Project Title: Upgrading a climate model to improve regional climate projections

Acronym: UpClim

Deliverable 4.11
Implementation of a new urban forcing

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Technical References

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List of tables and figures

Terms, definitions and abbreviated terms

The following acronyms have been used across this document:

ACRONYM	FULL TERM
BEP	Building Environment Parameterization
BEM	Building Energy Model
CORDEX	Coordinated Regional Downscaling Experiment
EO	Earth Observation
LCZ	Local Climate Zones
RCM	Regional Climate Model
WRF	Weather Research and Forecasting Model

1 Introduction

A major focus of the UpClim project is the urban environment and how it is represented in regional climate models (RCMs). Here we investigate how the Weather Research and Forecasting model (WRF) (Powers et al., 2017) can be modified to represent better the urban environment. WRF is a mesoscale atmospheric numerical model, which has been widely used as a regional climate model (Katragkou et al., 2015). It is also an official member of the Ensemble Desing Matrix of CMIP6/EURO-CORDEX initiative, operating under the auspices of the World Climate Research Program (Sobolowski et al., 2025). In this study we use the non-hydrostatic version of the WRF model with the Advanced Research dynamic solver (WRF-ARW v4.5.1).

WRF can consider the urban environment using different options and parameterizations of varying complexity. The core of this WRF-urban modelling system consists of three methods with different degrees of freedom to parameterize urban surface processes, ranging from a simple bulk parameterization to a sophisticated multi-layer urban canopy model with an indoor–outdoor exchange sub-model that directly interacts with the atmospheric boundary layer. The first option (urb_opt=0) does not use an urban parameterization; it only recognizes the urban environment from the land use category. The second WRF option (urb_opt =1) uses a single layer urban canopy model, with the option to handle (or not) anthropogenic heat fluxes. The third option (urb_opt=2) includes a multi-layer Building Environment Parameterization (BEP), allowing the representation of more complex urban structures. The fourth option (urb_opt=3) allows the use of a Building Energy Model (BEM) and adds heat and air-conditioning to BEP.

Within WP4 we investigate the sensitivity of the urban options built within WRF and additionally, try to customize the urban options to fit the city of Paris. By default, WRF applies an “average urban” profile over all urban environments, ignoring the specificities of each city in the domain. Within the UpClim Deliveralbe 4.10, we delivered a detailed urban profile for the city of Paris based on Earth Observation (EO) data. In the current Deliverable (4.11), we apply as input the urban dataset produced within D4.10 and investigate how the regional climate of the Paris greater area is affected.

2 Urban representation in WRF

2.1 Urban Parameterization

The most complex and detailed urban option within WRF is the BEP-BEM scheme, a multi-layer urban canopy model (Chen et al., 2011). This scheme relies on a text file, namely URBPARAM.TBL or URB_PARAM_LCZ.TBL, to represent the basic characteristics of the urban environment. This file contains data for several urban variables e.g. building height and width, albedo, emissivity, road width and direction. The default file represents a generic profile of the urban environment, since these variables can significantly change from city to city. Therefore, updating this file with more accurate and detailed data will provide an enhanced description of the urban environment.

2.2 Local Climate Zones

Moreover, within WRF the Local Climate Zone (LCZ) approach can be used to more accurately classify the urban environment (Demuzere et al., 2022a). In the traditional approach each grid cell of the domain is assigned to one land use category, including the urban category. Therefore, all urban cells have indistinguishable properties from each other. In the LCZ approach, each urban cell can be further categorized within 11 categories, the Local Climate Zones, thus allowing for the much-needed variability within the urban environment and thus greatly enhancing its representation.

If the LCZ approach is used, the BEM-BEP scheme uses the URBPARM_LCZ.TBL file (hereafter TBL) to provide specific characteristics for each LCZ.

3 Earth Observation Data

The EO data used for an enhanced representation of Paris are thoroughly described in Deliverable 4.10. They cover the entire Paris metropolitan area and include the following crucial parameters:

- Building Heights
- Roof Width
- Road Width
- Surface albedo and emissivity
- Vegetation cover and phenology

They have been prepared to very fine spatial resolution by using a variety of primary datasets such as the ASTER Global Emissivity Dataset (ASTER GED) for surface emissivity, the THeia and Irstea Soil MoisturE catalog (THISME) for surface albedo and the Urban Altas for building height. Finally, all variables have been aggregated from their native resolutions to the 2-km grid of the WRF model and then statistics have been calculated for each LCZ class.

4 Implementation

4.1 Local Climate Zones implementation

The implementation of LCZs in WRF requires the incorporation of climate zone information in the geo_em files that provide the model geographical and terrestrial data information (e.g land use category, terrain height, soil properties etc.). For this purpose, we used the w2w tool (Demuzere et al., 2022b), a specialized python tool, to introduce LCZ data from the World Urban Database (WUDAPT) in the model. Since we plan to conduct nested simulations with WRF, the incorporation of the LCZs was implemented in the geo_em files for both the main (d01) and the nested (d02) domains. Finally, the use of the LCZ data in the model is enabled through the “use_wudapt_lcz” flag in the namelist.

4.2 EO data for Paris implementation

The EO data for Paris, for the various LCZs, are incorporated through changes in the URBPARM_LCZ.TBL file. This is a text file that contains information for various parameters used by the urban schemes. It is characteristic that in the very beginning of the file it is stated that “*The default values are probably not appropriate for any given city. Users should adapt these values based on the city they are working with*.”. The parameters updated in the TBL file are: building height, roof width, road width, roof and wall albedo, road albedo, roof and wall emissivity, road emissivity, fraction of urban landscape that does not have vegetation. An example is given in Figure 1. Mind that:

- Only satellite data for roof albedo and emissivity were available. Thus, we made the assumption that wall albedo was identical to roof albedo and wall emissivity identical to roof emissivity.
- The building height was incorporated in the TBL file as a distribution per LCZ and not just as a mean value. This is an important feature available since significant height variability can occur even within the same LCZ. Building height percentage was provided for several classes of 5m width, for each LCZ. The number of classes varied between LCZs, with the highest number being 21 classes for (LCZ 4).
- In WRF the largest number of building height classes is hardcoded to 18 (parameter nz_um in module_sf_bep_bem.F). Therefore, after changing the TBL file, we needed to increase this parameter and recompile WRF in order to proceed with the model simulation.

```
STREET PARAMETERS:
#       (sf_urban_physics=2,3)

#  urban       street       street      building
# category  direction      width       width
# [index]  [deg from N]    [m]          [m]

    1         0.0          15.         12.
    1        90.0          15.         12.
    2         0.0          9.4         35.6
    2        90.0          9.4         35.6
    3         0.0          9.4         52.2
    3        90.0          9.4         52.2
    4         0.0          10.9        43.5
    4        90.0          10.9        43.5
    5         0.0          11.3        31.5
    5        90.0          11.3        31.5
    6         0.0          9.15        21.
    6        90.0          9.15        21.
    7         0.0          10.         20.
    7        90.0          10.         20.
    8         0.0          16.1        28.7
    8        90.0          16.1        28.7
    9         0.0          10.         26.8
    9        90.0          10.         26.8
    10        0.0          28.5        23.8
    10       90.0          28.5        23.8
    11        0.0          100.        5.
    11       90.0          100.        5.

END STREET PARAMETERS
```

```
BUILDING HEIGHTS: 5
#       (sf_urban_physics=2,3)

#      height    Percentage
#       [m]         [%]
      2.5          2.6
      7.5         45.3
      12.5        19.5
      17.5        11.1
      22.5         9.9
      27.5         5.2
      32.5         3.2
      37.5         1.4
      42.5         0.7
      47.5         0.4
      52.5         0.3
      57.5         0.1
      62.5         0.3
END BUILDING HEIGHTS

BUILDING HEIGHTS: 6
#       (sf_urban_physics=2,3)

#      height    Percentage
#       [m]         [%]
       2.5        10.0
       7.5        71.5
       12.5       10.9
       17.5        4.5
       22.5        1.4
       27.5        0.7
       32.5        0.5
       37.5        0.2
       42.5        0.1
       47.5        0.2
END BUILDING HEIGHTS
```

Figure 1: Two examples of the changes made in the URBPARM_LCZ.TBL file. Left panel: street and building width data for all LCZs. Right panel: building heigh distributions for LCZ 5 and LCZ6.

The parameter changes between the default values in the TBL and those implemented by using the FORTH EO data can be in some cases substantial. A prominent example is the building height parameter. We present in Figure 2 the mean building height per grid point, for the default and EO data-based cases. It is clear that the EO data-based building height is considerably lower over most of the central Paris, with the differences from the default values reaching is several cases as large as 10-15m.

H.F.R.I. Hellenic Foundation for Research & Innovation
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UpClim

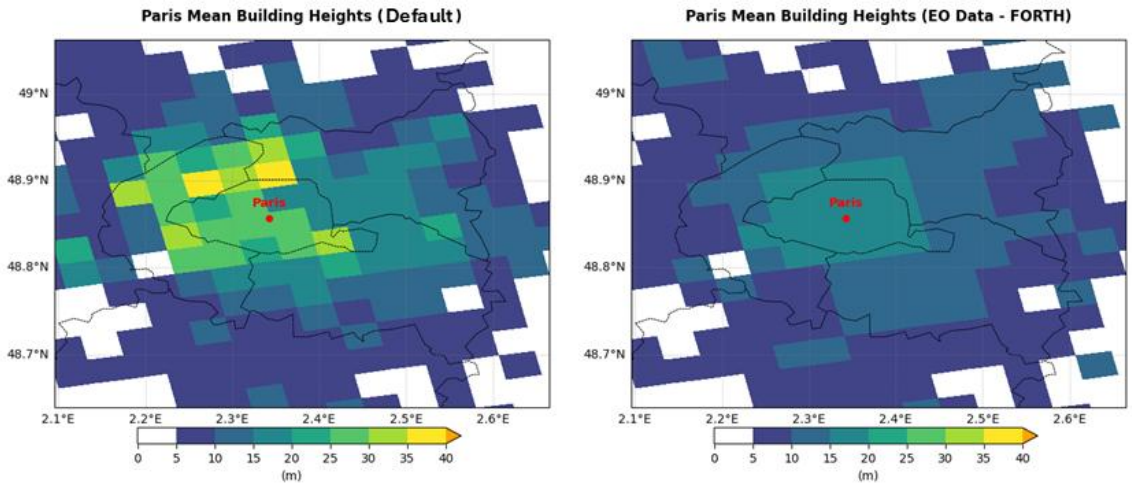

Figure 2: Mean buliding height per grid point over the city of Paris. For the defalut values (left) and for the EO data preparde by FORTH (right).

5 Idealized testing

Before using in extended WRF simulations the EO-data enhanced TBL described in section 4.2, we conducted an idealized test to assess whether the BEP-BEM scheme reacts in a physically consistent way when parameters in the TBL are changed. Specifically, we conducted two small 3-day simulations: one using the default TBL (Control simulation) and one simulation with greatly reduced building heights in the TBL (Low-height sensitivity simulation). In the latter the building heights in all LCZs were reduced between 5-10m while in the default many LCZs contained heights well above 30-40m. Both simulations have nested domains, with the outer domain covering Europe with 12km resolution and the inner domain covering a large portion of France with a 2km resolution. In Figure 3 we present the domains used and visualize the urban fraction parameter that represents the urban areas as seen by the model. The analysis focuses on the region of Paris.

Comparison of the two simulations presented the expected results: the lower building heights resulted in lower near surface and surface temperature as well as in considerably stronger near surface winds over the city of Paris (Figure 4). Impact on surface temperature exceeded in places even 1.5 ^{o}C. Particularly strong was also the impact of eastward wind at 10m. Moreover, no specific changes were present over the non-urban areas. This showcased that the BEP-BEM scheme reacts in a physically consistent way, when the building height parameters are changed in the TBL file.

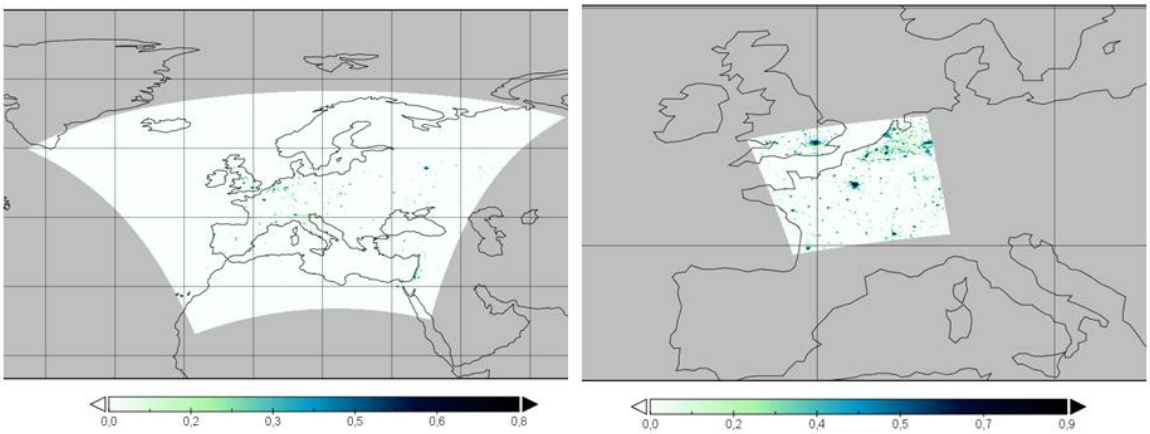

Figure 3: The urban fraction visualized over both domains used for the simulations. Left: Outter domain with 12km resolution. Right: inner nested domain with 2km resolution.

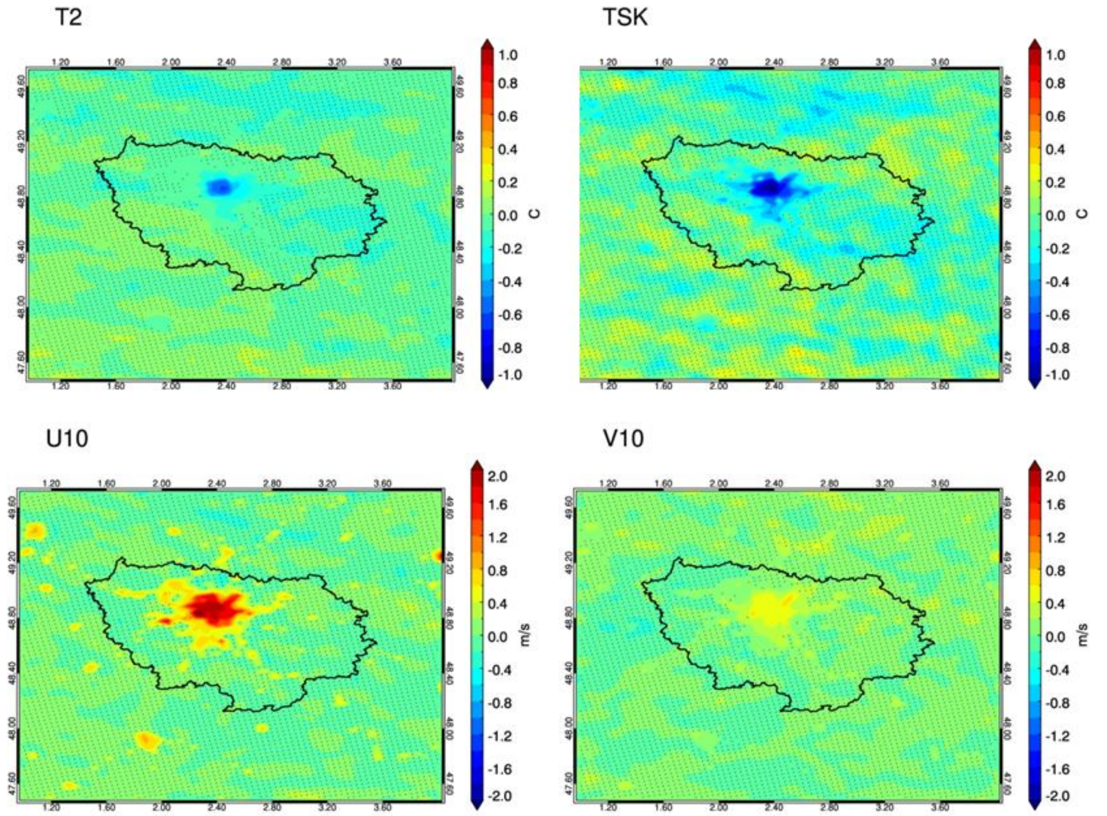

Figure 4: Mean difference over 3 days (1/3/2020 to 3/3/2020) between simulation with Lowered building heights and Control (default TBL). For near surface temperature at 2m (T2 - up left) , surface temperature (TSK - up right), eastward wind component at 10m (U10 - bottom left), northward wind component at 10m (V10 - bottom right). Black line indicates the wider prefecture that encompases Paris (Il-de-France). Stippling indicates grid points that are NOT urban.

6 WRF simulation with the EO data

After successfully conducting the idealized test, we proceeded to conduct a 3-day simulation (hereafter ParisSim) by implementing the FORTH EO data for Paris. The WRF model run successfully without any problems after introducing the changes. Simulation run time has been slightly increased compared to the previous tests due to the larger number of building height classes in the TBL file. Preliminary analysis indicates that the simulation behaves in a physically consistent way since the impact of urban areas was evident in many basic parameters, even in this limited 3-day period. Specifically, urban areas present considerably larger temperatures at 2m (up to 2 °C) and especially surface temperature (up to 4 °C) compared to the surrounding rural areas. Moreover, wind speed is greatly reduced within the urban area.

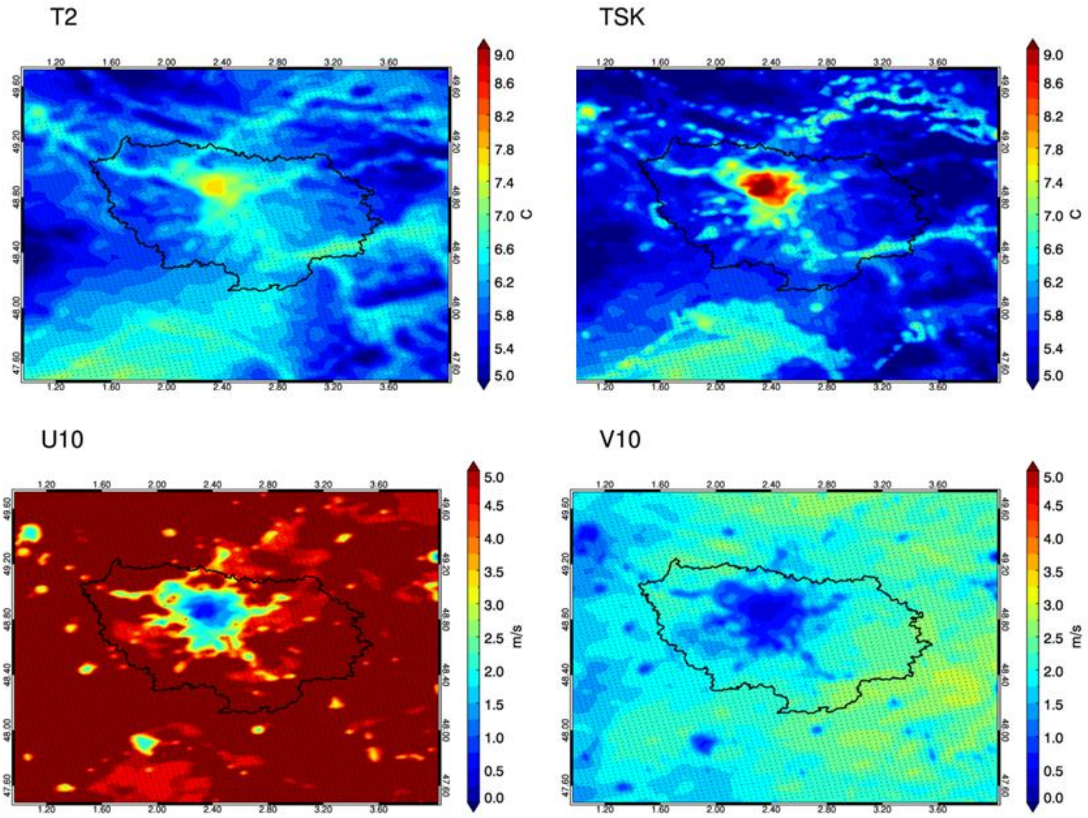

Figure 5: Mean values over 3 days (1/3/2020 to 3/3/2020) for simulation ParisSim that used the FORTH EO data. For near surface temperature at 2m (T2 - up left) , surface temperature (TSK - up right), eastward wind component at 10m (U10 - bottom left), northward wind component at 10m (V10 - bottom right). Black line indicates the wider prefecture that encompases Paris (Il-de-France). Stippling indicates grid points that are NOT urban.

Continuation of this simulation is ongoing, as is the quality checking of all the variables being produced. So far, all results indicate that the simulation is running as expected and no evident major bugs regarding the representation of the urban environment are present. As new data is being produced, we intend to repeat the above analysis, using a larger time period, in order to provide more robust results regarding the behavior of the urban element in WRF.

7 Conclusions

This report presents the steps taken to implement in the WRF model a detailed EO dataset for better representation of the Paris urban area. Moreover, it presents results from idealized testing of the urban options as well as preliminary data from a simulation over France that includes the EO dataset.

Key outcomes include:

- The idealized testing indicated that changes in the TBL file are taken into account by the model which reacts in a physically consistent way. When the building heights were considerably lowered, variables like temperature and wind speed were greatly affected.

- The FORTH EO data regarding building heights have considerable differences compared to the default data used.
- Implementation of the EO data in WRF was successful. After including more building height classes and changed the hardcoded maximum number of classes the model run successfully.
- Initial results with WRF simulation using the EO data indicate that the model behaves as expected with the urban areas having considerable impact on variables like temperature and wind speed compared to the surrounding rural areas.
- The WRF simulation using the EO data is ongoing and continuous quality checking of the output indicates no issues.

The implementation of the EO data set was successful. Further future analysis over larger periods and expanded over more variables is expected to provide robust answers as to whether this methodology has the potential to greatly increase the accuracy of WRF simulations over urban areas.

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