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Analysis and Evaluation of TERRA_URB Scheme:

PT AEVUS Final Report

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Contents

Abstract

The main aim of PT AEVUS was the implementation and testing of the TERRA_URB scheme into the COSMO model. The PT was led by the Italian Aerospace Research Center (CIRA, Italy) and involved researchers from four institutions: ARPA Piemonte (Italy), Russian Hydrometeorological Center (RHM, Russia), German Meteorological Service (DWD, Germany) and the University of Ghent (Belgium). Several case studies have been selected in Europe, according to the availability of data from the different research teams involved in the task. Selected periods have been simulated, in order to test the capabilities of the COSMO model with TERRA_URB (TU) in reproducing the main features of specific dynamics such as the Urban Heat Islands (UHIs). The key conclusion of the work is that the version of COSMO model including TU, 5.05urb5, in general successfully simulates the key features of the UHIs. The outcomes of the PT have also stimulated the research groups to continue the activities in a new priority task (PT AEVUS 2) started in September 2019. The description of the PT with the Gantt chart and the related FTEs can be found on the COSMO web site: http://www.cosmo-model.org/content/tasks/pastTasks/pt_aevus.priv.pdf

1 Introduction

The modelling of urban environment has increased significantly in the last years; in fact, different parametrizations for the land use type have been developed. In COSMO model, cities are represented by natural land surfaces with an increased surface roughness length and a reduced vegetation cover (modification of soil and vegetation parameters of the TERRA model). However, in this representation, urban areas are still treated as water-permeable soil with aerodynamic, radiative and thermal parameters similar to the surrounding natural land. Therefore, this basic representation could not reliably capture the urban physics and associated urban-climatic effects including urban heat islands. For this reason, further developments of the parametrization of the urban land have been carried out. In the last years, three urban parametrizations have been incorporated in COSMO for the standard land-surface module TERRA-ML: a DCEP - multilayer urban canopy model, TEB - single layer urban canopy model, and TERRA_URB - bulk parametrization scheme with a prescribed anthropogenic heat flux. Anthropogenic heat emissions are included as an additional heat source to the first aboveground model layer. The urban canopy scheme DCEP coupled with COSMO-CLM has been evaluated extensively against data over Basel (Schubert and Grossman-Clarke, 2014), while TEB has been evaluated over Berlin (Trusilova et al. 2013). However, later study for Moscow revealed a problem in coupling between urban module and the atmospheric module in COSMO version with TEB scheme, which does not allow to adequately simulate the heat transfer from the urban surface to the lower atmosphere (Varentsov et al. 2017). TERRA_URB offers an intrinsic representation of the urban physics with modifications of the input data, soil module and land atmospheric interactions (the details can be found in Wouters et al. (2016)). TERRA_URB (in the following TU) includes the effects of buildings on the air flow without resolving the energy budgets of the buildings themselves, but using the externally calculated anthropogenic heat flux. This approach allows representing effects of multiple cities on the atmosphere without requiring additional data on the building structure. TU is computationally fast and is recommended for studies with spatial and temporal scales where the interactions between the urban canyon air and the atmosphere do not need to be resolved in detail. The latest version of TU implements the Semi-empirical Urban canopy parametrization (SURY). It translates urban-canopy parameters (containing 3D information) into bulk parameters. TU takes additional surface parameter input fields:

ISA (Impervious Surface Area, see Flanner, 2009) and AHF (Annual-mean anthropogenic Heat Flux, see Maucha et al.,2010), generated with EXTPAR via the WebPEP interface. By default, TU takes fixed values for the urban canopy parameters: variation of urban-canopy parameters is optional and could be don inside the model code. The aim of this PT is an evaluation and a deep verification of the performances of the code using a series of selected case studies, in particular in order to verify the capabilities in reproducing the urban dynamics and specific phenomena, e.g. Urban Heat Islands (UHIs) (Milelli, 2016), in order to decide if (and how) to improve the calibration of the namelist parameters, or the parametrization itself. Since the goal of the urban scheme is to catch small-scale features, only very-high resolution runs have been considered. This document is organized as follows: Section 2 contains a list and description of the subtasks in which the PT is organized. Sections 3 to 7 contain a description of the activities performed by the several research teams involved in the PT (UniGhent, DWD, CIRA, RHM, ArpaP) and the main conclusions are described in Section 8. A technical description of the TU implementation in COSMO model is included as Appendix to this report.

2 Tasks and achievements

A concise summary of the tasks and achievements during the project is presented in this section.

<u>Task 0</u>: installation and debugging of the beta COSMO version including TERRA_URB

The primary task of PT was installation and debugging of the different version of COSMO on the supercomputing facilities of the research centres involved in this PT. In total, 6 versions of the model were installed and tested, namely COSMO5.04g_urb1, COSMO5.05_urb1, COSMO5.05_urb2, COSMO5.05_urb3, COSMO5.05_urb4, COSMO5.05_urb5. These versions were consequently developed and updated during the PT. Initial releases contained a number of bugs (COSMO5.04g_urb1, COSMO5.05_urb1), which were found and fixed by PT participants during the debugging activities (details could be found in Appendix A). The revealed bugs were related with the implementation of TU itself, implementation of the skin-layer temperature scheme, input and output issues. All the problems and bugs, which were revealed during the PT AEVUS, were completely fixed in the recent release, COSMO5.05_urb5, which could be considered as a stable model version for further development.

<u>Task 1</u>: selection of case studies

The selection of certain periods for the each of study areas was based on the experience of each participating institution. In general, considered cases include the days with pronounced urban heat islands and extreme temperature events (warm weather in summer or cold weather in winter). More specifically, two regions have been considered in Italy: the urban areas of Turin and Naples, for which observations in urban and rural context are available. Simulations have been performed over periods selected in recent summer and winter seasons. Moscow (about 35 km diameter of urban landscapes, the biggest European city) with 50-80 km surrounding rural region has been chosen as test domain for Russia. Urban areas of Belgium, selecting summer and winter periods (from 2012 onwards) have been considered, performing an extensive evaluation using "standard" scores, with urban climate observations (in terms of air temperature at 2 m and UHI for Antwerp and Ghent, and boundary-layer temperatures and UHI observed from 100m high mast towers), boundary-layer profiles and satellite imagery.

Task 2: simulation setup and runs

Appropriate simulation setups have been selected for all the considered test cases. In particular, the reference configuration (ctrl) has been built in order to perform a comparison, ctrl (with TU scheme off) and ctrl-TU (with TU scheme on).

Task 3: calibration of TERRA_URB scheme

The TU scheme has two mandatory input fields, namely the Impervious Surface Area (ISA) and the annual-mean Anthropogenic Heat Flux (AHF), varying throughout the domain. The TU scheme also uses the Semi-Empirical Urban Canopy parametrization (SURY) (Wouters et al, 2016) in order to calculate the additional bulk parameters needed. These additional parameters are currently set to default values and hard-coded. Default values could not be suitable for the area under study, depending on the urban canopy properties. For this reason, it would be necessary to investigate the model sensitivity to these parameters, but for time constrains this task has been postponed to the follow-up of the PT.

Task 4: evaluation and verification of the case studies

The verification is the key point of the work. It has been used a dense network of weather stations, to determine the performance of the model in its various flavours, both at the surface and in the atmosphere.

Task 5: writing of the final report

A significant amount of documentation has been produced, and, in particular, the goal to make public the work performed within the COSMO PT, not only to the COSMO members but also to the wider scientific community, has been achieved.

3 Activity performed at University of Ghent: perturbation experiments for Brussels during the 2003 heat wave (H. Wouters)

A range of experiments has been performed to test the sensitivity of climate modelling to urban parametrization for Brussels during the heat wave of 2003 (1st August 2003 until 15th August 2003). The simulations have been performed on a 80x80 grid cell domain (0.025 degree resolution) centred over Brussels, and they are nested in Era-Interim (0.75 degree resolution) driven simulations over the EURO-CORDEX domain (0.11 degree resolution). Six perturbation experiments have been performed with different variants and parameters: the first one is a simulation with the default COSMO model 5.05 without urban parametrization (COSMO5.05 (no urb)). The second one is the initial implementation of TU2.3 (COSMO 5.05_urb_ini), which represents the buildings in the domain, but excluding the anthropogenic heat flux due to human activity.

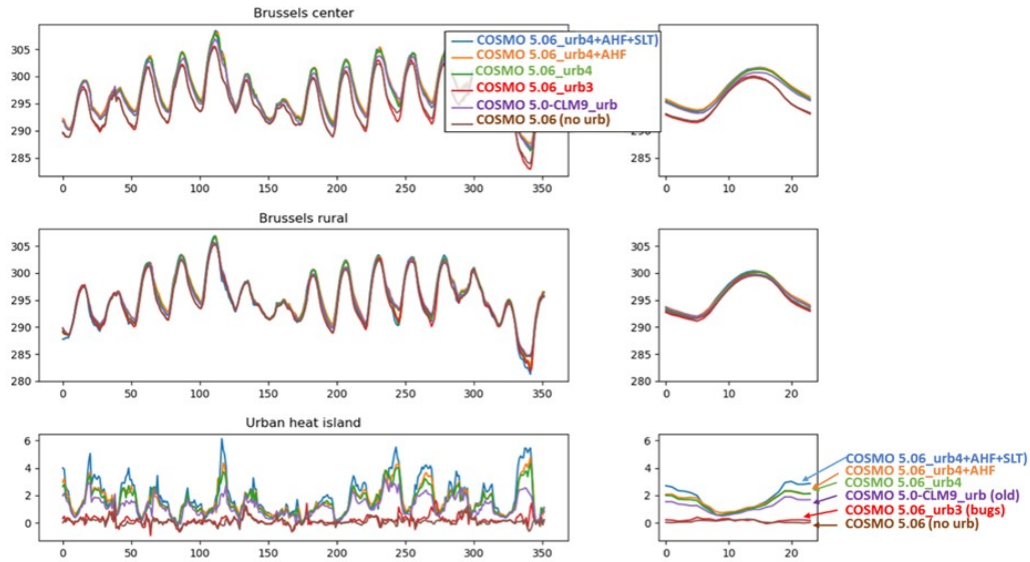


Figure 1: Model time series of T_2m for Brussels center, a rural location and the associated urban heat islands (urban-rural difference) during the heat wave of 2003 for the different perturbation experiments.

The third one refers to a simulation with the same version TU2.3, but implemented in a previous COSMO model (COSMO5.0_clm9_urb), which has been developed and used for climate applications. For description, evaluation and applications, see Wouters et al., 2015; Wouters et al., 2016; Wouters et al., 2017; Demuzere et al., 2017. A fourth simulation refers to a bug fix release of the implementation of TU2.3 into COSMO 5.05 (COSMO 5.05_urb4). The fifth simulation is analogous to the previous simulation, but including the anthropogenic heat flux. The last simulation is the same as the fifth simulation but activating the skin-layer resistance formulation that has been recently integrated into COSMO.

Time series and horizontal profiles of T_2m are shown in Figs. 1 and 2. They indicate that both the COSMO model version and the (urban) land-surface parametrization scheme substantially affect the urban heat wave model results, especially regarding the simulation of the UHI intensities. While the default COSMO model version did not show any UHI, the implementation of TU and additional bug fixes lead to a higher urban air temperature and hence a realistic simulation of the UHI intensity that is most pronounced during the evening and night time. While the formulation of the TU in the new COSMO model version (COSMO5.05_urb4) is similar to the implementation in the previous version (COSMO5.0_clm9_urb), urban heat island intensities now appear to be more pronounced. This suggests that not only the urban land-surface parametrization itself but also changes in the atmospheric model physics and the associated changes in the land-atmosphere feedbacks are determinant for urban climate modelling results. Moreover, the implementation of the skin-layer resistance formulation leading the higher decoupling of surface and air temperature and hence to lower temperature in the rural areas, also results in a more pronounced urban heat island intensity. Since the previous version was showing an overall underestimated UHI according to in situ measurements for Antwerp Belgium (Wouters et al., 2017), the higher UHI values suggest that the new implementation in COSMO5.05_urb4 may have a better model performance in representing urban climate than the previous one in COSMO5.0_clm9.

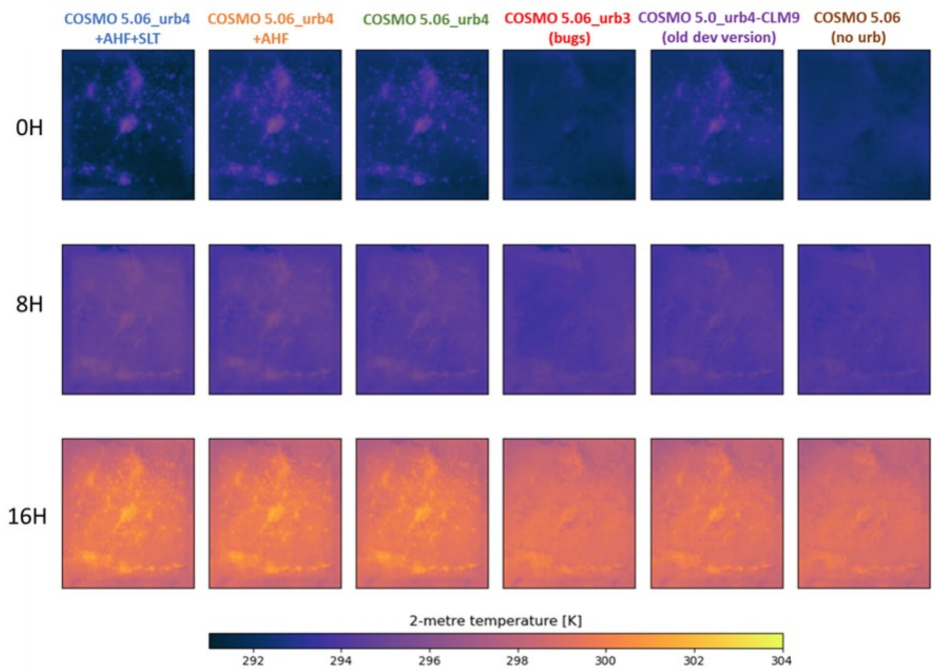


Figure 2: Horizontal profiles of modelled absolute 2-metre air temperature for Brussels at 0H 8H and 16H UTC averaged for the 2003 heat wave (1st August 2003 to 15th August 2003) for different perturbation experiments.

4 Activity performed at DWD: Improved processes in the land surface model TERRA: Bare soil evaporation and skin temperature (J.-P. Schulz, G. Vogel)

Land surface processes have a significant impact on near-surface atmospheric phenomena. They determine near surface sensible, latent heat fluxes, and the radiation budget, and thus influence atmosphere and land characteristics, such as temperature and humidity, the structure of the planetary boundary layer, and even cloud formation processes. All these processes are also very relevant for urban-atmospheric interactions. For example, the UHI is defined as a difference between urban and rural temperatures, so an adequate simulation of the UHI intensity, its dynamics and impacts on atmospheric processes in the model requires a realistic simulation of urban temperature and the rural temperate as well. The typical problem of COSMO model is an overestimation of nocturnal temperatures, which is also a problem for reproducing the observed UHI intensity (see Sec. 6 and Varentsov et al., 2017). It is therefore essential to simulate the land surface processes for rural areas in atmospheric models as realistically as possible.

Verifications have shown that the bare soil evaporation simulated by the land surface scheme TERRA of the COSMO model is systematically overestimated under wet conditions. Furthermore, it turned out that the amplitude of the diurnal cycle of the surface temperature is systematically underestimated. In contrast, the diurnal cycles of the temperatures in the soil are overestimated, instead. This means that the other components of the surface energy and water balances are biased as well, for instance, the surface turbulent heat fluxes as well as the soil water content. Data from the Meteorological Observatory Lindenberg of the German Meteorological Service (DWD) were used to analyse this model behaviour. The erroneous formulation of bare soil evaporation was replaced by a scheme based on a resistance formulation, which efficiently reduces the simulated vapour flux (Schulz and Vogel 2016). In the standard model configuration of TERRA, there is no representation of the vegetation in the surface energy balance. This means, there is no energy budget including a temperature for the vegetation layer. Furthermore, the insulating effects by the vegetation at the sub-canopy level are missing as well. A scheme providing both of these missing model characteristics was implemented in TERRA, the so-called skin temperature formulation (Viterbo and Beljaars 1995, Schulz and Vogel 2017). As a result, the simulated diurnal amplitude of the surface temperature is increased and the one of the soil temperature is reduced.

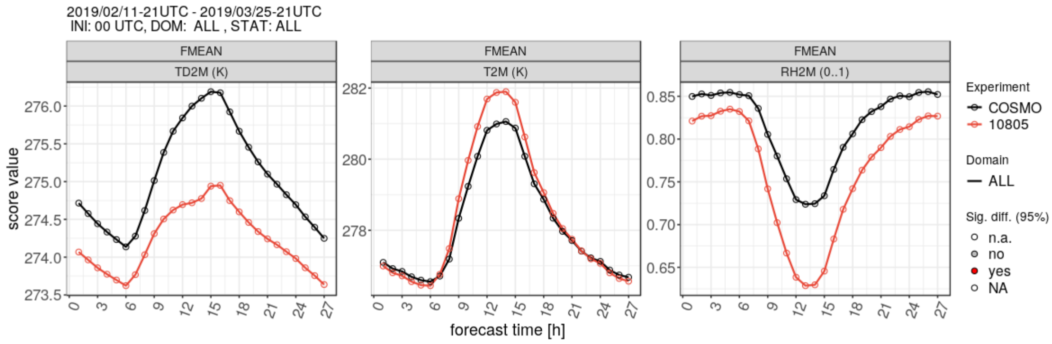


Figure 3: Diurnal cycles of the dew point temperature (TD2M), atmospheric temperature (T2M) and relative humidity (RH2M), all at 2-m above ground, averaged over the whole experimental period of 11 February to 25 March 2019. The COSMO operational reference version is depicted in black, the experiment in red.

A numerical experiment with the COSMO model was carried out that uses, beside the new formulations of bare soil evaporation and the skin temperature, a more realistic exponential root profile, a new interception reservoir for collecting dew on the leaves, and an improved formulation of the dependence of the soil thermal conductivity on soil moisture (Schulz et al. 2016). A comparison of this experiment with the operational COSMO model at DWD as reference is shown in Fig. 3. The experimental period is 11 February to 25 March 2019, i.e. six weeks. The figure shows the diurnal cycles of the dew point temperature, atmospheric temperature and relative humidity, all at 2-m above ground, averaged over the whole period. The experiment is substantially drier, as seen in the dew point temperature and relative humidity. This is mainly due to the new formulation of bare soil evaporation, which corrects for the systematically overestimated moisture fluxes of the reference model version. Furthermore, the simulated diurnal amplitude of the 2-m temperature is increased in the experiment. This is partly due to the decrease of the latent heat flux and its cooling effect, and partly due to the skin temperature formulation. The reference model version shows a substantial moist bias which is almost completely removed in the experiment (see Fig. 4). A pronounced cold bias during daytime in the reference model is considerably reduced in the experiment. The root mean square errors of the humidity and temperature fields are significantly reduced during the whole day.

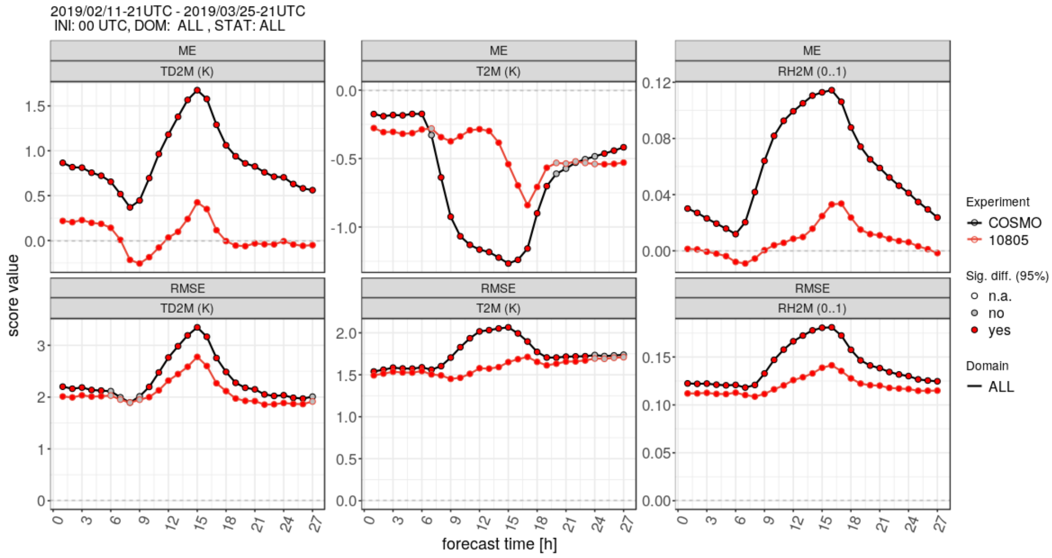


Figure 4: Same as Fig. 3, but for the mean error (ME) and the root mean square error (RMSE) of TD2M, T2M and RH2M.

5 Activity performed ad CIRA: High resolution simulations for the representation of Urban Heat Islands over South Italy (E. Bucchignani, P. Mercogliano)

Numerical simulations have been performed in order to test the capabilities of the COSMO-LM model with TU in reproducing the main climate features of urban areas, and in particular, of the UHIs in a selected area of southern Italy. Tests have been performed over a domain centred over Campania and Lazio region (Fig. 5), employing a spatial resolution of 0.009°(about 1 km), for two selected test cases: the first one (A) is 8-10 August 2017, since in these days the city of Naples experienced extreme temperature and uncomfortable conditions for the population. The second one (B) is 6-8 June 2019, since in these days a sudden increase of the daily maximum temperature was recorded, from about 27 °C to about 33 °C. Therefore, these periods represent a suitable benchmark to test the urban parametrization of COSMO-LM.

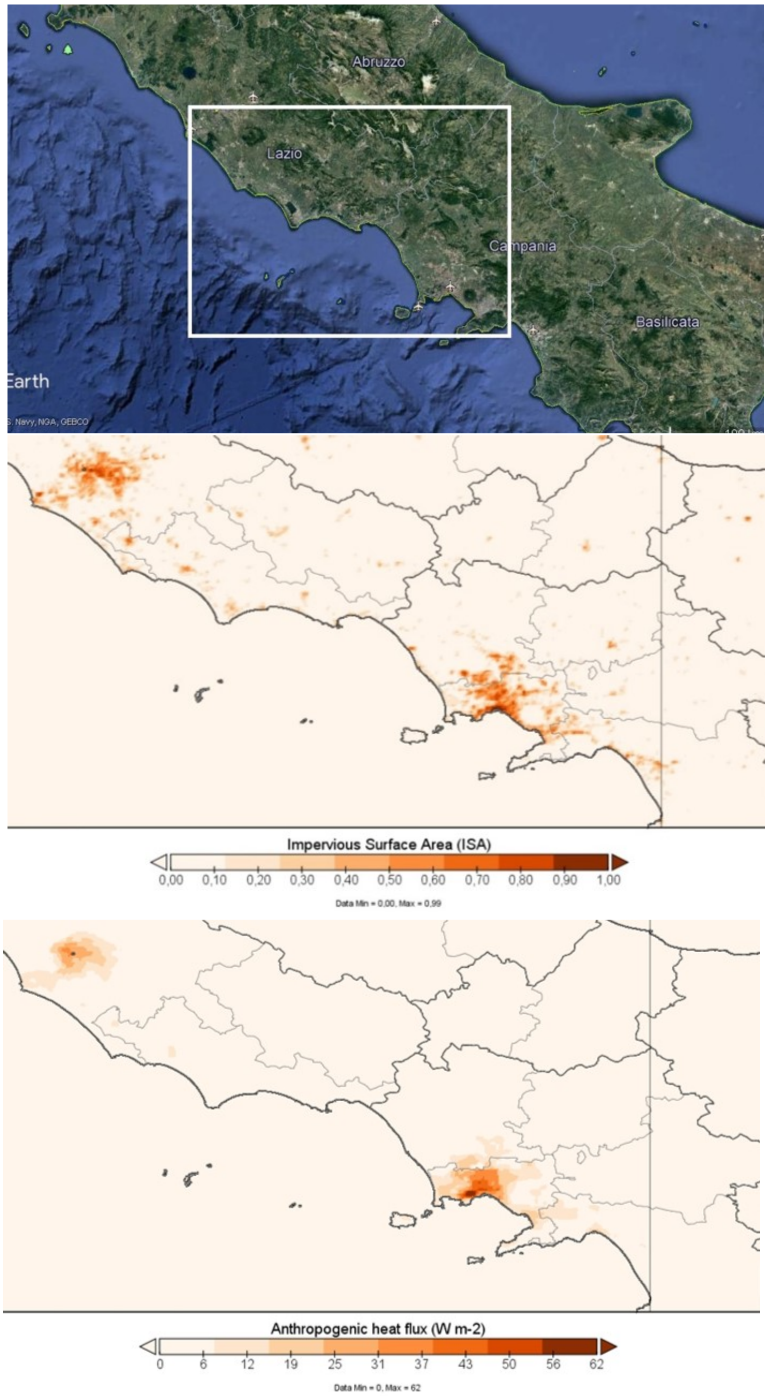


Figure 5: top: the computational domain; middle: impervious surface area; bottom: anthropogenic heat flux distributions.

Two different schemes of canopy parametrizations with respect to the surface energy balance have been considered: the "surface energy balance equation" solved at the ground surface (canopy energetically not represented, itype_canopy = 1) and the skin temperature formulation (itype_canopy = 2). In the second case, the value of implicitness of the vegetation-skin temperature parametrization (cimpl) must be specified. Previous sensitivity tests showed that this second option 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. For each day considered, the following simulations have been performed:

- **NOURB**: Setting OFF the TU scheme
- **URB**: Setting ON the TU scheme and itype_canopy =1
- **URB_itc2**: Setting ON the TU scheme and itype_canopy =2, cimpl =120
- **URB_itc22**: Setting ON the TU scheme and itype_canopy =2, cimpl = 600

Model evaluation has been performed in terms of 2m temperature (T_2m) and 2m relative humidity (Rel_hum) against the following observational data:

- hourly time series of T_2m and Rel_hum provided by the University of Naples, meteorological station located in Fuorigrotta quarter (urban area 14.19°E, 40.82°N).
- daily time series of T_2m and Rel_hum provided by SCIA ISPRA for the rural station of Grazzanise.

In the figures of the next section, observational values are identified as OBS.

5.1 Test case A: 8 - 10 August 2017

Fig. 6 shows the time series of T_2m over the period 8-10 Aug 2017 at the urban area of Naples (top) and the rural area of Grazzanise (bottom). For Grazzanise, only max and min daily observational values are available. The middle panel shows the spatial T_2m distribution for Aug 10th 2017 at 13.00 in a series of points close to Naples location (Naples is located in point 8). AHF is the Anthropogenic Heat Flux Distribution. In Naples, for this test case, it is evident (see also values shown in Tabs. 1-2-3) that URB simulation improves the representation of the mean daily T_2m values with respect to NOURB (improvements larger than 1 °C). Moreover, URB significantly increases the daily minimum values and this has a positive effect in the reduction of the bias. Benefits are achieved also for the daily maximum temperature, anyway a general underestimation with respect to observational data is still evident. The usage of "skin temperature scheme" does not provide any change, as it should not make a significant effect on the temperature in urban areas, because when TU is switched on, it uses a very high skin-layer conductivity for urban areas. Tab. 4 shows the spatial correlation values between simulated (all the simulations) and observed time series of T_2m, revealing that URB values are better correlated to observation than NOURB values. In Grazzanise as expected, URB simulation does not provide changes on the maximum temperature (Tab. 5), but an increase on the minimum one (Tab. 6). This has positive effects on reducing the bias in some days, but in other cases has a negative effect. The usage of itype_canopy=2, as expected in points where AHF is zero or very low, decreases the nocturnal temperatures in rural areas and increase the UHI intensity (urban-rural temperature difference). Setting cimpl = 600 does not provide relevant improvements. Fig. 7 shows the time series of relative humidity (Rel_hum) over the period 8-10 Aug 2017 at (a) the urban area of Naples and (c) the rural area of Grazzanise. For Grazzanise, only daily average observational values are available. Panel (b) shows the spatial Rel_hum distribution for Aug 10th 2017 at 13.00 in a series of points close to Naples location.

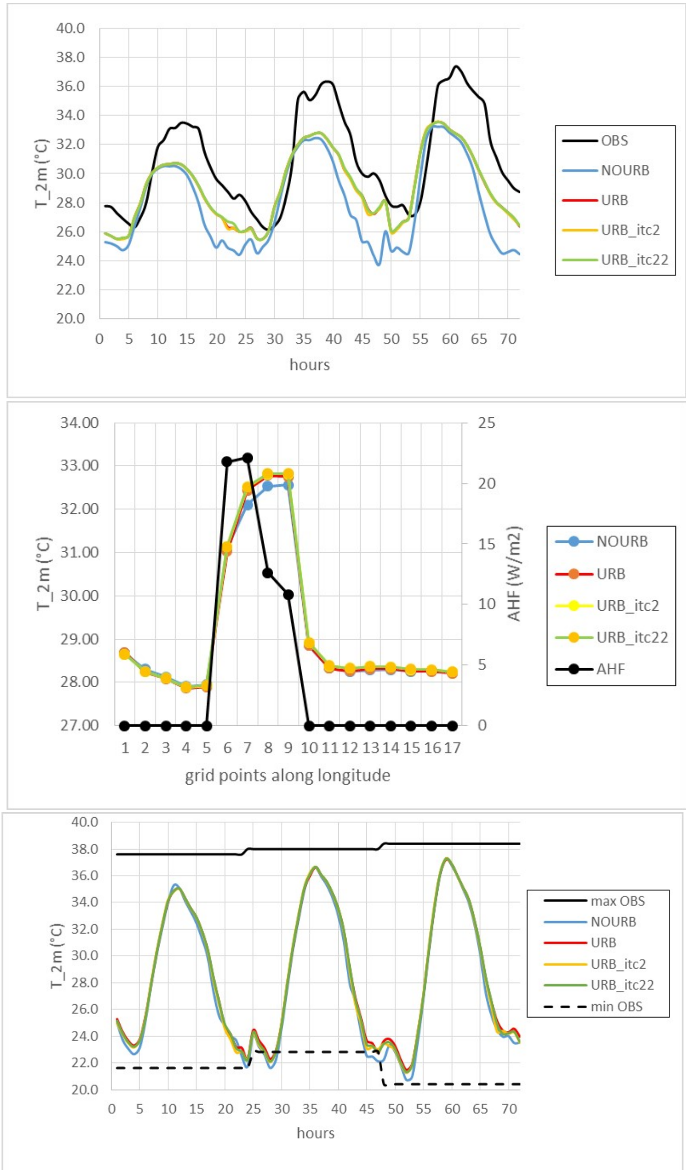


Figure 6: Time series of T_2m over the period 8-10 Aug 2017 at the urban area of Naples (top) and the rural area of Grazzanise (bottom); middle panel: spatial T_2m distribution for Aug 10th 2017 at 13.00 in a series of points close to Naples location (Naples is located in point 8). AHF is the Anthropogenic Heat Flux Distribution.

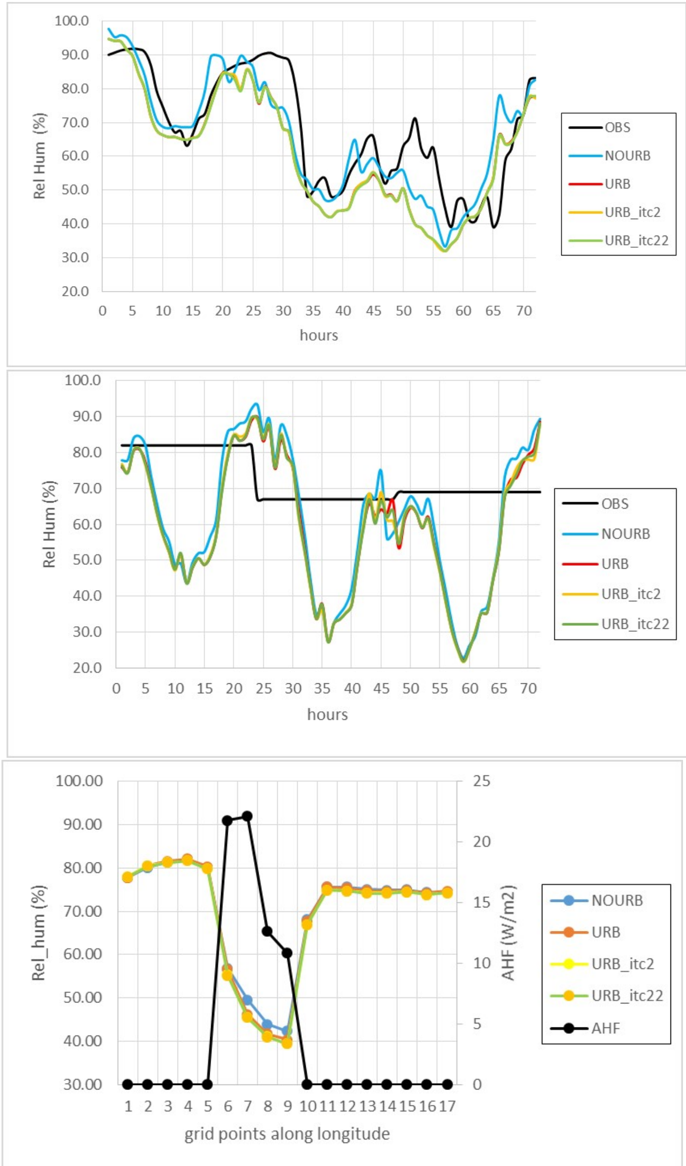


Figure 7: Time series of Rel_hum over the period 8-10 Aug 2017 at the urban area of Naples (top) and the rural area of Grazzanise (bottom). For Grazzanise, only daily average observational values are available; middle panel: spatial Rel_hum distribution for Aug 10th 2017 at 13.00 in a series of points close to Naples location

In Naples, URB simulation provides lower values of relative humidity with respect to NOURB (Tab. 7), leading to a general worsening of performances, with few exceptions. A slight improvement is recorded assuming itype_canopy =2: in fact Tab. 8 shows that in this case simulated values are better correlated to observations. A similar behaviour is recorded also in Grazzanise (Tab. 9), since in this rural area the usage of itype_canopy=2 provides slight better values with respect to itype_canopy = 1. In general, the configuration with itype_canopy=2 does not show consistent improvements with respect to other test cases where it has been tested. This is probably due to the short distance from the sea of the city of Naples. Further investigations need to be done to confirm this hypothesis.

	OBS	NOURB	URB	URB_itc2	URB_itc22
08 Aug 2017	33.5	30.5	30.7	30.7	30.7
09 Aug 2017	36.3	32.4	32.8	32.8	32.8
10 Aug 2017	37.4	33.2	33.6	33.6	33.6

Table 1: Daily maximum values of T_2m in Naples (urban) for the three days considered.

	OBS	NOURB	URB	URB_itc2	URB_itc22
08 Aug 2017	26.3	24.4	25.5	25.5	25.5
09 Aug 2017	26.1	23.7	25.5	25.5	25.5
10 Aug 2017	27.2	24.4	26.0	26.0	26.0

Table 2: Daily minimum values of T_2m in Naples (urban) for the three days considered.

	OBS	NOURB	URB	URB_itc2	URB_itc22
08 Aug 2017	29.9	27.2	28.0	28.0	28.1
09 Aug 2017	31.2	28.2	29.4	29.3	29.4
10 Aug 2017	31.8	28.2	29.8	29.7	29.8

Table 3: Daily mean values of T_2m in Naples (urban) for the three days considered.

	NOURB	URB	URB_itc2	URB_itc22
08 Aug 2017	0.74	0.84	0.84	0.85
09 Aug 2017	0.82	0.90	0.90	0.91
10 Aug 2017	0.76	0.76	0.76	0.77

Table 4: Spatial correlation between simulated and observed time series of T_2m in Naples (urban).

	OBS	NOURB	URB	URB_itc2	URB_itc22
08 Aug 2017	37.6	35.3	35.1	35.0	35.0
09 Aug 2017	38.0	36.6	36.6	36.7	36.6
10 Aug 2017	38.4	37.3	37.2	37.3	37.2

Table 5: Daily maximum values of T_2m in Grazzanise (rural) for the three days considered.

	OBS	NOURB	URB	URB_itc2	URB_itc22
08 Aug 2017	21.6	21.7	22.3	22.2	22.2
09 Aug 2017	22.8	21.6	22.2	22.0	22.1
10 Aug 2017	20.4	20.7	21.5	21.2	21.3

Table 6: Daily minimum values of T_2m in Grazzanise (rural) for the three days considered.

	OBS	NOURB	URB	URB_itc2	URB_itc22
08 Aug 2017	81.3	82.2	77.9	78.0	77.8
09 Aug 2017	66.5	61.0	56.4	56.4	56.4
10 Aug 2017	56.5	55.2	49.5	49.4	49.4

Table 7: Daily mean values of Rel_Hum in Naples (urban) for the three days considered.

	NOURB	URB	URB_itc2	URB_itc22
08 Aug 2017	0.89	0.85	0.89	0.89
09 Aug 2017	0.94	0.91	0.94	0.94
10 Aug 2017	0.34	0.33	0.33	0.34

Table 8: Spatial correlation between simulated and observed time series of Rel_Hum in Naples (urban).

	OBS	NOURB	URB	URB_itc2	URB_itc22
08 Aug 2017	82.0	70.2	67.0	67.2	67.0
09 Aug 2017	67.0	59.3	56.9	57.0	56.8
10 Aug 2017	69.0	56.5	53.8	53.8	53.7

Table 9: Daily mean values of Rel_Hum in Grazzanise (rural) for the three days considered.

5.2 Test case B: 6 - 8 June 2019

For this test case, only urban simulations assuming itype_canopy = 1 have been performed. Fig. 8 shows the time series of T_2m over the period 8-10 Aug 2017 at the urban area of Naples (top) and the rural area of Grazzanise (bottom). For Grazzanise, only max and min daily observational values are available. In the urban area of Naples, the maximum daily values increase of 0.6 °C (on 6th), 0.8 °C (on 7th) and 0.6 °C (on 8th), but anyway a general underestimation with respect to observational data is still evident. Improvements is confirmed by the higher values of correlation for URB simulation with observations (Tab. 10). In Grazzanise, URB simulation generally does not provide changes on the temperature values, apart from a few nocturnal values that are increased. The diurnal cycle amplitude is always underestimated with respect to observations. Fig. 9 shows the time series of Rel_hum over the period 8-10 Aug 2017 at (a) the urban area of Naples and (c) the rural area of Grazzanise. For Grazzanise, only daily average observational values are available. In Naples, URB simulation provides lower values of humidity, which are better correlated to observation than NOURB (Tab. 11). Also in the rural area of Grazzanise, URB provides a general increase of performances.

	NOURB	URB
06 Jun 2019	0.69	0.76
07 Jun 2019	0.72	0.83
08 Jun 2019	0.43	0.49

Table 10: Spatial correlation between simulated and observed time series of T_2m in Naples (urban).

	NOURB	URB
06 Jun 2019	0.38	0.58
07 Jun 2019	0.59	0.92
08 Jun 2019	0.28	0.55

Table 11: Spatial correlation between simulated and observed time series of Rel_hum in Naples (urban).

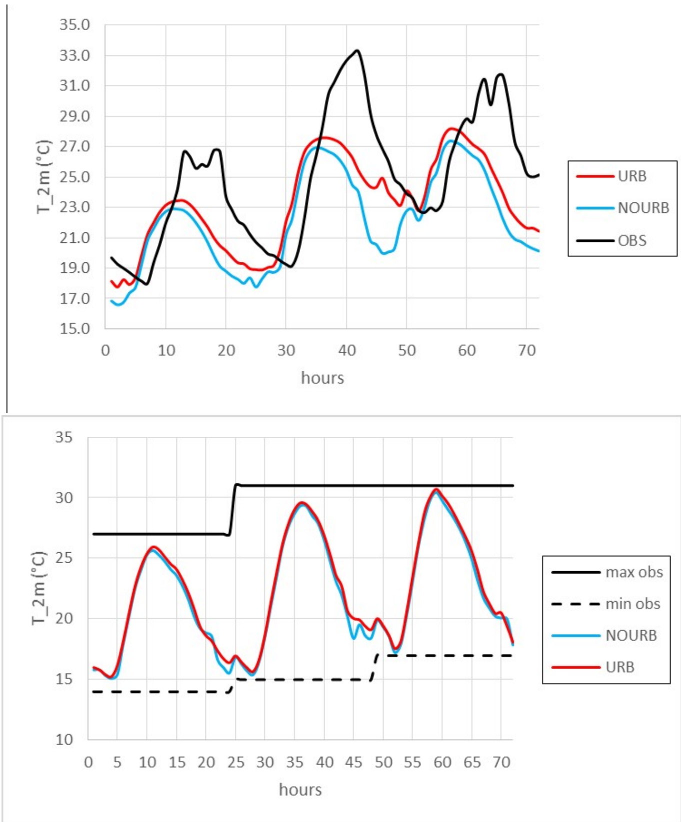
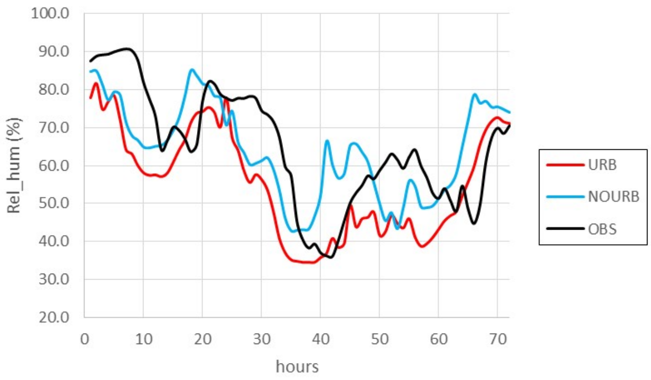


Figure 8: Time series of T_2m over the period 6-8 Jun 2019 at the urban area of Naples (top) and the rural area of Grazzanise (bottom).



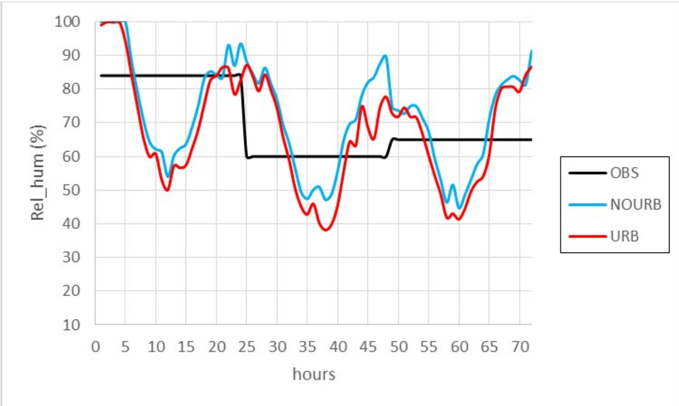


Figure 9: Time series of Rel_hum over the period 6-8 Jun 2019 at the urban area of Naples (top) and the rural area of Grazzanise (bottom).

6 Activities performed at RHM: high resolution simulations of the urban heat island of Moscow megacity (M. Varentsov, I. Rozinkina, G. Rivin, D. Blinov, A. Kirsanov)

The simulations for the selected cases were performed using the same modelling framework that was used in the previous modelling studies for Moscow (Varentsov et al., 2018; 2019). A chain of nested domains (D3-D1) was used, for a dynamic downscaling of the ERA-Interim reanalysis data for Moscow region for the periods of selected case-studies (about 15 days). The horizontal grid spacing for the domains D3, D2 and D1 was 12, 3 and 1 km respectively (Fig. 10). The TERRA_URB scheme was used only for the final D3 domain with 1-km grid step (180x180 grid cells). In contrast to tests for other cities, where default external parameters AHF and ISA from EXTPAR were used, for Moscow region these external fields were clarified based on OpenStreetMap data (Samsonov et al., 2015; Varentsov et al., 2017; Varentsov et al., 2017).

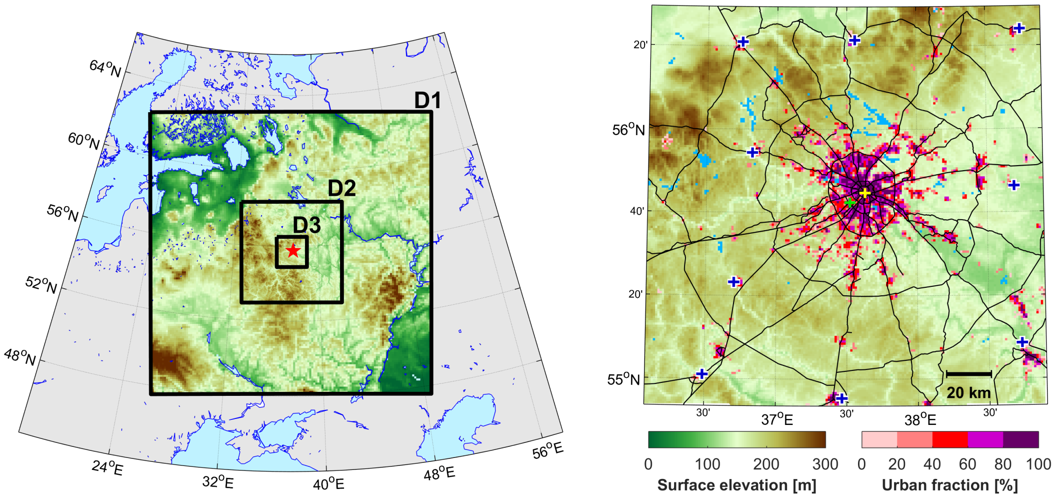


Figure 10: The configuration of the nested domains, used for simulations with the COSMO model, with surface elevation shown by the color scale, and water surfaces shown by the light-blue color (left). A detailed map of the finest D3 domain, used for the urban climate simulations with the COSMO-CLM model coupled to TERRA_URB, with urban fraction shown by an additional color scale (right). The location of the weather stations used for the estimation of the urban heat island (UHI) intensity is also shown (right). The yellow cross indicates Balchug station (considered as the city center), the green cross indicates MSU (Moscow State University) station, and blue crosses indicate the nine rural reference stations around Moscow. The black lines represent the primary road network (right).

For each considered case, three different simulations were performed. The older model version COSMO5.0_clm9_urb was used in the simulations called v5_REF and v5_MOD. In v5_REF simulations, the default values were used for the most of namelist settings; in the v5_MOD simulations, it was used the namelist settings that were carefully tuned in the previous modelling studies for Moscow in order to minimize the systematic model errors, including the well-known nocturnal warm bias. The most important differences between the tuned and default setup include the changes of the minimum coefficients of turbulent diffusion (tkhmin and tkmmin) and the scale of the subgrid thermal inhomogeneity (pat_len) according to (Cerenzia et al., 2014), the use of a new parametrization of bare soil evaporation (Schulz & Vogel, 2016) and a new skin-layer temperature scheme (Schulz & Vogel, 2017). The last set of simulations, v505_REF, was performed with a use of the new model version 5.05urb4. In general, the default namelist settings were used for v505_REF simulations, however, these settings are different from the default settings of the model version 5.0. It is important to highlight that all of new turbulence developments were switched on in simulations with 5.05 model version (loldtur = FALSE). The skin-layer temperature scheme was not used in the simulations with new model version. The key differences among namelist settings for v5_REF, v5_MOD and v505_REF simulations are given in Table 12.

The model verification was performed using the observational data from a dense network of the weather stations and air pollution control stations (more than 70 points in total within the D3 domain), as well as the data from the network of microwave temperature profilers MTP-5. MTP-5 profilers are remote sensing devises which provide temperature profile in the lowest 600 or 1000 m (depends on modification) with 50 m vertical resolution every 5 minutes. The MTP-5 data were provided by Lomonosov Moscow State University, A.M. Obukhov Institute of Atmospheric Physics of Russian Academy of Science (IAP RAS),

Parameter	v5_REF	v5_MOD	v5.05_REF
PHYCTL namelist			
itype_rootdp	1	2	2
itype_evsl	1	4	4
itype_heatcond	1	2	3
itype_canopy	1	2	1
calamrur (skin-layer conductivity)	-	30	-
loldtur	-	-	TRUE
TUNING namelist			
tkmmin & tkhmin	0.4	0.1 or 0.05	0.75
pat_len	500	100 or 50	100
DYNCTL namelist			
hd_corr_(t, u, p)	defaults	0.25 for all	defaults

Table 12: The key differences between namelist settings for v5_REF, v5_MOD and v5.05_REF simulations. Note that in v5_REF and v5_MOD the old turbulence was used as default.

Central Aerological Observatory (CAO) and Mosecomonitoring agency. The location of the observational sites in Moscow city and its closest surroundings is shown in Fig. 11.

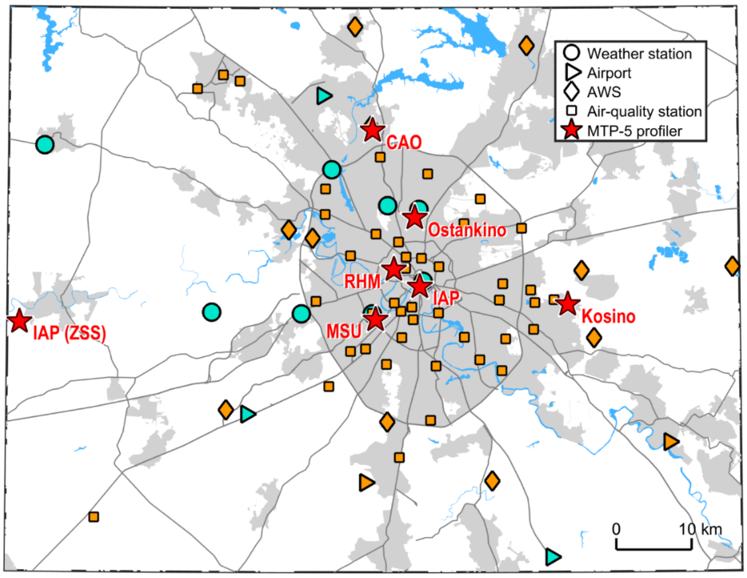


Figure 11: The location of the observational sites, used for the model verification for Moscow region. The orange colour indicates the relatively new observational sites; the cyan colour indicates the sites with long-term observational series.

The verification was focused mainly on the rural temperature and the UHI intensity (a difference between air temperature at the given urban site and mean rural temperature, averaged over 9 stations around Moscow, see Fig. 11). The UHI intensity was defined as a temperature anomaly with respect to the mean rural temperature, which was averaged over the 9 rural stations around Moscow. The greatest attention was paid to the UHI intensity in the city centre, where the Balchug weather station is located. Two case studies were considered for Moscow. The first case is from 17.05.2014 to 29.05.2014. It was a period in late spring (May) with warm, calm and clear weather which included several days with intensive UHI. The second case study is from 01.01.2017 to 15.01.2017. It was a winter period which included a sub-period of the extremely cold weather from 6 to 10 of January, when temperature dropped below -35°Cin the countryside, and the intensive UHI was observed during more than one day under the conditions of strongly stable stratification of the atmosphere (Yushkov et al., 2019). The unique feature of winter period is that MTP-5 data were also available for city centre, for the IAP RAS site.

6.1 Test case A: 17 - 29 May 2014

For the first considered case in May 2014, the comparison between the modelling results and observations has clearly shown the significant difference between REF and MOD simulations with an older model version COSMO5.0_clm9_urb. The REF simulations strongly overestimate the nocturnal temperature at rural areas and underestimate the UHI intensity, while in the MOD simulations the nocturnal temperature and UHI intensity are much closer to the observations (Fig. 12).

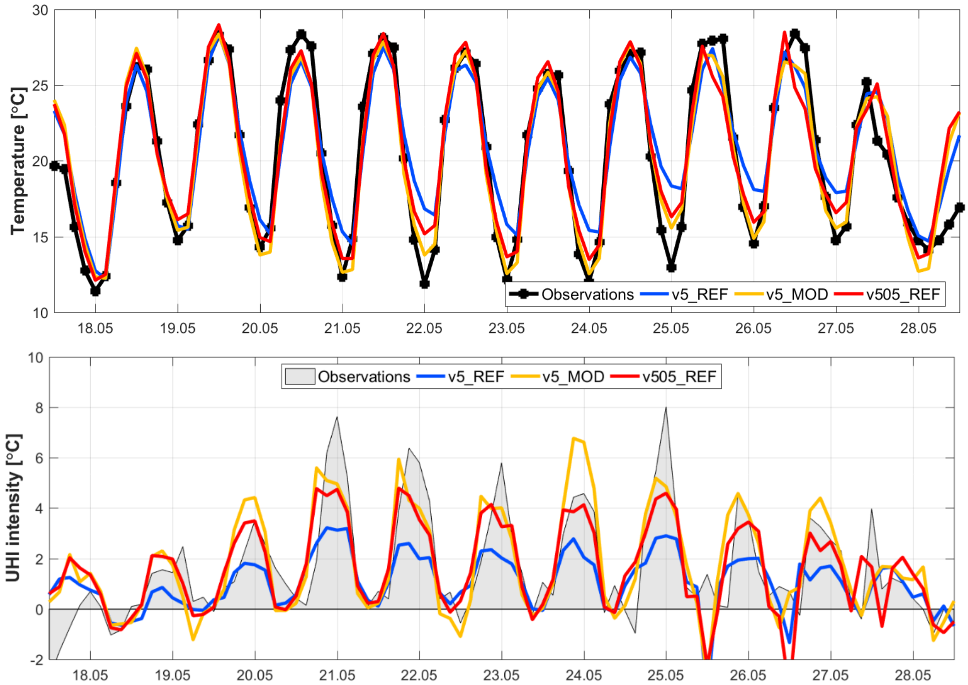


Figure 12: The variations of the mean rural air temperate and the UHI intensity for the city centre (temperature difference between the value for Balchug weather stations and the mean rural value) according to observations and modelling results for case (18-28 May 2014).

The new model version (v505_REF) simulates the rural temperate and UHI intensity almost as well as the old version with tuned settings (v5_MOD). A comparison between the simulated vertical temperature profiles and observations of MTP-5 profiler at a rural site (Zvenigorod, 50 km to the west from Moscow) and a suburb site (CAO, northern suburb of Moscow) has clearly shown that the differences between the different simulations in field of the near-surface temperature are densely linked with the differences in vertical temperature profiles. The v5_REF simulations strongly underestimate the strength of the nocturnal temperature ingestion, while v5_MOD and v505_DEF simulations reproduce it much closer to observations (Fig. 13). In general, v505_DEF simulations still slightly overestimate the minimal nocturnal temperatures and slightly underestimate the maximum UHI intensity as well as the strength of nocturnal temperature invasion. However, the Skin Layer Temperature Scheme was not used in v505_DEF simulations, so we could expect that the use of Skin Layer Temperature Scheme in new model version will eliminate these biases. Figs. 14 and 15 show that v505_DEF simulation generally nicely captures the spatial structure of the nocturnal UHI of Moscow, as well as v5_MOD simulation.

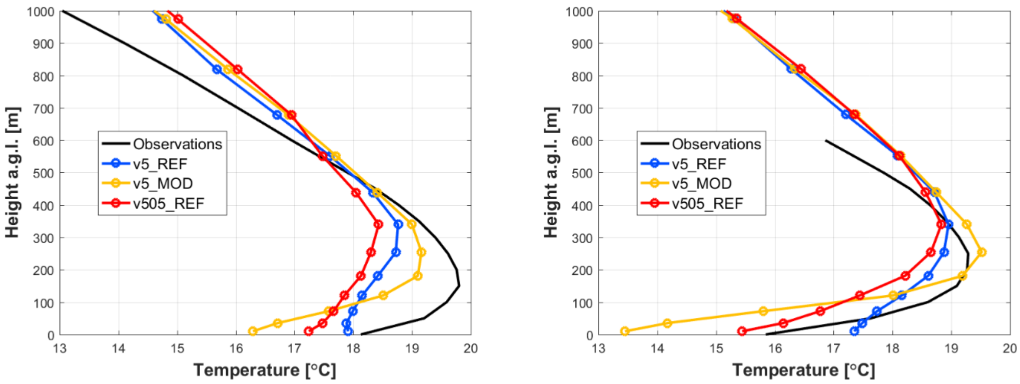


Figure 13: The observed and simulated nocturnal (00UTC) vertical temperature profiles, averaged over the period of 20-27 May 2014 for CAO suburb site (left) and Zvenigorod rural site(right).

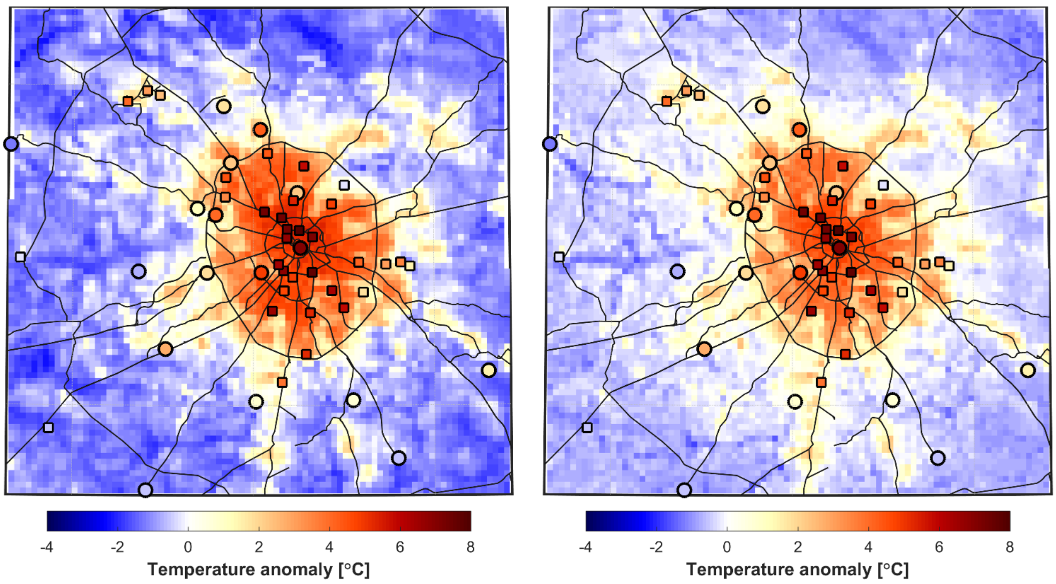


Figure 14: The spatial structure of the average nocturnal (00UTC) urban temperature anomaly in Moscow region according to observations (coloured squares and circles) and simulations v5_MOD (left) and v505_REF (right), shown as coloured background. The averaging is performed over 20-27 May 2014. The temperature anomaly is defined as a deviation from the mean rural value, averaged over 9 rural reference weather stations.

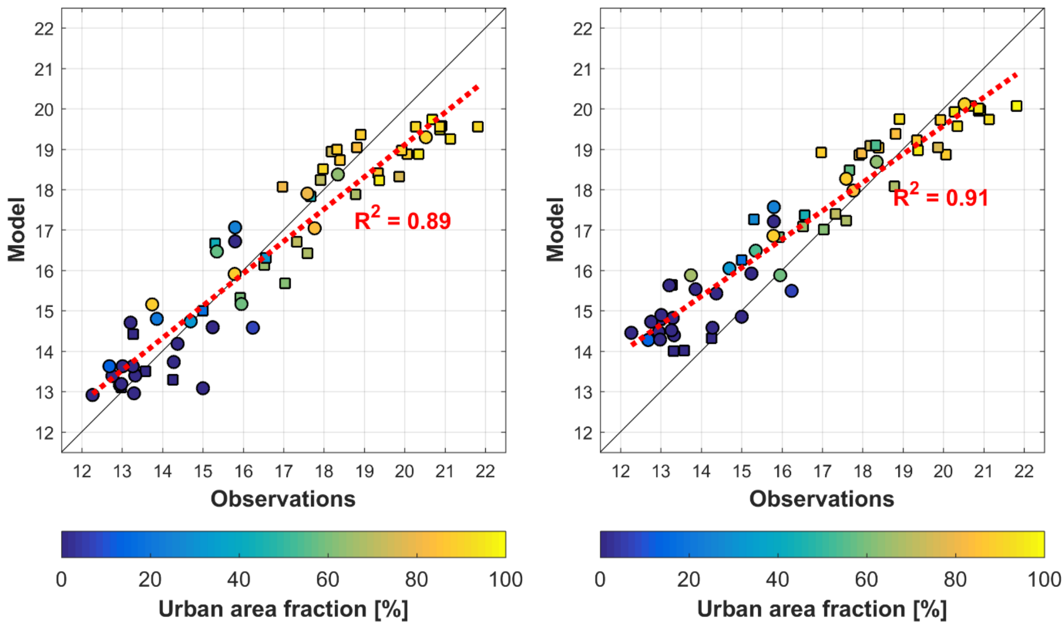


Figure 15: The dependence between the observed and modelled values of the mean nocturnal (00UTC) temperature for v5_MOD (left) and v505_REF (right) simulations. The averaging is performed over 20-27 May 2014. Each point corresponds to a different weather station (circles) or air-quality control stations (squares), the colour of the point represents the urban area fraction for corresponding model grid cell.

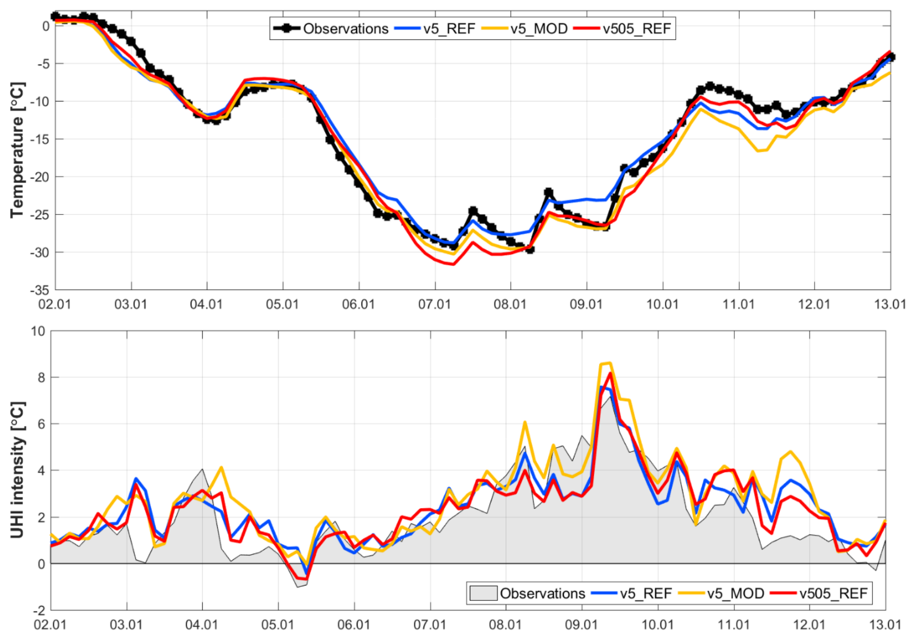


Figure 16: The variations of the mean rural air temperate and the UHI intensity for the city centre (temperature difference between the value for Balchug weather stations and the mean rural value) according to observations and modelling results for case (2-13 January 2017).

6.2 Test case B: 1 - 15 January 2017

For the winter case, all of the considered model runs generally nicely simulate the temporal dynamics of the mean rural air temperature and the UHI intensity for the city centre during this case (Fig. 16). The simulation with the newest model version, 5.05urb, has a cold bias for the peak of cooling at 7th of January, but shows the best correlation with observations, especially after the peak of cooling. Despite a very simple approach used for the AHF definition in TU, the simulations capture the dynamics of the UHI intensity quite nicely. The considered case allows verifying the model ability to simulate the spatial structure of the UHI in different conditions. At 8th of January the UHI was shifted to the southwest by prevailing north-eastern wind, and at the 9th January the UHI was collocated with the urban areas under calm weather conditions. The model generally successfully captures these features; however, the v505_REF simulation shows a lower agreement with observations than v5_MOD simulation (Fig. 17). The data from the network of MTP-5 profiles give a unique possibility to evaluate the vertical temperature profiles in the rural and urban sites during the period of frosty weather. All of the model runs successfully simulate the intensive temperature inversion in the lower atmosphere, which was observed during the last day of the frosty period and promoted the development of the UHI (Fig. 18). The model run with old model version without tuning, v5_REF underestimates the strength of inversion and overestimates the near-surface temperatures. The tuned model run with the old version (v5_MOD) captures the observed vertical temperature profile the best. The model run with the new version (v505_REF) also captures the near-surface temperatures and the inversion strength, but overestimates the height of inversion. All of the model runs successfully simulate the difference between rural and urban temperature profiles, including the UHI in the lowest 100 m above the ground, and a negative temperature anomaly over the city. Such anomaly corresponds to a so-called crossover-effect, which is known from the literature but is still poorly investigated (Khaikine et al., 2006; Lokoshchenko et al., 2016).

The key conclusion from the presented verification results is that the new version of COSMO model including TU, 5.05urb4, in general successfully simulates the key features of the UHI of Moscow megacity for the considered cases, including the spatio-temporal variations of the UHI intensity. The results obtained with the new version (v505_REF runs) are generally consistent with the results obtained with the old version COSMO5.0_clm9_urb (v5_REF and v5_MOD runs). Moreover, even without any special tuning, the simulations with the new model version (v505_REF runs) show almost as good verification results as the carefully tuned simulations with the old model version (v5_MOD runs). Such result indicates the improvements that come from a use of the new ICON-based model physics in the new model version. However, in some cases the new model version is still not perfect, which is shown based on the example of the extreme winter frosts in Moscow. Further improvements are expected from the tuning and calibration of the new model version, including the tuning for the namelist settings, the use of the skin-layer temperature scheme and the improvements of the external parameters for the TERRA_URB scheme.

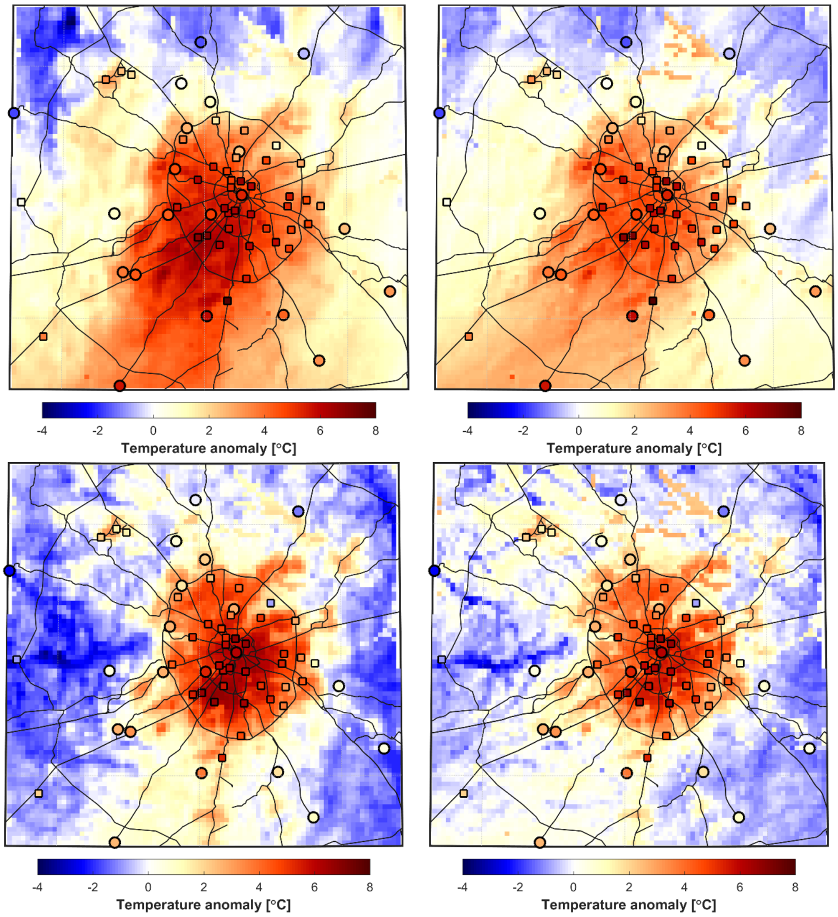


Figure 17: The spatial structure of the urban temperature anomaly in Moscow region according to observations (coloured squares and circles) and simulations v5_MOD (top left,bottom left) and v505_REF (top right, bottom right), shown as coloured background. The averaging is performed over the whole day of 8th of January 2017 (top panels) and 9th of January 2017 (bottom panels). The temperature anomaly is defined as a deviation from the mean rural value, averaged over 9 rural reference weather stations.

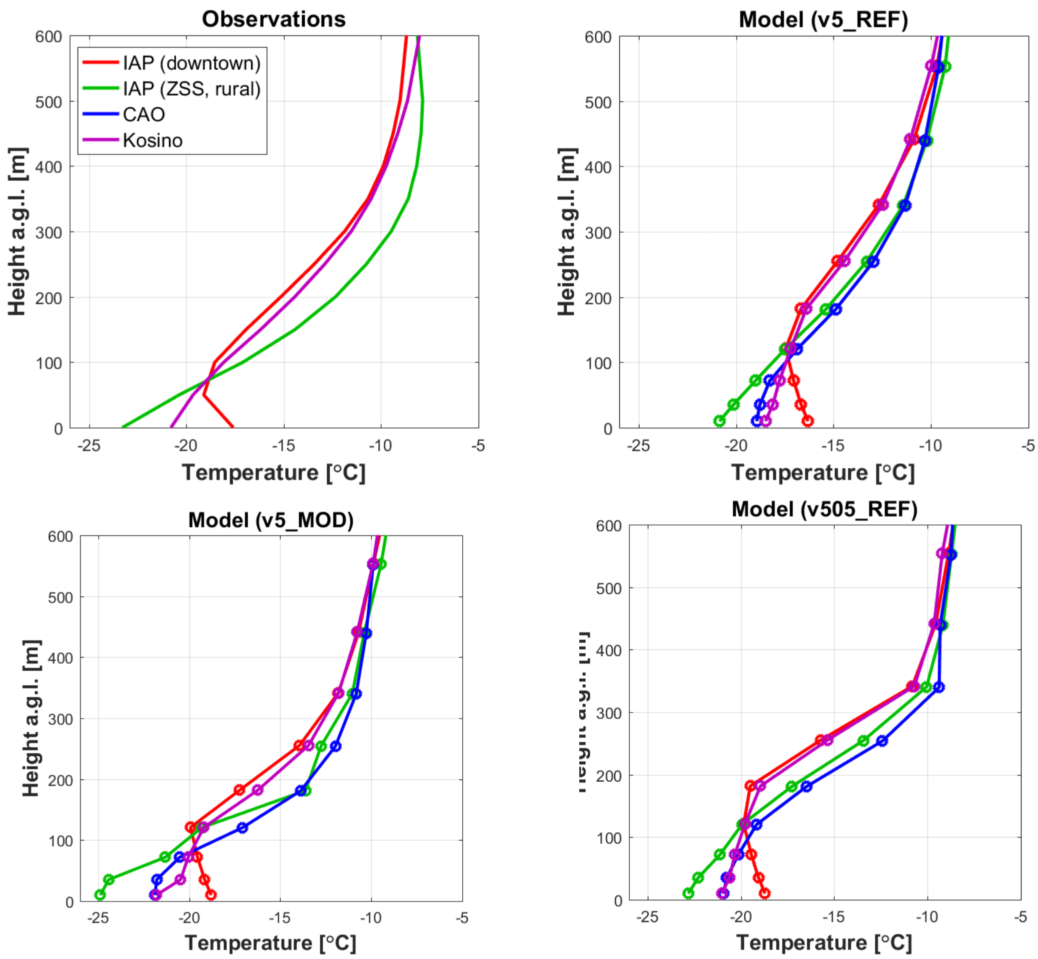


Figure 18: The vertical temperature profiles, averaged of 9th of January 2017, for four sites of Moscow region according to observations (top left) and different model runs (top right and bottom panels). The sites are: city centre (IAP site), rural area near Zvenigorod in 50 km to the west from Moscow (IAP ZSS site), Kosino site in the eastern suburb and CAO site in the northern suburb. The observations for CAO site are not available for the considered period.

7 Activities performed at Arpa Piemonte (V. Garbero, M. Milelli)

This study uses COSMO runs over a domain that includes the Piemonte region (Fig. 19) with a 1 km grid step (480x320 grid cells), driven by initial and boundary conditions provided by the ECMWF Operational Analysis at 9 km horizontal resolution every 6 hours. Simulations were conducted by activating or not the urban scheme TERRA_URB and by using different schemes to calculate the surface temperature, the canopy scheme or the skin conductivity scheme respectively. The urban scheme needs new external parameters (Fig. 21), ISA (impervious surface area) and AHF (anthropogenic heat flux), while the conductivity scheme requires the skin conductivity field (SKC, Fig. 22): all these parameters have been provided by EXTPAR.

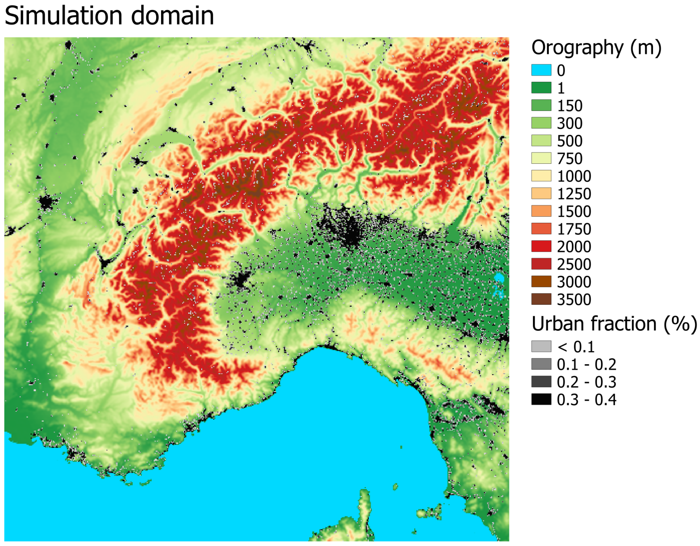


Figure 19: Domain of the simulations.

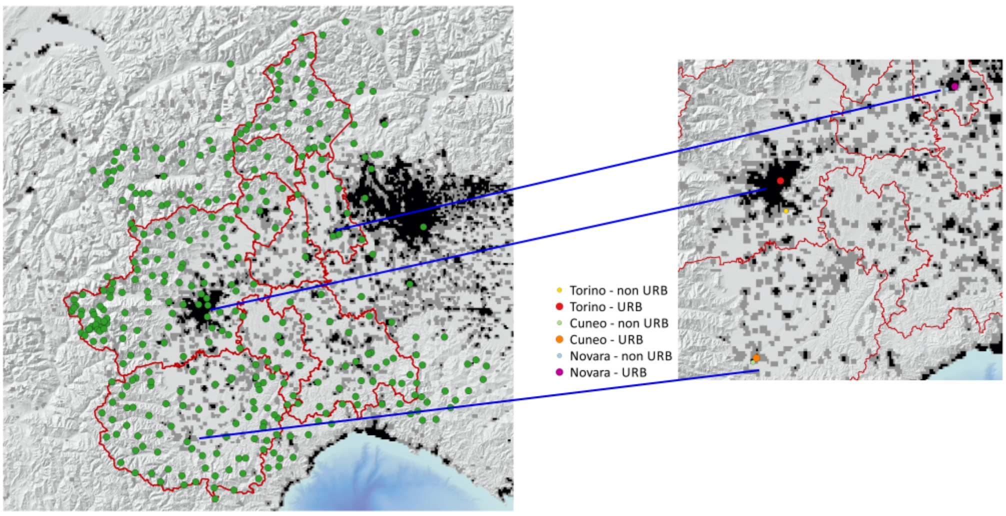


Figure 20: Ground network (left) with the rural/urban stations of the main cities, Torino, Cuneo and Novara (detail on the right).

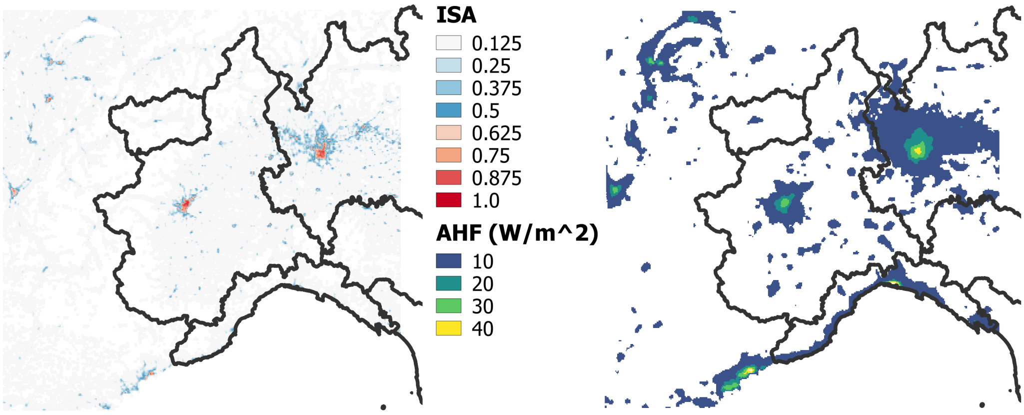


Figure 21: ISA (left) and AHF (right) fields.

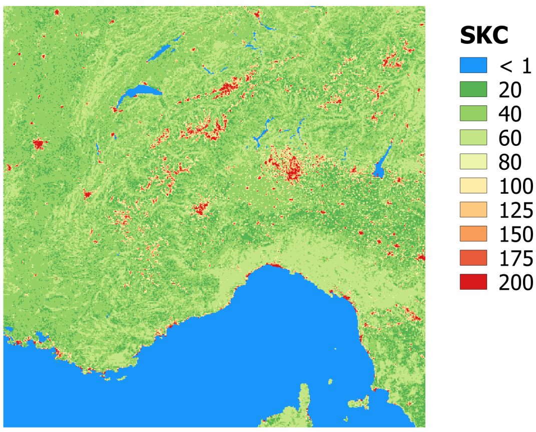


Figure 22: SKC field.

First of all a careful analysis of the UHI in the main cities has been conducted (see Fig. 20), starting from the study of Milelli (2016) and Milelli et al. (2017). In Figs. 24, 25 and 26 the UHI (difference between T2m_urban and T2m_rural) of Cuneo, Novara and Torino (respectively) has been compared. As expected, In Cuneo and Novara the effect is much less evident then in Torino, being smaller cities, nevertheless in Cuneo there is an indication of UHI influence. Therefore, for the selection of the case studies, we focused on the Torino area (Fig. 23), selecting stations 1 and 9 as reference for urban and rural area respectively. After looking at the UHI index defined as $T2m\_urban - T2m\_rural$ (see Fig. 27), two case studies have been selected, one in July 2015 (case A) and the other one in October 2017 (case B). The general scheme of the runs is described in Tab. 13.

Figure 23: Location of the observation stations considered in the Torino area.

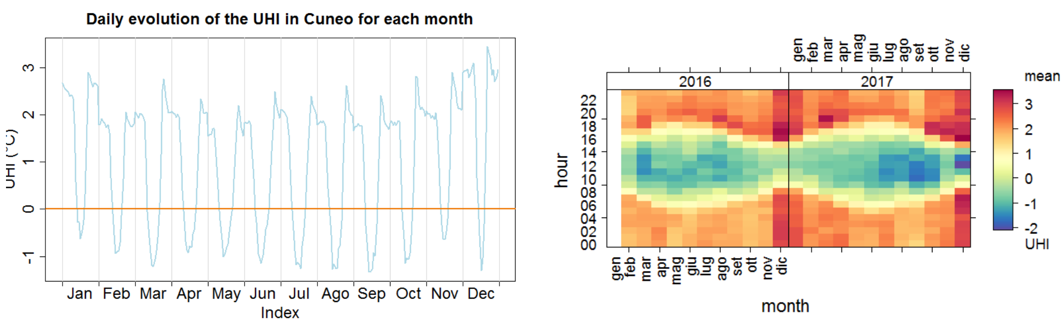


Figure 24: Mean daily UHI in Cuneo in 2016 and 2017 (left) and month by month (right).

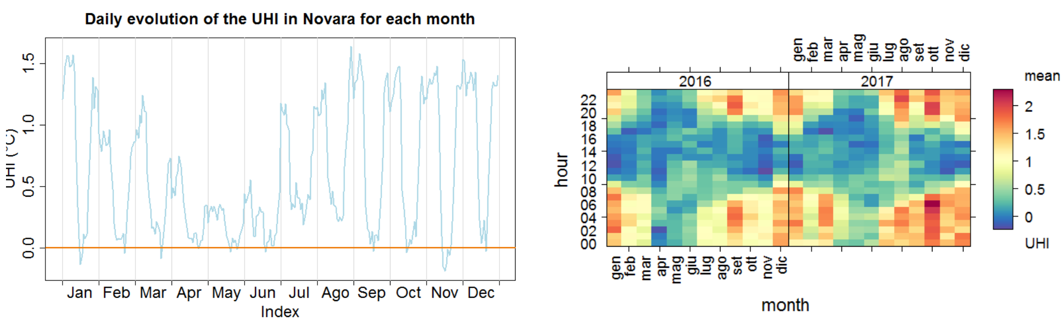


Figure 25: Mean daily UHI in Novara in 2016 and 2017 (left) and month by month (right).

		SKIN T	
		OFF	ON
TERRA_URB	OFF	CC1	CC2
	ON	UC1	UC2

Table 13: Scheme of the simulations.

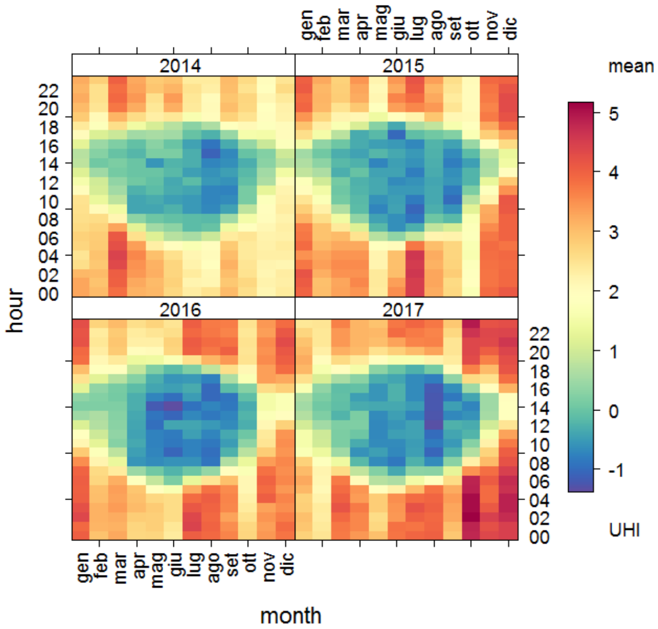


Figure 26: Mean daily cycle of UHI in Torino during 2014-2017 month by month.

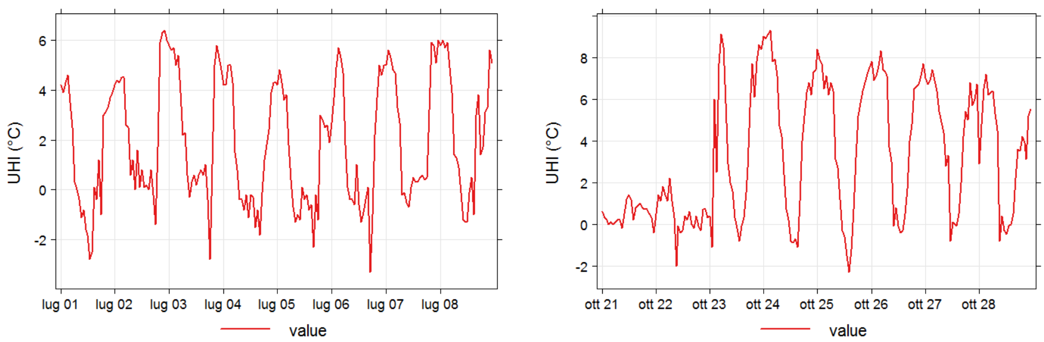


Figure 27: Detail of UHI in Torino in July 2015 (left) and October 2017 (right).

7.1 Test case A: July 2015

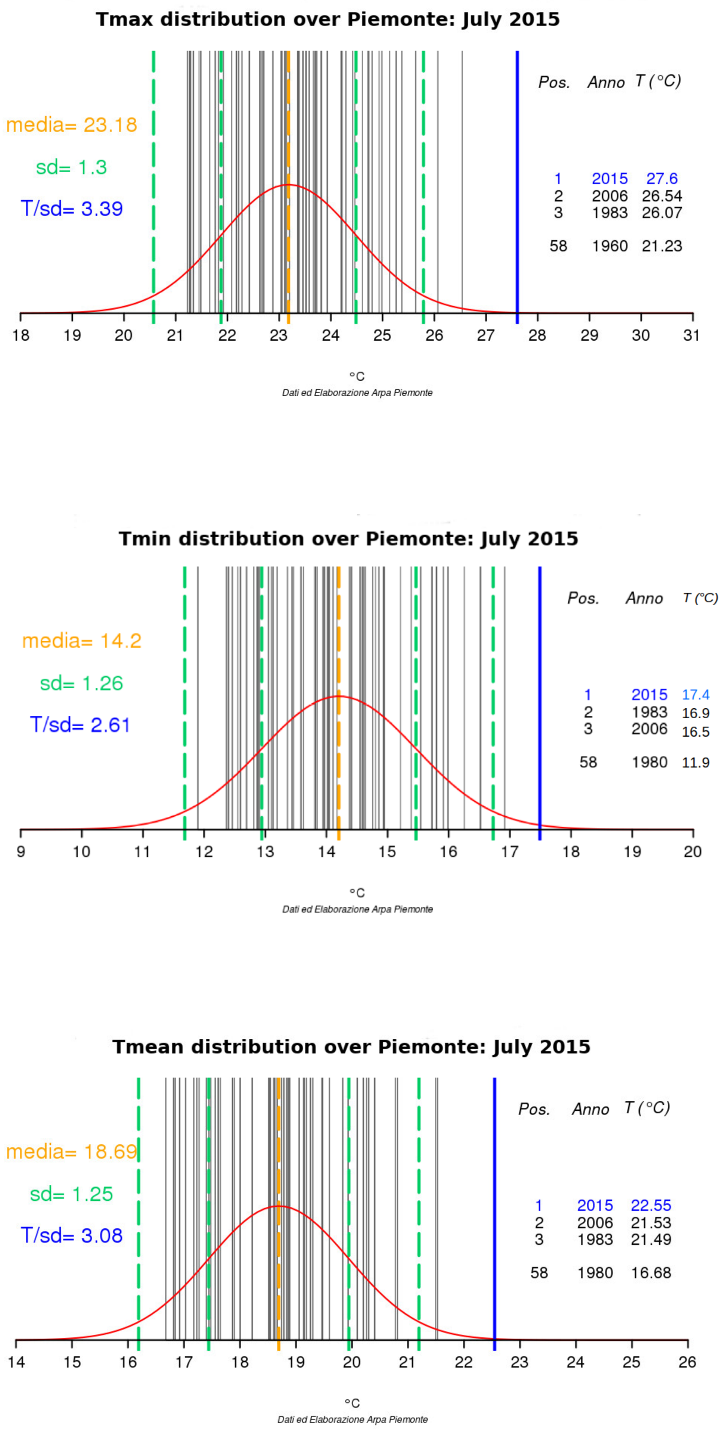


Figure 28: Distribution of T2m max (top), min (middle) and mean (bottom) in July 2015 over Piemonte.

During the first half of July 2015, an intense heat wave stroke Northern Italy with extreme temperature values and uncomfortable conditions for the population. In particular July 2015 has been the hottest July since 1958 (Fig. 28). It comes out that July 2015 is ranked first in all the measurements. In Torino, the maximum temperature reached 38.5°C during that period and ground stations data pointed out the presence of a clear UHI effect. This is the reason why this area and this period represent a suitable benchmark to test the capabilities of COSMO, and in particular of the urban parametrisation. The simulation in hindcast mode focused on the first week (20150701 00UTC - 20150707 00UTC). In Fig. 29 is plotted the mean bias of UHI index averaged over the entire period of simulation, for the 4 runs. In general the introduction of TERRA_URB (UC1 and UC2) changes the sign and reduces the bias with respect to the respective runs without (CC1 and CC2), although in Cuneo and Novara there is a slight worsening. The effect is more pronounced using Torino Consolata which is in fact the referent urban station in Torino. The SKC scheme improves the UHI slightly (runs CC2 and UC2) with respect to CC1 and UC1.

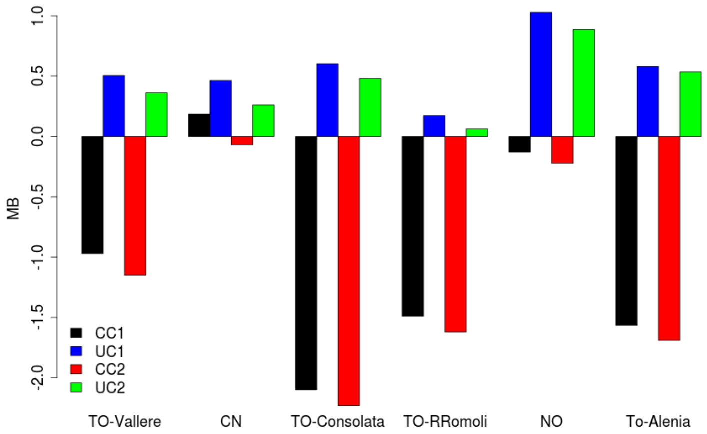


Figure 29: Mean Bias of UHI index over the entire period in a selection of stations. For Torino, different urban stations are used here.

Looking at the mean diurnal cycle, in Fig. 30 we plotted the MB and the RMSE using different samples of stations. In the top row the verification is performed with the whole network available (Fig. 20). The differences among the four runs are negligible, but this is a positive result because the impact of TERRA_URB should be limited to urban areas which are much less extended than rural ones. In the bottom row, the same plots have been made with urban stations only. There it is possible to appreciate the improvement of the new parametrisation, although there is a general heating as it can be better seen in the bias plot. Concerning the impact of SKC, a small difference (in positive direction) can be seen only during night time. Finally, having a look at Fig. 31, the time series of UHI index in Torino are plotted for the entire period. In each graph we compare only two pairs of runs, to better highlight the differences. In the first row it is evident the impact of TERRA_URB with a strong improvement during the night, catching the positive peaks of UHI. On the other hand, during day time the negative peaks of UHI are not seen by the model, with or without urban parametrisation. In the bottom row, SKC seems to have a neutral impact.

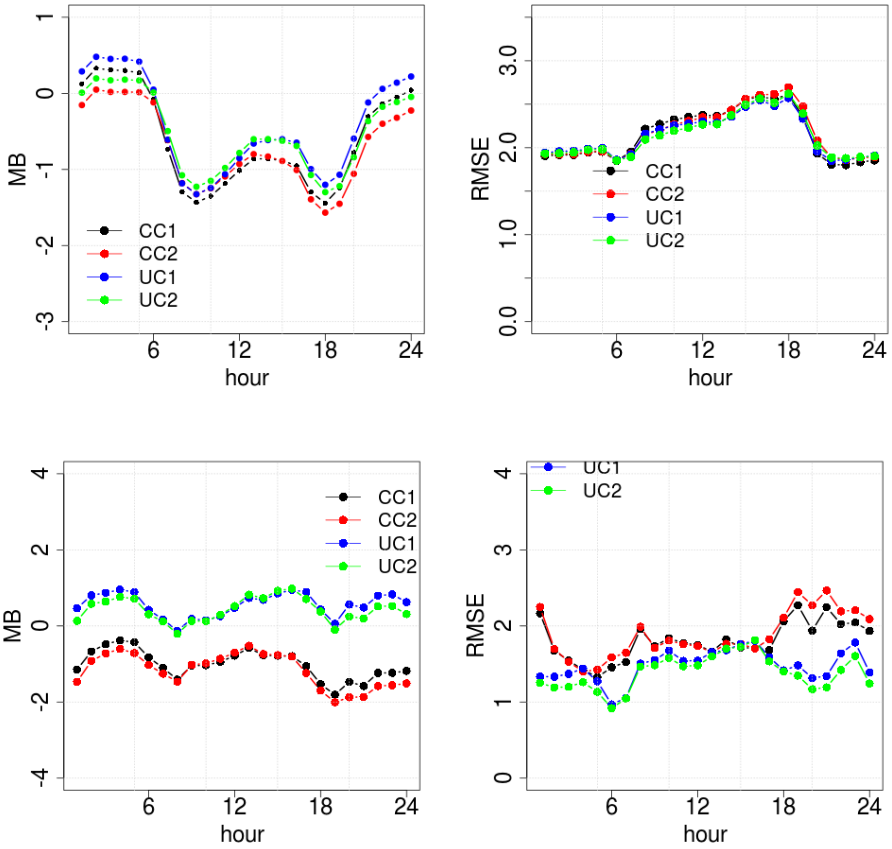


Figure 30: Mean Bias (left) and RMSE (right) using the four configurations in Table 13. All stations of Fig. 19 included (top row); only urban stations included (bottom row).

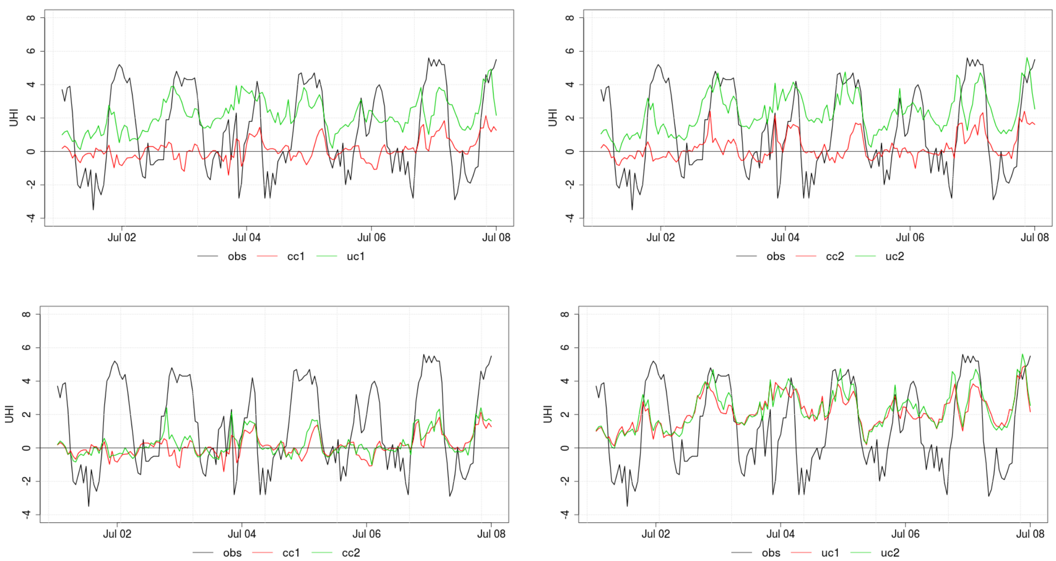


Figure 31: UHI index in Torino for the whole period of simulation. CC1 vs UC1 (top left), CC2 vs UC2 (top right), CC1 vs CC2 (bottom left), UC1 vs UC2 (bottom right).

7.2 Test case B: October 2017

A second test case has been selected, during a much more "normal" meteorological configuration (no heat wave), but standard autumn high pressure. It has to be pointed out that the UHI is more pronounced in this case, probably because the heating was already on. The simulation started on October 23 at 00UTC for 6 days, ending on October 29 at 00UTC, again in hindcast mode. In Fig. 32 the average bias shows a larger improvement with respect to the previous case, although in To-Vallere the T2m gets overestimated. Unfortunately there were problems with the Cuneo station which is not included. The improvement in urban areas is confirmed also from Fig. 33 (bottom row), but still with a general heating (the bias is shifted by 2 °C). In this test case, bias and rmse have higher values with respect to the previous test case. In Fig. 34 it is confirmed the positive impact during the night, but UC2 (bottom right panel) shows slightly better results than UC1 in the peaks. In other words, the amplitude of the cycle is larger with higher maxima and lower minima.

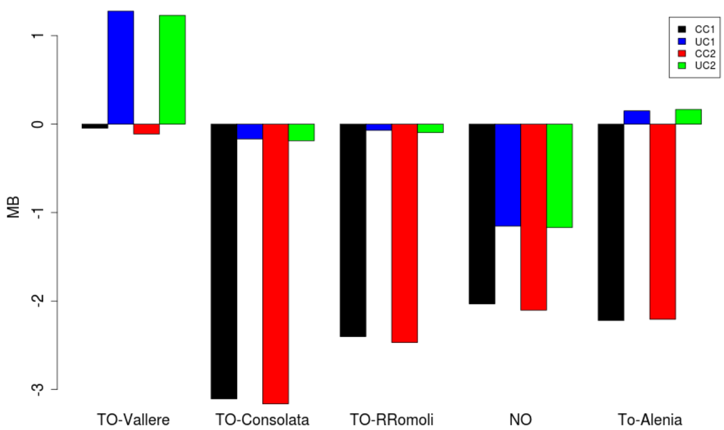


Figure 32: Mean Bias of UHI index over the entire period in a selection of stations. For Torino, different urban stations are used here.

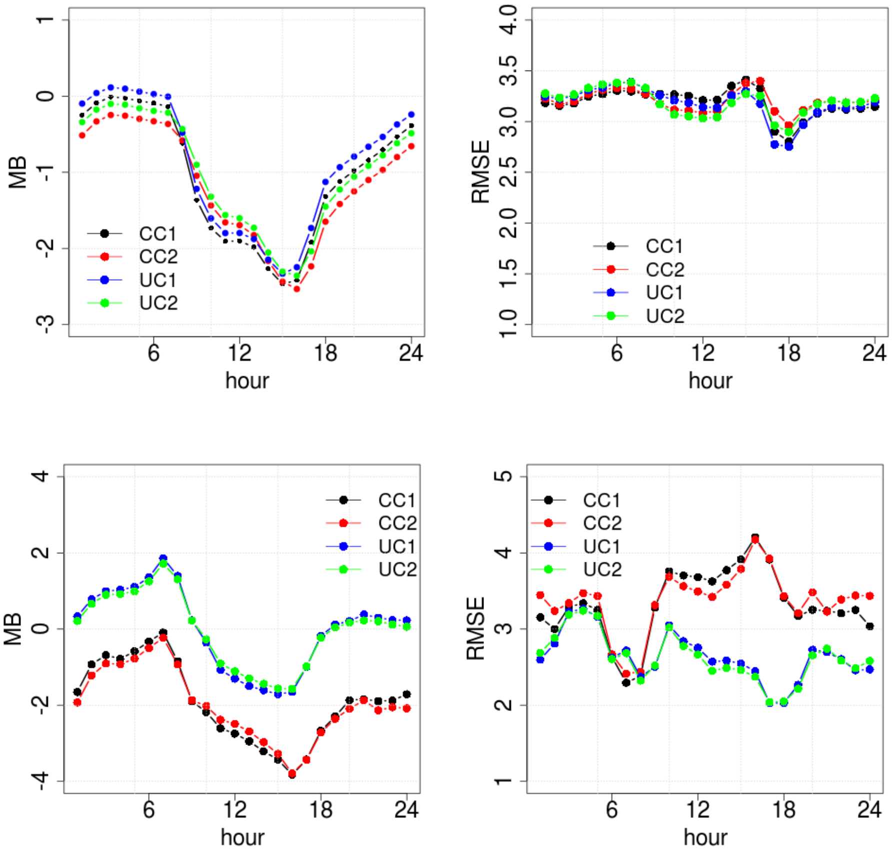


Figure 33: Mean Bias (left) and RMSE (right) using the four configurations in Table 13. All stations of Fig. 19 included (top row); only urban stations included (bottom row).

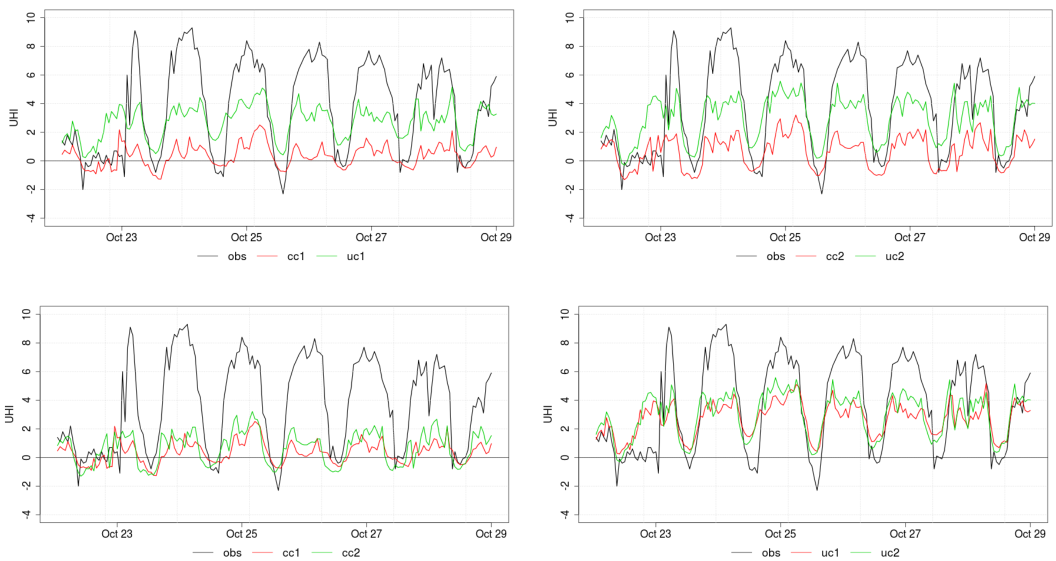


Figure 34: UHI index in Torino for the whole period of simulation. CC1 vs UC1 (top left), CC2 vs UC2 (top right), CC1 vs CC2 (bottom left), UC1 vs UC2 (bottom right).

8 Conclusions

In this report, the activities performed in the framework of PT AEVUS are presented. The main aim of this PT was an evaluation of the performance of a COSMO model version including the urban parametrization TERRA_URB (TU). It is a bulk parametrization scheme including prescribed Anthropogenic Heat Flux and Impervious Surface Area datasets which provides an intrinsic representation of the urban physics. For this purpose, modifications are applied to the model input data, the land surface scheme, and to the land-atmosphere interactions.

The activities were carried out by the modelling groups participating in the task, covering wide ranges of computational domains and periods. A support activity was carried out at DWD, in order to provide the so called skin temperature formulation as part of the land surface scheme TERRA. The skin temperature scheme provides an explicit representation of the vegetation canopy as a component of the surface energy balance. Therefore, it lead to a more efficient decoupling between the surface and the air temperature. In particular, the scheme allows for a more efficient night-time cooling, particularly in the rural areas, and therefore corrects for an important systematic model error of TERRA. As a result, the Urban Heat Island (UHI) intensity, i.e. the temperature difference between urban and rural areas, can be simulated more accurately. Experiments performed over the area of Brussels during the heat wave of 2003 revealed that TU allows an accurate representation of the UHI intensity, most pronounced during the evening and night-time. The numerical simulations over southern Italy on selected test cases have shown that the usage of TU produces a remarkable increase of temperature in urban areas, reducing the model bias. In rural areas, TU provides slight increases on both maximum and minimum temperature daily values, so that the diurnal cycle is always underestimated. Preliminary tests conducted using the skin temperature formulation have shown a reduction of the nocturnal temperatures in rural areas and an increase of the UHI intensity. A careful analysis and comparison with detailed near-surface and boundary layer observations has been conducted over the Moscow megacity area. Results reveal that the model with TU reasonably captures the spatial structure of the UHI by reducing the nocturnal temperature, including the spatio-temporal variations of the UHI intensity. The vertical structure of the UHI (only the lowest 100 m in the considered winter case) is well captured in comparison with the observed temperature profiles. Numerical simulations were conducted over the Piemonte region in order to test the capabilities of TU in simulating UHI in periods characterized by intense heat waves. It was found that the introduction of TU generally reduces the bias. Moreover, the usage of the skin temperature formulation improves the UHI representation slightly. Benefits provided by TU are particularly evident during the night, catching the positive peaks of UHI.

Overall, satisfactory results have been achieved in the framework of PT AEVUS. Further improvements are expected from a more accurate calibration and tuning of the last model version. In particular, an optimized namelist setting for an improved COSMO model performance will be specified, this includes the usage of the skin temperature scheme, and the external physiographic parameters will be improved. These activities will be carried out in the frame of the ongoing PT AEVUS2 (September 2019 - September 2020).

Summarizing, looking at the whole set of results, the authors believe that the TU scheme is suitable to be inserted into the main trunk of the COSMO model and to be distributed in the next official release.

9 Acknowledgements

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A Appendix

Implementing TERRA_URB in COSMO-Model Version 5.05

Ulrich Schättler

Deutscher Wetterdienst

Version 3.0, November 2019

The urban-canopy land-surface scheme TERRA_URB has been implemented in COSMO-Model Version 5.05. The TERRA_URB version used is 2.3, which is taken from the CCLM version COSMO-5.0-clm9. in the following we want to document this implementation into COSMO and try to highlight the technical differences to the implementation in COSMO-5.0-clm9.

Latest Actions in November 2019

This branch of the COSMO-Model is called COSMO-Model 5.05_urb5.
(`cosmo_191119_5.05_urb5.tar.bz2`).

NOTE:
The version `cosmo_191107_5.05_urb5.tar.bz2`, distributed early November 2019 was NOT CORRECT, due to a problem in the source code management.

Implemented a bug fix from Mikhail Varentsov in module `sfc_utilities.f90`, routine `diag_snowfrac_tg`, where usage of skin temperature `t_skin` has been forgotten in case of `itype_canopy = 2`.

Latest Actions in March 2019

This branch of the COSMO-Model is called COSMO-Model 5.05_urb4.
(`cosmo_190329_5.05_urb4.tar.bz2`).

Version 5.05_urb3 gives different results when running the model with `lterra_urb = .FALSE.` or running with `lterra_urb = .TRUE.`, and `ntiles = 0` and setting `FR_PAVED` and `AHF` to zero. In principle, these two runs should have the same results. This has been fixed by the following modifications:

- Treatment of `fr_snow` (fraction of snow): in the former TERRA_URB V5.0_clm19_urb2.3 the fraction of snow was computed at the beginning of TERRA. Now it is calculated in an extra routine, which is called after TERRA. This makes it necessary to introduce `fr_snow` as a tile variable to save the values of each tile for the next step. This was not done up to now, therefore using a value of the wrong tile in the next step.
- Treatment of `tl_freshsnow`: the values of the two tiles were not averaged up now, which gave wrong values for computing the surface albedo during a radiation step.
- The tile variables `tl_snow_melt`, `tl_runoff_s`, `tl_runoff_g` were not averaged to the 0-tile. This does not modify the results, as these are only diagnostic values. But now also the meteograph files `M_xxx` are identical.

Besides these real bugs, there were a few other modifications necessary ro really get bit reproducible results:

1. Setting of the natural tile `plcov`: all plants are considered to be in the natural tile, so `plcov` (urban tile) is 0.0 and the `plcov` (natural tile) has to be modified accordingly. But how it was done gave a different value even in grid points where `FR_PAVED=0.0` (no urban tile). Just for these cases I set `plcov` (natural tile) to the value read for `plcov` for the whole grid box (in module `sfc_tile_approach`, subroutine `tile_define_vegetation_canopy`, settings for `itl=1` (natural tile).

2. Averaging of the two tiles to the 0-tile in subroutine `tile_average_ground` (in module `sfc_tile_approach.f90`) is done with `temp**4` and then taking the 4th root of the result: `EXP (0.25_wp * LOG(temp))`. But this changes the result numerically. For now I do the averaging just as with the other variables.

3. `turb_transfer.f90`: calculation of variables `kbmo` and `dz_s0_h` for `lterra_urb=.TRUE.`: also these computations I modified in a way that they are bit reproducible in case there is only the natural tile.

4. `turb_interface.f90`: The transfer-scheme `turbtran` also uses the `ke`-values of the variables `tkvm`, `tkvh` and `tke`, but only the values for `ke1` are set in `turbtran`. The `ke`-values are only set in `turbdiff` (the atmospheric scheme). But `turbdiff` is not computed for all tiles, only for the averaged 0-tile. Therefore I do a copying of the 0-tile to the natural and the urban tile just for the `ke`-values.

Issues that have to be investigated / clarified:

- Re-think the formula of how `plcov` is modified to get the part of the urban tile (issue 1: above). What I did is only for urban tile=0, but what to do, if urban tile > 0 and natural tile > 0?
- Averaging of the temperatures with `**4`: this gives really big values (about 10E+9); is this really necessary? What is the advantage compared to the usual way? (issue 2: above)
- What to do with the `ke`-values of `tkvm`, `tkvh` and `tke` for the different tiles (issue 4: above)?

Additional technical changes and bug fixes:

- The rank of the external parameter `SKC` was erroneously set to 3, but has to be 2 (in `src_setup_vartab.f90`). Therefore the SKC could not be read and an error was reported by the model. This has been fixed now.
- Implemented additional debug output for a user-defined grid point in TERRA and the turbulence routines.

Latest Actions in October 2018

This branch of the COSMO-Model is called COSMO-Model 5.05_urb3.

- The skin temperature approach has been introduced by Jan-Peter Schulz

- The option `itype_canopy == 2` is fully working now

Latest Actions in September 2018

This branch of the COSMO-Model is called COSMO-Model 5.05_urb2.

- The files `ObjFiles` and `ObjDependencies` have been corrected. The definition of the new modules were missing (thanks to Mikhail).
- A bug fix in `turb_transfer.f90` has been implemented (similar to COSMO 5.05_1 from 31. July 2018).
- In the documentation some default values have been corrected (thanks to Pavel).

Latest Actions in April 2018

This branch of the COSMO-Model is called COSMO-Model 5.05_urb1.

- The former implementation of TERRA_URB in COSMO-Model 5.04g has been updated to the latest COSMO version 5.05.
- Output of tile variables has been implemented in GRIB1 and in restart files. A proper restart is now possible with this version.
- Modifications to the subroutine `tile_average_ground` to perform stable runs with different test cases (from module `sfc_tile_approach.f90`).
- Bug fix in `organize_physics.f90`: the variable `zqv_s` has to be set in all time steps, because this variable is used in the tracer module. This bug was the reason that there were no bit-identical results between version 5.04g and 5.04g_urb1 with setting `lterra_urb=.FALSE.`
- A few other technical modifications (described in DOCS/misc.global).

Latest "CAUTIONS" detected

- TERRA_URB cannot run with a coarse radiation grid. Something is going wrong in the radiation then. This has not been investigated further, because we want to remove this coarse radiation grid anyhow. For TERRA_URB you have to run with `nradcoarse=1`.

1. Using a Tile Approach in the COSMO-Model

1.1. Implementation of Tile Variables

The poor man's tile approach from TERRA_URB has been adopted in the COSMO-Model in a slightly different form. For every variable `var` an additional variable `tl_var` is declared in COSMO-5.0-clm9 with an extra dimension for the tiles. For example

surface roughness * g	`gz0 (ie,je)`	`tl_gz0 (ie,je,0:ntiles)`
fraction of plant cover	`plcov(ie,je)`	`tl_plcov(ie,je,0:ntiles)`

where `ntiles` is the number of tiles used. Before calling a routine which should use the tiles, the corresponding index from the tile-variable is copied to the usual variable and this is used in the routine. Afterwards, the result in the usual variable is copied to the corresponding tile index. Index 0 is used for aggregating the different values for the tiles.

In COSMO-Model 5.04g the new COSMO-ICON physics is written using argument lists for all subroutines. With this the copying of variables can be avoided easily by just writing a loop over all tiles around the call to subroutines. Therefore, in the implementation in COSMO-Model 5.04g we only use the tile-variable `tl_var(ie,je,0:ntiles)`. If no tiles are used, `ntiles` is 0 and the usual values are in `tl_var(:,:,0)`.

Implications to the rest of the COSMO-implementation:

- Throughout the COSMO-Model the use of tile-variables has to be adapted from `var(...)` to `tl_var(...,0)`, but not in the I/O.
- In the I/O we do not want to change the pointers in `src_setup_vartab.f90`. Some special implementation is needed for that. For more details see Section 3.

For the COSMO-ICON physics all variables are needed in a different data structure, which we call the blocked structure. One block consists of a part of the grid points of the two-dimensional domain and can be considered as a vector of grid columns. The name of the blocked variables is just the name of the variable with a suffix `_b`. For variables with a time dimension `tl_var(:,:,ntim=2)`, two variables in blocked format are allocated: `tl_var_b(:,:)` and `tl_var_new_b(:,:)`. Automatic copying of the `ijk`-structure to the block structure and back has been implemented for the tiles.

1.2. List of Variables with a Tile Dimension

The following table shows all variables from the COSMO-Model which are now implemented as tile variables (usual variable with dimensions, tile-variables now used in the COSMO-Model with dimensions, corresponding block variables with dimensions). The first line gives the dimensions of the variables in the program.

Two-dimensional variables:

(ie,je)	(ie,je,0:ntiles)	(nproma,0:ntiles)
gz0	tl_gz0	tl_gz0_b
plcov	tl_plcov	tl_plcov_b
lai	tl_lai	tl_lai_b
tai	tl_tai	tl_tai_b
sai	tl_sai	tl_sai_b
eai	tl_eai	tl_eai_b
tcm	tl_tcm	tl_tcm_b
tch	tl_tch	tl_tch_b
tfm	tl_tfm	tl_tfm_b
tfh	tl_tfh	tl_tfh_b
tfv	tl_tfv	tl_tfv_b
t_2m	tl_t_2m	tl_t_2m_b
qv_2m	tl_qv_2m	tl_qv_2m_b
td_2m	tl_td_2m	tl_td_2m_b
rh_2m	tl_rh_2m	tl_rh_2m_b
u_10m	tl_u_10m	tl_u_10m_b
v_10m	tl_v_10m	tl_v_10m_b
shfl_s	tl_shfl_s	tl_shfl_s_b
qvfl_s	tl_qvfl_s	tl_qvfl_s_b
lhfl_s	tl_lhfl_s	tl_lhfl_s_b
runoff_s	tl_runoff_s	tl_runoff_s_b
runoff_g	tl_runoff_g	tl_runoff_g_b
fr_snow	tl_fr_snow	tl_fr_snow_b
freshsnow	tl_freshsnow	tl_freshsnow_b
snow_melt	tl_snow_melt	tl_snow_melt_b

New two-dimensional variables for TERRA_URB:

(ie,je)	(ie,je,0:ntiles)	(nproma,0:ntiles)
frc	tl_frc	tl_frc_b
isa	tl_isa	tl_isa_b
isa_uc	tl_isa_uc	
sa_uc	tl_sa_uc	tl_sa_uc_b
w_imp	tl_w_imp	tl_w_imp_b
w_isa	tl_w_isa	tl_w_isa_b
kbmo	tl_kbmo	tl_kbmo_b

Two-dimensional variables with a time-dimension. Note that the time-dimension is always the last one!

(ie,je,ntim)	(ie,je,0:ntiles,ntim)	(nproma,0:ntiles,ntim)
t_snow	tl_t_snow	tl_t_snow_b
		tl_t_snow_new_b
t_s	tl_t_s	tl_t_s_b
		tl_t_s_new_b
t_sk	tl_t_sk	tl_t_sk_b
		tl_t_sk_new_b
t_g	tl_t_g	tl_t_g_b
		tl_t_g_new_b
qv_s	tl_qv_s	tl_qv_s_b
		tl_qv_s_new_b
w_i	tl_w_i	tl_w_i_b
		tl_w_i_new_b
w_p	tl_w_p	tl_w_p_b
		tl_w_p_new_b
w_s	tl_w_s	tl_w_s_b
		tl_w_s_new_b
w_snow	tl_w_snow	tl_w_snow_b
		tl_w_snow_new_b
h_snow	tl_h_snow	tl_h_snow_b
		tl_h_snow_new_b
rho_snow	tl_rho_snow	tl_rho_snow_b
		tl_rho_snow_new_b

And for the multi-layer snow model:

(ie,je,ntim)	(ie,je,0:ntiles,ntim)	(nproma,0:ntiles,ntim)
t_snow_mult	tl_t_snow_mult	tl_t_snow_mult_b
dzh_snow_mult	tl_dzh_snow_mult	tl_dzh_snow_mult_b
wliq_snow	tl_wliq_snow	tl_wliq_snow_b
w_snow_mult	tl_w_snow_mult	tl_w_snow_mult_b
rho_snow_mult	tl_rho_snow_mult	tl_rho_snow_mult_b

Three-dimensional variables:

(ie,je,ke1)	(ie,je,ke1,0:ntiles)	(nproma,ke1,0:ntiles)
tkvm	tl_tkvm	tl_tkvm_b
tkvh	tl_tkvh	tl_tkvh_b
edr	tl_edr	tl_edr_b

Three-dimensional variables with a time-dimension. Note that `kex` stands for a variable third dimension, because all these variables do have a different extent in the vertical. Again note that the time-dimension is the last one!

(ie,je,kex,ndim)	(ie,je,kex,0:ntiles,ndim)	(nproma,kex,0:ntiles,ndim)
tke	tl_tke	tl_tke_b
t_so	tl_t_so	tl_t_so_b
		tl_t_so_new_b
w_so	tl_w_so	tl_w_so_b
		tl_w_so_new_b
w_so_ice	tl_w_so_ice	tl_w_so_ice_b
		tl_w_so_ice_new_b

NOTE:

This is just a slightly different way of implementing the poor man's tile approach. It is not (and even not similar) to the tile approach used in ICON!

2. Additional Namelist Variables for TERRA_URB

Several new namelist variables have been implemented in COSMO-5.0-clm9, TERRA_URB 2.3 in the group /PHYCTL/. All but one have also been implemented in COSMO-Model 5.04g_urb1. The one not implemented is the logical variable itype_tile, which is redundant. The actions of itype_tile (0: no tiles, 1: tiles) can also be taken from the number of tiles being = 0 or > 0.

The implmented namelist variables are described shortly:

Name	Type	Definition / Purpose / Comments	Default
ntiles	INT	Number of total tiles. • If the COSMO-Model should run without tiles, the default ntiles = 0 has to be used. • If the COSMO-Model should run with tiles, ntiles has to be set explicitly (in contrast to COSMO-5.0-clm9, where the default of this variable was 2).	0
lterra_urb	LOG	To switch on/off the urban parametrization.	.FALSE.
lurb_fab	LOG	To switch on/off the urban fabric (in a bulk approach). It is only active, if also lterra_urb is set.	.TRUE.
itype_ahf	INT	Switch for anthropogenic heat flux. Options are: 0: no anthropogenic heat flux; 1: (default) anthropogenic heat according to *Flanner* (2009); latitudinal, annual, and diurnal-dependent anthropogenic heat flux based on an annual-mean input dataset.	1
itype_kbmo_uf	INT	$kB^{-1} = \ln(z_0/z_{0h})$ parametrization in the surface-layer transfer scheme for the urban fabric. Options are: 0: standard from the surface-layer transfer scheme 1: (default) external parametrization according to Brutsaert/Kanda 2: external from Zilitinkevich	1

Name	Type	Definition / Purpose / Comments	Default
`itype_eisa`	INT	Type of evaporation from impervious surfaces. Options are: 0: evaporation just like bare soil (of course, not recommended) 1: no evaporation (dry surface) 2: (default): density function of puddle depths (Wouters et al., 2015)	2
`itype_canopy`	INT	Type of canopy parametrization with respect to the surface energy balance. Options are: 1: Surface energy balance equation solved at the ground surface, canopy energetically not represented. 2: Skin temperature formulation by Schulz and Vogel (2017), based on Viterbo and Beljaars (1995). This is provided by the new COSMO/ICON code by Jan-Peter Schulz, which is recently adopted by TERRA URB. Model sensitivity tests show that this option leads to a better representation of the urban/rural contrasts in surface-atmosphere exchanges, hence largely improves urban climate modelling. This option also allows to investigate the vegetation insulation in urban areas on urban climate. Please note that this feature is still in experimental stage.	1
`cimpl`	REAL	value of implicitness of the vegetation-skin temperature parametrization.	120
`calamrural`	REAL	value of skin-layer conductivity for rural areas (in $Wm^{-2}K^{-1}$).	10
`calamurb`	REAL	value of skin-layer conductivity for rural areas (in $Wm^{-2}K^{-1}$).	1000

When activating `lterra_urb` the default of the above variables are used. Only the variable `ntiles` has to be set explicitly to 2!

3. Input and Output for the Tile Variables

The I/O implemented for the tile-variables in COSMO-5.0-clm9 is not practical with GRIB. A different method has now been implemented in COSMO-Model 5.05_urb1 for GRIB1 and for restart files (which uses GRIB1-like meta data).

A new namelist variable `lwrite_tiles` has been implemented in the namelist group `/GRIBOUT/`. If this variable is set to `.TRUE.`, all different tiles of a variable are written to output. To distinguish the different tiles, the additional element number is set to the number of the tile (in GRIB1 and in restart files). If writing a restart file, `lwrite_tiles` is set to `.TRUE.`, if `ntiles > 0`.

In order not to have to change the pointering in the module `src_setup_vartab.f90` we kept the *usual* arrays for the tile variables without the additional tile dimension, but put a "`z`" in front of the name, to make it different. In `src_input.f90` the fields are read into the fields zvar and copied to the tile-variables tl_var afterwards.

In src_output.f90, all tile variables are added to the write_loop. If lwrite_tiles=.TRUE., a loop over all tiles is started to write all tile variables using the correct number of tile as additional element number. If lwrite_tiles=.FALSE., only tile 0 is written to output.

NOTE:

Implementation of all tile variables to NetCDF or GRIB2 is still ongoing.

4. Special Highlights of the Implementation in COSMO-Model 5.05_urb1

1. Implementation of the 2 new modules:
   - The module src_ahf has been named sfc_ahf. It contains one subroutine ahf. In COSMO-Model 5.04g_urb1 this routine is called in organize_physics.f90, after all parametrizations have been calculated and all data have been copied back to the ijk-data structure (because it is written for this data structure).
   - The module src_tile_approach.f90 has been named sfc_tile_approach.f90. It contains the subroutines
     - tile_define_urban_canopy:
     - tile_define_vegetation_canopy: These two routines are called in the module organize_data.f90 after reading the initial and the first two boundary data sets (not in src_input.f90 as in COSMO-5.0-clm9, because after the first boundary data set has been read, also the initial data can be modified again).
     - tile_filling: This new subroutine fills all tiles with the initial values and is also called in organize_data.f90, as the routines above.
     - tile_average_ground: This routine is written for the blocked data format now and is called just after TERRA.
     - tile_average_near_surface:
     - tile_average_near_surface_blocked: This routine is called after the call to the turbulence transfer scheme. It is now written with an argument list and is the blocked version of tile_average_near_surface.
2. The namelist variable tle has been renamed in ntiles (is a more "speaking name").
3. The external parameter data field for the total impervious surface-area index is called ISA in the version COSMO-5.0-clm9, but is now called FR_PAVED (similar to FR_LAND). This has already been implemented at DWD in the GRIB (shortNames) environment. The actual implementation in COSMO-Model 5.04g_urb1 accepts both names (but this is only a hack, because an extra GRIB 1 number is now used for ISA).
4. The new version of the turbulence scheme needs another external parameter SSO_STDH (from the SSO scheme). This parameter is not available in some test data set, therefore its usage has to be switched off, if necessary (modifications necessary in organize_physics and in organize_data.
5. In near_surface, a part "HSM" has been implemented, but only for itype_synd == 1, which is normally not used any more.
   This has not yet been implemented in COSMO-Model 5.04g_urb1.

6. In module src_slow_tendencies_rk.f90, a part has been implemented in subroutine implicit_vert_diffusion_uvwt for "additional security". In my opinion this is not necessary for COSMO-Model 5.05_urb1, because within TERRA and tile_average_ground all variables are only treated for landpoints.

7. Also in module src_slow_tendencies_rk.f90, the sensible heat flux is modified by substracting the field ahf_now when computing the vertical diffusion of the tendencies. With the new COSMO-ICON physics there is the possibility to compute this vertical diffusion after the physics. This is controlled with the namelist switch itype_vdif:

   -1: Vertical diffusion is computed in the dynamics (old behaviour)

   +1: Vertical diffusion is computed after the physics in the blocked data structure. Modification of the sensible heat flux with ahf_now is not yet implemented here (still have to think how to do it best).

5. Tests

A data set has been provided by Hendrik Wouters for 1st of July, 2012, for up to 15 hours in NetCDF data format. Tests have been performed with COSMO-5.0-clm9 and with COSMO-Model 5.04g_urb1. The following pictures show the 2m temperature computed by COSMO-5.0-clm9 (left) and by 5.04g_urb1 (right). This is just to show that the new version is running and not producing nonsense.

Runs have also been performed to test, whether the version COSMO-Model 5.04g_urb1 gives the same results as version COSMO-Model 5.04g without TERRA_URB. With the bug fix in organize_physics.f90 (setting zqv_s in all time steps) this is now the case.

5.1 Problems with the Test Cases from Piemonte and Moscow

The version cosmo_171113_5.04g_urb1 could not be used for test cases from Piemonte and Moscow. This model version crashes, no matter which configuration is used. These problems have been investigated:

5.2. Piemonte: Initial and Boundary Conditions derived from IFS Data

This data seems to be be problematic, because in the first few steps there are several grid points which have a negative value for the variable QV_S. This is also the case when using the former version COSMO-5.0-clm9, but this version does not crash, but silently ignores these values. Modifications in the computation of the 2m temperature now lead to crashes in such situations. This could be avoided using itype_synd=1.

We also prepared some ICON data for this test case, which did not show this behaviour regarding QV_S. But using the ICON data or the IFS data with itype_synd=1 shows the same problems as the Moscow case.

5.3. Moscow: Initial Conditions without SSO_STDH

The new formulation of the turbulence scheme requires SSO_STDH as initial field, which was not present in the Moscow test data. To run this case two adaptations are necessary in the source code:

- organize_data.f90: Section 3.2, about line 1573: Comment the lines:

```
IF (itype_vdif > -2) THEN
  yvarini(nyvar_i + 1) = 'SSO_STDH  '
  nyvar_i = nyvar_i + 1
ENDIF
```

- organize_physics.f90: There are two calls to the subroutine init_canopy, in which you have to comment the lines with d_pat (line 1468 and 1702):

```
d_pat   = sso_stdh (:,j),     &
```

5.4. Analyzing the Problems

Depending on the configuration, the COSMO-Model shows a few different crashes:

- Crash in turb_transfer with negative values of tl_qv_s for tile 0.
- Crash in gscp_graupel with a negative value of rho or negative values of tl_t_g.

After some time of debugging, all crashes could be traced back to some calculations in the routine tile_average_ground in sfc_tile_approach.f90. This subroutine calculates the grid averages from the different tiles for all tile variables.

But for some variables not a grid averaged is used, but a new diagnosis is calculated. This is done for the sensible heat flux, the latent heat flux and the moisture flux. Also the variable tl_qv_s is computed again (and some variables necessary for that).

While these new computations seem to be ok for the old version COSMO-5.0-clm9, they seem to be problematic for the new version COSMO 5.05. Therefore we tested to use the fluxes as they are now computed in the physics from Version 5.05 and just aggregated tl_qv_s from the different tiles.

With this approach we could run the Piemonte and the Moscow cases without any problems using different configurations ("old" and "new" physics).

6. Major Changes between COSMO Versions 5.0 and 5.04g

6.1. Source Code

The following list gives the major changes in the COSMO-Model since version 5.0. Most of these changes had only a minor impact on the results. Only the bug fix in the dynamics for slope-dependent divergence damping coefficients showed clear differences in the results (with a better verification for our NWP tests).

The replacement of the turbulence and the soil and surface schemes by the ICON version has a major impact on the results, depending on the namelist configuration used (see Section A).

For a full list of changes for each version, please visit
http://www.cosmo-model.org/content/model/releases/histories/default.htm

Version 5.01:

- `src_slow_tendencies_rk.f90`: Use `t_g` instead of `t_s` for the flux computations.
- `pp_utilities.f90`: Optimization of the gamma-function.
- Removal of inconsistencies for the tracers
- Work in Dynamics:
  - targeted diffusion to avoid cold pools
  - reformulation of divergence damping coefficients in the new fast-waves solver
  - adaptation of the Runge-Kutta dynamical core to the SPPT (stochastic perturbation of physics tendencies)
- Modifications to lateral Davies relaxation

Version 5.02:

- Bug fix for computation of `kflat` (only when using GRIB2)
- Bug fix in use of MPI data types (only when using `ldatatypes=.TRUE.`

Version 5.03:

- Various bug fixes in the dynamics, TERRA and the radiation.

Version 5.04a:

- Bug fix in the dynamics for slope-dependent divergence damping coefficients

Version 5.04b:

- Introducing a new boundary condition module (only numerical changes)

Version 5.04a-g:

- Introducing ICON versions of parametrizations for turbulence, soil model, sea-ice scheme and FLake. But these schemes can be run in a configuration which reproduces the results from the corresponding COSMO schemes rather closely (see Section A).

6.2. Namelist Variables

The following namelist variables have been deleted or have changed their meaning (range, default value):

`/DYNCTL/`:

Name	Change	Comment
crltau	renamed	The new name now is crltau_inv and is just the inverse of crltau. Since the default is 1.0, this is not changed. Only if you used a different value, you have to adapt that now.
lexpl_lbc	deleted	No more explicit formulation of lateral boundary relaxation possible.
divdamp_slope	changed	This variable changed its default and the possible range (due to the bug fix). Before it was 10.0 < divdamp_slope <= 100.0 (with default 20.0). Now it is 0.1 < divdamp_slope <= 3.0 (with default 1.0).

/PHYCTL/:

In /PHYCTL/ the following namelist variables have been deleted, because now only the multi-layer version of TERRA is possible: lmulti_layer, nlgw, nlgw_ini, nlgw_bd

A few variables have been added for the COSMO-ICON physics: itype_vdif, ltkeshs, idiag_snowfrac, cwimax_ml

Please see the web site cited above for a description of these variables.

/TUNING/:

In /TUNING/ the following namelist variables have been deleted: wichfakt, securi

6.3. A Special Change for the Climate Mode

The treatment of statistically processed fields in the COSMO-Model is different for the NWP- or for the CLM-mode. This is especially true for fields that are accumulated, like the total precipitation TOT_PREC. In NWP-mode these fields are summed up from the beginning up to the end of the forecast, while in CLM-mode these fields are reset to 0.0 after every output step.

In COSMO-Model Version 5.04f we introduced special fields for cell tracking, which also have to be reset to 0.0 after every output. Therefore we had to change the handling of such fields and introduced additional namelist variables to control the way how and when statistically processed fields are reset.

We introduced 4 categories of statistically processed fields:

- Temperatures, e.g.: TMIN_2M, TMAX_2M
- Winds, e.g.: VMAX_10M, VABSMX_10M
- Summations, Averages, e.g.: TOT_PREC, ASHFL_S
- Cells, e.g.: LPI_MAX, TCOND_MAX

Resetting the variables for each category can now be controlled by the namelist variables

- ireset_temps
- ireset_winds

- ireset_sums
- ireset_cells

Possible values for these four variables are:

- 0: no resetting at all (default for sums and averages)
- 1: reset after given time interval (default for temps and winds)
- 2: reset after every output (default for cells)

These defaults ensure the current behaviour of the COSMO-Model in NWP-mode.

In CLM Mode (lbdclim=.TRUE.), the namelist variable ireset_sums = 2 has to be chosen to reset all summation variables after every output step!

7. Recommended Namelist Configurations for COSMO-Model 5.04g

At DWD we have problems when activating all new features in the COSMO-ICON physics, therefore it is difficult to recommend a special namelist configuration. We tested three different configurations:

- Old Settings: Turbulence and TERRA are run in a way to reproduce the results of the old COSMO-Versions as close as possible.
  These settings are now preferred at DWD.
- Conservative: The settings for the turbulence scheme activate the new parts of the code, while settings for TERRA still are for the old scheme. Alternatively, also some new features of TERRA can be activated (e.g. itype_evsl=4).
- Advanced: These settings come very close to the ICON settings, but COSMO results are not really satisfying. Please note that you need to run INT2LM also with special namelist settings:
  - itype_aerosol = 2
  - itype_ndvi = 1
  - itype_rootdp = 4
  - lemiss = .TRUE.
  - lstomata = .TRUE.

In addition to the namelist variables, that have to be set in a different way for the above configurations, there are also some hardcoded switches in the turbulence, that have to be different when reproducing the old COSMO-version of the turbulence. To be able to modify these switches at once, we implemented a new namelist switch loldtur. Per default loldtur=.FALSE. and the new way of running the turbulence is activated. To reproduce the old way, it has to be set to .TRUE. and all other namelist switches regarding turbulence have to be set for the "Old Settings".

The following table lists all namelist variables that have to be set for the three different configurations and specifies, which are related to turbulence, and which are not. Because of ongoing problems with running the vertical diffusion after the physics, we only can recommend to use the former vertical diffusion in the dynamics. For this you have to set `itype_vdif=-1`:

Name	Old Settings	Conservative	Advanced
/TUNING/ (turbulence)			
tkhmin	0.4	0.75	0.75
tkmmin	0.4	0.75	0.75
rat_sea	20.0	7.5	7.5
patlen	500.0	750.0	750.0
turlen	150.0	500.0	500.0
a_hshr	0.2	2.0	2.0
c_soil	1.0	1.75	1.75
/PHYCTL/ (turbulence)			
loldtur	.TRUE.	.FALSE.	.FALSE.
itype_vdif	-1	-1	-1
ltkeshs	.FALSE.	.TRUE.	.TRUE.
itype_sher	1	0	0
imode_tran	1	0	0
imode_turb	1	1	1
icldm_tran	0	2	2
/PHYCTL/ (other)			
itype_aerosol	1	1	2
itype_root	1	1	2
itype_heatcond	1	3	3
itype_evsl	2	2	2
idiag_snowfrac	1	1	1
cwimax_ml	1.0E-6	0.0005	0.0005
lemiss	.FALSE.	.FALSE.	.TRUE.
lstomata	.FALSE.	.FALSE.	.TRUE.

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List of COSMO Newsletters and Technical Reports

(available for download from the COSMO Website: www.cosmo-model.org)

COSMO Newsletters

No. 1: February 2001.

No. 2: February 2002.

No. 3: February 2003.

No. 4: February 2004.

No. 5: April 2005.

No. 6: July 2006.

No. 7: April 2008; Proceedings from the 8th COSMO General Meeting in Bucharest, 2006.

No. 8: September 2008; Proceedings from the 9th COSMO General Meeting in Athens, 2007.

No. 9: December 2008.

No. 10: March 2010.

No. 11: April 2011.

No. 12: April 2012.

No. 13: April 2013.

No. 14: April 2014.

No. 15: July 2015.

No. 16: July 2016.

No. 17: July 2017.

No. 18: November 2018.

No. 19: October 2019.

COSMO Technical Reports

No. 1: Dmitrii Mironov and Matthias Raschendorfer (2001):
Evaluation of Empirical Parameters of the New LM Surface-Layer Parameterization Scheme. Results from Numerical Experiments Including the Soil Moisture Analysis.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_1

No. 2: Reinhold Schrodin and Erdmann Heise (2001):
The Multi-Layer Version of the DWD Soil Model TERRA_LM.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_2

No. 3: Günther Doms (2001):
A Scheme for Monotonic Numerical Diffusion in the LM.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_3

No. 4: Hans-Joachim Herzog, Ursula Schubert, Gerd Vogel, Adelheid Fiedler and Roswitha Kirchner (2002):
LLM ⁻ the High-Resolving Nonhydrostatic Simulation Model in the DWD-Project LITFASS. Part I: Modelling Technique and Simulation Method.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_4

No. 5: Jean-Marie Bettems (2002):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_5

No. 6: Heinz-Werner Bitzer and Jürgen Steppeler (2004):
Documentation of the Z-Coordinate Dynamical Core of LM.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_6

No. 7: Hans-Joachim Herzog, Almut Gassmann (2005):
Lorenz- and Charney-Phillips vertical grid experimentation using a compressible non-hydrostatic toy-model relevant to the fast-mode part of the 'Lokal-Modell'.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_7

No. 8: Chiara Marsigli, Andrea Montani, Tiziana Paccagnella, Davide Sacchetti, André Walser, Marco Arpagaus, Thomas Schumann (2005):
Evaluation of the Performance of the COSMO-LEPS System.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_8

No. 9: Erdmann Heise, Bodo Ritter, Reinhold Schrodin (2006):
Operational Implementation of the Multilayer Soil Model.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_9

No. 10: M.D. Tsyrulnikov (2007):
Is the particle filtering approach appropriate for meso-scale data assimilation ?
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_10

No. 11: Dmitrii V. Mironov (2008):
Parameterization of Lakes in Numerical Weather Prediction. Description of a Lake Model.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_11

No. 12: Adriano Raspanti (2009):
COSMO Priority Project "VERification System Unified Survey" (VERSUS): Final Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_12

No. 13: Chiara Marsigli (2009):
COSMO Priority Project "Short Range Ensemble Prediction System" (SREPS): Final Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_13

No. 14: Michael Baldauf (2009):
COSMO Priority Project "Further Developments of the Runge-Kutta Time Integration Scheme" (RK): Final Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_14

No. 15: Silke Dierer (2009):
COSMO Priority Project "Tackle deficiencies in quantitative precipitation forecast" (QPF): Final Report.
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No. 16: Pierre Eckert (2009):
COSMO Priority Project "INTERP": Final Report.
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No. 17: D. Leuenberger, M. Stoll and A. Roches (2010):
Description of some convective indices implemented in the COSMO model.
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No. 18: Daniel Leuenberger (2010):
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No. 19: A. Montani, D. Cesari, C. Marsigli, T. Paccagnella (2010):
Seven years of activity in the field of mesoscale ensemble forecasting by the COSMO–LEPS system: main achievements and open challenges.
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No. 20: A. Roches, O. Fuhrer (2012):
Tracer module in the COSMO model.
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No. 21: Michael Baldauf (2013):
A new fast-waves solver for the Runge-Kutta dynamical core.
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No. 22: C. Marsigli, T. Diomede, A. Montani, T. Paccagnella, P. Louka, F. Gofa, A. Corigliano (2013):
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No. 24: A. K. Miltenberger, A. Roches, S. Pfahl, H. Wernli (2014):
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No. 25: P. Khain, I. Carmona, A. Voudouri, E. Avgoustoglou, J.-M. Bettems, F. Grazzini (2015):
The Proof of the Parameters Calibration Method: CALMO Progress Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_25

No. 26: D. Mironov, E. Machulskaya, B. Szintai, M. Raschendorfer, V. Perov, M. Chumakov, E. Avgoustoglou (2015):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_26

No. 27: J-M. Bettems (2015):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_27

No. 28: Ulrich Blahak (2016):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_28

No. 29: M. Tsyrulnikov and D. Gayfulin (2016):
A Stochastic Pattern Generator for ensemble applications.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_29

No. 30: D. Mironov and E. Machulskaya (2017):
A Turbulence Kinetic Energy – Scalar Variance Turbulence Parameterization Scheme.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_30

No. 31: P. Khain, I. Carmona, A. Voudouri, E. Avgoustoglou, J.-M. Bettems, F. Grazzini, P. Kaufmann (2017):
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No. 32: A. Voudouri, P. Khain, I. Carmona, E. Avgoustoglou, J.M. Bettems, F. Grazzini, O. Bellprat, P. Kaufmann and E. Bucchignani (2017):
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No. 33: N. Vela (2017):
VAST 2.0 - User Manual.
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No. 34: C. Marsigli, D. Alferov, M. Arpagaus, E. Astakhova, R. Bonanno, G. Duniec, C. Gebhardt, W. Interewicz, N. Loglisci, A. Mazur, V. Maurer, A. Montani, A. Walser (2018):
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No. 35: G. Rivin, I. Rozinkina, E. Astakhova, A. Montani, D. Alferov, M. Arpagaus, D. Blinov, A. Bundel, M. Chumakov, P. Eckert, A. Euripides, J. Förstner, J. Helmert, E. Kazakova, A. Kirsanov, V. Kopeikin, E. Kukanova, D. Majewski, C. Marsigli, G. de Morsier, A. Muravev, T. Paccagnella, U. Schättler, C. Schraff, M. Shatunova, A. Shcherbakov, P. Steiner, M. Zaichenko (2018):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_35

No. 36: A. Raspanti, A. Celozzi, A. Troisi, A. Vocino, R. Bove, F. Batignani (2018):
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DOI: 10.5676/DWD_pub/nwv/cosmo-tr_36

No. 37: A. Bundel, F. Gofa, D. Alferov, E. Astakhova, P. Baumann, D. Boucouvala, U. Damrath, P. Eckert, A. Kirsanov, X. Lapillonne, J. Linkowska, C. Marsigli, A. Montani, A. Muraviev, E. Oberto, M.S. Tesini, N. Vela, A. Wyszogrodzki, M. Zaichenko, A. Walser (2019):
The COSMO Priority Project INSPECT Final Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_37

No. 38: G. Rivin, I. Rozinkina, E. Astakhova, A. Montani, J-M. Bettems, D. Alferov, D. Blinov, P. Eckert, A. Euripides, J. Helmert, M.Shatunova (2019):
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No. 39: C. Marsigli, D. Alferov, E. Astakhova, G. Duniec, D. Gayfulin, C. Gebhardt, W. Interewicz, N. Loglisci, F. Marcucci, A. Mazur, A. Montani, M. Tsyrulnikov, A. Walser (2019):
Studying perturbations for the representation of modeling uncertainties in Ensemble development (SPRED Priority Project): Final Report.
DOI: 10.5676/DWD_pub/nwv/cosmo-tr_39

COSMO Technical Reports

Issues of the COSMO Technical Reports series are published by the *COnsortium for Small-scale MOdelling* at non-regular intervals. COSMO is a European group for numerical weather prediction with participating meteorological services from Germany (DWD, AWGeophys), Greece (HNMS), Italy (USAM, ARPA-SIMC, ARPA Piemonte), Switzerland (MeteoSwiss), Poland (IMGW), Romania (NMA) and Russia (RHM). The general goal is to develop, improve and maintain a non-hydrostatic limited area modelling system to be used for both operational and research applications by the members of COSMO. This system is initially based on the COSMO-Model (previously known as LM) of DWD with its corresponding data assimilation system.

The Technical Reports are intended

- for scientific contributions and a documentation of research activities,
- to present and discuss results obtained from the model system,
- to present and discuss verification results and interpretation methods,
- for a documentation of technical changes to the model system,
- to give an overview of new components of the model system.

The purpose of these reports is to communicate results, changes and progress related to the LM model system relatively fast within the COSMO consortium, and also to inform other NWP groups on our current research activities. In this way the discussion on a specific topic can be stimulated at an early stage. In order to publish a report very soon after the completion of the manuscript, we have decided to omit a thorough reviewing procedure and only a rough check is done by the editors and a third reviewer. We apologize for typographical and other errors or inconsistencies which may still be present.

At present, the Technical Reports are available for download from the COSMO web site (www.cosmo-model.org). If required, the member meteorological centres can produce hard-copies by their own for distribution within their service. All members of the consortium will be informed about new issues by email.

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