SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2022
Project Title:	Implementation and test of a urban parameterization module in ICON Model
Computer Project Account:	Spitmil2
Principal Investigator(s):	Massimo Milelli (mcy)
Affiliation:	CIMA Research Foundation
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Valeria Garbero (mcy0) – Arpa Piemonte, Francesca Bassani – Polytechnic of Turin
Start date of the project:	2021
Expected end date:	2022

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	900000	477.120	900000	0
Data storage capacity	(Gbytes)	200	174	200	174

Summary of project objectives (10 lines max)

The final goal of the project is to finalize the implementation of the urban parametrization (called TERRA_URB) in the official release of COSMO model and, consequently, to implement it into ICON model. The technical part of the work is supported by verification, using the data of the Italian network. Two case studies have been selected, in October 2017 and July 2020 in Torino.

Summary of problems encountered (10 lines max)

There were technical problems when installing the latest version of ICON (the one with TERRA_URB) on cca. The German Weather Service (DWD) is aware of this problems, but in order to speed up the work, we started the migration to ATOS and this took more time than what we expected. For this reason, no results with ICON Model are available up to now. Also for the same reason, we did not use resources on cca in 2022, but only a small amount of them on ATOS.

Summary of plans for the continuation of the project (10 lines max)

In 2022 we will perform ICON case studies on ATOS to assess the parameterization, fix the bugs and test different external parameters databases. The idea then is to have a continuation in 2023 in order to run the (hopefully) stable version of ICON+TERRA_URB for longer periods because a larger statistics is needed.

List of publications/reports from the project with complete references

Garbero, V.; Milelli, M.; Bucchignani, E.; Mercogliano, P.; Varentsov, M.; Rozinkina, I.; Rivin, G.; Blinov, D.; Wouters, H.; Schulz, J.-P.; Schättler, U.; Bassani, F.; Demuzere, M.; Repola, F. Evaluating the Urban Canopy Scheme TERRA_URB in the COSMO Model for Selected European Cities. Atmosphere 2021, 12, 237. https://doi.org/10.3390/atmos12020237.

Summary of results since the beginning of the project

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

The area of study is the city of Torino, Northern Italy (FIG. 1), where we have selected 3 urban stations (Reiss Romoli, Alenia, Consolata) and a reference rural station (Bauducchi). The simulations, obtained with a parallel branch of the mode (not official) have the following structure:

- initial and boundary conditions from the Integrated Forecast System (IFS, grid resolution: 9km)
- nesting: domain size 350x350 km centered around Turin → final grid spacing: 1km
- observations provided by the Arpa Piemonte network (hourly data)
- case study 1: 22-29 October 2017
- case study 2: 16-22 March 2020
- zero-order model (TERRA_URB off) – SIM0 / REF_TUF
- urban parameterization (TERRA_URB on) – SIM1 / REF
- TU on, ISA & AHF from LCZs – SIM2 / LCZ
- for SIM1 (and REF), the city-descriptive parameters ISA (impervious surface area) and AHF (anthropogenic heat flux) are provided by COSMO software EXTPAR
- for SIM2 (and LCZ) they derive from the Local Climate Zones (LCZs) classification system [1]
- urban stations are averaged in order to have a single urban super-obs

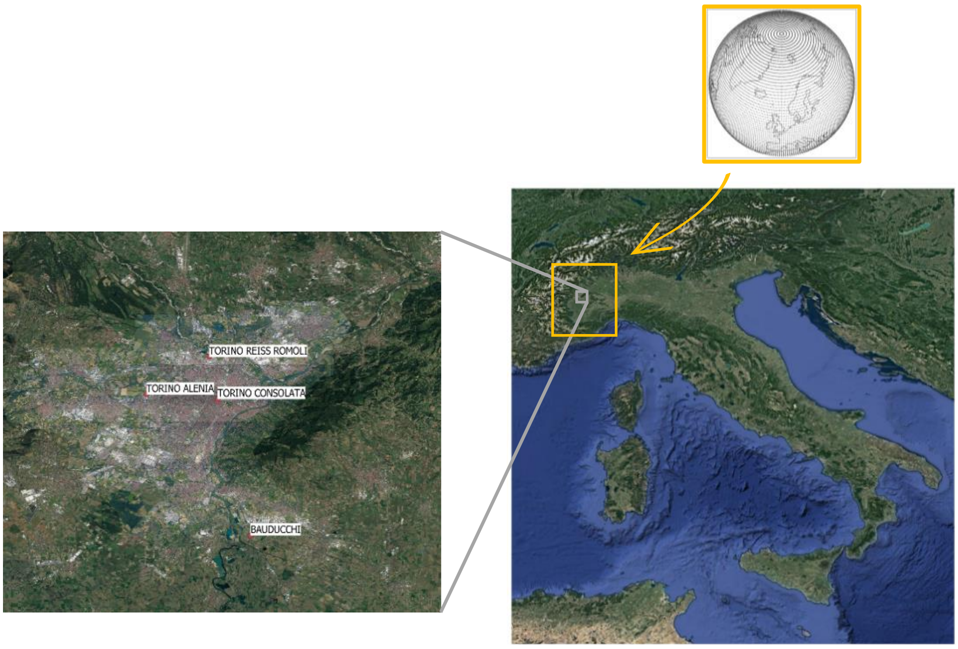


FIG. 1: domain of the study

The city stores heat during the day and releases it during the night, having warmer urban temperatures than the surroundings and this is well reproduced by the activation of TERRA_URB, while SIM0/REF_TUF are not able to capture the UHI intensity (FIG. 2).

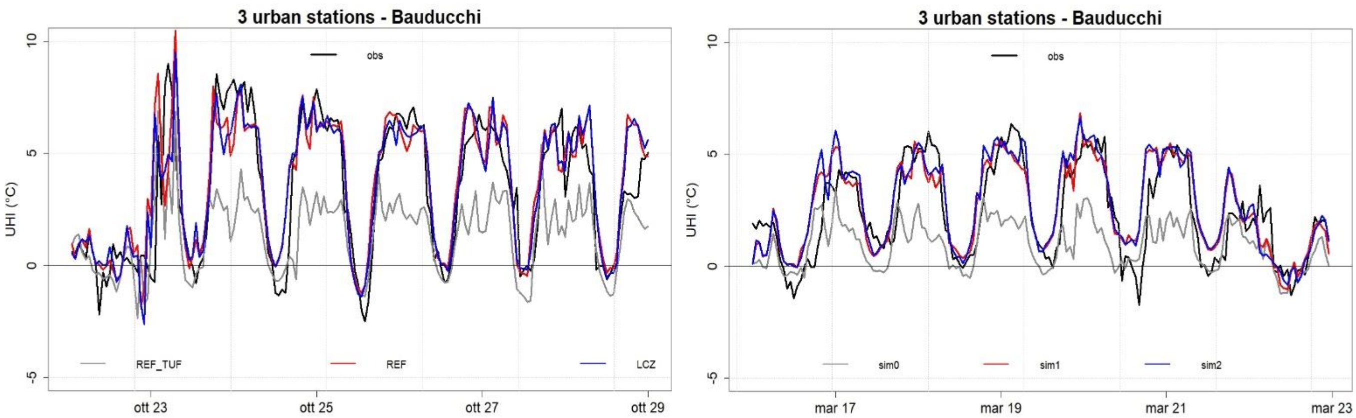


FIG. 2: UHI, October 2017 (left) and March 2020 (right).

Then we studied the impact of the 3 urban canopy parameters used in TERRA_URB, that is Building area Fraction (BF), building Height (H) and canyon Height-to-Width ratio (H/W). We used (for the 2017 case) different values of the parameters (TAB. 1), comparing to the LCZ simulation that contains the default values defined in [2].

The resulting UHI is in FIG. 3. In this case, only the station of Torino Consolata has been used.

It can be seen that the main impact is given by the Building area Fraction (in green), which reduces Tmax and increases Tmin (moving from 0.67 to 0.5).

	BF (%)	H (m)	H/W
LCZ	0.67	15	1.5
LCZ_BF	**0.5**	15	1.5
LCZ_H	0.67	**8**	1.5
LCZ_HW	0.67	15	**1**

TAB. 1: values of the parameters for the sensitivity study.

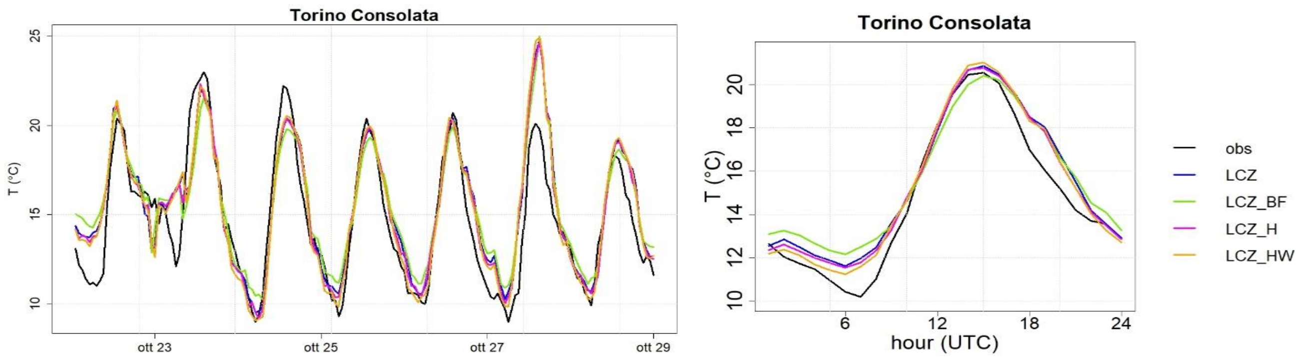
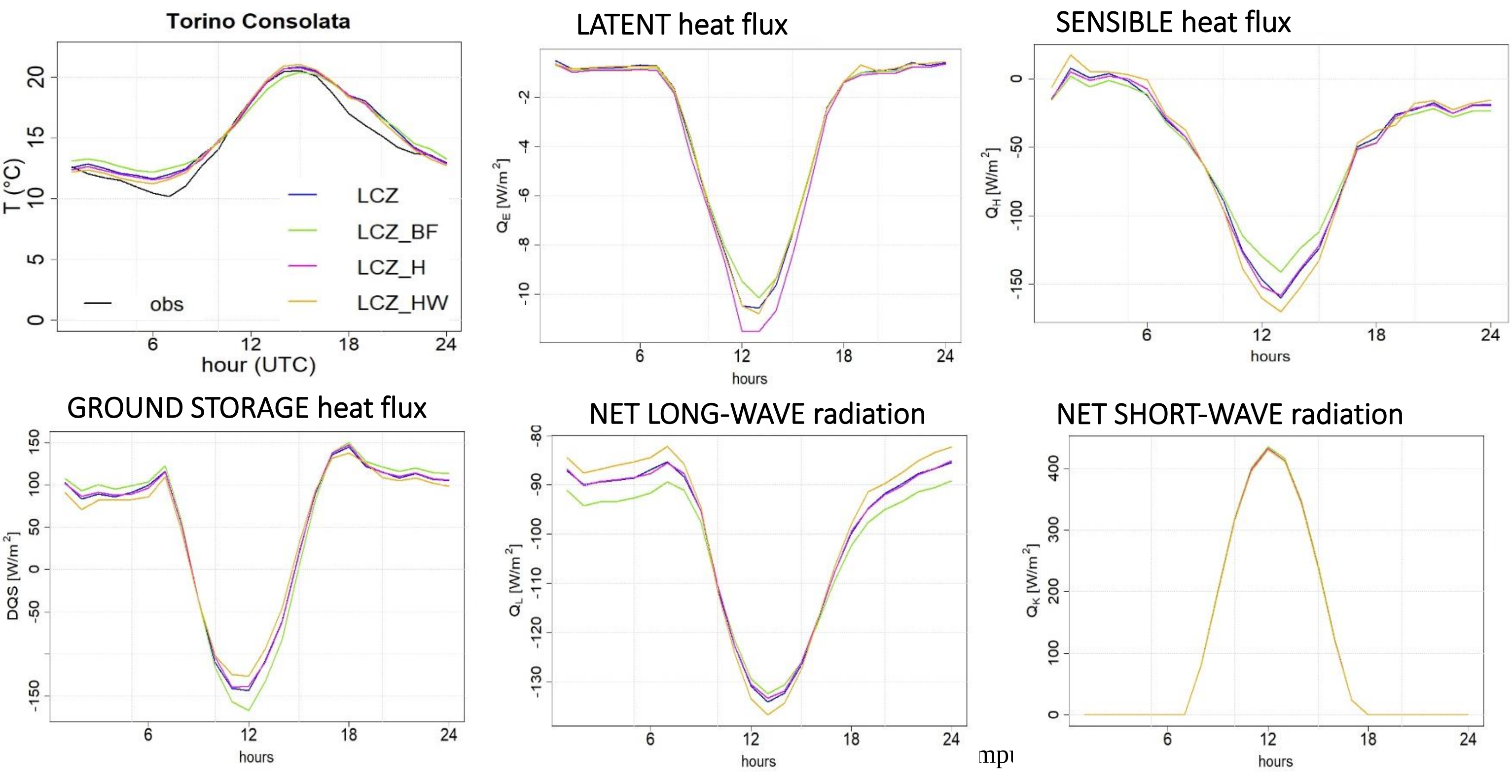


FIG. 3: T2m (left) and mean T2m (right).

Eventually we looked at the Surface Energy Balance (SEB) for the 2017 case, although there is no observation available (see TAB. 1 for the different simulations name). Following [3]:

- Q_K: net short-wave radiation
- Q_L: net long-wave radiation
- Q_H: sensible heat flux
- Q_E: latent heat flux
- ΔQ_S: ground storage heat flux
- $Q_K + Q_L + Q_H + Q_E + \Delta Q_S = 0$



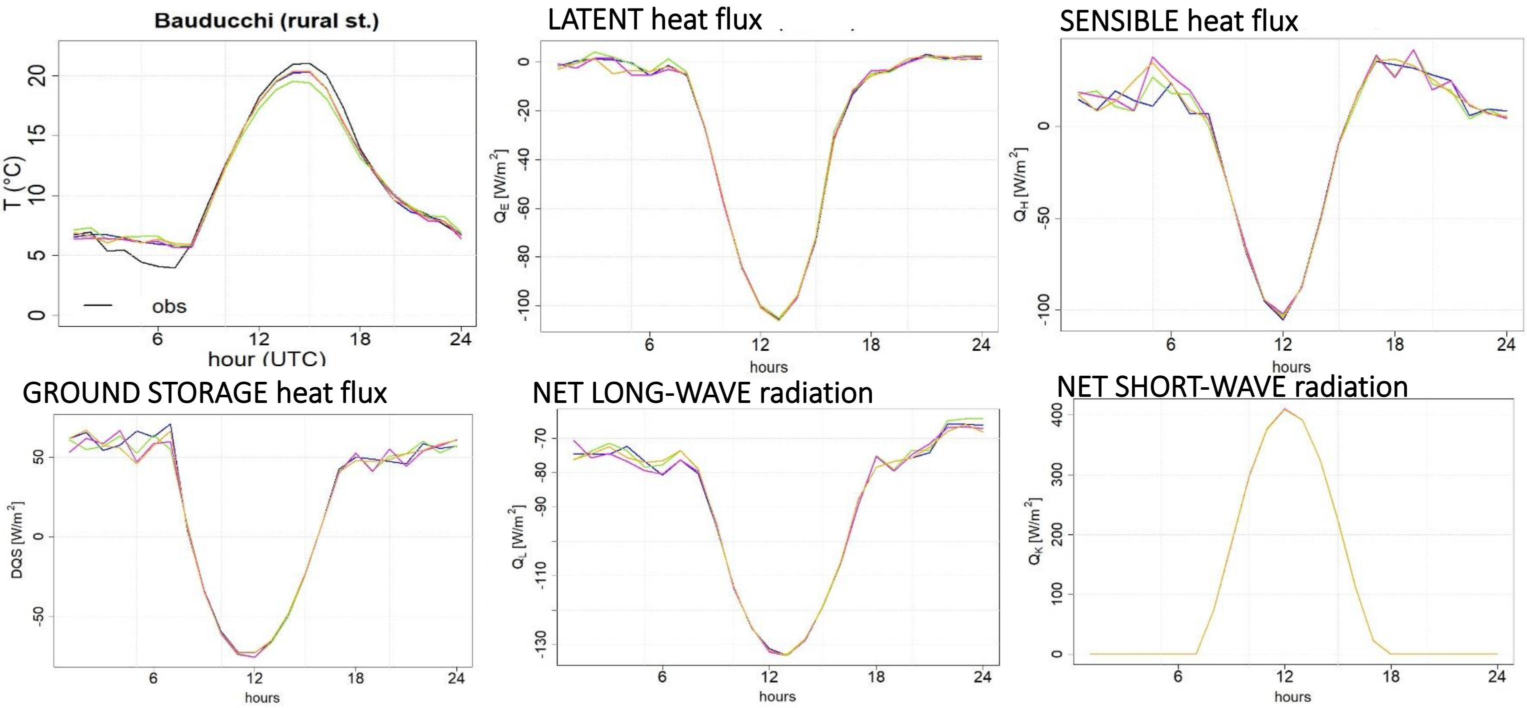


FIG. 4: surface fluxes for the simulations in TAB. 1.

In FIG. 4 are shown temperature and fluxes for the urban station of Torino Consolata (first two rows) and the rural station of Bauducchi (third and fourth rows), while the plots in FIG. 5 show the detail of the LCZ sim (TAB. 2). In particular, FIG. 5 (right) shows that the greatest differences between urban and rural areas are during daytime in the latent heat ($|Q_E|_{URB} \ll |Q_E|_{RUR}$), sensible heat (increased $|Q_H|$ in the city) and ground storage (increased $|\Delta Q_S|$ in the city), in accordance with the UHI effect.

BF (%)	H (m)	$\frac{H}{W}$
0.67	15	1.5

TAB. 2: values of the external parameters.

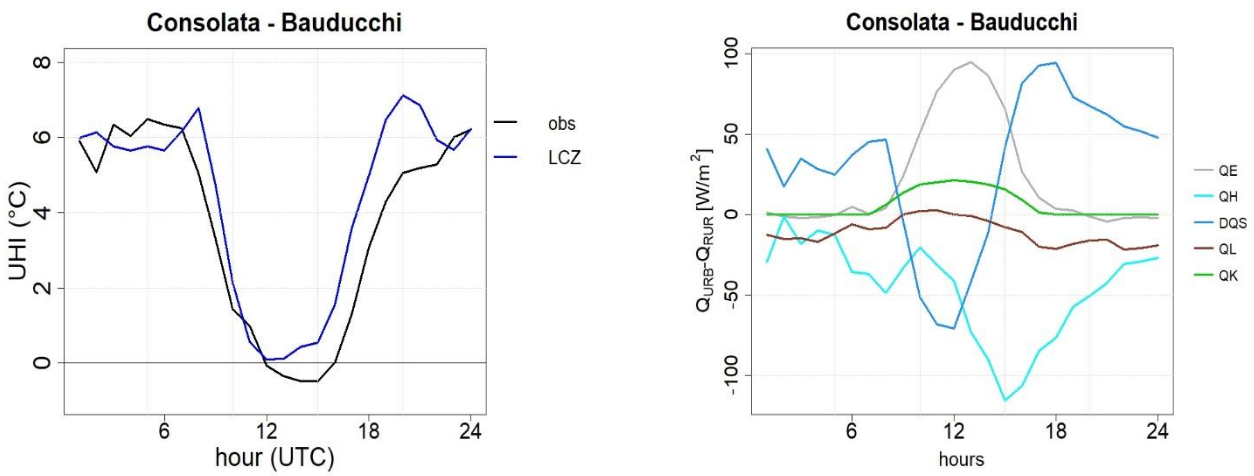


FIG. 5: LCZ sim, UHI (left) and SEB (right).

The main conclusions are the following:

This template is available at:
http://www.ecmwf.int/en/computing/access-computing-facilities/forms

- The activation of TERRA_URB (TU) positively improves the representation of the UHI phenomena over Torino
- The use of different datasets for the input external parameters ISA and AHF required in TU, does not provide a substantial improvement on the results
- However, the Local Climate Zones classification system yields to more accurate data as input values, with the possibility to describe the heterogeneity of different cities
- The urban-geometry parameters (required in TU) offer an even more realistic representation of an urban area. Their sensitivity analysis shows that the Building Fraction (BF) has the greatest impact on the results
- The largest differences between urban and rural occur for sensible heat flux (Q_H) and ground storage heat flux (ΔQ_S). The storage heat stored during the day is released during the night at higher rates for the urban area (UHI)

In a second step, the aim was to further explore the features on a three-dimensional level over the city of Turin (Italy), by analysing the vertical profiles simulated by the latest release of COSMO (6.0) at 1km resolution. We performed a sensitivity analysis on the same one week-case study, where the default values of the Urban Canopy Parameters were changed from lower to higher settings in order to understand their potential impact on the overlying atmosphere (TAB. 3). The simulation results were compared with 2m data in the city (FIG. 6) and with data observed by radiometers, one located in the city centre and the other one in the rural surroundings. Indeed, our results showed the relevance of analysing the urban parameterization also from the poorly investigated 3D point of view, at least up to 1000m of elevation reached by the radiometers (FIG. 7).

	Building height (hb)	Roof fraction (fr)	Height/Width (hw)	Surface albedo (as)	Emissivity (at)	Heat capacity (ca)	Heat conductivity (co)
default (LCZ)	15	0.67	1.5	0.10	0.86	1.25 x10^6	0.77
Low (_L)	3	0.3	0.5	0.05	0.75	0.3 x10^6	0.2
High (_H)	30	0.8	2	0.25	0.95	2 x10^6	1.3

TAB. 3: sensitivity analysis performed by varying the default values of UCP with H or L values.

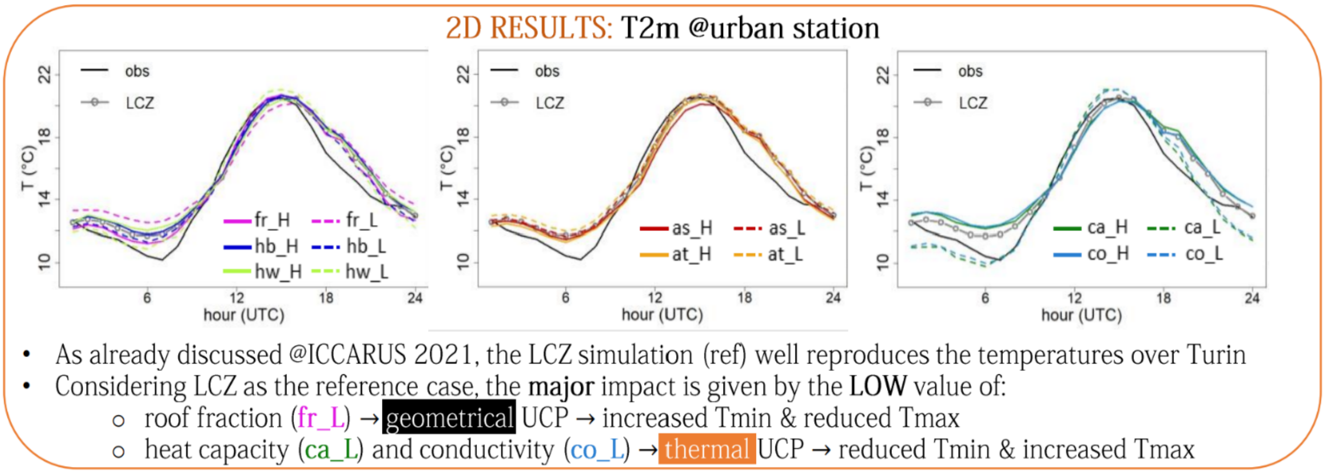


FIG. 6: T2m average daily cycle in Torino.

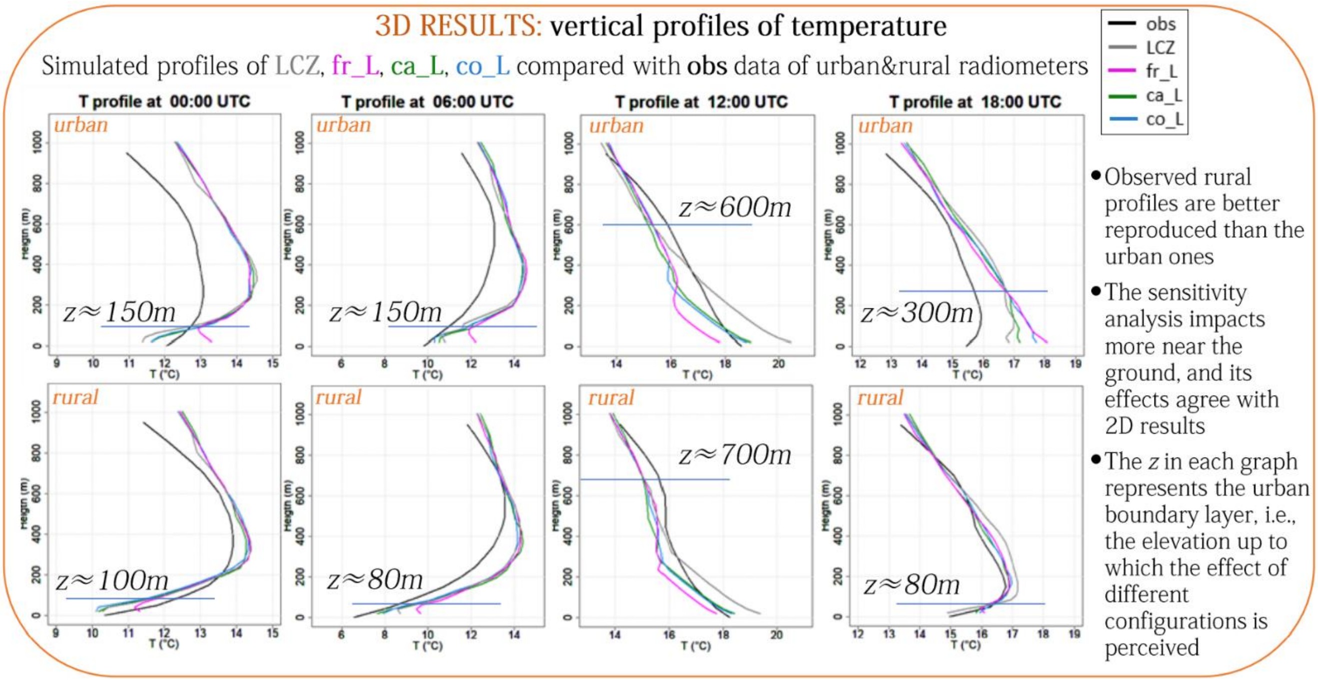


FIG. 7: vertical profiles of T.

The final step concerned a sensitivity analysis of the ICs/BCs, resolution and external dataset, according to the following scheme (TAB. 4):

- ICs/BCs:
  1. Integrated Forecast System (IFS)
  2. analysis of COSMO-2I (by ArpaE in Bologna)
- Horizontal Resolution:
  1. 1 km
  2. 500 m
- Dataset for Impervious Surface Area and Anthropogenic Heat Flux:
  1. GLC: ISA from *European Environmental Agency* and AHF from Flanner (2009) [4]
  2. WUDAPT: ISA and AHF from WUDAPT [5]
  3. ECO: ISA and AHF from ECOCLIMAP Second Generation 2018 [6]

For this analysis, we used a more recent case study, 16-22 March 2020, a clear-sky period over Turin.

ICs/BCs	Resolution	ISA and AHF (dataset)	Simulation name
IFS 9 km	1 km	WUDAPT	ref 1km
IFS 9 km	500 m	WUDAPT	ref 500m
IFS 9 km	500 m	GLC	GLC
IFS 9 km	500 m	ECO	ECO
ArpaE 2.2 km	500 m	WUDAPT	LCZ-2.2
ArpaE 2.2 km	500 m	ECO	ECO-2.2

TAB. 4: scheme of the simulations.

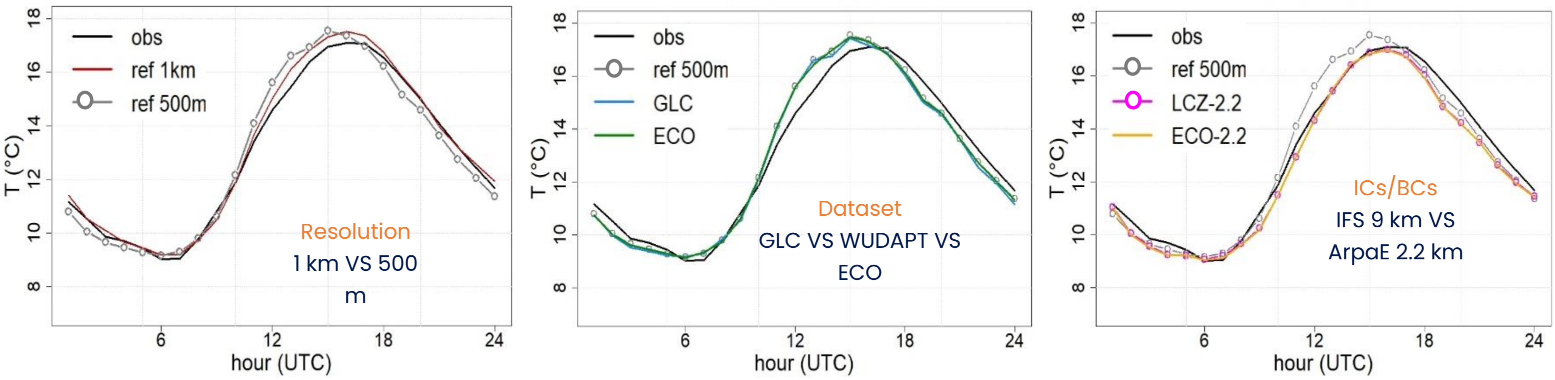


FIG. 8: T2m average daily cycle in Torino.

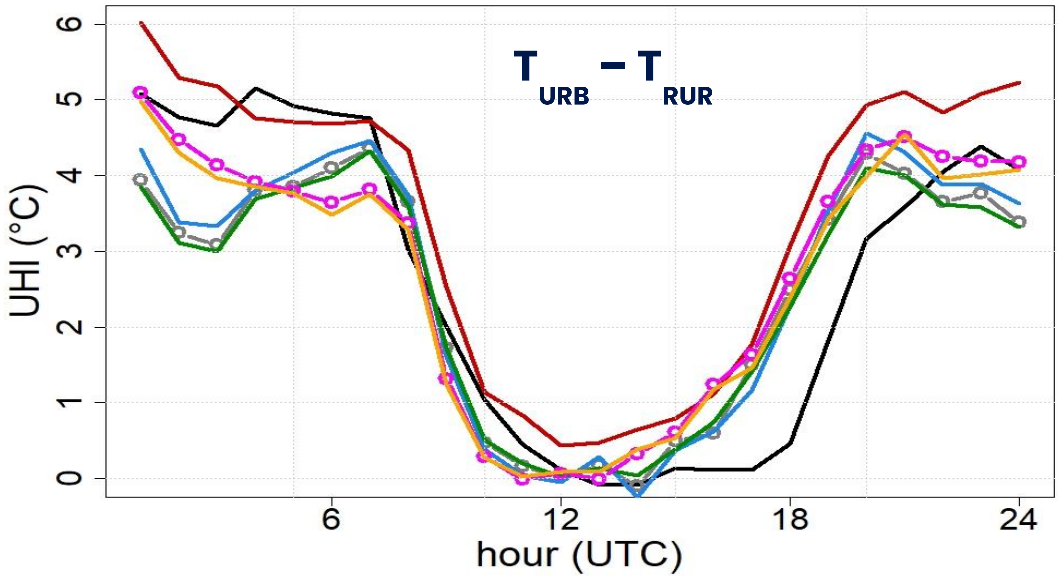


FIG. 9: average UHI daily cycle. All simulations, the legend is the same as in FIG. 8.

The overall considerations are the following:

- There is no particular improvement moving from 1km to 500 m resolution;
- The different datasets produce similar results;
- There are slightly better results with LCZ-2.2 and ECO-2.2, ICs/BCs provided by ArpaE (Bologna) @2.2km:
- The amplitude of the nocturnal UHI is in general well represented (up to 5°C).

[1] Stewart, I.D.; Oke, T.R. Local Climate Zones for Urban Temperature Studies. Bull. Am. Meteorol. Soc. 2012, 93, 1879–1900
[2] Wouters, H.; Demuzere, M.; et al. The Efficient Urban Canopy Dependency Parametrization (SURY) v1.0 for Atmospheric Modelling: Description and Application with the COSMO-CLM Model for a Belgian Summer. Geosci. Model Dev. 2016, 9, 3027–3054
[3] Wouters, H., et al. The diurnal evolution of the urban heat island of Paris: a model-based case study during Summer 2006. Atmos. Chem. Phys. 2013, 13, 8525-8541
[4] Flanner, M. G.: Integrating anthropogenic heat flux with global climate models, Geophys. Res. Lett. 2009, 36
[5] Demuzere, M., Bechtel, B., Middel, A., & Mills, G. Mapping Europe into local climate zones. PloS one 2019, 14(4)
[6] ECOCLIMAP-SG 2018, accessible from https://opensource.umr-cnrm.fr/projects/ecoclimap-sg