



Urban SIS

D441_Lot3.5.2 Validation of air quality variables

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Table of Contents

1. Introduction	7
2. Air quality data in Urban SIS	9
2.1 Simulated air quality data	9
2.2 Observed air quality data	9
3. Validation methodology	10
3.1 Visual inspection	10
3.2 General validation	10
3.3 Tailored validation	11
4. Validation results	11
4.1 Ozone general validation	12
4.2 NO ₂ general validation	13
4.3 PM _{2.5} general validation	15
4.4 PM ₁₀ general validation	17
4.5 Ozone tailored validation	19
4.6 NO ₂ tailored validation	20
4.7 PM _{2.5} tailored validation	22
4.8 PM ₁₀ tailored validation	23
5. Conclusions and discussion	24
6. Acknowledgement	25



1. Introduction

The goal of Urban SIS is to develop and demonstrate a method to downscale climate and impact indicators to the urban scale, delivering the information with a space/time resolution and format that makes it useful for consultants, urban planners, engineers and scientists dealing with intense rainfall, heat waves, and air pollution hazards. Within the project, WP5 targets the validation of downscaled climate, air quality and hydrological data over three selected urban landscapes: Stockholm, Amsterdam/Rotterdam and Bologna. Validation is performed for the five selected historical years representing today's climate: 2006-2007 and 2012-2014.

The current deliverable (D441.5.2) addresses specifically the air quality downscaling in the historical period. Two other reports complete the validation, D441.5.1 and D441.5.3, respectively for the urban climate and the hydrological components. Downscaled urban data for future conditions will be delivered with reports D441.3.4-6.

The downscaling modelling chain consists of three numerical models as depicted in Figure 1: the meteorological/climate model HARMONIE-AROME, the air quality model MATCH and the hydrological model HYPE. The two latter models are driven by output data from HARMONIE-AROME.

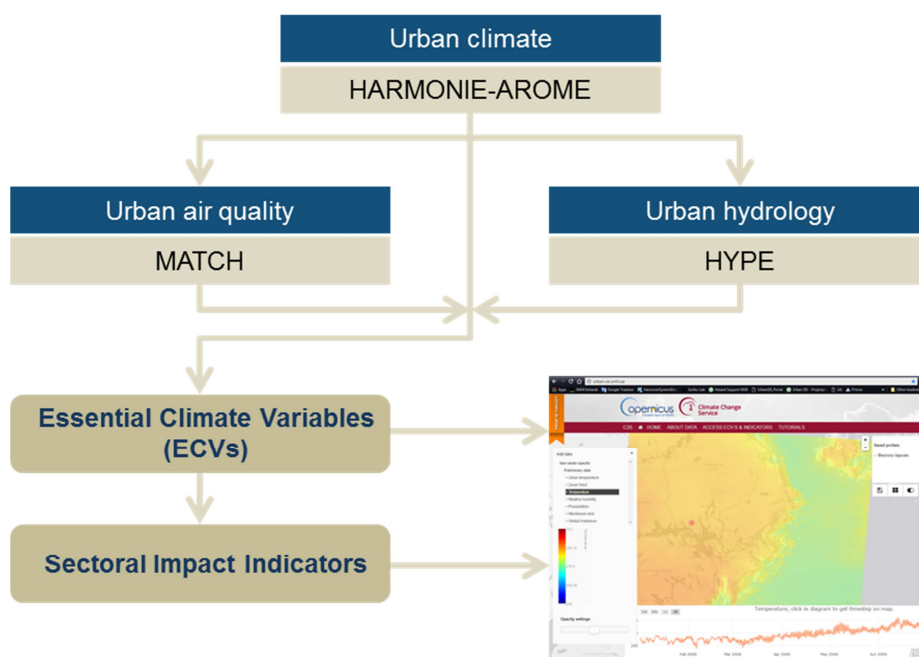


Figure 1 – General flowchart representing the downscaling approach applied in Urban SIS. More detailed information about the air quality model MATCH is given in D441.3.3.

This report summarizes the key results from the validation, information required to assess the downscaling performance. It may be remarked that a fair amount of additional validation, not

presented here, has been performed in the course of the model development and data production by e.g. expert judgement, visual inspection and qualitative assessment.

The validation has aimed at fulfilling the KPI requirements for qualified Essential Climate Variables (ECVs), as specified in D5.4.1:

1. *The downscaled urban ECV data for a historical period have been evaluated against observations. As relevant observations for the comparison are not always available, evaluation will not be possible for all ECVs.*
2. *The ECV is accompanied by metadata fulfilling general requirements.*
3. *The ECV can be downloaded from the Urban SIS portal (linked from CDS portal) with verified functionality.*

The results provided in this deliverable, and the accompanying deliverables D441.5.1 and D441.5.3, fulfil the first above mentioned requirement. The second requirement is met by the provision of qualified metadata on the Urban SIS portal. The third requirement has been accomplished by downloading all simulated data from the Urban SIS prior to the validation process.

The target number of qualified ECVs given in D5.4.1 consists of five climate ECVs, two air quality ECVs and two hydrological ECVs. Due to the availability of data, we have evaluated four air quality ECVs. Table 1 below gives an overview of the formal validation performed which shows that the target has been reached; see further below and deliverables D441.5.1 and D441.5.3.

Table 1 - Overview of the ECV validation performed in Urban SIS.

		General			Tailored		
		STH	BOL	AMS	STH	BOL	AMS
Climate	Temp.	x	x	x	x	x	x
	Prec.	x	x	x	x		x
	Rel.Hum.	x	x	x			
	Wind	x	x	x			
	Glob.Rad.	x	x	x			
Air Quality	O3	x	x	x	x	x	x
	NO2	x	x	x	x	x	x
	PM2.5	x	x	x	x		x
	PM10	x	x	x	x		x
Hydrology	Extr.Prec.				x		x
	Discharge	x	x		x	x	

The last section of this report intends to provide an overall assessment of downscaling performance as well as to share some experiences from the validation, in particular reasons for deviations from observations and implications for using the downscaled data in different applications. This is important for the end-users exploiting the data or for those willing to replicate this method in other European cities, in agreement with the proof-of-concept nature of this project.



2. Air quality data in Urban SIS

The target for the Key Performance Indicators (KPIs) earlier defined in D5.4.1, was to validate two air quality ECVs against observations. However, since observational data have been available for all four air quality ECVs, the general validation process has been performed for all of them. The general validation covers monthly mean, monthly maximum and monthly minimum values, thus reflecting the overall model performance of average and extreme values, as well as possible seasonal trends. For air quality it is also important to capture daily variations e.g. those caused by traffic and other local sources in combination with meteorological variations. The latter will be focus for the tailored validations between Urban SIS output and observations.

The evaluation covers all three cities, and where possible two stations, one urban background and one regional background station.

2.1 Simulated air quality data

The air quality downscaling was performed with the chemical transport model MATCH, set up for each of the three Urban SIS domains. As described in D441.3.2., MATCH uses three-dimensional meteorological fields from HARMONIE-AROME and these data determine how the pollutants are chemically and physically transformed, transported with the mean wind and dispersed through turbulent mixing. Boundary conditions, i.e. temporally varying air pollutant concentrations at the borders of the urban domain, are generated by first running a pan-European application of MATCH covering Europe and adjacent regions. Crucial for the air quality downscaling are local emissions from industrial, transport and residential sources within the city. For all three cities Stockholm, Bologna and Amsterdam/Rotterdam emission data with 1x1 km² spatial resolutions have been obtained.

Note: For Stockholm and Amsterdam O₃ and NO₂ there are a few individual grid values without data, this due to an error in the handling of land use data during the post-processing calculations of near-surface concentrations within the MATCH model. The error appears in grids with a both water and land. Due to the low number of missing values, we have not recalculated the full historical periods (the error does not affect neighbouring grid data).

2.2 Observed air quality data

Table 2 provides an overview of the observational data available for validating the MATCH output concentrations. In Stockholm and Bologna the stations Torkel Knutsson and Giardini Margherita are within the city borders and representing urban background concentrations, the other two stations are outside representing the rural background. For the Amsterdam/Rotterdam domain the evaluation has been for the Rotterdam city, where both stations represent the urban background. Air quality observations are based on hourly data, except for the PM_{2.5} and PM₁₀ data from Bologna which are only available as daily average levels.



Table 2 - Available air quality observations used in Urban SIS evaluation.

City	Nr	Station	lat	lon	Period	Type
Stockholm	1	Torkel Knutsson	59.2612	18.0618	2006-2007, 2012-2014	Urb. backgr.
	2	Norra Malma	59.8325	18.6313	2006-2007, 2012-2014	Reg. backgr.
Bologna	1	Giardini Margherita	44.4836	11.3550	2013-2014 ¹	Urb. backgr.
	2	San Pietro de Capofiume	44.6538	11.6226	2013-2014	Reg. backgr.
Rotterdam	1	Shiedam	51.9214	4.4015	2006-2007 ² , 2012-2014	Urb. backgr.
	2	Zwartewaalstraat	51.8939	4.4875	2012-2014 ³	Urb. backgr.

¹⁾ PM₁₀ missing during 2013; ²⁾ PM_{2.5} missing during 2007; ³⁾ Only NO₂, PM_{2.5} and PM₁₀

3. Validation methodology

In this chapter, the validation procedure is described. The descriptions of Visual inspection (section 3.1) and General validation (section 3.2) are the same for all ECV categories (climate, air quality, and hydrology) whereas Tailored validation (section 3.3) differs.

3.1 Visual inspection

All ECVs, i.e. also the ones not validated against observations, were inspected visually using the Urban SIS web portal. This was done to identify any artefacts in the data related to e.g. visualization settings and generally to assess the realism and accuracy of the data using expert judgment.

3.2 General validation

A number of ECVs were selected for general validation (see Table 1). This selection was made based on the availability of consistent observational data in the three cities.

The general validation was performed in terms of the standard ECV statistics, which are based on monthly minimum, average and maximum hourly values throughout the 5-year historical period (see D2.1, D441.3.1-3 for the selection and production process of simulated historical data). These monthly series were plotted for both observations and the MATCH model simulations in order to assess the agreement in terms of the seasonal cycle as well as differences between different years in the 5-year simulation period.

Additionally the mean values and standard deviations over the entire period were calculated for both observations and simulations, and the agreement was also quantified by the Root Mean Square Error (RMSE) of the hourly values.



3.3 Tailored validation

For air quality, this includes an assessment of the average January and July diurnal cycle of the four ECVs at one urban background site in each modelling domain.

Finally, we also present a brief evaluation of the specific statistics behind some key air quality indicators for the health sector:

- O₃: 93.15th percentile of the daily maximum 8-hour running averages
- O₃: SOMO35, sum of excess of maximum daily 8-hour averages over 70 µg/m³
- NO₂: 99.8th percentile of the hourly concentrations during a year
- PM₁₀: 90th percentile of the hourly concentrations during a year

Measured and Urban SIS model output of the statistic values listed above will be evaluated for one urban station in each of the three cities.

4. Validation results

The four air quality ECVs O₃, NO₂, PM_{2.5}, PM₁₀ are evaluated one by one for all three cities.

Table 3 - Statistics for general validation of air quality ECVs (grey = urban background, yellow = regional background). The results are based on hourly data from all five years for which there are available simultaneous measured and simulated data (daily data for PM variables in Bologna).

Variable	Station 1							Station 2						
	Mean			Std.dev			RMSE	Mean			Std.dev			RMSE
	OBS	SIM	DIFF	OBS	SIM	DIFF		OBS	SIM	DIFF	OBS	SIM	DIFF	
Stockholm														
O ₃	51.4	72.8	21.4	21.7	16.9	-4.8	27.0	55.8	66.5	10.7	21.8	18.9	-2.9	20.8
NO ₂	13.3	7.8	-5.5	11.6	7.3	-4.3	11.5	1.9	1.7	-0.2	7.7	1.6	-6.1	7.6
PM _{2.5}	6.0	6.1	0.1	6.5	3.8	-2.7	5.8	4.1	4.1	0.0	5.9	3.2	-2.7	5.1
PM ₁₀	14.6	8.7	-5.9	11.6	5.2	-6.5	12.5	9.8	5.1	-4.7	7.5	4.1	-3.5	8.1
Bologna														
O ₃	48.3	64.5	16.2	44.5	36.3	-8.2	31.7	44.9	78.0	33.1	36.0	35.6	-0.4	40.5
NO ₂	31.8	25.5	-6.3	21.2	20.2	-1.0	20.9	14.1	14.3	0.2	12.5	14.4	1.9	10.9
PM _{2.5}	14.8	15.5	0.7	11.1 ^{*)}	8.6 ^{*)}	-2.5 ^{*)}	10.8 ^{*)}	16.7	15.2	-1.5	12.0 ^{*)}	8.2 ^{*)}	-3.8 ^{*)}	12.1 ^{*)}
PM ₁₀	18.6	20.0	1.4	12.9 ^{*)}	9.5 ^{*)}	-3.4 ^{*)}	15.0 ^{*)}	22.0	19.0	-3.0	13.6 ^{*)}	12.0 ^{*)}	-1.6 ^{*)}	15.8 ^{*)}
Rotterdam														
O ₃	37.8	51.2	13.4	28.8	29.6	0.8	24.1	-	-	-	-	-	-	-
NO ₂	36.1	28.9	-7.3	19.8	17.1	-2.8	18.8	28.9	33.8	4.9	17.3	17.6	0.3	15.2
PM _{2.5}	14.9	11.1	-3.8	12.1	6.4	-5.7	10.3	13.8	11.4	-2.4	12.8	6.8	-6.0	9.9
PM ₁₀	24.0	14.6	-9.4	15.4	7.9	-7.4	16.3	20.8	15.2	-5.6	14.3	8.5	-5.8	12.6

^{*)} calculation based on daily averages



4.1 Ozone general validation

MATCH overestimates annual mean O_3 concentrations at all investigated sites. In Stockholm, the model behaves significantly better at the regional background site compared to the urban site. In Bologna, on the other hand, MATCH performs equally poor, or worse, at the regional background site compared to the urban site. As can be inferred from the observed and modelled $PM_{2.5}$ and PM_{10} mean levels in San Pietro de Capofiume, it is clear that this site is not an unperturbed regional background site but represents the highly polluted Po valley.

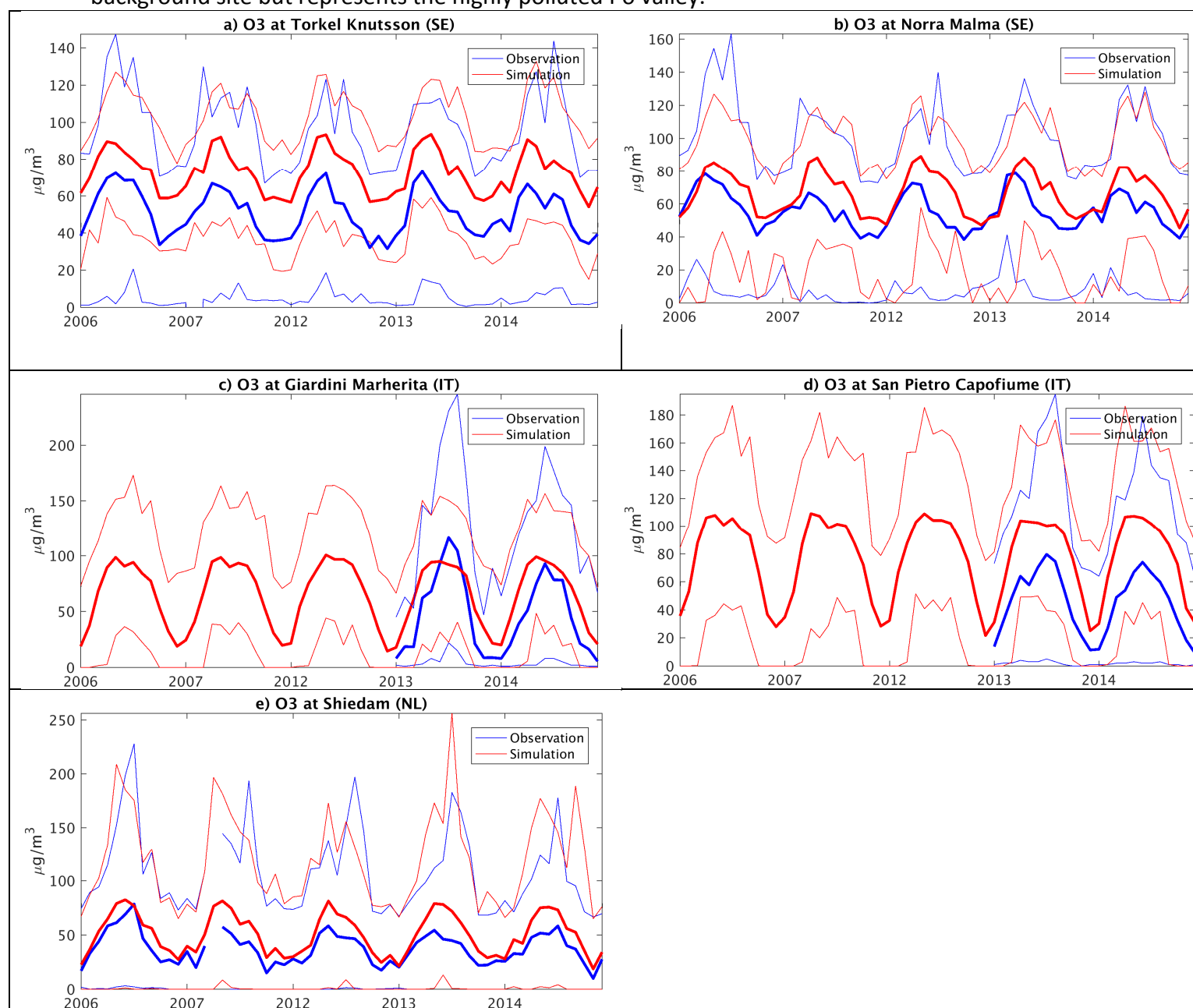


Figure 2 - Time series of O_3 in Stockholm (a-b), Bologna (c-d) and Rotterdam (e) for the years 2006-2007 and 2012-2014. The thick lines show monthly mean values and the thin lines monthly maximum and minimum hourly values, respectively. Note that there should be a time gap in the x-axis between years 2007 and 2012. For Rotterdam O_3 data are only available for the Shiedam station.



When comparing monthly ozone averages with monthly minimum and monthly maximum concentrations it is clear that the model does a reasonable job reproducing the maximum concentrations but strongly overestimates the (night-time, see below) minimum concentrations. This failure of reproducing the lowest concentrations contributes to the erroneously estimated annual and monthly averages.

For health considerations, the high extreme values are most relevant. It is therefore assuring to note that monthly maximum ozone is reasonably reproduced by the Urban SIS air quality model.

4.2 NO₂ general validation

The MATCH model generally does a fair job reproducing NO₂ concentrations at the stations included in the present analysis. There is a tendency for underestimating annual and monthly averages at some of the urban sites but the seasonal variation of monthly mean concentrations are excellently simulated by the model. Also the extreme (monthly minimum and monthly maximum) are well reproduced by the model.

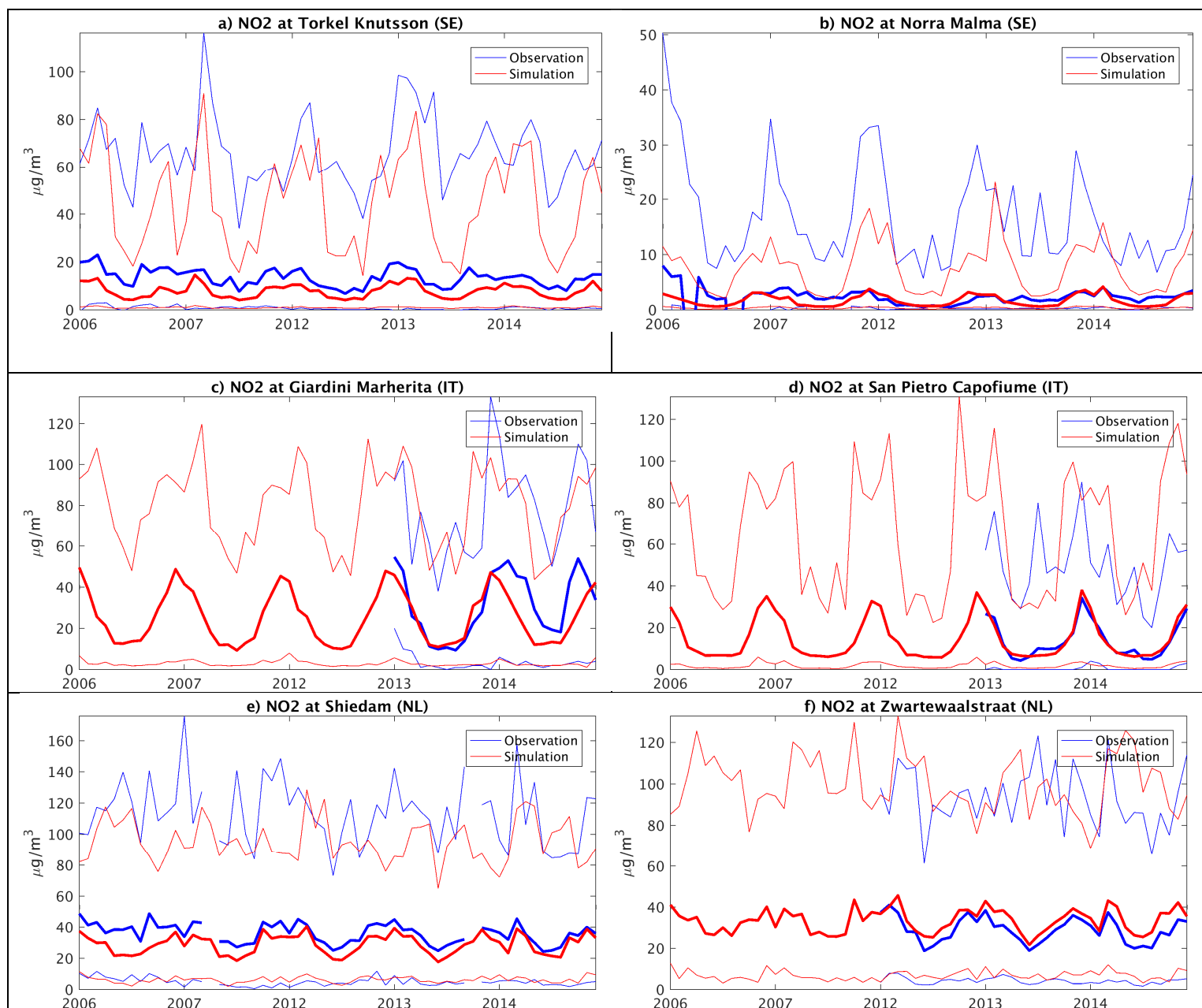


Figure 3 - Time series of NO₂ in Stockholm (a-b), Bologna (c-d) and Rotterdam (e) for the years 2006-2007 and 2012-2014. The thick lines show monthly mean values and the thin lines monthly maximum and minimum hourly values, respectively. Note that there should be a time gap in the x-axis between years 2007 and 2012.



4.3 PM_{2.5} general validation

Annual and monthly average PM_{2.5} concentrations are reasonably simulated by the MATCH model. The model also captures the seasonal variation with higher concentrations during winter than in summer. MATCH cannot reproduce some of the very high hourly values in the Stockholm and Amsterdam/Rotterdam domains. This data do not affect the annual or monthly mean values and only represent a tiny fraction of all data from the respective sites. The high concentrations mainly occur during winter and are caused by enhanced emissions during stable very conditions – a situation that is difficult to model for any modelling system. For Bologna the two graphs displaying the monthly maximum values looks better, but this is due to the fact that the observations are only available as daily averages, i.e. the plotted comparison is between simulated hourly and observed daily maxima.

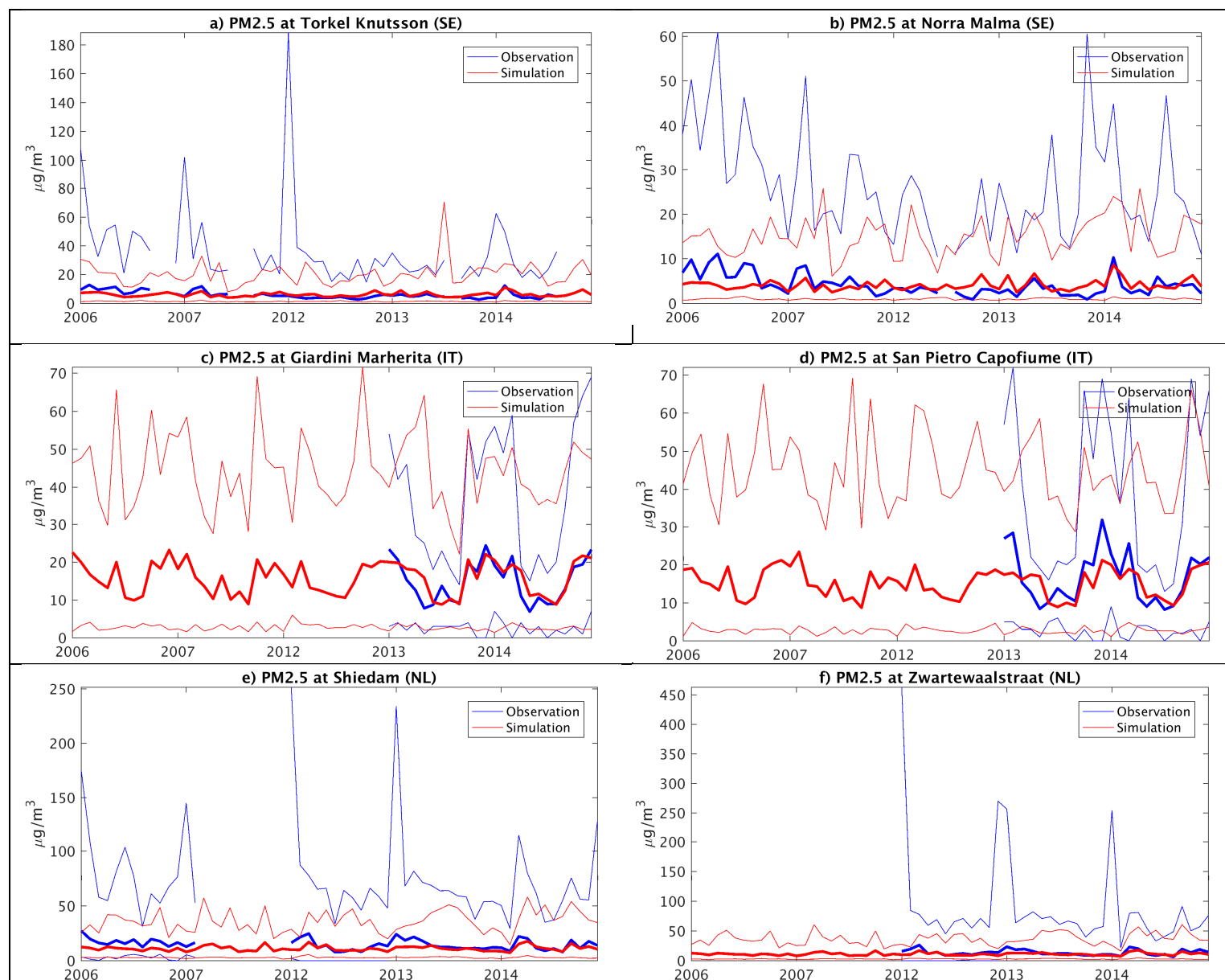


Figure 4 - Time series of PM_{2.5} in Stockholm (a-b), Bologna (c-d) and Rotterdam (e) for the years 2006-2007 and 2012-2014. The thick lines show monthly mean values and the thin lines monthly maximum and minimum hourly values (for Bologna observations of daily values), respectively. Note that there should be a time gap in the x-axis between years 2007 and 2012.



4.4 PM₁₀ general validation

PM₁₀ is a more locally emitted pollutant than PM_{2.5}, still the model has a larger negative bias (also in relative numbers) for PM₁₀ than for, the regional air pollutant, PM_{2.5} - which indicates an underestimation of local PM₁₀ emissions in the Stockholm and Rotterdam modelling domains, or too low background concentrations (see below). The observational data from Stockholm show pronounced winter and spring peaks in PM₁₀ which the model cannot resolve. These peaks are related to re-suspension of road dust, which show annual maximums during the spring while the roads are drying up after snow/ice smelting. The inclusion of non-exhaust PM emissions from traffic is simplified in the Urban SIS simulations and does not contain time varying emissions describing individual extreme events produced by roads drying-up.

The PM₁₀ data series from the sites in Bologna are generally shorter and it is difficult to discern any seasonal variation in the observations or model results. For the short period of available observations, the monthly average values of the simulated and observed follow each other fairly well. The long observational series from Shiedam (Rotterdam) indicates decreasing levels of PM₁₀ from the onset of 2006 to the end of 2015. If the general shift is due to changes in local emissions and not driven by climatic changes, it is not expected that our modelling system should capture this trend, this since identical emissions have been used for all years of the historical period.

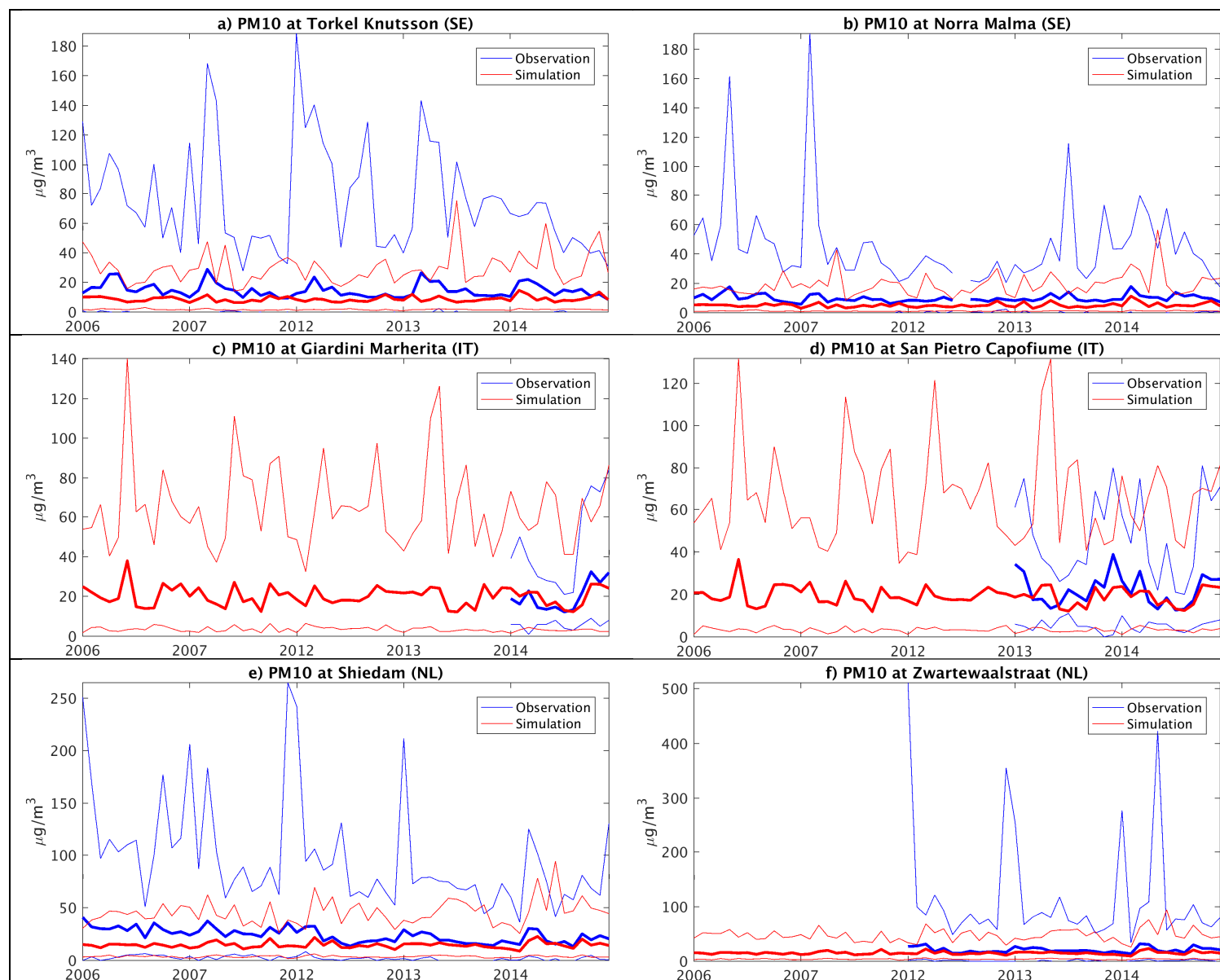


Figure 5 - Time series of PM₁₀ in Stockholm (a-b), Bologna (c-d) and Rotterdam (e) for the years 2006-2007 and 2012-2014. The thick lines show monthly mean values and the thin lines monthly maximum and minimum hourly values (for Bologna observations of daily values), respectively. Note that there should be a time gap in the x-axis between years 2007 and 2012.



4.5 Ozone tailored validation

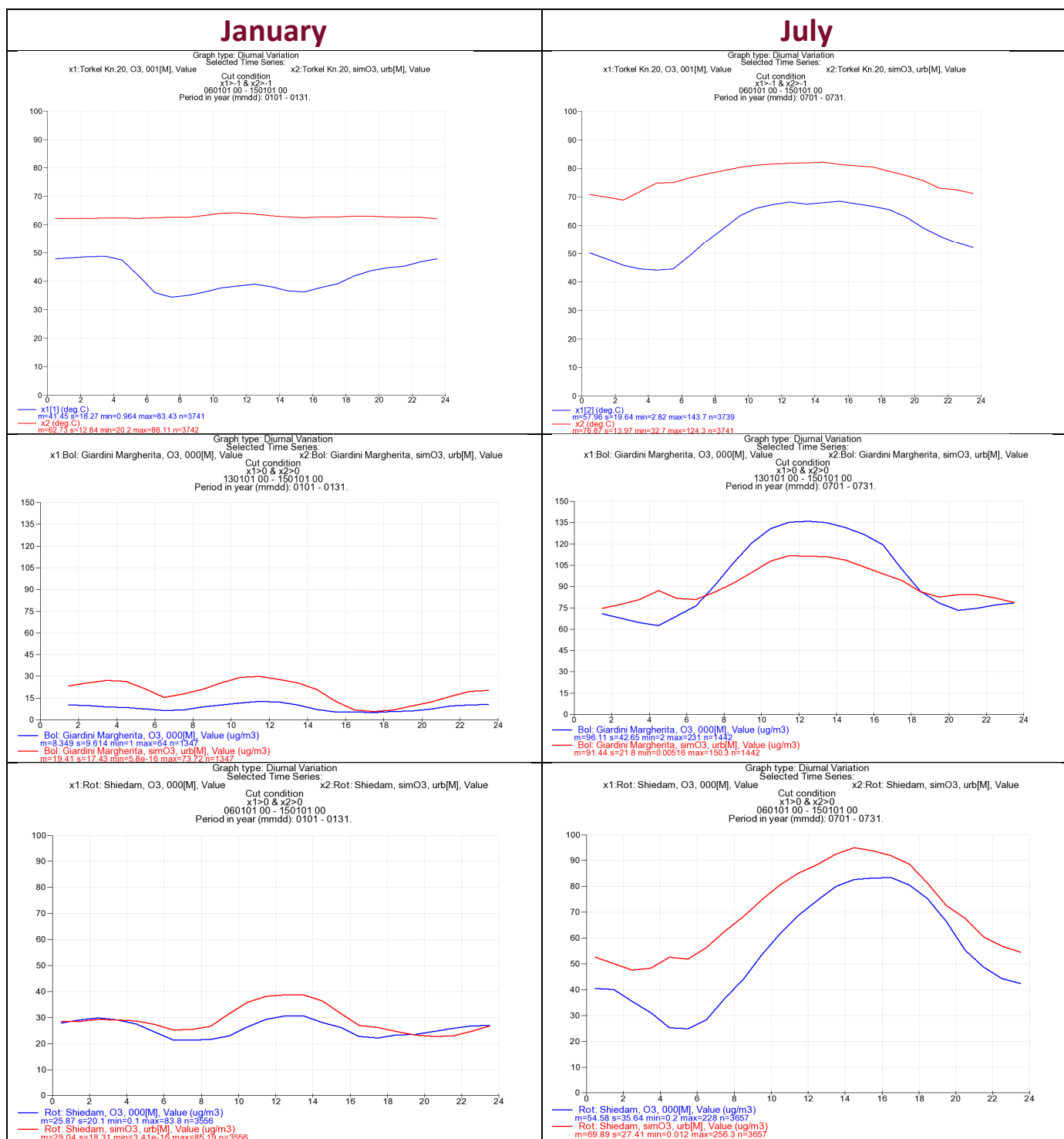


Figure 6 - Average daily variation of measured and simulated ozone levels in Stockholm (top), Bologna (middle) and Rotterdam (bottom), for winter conditions (January; left) and summer conditions (July; right). The evaluation based on hourly data for which simultaneous measured and simulated data are available. Time in UCT.



From the average diurnal cycles of O₃ displayed in Figure 6 it is clear that MATCH always overestimates the lowest O₃ concentrations. During January, observed O₃ concentrations are anti-correlated with locally emitted NO₂ (see Figure 7) and displays minimum values during the morning and afternoon rush-hours, this feature is reasonably captured in Bologna and Rotterdam but not in Stockholm. During July the lowest O₃ concentrations typically occur during night-time and early morning at all sites; the model grossly captures this feature albeit often with a smaller amplitude compared to observations.

Table 4 - Statistics related to health indicator calculations, for tailored validation of ozone ECVs based on hourly data for which both monitored and simulated data were available. Reported values for this evaluation are calculated for all years together, where SOMO35 is later divided by 5 (Stockholm, Rotterdam) and 2 (Bologna) to yield a comparable magnitude to the true indicator that is based on accumulation throughout a year.

Variable	period	OBS	SIM	unit
Stockholm (Station 1 Torkel Knutsson)				
O3: 93.15 th percentile 8-hour running mean	2006-2007, 2012-2014	81.7	98.7	µg/m ³
O3: SOMO35	2006-2007, 2012-2014	1257	4165	µg/m ³ day
Bologna (Station 1 Giardini Margherita)				
O3: 93.15 th percentile 8-hour running mean	2013-2014	119.7	111.5	µg/m ³
O3: SOMO35	2013-2014	6668	6500	µg/m ³ day
Rotterdam (Station 1 Shiedam)				
O3: 93.15 th percentile 8-hour running mean	2006-2007, 2012-2014	79.5	93.5	µg/m ³
O3: SOMO35	2006-2007, 2012-2014	1238	3162	µg/m ³ day

The ozone-related indicators dealing with human health are based on the higher concentrations, which means that the model's (in-)ability to reproduce the lower, night-time, values are not a concern for this particular application. The simulated 93.15th percentile of hourly O₃ concentrations in Bologna is thus slightly underestimated although this indicator is still overestimated in Stockholm and Rotterdam - although much closer to observations than the annual and monthly averages discussed earlier. SOMO35 is based on exceedances over the threshold 70 µg/m³ (35 ppb(v)) and is notoriously difficult to reproduce similarly to observations, since daily values of ozone typically are found close to this value. The comparison for the Bologna station, based on only two years of observations, indicate a good agreement between the Urban SIS data and the observations.

4.6 NO₂ tailored validation

NO₂ has a more or less pronounced bimodal average diurnal cycle which is closely related to the intensity of local traffic emissions. NO₂ concentrations at urban background stations are higher during winter-time due to less efficient turbulent mixing. Both these features are grossly captured by the model at all the sites.

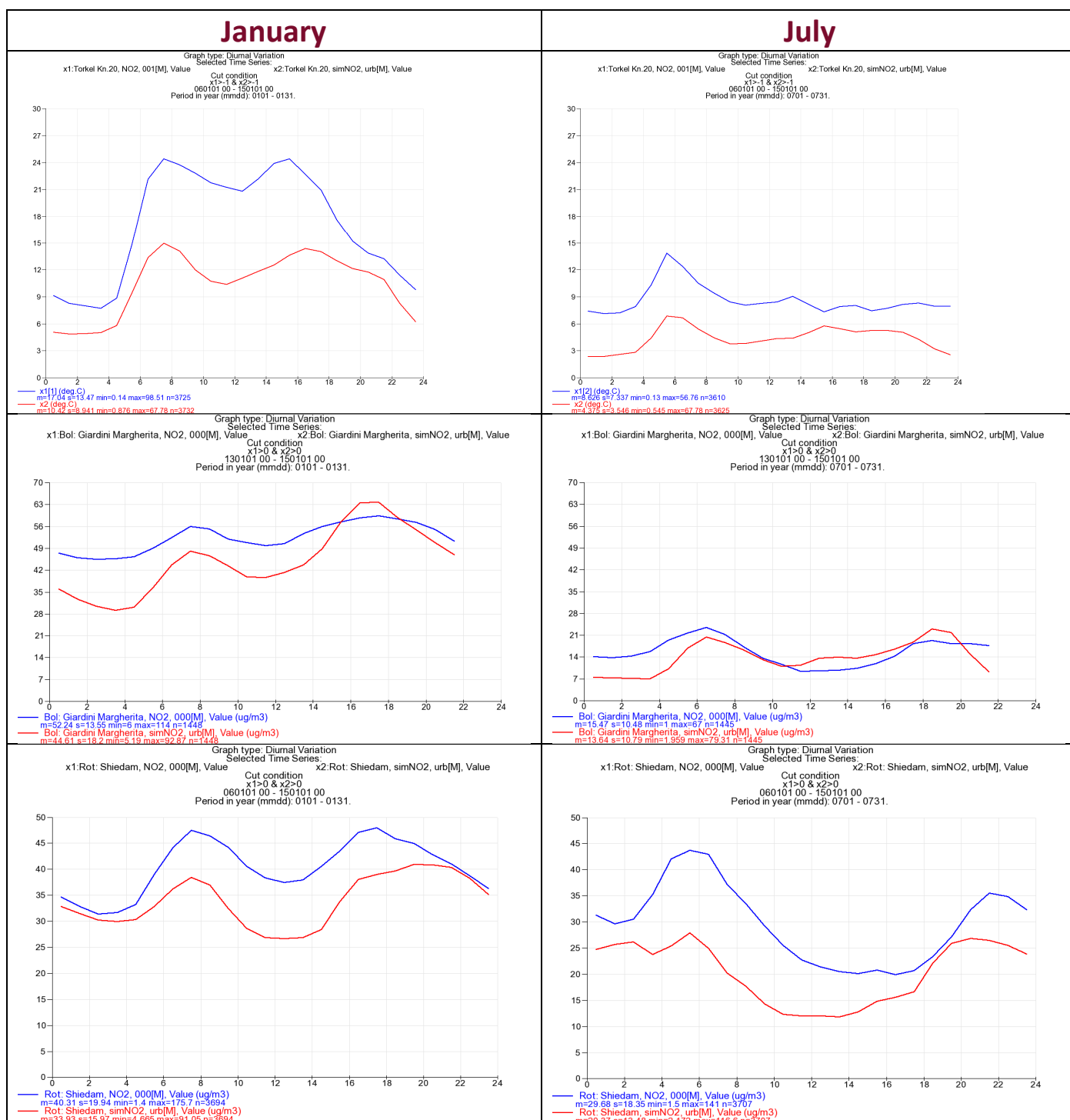


Figure 7 - Average daily variation of measured and simulated NO₂ levels in Stockholm (top), Bologna (middle) and Rotterdam (bottom), for winter conditions (January; left) and summer (July; right). The evaluation based on hourly data for which simultaneous measured and simulated data are available. Time in UCT.

Table 5 gives an indication on how the simulated extreme value indicator for NO₂ compare to observed values. In all cities this indicator is somewhat underestimated.



Table 5 - Statistics related to health indicator calculations, for tailored validation of NO₂ ECVs based on hourly data for which both monitored and simulated data were available. Reported values for this evaluation are calculated for all years together, while the true indicator is calculated for each year.

Variable	period	OBS	SIM	unit
Stockholm (Station 1 Torkel Knutsson)				
NO ₂ : 99.8 th percentile hourly averages	2006-2007, 2012-2014	73.1	60.1	µg/m ³
Bologna (Station 1 Giardini Margherita)				
NO ₂ : 99.8 th percentile hourly averages	2013-2014	103.8	92.8	µg/m ³
Rotterdam (Station 1 Shiedam)				
NO ₂ : 99.8 th percentile hourly averages	2006-2007, 2012-2014	118.5	100.2	µg/m ³

4.7 PM_{2.5} tailored validation

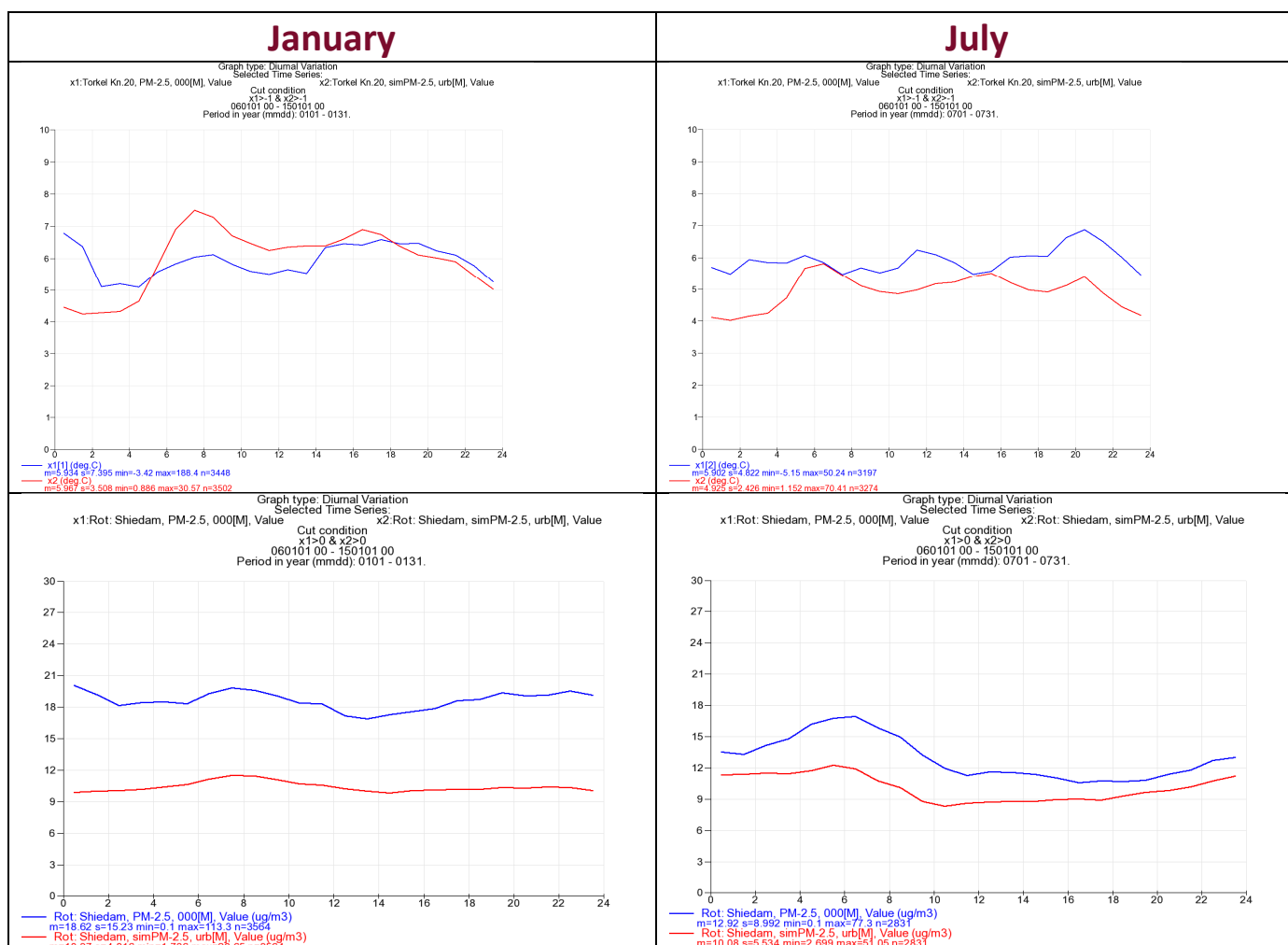


Figure 8 - Average daily variation of measured and simulated PM_{2.5} levels in Stockholm (top) and Rotterdam (bottom), for winter conditions (January; left) and summer (July; right). The evaluation based on hourly data for which simultaneous measured and simulated data are available (in Rotterdam only daily observations are made). Time in UCT.



The observed average diurnal cycle of PM_{2.5} in Stockholm is much less pronounced than for NO₂, indicating the large contribution of long-range transported PM_{2.5} in comparison to local emissions. The average diurnal cycle from Rotterdam indicates underestimated levels, especially during January. Although PM_{2.5} is underestimated by MATCH in Rotterdam the shape of the average diurnal variation is well captured at this site. For Bologna PM_{2.5} data is only available as daily averages and no evaluation of diurnal cycle is possible.

4.8 PM₁₀ tailored validation

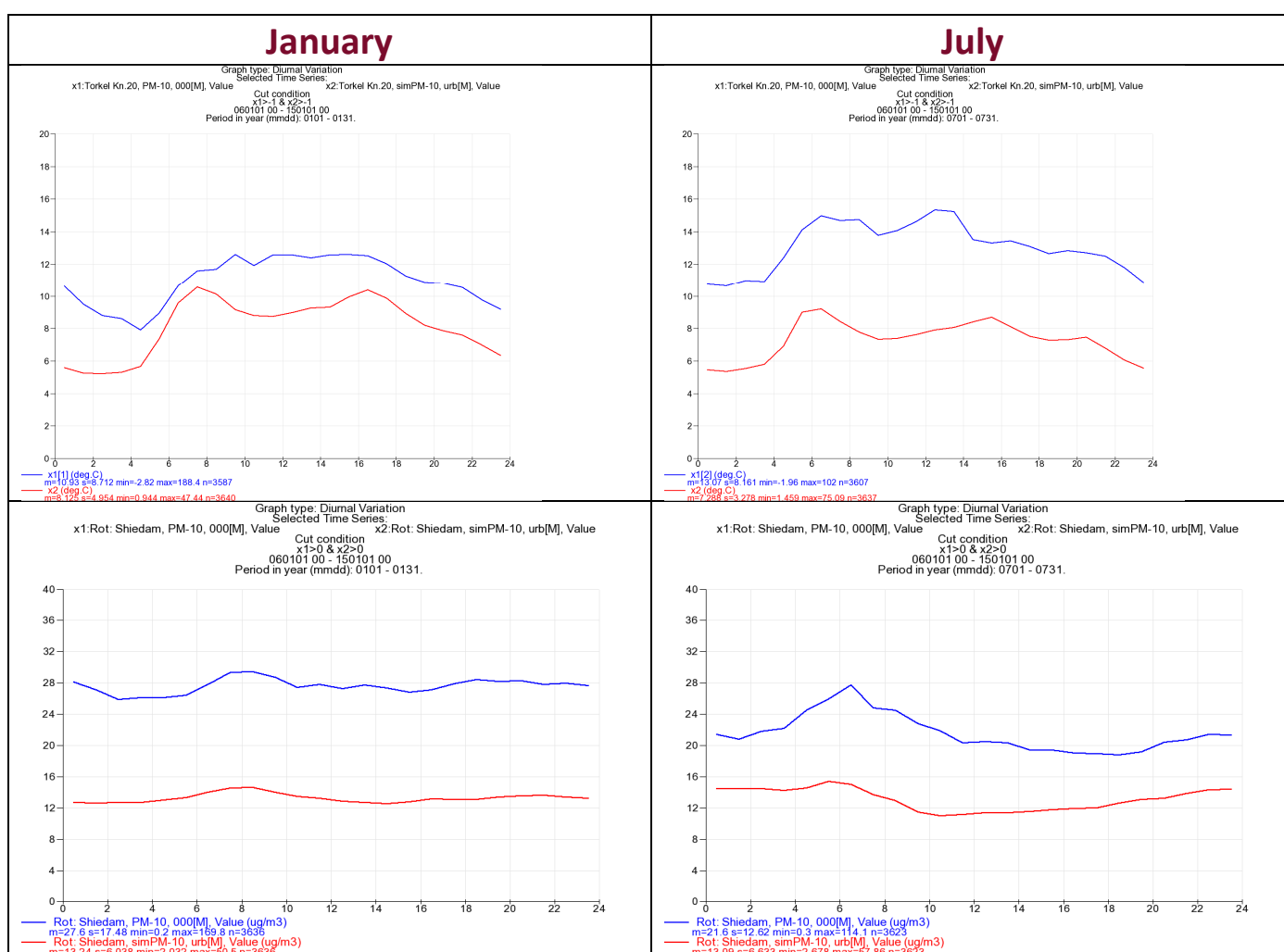


Figure 9 - Average daily variation of measured and simulated PM₁₀ levels in Stockholm (top) and Rotterdam (bottom), for winter conditions (January; left) and summer (July; right). The evaluation based on hourly data for which simultaneous measured and simulated data are available (in Rotterdam only daily observations are made). Time in UCT.

The average diurnal cycle of PM₁₀ in Stockholm is clearly correlated with traffic intensity with minimum values during the night and higher values during day time. These features are reasonably well resolved by MATCH, but the levels are consistently underestimated, especially during July, which indicates an underestimated long-range contribution. In the Rotterdam station Shiedam the



average diurnal cycle is less pronounced indicating an even stronger regional to local contribution ratio of PM₁₀. Urban SIS PM₁₀ levels in Rotterdam are significantly underestimated, only explaining about half of the observed levels. For Bologna only daily observations from 2014 are available, for which a simulated annual mean level of 20.0 µg/m³ can be compared to the observed 18.6 µg/m³ (Table 3), i.e. fairly similar levels.

Table 6 below gives the EU limit values for daily PM₁₀, in which the 90th percentile should not exceed 50 µg/m³. The comparison indicates that for Stockholm and Rotterdam, Urban SIS output is strongly underestimating PM₁₀ levels and this indicator value. However, in Bologna both PM₁₀ mean levels as well as the 90th percentile are reasonably similar, both below the EU limit value (as is expected in an urban background station).

Table 6 - Statistics related to health indicator calculations, for tailored validation of PM₁₀ ECVs based on hourly data for which both monitored and simulated data were available. Reported values for this evaluation are calculated for all years together, while the true indicator is calculated for each year.

Variable	period	OBS	SIM	unit
Stockholm (Station 1 Torkel Knutsson)				
PM10: 90 th percentile daily averages	2006-2007, 2012-2014	26.0	14.4	µg/m ³
Bologna (Station 1 Giardini Margherita)				
PM10: 90 th percentile daily averages	2014	30.3	35.1	µg/m ³
Rotterdam (Station 1 Shiedam)				
PM10: 90 th percentile daily averages	2006-2007, 2012-2014	40.2	24.1	µg/m ³

5. Conclusions and discussion

In the present set-up, MATCH has difficulties reproducing annual and monthly average O₃ at all investigated sites. O₃ is over-estimated by MATCH both at the urban background and regional background sites. The over-estimation is partly caused by overestimated boundary conditions although the pan-European model generally shows very good performance when evaluated against O₃ data collected at regional background sites (Table 7 below). The overestimation is likely also caused by non-perfections in the deposition scheme and the photochemical model used in the urban application of MATCH. The general overestimation of ozone have smaller impact on the indicators based on the higher percentiles, but very strong influences on the SOMO35 indicator which is based on a specific threshold. MATCH was originally developed for describing regional background concentrations and for further high-resolution urban downscaling it is recommended to revise both deposition and the photochemistry properties to assure consistency between simulated and observed O₃ and NO₂ levels.



Table 7 - General performance of the pan-European application of MATCH evaluated against observations from EMEP sites across Europe for the year 2011.

	Mean relative bias	Mean correlation coefficient (r)	#stations
NO ₂	-0.23	0.48	37
PM _{2.5}	-0.22	0.50	33
PM ₁₀	-0.30	0.52	31
O ₃ (all hours)	+1.8	0.56	102
O ₃ (daily-maximum)	+0.6	0.71	102

For NO₂ and PM₁₀ it is clear that the model cannot resolve the highest (99.8 percentile of hourly-mean values and 90 percentile of daily-mean values, respectively) values observed. These high concentrations typically occur episodically under stagnant (i.e. low mixing) and high emission (cold days resulting in increased emissions due to residential burning for warming) situations during winter. It is a well-known fact that both the meteorological and the air quality models have difficulties describing anomalously stable situations. In the present configuration of our air quality model we have also not prescribed temperature dependent emissions (i.e. from the energy production) and it is therefore not expected that the individual air pollution episodes should be adequately described by the present modelling system.

The MATCH model is able to reproduce the gross features of the diurnal profiles of the atmospheric pollutants, which is stronger for NO₂/O₃ and less strong for particulate matter PM_{2.5} and PM₁₀. As discussed above was MATCH originally developed to describe air pollution at regional background stations but the fair correspondence between modelled and observed diurnal cycles of the reactive and inert species means that although there are imperfections in the chemical and physical transformation schemes, the model may still be used to determine the levels of air pollution in an urban environment.

Of the three cities, the air quality downscaling show best performance for Bologna, likely due to a combination of better boundary conditions and local emission information.

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