# COSMO Priority Task:

# *A*nalysis and *Ev*aluation of TERRA_*U*RB *S*cheme 2 (ÆVUS 2)

*Version 2.0, 23/08/2019*

**Task Leader:** **CIRA**

**Participants:** ***COSMO*: ARPA Piemonte, DWD, RHM**

***Externals partners*: Ruhr University of Bochum,**

**Flemish Institute for Technological Research (VITO),**

**Polytechnic of Torino.**

### Goal

Consolidate the implementation of the TERRA_URB scheme in the COSMO model, draft a new PT or PP aiming at transferring these developments into the ICON model. ***This PT should be considered as a second part of the work started in PT AEVUS, aiming at having a robust and well documented representation of urban effects in the final unified COSMO release.***

### Introduction

In the period from September 2017 to June 2019, the PT AEVUS has been carried out, with the aim of testing the implementation of the TERRA_URB scheme in COSMO.

TERRA_URB (in the following TU) is an urban scheme, which parametrises the effects of buildings, streets and other man-made impervious surfaces on energy, moist and momentum exchanges between the surface and the atmosphere, and additionally accounts for the anthropogenic heat flux (QF) as a heat source from the surface to the atmosphere. The use of the anthropogenic heat flux and modified thermal and radiative parameters is able to reproduce the urban heat island with a realistic amplitude and diurnal phase. The magnitude of QF and the urban canopy parameters can be adapted to improve the mean measured signal. TU uses a pre-calculated QF, which accounts for country-specific data of energy consumption, calculated on the basis of the population density and with a latitude dependent diurnal and seasonal distribution. Due to this simple representation of the urban land as a bulk, TU is computationally inexpensive. The latest version of TU implements the semi-empirical urban canopy parametrisation (SURY). It translates urban canopy parameters (with 3D information) into bulk parameters while preserving the low computational cost. Urban canopy parameters (except for the impervious surface area fraction and QF) are specified as fixed field parameters (hard-coded constants) in the current implementation.

At the beginning of PT AEVUS, TU was implemented in a test-version of COSMO (i.e. 5.04g_urb1), which has been used in order to carry out some preliminary tests. However, several bugs were detected in this version and the official beginnings of the activities (scheduled for September 2017) have been delayed. An extra sub-task was established in order to speed-up the debugging activities. In June 2018 the COSMO version 5.05 (including TU) has been officially released. During the last year, several versions have been released (5.05_urb2, 5.05_urb3, 5.05_urb4) to fix some bugs and a new version of INT2LM (2.05a) has been released too, allowing the possibility of using the skin temperature scheme.

Model sensitivity tests showed that skin temperature scheme leads to a better representation of the urban/rural contrasts in surface-atmosphere exchanges, which was found to reduce the negative bias in the UHI intensity. This option also allows investigating the effects of vegetation insulation on urban climate. The usage of the skin temperature scheme requires an additional external parameter, i.e. the skin conductivity (SKC) which currently is provided by EXTPAR by selecting GlobCover as raw data set for the land use data (only in NetCDF format).

The aim of PT AEVUS was an evaluation and a comprehensive verification of the performances of the scheme, using different case studies, in order to check the physical consistency of the modelling results and to check the model capability to reproduce the urban-induced meteorological features such as UHI. Additionally, attempts were made towards the calibration of the COSMO parameters (exposed in the model namelist) and of the TU scheme itself. Since the goal of the urban scheme is to catch small-scale features, only very-high resolution runs were considered.

Detailed tests, conducted within the framework of AEVUS, allowed to reveal and fix a number of code bugs, responsible for physical inconsistencies in the first releases of COSMO 5.05urb. In particular, a bug that led to artificial heating in the rural areas, and a bug that led to an incorrect behaviour of the skin-layer temperature scheme have been fixed. The latest model version (5.05_urb4) shows physically consistent result and reasonably reproduces the UHI effect for the considered urban areas.

***A report will be available in September 2019 documenting the most important PT AEVUS results.***

**Motivations**

With the PT AEVUS, a milestone has been reached: to have a parallel branch of COSMO working properly with TU. The tests have been performed with a namelist derived from a standard COSMO-D2 configuration. The plan is to include TU in the official COSMO v6.0 version.

Nevertheless, several issues are still open, as described in the next section, which motivates the current proposal. In particular, ***a significant weakness of the current TU implementation is the use of hard-coded values for the urban canopy parameters***. It is reasonable to expect modelling quality improvements when using spatially variable urban canopy parameters, defined for different cities and different parts of the cities based on state-of-the art methods; this issue should be investigated, and the corresponding code developments should be implemented before the freezing of the COSMO code.

Most of the proposed research topics of AEVUS2 will be valuable preparation for the future migration of the TU scheme from the COSMO model to the ICON model.

A number of external institutions are willing to participate to this new PT, as it happened for PT AEVUS. In particular, from November on, a PhD student from Polytechnic of Torino will work on this topic in collaboration with ARPA.

New urban canopy parameters

In the most recent COSMO version, 5.05urb4, the disposable urban canopy parameters (describing the urban morphology and the thermal properties) required by the TU parametrisation are specified as constant field parameters. These constants are not universal, their current values are calibrated for a limited number of West-European cities (Wouters et al, 2016). However, recent research has shown that the urban canopy parameters values have a substantial effect on urban climate modelling. As such, 2D external-parameter fields are needed, which should also better represent the heterogeneity of the city's morphology. These parameters include the building height, building fraction area, aspect ratio of street canyon and a number of thermophysical parameters such as albedo, emissivity and heat capacity of urban materials. Therefore, one major aim of AEVUS2 will be to implement the possibility to define urban canopy parameters as 2D external-parameter fields; this is especially important with the future freezing of the COSMO code development.

We will implement and test the modifications to the model code supporting three options: to use default values (as it is now), to use a user-defined constant, or to use 2D external-parameter fields. The code modifications will be implemented and tested before the official release of COSMO 6.0, which will allow the inclusion of these modifications in the final unified COSMO version.

Different possibilities to produce the required datasets of 2D external parameters will be investigated. First, the concept of *Local Climate Zone* (LCZ) will be considered. LCZs are "regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometres in horizontal scale" (Oke, 2012); each LCZ has a characteristic screen-height temperature regime that is most apparent over dry surfaces, on calm, clear nights. A new European-wide dataset has been released recently (Demuzere et al., 2019). Then, we will consider the possibility to define the urban canopy parameters using GIS-based processing of OpenStreetMap data, as suggested in (Samsonov et al., 2015; Varentsov et al., 2019), or using other building-resolving vector data.

New tests will be performed to show the added-value of the new urban parameters obtained by these different approaches. Moreover, sensitivity analysis will be performed, changing the different urban canopy parameters according to local climate zones specific ranges, to gain an understanding of the relative importance of the different parameters. Because the urban canopy parameters affect the representation of the urban physics in the TERRA_URB scheme, the obtained results will also be relevant for a future TERRA_URB implementation in ICON.

<u>Improve EXTPAR urban related datasets</u>

Results of AEVUS have shown that even the basic urban canopy parameters, the impervious surface area fraction and QF, are far away from being perfect in the existing datasets available in EXTPAR. Therefore, one of the aims of AEVUS2 will be the provision of improved worldwide urban datasets.

The following datasets will be considered for the *paved fraction* and for *QF*:

- Update EEA imperviousness with new products (100m, state of 2006, 2009, 2012, 2015) (EUROPE)
- ESA CCI urban land cover (300m, per year from 1992-2015) (viewer) (Global)
- An update for the anthropogenic heat flux (hourly, ~1km, state of 2013) by Dong et al. (2017)

As indicated above, the possibility of including the concept of *Local Climate Zone* (LCZ), in relation with a new European-wide dataset (Demuzere et al., 2019), will also be investigated.

Finally, we will investigate the consistency between different sets of external parameters which are important for the representation of urban areas and of urban-rural meteorological contrasts (impervious surface area fraction, anthropogenic heat flux, vegetation skin-layer conductivity, roughness length, etc.). This is an important task, because these parameters are derived from different datasets with different spatial resolution, and inconsistencies could lead to double counting of several urban-induced effects. The representation of the cities in terms of different parameters should be synchronized; methods for checking and maintaining the consistency between different external parameters for urban areas will be suggested.

Calibration of the model physical parameters

Within the framework of AEVUS2, we will make further steps towards a better calibration of the COSMO model for the considered urban areas, including the calibration of the switches and parameters in INPUT_PHY and TUNING namelists, and we will investigate the sensitivity of the simulated urban-induced meteorology to these changes.

We will in particular focus on the COSMO canopy parameterization. With respect to the surface energy balance, two different schemes of canopy parametrisations are available: a "surface energy balance equation" solved at the ground surface (canopy energetically not represented, itype_canopy = 1) and a skin-layer temperature formulation by Schulz and Vogel (2017) (itype_canopy = 2). Previous studies have reported the high sensitivity of the urban climate simulations to the skin-layer temperature formulation (Wouters et al., 2017; Varentsov et al., 2018). While the first scheme was extensively tested during AEVUS, the second one was only shortly considered; one of the aim of AEVUS2 will be a comprehensive testing of the effects of the skin-layer formulation on the simulated urban-induced meteorological effects.

Usage of different data forcing

Most of the PT AEVUS test cases were performed using ECMWF IFS or ERA-Interim data as forcing. The urban-induced meteorological features (e.g. urban heat island) depends also on the larger-scale atmospheric processes. Hence, it will be useful to analyse the performances of TU using ICON as driving model, also in view of the transition process from COSMO to ICON.

Towards TERRA_URB implementation in ICON

The ICON (ICOsahedral Nonhydrostatic) is a joint project between the Deutscher Wetterdienst (DWD) and the Max-Planck-Institute for Meteorology (MPI-M) for the development of a unified next-generation numerical weather prediction system, used both for global and local applications. The transition from COSMO to the ICON Limited Area Model (LAM) is currently in progress.

In this perspective, one goal of AEVUS2 will be to make the necessary preparations for *a new PT or PP*, aimed at the TU implementation in the ICON model. This includes a close coordination with the ICON community and the ICON developers.

In addition, we will run preliminary tests of high-resolution ICON-LAM simulations, without the TU scheme, for the considered urban areas. It will be an important step towards the creation of testbeds for the future implementation of the TU scheme in the ICON-LAM model.

Note that the AEVUS2 results will form a very valuable basis for this future migration. For example, the work on the external parameters will be important for both COSMO and ICON communities; improved raw datasets and the adapted software (EXTPAR) will facilitate the transition of TERRA_URB to ICON.

**Expected results**

***A documented, stable, calibrated and flexible urban scheme will be provided in the final unified COSMO code release.*** The flexibility will lie in the possibility of using different methods to define *the urban canopy parameters*, from using default constants to using full 2D external parameters fields. Moreover, ***an improvement of the external parameters*** and the necessary adaptations of the EXTPAR software is foreseen. This is of great importance in view of the expected increase of horizontal resolution in the operational configuration of the COSMO members; the improvement of the screen level parameters will have beneficial effects in the operational forecast on densely populated regions where the urban heat island and other urban-induced meteorological effects are important.

***Recommendations*** on urban parameters, about the usage of the different data sources used for the external parameters, and on the model physical settings will be provided for the COSMO consortium and the CLM community. A comprehensive and clear ***documentation*** will also be prepared.

The ***verification*** is an important aspect of this priority task; this is of course necessary to evaluate the performance of the model in its various flavours, both at the surface and in the free atmosphere. The experiments will be performed over the test cases already defined in the frame of PT AEVUS, namely the urban areas of Turin (Italy), Naples (Italy), some urban areas of Belgium, and the Moscow megacity (Russia). The verification methods have been presented in AEVUS (final report pending, but see e.g. http://www.cosmo-model.org/content/tasks/workGroups/wg3b/docs/PT_AEVUS_Varentsov_201903.pdf), In particular, we will use the dense surface-layer and boundary-layer meteorological observations available in the considered cities.

## Description of Individual Sub-Tasks

### SubTask1: Code developments and tests, related to new urban canopy parameters

The option to define urban canopy parameters (building height, building fraction area, aspect ratio of street canyons, thermophysical parameters of urban materials such as albedo, emissivity, heat capacity, etc.) as 2D external parameters will be implemented in COSMO and INT2LM. At the same time, the possibility to use the default values (as it is done in current model version) or some user-defined constants will also be implemented. New developments will be tested to support physical consistency. This part of the PT will be done before the official release of COSMO 6.0.

**Deliverables**

Code developments in COSMO and IN2LM codes, included in the official COSMO 6.0 release.

**Participating scientists**

Edoardo Bucchignani (CIRA), P. Mercogliano (CIRA), V. Garbero (ArpaP), M. Milelli (ArpaP), J.P. Schulz (DWD), H. Wouters (VITO), Varentsov (RHM), A.Kirsanov (RHM), Rozinkina (RHM)

### SubTask2: Testing of new external parameters

This subtask will be focused on a detailed testing of new datasets representing the urban canopy parameters. For the impervious area fraction and for QF the recently developed global or European datasets (see above) will be tested and added to the EXTPAR tool. For the new urban canopy parameters (see Subtask 1), we will investigate the opportunity to obtain their values using LCZ approach at the global and at the European scale, and using the GIS-processed OpenStreetMap data on smaller scales. Different datasets and approaches will be tested and evaluated in high-resolution simulations for the considered cities.

Planned simulations will also include sensitivity tests, aimed at investigating the added value of the new urban canopy parameters. Such tests will give us an understanding of the relative importance of the new parameters, and, consequently, to focus further developments on these parameters.

Finally, in order to avoid a double counting of the different urban-induced effects, we will further investigate the consistency between the different urban related external parameters (i.e. impervious surface area fraction, anthropogenic heat flux QF, vegetation skin-layer conductivity SKC, roughness length $z_0$, etc.).

**Deliverables**

A reliable set of up-to-date external parameters for urban areas, and the associated processing algorithms for their inclusion in EXTPAR (at the end of the PT); recommendations about the importance and the added-value of these new urban canopy parameters.

**Participating scientists**

Edoardo Bucchignani (CIRA), P. Mercogliano (CIRA), V. Garbero (ArpaP), M. Milelli (ArpaP), M. Demuzere (Bochum), H. Wouters (VITO), M. Varentsov (RHM), T. Samsonov (RHM), D.Blinov (RHM).

## SubTask3: Calibration of the COSMO model for urban areas

Further steps towards the calibration of the COSMO model for high-resolution urban-resolving simulation will be performed. Many parameters defined in TUNING and INPUT_PHY influence the behavior of the TU scheme and of the simulated urban meteorological features; one will investigate the sensitivity of the simulated urban meteorological features, such as UHI, to these parameters. The first focus will be on the canopy parameterization type (itype_canopy = 1 or itype_canopy = 2), which importance has already been documented in AEVUS. Other namelist parameters will be considered as far as possible.

**Deliverables**

Results of the sensitivity study on selected namelist parameters, and guidelines about the optimal set-up of the namelist parameters for the considered urban areas.

**Participating scientists**

Edoardo Bucchignani (CIRA), P. Mercogliano (CIRA), V. Garbero (ArpaP), M. Milelli (ArpaP), J. P. Schulz (DWD), M. Varentsov (RHM), A.Kopeykin (RHM), A.Kirsanov (RHM).

## SubTask4: Test with different driving models

The behaviour of the model when driven by different forcing data will be documented.

**Deliverables**

Results of the verification process.

**Participating scientists**

Edoardo Bucchignani (CIRA), P. Mercogliano (CIRA), V. Garbero (ArpaP), M. Milelli (ArpaP), M. Varentsov (RHM), D.Blinov (RHM), I. Rozinkina (RHM).

## SubTask5: towards TERRA URB implementation in ICON

The preparations towards the implementation of the TU scheme in the ICON model will be started, including the setting up and testing of high-resolution simulations with ICON-LAM for selected urban areas (but without the TU scheme). Close coordination with the ICON community and the ICON developers will be put in place. A PT or PP plan aimed at integrating TU in ICON will be prepared.

**Deliverables**

Basic configuration of high-resolution ICON-LAM simulations for selected urban areas. Draft of a PT or PP plan aimed at implementing the TU scheme in ICON

**Participating scientists**

PhD student (Polytechnic of Torino), M.Varentsov (RHM), V.Kopeykin (RHM), G.S. Rivin (RHM)

## SubTask6: production of the final report

All the work will be summarized in a document useful for all the scientists of the Consortium. In particular, the urban model documentation, from a scientific and from a user point of view, and the documentation about the external parameters will be made available.

**Deliverables**

Results of the project in the form of a COSMO Technical Report, and/or paper, and/or COSMO Newsletter. Full documentation of TERRA_URB scheme.

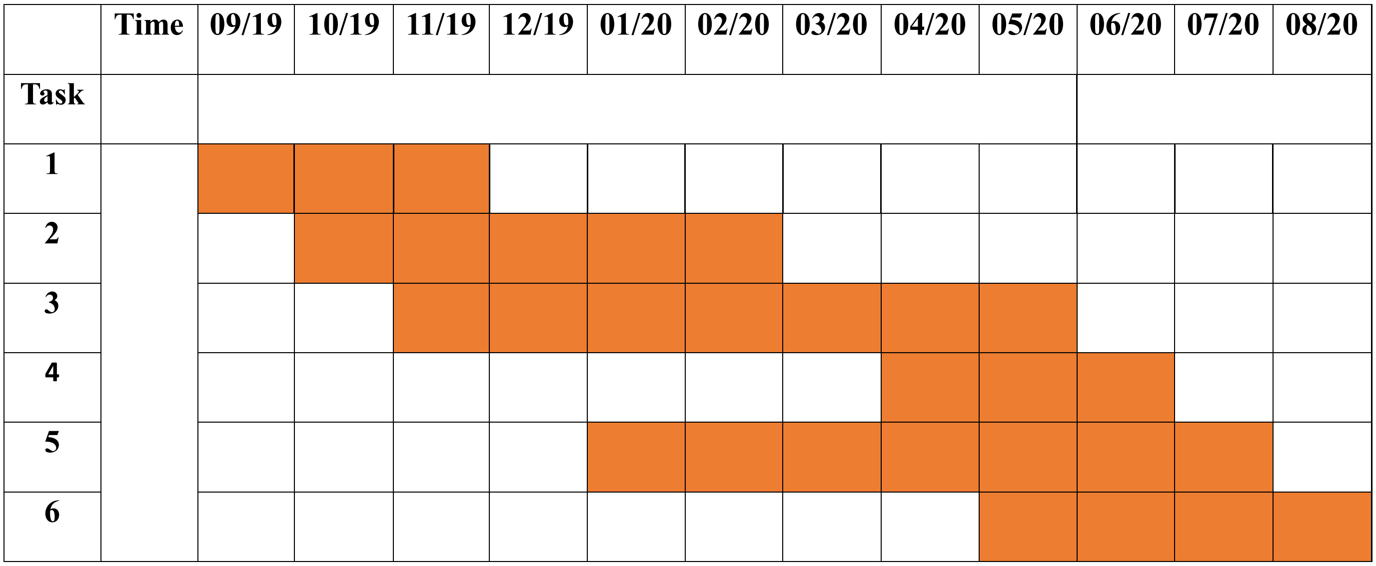
**Participating scientists**

All.

## Advising and collaborations

J.M. Bettems (MeteoSwiss), M. Demuzere (Ruhr University Bochum).

## Gantt chart




## FTE summary

| | Institution | CIRA | ARPA P. | RHM | DWD | VITO/ Bochum | Polytechnic of Torino |
|---|---|---|---|---|---|---|---|
| **Task** | | | | | | | |
| 1 | | 0.07 | 0.07 | 0.07 | 0.10 | 0.10 | |
| 2 | | 0.07 | 0.07 | 0.07 | | 0.20 | |
| 3 | | 0.07 | 0.07 | 0.07 | 0.10 | | |
| 4 | | 0.02 | 0.02 | 0.02 | | | |
| 5 | | | | 0.1 | | | 0.30 |
| 6 | | 0.07 | 0.02 | 0.02 | | | |
| **Total FTEs** | | 0.30 | 0.25 | 0.35 | 0.20 | 0.30 | 0.30 |

**Total of 1.10 FTE (COSMO) + 0.6 External partners**

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