ECMWF COPERNICUS REPORT

Copernicus Climate Change Service

Urban SIS
D441.2.3 Recommendations of input for operational production

Issued by: Swedish Meteorological and Hydrological Institute (SMHI)

Date: 30/11/2017

Ref: C3S_D441.2.3_UrbanSIS_201711_Recommendations_of_input_for_operational_production.docx

Official reference number service contract: C3S_441_Lot3_SMHI_2017/SC2

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1. Introduction

Urban SIS information generated during the proof-of-concept (POC) project are available for a historical period (5 selected years between 2006 and 2014) and for two 5-year windows of a downscaled climate scenario, selected to represent “present” (1980-2010) and “future” (2030-2065) climate conditions. The input data required for the historical period has been documented in C3S_D441.2.1 (submitted April 30, 2016) and the description of the input data for the climate scenario in a second report C3S_D441.2.2 (submitted August 31, 2016). The purpose of this report is to document the input data finally used, lessons learned during the production of the data sets and to give, where possible, recommendations for a possible future production of Urban SIS data sets.

The downscaling modelling chain consists of three components, namely the climate model, the air quality model and the hydrological model. These models produce the Urban SIS output, i. e. the data referred to in the project as urban Essential Climate Variables (ECVs) and which are postprocessed to impact indicators. The fundamental goal with Urban SIS as a climate service for urban assessments is to provide high spatial (1x1 km^2) and temporal (hourly, partly 15 min) information, useful as input to further downscaling modelling and to postprocessed statistics. The ECVs and impact indicators should show internal consistency, i.e. all ECVs should describe the same instant and domain, allowing the user to assess climate events and characteristics based on a number of different variables. Urban SIS outputs in total 24 ECVs.

The high-resolution climate model requires initial and boundary conditions from a European scale model and also detailed information of the urban surface as input to the urban sub-models that determine the fluxes between the ground and the atmosphere. The high-resolution air quality dispersion model equally requires chemical initial and boundary conditions from a European-scale dispersion model simulation and detailed emissions from the city itself. The meteorological forcing and surface characteristics are taken from the downscaled climate model output. The hydrological downscaling, finally, requires hydrological boundary conditions from a Pan-European hydrological model and climate variables from the downscaled climate model. Additional data concerning urban watersheds and soil characteristics can be used to further improve model output.

The discussion of input data to the Urban SIS downscaling models is separated in four sections, the first discussing the general selection process of which climate forcing and time periods to use, then three sections defining the needs of the three models for climate, air quality and hydrology. Each section describes the input data used during the POC and also experiences gained and recommendations for the future.

The purpose of this report is to give an overview over the total amount of input data required to generate the Urban SIS output and how the sources to input data were selected. For each type of input data we also give, if relevant, recommendations on alternative data sources or technical approaches. Specific technical details on the model systems used during the Urban SIS POC are given in the WP3 reports C3S_D441.3.1-3 and C3S_D441.3.4-6.

2. The process of selecting climate forcing and time windows for urban downscaling

Urban SIS outputs include both historical data, which should be as similar to "true" measurement values, and climate scenario data representing present and future conditions. Balancing user requirements – as gathered at WP4 workshops held in Stockholm and Bologna – and resources available in terms of CPU/storage capacity, the Urban SIS POC project finally decided to work with 5-year windows, urban domains covering 110x110 km^2 and to only produce one climate scenario. In total this means three similar downscaled data sets, describing a) a historical period, b) a climate scenario output for present conditions and c) a climate scenario output for future conditions.

2.1 Selecting forcing and time window for urban downscaling of a historical period

For the historical period, the urban meteorological downscaling was forced by modelled Pan-European re-analyses from the UERRA project (Ridal et al. 2017). UERRA is the most recent three-dimensional re-analysis of the European climate. Five years were selected to represent close-to-present conditions and to have at disposal as many as possible high quality data sets for model validation. For the historical period the same five years 2006, 2007, 2012, 2011 and 2014 were downscaled in all three cities.

Lessons learned

The period of 5 years is relatively short to assess climatological impacts. This limitation resulted from the computational costs related to the dynamical downscaling. It is therefore important to select years carefully and examine how well these years sample the probability distribution for the different indicators of interest. Although the users stressed that they would like to get normal variations in the downscaled years, it might be useful to downscale also single extreme events as worst case scenarios. Furthermore, the selection of the years was affected by the availability of observational data for validation.

Recommendations for future urban downscaling of a historical period

Computational costs for high-resolution dynamical downscaling will be considerable, so it seems necessary to run selected years. It is vital that these selected years represent normal variability of the indicators of interest. Furthermore, it is recommended to include some extreme event as a worst case scenario. Such information is valuable for urban planners. In order to put the selected years into a climatological perspective, a longer dataset needs to be ensured for analysis. For validation sufficient observational data during the selected years is recommended.

2.2 Selecting forcing and time period for urban downscaling of a climate scenario

The selection process of input data for the climate scenario was more complex. Since there were user requirements to have some more extreme alternatives for the future, it was early decided to use a RCP8.5 scenario. First considered was a regional (European) climate model simulation with a very high (6x6 km^2) spatial resolution, planned to be accomplished in the FP7 HELIX project (https://www.helixclimate.eu/). Due to reasons outside the Urban SIS project this was not possible, instead the regional model output was taken from the FP7 GLOBAQUA project (http://www.globaqua-project.eu/en/home/), for which the output provided a spatial resolution of 20x20 km^2. Details on this setup can be found in report C3S_D441.3.4.

GLOBAQUA offered full three-dimensional input data for the periods 1980-2010 and 2030-2065, from which Urban SIS had to select 5 individual years representing one “present” and one “future” window. This selection process, in detail described in C3S_D441.3.4, looked at precipitation and temperature statistics of all years and identified four extremes (cold/wet, cold/dry, warm/wet, warm/dry) and one year with conditions in the middle (“normal”). Table 1 summarizes the selected years within the two GLOBAQUA windows.

Table 2.2.1 Selected years of GLOBAQUA output, used for urban downscaling.

city	period	normal	cold/wet	cold/dry	warm/wet	warm/dry
Stockholm	Present	2009	1995	1994	2005	1985
Stockholm	Future	2032	2053	2046	2035	2064
Amsterdam/Rotterdam	Present	2005	2000	1996	2010	2007
Amsterdam/Rotterdam	Future	2053	2038	2034	2035	2049
Bologna	Present	2005	1987	1996	2010	2006
Bologna	Future	2050	2037	2053	2063	2044

Lessons learned

Recent studies indicate that the horizontal distance required for building up smaller-scale energy in a downscaling model (referred to as “spatial spin-up”) depends only on the resolution of forcing data (e.g. Matte et al., 2017). However, experience from this project shows that the spatial spin-up is characterized by a fixed physical distance for given atmospheric conditions. For example, in the weather situation most strongly forced from the lateral boundaries, i.e. in the storm track region during winter when horizontal advection is strong and dominates the generation of precipitation, the spatial spin-up for precipitation is around 500 km regardless of the resolution of forcing data. This is currently prohibitively expensive if the model resolution is 1 km, because the unusable part of the domain might approach 1000 grid points in each direction.

Recommendations for future urban downscaling of climate scenarios

The minimum domain size (in physical space) needs to be considered before planning experiments. Since it is currently not known how the spatial spin-up depends on the details of model physics, dynamics and coupling, dedicated sensitivity studies should be performed for different project applications. For conditions that are strongly forced from the lateral boundaries, it appears that the domain size needs to be larger than anticipated from previous studies. Consequently, the downscaling model resolution and the scope of the project (e.g. number of cases, length of simulations) need to be adjusted to the available computing resources. One option is to only run case studies for specific atmospheric or other conditions that are considerably affected by high resolution. This would free up computational resource for creating larger domains or larger ensembles. Furthermore, extreme cases can provide useful input for urban planners as worst case scenarios.

3. Input to the climate downscaling

3.1 Boundary data for the climate downscaling of the historical period

For the dynamical downscaling we have used the model HARMONIE-AROME cycle 40h1 (Bengtsson et al. 2017) for both the historical period and climate scenarios. The model is based on the shared ALADIN-HIRLAM system. The AROME physics have earlier been used for urban climate simulations (e.g. Lemonsu et al. 2012). The tiled surface scheme allows for a detailed description of the physiography in the urban area. Details are described in deliverable C3S_D441.2.1 and C3S_D441.3.4.

For the historical period, the boundary data was taken from the UERRA-ALADIN dataset (Ridal et al. 2017).

Lessons learned

The model delivered reasonable results especially during the summer season. The model was able to reproduce inner-city gradients as found in observational data. Also, convective rain amounts were realistic. However, especially for wintertime precipitation the model displayed a clear underestimation of the precipitation amounts. This deficit was related to the relatively small domain size under strongly forced conditions as discussed above under 2.2.

When selecting the forcing data set, we chose UERRA-ALADIN as it is already relatively high resolution with 11 km and contains a long time period allowing to select different years and to examine the climatology on basis of UERRA. Here, it was vital to have access to model level data. Although the model level data was not part of the UERRA project, SMHI chose to store this large data set at ECMWF.

Recommendations for future urban downscaling of a historical period

Concerning the challenges with the domain size, it could be considered to apply a nesting strategy with an intermediate model at 5-km resolution. As pointed out above, it is not clear whether this solves the problem. Alternatively, a larger model domain should be adapted.

For the boundary data, the vertical resolution is also important. Thus, it should be ensured that model level data of the forcing data set is available.

3.2 Interaction with the surface for the historical period

The physiographic characterization of the surface in SURFEX/HARMONIE-AROME is driven by the European, 1 km resolution, land cover database ECOCLIMAP-II (Faroux et al., 2013). This database aggregates information on an ecosystem classification and a coherent set of land surface parameters that are primarily mandatory in meteorological modelling (notably, leaf area index and albedo). Due to the focus of Urban SIS on urban environments, we were particularly interested in the way this dataset represents the spatial gradients of the surface within the city (including the interactions between built-up areas and green-infrastructure) and in the urban/rural interface, and specifically in the case of Stockholm and Amsterdam, how realistically is the interface land/water captured.

Aiming to assure that the land cover data used as input to HARMONIE-AROME over cities were the "best available" we have compiled, aggregated and processed high-resolution surface data that was used to enhance the information originally available in ECOCLIMAP-II. The criteria for selecting these additional data sources were the accuracy, resolution, and availability of the information. We have also privileged the use of Copernicus products. This resulted in the selection of the following open-access products: land cover from Urban Atlas 2012 (Copernicus Land Monitoring Services), building polygons from OpenStreetMap and Leaf area index (LAI) of vegetation from Copernicus Global Land Service. Additionally, for Stockholm we have extracted and aggregated building heights from Lidar measurements available from the Swedish Forest Agency website (see D441.3.1 for more details).

This data is supplied to HARMONIE-AROME as gridded data files (latitude, longitude, parameter value) with an average spatial resolution of approximately 300x300 m^2. These are then interpolated by SURFEX to the final model grid (1x1 km^2 resolution) and combined with the default ECOCLIMAP-II database where needed. In deliverables C3S_D441.3.1 and C3S_D441.5.1, a quality analysis of the refined surface data can be found, namely in what concerns its capacity to capture the intra-city gradients of air temperature as a response to surface characteristics (revealed in the simulation of the Urban Heat Island (UHI) and the Park Cool Island (PCI) effects), as well as the interface land/water.

Lessons learned

The processing of land-use data in Stockholm as given originally by ECOCLIMAP-II did not offer the level of detail required, namely in what concerns the description of the urban surface, but also in the characterisation of land/water interface along the Baltic Sea coast line and in the lakes that characterize the Swedish landscape (see deliverable C3S_D441.2.1 for more details). The improvement of the land-use description was therefore a necessary and important step towards the increase of detail at this fine spatial scale and a better understanding of the resulting fluxes and interactions.

Recommendations for operational climate downscaling of a historical period

HARMONIE-AROME has proved to respond realistically to detailed surface features, including the strong spatial and time gradients that characterize the atmospheric boundary layer over urban canopies. While default physiography datasets such as ECOCLIMAP-II offer valuable information at high resolution they fail to capture some intricate details of the urban surface or the interfaces urban to rural or land to water. At the same time, this gap can be overcome by complementary sources of data that are freely available for Europe. The method developed in Urban SIS for refining the surface description can be replicated and automatized to a high degree for other cities using open-access high-resolution data as input.

3.3 Boundary data for the climate downscaling of the climate scenario

The lateral and surface boundary data utilized in the dynamical downscaling are provided by the GLOBAQUA project. There, the earth system model EC-Earth provided global data at a horizontal resolution of 80 km (T255) which were used in a secondary step as forcing data for HCLIM-ALARO with a grid spacing of 20 km.

Lessons learned

Since downscaled climate simulations strongly depend on the initial and boundary data, it is important to carefully select the forcing. In the current project, the initial and boundary data came from a model realization that had persistently colder climate over Europe compared to the observations. This choice was partially influenced by time and computational constraints, and the availability of full output from large-scale models that could be used for downscaling.

Recommendations for operational climate downscaling of a climate scenario

If the comparison to observations is important in a project, the choice of the large-scale forcing model should be made based on proximity to the present climate. However, due to natural climate variability and strong dependence of small-scale downscaling models on boundary data, using a single realization of forcing necessarily limits the applicability of downscaled scenarios for end users. It is therefore recommended to use large-scale data with different climates for boundary forcing, i.e. to use an ensemble of model realizations. Since the computational resources are limited, particularly for high-resolution climate modeling, a suggestion is to use techniques similar to the one used in this project for choosing the downscaled years (see report C3S_D441.3.4), but in this context for choosing specific large-scale forcings. In this way a sufficiently large spread of different climates can be achieved for the specific goals of each project at a smaller cost of computing resources.

3.4 Interaction with the surface for the climate scenario

No changes in urban planning were introduced in the HCLIM-AROME simulations of the future scenario, where the same refined physiography developed for the historical period (see section 3.2) was used. The reason behind this simplification was the difficulty in holding realistic projections on how the different cities will evolve in 50 years from present time.

Lessons learned

A sensitivity analysis of the model response to future changes in urban physiography is out of the scope and the timeline of Urban SIS. However, this task was undertaken by SMHI for the city of Stockholm, under the scope of the research project HazardSupport with funding from the Swedish Civil Contingencies Agency (results to be delivered during 2018).

Recommendations for operational climate downscaling of a climate scenario

If available, land use projections should be used to drive the description of surface physiography in the future. Close communication with local stakeholders, especially urban planners from the municipality offices, is vital for attaining a realistic vision of the future master plan for the city. Ideally this information should be in line with the emissions scenarios used as input to the air quality model.

4. Input to the air quality downscaling

The MATCH model needs four different types of inputs in order to calculate the air pollutants concentrations over the urban domain of interest: 1) three-dimensional meteorological fields; 2) spatially distributed local emissions); 3) physiography (i.e. spatially distributed surface characteristics; and 4) chemical species concentrations on the model boundaries.

The fields of the concentrations simulated on the cities chosen within the Urban SIS project are then obtained through the MATCH air quality simulation downscaling. Firstly the MATCH model is applied over a pan-European domain (MATCH-pan-E), subsequently the obtained concentrations of chemical species are given as values at the boundaries of the metropolitan areas of Stockholm, Amsterdam/Rotterdam and Bologna to the MATCH-local domains, with 1 hour frequency.

This section describes each one of the inputs needed by the MATCH-local application, the lessons learned and recommendations for future operationalization of the system tested.

4.1 Boundary data for the air quality downscaling of the historical period

The concentrations of chemical species given as boundaries values to the MATCH-local simulations in the historical period were obtained through the application of the MATCH-pan-E forced with the meteorological field variables produced by the HARMONIE-AROME model (please see point 2.1 of this report on the description of the dynamical meteorological downscaling, and forcings; and the delivered report C3S_D441.2.1 – Input for historical period).

In the MATCH-pan-E, the meteorology considered in the chemical continuity equations of the chemical mechanism species is derived from the UERRA-ALADIN model results, the remaining inputs (emissions, boundary conditions, physiography) are the same as in use in the CAMS Copernicus daily forecast (please see the delivered report C3S_D441.2.1 for details on emissions, chemical boundary conditions and physiography). Over each one of the urban cities, the MATCH-local model considers the refined physiography database, developed for the Urban SIS project, and already described in the same deliverable.

Lessons learned

A 1-year simulation with MATCH-pan-E, needed to provide boundary data for the urban downscaling, took ~30 hours to complete on 64 cores. The modelling domain covered an area of 172×200 cells, but as the advection time step could be kept at 300 s (instead of 20 s as in the case of the urban downscaling) these simulations were reasonably efficient.

Recommendations for operational air quality downscaling of a historical period

It is expected that the results would improve if we had operated MATCH-pan-E on the original resolution of the UERRA meteorology (11 km × 11 km), instead of the presently selected 22 km × 22 km (this would also increase simulation times with a factor of 4×2, as the number of grid cells would increase by a factor of 4 and the time step would need to be halved).

The pan-European simulations lacked emissions from forest fires and wind-blown dust from Sahara or other arid lands. This is likely not a problem for the long-term averages but will undoubtedly result in underestimations of some air pollution episodes. Future simulations should strive for including these omitted sources.

The MATCH-pan-E simulations used identical emissions for all the 5 years simulated. While this approach is probably valid over 5-10 year time period it may result in a erroneously estimation of the background concentrations if the simulated year deviates more than, say, 5 years of from the year of European emissions. For future applications we recommend to use temporally varying pan-European emissions

4.2 Local emissions for the air quality downscaling of the historical period

Estimates of local emissions were derived by the respective local authority and made available to the project for each MATCH-local application. To run the chemical mechanism of the MATCH model a minimum set of chemical species emissions need to be provided, namely sulphur dioxide - SO2, nitrogen dioxide – NO2, carbon monoxide - CO, total amount of non-methane volatile organic compounds - Total NMVOC, ammonia - NH3 and particulate matter – PM. These emissions were considered by MATCH as a 1 km x 1 km gridded yearly amount of each species, processed according to monthly and daily profiles (described in the report C3S_D441.2.1 – Input for historical period), which in turn, are also dependent on the economic sector they derived from.

Lessons learned

In presence of yearly amounts of the emitted chemical species, there is a possibility to tune the daily, monthly and/or seasonal profiles at the urban applications using sector related proxies concentrations (e.g. through the comparison of modelled and observed mean profiles of NO2 concentrations in urban regions dominates by traffic; the same for SO2 concentrations in areas dominated by industrial sector).

Recommendations for operational air quality downscaling of a historical period

For further downscaling of the MATCH-local results available at the Urban SIS portal, either in a dynamical or statistical approach, the considered emissions must be in accordance with the part of the city that will be modelled. Traffic emissions may be even more refined, resuspension and elevated point sources can be introduced with higher accuracy; and other relevant sources over the domain of interest must also be taken into consideration, both in space and time.

4.3 Boundary data for the air quality downscaling of the climate scenario

Two slots of 5 years each were defined according to the description made in C3S_D441.3.4, and summarized in Table 1. These periods of time represent different aspects of the present and future climate conditions, in accordance with the imposed criteria to the lower, higher and mean values of the temperature and precipitation values distributions, and their combinations. The obtained concentrations fields with each MATCH-local application are then expected to also reflect these conditions.

The MATCH-pan-E and MATCH-local setups were kept constant as much as possible in the climatic scenarios simulations. In the climatic scenarios only meteorological fields and emissions were changed in regard to the historical period application. No hypothesis were made for changes in physiography, monthly and daily anthropogenic emission profiles within MATCH-pan-E, so the historical ones were used also in the two climatic scenario windows. The new meteorological pan-E forcings had resulted from the climatic runs made with regional climate model HARMONIE in climate mode – HCLIM-ALARO (C3S_D441.3.4 Urban climate ECV and impact indicator data for present and future climate).

To get the chemical boundary conditions for the MATCH-local applications the MATCH-pan-E setup was then ran for 11 years in the present climate (1985, 1987, 1994, 1995, 1996, 2000, 2005, 2006, 2007, 2009, 2010), and 12 in future climate scenario (2032, 2034, 2035, 2037, 2038, 2044, 2046, 2049, 2050, 2053, 2063, 2064), according to the years previously selected for each urban area (Table 1).

Under the present climate conditions MATCH-pan-E simulations the emissions at the European scale were kept constant regarding the historical application, which means that the CAMS emissions were used, whereas in future climate conditions the current legislation scenario ECLIPSE V5a global emissions (http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv5a.html) were assigned. To have a correspondence between the EMEP – SNAP and the ECLIPSE activity sectors a reclassification of the ECLIPSE sectors was made according to Table 2.

The resulting air quality fields from the MATCH-pan-E simulations along with the downscaled meteorological fields obtained with the HCLIM regional model at 1-km grid resolution were applied as forcing and boundary fields to MATCH-local over each urban domain.

Table 2: Correspondence between ECLIPSE and SNAP activity sectors

ECLIPSE - sector	SNAP -sector	SNAP – sector code number
Power plants, energy conversion, extraction	Combustion in energy and transformation industries	1
Residential and commercial	Non-industrial combustion plants	2
Industry (combustion and processing)	Combustion in manufacturing industry	3
	Production processes	4
Agriculture (waste burning on fields)	Extraction and distribution of fossil fuels and geothermal energy	5
Solvents	Solvent use and other use	6
Surface transportation	Road transport emissions	7
Shipping emissions	Other mobile sources and machinery	8
Waste	Waste treatment and disposal	9
Agriculture (animals, rice, soil)	Agriculture	10

Lessons learned
More in depth sensitivity studies may be needed to turn compatible the emission inventory scenarios between the MATCH-pan-E and MATCH-local simulations.

Recommendations for operational air quality downscaling of a climate scenario
Two more sets of MATCH-pan-E runs may be needed to produce chemical boundary conditions to the urban domains, in case for climate change impacts studies on the air quality indicators: (I) concentrations of air pollutants derived only with meteorological fields in different climate conditions, and (II) historical runs with historical ECLIPSE emissions, or other comparable set of emission estimations. With these group of runs is possible to determine separately the influence of the meteorology and the emission conditions on the concentrations of air pollutants derived in each historical and scenario simulation.

4.4 Local emissions for the air quality downscaling of the climate scenario

For each local application the given emission input was considered according to what the respective local partner thought being of interest.

Over Bologna the local emission inventory was derived from the GAINS – Italy model (http://gains-it.bologna.enea.it/gains/IT/index.login) for the year 2030.

Amsterdam/Rotterdam adjusted the actual emissions also for 2030 based on the established and planned Dutch National energetic policy (Smeets, et al., 2016).

Over the city of Stockholm the focus was on searching for impacts on air quality driven by future traffic planning to be implemented for the year 2030.

Lessons learned
A plethora of combinations between the meteorology derived from climate scenarios, emissions on pan-European and local inventories is possible. Setting the goals for the local applications, and the assumptions made, is of high importance both for further use of the data resulting from MATCH-local, at 1 km x 1 km, and for the analysis of the obtained results.

Recommendations for operational air quality downscaling of a climate scenario
For sake of consistency, the underlying assumptions on the estimations of the urban emissions should be as close as possible as the ones driven the MATCH-pan-E air concentration fields, since they are imposed as boundary values in the MATCH-local applications. In case of further downscaling procedures of the MATCH-local 1 km x 1 km model results (with CDF, statistical modelling), it should be kept in mind the possible discrepancies that may arise from the different assumptions made in the emission inventories used.

5. Input to the hydrological downscaling

5.1 Boundary data for the hydrological downscaling of the historical period

In order to base the hydrological model on detailed urban land use we used Urban Atlas 2012 (http://land.copernicus.eu/local/urban-atlas) for definition of the domain and land use conditions. See C3S_D441.3.3 Hydrological ECVs and Indicators sections 1 and 2.2 for a more thorough description. In addition observations were used for calibration of the models (c.f. C3S_D441.3.3 Sec 2.5).

The meteorological output from HARMONIE-AROME (described in C3S_D441.3.1) are used as forcing data for the historical HYPE simulations. No upstream data outside the Urban SIS domains was used for the three cities as upstream hydrological impacts had little effect on the local conditions in the domain (c.f. C3S_D441.3.3 section 2.3).

Lessons learned

In general the approach for hydrological downscaling works well and is relatively easy to apply on new domains. In particular the grid based approach is very interesting. In addition the approach of producing data based on land use is promising, but was not fully developed in the project (c.f. D441.3.3 section 5).

The validation of models based on observation data was very promising. However, the dry bias in precipitation, especially during the winter in the forcing data affects the results of the hydrological downscaling. In particular this means that we do not, with the current Urban SIS concept, directly simulate the upstream river inflow to cities with any confidence (c.f. D441.5.3 section 4 and 5). However, if upstream inflow is needed it is likely that these simulations can use lower-resolution forcing than HARMONIE-AROME, e.g. the UERRA data used as boundaries for HARMONIE-AROME.

There were many discussions during the project whether we should apply some bias-adjustment to the climate model precipitation. At least in Bologna, the precipitation in HARMONIE-AROME was fairly accurate in most of the Urban SIS domain, even if substantially underestimated in the south-western high-altitude part, and bias adjustment could have been feasible. But it was decided to await the HCLIM-AROME simulations before taking the final decision, see further section 5.2 below.

Recommendations for future hydrological downscaling of a historical period

The approach of creating a downscaled hydrological model is promising and can be applied to other cities in Europe where input data from Urban Atlas is available. However, the approach used assumes that the rivers follow the natural conditions. For all cases, there is a need to use local observations for calibration and validation of the performance of the local mode. For areas where the river flow is highly affected by channels and dams there is a need to include detailed information of the local conditions. For areas where upstream conditions outside the local domain has a mayor impact data can be using pan-European climate run with the UERRA data used for forcing the downscaling data.

The quality of the hydrological simulations is highly dependent on the quality of the forcing data why recommendations described above are also of importance for hydrology. However, to take into consideration is that discharge is dependent on long term conditions, such as snow accumulation, and therefore needs longer periods of forcing data than single events-

5.2 Boundary data for the hydrological downscaling of the climate scenario

The model setup and domains used for present and future conditions are the same as for the historical period (c.f. D441.3.6 section 2.2 to 2.5). This means we make no assumption changes in land use due to future urban development of the cities.

Temperature and precipitation from the HCLIM-AROME climate runs produced for respective city in Urban SIS (c.f. C3S_D441.3.6 section 2.1). As for the historical period, no upstream information is needed for the climate data production in Urban SIS, but if required it is likely that the HCLIM-ALARO could have been used as forcing in these simulations.

Lessons learned

As for the historical period, the dry bias in precipitation in the forcing data will affect the hydrological result (c.f. C3S_D441.3.6 section 5).

Considering the pronounced dry bias in all HCLIM-AROME simulations, including Bologna, it was finally decided not to perform any bias adjustment in Urban SIS. The motivation was that biases need to be small-to-moderate for bias adjustment to be meaningfully applied. The (very) high bias found in HCLIM-AROME implies that major modifications of the climate model set-up are required, such as increasing the domain (see above and D441.3.6). It is indeed possible to adjust very high biases with statistical methods such as quantile mapping, but this is very questionable as the high bias implies fundamental weaknesses in the process descriptions.

Recommendations for future hydrological downscaling of a climate scenario

High-resolution hydrological climate projections are clearly possible, the main issues likely being:

- <u>The precipitation forcing</u>. Whereas large-scale hydrological processes are generally governed by large-scale precipitation processes, which are often acceptably well described in climate projections (after bias adjustment, generally), small-scale hydrology requires an accurate description of also small-scale precipitation processes such as convection. Generating climate model precipitation that is accurate at both scales is very challenging, as clearly demonstrated in Urban SIS. It appears currently difficult to attain complete “multi-scale” hydrological climate change impact assessment in one “chunk”. It may be advisable to continue performing separate tailored assessments of natural (river discharge) and urban (flash floods) climate impacts, as done so far, and await further development on very-high-resolution climate projections.

- <u>The (urban) land-use development</u>. It is sometimes demonstrated that future (urban) land-use changes may have a (much) stronger impact on (urban) hydrological fluxes, as compared to climate change impacts on the drivers (temperature and precipitation). The most obvious change is densification of central city areas, with more impervious surface and “flashier floods”, but also city sprawl into flood-prone areas is important. Including this aspect for single cities may be possible, if long-term spatial development plans are available and open, but it is naturally more difficult to implement in a general service. Possibly the option of assessing the impact of simple land-use changes, such as modifying the fraction of impervious surface in a sub-basin, can be offered in future tools.

6. References

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