Preliminary activity with COSMO-1 over Turin including TERRA-URB parameterisation

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Introduction

The increase of built surfaces constitutes the main reason for the formation of Urban Heat Islands (UHIs).

While natural soil with vegetation uses most of the absorbed radiation in evapotranspiration processes with release of water vapor cooling the surrounding air, paved terrains and buildings tend to absorb a lot of the incident radiation, which is then released as heat.

The main characteristics of UHIs are the following:

- **During the warmest hours of the day there are small differences between urban and suburban areas;**
- **At sunset the thermal inertia of the city is higher than elsewhere, so there the temperature decreases much less than in rural areas, leading to the maximum temperature differences during the night.**

The urban land use

The modelization of urban environment has gained much attention in the last years; in fact, multiple parameterisations for the land use type have been developed.

•**The** bulk schemes **take into account the overall radiative, thermal, turbulent-transfer properties, and water-storage capacity of the urban canopy with a set of bulk parameters. These model parameters are estimated from model sensitivity experiments. The bulk schemes are suitable for capturing the general characteristics of the urban climate in regional climate modelling in an efficient way. However, they do not explicitly resolve the complex processes depending on the local characteristics of the urban canopy, which further modulate the urban climate.**

•**The** explicit canyon schemes **explicitly capture the complex physical processes depending on the local characteristics of the urban canopy, which further modulate the urban climate. Yet, the applicability of these explicit-canyon schemes for atmospheric modelling is sometimes limited by either the lack of detailed urban canopy information, computational cost and their model complexity.**

Urban models in COSMO-CLM

In COSMO-CLM 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 parameterisation of the urban land have been carried out.

Up to now, three urban land use parameterisations have been developed in COSMO-CLM.

1. **Model CCLM-DCEP: multilayer urban canopy model**
2. **Model CCLM-TEB: single layer urban canopy model**
3. **Model CCLM-TERRA-URB: bulk parameterisation scheme with a prescribed anthropogenic heat flux.**

Details of the urban models

Each urban canopy model accounts for the anthropogenic heat flux, Q_F, which can be divided into four components:

$$Q_F = Q_{Fv} + Q_{Fb} + Q_{Fm} + Q_{Fi}$$

The subscripts *v*, *b*, *m* and *i* refer to vehicular, building, human metabolic and industrial heat emissions respectively.

DCEP and TEB <u>explicitly calculate</u> these components, using a detailed representation of the generic street canyon. <u>TEB in particular uses a tile approach</u>: each grid cell has a fraction of urban land resolved by TEB and a fraction of non-urban land resolved by TERRA. The urban canopy parameters used in DCEP and TEB (building fraction, height and width) are derived from a data set of impervious surfaces and a digitalized 3D data set.

TERRA-URB and SURY

The simple bulk-model CCLM-TERRA-URB parameterizes 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. The use of the previously estimated anthropogenic heat flux, modified thermal and radiative parameters and a modified surface-layer transfer scheme, provides the urban heat island with the correct diurnal phase. The magnitude of this flux can potentially be revised to fit the mean measured signal.

TERRA-URB uses a pre-calculated Q_F, which accounts for country-specific data of energy consumption, calculated based on the population density and the latitude dependent diurnal and seasonal distribution. Due to this simple representation of the urban land as a bulk, TERRA-URB is computationally inexpensive.

The latest version of TERRA-URB implements the Semi-empirical Urban canopy parameterization (SURY)**. It translates urban-canopy parameters (containing 3D information) into bulk parameters.**

TERRA-URB: additional parameters

TERRA-URB takes additional surface parameter input fields:

ISA, AHF

Namelist ID	Full name	Symbol[a]	Unit	I/O
ISA	Impervious surface area	f_{imp}		I
AHF	Annual-mean anthropogenic heat flux	-	W m^{-2}	I
UCS_SALB[b]	Urban-canopy substrate shortwave albedo	α	-	I
UCS_TALB[b]	Urban canopy substrate thermal albedo	$(1-\epsilon)$		I
UCS_LAM[b]	Urban canopy substrate heat conductivity	λ_s	$\text{W m}^{-1}\text{K}^{-1}$	I
UCS_RHOC[b]	Urban canopy substrate heat capacity	$C_{v,s}$	$\text{J m}^{-3}\text{K}^{-1}$	I
UC_H[b]	Building height	H	m	I
UC_HTW[b]	Canyon height-to-width ratio	$\frac{H}{W}$		I
UC_ROOF[b]	Roof fraction	-	W m^{-2}	I
KBMO	Inverse Stanton number	κB^{-1}	-	O
W_IMP	Water-storage content on the impervious surface area	w_{imp}	kg m^{-2}	O
W_ISA	Water-storage content on the impervious surface area (weighted according to the ISA fraction)	$w_{\text{imp}} f_{\text{imp}}$	kg m^{-2}	O
AHF_NOW	Anthropogenic heat flux of the current timestep	w_{imp}	kg m^{-2}	O

The mandatory fields are the Impervious Surface Area (ISA) and the Annual-mean anthropogenic Heat Flux (AHF). These fields can be generated with EXTPAR version 3.

Activation of TERRA_URB can be achieved by turning on the main switch:

```
&PHYCTL
l_urb = .TRUE.
```

The fields are transferred to the COSMO model by INT2LM, by using the following switches:

```
&CONTRL
…
l_isa = .TRUE.
l_ahf = .TRUE.
…
```

SURY input and output

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By default, TERRA-URB takes fixed values for the urban canopy parameters. Varying urban-canopy parameters are optional.

Input of SURY

urban-canopy parameters (input of SURY)		
parameter name	symbol	default values
substrate albedo	α	0.101
substrate emissivity	ϵ	0.86
substrate heat conductivity	λ_s	$0.777\,\mathrm{W\,m^{-1}\,K^{-1}}$
substrate heat capacity	$C_{v,s}$	$1.25 \times 10^6\,\mathrm{J\,m^{-3}\,K^{-1}}$
building height	H	15 m
canyon height-to-width ratio	$\frac{H}{W}$	1.5
roof fraction	R	0.667

Output of SURY

bulk parameters (output of SURY)		
parameter name	symbol	surface-level values corresponding to urban-canopy defaults
bulk albedo	α_{bulk}	0.081 (snow-free)
bulk emissivity	ϵ_{bulk}	0.89 (snow-free)
bulk heat conductivity	λ_{bulk}	$1.55\,\mathrm{W\,m^{-1}\,K^{-1}}$
bulk heat capacity	$C_{v,\mathrm{bulk}}$	$2.50 \times 10^6\,\mathrm{J\,m^{-3}\,K^{-1}}$
bulk thermal admittance	$\mu_{\mathrm{bulk}} \left(= \sqrt{C_{v,\mathrm{bulk}}\,\lambda_{\mathrm{bulk}}}\right)$	$1.97 \times 10^3\,\mathrm{Jm^{-2}K^{-1}s^{-1/2}}$
aerodynamic roughness length	z_0	1.125 m
inverse Stanton number	kB^{-1}	13.2 [in case that $u_* = 0.25\,\mathrm{m\,s^{-1}}$]

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The Test Case considered

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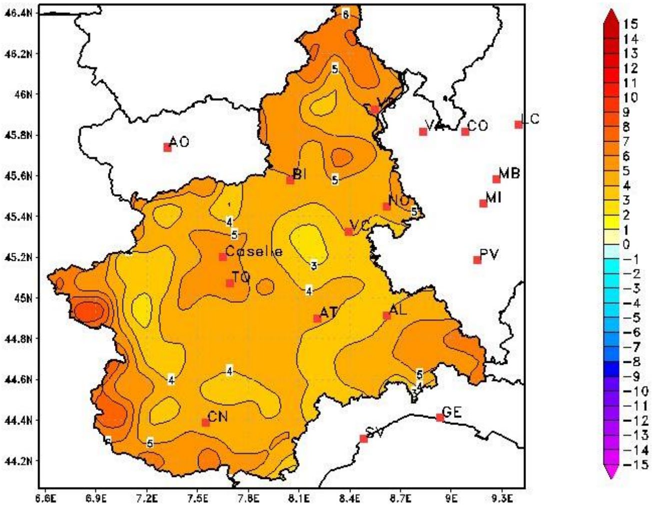
In the period 1-16 July 2015, Piedmont region and Turin in particular experienced extreme temperature values and uncomfortable conditions for the population.
In Turin, the maximum temperature since 1990 (38.5°) has been recorded in July 2015.
Ground stations data highlighted the presence of a UHI effect over Turin.



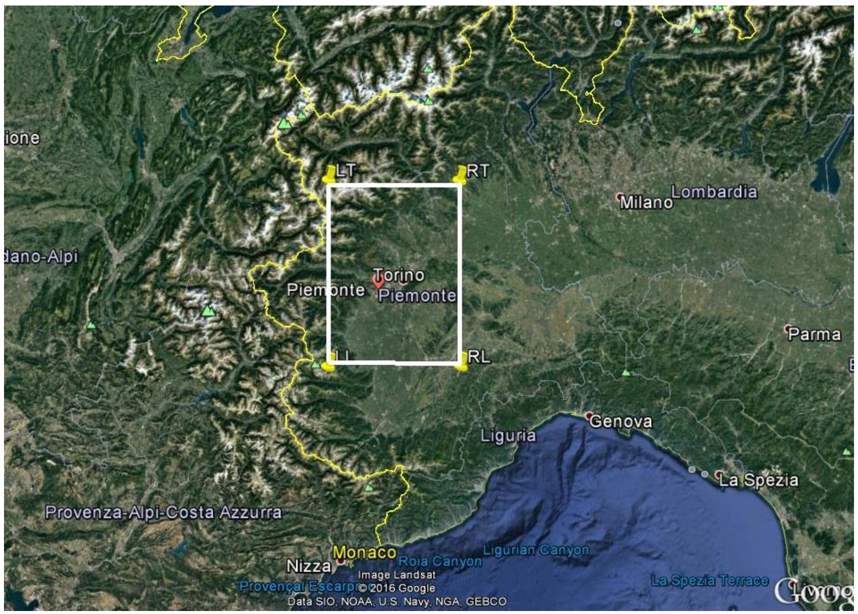
Anomaly of Maximum temperature of the period 1-16 July 2015 with respect to the reference period 1971-2000.
Source: ARPA Piemonte

This is the reason why this area and this period represent a suitable benchmark to test the capabilities of COSMO-CLM, and in particular of the urban parameterization.

The Test Case considered

Domain**: 7.15 – 8.05 E ; 44.6 – 45.5 N**

Rotated North Pole**: 8 (-172)° ; 45°**



The computational domain

Location of the three observation stations considered in the Torino area (1, 2 and 9). The choice has been decided on the base of a previous study published in COSMO Newsletter n°16.

Model version and set-up

- Model versions:

  - int2lm_2.0_clm4

  - cosmo_5.0_clm8

- COSMO-CLM resolution: **0.009° (about 1 km)**
- Computational domain**: 100 x 100 points; 60 vertical levels, time step 3 s.**
- Deep-convection resolving set-up, also including tuning settings regarding soil heat conductivity
- Time period: From 1 to 7 July 2015
- Forcing data: ECMWF IFS analysis (resolution of 0.075°)
- Validation dataset provided by ARPA Piemonte for the stations:

Moncalieri/Bauducchi	**44.961111°**	**7.709227°**
Giardini Reali	**45.073699°**	**7.688576°**
Consolata	**45.076667°**	**7.679444°**

List of simulations performed

Basic simulations:

•NON-URB: **Simulation with TERRA-URB off**

•URB: **Simulation with TERRA-URB on and setting itype_turb = 3 (prognostic TKE turbulent scheme)**

•URB_1: **Simulation with TERRA-URB on and setting itype_turb = 1 (diagnostic TKE turbulence scheme)**

•I1: **Simulation performed with the COSMO operational Italian setup, at 0.009° resolution (CTRL)**

Supplementary simulations:

•URB_1 AHF mod: **Similar to URB_1, but with redistribution of the AHF field (according to the ISA field).**

•URB_1 AHF 0: **Similar to URB_1, but with AHF = 0**

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Distribution of the additional parameters the area considered

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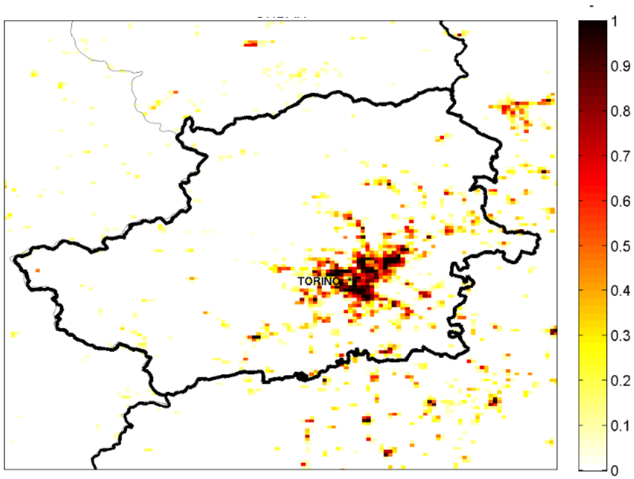
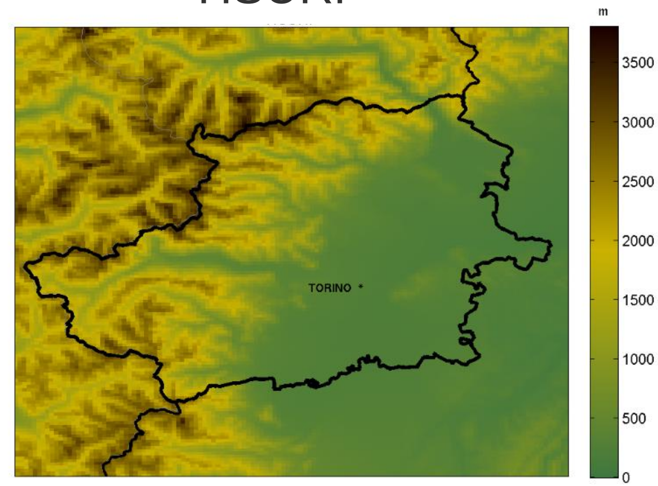
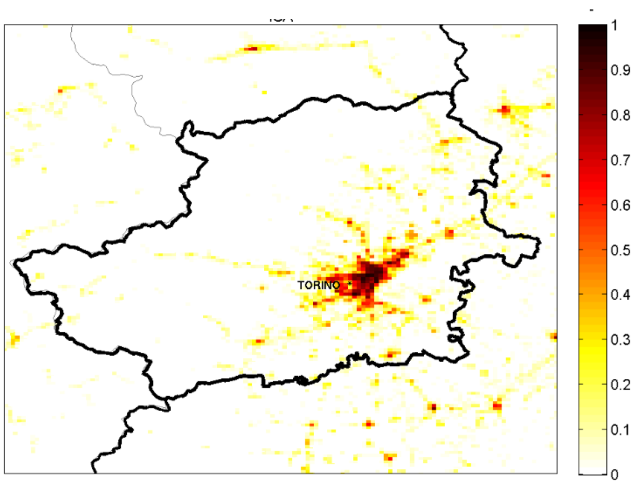
URBAN



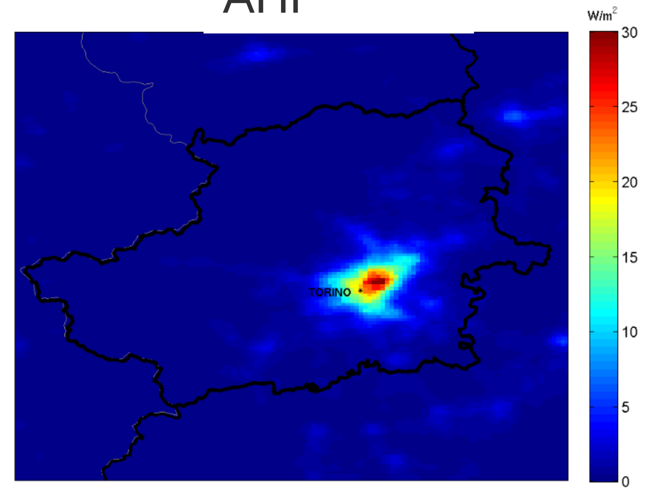
HSURF



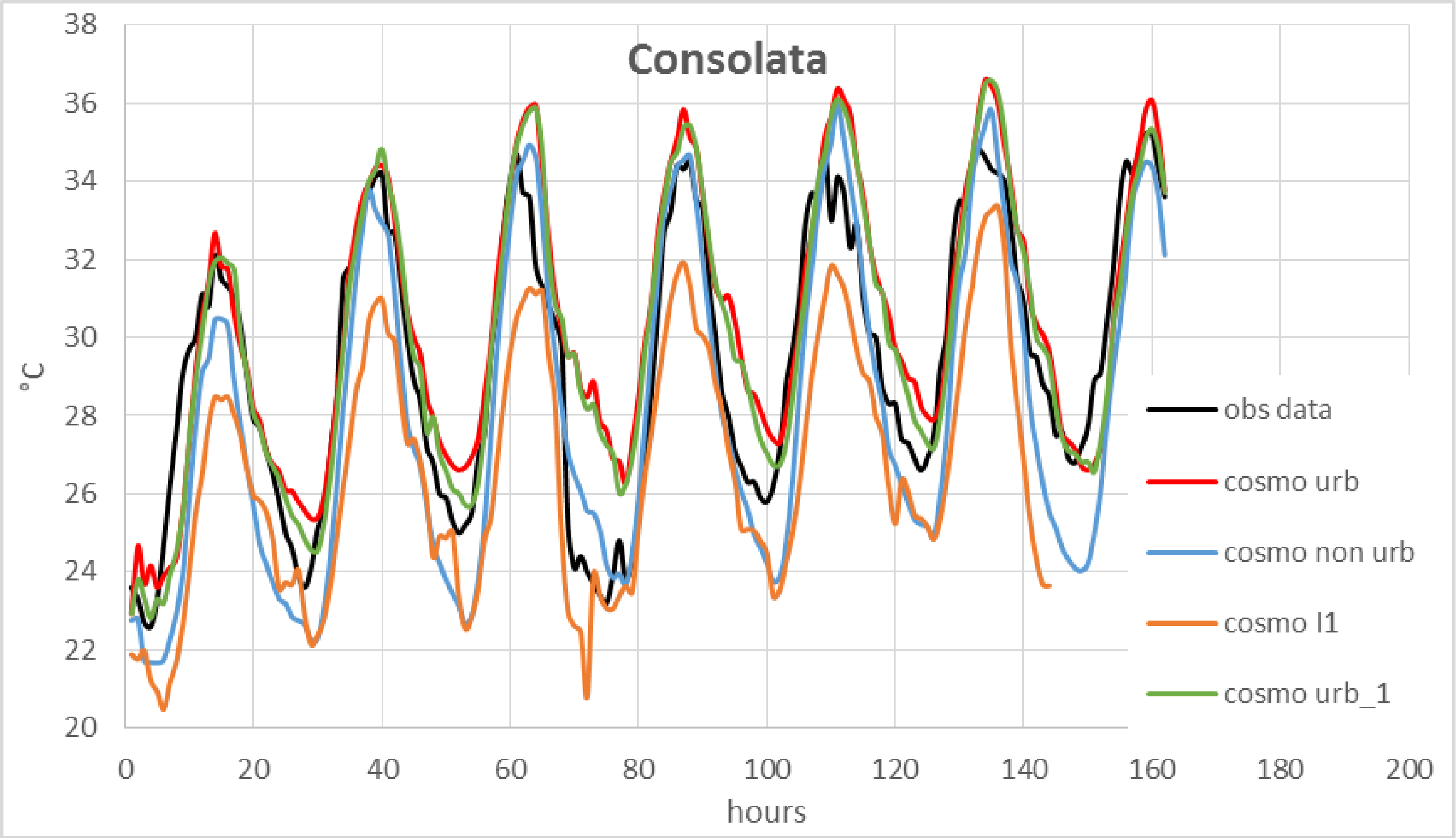
ISA



AHF



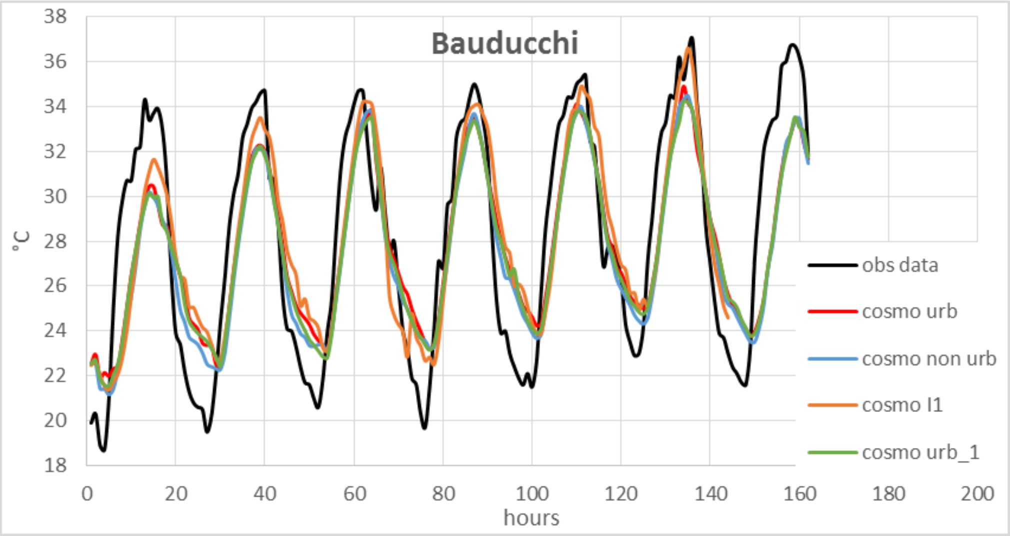
Results: Time series of T2m



Time series T2m for Consolata station (urban cell) with the different simulations and observational data.

-**The daily maximum temperature is overestimated, especially by** URB
-**The daily minimum temperature is simulated better with** URB **than** NON-URB**.**
-**Setting itype_turb = 1 produces slight better results if compared with itype_turb = 3**

Results: Time series of T2m



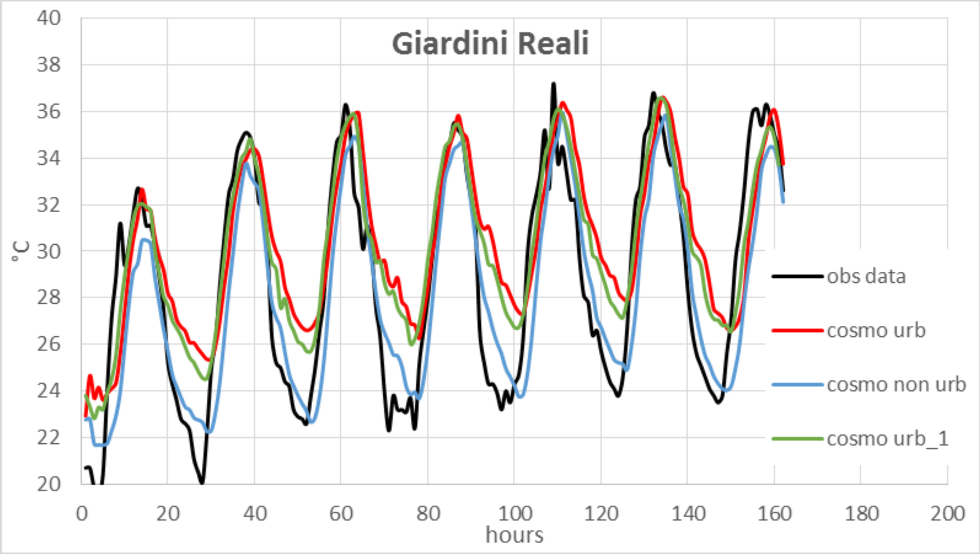
Time series T2m for Moncalieri/Bauducchi station (rural cell) with the different simulations and observational data.

- As expected, no significant differences between URB **and** NON-URB.

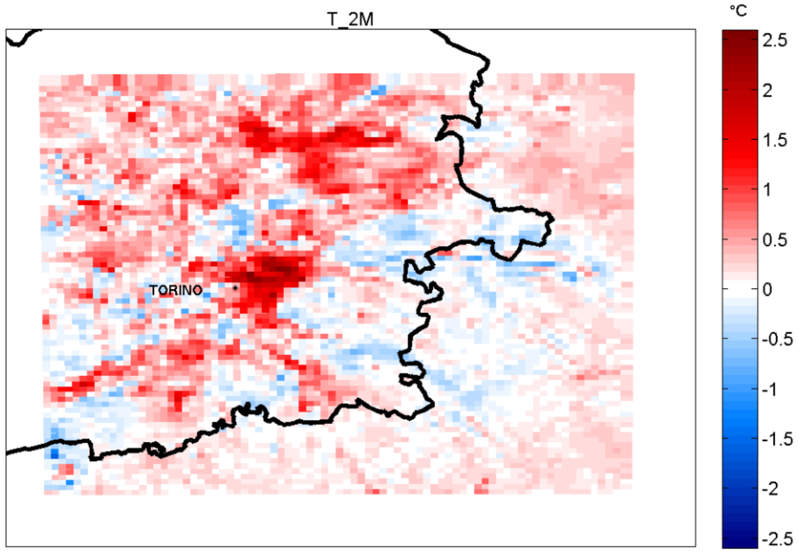
Time series T2m for Giardini Reali station with the different simulations and observational data.

- As expected, no significant differences between URB **and** NON-URB

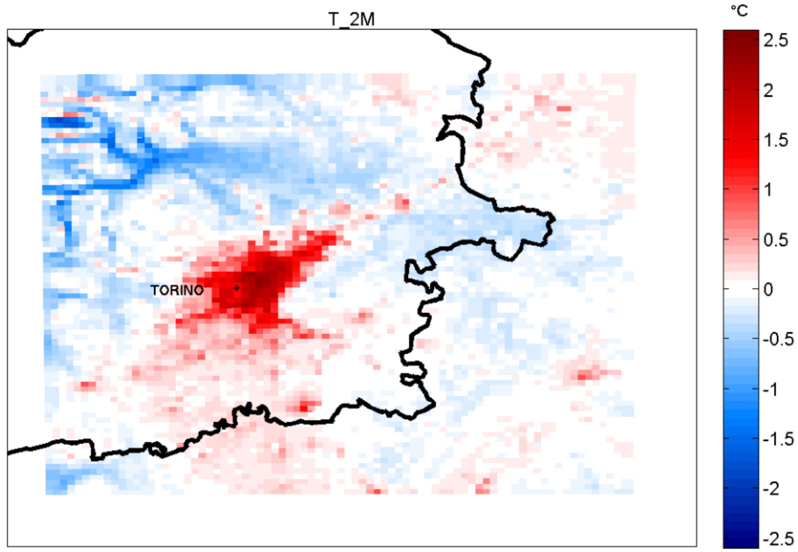
This station is placed in a city park, therefore it is more correlated to a rural station rather than a urban one.



T2m distribution fields



T2m at 3 pm of July 5: difference between URB_1 **and** NON URB**.**



average T2m value: difference between URB_1 **and** NON URB**.**

The picture on the left shows the difference between URB_1 and NON URB of the distribution of T2m at 3 pm of July 5th.
The picture on the right shows the difference between URB_1 and NON URB of the distribution of T2m, averaged over the whole simulation period.

T2m (°C) observed value and Average bias on the period 1-7 July

	Obs	BIAS URB	BIAS URB_1	BIAS NON URB	BIAS I1
Consolata	**29.4**	**0.94**	**0.68**	**-1.22**	**-2.53**
Moncalieri	**28.2**	**-0.39**	**-0.55**	**-0.74**	**0.11**
G. Reali	**28.7**	**1.57**	**1.37**	**-0.59**	**-**

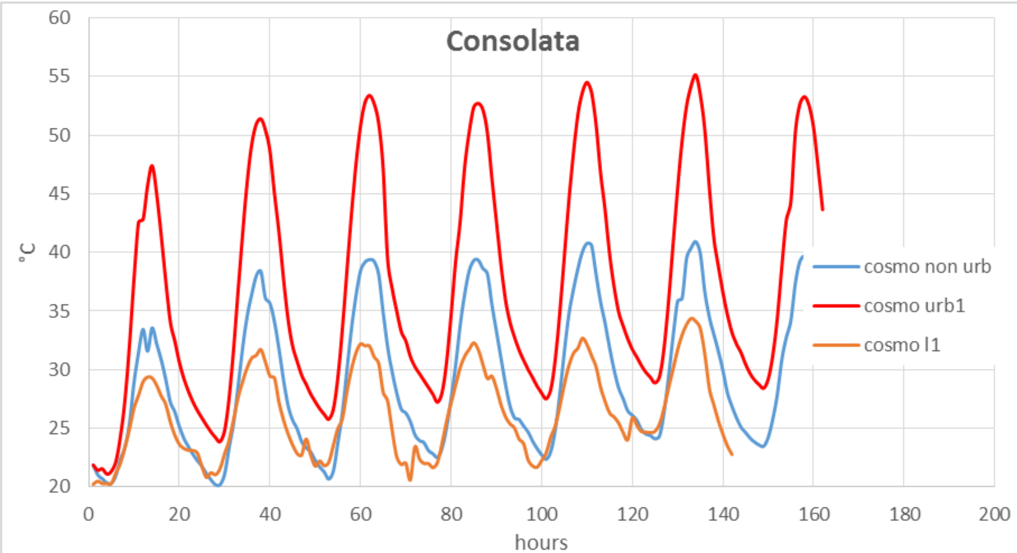
This table shows the average observed T2m value and the average bias (model minus observation) related to the basic simulations.

Comments

-URB **allows a reduction of the average bias compared with** NON URB**.**

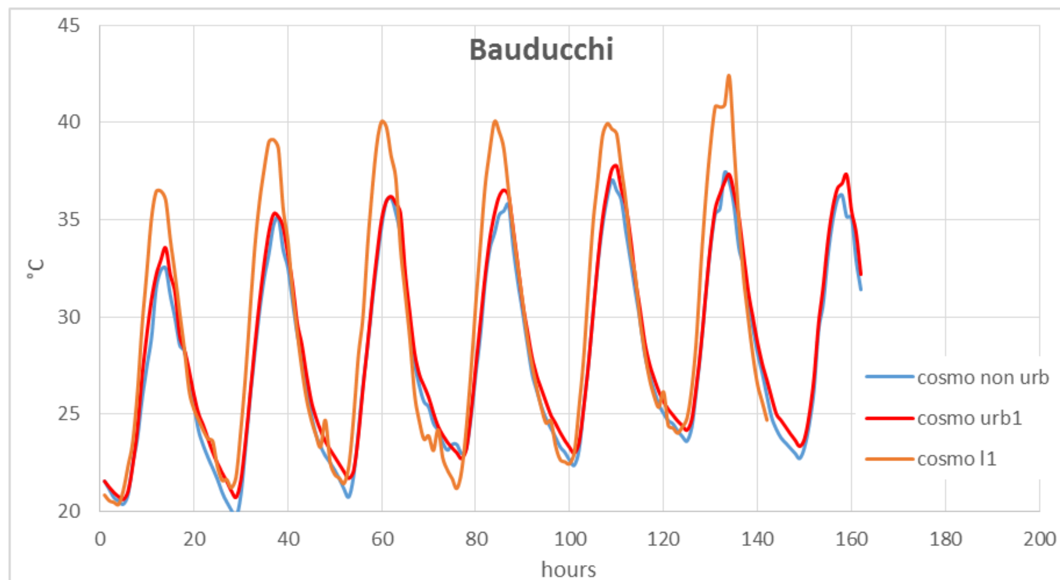
-setting itype_turb = 1 produces better results, according also with Wouters (2016, personal communication).

Time series of T soil



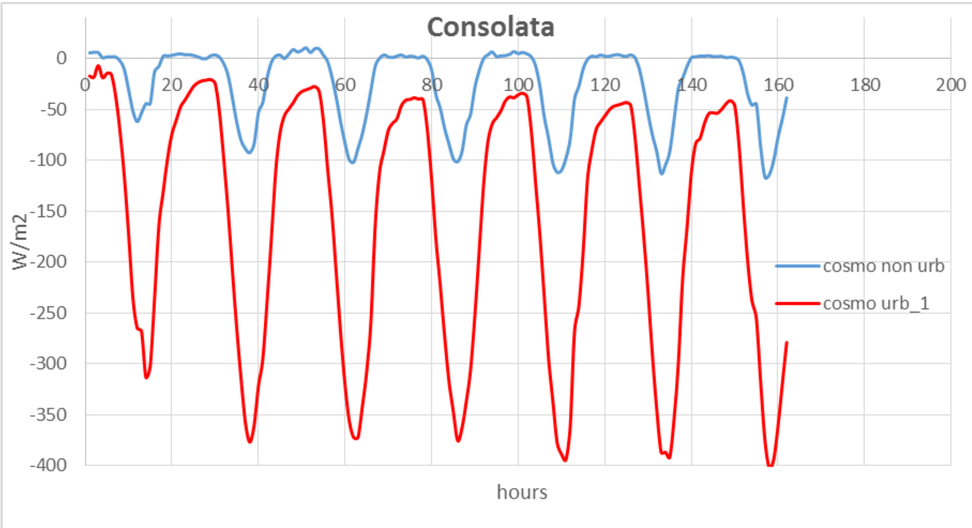
Time series of T soil for Consolata and Bauducchi stations with three different simulations (URB_1, NON URB **and** I1**).**

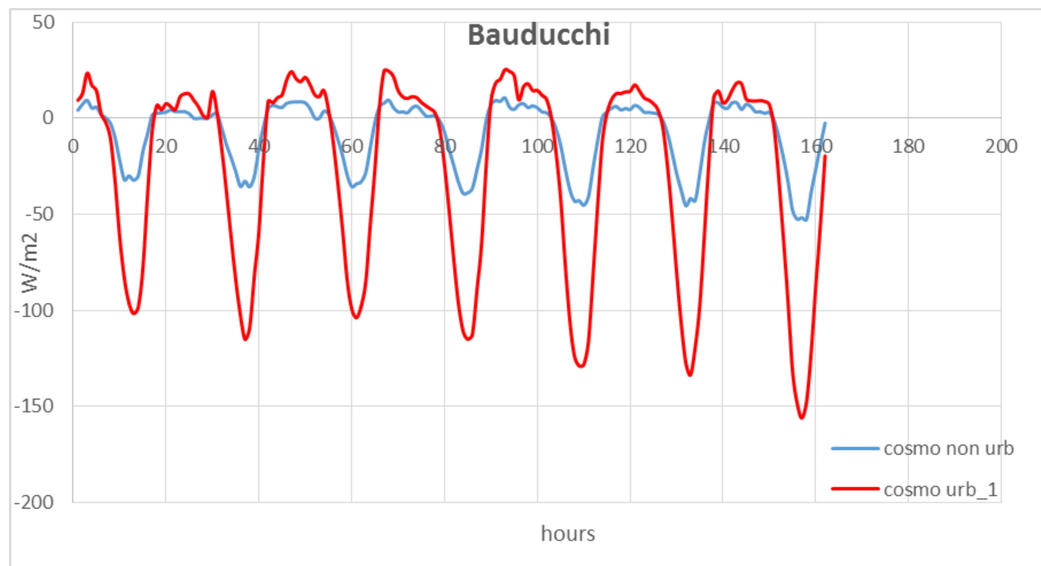
URB_1 allows a significant modification of T soil (with respect to **NON URB**) only in Consolata (urban area).



Time series of sensible heat flux

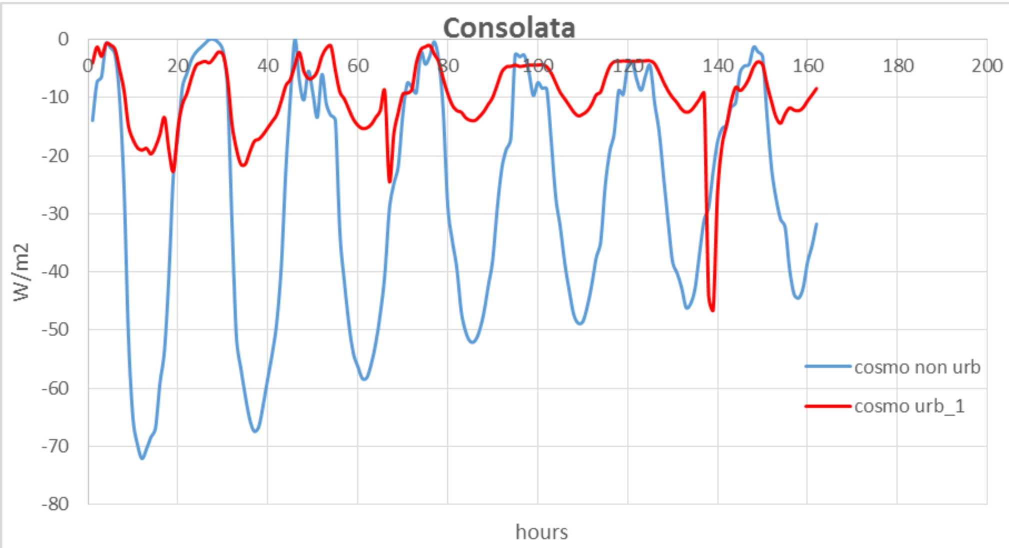
Time series of sensible heat flux for Consolata and Bauducchi stations with two different simulations (URB_1**,** NON URB**).**





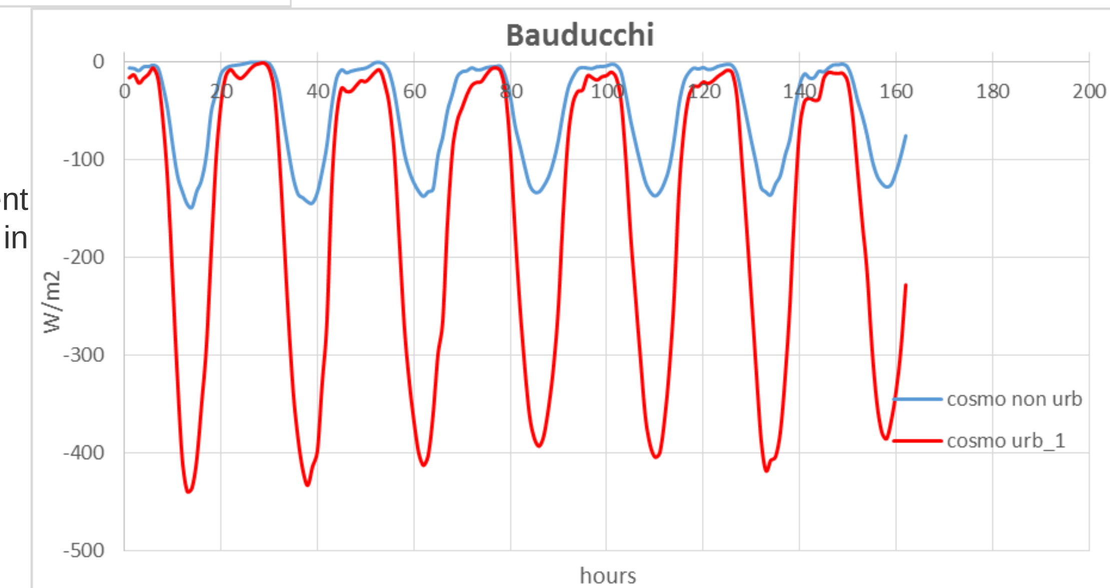
URB_1 allows a significant modification of the sensible heat flux time series (with respect to **NON URB**) in both the stations.

Time series of latent heat flux



Time series of latent heat flux for Consolata and Bauducchi stations with two different simulations (URB_1**,** NON URB**).**

URB_1 allows a significant modification of the latent heat flux time series (with respect to **NON URB**) in both the stations.



Conclusions

- **Simulations performed with COSMO-CLM over Turin area at very high resolutions (about 1 km) have been performed over the period 1 to 7 July 2015.**

- **The bulk model TERRA-URB parameterizes the effects of buildings on the air flow using the externally calculated anthropogenic heat flux.**

- **The effects of the introduction of urban parameterization on the quality of results have been quantified.**

- **TERRA-URB allows a better representation of the daily minimum temperature. This is a remarkable results, since it is the minimum temperature that determines the UHI.**

- **However, considerable work is still needed, especially for what concerns the optimization of the model configuration.**

Future work at CIRA and ARPA Piemonte

- **To provide the other urban parameter fields as input for the simulations eg., by means of the WUDAPT framework. (For now, these other parameters are set to default values).**

- **To reconsider the default values (which are currently hard-coded in data_soil.f90) depending on the urban canopy properties of Turin.**

Thanks for your attention

Hendrik Wouters (KU Leuven, Belgium) and Uli Blahak (DWD) are gratefully acknowledged for providing the COSMO/TERRA-URB software package and for the support.

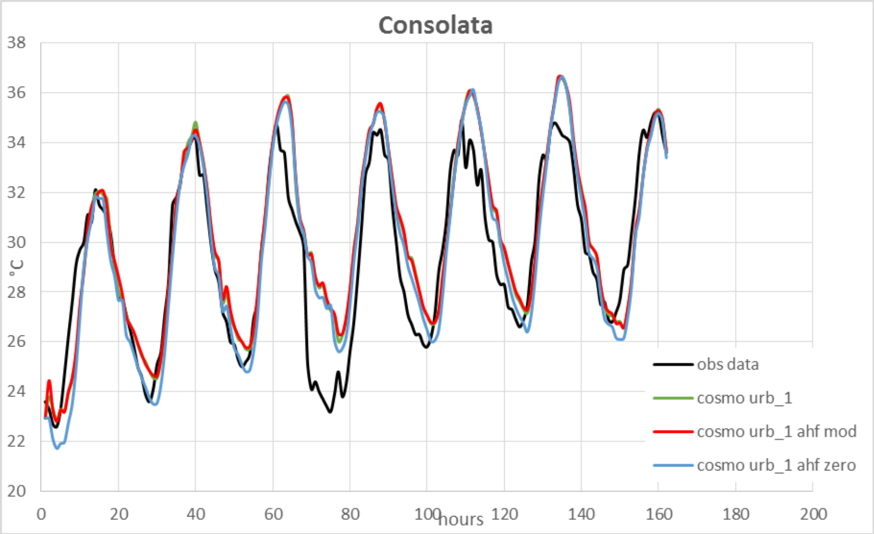
Daily T2m observed value and maximum bias

	Obs	BIAS URB	BIAS URB_1	BIAS NON URB	BIAS I1
Consolata	**29.4**	**5.5**	**5.4**	**-5.1**	**-6.4**
Moncalieri	**28.2**	**-6.6**	**-6.6**	**-6.9**	**-7**
G. Reali	**28.7**	**6.7**	**5.8**	**-7.2**	**-**

This table shows the average observed T2m value and the maximum daily bias (model minus observation) related to the basic simulations.

Results: Time series of T2m

Analysis of supplementary simulations



Time series of T2m for Consolata and Bauducchi stations with the supplementary simulations (AHF MOD **and** AHF0**),** URB_1 **and observational data.**

AHF MOD and AHF0 do not provide relevant difference with respect to the basic simulation.