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Urban SIS
D441_Lot3.5.1 Validation of climate variables

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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 (D441.5.1) addresses specifically the validation of the urban climate downscaled variables. Two other reports, D441.5.2 and D441.5.3, complete the validation, respectively for the urban air quality and the hydrological components.

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. Both MATCH and HYPE are driven by output data from HARMONIE-AROME.

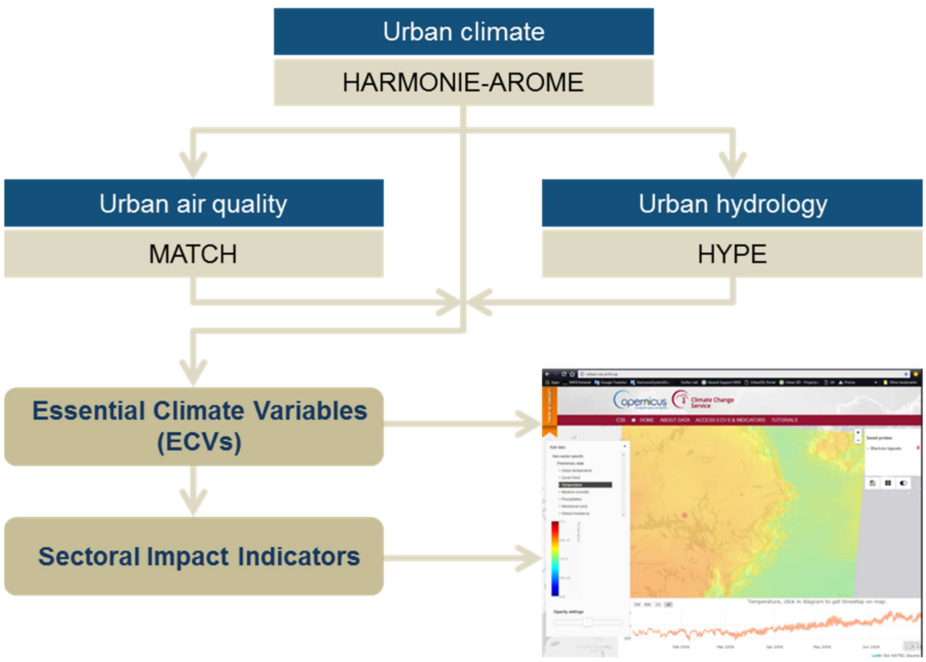


Figure 1 – General flowchart representing the downscalling approach applied in Urban SIS. More detailed information about the meteorological model HARMONIE-AROME is given in D441.3.1.

This report summarizes the key results from the validation that are needed 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 both qualitative and quantitative 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 given below in this deliverable, and the accompanying deliverables D441.5.2 and D441.5.3, fulfil the first requirement above. The second requirement is fulfilled by the provision of qualified metadata on the Urban SIS portal. The third requirement has been fulfilled 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 is five climate ECVs, two air quality ECVs and two hydrological 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 D441.5.2 and D441.5.3).

Table 1 - *Overview of the validation performed in Urban SIS for Stockholm (STH), Bologna (BOL) and Amsterdam (AMS).*

		General			**Tailored**		
		STH	BOL	AMS	STH	BOL	AMS
Climate (D441.5.1)	Temp.	x	x	x	x	x	x
	Prec.	x	x	x			
	Rel.Hum.	x	x	x			
	Wind	x	x	x			
	Glob.Rad.	x	x	x			
Air Quality (D441.5.2)	O_3	x	x	x	x	x	x
	NO_2	x	x	x	x	x	x
	PM2.5	x	x	x	x		x
	PM10	x	x	x	x		x
Hydrology (D441.5.3)	Prec.				x		x
	Extr.Prec.				x		x
	Discharge	x	x		x	x	

Sections 4 and 5 of this report intend 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. Climate data in Urban SIS

As shown in Table 1, the validation of Urban SIS downscaled variables against observations consists of two components: the first is a generic statistical analysis of five climate-related ECVs: air temperature, precipitation, relative humidity, wind, and global radiation. Then, a more in-depth validation was carried out for air temperature as it will be described in section 3 (the tailored validation of precipitation is part of D441.5.3).

2.1 Simulated climate data

The urban climate simulations were performed with the HARMONIE-AROME model (Bengtsson et al., 2017), set up for each of the Urban SIS domains, as described in D441.3.1. The validation is performed using the HARMONIE-AROME outputs over the inner 110×110 km² domain at its highest spatial resolution (1×1 km²) and hourly temporal resolution.

2.2 Observed climate data

Table 2 provides an overview of the data available for validating HARMONIE-AROME. The criteria for the selection of the meteorological stations were the following:

- Spatial representativeness, ideally urban,
- Availability of the data.

Table 2 - Available meteorological observations during the historical period (2006-2007, 2012-2014) used in the validation of Urban SIS output.

City	Station	lat	lon	Classification	Siting
Stockholm	Torkel Knutsson	59.3160	18.0577	urban	roof top
	Högdalen	59.2612	18.0618	outskirts (industrial)	ground
Bologna	Bologna Urbana	44.5008	11.3288	urban	roof top
	San Pietro de Capofiume	44.6538	11.6226	rural	ground
Rotterdam	Rotterdam Airport	51.9620	4.4470	airport	ground

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 similar for all ECV categories (climate, air quality, 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 data in the three cities. As it will be seen in section 4, air temperature is decomposed into 6 parameters:

- air temperature at 2 m above ground (T2M), corresponding to the weighted average of the different 'tiles' (see section 3.3),
- air temperature at 2 m above urban (T2Murban) and nature (T2Mnature) 'tiles',
- air temperature at the first three levels of model output, corresponding to heights above ground of aprox. 12 m (TLevel1), 38 m (TLevel2), and 50 m (TLevel3).

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 period (see D2.1 and D441.3.1-3 for the selection and production process of simulated historical dataset). These monthly series were plotted for both observations and HARMONIE-AROME simulations in order to assess the agreement in terms of the annual cycle as well as differences between different years in the 5-year simulation period.

Additionally the mean value and standard deviation over the entire period was calculated for both observations and simulations, and the agreement was also quantified by the Root Mean Square Error (RMSE).

3.3 Tailored validation

The tailored validation of climate outputs from HARMONIE-AROME is focused on air temperature while, as mentioned, the tailored validation of precipitation is described in D441.5.3. Sub-chapter 3.3 describes the method used in the tailored validation of temperature that includes the analysis of:

- air temperature over different land-uses,
- the diurnal cycle of temperature,

- temperature-related indicators with relevance for the health and the infrastructure sectors.

3.3.1 Temperature land-use dependence

As detailed in D441.3.1 (section 2.4), HARMONIE-AROME describes the surface using a 'tiling method' that allows to account for sub-grid ground/atmosphere interactions. This approach allows, for each grid cell, to extract T2m over four possible land-use typologies (known as 'tiles'): 'Urban' (composed of buildings, roads and other transportation infrastructure, and gardens); 'Nature' (which can be further divided into 12 patches encompassing bare soils, rocks, permanent snow, glaciers, natural vegetation and agricultural landscapes); 'Lake' (inland waters, including lakes and rivers); and 'Sea' (including both sea and ocean). For the analysis of urban climate we will be focusing the analysis on the 'Urban' and 'Nature' tiles.

One important use of this sub-grid data is the analysis of the capacity of the model to respond to the heterogeneity of the surface physiography characteristics. An example of the investigation of spatial gradients is the quantification of the local impact of parks on urban temperature, an effect known as Park Cool Island (PCI), simply by calculating the temperature difference between the 'Urban' and 'Nature' tiles within a given computational cell where a park exists.

3.3.2 Diurnal temperature cycle

Air temperature data were statistically processed with the objective of extracting diurnal variations for representative winter (January) and summer (July) months. The analysis is carried out for the two urban stations Torkel Knutsson in Stockholm and Bologna Urbana in Bologna.

3.3.3 Sectoral indicators

The tailored analysis of the climate outputs delivered by Urban SIS focused also on the agreement between modeled and observed sectoral indicators. We focus here on three indicators:

- two for health: number of hot days (Apr-Sep) and heat degrees above threshold (Apr-Sep);
- one for the infrastructure sector: number of frost days (Jan-Dec).

A detailed description of these indicators can be found in D4.3 ('Indicators for urban assessments') or online at the project web portal (http://urbansis.climate.copernicus.eu/urban-sis-climate-indicators/).

For the health indicators we have calculated the local air temperature threshold for the classification as hot day as the 75th percentile of daily mean temperatures for the period between April and September over the 5 years. As reference meteorological observations we have selected stations located at airports close to the cities following other heat-attributable mortality studies (e.g. Donato et al., 2015). The resulting thresholds are shown in Table 3.

Table 3 - Reference stations for temperature and determination of local threshold for hot days (75th percentile of daily mean temperatures from April to September).

Station	**lat**	**long**	**Threshold for hot days**	**Unit**
Stockholm: Bromma airport	59.351241	17.953245	18.05	℃
Bologna: Bologna airport	44.537015	11.293160	23.60	℃
Rotterdam: Amsterdam airport	52.309993	4.787742	16.89	℃

4. Validation results

Table 4 shows the statistical analysis of HARMONIE-AROME results following the general validation method described in section 3.2.

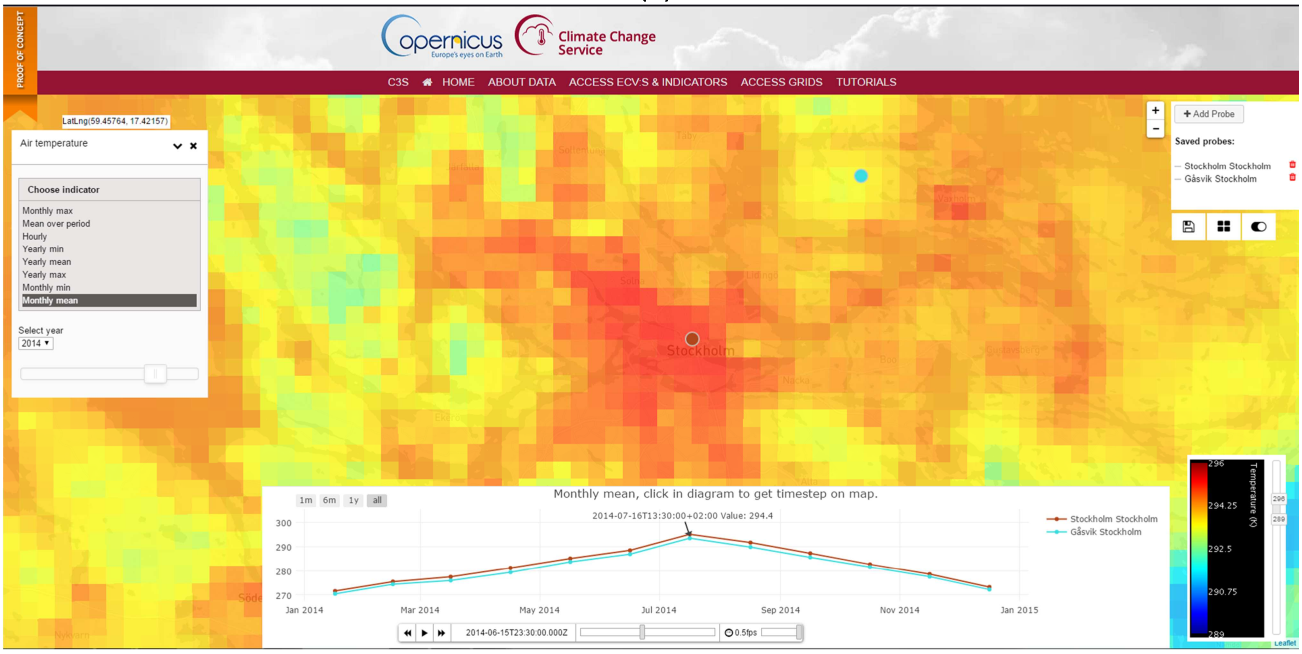
Table 4 - Results from the general validation of modelled climate data for the three demo cities over the 5 years. Units: T in °C, PREC1H in mm.h^{-1}, RH in %, GlobRad in W.m^{-2}, and Windspeed in m.s^{-1}. Values in parenthesis are shown only for inter-comparison with modelled data and do not represent actual measurements. For example, observations at Torkel are made at a height equivalent to model level 1 (TLevel1), while at Högdalen they correspond to T2m.

	Mean			Std.dev			RMSE	Mean			Std.dev			RMSE
	OBS	SIM	DIFF	OBS	SIM	DIFF		OBS	SIM	DIFF	OBS	SIM	DIFF	
Stockholm	Torkel Knutsson							Högdalen						
T2M	(8.02)	8.42	0.39	8.04	8.43	0.39	1.51	7.41	7.40	-0.01	8.16	8.36	0.21	1.43
T2Murban	(8.02)	8.51	0.48	8.04	8.41	0.37	1.53	(7.41)	7.90	0.49	8.16	8.37	0.21	1.57
T2Mnature	(8.02)	7.02	-1.01	8.04	8.73	0.69	2.46	(7.41)	6.66	-0.75	8.16	8.39	0.23	1.87
TLevel1	8.02	7.96	-0.06	8.04	8.18	0.14	1.31	(7.41)	7.33	-0.08	8.16	8.11	-0.05	1.42
TLevel2	(8.02)	7.71	-0.31	8.04	8.13	0.08	1.33	(7.41)	7.22	-0.19	8.16	8.03	-0.12	1.51
TLevel3	(8.02)	7.51	-0.51	8.04	8.08	0.04	1.39	(7.41)	7.13	-0.28	8.16	7.98	-0.17	1.65
PREC1H	0.035	0.049	0.014	0.301	0.420	0.119	0.468	0.069	0.046	-0.023	0.475	0.392	-0.083	0.548
RH	77.1	73.3	-3.9	18.6	16.1	-2.5	10.4	76.8	77.4	0.7	18.6	16.1	-2.5	9.7
GlobRad	118	127	9	197	204	6	75	111	126	15	190	203	13	74
Windspeed	3.59	3.25	-0.34	1.66	1.42	-0.24	1.05	3.18	3.31	0.14	1.53	1.52	-0.01	0.88
Bologna	Bologna Urbana							San Pietro de Capofiume						
T2M	(15.23)	15.57	0.35	8.49	8.59	0.1	1.64	14.15	13.57	-0.58	9.2	9.04	-0.16	1.81
T2Murban	(15.23)	16.11	0.89	8.49	8.67	0.18	1.81	(14.15)	14.97	0.82	9.2	9.33	0.13	2.11
T2Mnature	-	-	-	-	-	-	-	(14.15)	13.57	-0.58	9.2	9.02	-0.17	1.81
TLevel1	15.23	14.73	-0.5	8.49	8.22	-0.27	1.7	(14.15)	13.98	-0.17	9.2	8.78	-0.42	2.13
TLevel2	(15.23)	14.83	-0.39	8.49	8.2	-0.3	1.91	(14.15)	14.56	0.41	9.2	8.6	-0.6	2.74
TLevel3	(15.23)	14.84	-0.38	8.49	8.21	-0.28	2.11	(14.15)	14.87	0.73	9.2	8.47	-0.73	3.21
PREC1H	0.081	0.090	0.009	0.617	0.714	0.097	0.863	0.072	0.083	0.012	0.535	0.693	0.158	0.815
RH	63.5	63.1	-0.5	22.0	17.8	-4.1	11.3	73.2	79.8	6.6	19.0	17.5	-1.5	12.2
GlobRad	152	174	22	238	256	18	88	167	176	9	262	259	-2	97
Windspeed	2.23	2.63	0.41	1.35	1.45	0.09	1.45	2.18	2.3	0.12	1.47	1.34	-0.13	1.35
Rotterdam	Rotterdam Airport													
T2M	11.02	11.45	0.43	6.52	7.05	0.52	1.55							
T2Murban	(11.02)	11.54	0.51	6.52	7.06	0.54	1.61							
T2Mnature	-	-	-	-	-	-	-							
TLevel1	(11.02)	11.04	0.01	6.52	6.69	0.16	1.4							
TLevel2	(11.02)	10.96	-0.06	6.52	6.56	0.04	1.57							
TLevel3	(11.02)	10.87	-0.15	6.52	6.43	-0.09	1.85							
PREC1H	0.094	0.049	-0.045	0.534	0.484	-0.051	0.658							
RH	81.4	74.8	-6.6	13.6	15.7	2.2	11.2							
GlobRad	119	140	22	194	219	24	88							
Windspeed	3.91	3.86	-0.05	2.69	1.89	-0.8	1.97							

4.1 Temperature

The visual inspection of the climate data, including air temperature, was made directly at the web portal, as illustrated in Figure 2a, through the analysis of 2D maps or time series extracted at specific locations. Additionally, and with the goal of testing the functionality of the end-user interface, we have also exported netCDF files from the portal for subsequent processing with a GIS tool (see Figure 2b).

(a)



(b)

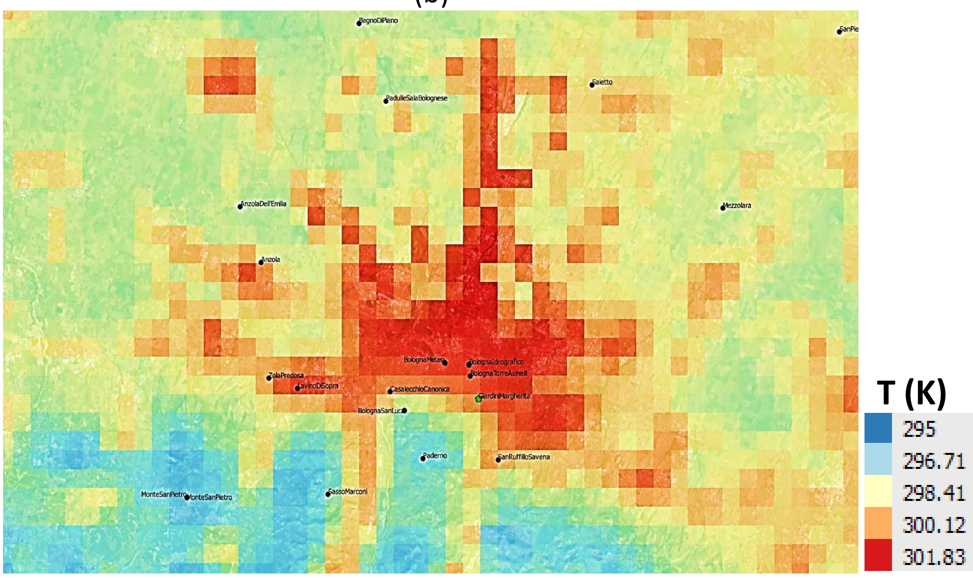


Figure 2 - Monthly mean T2m as captured by HARMONIE-AROME showing the UHI over (a) Stockholm in July 2014, and (b) Bologna in July 2012. Image (a) is a printscreen of the on-line visualization at Urban SIS portal (http://urbansis.climate.copernicus.eu/), while (b) exemplifies the use of QGIS to plot T2m exported from the portal in netCDF format and subsequently converted to shapefile using GDAL.

As can be seen in the two examples of Figure 2, the model is responsive to the urban surface characteristics and gives a good representation of the cities' thermal fingerprints, such as the Urban Heat Island (UHI), which is clearly pictured by the model in both Stockholm and Bologna.

Figure 3 shows the time-series of minimum, mean and maximum monthly values of modelled and observed T2m at the 5 selected sites over the 5 years historical period. The same statistical analysis of data will be shown in the following sections for the other meteorological variables of interest.

In general, a good agreement of modelled values against observations was obtained, with a good representation of the mean annual cycle of air temperature at the different locations, even the urban ones. There is a tendency for the model to underestimate the monthly maximum hourly temperature, which in Sweden is particularly evident in the winter. During the summer, however, modelled peaks are quite close to observations indicating a good performance during warmer periods. In Bologna Urbana we found a better agreement for modelled T2m (not shown) than for TLevel1 plotted in Figure 3c, which raises the possibility that the local climate conditions at this spot are probably more canyon-influenced than it is possible to obtain with TLevel1. At the other extreme of the temperature range it is possible to observe that the model is showing some tendency for being warmer than the lowest temperature dips (below -10 °C).

At Rotterdam Airport, a warm bias of about 1 K in average is found during the summer. Furthermore, the land use in the model consists of 100 % urban tile at the observing site, while an inspection of satellite imagery shows a significant presence of agricultural fields north of the runway. This overrepresentation of the impervious surface in the model physiography leads to reduced evapotranspiration with higher air temperature in the simulations.

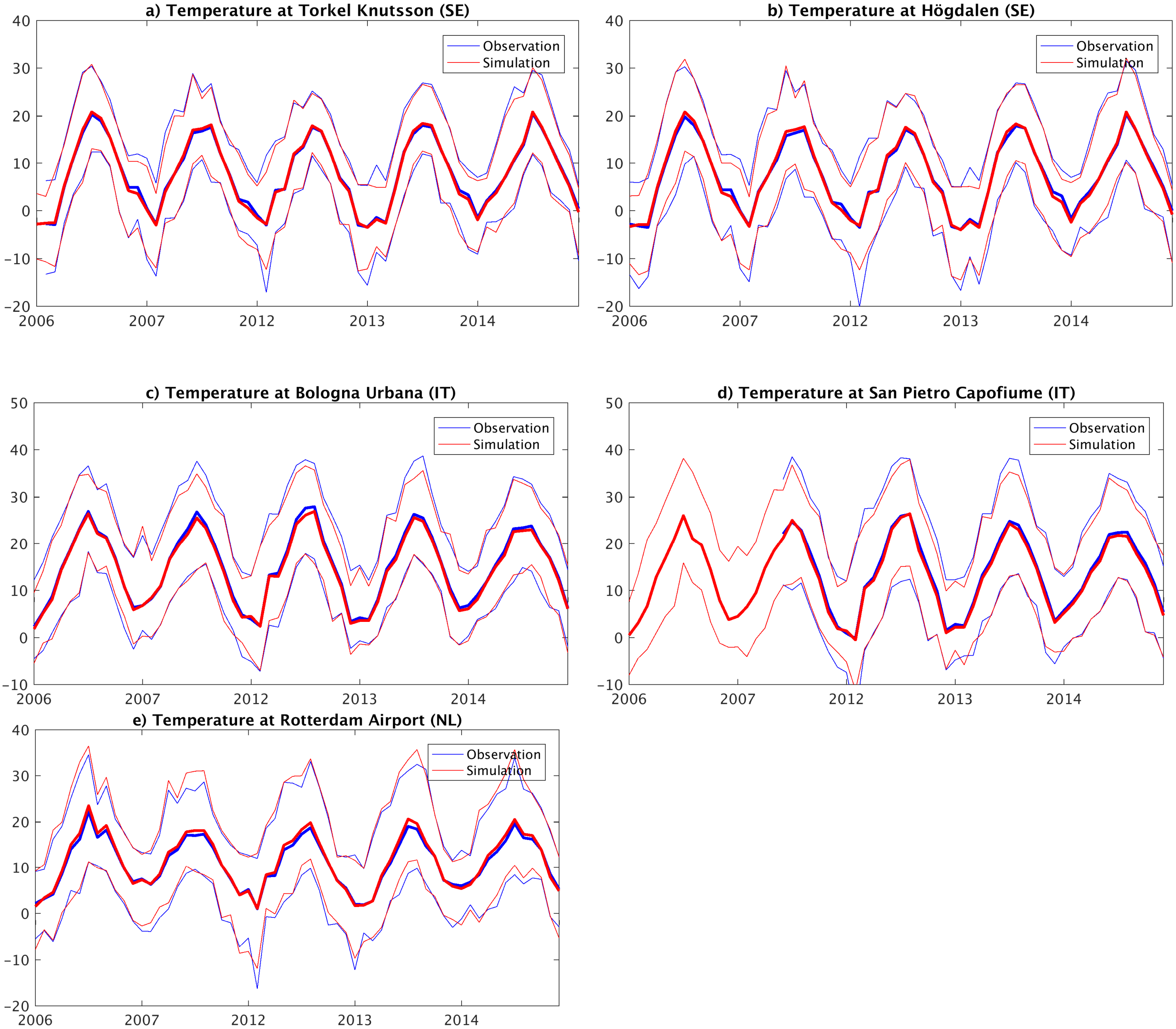


Figure 3 - Time series of air temperature (in °C) in Stockholm (a-b), Bologna (c-d) and Rotterdam (e). Graphs (a) and (c) show temperature at TLevel1, while the others are for T2m. The thick lines show monthly mean values and the thin lines monthly maximum and minimum hourly values, respectively. Note that there is a gap in the x-axis between years 2007 and 2012.

4.1.1 Land-use dependence

As it was shown in Figure 2, HARMONIE-AROME is clearly capable of capturing the warmer urban surface layer, the so-called UHI effect. The trapping of radiation in street canyons and its conversion into sensible heat and heat storage are computed in HARMONIE-AROME by its urban canopy module TEB (Town Energy Balance), which enables a more accurate simulation of the fluxes to the atmosphere than modified-vegetation models (Masson et al., 2013). However, no good quality measurements inside street-canyons (2 m level) are available for the 3 demo cases during the historical period. The urban stations selected (Torkel and Bologna Urbana) have measurements at roof level, reason why the comparison is made against model level 1 (TLevel1) and does not allow to fully explore the performance of canyon temperature modelling by TEB.

As an example of the model capacity to cope with the heterogeneity of the surface and resulting fluxes even inside the city, Figure 4 plots the simulated diurnal profiles of T2m (averaged over the entire 5 years period) over urbanized and vegetated areas in the cities of Stockholm and Bologna, following the method described in section 3.3.1.

The model is shown to respond to the distinct interaction of built-up and green surfaces with the atmosphere, showing a consistent PCI intensity in the range 1.5−2K, in line with other studies reported in literature (see, e.g., the review by Bowler et al., 2010).

A clear feature that is visible in the data is the distinct diurnal trends of T2m over the two surfaces, with the park cooling faster at night than the built-up area and a stronger nighttime PCI intensity, again in accordance with other studies. In addition to the diurnal cycle, there is also a seasonality in the results, with a stronger cooling effect induced by the park during the summer.

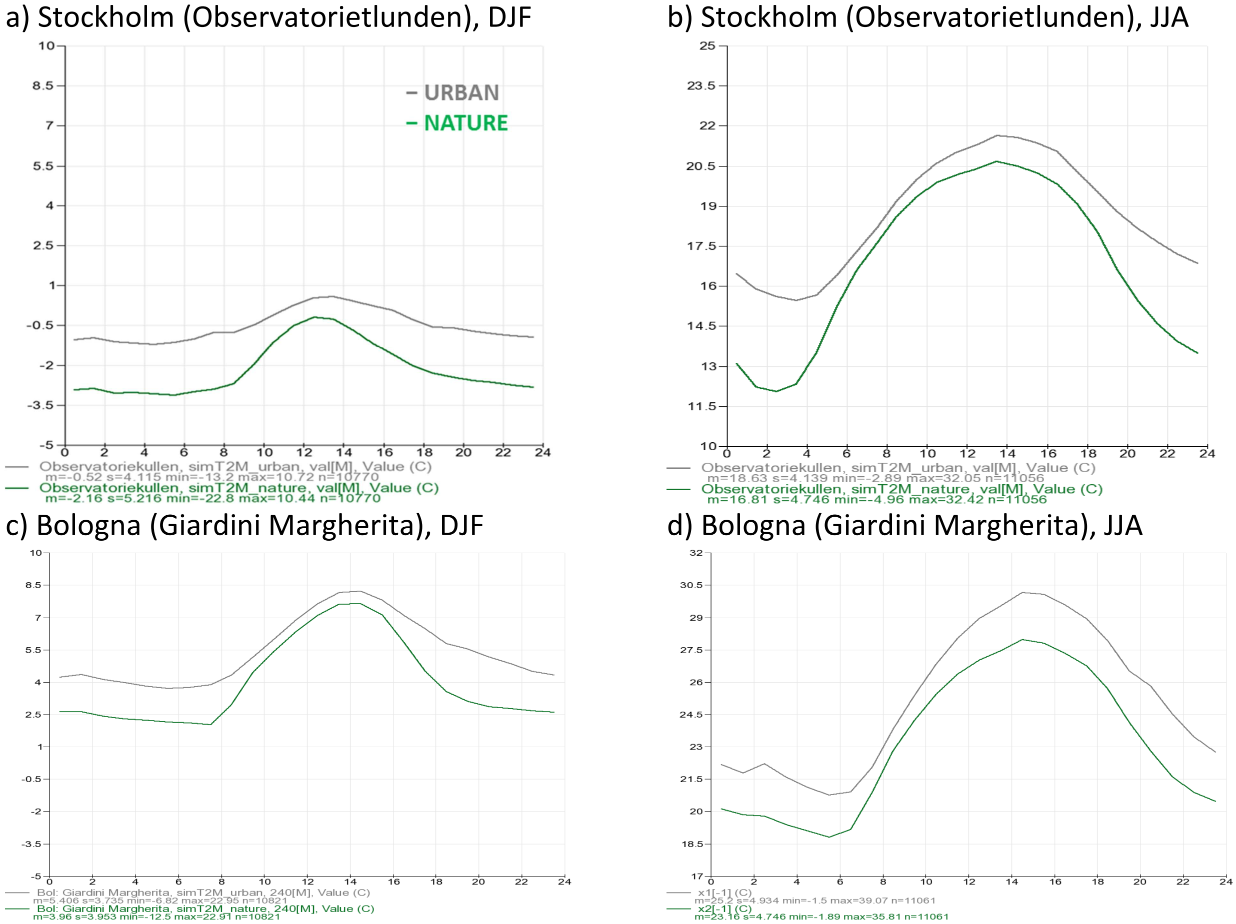
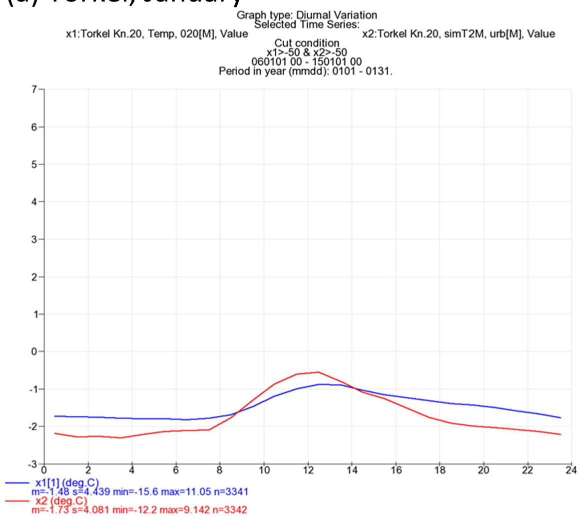


Figure 4 - Mean daily profile of computed T2m in the winter (DJF) and summer (JJA) over 5-years (2006-2007 and 2012-2014) at two urban parks: Observatorietlunden (with 4 ha of size) in Stockholm (a-b), and Giardini Margherita (26 ha) in Bologna (c-d). Results are given for the 'urban' and 'nature' tiles representing, respectively, the built-up and the vegetated fractions of the grid cell. Note that these results compare the effect of distinct land-uses on modelled T2m and do not refer to an inter-comparison against observations.

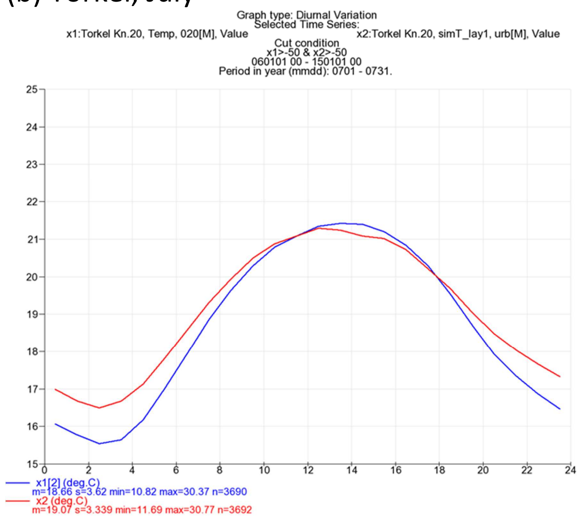
4.1.2 Diurnal cycle

Figure 5 presents the mean diurnal profiles for selected locations. Summer and winter are plotted separately due to the distinct magnitude of the values. First conclusion is that there is a clear signal of the diurnal cycle in the computed air temperature, which generally follows the observed trend. The nighttime brings a cold bias at the two Swedish locations in the winter, while a nearly perfect match is found in Bologna. This behavior is inverted in the summer, with a nighttime warm bias in Sweden that in Högdalen extends up to 12h UTC. The maximum temperatures at daytime in the urban station of Torkel, on the other hand, are in good agreement with measurements, which is an important outcome for heat-related mortality studies in urban environments. Unfortunately, there is a noticeable underestimation tendency of the daytime summer temperature in Bologna, particularly in the city (maximum bias of ca. 1.6 °C). There is also some cooling of the peak temperatures at the rural station of San Pietro Capofiume raising the possibility of a larger scale effect.

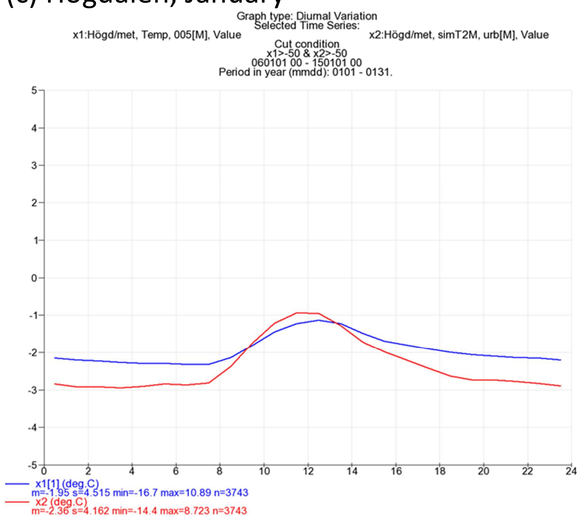
(a) Torkel, January



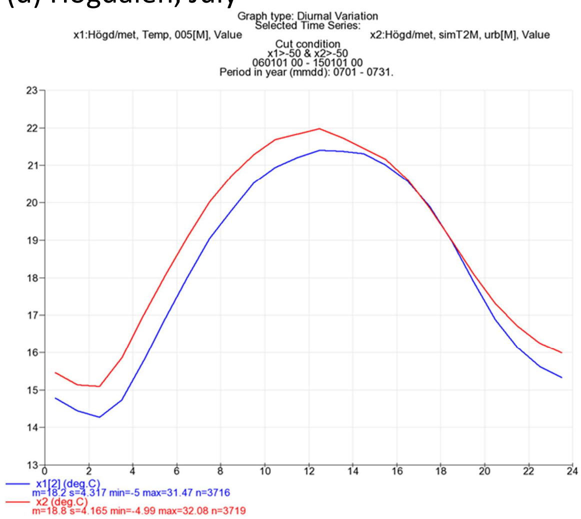
(b) Torkel, July



(c) Högdalen, January



(d) Högdalen, July



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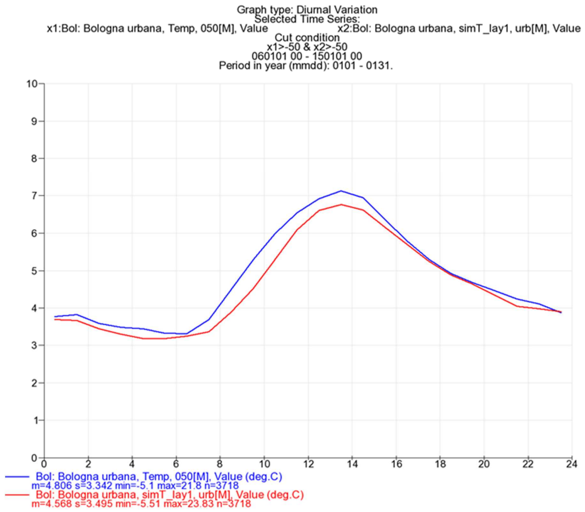
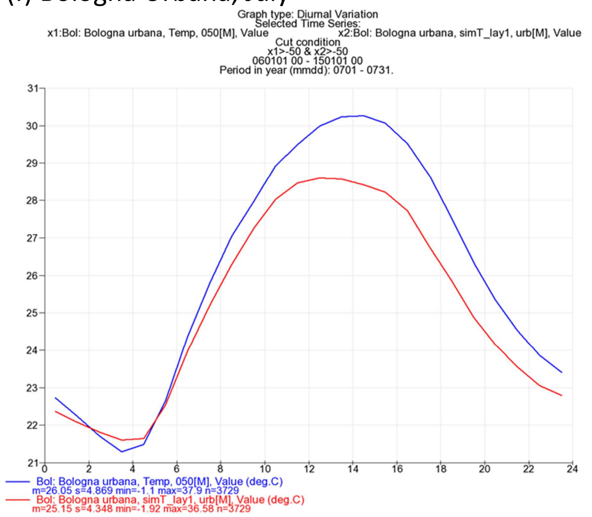
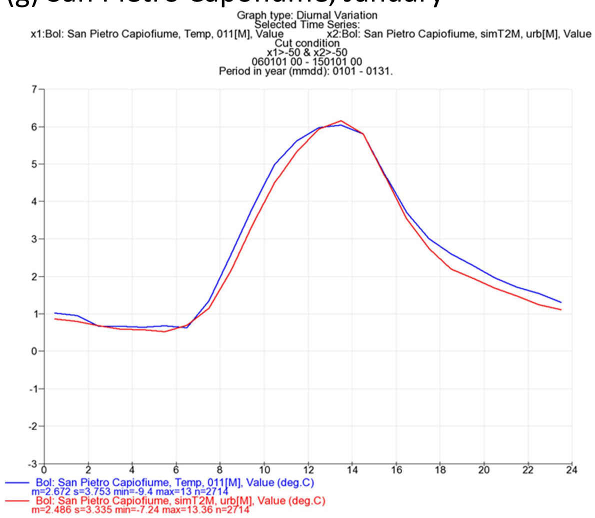
(e) Bologna Urbana, January



(f) Bologna Urbana, July



(g) San Pietro Capofiume, January



(h) San Pietro Capofiume, July

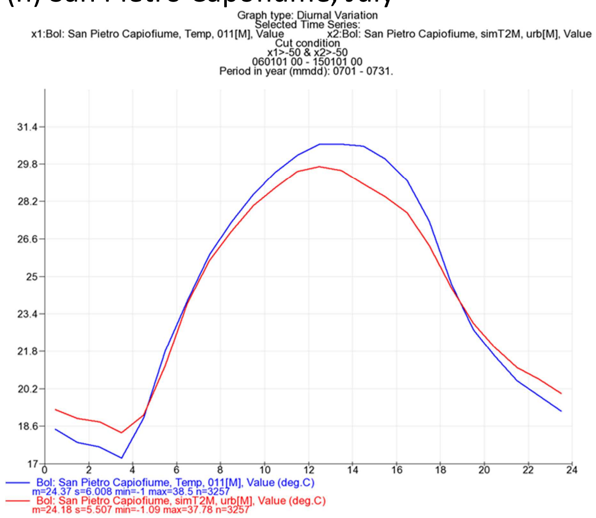


Figure 5 - Mean daily profile of computed air temperature in January and July over 5-years (2006-2007 and 2012-2014) at Stockholm (a-d), and in Bologna (e-h). Time in UTC.

4.1.3 Sectoral indicators

Table 5 reports the evaluation of some selected indicators, following the methodology presented in section 3.3.3. Starting with the analysis of the 'number of frost days', which is of interest especially for the infrastructure and agriculture sectors, a very good correspondence between model and measurements is found in the three locations.

The analysis of the two heat-related indictors is far more complex. We have followed the same method as in health studies (see e.g., Donato et al., 2015) on heat-induced mortality which have been performed using reference temperature data from outside the city, typically at the airport. The criteria for selecting this station, and particularly the possibility of these reference observations to be under the influence of the UHI, is not addressed in this discussion but should be the target of further analysis.

In Stockholm the modelled number of days above the threshold defined for Bromma is 16.7 % higher than the observed, while in Rotterdam a more expressive overestimation by 28.6 % was obtained. These results are consistent with some overestimation of air temperature at these locations during the summer months (as seen in Figure 3a and Figure 3e), which in Rotterdam is associated to the overrepresentation of the built-up fraction previously identified. Bologna shows a cold bias, with an underestimation of the number of summer hot days in the order of 13.8 %. Despite the identified biases these results can be considered very positive in light of the uncertainty associated to the dynamical downscaling method and also to the calculation and interpretation of these heat-related indicators.

Table 5 - Statistics for tailored validation of temperature based on hours for which measured temperature data (OBS) were available. Results given as average for the five years (2006-2007 and 2012-2014). Simulated air temperature (SIM) corresponds to TLevel1 in Stockholm and Bologna, and to T2m in Amsterdam.

Variable	OBS	SIM	unit
Stockholm (Torkel Knutsson)			
Number of hot days (Apr-Sep)	36	42	days/year
Heat degrees above threshold (Apr-Sep)	80.3	97.0	degree days/year
Number of frost days (Jan-Dec)	85	96	days/year
Bologna (Bologna Urbana)			
Number of hot days (Apr-Sep)	65	56	days/year
Heat degrees above threshold (Apr-Sep)	202.6	150.4	degree days/year
Number of frost days (Jan-Dec)	15	17	days/year
Rotterdam (Airport)			
Number of hot days (Apr-Sep)	63	81	days/year
Heat degrees above threshold (Apr-Sep)	159.7	245.2	degree days/year
Number of frost days (Jan-Dec)	15	15	days/year

4.2 Precipitation

Comparing observations and simulations, both Stockholm and Bologna show reasonable statistics for mean and standard deviation. This can also be seen in the figures of the monthly mean time series. Monthly and inter-annual variations are well captured by the simulations for both cities.
Additionally, the model copes very well with the strong fluctuation of values, such as in Bologna (see Figure 6c), where observed standard deviation is 0.6 against 0.7 from the model (see Table 4).

In Torkel, simulations are wetter, while in Högdalen the opposite tendency is found. This is particularly due to the low mean observed precipitation intensity in Torkel (0.035 mm.h^{-1} against 0.069 mm.h^{-1} in Högdalen) raising some doubts on the quality of precipitation measurements in Torkel. Despite the overall good performance of the model, in Amsterdam-Rotterdam the simulations are underestimating the average precipitation amount by about 50 %. As we can see in Figure 6 of the hydrology deliverable (D441.5.3) and in the monthly mean plots (Figure 6 of the current report), the winter precipitation is strongly underestimated by the model at this location.

This mismatch can be caused by spin-up problems that are advected with strong westerlies into the model domain from the boundaries and needs further investigation.

Apart from the reported bias in Amsterdam, monthly statistics are generally well captured. Despite the fact that hourly precipitation, especially under convection, suffers from low predictability and the possibility of double penalty errors, maximum precipitation (thin lines in Figure 6) is generally well captured in all three cities, which is a relevant outcome. For more details on the evaluation of modelled precipitation, an extensive analysis of precipitation can be found in the hydrological validation report D441.5.3, which also involves radar observations.

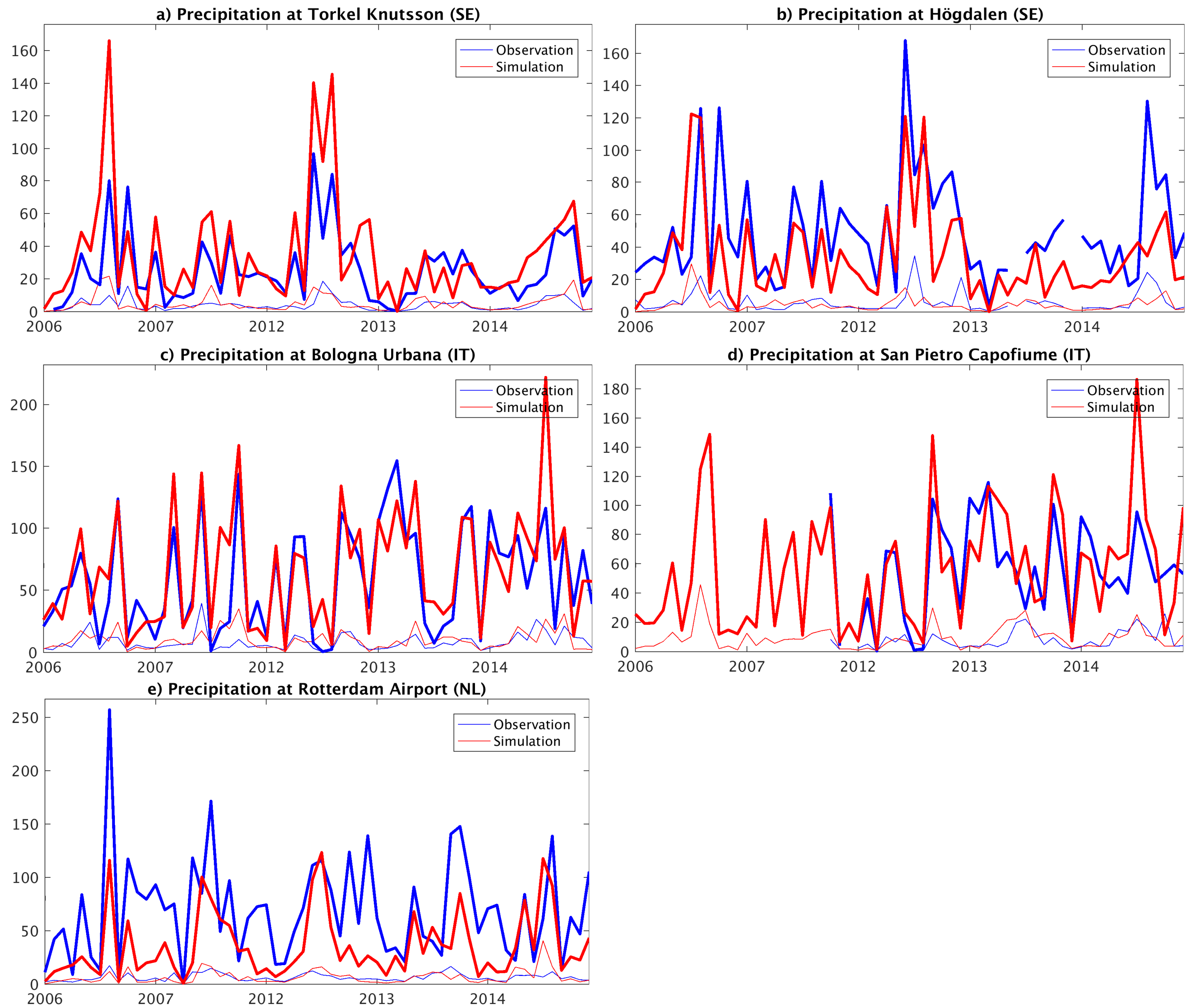


Figure 6 - Time series of precipitation (in mm) in Stockholm (a-b), Bologna (c-d) and Rotterdam (e). The thick lines show monthly mean values (unit: mm/month) and the thin lines monthly maximum values (unit: mm/hour), respectively. Note that there is a gap in the x-axis between years 2007 and 2012.

4.3 Relative humidity

In general, monthly and inter-annual variations in the observations are well captured in the simulations as shown in Figure 7. Rotterdam Airport shows an underestimation in the modelled relative humidity, both for monthly mean and monthly extrema. It should be stressed though that even in the urban areas (Torkel and Urbana) the relative humidity is well described in the model. At the rural station of San Pietro Capofiume (Bologna) we find a wet bias in the model after the summer of 2012. It is not clear whether local changes in land use not included in the model physiography (latest dataset pertains to 2012, as reported in section 2.4 of D441.3.1) could have caused this bias.

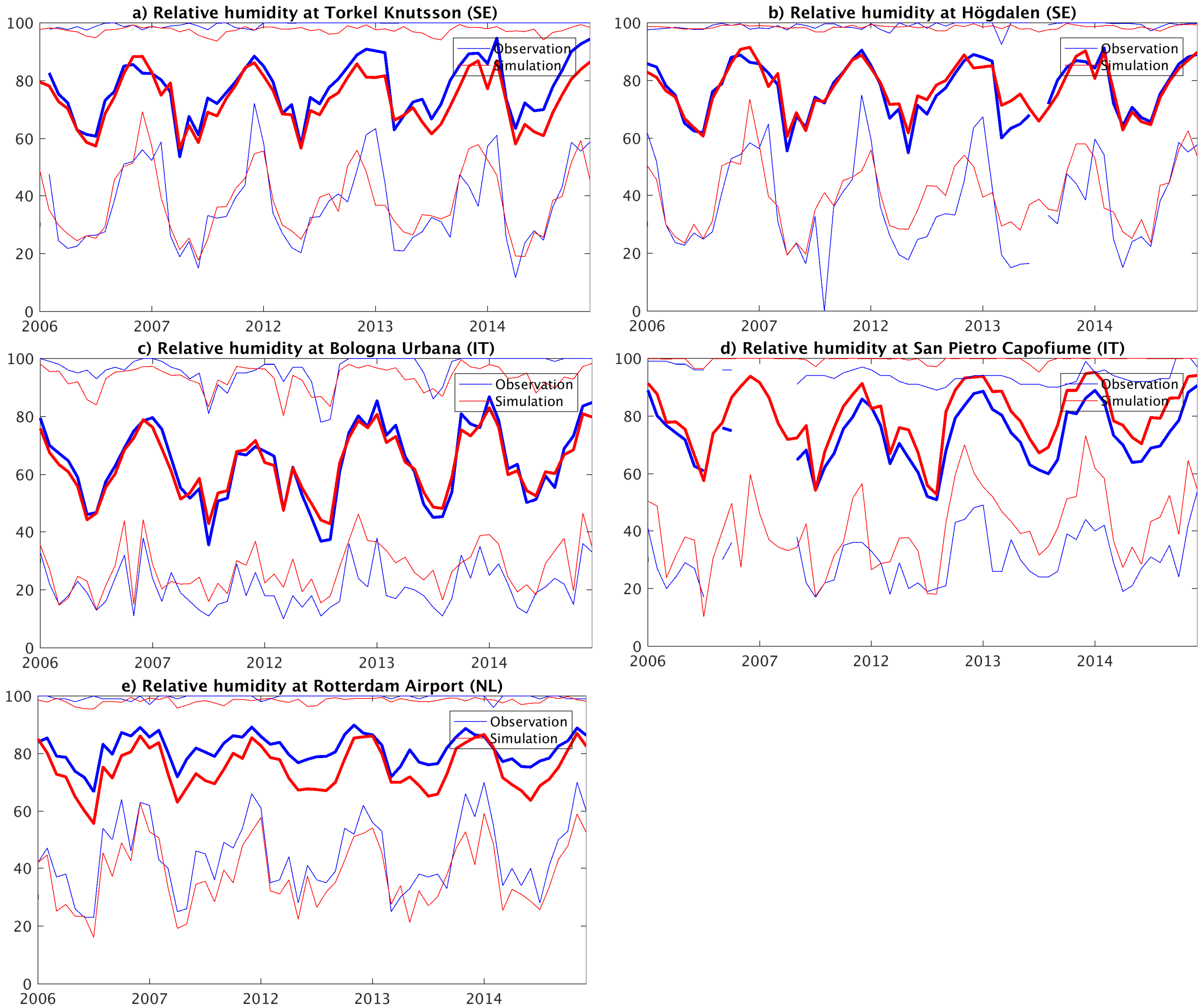


Figure 7 - Time series of relative humidity (in %) in Stockholm (a-b), Bologna (c-d) and Rotterdam (e). The thick lines show monthly mean values and the thin lines monthly maximum and minimum hourly values, respectively. Note that there is a gap in the x-axis between years 2007 and 2012.

At Rotterdam Airport, the observations show higher relative humidity than the simulations especially during the summer months. We have seen a small temperature bias of about 1 K for Rotterdam Airport that would be consistent with a lowering of only about 5 % in relative humidity. Furthermore, the already identified overrepresentation of the impervious surface in the model physiography leads to reduced evapotranspiration with higher surface temperature and lower relative humidity in the simulations.

4.4 Wind

Observed mean wind is generally well captured by the model at all stations (see Figure 8). Both stations in Stockholm, as well as in Rotterdam-Amsterdam, show a high correlation for the monthly mean wind with each other, closely followed by the simulated winds. However, for the two stations in the Bologna domain, the urban station shows a clear annual variation with stronger winds during the summer season, while the rural station remains rather flat. The quality of the wind observations at San Pietro Capofiume could be questioned.

Observed maximum wind speeds are generally well represented in the simulations, except for Torkel and Rotterdam Airport where the model underestimates the maximum winds.

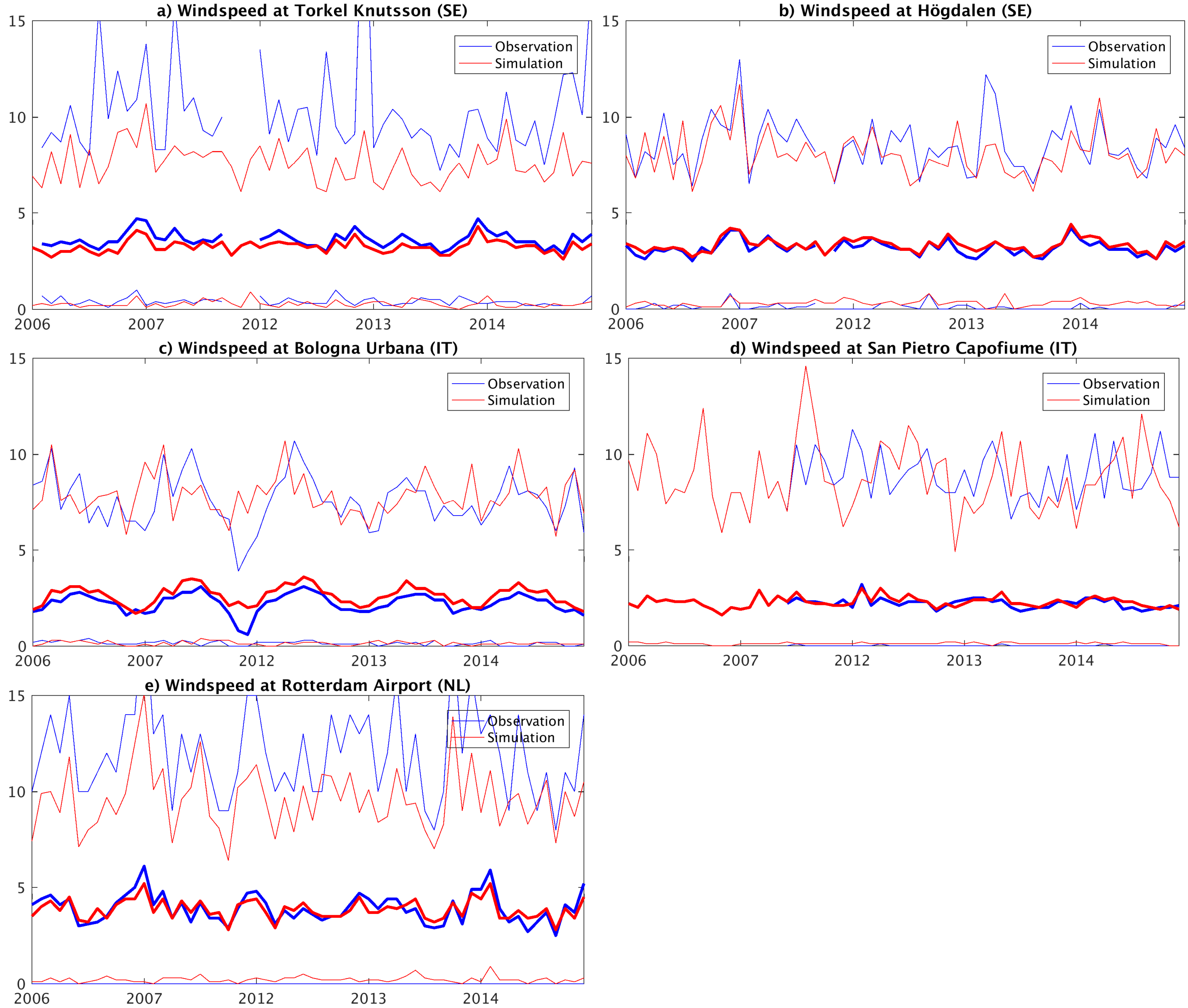


Figure 8. Time series of wind speed (in m.s^{-1}) in Stockholm (a-b), Bologna (c-d) and Rotterdam (e). The thick lines show monthly mean values and the thin lines monthly maximum and minimum hourly values, respectively. Note that there is a gap in the x-axis between years 2007 and 2012.

4.5 Global Radiation

As can be seen in Figure 9, the observed monthly mean radiation is well represented by the simulation for all sites with a slight overestimation by the model, particularly in Rotterdam Airport. However, the observed maximum radiation is underestimated by the model for all sites. A systematic offset for the short-wave radiation was also noted in the FP7-project DNICast (http://www.dnicast-project.net/) where a constant reduction of 10 % was applied to the short-wave radiation for the usage in solar forecasting. Given the underestimation of mainly clear-sky radiation and a slight overestimation of the mean radiation, the model seems to either underestimate cloud cover or the interaction of clouds with radiation.

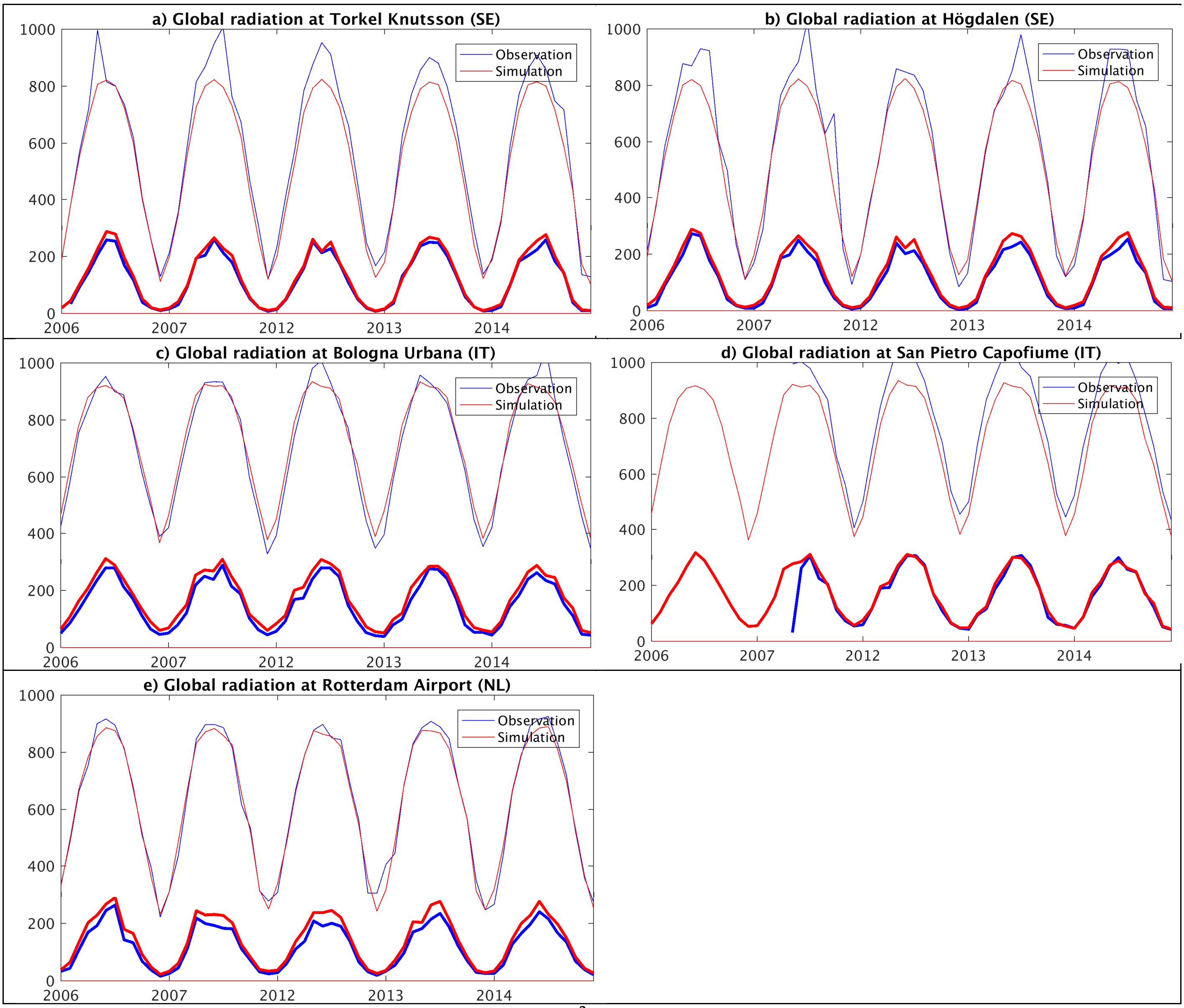


Figure 9 - Time series of global radiation (in $W.m^{-2}$) in Stockholm (a-b), Bologna (c-d) and Rotterdam (e). The thick lines show monthly mean values and the thin lines monthly maximum and minimum hourly values, respectively. Note that there is a gap in the x-axis between years 2007 and 2012.

5. Discussion and conclusions

The validation of the climate data calculated by HARMONIE-AROME for the 5-year historical period defined in Urban SIS was the target of this report. The validation method has focused on 5 main ECVs, plus 5 additional ECVs that basically decompose the air temperature into different physiographic tiles and heights. Together with the ECVs evaluated in the air quality and hydrology reports (D441.5.2 and D441.5.3, respectively) this analysis gives a broad and overall diagnosis and understanding of the performance of the Urban SIS downscaled ECVs, but cannot be considered as an exhaustive and thorough validation of the extensive dataset produced by the HARMONIE-AROME, MATCH and HYPE models.

First comment relates the observations. We have selected 5 meteorological stations that, in one hand, offer generally good quality observations and, on the other, are not used in the data assimilation. From these stations, however, none is measuring at street-level (ca. 2 m high) inside a street-canyon, which, despite the small spatial representativeness, would permit an enhanced interpretation of model performance within the urban canopy layer (UCL).

In overall, and despite the limitation mentioned in the previous paragraph, we have concluded that with the present set-up of HARMONIE-AROME a credible representation of the urban boundary layer (UBL) is attained. Spatial heterogeneities are in general well represented, as also the diurnal cycle. The inter-annual variability has shown to be consistent when compared to observations for all the 5 ECVs under analysis. Some deviations were identified and reported in this deliverable.

This report emphasizes the evaluation of temperature with an additional tailored validation. For the sake of consistency in the analysis, precipitation is subject to a more in-depth validation in D441.5.2.

With the focus of Urban SIS on cities, a large effort was made to understand how good the model could tackle with the intense intra-city gradients. The analysis of T2m data revealed a strong interaction with the surface characteristics, with the model capturing both the spatial coverage of the UHI in the different cities, as also its diurnal cycle. Implications of these outputs to the health and infrastructure sectors targeted by Urban SIS is clear.

In addition to the urban-to-rural gradients, the model is also very responsive to the heterogeneity of the urban tissue, namely in what concerns the imperviousness of the surface. The signal coming from urban parks in the urban atmosphere is also present in the model outputs, delivering a PCI estimate (both in magnitude and time evolution) that is consistent with the literature. The usefulness of this type of information to urban planners dealing with urban adaptation to climate change is very significant.

One of the added-values of the air temperature data produced by HARMONIE-AROME is the possibility offered to the user of the web portal to access not only 4 model heights, but also 4 different land-use types (or tiles) in addition to the weighted average. This set of data allows a much better understanding of the response of a given city to the climate signal.

In general the model follows the temporal evolution of mean temperature in all the locations, with some deviations in relation to the hourly peaks that were associated to problems in the definition of the surface characteristics (Rotterdam Airport), or to some mismatch in model height compared to observations (Bologna Urbana). This is somehow expected when doing a point-wise validation as here, especially when a small number of stations is available.

The model is also coping well with mean and standard deviation statistics of precipitation, even when strong fluctuation is present (Bologna), except for one station (Torkel, whose reliability is of concern). Spin-up problems that are advected from the boundaries into the model domain by strong westerlies was also pointed out as a possible cause for some of the identified deviations and is evaluated in more detail in D441.5.2.

The time evolution of computed mean values of relative humidity, wind speed and global radiation is in overall in good agreement with observations. Some of the local biases identified are, to some extent, also connected to the mismatch in physiography already mentioned, which become evident when analyzing the extreme values. This fact stresses the importance of an accurate description of the surface, and justifies the effort dedicated in Urban SIS to produce a refined physiography dataset (as explained in section 2.4 of D441.3.1).

6. References

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