22nd International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
10-14 June 2024, Pärnu, Estonia

DEVELOPMENT OF A MODELLING CHAIN FROM CONTINENTAL TO URBAN SCALE APPLIED OVER ITALY

Tony Christian Landi [1], Luca Mortarini[1], Daiane Brondani[1], Oxana Drofa[1], Silvia Trini Castelli[1], Cinzia De Benedictis[2], Edoardo Fiorillo[2], Luisa Neri[2], Tommaso Sorgente[3], Francesca De Santi[3], Daniela Cabiddu[3], Michela Mortara[3] and Michela Spagnuolo[3]

[1] CNR – ISAC Consiglio Nazionale delle Ricerche – Istituto di Scienze del Clima e dell'Atmosfera
[2]CNR – IBE Consiglio Nazionale delle Ricerche – Istituto di BioEconomia
[3] CNR – IMATI Istituto di Matematica Applicata e Tecnologie Informatiche

Abstract:
The recent implementation of a modelling system interfacing the meteorological chain GLOBO-BOLAM-MOLOCH with the LES building-resolving model PALM-4U is presented. For the accurate modelling of the urban climate and air quality, a detailed local environment description and realistic meteorological boundary conditions are needed. Our current efforts are aimed at (i) preparing detailed static drivers for the region of interest, with a special focus on the buildings and vegetation characterization, and (ii) implementing the dynamic drivers by using the regional meteorological model MOLOCH as boundary conditions. Preliminary applications of the system regarded a 1-km squared area in the city of Bologna ("Bolognina" case study), characterized by a high presence of public and private greenery, and the city center of Catania ("CT Digital-twin" case study), where the focus is on resolving the flow in built environment and assessing the impact of emissions from the streets. For both experiments, the meteorological boundary conditions were provided by the convection-permitting MOLOCH model. For Bolognina, to compile the static driver, we adopted various data sources, including remote sensing, municipal data collections and open data. For private trees, a specific census was carried out. This led to the creation of a geodatabase of public and private trees with detailed information including more than 5000 elements. For CT-Digital twin, the static input files include the DEM data of the buildings in the area and the relative road graph classified according to OpenStreetMap. Our preliminary findings pointed out: in Bolognina case study, the extremely detailed information on the urban vegetation, down to the single tree, allowed testing and assessing NBS (Natural-Based Solutions) strategies in urban context. Such modelling system proved to be a suitable tool for testing natural mitigation strategies in urban context and for evaluating their effectiveness; in CT Digital-twin test, we were able to provide a demo on the potentiality of this modelling approach for the implementation of digital twins of urban environments. The fields output from the modelling system can be used to assess different scenarios of air quality and human comfort depending, for instance, on emission-reduction strategies. This, leads to useful guidelines for urban planners and decision makers in devising specific mitigation plans for their cities.

Key words: *LES, Natural-Based Solution, thermal comfort, urban-scale*

INTRODUCTION

The development of a modeling chain from continental to urban scale involves integrating various computational tools and approaches to analyze the key features from synoptic circulation up to building-resolved atmospheric dynamics. Currently, such approach is essential for developing comprehensive models that can inform decision-making and urban planning in response to climate change and urbanization challenges. These resources reflect the interdisciplinary nature of the field, combining climate science,

mesoscale and microscale meteorology, atmospheric composition, urban planning, and computational modeling to address complex environmental. During the last years, much effort was made to enhance the numerical models with components needed for applications in urban environments, like fully interactive land surface and radiation schemes, chemistry. As reported in Baklanov and Zhang (2020) numerical modeling systems help decision makers to improve air quality and public health, mitigate the occurrence of both severe meteorological events and acute polluted episodes, particularly in urban areas, and reduce the associated impacts on agriculture, ecosystems and climate. Advanced approaches in combine of state-of-the-art models, high-resolution emission inventories, satellite observations, and surface measurements of most relevant chemical species to provide hindcasts, analyses, and forecasts from global to regional scale and downscaling for selected countries, regions, and urban areas.

This paper describes the first implementation of meteorological chain GLOBO-BOLAM-MOLOCH (Davolio et al., 2020) with the LES building-resolving model PALM-4U model system (Maronga et al., 2020) for urban applications throughout one case study focused on a 1-km squared area in the city of Bologna ("Bolognina" case study) characterized by a high presence of public and private greenery. A second case study regarding the city centre of Catania ("CT Digital-twin" case study) is under development, with focus on urban emissions and aimed at creating scenarios to be integrated in a city digital twin.

DATA AND METHODS

Bolognina case study

This case study has been carried out over *Bolognina* area, a residential part of Bologna municipality in Emilia Romagna region located in the northern Italy. The integration domain, centered at 44.512 N - 11.347 E, is a 1 square km with 5 meters of cell dimension, as depicted in Figure 1.

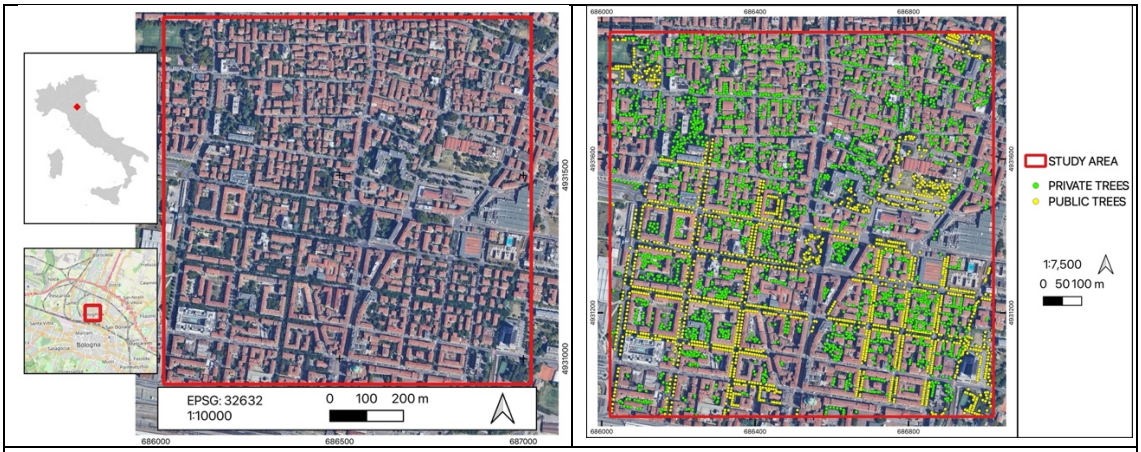

Figure 1. Left panel: Bolognina domain (right) and its location in Italy (top left) and Bologna (bottom left). Right panel: public (yellow circles) and private (green circles) trees in the *Bolognina* study area (red square).

The most important efforts have been done in preparing (i) the static driver and (ii) the dynamic driver as reported by PALM user guide. The originality of this experiment relies on the high detailed geodatabase of public and private trees located in the area of interest (see Figure 2, information regarding public trees was downloaded from the Geoportal of the Municipality of Bologna, while for private trees an ad hoc sampling was carried out. On the whole, more than 5000 plants were censed (see Figure 1, right panel), and the related information included geo-localization, species, height, canopy diameter, trunk circumference, crown condition and light exposure. An original contribution has been the development of a dedicated Fortran script for preparing the meteorological fields as initial and boundary conditions generated by MOLOCH model. Such software is based on the already existing PALM INIFOR interface provided for the COSMO meteorological model and was adapted to potentially use the daily regional forecasts produced by MOLOCH.

To shed light on the human thermal comfort during a heat wave event, a three days period, 15th - 18th August 2023, was chosen to be simulated by the PALM model. For the different urban textures (i.e. vegetated areas, asphalted streets, around buildings) described in the static files the relative differences of perceived temperature were quantified.

A three-days period – 15th - 18th August 2023 - was chosen for the experiment to shed light on the human thermal comfort calculated by PALM model during a heat wave event. The relative differences of perceived temperature are quantified for different urban texture values (i.e. vegetated areas, asphalted streets, around buildings) were evaluated.

Preparation of CT Digital-Twin case study

For the second test case, the structure of the buildings for the central district of Catania city has been processed. Dedicated acquisition campaigns with different approaches (photogrammetry, fixed and mobile LiDAR) provided a high-resolution point cloud with colorimetric/photographic data. The point cloud is reconstructed to obtain triangular surface meshes at different resolutions. Such triangular mesh is cropped to fit a straight parallelepiped, and annotated with information from OpenStreetMap (OSM) cartography. The mesh is then "closed" by attaching a rectangular element on each boundary edge (all pointing towards the direction of the sky and reaching the same fixed quote), and adding a single top polygonal element. In Fig. 2 the 3D modeling pipeline is illustrated.

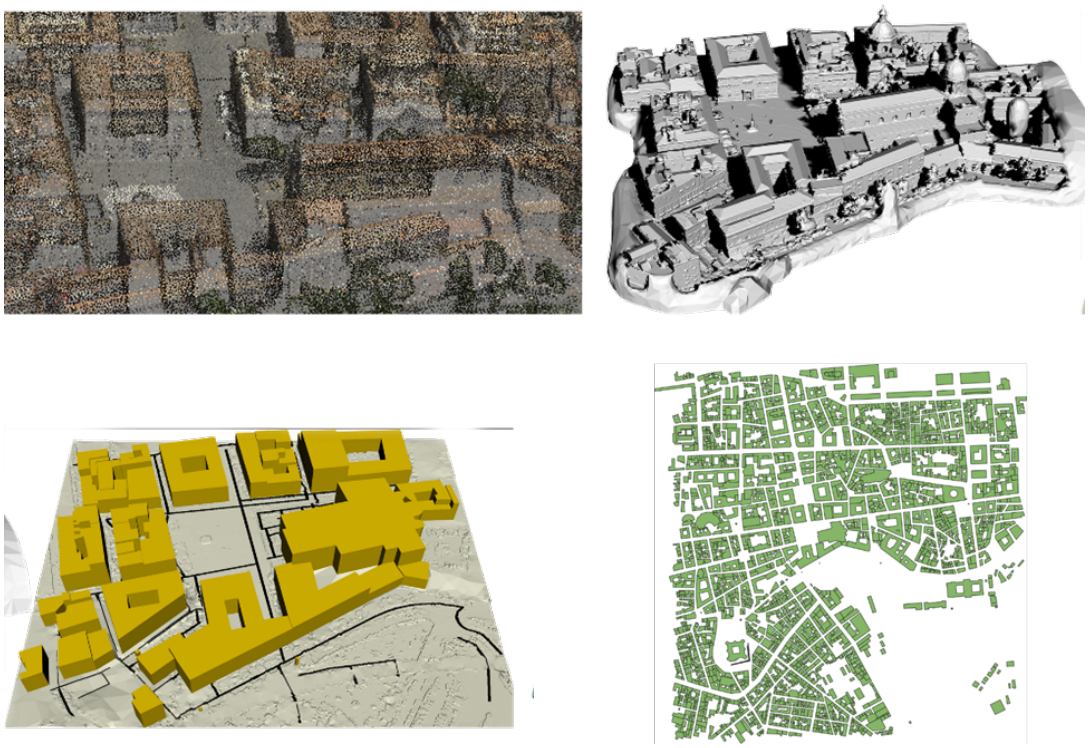

Figure 2. Area of "Piazza del Duomo" in Catania city centre. Acquired point cloud (top left), high resolution mesh model, low resolution mesh model with annotation, original OSM model to be used to create PALM static inputs.

The geometric model is used to build the static input file containing topography information and the type of land and urban surfaces in the model. PALM-4U imports information structured into a grid of known resolution, chosen as 5×5×5 meter cells in for the ongoing preliminary tests. Morphological information and semantic annotation from the surface model to the volumetric grid model are mapped at the same resolution to provide the following information related to the volumetric cells at ground level:

• ground type, classified with "building", "soil", "water", "vegetation", or "pavement";
• street type, classified with "primary", "secondary", "tertiary", "cycleway", "residential", or "pedestrian".
• terrain height in meters relative the lowest grid point;

• building height in meters relative to the terrain height.
For this case study, the meteorological dynamic driver is produced by the new code interfacing MOLOCH outputs with PALM-4U inputs.

RESULTS

First applications of PALM-4U regarded a 1-km squared area with a 5m horizontal resolution (200 x 200 grid points) and a vertical stretched grid with a constant resolution of 5 m up to 300 m and a total height of ~1700 m (stretch factor = 1.08, 100 grid points) in the *Bolognina* area, part of Bologna municipality, is implemented by using the meteorological modeling system GLOBO-BOLAM-MOLOCH - developed by CNR-ISAC, to represent realistic meteorology. Highly accurate geospatial data (buildings, vegetations, streets, soil, water bodies, etc..) are used to generate PALM static driver, which are strongly recommended to achieve representative results to understand the quantitative impact of the near-surface microscale structures.

The experiment was carried out for a three days period, 15-18 August of 2023, in clear-sky conditions. The mesoscale meteorological driver is verified for by comparing surface temperature with observations as reported in Figure 3:

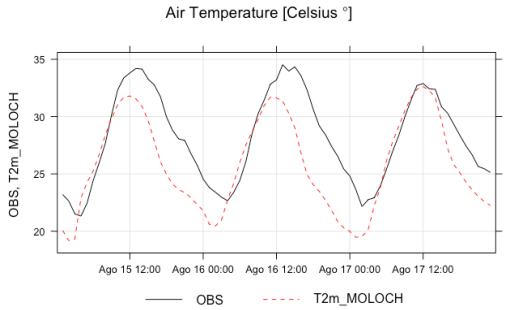

Figure 3. Air temperature measured (black solid line) at CNR-ISAC roof building (44.5120 N - 11.3467 E) compared with 2m temperature as calculated by MOLOCH (red dashed line) in spatial-temporal correspondence.

Besides, the biometeorological module was successful implemented to calculate of the three widely used thermal indices: perceived temperature (PT), Universal Thermal Climate Index (UTCI), as well as physiologically equivalent temperature (PET) (Fröhlich et al., 2020). A preliminary quantitative investigation of air temperature and perceived temperature at ground level is presented in Figure 4:

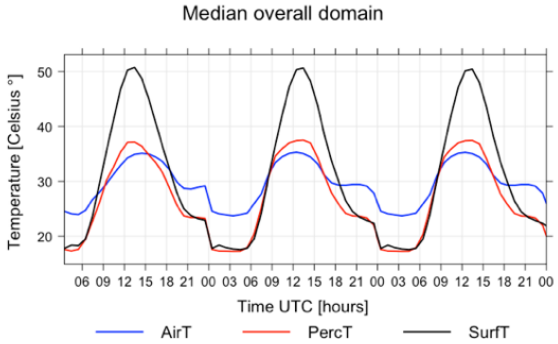

Figure 4. Time series of air temperature (blue line), perceived temperature (red line) at 2.5 m and surface temperature (black line) as calculated by PALM-4U. Time series refer to overall domain of interest as median value calculated for all grid points at each time slot.

Such preliminary comparison points out that – in general - the perceived temperature is higher during daytime and lower during the nighttime respect to air one overall the investigated area. It is worth notice that the surface temperature reaches very high values during daytime showing a large gradient throughout the daily cycle. Further analyses are still in progress to identify the different places where these differences

are larger and smaller, e.g. in vegetated or highly urbanized areas, compared with the median shown in the Figure 4. On the other hand, concerning the CT Digital-Twin case study, exploratory simulations MOLOCH-PALM4U are in process and alternative scenarios of changes in the urban design, of interest for the stakeholders, are under consideration.

CONCLUSIONS

This study presents the first applications of PALM-4U by using the meteorological modeling system GLOBO-BOLAM-MOLOCH - developed by CNR-ISAC, to represent realistic meteorology. Validation of its application has been conducted through one case study during the summer season in Bologna, Italy. Besides, for incorporating surface heterogeneities, the PALM static driver is utilized to account for microstructures in urban settings (building 3D, vegetation, soil type, etc. ..), ensuring realistic results in PALM simulations. The application of PALM-4U in the case studies involves weather events simulated by MOLOCH for a three days period, 15-17 August 2023, for *Bolognina* area, part of Bologna municipality, Italy. The preparation of the inputs and exploratory simulations are in process for the *CT Digital-Twin* test case. These case studies aim to evaluate the numerical stability of the novel meteorological driver rather than serve as definitive validations of meteorological accuracy in the simulations, even if preliminary evaluation of human thermal comfort parameters have been performed, given the high detailed information on greenery implemented in the static driver.

ACKNOWLEDGMENT: This work has been performed in the framework of ECOSISTER project funded under the National Recovery and Resilience Plan (NRRP), Mission 04 Component 2 Investment 1.5 – NextGenerationEU, Call for tender n. 3277 dated 30/12/2021 and Urban Intelligence Science Hub for city network project, (POCCM) 2022-2025.

REFERENCES

Baklanov, Alexander, and Yang Zhang. "Advances in air quality modeling and forecasting." Global Transitions 2 (2020): 261-270.

Davolio, S., Malguzzi, P., Drofa, O., Mastrangelo, D., & Buzzi, A. (2020). The Piedmont flood of November 1994: A testbed of forecasting capabilities of the CNR-ISAC meteorological model suite. *Bulletin of Atmospheric Science and Technology*, *1*, 263-282.

Fröhlich, D. and Matzarakis, A.: Calculating human thermal comfort and thermal stress in the PALM model system 6.0, Geosci. Model Dev., 13, 3055–3065, https://doi.org/10.5194/gmd-13-3055-2020, 2020

Maronga, B., Banzhaf, S., Burmeister, C., Esch, T., Forkel, R., Fröhlich, D., Fuka, V., Gehrke, K. F., Geletič, J., Giersch, S., Gronemeier, T., Groß, G., Heldens, W., Hellsten, A., Hoffmann, F., Inagaki, A., Kadasch, E., Kanani-Sühring, F., Ketelsen, K., Khan, B. A., Knigge, C., Knoop, H., Krč, P., Kurppa, M., Maamari, H., Matzarakis, A., Mauder, M., Pallasch, M., Pavlik, D., Pfafferott, J., Resler, J., Rissmann, S., Russo, E., Salim, M., Schrempf, M., Schwenkel, J., Seckmeyer, G., Schubert, S., Sühring, M., von Tils, R., Vollmer, L., Ward, S., Witha, B., Wurps, H., Zeidler, J., and Raasch, S.: Overview of the PALM model system 6.0, Geosci. Model Dev., 13, 1335–1372, https://doi.org/10.5194/gmd-13-1335-2020, 2020.

A. PERSONAL DETAILS

CORRESPONDING AUTHOR NAME: Tony Christian LANDI
CORRESPONDING AUTHOR EMAIL: t.landi@isac.cnr.it

TITLE OF EXTENDED ABSTRACT: **DEVELOPMENT OF A MODELLING CHAIN FROM CONTINENTAL TO URBAN SCALE APPLIED OVER ITALY**

EXTENDED ABSTRACT ID NUMBER: H22-121
TYPE OF PRESENTATION: ORAL

B. ONLINE PUBLICATION OF EXTENDED ABSTRACT

WOULD YOU LIKE YOUR EXTENDED ABSTRACT TO APPEAR ONLINE? YES

C. ONLINE PUBLICATION OF PRESENTATION / POSTER

WOULD YOU LIKE YOUR PRESENTATION / POSTER TO APPEAR ONLINE? YES