Assessment of Air Quality in the Vicinity of Delimara Power Station, Malta

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Executive Summary

The Air Quality Management Resource Centre (AQMRC), University of the West of England, Bristol (UWE) was appointed by the Malta Environment and Planning Authority (MEPA) and the Monitoring Committee, following a competitive tendering process, to assess the impact of using Heavy Fuel Oil (HFO) at Delimara Power Station (DPS).

The Terms of Reference for this project set out a principal project objective and several key deliverables. The principal project objective is to evaluate air and other monitoring data, to assess whether the operation of eight diesel engines on Heavy Fuel Oil (HFO) at Delimara Power Station is contributing towards exceedances of the relevant air quality Limit Values established under Legal Notice 478 of 2010, as amended by Legal Notice 482 of 2011.

Following a review of the Terms of Reference, site visits and discussions with the project team led by Rachel Decelis[1], Senior Environment Protection Officer at MEPA, our understanding of the project is as follows:

- Enemalta, operators of Delimara Power Station, are currently running eight medium-speed combined cycle diesel engines (DPS6) on HFO with the plant being commissioned on 14th December 2012. Continuous stack emissions are monitored and reported to MEPA as a condition of the IPPC permit. Hourly wind speed and direction are also monitored at the power station.
- As part of the IPPC conditions Enemalta have commissioned PM_{10} and $PM_{2.5}$ monitoring at Marsaxlokk and Birżebbuġa undertaken by AIS Environmental Ltd (using low-volume gravimetric samplers) with analysis by Ambiente, and Environmental Monitoring Services (using Opsis SM-200 combined beta attenuation and gravimetric monitors). Samples are also analysed quarterly for heavy metals (arsenic, cadmium, nickel, lead and vanadium) by the operator’s consultants. The low volume samplers (LVS) have been in operation since 5th April 2012, but were relocated by approx. 5 metres on 27th August 2012 to give more open aspect for all wind directions. The beta attenuation monitors (BAM) have been operating since July 2012, though recalibrated data has only been provided from 10th December 2012.
- MEPA operate continuous monitoring of ambient air in Żejtun, Msida, Kordin, Attard (ozone only) and Għarb (background site). All sites (except Attard) monitor Benzene, Carbon Monoxide (CO), Nitrogen Oxides (NOx)/Nitrogen Dioxide (NO_2), Ozone (O_3), PM_{10}, $PM_{2.5}$ and Sulphur Dioxide (SO_2), as well as wind speed and direction.

[1]Rachel Decelis has been replaced by Nathalie Ellul as project lead for MEPA.

- The role of AQMRC is to analyse the monitoring data from Marsaxlokk and Birżebbuġa, together with ambient monitoring data from MEPA, continuous stack monitoring and meteorological data to determine whether the emissions from the diesel engines at Delimara Power Station during the period of HFO use is contributing to exceedances of the limit values for PM_{10} and/or $PM_{2.5}$, established under Legal Notice 478 of 2010, as amended by Legal Notice 482 of 2011.

A baseline analysis of all available data for all sites from 1st January 2009 to 13th December 2012 inclusive, prepared by AQMRC, revealed no evidence to suggest that the Delimara Power Station was contributing to elevated concentrations of particulate matter at Birzebbuga or Marsaxlokk pre-commissioning of the diesel engines using HFO.

Two three-month post-commissioning reports were produced in June and December 2013, covering 14th December 2012 to 3rd March 2013 and 4th March to 14th June 2013 respectively. These reports presented spatial, temporal and exceedance analysis of PM_{10} and $PM_{2.5}$ monitoring data together with DPS dust emissions following the commissioning of eight diesel engines to use HFO on 14th December 2013. The reports did not indicate that the DPS had contributed to any exceedances of the EU Limit Values for PM_{10} or $PM_{2.5}$ during the period 14th December 2012 to 14th June 2013 at any sites. The recorded exceedances of the daily mean Limit Value for PM_{10} were attributed to regional sources, sometimes specifically to Saharan dust events, or more localised events associated with wind directions other than from the direction of the DPS.

This report represents the final report of this study, bringing together the baseline analysis and results of the 6-months post-commissioning monitoring data analysis to determine whether the emissions from the diesel engines at Delimara Power Station during the period of HFO use is contributing to exceedances of the limit values for PM_{10} and/or $PM_{2.5}$, established under Legal Notice 478 of 2010, as amended by Legal Notice 482 of 2011.

Spatial analysis of the data from 14th December 2012 to 14th June 2013 has indicated that at all MEPA sites and at the consultants' Birzebbuga and Marsaxlokk sites the highest concentrations of PM_{10} and $PM_{2.5}$, during both the baseline and post-commissioning periods, are found when the wind is from the south or south-west (contrary to the predominant wind direction). The wind speed and direction and the occurrence at all sites suggests that there is a transboundary source, e.g. Saharan dust, relating to the west/south-westerly measured concentrations. High concentrations of PM associated with winds from the direction of the DPS at Birzebbuga or Marsaxlokk are not apparent in the polar plots, suggesting if there is any impact of the DPS on PM_{10} concentrations it is minimal.

The analyses of temporal patterns in the pollution data has focussed on PM_{10} and $PM_{2.5}$ data from MEPA and consultants' sites and dust emissions data from DPS. It is possible to identify shared peak PM_{10} and $PM_{2.5}$ episodes across multiple sites as well as other, potentially more local events. The presence of multiple-site peaks and similar peak ranges across all sites indicates that the predominant source contributing to short-term peaks is likely to be regional, e.g. transboundary. There does not appear to be any clear temporal relationship between the DPS dust emissions and the particulate matter concentrations recorded at either Birzebbuga or Marsaxlokk.

Based on the post-commissioning period data, there are potential exceedances of the annual mean Limit Value for PM_{10} in 2013 at Msida and also at Birzebbuga and Marsaxlokk according to the LVS data, but not the BAM data. There are no recorded exceedances of the $PM_{2.5}$ annual mean threshold indicated at any site. The permitted 35 exceedances of the daily mean in a calendar year was not breached at any site within the period covered in this report. Based on the 90th percentiles, exceedances of the daily mean Limit Value were predicted at Msida and also at Birzebbuga and Marsaxlokk using the LVS data; however, the BAM data did not indicate any exceedance of the Limit Values.

Exceedances of the daily mean 50 $\mu g/m^3$ were identified as occurring exclusively at the consultants' sites on a number of occasions, however these were either associated with winds that were not from the direction of the DPS or that could also be linked to local or regional events, e.g. fireworks or Saharan dust events. Annual exceedance analysis for the baseline period indicated that the annual mean PM_{10} and $PM_{2.5}$ concentrations were higher in the post-commissioning period than in the baseline period. Proportional to the period of time for which data were available, there were also more exceedances of the daily mean threshold. Annual mean and daily mean concentrations for the MEPA sites during the post-commissioning period, however, are comparable with previous years. The inconsistencies between the BAM and LVS data in the post-commissioning period were noted and would tend to suggest that the LVS monitors may be over-reading. In any case there is no indication that the additional exceedances recorded using the LVS monitors can be associated with dust emissions from the DPS.

In summary, spatial, temporal and exceedance analysis of PM_{10} and $PM_{2.5}$ data and dust emissions has not indicated that the DPS has contributed to any exceedances of the EU Limit Values for PM_{10} or $PM_{2.5}$ during the post-commissioning period 14th December 2012 to 14th June 2013 at any sites. The recorded exceedances of the daily mean Limit Value for PM_{10} have been attributable to regional sources, sometimes specifically to Saharan dust events, or more localised events associated with wind directions other than from the direction of the DPS.

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Glossary of Terms

Abbreviation	Definition
$\mu g/m^3$	Micrograms per cubic metre
µm	Micrometres
AQMRC	Air Quality Management Resource Centre
BAM	Beta Attenuation Monitors
CET	Central European Time
CO	Carbon monoxide
DPS	Delimara Power Station
DST	Daylight Saving Time
HFO	Heavy Fuel Oil
LVS	Low Volume Samplers
MEPA	Malta Environment and Planning Authority
mg/m^3	Milligrams per cubic metre
MPS	Marsa Power Station
m/s	Metres per second
NO_2	Nitrogen dioxide
NO_X	Oxides of nitrogen
O_3	Ozone
PM_{10}	Particulate matter which passes through a size selective inlet with a 50% efficiency cut-off at 10 µm aerodynamic diameter
$PM_{2.5}$	Particulate matter which passes through a size selective inlet with a 50% efficiency cut-off at 2.5 µm aerodynamic diameter
SO_2	Sulphur dioxide
UWE	University of the West of England, Bristol

1. Introduction to the Project

The Air Quality Management Resource Centre (AQMRC), University of the West of England, Bristol (UWE) was appointed by the Malta Environment and Planning Authority (MEPA) and the Monitoring Committee, following a competitive tendering process, to assess the impact of using Heavy Fuel Oil (HFO) at Delimara Power Station (DPS).

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- As part of the IPPC conditions Enemalta have commissioned PM_{10} and $PM_{2.5}$ monitoring at Marsaxlokk and Birżebbuġa undertaken by AIS Environmental Ltd (using low-volume gravimetric samplers) with analysis by Ambiente, and Environmental Monitoring Services (using Opsis SM-200 combined beta attenuation and gravimetric monitors). Samples are also analysed quarterly for heavy metals (arsenic, cadmium, nickel, lead and vanadium) by the operator's consultants. The low volume samplers (LVS) have been in operation since 5th April 2012, but were relocated by approx. 5 metres on 27th August 2012 to give more open aspect for all wind directions. The beta attenuation monitors (BAM) have been operating since July 2012, though recalibrated data has only been provided from 10th December 2012.
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This report represents the final report of this study, bringing together the baseline analysis and results of the 6-months post-commissioning monitoring data analysis to determine whether the emissions from the diesel engines at Delimara Power Station during the period of HFO use is contributing to exceedances of the limit values for PM_{10} and/or $PM_{2.5}$, established under Legal Notice 478 of 2010, as amended by Legal Notice 482 of 2011.

2. Description of the Study Area

Delimara Power Station is located in the far south-east of Malta on the Delimara peninsula in Marsaxlokk Bay. The predominant wind direction for the Maltese islands is north-westerly (Galdies, 2011) (Appendix A) and hence emissions from the station are expected to be exported offshore. The closest monitoring sites, operated by the consultants, Environmental Monitoring Services Ltd and AIS Environmental Ltd, are located in Birzebbuga and Marsaxlokk to the west and north-west of the DPS respectively. There is another, older power station on Malta located closer to the capital, Valletta, at Marsa (MPS).

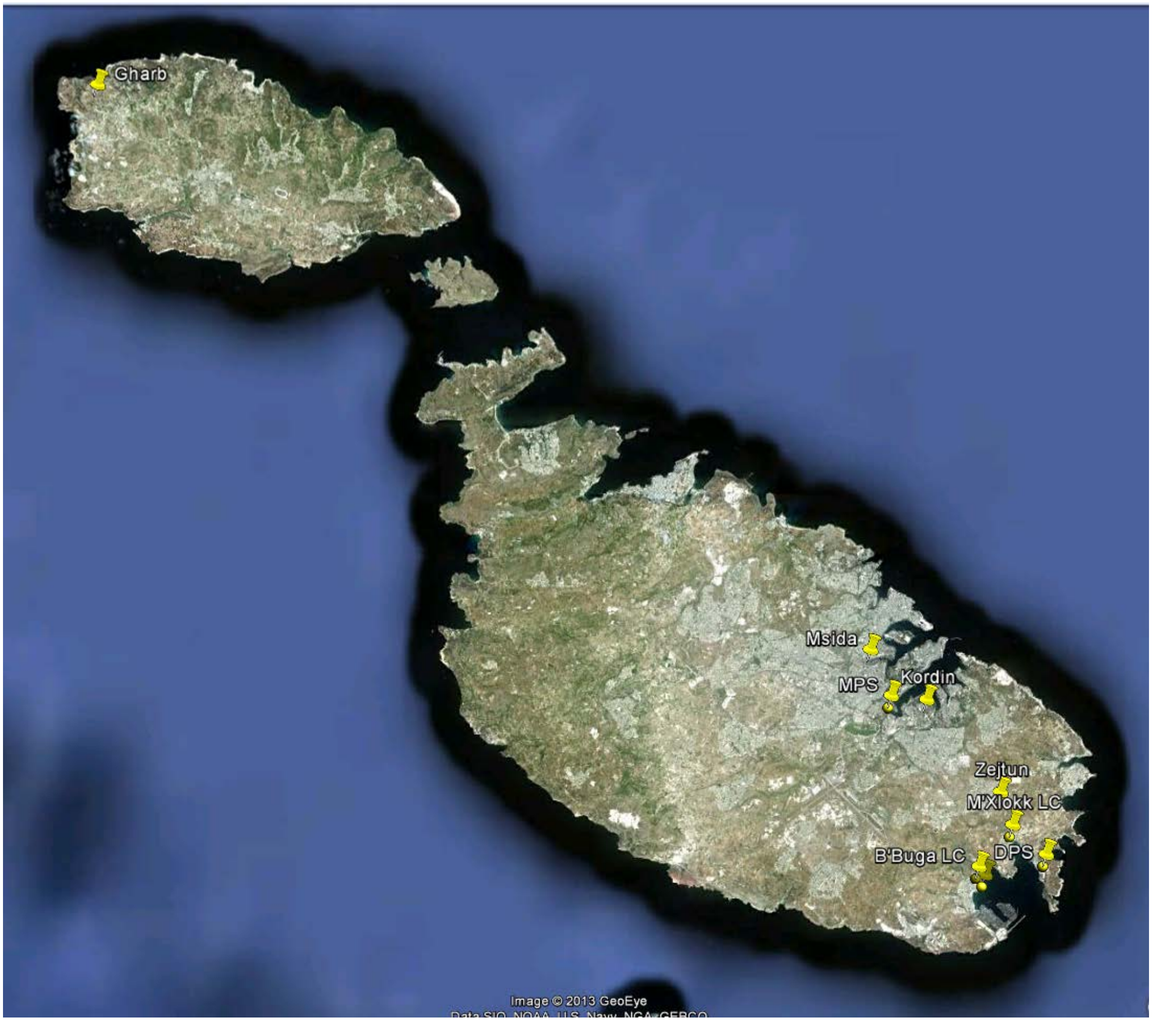


Figure 1: Site map of Maltese Islands (Source: Google Earth)

3. Data Analysis

3.1. Description of Analysis Methodology

Monitoring and emissions data has been analysed using Openair software (http://www.openair-project.org/)[3]. Openair is based on the open-source programming language statistical package R (http://www.r-project.org/). R is open-source software that has been designed to facilitate more in-depth analysis of air quality monitoring data in order to provide a greater understanding of the source and improve management. Further information on any of the functions used can be found in the Openair manual available at the Openair project website. Openair utilises local monitoring data, meteorological data, emissions and GIS to examine:

- Spatial patterns – to show intensity and direction of contributions as a wind rose.
- Temporal patterns – to show diurnal, weekly, monthly, annual and historic trends.
- Exceedance days/hours – to understand the nature of the exceedances.

Spatial, temporal and exceedance analyses can also be combined to show, for example, spatial patterns over time, and temporal patterns spatially, and to compare monitoring sites, pollutants and exceedance periods. These analyses when integrated with GIS data help visualise spatial patterns and indicate source apportionment through the use of triangulation.

Data for the periods 1st January 2009 to 13th December 2012 and 14th December 2012 to 14th June 2013 inclusive have been used for these analyses, representing the baseline and post-commissioning periods respectively. The analyses in this report focus on particulate matter (PM_{10} and $PM_{2.5}$) concentrations and emissions of total dust in order to determine whether the DPS is likely to have contributed to exceedances of the EU Limit Values for PM_{10} and $PM_{2.5}$. Data analysis was compared between sites spatially and temporally to determine any changes between the baseline and post-commissioning monitoring periods. Comparison of monitoring site data with emissions data from DPS has enabled source apportionment estimations. While this report provides the data analysis and indicative conclusions, local knowledge is essential in order to facilitate interpretation of the results that may have been affected by local events, e.g. fireworks, biomass burning, etc.

[3] The software was developed as part of a Natural Environment Research Council (NERC) funded knowledge exchange project led by the Environmental Research Group at King's College London, supported by the University of Leeds and the UK Department of Environment, Food and Rural Affairs (Defra)

3.2. Data Used Within this Study

There are four main sources of data available for use within this project (Table 1).

Table 1: Data sources

Operator	***Site***	***Monitoring type***
Malta Environment and Planning Authority (MEPA) monitoring sites	Gharb (rural background site) Kordin (industrial background site close to Marsa Power Station) Msida (roadside site), and Zejtun (urban background site.	Automatic continuous analysers Automatic continuous analysers Automatic continuous analysers Automatic continuous analysers
Environmental Monitoring Services Ltd (Consultants)	Birzebbuga Marsaxlokk	BAM BAM
AIS Environmental Ltd (Consultants)	Birzebbuga Marsaxlokk	LVS LVS
Enemalta	DPS stack emissions[4]	Continuous emissions monitoring systems

Table 5 shows the data available from each of these sources, the period covered, the site locations and the temporal resolution of the data. Summary plots of the data for each site can be found in Appendix B showing distributions of values and periods of missing data with explanations, where available. No adjustment has been made to basic pollution data subsequent to its receipt by AQMRC, UWE.

3.2.1. Particulate matter sampling

EMS used Beta Attenuation Monitors (BAM) to give continuous measurements of PM_{10} and $PM_{2.5}$, whereas AIS Environmental Ltd used gravimetric Low Volume Samplers, which, although the EU reference method, only provide 24-hour mean data. In order to facilitate comparison with the hourly MEPA monitoring data and Enemalta emissions data, only the BAM data have been analysed in the spatial and temporal analyses of this report; the LVS data has been included in the daily mean exceedance analysis.

[4] Emissions data and ELVs for diesel engines and gas turbines are at a reference oxygen content of 15%, whereas those for the boilers are at a reference oxygen content of 3% in accordance with the IPPC permit

The BAM (technically a dual-BAM/gravimetric Opsis 200) contains two instruments: a visible laser diode 635nm 15mW, which provides real-time measurements, and a beta-ray attenuation on the filter giving a 24-hour average. The raw real-time laser measurements are not considered accurate due to atmospheric and metrological reasons, but when calibrated and scaled against the daily BAM measurement of the conditioned filter, give hourly readings that enable observation of variations during the 24-hour measurement period.

3.2.2. Wind speed and direction

Each of the MEPA monitoring stations has their own wind speed and direction data. For Birzebbuga and Marsaxlokk (and the DPS sites) wind data was taken from the DPS data. Wind data for Marsa Power Station (MPS) was not available in a suitable format for analysis. Wind plots for the baseline and post-commissioning periods are presented in Appendix A.

3.3. Units

Unless otherwise stated, all units for pollutants are in $\mu g/m^3$.

Emissions data are in mg/m^3 or mg/Nm^3.

Windspeed is in m/s. Wind direction is in degrees (360° indicates north).

Different scales have frequently been used on similar looking plots – this is often because patterns of pollution have been considered to be more important than absolute concentrations. The reader is alerted to this fact and advised to pay close attention to scales on the axes when comparing plots. In many cases, where practicable, differences in scales have been indicated.

3.4. Data availability

The Summary plots in Appendix B show an overview of the available data from each site.

Baseline data for the MEPA sites are available for most pollutants from 1st January 2009 to 13th December 2012, although PM_{10} data for Kordin are only available for the first half of 2011 and the latter part of 2012, and there are no $PM_{2.5}$ data for this site. Wind data at Kordin are only available from late 2011 and wind data for Msida are absent for the first half of 2012. Baseline data for both of the consultants' LVS sites in Birzebbuga and Marsaxlokk are available from 5th April to 13th December 2012. Recalibrated BAM data, however, were only provided from 10th December 2012, so essentially there are no hourly baseline data at either site. Baseline emissions data for the DPS are available for DPS1A and 1B from 1st January 2009, for DPS 4 and 5 from 1st January

2010 and for DPS6A-D for just 2012. Wind data for the DPS are also only available from April 2012.

Post-commissioning data are available for all sites from 14th December 2012 to 14th June 2013. Data availability is good for the MEPA sites, although PM_{10} data for Gharb and Zejtun are only available from March 2013 and there are no $PM_{2.5}$ data for Kordin. Data availability is also good for the monitoring at the consultants' sites, though explanations for notable exceptions are provided in Table 2 to Table 4. Only PM_{10} and $PM_{2.5}$ data are available for these sites, with wind data taken from the DPS site. Post-commissioning emissions data availability from the DPS plant is generally good, although DPS4, DPS5 and DPS6A, DPS6B and DPS6C have data capture of less than 75% across the period. According to MEPA, an absence of data relating to the stack emissions normally signifies that the plant has been switched off. It is important to note that the interpretation of the plots where data capture may be limited should be made with caution.

Table 2: Reasons for data gaps in Birzebbuga LVS data (provided by consultants)

Period	Reason	Analyser affected
08-09/04/2012	Power interruption	PM_{10} and $PM_{2.5}$
14-15/05/2012	Power interruption	PM_{10} and $PM_{2.5}$
09/06/2012	Power interruption	PM_{10} and $PM_{2.5}$
07/08/2012	Sampling volume below minimum data capture	PM_{10} and $PM_{2.5}$
23/08/2012	Sampling volume below minimum data capture	PM_{10}
03-04/09/2012	Power interuption due to bad weather	PM_{10} and $PM_{2.5}$
03-09/09/2012	A new PM2.5 LVS was installed at Bbugia	$PM_{2.5}$
20/09/2012	Sampling volume below minimum data capture	$PM_{2.5}$
24-25/09/2012	Filters broken during shipment	$PM_{2.5}$
25-31/10/2012	Power interruption	PM_{10} and $PM_{2.5}$
15-28/11/2012	Power interruption	PM_{10} and $PM_{2.5}$
12-17/12/2012	Delays in delivery of filters by courier Italy-Malta due to weather conditions	PM_{10} and $PM_{2.5}$
14/02/2013	Power interruption	$PM_{2.5}$
20/02-07/03/2013	Power interruption	PM_{10} and $PM_{2.5}$
09-11/04/2013	Power interruption	$PM_{2.5}$
20/12/2012	Maintenance	PM_{10} and $PM_{2.5}$
25/04/2013	Malfunctioning of instrument	$PM_{2.5}$
26/04/2013	Malfunctioning of instrument	PM_{10}
13-15/05/2013	Power interruption	PM_{10} and $PM_{2.5}$

Table 3: Reasons for data gaps in Marsaxlokk LVS data (provided by consultants)

Period	Reason	Analyser affected
27/04/2012	Sampling volume below minimum data capture due to relocation	PM_{10} and $PM_{2.5}$
14-15/05/2012	Power interruption	PM_{10}
20-24/07/2012	Power interruption	PM_{10} and $PM_{2.5}$
08-11/08/2012	Power switched off	PM_{10} and $PM_{2.5}$
13-22/08/2012	Power switched off	PM_{10} and $PM_{2.5}$
03-04/09/2012	Power interuption due to bad weather	PM_{10} and $PM_{2.5}$
07-26/11/2012	New PM_{10} LVS was installed at MXlokk	PM_{10}
19/11/2012	Power interruption	PM_{10} and $PM_{2.5}$
12-17/12/2012	Delays in delivery of filters by courier Italy-Malta due to weather conditions	PM_{10} and $PM_{2.5}$
14/02/2013	Power interruption	PM_{10} and $PM_{2.5}$
23-25/02/2013	Power interruption	PM_{10} and $PM_{2.5}$
02-07/03/2013	Power interruption	PM_{10} and $PM_{2.5}$
09-11/04/2013	Power interruption	$PM_{2.5}$
26/04/2013	Malfunctioning of instrument	PM_{10} and $PM_{2.5}$
27/04/2013	Malfunctioning of instrument	$PM_{2.5}$
02-08/05/2013	Malfunctioning of instrument	$PM_{2.5}$
09/05/2013	Sampling volume below minimum data capture	PM_{10} and $PM_{2.5}$

Table 4: Reasons for data gaps in Marsaxlokk BAM data (provided by consultants)

Period	Reason	Analyser affected
02-04/03/2013	No electricity in mains	PM_{10} and $PM_{2.5}$
13-18/03/2103	Filter got stuck in loading carousel. Mechanical fault in analyser	$PM_{2.5}$
05-10/06/2013	Maintenance on pump which than resulted into a leak of airflow	PM_{10}
11-12/06/2013	Power Cuts in mains which resulted into an electrical error in the analyser	PM_{10} and $PM_{2.5}$

Table 5: Details of Concentration and Emissions Monitoring Locations and Data Used in this Study

Operator	Site	Start	End	X-Ref	Y-Ref	PM_{10}	$PM_{2.5}$	Wind Spd & Dir.	Total Dust[5]	Time Res.
MEPA	Gharb (rural background)	1/1/2009	14/6/2013	14.198	36.068	✓	✓	✓	✗	1hr
	Kordin (urban industrial)	1/1/2009	14/6/2013	14.511	35.881	✓	✗	✓	✗	1hr
	Msida (urban roadside)	1/1/2009	14/6/2013	14.490	35.896	✓	✓	✓	✗	1hr
	Zejtun (urban background)	1/1/2009	14/6/2013	14.539	35.852	✓	✓	✓	✗	1hr
EMS	Birzebbuga BAM	3/9/2012	14/6/2013	14.531	35.829	✓	✓	✗	✗	1hr
	Marsaxlokk BAM	3/9/2012	14/6/2013	14.544	35.842	✓	✓	✗	✗	1hr
AIS	Birzebbuga LVS	5/4/2012	14/6/2013	14.531	35.829	✓	✓	✗	✗	24hr
	Marsaxlokk LVS	5/4/2012	14/6/2013	14.544	35.842	✓	✓	✗	✗	24hr
Enemalta	DPS1A (Boiler)	1/1/2009	14/6/2013	14.556	35.833	✗	✗	✗	✓	1hr
	DPS1B (Boiler)	1/1/2009	14/6/2013	14.556	35.833	✗	✗	✗	✓	1hr
	DPS4 (Combined Cycle Gas Turbine)	1/1/2010	14/6/2013	14.556	35.833	✗	✗	✗	✓	1hr
	DPS5 (Combined Cycle Gas Turbine)	1/1/2010	14/6/2013	14.556	35.833	✗	✗	✗	✓	1hr
	DPS6 Stack A (Diesel)	24/2/2012	14/6/2013	14.556	35.833	✗	✗	✗	✓	1hr
	DPS6 Stack B (Diesel)	24/2/2012	14/6/2013	14.556	35.833	✗	✗	✗	✓	1hr
	DPS6 Stack C (Diesel	24/2/2012	14/6/2013	14.556	35.833	✗	✗	✗	✓	1hr
	DPS6 Stack D (Diesel)	24/2/2012	14/6/2013	14.556	35.833	✗	✗	✗	✓	1hr
	DPS Wind	1/4/2012	14/6/2013	14.556	35.833	✗	✗	✓	✗	1hr

[5] Total dust emissions are used as a proxy for PM_{10} and $PM_{2.5}$. Emissions of PM_{10} and $PM_{2.5}$ are not measured directly in line with standard practice, the provisions of the Large Combustion Plant Directive and the Industrial Emissions Directive and the absence of international standards for PM_{10} or $PM_{2.5}$ emissions data.

3.5. Spatial Analysis

3.5.1. Description of Polar Plots

The main analyses in this section have been carried out using the *polar plot* function in Openair. The purpose of polar plots is to summarise the hourly pollutant data over long periods against the wind speed and direction data in order to give some directional analysis which can then be related to potential sources. Polar plots are bivariate plots of pollution concentrations indicating how pollution concentrations vary by wind speed and wind direction. These plots are calculated using statistical smoothing techniques to show a continuous surface. The colour represents the pollutant concentration (blue = low, red = high) and the degrees show the wind direction (e.g. the upper quadrants show concentrations with wind/pollution coming from the north). The distance from the centre indicates the wind speed and therefore gives an indication of how far pollutants are likely to have travelled.

To better understand the uncertainty of the data, three plots are produced on the same scale showing the predicted surface together with the estimated lower and upper uncertainties at the 95% confidence interval. Plotting the uncertainties is useful to understand whether features are real or not. For example, at high wind speeds where there are few data there is greater uncertainty over the predicted values. If the trend is apparent across all three plots, there can be more confidence that it is ‘real’.

Two different types of polar plots have been used in this report to represent monitored concentrations and emissions data respectively. For the monitored concentrations data (Figure 2–Figure 19), the monitoring station (receptor) is represented by the centre of the plot and the plot relates to the concentrations monitored at that site. For the DPS emissions data (Figure 20 to Figure 35), the stack (source) is represented by the centre of the plot and the plot relates to the emissions data from that stack. In this way the two plot-types complement each other as it is possible to see what the wind direction was when the highest levels of emissions were released and this can be compared to the wind direction at nearby monitoring sites when the highest concentrations of corresponding pollutants were recorded. For example, if the emissions plots show high levels of dust with the wind in the south east quadrant, it may be possible to identify whether there were corresponding high concentrations of PM_{10}/$PM_{2.5}$ in the same quadrant at Marsaxlokk for the same period, and vice versa.

Two sets of polar plots are shown for each site representing baseline and post-commissioning data.

3.5.2. PM_{10} and $PM_{2.5}$ Polar Plots from MEPA Monitoring Stations

Figure 2 to Figure 15 show concentrations of PM_{10} (µg/m^3) and $PM_{2.5}$ (µg/m^3), where available, plotted with wind speed (m/s) and direction (degrees) at the four MEPA monitoring sites for the baseline and post-commissioning periods. Interpretation of the Kordin baseline PM_{10} plot, and Gharb and Zejtun post-commissioning PM_{10} and $PM_{2.5}$ plots should bear in mind the availability of PM and wind data as detailed in section 0.

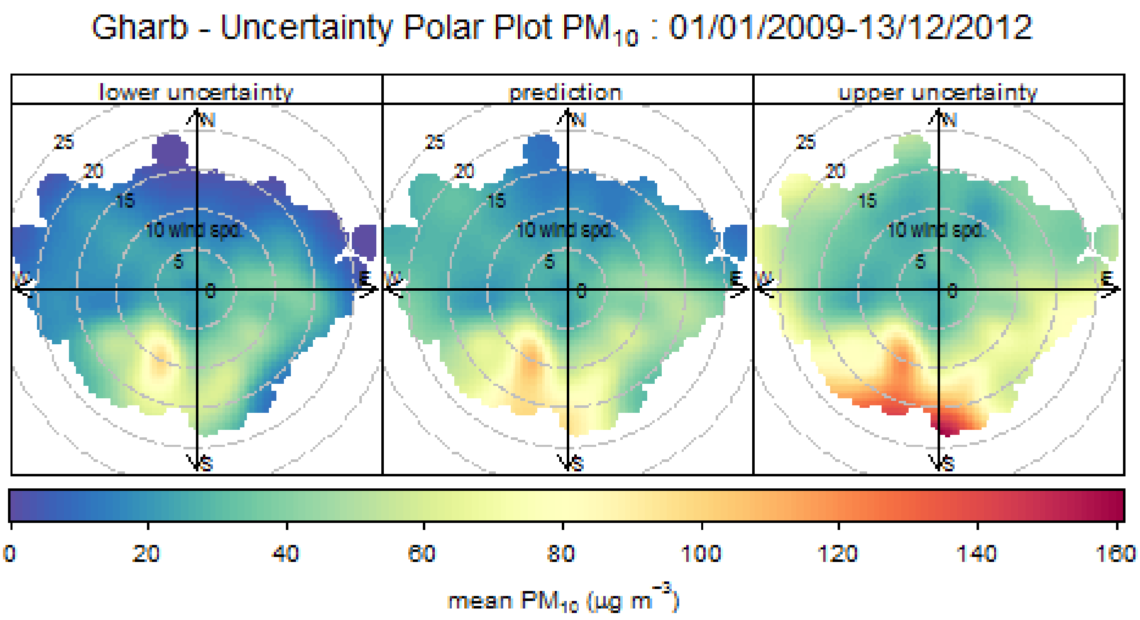


Figure 2: Gharb baseline PM_{10} polar plot

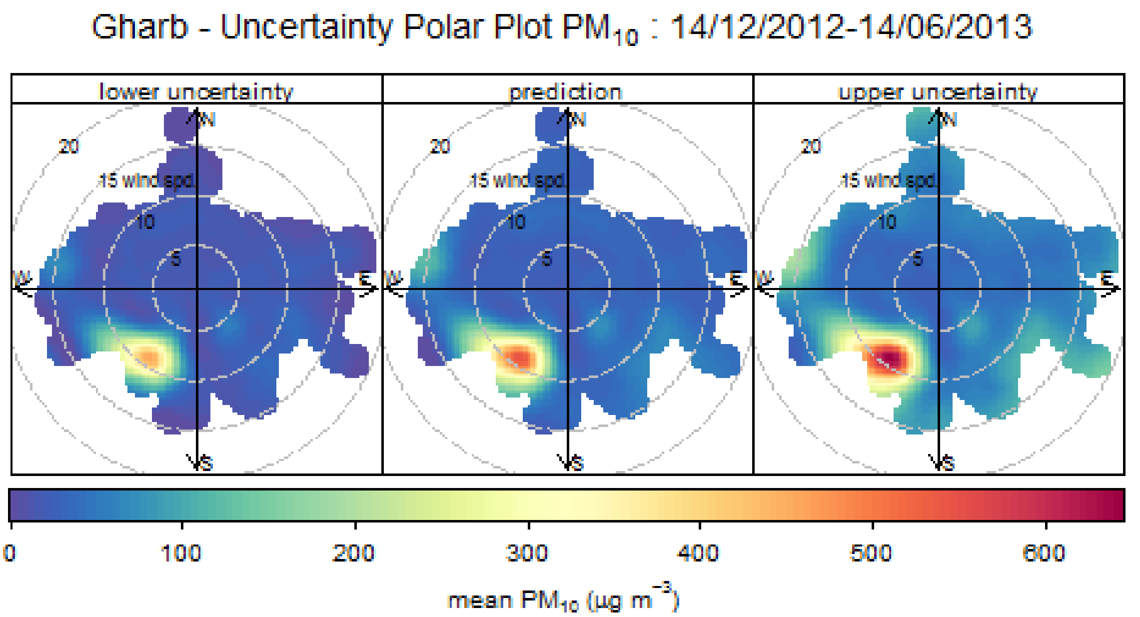


Figure 3: Gharb post-commissioning PM_{10} polar plot

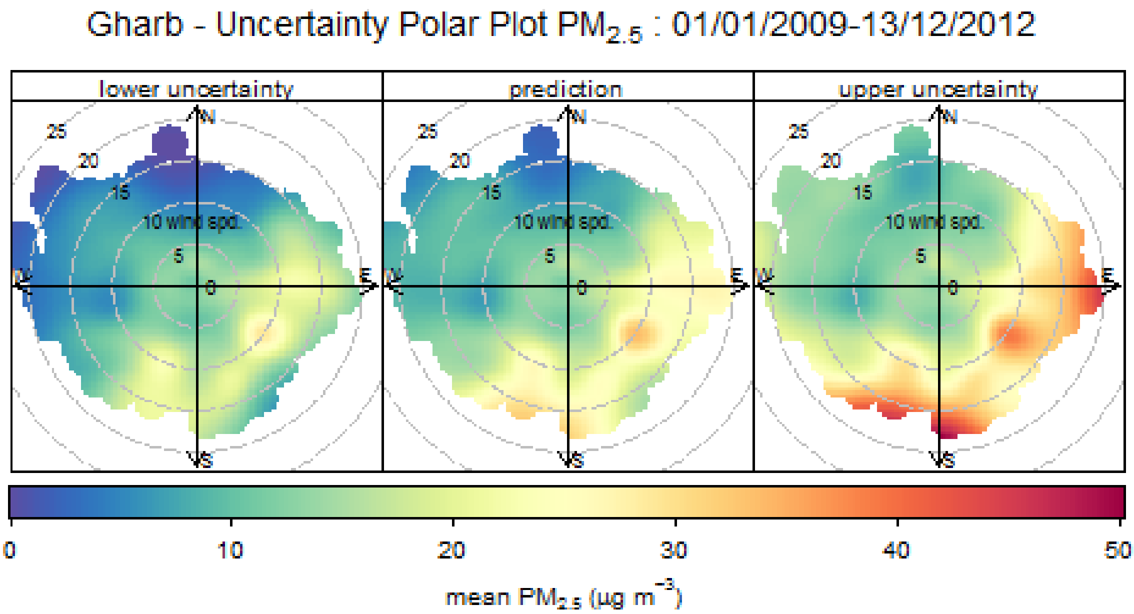


Figure 4: Gharb baseline $PM_{2.5}$ polar plot

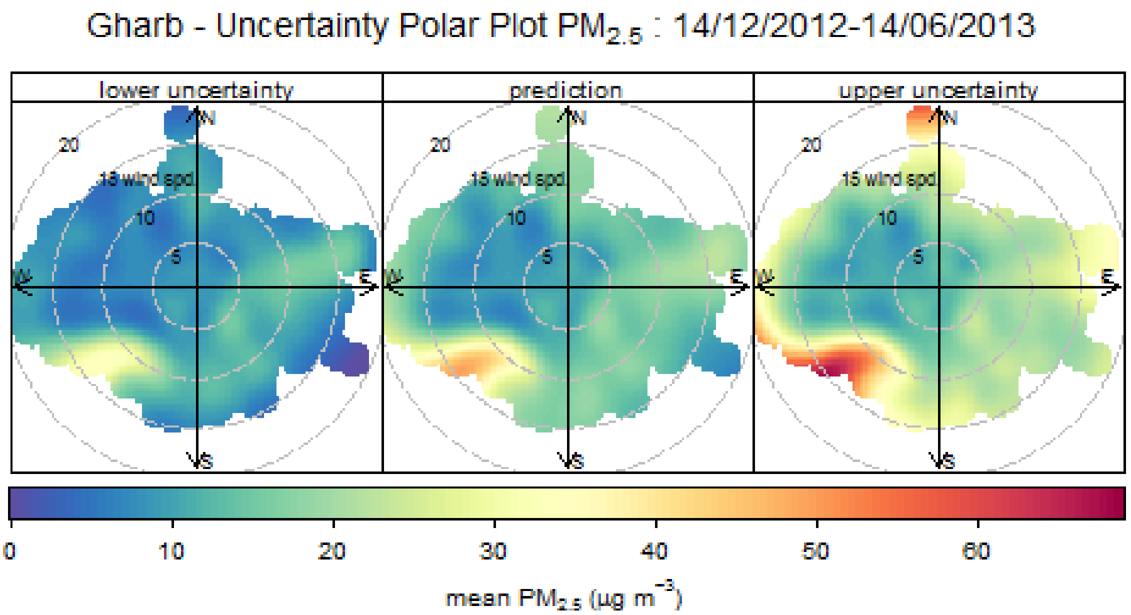


Figure 5: Gharb post-commissioning $PM_{2.5}$ polar plot

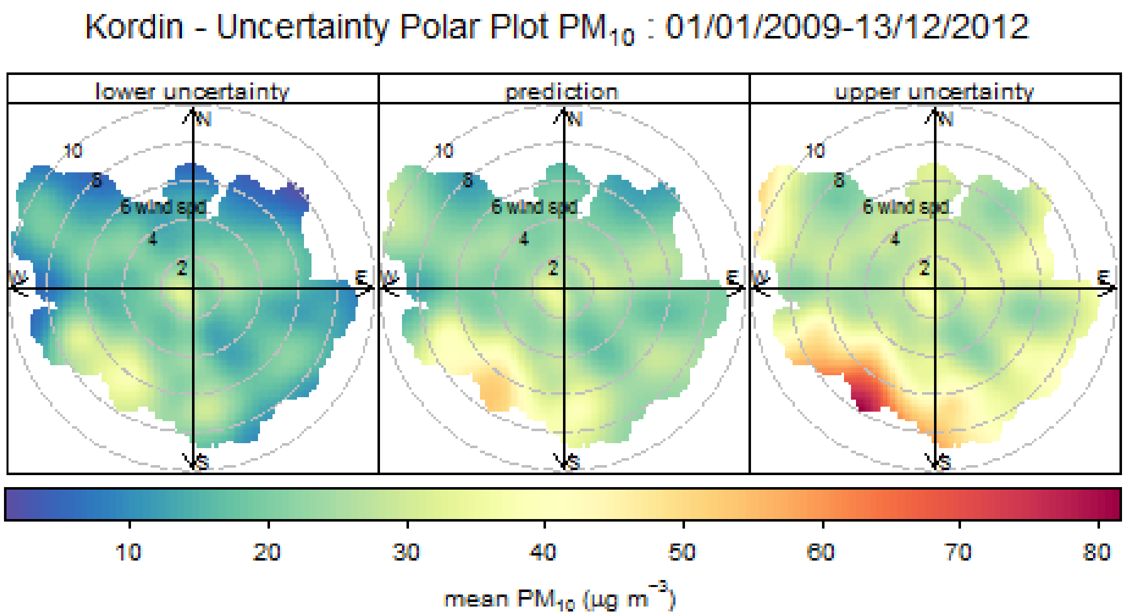


Figure 6: Kordin baseline PM_{10} polar plot

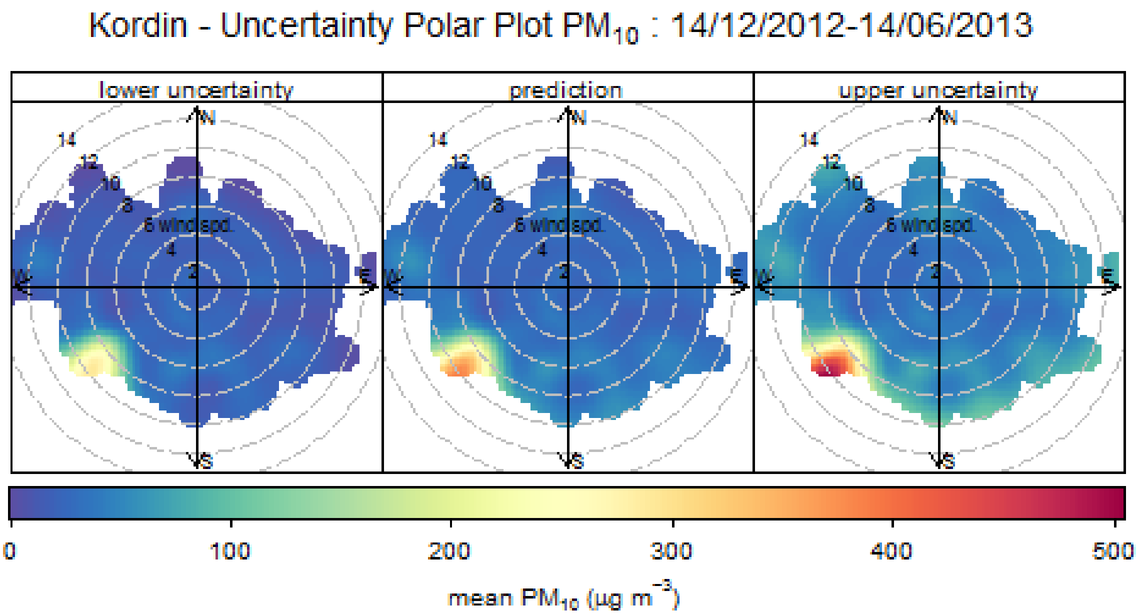


Figure 7: Kordin post-commissioning PM_{10} polar plot

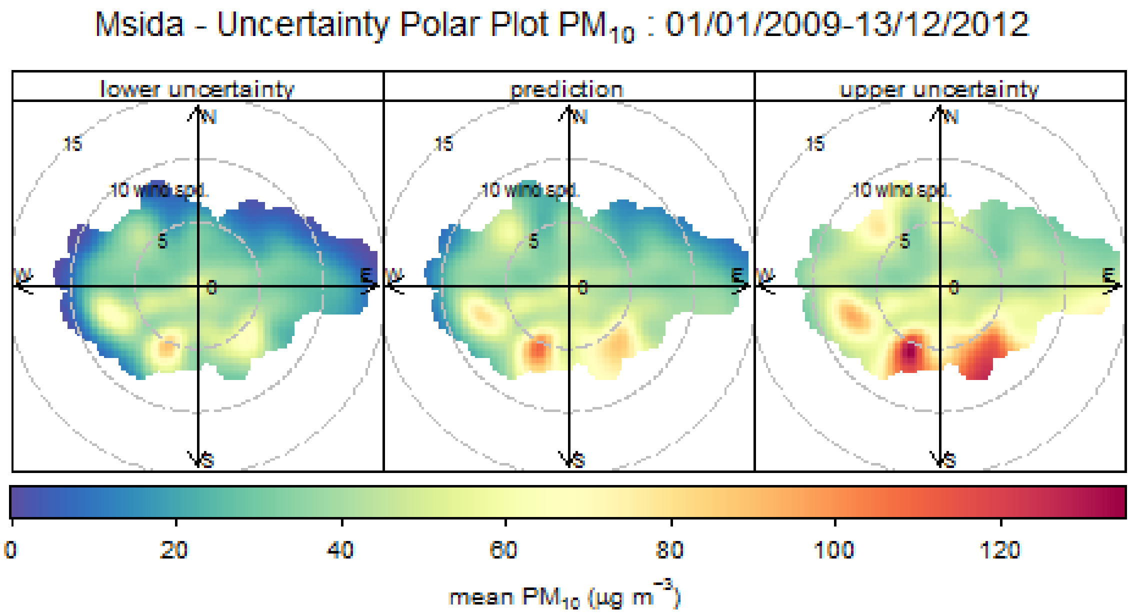


Figure 8: Msida baseline PM$_{10}$ polar plot

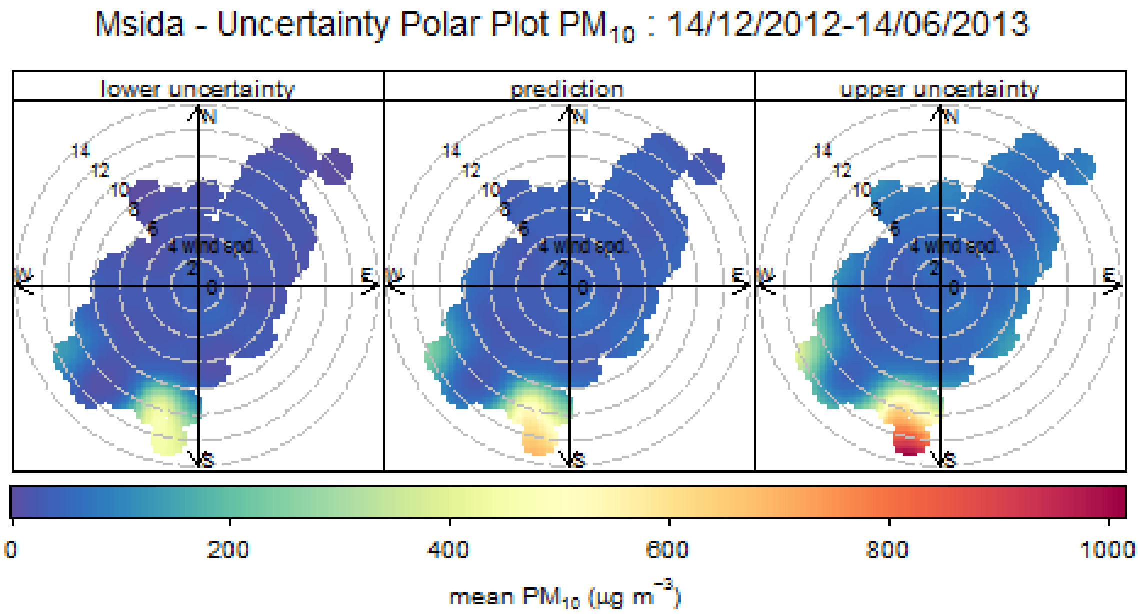


Figure 9: Msida post-commissioning PM$_{10}$ polar plot

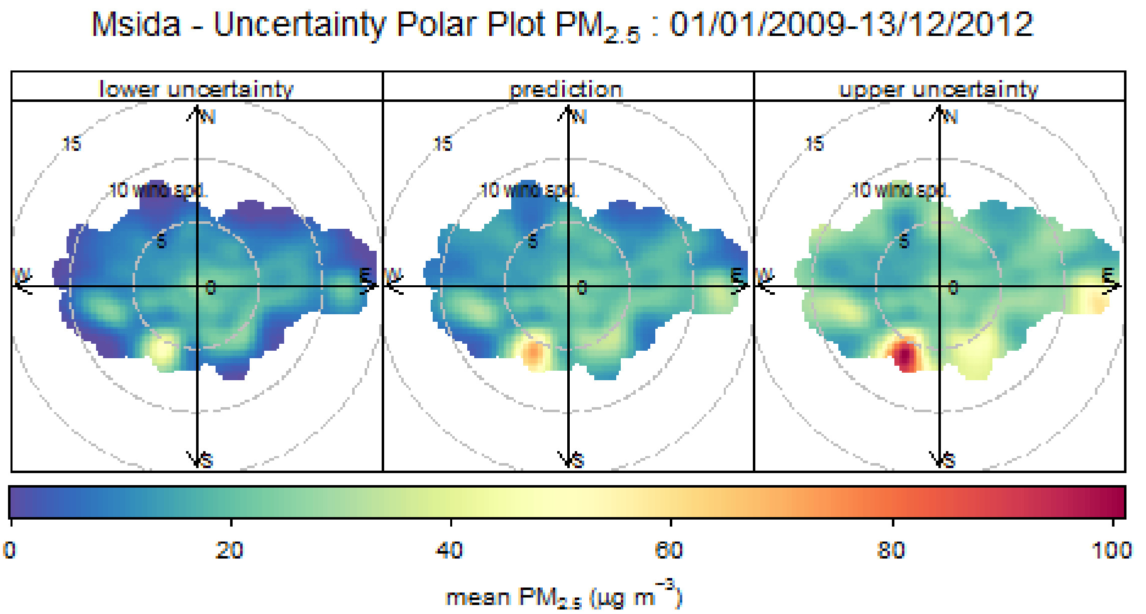


Figure 10: Msida baseline $PM_{2.5}$ polar plot

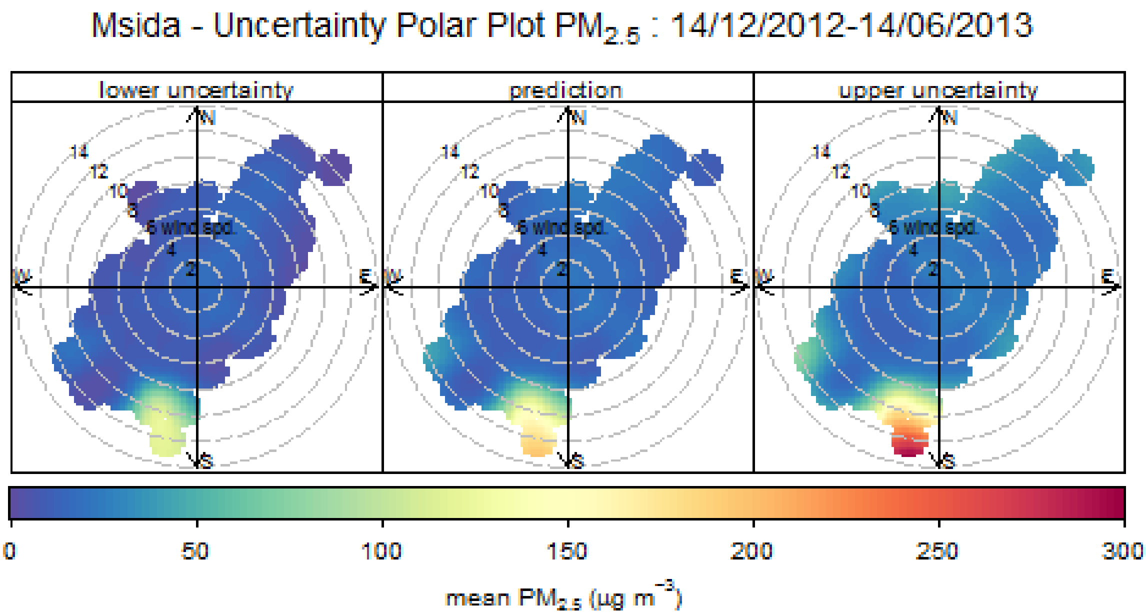


Figure 11: Msida post-commissioning $PM_{2.5}$ polar plot

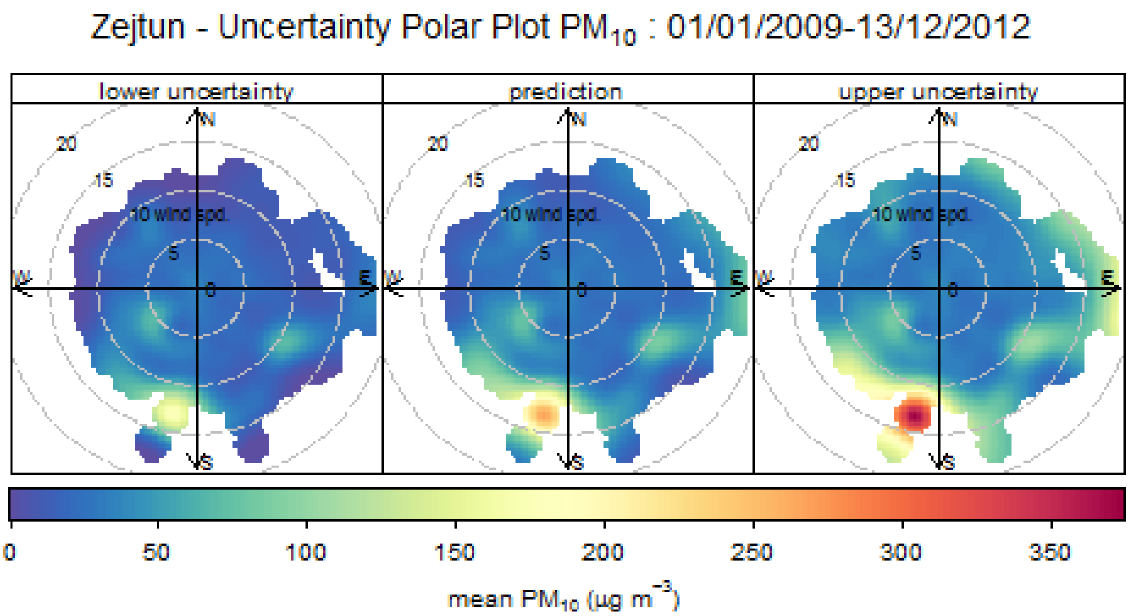


Figure 12: Zejtun baseline PM_{10} polar plot

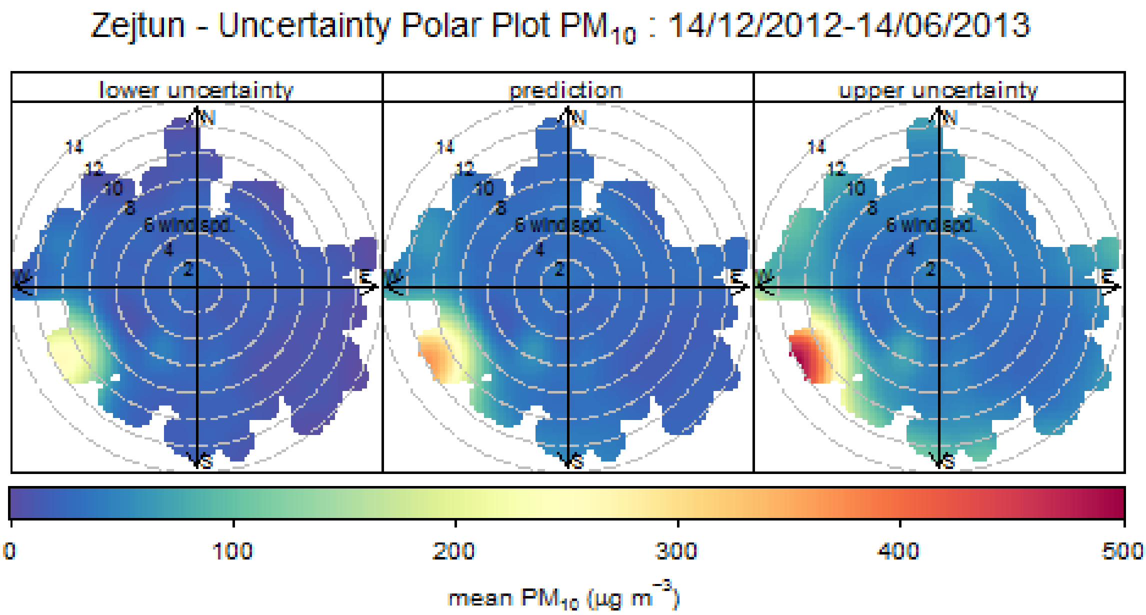


Figure 13: Zejtun post-commissioning PM_{10} polar plot

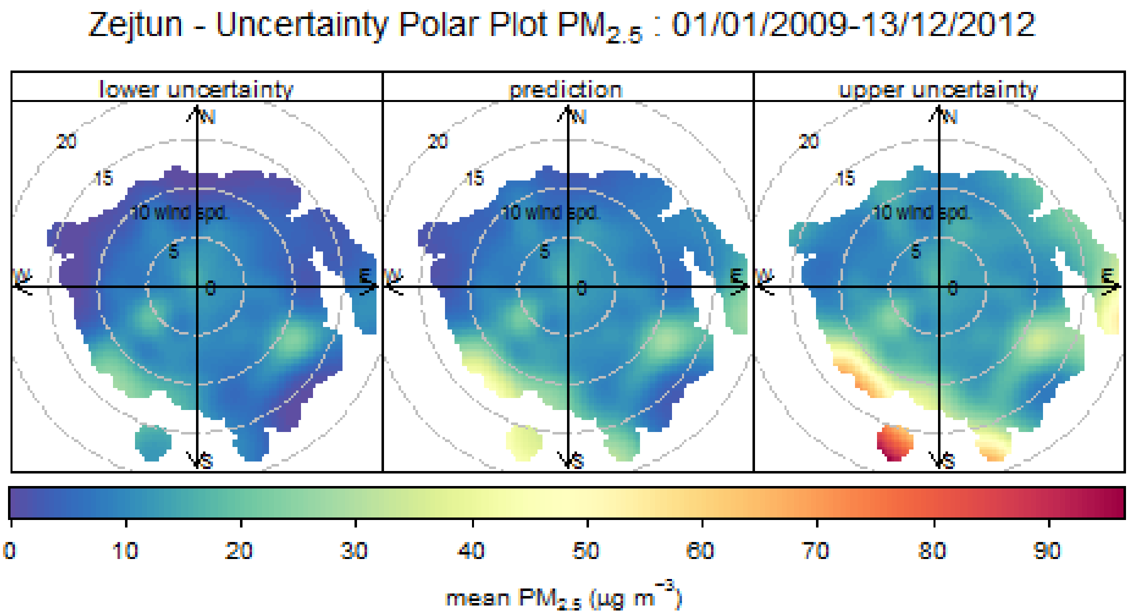


Figure 14: Zejtun baseline $PM_{2.5}$ polar plot

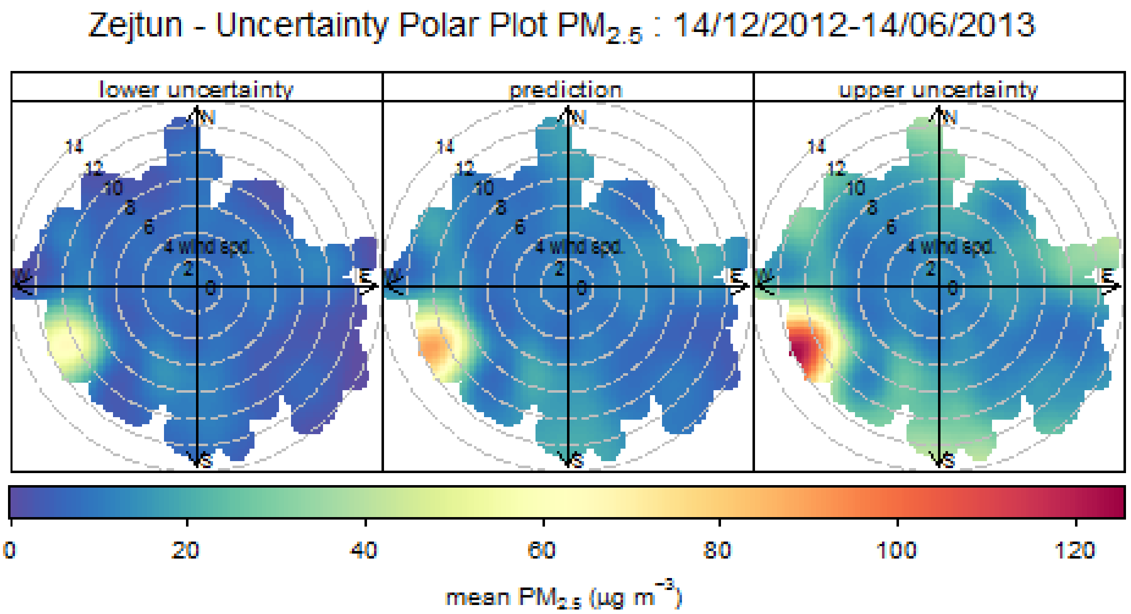


Figure 15: Zejtun post-commissioning $PM_{2.5}$ polar plot

The plots indicate that the highest concentrations of PM_{10} and $PM_{2.5}$ during the baseline period were monitored under southerly or south-westerly wind conditions, contrary to prevailing wind directions (Appendix A) (although during the post-commissioning period the predominant wind direction at Msida was south-westerly). During the post-commissioning period, the highest PM_{10} and $PM_{2.5}$ concentrations tended to come from the SW.

Concentrations tend to be highest at moderate to high wind speeds (between 8-15 m/s) during both the baseline and post-commissioning periods, potentially indicating:

- predominant sources are not in immediate proximity to the sites; and
- concentrations are likely to be related to sources where emission or dispersion characteristics are affected by wind speed (such as wind-raised dust, or turbulent grounding of plumes).

Given that data has not been adjusted for natural sources it is likely that the predominant source may be from transboundary sources, e.g. Saharan dust.

The total mean concentrations of PM_{10} and $PM_{2.5}$ during the post-commissioning period are much higher than the baseline at most sites (Zejtun being an exception), up to eight times higher at Msida, six times higher at Kordin and four times higher at Gharb. These data indicate that there was a significant south-westerly source dominating concentrations in the post-commissioning period.

3.5.3. PM_{10} and $PM_{2.5}$ Polar Plots from Birzebbuga and Marsaxlokk

Figure 16 to Figure 19 show concentrations of PM_{10} (µg/m^3) and $PM_{2.5}$ (µg/m^3) plotted with wind speed (m/s) and direction (degrees) at the two consultants' monitoring sites. The PM data are taken from the BAM stations, as hourly data are required to create polar plots, while the wind data are from the DPS. There are no hourly baseline data available as recalibrated data was only provided from 10th December 2012, so the plots only represent post-commissioning data.

As with the MEPA sites, highest PM_{10} and $PM_{2.5}$ concentrations were found at low to moderate wind speeds (~10 m/s), contrary to prevailing wind directions. Highest concentrations at both sites appear to have been from a SW direction for both PM_{10} and $PM_{2.5}$, though there is also a slight contribution from the SE. Both sites show a very similar spatial pattern of pollution for both PM_{10} and $PM_{2.5}$. Maximum mean concentrations at both sites were similar between the sites and also similar to concentrations at Zejtun, an urban background site.

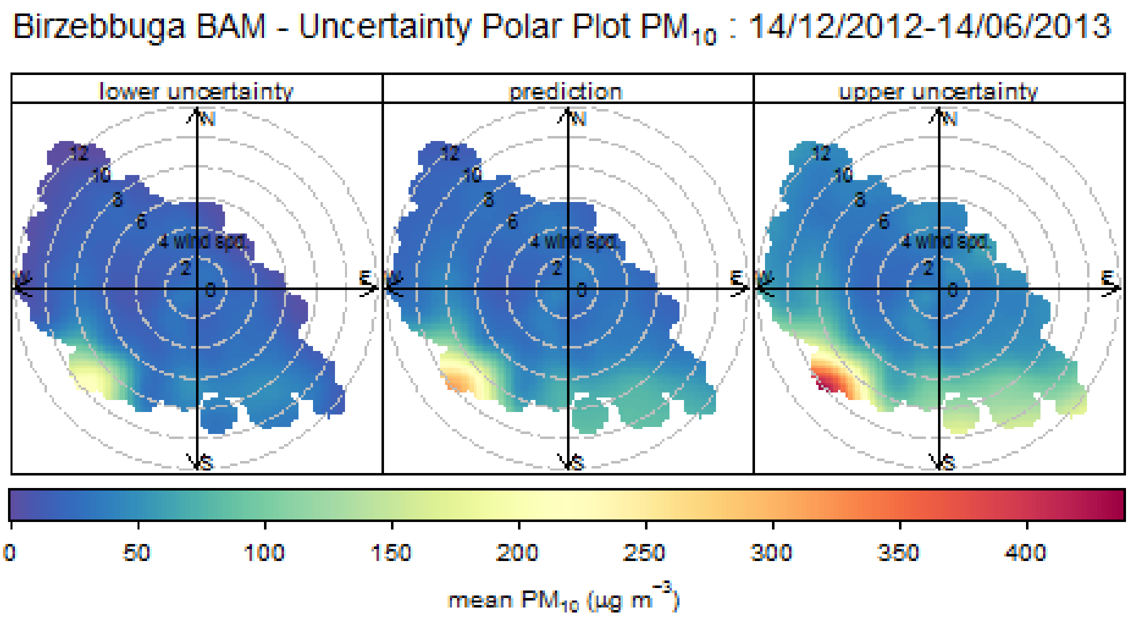


Figure 16: Birzebbuga BAM post-commissioning PM_{10} polar plot

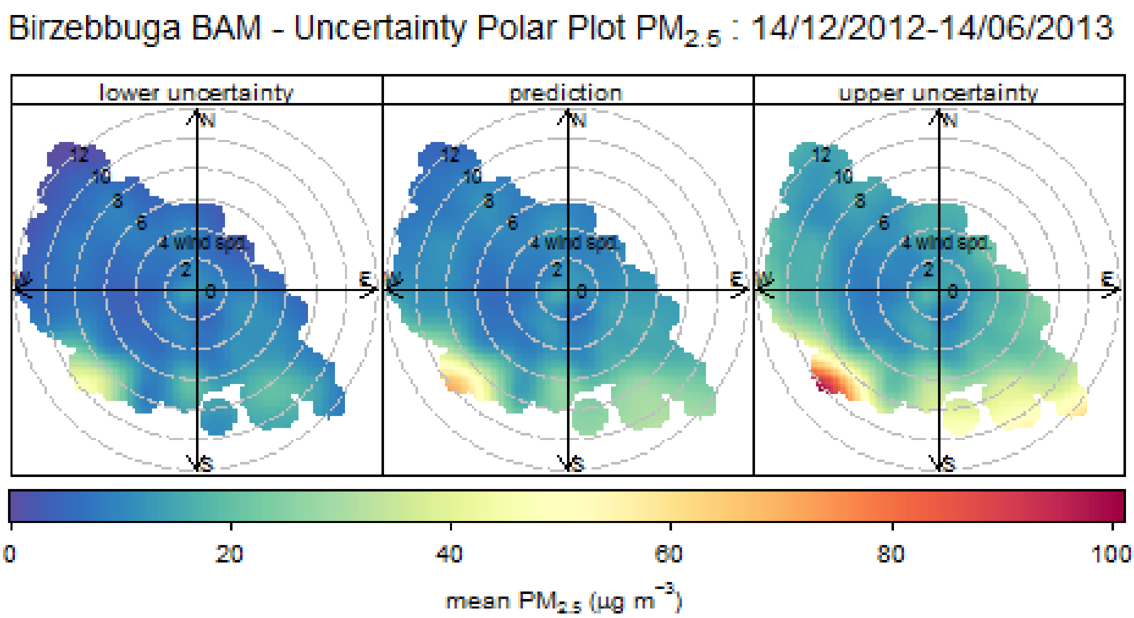


Figure 17: Birzebbuga BAM post-commissioning $PM_{2.5}$ polar plot

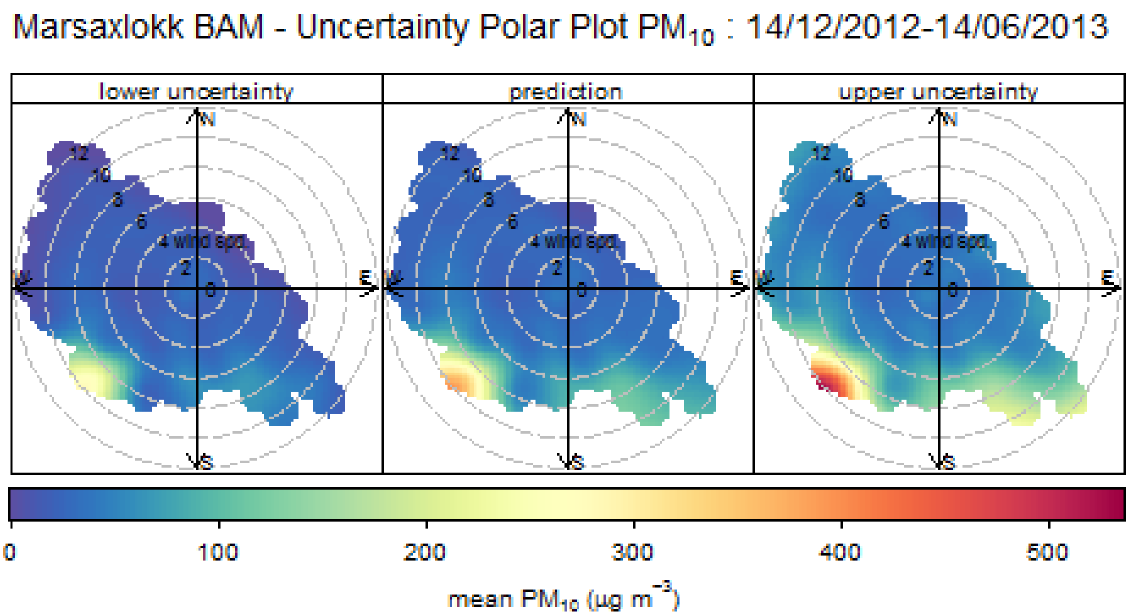


Figure 18: Marsaxlokk BAM post-commissioning PM_{10} polar plot

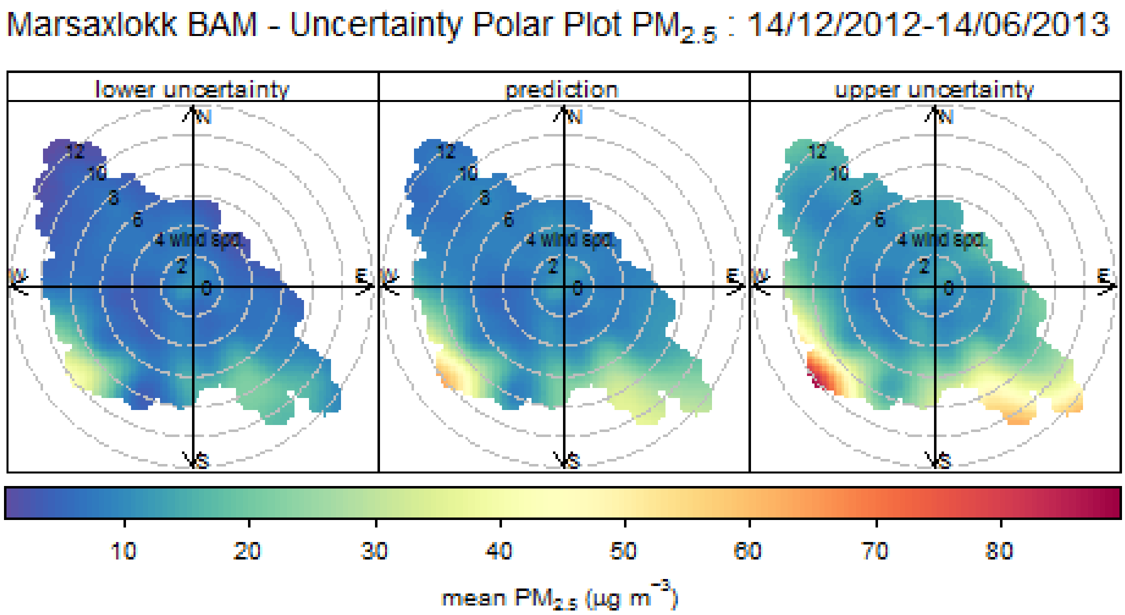


Figure 19: Marsaxlokk BAM post-commissioning $PM_{2.5}$ polar plot

3.5.4. Polar Plots from DPS Emissions Data

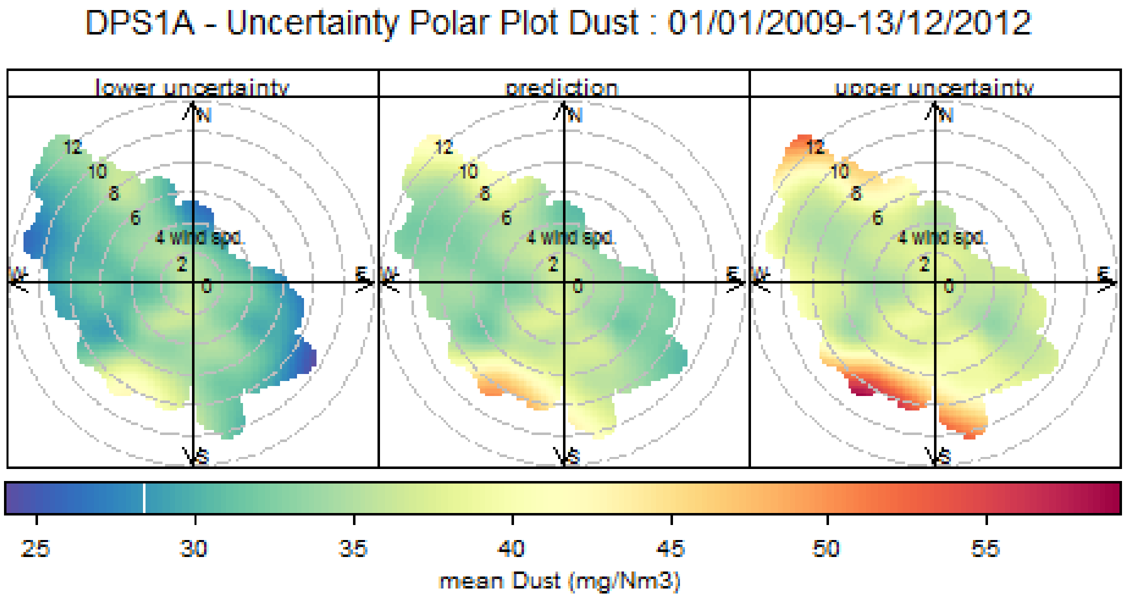


Figure 20: DPS1A baseline dust polar plot

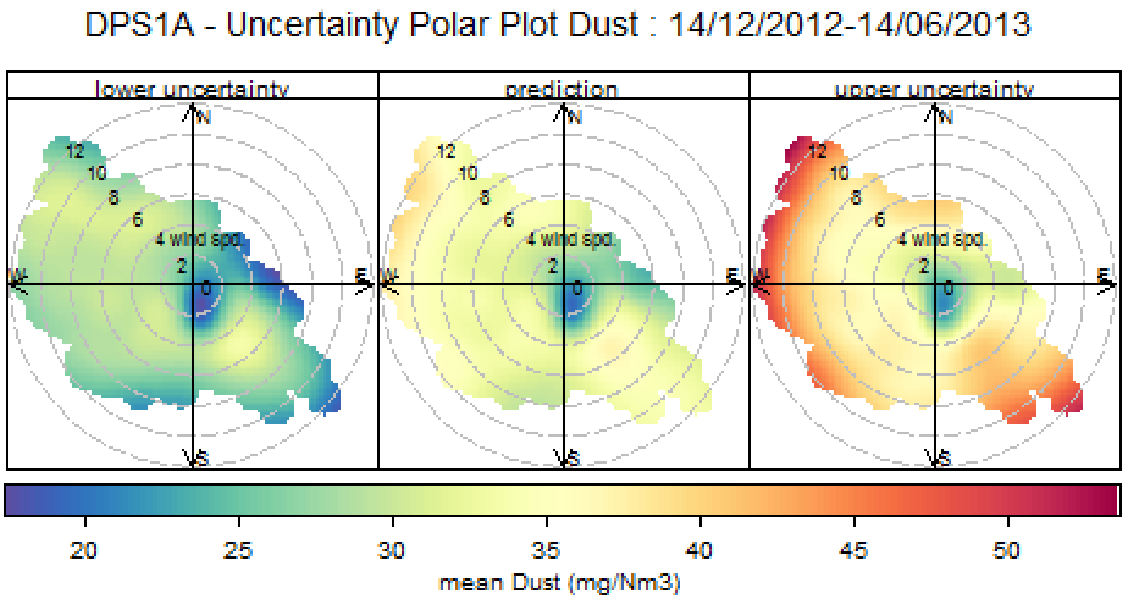


Figure 21: DPS1A post-commissioning dust polar plot

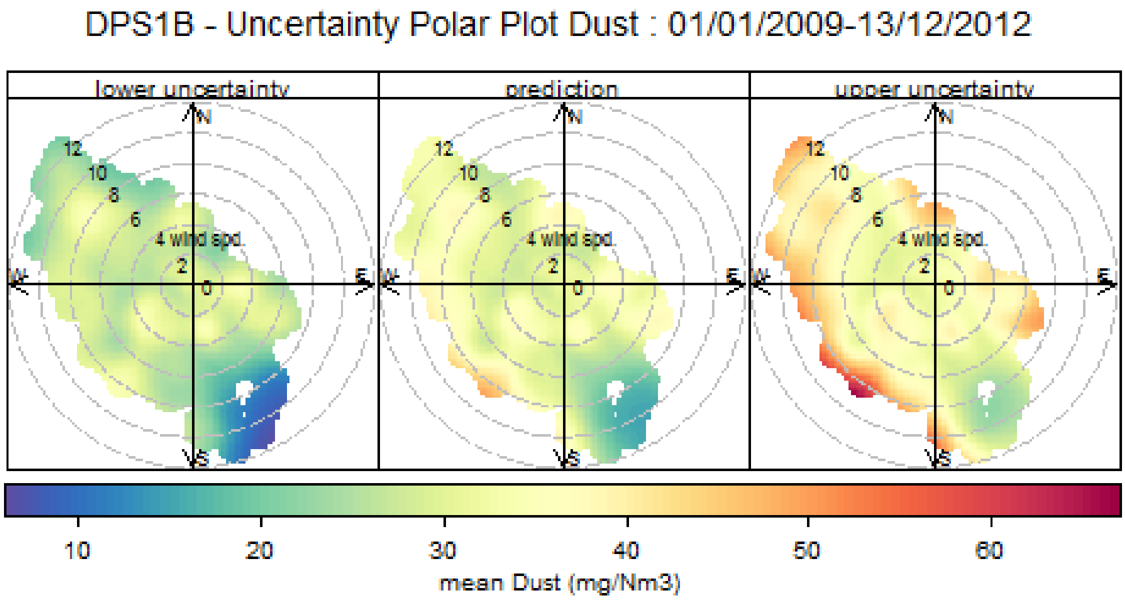


Figure 22: DPS1B baseline dust polar plot

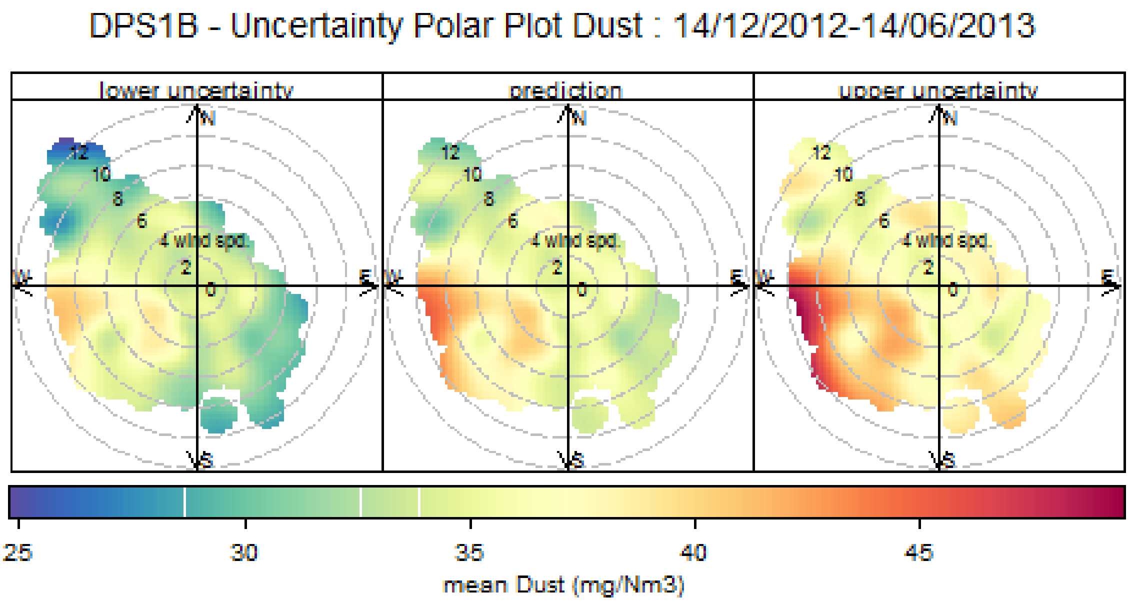


Figure 23: DPS1B post-commissioning dust polar plot

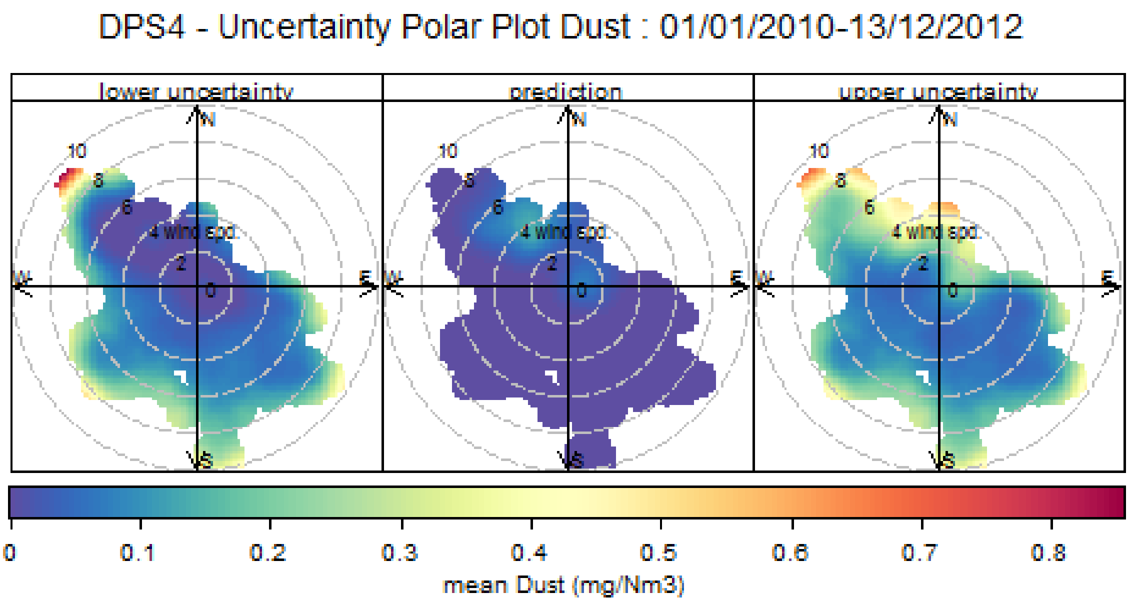


Figure 24: DPS4 baseline dust polar plot

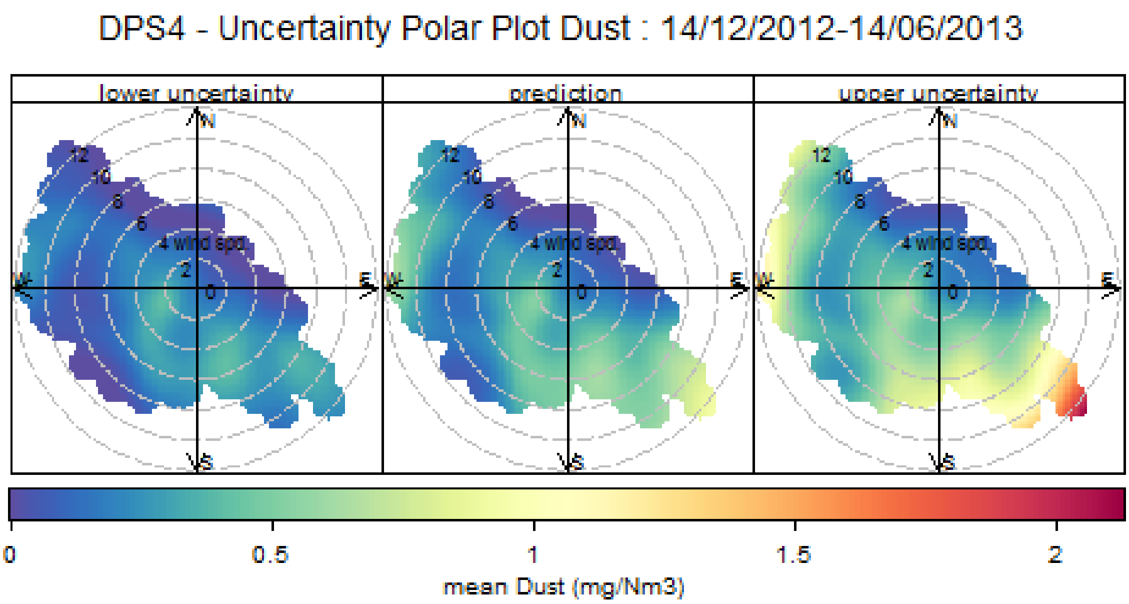


Figure 25: DPS4 post-commissioning dust polar plot

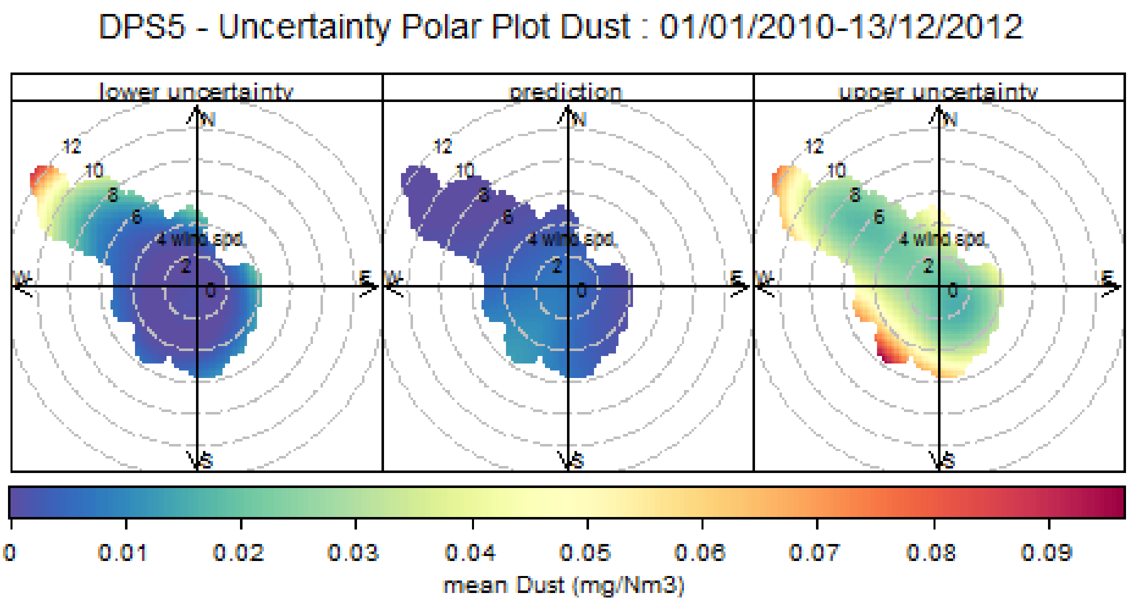


Figure 26: DPS5 baseline dust polar plot

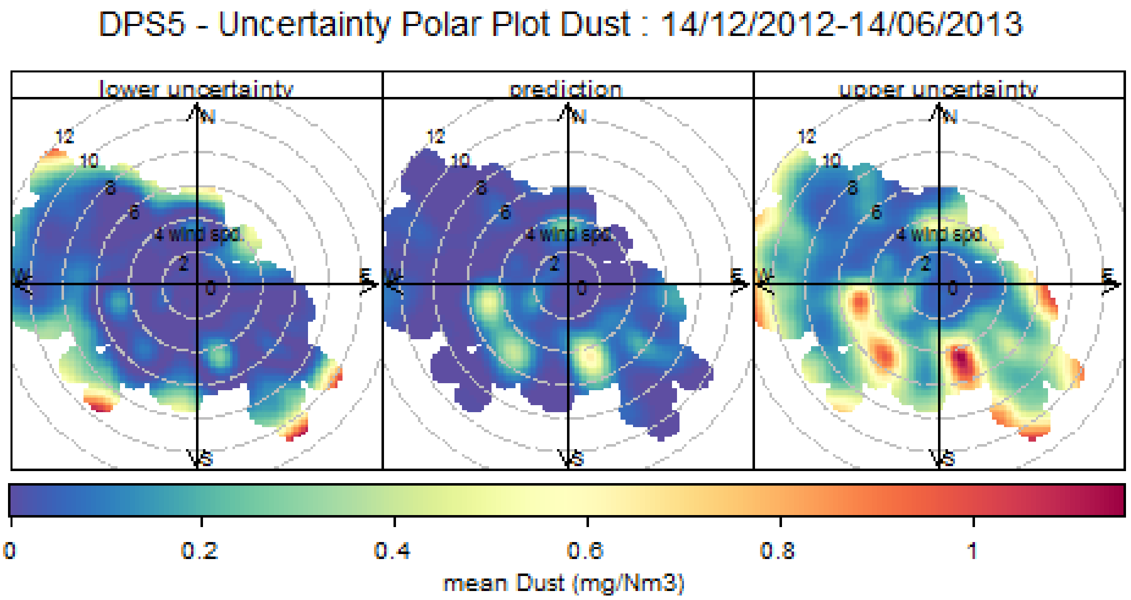


Figure 27: DPS5 post-commissioning dust polar plot

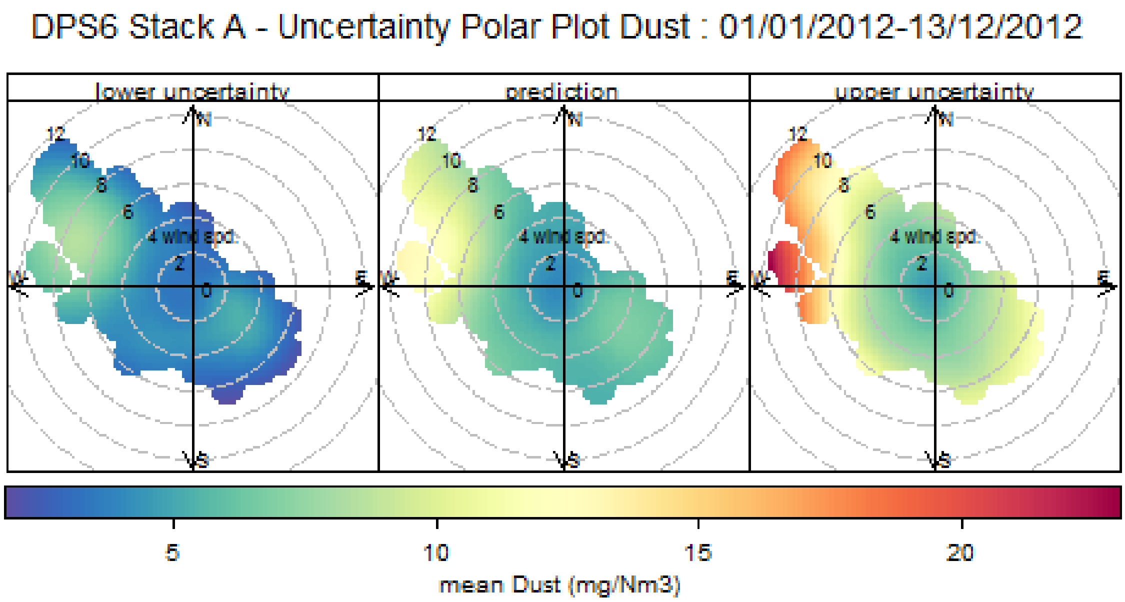


Figure 28: DPS6A baseline dust polar plot

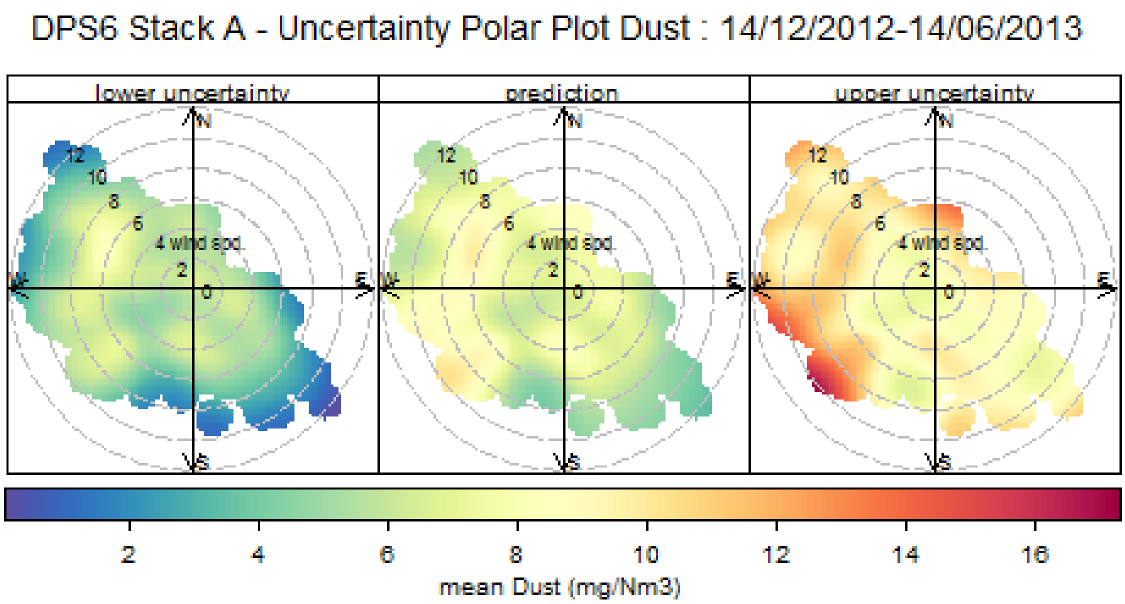


Figure 29: DPS6A post-commissioning dust polar plot

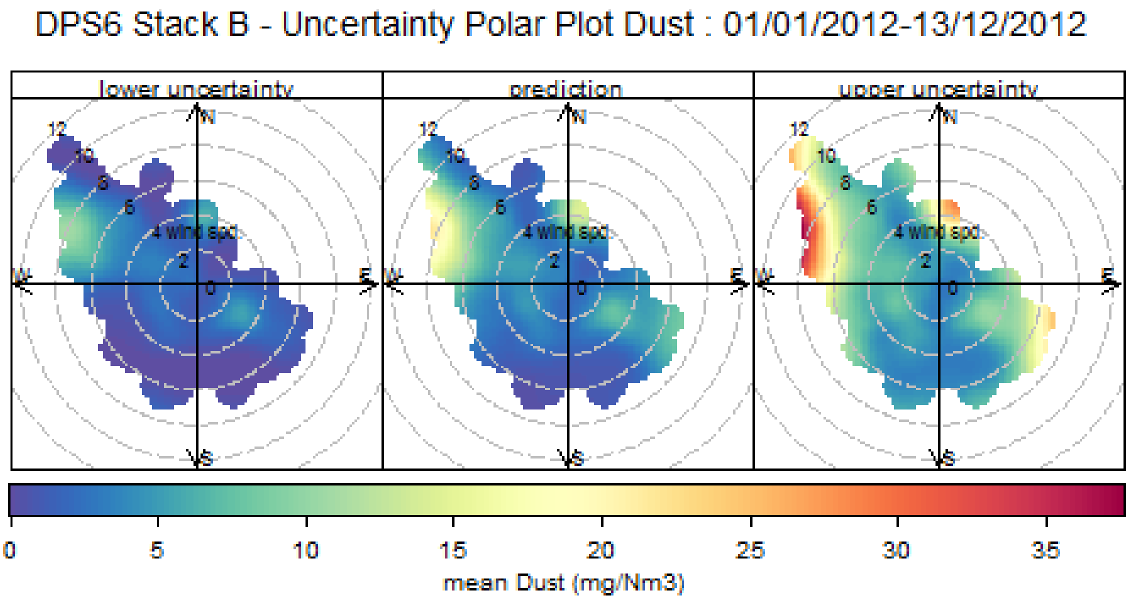


Figure 30: DPS6B baseline dust polar plot

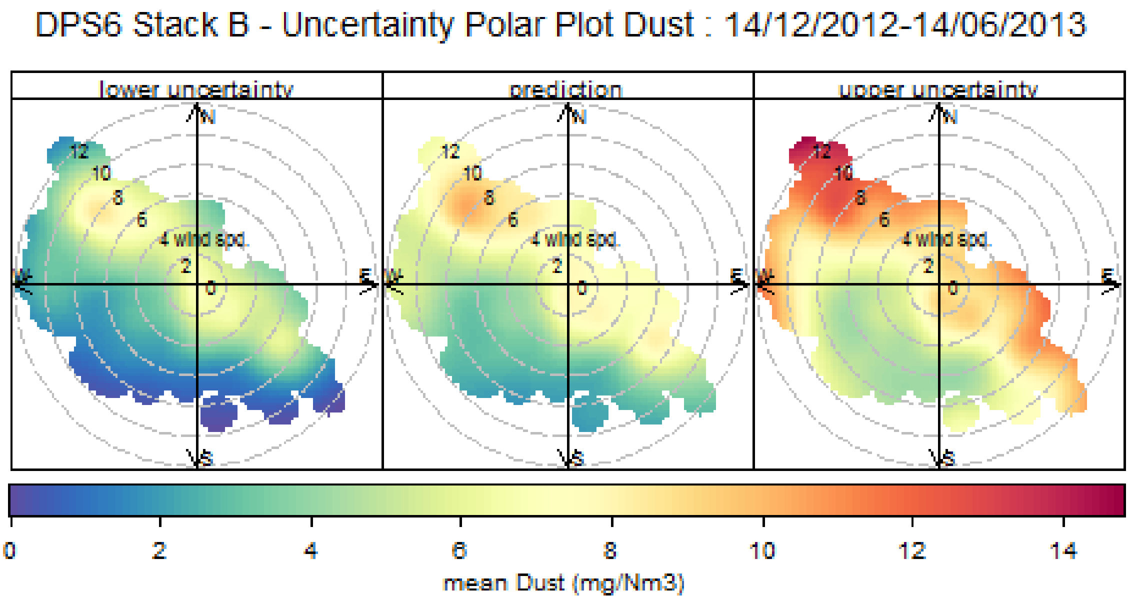


Figure 31: DPS6B post-commissioning dust polar plot

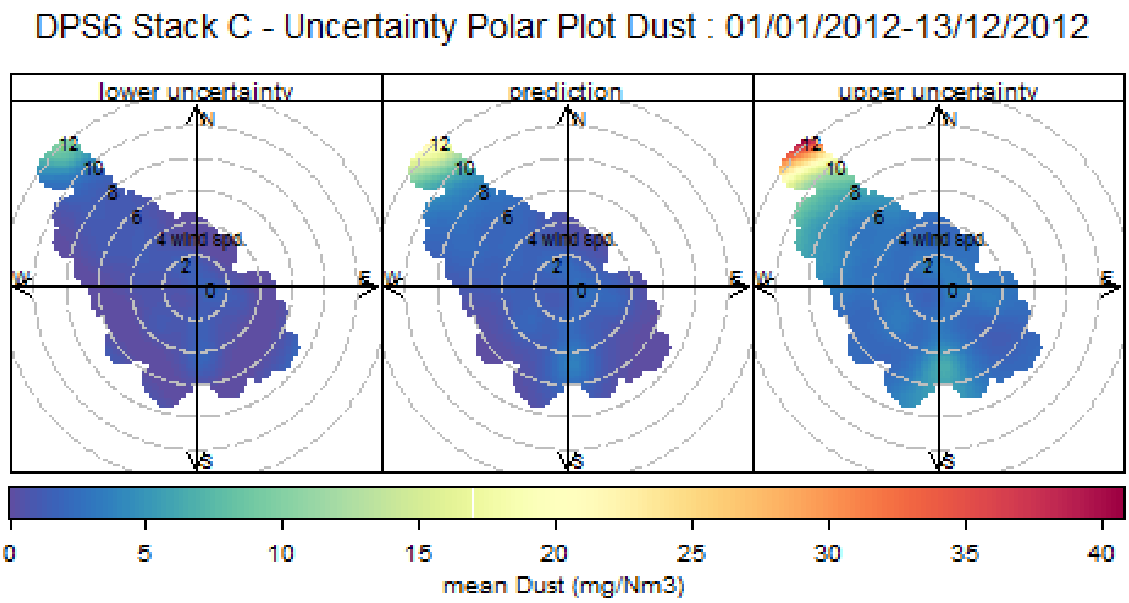


Figure 32: DPS6C baseline dust polar plot

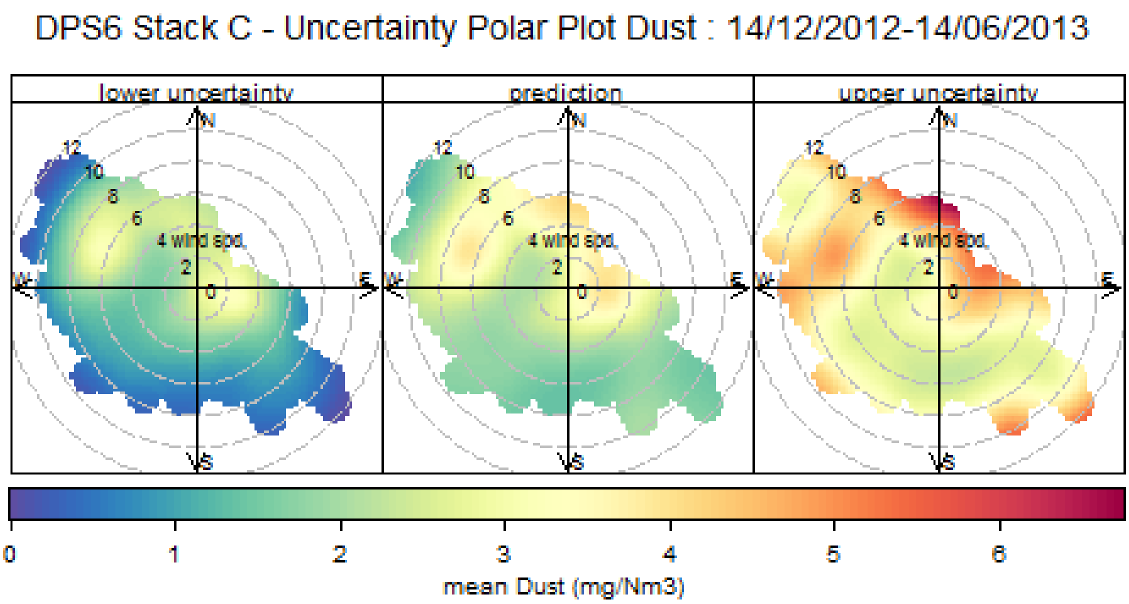


Figure 33: DPS6C post-commissioning dust polar plot

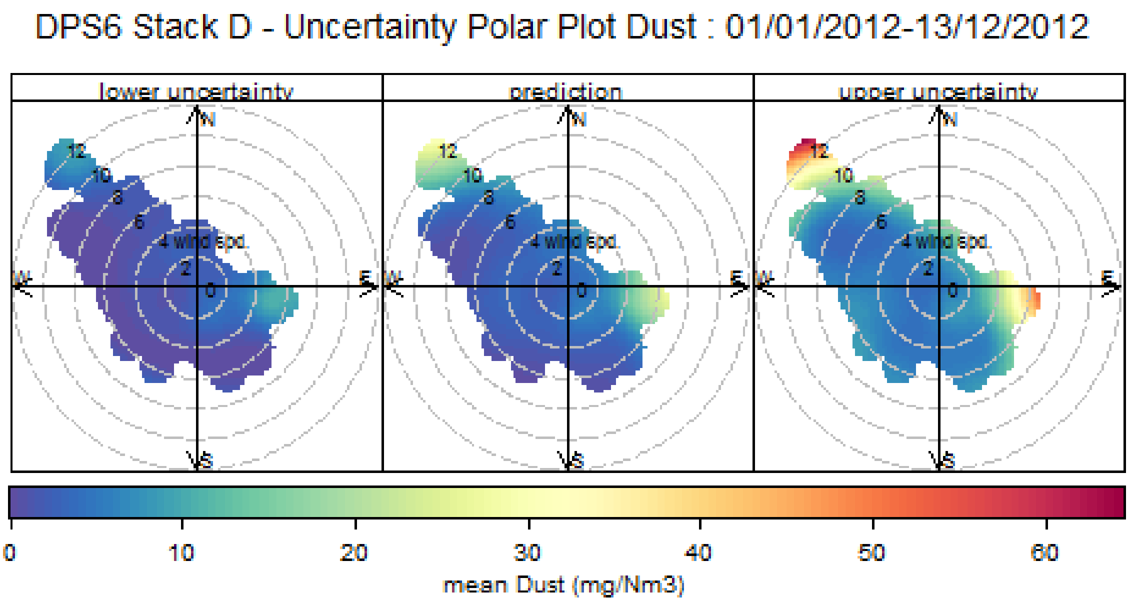


Figure 34: DPS6D baseline dust polar plot

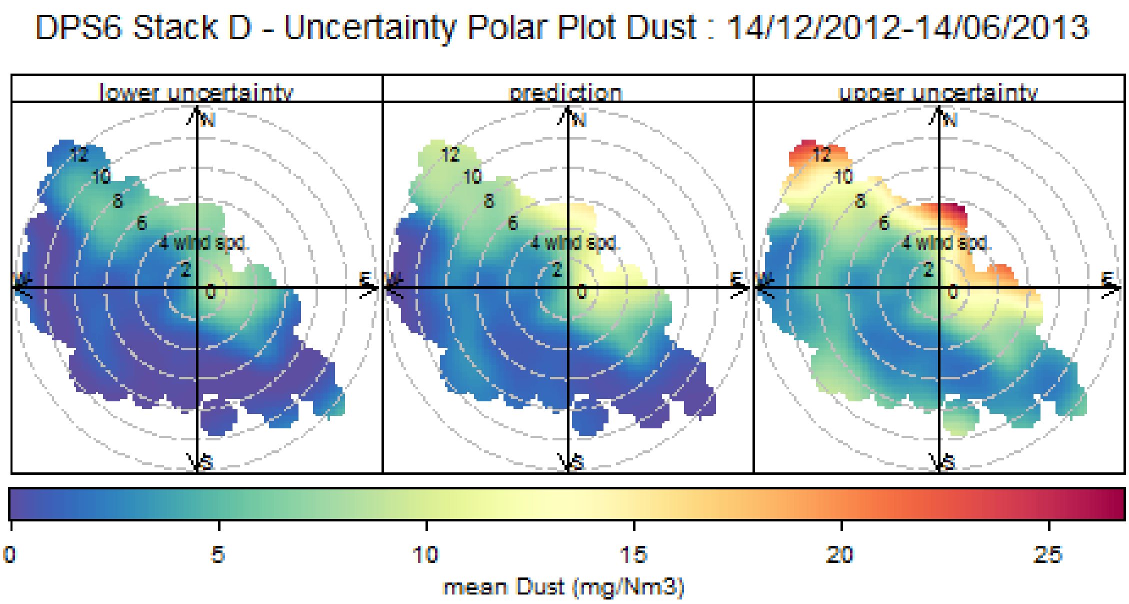


Figure 35: DPS6D post-commissioning dust polar plot

Figure 20 to Figure 35 show emissions of dust (mg/Nm^3) from the DPS plotted with wind speed (m/s) and direction (degrees). As described in 3.5.1 above, rather than showing the direction that pollutants are likely to have arisen from as with the monitoring concentration plots, these plots show the wind speed and direction related to the level of emissions from the site. The wind directions remain the same as previous plots (i.e. the plots are not inverted), but resulting emissions would be carried in the opposite direction. For example, if high emissions were recorded when the wind was blowing strongly from the NW (as in Figure 32) then these emissions would be carried in a SE direction. The Birzebbuga monitors are located to the west of the DPS and the Marsaxlokk monitors are to the NW of the DPS.

There are no consistent patterns apparent between the baseline and post-commissioning periods' emissions data. Maximum mean emissions at those stacks with the highest levels (DPS1A, DPS1B, DPS6A, DPS6B and DPS6D) were lower in the post-commissioning period, some significantly so (e.g. DPS6C), whereas those with the lowest levels of emissions (DPS4 and DPS5) were higher post-commissioning; however, emission levels at these two stacks are very low (maximum mean <2.5 mg/Nm^3).

These dust emissions polar plots indicate that there are occasions when relatively higher levels of emissions from DPS1A, DPS4, DPS6B, DPS6C and DPS6D were associated with easterly or SE winds that may have transported particulate matter in the direction of these monitoring sites. However, interpretation of these plots should bear in mind the availability of data as described in section 0; in particular, that wind data is only available from 1st April 2012 for the baseline period, and that there is less than 75% data available for DPS4, DPS5 and DPS6A, DPS6B and DPS6C for the post-commissioning period.

3.5.5. Summary of Spatial Analysis

Spatial analysis of the data from 14th December 2012 to 14th June 2013 has indicated that at all MEPA sites and at the consultants' Birzebbuga and Marsaxlokk sites the highest concentrations of PM_{10} and $PM_{2.5}$, during both the baseline and post-commissioning periods, are found when the wind is from the south or south-west (contrary to the predominant wind direction). The wind speed and direction and the occurrence at all sites suggests that there is a transboundary source, e.g. Saharan dust, relating to the west/south-westerly measured concentrations.

Maximum mean concentrations of PM_{10} and $PM_{2.5}$ at the MEPA sites and consultants' sites were generally much higher during the post-commissioning period, however, maximum mean dust emissions at the DPS are generally lower during the post-commissioning period, and at some stacks have reduced substantially.

Spatial analysis of the data does suggest the potential for incursions of dust emissions from DPS1A, DPS4, DPS6B, DPS6C and DPS6D; although the negligible emissions recorded at DPS4 indicate that any significant incursions would more likely be associated with the other stacks. High concentrations of PM associated with winds from the direction of the DPS at Birzebbuga or Marsaxlokk are not apparent in the polar plots, suggesting if there is any impact of the DPS on PM_{10} concentrations it is minimal.

3.6. Temporal Analysis

This section of the report looks at temporal patterns in the pollution data. This consists of two different analyses:

- Time plots of pollutants/emissions at each site.
- Time variation plots in pollution concentrations/emissions by time of day, week and year.

3.6.1. Time Plots of Pollutants

Time plots enable comparisons of trends by pollutant and by year for each site and give a clearer indication of absence of data than the Summary plots in Appendix B. It is also easier to see any relationships between peaks in data across pollutants without plotting them together on the same graph. This may be useful to identify widespread pollution episodes as opposed to local events. Time plots for the baseline and post-commissioning periods are presented in Appendix C: Figure 109 to Figure 116 show the time plots for the consultants' sites, Figure 117 to Figure 124 show the time plots for all MEPA sites and Figure 125 to Figure 142 show the DPS site emissions.

The time plots for the baseline and post-commissioning periods are shown side-by-side for each site to allow comparison between them. The y-axis scales on the respective periods' plots and between sites and pollutants differ, so care in comparing data is advised. Examination of the 6-month post-commissioning period with the longer-term baseline reveals that the LVS data for Birzebbuga and Marsaxlokk do not differ significantly, excepting the peak in PM_{10} and $PM_{2.5}$ data in April and May 2013. There are no baseline period data for the hourly BAM monitors so no comparison of short-term peaks between the periods is possible. Comparison between the baseline and post-commissioning periods' hourly MEPA data for PM_{10} and $PM_{2.5}$ do not indicate any substantial change in concentrations, with generally similar short-term peaks apparent in both datasets. DPS data also do not indicate an increase in stack emissions post-commissioning.

Given their proximity to each other and to the DPS, it is interesting to compare the time plots of the two monitoring techniques (BAM and LVS) at both Birzebbuga and Marsaxlokk, and also to compare these two sites with each other. It is apparent that the daily mean LVS data reflects the hourly BAM data pattern at both sites for PM_{10} and $PM_{2.5}$ in most cases, but generally showing a flattening off of the short-term hourly peaks, with a lower range of concentrations from the LVS monitors. The peak in January, particularly at Marsaxlokk, is more apparent in the hourly BAM data than in the daily LVS, suggesting this was a very short-term event. There are also close similarities between the data from both Birzebbuga and Marsaxlokk. Both PM_{10} and $PM_{2.5}$

show similar patterns at each site, however there are peaks in $PM_{2.5}$ data at both sites in March and April 2013 that are less apparent in the PM_{10} data.

A comparison between the hourly PM_{10} and $PM_{2.5}$ at the consultants' sites and MEPA sites show similar patterns with most short-term peaks observed at all sites (where data is available). Scales are also similar across the sites, indicating that these peak concentrations are not localised and are likely to be regionally sourced. There are several dominant short-term events apparent at multiple sites in the post-commissioning data: 24th January, 2nd February, 2nd March, 6th-7th March, 24th March, 18th April, 16th May and 22nd May. Peaks in dust emissions from DPS, however, do not appear to be temporally correlated with peaks in PM_{10} or $PM_{2.5}$ at Birzebbuga or Marsaxlokk. A closer inspection of the exceedance days in section 3.7 will determine whether this is the case.

3.6.2. Time Variation Plots of Pollutants

The following plots are created using the *time variation* function in Openair. This presents plots showing how average concentrations of pollutants/emissions vary over time – over an average day, by hour over a whole week, by day of the week and by month of the year. Where a shaded region surrounds the line, this indicates the boundaries of the 95% confidence interval for the averaging. It should be kept in mind when viewing these plots that they represent average concentrations of pollution over the relevant time series and will not show up short-term exceedances of the daily mean PM_{10} objective. Data has been corrected for local time so that, under the diurnal cycles, 8am during the winter under CET is matched with 8am in the summer under DST, so that patterns such as shift start times occur at the same time throughout the year. The time variation plots for the baseline and post-commissioning periods are shown side-by-side for each site to allow comparison between them. The y-axis scales on the respective periods' plots and between sites differ, so care in comparing data is advised.

Figure 36 to Figure 43 show the time variation plots for each of the MEPA sites for PM_{10} (µg/m^3) and $PM_{2.5}$ (µg/m^3) (where available) for the baseline and post-commissioning periods. Interpretation of the Kordin baseline PM_{10} plot, and Gharb and Zejtun post-commissioning PM_{10} and $PM_{2.5}$ plots should bear in mind the availability of PM data as detailed in section 0. As might be expected, both PM_{10} and $PM_{2.5}$ show a similar relationship at all sites, with a reasonably strong diurnal pattern typical of traffic sources apparent at the roadside site (Msida) and slightly weaker at the urban industrial site (Kordin) and the urban background site (Zejtun) and no clear temporal pattern at the rural background site (Gharb). These site-specific patterns are apparent in both the baseline and post-commissioning period data, but are less marked due in part to the relatively shorter period of data on which the analysis is being undertaken and also that the pollution patterns are masked somewhat by peak concentrations occurring on a Wednesday-Thursday period. This dominant event is apparent across all sites and is probably linked to the data spikes observed in the time plots (section 3.6.1). More specific analysis of these peak concentrations are undertaken in the exceedance analysis in section 3.7, but as they apparent at all of the MEPA sites, this would indicate that they are associated with a regional event. Hourly PM_{10} concentrations at Msida are higher than at Kordin reflecting the former's closer proximity to traffic sources. Peak concentrations of both PM_{10} and $PM_{2.5}$ are highest at Gharb, which, given its open aspect, is likely to have been more affected by regional dust events than more sheltered inland sites.

Figure 44 to Figure 45 show the time variation plots for PM_{10} ($\mu g/m^3$) and $PM_{2.5}$ ($\mu g/m^3$) for the consultants' monitoring sites at Birzebbuga and Marsaxlokk for the post-commissioning period. There were insufficient data available on which to calculate plots for the baseline period. There are strong similarities between the consultants' sites, reflecting their proximity, and there are also similarities with the MEPA sites'. There is a similar weak diurnal pattern typical of traffic sources at both sites and, as with the MEPA sites, the Wednesday-Thursday concentration peak is dominant.

Figure 46 to Figure 61 show the time variation plots for dust emissions (mg/Nm^3) from DPS for the baseline and post-commissioning periods. Dust emissions at DPS1A and DPS1B show a clear bimodal peak on each day across both periods, perhaps related to soot-blowing operations. The timing of these peaks (after 06:00 and around 15.00) does not correspond with the diurnal pattern of concentrations recorded at Birzebbuga or Marsaxlokk. The dust emissions pattern is less clear at the remaining sites, though this may be due to there being fewer than 75% data available for DPS4, DPS5 and DPS6A, DPS6B and DPS6C for the post-commissioning period. According to MEPA, an absence of data relating to the stack emissions normally signifies that the plant has been switched off. DPS4 and DPS5 appear to share a similar temporal pattern, though the pattern in the post-commissioning period has a more pronounced morning trough than the baseline data. The DPS6 stacks show weak bimodal or trimodal peaks, which are similar across the periods, though the post-commissioning periods are based on limited data.

3.6.2.1. MEPA sites PM_{10} and $PM_{2.5}$ Time variation Plots

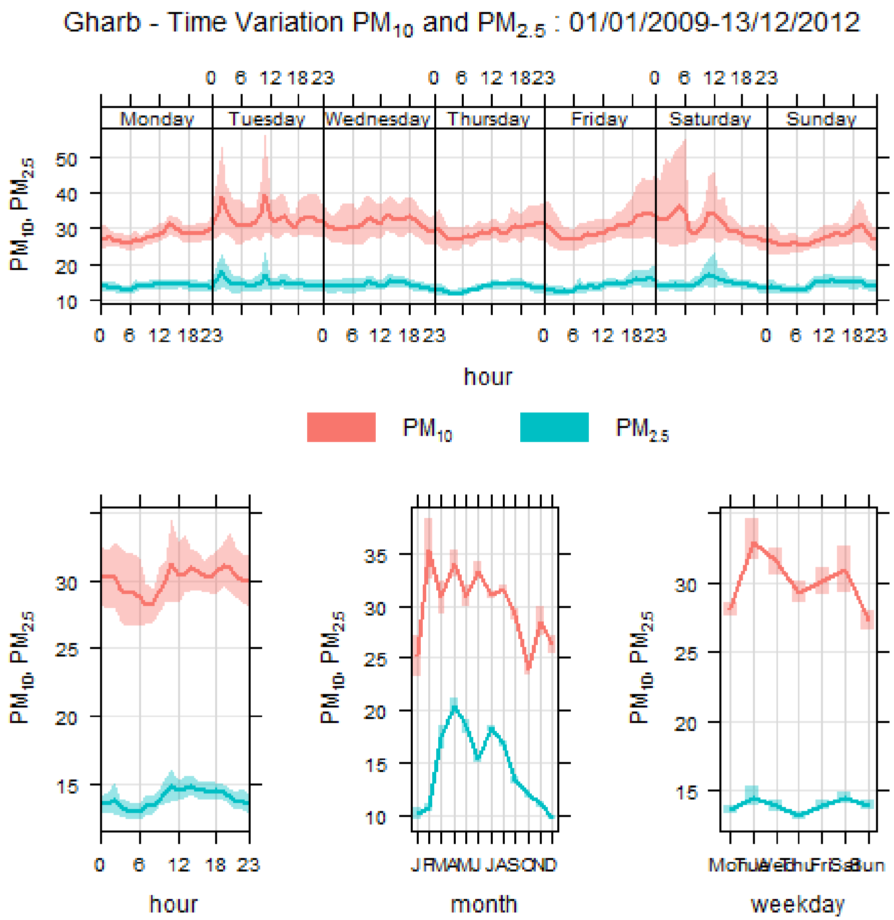


Figure 36: Gharb baseline PM_{10} and $PM_{2.5}$ time variation plot

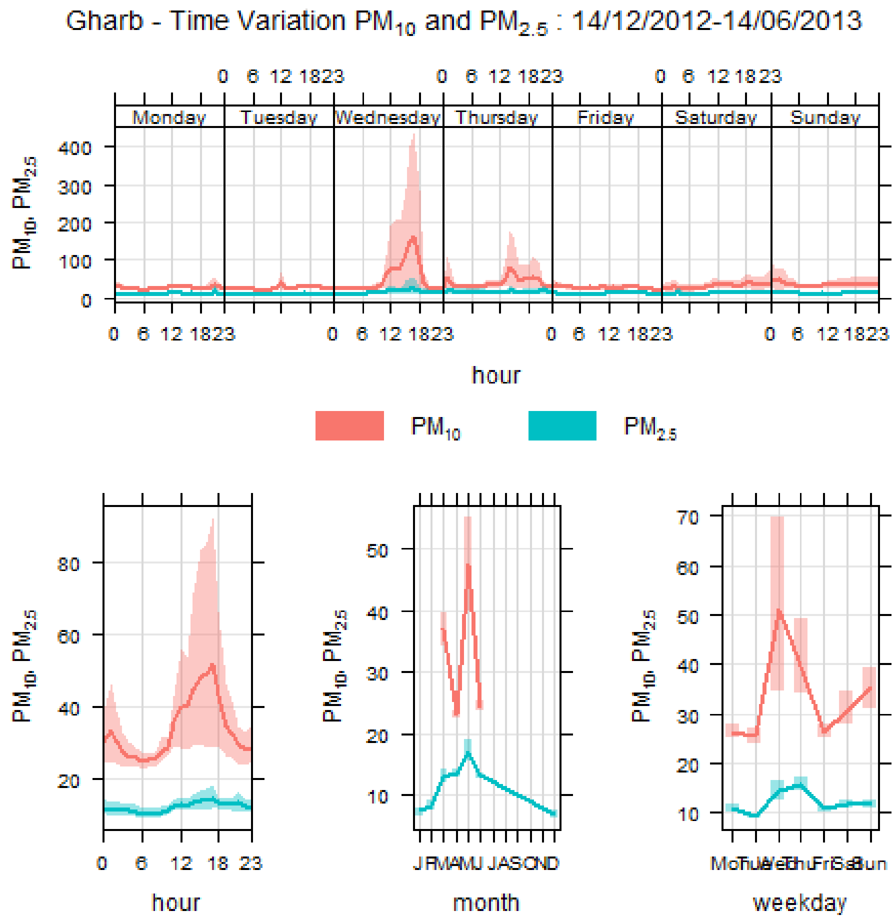


Figure 37: Gharb post-commissioning PM_{10} and $PM_{2.5}$ time variation plot

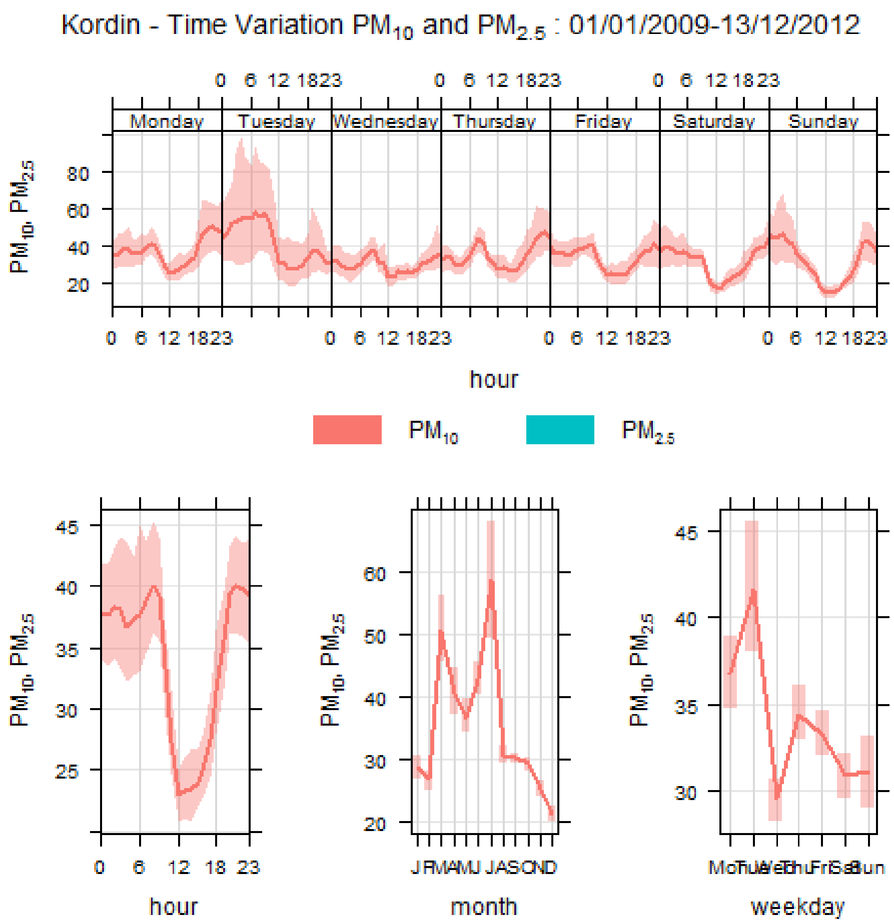


Figure 38: Kordin baseline PM_{10} and $PM_{2.5}$ time variation plot

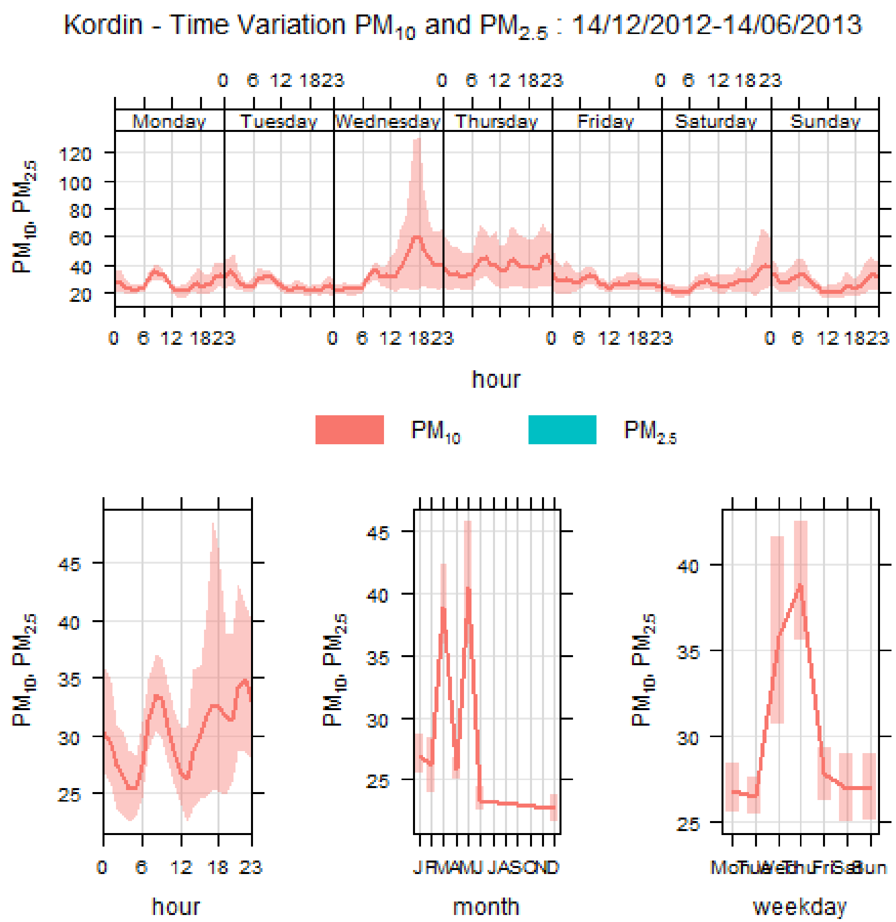


Figure 39: Kordin post-commissioning PM_{10} and $PM_{2.5}$ time variation plot

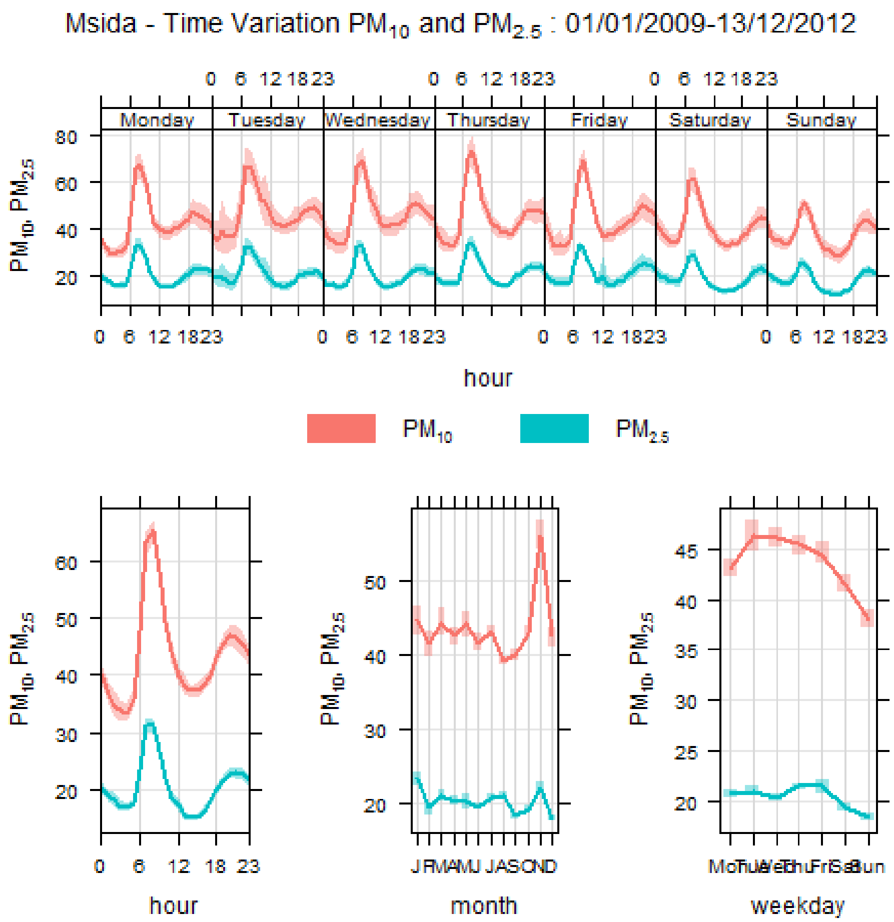


Figure 40: Msida baseline PM_{10} and $PM_{2.5}$ time variation plot

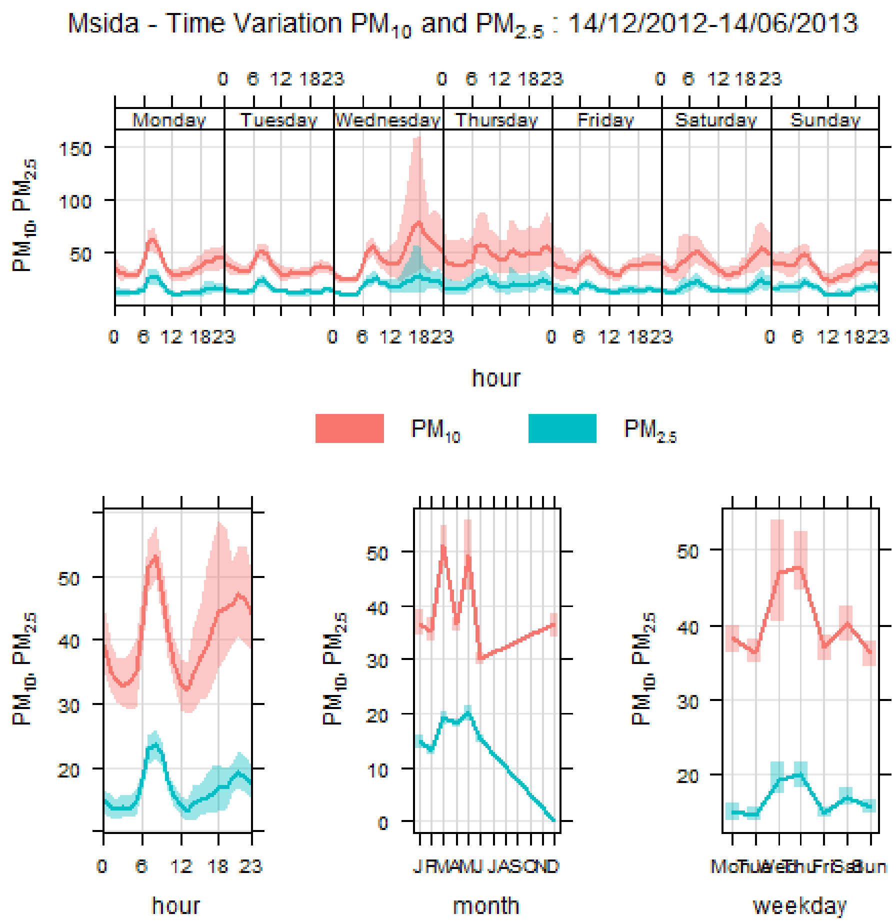


Figure 41: Msida post-commissioning PM_{10} and $PM_{2.5}$ time variation plot

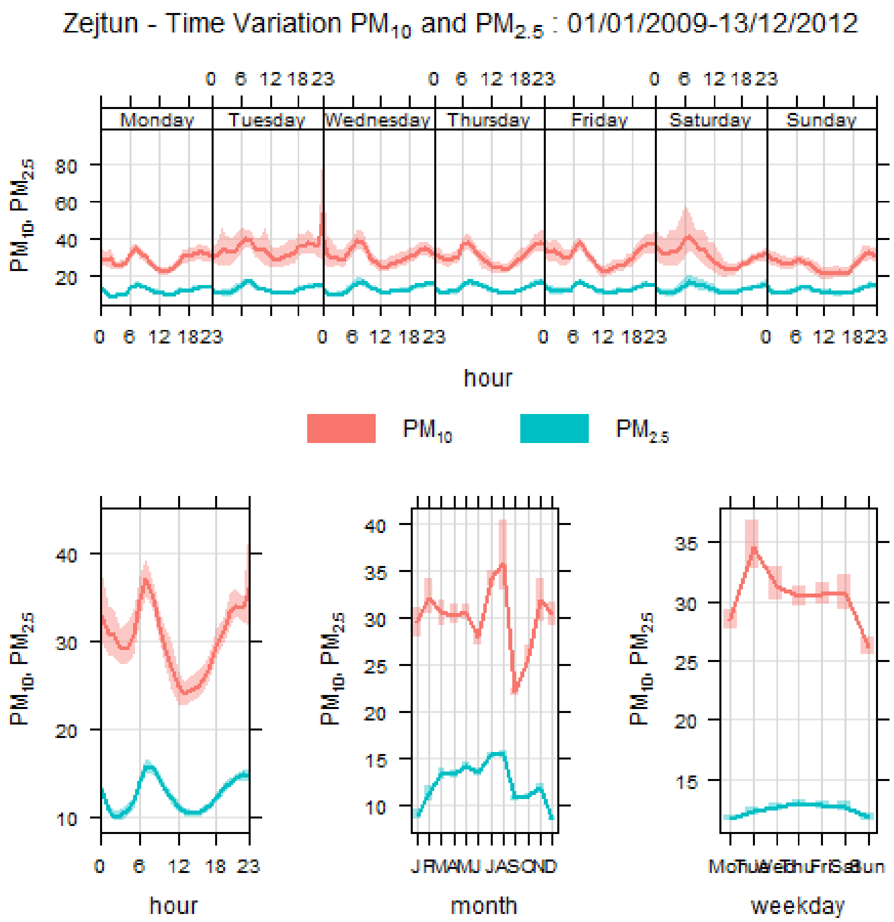


Figure 42: Zejtun baseline PM_{10} and $PM_{2.5}$ time variation plot

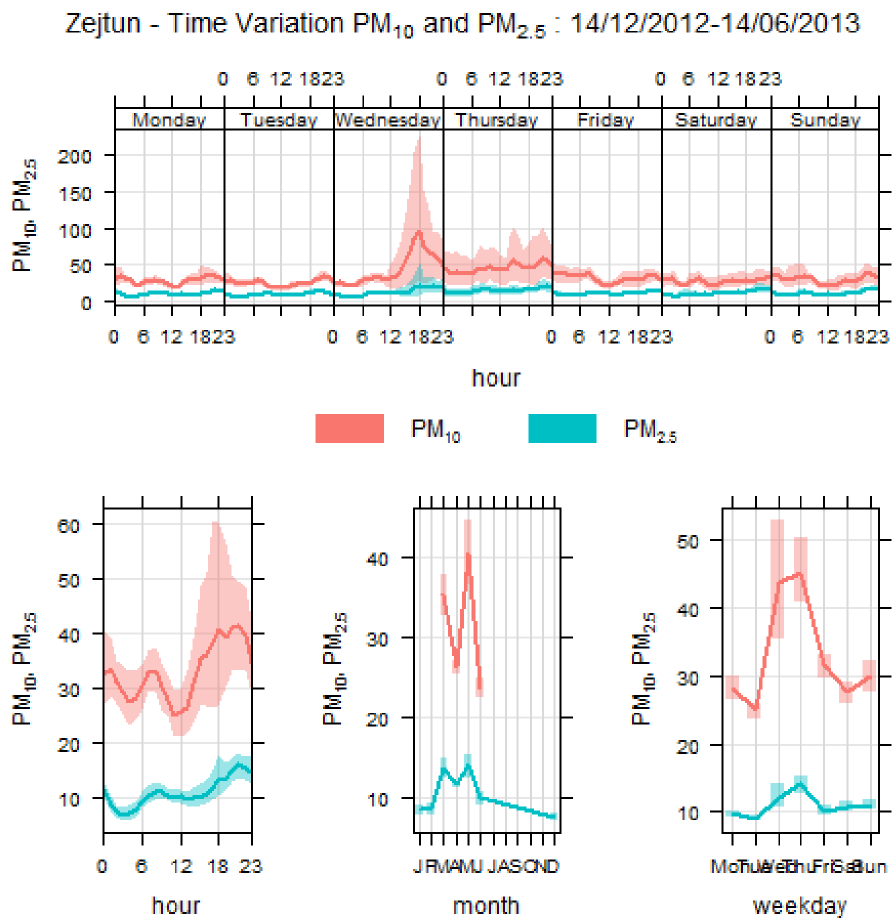


Figure 43: Zejtun post-commissioning PM_{10} and $PM_{2.5}$ time variation plot

3.6.2.2. Birzebbuga and Marsaxlokk PM_{10} and $PM_{2.5}$ Time variation Plots

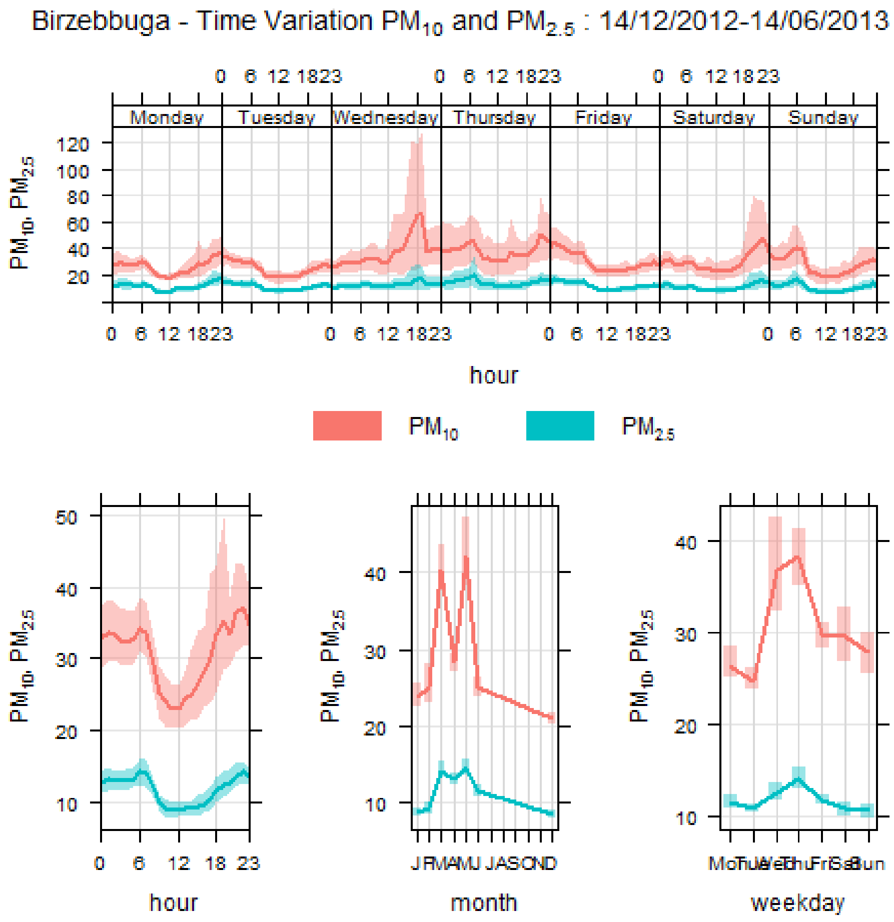


Figure 44: Birzebbuga BAM post-commissioning PM_{10} and $PM_{2.5}$ time variation plot

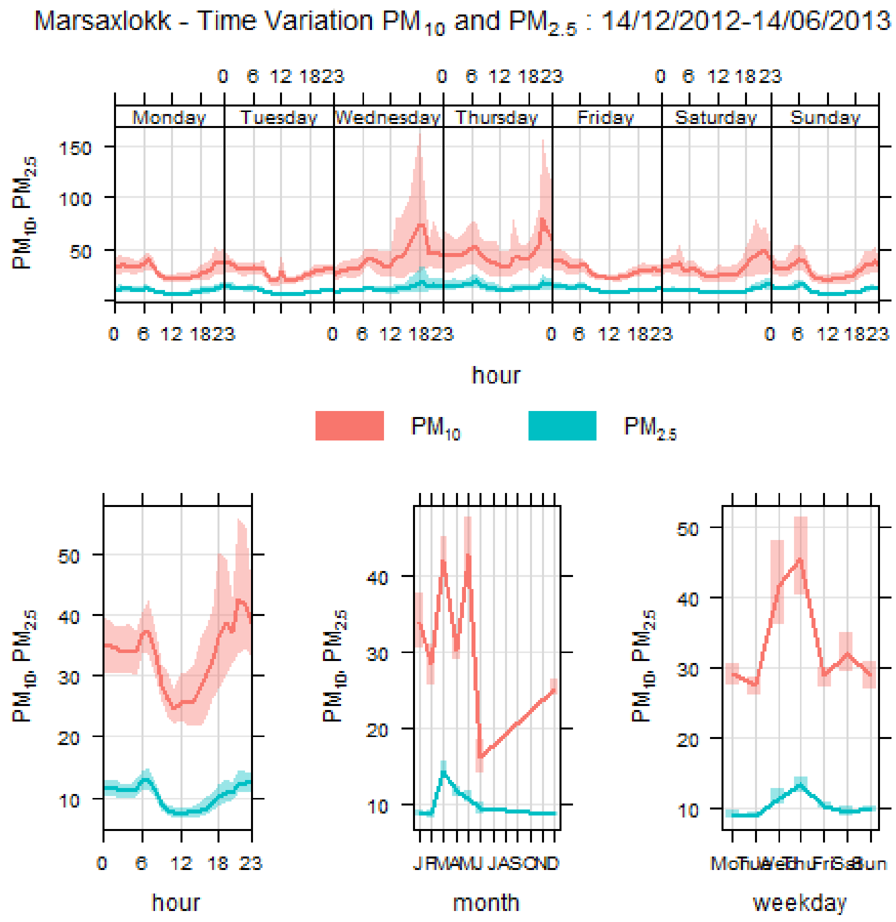


Figure 45: Marsaxlokk BAM post-commissioning PM_{10} and $PM_{2.5}$ time variation plot

3.6.2.3. DPS Dust Emissions Time variation Plots

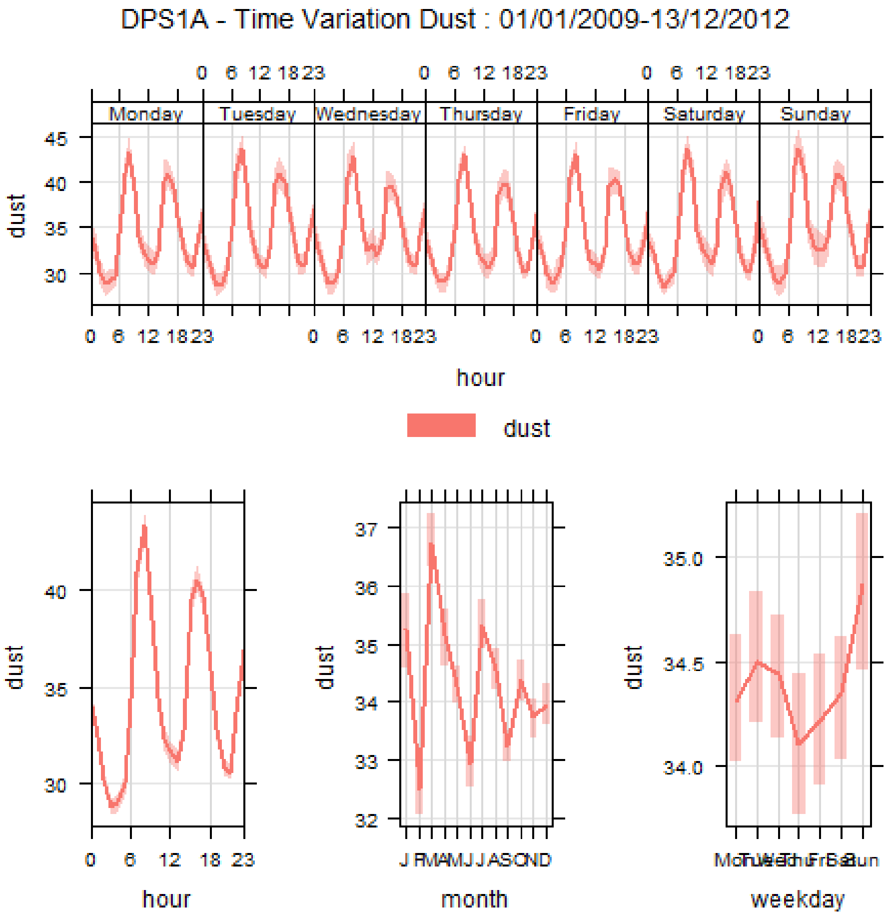


Figure 46: DPS1A baseline dust time variation plot

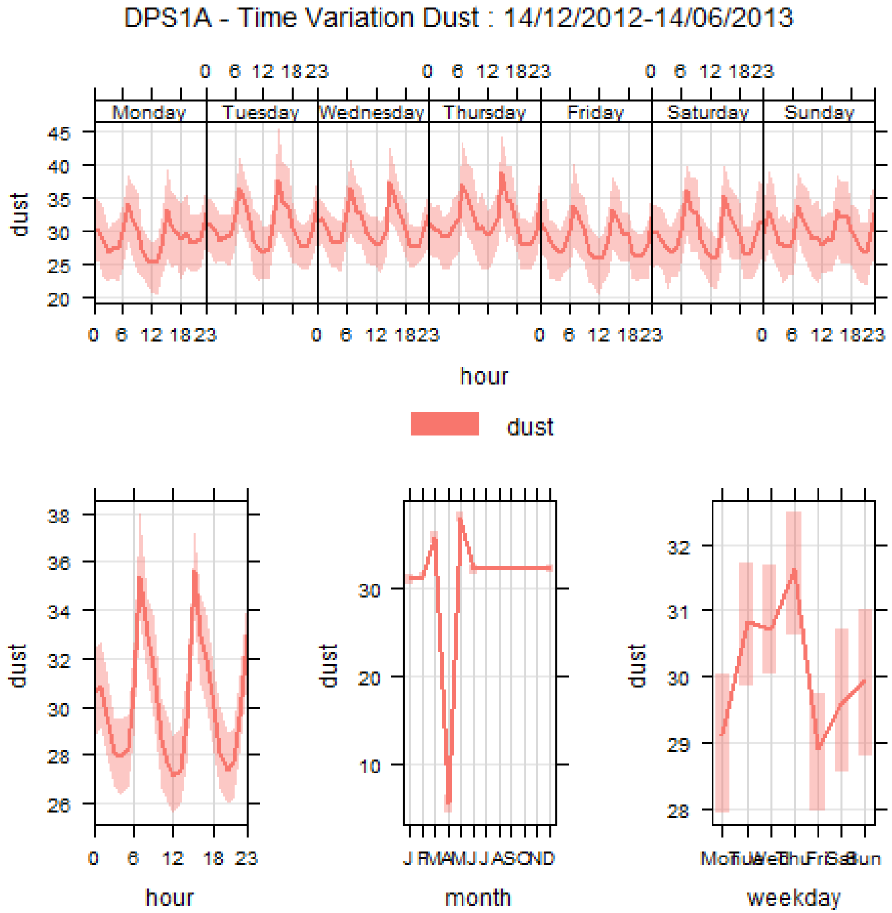


Figure 47: DPS1A post-commissioning dust time variation plot

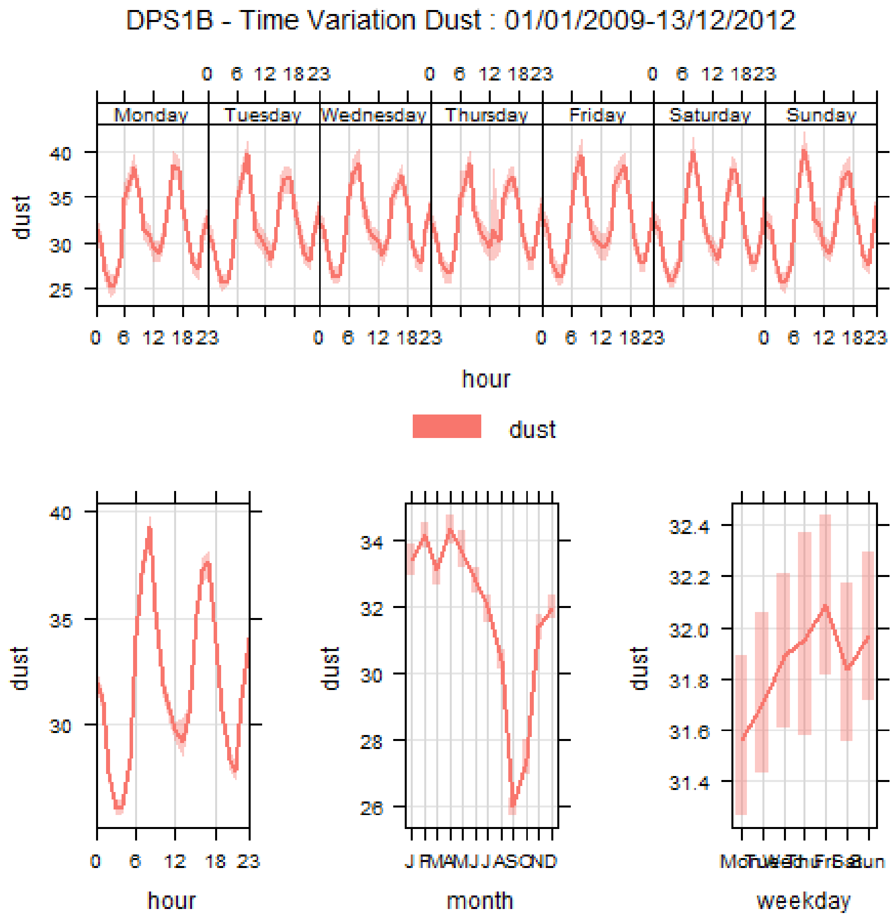


Figure 48: DPS1B baseline dust time variation plot

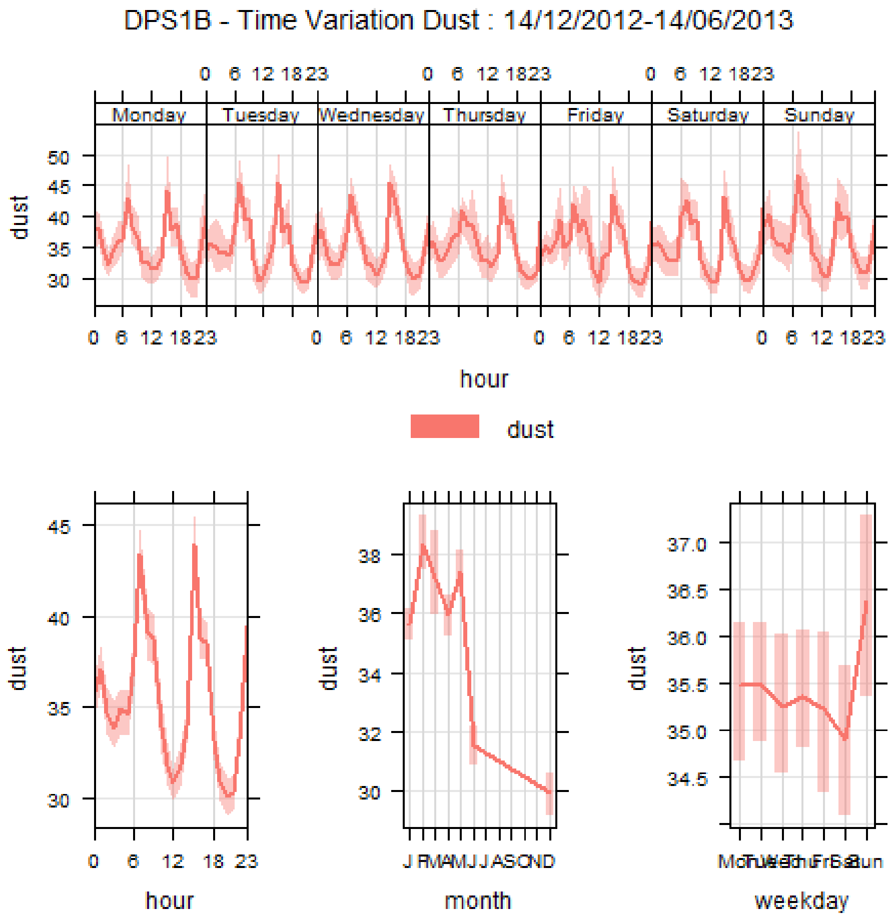


Figure 49: DPS1B post-commissioning dust time variation plot

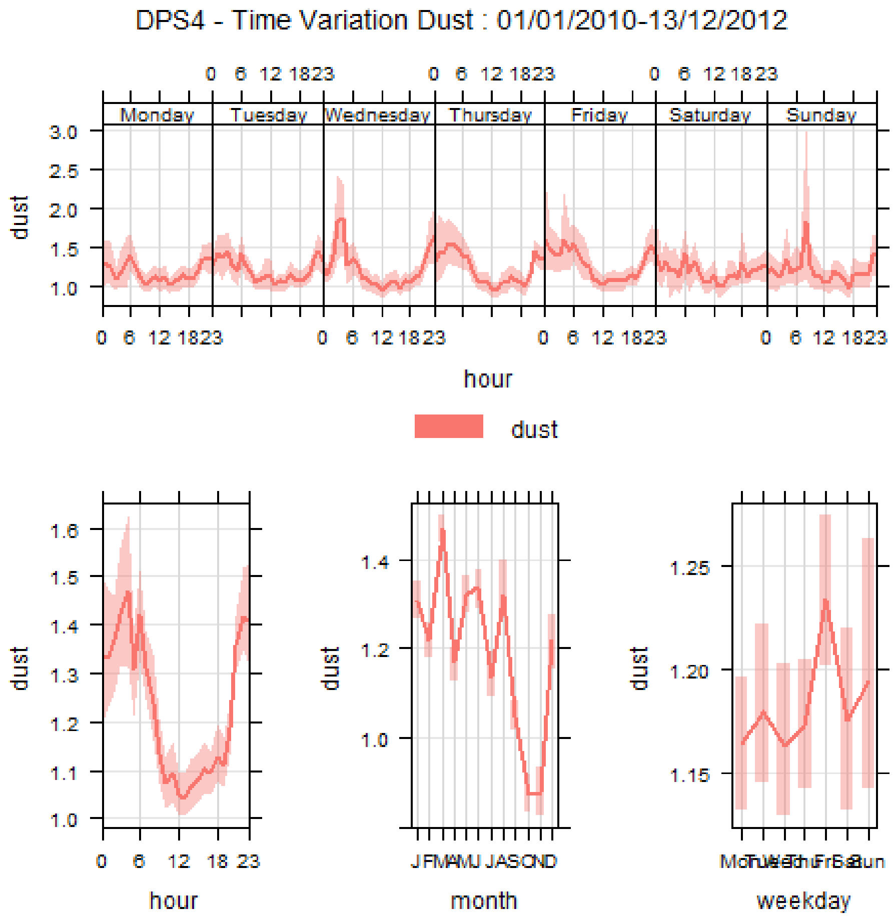


Figure 50: DPS4 baseline dust time variation plot

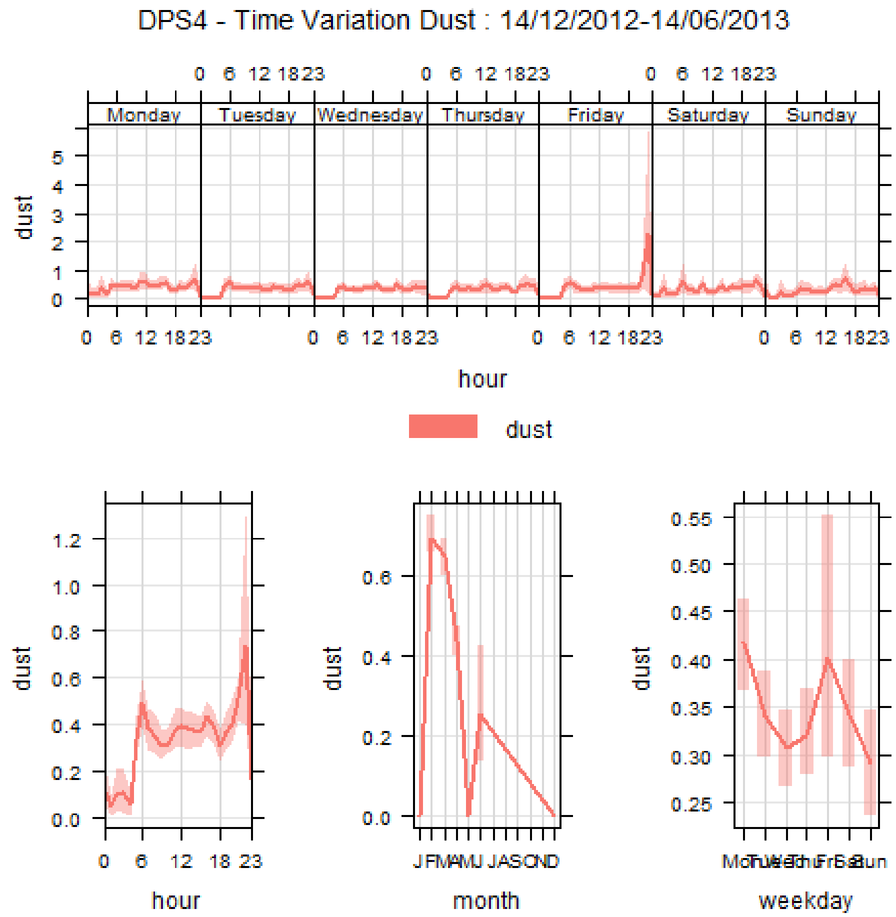


Figure 51: DPS4 post-commissioning dust time variation plot

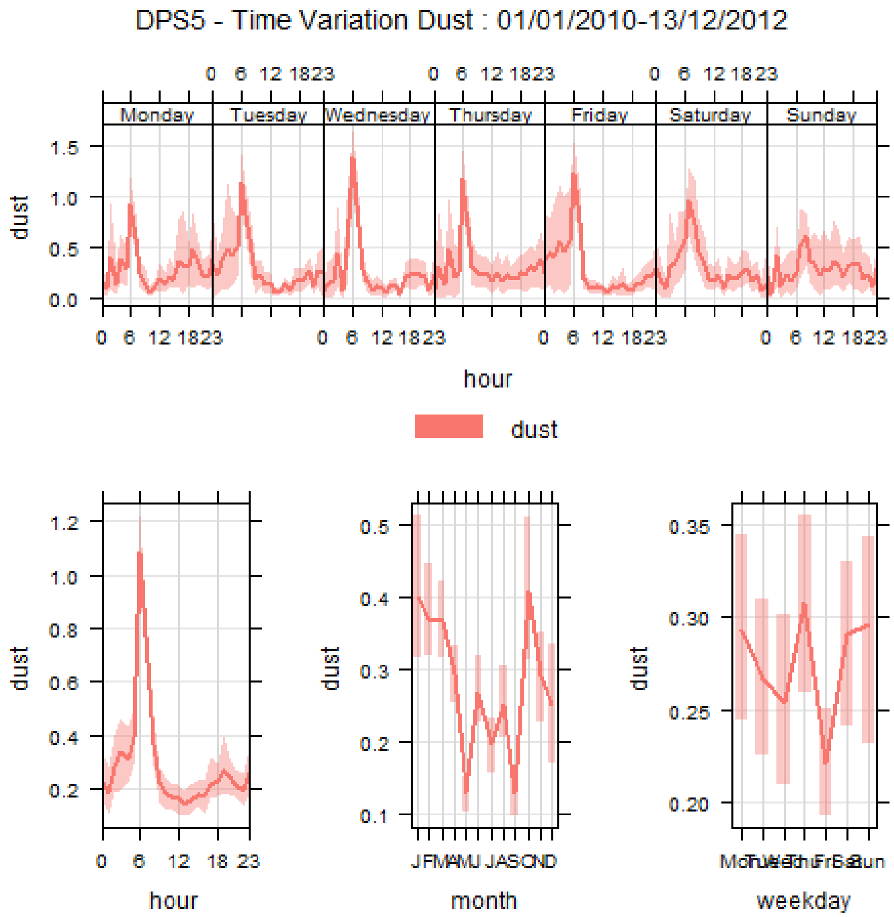


Figure 52: DPS5 baseline dust time variation plot

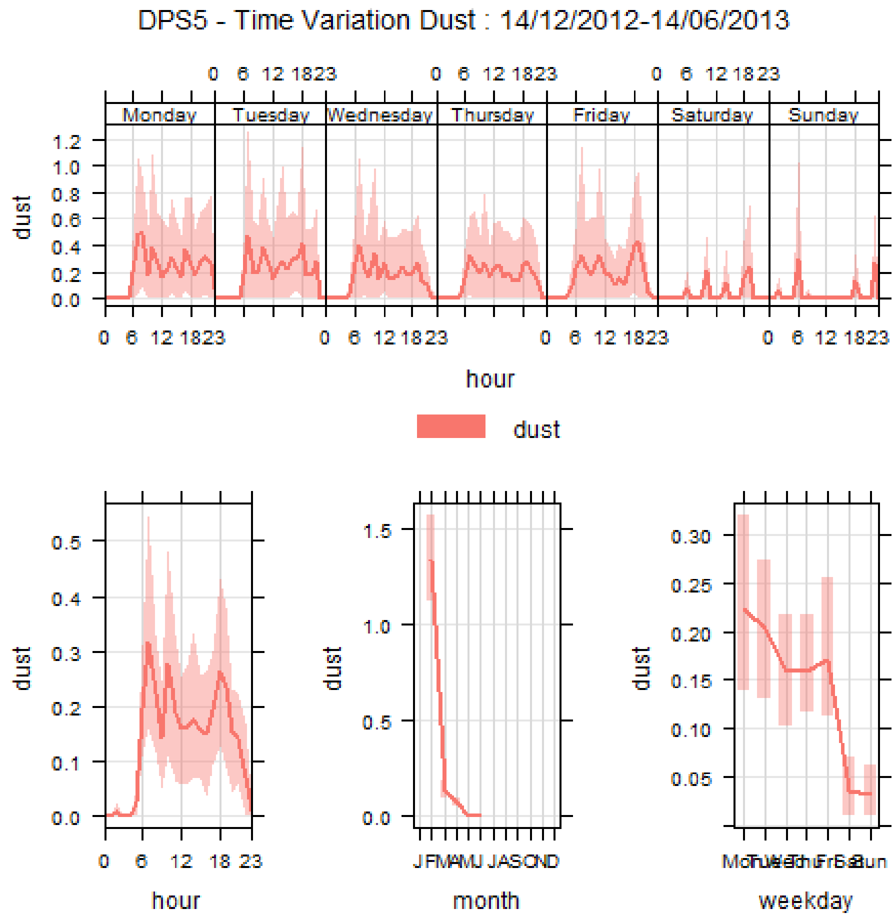


Figure 53: DPS5 post-commissioning dust time variation plot

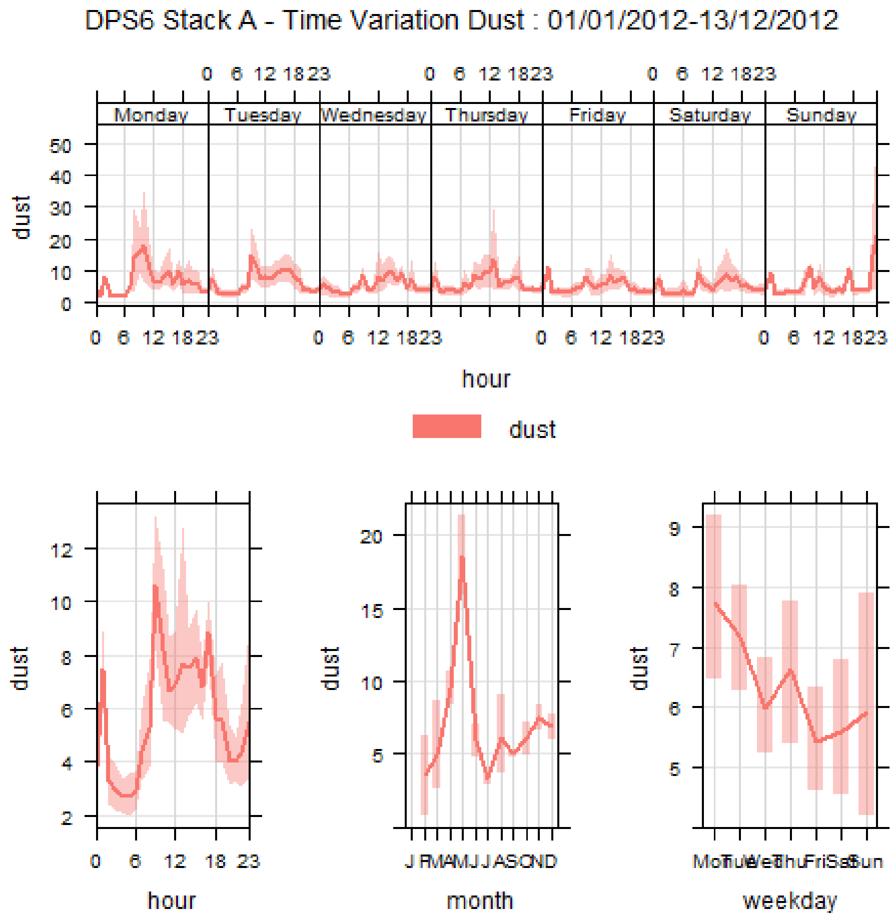


Figure 54: DPS6A baseline dust time variation plot

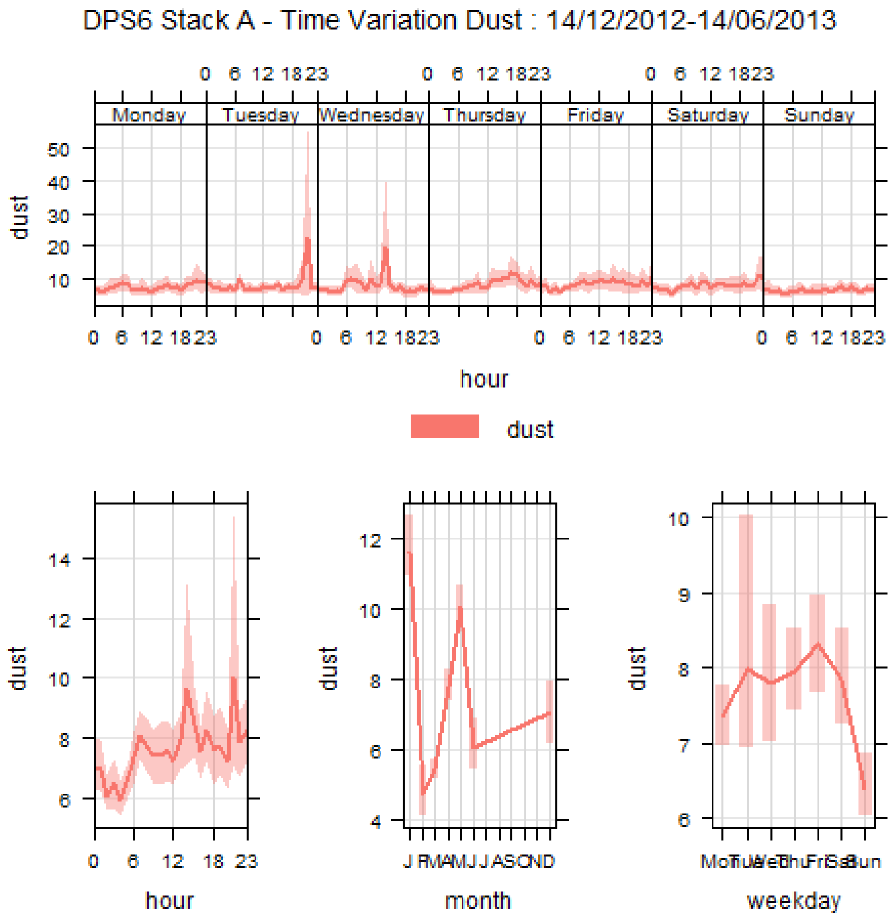


Figure 55: DPS6A post-commissioning dust time variation plot

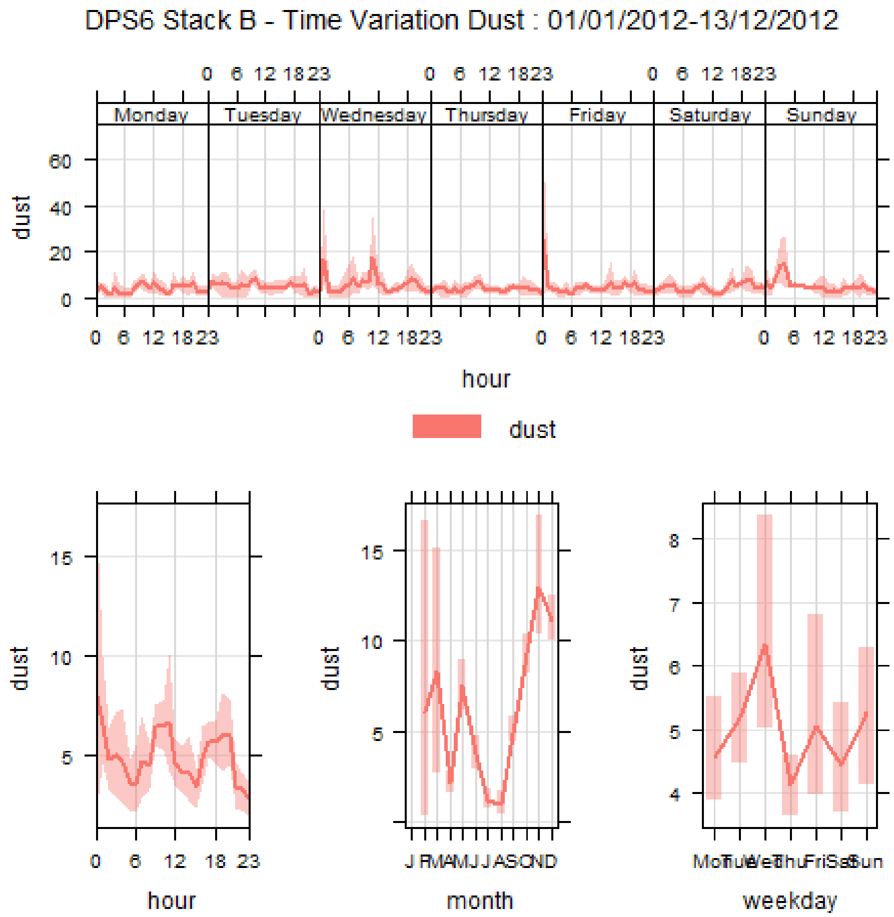


Figure 56: DPS6B baseline dust time variation plot

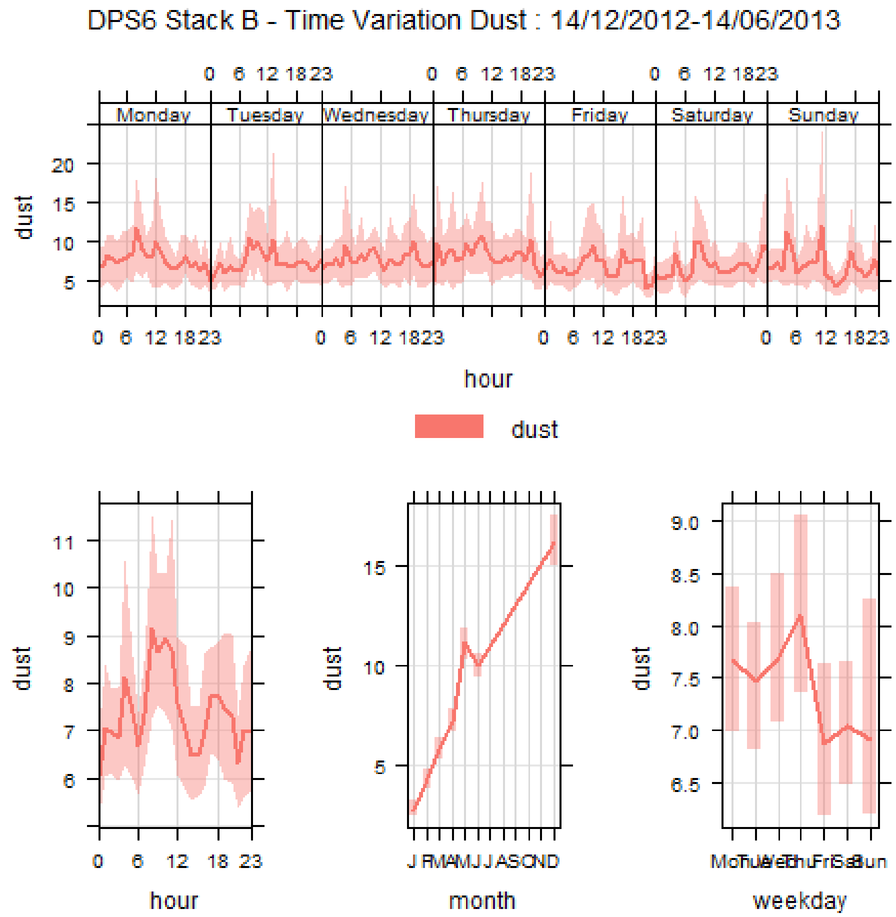


Figure 57: DPS6B post-commissioning dust time variation plot

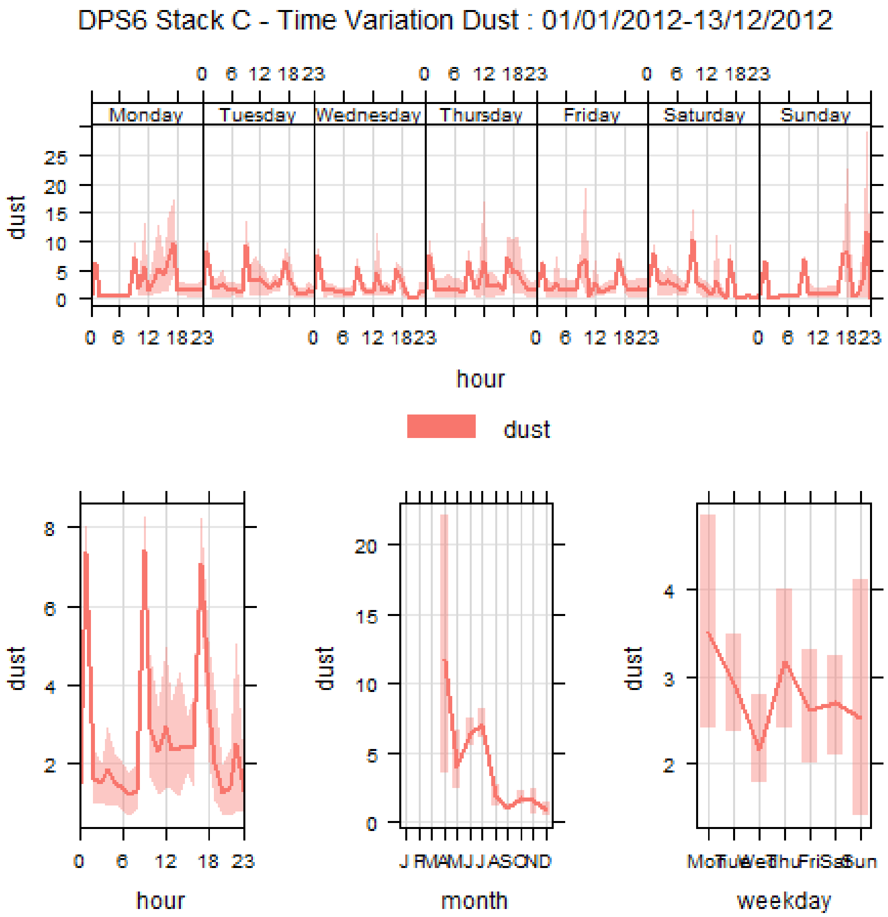


Figure 58: DPS6C baseline dust time variation plot

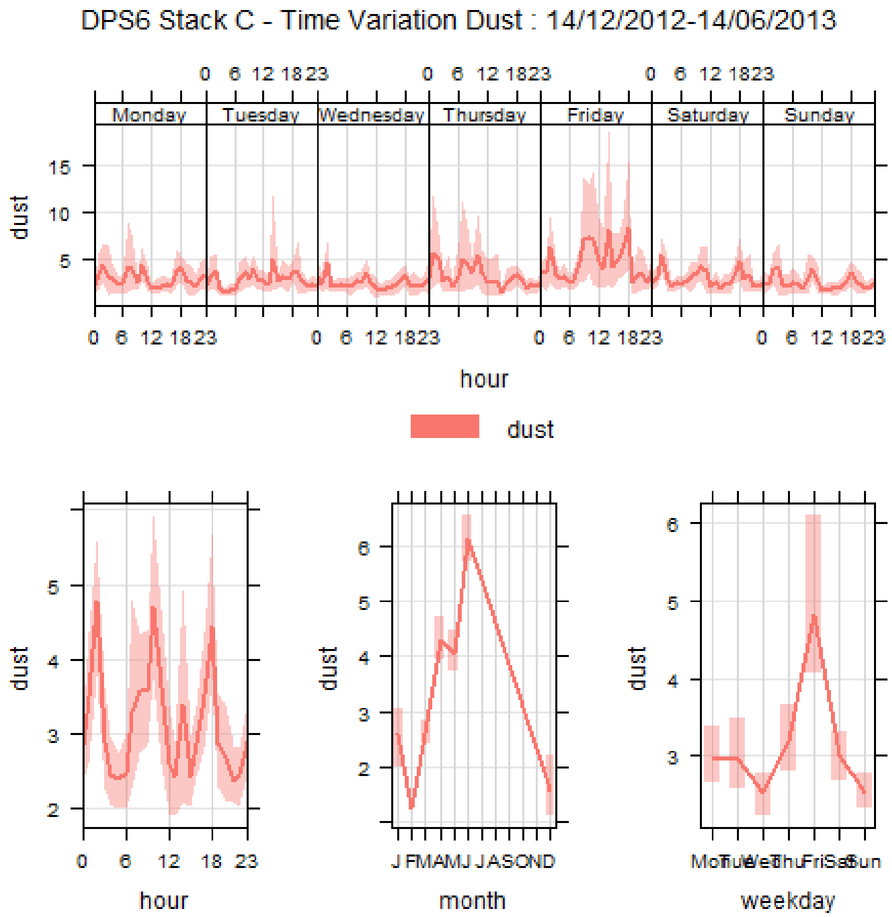


Figure 59: DPS6C post-commissioning dust time variation plot

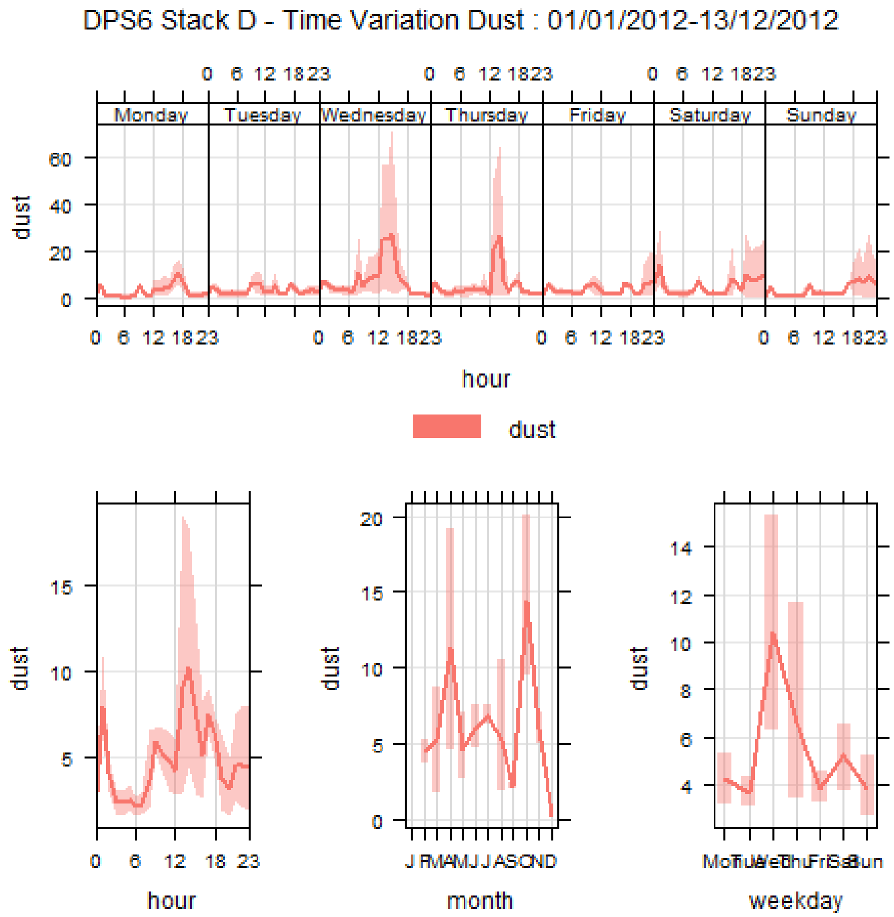


Figure 60: DPS6D baseline dust time variation plot

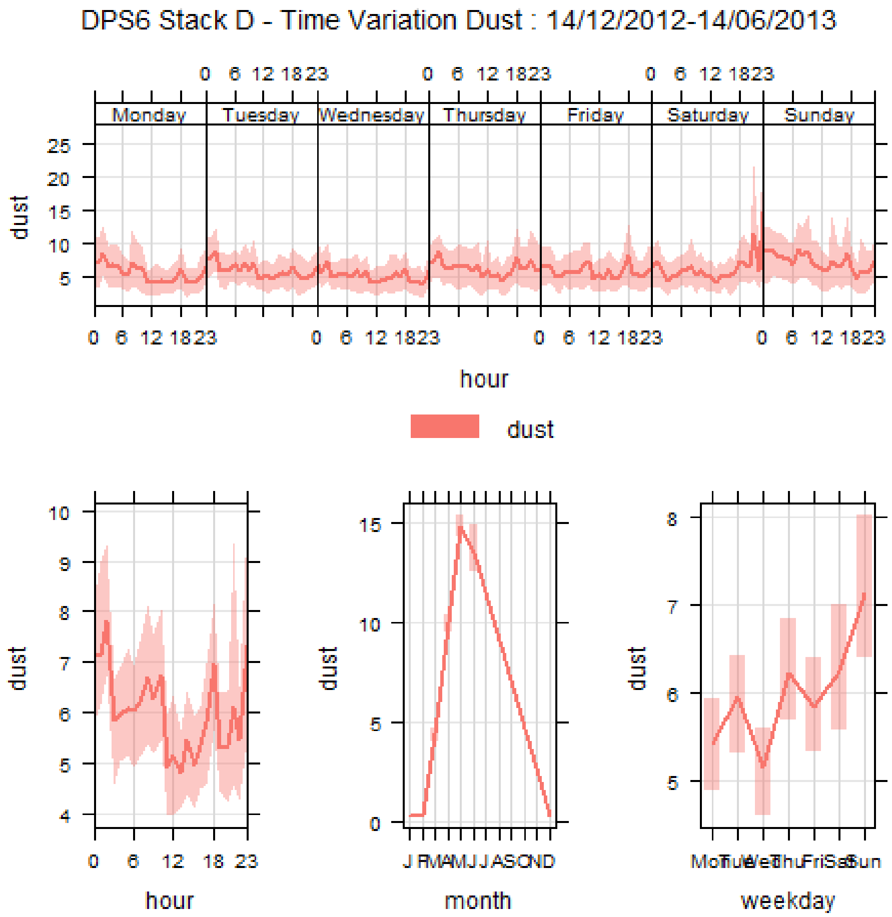


Figure 61: DPS6D post-commissioning dust time variation plot

3.6.3. Summary of Temporal Analyses

The analyses of temporal patterns in the pollution data has focussed on PM_{10} and $PM_{2.5}$ data from MEPA and consultants' sites and dust emissions data from DPS. It is possible to identify shared peak PM_{10} and $PM_{2.5}$ episodes across multiple sites as well as other, potentially more local events. The presence of multiple-site peaks and similar peak ranges across all sites indicates that the predominant source contributing to short-term peaks is likely to be regional, e.g. transboundary.

Analysis of the diurnal profiles of PM_{10} and $PM_{2.5}$ concentrations also show that all sites (except Gharb) appear to have a traffic-related contribution. Diurnal patterns of the DPS1A and B emissions data show a clear bimodal peak for dust emissions, perhaps related to soot-blowing activities as indicated by Enemalta in previous reports. There does not appear to be any clear temporal relationship between the DPS dust emissions and the particulate matter concentrations recorded at either Birzebbuga or Marsaxlokk.

Temporal patterns in the pollution data indicate that concentrations and patterns are similar between the baseline and post-commissioning periods at the MEPA sites, however, post-commissioning period data are dominated by regional peak concentrations occurring over a Wednesday-Thursday. The absence of recalibrated hourly baseline data for the consultants' sites' precluded a temporal comparison data. Emissions data between the two periods showed similar patterns, apart from DPS4 and DPS5, however low data availability at the majority of sites means that temporal patterns are unclear in the post-commissioning period.

3.7. Exceedance analysis

3.7.1. Limit Values for PM_{10} and $PM_{2.5}$

Table 6 presents the Limit Values for PM_{10} and $PM_{2.5}$ according to Legal Notice 478 of 2010. These Limit Values apply to a calendar year, however the post-commissioning data in this report covering the 28-week period, 14th December 2012 to 14th June 2013, have been compared with them to give an indication of the likelihood of occurrence of exceedances. Given the short monitoring period the 90th percentile (equivalent to the 35 permitted exceedances) was calculated to compare with the PM_{10} daily mean Limit Value.

Table 6: Limit Values for PM_{10} and $PM_{2.5}$ according to Legal Notice 478 of 2010

Pollutant	Daily mean	Annual mean	Date by which the Annual Mean Limit Value to be met/Margin of Tolerance (MOT)
PM_{10}	50 µg/m^3 not to be exceeded more than 35 times a calendar year	40 µg/m^3	1st January 2005
$PM_{2.5}$	N/A	25 µg/m^3	MOT 20% on 11th June 2008, decreasing on the next 1st January and every 12 months thereafter by equal percentages to reach 0% by January 2015

3.7.2. Annual mean exceedances (PM_{10} and $PM_{2.5}$)

This section calculates the mean concentrations of PM_{10} and $PM_{2.5}$ for the baseline and post-commissioning periods (Table 7). The means for this period suggest the potential for an exceedence of the Limit Values for PM_{10} at Msida in 2013, consistent with previous years. The LVS monitors at Birzebbuga and Marsaxlokk also exceed the Limit Value for this period, contrary to the BAM instruments located at these sites. There are no recorded exceedances of the $PM_{2.5}$ annual mean threshold indicated. Although the LVS is a gravimetric instrument, which is the EU reference method, there appears to be more consistency between the MEPA site data and the BAM period means. This may be due to the granularity of the data as LVS instruments record daily means, whereas the BAMs and MEPA's instruments record hourly data. It is also important to bear in mind that these are period means calculated over a 28-week period so are not directly comparable with the Limit Values. Averages calculated over the course of a full years' data may be lower or higher than the period means calculated here.

Table 7: Mean PM_{10} and $PM_{2.5}$ concentrations for the baseline and post-commissioning periods

Site	Mean PM_{10} (µg/m^3)					Mean $PM_{2.5}$ (µg/m^3)				
	2009	**2010**	**2011**	**2012[a]**	**14/12/12-14/06/13**	**2009**	**2010**	**2011**	**2012[a]**	**14/12/12-14/06/13**
Birzebbuga LVS	N/A	N/A	N/A	31.50[b]	**41.89**	N/A	N/A	N/A	13.76[b]	16.15
Marsaxlokk LVS	N/A	N/A	N/A	36.37[b]	**48.35**	N/A	N/A	N/A	15.37[b]	19.10
Birzebbuga BAM	N/A	N/A	N/A	N/A	30.60	N/A	N/A	N/A	N/A	11.71
Marsaxlokk BAM	N/A	N/A	N/A	N/A	33.20	N/A	N/A	N/A	N/A	10.28
Gharb	33.66[b]	32.88	29.31	26.49	33.74	16.14[b]	11.48	15.52	13.55[b]	12.04
Kordin	N/A	N/A	38.07[b]	28.01[b]	30.11	N/A	N/A	N/A	N/A	N/A
Msida	**42.77**	**45.59**	**44.75**	**40.16**[b]	**40.49**	22.62	20.00	20.29	18.22[b]	16.65
Zejtun	28.05	32.46	29.75[b]	31.59[b]	32.97	13.91[b]	13.55	12.17	10.49	11.03

[a] Up to 13/12/2012; [b] <75% data capture; **bold** = exceedance of the annual mean Limit Value

3.7.3. Daily mean exceedances (PM_{10})

This section focuses on exceedance days, i.e. days when the daily mean concentration of PM_{10} exceeded 50 µg/m^3. Hourly mean PM_{10} concentrations from the consultant's BAM monitoring sites and MEPA monitoring sites were averaged to daily mean values (for days with at least 75% data capture) and the number of exceedances of the daily mean Limit Value (50 µg/m^3) were identified. The hourly mean PM_{10} BAM data for Marsaxlokk and Birżebbuġa reported here are real-time measurements that have been recalibrated to the daily mean BAM. Daily mean data from the consultant's LVS data were also included in the analysis. No sites have breached the permitted number of 35 exceedances of the daily mean threshold.

As well as calculating the number of days exceeding the threshold, the 90th percentile has been calculated to effectively extrapolate the data for the year. The 90th percentile is comparable with the 24-hour mean threshold to determine whether there is an anticipated breach of the Limit Value (50 µg/m^3). As with the annual mean exceedances, the MEPA site at Msida and the LVS monitors at Birzebbuga and Marsaxlokk indicate potential exceedances of the daily mean PM_{10} Limit Value. Again, this is in contrast to the BAM monitors, which are more in line with the MEPA sites.

Table 8: Number of exceedances of the daily mean Limit Value for PM_{10} for the baseline and post-commissioning periods (not accounting for subtraction of natural sources) and 90^{th} percentiles for the post-commissioning period

Site	Number of exceedances of the PM_{10} daily mean Limit Value					90^{th} percentile (equivalent to 35 permitted exceedances)
	2009	**2010**	**2011**	**2012**[a]	**14/12/12-14/06/13**	**14/12/12-14/06/13**
Birzebbuga LVS	N/A	N/A	N/A	20[b]	28	**66.91**
Marsaxlokk LVS	N/A	N/A	N/A	25[b]	32	**67.29**
Birzebbuga BAM	N/A	N/A	N/A	N/A	13	41.04
Marsaxlokk BAM	N/A	N/A	N/A	N/A	14	44.66
Gharb	13[b]	**38**	19	12	5	41.86
Kordin	N/A	N/A	24[b]	2[b]	12	41.74
Msida	**57**	**79**	**64**	**43**	26	**55.94**
Zejtun	23	34	16[b]	14[b]	9	44.27

[a] Up to 13/12/2012; [b] <75% data capture; **bold** = exceedance of the daily mean Limit Value (not accounting for subtraction of natural sources)

3.7.4. Calendar plots

Figure 143 to Figure 150 (Appendix D) show calendar plots for the period 1st January to 14th June 2013 for each site. Each set of figures comprises three calendar plots. All three plots are shaded to represent the concentrations at each site across the period with the first plot showing the dates, the second plot showing the concentrations with exceedances of the daily mean Limit Value in bold, and the third showing the predominant wind direction and strength on each day. Each set of plots therefore allows the viewer to simultaneously identify the dates on which there were exceedances of the daily mean and from which direction the source of particulate matter was likely to have been blown. Comparison between the sites enables identification of dates on which exceedances are common or discrete to particular sites, and further examination of the wind direction on those discrete dates facilitates source identification in a similar way to the polar plots. These calendar plots show the concentrations on all days with available data, not just those with more than 75% data availability as in Table 8. Due to restrictions in the plot design, these plots do not include the post-commissioning period 14th – 31st December 2012. However, the polar plot in Figure 62 shows the wind direction associated with exceedances for this period.

Examination of the calendar plots has indicated that there were only two periods when the daily mean Limit Value 50 $\mu g/m^3$ threshold was exceeded exclusively at one or both of the consultants' monitoring sites when the wind was from the direction of the DPS (i.e. E-SE): 22nd to 25th April 2013 and 15th May 2013. Both occasions were only recorded by the LVS monitors. The remaining exceedance days were all shared with MEPA sites or did not coincide with winds from the direction of the DPS. Further investigation of these and other elevated concentrations are discussed in section 3.7.5 below.

3.7.5. Time series plots

Figure 63 shows a time series of the daily mean PM_{10} (>75% data capture) for the two consultants' sites at Birzebbuga and Marsaxlokk and the four MEPA sites. It is possible to see from Figure 63 that there were around seven short-term exceedence events occurring every few days in January and early February and again in March and early April, including a significant event on 6th-7th March 2013. These events affected all sites resulting in exceedences or elevated concentrations being recorded across the islands. During December and April, concentrations at most sites were generally lower, however, the LVS monitors at Marsaxlokk and Birzebbuga showed exceedences and elevated concentrations during the periods 27th – 31st December 2012 (Marsaxlokk only) and 22nd – 25th April (both Marsaxlokk and Birzebbuga). These data are contrary to the BAM data for the same sites during this period, which showed a pattern of concentrations more closely relating to the MEPA sites. A polar plot of PM_{10} for Marsaxlokk BAM for the December period shows that the wind direction was predominantly from the north-west, i.e. the opposite direction from the DPS (Figure 62). Given the time of year (Christmas/New Year) it is suggested that these exceedances may be attributable to local festivities and associated increased traffic. The period of exceedences recorded by the LVS monitors in April was associated with winds from the direction of the DPS (see section 3.7.4). This period of elevated concentrations was followed by a one-day break in the data on 26th April, following which concentrations dropped back to levels comparable with the other monitors. This period of exceedences coincided with the Malta International Fireworks festival event held in Marsaxlokk on 26th April, and it is possible that the elevated concentrations of PM_{10} recorded in this area over the preceding period may have been partially due to related pre-event festivities. Between 10th and 22nd May there was an extended period of continuously very high concentrations recorded by the LVS monitors at Marsaxlokk and Birzebbuga. On 16th – 19th and 22nd May there were also very high exceedences or elevated concentrations recorded at all sites. While the other monitors, including the BAM instruments at Marsaxlokk and Birzebbuga, show similar temporal patterns, the LVS concentrations, particularly at Marsaxlokk, were much higher. Exceedences and elevated concentrations recorded by the LVS monitors at Marsaxlokk and Birzebbuga continued after this event until 5th June when concentrations fell to levels comparable with the other monitors. The highest daily mean concentrations at all sites were recorded on 16th and 22nd May. These were a Thursday and Wednesday respectively and correspond with the dominant peak in concentrations apparent at all sites in the time variation plots (section 3.6.2) as a Saharan dust event (section 3.7.6).

Figure 64 shows a time series of the daily mean DPS emissions (>75% data capture) from all stacks. While DPS1A and DPS1B show fairly consistently elevated dust emissions across the period, DPS4, DPS5 and DPS6A to DPS6D show consistently low emissions. There are no unusual peaks or particularly elevated levels in the emissions data that may be attributable to elevated PM_{10} concentrations.

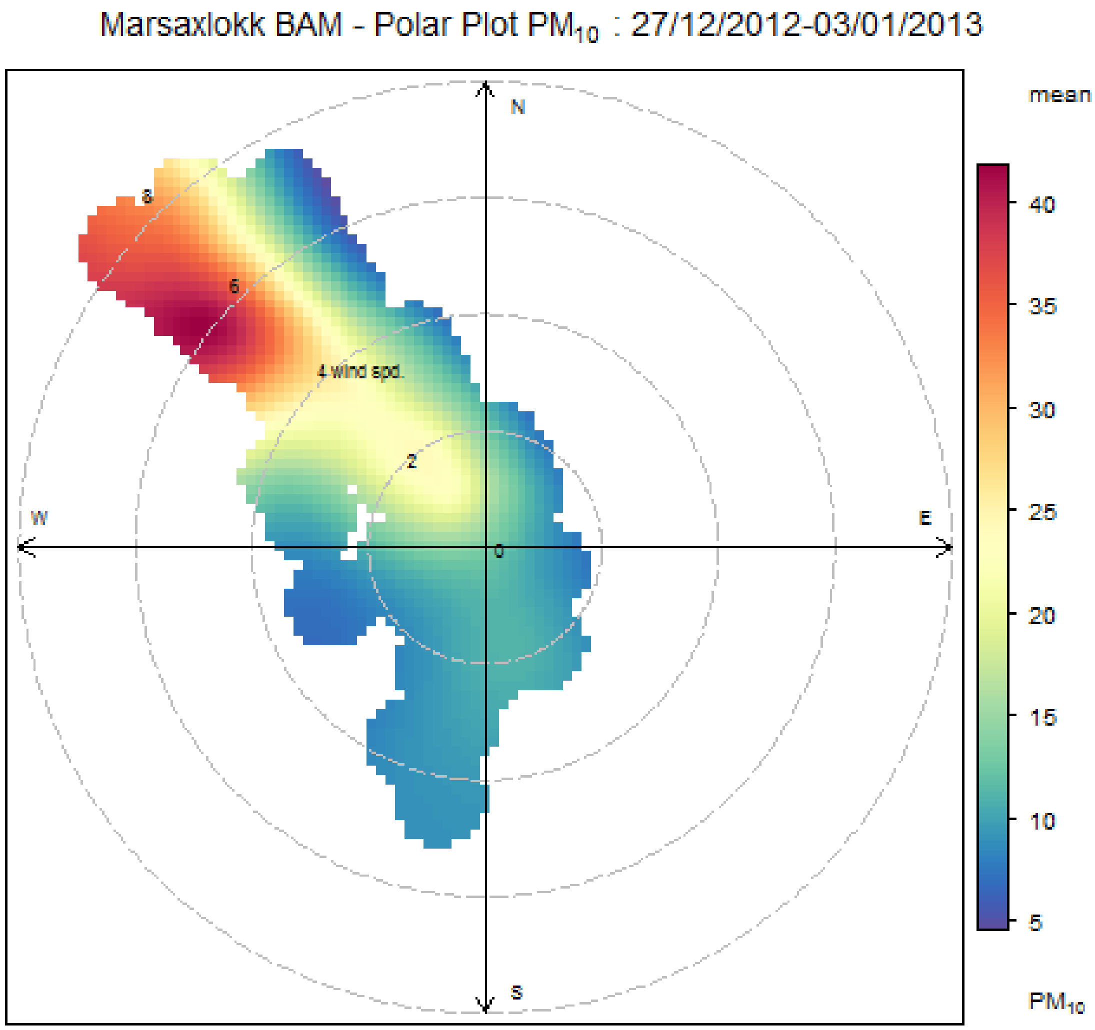


Figure 62: Polar plot showing PM_{10} for Marsaxlokk for the period 27/12/12-03/01/13

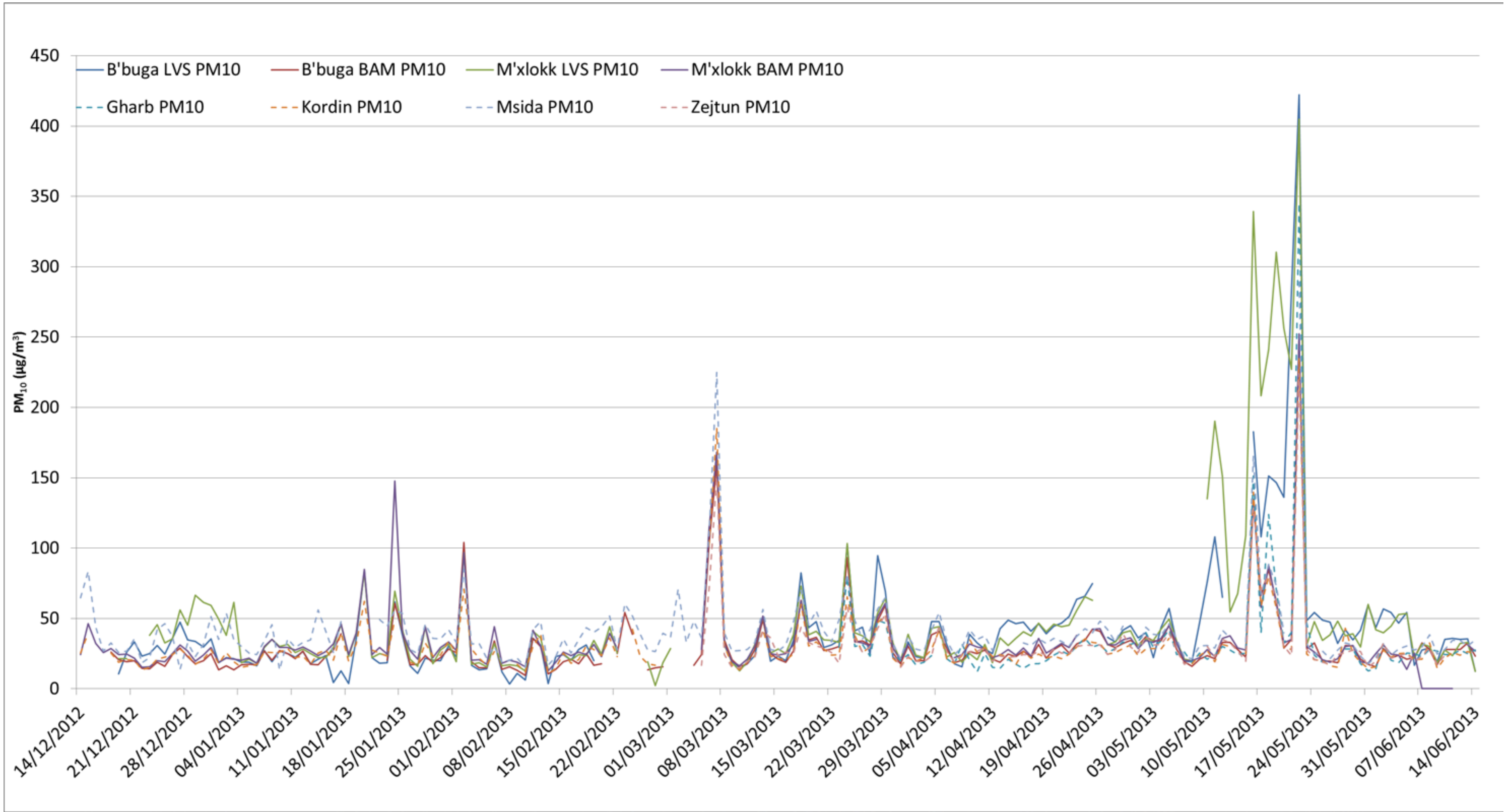


Figure 63: Time series daily mean PM_{10} concentrations at consultants' sites (Birzebbuga and Marsaxlokk) and MEPA sites (Gharb, Kordin, Msida and Zejtun) for the period 14/12/12 – 14/06/13

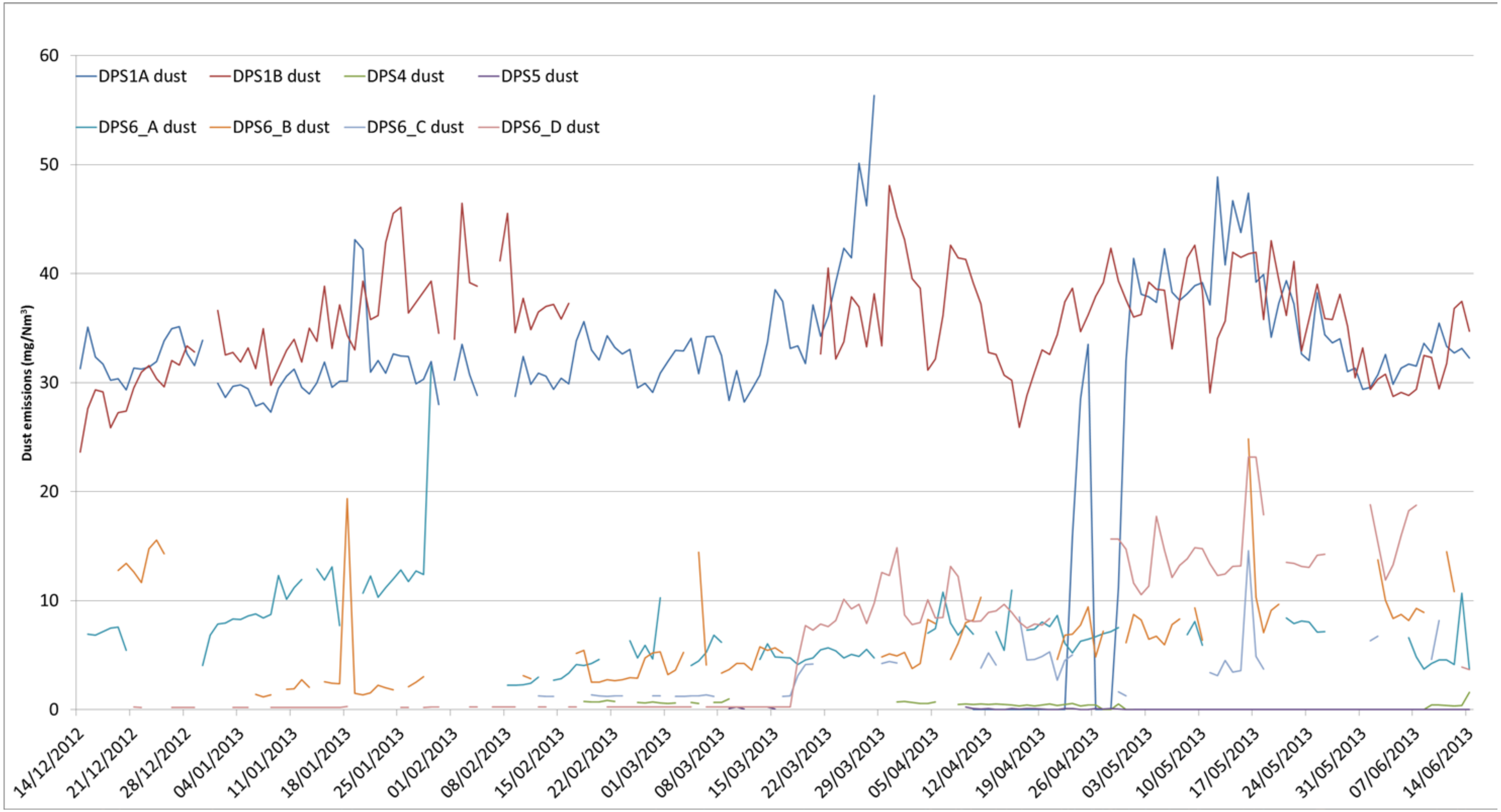


Figure 64: Time series daily mean dust emissions from the DPS site stacks for the period 14/12/12 – 14/06/13

3.7.6. Saharan dust episodes

Exceedances associated with natural events, such as Saharan dust events, can be discounted when assessing compliance with the limit values, in accordance with Directive 2008/50/EC. Saharan dust episodes were recorded by AIS Environmental Ltd for days when the LVS monitors recorded exceedances. This is therefore not a complete record of Saharan dust events, due to gaps in the data availability and the occurrence of dust events which may not have caused an exceedance of the daily mean at either of the LVS monitors. With that caveat, Saharan dust events were noted to have occurred on 3rd, 20th and 24th January, 2nd February, 13th, 18th, 24th, 28th and 29th March and 16th – 22nd May 2013 during the post-commissioning period. These events coincide with and therefore help to explain the majority of exceedances at most sites.

3.7.7. Summary of Exceedance Analyses

Based on the post-commissioning period data, there are potential exceedances of the annual mean Limit Value for PM_{10} in 2013 at Msida and also at Birzebbuga and Marsaxlokk according to the LVS data, but not the BAM data. There are no recorded exceedances of the $PM_{2.5}$ annual mean threshold indicated at any site.

Daily mean exceedances of the EU Limit Value for PM_{10} (50 µg/m^3) were calculated for the consultants' sites, Birzebbuga and Marsaxlokk, and the MEPA sites for the period 14th December 2012 to 14th June 2013. The permitted 35 exceedances of the daily mean in a calendar year was not breached at any site within the period covered in this report. Based on the 90th percentiles, exceedances of the daily mean Limit Value were predicted at Msida and also at Birzebbuga and Marsaxlokk using the LVS data; however, the BAM data did not indicate any exceedance of the Limit Values.

The reason behind the discrepancy between the LVS and BAM/MEPA data in identifying exceedences is unclear. Typically the gravimetric LVS data would be preferential as it is the European reference method, however the correlation between the BAM and MEPA data would give more credibility to the BAM data in this case. It is noted that there is a tendency for the LVS data to typically give higher concentrations than the corresponding BAM instruments in this study, which may call into question the validity of data from one or either of these monitors.

Exceedances of the daily mean 50 µg/m^3 were identified as occurring exclusively at the consultants' sites on 27th December 2012, 29th – 30th December 2012, 3rd January, 22nd – 25th April, 4th May, 10th – 15th May, 20th – 21st May, 24th May, 31st May and on 2nd – 5th June 2013. All other exceedances during the post-commissioning period were also experienced either as exceedances or elevated concentrations at MEPA sites and therefore considered to be regional (transboundary) in nature.

Saharan dust events were noted to have occurred on 3rd, 20th and 24th January, 2nd February, 13th, 18th, 24th, 28th and 29th March and 16th – 22nd May 2013. Localised exceedences at the consultants' sites were therefore identified for 22nd – 25th April and 10th – 15th May. These periods could be at least partially associated with winds from the direction of the DPS (22nd – 25th April and 15th May), but these could also be linked to local or regional events. The former, occurring just prior to the Malta International Fireworks festival in Marsaxlokk, and the latter related to the onset of the recorded significant Saharan dust event following on 16th – 22nd May.

Annual exceedance analysis for the baseline period was undertaken for the MEPA sites and available data for the consultants' sites. There was insufficient data available for the baseline period for the hourly BAM measurements, but analysis of the LVS data indicated that the annual mean PM_{10} and $PM_{2.5}$ concentrations were higher in the post-commissioning period than in the baseline period. Proportional to the period of time for which there was data available, there were also more exceedances of the daily mean threshold. Annual mean and daily mean concentrations for the MEPA sites during the post-commissioning period, however, are comparable with previous years. The inconsistencies between the BAM and LVS data in the post-commissioning period have been highlighted above and would tend to suggest that the LVS monitors may be over-reading. In any case there is no indication that the additional exceedances recorded using the LVS monitors can explicitly be associated with dust emissions from the DPS.

3.8. Summary of Data Analysis

This report represents the final report of this study, bringing together the baseline analysis and results of the 6-months post-commissioning monitoring data analysis to determine whether the emissions from the diesel engines at Delimara Power Station during the period of HFO use is contributing to exceedances of the limit values for PM_{10} and/or $PM_{2.5}$, established under Legal Notice 478 of 2010, as amended by Legal Notice 482 of 2011. This report provides spatial, temporal and exceedance analysis of the data to facilitate source apportionment.

Spatial analysis of the data from 14th December 2012 to 14th June 2013 has indicated that at all MEPA sites and at the consultants' Birzebbuga and Marsaxlokk sites the highest concentrations of PM_{10} and $PM_{2.5}$, during both the baseline and post-commissioning periods, are found when the wind is from the south or south-west (contrary to the predominant wind direction). The wind speed and direction and the occurrence at all sites suggests that there is a transboundary source, e.g. Saharan dust, relating to the west/south-westerly measured concentrations. High concentrations of PM associated with winds from the direction of the DPS at Birzebbuga or Marsaxlokk are not apparent in the polar plots, suggesting if there is any impact of the DPS on PM_{10} concentrations it is minimal.

The analyses of temporal patterns in the pollution data has focussed on PM_{10} and $PM_{2.5}$ data from MEPA and consultants' sites and dust emissions data from DPS. It is possible to identify shared peak PM_{10} and $PM_{2.5}$ episodes across multiple sites as well as other, potentially more local events. The presence of multiple-site peaks and similar peak ranges across all sites indicates that the predominant source contributing to short-term peaks is likely to be regional, e.g. transboundary. There does not appear to be any clear temporal relationship between the DPS dust emissions and the particulate matter concentrations recorded at either Birzebbuga or Marsaxlokk.

Based on the post-commissioning period data, there are potential exceedances of the annual mean Limit Value for PM_{10} in 2013 at Msida and also at Birzebbuga and Marsaxlokk according to the LVS data, but not the BAM data. There are no recorded exceedances of the $PM_{2.5}$ annual mean threshold indicated at any site. The permitted 35 exceedances of the daily mean in a calendar year was not breached at any site within the period covered in this report. Based on the 90th percentiles, exceedances of the daily mean Limit Value were predicted at Msida and also at Birzebbuga and Marsaxlokk using the LVS data; however, the BAM data did not indicate any exceedance of the Limit Values.

Exceedances of the daily mean 50 $\mu g/m^3$ were identified as occurring exclusively at the consultants' sites on a number of occasions, however these were either associated with winds that were not from the direction of the DPS or that could also be linked to local or regional events, e.g. fireworks or Saharan dust events. Annual exceedance analysis for the baseline period indicated that the annual mean PM_{10} and $PM_{2.5}$ concentrations were higher in the post-commissioning period than in the baseline period. Proportional to the period of time for which there was data available, there were also more exceedances of the daily mean threshold. Annual mean and daily mean concentrations for the MEPA sites during the post-commissioning period, however, are comparable with previous years. The inconsistencies between the BAM and LVS data in the post-commissioning period were noted and would tend to suggest that the LVS monitors may be over-reading. In any case there is no indication that the additional exceedances recorded using the LVS monitors can be associated with dust emissions from the DPS.

3.8.1. Key Points Resulting from the Data Analyses

In summary, spatial, temporal and exceedance analysis of PM_{10} and $PM_{2.5}$ data and dust emissions has not indicated that the DPS has contributed to any exceedances of the EU Limit Values for PM_{10} or $PM_{2.5}$ during the post-commissioning period 14th December 2012 to 14th June 2013 at any sites. The recorded exceedances of the daily mean Limit Value for PM_{10} have been attributable to regional sources, sometimes specifically to Saharan dust events, or more localised events associated with wind directions other than from the direction of the DPS.

References

Carslaw, D.C. and Ropkins K., (2012) openair --- an R package for air quality data analysis. Environmental Modelling & Software. Volume 27-28, 52-61.

Carslaw, D. and Ropkins, K. (2012). openair: Open-source tools for the analysis of air pollution data. R package version 0.7-0.

Galdies, C. (2011). The Climate of Malta: statistics, trends and analysis 1951-2010, National Statistics Office, Malta.

R Core Team (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Appendix A: Wind plots

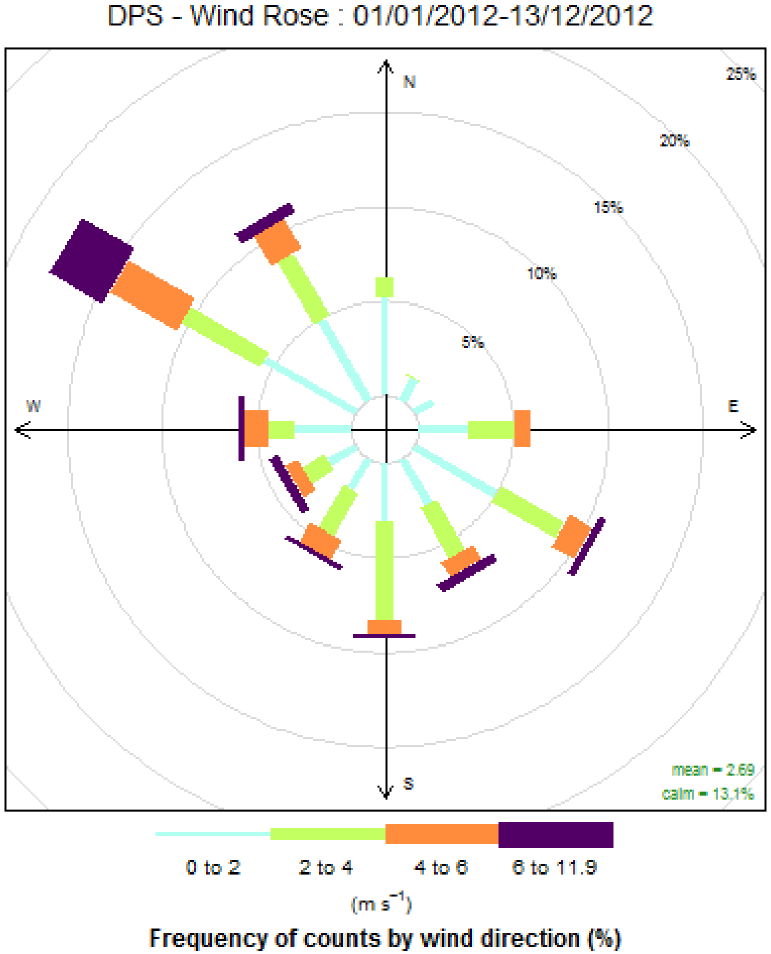


Figure 65: DPS baseline wind rose

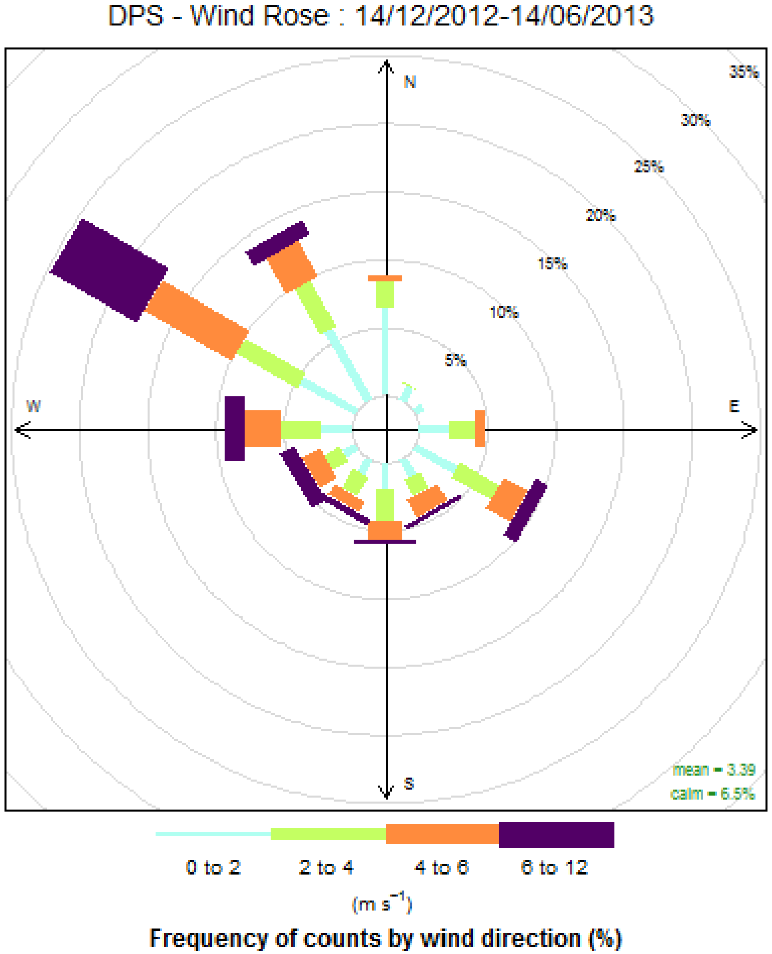


Figure 66: DPS post-commissioning wind rose

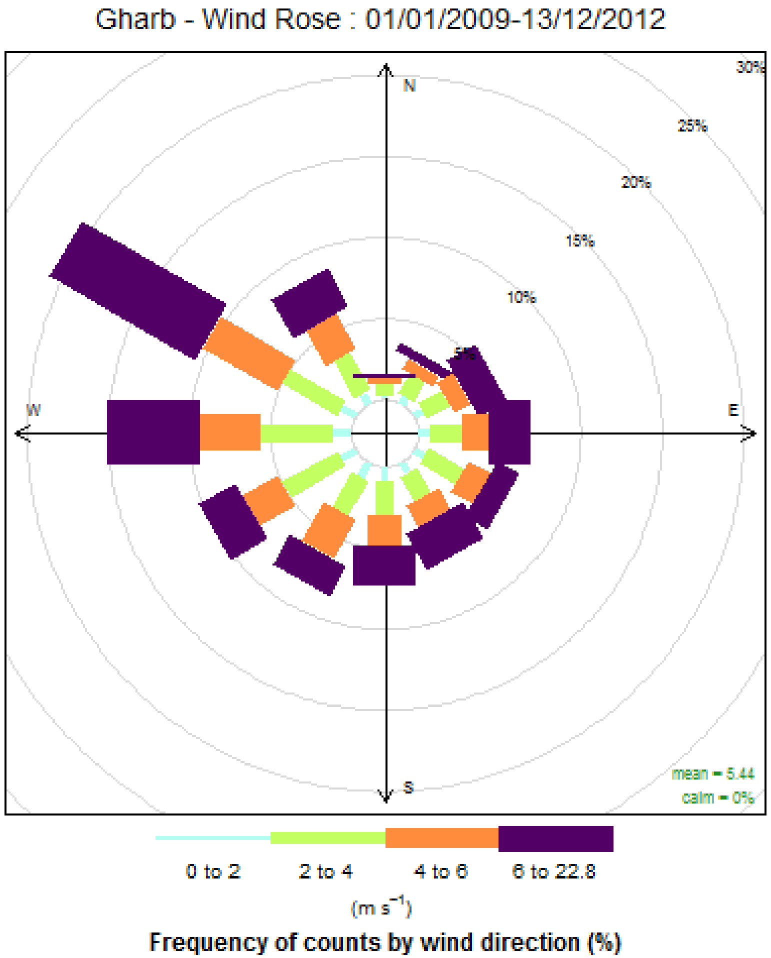


Figure 67: Gharb baseline wind rose

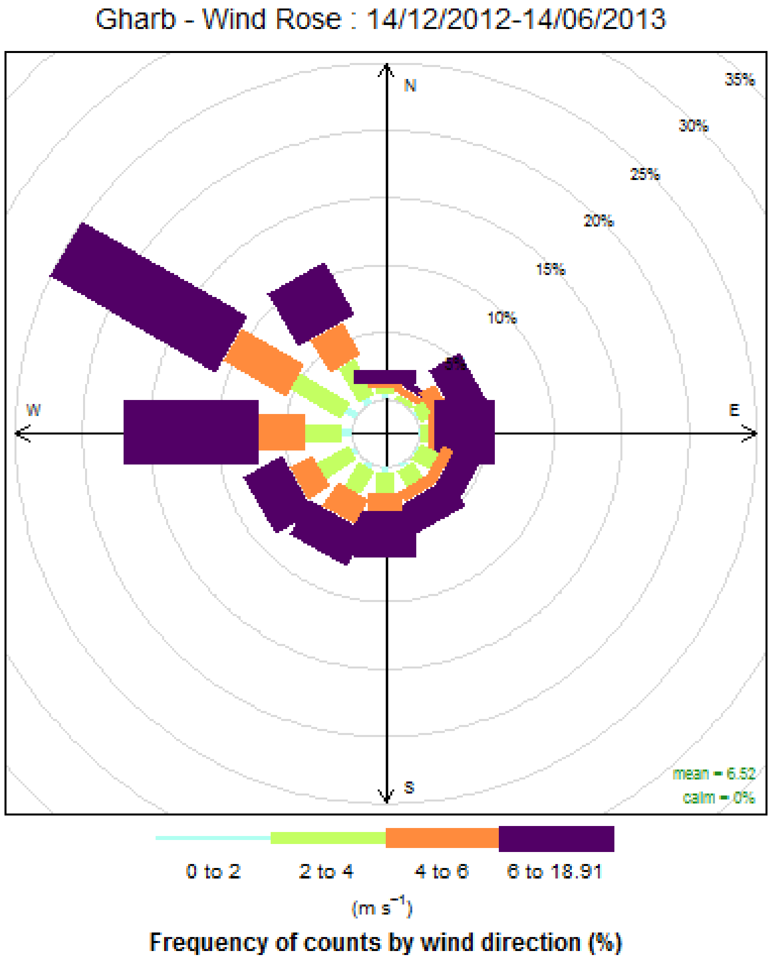


Figure 68: Gharb post-commissioning wind rose

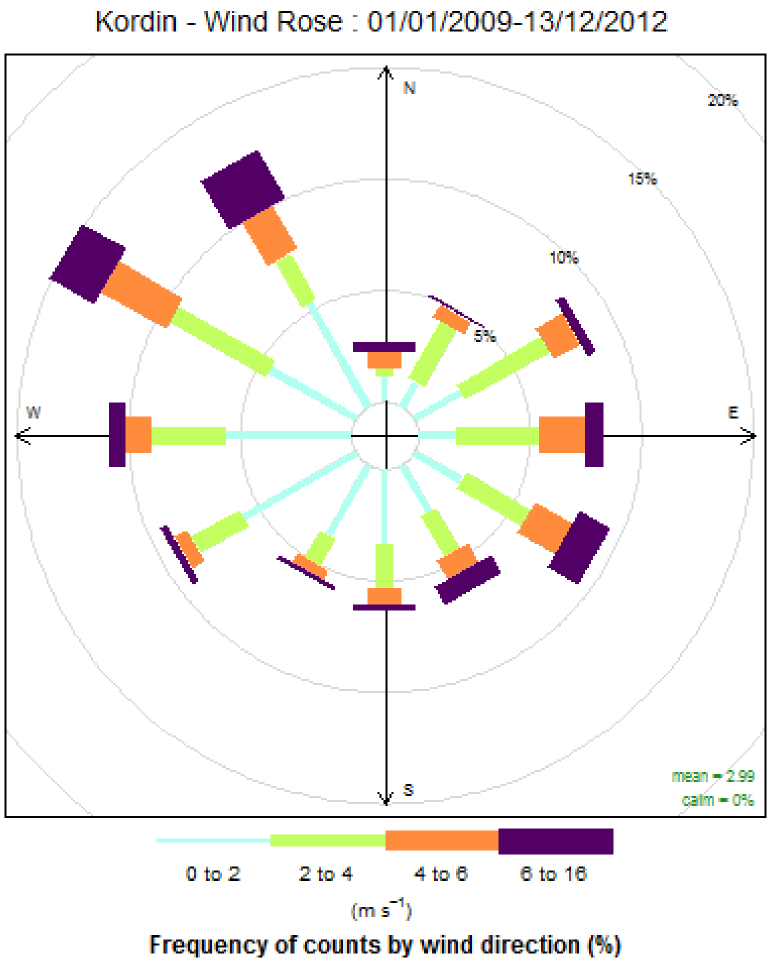


Figure 69: Kordin baseline wind rose

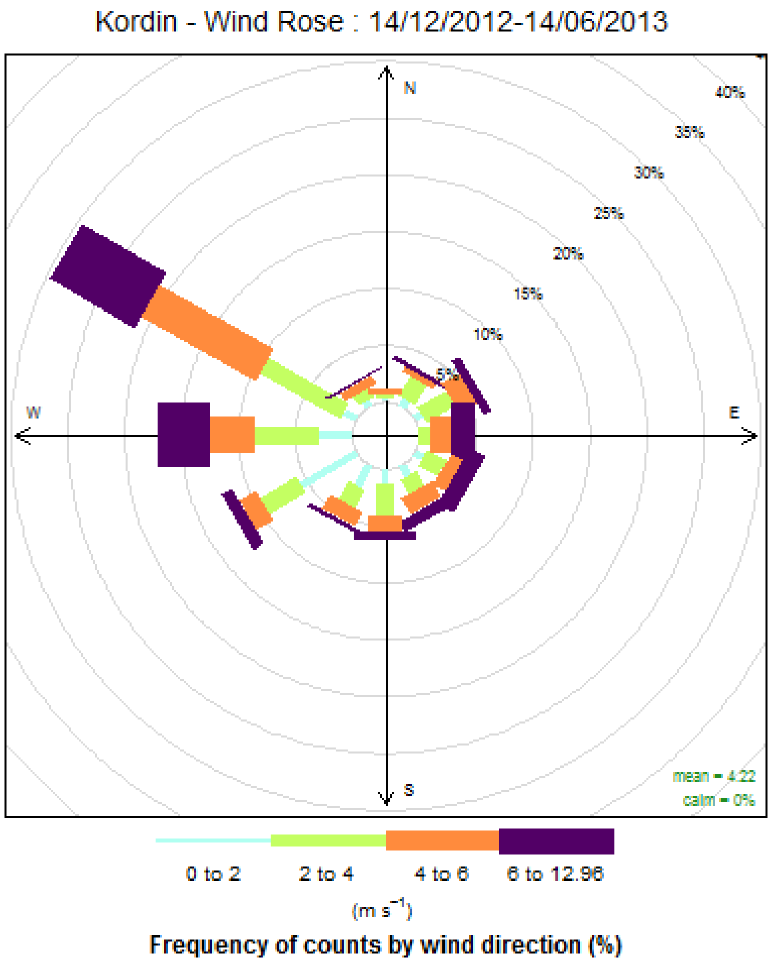


Figure 70: Kordin post-commissioning wind rose

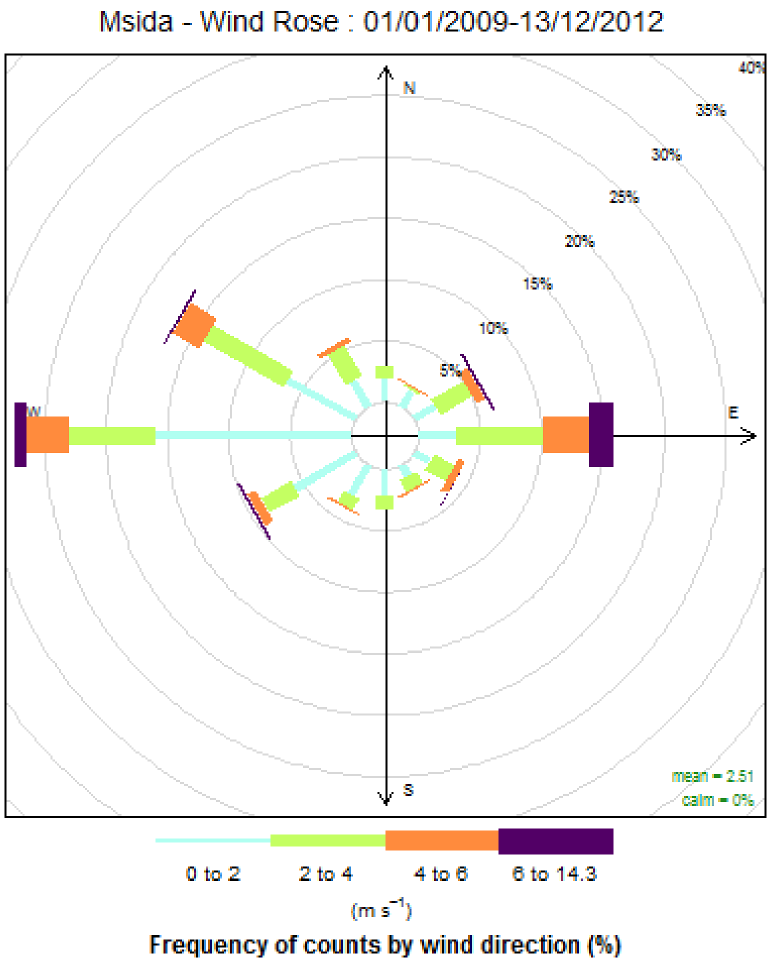


Figure 71: Msida baseline wind rose

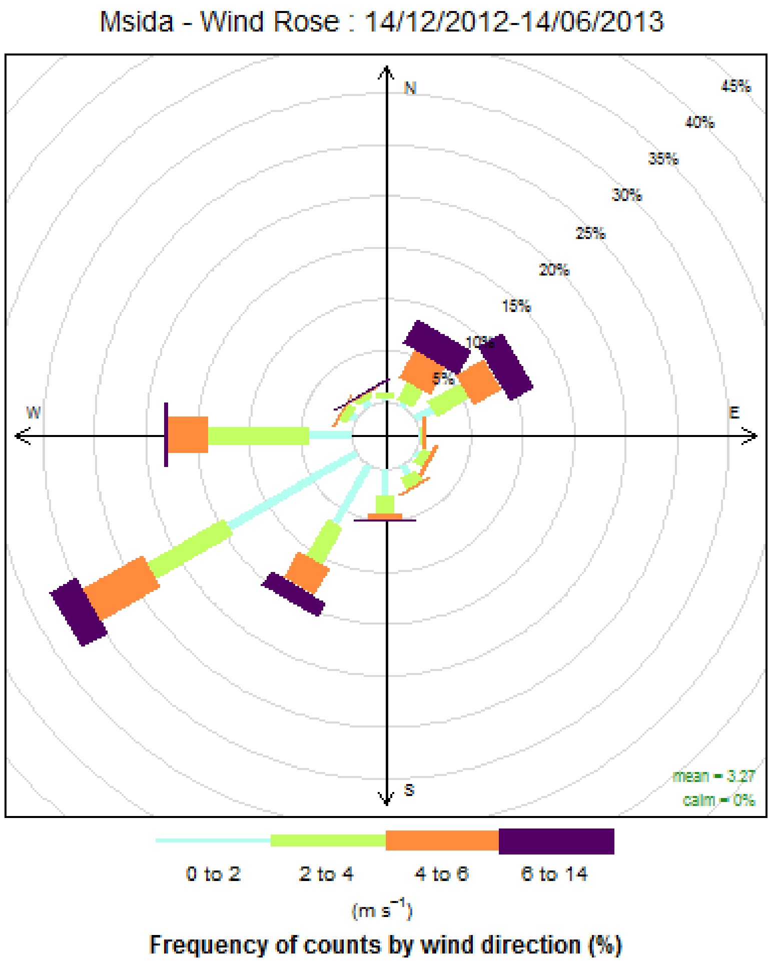


Figure 72: Msida post-commissioning wind rose

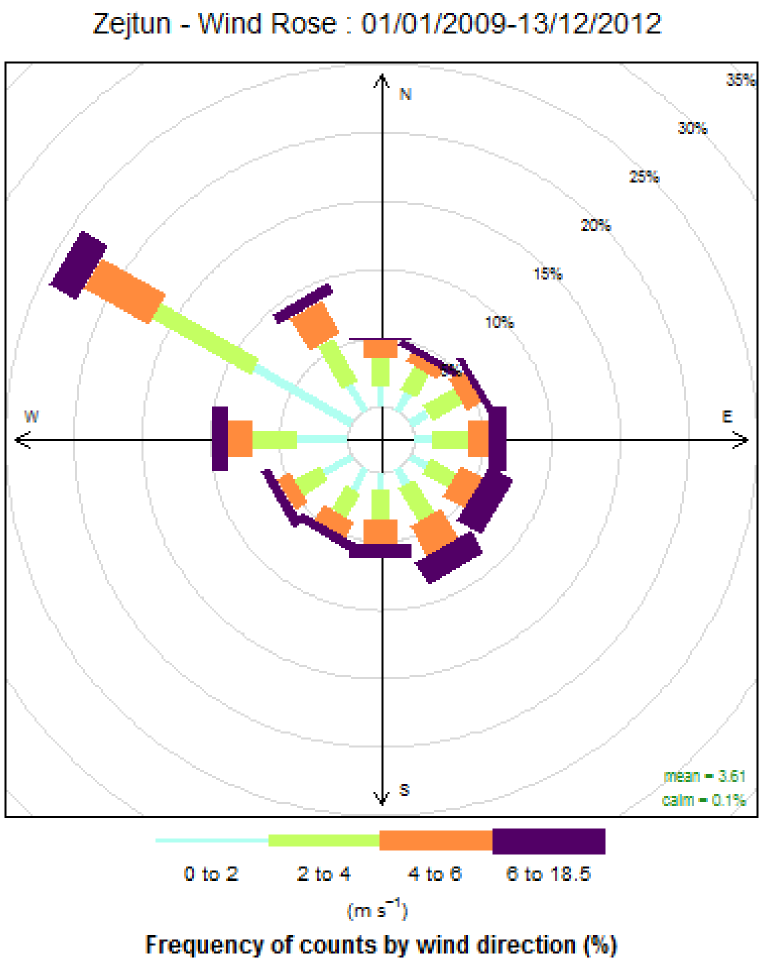


Figure 73: Zejtun baseline wind rose

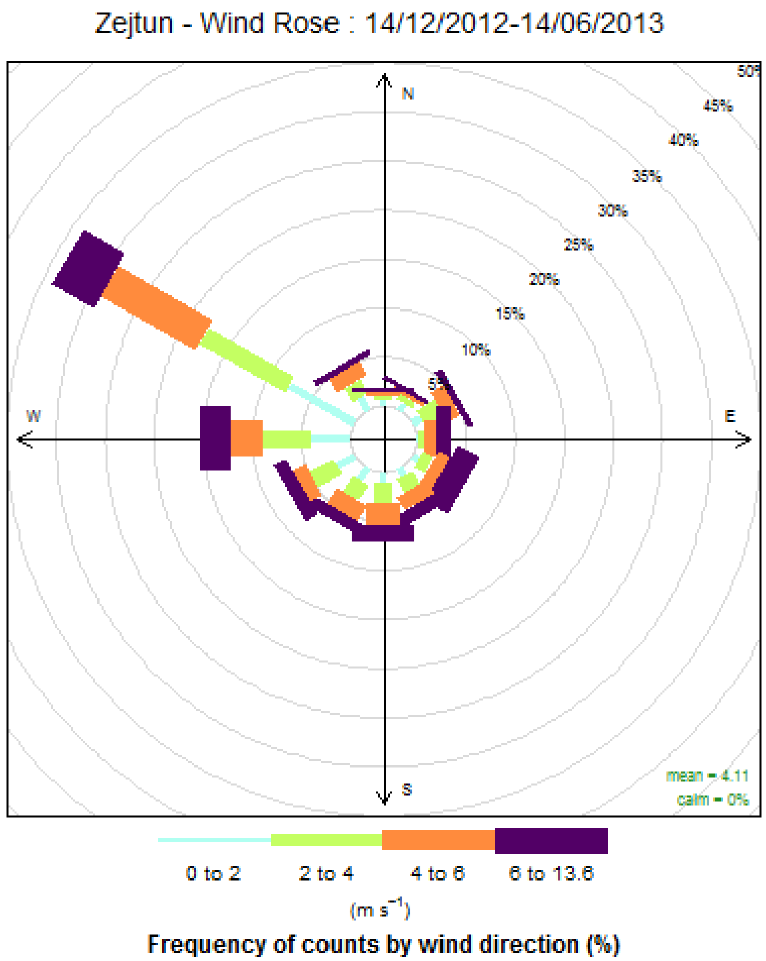


Figure 74: Zejtun post-commissioning wind rose

Appendix B: Summary plots of available data

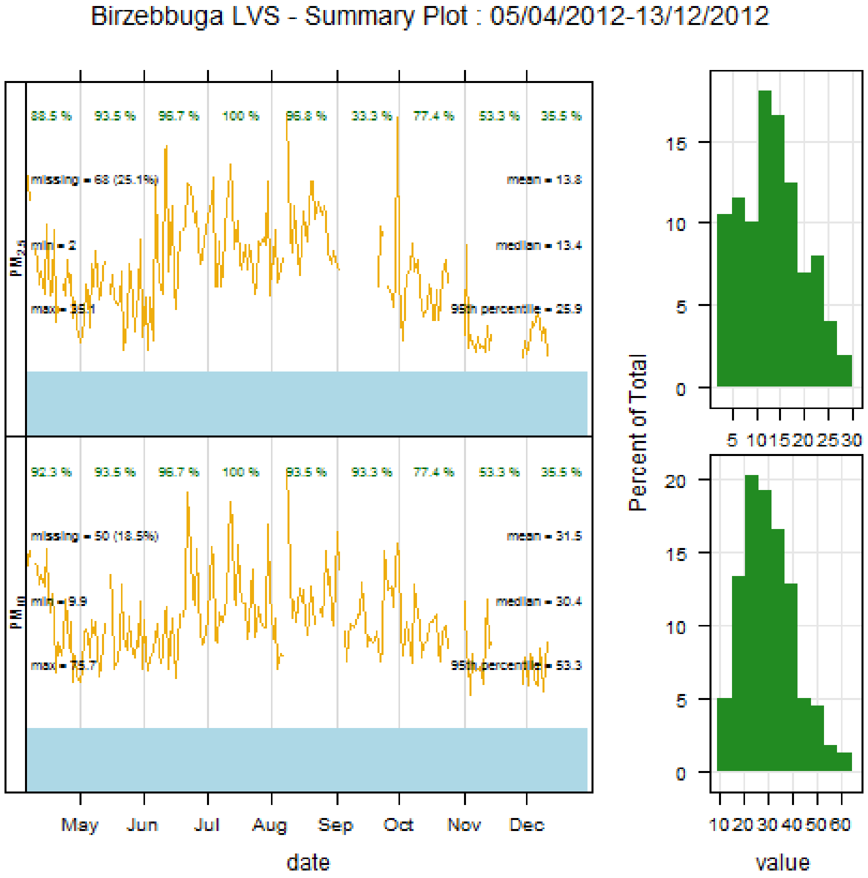


Figure 75: Birzebbuga LVS baseline summary plot

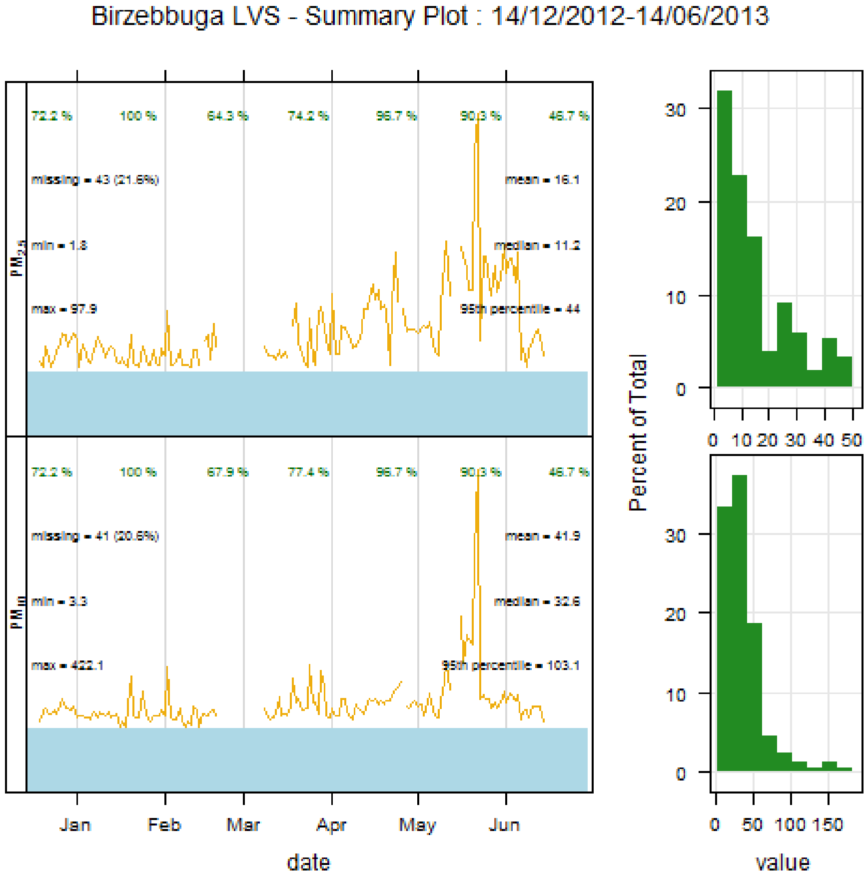


Figure 76: Birzebbuga LVS post-commissioning summary plot

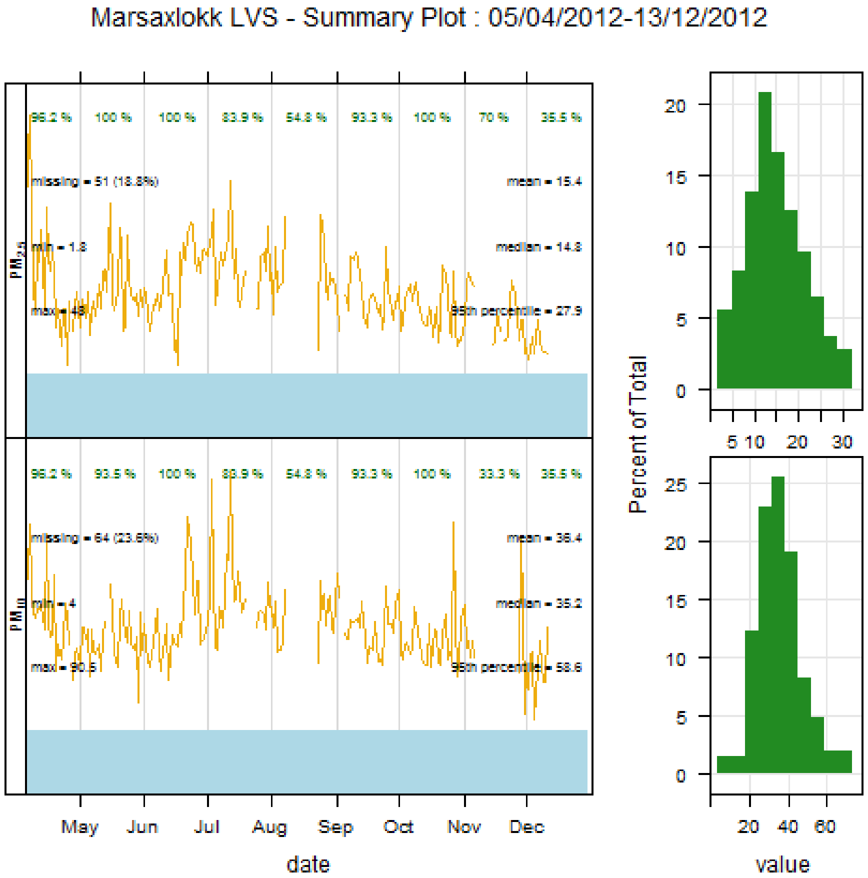


Figure 77 Marsaxlokk LVS baseline summary plot

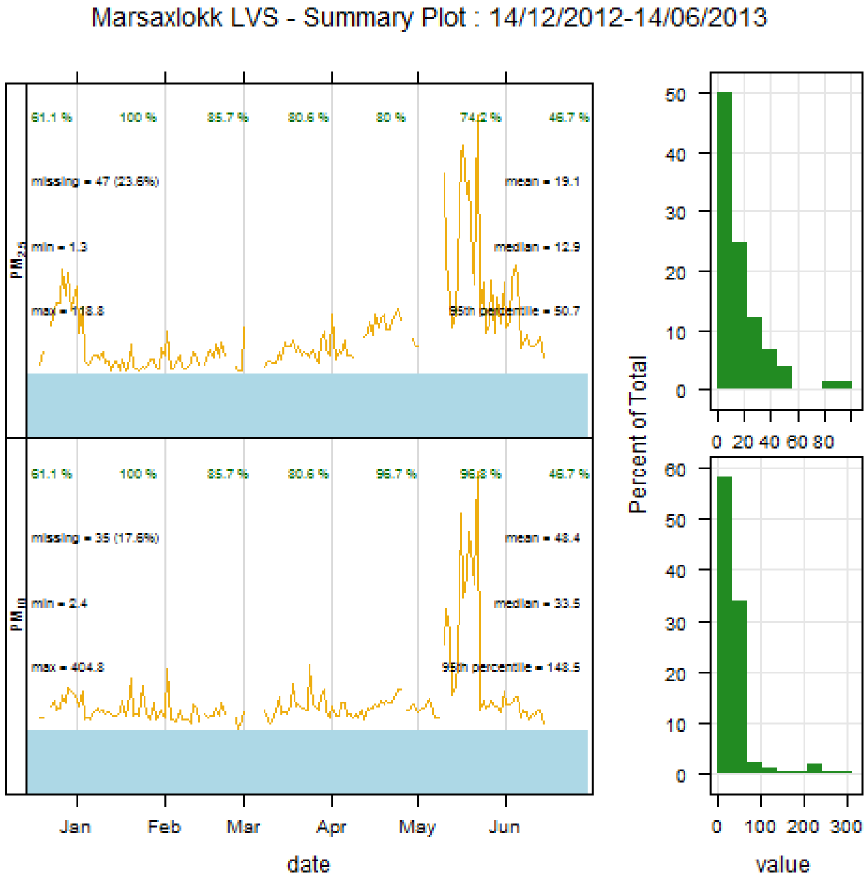


Figure 78: Marsaxlokk LVS post-commissioning summary plot

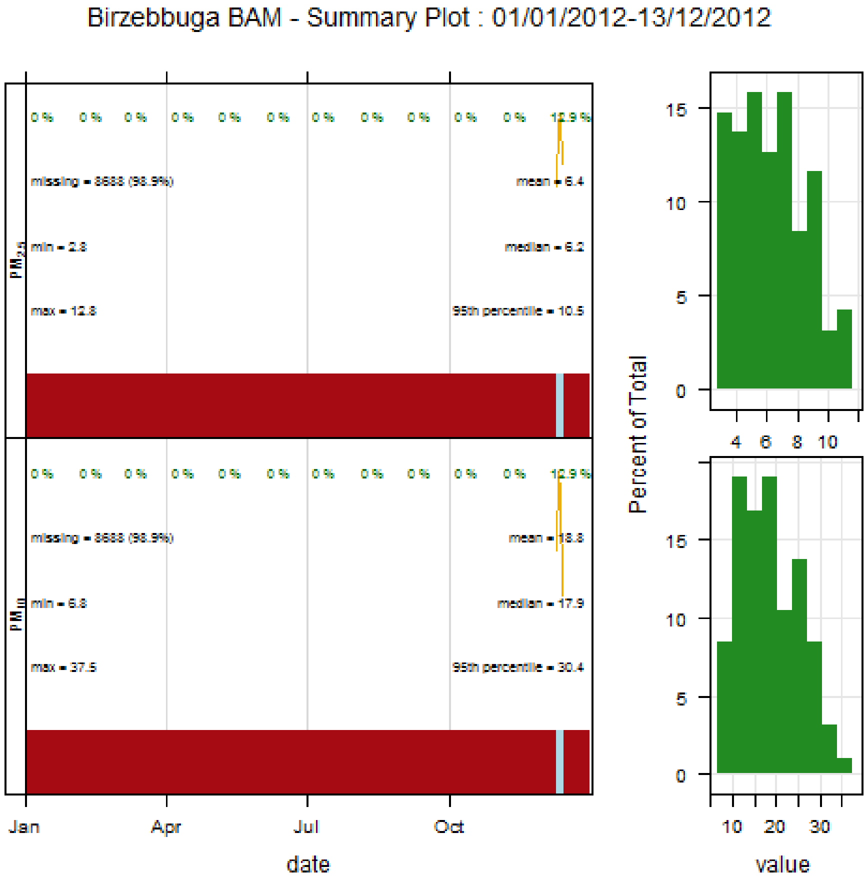


Figure 79: Birzebbuga BAM baseline summary plot

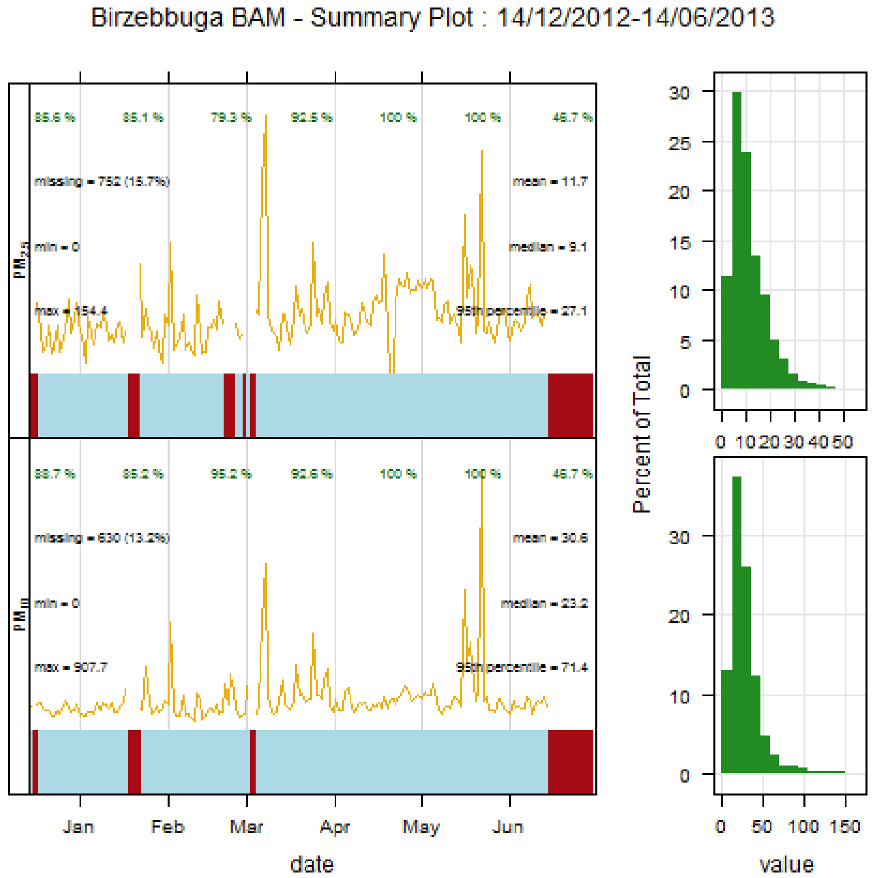


Figure 80: Birzebbuga BAM post-commissioning summary plot

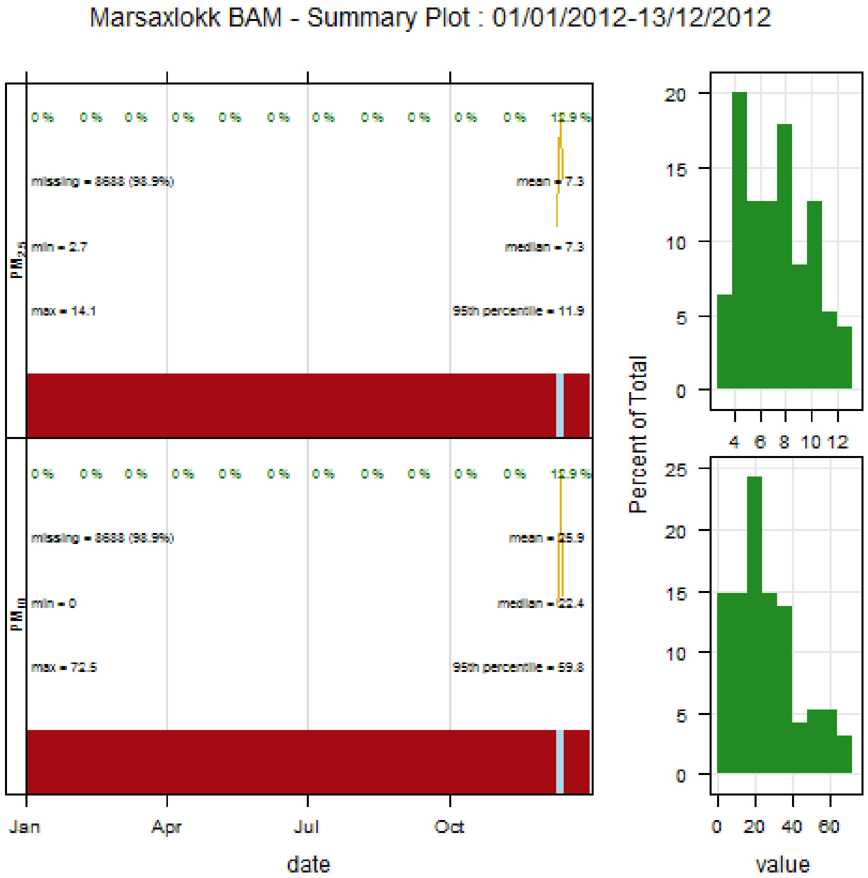


Figure 81: Marsaxlokk BAM baseline summary plot

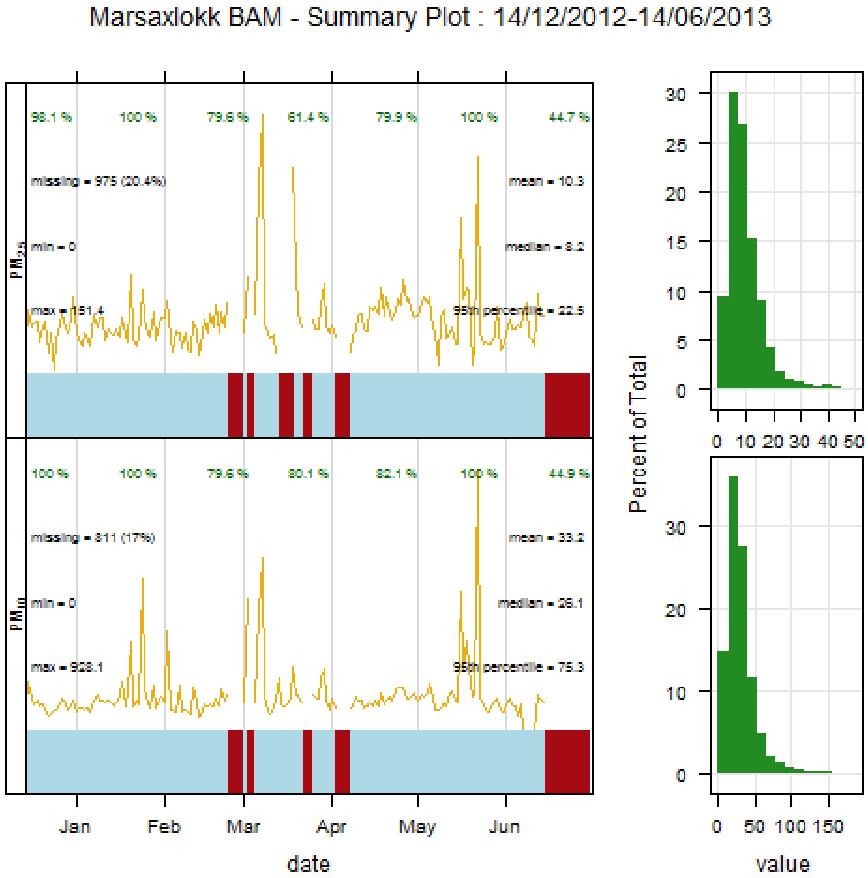


Figure 82: Marsaxlokk BAM post-commissioning summary plot

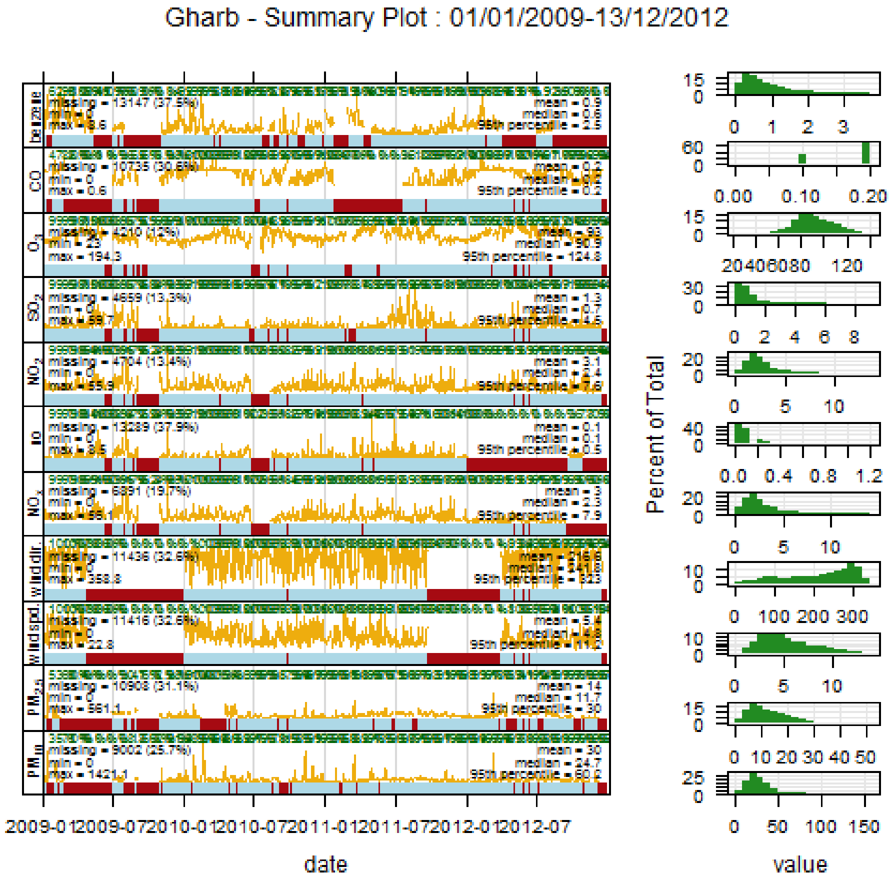


Figure 83: Gharb baseline summary plot

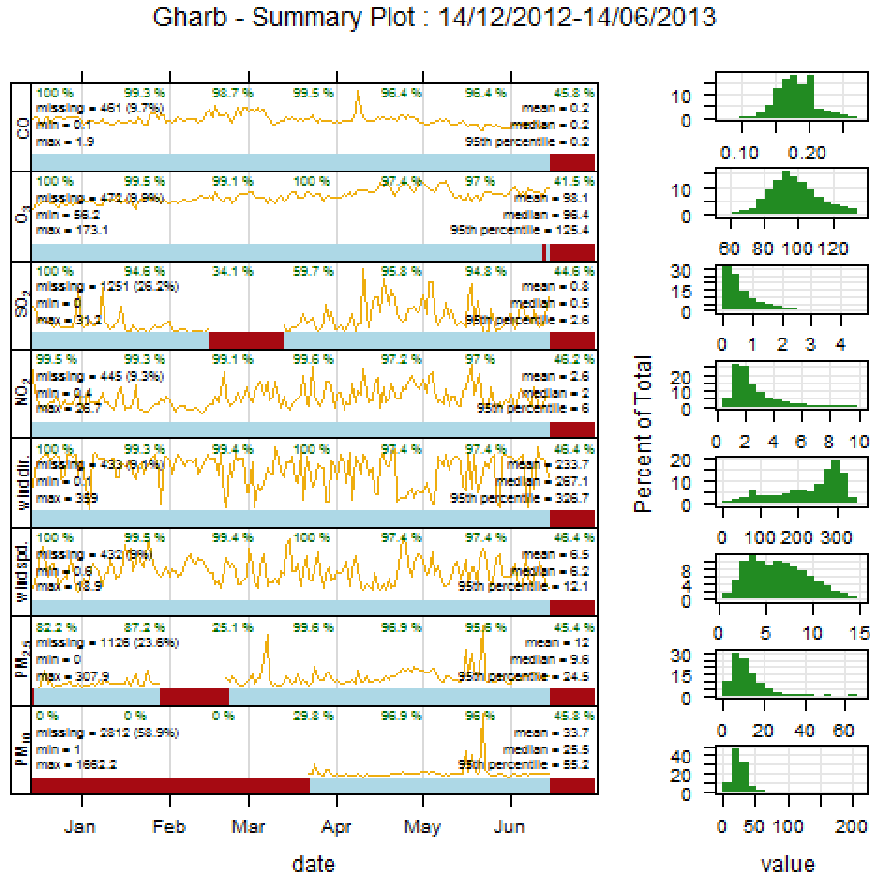


Figure 84: Gharb post-commissioning summary plot

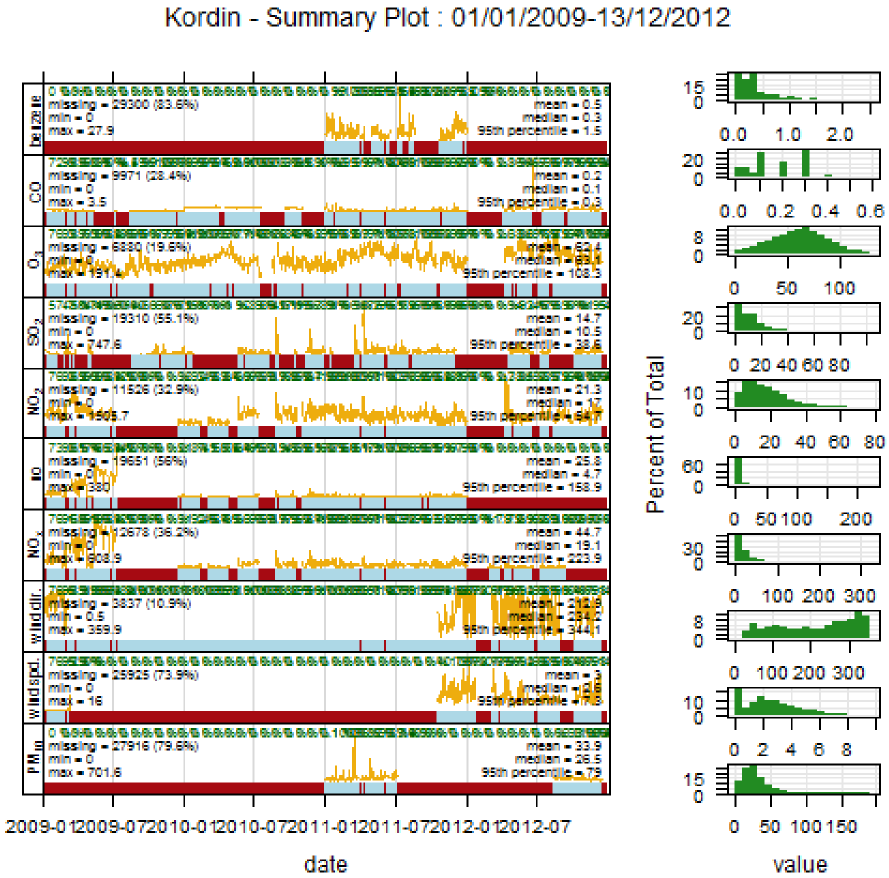


Figure 85: Kordin baseline summary plot

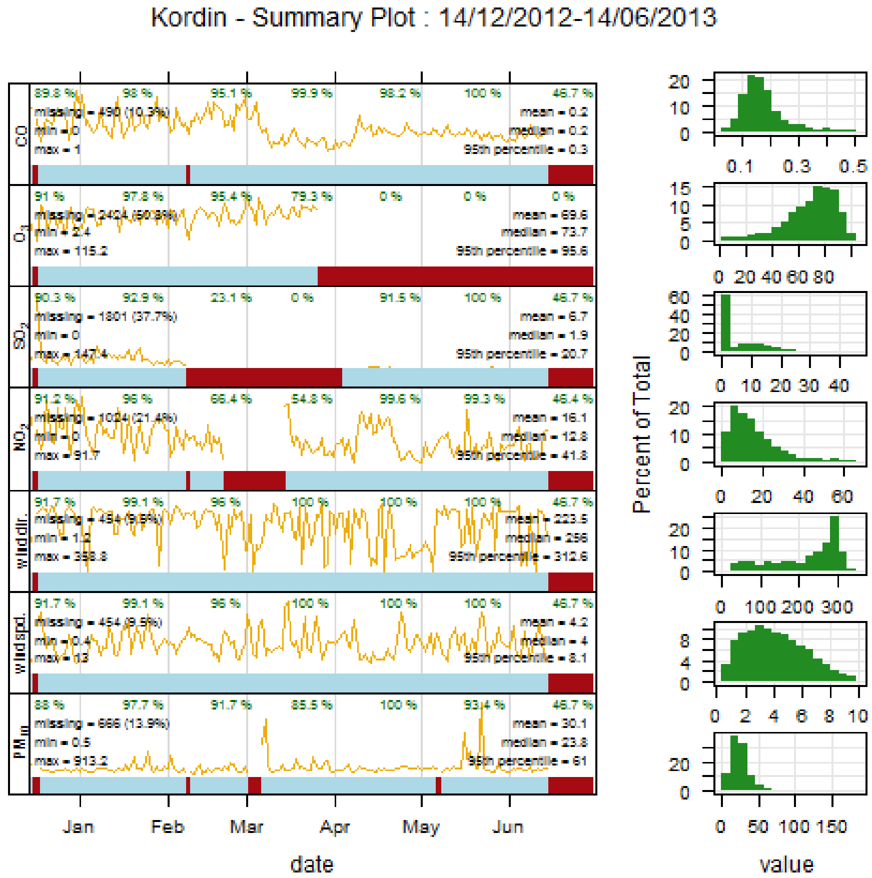


Figure 86: Kordin post-commissioning summary plot

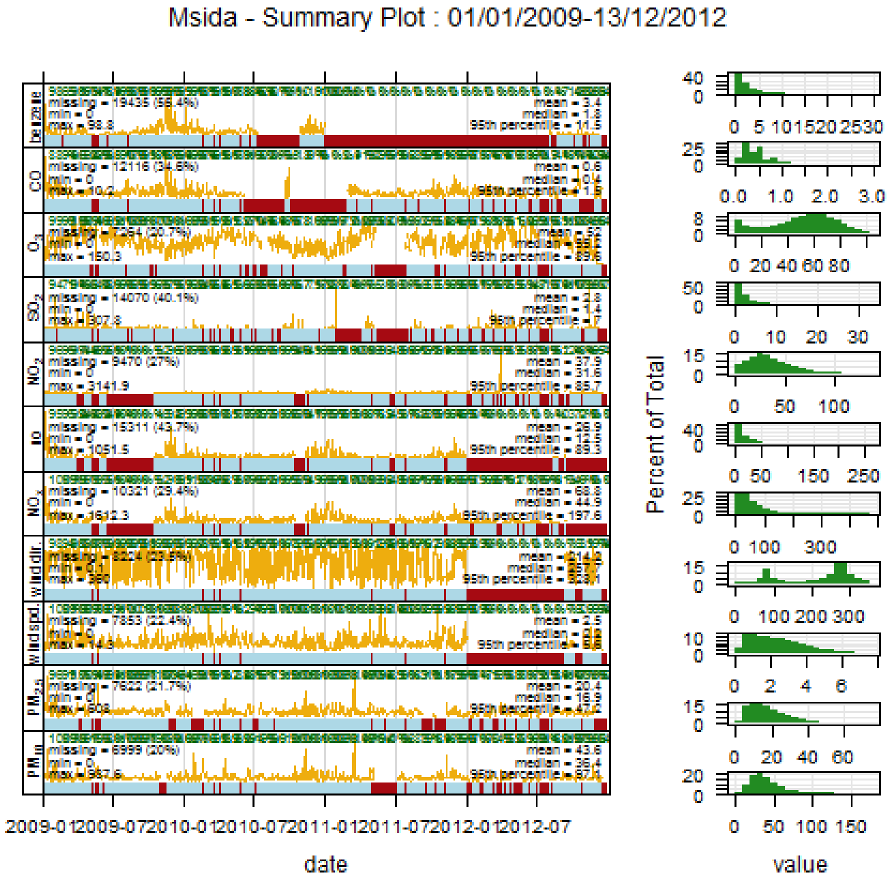


Figure 87: Msida baseline summary plot

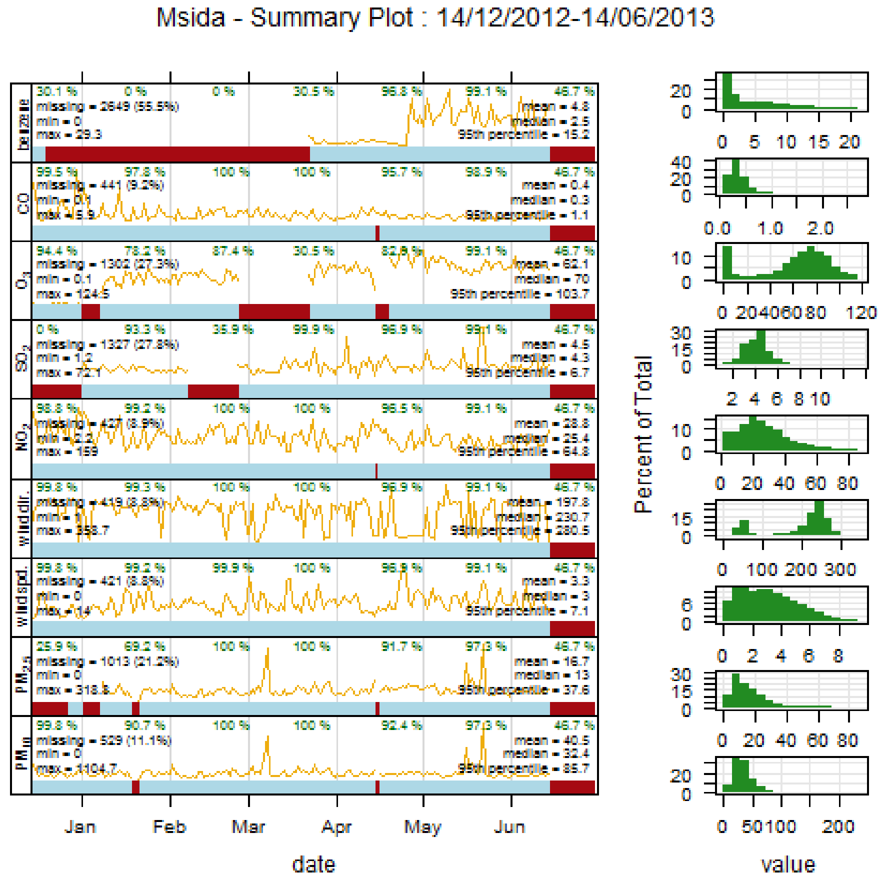


Figure 88: Msida post-commissioning summary plot

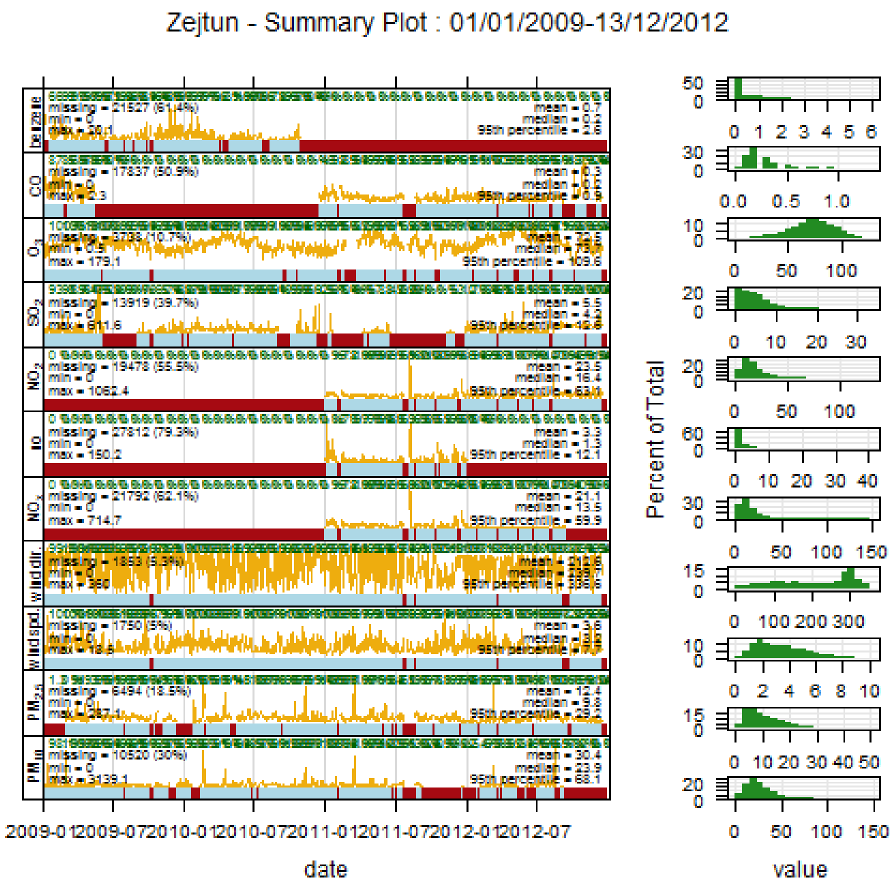


Figure 89: Zejtun baseline summary plot

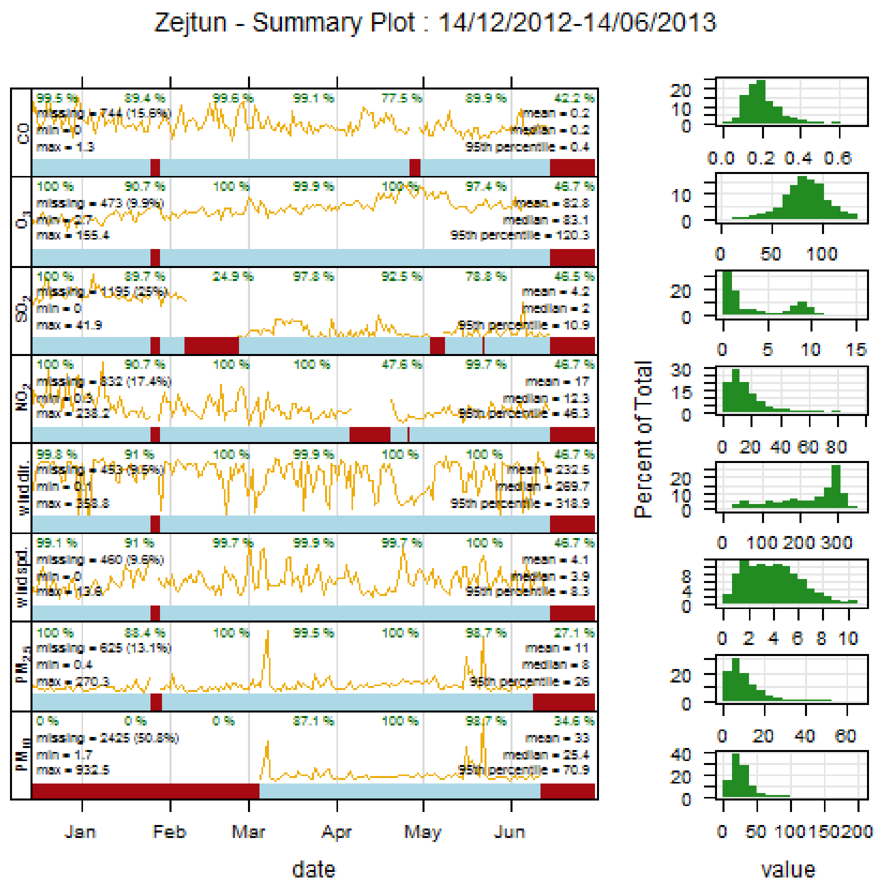


Figure 90: Zejtun post-commissioning summary plot

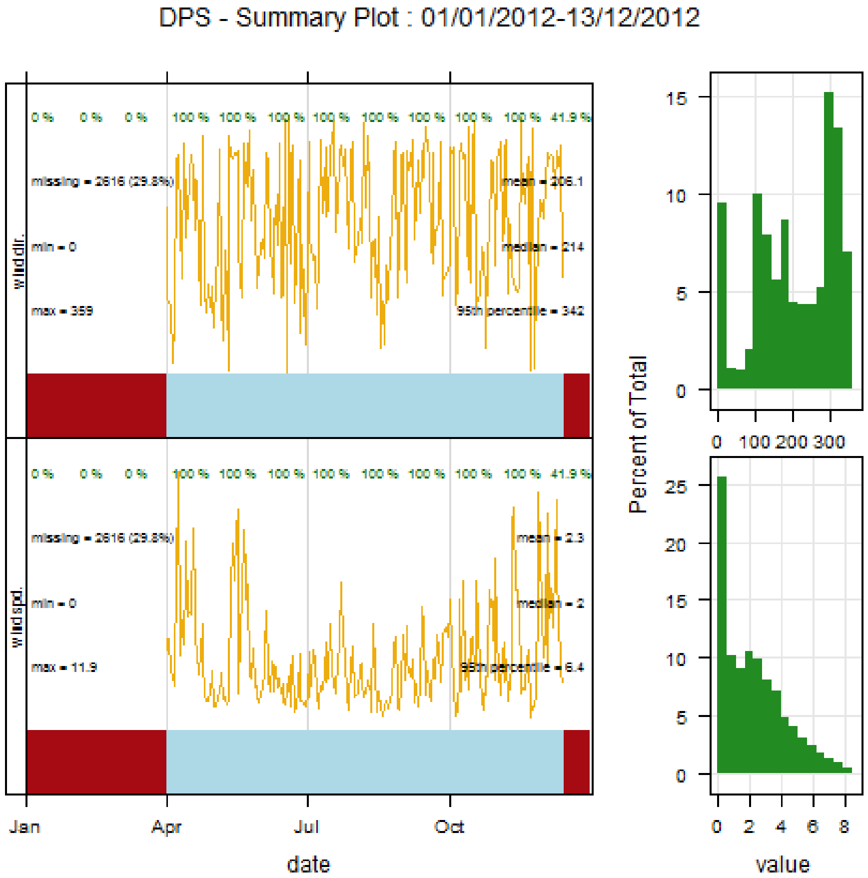


Figure 91: DPS wind baseline summary plot

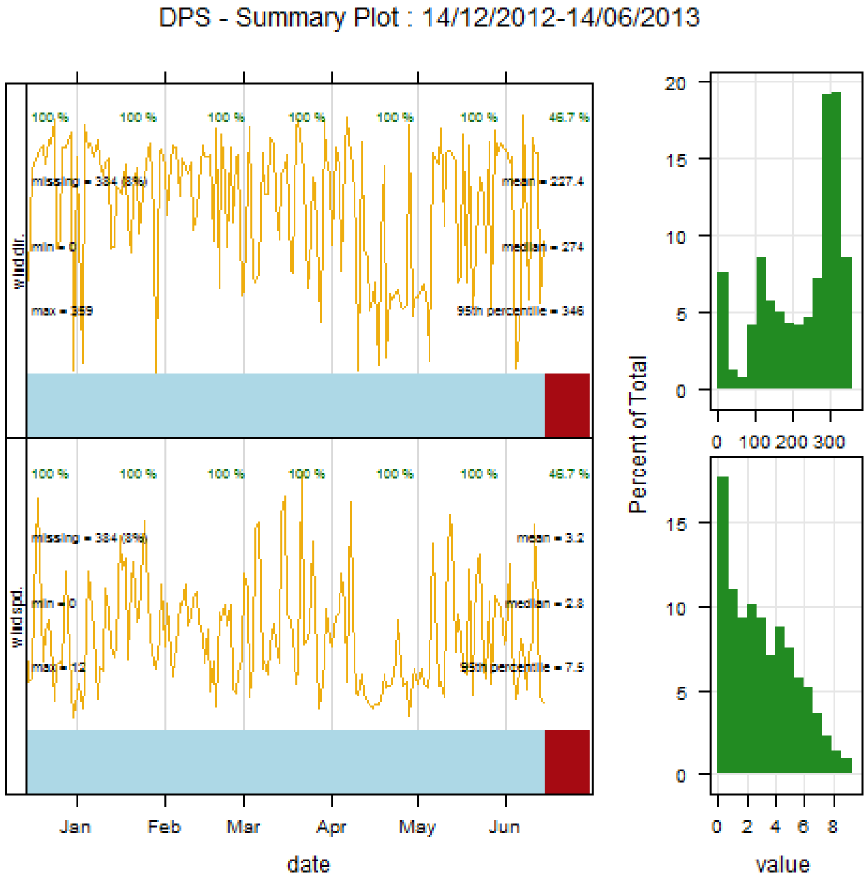


Figure 92: DPS wind post-commissioning summary plot

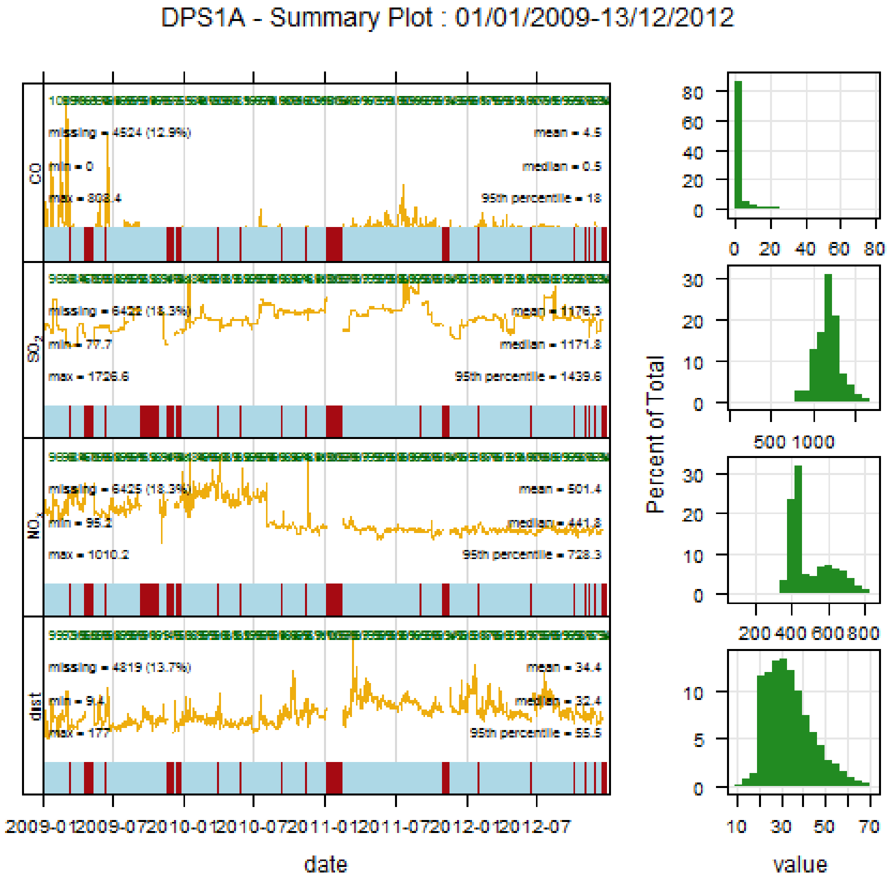


Figure 93: DPS1A baseline summary plot

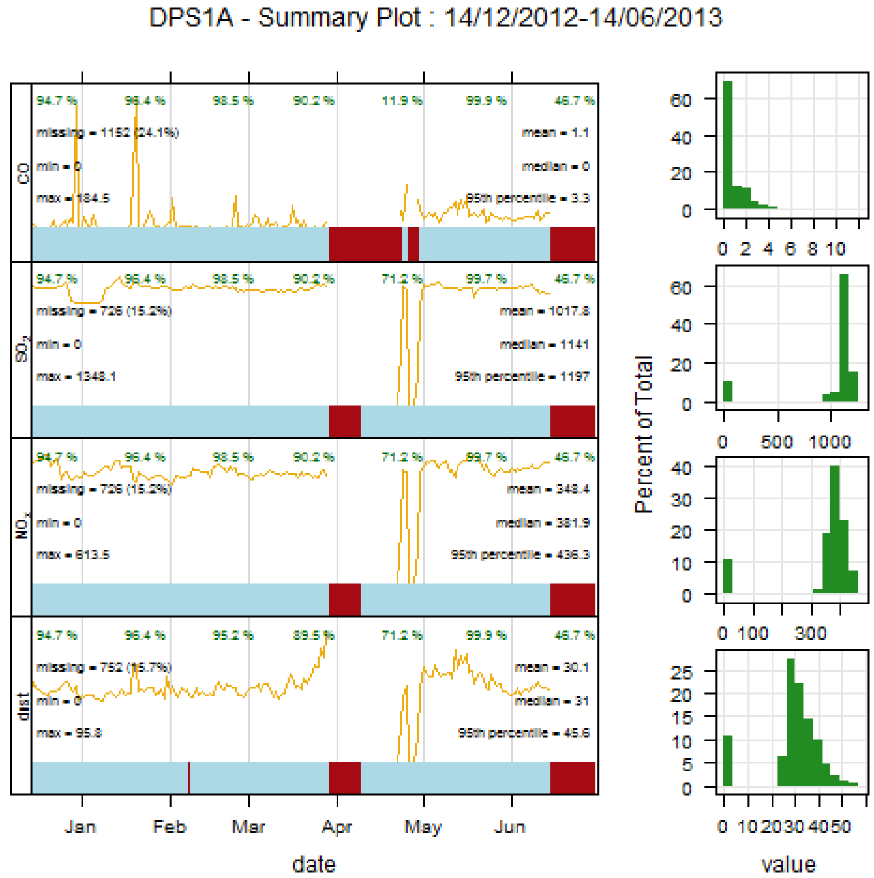


Figure 94: DPS1A post-commissioning summary plot

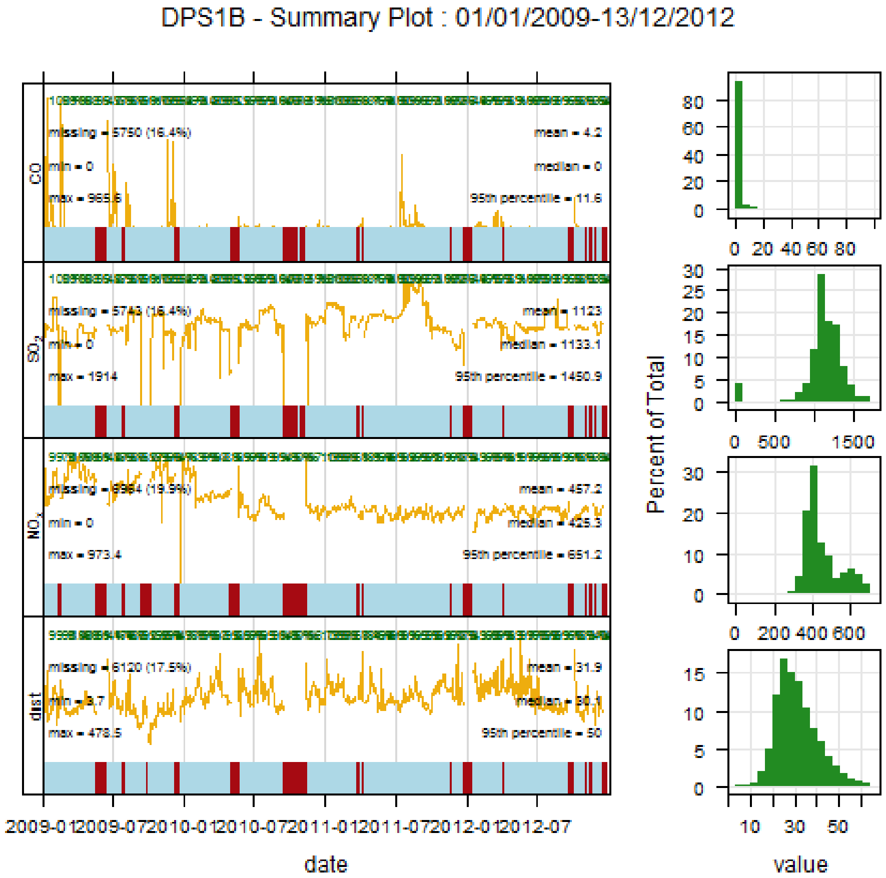


Figure 95: DPS1B baseline summary plot

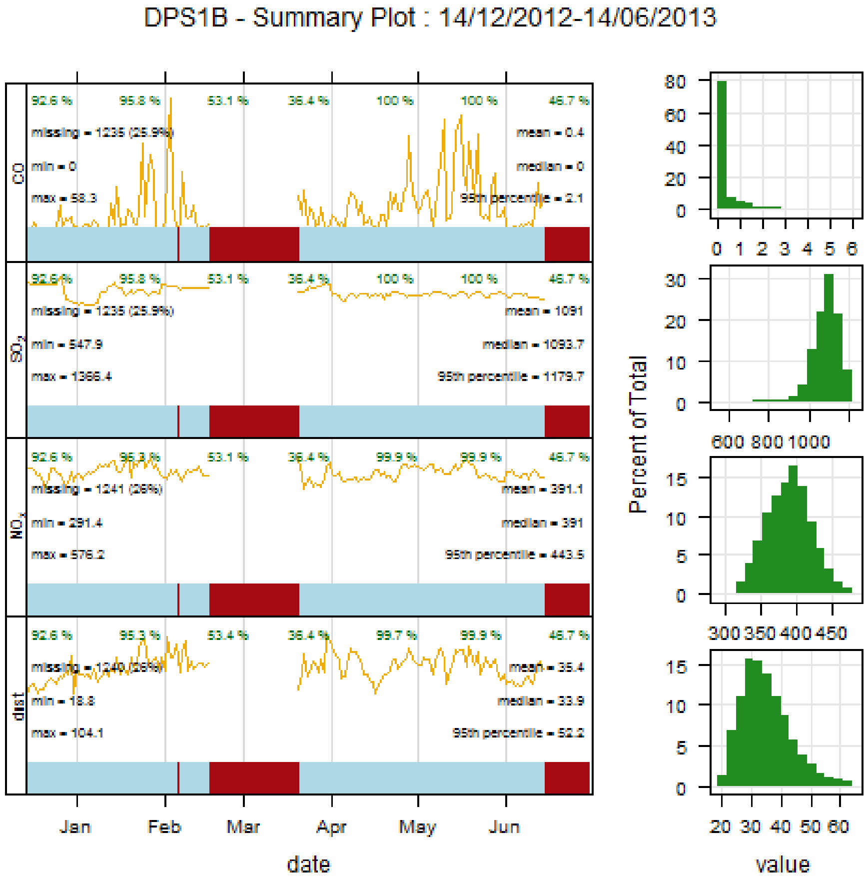


Figure 96: DPS1B post-commissioning summary plot

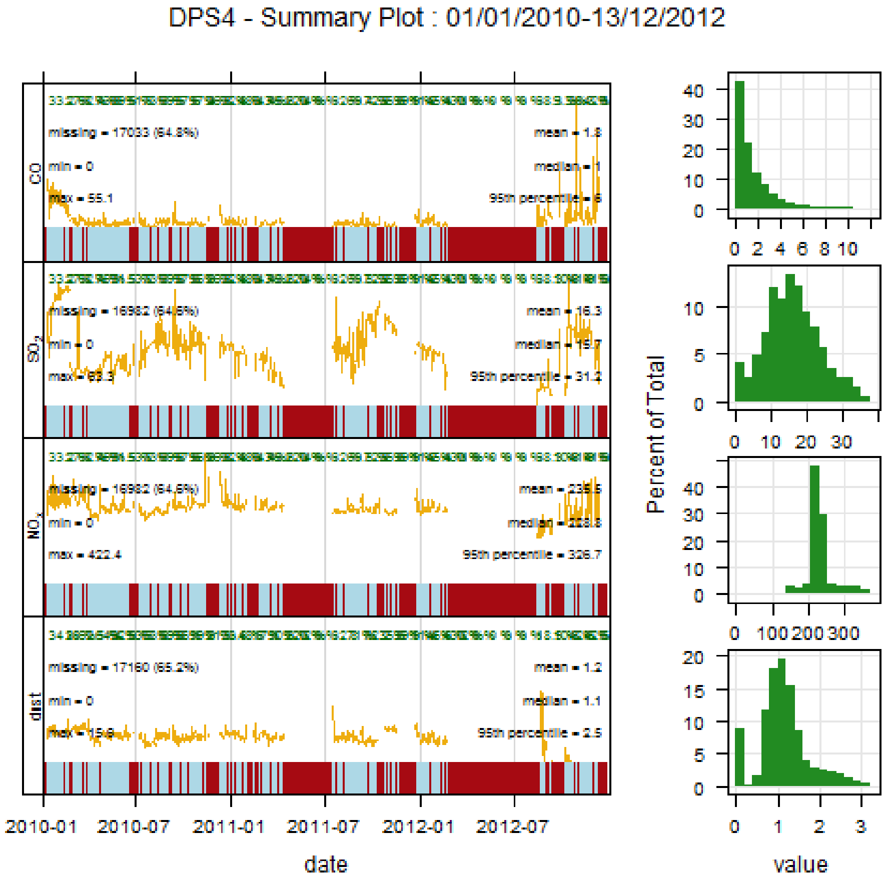


Figure 97: DPS4 baseline summary plot

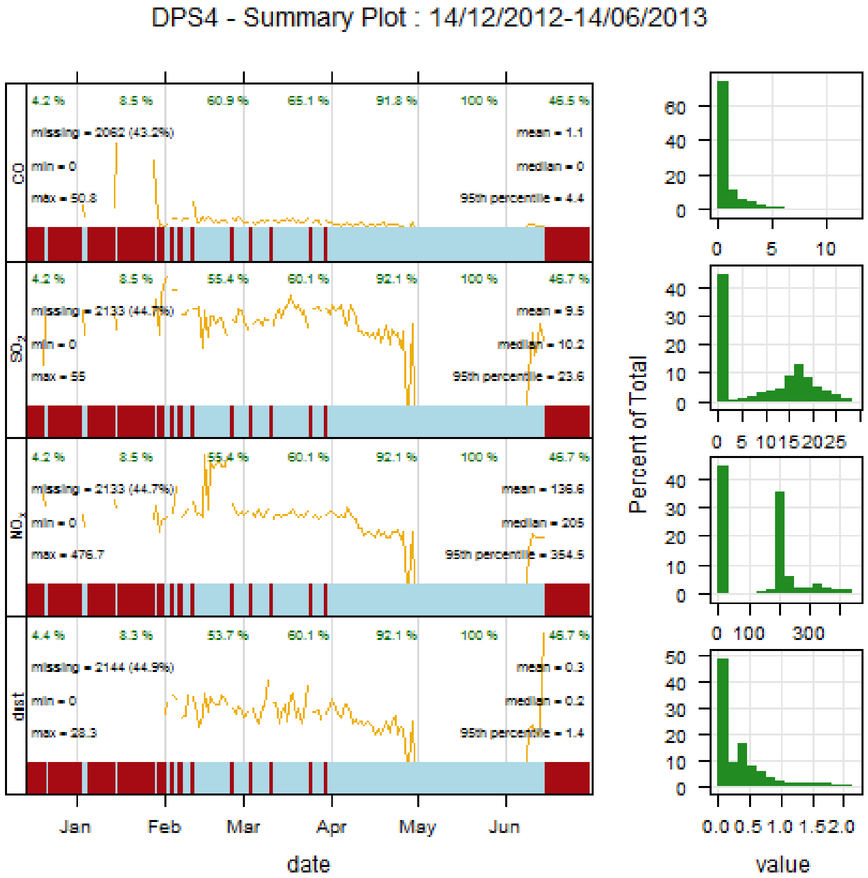


Figure 98: DPS4 post-commissioning summary plot

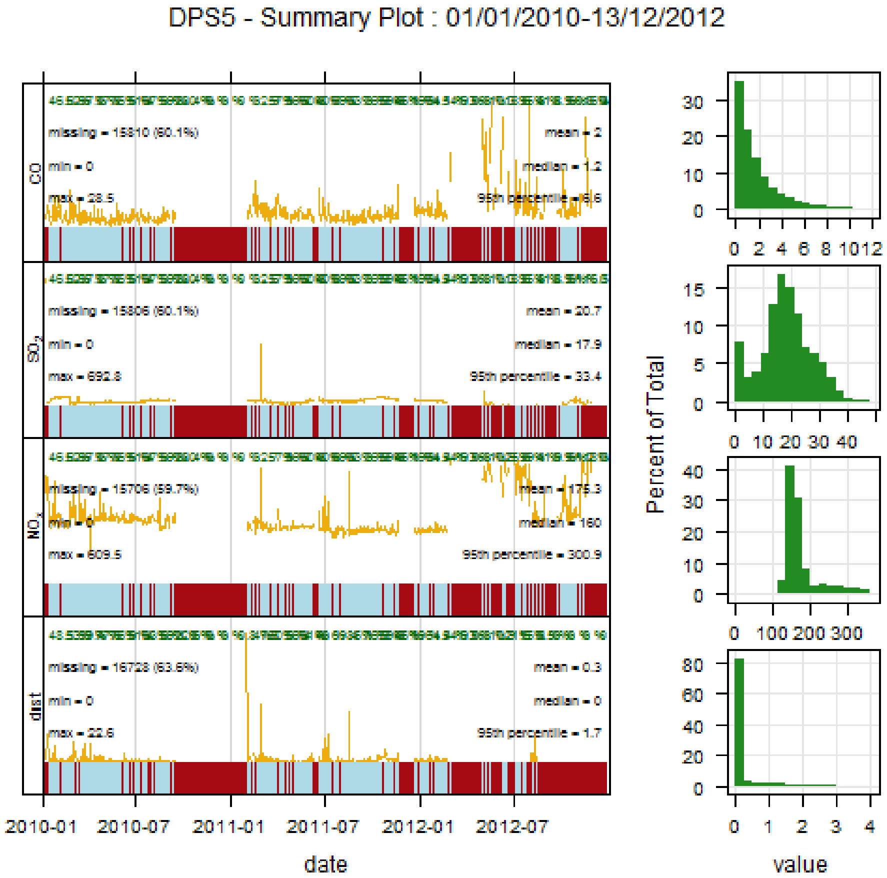


Figure 99: DPS5 baseline summary plot

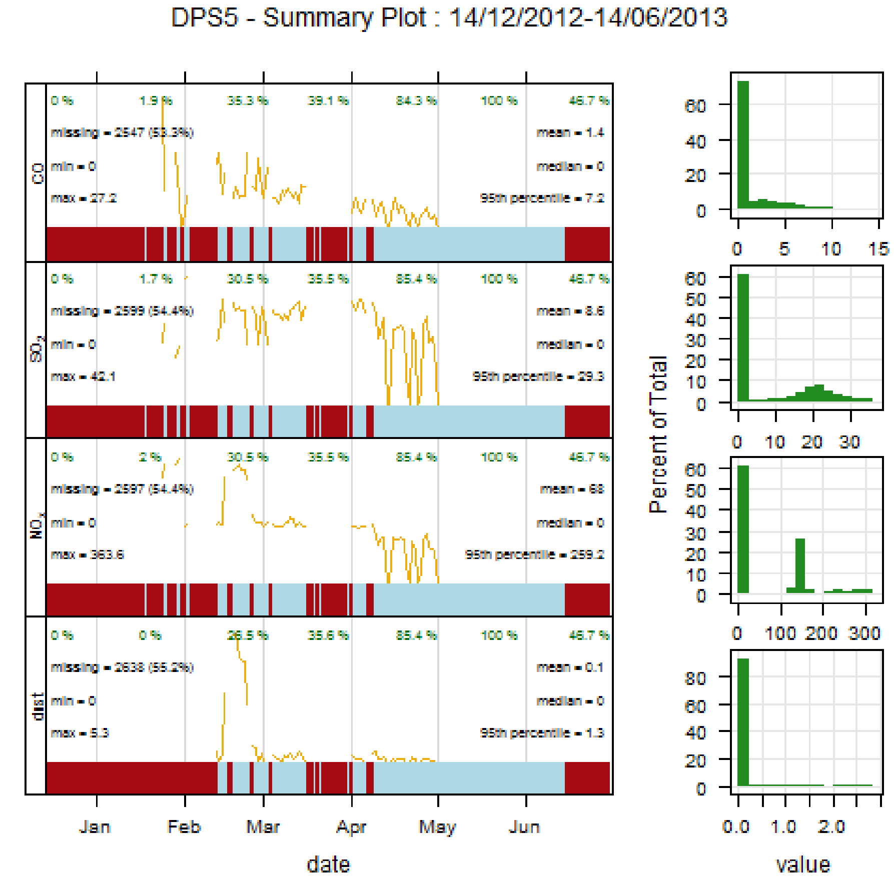


Figure 100: DPS5 post-commissioning summary plot

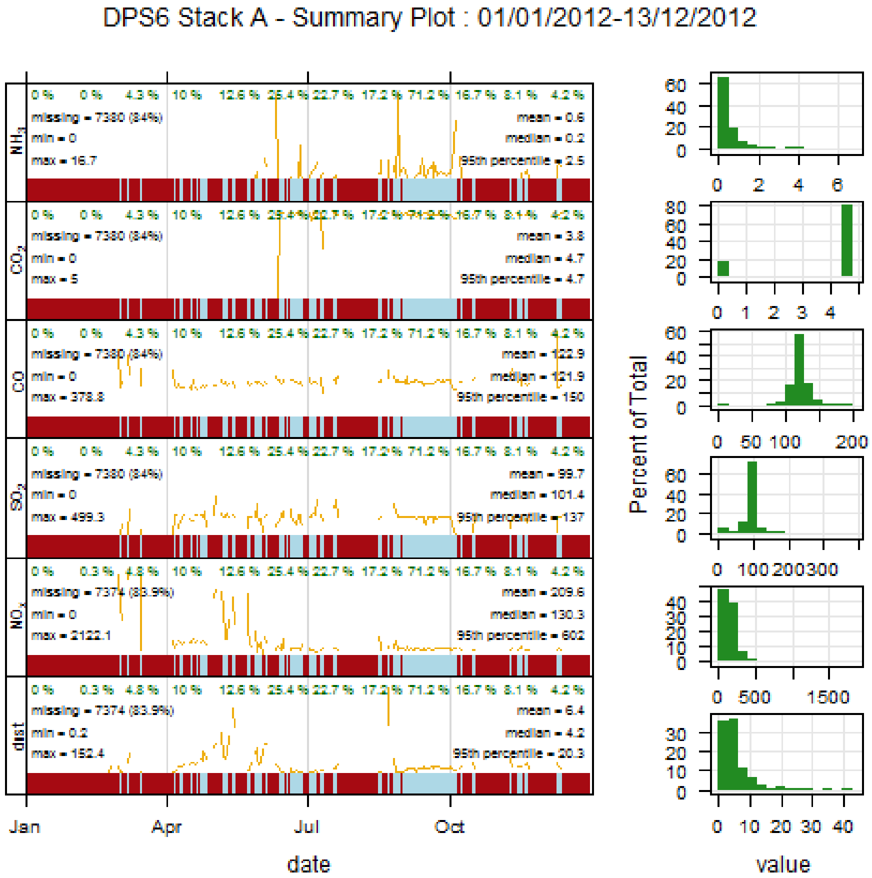


Figure 101: DPS6A baseline summary plot

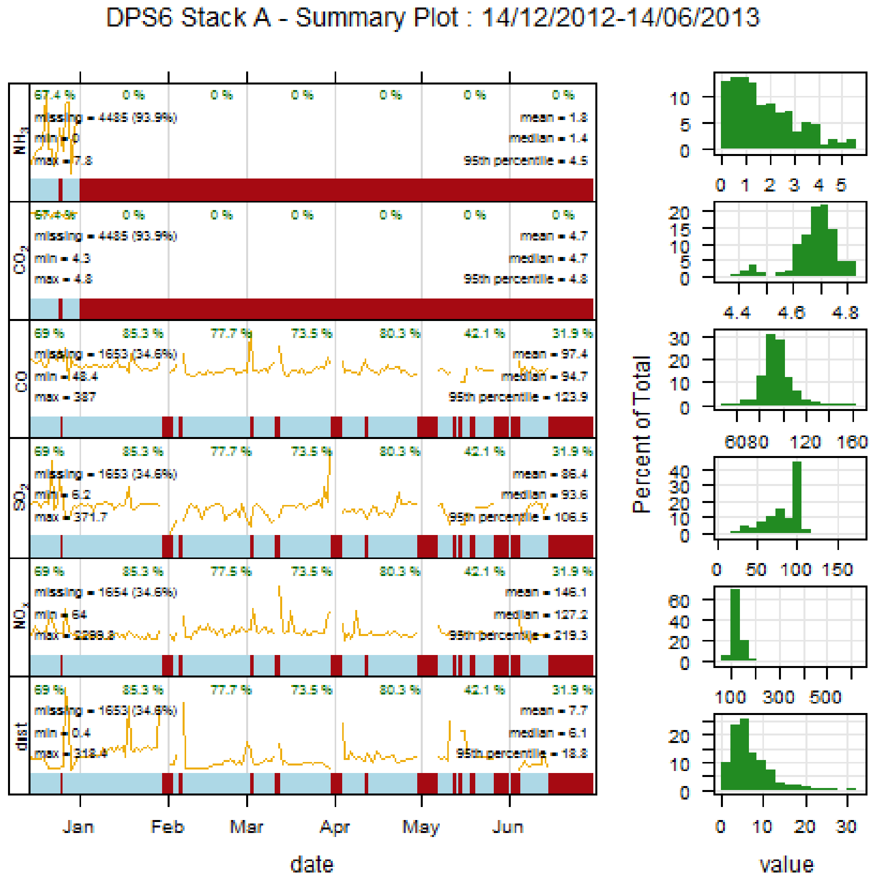


Figure 102: DPS6A post-commissioning summary plot

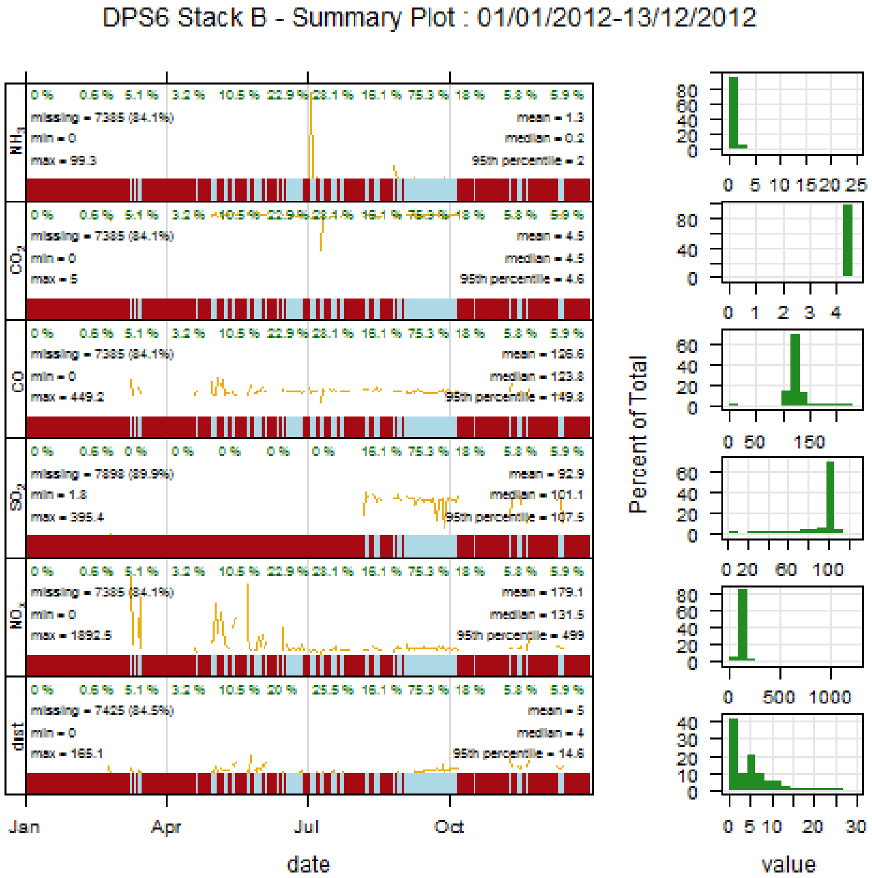


Figure 103: DPS6B baseline summary plot

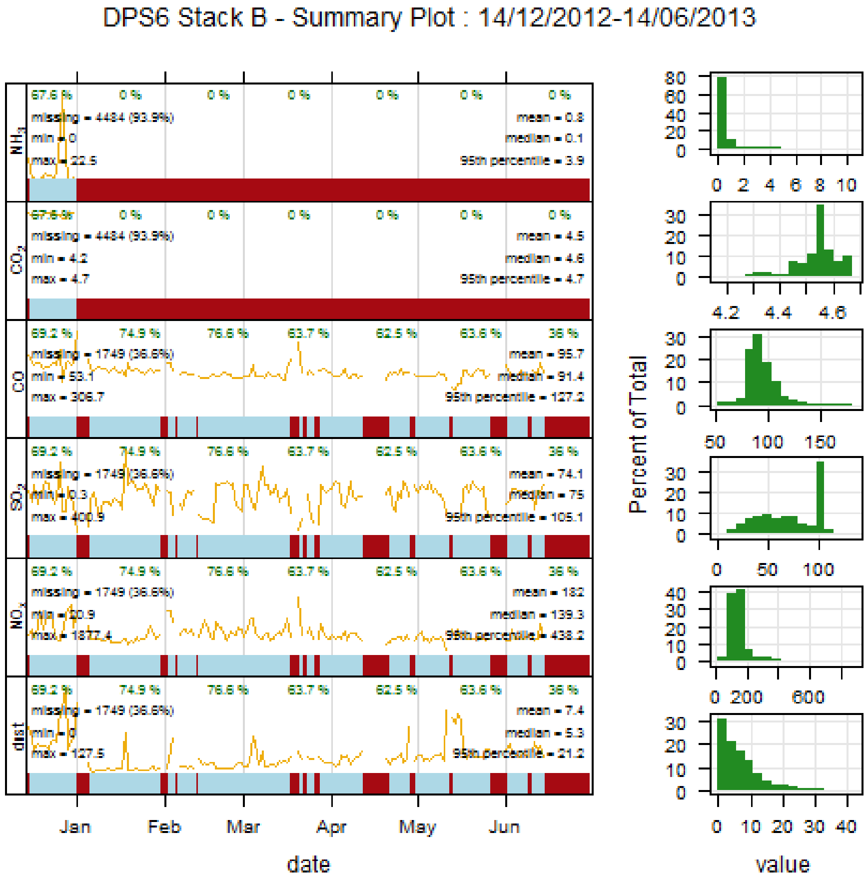


Figure 104: DPS6B post-commissioning summary plot

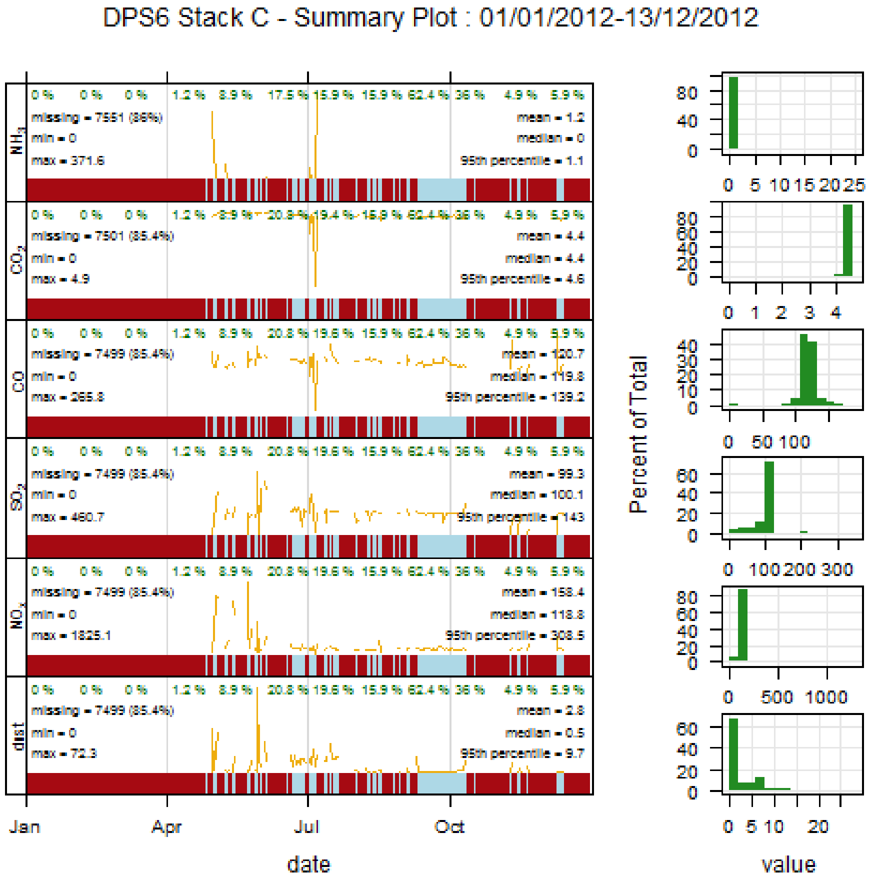


Figure 105: DPS6C baseline summary plot

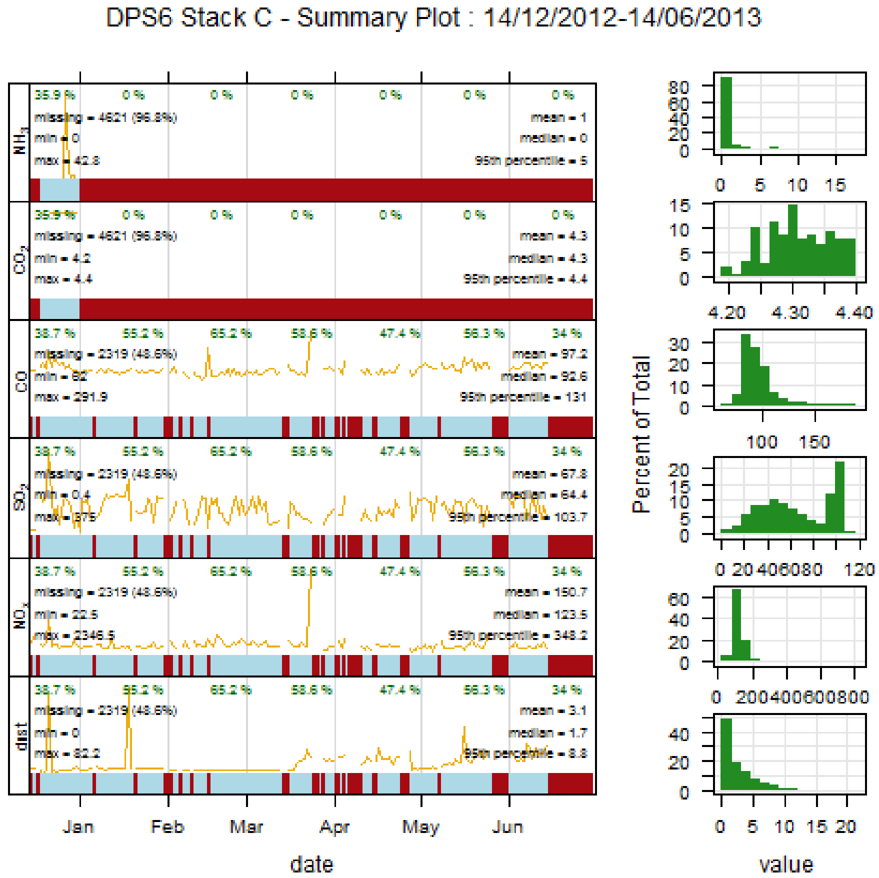


Figure 106: DPS6C post-commissioning summary plot

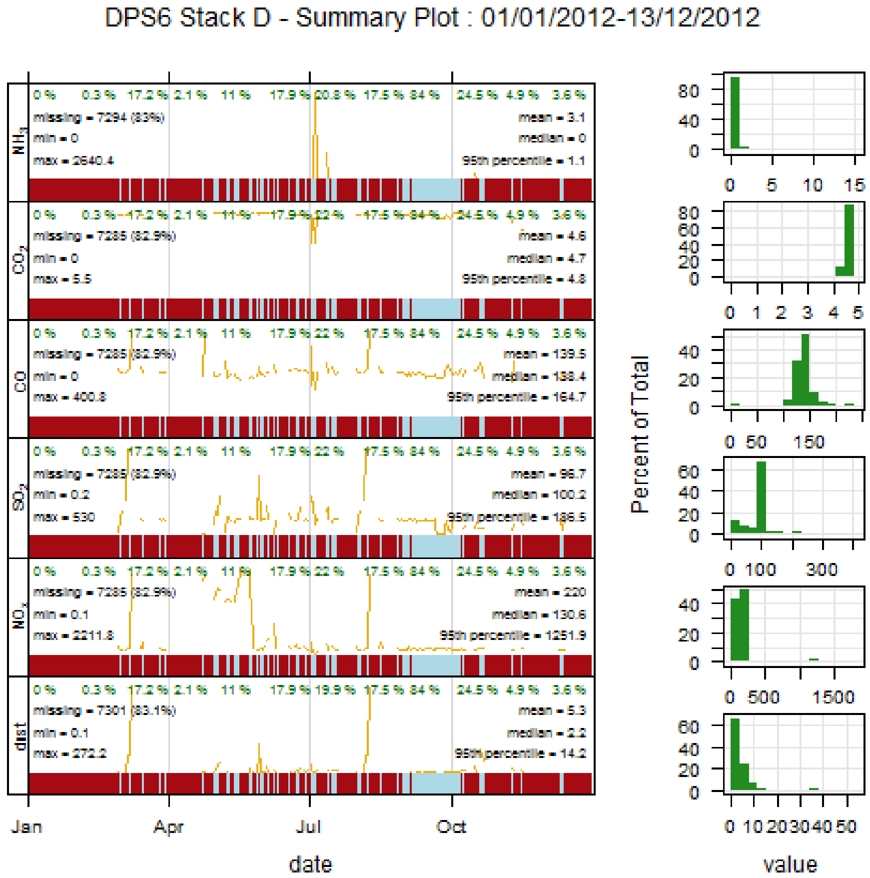


Figure 107: DPS6D baseline summary plot

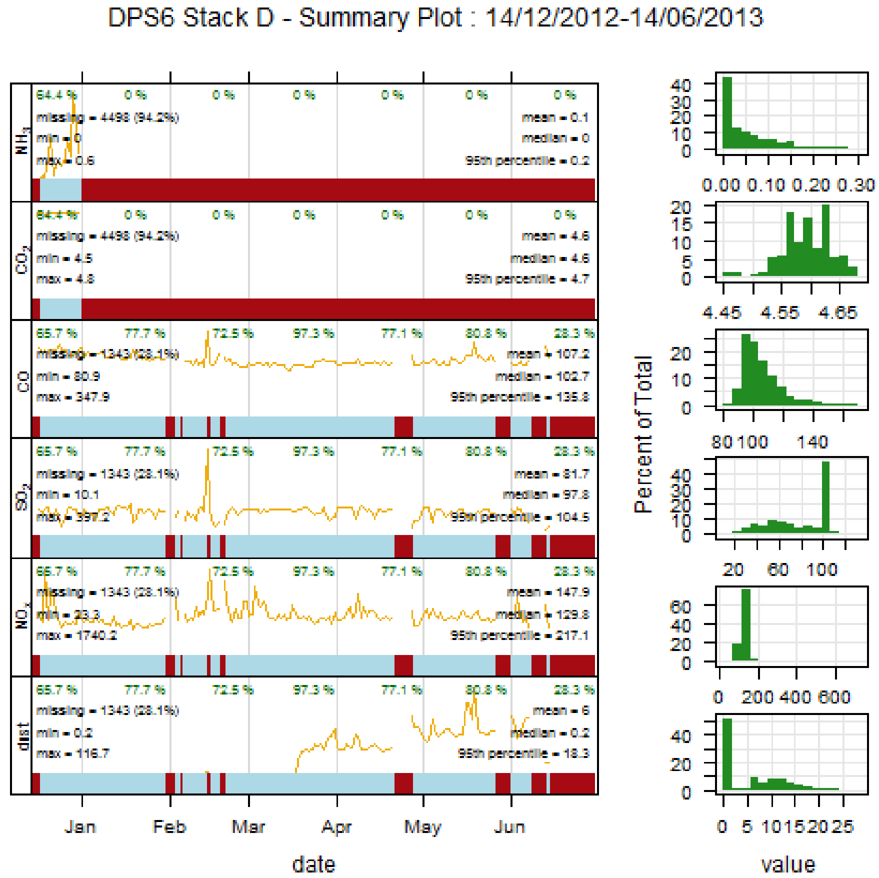


Figure 108: DPS6D post-commissioning summary plot

Appendix C: Time plots

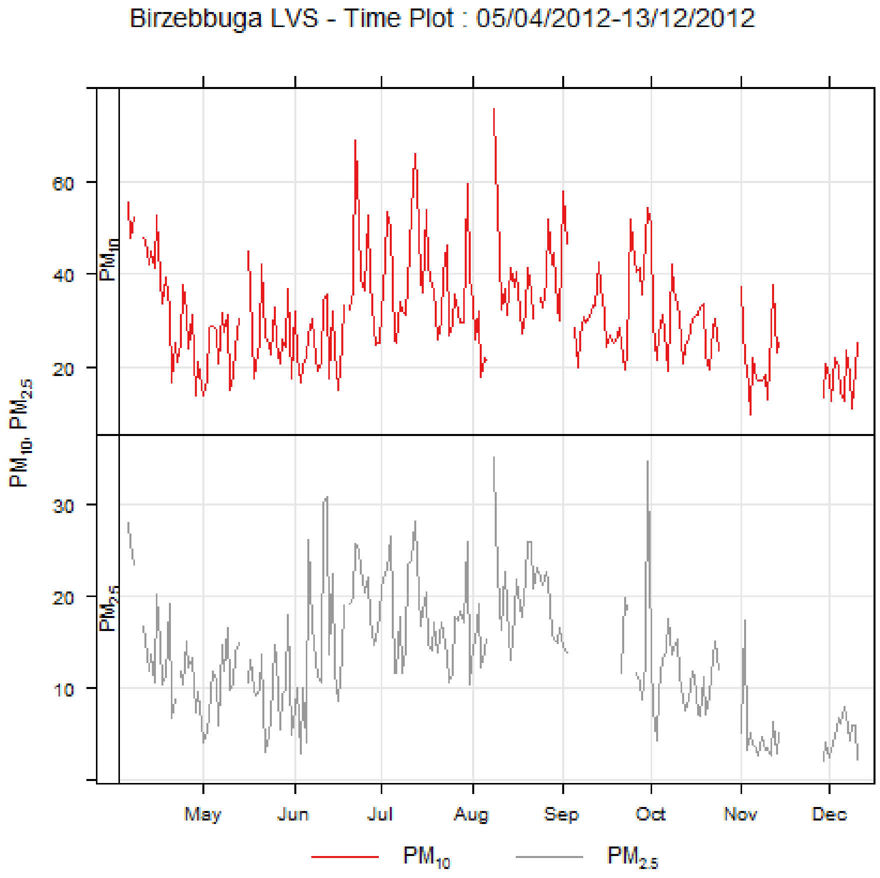


Figure 109: Birzebbuga LVS baseline time plot

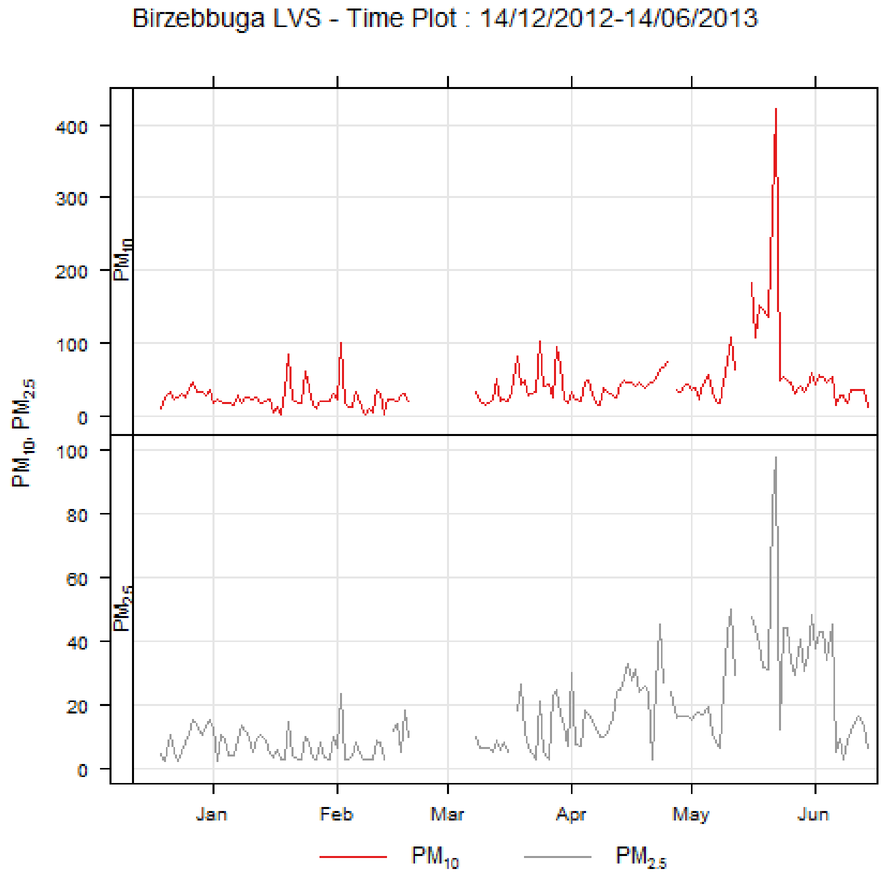


Figure 110: Birzebbuga LVS post-commission time plot

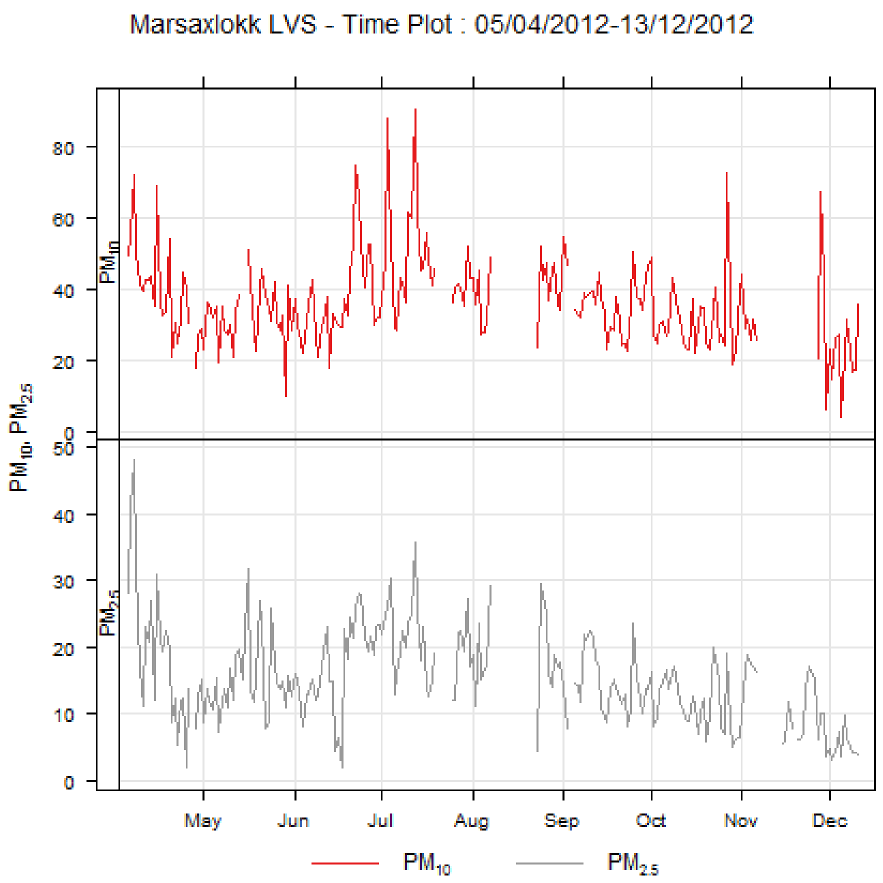


Figure 111: Marsaxlokk LVS baseline time plot

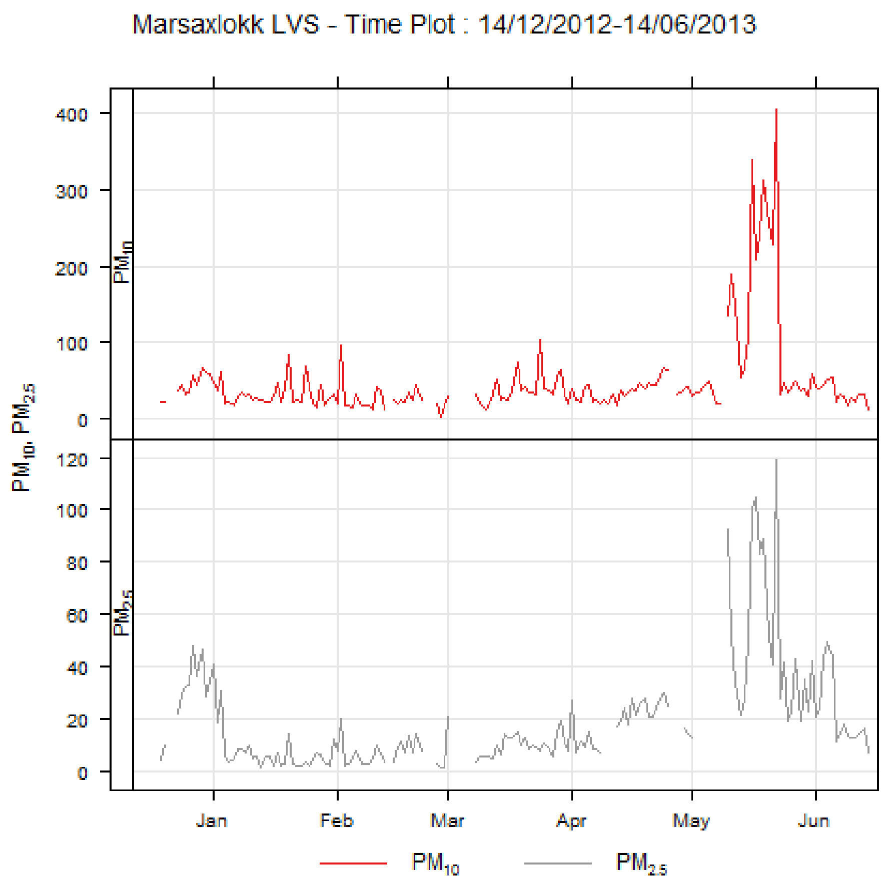


Figure 112: Marsaxlokk LVS post-commissioning time plot

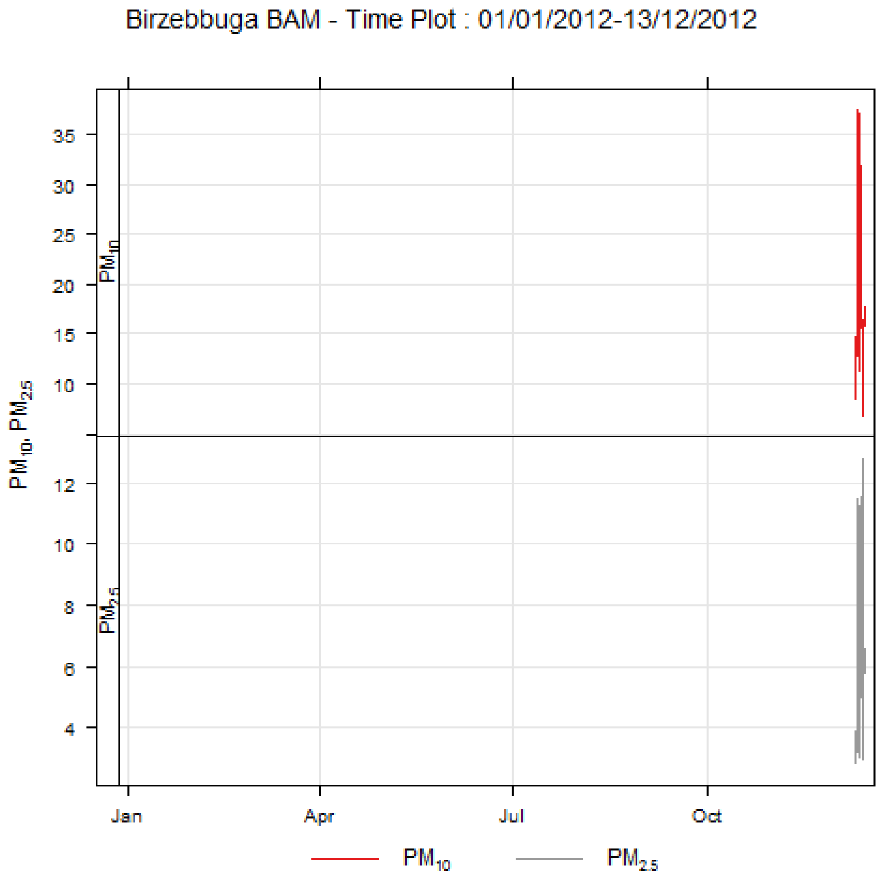


Figure 113: Birzebbuga BAM baseline time plot

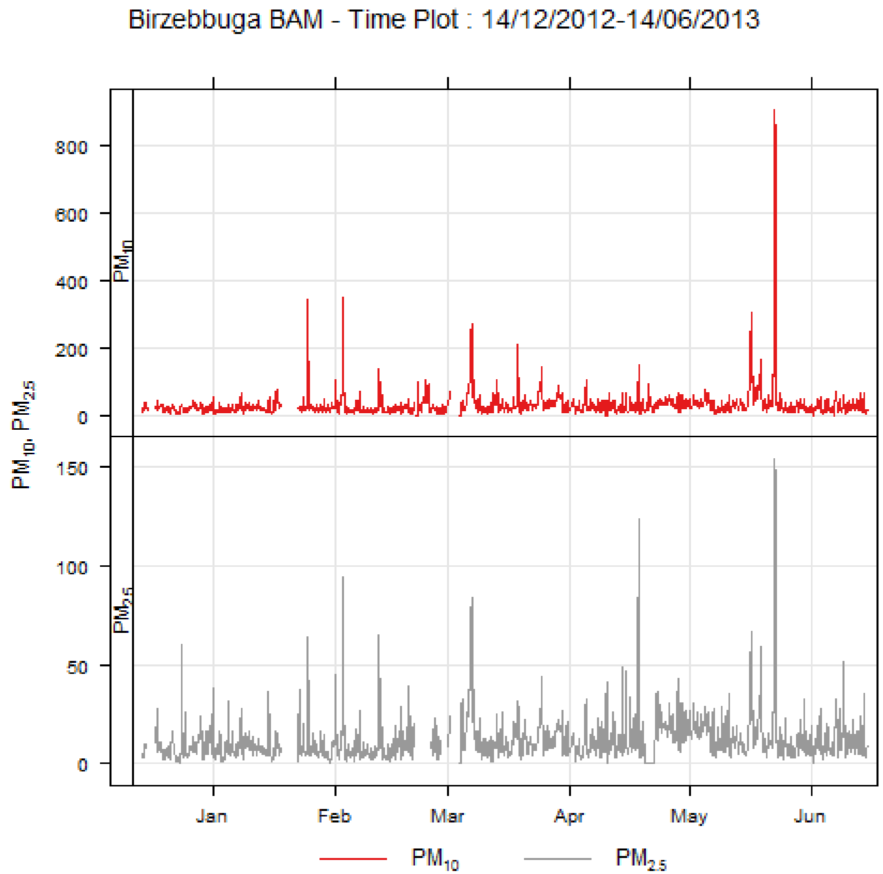


Figure 114: Birzebbuga BAM post-commissioning time plot

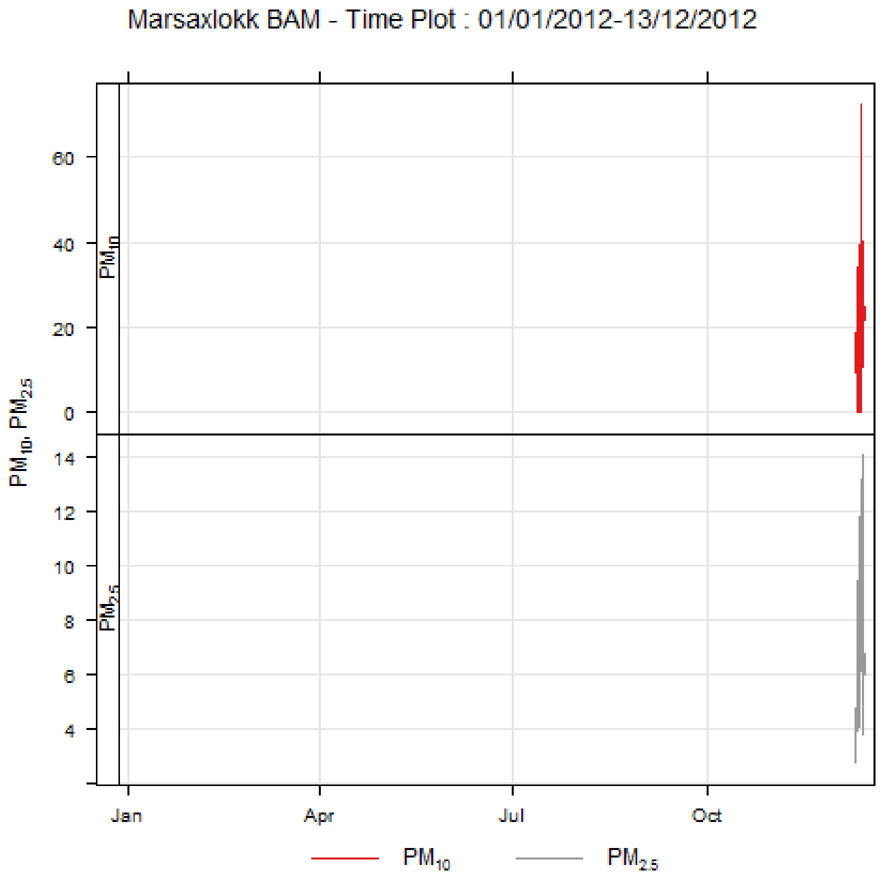


Figure 115: Marsaxlokk BAM baseline time plot

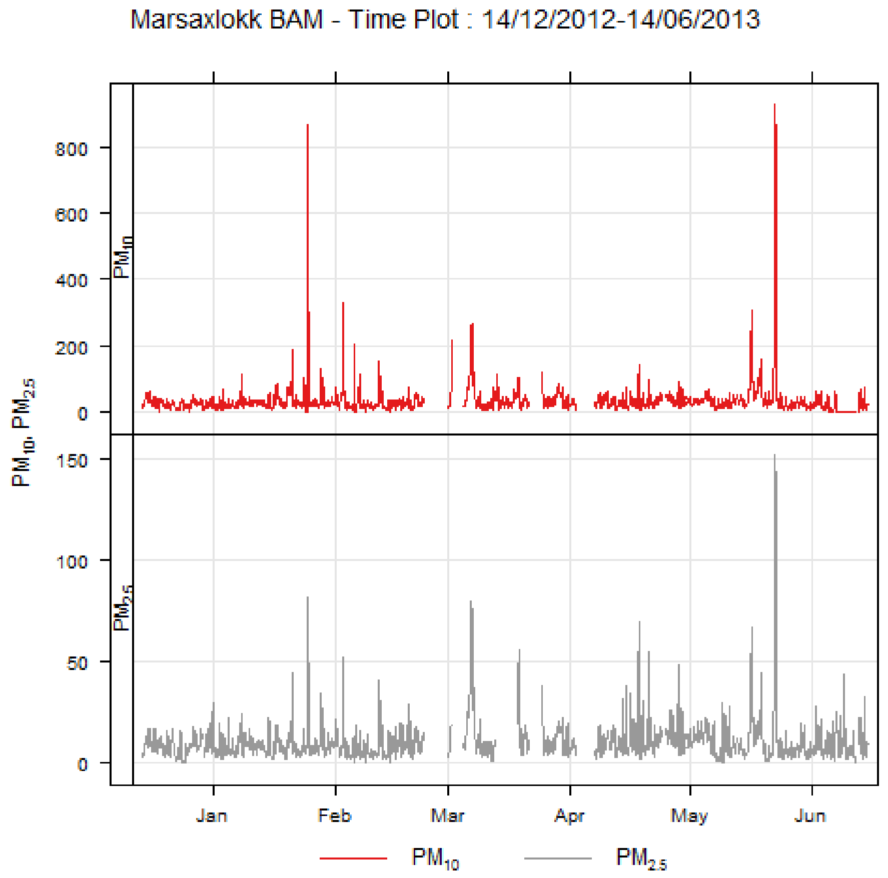


Figure 116: Marsaxlokk BAM post-commissioning time plot

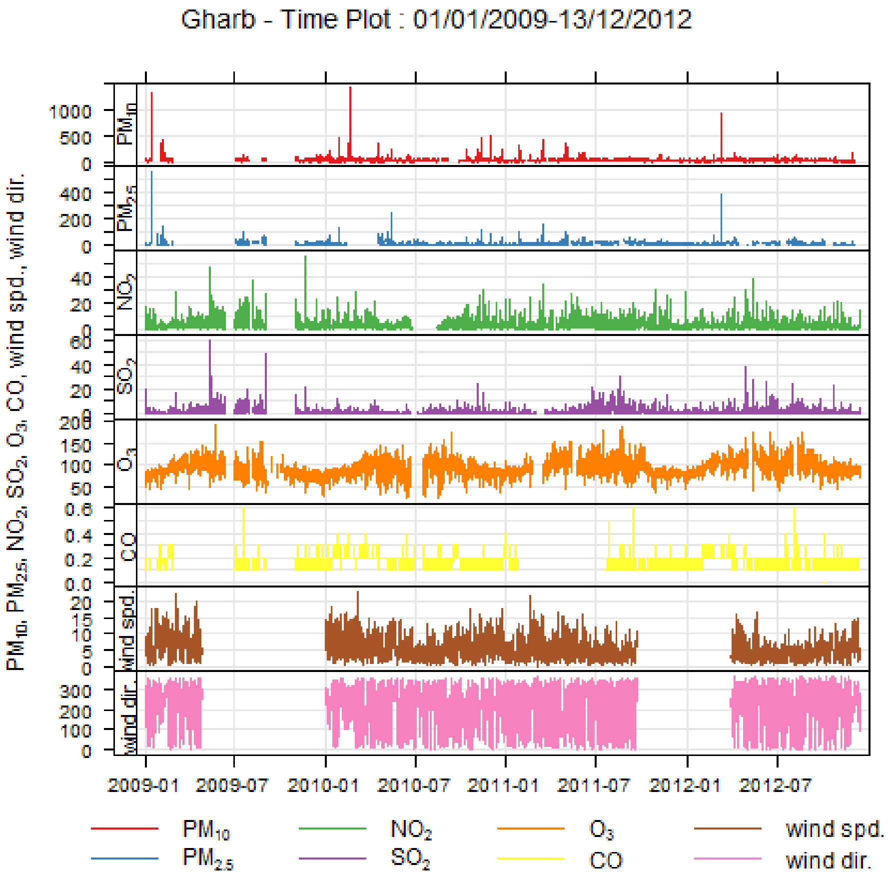


Figure 117: Gharb baseline time plot

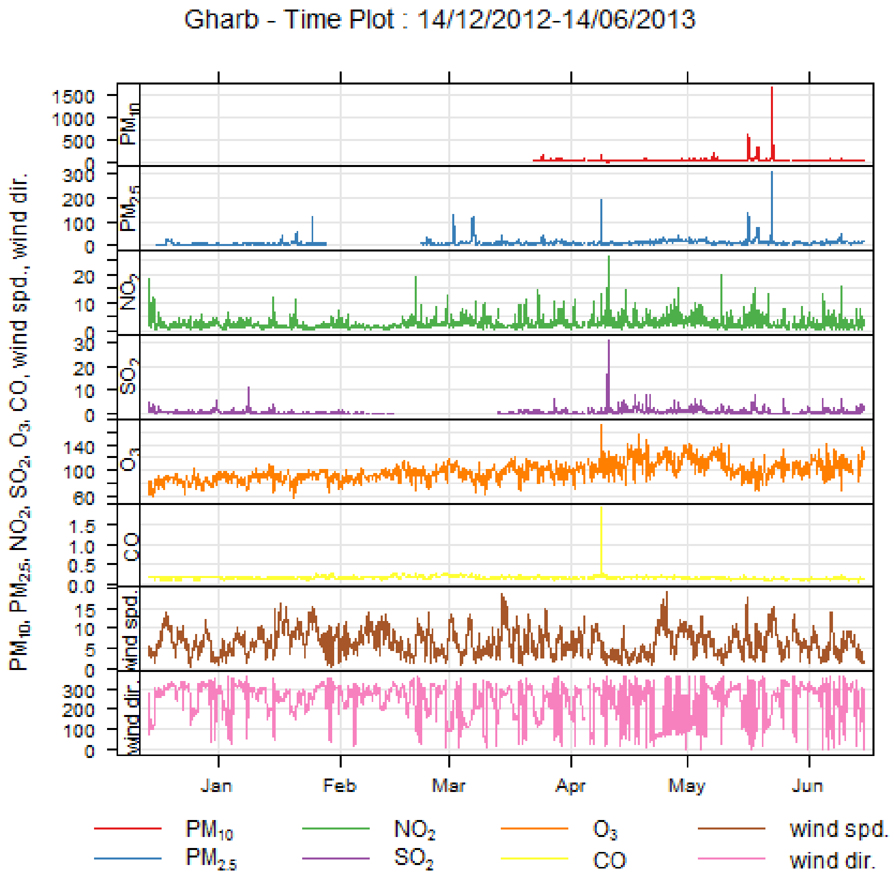


Figure 118: Gharb post-commissioning time plot

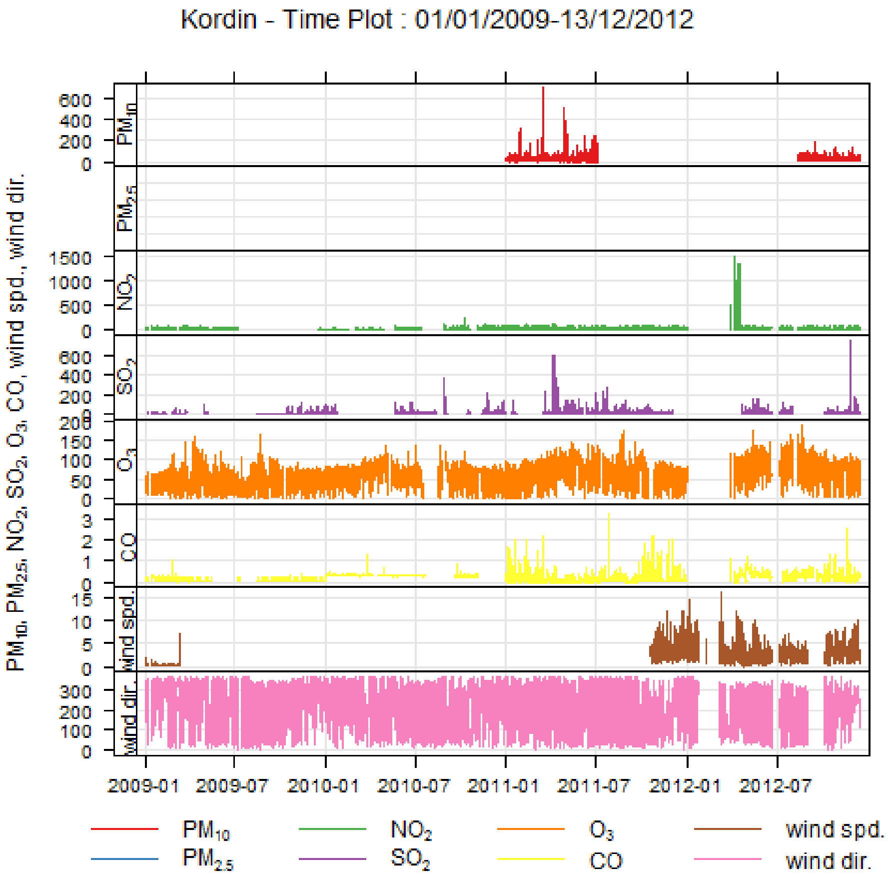


Figure 119: Kordin baseline time plot

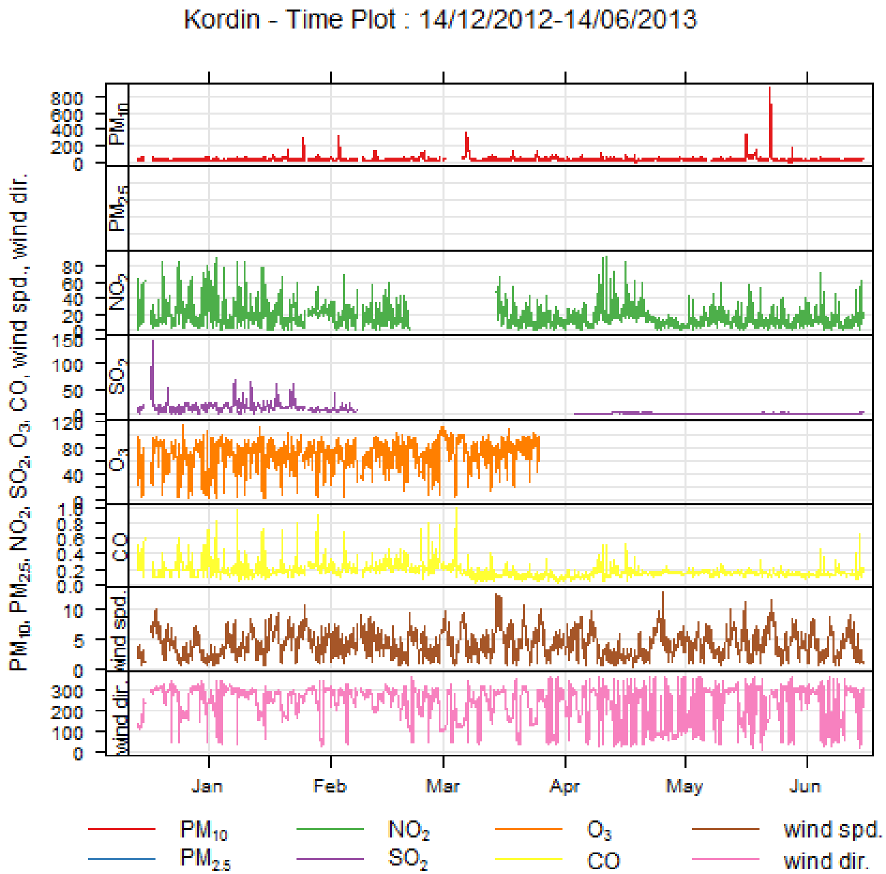


Figure 120: Kordin post-commissioning time plot

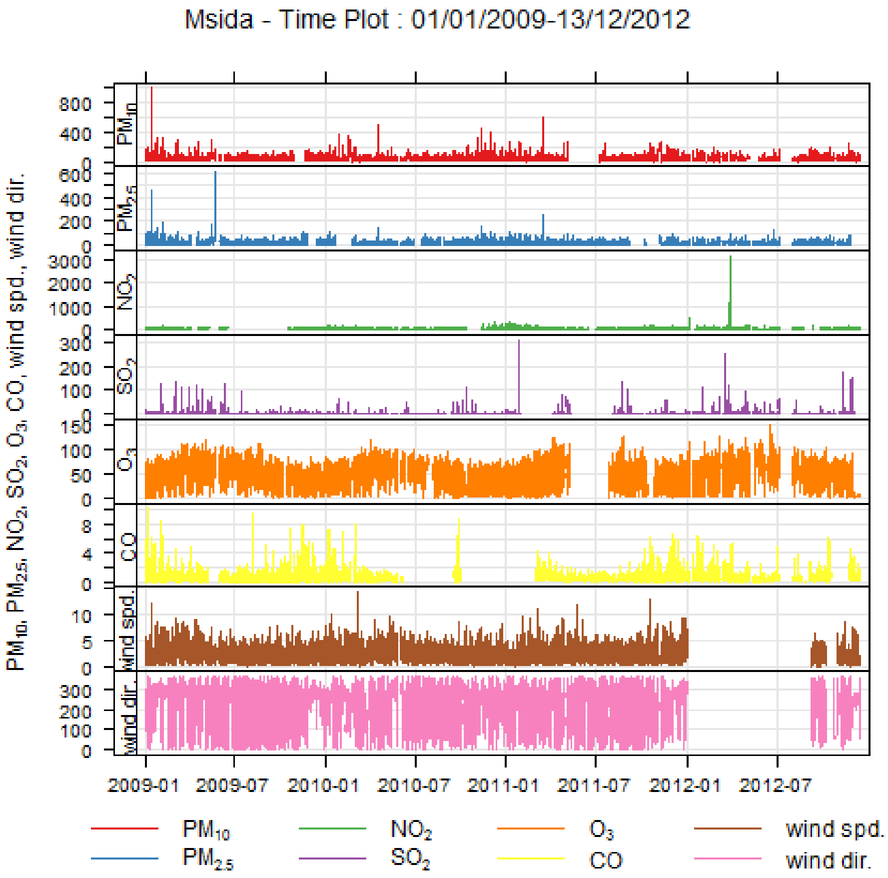


Figure 121: Msida baseline time plot

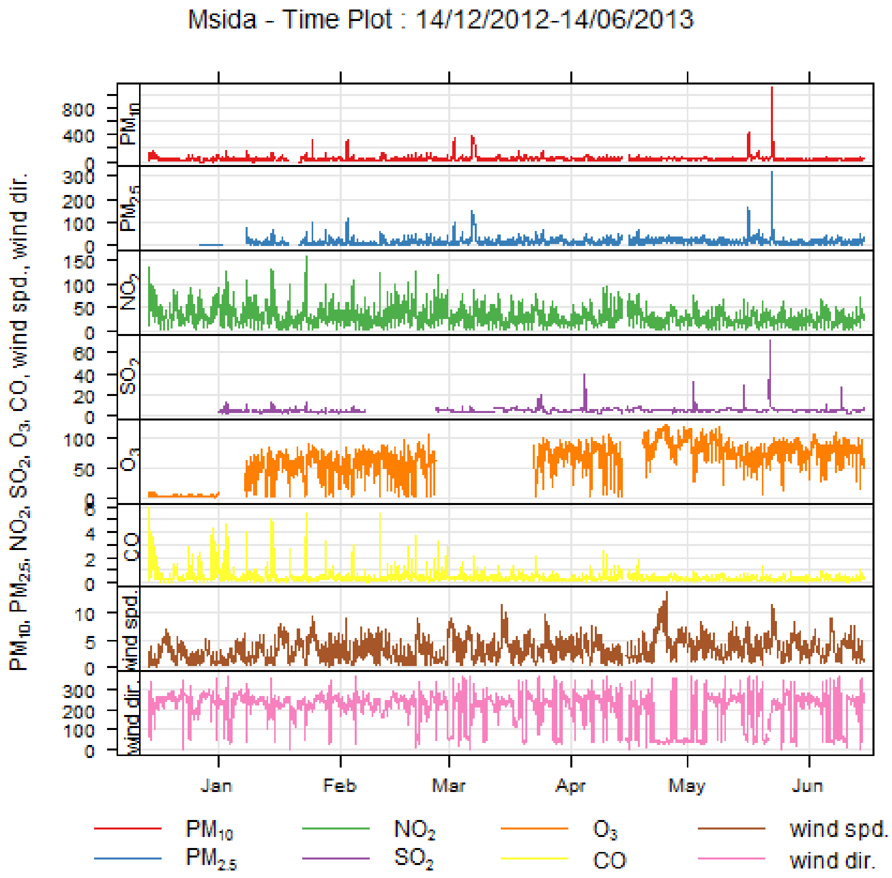


Figure 122: Msida post-commissioning time plot

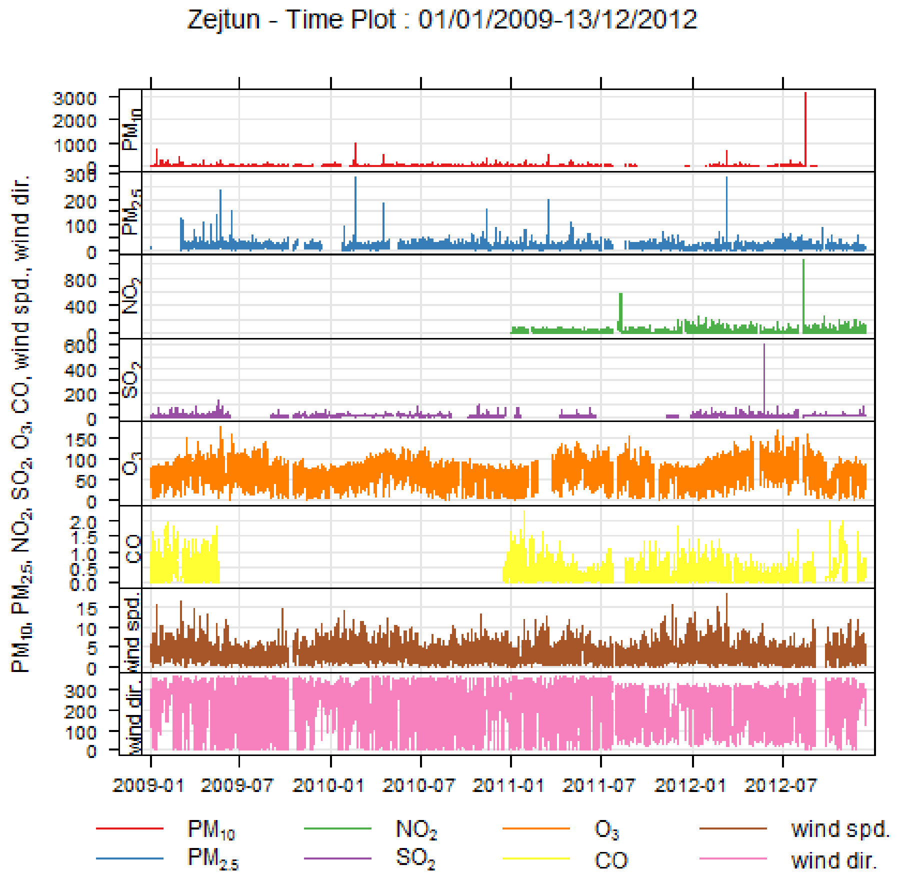


Figure 123: Zejtun baseline time plot

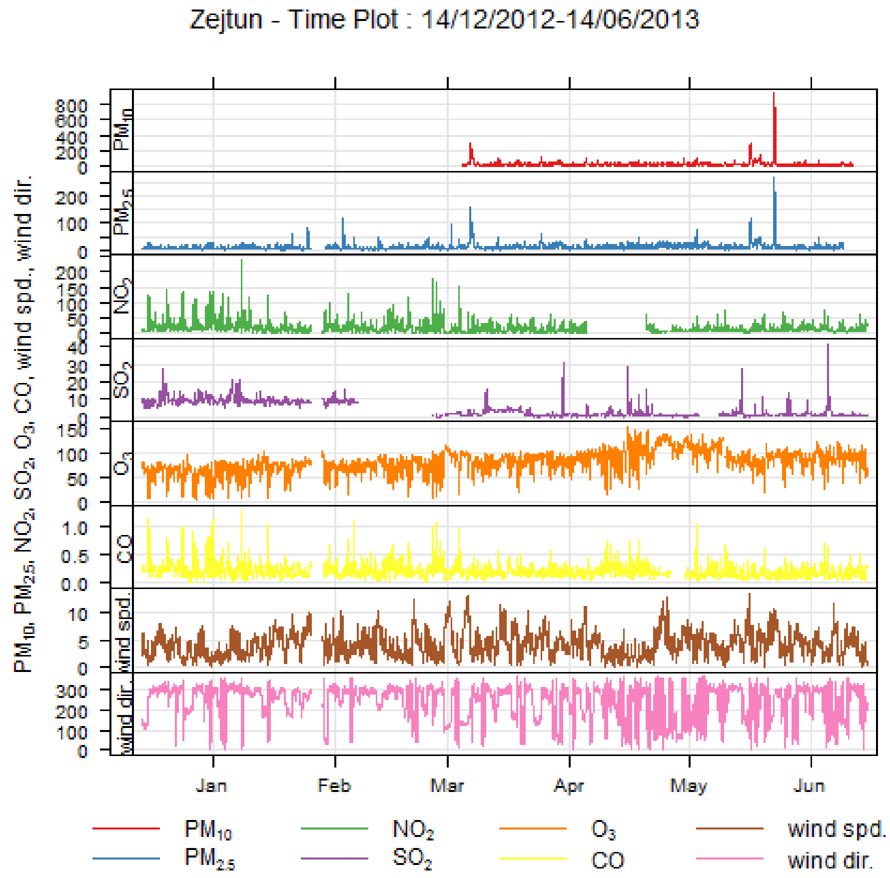


Figure 124: Zejtun post-commissioning time plot

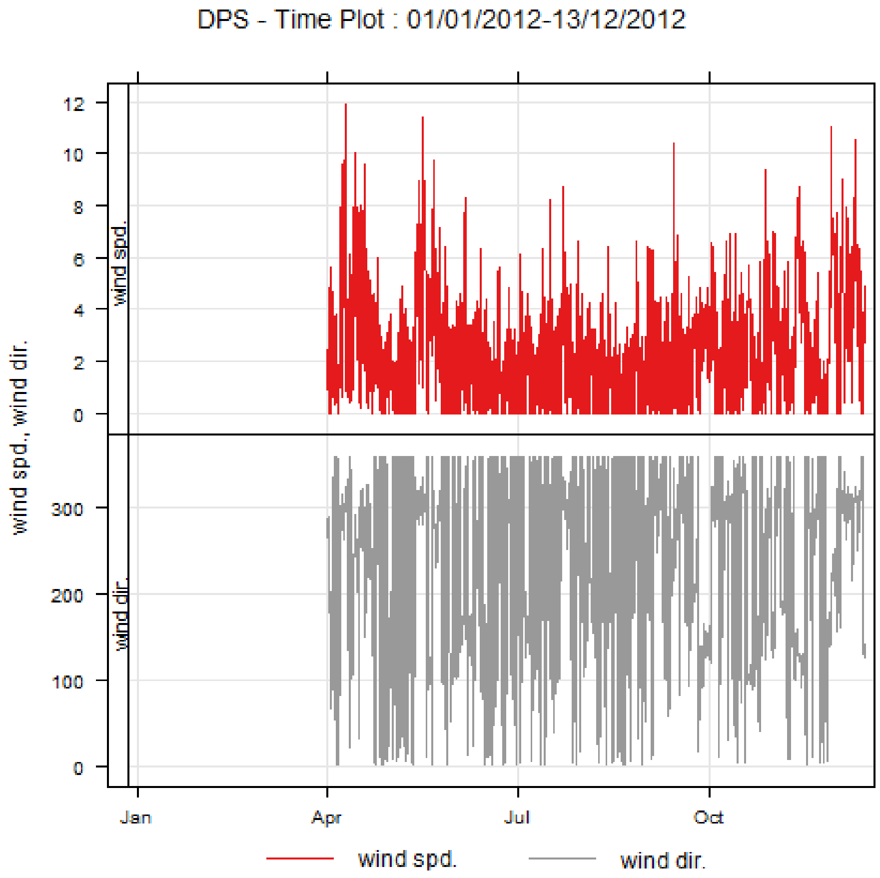


Figure 125: DPS wind baseline time plot

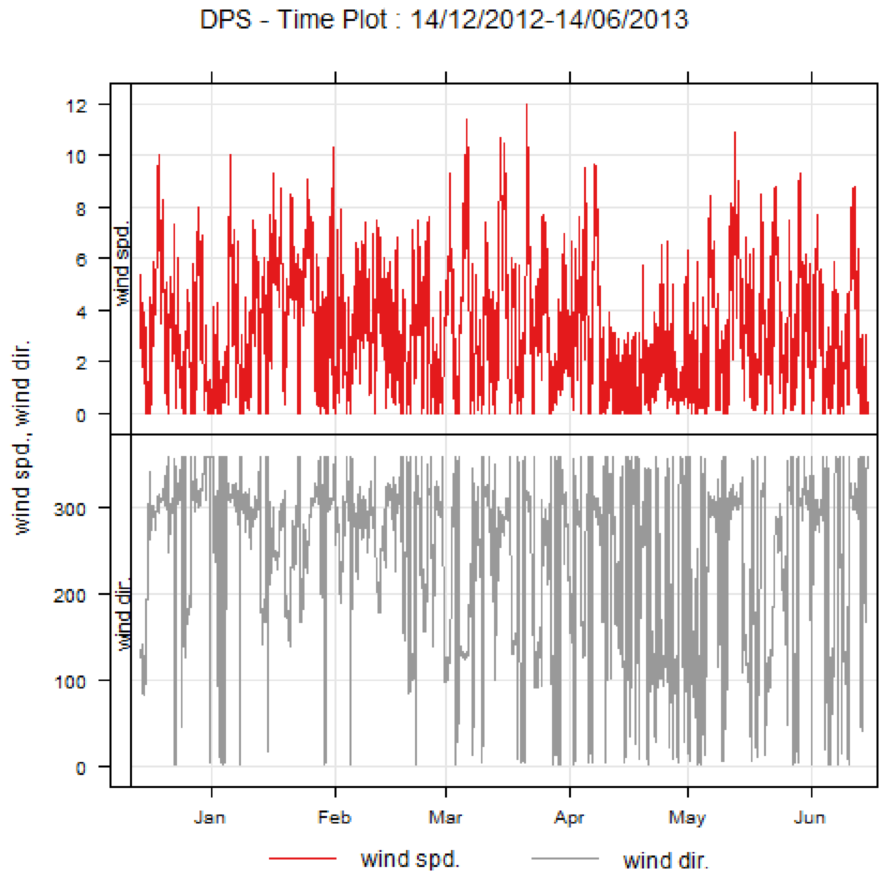


Figure 126: DPS wind post-commissioning time plot

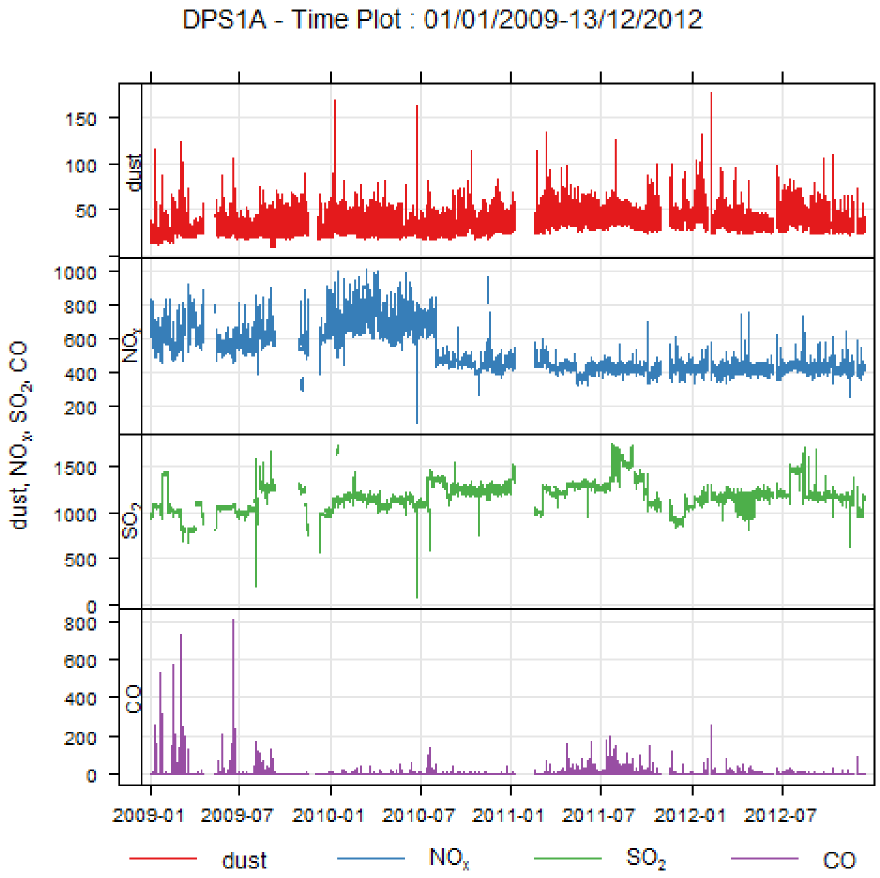


Figure 127: DPS1A baseline time plot

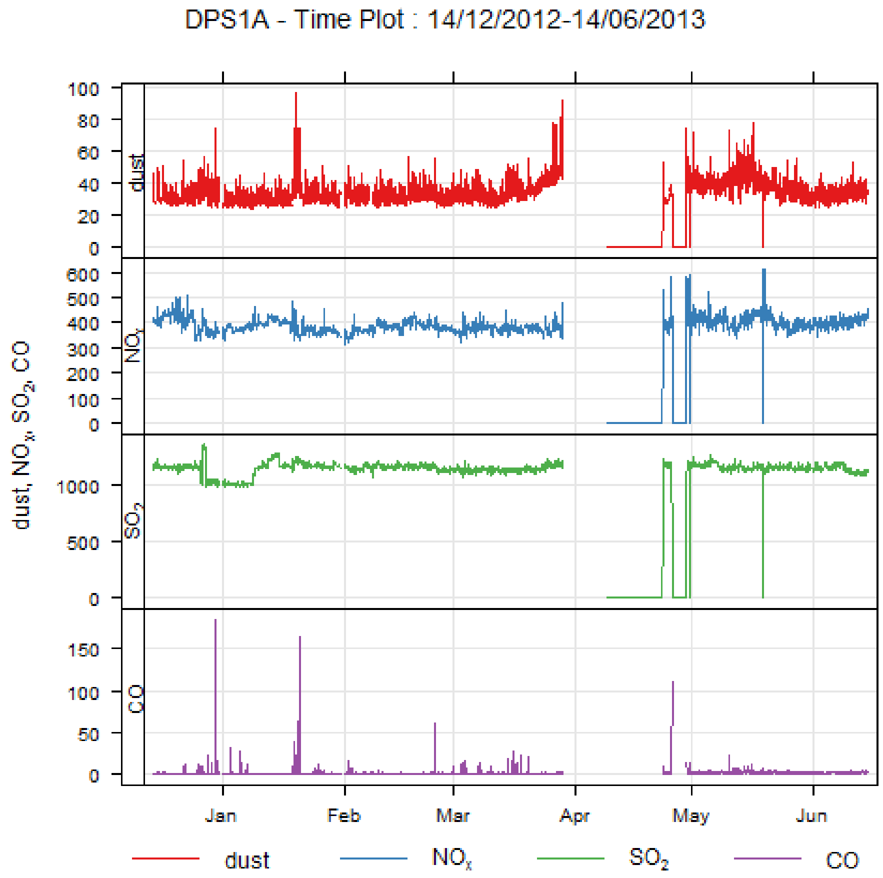


Figure 128: DPS1A post-commissioning time plot

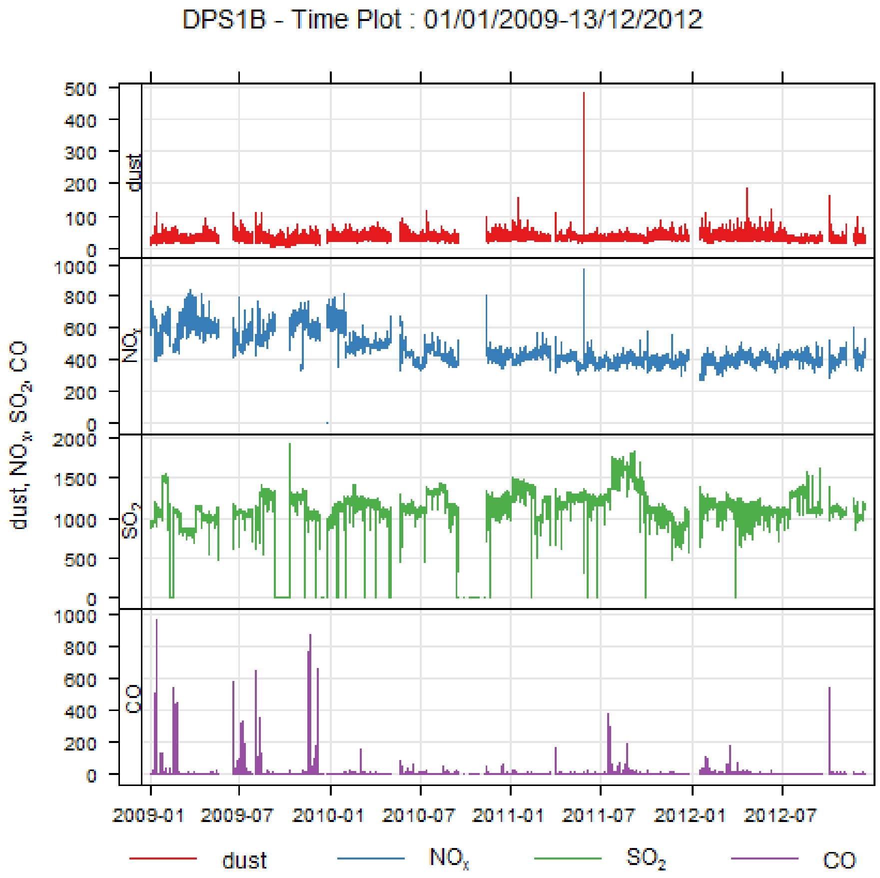


Figure 129: DPS1B baseline time plot

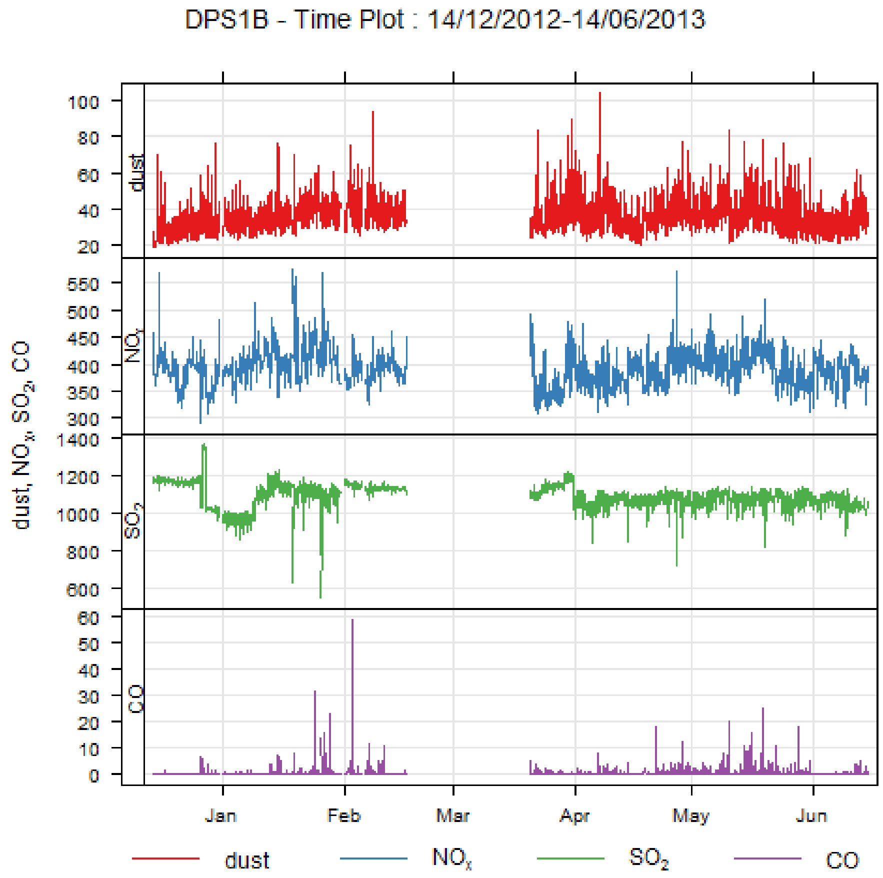


Figure 130: DPS1B post-commissioning time plot

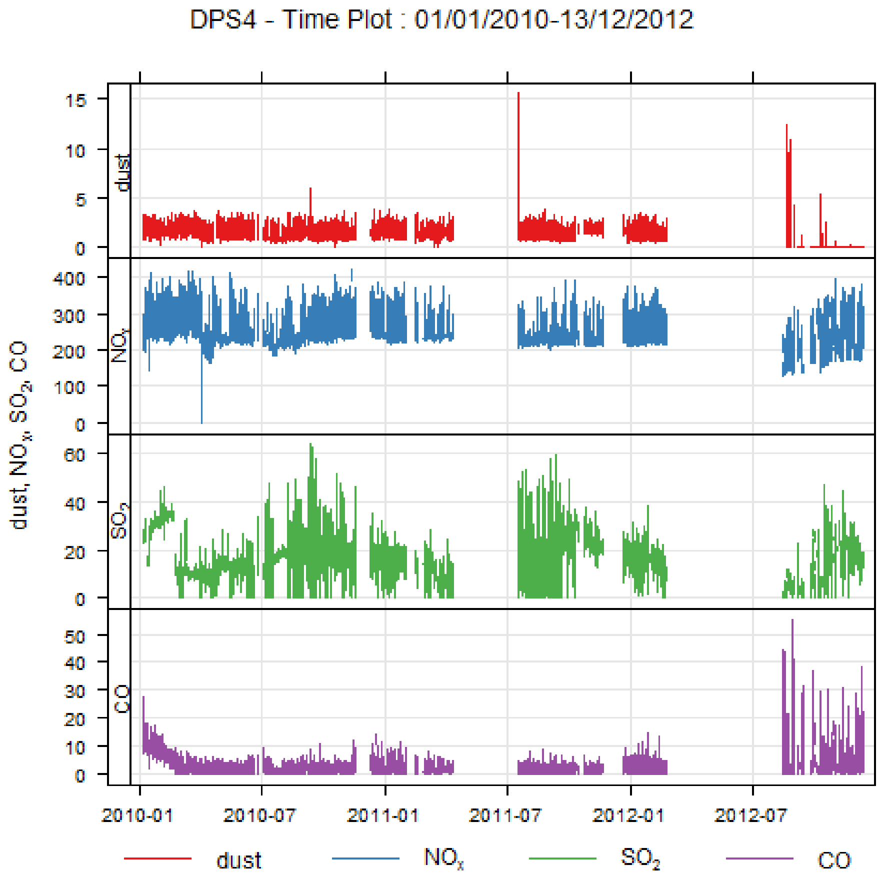


Figure 131: DPS4 baseline time plot

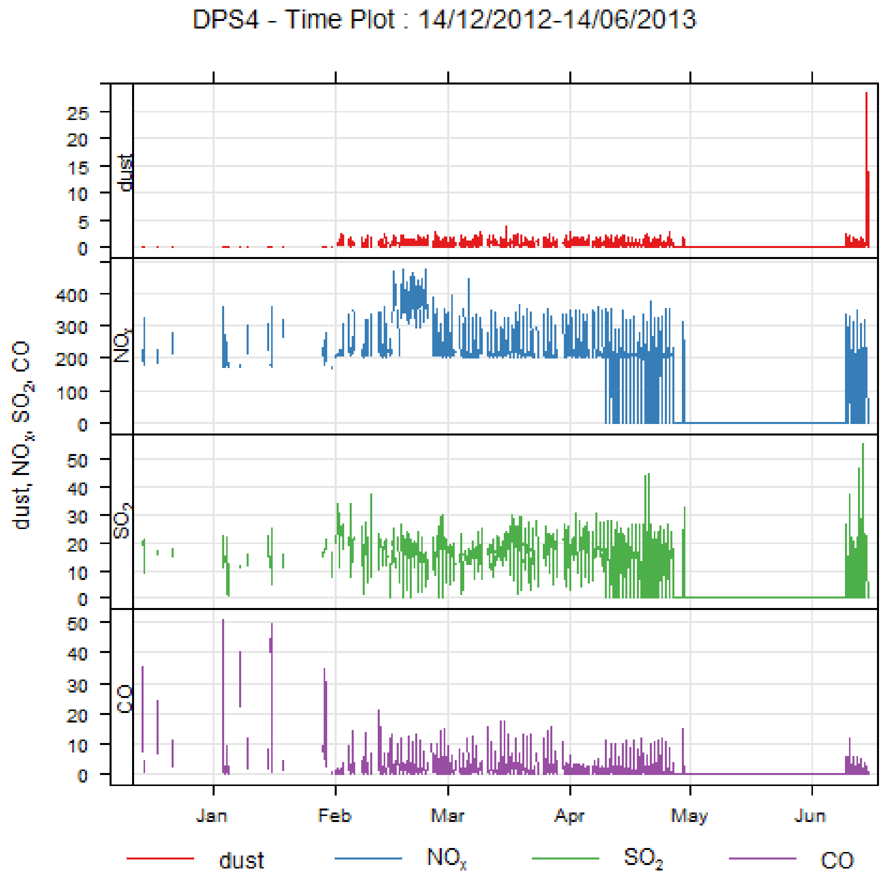


Figure 132: DPS4 post-commissioning time plot

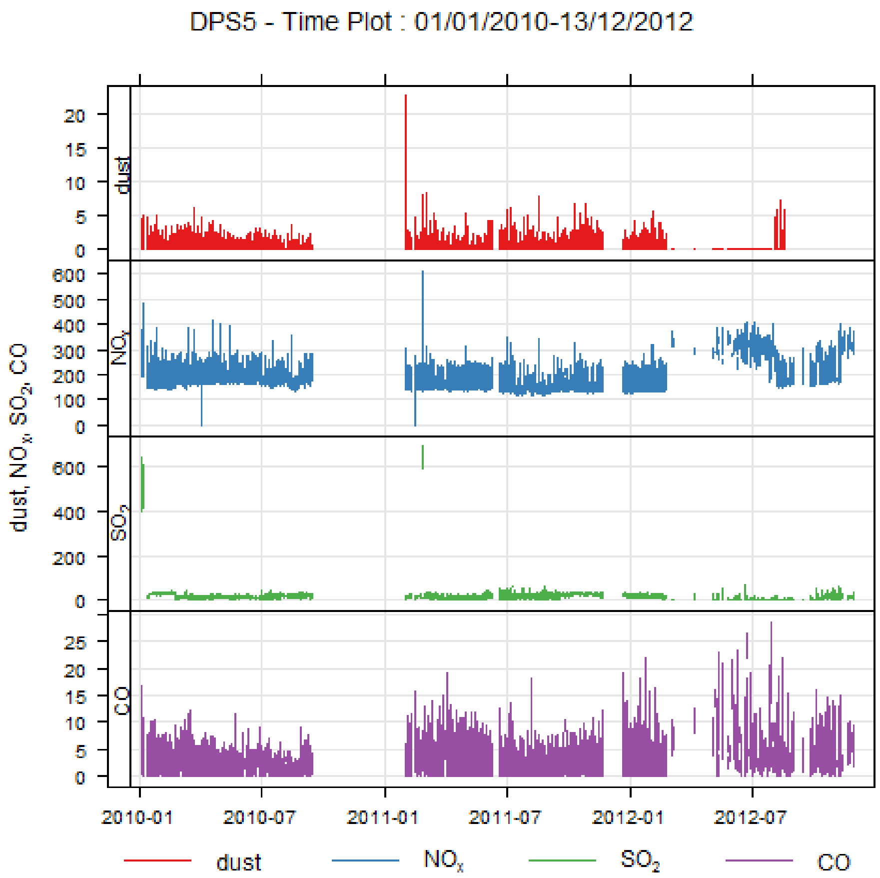


Figure 133: DPS5 baseline time plot

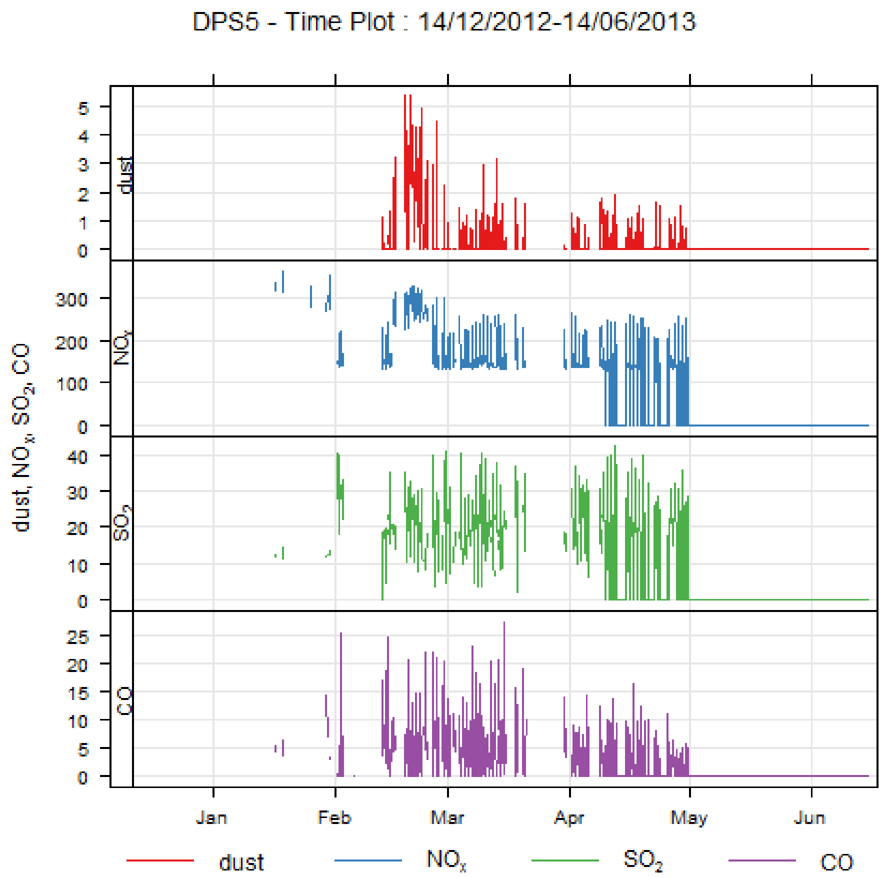


Figure 134: DPS5 post-commissioning time plot

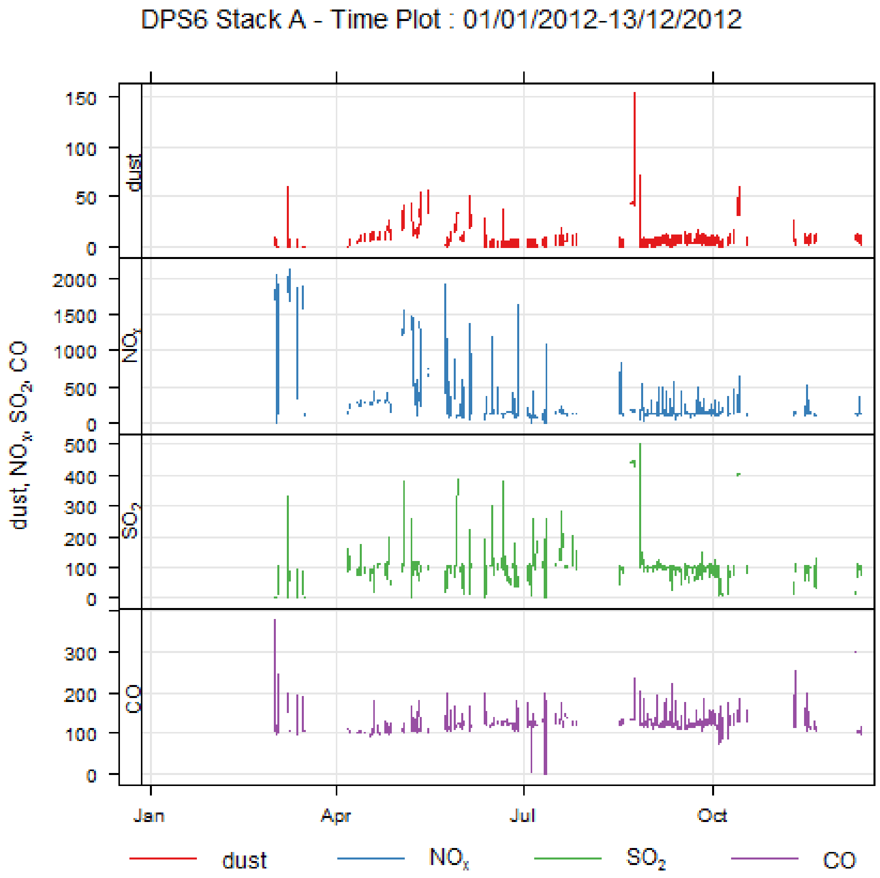


Figure 135: DPS6A baseline time plot

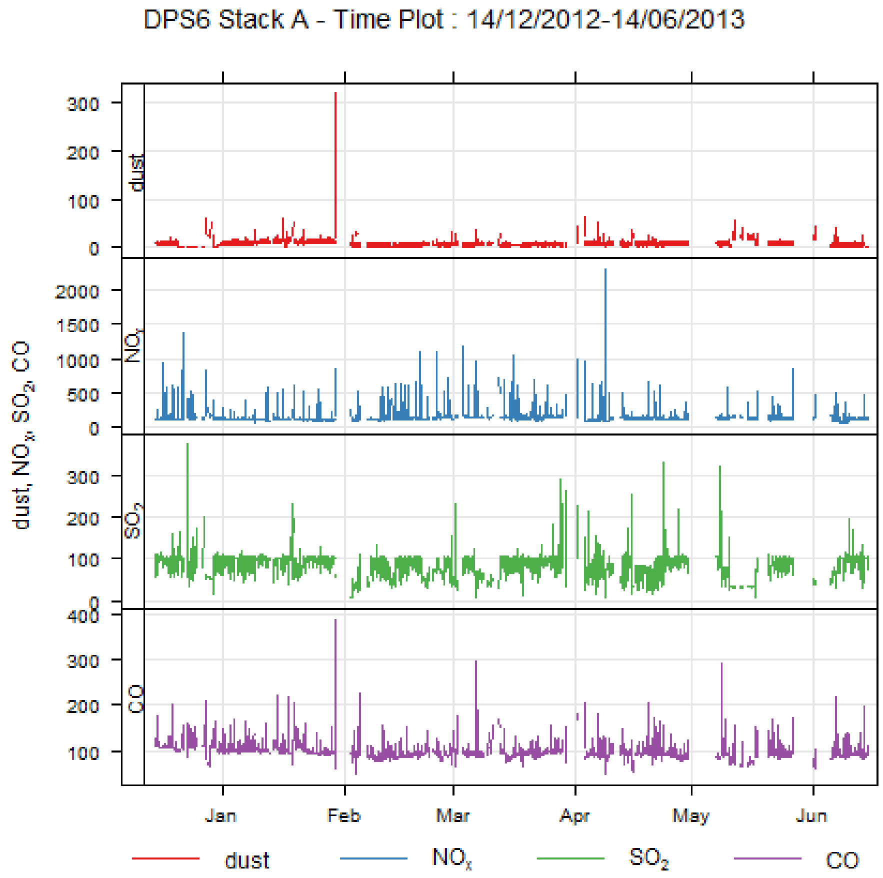


Figure 136: DPS6A post-commissioning time plot

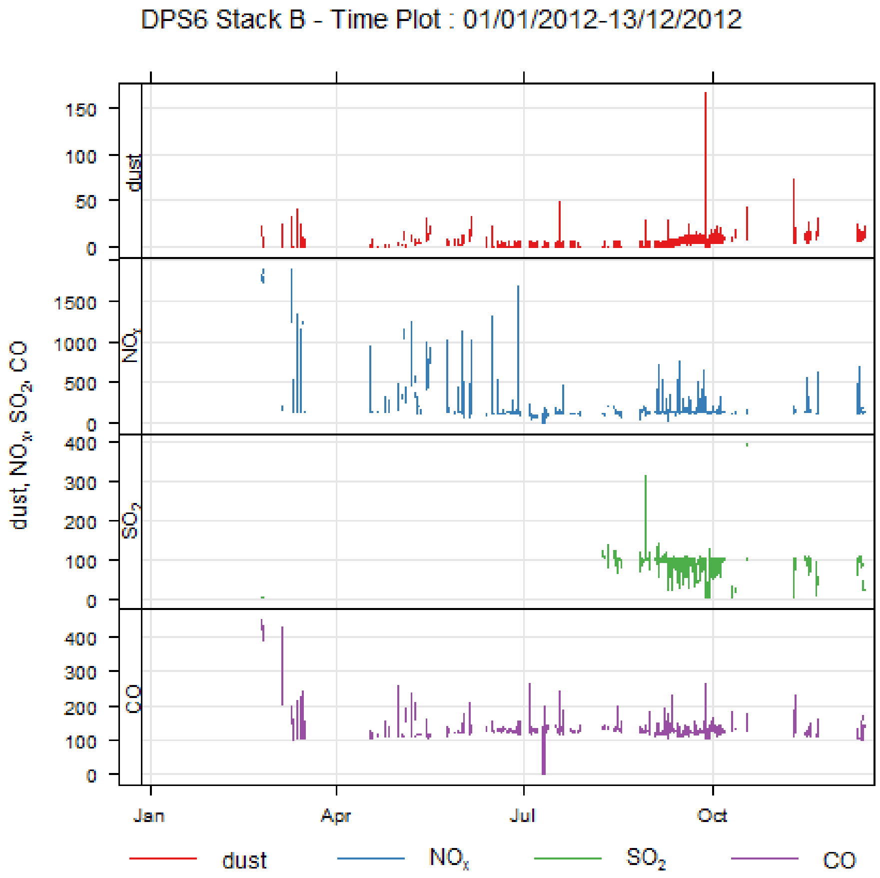


Figure 137: DPS6B baseline time plot

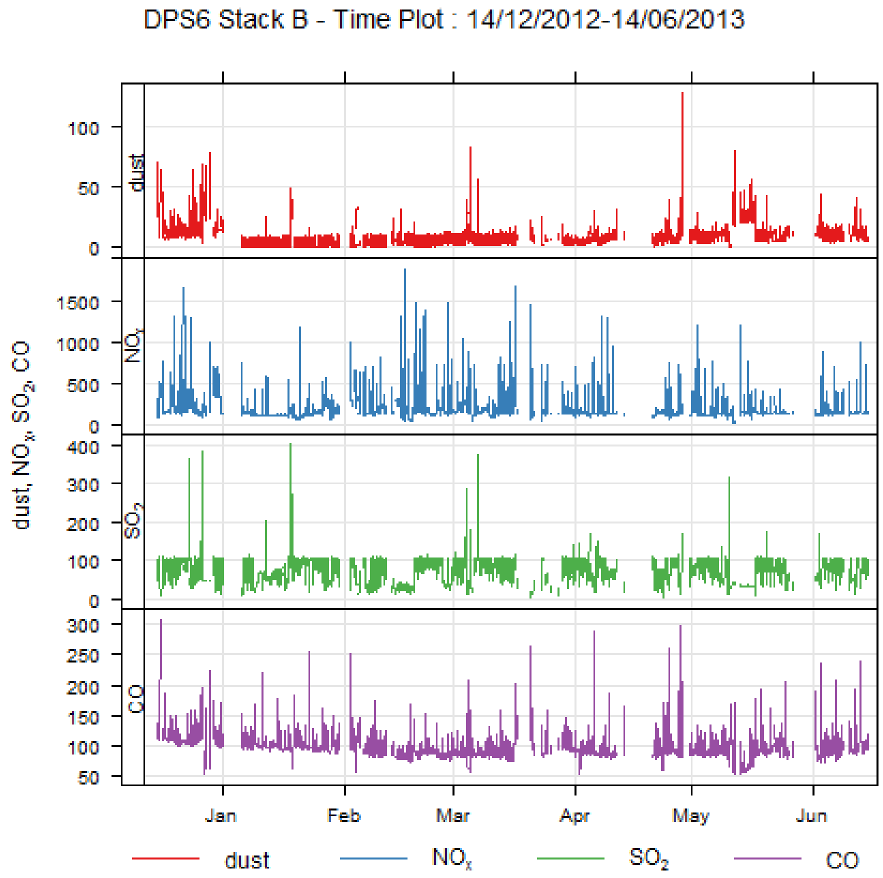


Figure 138: DPS6B post-commissioning time plot

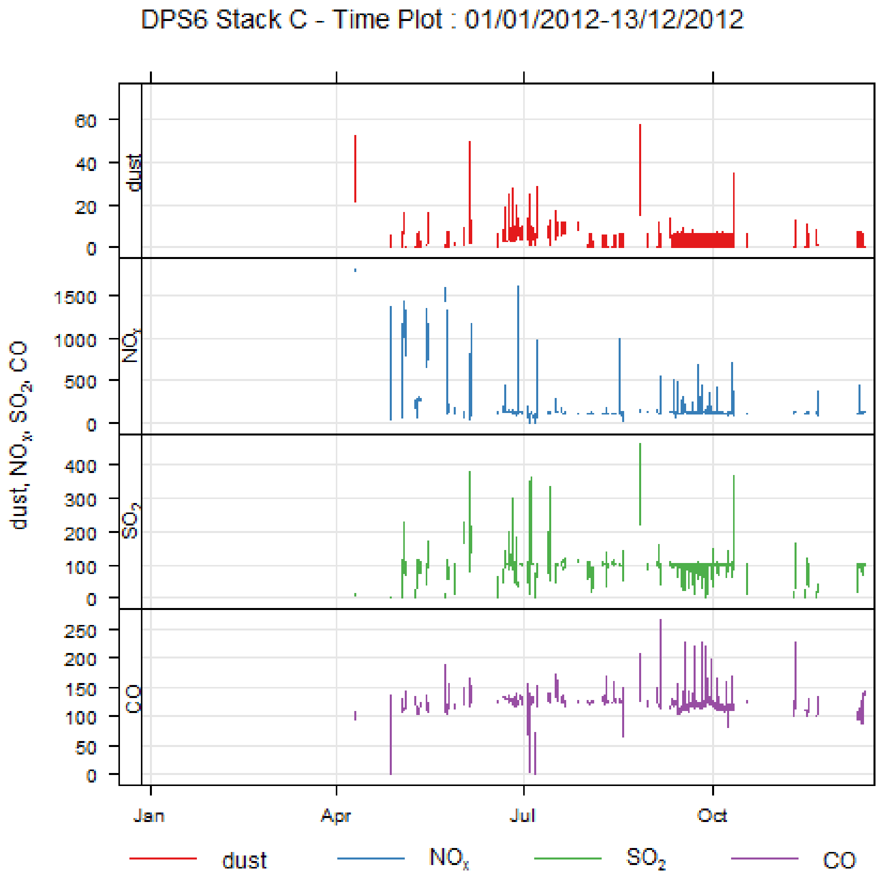


Figure 139: DPS6C baseline time plot

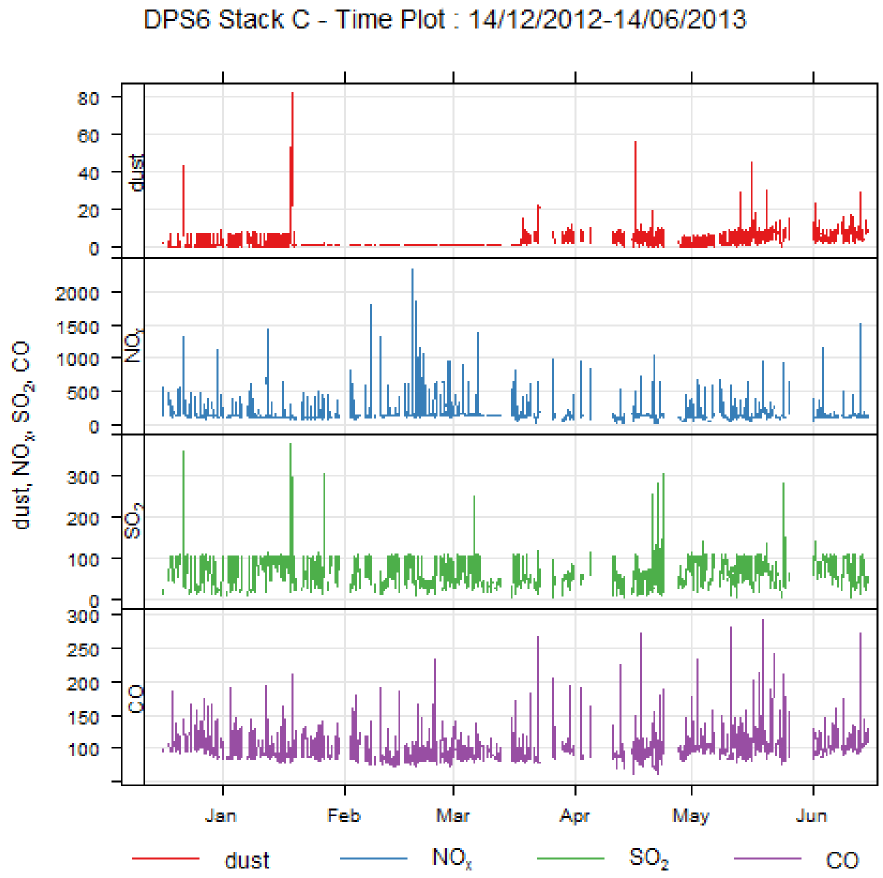


Figure 140: DPS6C post-commissioning time plot

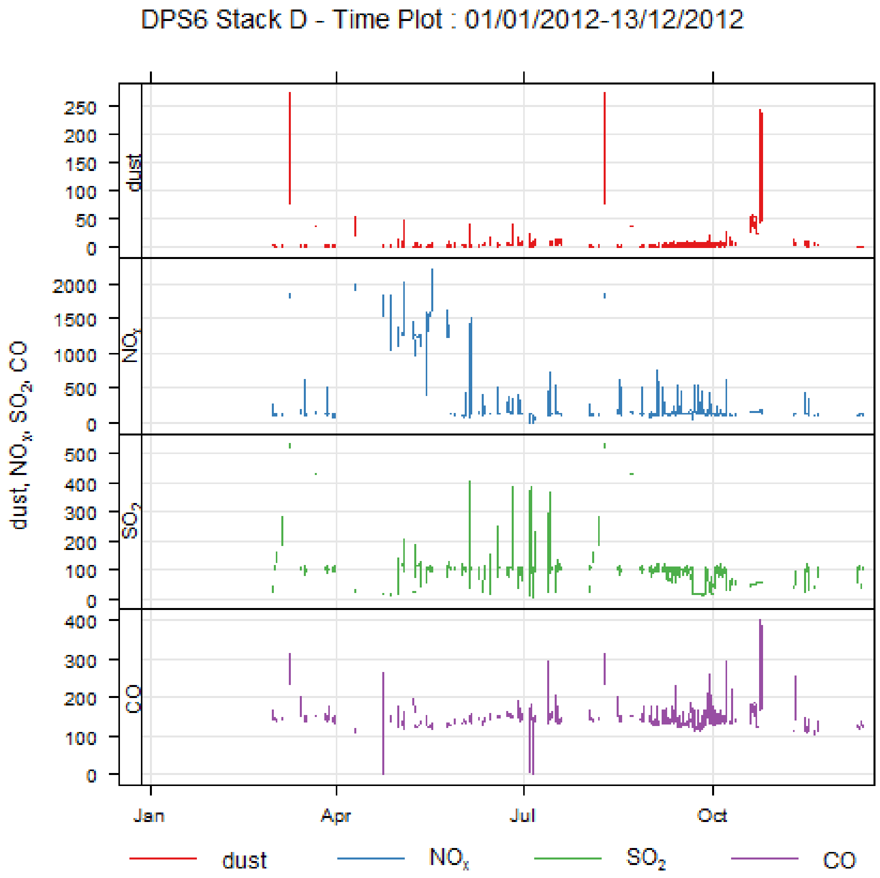


Figure 141: DPS6D baseline time plot

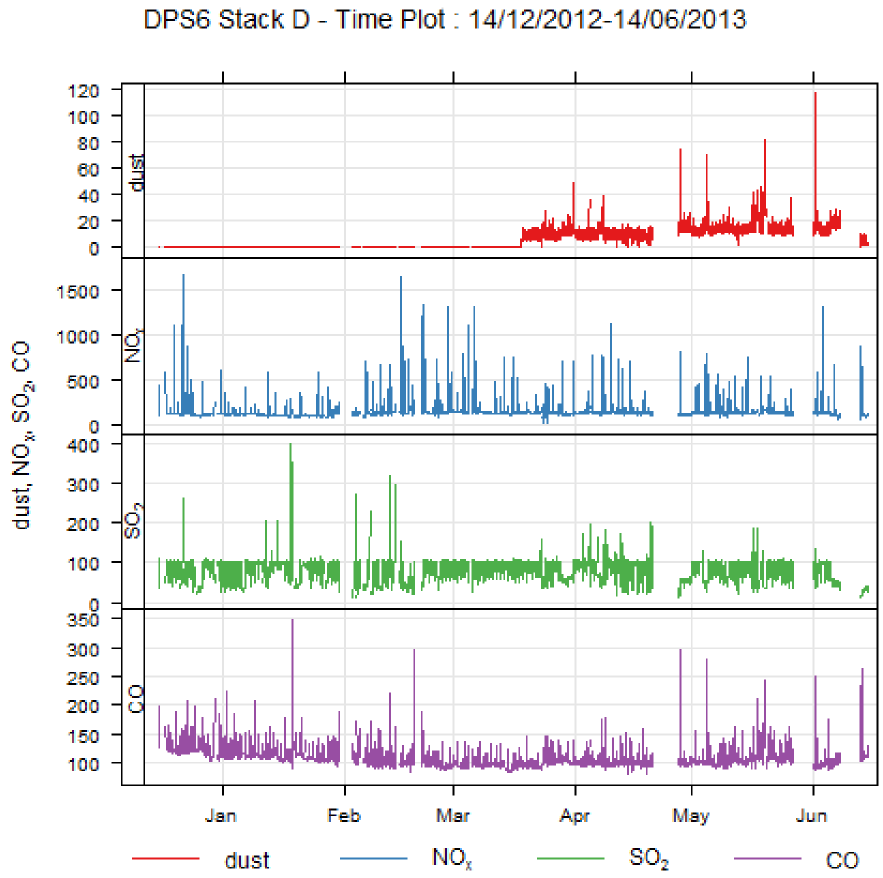


Figure 142: DPS6D post-commissioning time plot

Appendix D: Calendar plots

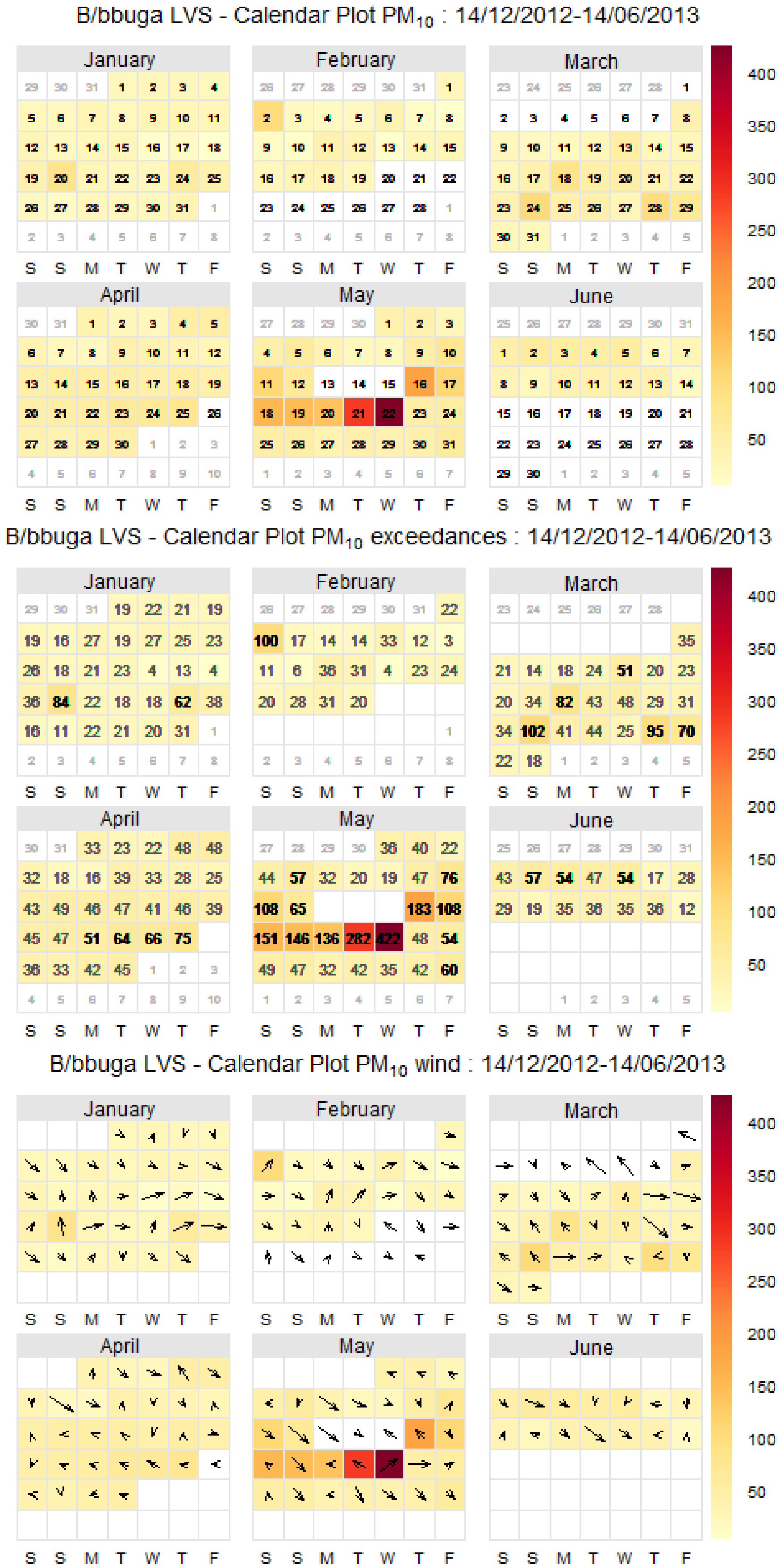


Figure 143: Birzebbuga LVS PM_{10} calendar plots

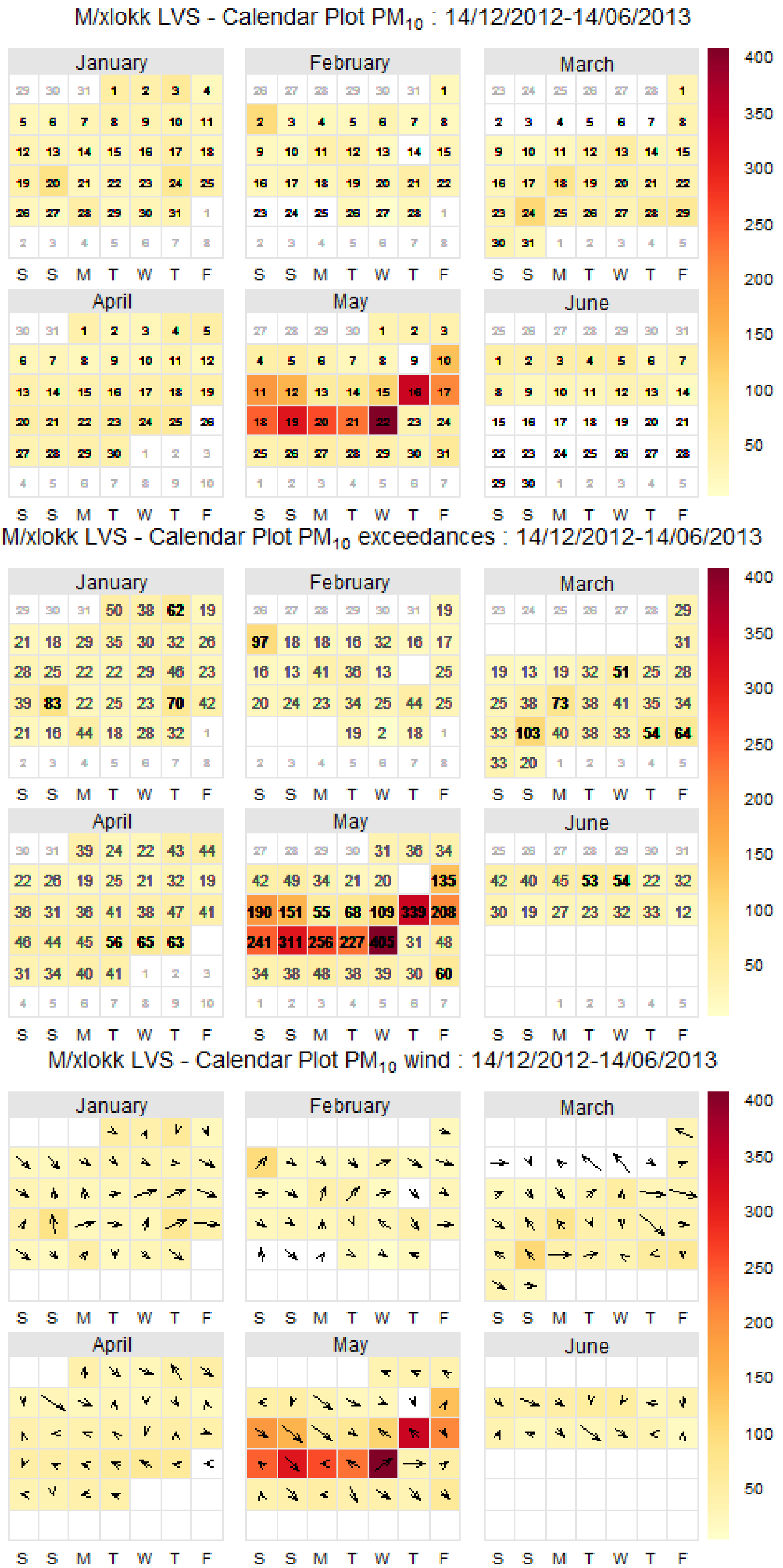
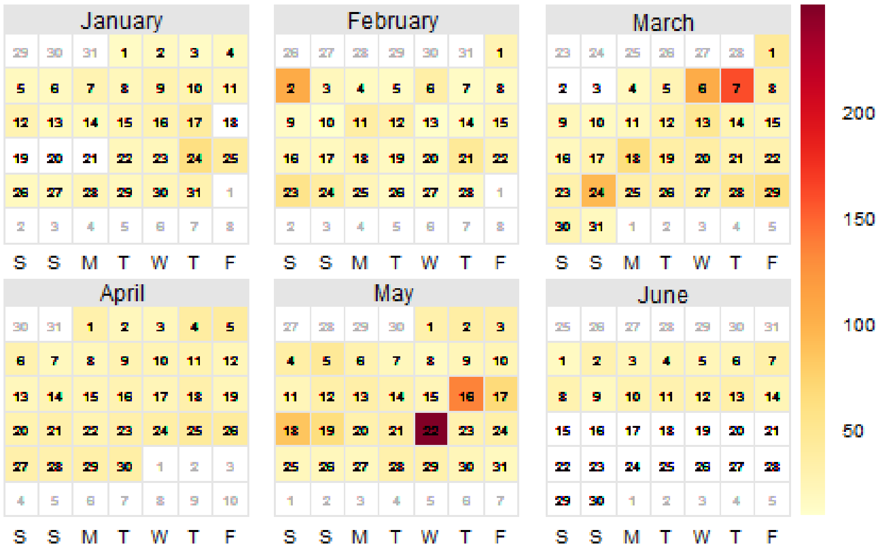
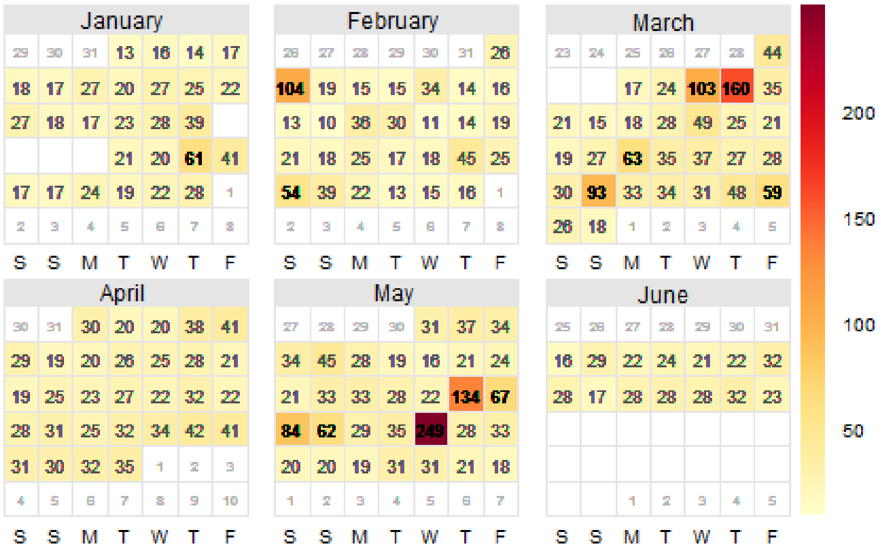


Figure 144: Marsaxlokk LVS PM_{10} calendar plots

B/bbuga BAM - Calendar Plot PM_{10} : 14/12/2012-14/06/2013



B/bbuga BAM - Calendar Plot PM_{10} exceedances : 14/12/2012-14/06/2013



B/bbuga BAM - Calendar Plot PM_{10} wind : 14/12/2012-14/06/2013

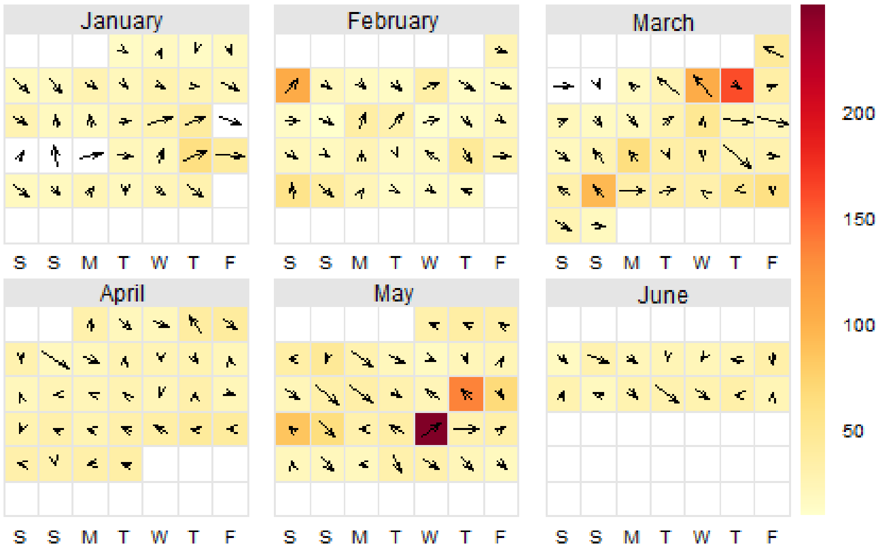


Figure 145: Birzebbuga BAM PM_{10} calendar plots

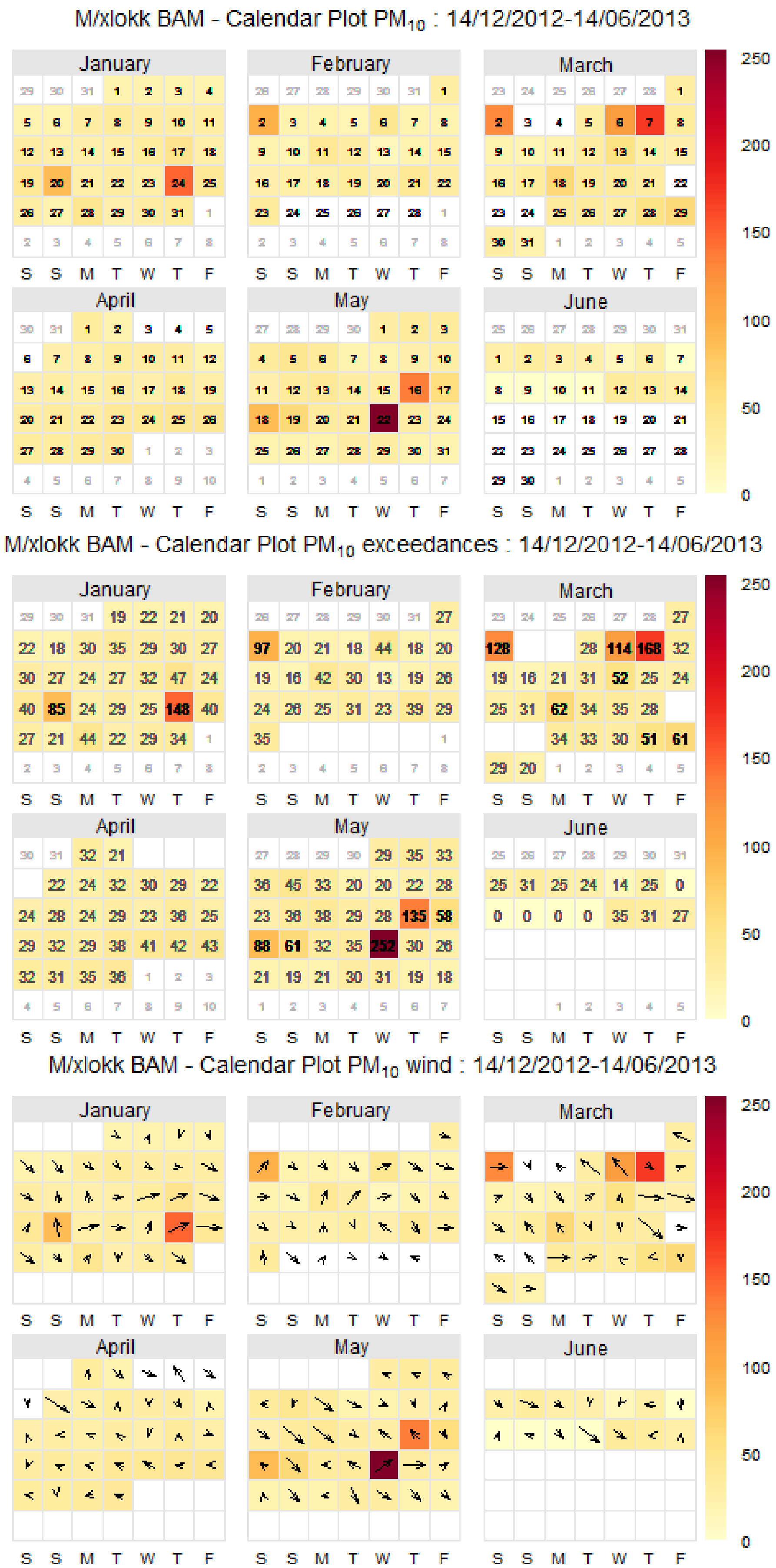


Figure 146: Marsaxlokk BAM PM_{10} calendar plots

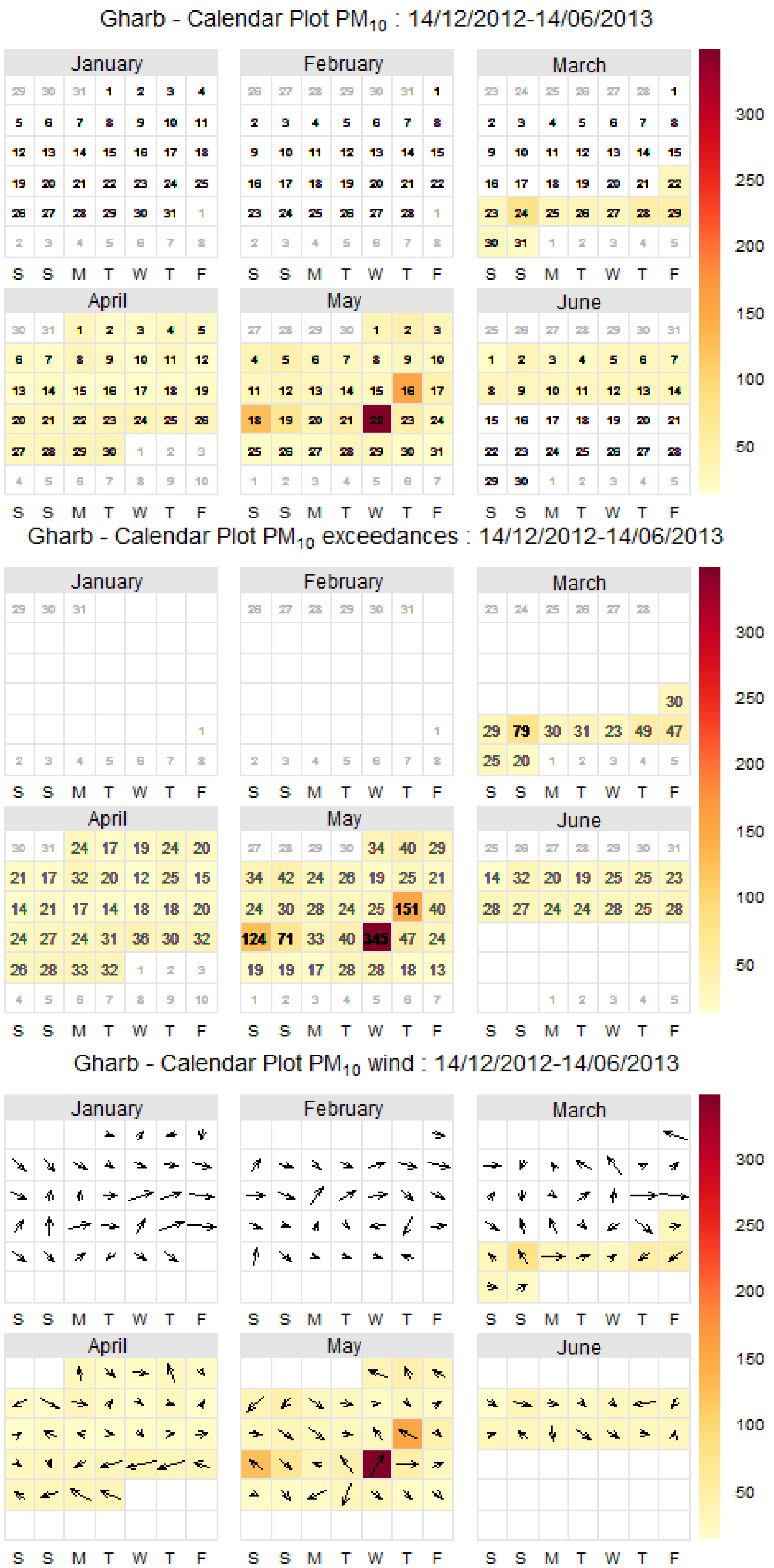
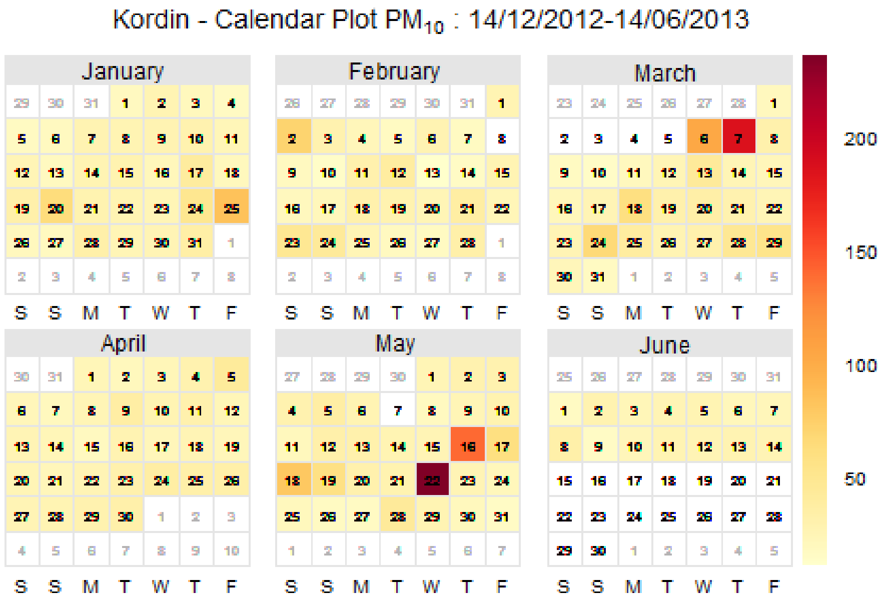
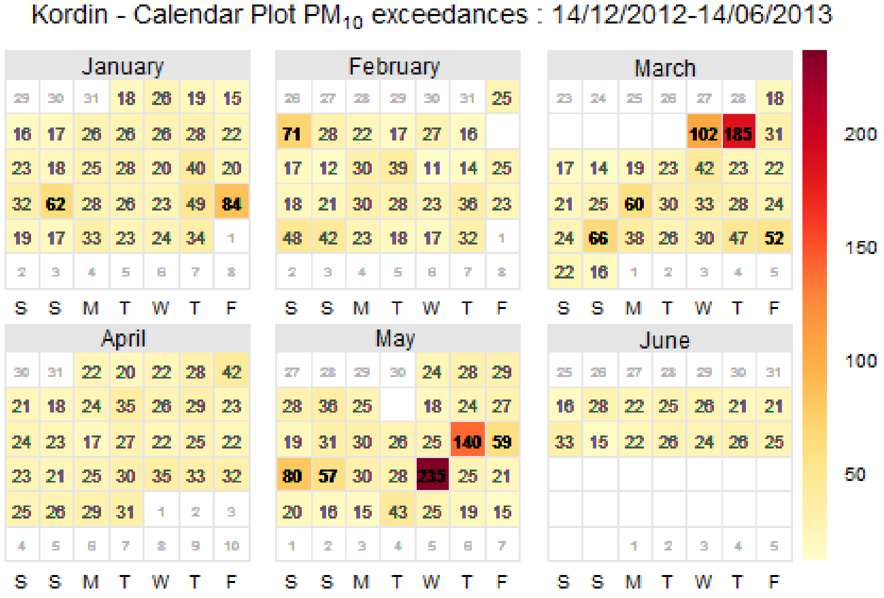


Figure 147: Gharb PM_{10} calendar plots





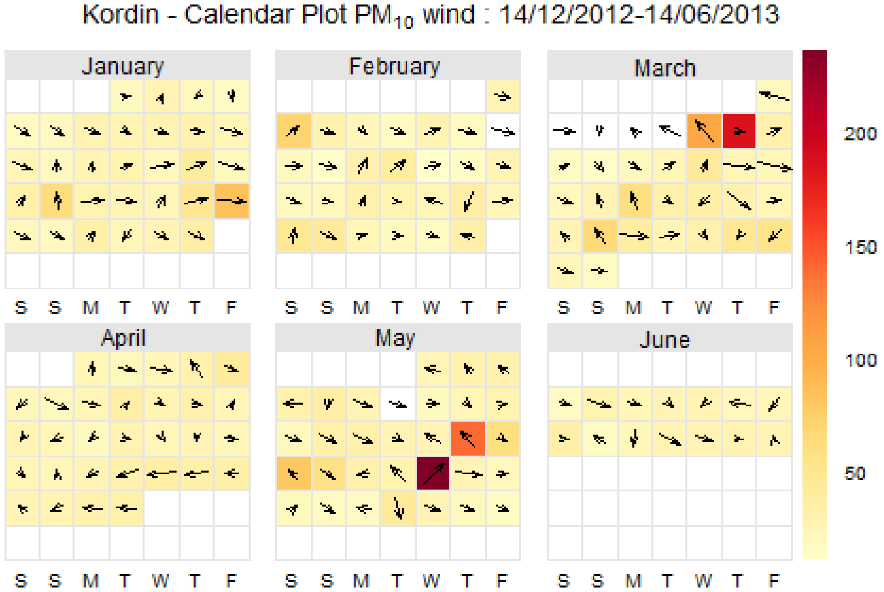


Figure 148: Kordin PM_{10} calendar plots

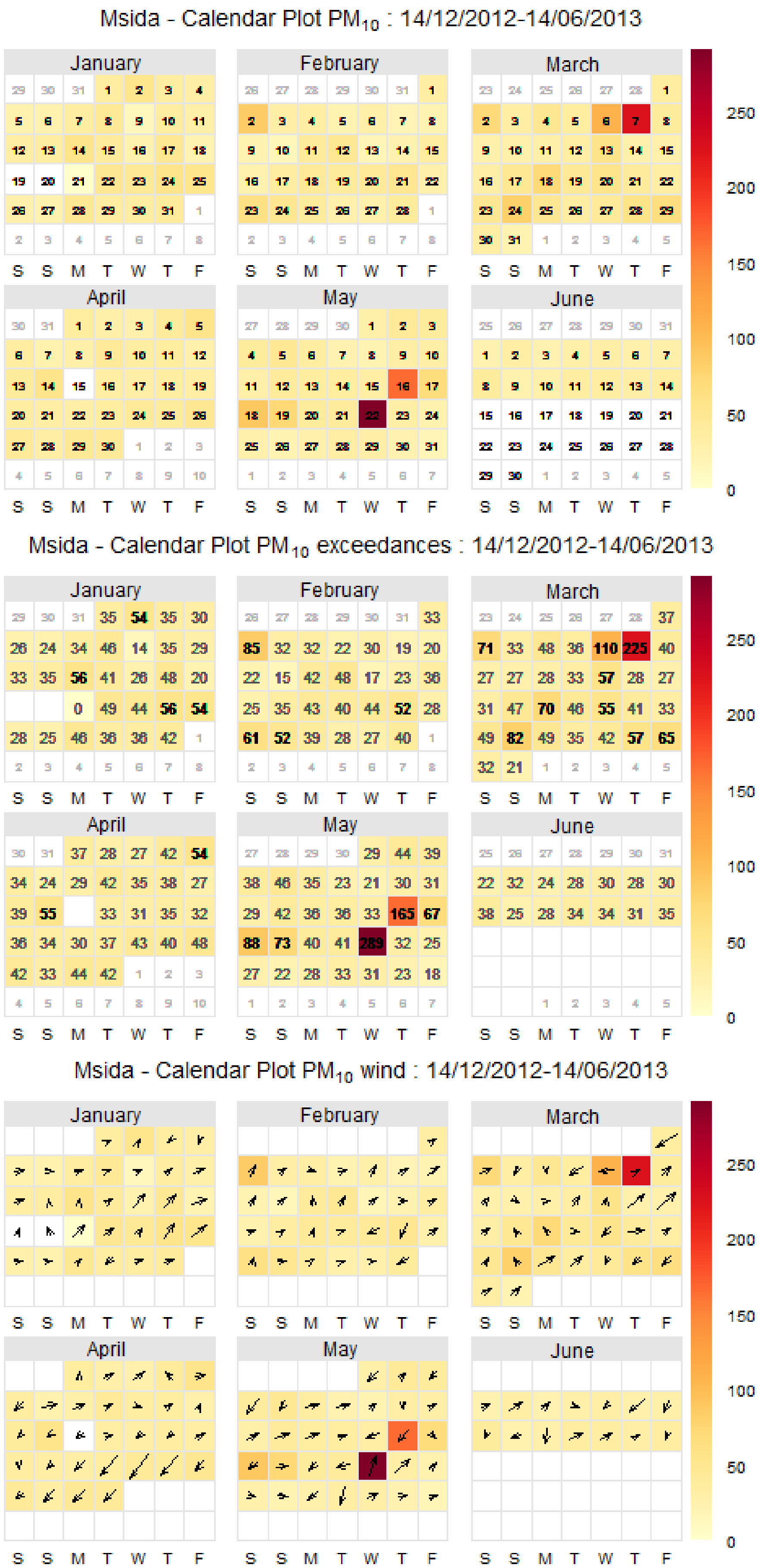


Figure 149: Msida PM_{10} calendar plots

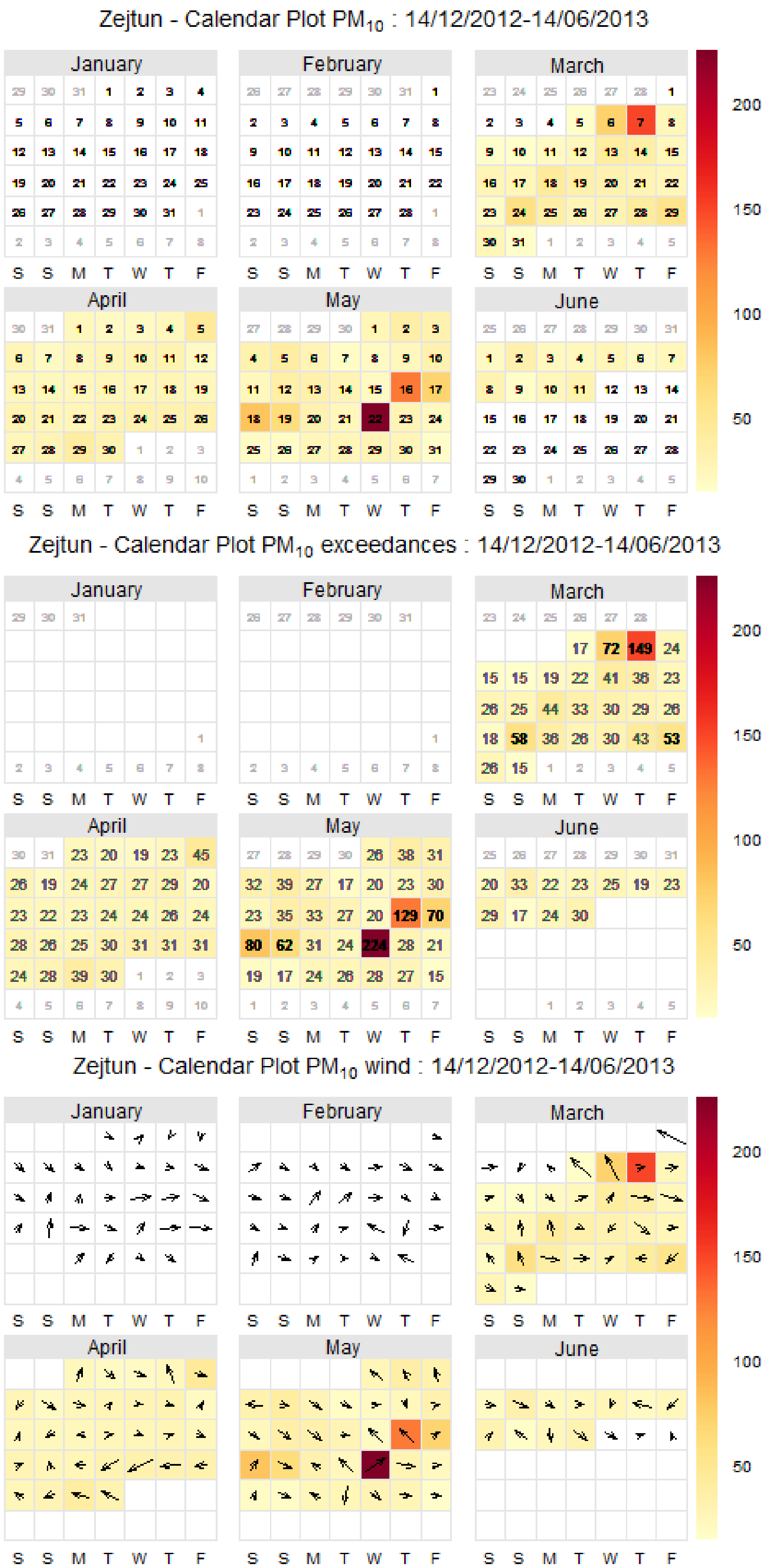


Figure 150: Zejtun PM_{10} calendar plots