COSMO Priority Project CITTA':

City Induced Temperature change Through A'dvanced modelling

Project Plan

Revision 4, 8 Jun. 2021

Project leader: **Jan-Peter Schulz (DWD)**

Project duration: **Jul. 2021 – Aug. 2024**

Summary

The aim of the COSMO Priority Project CITTA' is to transfer the achievements of the COSMO Priority Tasks AEVUS and AEVUS2 with respect to the urban canopy parameterisation TERRA_URB and its external parameters from the COSMO atmospheric model to the ICON model. The project will also include extensive experiments with the new package and further developments and applications of TERRA_URB within ICON(-LAM).

Background and motivation

The COSMO Priority Project CITTA' arises from the need that, due to the transition of the Consortium from the COSMO to the ICON model, the achievements of the COSMO Priority Tasks AEVUS and AEVUS2 with respect to the urban surface parameterisation TERRA_URB have to be transferred as well. Within these Priority Tasks, TERRA_URB was shown to be able to reproduce the key urban meteorological features for different European cities in the COSMO model (Bucchignani et al. 2019, Garbero et al. 2021).

Due to these positive results the current project is dedicated to implement TERRA_URB in the ICON code, for usage mainly in its limited-area version ICON-LAM, the replacement of the COSMO model for the member states' domains. Furthermore, it is necessary to continue the activities already started in the previous Priority Tasks, such as the development and implementation of a method to avoid inconsistencies among the different data sets used to define the urban external parameters, and a sensitivity analysis regarding the parameters describing the urban geometry and the urban thermal and radiative properties. The latter are currently hard-coded in TERRA_URB. Finally, a representation of vegetation in urban areas should be developed, and boundary layer clouds over urban areas should be studied in ICON-

LAM-ART including TERRA_URB, both with the goal to further improve the performance of the urban surface parameterisation.

The COSMO Priority Project CITTA’ will involve the entire team that has already successfully collaborated in the previous Priority Tasks and will expand on further skills. This will ensure a fast and efficient continuation of what has already been achieved. Therefore, in CITTA’ we will have an experienced team which already has identified several problems related to the use of the urban surface parameterisation and its external parameters and has solved them or is working on it.

Description of individual tasks

Task C Project coordination

The COSMO Priority Project CITTA’ coordinates activities aimed at the development of an urban module in ICON. This includes the implementation of an urban surface parameterisation in the ICON code, the provision of improved and new urban external parameters from EXTPAR and extensive experiments with the new package. Furthermore, urban and rural in-situ observations need to be provided for an evaluation of the model. Therefore, a coordination task is activated, dealing with the organisation of virtual and physical meetings, writing of reports, and frequent e-mail exchange. A final report will be provided.

Deliverables: Meetings, reports, Final Report.

Involved scientists: Jan-Peter Schulz (DWD) 0.1 FTE/year, Paola Mercogliano (CMCC) 0.05 FTE/year

FTEs: 0.15 FTE/year (Jul. 2021 – Aug. 2024)

Task 1 Implementation of TERRA_URB in ICON

The urban surface parameterisation TERRA_URB (Wouters et al. 2016, 2017) was originally implemented in COSMO-CLM (Rockel et al. 2008), the climate version of the COSMO atmospheric model (Doms et al. 2011, Baldauf et al. 2011). The purpose was to include urban effects (Wouters et al. 2016, Varentsov et al. 2017, 2018, 2019, Rivin et al., 2020) in its land surface scheme TERRA (Schulz et al. 2016, Schulz and Vogel 2020). Within the framework of the COSMO Priority Tasks AEVUS and AEVUS2 during the last years, TERRA_URB was ported to the recent COSMO NWP model version 5.05urb and successfully tested and evaluated against observations in various applications for different cities (Bucchignani et al. 2019, Garbero et al. 2021). The ability to reproduce the key urban meteorological features was shown.

In the framework of the transition of the COSMO Consortium to the ICON model TERRA_URB needs to be implemented in ICON. The code will be implemented in the ICON-COSMO-Development trunk (icon-cosmo-dev) in gitlab at DKRZ in Hamburg.

Deliverables: TERRA_URB in ICON.

Involved scientists: Jan-Peter Schulz (DWD) 0.4 FTE, Mikhail Varentsov (RHM) 0.1 FTE, Carmine De Lucia (CMCC) 0.1 FTE

FTEs: 0.6 FTE (Jul. 2021 – Jun. 2022)

Task 2 External parameters

The land use related external parameters in the COSMO model are provided by EXTPAR as area-weighted averages over the land use classes. In the COSMO Priority Tasks AEVUS and AEVUS2 the GlobCover dataset was used for the land use classification. There are different issues concerning the external parameters when using TERRA_URB in COSMO or ICON.

Before the TERRA_URB parameterisation became available, a zero-order description of urban areas was used for COSMO and ICON based on land use data. Now, when the urban scheme is activated in COSMO (lterra_urb=TRUE), a "poor-man's" tile approach is utilized in which each cell is divided into two tiles, an urban tile and a rural (natural) tile. The urban tile is assumed to be completely paved and not vegetated, and its area fraction is defined according to an additional external parameter called Impervious Surface Area (ISA). ISA is not the same as the urban land use area fraction, and different spatial data sets are proposed as a data source for ISA. The urban scheme calculates the model variables for the urban tile, whereas the zero-order urban description provides the model variables for the natural tile. This means that the current external parameters associated to the natural tile are those provided by EXTPAR and calculated by considering also the urban contribution. This is what we call the 'urban double-counting' effect, because urban is counted twice, once when adopting the urban scheme, and otherwise when referring to natural tile external parameters which take into account urban surfaces.

In order to avoid this 'urban double-counting' effect, a new dataset was constructed in which the affected external parameters (PLCOV_MAX, PLCOV_MIN, LAI_MAX, LAI_MIN, ROOTDP, Z0, FOR_E, FOR_D, RSMIN, EMIS_RAD, SKC) were recalculated according to the functions implemented in EXTPAR, but area-weighted excluding land use class 19 of GlobCover. This class represents urban areas (artificial surfaces). ARPAP developed an R script which recalculates the external parameters to be associated to the natural tile for those cells in which the urban tile is greater than zero.

Subtask 2.1 Consistency of urban external parameters

For TERRA_URB in COSMO-CLM, two urban external parameters were implemented in EXTPAR: The Impervious Surface Area (ISA = FR_PAVED) and the Anthropogenic Heat Flux (AHF). Since in EXTPAR the urban area fraction (URBAN) represents the land use class 19 of GlobCover (urban areas) and the external parameters are calculated as area-weighted averages of the land use classes, some inconsistency can arise when ISA and URBAN have different data sources. In TERRA_URB, the fraction of the urban tile is defined by ISA, and it could happen, for example, that in a grid element there is ISA=0 and URBAN=1, which means that the grid element in TERRA_URB is 100% rural (ISA=0), but the associated external parameters are typically "urban" since they are calculated based on URBAN.

ARPAP and RHM will contribute to design and implement a method in order to avoid inconsistencies due to the differences between the URBAN and ISA fields. Furthermore, ARPAP will provide support in order to avoid the double-counting effect both in EXTPAR and in ICON. Besides this, it will be made sure that this work is consistent with the “real” tile approach in ICON.

Deliverables: Consistent way to derive urban external parameters in EXTPAR.

Involved scientists: Valeria Garbero (ARPAP) 0.1 FTE, Mikhail Varentsov (RHM) 0.1 FTE, Alfredo Reder (CMCC) 0.1 FTE

FTEs: 0.3 FTE (Jul. 2021 – Jun. 2022)

Subtask 2.2 New urban external parameters in EXTPAR for ICON(-LAM)

Meanwhile, the raw EXTPAR datasets of ISA and AHF are outdated and should be replaced. This can be done in three ways:

1) Replacing the ISA and AHF global fields with more recent datasets such as those from Gong et al. (2020) and Dong et al. (2017), respectively.
2) Using Local Climate Zones (Stewart and Oke 2012) as a proxy for these urban canopy parameters.
3) Developing a unified approach to obtain the required parameters involving a GIS-based method based on vector-formatted cartographic data such as OpenStreetMap (Samsonov and Varentsov 2020, Samsonov et al. 2015).

The Local Climate Zone (LCZ) approach (2) requires more work than (1), because first a new land use classification needs to be implemented in EXTPAR. For this purpose, e.g. the land cover dataset ECOCLIMAP-SG (Météo-France/CNRS 2018) appears to be very suitable, because it already contains LCZ-based urban land use classes.

On the other hand, this offers the possibility to replace several internal parameters describing the urban geometry and the urban thermal and radiative properties, which were hardcoded in TERRA_URB as global constants, by 2-dimensional fields from EXTPAR. In a further step, the LCZ maps will be converted by look-up tables in ICON into urban canopy parameters needed by TERRA_URB, i.e. building area fraction, building height, street canyon height-to-width ratio, thermal conductivity, heat capacity, albedo, emissivity, and ISA and AHF. This allows TERRA_URB to use spatially explicit urban canopy information.

CMCC and IMGW-PIB will contribute to implement the dataset in EXTPAR and to test its impact on the modelled thermal environment. First tests indicate that the use of Local Climate Zone information performs as good or even better for summer conditions compared to using best-available datasets sourced from OpenStreetMap, recent global land cover data and Sentinel satellite images (Varentsov et al. 2020). ARPAP will carry out a survey using satellite data, OpenStreetMap, local cartographic data (such as shapefiles of buildings or information on building heights and street widths) and other sources (for instance ERA5-Land) to improve the characterisation of these new urban parameters for Turin. RHM will continue the development of the unified approach (3) to obtain the input parameters for TERRA_URB based on the vector-formatted cartographic data (e.g. from OpenStreetMap) together with other data sources, e.g. global data bases and satellite images. Due to the high labour and computational demand, this approach can not be applied to a global or even national scale, however it may provide detailed data for high-resolution limited-area studies and may be used as a reference in comparison to other approaches. Currently, this approach is proposed and tested for Moscow (Samsonov and Varentsov 2020), however it relies on data with global coverage and may be adopted for other regions.

In any case, it will be made sure that the urban external parameters are available with global coverage, either for usage in ICON-LAM or ICON global.

Deliverables: New urban external parameters in EXTPAR for ICON-LAM.

Involved scientists: Carmela Apreda (CMCC) 0.2 FTE, Adam Jaczewski (IMGW-PIB) 0.35 FTE, Andrzej Wyszogrodzki (IMGW-PIB) 0.15 FTE, Mikhail Varentsov (RHM) 0.2 FTE, Timofey Samsonov (RHM) 0.2 FTE, Valeria Garbero (ARPAP) 0.15 FTE, Massimo Milelli (ARPAP) 0.05 FTE, Francesca Bassani (PoliTo) 0.2 FTE, Jan-Peter Schulz (DWD) 0.2 FTE

FTEs: 1.7 FTE (Jul. 2021 – Jun. 2022)

Task 3 Numerical experiments

The numerical experiments will be carried out in a coordinated way in the different model domains of the project partners involved. One strength of this project is that there are six different domains available, therefore the performance of TERRA_URB can be analysed in different climate zones, including continental and maritime locations, and furthermore, for very different urban morphologies.

Subtask 3.1 Moscow

Moscow, the largest Russian and European megacity, will serve as test bed for an intensive evaluation of the ICON-LAM model with the TERRA_URB scheme, as it served for the same purpose with the COSMO model in the previous COSMO PTs AEVUS and AEVUS2 and other modelling studies with COSMO-CLM (Varentsov et al. 2017, 2018, 2019). Moscow has a population of about 17 million inhabitants (in the agglomeration) and covers an area of more than 1000 km^2. The city is located within a flat and homogeneous landscape which simplifies the investigation of the urban-induced atmospheric phenomena. This turns Moscow into a prospective site for urban climate research and urban model verification. The city experiences an intense urban heat island and other urban-induced meteorological effects (Lokoshchenko 2017, Varentsov et al. 2018).

Simulations for Moscow will be conducted with ICON-LAM/TERRA_URB on the Cray-XC40 supercomputer at RHM and will include hindcast experiments for specific periods with lengths of a few weeks for different seasons as well as quasi-operational NWP runs, using the domain and further specifications equivalent to the current operational system (Rivin et al. 2015, 2020). The model will be supplied by detailed city-descriptive external parameters, obtained by a comprehensive original approach that combines OpenStreetMap vector-formatted cartographic data, satellite images and recent land cover products (Samsonov and Varentsov 2020). Such an approach is already developed for COSMO and will be adopted also to ICON. For the model evaluation and verification, a dense network of near-surface and boundary layer observations will be used, including data from dozens of urban and rural weather stations and microwave temperature profilers.

Deliverables: Assessment of the new scheme in the Moscow mega-city domain.

Involved scientists: Mikhail Varentsov (RHM), Denis Blinov (RHM), Vladimir Kopeykin (RHM), Gdaly Rivin (RHM)

FTEs: 1.0 FTE (Jul. 2022 – Aug. 2024)

Subtask 3.2 Turin

Turin is the capital of Piedmont and its metropolitan area has a population of almost 1.5 million inhabitants, covering an area of about 600 km^2. The city is located mainly over a plain (250 m a.s.l.), but it has a hilly part on the east side (up to 600 m), and it is surrounded by the Alps on the western side. Furthermore, the plains in the north and south of the city have a different climate, the southern one being colder in winter and warmer in summer with respect to the northern one. This makes the configuration quite peculiar and challenging. The greater urban area of Turin experiences a significant urban heat island effect (see Milelli 2016) and it is very interesting to investigate and understand the role of its morphological structure in this phenomenon.

TERRA_URB will be run in ICON-LAM in order to test the urban external parameter datasets, described in the previous section and provided by different sources, and then to evaluate the optimal configuration of urban external parameters. Here, former simulations with the COSMO model including TERRA_URB will be used for comparison, since this system was thoroughly tested in the COSMO PTs AEVUS and AEVUS2. The simulations will cover two different case studies to be selected, one in summer and the other one in autumn/winter, for a 2-week period in order to have more robust statistics. The simulations will be performed in hindcast mode like in the previous PTs.

The model evaluation and verification will be performed using a dense network of surface stations, three radiometers, satellite data, and possibly ERA5-Land reanalyses.

Deliverables: Assessment of the new scheme in the Turin domain.

Involved scientists: Valeria Garbero (ARPAP) 0.4 FTE, Massimo Milelli (ARPAP) 0.25 FTE, Francesca Bassani (PoliTo) 0.35 FTE

FTEs: 1.0 FTE (Jul. 2022 – Aug. 2024)

Subtask 3.3 Naples

Naples is the capital of the Campania Region and Province of Naples. Covering an area of over 1000 km^2, its densely populated metropolitan area of around 4 million people sprawls along the Mediterranean coast and up the surrounding mountains. Naples is the third largest city in Italy after Rome and Milan. The proximity of the city to the sea is a unique characteristic that deserves to be investigated specifically in this context.

Simulations adopting TERRA_URB will be performed with ICON-LAM. Numerical simulations at very high resolution will be used in order to test the capabilities of the model (with TERRA_URB) to reproduce the main features for the Naples urban heat island. The evaluation of the urban scheme will be performed for this domain taking into account the different meteorological observations available in the area, either in rural or urban context. Currently, nine in-situ stations are available, reporting different atmospheric variables at hourly resolution. Among them, three are located in the urban area. Additionally, the verification will be performed also using satellite data and Copernicus reanalysis.

Deliverables: Assessment of the new scheme in the Naples domain.

Involved scientists: Edoardo Bucchignani (CIRA) 0.3 FTE, Paola Mercogliano (CMCC), Francesco Repola (CMCC), Alfredo Reder (CMCC), Carmela Apreda (CMCC)

FTEs: 1.0 FTE (Jul. 2022 – Aug. 2024)

Subtask 3.4 Bucharest

Bucharest is proposed as a domain of interest due to the fact that it is the largest city in Romania and the sixth largest European capital city (per number of inhabitants who live in the city). The Bucharest urban area is slightly larger than the city itself and is classified as a Larger Urban Zone (LUZ), with a high population density.

Simulations for TERRA_URB will be performed with ICON-LAM. Numerical simulations will be used in order to test the capabilities of the models (with TERRA_URB) to reproduce the main features for the Bucharest urban heat island. The evaluation of the scheme will be performed for this domain taking into account meteorological observations available in the area.

For Bucharest, three meteorological stations are considered as being representative, one urban – Bucuresti Filaret (located in the city center), one peri-urban – Bucuresti Baneasa (towards the northern limit of the city) and one rural – Bucuresti Afumati (east of the city). These stations have continuous measurement datasets for the main meteorological parameters.

Selective cases of urban heat island episodes will be identified, in order to perform the numerical simulations. For these cases, apart from classical scores such as BIAS or RMSE that can generally be computed for all continuous variables, specific methods for the evaluation of simulated UHI intensity can be employed, such as an analysis of urban-periurban / urban-rural differences and temperature isotherms, percent frequencies of 1°C temperature differences and the normalization method proposed by Oke (1998).

Deliverables: Assessment of the new scheme in the Bucharest domain.

Involved scientists: Rodica Dumitrache (NMA), Amalia Iriza-Burca (NMA), Bogdan Maco (NMA)

FTEs: 1.0 FTE (Jul. 2022 – Aug. 2024)

Subtask 3.5 Jerusalem and Tel Aviv

It is proposed that the TERRA_URB influence on the urban heat island and wind profile will be tested with observations from Jerusalem and Tel Aviv. Jerusalem is a city with a population of about 1 million inhabitants. The city is located on a hilly ridge at an altitude of 600-800 m, where the urban area is usually on top of the hills and the valleys are generally preserved as green areas. Tel Aviv metropolis is an urban area of 1500 km^2 and 3.7 million inhabitants, the area is located on the coastal plain. The influence of the sea and land breeze will be evaluated. Furthermore, the effect of the urban roughness on precipitation patterns will be evaluated with the IMS radar.

Simulations with TERRA_URB will be carried out with the currently operational ICON-LAM model. Numerical simulations will be used in order to test the capabilities of the model (with TERRA_URB) to reproduce the main features for the Jerusalem and Tel Aviv urban heat island and enhanced roughness. The evaluation of the scheme will be performed for this domain taking into account meteorological observations available in the area.

For Jerusalem, four meteorological stations are considered as being representative, one urban – Generali (located in the city center, 810 m a.s.l.), one semi-urban – Hebrew University (770 m a.s.l.), and two rural – Zova (west of the city, 710 m a.s.l.) and Maale Adumim (east of the city, 490 m a.s.l.). These stations have continuous measurement datasets for the main meteorological parameters. In central Jerusalem, there is also a ceilometer that can provide cloud base and mixing levels. Particular attention will be paid on snow events in Jerusalem (which occur rarely, roughly one day a year). It is expected that the heat island will have an effect on the snow depth during these events.

For Tel Aviv, twelve urban stations from the coastline in the west to the rural area in the east will be used. The radiosonde from Bet Dagan will be used to evaluate the temperature and wind profiles.

Selective cases of urban heat island, sea-land breeze, and precipitation cases will be identified, in order to perform the numerical simulations. For these cases, the differences between the runs with and without TERRA_URB will be evaluated.

Deliverables: Assessment of the new scheme and generally the urban effects on temperature and wind profiles in Jerusalem and Tel Aviv.

Involved scientists: Itsik Carmona (IMS), Pavel Khain (IMS), Yoav Levi (IMS)

FTEs: 1.0 FTE (Jul. 2022 – Aug. 2024)

Subtask 3.6 Warsaw

Warsaw is the capital of Poland located at the Vistula river in the greater North European Plain. Its population is estimated to 1.8 million residents within a greater metropolitan region of 3.1 million residents. An observed increase of temperature is attributed to urban development and it is intensifying during this century (Kuchcik et al. 2014, Rozbicki et al. 2020). Land use changes lead to an increase not only of the UHI effect but also of urban ventilation (Osińska-Skotak and Zawalich 2016) and trigger flash flood hazards (Żmudzka et al. 2019).

New global urban external parameter datasets will be tested in ICON-LAM simulations in hindcast mode. Additional simulations will be performed with external parameter data based on local high resolution urban geomorphological datasets. A local AHF field will be elaborated based on energy consumption and population density.

Data from over a dozen of meteorological stations are available in the urban area for verification. Most of them work in operational mode and others were operating in 2014-2017. Measurements of surface atmospheric variables are available at hourly resolution. Special attention will be paid to extreme precipitation case studies leading to local flash flood events.

Deliverables: Assessment of the new scheme and the urban effects in Warsaw.

Involved scientists: Adam Jaczewski (IMGW-PIB), Andrzej Wyszogrodzki (IMGW-PIB), Witold Interewicz (IMGW-PIB), Alan Mandal (IMGW-PIB)

FTEs: 1.0 FTE (Jul. 2022 – Aug. 2024)

Task 4 Further developments and applications of TERRA_URB

Once the model is successfully implemented and tested, further scientific developments and applications of TERRA_URB will be carried out.

Subtask 4.1 Improved representation of vegetated urban areas in TERRA_URB

The inconsistency between the parameters of the land use class for urban areas (urban fraction) and of the impervious area fraction is important not only for technical issues, but also from a physical point of view. As already noted, the urban tile in TERRA_URB is assumed to be completely paved and not vegetated, while all vegetation is assumed to be within a natural tile. For the urban tile, semi-empirical corrections are applied for the thermal conductivity, heat capacity, albedo and emissivity in order to take into account the geometrical effects of a building-covered environment for the heat and radiation transfer. In reality, the building-covered environment includes also vegetated surfaces such as lawns, gardens, etc. Hence, there is an area fraction that should be considered as pervious and vegetated, but should still be affected by the geometrical effects of the building-covered environment. On the other hand, there are impervious surfaces outside the urban environment, such as roads and airfields.

Therefore, it is planned to modify the representation of the urban tile in TERRA_URB allowing it to include a part of vegetated fraction, and to implement an additional tile for impervious area outside of the building-covered environment. The possibility to provide additional external parameters for a modified representation of urban/impervious areas will be investigated.

Deliverables: Vegetated urban areas implemented in TERRA_URB. Assessment of the impact of this new development in the Moscow domain.

Involved scientists: Mikhail Varentsov (RHM) 1.0 FTE, Hendrik Wouters (VITO) 0.05 FTE

FTEs: 1.05 FTE (Jul. 2022 – Aug. 2024)

Subtask 4.2 Boundary layer clouds over urban areas in ICON-LAM-ART

The aim of this subtask is the spatiotemporal quantification of urban cloud patterns and properties as well as the analysis of their main influences using satellite observations and numerical modelling over European urban areas.

Clouds in the urban boundary layer are expected to interact with the urban climate by modulating and responding to the exchange of radiation, heat, and moisture within the boundary layer (Inoue and Kimura 2004, Oke et al. 2017), resulting in prominent spatial and temporal patterns of boundary layer clouds over or downwind of cities. These urban-induced cloud modifications can be identified by a contrasting spatial pattern compared to the rural area for specific cloud types, thermodynamic conditions and location as suggested by model- and satellite-based studies (Romanov 1999, Zhong et al. 2015). Depending on meteorological context, an enhancement of fair-weather cumulus clouds or a faster dissipation/delayed formation of fog, visible in so-called fog holes is encountered.

Although knowledge exists on the mechanisms of these two types of urban cloud modification, the complex interactions of large-scale dynamics, surface roughness, the urban heat island, aerosols and cloud processes in urban areas are difficult to untangle (Oke et al. 2017).

Based on measurements by the satellite sensor MODIS (MODerate Resolution Imaging Spectroradiometer) carried by the two polar-orbiting platforms Terra and Aqua, characteristics of clouds are retrieved about twice a day at a spatial resolution of 1 km (Level 2 data, Platnick et al. 2003). This spatial scale is relevant and appropriate for the analysis of patterns and interactions of urban cloud mechanisms with the urban land surface (Jin et al. 2005, Gautam and Singh 2018). The Spinning-Enhanced Visible and Infrared Imager (SEVIRI) onboard the geostationary Meteosat Second Generation (MSG) satellites complements MODIS by providing cloud properties in a 15-minutes repeat cycle at a spatial resolution of 3 km at nadir for the standard channels (1km, HRV, Schmetz et al. 2002). On the basis of this data spatial insights can be obtained into the formation of short-lived clouds over urban areas (Theeuwes et al. 2015), instantaneous changes of cloud structure and microphysics driven by mesoscale convective systems (Fuchs et al. 2017), as well as cloud dissipation processes.

In order to analyse urban effects on cloud modifications using ICON, initial boundary conditions for the formation of urban FWC and fog holes are specified (IFS and ICON data) based on meteorological conditions and locations, where changes of cloud property and cloud cover have been observed. The representation of the atmospheric state by ICON-LAM-ART (Rieger et al. 2015) and the urban-canopy land surface scheme TERRA_URB (Wouters et al. 2017) is tested in limited urban areas of four different grid sizes (5 km, 2 km, 1 km, 500 m). Subsequently, multiple ICON-ART LAM simulations are performed by switching aerosol processes (ART module), dynamical and thermodynamic processes (ICON) and the urban canopy model TERRA_URB on and off. In this way, the model response to each impact (relevance and spatial patterns) on cloud development can be determined by model differences of ART/noArt/Urb/noUrb simulations and sensitivity analyses.

The locations are chosen in order to cover a wide range of European climate, e. g., maritime vs. continental, and thus be representative for a wide range of situations:

Paris is one of the cities with the highest population densities (person/km^2) within the first 10 km from the city centre among European cities (European Commission 2016). Paris is characterized by western European oceanic climate, surrounded by relatively flat terrain outside of the range of direct coastal influence. Here, temporal and spatial urban-induced changes in cloud cover can likely be observed using satellite data.

Istanbul is a highly populated city with maritime influence and located in a complex climate zone. Changes in cloud cover and cloud microphysics due to urban effects as the urban heat island effect and air pollution are expected (Rosenfeld 2000, Ünal et al. 2020).

The systematic quantification of patterns and drivers of urban cloud modification using MODIS and SEVIRI observations combined with ICON-ART numerical modelling is expected to improve the understanding boundary-layer cloud modifications in urban regions. Results will support the assessment of the new TERRA_URB scheme in ICON-LAM-ART simulations.

Deliverables: Assessment of the new scheme in ICON-LAM-ART.

Involved scientist: Julia Fuchs (KIT)

FTEs: 1.0 FTE (Jul. 2022 – Aug. 2024)

Risks

Some tasks are affected by the risk of a reduction of human resources, either because they are based on non-permanent personnel or because the research work can be delayed by operational needs. This risk may bring delays to the project, but not as serious as a cancelation of activities, because these activities are part of the plans of the respective COSMO Members.

Links with COSMO projects or activities

- COSMO WG3a (Matthias Raschendorfer): With respect to questions about the planetary boundary layer and the transfer scheme TURB_TRAN.
- COSMO WG3b (Jean-Marie Bettems): With respect to all activities concerning surface aspects.
- COSMO WG5 (Flora Gofa): With respect to all activities concerning verification.
- COSMO PP C2I (Daniel Rieger): With respect to the transition from COSMO to ICON.
- SCA COSMO (Ulrich Schättler): With respect to all activities concerning the ICON code in icon-cosmo-dev in gitlab at DKRZ.
- SCA EXTPAR (Jonas Jucker): With respect to all activities concerning the EXTPAR code.

Participants

ARPAP: Arpa Piemonte

Valeria Garbero, Massimo Milelli

CIRA: Centro Italiano Ricerche Aerospaziali

Edoardo Bucchignani

CMCC: Centro Euro-Mediterraneo sui Cambiamenti Climatici

Paola Mercogliano, Carmela Apreda, Carmine De Lucia, Alfredo Reder, Francesco Repola

DWD: German Meteorological Service

Jan-Peter Schulz

IMGW-PIB: Polish Hydro-Meteorological Service

Adam Jaczewski, Andrzej Wyszogrodzki, Witold Interewicz, Alan Mandal

IMS: Israel Meteorological Service

Itsik Carmona, Pavel Khain, Yoav Levi

KIT: Karlsruhe Institute of Technology

Julia Fuchs

NMA: Romanian Meteorological Service

Rodica Dumitrache, Amalia Iriza-Burca, Bogdan Maco

PoliTo: Polytechnic of Turin

Francesca Bassani

RHM: Roshydromet

Mikhail Varentsov, Denis Blinov, Vladimir Kopeykin, Timofey Samsonov, Gdaly Rivin

VITO: Flemish Institute for Technological Research

Hendrik Wouters

References

Baldauf, M., A. Seifert, J. Förstner, D. Majewski, M. Raschendorfer and T. Reinhardt, 2011: Operational convective-scale numerical weather prediction with the COSMO model: Description and sensitivities, *Mon. Weather Rev.*, **139**, 3887–3905.

Bucchignani, E., P. Mercogliano, V. Garbero, M. Milelli, M. Varentsov, I. Rozinkina, G. Rivin, D. Blinov, A. Kirsanov, H. Wouters, J.-P. Schulz and U. Schättler, 2019: Analysis and evaluation of TERRA_URB scheme: PT AEVUS Final Report, *COSMO Technical Report*, **40**, 60 pp. (Available at http://www.cosmo-model.org/).

Doms, G., J. Förstner, E. Heise, H.-J. Herzog, D. Mironov, M. Raschendorfer, T. Reinhardt, B. Ritter, R. Schrodin, J.-P. Schulz and G. Vogel, 2011: A description of the nonhydrostatic regional COSMO model. Part II: Physical parameterization, *Deutscher Wetterdienst*, Offenbach, 154 pp. (Available at http://www.cosmo-model.org/).

Dong, Y., A. C. G. Varquez and M. Kanda, 2017: Global anthropogenic heat flux database with high spatial resolution, *Atm. Env.*, **150**, 276–294. DOI: 10.1016/j.atmosenv.2016.11.040.

European Commission and United Nations Human Settlements Programme (UN-Habitat), 2016: The State of European Cities 2016 - Cities leading the way to a better future, *European Commission*, Brussels. DOI: 10.2776/636682.

Fuchs, J. et al., 2017: On the influence of air mass origin on low-cloud properties in the southeast Atlantic, *J. Geophys. Res.: Atmospheres*, **122**, 11,076–11,091. DOI: 10.1002/2017JD027184.

Garbero, V., M. Milelli, E. Bucchignani, P. Mercogliano, M. Varentsov, I. Rozinkina, G. Rivin, D. Blinov, H. Wouters, J.-P. Schulz, U. Schättler, F. Bassani, M. Demuzere and F. Repola, 2021: Evaluating the urban canopy scheme TERRA_URB in the COSMO model for selected European cities, *Atmosphere*, **12**, 237. DOI: 10.3390/atmos12020237.

Gautam, R. and M. K. Singh, 2018: Urban heat island over Delhi punches holes in widespread fog in the Indo-Gangetic Plains, *Geophys. Res. Letters*, **45**, 1114–1121. DOI: 10.1002/2017GL076794.

Gong, P., X. Li, J. Wang, Y. Bai, B. Chen, T. Hu, X. Liu, B. Xu, J. Yang, W. Zhang and Y. Zhou, 2020: Annual maps of global artificial impervious area (GAIA) between 1985 and 2018, *Remote Sens. Env.*, **236**, 111510. DOI: 10.1016/j.rse.2019.111510.

Inoue, T. and F. Kimura, 2004: Urban effects on low-level clouds around the Tokyo metropolitan area on clear summer days, *Geophys. Res. Letters*, **31**. DOI: 10.1029/2003GL018908.

Jin, M. et al., 2005: The footprint of urban areas on global climate as characterized by MODIS, *J. Clim.*, **18**, 1551–1565. DOI: 10.1175/JCLI3334.1.

Kuchcik, M., K. Błażejczyk, P. Milewski and J. Szmyd, 2014: Urban climate research in Warsaw: The results of microclimatic network measurements, *Geogr. Pol.*, **87**, 491–504. DOI: 10.7163/GPol.2014.33.

Lokoshchenko, M. A., 2017: Urban heat island and urban dry island in Moscow and their centennial changes, *J. Appl. Meteor. Climat.*, **56**, 2729–2745. DOI: 10.1175/JAMC-D-16-0383.1.

Météo-France/CNRS, 2018: ECOCLIMAP-SG. (Available at https://opensource.umr-cnrm.fr/projects/ecoclimap-sg/wiki)

Milelli, M., 2016: Urban heat island effects over Torino, *COSMO Newsletter*, **16**, 3–12. (Available at http://www.cosmo-model.org/).

Oke, T. R., 1998: An algorithmic scheme to estimate hourly heat island magnitude, 2nd Symp. Urban Environ., Albuquerque, NM, Amer. Meteor. Soc., 80–83.

Oke, T. R. et al., 2017: Urban Climate, *Cambridge University Press*, Cambridge.

Osińska-Skotak, K. and J. Zawalich, 2016: Analysis of land use changes of urban ventilation corridors in Warsaw in 1992-2015, *Geogr. Pol.*, **89**. DOI: 10.7163/GPol.0057.

Platnick, S. et al., 2003: The MODIS cloud products: Algorithms and examples from Terra, *IEEE Transactions Geosci. Remote Sens.*, **41**, 459–472. DOI: 10.1109/TGRS.2002.808301.

Rieger, D. et al., 2015: ICON–ART 1.0 – a new online-coupled model system from the global to regional scale, *Geosci. Model Dev.*, **8**, 1659–1676. DOI: 10.5194/gmd-8-1659-2015.

Rivin, G. S., I. A. Rozinkina, R. M. Vil'fand, D. Y. Alferov, E. D. Astakhova, D. V. Blinov, A. Y. Bundel, E. V. Kazakova, A. A. Kirsanov, M. A. Nikitin, V. L. Perov, G. V. Surkova, A. P. Revokatova, M. V. Shatunova and M. M. Chumakov, 2015: The COSMO-Ru system of nonhydrostatic mesoscale short-range weather forecasting of the Hydrometcenter of Russia: The second stage of implementation and development, *Russ. Meteor. Hydrol.*, **40**, 400–410. DOI: 10.3103/S1068373915060060.

Rivin, G. S., I. A. Rozinkina, R. M. Vil'fand, D. B. Kiktev, K. O. Tudriy, D. V. Blinov, M. I. Varentsov, D. I. Zakharchenko, T. E. Samsonov, I. A. Repina and A. Y. Artamonov, 2020: Development of the high-resolution operational system for numerical prediction of weather and severe weather events for the Moscow region, *Russ. Meteor. Hydrol.*, **45**.

Rockel, B., A. Will and A. Hense, 2008: The regional climate model COSMO-CLM (CCLM), *Meteor. Z.*, **17**, 347–348.

Romanov, P., 1999: Urban influence on cloud cover estimated from satellite data, *Atm. Env.*, **33**, 4163–4172. DOI: 10.1016/S1352-2310(99)00159-4.

Rosenfeld, D., 2000: Suppression of rain and snow by urban and industrial air pollution, *Science*, **287**, 1793–1796. DOI: 10.1126/science.287.5459.1793.

Rozbicki, T., M. Kleniewska, K. Rozbicka, G. Majewski and D. Gołaszewski, 2020: Relating urban development and densification to temporary changes in the air temperature in Warsaw (Poland), *Theo. Appl. Climatol.*, **142**, 513–523. DOI: 10.1007/s00704-020-03311-3.

Samsonov, T. E. and M. I. Varentsov, 2020: Computation of city-descriptive parameters for high-resolution numerical weather prediction in Moscow megacity in the framework of the COSMO model, *Russ. Meteor. Hydrol.*, **45**.

Samsonov, T. E., P. I. Konstantinov and M. I. Varentsov, 2015: Object-oriented approach to urban canyon analysis and its applications in meteorological modelling, *Urban Climate*, **13**, 122–139. DOI: 10.1016/j.uclim.2015.07.007.

Schmetz, J. et al., 2002: An introduction to METEOSAT Second Generation (MSG), *Bull. Amer. Meteor. Soc.*, 977–992. DOI: 10.1175/1520-0477(2002)083<0977.

Schulz, J.-P. and G. Vogel, 2020: Improving the processes in the land surface scheme TERRA: Bare soil evaporation and skin temperature, *Atmosphere*, **11**, 513.

Schulz, J.-P., G. Vogel, C. Becker, S. Kothe, U. Rummel and B. Ahrens, 2016: Evaluation of the ground heat flux simulated by a multi-layer land surface scheme using high-quality observations at grass land and bare soil, *Meteor. Z.*, **25**, 607–620.

Stewart, I. D. and T. R. Oke, 2012: Local Climate Zones for urban temperature studies, *Bull. Amer. Meteor. Soc.*, **93**, 1879–1900. DOI: 10.1175/BAMS-D-11-00019.1.

Theeuwes, N. E. et al., 2015: Cool city mornings by urban heat, *Env. Res. Letters*, **10**. DOI: 10.1088/1748-9326/10/11/114022.

Ünal, Y. S. et al., 2020: Investigating urban heat island intensity in Istanbul. *Theo. Appl. Climatol.*, **139**, 175–190. DOI: 10.1007/s00704-019-02953-2.

Varentsov, M. I., T. E. Samsonov, A. V. Kislov and P. I. Konstantinov, 2017: Simulations of Moscow agglomeration heat island within framework of regional climate model COSMO-CLM [in Russian], *Moscow University Vestnik*, Series 5, Geography, 6.

Varentsov, M. I., H. Wouters, V. Platonov and P. I. Konstantinov, 2018: Megacity-Induced mesoclimatic effects in the lower atmosphere: A modeling study for multiple summers over Moscow, Russia, *Atmosphere*, **9**, 50. DOI: 10.3390/atmos9020050.

Varentsov, M. I., M. Y. Grishchenko and H. Wouters, 2019: Simultaneous assessment of the summer urban heat island in Moscow megacity based on in situ observations, thermal satellite images and mesoscale modelling, *Geogr., Env., Sustain.*, **12**, 74–95. DOI: 10.24057/2071-9388-2019-10.

Varentsov, M. I., T. E. Samsonov and M. Demuzere, 2020: Impact of urban canopy parameters on a megacity's modelled thermal environment, *Atmosphere*, **11**, 1349.

Wouters, H., M. Demuzere, U. Blahak, K. Fortuniak, B. Maiheu, J. Camps, D. Tielemans and N. P. M. van Lipzig, 2016: The efficient urban canopy dependency parametrization (SURY) v1.0 for atmospheric modelling: Description and application with the COSMO-CLM model for a Belgian summer, *Geosci. Mod. Dev.*, **9**, 3027–3054. DOI: 10.5194/gmd-9-3027-2016.

Wouters, H., M. Varentsov, U. Blahak, J.-P. Schulz, U. Schättler, E. Bucchignani and M. Demuzere, 2017: User guide for TERRA_URB v2.2: The urban-canopy land-surface scheme of the COSMO model, *Ghent University*, 12 pp. (Available at http://www.cosmo-model.org/).

Zhong, S. et al., 2015: A case study of urbanization impact on summer precipitation in the Greater Beijing Metropolitan Area: Urban heat island versus aerosol effects, *J. Geophys. Res.: Atmospheres*, **120**, 10,903–10,914. DOI: 10.1002/2015JD023753.

Żmudzka, E., K. Kulesza, M. Lenartowicz, K. Leziak and A. Magnuszewski, 2019: Assessment of modern hydro-meteorological hazards in a big city – identification for Warsaw, *Meteor. Appl.*, **26**, 500–510. DOI: 10.1002/met.1779.

Appendix 1: Task table

FTE-y 2021 (from Jul. to Dec. 2021):	**1.275** (COSMO) + **0.10** (PoliTo)
FTE-y 2022 (from Jan. to Dec. 2022):	**3.000** (COSMO) + **0.71** (PoliTo, VITO, KIT)
FTE-y 2023 (from Jan. to Dec. 2023):	**3.450** (COSMO) + **0.53** (VITO, KIT)
FTE-y 2024 (from Jan. to Aug. 2024):	**1.775** (COSMO) + **0.26** (VITO, KIT)

FTE-y total (from Jul. 2021 to Aug. 2024): **9.500** (COSMO) + **1.60** (PoliTO, VITO, KIT)

Task	**Subtask**	**Contributing scientist(s)**	**FTE-y Total**	**FTE-y 2021**	**FTE-y 2022**	**FTE-y 2023**	**FTE-y 2024**	**Start**	**Deliverables**	**Date of delivery**	**Preceding tasks**
C total 0.45		J.-P. Schulz P. Mercogliano	0.3 0.15	0.05 0.025	0.1 0.05	0.1 0.05	0.05 0.025	Jul. 2021	Meetings, Reports	permanent	
1 total 0.6		J.-P. Schulz M. Varentsov C. De Lucia	0.4 0.1 0.1	0.2 0.05 0.05	0.2 0.05 0.05			Jul. 2021	Implementation of TERRA_URB in ICON	Jun. 2022	
2 **total 2.0**	2.1	V. Garbero M. Varentsov A. Reder	0.1 0.1 0.1	0.05 0.05 0.05	0.05 0.05 0.05			Jul. 2021	Consistency of urban external parameters	Jun. 2022	
	2.2	C. Apreda A. Jaczewski A. Wyszogrodzki M. Varentsov T. Samsonov V. Garbero M. Milelli F. Bassani J.-P. Schulz	0.2 0.35 0.15 0.2 0.2 0.15 0.05 0.2 0.2	0.1 0.175 0.075 0.1 0.1 0.075 0.025 0.1 0.1	0.1 0.175 0.075 0.1 0.1 0.075 0.025 0.1 0.1			Jul. 2021	New urban external parameters in EXTPAR for ICON (-LAM)	Jun. 2022	
3 **total 6.0**	3.1	M. Varentsov D. Blinov V. Kopeykin G. Rivin	1.0		0.25	0.5	0.25	Jul. 2022	Moscow	Aug. 2024	1,2
	3.2	V. Garbero M. Milelli F. Bassani	0.4 0.25 0.35		0.1 0.05 0.35	0.2 0.1	0.1 0.1	Jul. 2022	Turin	Aug. 2024	1,2
	3.3	E. Bucchignani P. Mercogliano F. Repola A. Reder C. Apreda	0.3 0.7		0.075 0.175	0.15 0.35	0.075 0.175	Jul. 2022	Naples	Aug. 2024	1,2
	3.4	R. Dumitrache A. Iriza-Burca B. Maco	1.0		0.25	0.5	0.25	Jul. 2022	Bucharest	Aug. 2024	1,2
	3.5	I. Carmona P. Khain Y. Levi	1.0		0.25	0.5	0.25	Jul. 2022	Jerusalem, Tel Aviv	Aug. 2024	1,2
	3.6	A. Jaczewski A. Wyszogrodzki W. Interewicz A. Mandal	1.0		0.25	0.5	0.25	Jul. 2022	Warsaw	Aug. 2024	1,2
4 **total 2.05**	4.1	M. Varentsov H. Wouters	1.0 0.05		0.25 0.01	0.5 0.03	0.25 0.01	Jul. 2022	Improved representation of vegetated urban areas in TERRA_URB	Aug. 2024	1,2, 3

	4.2	J. Fuchs	1.0		0.25	0.5	0.25	Jul. 2022	Boundary layer clouds over urban areas in ICON-LAM-ART	Aug. 2024	1,2, 3