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

Baseline Analysis 2009-2012

Source: Jonathan Vella - Panoramio

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UWE BRISTOL — AIR QUALITY MANAGEMENT aqm RESOURCE CENTRE, BRISTOL

Document Control Sheet

CLIENT CONTACT	Ms Rachel Decelis Malta Environment and Planning Authority (MEPA) Email: Rachel.Decelis@mepa.org.mt		
UWE CONTACT	Ms Jo Barnes University of the West of England, Bristol Email: jo.barnes@uwe.ac.uk		
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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 undertake a project 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 exceedences 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, 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. 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 will also be 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 slightly on 27th August 2012 to give more open aspect for all wind directions. The beta attenuation monitors (BAM) have been operating since July 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.
- 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 exceedences 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 represents an analysis of all available monitoring data from 1st January 2009 up to the commissioning of the plant to use HFO on 14th

December 2012 in order to provide a baseline for the monthly analysis and reporting of monitoring data over the six months following commissioning. As such this report provides only spatial and temporal analysis of the data. Exceedence analysis will be included in the monthly reports together with the spatial and temporal analysis to facilitate source apportionment. A synopsis of all the key conclusions from this study is provided below.

Monitoring data analysis summary

Based on the available data there are no significant observations to be made from the spatial and temporal analyses presented in this report. Sources of pollutants appear to be local traffic and transboundary pollution episodes with no conclusive evidence of emissions from the DPS contributing to monitored pollution concentrations. Spatial analysis of emissions data from DPS indicates that there may have been incursions of NOx, SO_2 and CO, however there is no monitoring data available for Birzebbuga or Marsaxlokk to determine whether this is likely to have affected local ambient concentrations. There may be some indication of a contribution from Marsa Power Station (MPS) to particulate matter at Kordin apparent in the temporal analysis, though the absence of wind data for this site means no spatial analysis could be used to corroborate this assumption. MPS may also be contributing to SO_2 concentrations at Msida and Zejtun according to the spatial analysis, however no emissions data for this site is available to verify.

In summation, this baseline analysis provides a useful benchmark against which to compare the post-commissioning pollutant concentrations, as will be reported in the coming six months.

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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, to undertake a project to assess the impact of using Heavy Fuel Oil (HFO) at Delimara Power Station (DPS).

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

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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 will also be 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 slightly on 27th August 2012 to give more open aspect for all wind directions. The beta-attenuation monitors (BAM) have been operating since July 2012.
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This report represents an analysis of all available monitoring data from 1st January 2009 up to the commissioning of the plant to use HFO on 14th

December 2012 in order to provide a baseline for the monthly analysis and reporting of monitoring data over the six months following commissioning.

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 C) 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).

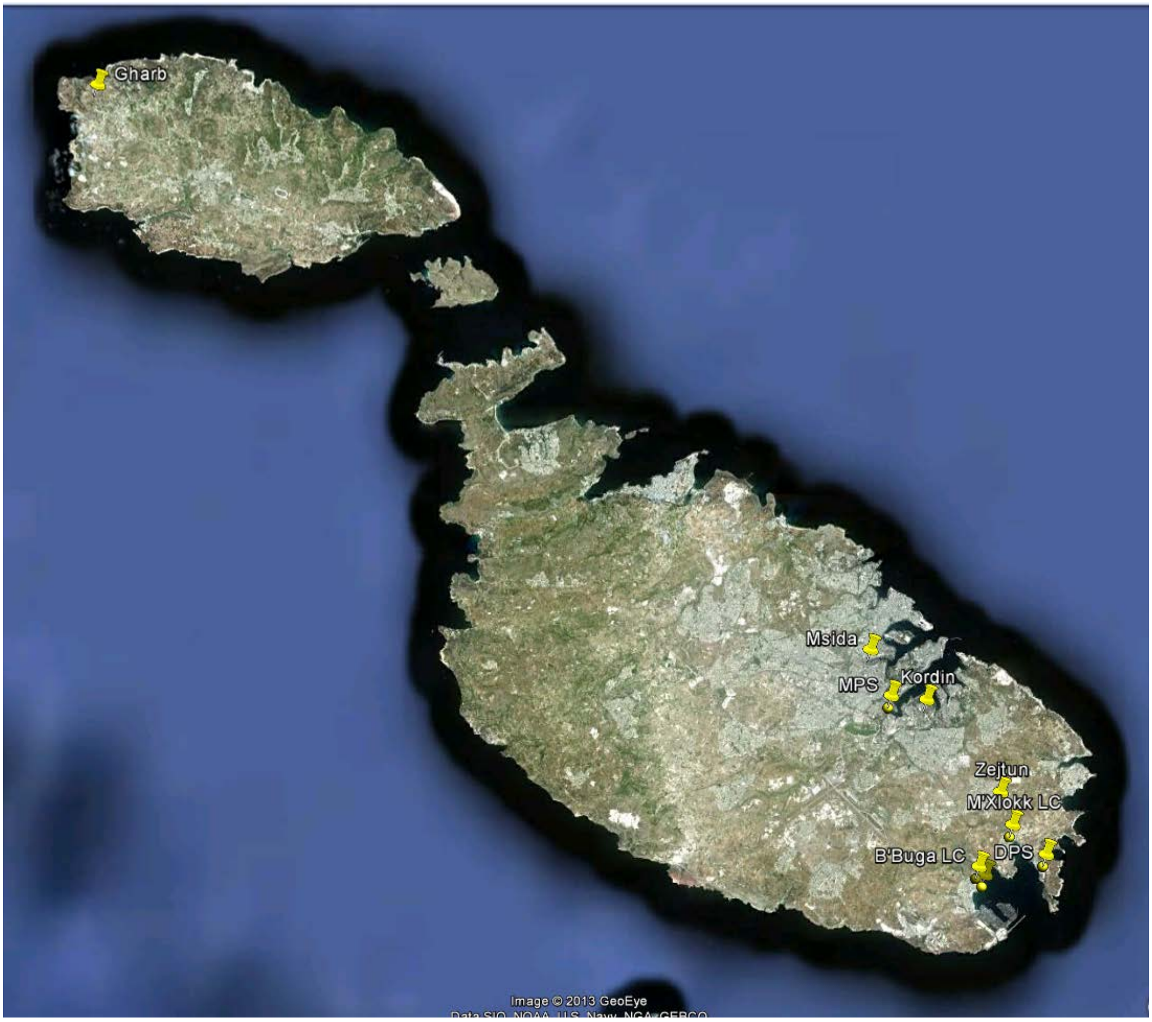


Figure 1: Site map of Maltese Islands (Source: Google Earth)

3. Data Analysis

3.1. Description of Analysis Methodology

Monitoring and emissions data has been analysed using Openair software (http://www.openair-project.org/)[1]. 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.
- Exceedence days/hours – to understand the nature of the exceedences.

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

Historical data for the period 1st January 2009 and 13th December 2012 have been used to establish a baseline and determine long-term trends against which the results from the subsequent monitoring programme may be compared. Local knowledge will be essential in order to facilitate interpretation of the results that may be affected by local events, e.g. fireworks, biomass burning etc.

As this is a baseline report, only spatial and temporal analysis of the data has been undertaken. Exceedence analysis will be included in the monthly reports together with the spatial and temporal analyses to facilitate source apportionment.

[1] 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)	Automatic continuous analysers
	Kordin (industrial background site close to Marsa Power Station)	Automatic continuous analysers
	Msida (roadside site), and	Automatic continuous analysers
	Zejtun (urban background site.	Automatic continuous analysers
Environmental Monitoring Services Ltd (Consultants)	Birzebbuga	BAM
	Marsaxlokk	BAM
AIS Environmental Ltd (Consultants)	Birzebbuga	LVS
	Marsaxlokk	LVS
Enemalta	DPS stack emissions[2]	Continuous emissions monitoring systems

Table 2 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 A showing distributions of values and periods of missing data. No adjustment has been made to basic pollution data subsequent to its receipt by AQMRC.

1st January 2009 was selected as the start date for the study in order to give a sufficient period of time on which to assess historical baseline data. The end date of 13th December 2012 was determined by the commencement of the commissioning and commercial operation of the plant using HFO on 14th December 2012.

[2] 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

3.2.1. Particulate matter sampling

EMS are using Beta Attenuation Monitors (BAM) to give continuous measurements of PM_{10} and $PM_{2.5}$, whereas AIS are using 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 this baseline report.

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, though these are only available from April 2012. Wind data for Marsa Power Station (MPS) could not be provided in a suitable format for analysis.

3.3. Units

Unless otherwise stated, all units for pollutants (other than CO) are in $\mu g/m^3$. CO is reported in mg/m^3.

Emissions data are in mg/m^3 or mg/Nm^3, except CO_2 which is in %vol.

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 capture

The Summary plots in Appendix A show an overview of the available data from each site. Data availability for most pollutants for most years is generally good for the MEPA sites, with the exception of Kordin for which there are significant data gaps, particularly in wind data, particulate matter and benzene, and Zejtun which lacks NO_2/NOx data for 2009-2010 and benzene data for 2011-2012.

Monitoring at the consultants' sites in Birzebbuga and Marsaxlokk only commenced part-way through 2012 and so data availability for these sites is obviously limited. In addition, only PM_{10} and $PM_{2.5}$ data are available for these sites with wind data taken from the DPS site.

Emissions data capture from the DPS plant is generally poor, with the exception of data from DPS1, which has reasonably good data capture across all four years for all pollutants, however with wind data only from April 2012.

The availability of data has naturally restricted the analysis included in this report, however, unless absence of data prevented it, all data have, as far as possible, been plotted and reported where relevant. It is important to note therefore that the interpretation of the plots where data capture has been limited should be made with caution.

Table 2: Details of Concentration and Emissions Monitoring Locations and Data Used in this Study.

Operator	Site	Start	End	X-Ref	Y-Ref	PM_{10}	$PM_{2.5}$	Benz-ene	CO	O_3	SO_2	NOx	NO_2	Wind Spd & Dir.	Other	Time Res.
MEPA	Gharb (rural background)	1/1/2009	13/12/2012	14.198	36.068	✓	✓	✓	✓	✓	✓	✓	✓	✓	NO	1hr
	Kordin (urban industrial)	1/1/2009	13/12/2012	14.511	35.881	✓	✗	✓	✓	✓	✓	✓	✓	✓	NO	1hr
	Msida (urban roadside)	1/1/2009	13/12/2012	14.490	35.896	✓	✓	✓	✓	✓	✓	✓	✓	✓	NO	1hr
	Zejtun (urban background)	1/1/2009	13/12/2012	14.539	35.852	✓	✓	✓	✓	✓	✓	✓	✓	✓	NO	1hr
EMS	Birzebbuga	3/9/2012	13/12/2012	14.531	35.829	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	1hr
	Marsaxlokk	3/9/2012	13/12/2012	14.544	35.842	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	1hr
AIS	Birzebbuga	5/4/2012	13/12/2012	14.531	35.829	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	24hr
	Marsaxlokk	5/4/2012	13/12/2012	14.544	35.842	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	24hr
Enemalta	DPS1	1/1/2009	13/12/2012	14.556	35.833	✗	✗	✗	✓	✗	✓	✓	✗	✓	Dust[3]	1hr
	DPS2	1/1/2009	13/12/2012	14.556	35.833	✗	✗	✗	✓	✗	✓	✓	✗	✓	Dust	1hr
	DPS4	1/1/2010	13/12/2012	14.556	35.833	✗	✗	✗	✓	✗	✓	✓	✗	✓	Dust	1hr
	DPS5	1/1/2010	13/12/2012	14.556	35.833	✗	✗	✗	✓	✗	✓	✓	✗	✓	Dust	1hr
	DPS6 Stack A	24/2/2012	13/12/2012	14.556	35.833	✗	✗	✗	✓	✗	✓	✓	✗	✓	Dust, CO_2, NH_3	1hr
	DPS6 Stack B	24/2/2012	13/12/2012	14.556	35.833	✗	✗	✗	✓	✗	✓	✓	✗	✓	Dust, CO_2, NH_3	1hr
	DPS6 Stack C	24/2/2012	13/12/2012	14.556	35.833	✗	✗	✗	✓	✗	✓	✓	✗	✓	Dust, CO_2, NH_3	1hr
	DPS6 Stack D	24/2/2012	13/12/2012	14.556	35.833	✗	✗	✗	✓	✗	✓	✓	✗	✓	Dust, CO_2, NH_3	1hr

[3] 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.

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 5), 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 6-Figure 9), 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 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.

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

Figure 2 shows concentrations of PM_{10} (µg/m^3) and $PM_{2.5}$ (µg/m^3) plotted with wind speed (m/s) and direction (degrees) at three of the four MEPA monitoring sites using all data from each site. (Wind data capture for Kordin was too low to plot.) The plots indicate that the highest concentrations of PM_{10} and $PM_{2.5}$ are monitored under southerly or south-westerly wind conditions, contrary to prevailing wind directions, though it is interesting to note that wind directions at the Msida site are predominantly east-west, perhaps due to air flow restrictions given the urban nature of this site (Appendix C). Apart from at Msida, concentrations tend to be highest at medium to high wind speeds, potentially indicating:

- predominant sources are not in immediate proximity to the sites;
- 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.

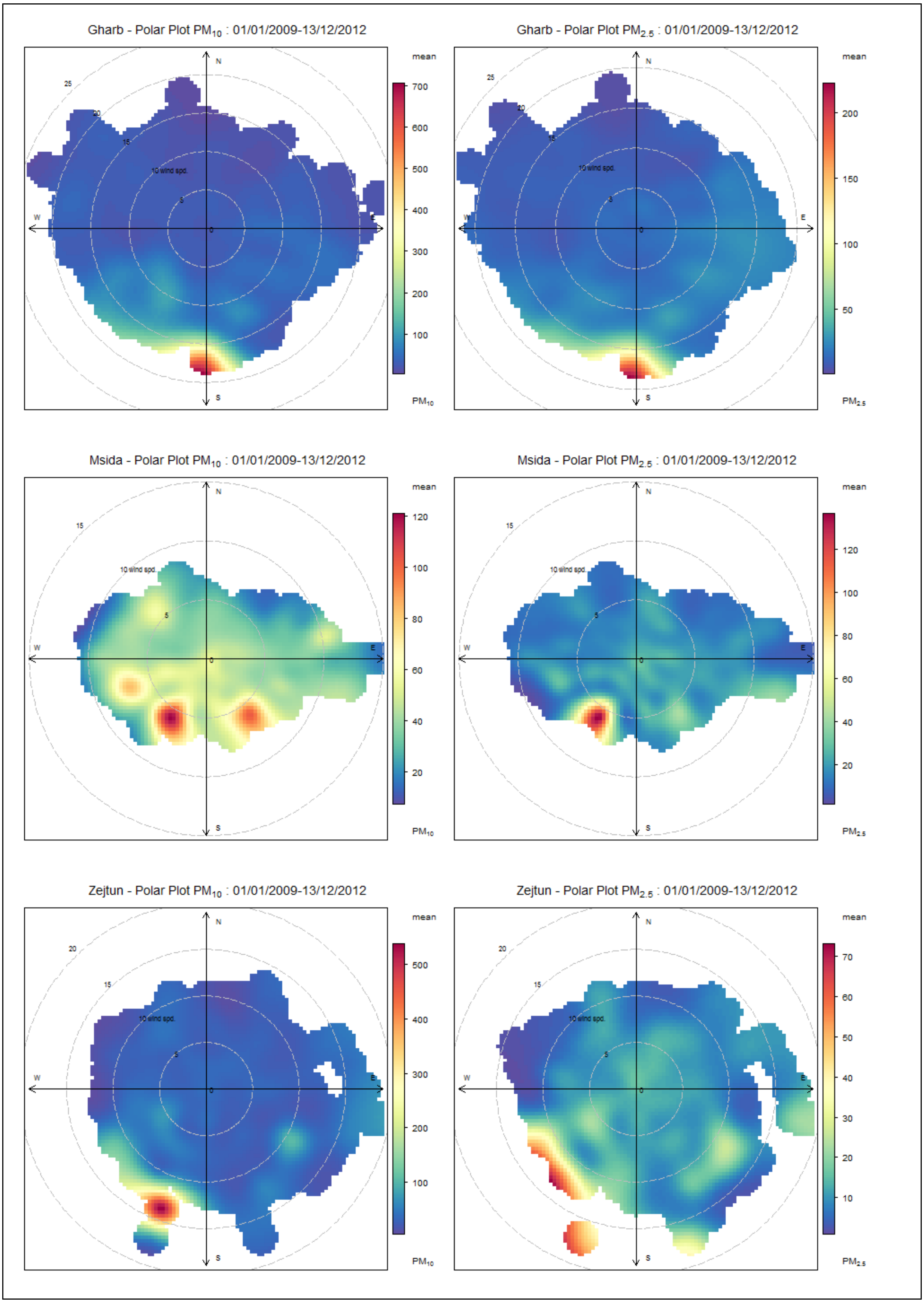


Figure 2: Polar Plots for PM_{10} and $PM_{2.5}$ at MEPA sites for 2009-2012

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

Figure 3 shows 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 data plotted are taken from the BAM stations. These data therefore only represent part of 2012 and should therefore be interpreted with caution, however, as with the MEPA sites, highest PM_{10} and $PM_{2.5}$ concentrations are found at high wind speeds contrary to prevailing wind directions, perhaps indicating a transboundary source. Maximum concentrations were higher at Marsaxlokk for both PM_{10} and $PM_{2.5}$.

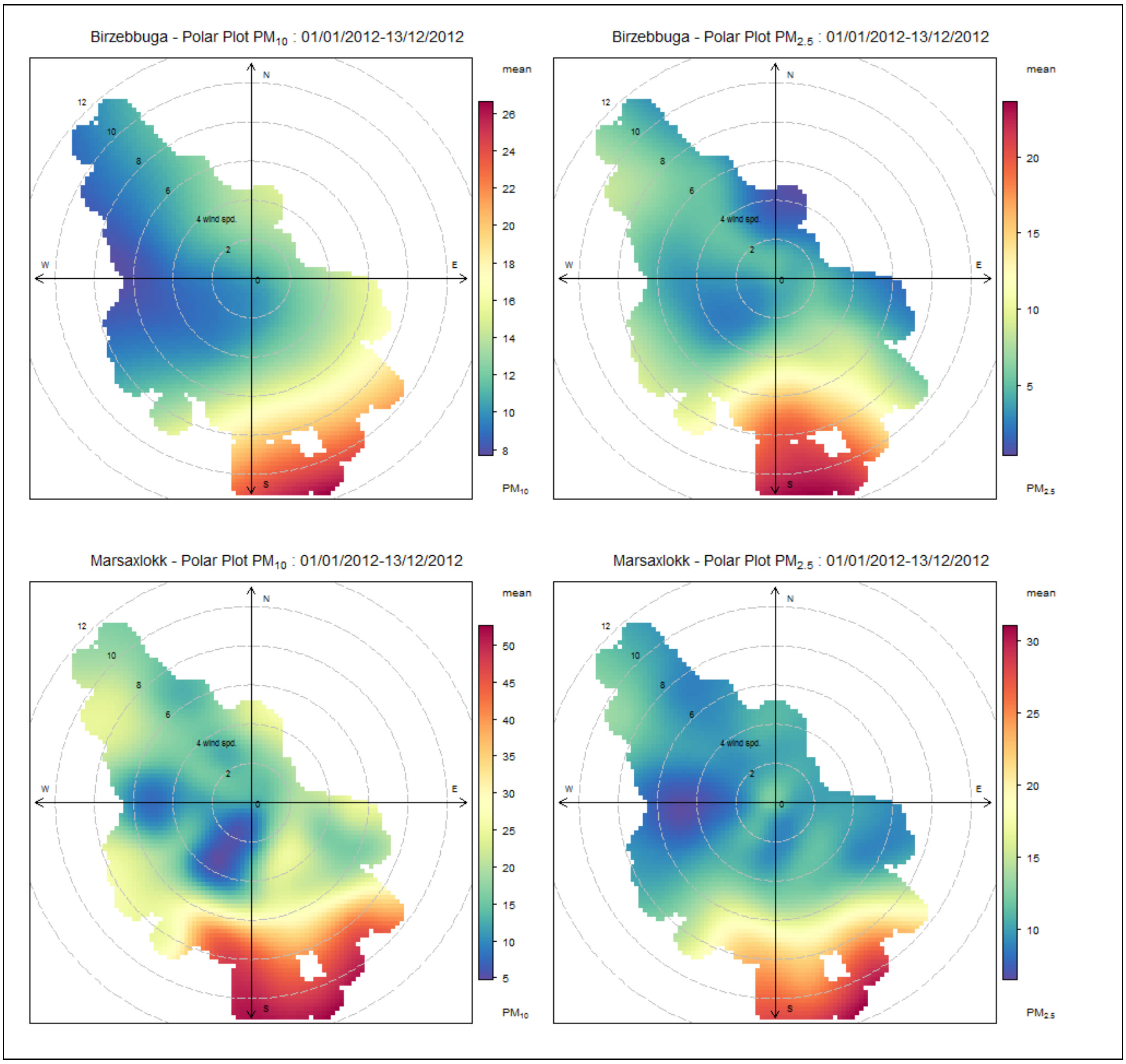
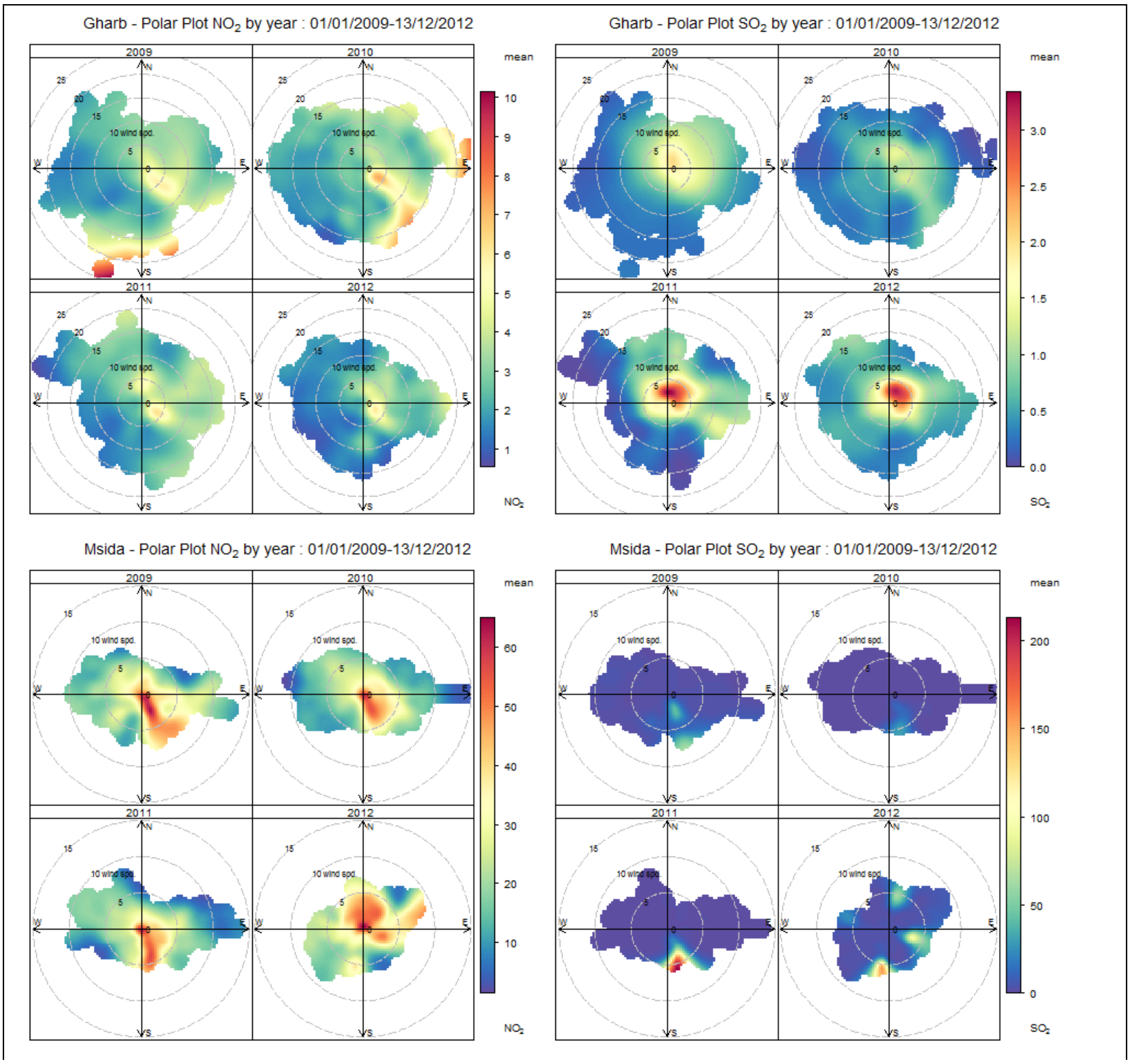


Figure 3: Polar plots for PM_{10} and $PM_{2.5}$ for Birzebbuga and Marsaxlokk

3.5.4. NO_2, SO_2 and CO Polar Plots from MEPA Monitoring Stations by year

Figure 4 shows concentrations of NO_2, (µg/m^3) SO_2 (µg/m^3) and CO (µg/m^3) by year plotted with wind speed (m/s) and direction (degrees) at three of the four MEPA monitoring sites using all data from each site. Plots have been grouped vertically by pollutant to determine whether there were any discernible patterns between sites.

As might be expected there is no clear pattern discernible for NO_2 at the rural background site, Gharb, while the roadside site (Msida) and the urban background site (Zejtun) indicate sources close to the monitoring sites. For SO_2, highest concentrations (albeit very low in total) are found close to the monitoring site, with SO_2 concentrations at Msida reflecting the pattern of NO_2 concentrations. High concentrations from the north-west in 2009 at Zejtun are masking patterns in other years, but there is an indication that in 2009 the predominant source is local and from the prevailing wind direction. There is no clear pattern of pollution of CO at either of the background sites, Gharb or Zejtun, but a relatively strong local source at the Msida roadside site.



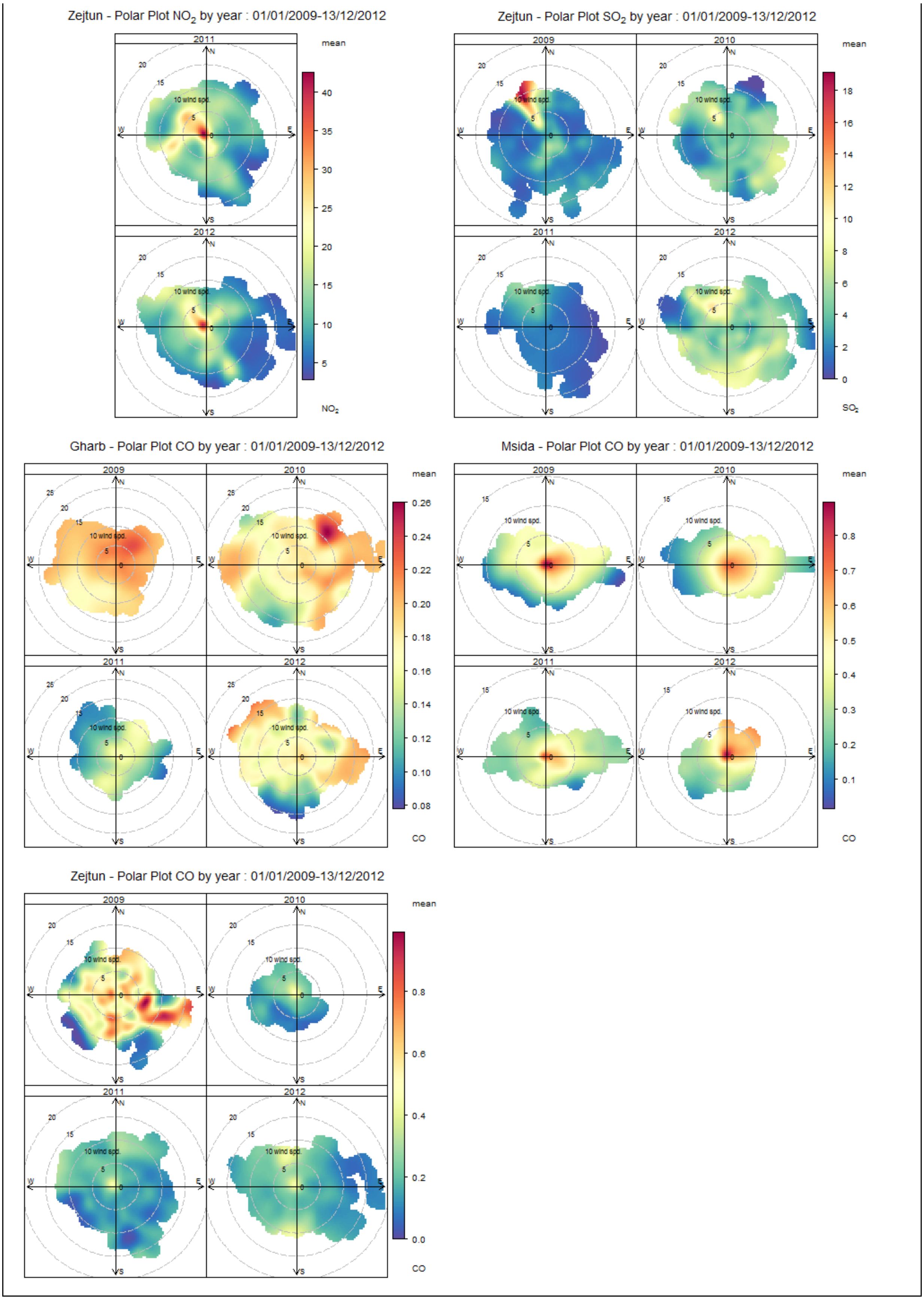


Figure 4: Polar plots for NO_2, SO_2 and CO for MEPA sites

3.5.5. SO_2 Polar Plots from MEPA Monitoring Stations pre- and post-August 2010

In addition to the annual polar plots by pollutant shown in Figure 4, Figure 5 shows the concentrations of SO_2 (µg/m^3) plotted with wind speed (m/s) and direction (degrees) at three of the four MEPA monitoring sites pre- and post-August 2010. These plots are intended to determine whether there was any discernible change in spatial patterns of SO_2 resulting from the change from 1% sulphur to 0.7% sulphur fuel at the Marsa Power Station (MPS) in August 2010. As can be seen, there are no obvious differences in the spatial patterns between the two periods, but, perhaps counter-intuitively, maximum concentrations of SO_2 appear to have increased by as much as 100%. Given that this trend is apparent at all sites, it is unlikely that this is directly related to the change in fuel type at the MPS as the effect appears to be more regional. The relative concentrations between sites is worthy of note, however, with both Figure 4 and Figure 5 indicating that maximum concentrations of SO_2 at the urban background site (Zejtun) are approximately 5-6 times greater than at the rural background site (Gharb), and concentrations at the urban roadside site (Msida) are up to ten times greater than at Zejtun. The relative spatial patterns between sites are also interesting. Msida is the closest site to MPS (that has sufficient wind data to plot) located approximately 1.7 km to the NNW, while Zejtun is sited approximately 5 km to the SE of MPS. The directional analysis of the polar plots indicates that the highest concentrations of SO_2 are emanating from this direction, however without reciprocal emissions data for MPS it is not possible to definitively identify this as a source.

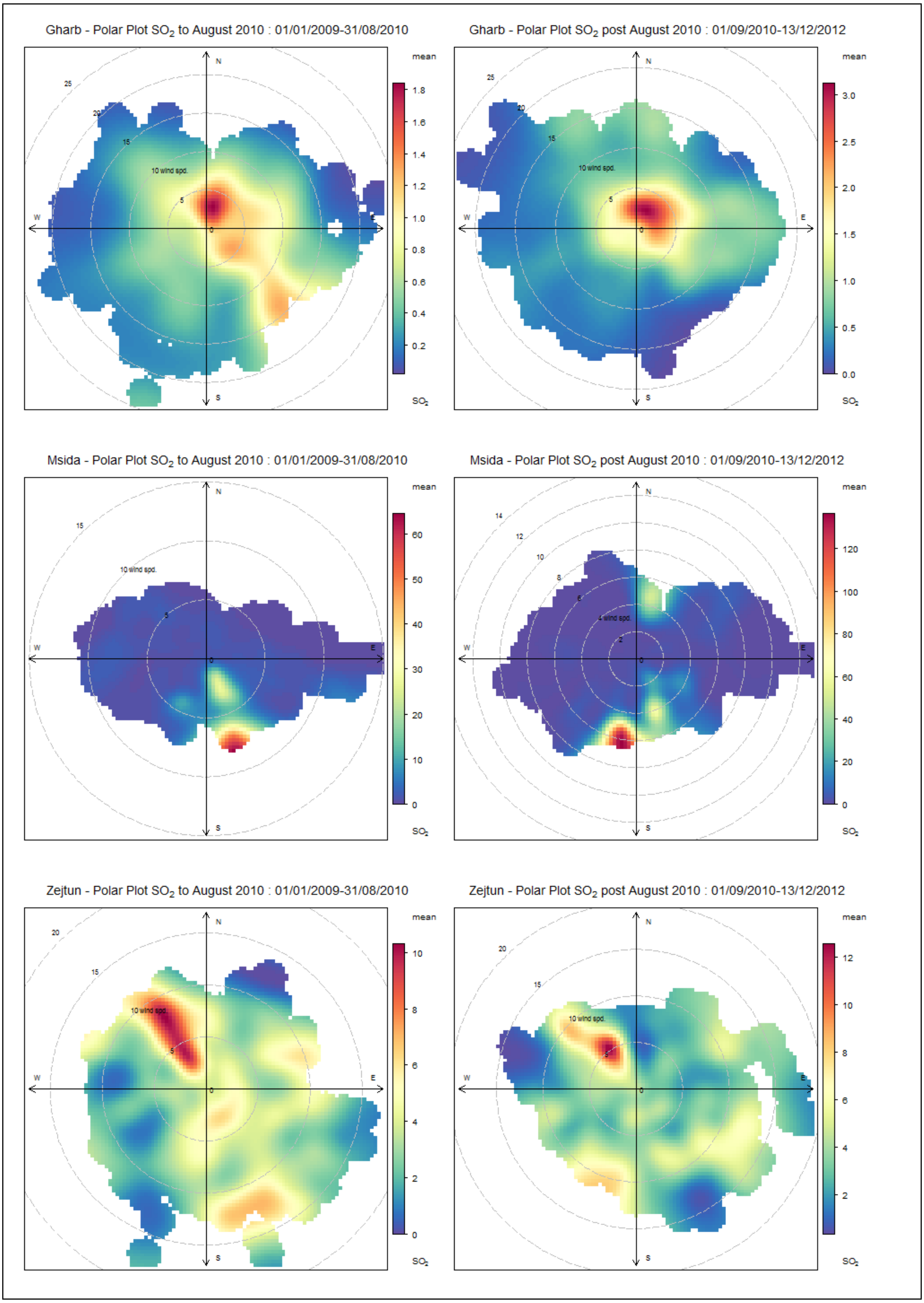
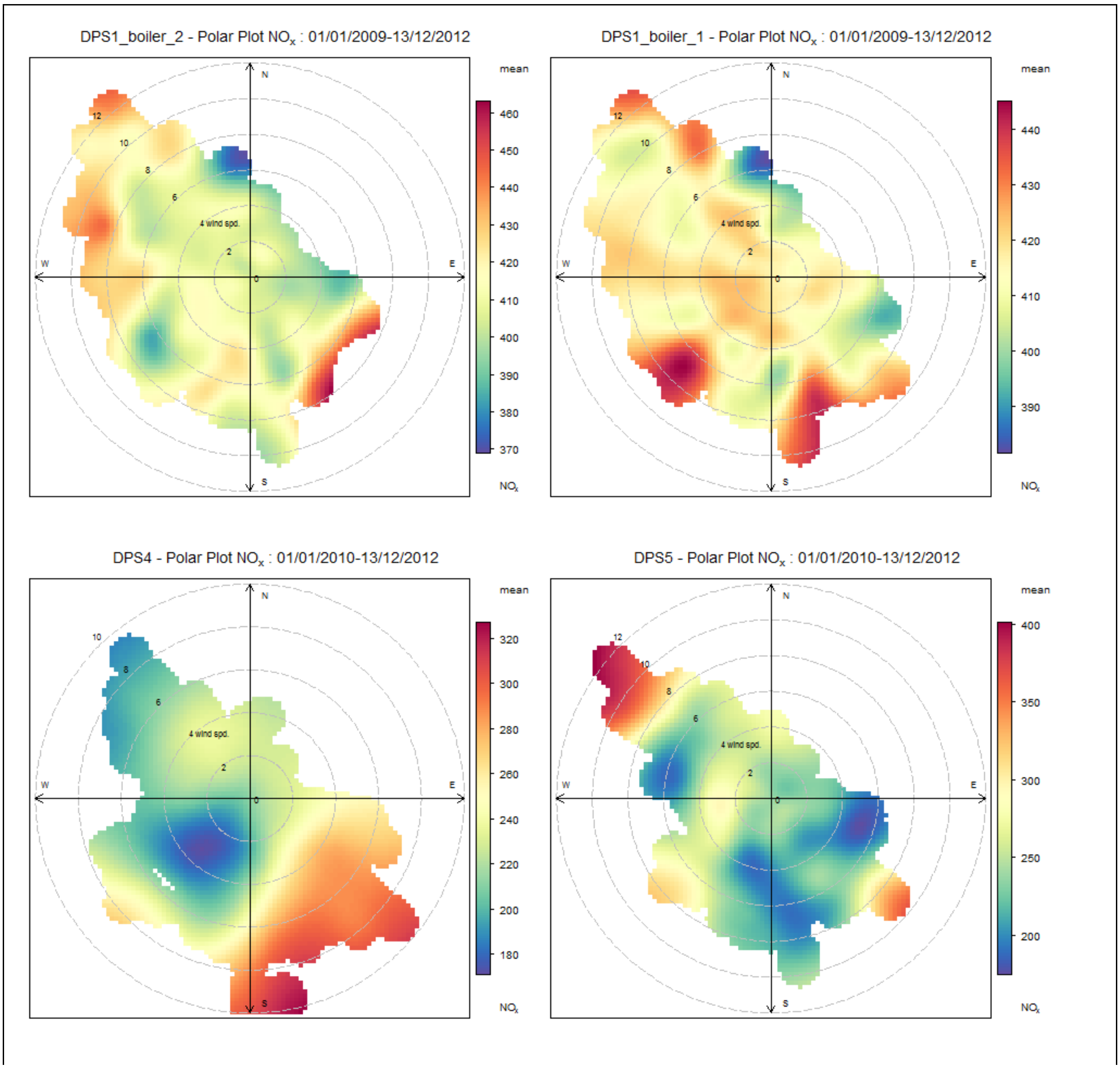


Figure 5: Polar plots for SO_2 for MEPA sites pre- and post- August 2010

3.5.6. Polar Plots from DPS Emissions Data

Figure 6 shows emissions of NOx (mg/m^3 or 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 SE (as in the DPS4 plot below) then these emissions would be carried in a NW direction, i.e. inland. These plots do indicate that there is the potential for NOx emissions from DPS1 and 4 to have been carried inland, however there are no NOx/NO_2 monitoring data in Marsaxlokk or Birzebbuga to confirm whether this affected local ambient concentrations. Highest maximum NOx emissions were recorded at DPS6, though it should be noted that data capture of NOx at DPS6 was poor. Figure 7 shows the similar plots for dust emissions (mg/m^3 or mg/Nm^3), but does not indicate that there were any significant onshore incursions from DPS. Dust emissions from DPS4 and 5 were negligible, with the highest maximum dust emissions from DPS1. However, it should be noted that data capture of dust emissions at DPS6 was poor.



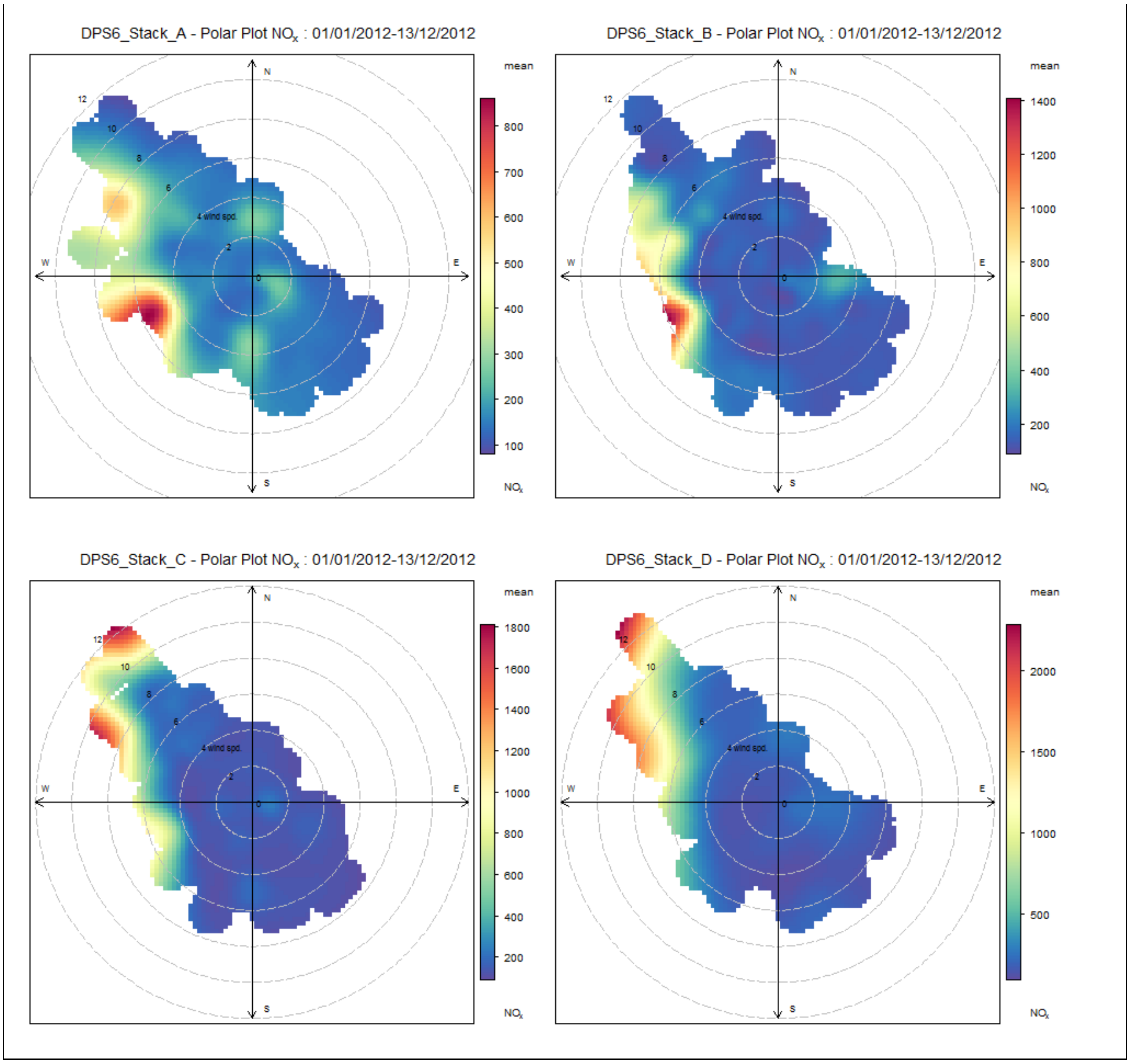
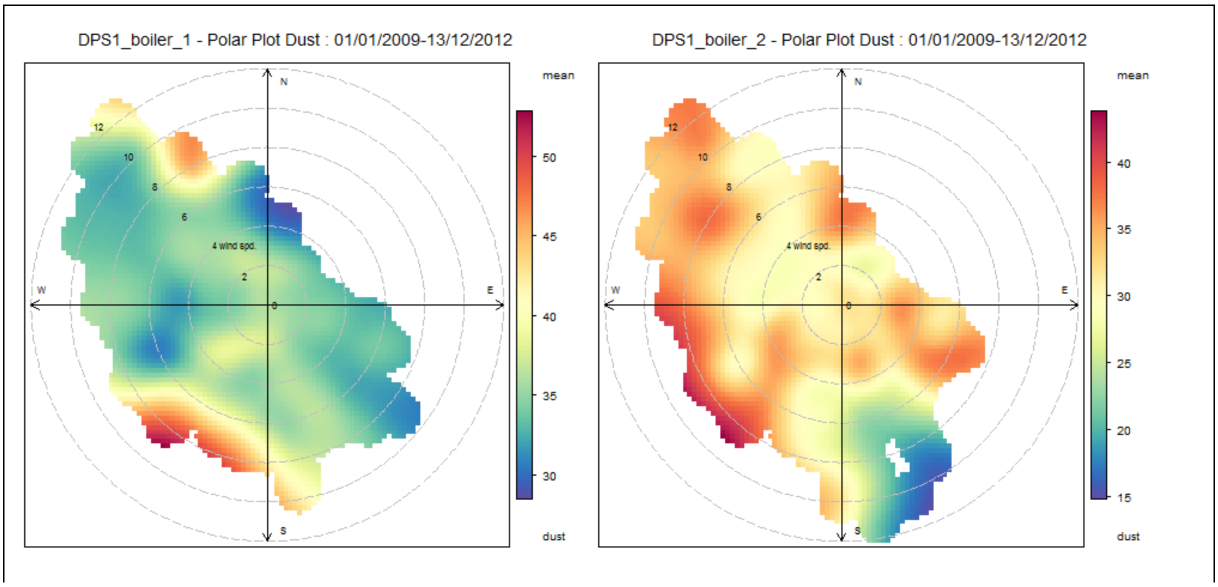


Figure 6: Polar plots for NOx from DPS sites



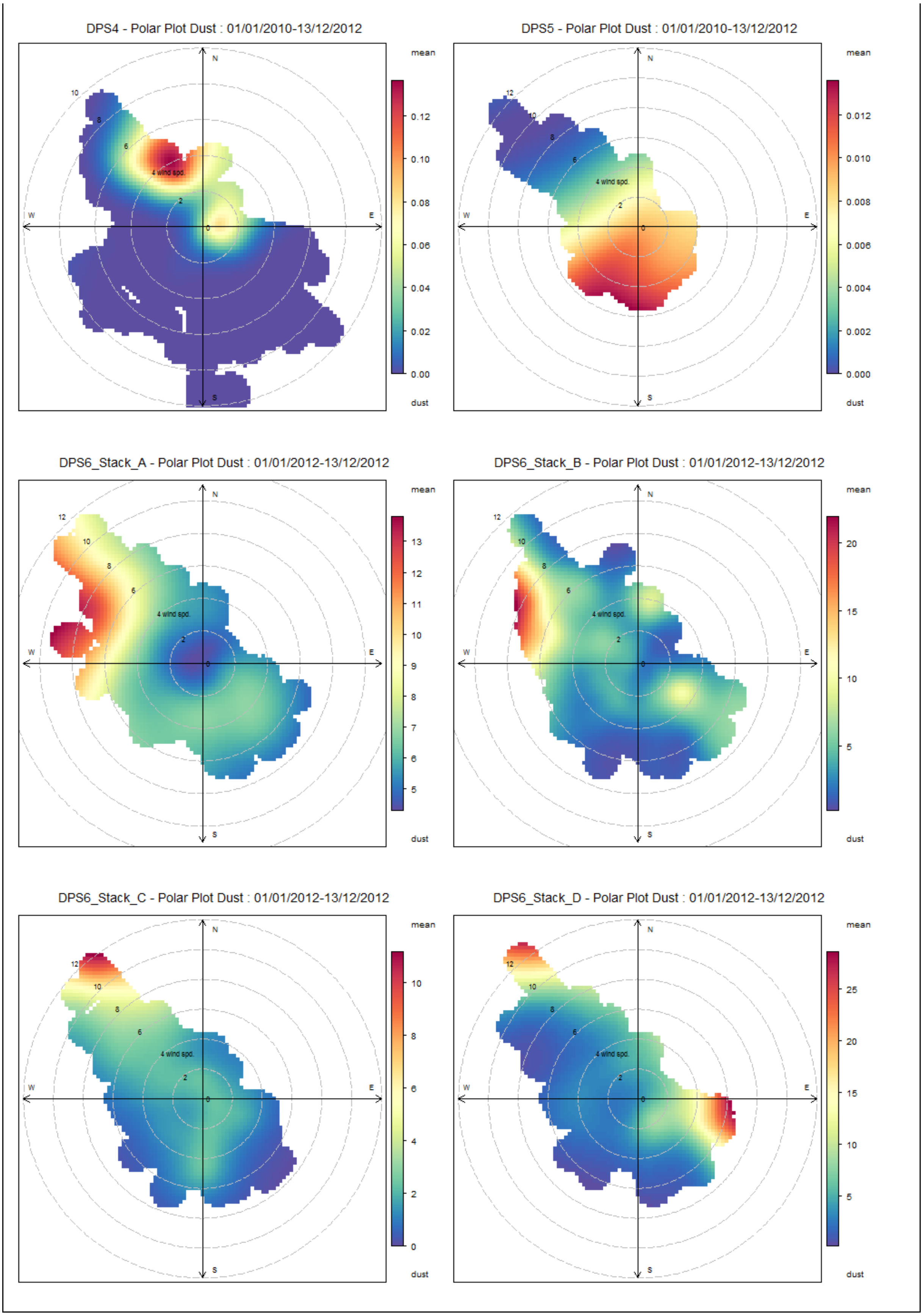
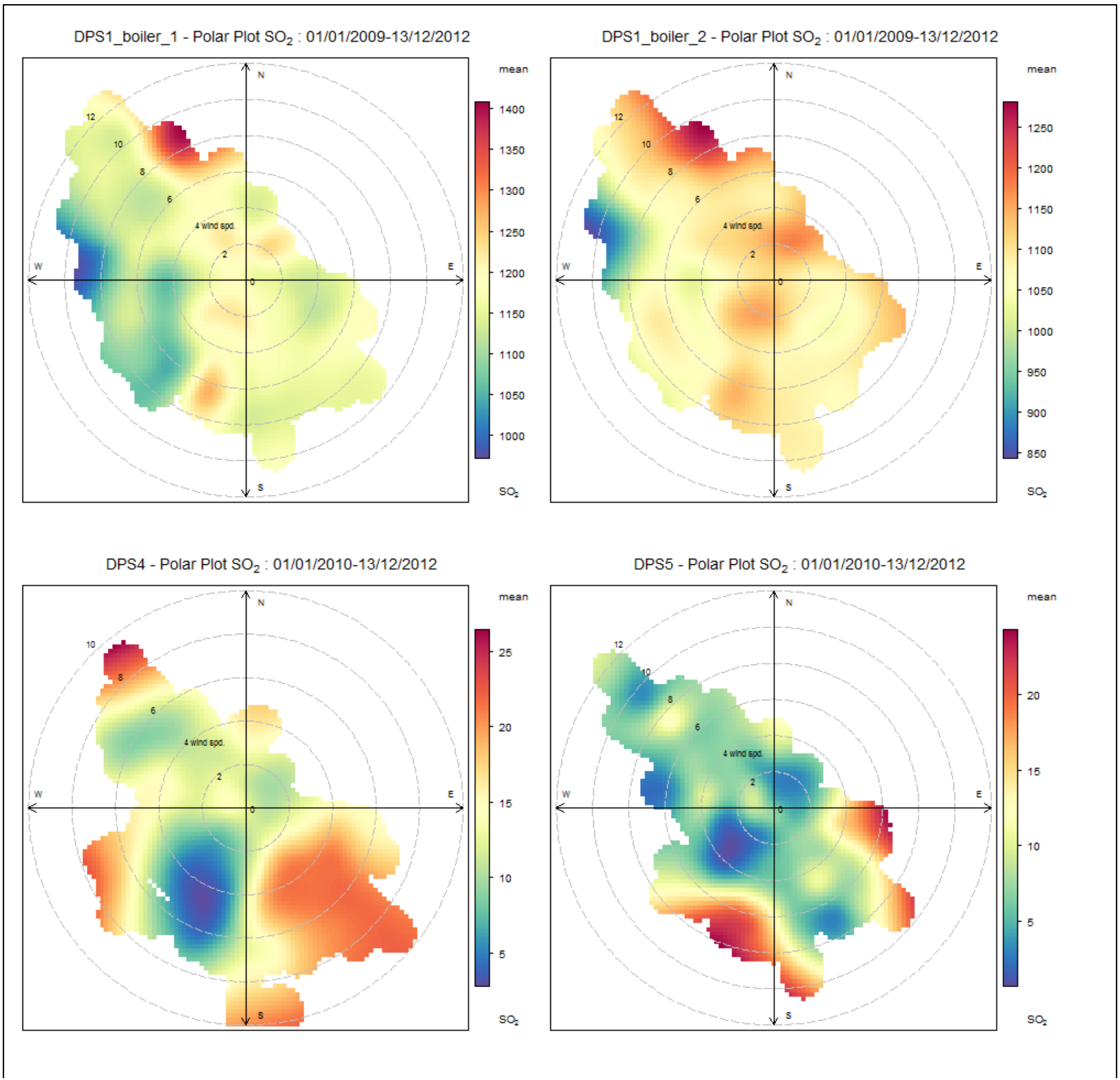


Figure 7: Polar plots of dust emissions from DPS sites

Figure 8 and Figure 9 shows emissions of SO_2 (mg/m^3 or mg/Nm^3) and CO (mg/m^3 or mg/Nm^3) from the DPS respectively plotted with wind speed (m/s) and direction (degrees). There is no clear spatial pattern between sites for these pollutants. The plots indicate that there may be the potential for SO_2 and CO emissions from DPS6 to have been carried inland, however there are no SO_2 or CO monitoring data in Marsaxlokk or Birzebbuga to confirm whether this affected local ambient concentrations. It should be noted that data capture of these pollutants at DPS6 was poor. Highest maximum SO_2 emissions were recorded at DPS1, and highest maximum CO emissions were recorded at DPS6.



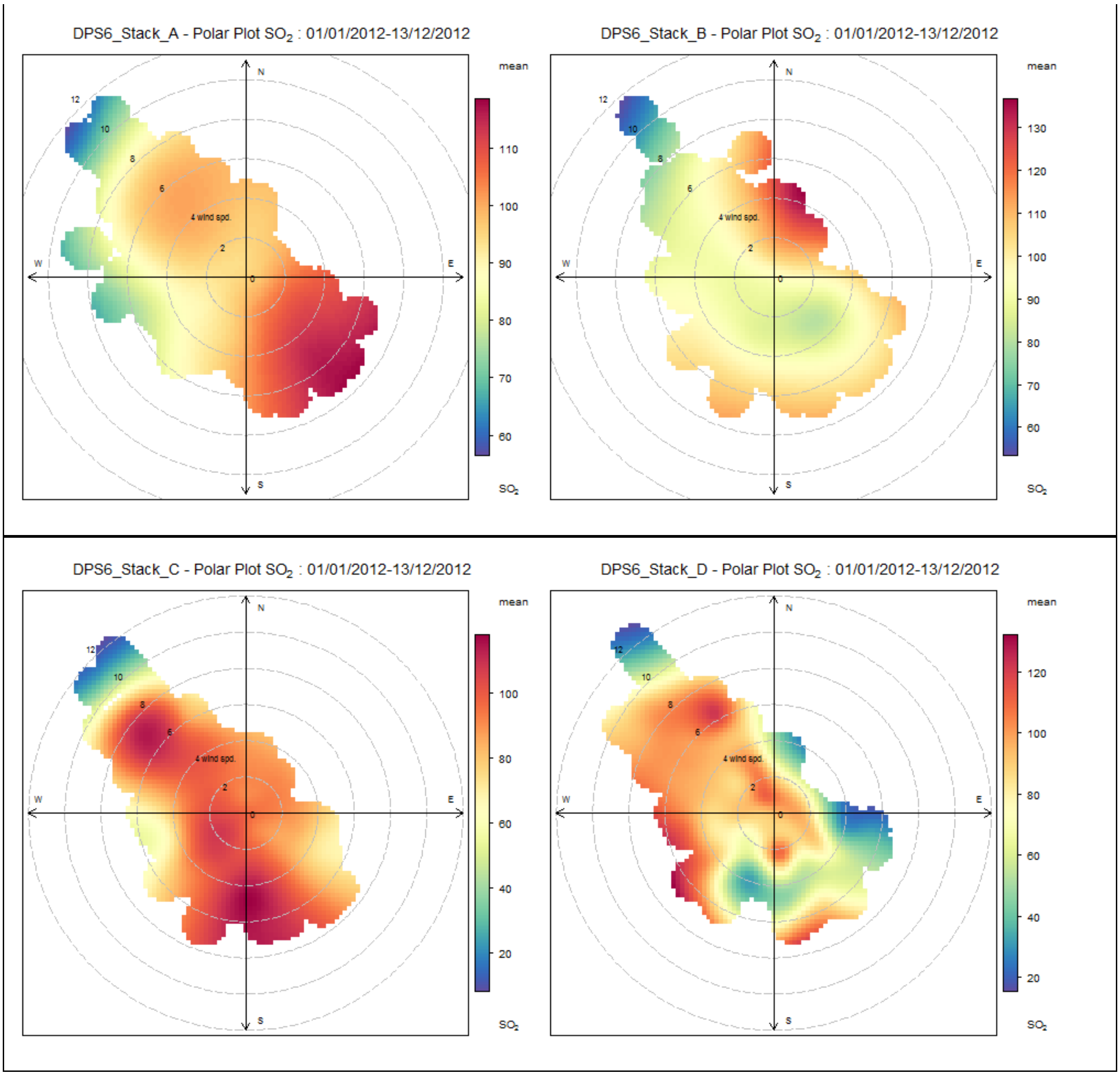
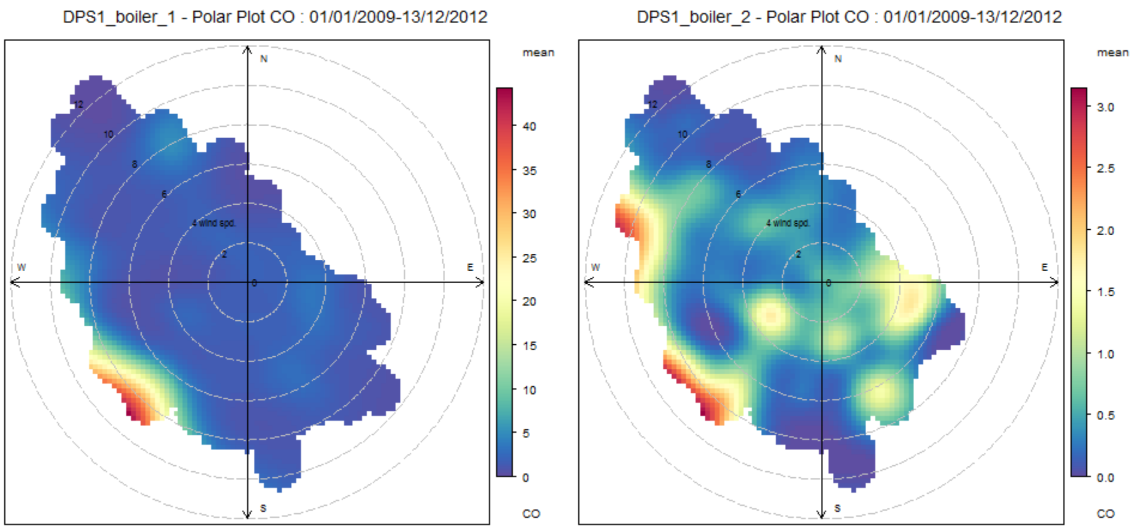


Figure 8: Polar plots of SO_2 emissions from DPS sites



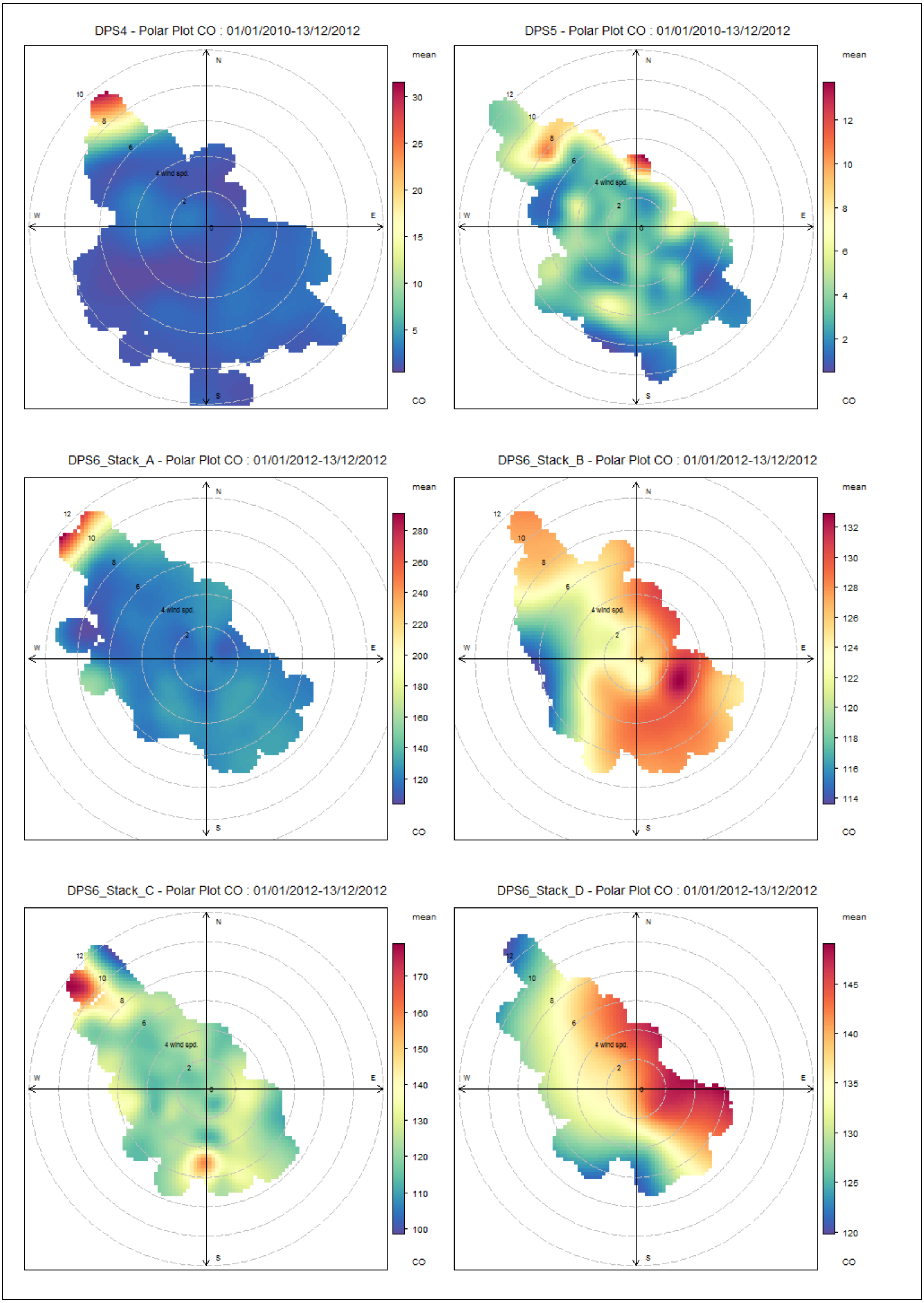


Figure 9: Polar plots of CO emissions from DPS sites

3.5.7. Summary of Spatial Analysis

Spatial analysis of the data from 2009 to 2012 has indicated that at all sites the highest concentrations of PM_{10} and $PM_{2.5}$ are found when the wind is from the south (contrary to the predominant wind direction). The wind speed and direction and the occurrence at all sites suggests that this is a transboundary source, e.g. Saharan dust, and unlikely to be related to recirculating air from local sources. There were also no significant incursions of dust emissions from DPS suggested by the data. Analysis of other pollutants has not revealed any dominant source, apart from SO_2 concentrations at Msida and Zejtun, which appear to originate in the vicinity of MPS, although this cannot be corroborated without reciprocal analysis of the SO_2 emissions from this site, which is beyond the remit of this study. Analysis of emissions data from DPS indicates that there may have been incursions of NOx, SO_2 and CO, however there is no monitoring data available to determine whether this is likely to have affected local ambient concentrations.

The baseline analysis of spatial patterns of pollutant concentrations and emissions from 2009 to 2012 does not suggest that DPS is a significant source of monitored PM_{10} or $PM_{2.5}$ concentrations at Marsaxlokk or Birzebbuga. This is useful as it should be clearer to see any apparent changes in these plots post-commissioning. It should be noted that although the analysis has, as far as possible, used data with relatively good data capture (exceptions are noted in the text), the presence of sites with poor data capture, including a partial years' wind data (70.2% capture), means interpretation of these plots should be treated with caution.

3.6. Temporal Analysis of Monitoring Data

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

- Time plots of pollutants by year at each site.
- Time variation plots in pollution concentrations 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 A. 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. Figure 14 shows the time plots of all for MEPA sites, Figure 15 shows the consultants' sites and Figure 16 shows the DPS site emissions. These plots have been included in Appendix B.

3.6.2. Time Variation Plots of Pollutants

The following plots are created using the *time variation* function in Openair. This presents plots of how average concentrations of pollutants (or other data) 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 those peak-hours that will lead to exceedences of the daily mean PM_{10} objective. Plots of multiple pollutants have been normalised[4] to show them on the same scale. Data has also 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.

Figure 10 shows 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). As might be expected, both pollutants show a

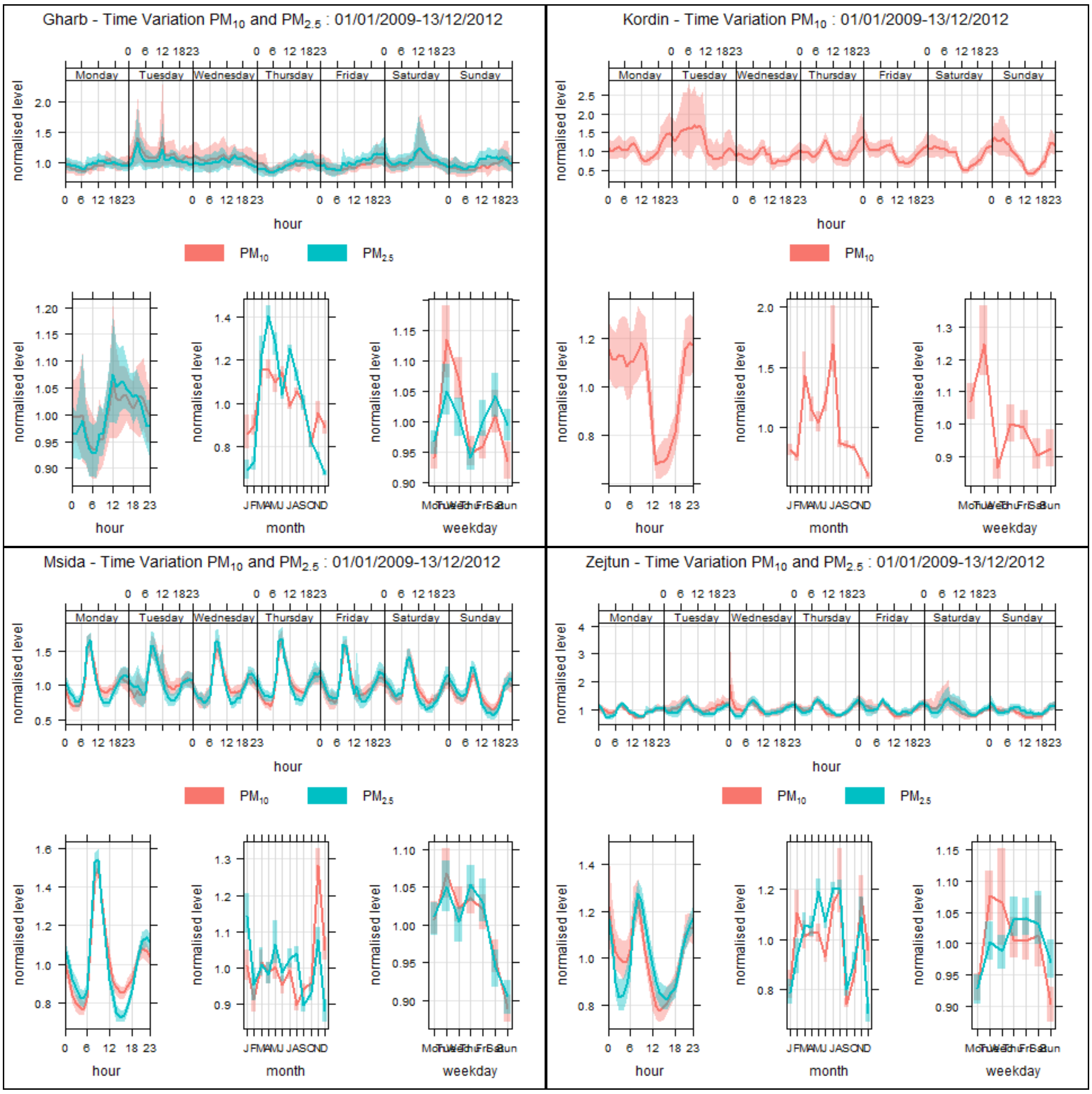


Figure 10: Time variation plots of PM_{10} and $PM_{2.5}$ for MEPA sites

[4] Concentrations are normalised by dividing by their mean value, thereby presenting concentrations as proportions rather than absolute values. This is particularly useful in comparing the patterns of concentrations for several pollutants on different scales. For the purposes of this report the data is presented as normalised data. For future monthly reports the data may be presented as both normalised and un-normalised data to allow for exceedence analysis.

similar relationship, with a strong diurnal pattern typical of traffic sources apparent at the roadside site (Msida) and to a lesser extent at the urban background site (Zejtun). The absence of $PM_{2.5}$ data for Kordin means a comparison is not possible here, but PM_{10} at this site appears to show a different pattern to the other sites with higher concentrations overnight, perhaps related to its location close to MPS. The scale of the diurnal patterns at all sites is similar, however there appears to be an anomalous peak of PM_{10} evident between Tuesday and Wednesday on the Zejtun daily plot that has skewed the scale.

Figure 11 shows the time variation plots for O_3 (µg/m^3) and NOx (µg/m^3) at each of the MEPA sites. These diurnal plots clearly show the typical inverse relationship between NOx and O_3 at all sites, though more pronounced at the non-rural sites. There is also a characteristic spring/summer peak of O_3. The scale of the diurnal pattern of O_3 concentrations is similar at all sites, however it is apparent that the scales for sites affected by traffic (Msida and Zejtun) are higher for NOx.

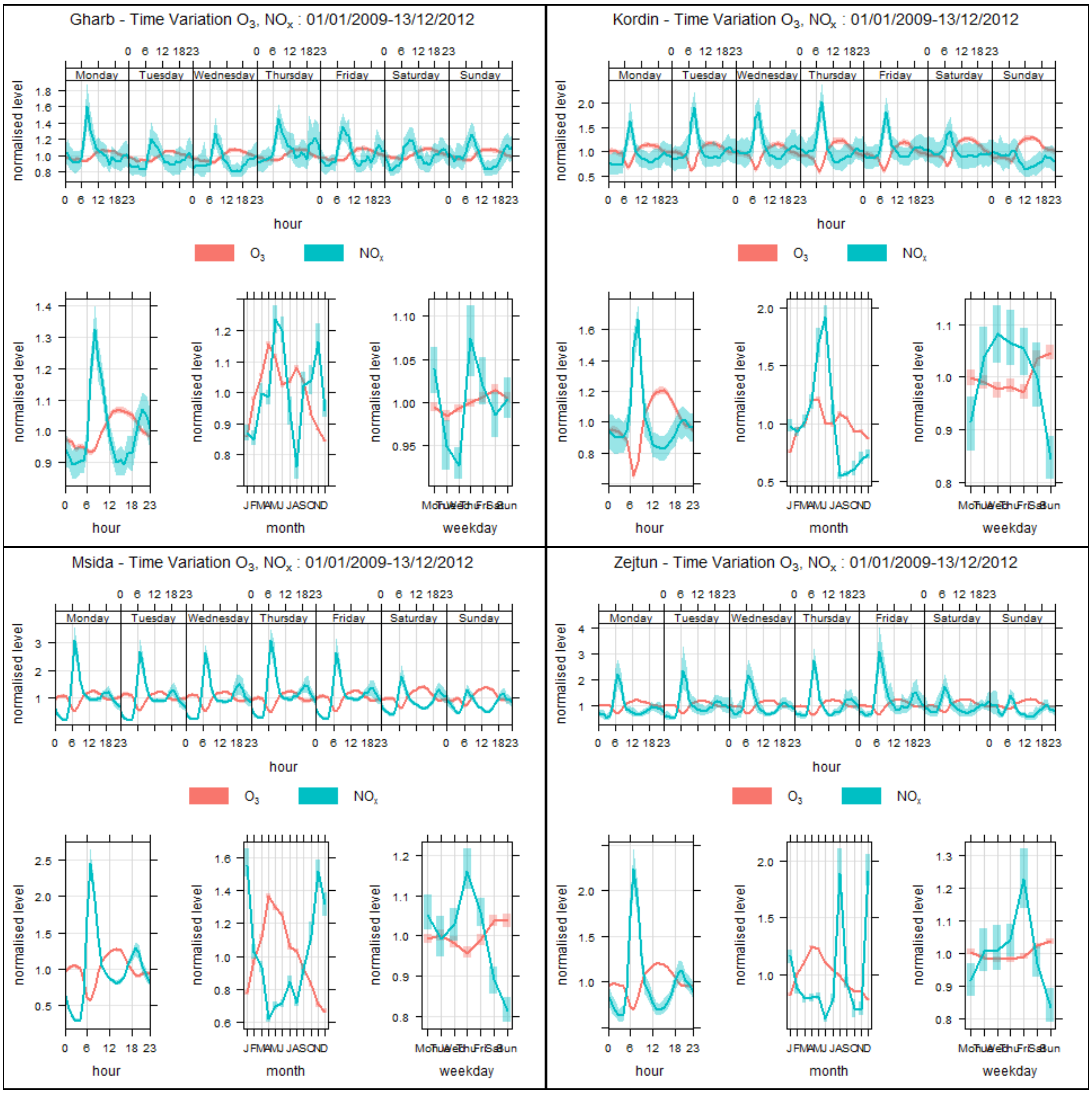


Figure 11: Time variation plots of O_3 and NOx for MEPA sites

Figure 12 shows the time variation plots for PM_{10} (µg/m^3) and $PM_{2.5}$ (µg/m^3) for the consultants' monitoring sites at Birzebbuga and Marsaxlokk. Given the short time period of this data there is a high level of uncertainty in these plots, however there is a diurnal pattern apparent typical of traffic sources, comparable with the scales shown at the traffic-affected sites, Msida and Zejtun.

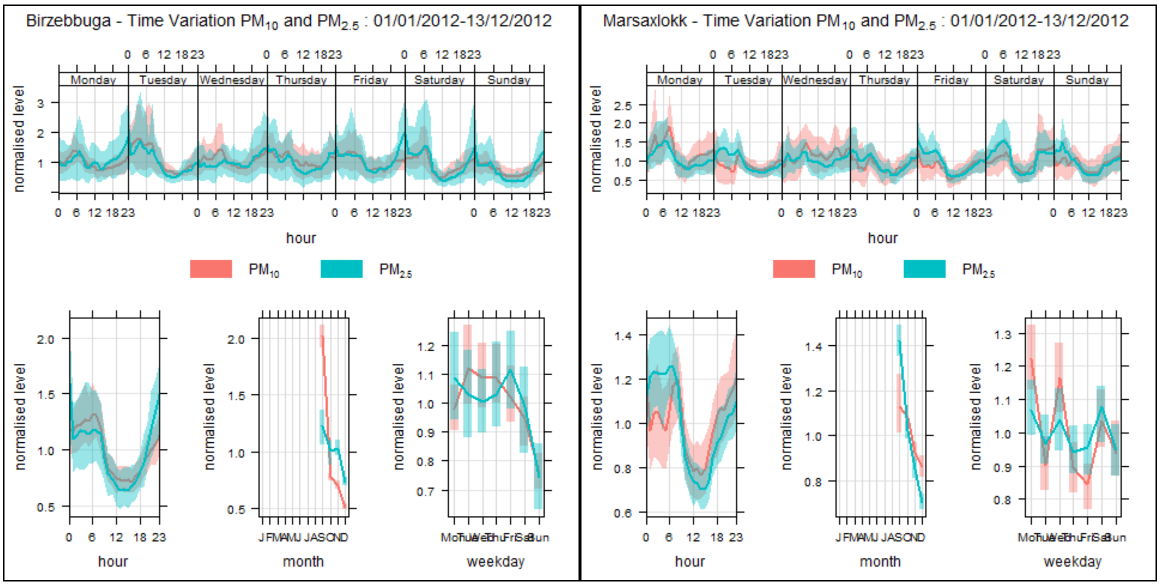


Figure 12: Time variation plots of PM_{10} and $PM_{2.5}$ for Birzebbuga and Marsaxlokk

Figure 13 shows the time variation plots for dust (mg/m^3 or mg/Nm^3), NOx (mg/m^3 or mg/Nm^3) and SO_2 (mg/m^3 or mg/Nm^3) emissions from the DPS1 boilers and for DPS4 and 5. (Plots for DPS6 have not been included due to poor data capture.) NOx and SO_2 emissions appear to remain relatively constant throughout the day whereas dust emissions at DPS1 show a clear bimodal peak on each day. The pattern is less clear at DPS4 and 5 though there appears to be a single morning peak. Seasonal variations are difficult to discern with seemingly elevated NOx in the early spring and higher SO_2 in autumn.

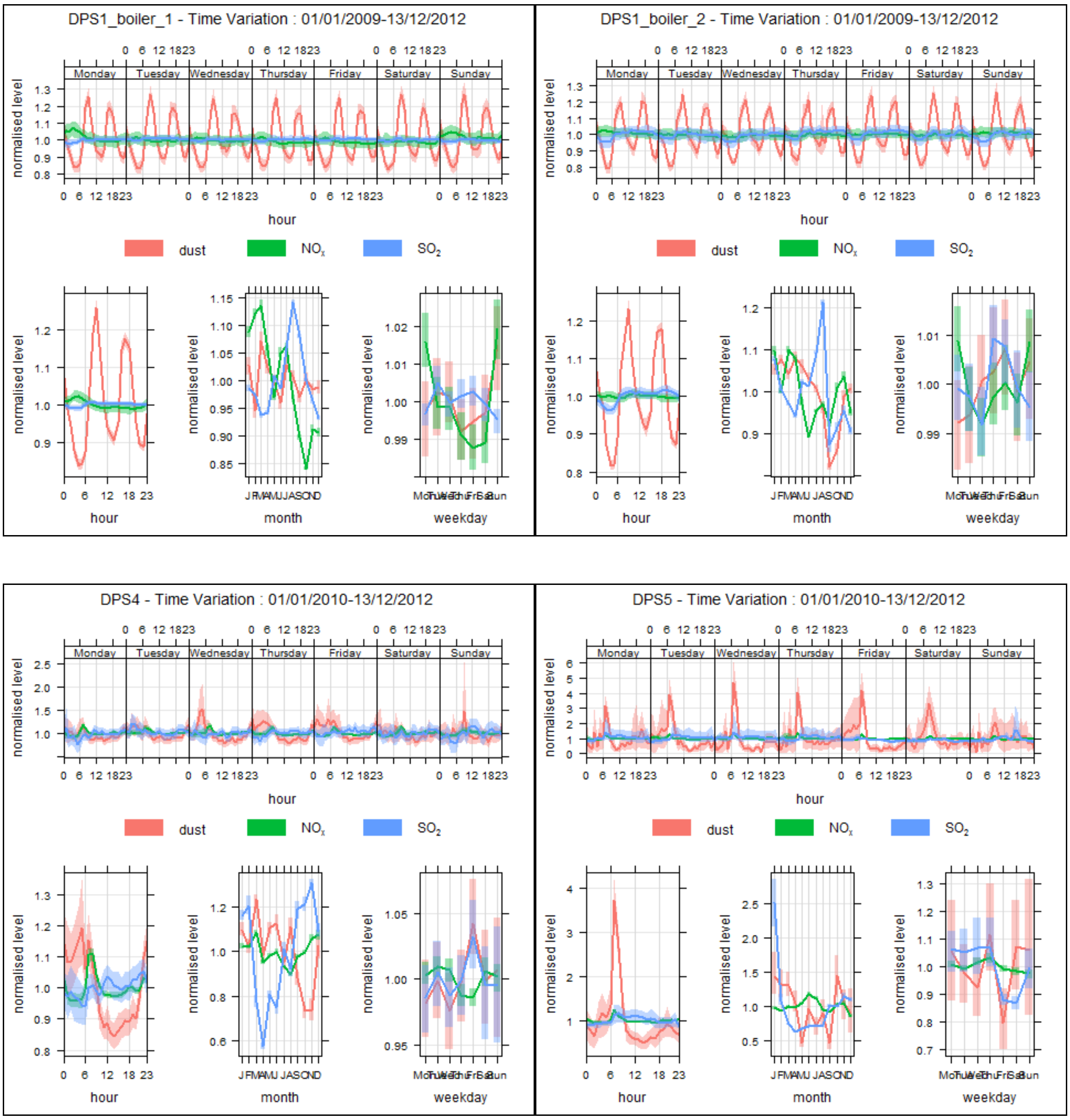


Figure 13: Time variation plots of Dust, NOx and SO_2 for DPS1, 4 and 5

3.6.3. Summary of Temporal Analyses

The analyses of temporal patterns in the pollution data has focussed principally on the MEPA data, as this forms the longest dataset from which trends and average patterns can be discerned. 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. There do not appear to be any significant trends in any of the pollutants analysed for these sites over the four years covered by this baseline report. This is also true for the DPS emissions data, though some of these are based on limited data availability.

Analysis of the diurnal profiles of pollution concentrations also show that PM_{10} and $PM_{2.5}$ at all sites appear to have a strong traffic-related element, as does NOx which shows a clear inverse relationship with O_3. There is also a clear seasonal pattern typical of transboundary O_3 concentrations.

Diurnal patterns of the DPS6 emissions data show a clear bimodal peak for dust emissions but more constant for NOx and SO_2. Enemalta have confirmed that this strong bimodal pattern of dust emissions at DPS1 is likely to be related to soot-blowing operations. There does not appear to be any clear relationship between the DPS dust emissions and the particulate matter concentrations recorded at either Birzebbuga or Marsaxlokk.

3.7. Summary of Data Analysis

The intention of this part of the report has been to present a baseline analysis of available monitoring data over the four years from 1st January 2009 to 13th December 2012 against which to assess the impact of the DPS plant post-commissioning. Long-term data from four MEPA monitoring sites (Gharb, Kordin, Msida and Zejtun) have been used to give an impression of typical rural background, industrial background, roadside and urban background sites respectively across the Maltese Islands. These sites monitor a range of pollutants and also record wind data, which has enabled spatial analysis of the data to be undertaken through the use of polar plots. PM_{10} and $PM_{2.5}$ data from Beta Attenuation Monitoring undertaken by consultants, Environmental Monitoring Services Ltd, have been used to establish typical concentrations at these sites prior to the HFO commissioning of the DPS plant. It should be noted, however, that this data only covers the second half of 2012 and may not necessarily be comparable with the first six months of 2013 when the post-commissioning monitoring is being reported. As well as the monitoring data, this baseline report has also included emissions data received to date in order to determine whether there was any discernible relationship between the emissions and measured concentrations of pollutants, particularly PM_{10} and $PM_{2.5}$, and also to indicate any subsequent changes in emissions post-commissioning. The data analysed here are ‘as received’ with no adjustment made for natural sources.

The data analysis that has been undertaken covers spatial and temporal analysis of the data, using polar plot, time plot summary plot, wind rose plot and time variation plot functions using Openair. As this is a baseline report, exceedence analysis has not been included at this stage though it will be appropriate to include exceedence analysis in the monthly reports to indicate the potential contribution of DPS emissions to exceedences of the PM_{10} Limit Value. The plots are presented in Section 3 and in the Appendices. The text accompanying the figures is not intended to completely describe everything that may be evident from the graphs, nor have all the possible graphs been included in the report (all data and code used to create the plots is available, as is the freely available open-source software used to do the analyses). Local knowledge is vital in the interpretation of the outputs.

3.7.1. Key Points Resulting from the Data Analyses

Based on the available data there are no significant observations to be made from the spatial and temporal analyses presented in this report. Sources of pollutants appear to be local traffic and transboundary pollution episodes with little conclusive evidence of emissions from the DPS contributing to monitored pollution concentrations. Spatial analysis of emissions data from DPS indicates that there may have been incursions of NOx, SO_2 and CO, however there is no monitoring data available for Birzebbuga or Marsaxlokk to determine whether this is likely to have affected local ambient concentrations. There may be some indication of a contribution from Marsa Power Station (MPS) to particulate matter at Kordin apparent in the temporal analysis, though the absence of wind data for this site means no spatial analysis could be used to corroborate this assumption. MPS may also be contributing to SO_2 concentrations at Msida and Zejtun according to the spatial analysis, however no emissions data for this is site available to verify.

In summation, this baseline analysis provides a useful benchmark against which to compare the post-commissioning pollutant concentrations, as will be reported in the coming six months.

References

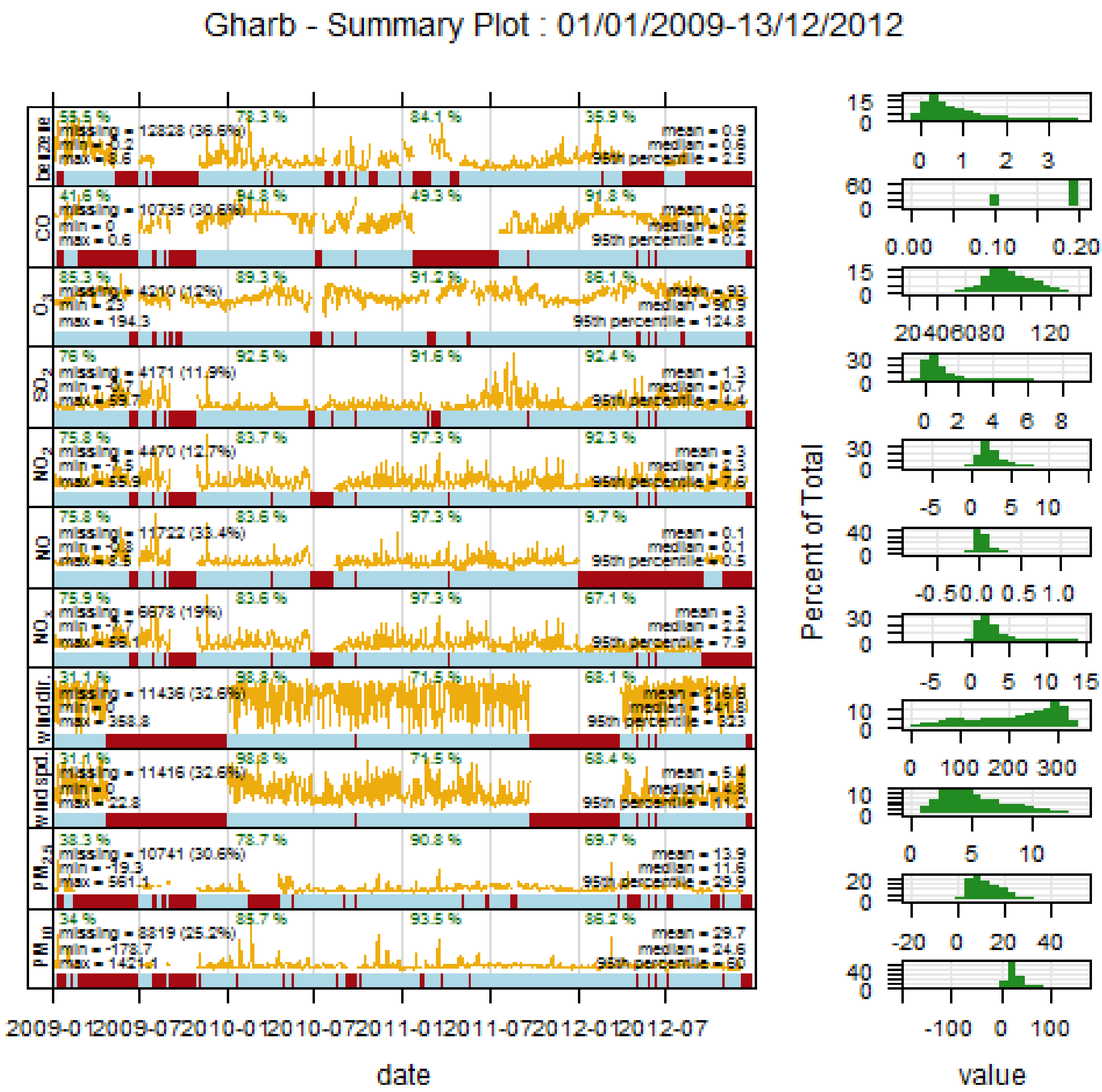
Carslaw, D.C. and Ropkins K., (2012) openair --- an R package for air quality data analysis. Environmental Modelling & Software. Volume 27-28, 52-61.

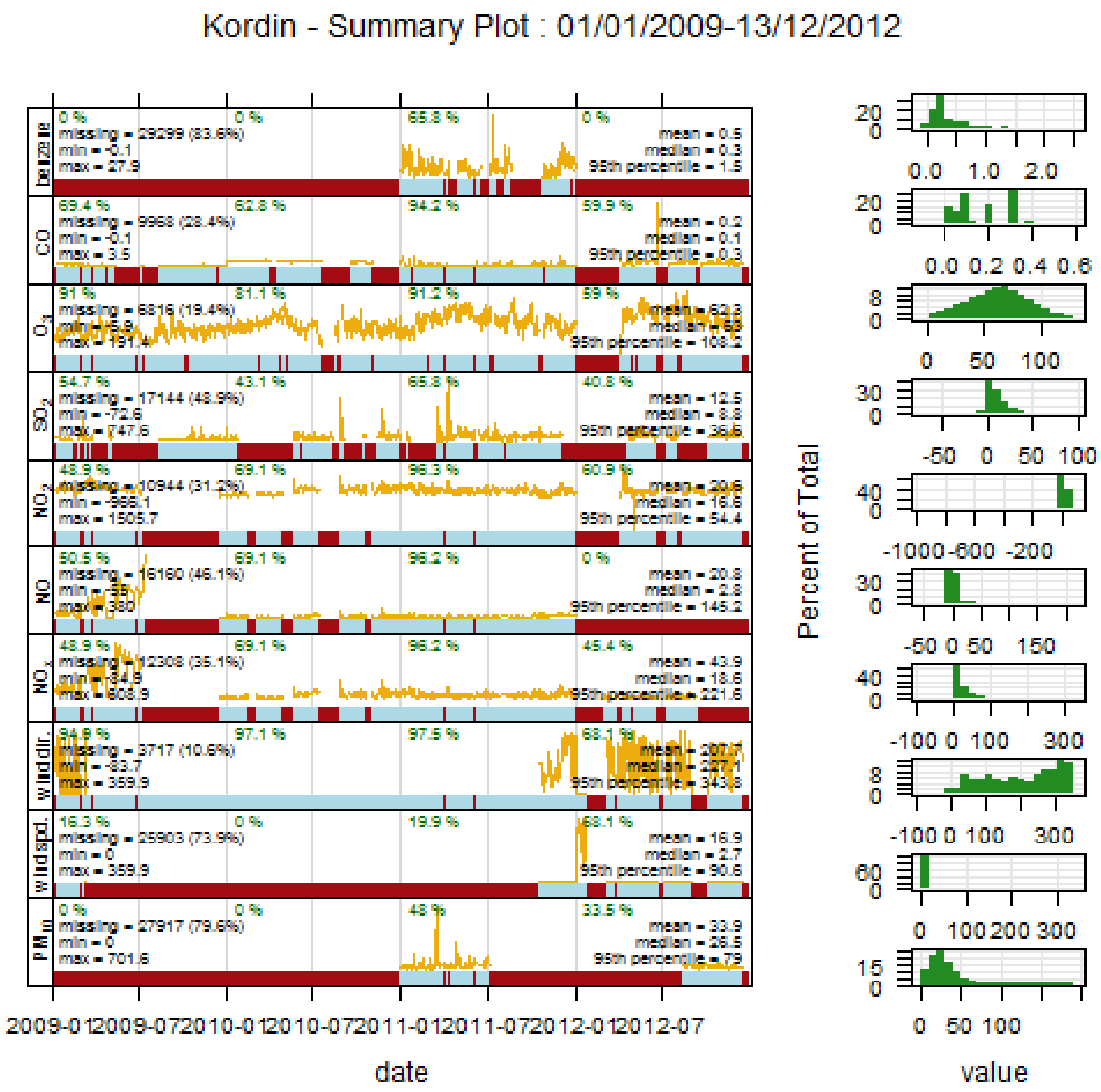
Carslaw, D. and Ropkins, K. (2012). openair: Open-source tools for the analysis of air pollution data. R package version 0.7-0.

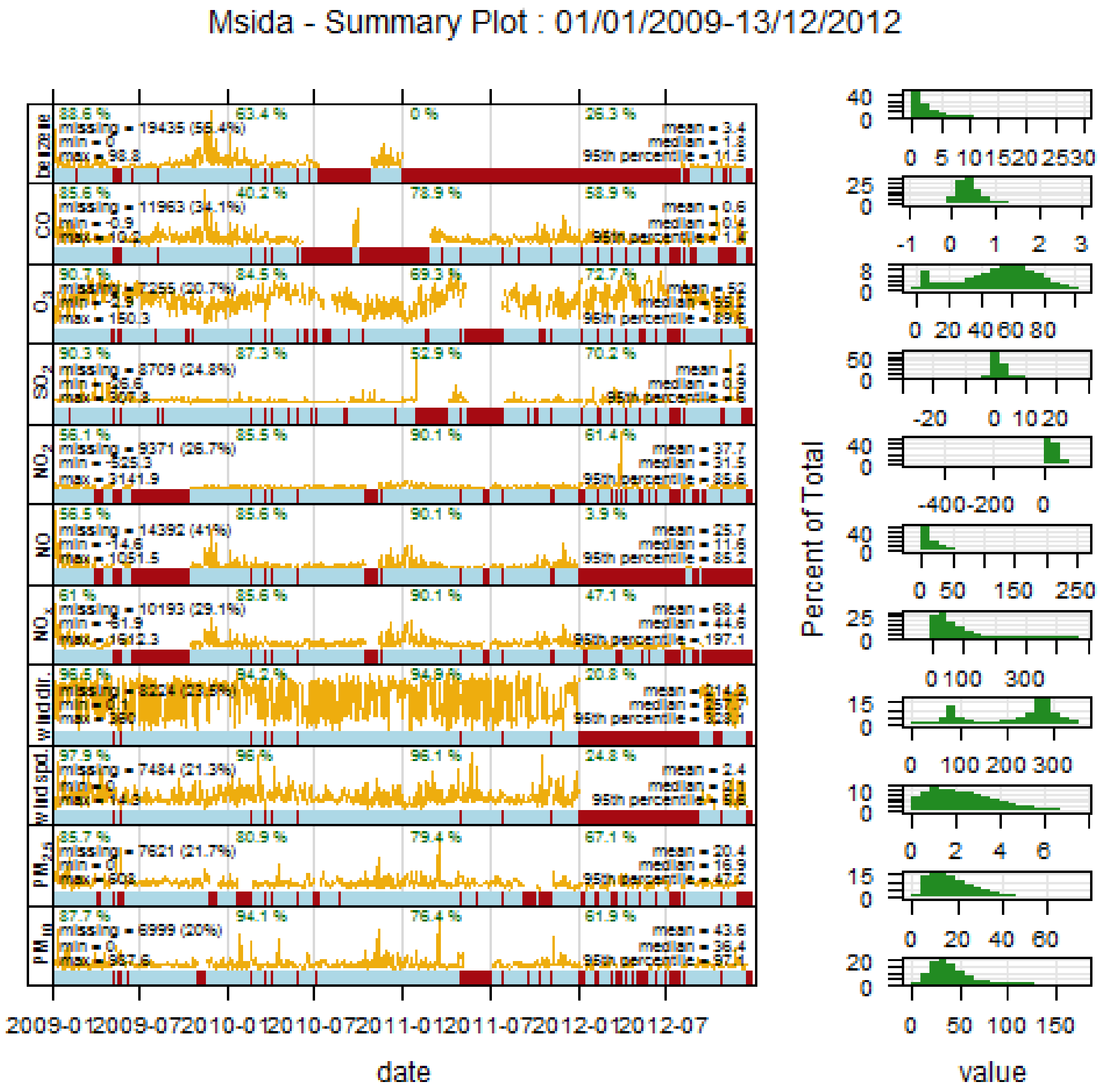
Galdies, C. (2011). The Climate of Malta: statistics, trends and analysis 1951-2010, National Statistics Office, Malta.

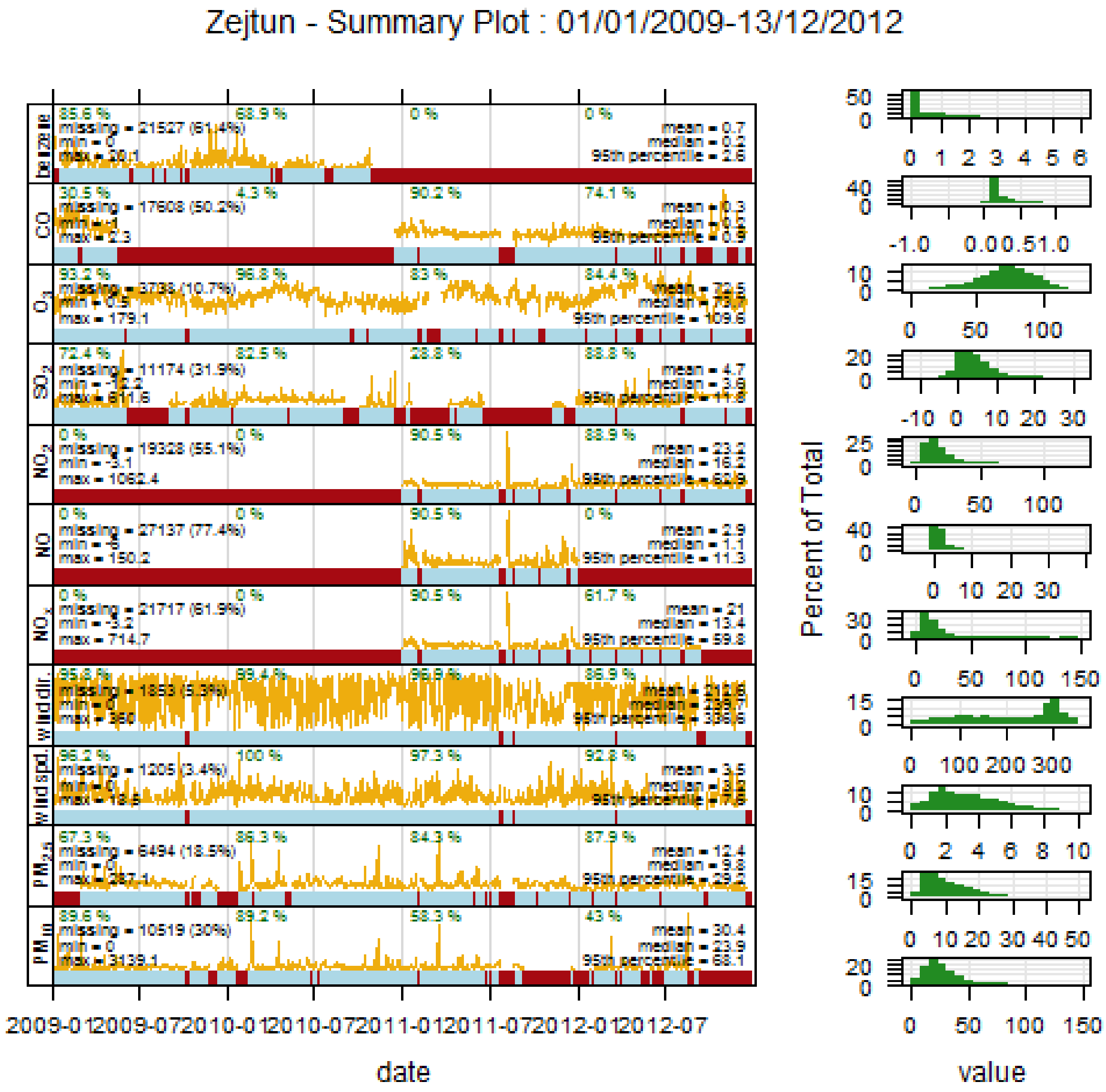
R Core Team (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

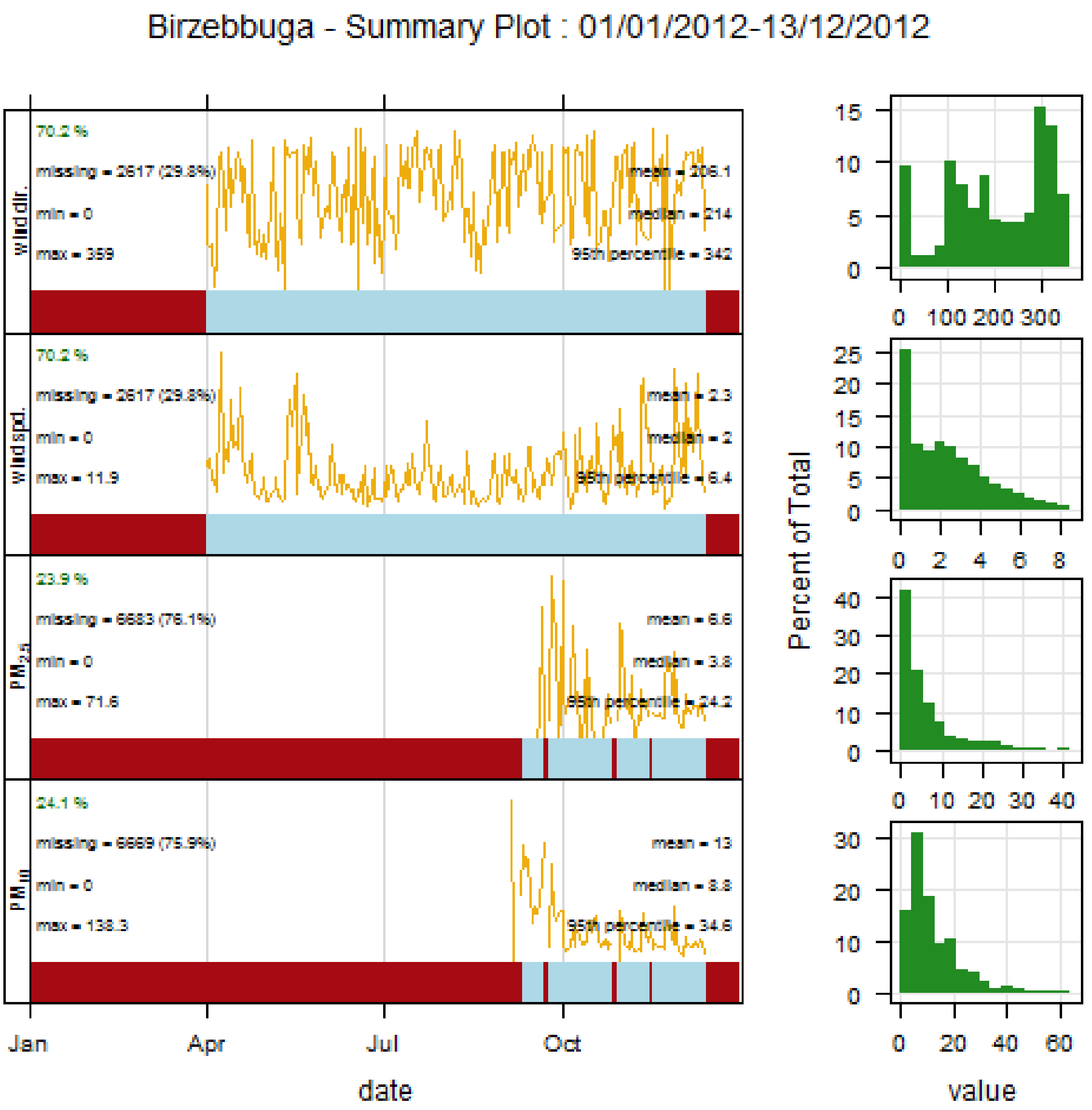
Appendix A: Summary plots of available data

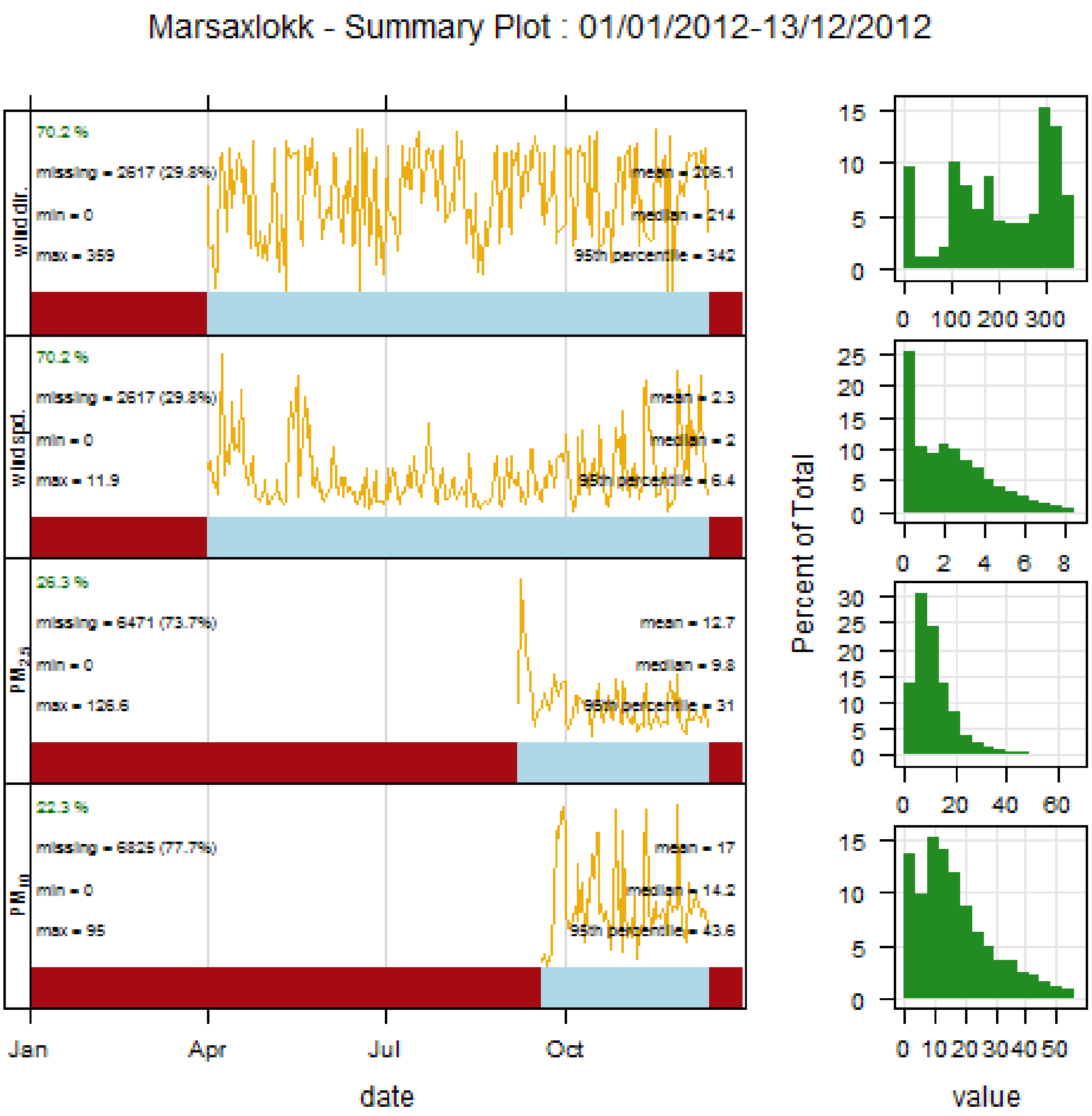


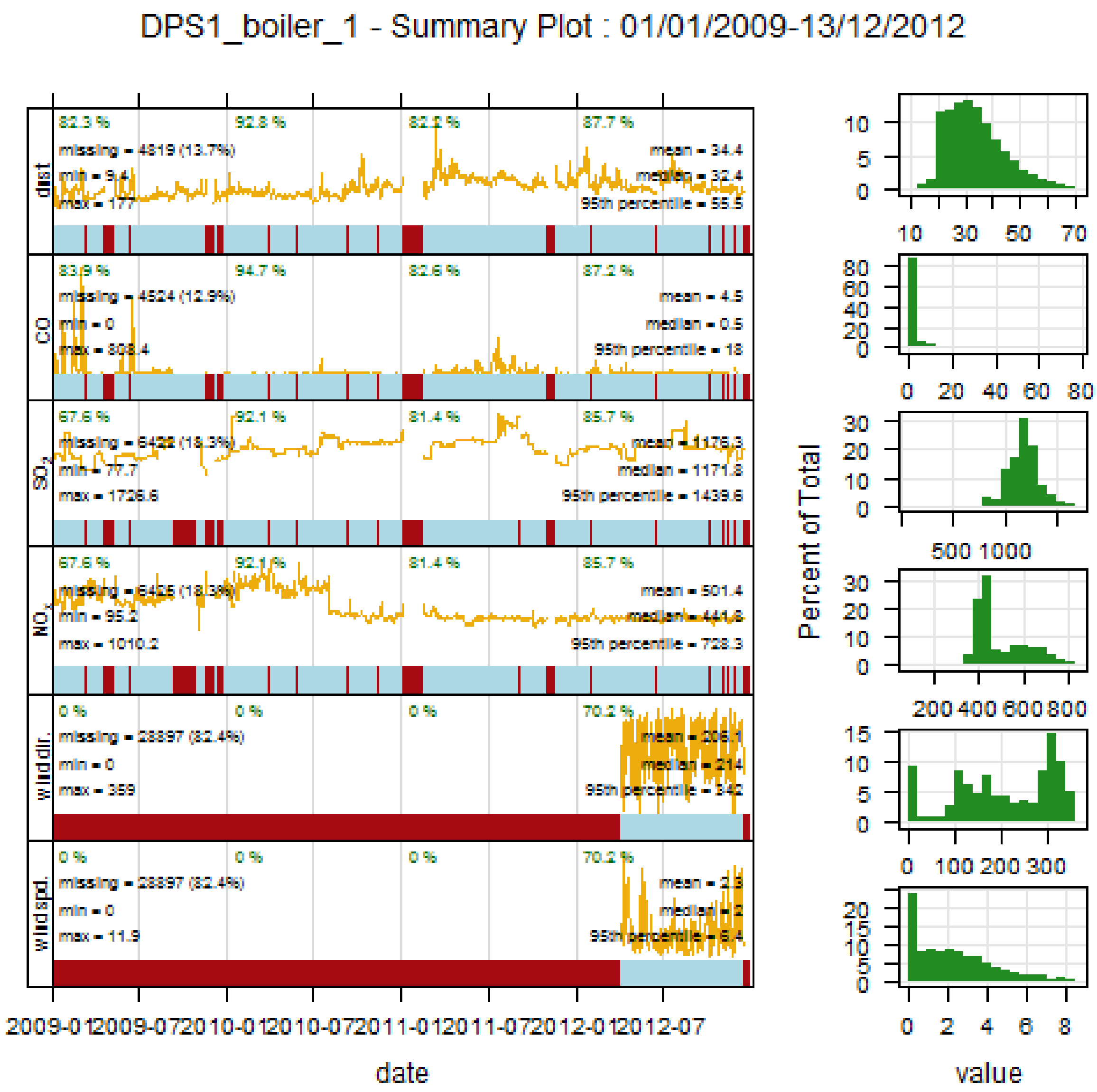

Kordin - Summary Plot : 01/01/2009-13/12/2012
date
value
Percent of Total

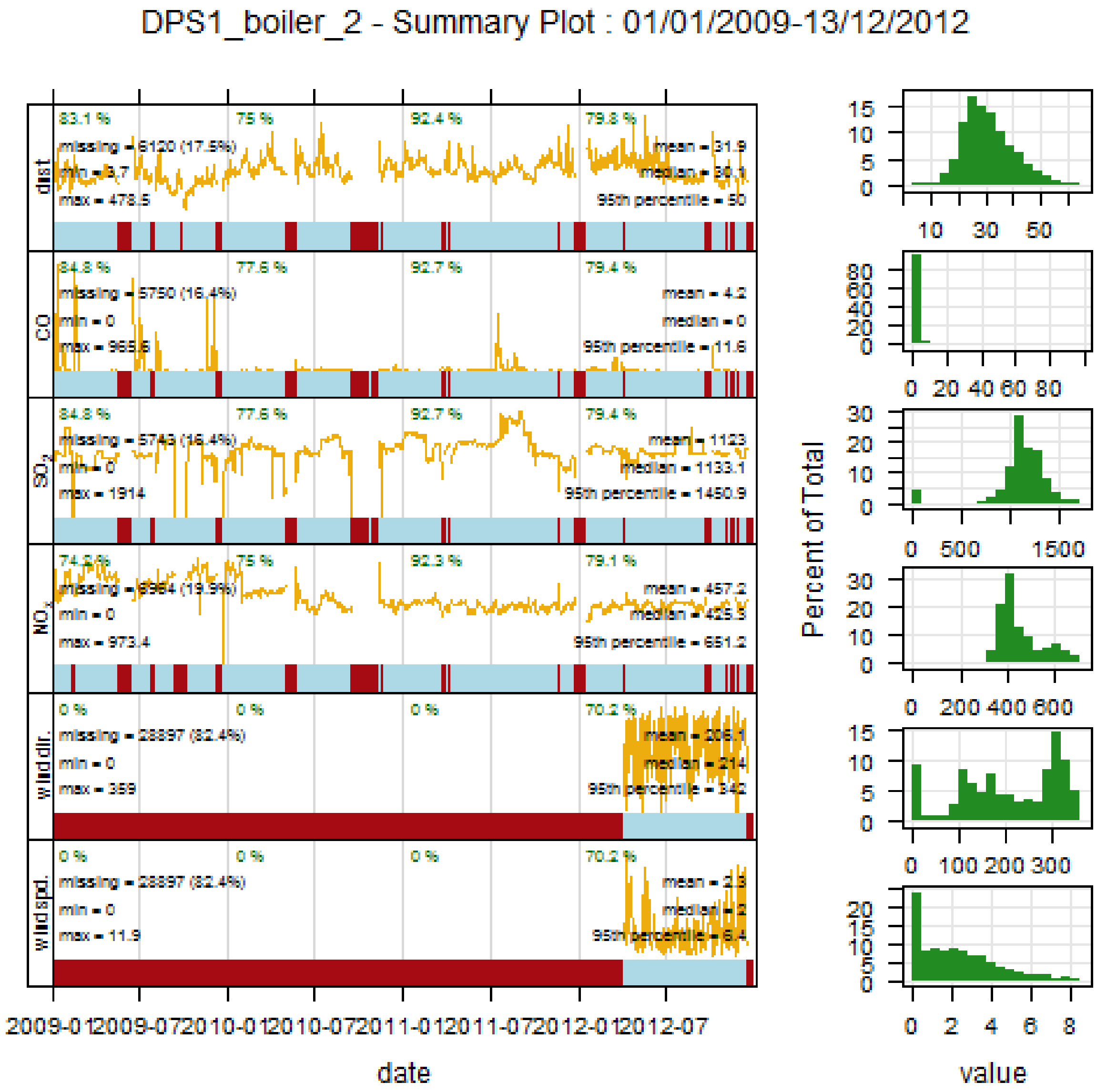

Msida - Summary Plot : 01/01/2009-13/12/2012
benzene
missing = 19435 (55.4%)
min = 0
max = 38.8
mean = 3.4
median = 1.8
95th percentile = 11.5
CO
missing = 11963 (34.1%)
min = -0.9
max = 10.2
mean = 0.6
median = 0.4
O3
missing = 7255 (20.7%)
min = -2.9
max = 150.3
SO2
missing = 8709 (24.8%)
NO2
missing = 9371 (26.7%)
min = -525.3
max = 3141.9
mean = 37.7
median = 31.5
95th percentile = 85.6
NO
missing = 14392 (41%)
min = -14.6
max = 1051.5
mean = 25.7
median = 11.6
95th percentile = 85.2
NOx
missing = 10193 (29.1%)
min = -51.9
max = 1612.3
mean = 68.4
median = 44.6
95th percentile = 197.1
wind dir.
missing = 8224 (23.5%)
min = 0.1
max = 360
wind spd.
missing = 7484 (21.3%)
mean = 2.4
PM2.5
missing = 7621 (21.7%)
mean = 20.4
median = 16.9
PM10
missing = 6999 (20%)
min = 0
max = 387.6
mean = 43.6
median = 36.4
2009-01 2009-07 2010-01 2010-07 2011-01 2011-07 2012-01 2012-07
date
Percent of Total
value

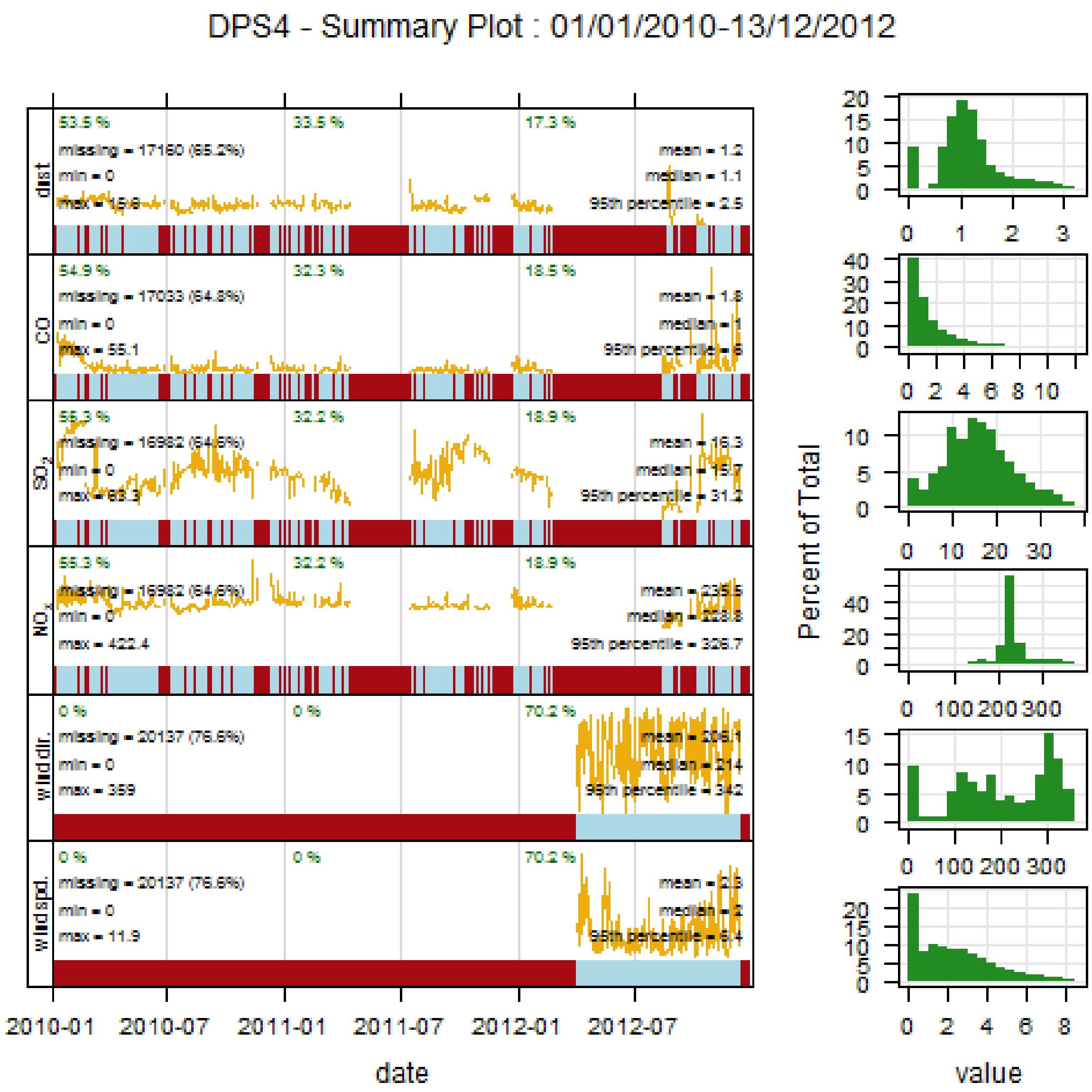

Zejtun - Summary Plot : 01/01/2009-13/12/2012
benzene
CO
O_3
SO_2
NO_2
NO
NO_x
wind dir.
wind spd.
$PM_{2.5}$
PM_{10}
missing = 21527 (61.4%)
min = 0
max = 20.1
mean = 0.7
median = 0.2
95th percentile = 2.6
missing = 17608 (50.2%)
missing = 3738 (10.7%)
min = 0.5
max = 179.1
95th percentile = 109.6
missing = 11174 (31.9%)
missing = 19328 (55.1%)
min = -3.1
max = 1062.4
mean = 23.2
median = 16.2
missing = 27137 (77.4%)
min = -5
max = 150.2
mean = 2.9
median = 1.1
95th percentile = 11.3
missing = 21717 (61.9%)
min = -3.2
max = 714.7
mean = 21
median = 13.4
95th percentile = 59.8
missing = 1853 (5.3%)
missing = 1205 (3.4%)
mean = 3.5
missing = 6494 (18.5%)
mean = 12.4
median = 9.8
missing = 10519 (30%)
min = 0
max = 3139.1
mean = 30.4
median = 23.9
95th percentile = 68.1
2009-01
2009-07
2010-01
2010-07
2011-01
2011-07
2012-01
2012-07
date
Percent of Total
value

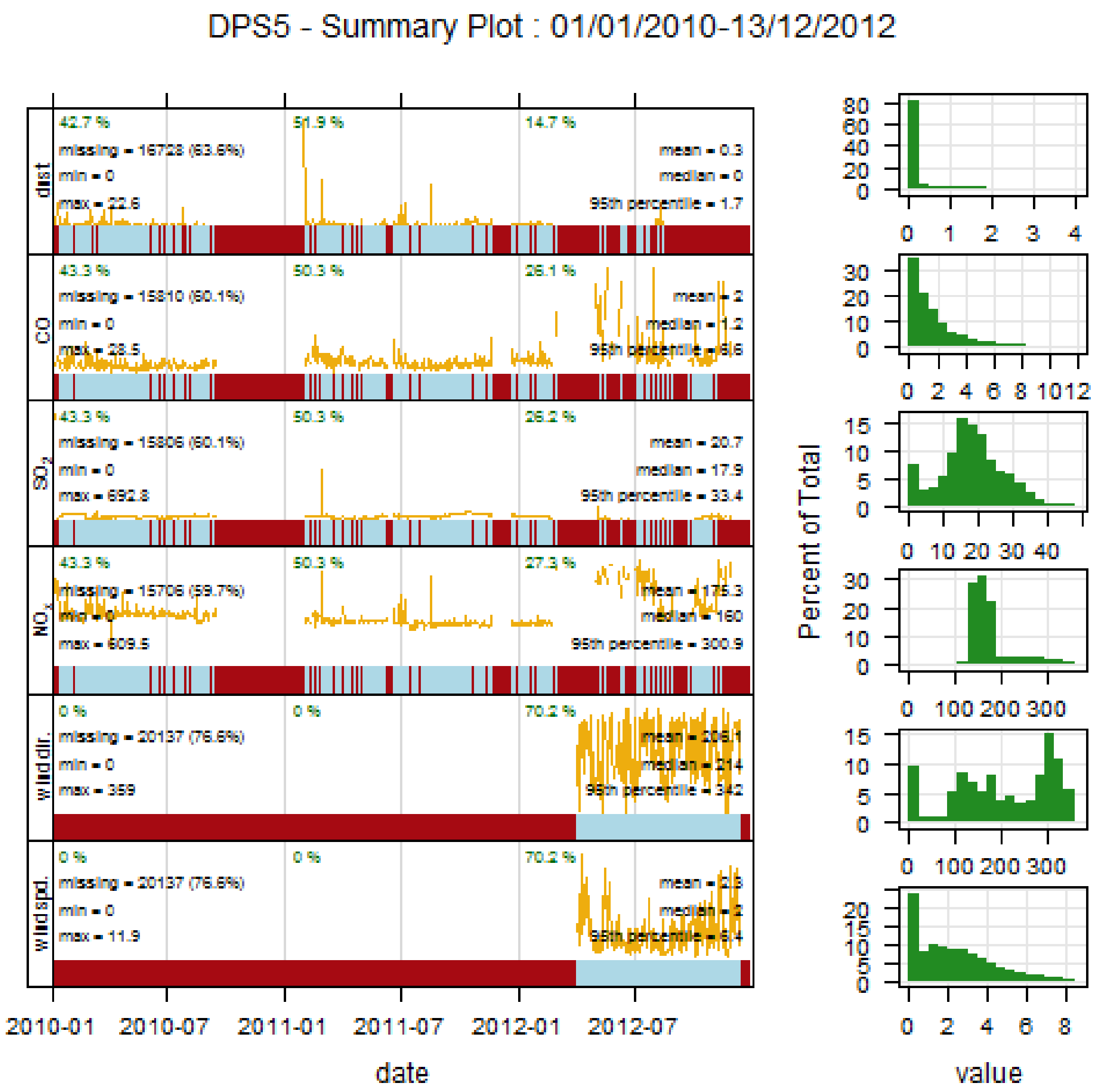

Birzebbuga - Summary Plot : 01/01/2012-13/12/2012
wind dir.
70.2 %
missing = 2617 (29.8%)
min = 0
max = 359
mean = 206.1
median = 214
95th percentile = 342
wind spd.
70.2 %
missing = 2617 (29.8%)
min = 0
max = 11.9
mean = 2.3
median = 2
95th percentile = 6.4
PM2.5
23.9 %
missing = 6683 (76.1%)
min = 0
max = 71.6
mean = 6.6
median = 3.8
95th percentile = 24.2
PM10
24.1 %
missing = 6669 (75.9%)
min = 0
max = 138.3
mean = 13
median = 8.8
95th percentile = 34.6
Jan
Apr
Jul
Oct
date
Percent of Total
value

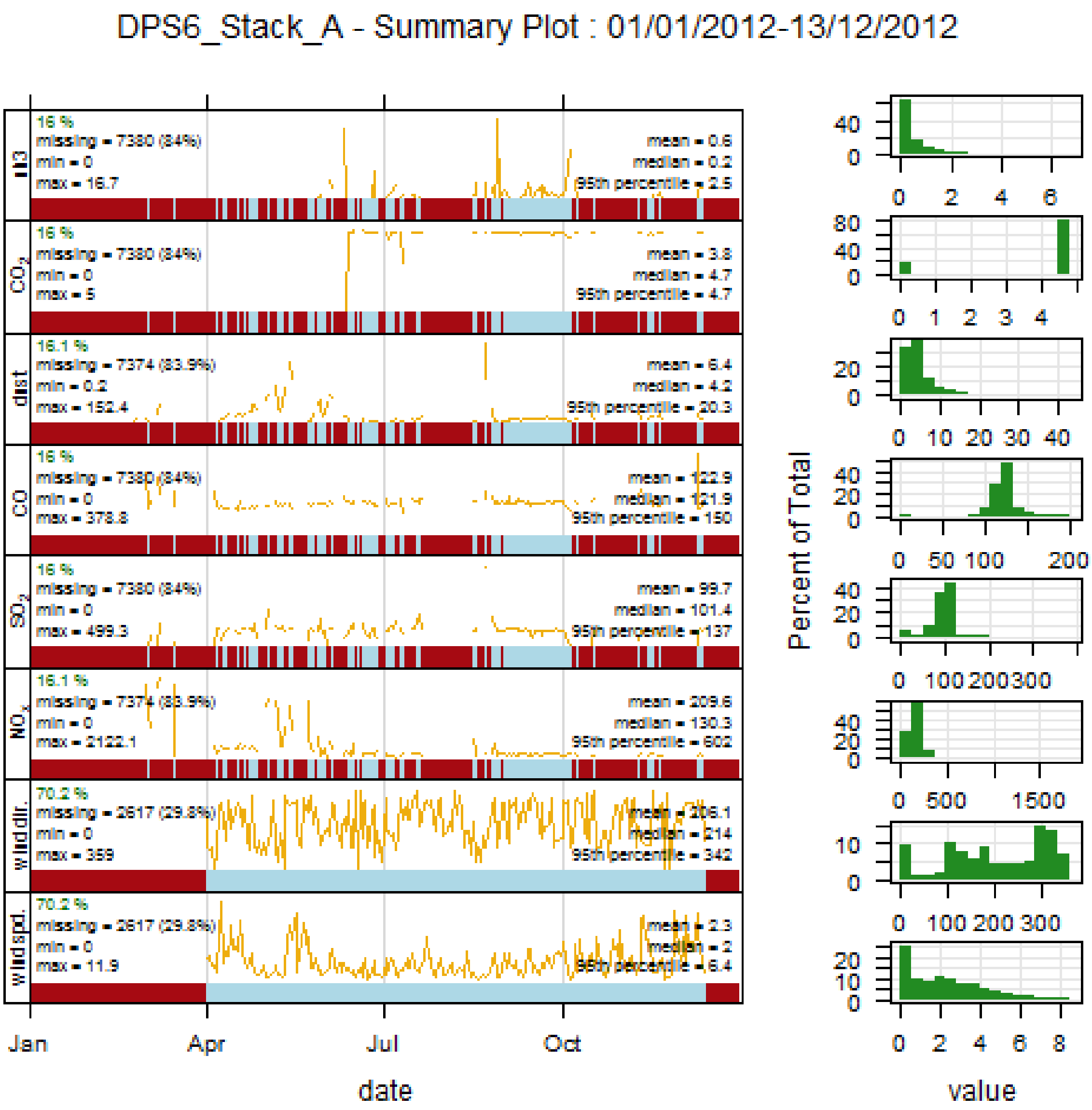

Marsaxlokk - Summary Plot : 01/01/2012-13/12/2012
wind dir.
70.2 %
missing = 2617 (29.8%)
min = 0
max = 359
mean = 206.1
median = 214
95th percentile = 342
wind spd.
70.2 %
missing = 2617 (29.8%)
min = 0
max = 11.9
mean = 2.3
median = 2
95th percentile = 6.4
PM2.5
26.3 %
missing = 6471 (73.7%)
min = 0
max = 126.6
mean = 12.7
median = 9.8
95th percentile = 31
PM10
22.3 %
missing = 6825 (77.7%)
min = 0
max = 95
mean = 17
median = 14.2
95th percentile = 43.6
Jan
Apr
Jul
Oct
date
Percent of Total
value


DPS1_boiler_1 - Summary Plot : 01/01/2009-13/12/2012
dust
missing = 4819 (13.7%)
min = 9.4
max = 177
mean = 34.4
median = 32.4
95th percentile = 55.5
CO
missing = 4524 (12.9%)
min = 0
max = 808.4
mean = 4.5
median = 0.5
95th percentile = 18
SO2
missing = 6422 (18.3%)
min = 77.7
max = 1726.6
mean = 1176.3
median = 1171.8
95th percentile = 1439.6
NOx
missing = 6425 (18.3%)
min = 95.2
max = 1010.2
mean = 501.4
median = 441.6
95th percentile = 728.3
wind dir.
missing = 28897 (82.4%)
min = 0
max = 359
mean = 206.1
median = 214
95th percentile = 342
wind spd.
missing = 28897 (82.4%)
min = 0
max = 11.9
mean = 2.3
median = 2
95th percentile = 6.4
date
Percent of Total
value

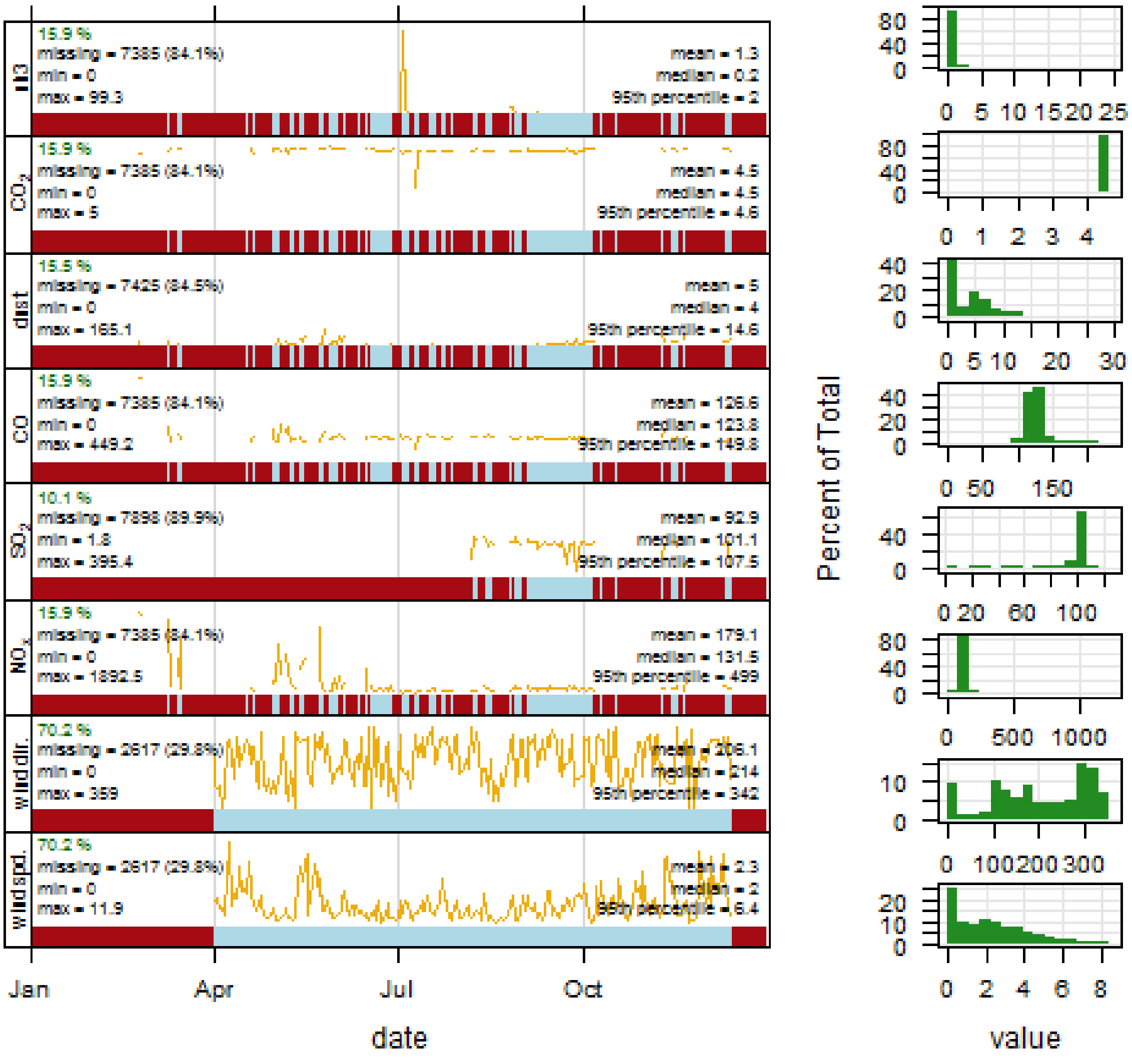

DPS1_boiler_2 - Summary Plot : 01/01/2009-13/12/2012
dust
83.1 %
75 %
92.4 %
79.8 %
missing = 6120 (17.5%)
min = 3.7
max = 478.5
mean = 31.9
median = 30.1
95th percentile = 50
CO
84.8 %
77.6 %
92.7 %
79.4 %
missing = 5750 (16.4%)
min = 0
max = 965.5
mean = 4.2
median = 0
95th percentile = 11.6
SO2
84.8 %
77.6 %
92.7 %
79.4 %
missing = 5743 (16.4%)
min = 0
max = 1914
mean = 1123
median = 1133.1
95th percentile = 1450.9
NOx
74.2 %
75 %
92.3 %
79.1 %
missing = 6964 (19.9%)
min = 0
max = 973.4
mean = 457.2
median = 425.3
95th percentile = 651.2
wind dir.
0 %
0 %
0 %
70.2 %
missing = 28897 (82.4%)
min = 0
max = 359
mean = 206.1
median = 214
95th percentile = 342
wind spd.
0 %
0 %
0 %
70.2 %
missing = 28897 (82.4%)
min = 0
max = 11.9
mean = 2.3
median = 2
95th percentile = 6.4
2009-01 2009-07 2010-01 2010-07 2011-01 2011-07 2012-01 2012-07
date
Percent of Total
value

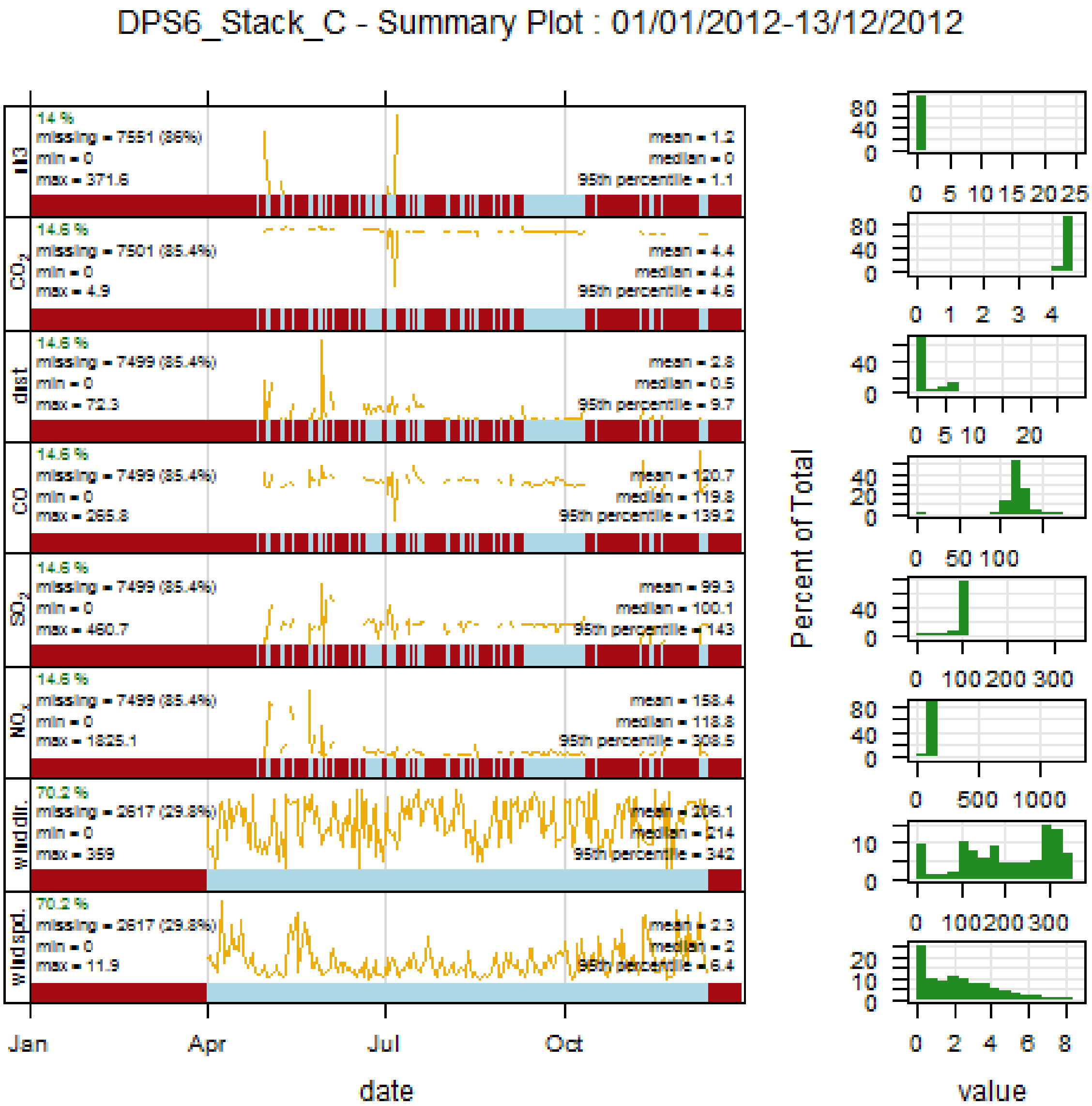

DPS4 - Summary Plot : 01/01/2010-13/12/2012
dust
53.5 %
33.5 %
17.3 %
missing = 17160 (65.2%)
min = 0
max = 15.8
mean = 1.2
median = 1.1
95th percentile = 2.5
CO
54.9 %
32.3 %
18.5 %
missing = 17033 (64.8%)
min = 0
max = 55.1
mean = 1.8
median = 1
95th percentile = 6
SO2
55.3 %
32.2 %
18.9 %
missing = 16982 (64.6%)
min = 0
max = 83.3
mean = 16.3
median = 15.7
95th percentile = 31.2
NOx
55.3 %
32.2 %
18.9 %
missing = 16982 (64.6%)
min = 0
max = 422.4
mean = 235.5
median = 228.8
95th percentile = 326.7
wind dir.
0 %
0 %
70.2 %
missing = 20137 (76.6%)
min = 0
max = 359
mean = 206.1
median = 214
95th percentile = 342
wind spd.
0 %
0 %
70.2 %
missing = 20137 (76.6%)
min = 0
max = 11.9
mean = 2.3
median = 2
95th percentile = 6.4
2010-01
2010-07
2011-01
2011-07
2012-01
2012-07
date
Percent of Total
value

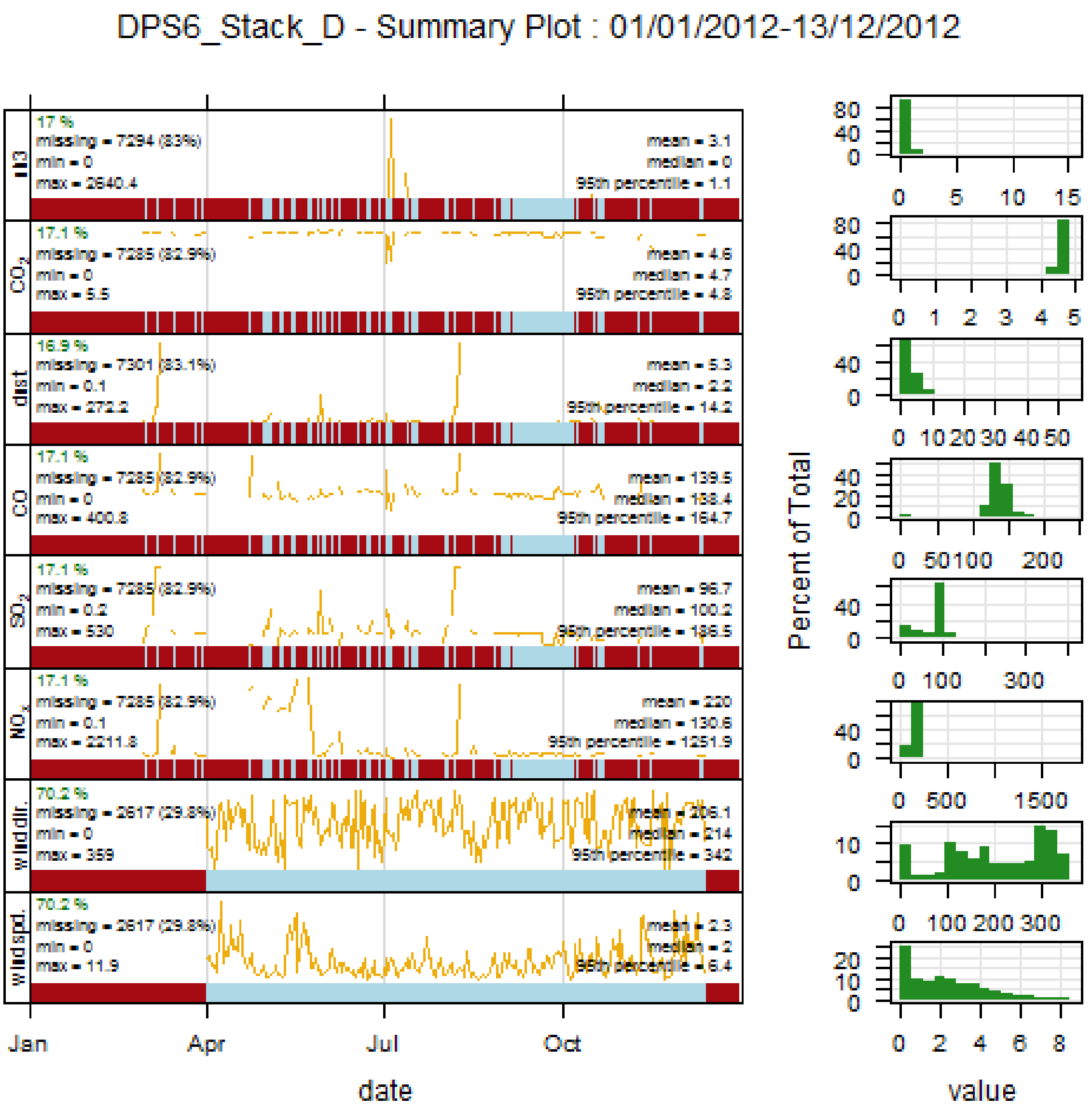

DPS5 - Summary Plot : 01/01/2010-13/12/2012
dist
missing = 16728 (63.6%)
min = 0
max = 22.6
mean = 0.3
median = 0
95th percentile = 1.7
CO
missing = 15810 (60.1%)
min = 0
max = 28.5
mean = 2
median = 1.2
95th percentile = 6.6
SO2
missing = 15806 (60.1%)
min = 0
max = 692.8
mean = 20.7
median = 17.9
95th percentile = 33.4
NOx
missing = 15706 (59.7%)
min = 0
max = 609.5
mean = 176.3
median = 160
95th percentile = 300.9
wind dir.
missing = 20137 (76.6%)
min = 0
max = 359
mean = 206.1
median = 214
95th percentile = 342
wind spd.
missing = 20137 (76.6%)
min = 0
max = 11.9
mean = 2.3
median = 2
95th percentile = 6.4
2010-01
2010-07
2011-01
2011-07
2012-01
2012-07
date
Percent of Total
value


DPS6_Stack_A - Summary Plot : 01/01/2012-13/12/2012
nh3
16 %
missing = 7380 (84%)
min = 0
max = 16.7
mean = 0.6
median = 0.2
95th percentile = 2.5
CO2
16 %
missing = 7380 (84%)
min = 0
max = 5
mean = 3.8
median = 4.7
95th percentile = 4.7
dust
16.1 %
missing = 7374 (83.9%)
min = 0.2
max = 152.4
mean = 6.4
median = 4.2
95th percentile = 20.3
CO
16 %
missing = 7380 (84%)
min = 0
max = 378.8
mean = 122.9
median = 121.9
95th percentile = 150
SO2
16 %
missing = 7380 (84%)
min = 0
max = 499.3
mean = 99.7
median = 101.4
95th percentile = 137
NOx
16.1 %
missing = 7374 (83.9%)
min = 0
max = 2122.1
mean = 209.6
median = 130.3
95th percentile = 602
wind dir.
70.2 %
missing = 2617 (29.8%)
min = 0
max = 359
mean = 206.1
median = 214
95th percentile = 342
wind spd.
70.2 %
missing = 2617 (29.8%)
min = 0
max = 11.9
mean = 2.3
median = 2
95th percentile = 6.4
Jan
Apr
Jul
Oct
date
Percent of Total
value

DPS6_Stack_B - Summary Plot : 01/01/2012-13/12/2012

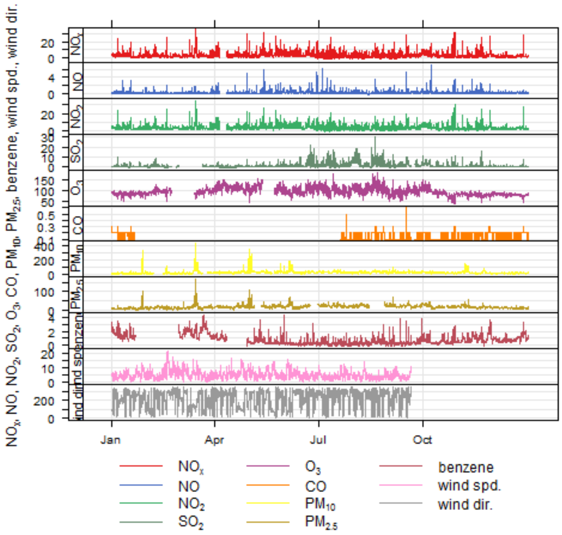



DPS6_Stack_C - Summary Plot : 01/01/2012-13/12/2012
14 %
missing = 7551 (86%)
min = 0
max = 371.6
mean = 1.2
median = 0
95th percentile = 1.1
14.6 %
missing = 7501 (85.4%)
min = 0
max = 4.9
mean = 4.4
median = 4.4
95th percentile = 4.6
14.6 %
missing = 7499 (85.4%)
min = 0
max = 72.3
mean = 2.8
median = 0.5
95th percentile = 9.7
14.6 %
missing = 7499 (85.4%)
min = 0
max = 265.8
mean = 120.7
median = 119.8
95th percentile = 139.2
14.6 %
missing = 7499 (85.4%)
min = 0
max = 460.7
mean = 99.3
median = 100.1
95th percentile = 143
14.6 %
missing = 7499 (85.4%)
min = 0
max = 1825.1
mean = 158.4
median = 118.8
95th percentile = 308.5
70.2 %
missing = 2617 (29.8%)
min = 0
max = 359
mean = 206.1
median = 214
95th percentile = 342
70.2 %
missing = 2617 (29.8%)
min = 0
max = 11.9
mean = 2.3
median = 2
95th percentile = 6.4
CO
SO
NO
wind dir.
wind spd.
Jan
Apr
Jul
Oct
date
Percent of Total
value

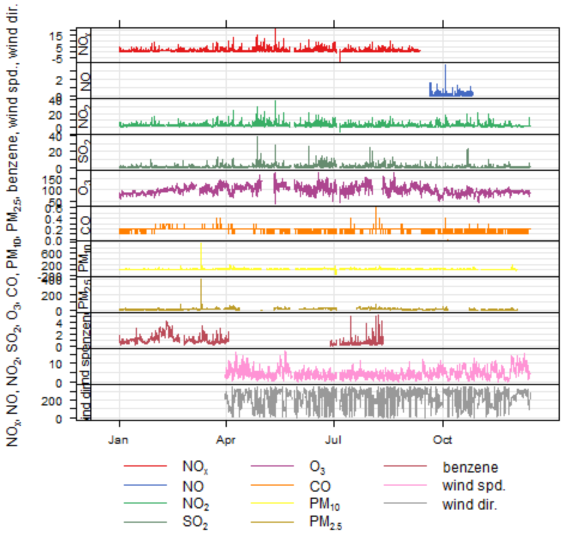

DPS6_Stack_D - Summary Plot : 01/01/2012-13/12/2012
H2S
17 %
missing = 7294 (83%)
min = 0
max = 2640.4
mean = 3.1
median = 0
95th percentile = 1.1
CO2
17.1 %
missing = 7285 (82.9%)
min = 0
max = 5.5
mean = 4.6
median = 4.7
95th percentile = 4.8
dust
16.9 %
missing = 7301 (83.1%)
min = 0.1
max = 272.2
mean = 5.3
median = 2.2
95th percentile = 14.2
CO
17.1 %
missing = 7285 (82.9%)
min = 0
max = 400.8
mean = 139.5
median = 138.4
95th percentile = 164.7
SO2
17.1 %
missing = 7285 (82.9%)
min = 0.2
max = 530
mean = 96.7
median = 100.2
95th percentile = 186.5
NOx
17.1 %
missing = 7285 (82.9%)
min = 0.1
max = 2211.8
mean = 220
median = 130.6
95th percentile = 1251.9
wind dir.
70.2 %
missing = 2617 (29.8%)
min = 0
max = 359
mean = 206.1
median = 214
95th percentile = 342
wind spd.
70.2 %
missing = 2617 (29.8%)
min = 0
max = 11.9
mean = 2.3
median = 2
95th percentile = 6.4
Jan
Apr
Jul
Oct
date
Percent of Total
value

Appendix B: Time plots

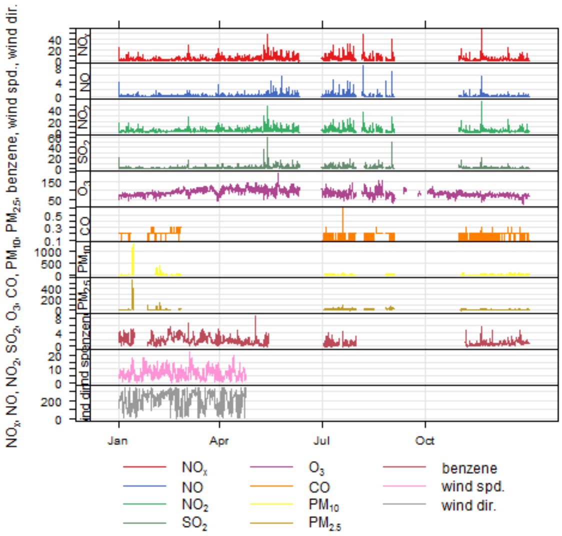
Gharb - Time Plot : 01/01/2011-31/12/2011



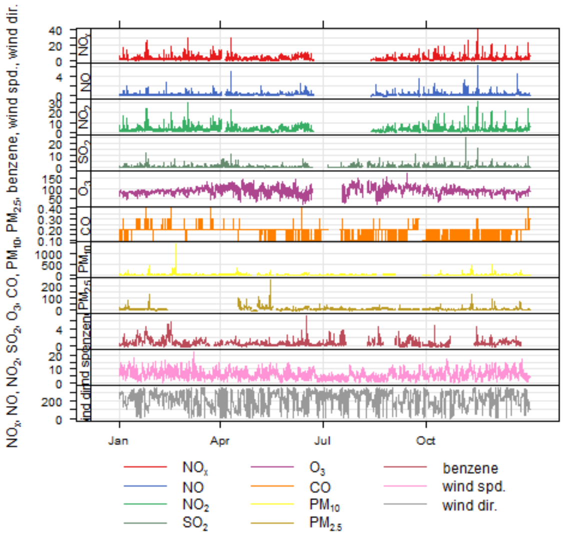
Gharb - Time Plot : 01/01/2012-13/12/2012



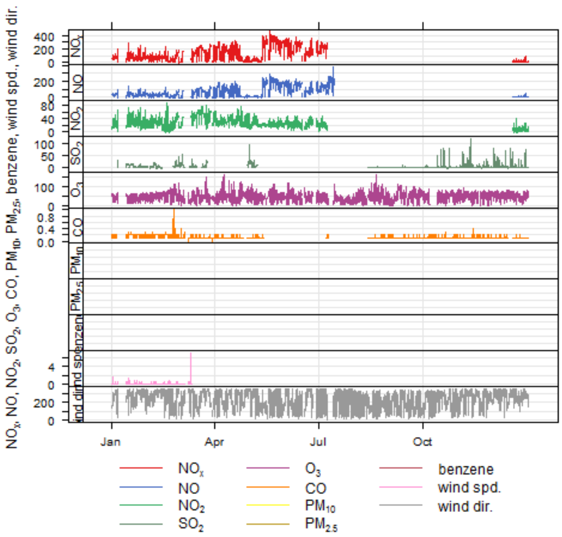
Gharb - Time Plot : 01/01/2009-31/12/2009



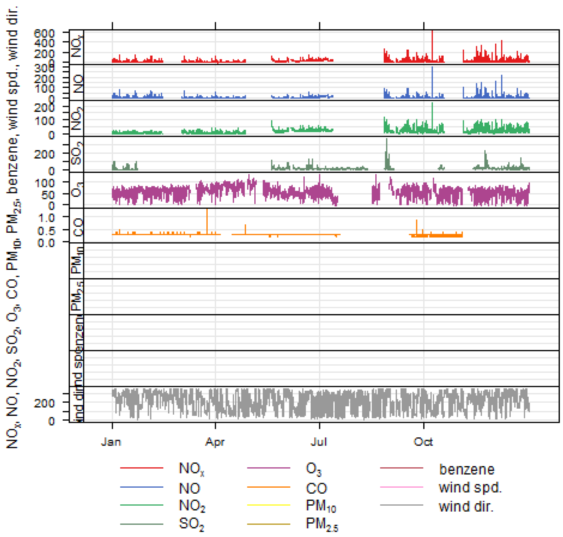
Gharb - Time Plot : 01/01/2010-31/12/2010

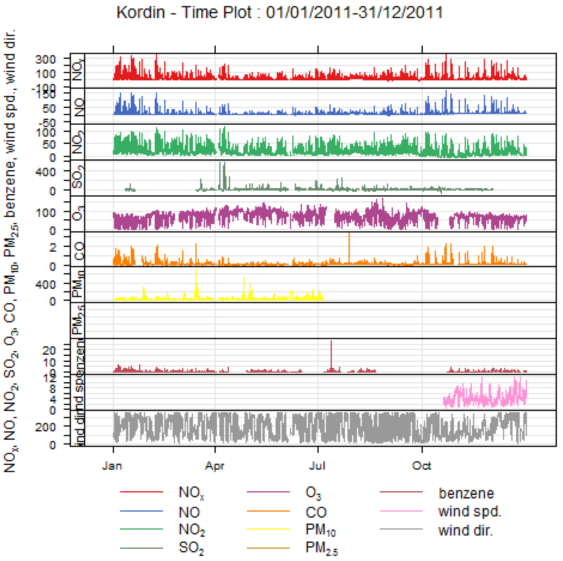


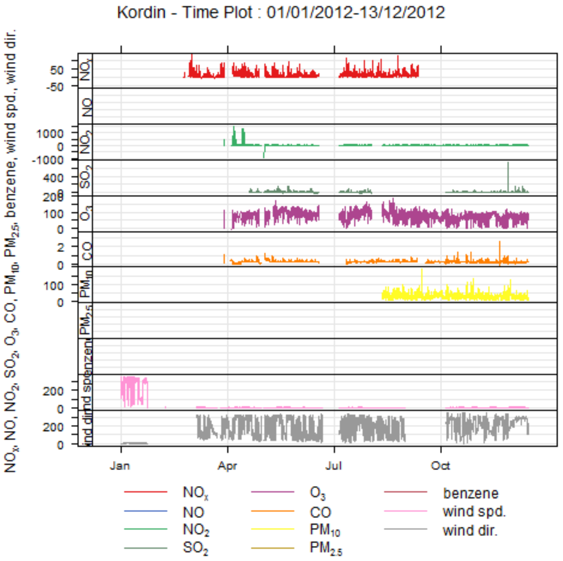
Kordin - Time Plot : 01/01/2009-31/12/2009

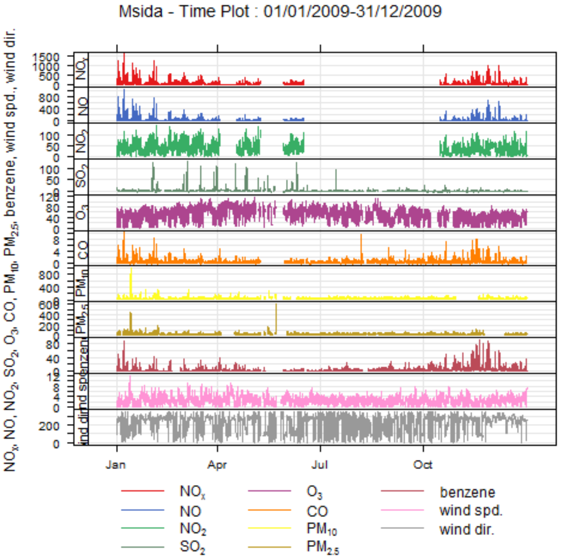


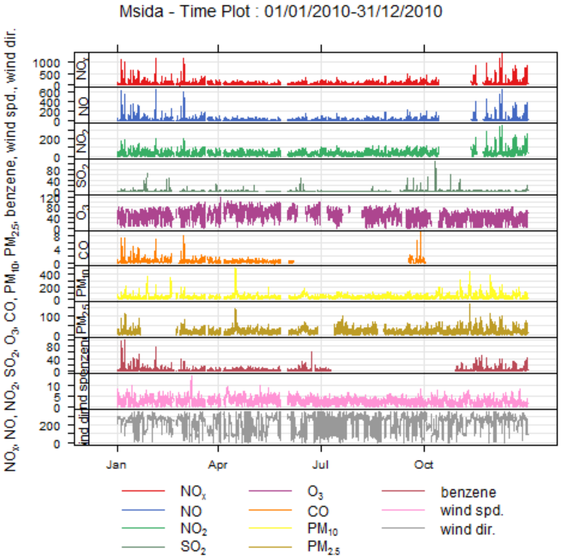
Kordin - Time Plot : 01/01/2010-31/12/2010

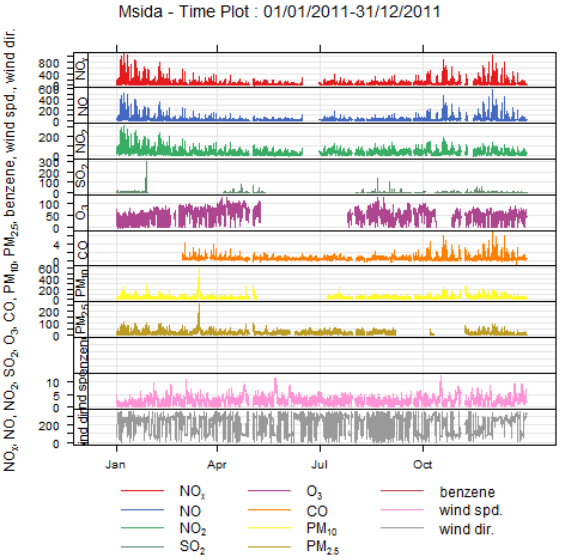


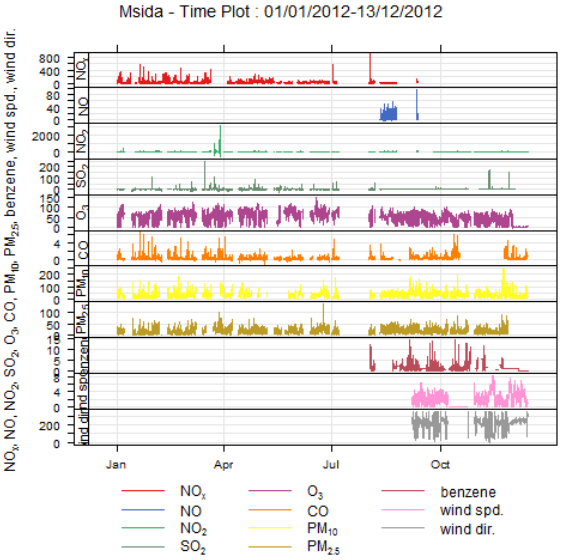

Kordin - Time Plot : 01/01/2011-31/12/2011
NO_x
NO
NO_2
SO_2
O_3
CO
PM_{10}
$PM_{2.5}$
benzene
wind spd.
wind dir.


Kordin - Time Plot : 01/01/2012-13/12/2012
NO_x
NO
NO_2
SO_2
O_3
CO
PM_{10}
$PM_{2.5}$
benzene
wind spd.
wind dir.


Msida - Time Plot : 01/01/2009-31/12/2009
NO_x
NO
NO_2
SO_2
O_3
CO
PM_{10}
$PM_{2.5}$
benzene
wind spd.
wind dir.


Msida - Time Plot : 01/01/2010-31/12/2010
NO_x
NO
NO_2
SO_2
O_3
CO
PM_{10}
$PM_{2.5}$
benzene
wind spd.
wind dir.


Msida - Time Plot : 01/01/2011-31/12/2011
NO_x
NO
NO_2
SO_2
O_3
CO
PM_{10}
$PM_{2.5}$
benzene
wind spd.
wind dir.


Msida - Time Plot : 01/01/2012-13/12/2012
NO_x
NO
NO_2
SO_2
O_3
CO
PM_{10}
$PM_{2.5}$
benzene
wind spd.
wind dir.

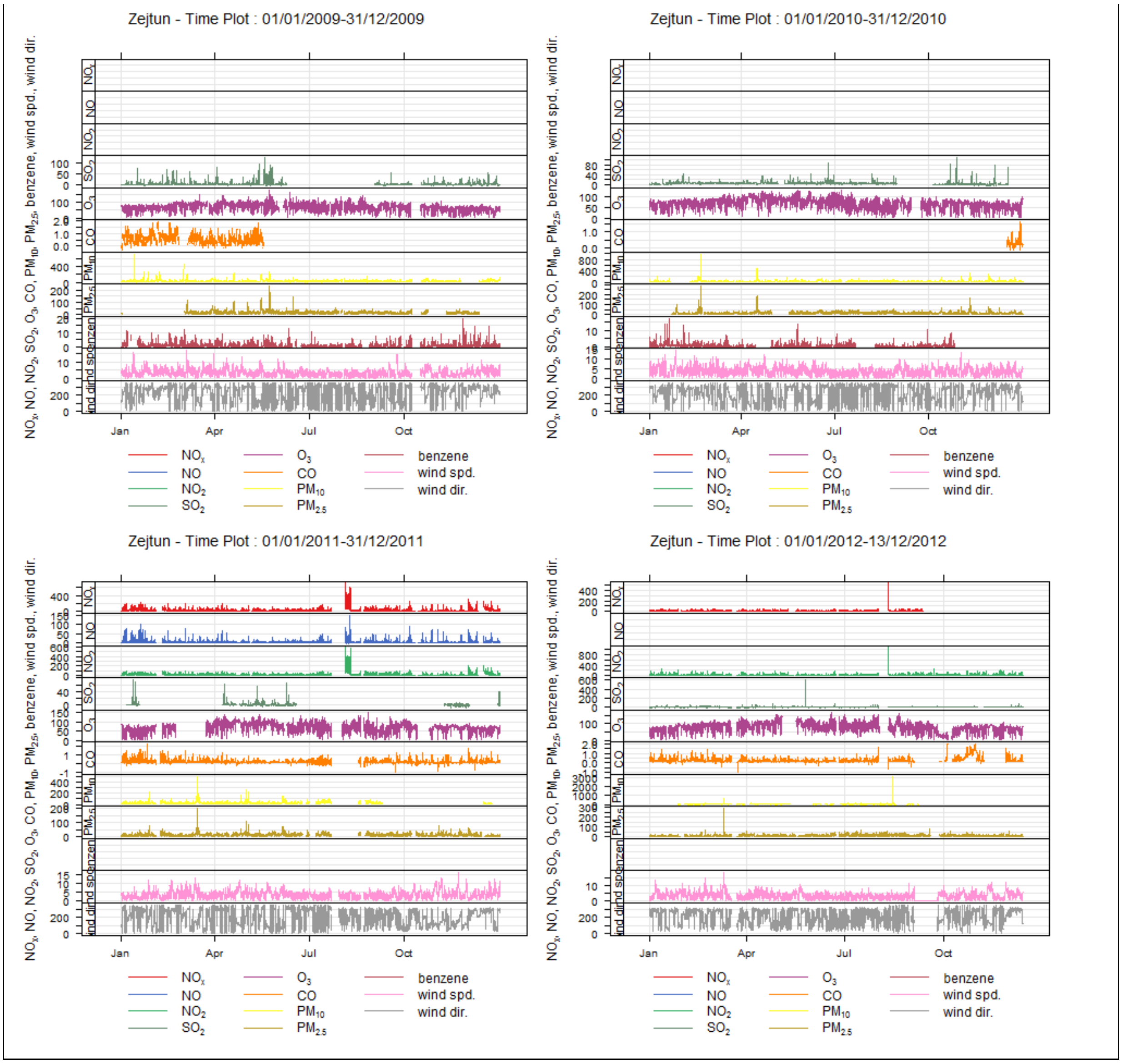


Figure 14: Time plots of the MEPA sites

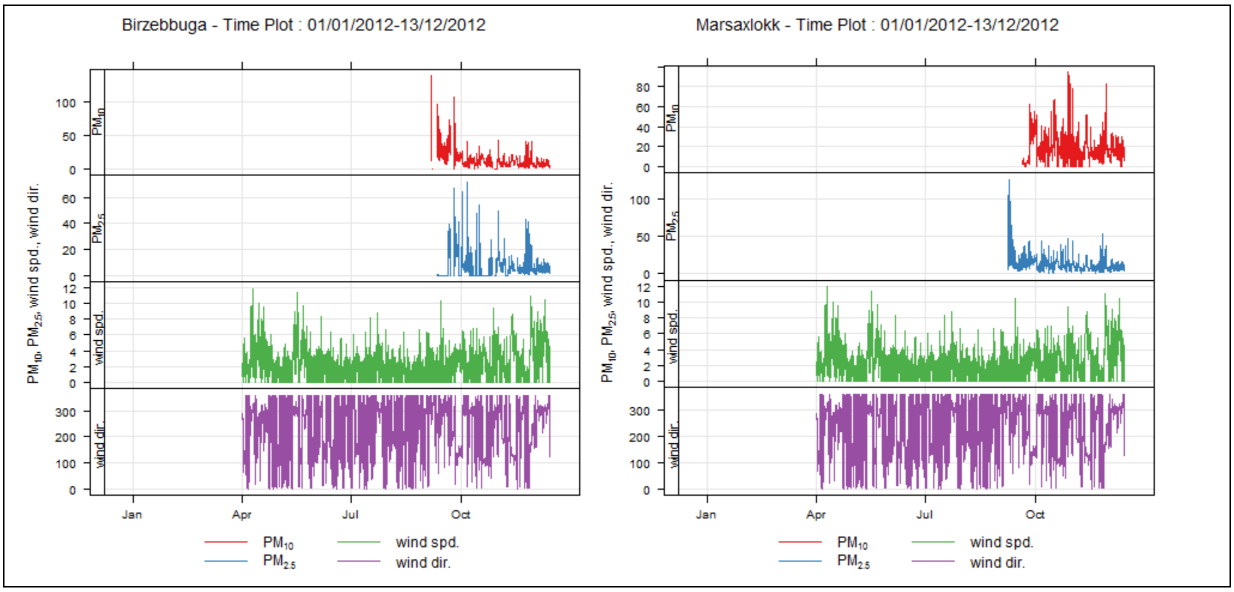
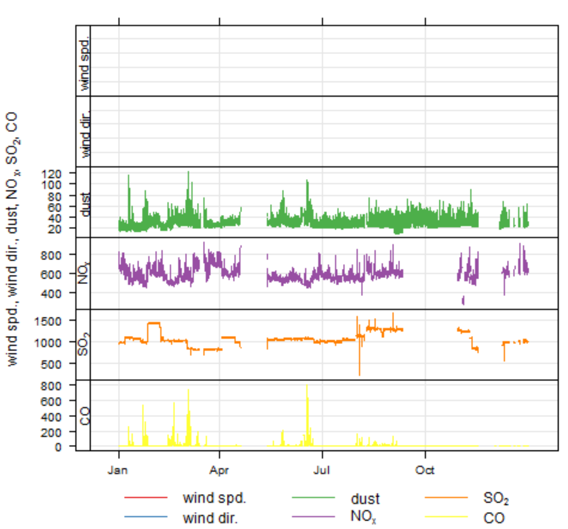
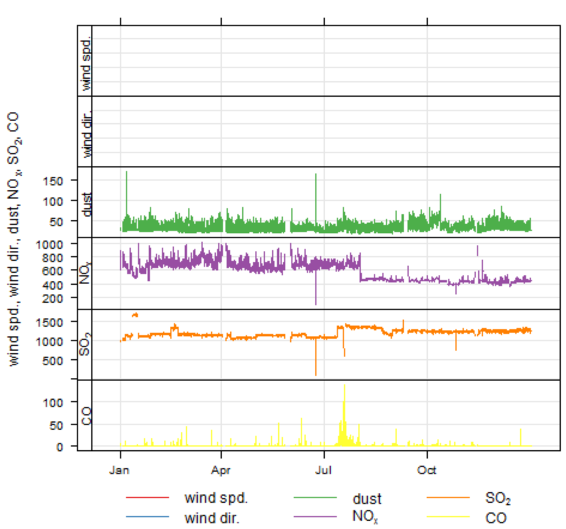


Figure 15: Time plots of the EMS consultant's sites

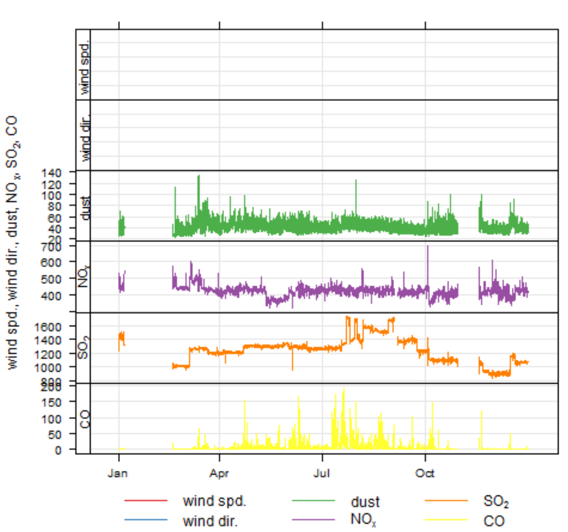
DPS1_boiler_1 - Time Plot : 01/01/2009-31/12/2009



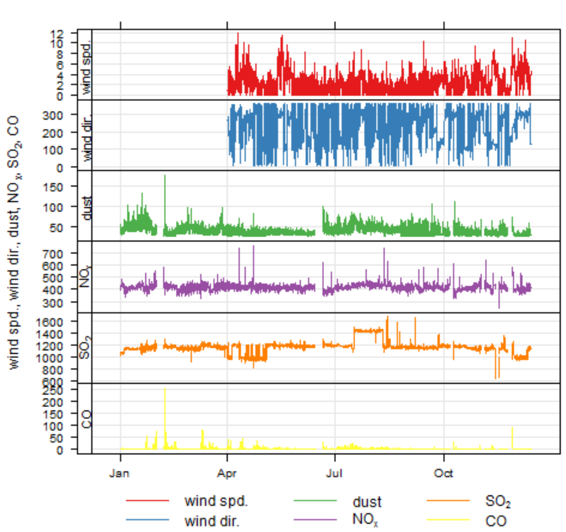
DPS1_boiler_1 - Time Plot : 01/01/2010-31/12/2010



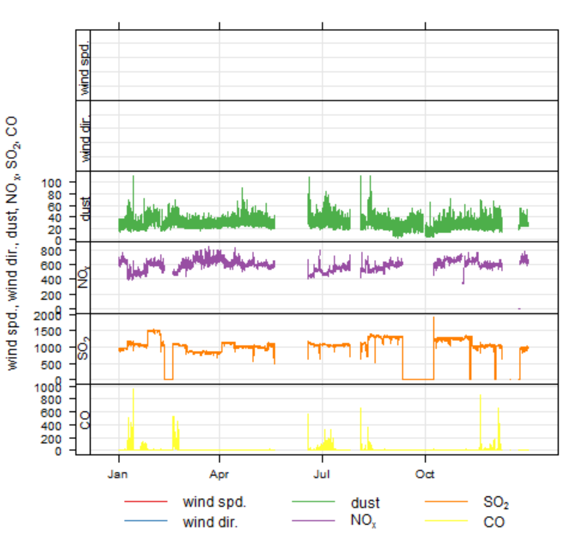
DPS1_boiler_1 - Time Plot : 01/01/2011-31/12/2011



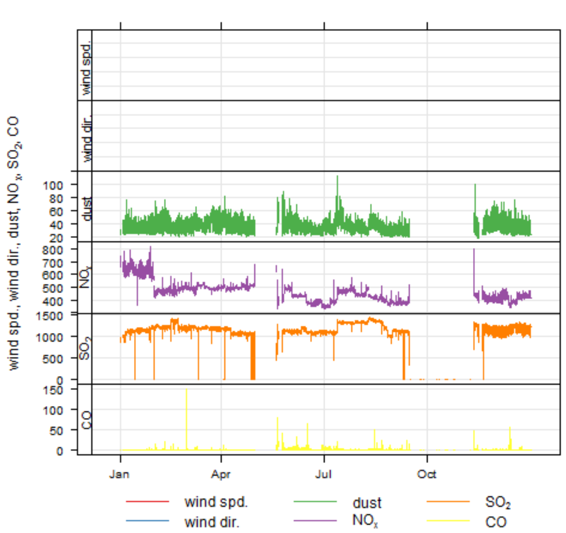
DPS1_boiler_1 - Time Plot : 01/01/2012-13/12/2012

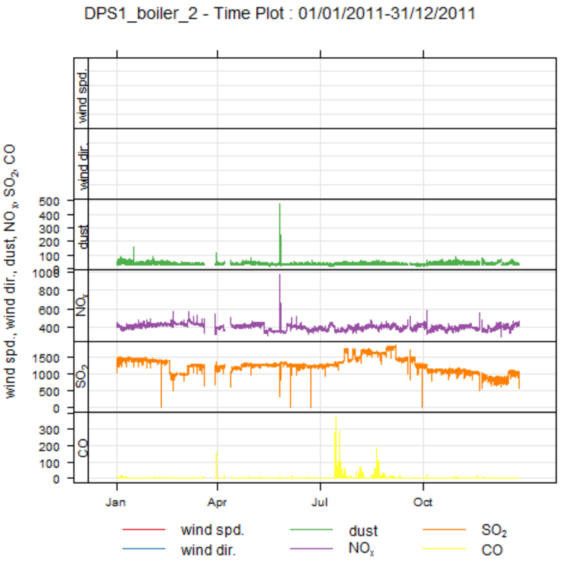


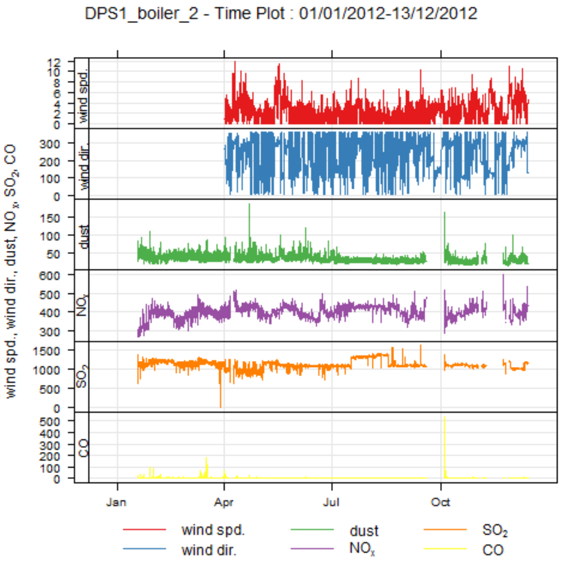
DPS1_boiler_2 - Time Plot : 01/01/2009-31/12/2009

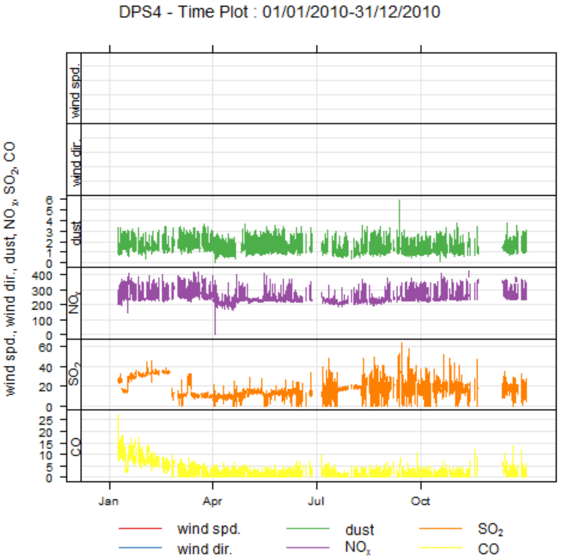


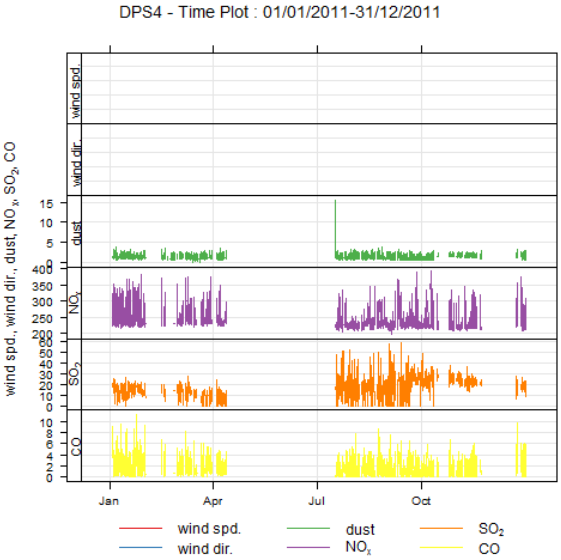
DPS1_boiler_2 - Time Plot : 01/01/2010-31/12/2010

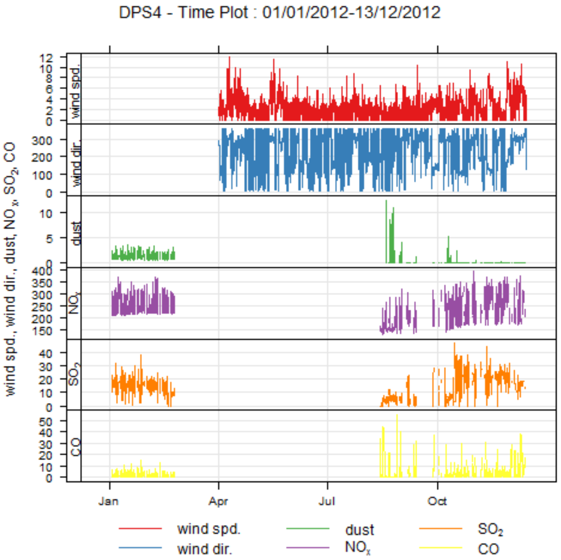


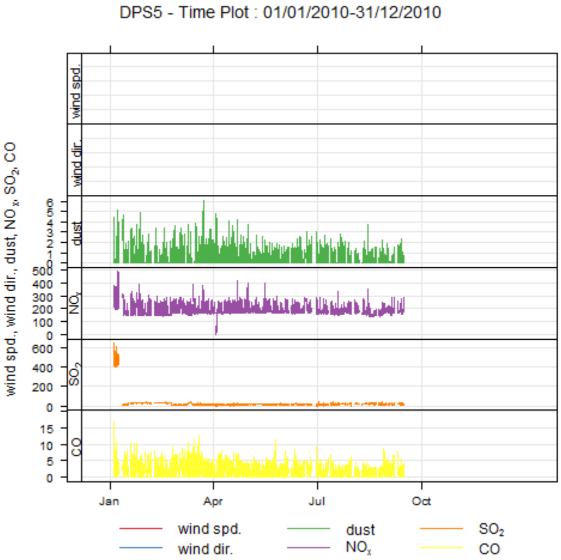

DPS1_boiler_2 - Time Plot : 01/01/2011-31/12/2011
wind spd., wind dir., dust, NO_x, SO_2, CO
Jan
Apr
Jul
Oct
wind spd.
wind dir.
dust
NO_x
SO_2
CO


DPS1_boiler_2 - Time Plot : 01/01/2012-13/12/2012
wind spd., wind dir., dust, NO_x, SO_2, CO
Jan
Apr
Jul
Oct
wind spd.
wind dir.
dust
NO_x
SO_2
CO


DPS4 - Time Plot : 01/01/2010-31/12/2010
wind spd., wind dir., dust, NO_x, SO_2, CO
Jan
Apr
Jul
Oct
wind spd.
wind dir.
dust
NO_x
SO_2
CO


DPS4 - Time Plot : 01/01/2011-31/12/2011
wind spd., wind dir., dust, NO_x, SO_2, CO
Jan
Apr
Jul
Oct
wind spd.
wind dir.
dust
NO_x
SO_2
CO


DPS4 - Time Plot : 01/01/2012-13/12/2012
wind spd., wind dir., dust, NO_x, SO_2, CO
Jan
Apr
Jul
Oct
wind spd.
wind dir.
dust
NO_x
SO_2
CO


DPS5 - Time Plot : 01/01/2010-31/12/2010
wind spd., wind dir., dust, NO_x, SO_2, CO
Jan
Apr
Jul
Oct
wind spd.
wind dir.
dust
NO_x
SO_2
CO

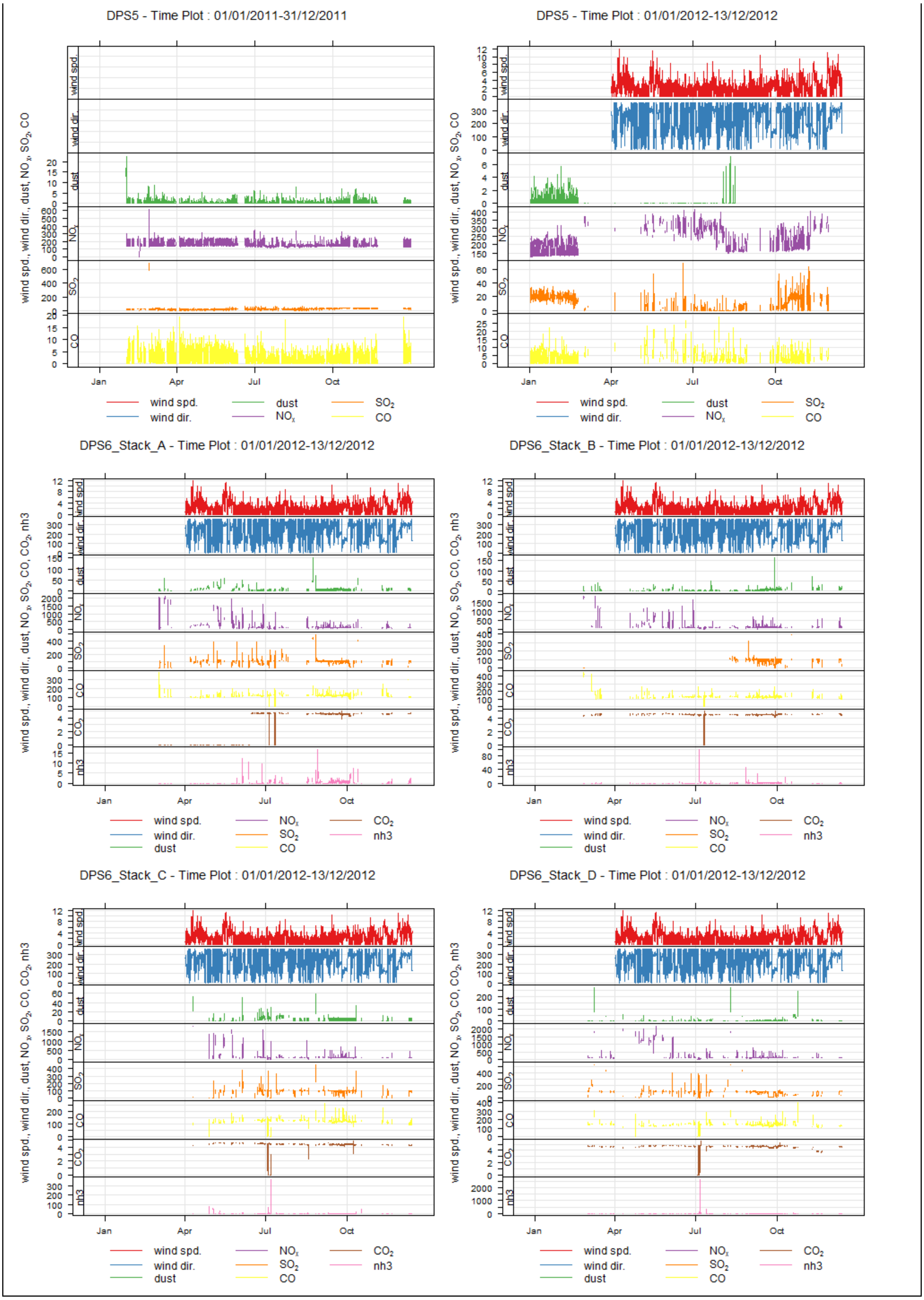


Figure 16: Time plots of DPS sites

Appendix C: Wind plots