period of this monitoring results in a far greater data volume to interrogate. A further advantage is that the uncertainties associated with the vector averaging from hourly to daily met data are not an issue. Of the available 9864 hours for this calculation, 32% satisfied the easterly wind direction criteria – for these reasons it has been considered that this approach is the more reliable of the two and is an approach sanctioned by the EEA.

Both approaches are summarised in Table 12-1.

[20] van Aalst, R (2003) The contribution of traffic to concentrations of PM_{10} in streets and urban areas http://ec.europa.eu/environment/archives/air/cafe/pdf/steering_technical_group/03092930traffic_contributions.pdf

Table 12-1 summary statistics, PM_{10} roadside increment

Method	Average background	Average roadside concentration	Average roadside increment	Percentage of available time from east
Daily Partisol calculation	36	25	14*	11%
Hourly FDMS calculation	32	26	6	32%

*** Note that the roadside increment is calculated on a daily basis and averaged to 14 µg m^{-3} rather than the difference between the average roadside and background concentration.**

12.2 Temporal variation at Rosia Road

Roadside concentrations of different pollutants were plotted using Openair to illustrate temporal variation at the Rosia Road site. NO_X (as NO_2), NO_2, CO, benzene and gravimetric PM_{10} were selected and are presented in Figure 12-1. This plot shows the diurnal variation by hour of the day (lower left pane), the seasonal variation by month (lower central pane) and weekly variation by day (lower right pane). The upper pane of the plot shows the typical hourly variation throughout the week. Examining the temporal variation in this way is an incisive method of analysis because road traffic patterns are known to vary over time according to working hours and days. Due to the differences in scale of measured benzene and CO concentrations compared with NO_X and PM_{10}, the plot has been normalised to better compare the trends. Note that the CO units are mg m-3 compared with the other pollutants that are µg m^{-3}. NO_X is as NO_2. The Partisol PM_{10} data was unsuitable for this analysis because it provides daily concentrations which prohibit examination of diurnal variation. Therefore, the FDMS data gathered from June to December 2008 was used instead.

Several aspects of this plot serve to demonstrate the roadside influence at this monitoring site. NO_X, NO_2, CO and PM_{10} are all sources that are associated with road traffic emissions and these are all highly correlated with one another. All pollutants peak in the morning at a time consistent with the morning rush hour (07:00 - 08.00 GMT). The concentrations of these pollutants decline sharply for Saturday and Sunday when traffic is typically lighter but are high during weekdays when traffic is also more common.

Figure 12-1 Rosia Road, time variation of NO_X, NO_2, CO, benzene and gravimetric PM_{10}

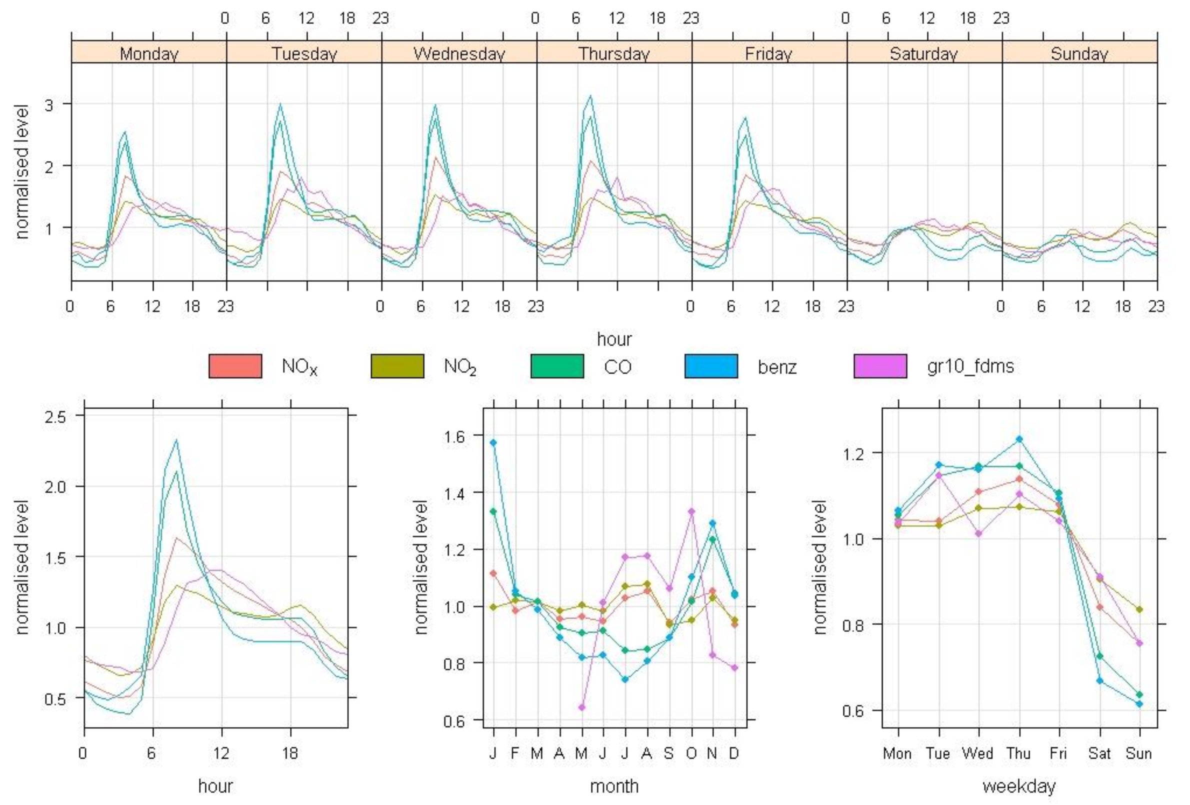


Figure 12-2 Rosia Road, time variation of NO_X, NO_2, CO, benzene and gravimetric PM_{10}, wind direction = 0-170º

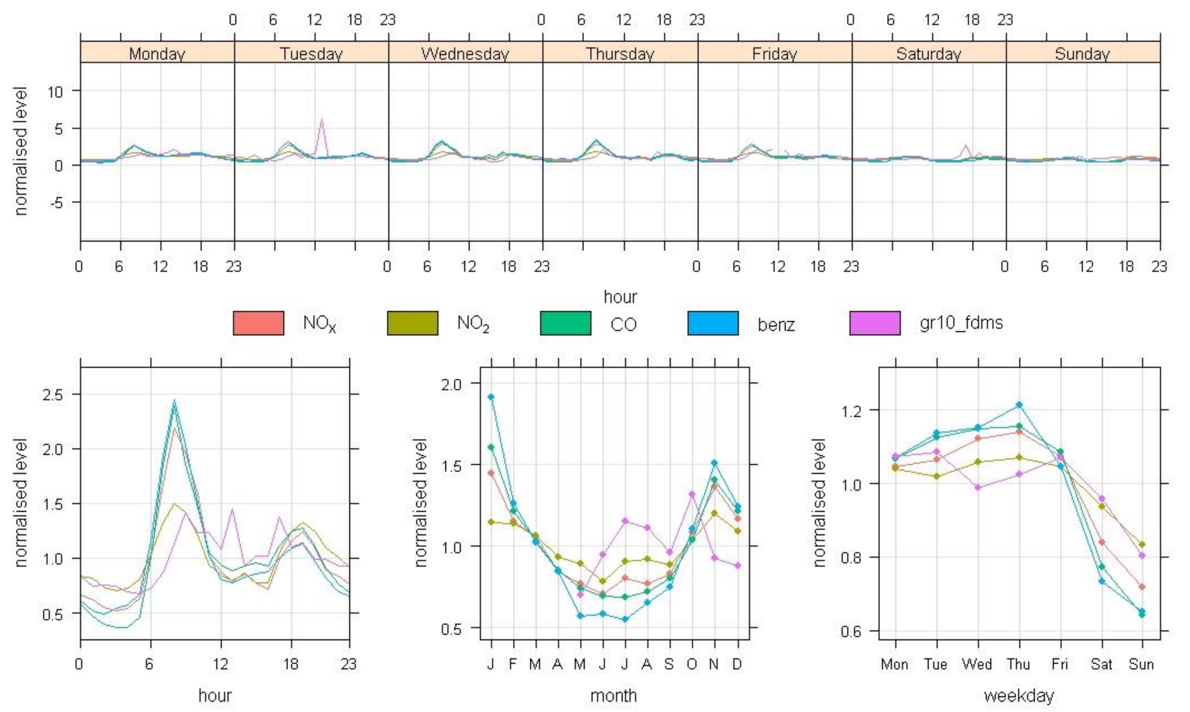


Figure 12-2 shows the same information as Figure 12-1 but the data has been filtered so that only observations when the wind direction was between 0-170 are shown. Filtering in this manner has the effect of isolating the roadside signal so that the influence of other sources is less apparent relative to road traffic contributions. The diurnal variation component of Figure 12-2 shows the distinctive double peak associated with road traffic – each peak corresponding to the rush hour in the morning and evening. NO_X, NO_2, CO and benzene all follow this profile strongly. In general terms PM_{10} also conforms to this pattern although there is more variability during the middle of the day – there are other PM_{10} sources that are not easily filtered out of the data set using wind direction such as natural African dust.

The most notable feature of Figure 12-2 is the high concentrations of benzene and CO measured at Rosia Road. The plot above illustrates the possible contribution from 2-stroke vehicles such as mopeds and scooters that are very common in Gibraltar. These pollutants are taken together as an indicator of incomplete combustion that is known to be related to 2-stroke vehicles. A comparison of benzene concentrations at Rosia Road with London's Marylebone Road monitoring site (Table 12-2) provides some context for this trend. Benzene concentrations measured at Rosia Road are between 30% and 60% higher than those at Marylebone Road and are very highly correlated with CO concentrations.

Table 12-2 Comparison of annual mean Rosia Road benzene concentrations with Marylebone Road, London (μg m^{-3})

Year	Rosia Road benzene	Marylebone Road
2005	2.33	2.28
2006	2.75	1.93
2007	2.28	1.42
2008	1.75	1.36

12.3 Breakdown by vehicle class

As a precursor to apportioning road traffic contributions to different vehicle types it is necessary to conduct a review of different vehicle classes on Rosia Road. This allows the overall influence from road traffic to be placed in context but also provides an idea of the impact that policy measures might have to alter the vehicle fleet composition. This assessment has been undertaken using sample road traffic count data at Rosia Road and the registered vehicle fleet composition for Gibraltar. Official automatic traffic counts for Rosia Road have been undertaken by the Highways Agency for

- 30/10/2006-12/11/2006 and 04/06/2007-17/06/2007 (Northbound)
- 30/10/2006-12/11/2006 and 04/06/2007-24/06/2007 (Southbound)

This data is based on the ARX classification scheme (a modified version of AustRoads94), which contains 12 specific classes of vehicle ranging from very small/light (Class 1) to very heavy (Class 12). Unfortunately the classification is principally based on vehicle length and number of axles rather than vehicle or engine type which is more useful for analysis of air quality issues. For example, in Class 1 it includes bicycles which are non-polluting and motorcycles which are polluting (particularly the 2-stroke variety which are very polluting). Class 2 includes vehicles ranging from small cars to large utility vehicles and light vans which may vary substantially in terms of emissions. Class 3 is a classification for vehicles towing (boats, caravans and trailers) and the vehicle type and pollution associated with it could be any type of vehicle. Classes 4 through 12 all cover heavier vehicles such as trucks or buses, non-articulated or articulated with different numbers of axles which aren't likely to vary significantly in terms of contribution to air quality. Therefore the lower classes are not disaggregated enough to provide very useful emissions information and the higher classes (4-12) are split up to an unnecessary extent for emissions analysis.

In order to provide more specific information on vehicle classes and relative contributions, the Gibraltar Environmental Agency undertook a small-scale road traffic counting campaign at Rosia Road. This occurred across three days in late July 2009. Although the reference year is 2007, the road layout, speed limit and traffic flow is not expected to have altered from 2007 to 2009 so this data is considered to be representative of the reference year. A morning rush hour period was taken (08:00 to 09:30) when peak traffic was expected and a quiet evening period (20:00-21:30) when traffic was expected to be minimal. Together it was assumed that these morning and evening samples would be representative of the busier and quieter times of the day and, taken together, representative of the day as a whole. The counts were split by vehicle type into the following classes:

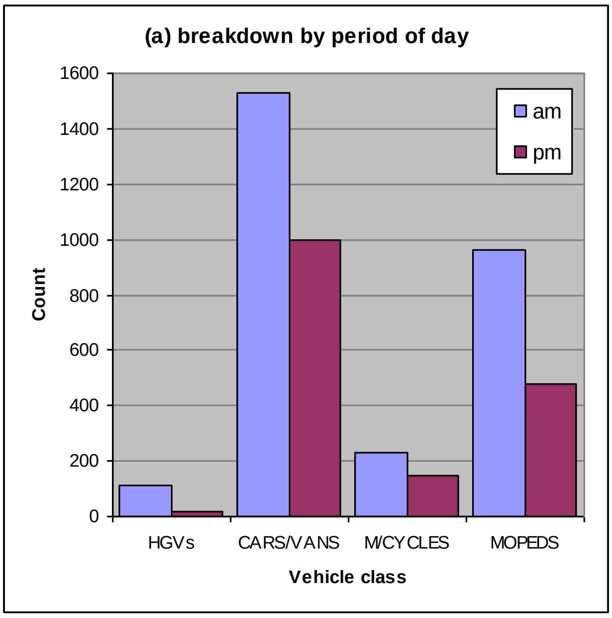
- Heavy goods vehicles (HGVs)
- Cars/vans
- Motorcycles
- 2-stroke scooters/mopeds

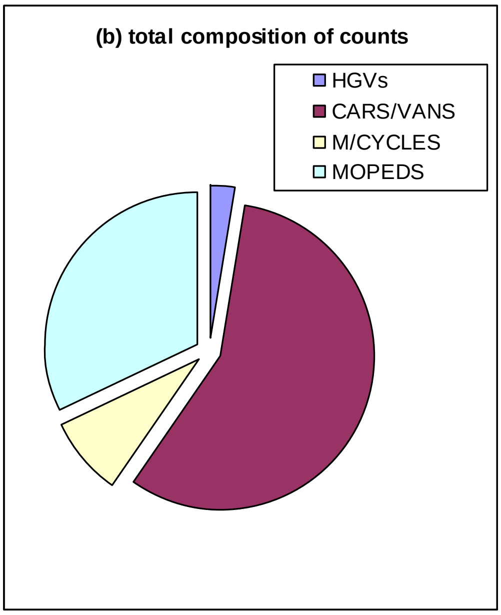
The traffic count results are presented in Table 12-3 along with percentages of the total in brackets and this is visually represented in Figure 12-3 (a) by morning or evening period; and (b) total composition of the counts by vehicle class.

Table 12-3 Sample road traffic count data at Rosia Road (July 2009)

Date	Period	Vehicle class (count (percentage))				Total
		HGVs	Cars/vans	Motorcycles	Scooters/ mopeds	
22/07/2009	**am**	27 (3.0%)	495 (55.6%)	74 (8.3%)	295 (33.1%)	891
	pm	7 (1.2%)	350 (62.2%)	56 (9.9%)	150 (26.6%)	563
23/07/2009	**am**	56 (5.2%)	560 (52.3%)	80 (7.5%)	375 (35.0%)	1071
	pm	4 (0.7%)	335 (62.0%)	43 (8.0%)	158 (29.3%)	540
27/07/2009	**am**	30 (3.4%)	475 (54.2%)	79 (9.0%)	293 (33.4%)	877
	pm	6 (1.1%)	310 (58.2%)	47 (8.8%)	170 (31.9%)	533
Total (am)		113 (4%)	1530 (53.9%)	233 (8.2%)	963(33.9%)	2839
Total (pm)		17 (1%)	995 (60.8%)	146 (8.9%)	478 (29.2%)	1636
Total		130 (2.9%)	2525 (56.4%)	379 (8.5%)	1441 32.2%)	4475

Figure 12-3 Plots of sample traffic count data at Rosia Road (July 2009)





This data suggests that, like many Mediterranean areas, small scooters/mopeds are a common means of vehicle transport and are much more prevalent as a proportion of the vehicle fleet than in western European countries. It is noteworthy that there are very few HGVs and no recorded coaches/buses in this sample of traffic count data.

Table 12-4 summarises the vehicles registered in Gibraltar by type. In this classification mopeds are only attributed 4.8% of the total vehicle fleet but the vast majority of two-wheeled vehicles in Gibraltar are small and likely to have 2-stroke engines. It is possible that there has been some misclassification between motorcycles and mopeds/scooters in this data. It is notable that when mopeds and motorcycles in this data are taken together, they make up 30.2% of the total vehicle fleet – this is consistent with the sample of road traffic count data at Rosia Road (Table 12-3) which showed 32.2% of vehicles on Rosia Road were small mopeds or scooters.

Table 12-4 Vehicle fleet breakdown (vehicles registered in Gibraltar)

Vehicle class	Number of vehicles	Percentage of fleet
Self Drive	335	1.4%
Mopeds	1154	4.8%
Goods	1284	5.4%
Motorcycle	6046	25.3%
Omnibus	76	0.3%
Private	14426	60.4%
Taxi	129	0.5%
Private	330	1.4%
Other	87	0.4%

Although numbers of visitors to Gibraltar entering across the Frontier by land are calculated by the Government of Gibraltar Statistics Office, there is no way of accurately equating this statistic with additional motor vehicles on the roads in Gibraltar not included in the Gibraltar registry. Anecdotal evidence from the Government of Gibraltar Department of the Environment and Gibraltar Environmental Agency is that vehicle traffic crossing the frontier is predominantly mopeds and scooters, reflecting the general fleet composition registered in Gibraltar.

12.4 Road traffic dispersion modelling

Dispersion modelling (AEA's LADSUrban tool) has been used to predict the contribution from road traffic to annual mean ground level PM_{10} concentrations. This alternative approach to apportioning PM_{10} to road traffic sources has been undertaken in addition to calculating the roadside increment. The advantage of this approach over the roadside increment alone is that it allows the explicit quantification of exhaust emissions and resuspended road dust. These are hard to disaggregate from one another using a single roadside increment value. For example, the analysis presented in Section 12.1 indicated a roadside increment of 6 $\mu g\ m^{-3}$ which includes PM_{10} from exhaust AND resuspended dust but no indication of the split between these two sources is possible to guide focussed policy measures to address these sources in the most effective manner.

12.4.1 Exhaust emissions contribution

AEA's LADSUrban modelling tool calculates atmospheric dispersion using a 10 m x 10 m x 3 m volume-source kernel derived from the dispersion model ADMS4 to represent elements of the road. The volume source depth takes account of the initial mixing caused by the turbulence induced by the vehicles. The model used hourly sequential wind speed and direction data for 2006 from the Rosia Road monitoring station and cloud cover data from Gibraltar Airport to derive the volume source kernel. The model application used a surface roughness of 1 m to represent the urban conditions and limited the Monin-Obukhov length to 30 m or greater to take account of the urban heat island effect. The model calculated the contribution from road traffic on a rectangular grid of receptors paced at 10 m intervals within 150 m of the modelled roads and more widely spaced receptors elsewhere. The model also calculated the contribution from the road traffic to concentrations at the Rosia Road monitoring site.

The model was used to represent the dispersion of emissions from road traffic on the roads close to the monitoring site. The roads included sections of Rosia Road, Boyd Street, Trafalgar Road, Ragged Staff Road and Queensway. Road traffic flows were taken from the official 2-way counts for Rosia Road taken by the Highways Agency as set out in Table 12-5 below.

It was assumed that the majority of towing vehicles would be in Class 2 so cars and vans were represented by both classes together. Class 1 was split into smaller bikes (mopeds and scooters with 2-stroke engines) and larger bikes (motorcycles) using a percentage split derived from the ratio of motorcycles to mopeds/scooters from the Environmental Agency traffic counts. It was assumed that none of the Class 1 vehicles were bicycles which are very rare in Gibraltar compared with mopeds and scooters. Resultant road traffic counts by vehicle class for Rosia Road are presented in Table 12-5. The road traffic counts were assumed to be half the stated value on 1-way sections of the road at the Rosia Road/Ragged Staff Road junction.

Table 12-5 Traffic count on Rosia Road by vehicle class (automatic traffic counts)

	Vehicle class			
	HGVs	**Cars/ Vans**	**M/cycles**	**Mopeds/ Scooters**
Vehicle count	5621	74117	5339	20327

Typical emission factors for PM_{10} were compiled for different vehicle classes at different speeds in Gibraltar. These are derived from the latest speed related emissions factors available from the DfT[21] and are summarised in Table 12-5. The emission factors for 20 mph were used to estimate the emissions from vehicle exhausts on Rosia Road. In addition, the emission factors for urban roads shown in

[21] http://www.dft.gov.uk/pgr/roads/environment/emissions/

Table 12-7 were used to take account of brake and tyre wear. Emission factors for tyre and brake wear for each class of vehicle were taken from the Air Quality Expert Group (AQEG) report on particulate matter in the UK (AQEG, 2005), based on vehicle class, road class and number of axles.

Table 12-6 Typical exhaust emission factors (g/km) for PM_{10} by vehicle class and speed for Gibraltar

Speed	Vehicle class			
	HGVs*	Cars/Vans**	M/cycles***	Mopeds/ Scooters ‡
20	0.161	0.040	0.02	0.2
25	0.140	0.037	0.02	0.2
30	0.124	0.036	0.02	0.2
35	0.111	0.035	0.02	0.2
40	0.102	0.035	0.02	0.2

* HGVs assumed to be EURO II HGVs
** Cars/vans assumed to be EURO 2 vehicles, petrol engines with 1.4-2.0 litre; diesel engines >2.0 litre; vans treated as N1 Class III; with split of 75% cars and 25% vans. 80% of cars treated as petrol and 20% diesel.
*** Motorcycles assumed to be 4-stroke 150-250cc engines
‡ Mopeds/scooters assumed to be 2-stroke <150cc engines

Table 12-7 Brake and tyre wear PM_{10} emission factors

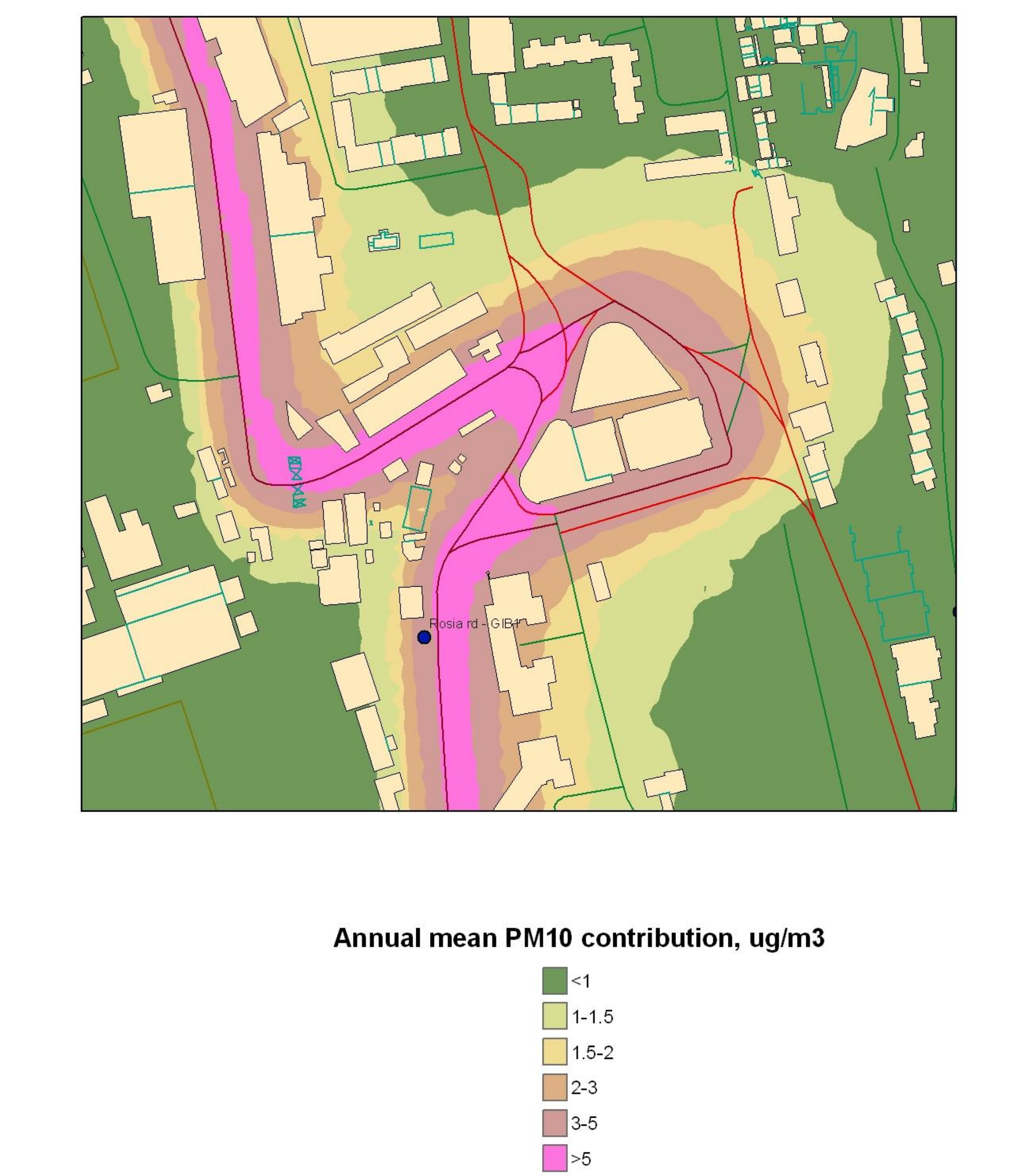
Vehicle type	Road class	Tyre wear		Brake wear	
Cars	Urban	0.00874	g/km	0.0117	g/km
	Rural	0.00680	g/km	0.0055	g/km
	Motorway	0.00579	g/km	0.0014	g/km
LGVs	Urban	0.01380	g/km	0.0182	g/km
	Rural	0.01074	g/km	0.0086	g/km
	Motorway	0.00915	g/km	0.0021	g/km
HGVs	Urban	0.00918	g/axle.km	0.0510	g/km
	Rural	0.00737	g/axle.km	0.0271	g/km
	Motorway	0.00608	g/axle.km	0.0084	g/km
Buses	Urban	0.00937	g/axle.km	0.0536	g/km
	Rural	0.00737	g/axle.km	0.0271	g/km
	Motorway	0.00608	g/axle.km	0.0084	g/km
Motorcycles	Urban	0.00376	g/km	0.0058	g/km
	Rural	0.00292	g/km	0.0028	g/km
	Motorway	0.00249	g/km	0.0007	g/km

Figure 12-4 shows the predicted contribution from road traffic to annual mean ground level PM_{10} concentrations. The predicted contribution at the Rosia Road monitoring site is 3.8 $\mu g\ m^{-3}$. This contribution is comparable with the roadside increment of 6 $\mu g\ m^{-3}$ estimated from the FDMS hourly measurements (Table 7.1) which includes the contribution from resuspended dust that is additional to the exhaust emissions contribution demonstrated here.

There are several possible reasons why the model prediction may differ from the measurement estimate, for example:

- The actual emissions may be greater than the modelled emissions because vehicles are accelerating or braking close to the junction;
- The dispersion of pollutants is affected by the presence of a large 8-storey building across the road from the monitor;
- The dispersion model has an inherent uncertainty of approximately a factor of 2.
- The analysis of the measurement data may overestimate the roadside increment because the night-time background concentrations may be an underestimate of day-time values.
- The modelling does not take account of dust resuspended by vehicle turbulence.

Figure 12-4 Modelled contribution from road traffic near the Rosia Road monitoring site



It is concluded that the dispersion modelling confirms that road traffic emissions make a substantial contribution to the measured concentrations at the Rosia Road monitoring site.

12.4.2 Road dust resuspension

An attempt has been made to estimate the potential contribution to PM_{10} emissions resulting from road dust resuspension using an empirical formula taken from the US EPA Compilation of air pollutant emission factors, AP42. The formula gives the emission factor, E g veh-km^{-1} as:

$$E = k\left(\frac{sL}{2}\right)^{0.65}\left(\frac{W}{3}\right)^{1.5} - C$$

where,

- k is a numerical factor, 4.6 g veh-km^{-1} for PM_{10};
- sL is the road surface silt loading, g m^{-2};
- W is the average weight of vehicles travelling on the road, US tons;
- C is a correction for the 1980's US vehicle fleet exhaust, brake and tyre wear, 0.1317 g veh-km^{-1} for PM_{10}.

Baseline silt loading values depend on the average daily traffic flow. In this case, for average daily traffic flows in the range 5000-10000, AP42 gives a baseline silt loading of 0.06 g m^{-2}.

The average weight of vehicles travelling on the road depends on the traffic composition and the weight of the vehicles. We have assumed that:

- The average weight of a car in Gibraltar is approximately 1 US ton;
- The average weight of a heavy goods vehicle is approximately 15 US tons;
- Mopeds and motorcycles can be ignored.

The average weight of vehicles on Rosia Road calculated on this basis is 2 US tons. The formula is applicable in the range 2 to 42 US tons, therefore the traffic weight on Rosia Road is at the bottom of the range of applicability. Evaluation of the AP42 formula gives an emission factor of 0.125 g veh-km^{-1} applicable for the car and HGV traffic. Application of this factor to the traffic on Rosia Road gives an emission of 903 g km^{-1} day^{-1}. Table 12-8 shows the emission rates for exhaust, brake and tyre wear for comparison. The predicted contribution from resuspension is almost as much as that from exhaust, brake wear and tyre wear combined.

Table 12-8 Contributions to vehicle emission rates on Rosia Road

Source	Emission rate, g km^{-1} day^{-1}
Resuspension	903
Exhaust	733
Brake wear	118
Tyre wear	77

The modelled contribution from road vehicles to PM_{10} concentrations increases from 3.8 μg m^{-3} without resuspension to 7.4 μg m^{-3} with resuspension. Therefore resuspended dust from road traffic is estimated to contribute 3.6 μg m^{-3} to annual mean concentrations. Taking the modelled road dust resuspension contribution AND the exhaust emission contribution together, a model contribution to measured annual mean PM_{10} concentrations at Rosia Road (7.4 μg m^{-3}) is highly consistent with the 6 μg m^{-3} roadside increment estimated using hourly FDMS data represented in Section 12.1. This therefore provides confidence in the model result.

12.5 Apportionment of exhaust PM_{10} by vehicle class

With an estimated contribution from road traffic exhaust emissions (3.8 μg m^{-3}) from the dispersion modelling study described above the further apportionment of this contribution according to vehicle type can be undertaken to better focus potential policy initiatives and abatement measures.

Using the calculated automatic road traffic counts from the Highways Agency for Rosia Road (Table 12-5) and the relevant emission factors for Rosia Road at 20 mph (Table 12-6), the relative contribution by vehicle class has been calculated as presented in Table 12-9. Once the percentage contribution was obtained, this was then applied to the modelled contribution of 3.8 μg m^{-3} to obtain the annual mean concentration associated with each vehicle class.

Table 12-9 Contribution to measured PM_{10} at Rosia Road by vehicle class (automatic traffic counts)

	Vehicle class			
	HGVs	Cars/ Vans	M/cycles	Mopeds/ Scooters
Vehicle count	5621	74117	5339	20327
Emission factor used (g/km)	0.161	0.04	0.02	0.2
Estimated contribution to roadside concentrations (%)	11.2	37.1	1.3	50.4
Estimated contribution to roadside concentrations (µg m^{-3}) *	0.4	1.4	0.05	1.9

* using modelled road traffic exhaust contribution of 3.8 µg m^{-3} to annual mean

Table 12-9 demonstrates that 2-stroke engined mopeds and scooters are the most highly polluting vehicle class in Gibraltar, accounting for over 50% of PM_{10} from exhaust emissions which relates to almost 2 µg m^{-3} in terms of absolute concentration. Motorcycles (taken to represent 4-stroke engines) were significantly cleaner than the mopeds as shown by the emissions factor being 10 times less than 2-stroke engines. The next highest contributor was the cars/vans category with 1.4 µg m^{-3} but this results from over three and a half times more cars than the number of mopeds.

13 Emissions from unmade ground

Figure 6-1c indicates that there are high concentrations of particulate matter, PM_{10} at Rosia Road when there are high wind speeds from the south-west. There is an area of approximately 4000 m^2 of bare unmade ground at the harbour edge approximately 50 m south-west of the Rosia Road monitoring station. This area of land is known to have accommodated unregulated bulk handling operations during 2007. It is likely therefore that this land was a source of fugitive coarse emissions of PM_{10} from the surface during this year. This section of the report contains an assessment of the contribution from dust suspended by the wind from this area to concentrations of PM_{10} at the Rosia Road monitoring site.

13.1 Modelling methodology

The assessment of emission rates follows the methods developed by the Western Region Air Partnership (WRAP)[22] in the United States.

Wind erosion occurs when the shear stress exerted by the wind on the surface, characterised by a friction velocity u_*, exceeds a threshold value that is characteristic of the soil and its aerodynamic surface roughness. This assessment assumed a threshold friction velocity of 0.39 m s^{-1}.

The meteorological preprocessor of the dispersion model, ADMS4 was used to calculate the friction velocity for each hour of the year 2006 using meteorological data for Gibraltar airport. Gibraltar airport data was considered to be the most representative of the coastal location of the unmade ground. A surface roughness of 0.001 m was used in the model to represent the sea surface upwind of the unmade ground.

Most soils consist of agglomerates of smaller particles. The component particles are typically characterised in terms of their particle sizes with clay particles less than 2 μm, silt particles in the range 2 μm to 50 μm and sand particles > 50 μm. The sand particles are only loosely attached to the agglomerates and are quickly separated. The large particles and the sand then "sand blast" the other agglomerates and gradually remove the silt particles. The clay particles tend to be more strongly bound and are removed more slowly, if at all. The silt particles released can then become suspended, resulting in vertical flux of particles typically in the range 2 μm –30 μm. WRAP estimates the vertical flux of PM_{10} particles, F_v for 4 categories of soil classified in terms of their geometric mean particle size determined by dry sieving. The relationships are described in terms of the power law relationship:

$$F_v = a u_*^b$$

where the constants a and b are shown in Table 13-1. The particle size class CS is most representative of the material that makes up the unmade ground. The other classes provide larger estimates of the rate of emission.

Table 13-1 Power law constants used by WRAP to estimate PM_{10} fugitive emissions from soils

Particle size class	Geometric mean particle diameter, μm	a, g m^{-2} s^{-1}	b
FFS	125	0.0245	3.97
FS	210	0.00933	2.44
MS	520	0.001243	2.64
CS	690	0.00124	3.44

[22] Western Region Air Partnership(WRAP) :Determining Fugitive Dust Emissions from Wind Erosion - Phase 1, 2004;
Western Region Air Partnership: Fugitive Wind Blown Dust Emissions and Model Performance Evaluation: Phase II, 2006

The estimated annual emission of particulate matter from the unmade ground was 2.1 kg m^{-2}.

The ADMS4.1 dispersion model was then used to predict the contribution from emissions from the unmade ground to annual mean ground level concentrations of PM_{10} at Rosia Road. The modelling took account of the hour-to-hour variations in the emissions. The model predicted a contribution of 15.9 $\mu g\ m^{-3}$ at ground level and 10.9 $\mu g\ m^{-3}$ at a height 2 m above ground, corresponding approximately to the height of measurement.

The estimate of the contribution to PM_{10} concentrations from unmade ground is very uncertain. The main sources of uncertainty are:

- The estimate of the threshold friction velocity;
- The estimation of the friction velocity during each hour;
- The use of the CS particle size class to represent the material of the unmade ground;
- The effect of the depletion of the surface dust with time;
- The use of Gibraltar air port meteorological data to represent wind conditions over the unmade ground;
- The effect of the local terrain on dust dispersion in the atmosphere.

Nevertheless, the analysis indicates that the area of unmade ground and other similar areas have the potential to contribute substantially to the PM_{10} concentrations at Rosia Road.

14 Analysis of fast-response data

This section considers the analysis of fast-response measurements that have been made at Rosia Road since mid-June 2009. These measurements were made as 1-minute averages rather than the 15-minute or 1-hour averages typically used. Faster response measurements may offer additional insight into the sources of air pollution at a site that can be lost when higher averaging times are used. Some of the potential advantages are:

- For complex source locations it may be possible to distinguish more source types.
- It may be possible to apply different analysis techniques that do not lend themselves to longer-term average data.
- The availability of different size fractions of PM_{10} makes it possible to gain a better idea about coarse and fine particles. In particular, PM_1 is a good indicator of combustion sources and the difference between PM_{10} and $PM_{2.5}$ (coarse particles) is a good indication of natural sources of PM_{10} and vehicle-induced re-suspension.

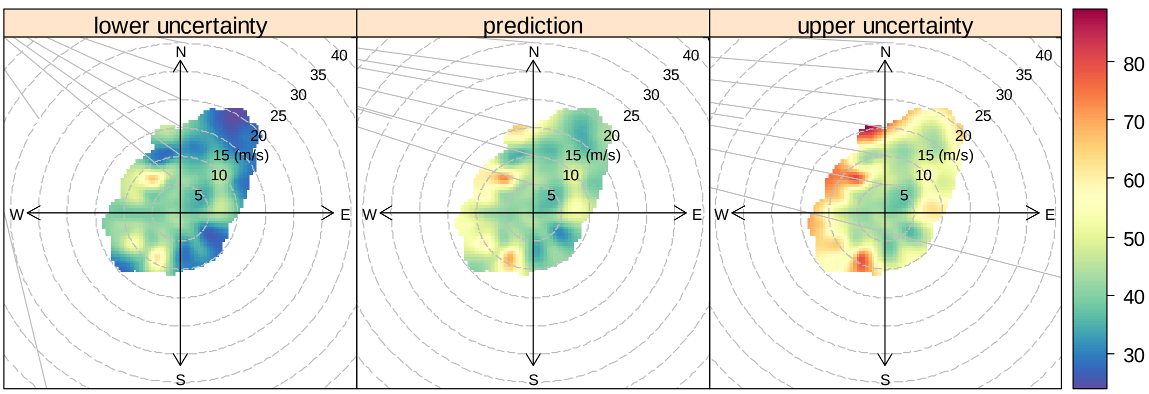
The gaseous data collected at a 1-minute resolution were: wind speed, wind direction, NO, NO_2, NO_X, SO_2 and CO. An Osiris monitor was used to measure TSP, PM_{10}, $PM_{2.5}$ and PM_1.

It should be stressed that the use of fast-response data in this setting is experimental and it is not known whether at this particular location additional source information can be gained. Nevertheless, the data set is valuable and can be revisited in future as techniques develop. The data is from a short-term monitoring campaign and is gathered only for research purposes and therefore does not undergo the rigorous checking and QA procedures that are applied to the routine monitoring campaign.

14.1 Particle size fraction analysis

The principal focus of this section is the origin and characteristic of particle sources. Considering the data set as a whole, the mean particle concentrations are as follows: PM_{10} = 55 µg m^{-3}, $PM_{2.5}$ = 14 µg m^{-3}, PM_1 = 3 µg m^{-3}. These concentrations show that coarse particle (PM_{10} – $PM_{2.5}$) sources are very important at this location i.e. 41 µg m^{-3} or 75 % of the total PM_{10}. This is consistent with the findings in Section 6. Given the magnitude of the coarse particle concentrations, a key question is whether the sources are combustion-related or natural in origin. Figure 14-1 shows the concentration of coarse particles by wind direction and wind speed. It also shows the uncertainty in the relationship, which shows that there is less certainty over concentrations at higher wind speeds. One of the striking features of Figure 14-1 is that coarse particles concentrations are high for all wind speed and direction conditions, with some evidence of higher concentrations at higher wind speeds. This suggests that no single source of coarse particles is dominant: they are high for almost all conditions, on average.

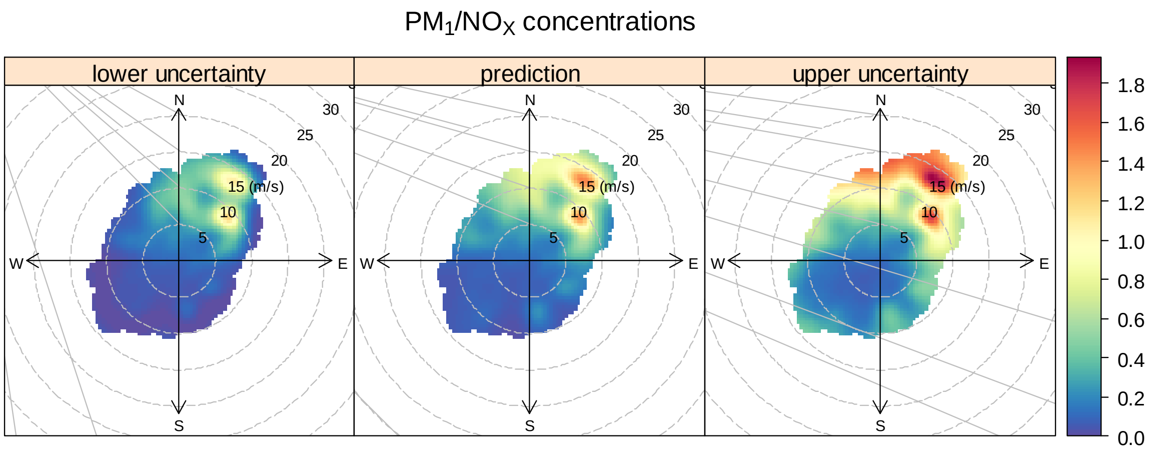
Figure 14-1 Polar plot of coarse particle concentrations from the high-resolution Osiris data



Also of interest is the emission of small particles (PM_1). Typically it would be expected that PM_1 would comprise of particles derived from combustion processes and not particle re-suspension or sea salt aerosol. Given that the concentration of these particles is so low, they have been divided by the concentration of NO_X, which is a good tracer for combustion processes. Dividing the concentrations in this way has the benefit of removing much of the variation due to meteorology because the ratio between two pollutants emitted nearby will be invariant to changes in meteorology.

Figure 14-2 shows the polar plot for the PM_1/NO_X ratio at Rosia Road. There is some evidence of a source of PM_1 to the north and north-east of the site at high wind speeds. It can also be shown that the ratio of PM_1/SO_2 is similar in pattern. Taken together, the results are indicative of a combustion source that emits fine particles, NO_X and SO_2. A potential candidate for an emissions source is shipping – either close to the harbour in Gibraltar itself, and more widely through the Straits of Gibraltar. As shown in Figure 4.1, the wind is rarely from the north with high wind speed. So while the analysis may well detect these sources, it is not the case that they will make an important contribution to overall concentrations.

Figure 14-2 Polar plot of ratio of PM_1/NO_X concentrations from the high-resolution Osiris data



14.2 Exploring the relationship between particle and NO_X emissions

One way of exploring the relationship between coarse particles and NO_X is to plot the relationship between them for short intervals of time[23]. The idea here is that over short time periods concentrations can undergo changes due to plume mixing and changes in the sources of emissions. Consider for example a plume from a single source that undergoes dispersion resulting in plume dilution. As the weather conditions change, so too will the dispersion of the plume. By considering consecutive periods of data it can be shown that linear patterns can occur in the data that are indicative of the relationship between two pollutants. Such information can be useful for understanding how well two pollutants are related, and provide a means of quantifying their ratio. The latter can be helpful for comparison with emission inventories.

For the fast-response Gibraltar data, this technique has been used to better understand whether there is a relationship between coarse particle concentrations and NO_X. Broadly speaking, if such a relationship is present it may indicate that the coarse particles are combustion-related and maybe controllable – which is important given the magnitude of coarse particle concentrations measured in Gibraltar, particularly at Rosia Road. Conversely, if the relationship is very poor, or maybe non existent, this may provide evidence that the vast bulk of coarse particle concentrations are natural and uncontrollable.

[23] Bentley, S.T. (2004) Graphical techniques for constraining estimates of aerosol emissions from motor vehicles using air monitoring network data, Atmospheric Environment}, vol. 38(10), 1491—1500

The data are partitioned into groups of three consecutive, non-overlapping minutes. For each of these groups a linear regression line is fitted. Only results from the regression where the r2 is >0.95 are used. This process yields a series of lines that can be plotted. Note that the data were also averaged to 5 and 15 minutes to test whether the averaging time affected the results and it was found that this made little difference.

First, the technique is applied to a location where there is known to be a strong traffic source of NO_X and PM_{10}. Figure 14-3 shows the results from a site in London dominated by road traffic sources (Marylebone Road). This site is chosen so that the Gibraltar data can be contrasted with it. What is evident from Figure 14-3 is that many of the lines have a similar slope. Note that there are no points where the concentration of NO_X is high and the concentration of PM_{10} is low, which indicates that high NO_X concentrations are always associated with higher concentrations of PM_{10}. Indeed, plotting a histogram of the slopes (
Figure 14-4) shows that there is a clear maximum around the 0.1 value, which is an estimate of the combustion PM_{10}/NO_X ratio at this site.

Figure 14-3 Regression lines from the Marylebone Road site in London

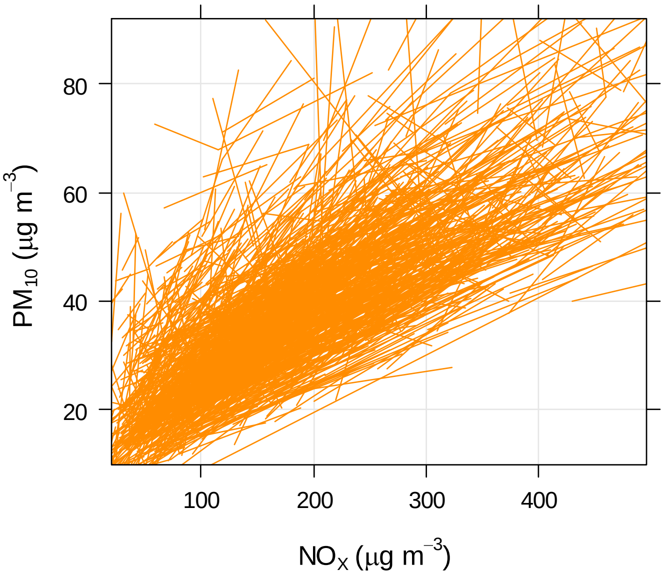
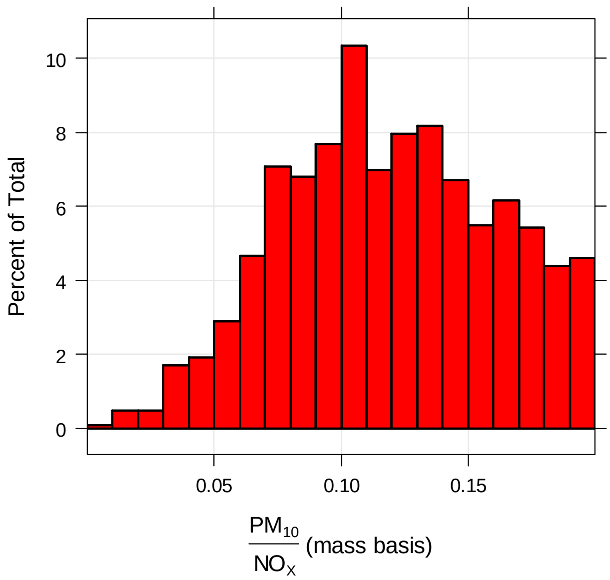


Figure 14-4 Histogram of regression slopes from Marylebone Road site



In contrast to the Marylebone Road site the Rosia Road results show no clear relationship between NO_X and PM_{10}, as shown in Figure 14-5. In this plot, there is almost a random collection of slopes suggesting that there is very little evidence of a relationship between PM_{10} and NO_X at this site. In other words, there is little evidence that combustion sources of PM are important. This result is better seen in the histogram plot (
Figure 14-6), where, unlike Marylebone Road, there is no obvious peak in the slopes of PM_{10} versus NO_X.

Figure 14-5 Regression-line approach applied to the PM_{10} and NO_X fast-response data at Rosia Road

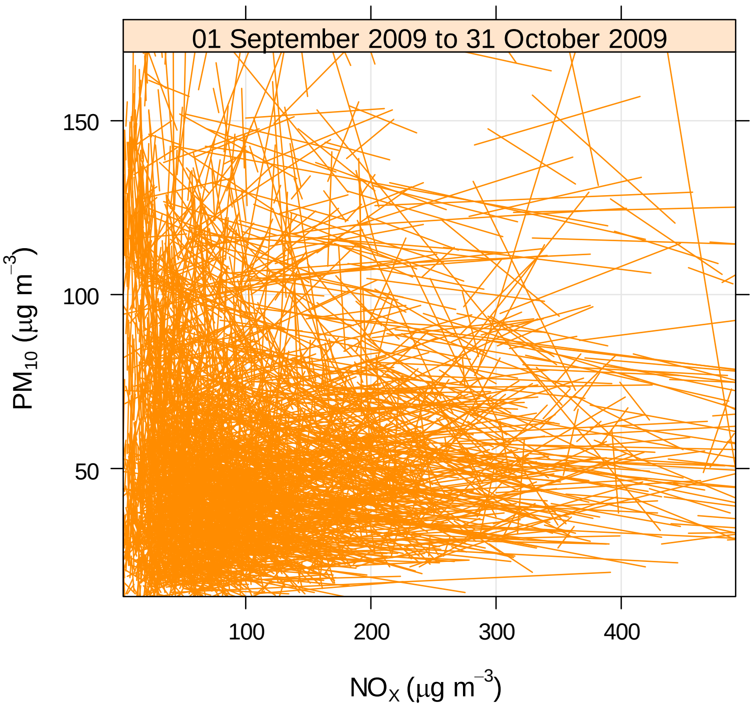
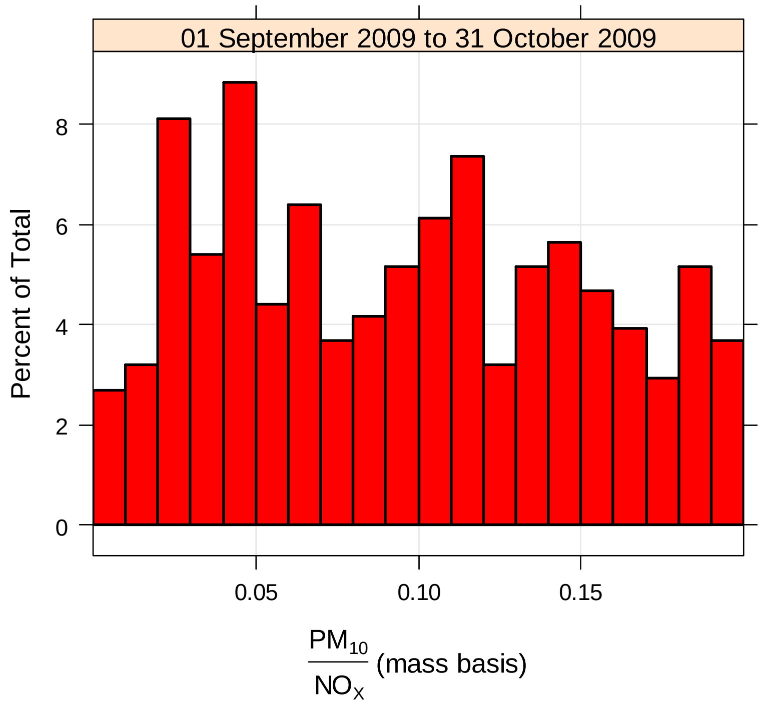


Figure 14-6 Histogram of regression slopes from Rosia Road site



14.2.1 Future analysis with fast response data

This section provides an initial analysis of the fast response data. When the data collection is complete, the analysis will be revisited. The ongoing analysis will:

- Identify specific periods for further analysis. For example, when PM_{10} concentrations are elevated together with other pollutants, which may help better identify specific sources.

- Apply local back-trajectory modelling as a means of trying to locate specific source types. Initial attempts at this for PM_{10} concentrations have not yet yielded useful additional information. This in part will be due to the ubiquitous affects of coarse particle concentrations that affect almost all wind speed and wind directions, swamping other source contributions.

15 Filter analysis

AEA has investigated the possibility of retrieving a full suite of speciated data from the Partisol instrument filters in coordination with IDAEA-CSIC (Barcelona). Such analysis, though prohibitively expensive on a routine basis, could be used to provide ’snap-shots’ of the pollution situation across a wide range of species that are not routinely monitored. This would help to fill a knowledge gap in relation to source-apportionment and help to reinforce existing analyses and conclusions and to steer further analysis in specific directions.

A total of 25 filters were sent for analysis. 20 of these were specifically selected to provide data to generate a relationship between wind speed and sea salt concentration and the remaining 5 were selected in order to provide an indication of PM_{10} contributions when the wind direction was easterly (i.e. from the land/road).

Unfortunately the number of filters required to provide a robust speciation assessment of sources is significantly higher than the 25 that were available for this work and there were specific issues with the sea salt quantification from speciation. The partisol instrument uses a Whatman QMA quartz filters. The quartz substrate is not ideal for speciated analysis and unforeseen issues have prevented the identification of a robust relationship between sea salt and wind speed data.

15.1 Implications for sea salt quantification

The Whatman QMA quartz PM_{10} filters from the Partisol instrument at Rosia Road were intended to provide concentrations of sea salt for 20 selected days from June 2008 onwards. Early drafts of the Commission’s guidance on how to address natural contributions to particulate matter for reporting suggest that an annual approach is not favoured when quantifying and correcting measured concentrations to account for sea salt contributions. The justification for this is the idea that sea salt is highly influenced by short-term meteorological conditions and that calculating an annual contribution of sea salt to PM_{10} and then relating this to daily exceedences does not adequately account for daily variations due to meteorology. However, the approach suggested in the guidance (speciated analysis on a daily basis) is prohibitively expensive, particularly for Gibraltar, where a considerable sum of resources is already spent on the high quality monitoring network in place.

As a result, an alternative approach was envisaged, pending availability of the necessary data. Based on the Commission guidance, it was hoped that a relationship between wind speed and sea salt concentration using met data from the monitoring station during westerly winds could be established. This could then be applied to daily wind speed from Rosia Road in the future and also for the 2007 reference year for the TEN application.

As a result of laboratory analysis by IDAEA-CSIC it has been shown that the speciated sea salt data from the Partisol filters is not reliable, giving high concentrations of sea salt. A similar, but we understand significantly longer, data set for the Spanish La Linea monitoring site a few kilometres north of the Gibraltar frontier may allow an alternative analysis and it is recommended that the Gibraltar Government request these data in the same way as the data required for the African dust quantification. Relying on the denuder instruments at Rosia Road and Bleak House will allow future quantification for sea salt (though not on a daily basis consistent with the Commission guidance) but will not allow a quantification/correction to be made for the 2007 reference year in support of the TEN application for PM_{10}.

16 Summary

16.1 Conclusions

- The complete quantitative apportionment of PM_{10} to measured concentrations in 2007 is presented in Table 16-1. This includes sources that were explicitly modelled/analysed. It does not include contributions from fugitive construction dusts, for which no data was available. There is a proportion of the 45 µg m^{-3} annual mean in 2007 that has not been accounted for by the analysis. This represents 22% of the measured annual mean concentration. It is thought that uncertainties in the modelling tasks and the absence of sea salt and construction dusts quantification account for the remaining proportion of unallocated PM_{10}.

- By far the greatest estimated contribution to measured PM_{10} concentrations at Rosia Road arise from the local area of unmade land to the west of the monitoring station. This area is estimated by modelling to contribute 10.9 µg m^{-3} to the annual mean. This is also a reasonably simple source to control and therefore represents the greatest opportunity for immediate improvements to air quality.

- Dispersion at Rosia Road is significantly less than the regional pattern (airport and Bleak House) due to the presence of complex topography related to the Rock.

- The OESCO and MOD power stations do not contribute as much as initially expected (0.6 µg m^{-3}) to annual mean concentrations. This is in contrast to contributions of NO_X for which the power stations are estimated to be by far the most dominant source.

- Road traffic is estimated to contribute 7.4 µg m^{-3} to annual mean concentrations of which approximately half (3.8 µg m^{-3}) is from exhaust emissions and the rest (3.6 µg m^{-3}) is estimated to result from road dust resuspension.

- Of the road traffic exhaust emissions, by far the most significant contribution to annual mean concentrations is from 2-stroke engined mopeds/scooters. These are numerous in Gibraltar and are estimated to contribute over 50% (2 µg m^{-3}) of the total contribution from exhaust emissions.

- Road dust resuspension is likely to have been over estimated by the modelling because an assumption was made that goods vehicles (HGVs) in Gibraltar were larger than they are in reality because the emission factor was based on significantly larger, multi-axle American HGVs. With this assumption, estimation was possible though the emission factor used remains at the bottom range of applicability.

- The estimated transboundary contribution to annual mean PM_{10} was significant with a cumulative contribution (primary and secondary) of 8.2 µg m^{-3}.

- Shipping activities are estimated to contribute 1.98 µg m^{-3} to annual mean concentrations of which 0.8 µg m^{-3} (Spanish Port of Algeciras and Straits of Gibraltar) is outside the direct control of Gibraltarian authorities.

- Though there is no provision in the Directives for the removal of transboundary or shipping contributions (from Port of Algeciras and Straits of Gibraltar) from measured PM_{10} concentrations. Emissions from these sources are expected to decline in future years as a result of international agreements and maritime Directives on shipping fuel standards.

- Natural contributions of PM_{10} from African dust events and sea salt are high. It is estimated that the contribution from African dust to annual mean concentrations in 2007 was 5.8 µg m^{-3}. The Directive makes provision for the removal of natural contributions from measured concentrations.

Table 16-1 Summary of source apportionment of PM_{10} measured at Rosia Road monitoring site (contribution to annual mean, µg m^{-3})

	Measured data		Natural		Power stations	Local unmade land	Transboundary		Shipping			Road traffic					Other***	Estimated minimum abatement needed, (2007)****
	Annual mean	Daily exceedences	African dust *	Sea salt **			Primary	Secondary	Straits of Gibraltar	Algeciras Port	Port of Gibraltar	HGVs	Cars/Vans	Motorcycles	Scooters/ Mopeds	Resuspended road dust		
Rosia Road (2007)	45	109	5.8	---	0.6	10.9	2.8	5.4	0.28	0.6	1.1	0.29	1.41	0.11	2.00	3.6	10.1	2.07

*** value presented here is indicative for comparison with other annual contributions – to calculate the necessary abatement, African dust is removed on a daily basis and a corrected annual average taken before subtraction of the other sources outside the Member State's control).**
**** no quantification of sea salt has yet been possible. It is possible that accounting for this potentially significant natural source would result in compliance with the annual and daily mean LV in 2007 for Gibraltar.**
***** measured concentration unaccounted for in modelled sources, reflecting the absence of quantification for sea salt, construction dusts and uncertainty in the individual modelling exercises**
****** difference between measured concentration in 2007 after deduction of natural sources and the annual mean equivalent of the daily LV in Gibraltar (taken to be 37.1338 µg m^{-3} (based on established relationship between measured annual mean concentrations and daily mean exceedences)**

A large number of these sources (totalling 14.88 µg m^{-3}) are beyond the direct control of the Gibraltarian authorities:

- Primary and secondary transboundary sources
- Natural sources - African dust (sea salt is not accounted for in the 14.88 µg m^{-3} but is expected to make a significant additional contribution)
- Shipping in Straits of Gibraltar and Port of Algeciras

It is estimated that the difference between the corrected (for natural sources) annual mean concentration and the estimated annual mean equivalent concentration to ensure daily mean compliance is 2.07 µg m^{-3}. The existing power stations contributing 0.6 µg m^{-3} PM_{10} will be replaced by a new power station estimated to contribute a maximum of 0.3 µg m^{-3} to Rosia Road. This means that additional policy measures are needed to abate an additional 1.77 µg m^{-3} PM_{10} in order to achieve compliance with the daily LV. The most effective sources to regulate in order to find this additional abatement are

- unmade land to west of Rosia Road and bulk handling operations on it.
- road traffic emissions (resuspended dust from road and exhaust emission, in particular 2-stroke vehicles such as the large scooter/moped fleet)
- shipping emissions from the Bay of Gibraltar.

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