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

Acronym: UpClim

Deliverable 4.12

Simulations including the urban forcings

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Terms, definitions and abbreviated terms

The following acronyms have been used across this document:

ACRONYM	FULL TERM
WRF	Weather Research and Forecasting model
CORDEX	Coordinated Downscaling Experiment
CMIP6	Coupled Model Intercomparison Project (Phase 6)
ARW	Advanced Research dynamic solver
IFS	Integrated Forecasting System
ECMWF	European Center for Medium-Range Weather Forecast
MYNN2	Mellor-Yamada Nakanishi and Niino Level 2.5
ERA5	ECMWF reanalysis data
BEP-BEM	Building Effect Parameterization - Building Energy Model
A/C	Air Conditioning system
LSM	Land Surface Model
LCZ	Local Climate Zone
PBL	Planetary Boundary Layer

1 Introduction

The purpose of this document is to describe Deliverable 4.12 (D4.12) of Task 4.3, "*Implementation of urban forcing in production simulations," under WP4, "Implementation of urban forcing*," within the framework of the UpClim project. One of the main objectives of UpClim is to implement an enhanced representation of urban areas in a regional climate model, to assess their impact on the regional climate across Europe, with a particular focus on a major European city: Paris. To achieve this, we use the Weather Research and Forecasting (WRF) model and conduct a series of simulations exploring various urban parameterizations and options, as well as detailed urban form data derived from Earth Observation sources and tailored specifically for Paris. This report presents the conducted simulations and describes their main characteristics. The detailed description of the urban form data for Paris, along with the methodology used for its creation, is provided in Deliverable 4.10, "Report on EO-data to support the implementation of urban forcing." The integration of this data into WRF is described in Deliverable 4.11, "Implementation of a new urban forcing."

2 Earth Observation Data tailored for Paris

The Earth Observation data implemented into WRF simulations 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 CoSIA (Couverture du Sol par Intelligence Artificielle - Artificial intelligence for country-scale land cover description) Land Cover map, 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 various resolutions to the coarser 2km grid of the WRF model and then statistics have been calculated for each LCZ class.

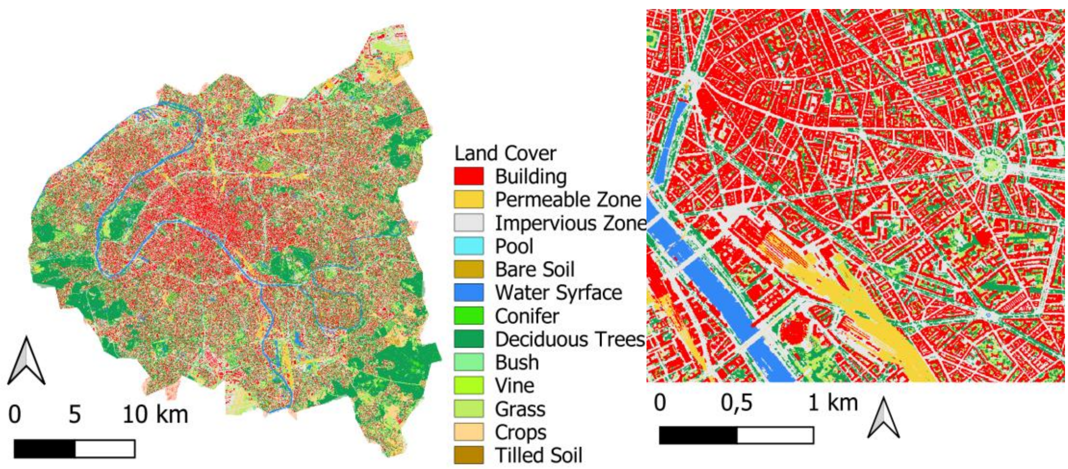

Figure 1: Land cover map of very high resolution (1m) for the city of Paris.

3 The Regional Climate Model WRF

We use the WRF model for the regional climate modelling simulations, a very popular climate and weather forecasting model. WRF has been widely used as a regional climate model (Katragkou et al. 2015; Fita et al. 2019; Ban et al. 2021) and is an official model-member of the Ensemble Desing Matrix of Coupled Model Intercomparison Project (CMIP6)/EURO-CORDEX (Katragkou et al. 2024). We use the non-hydrostatic WRF model with the Advanced Research dynamic solver (WRF-ARW, v4.5.1) has been utilized. More specifically, the selected model version is 4.5.1.4 (WRF451Q) which includes some additional modifications and improvements in NoahMP land use model (Yang et al. 2011), available from the CORDEX WRF community fork:

(git clone –recursesubmodules -b v4.5.1.4 https://github.com/CORDEX-WRF-community/WRF.git).

3.1 WRF urban physics

3.1.1 BULK

In WRF, the conventional representation of the urban environment—known as the *BULK* approach—treats urban grid cells as a separate land-use category ('urban'), with all surface processes handled by the land surface model (LSM). The distinct "urban" land category is associated with some predefined parameters that describe some basic characteristics of this surface (e.g. roughness length, albedo, heat capacity). This is the simplest way to describe the urban environment that is widely used in regional climate simulations.

3.1.2 BEP-BEP urban parameterization

A more detailed approach is to use an urban parameterization scheme. We make use of the BEP-BEM urban canopy model (Salamanca & Martilli, 2010), the most state-of-the-art and complex urban option available in WRF. This option considers many aspects of the urban form (building and road dimensions, thermal characteristics and albedo, etc.) and provides a more detailed representation of the urban environment by enhanced calculation of the surface energy fluxes, turbulent kinetic energy and humidity. Moreover, it includes the effects of shadowing and radiation trapping in urban canyons to provide a complete description of the urban environment. The required characteristics of the urban form are stored in a separate file (URBPARM.TBL or URBPARM_LCZ.TBL) and thus the end user may modify these numbers to better reflect the simulated target. Furthermore, the BEP-BEM scheme can consider air conditioning systems (A/C) and their impact on the surrounding environment. The parameters linked to A/C function like operating hours, and target temperature are stored in the same file among those of urban form and thus, the end user can modify them to better describe the simulated environment.

3.1.2.1 Local Climate Zones

Within WRF model, the user can incorporate the Local Climate Zone approach along with the BEP-BEM scheme to more accurately classify the urban environment (Demuzere et al., 2022). In the standard 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 (Figure 2).

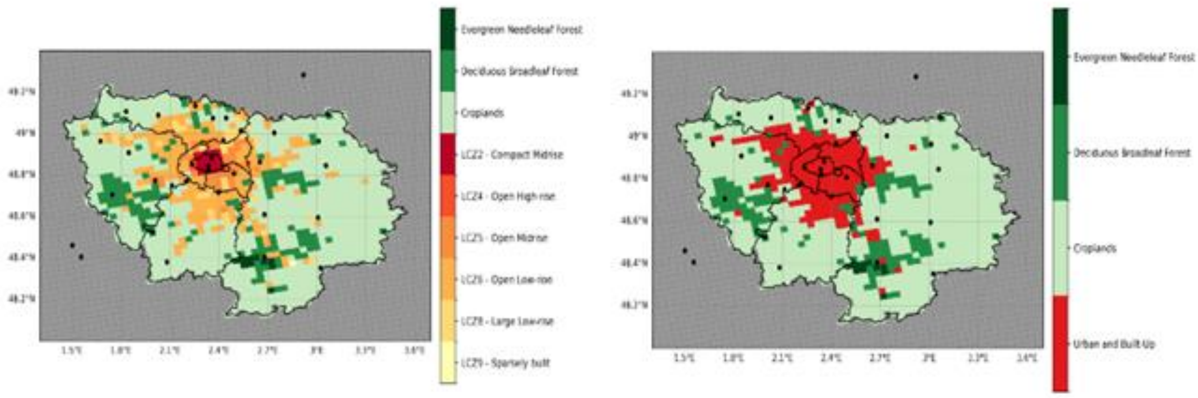

Figure 2: Land use categories over the wider Paris prefecture in the Local Climate Zone approach (left) and the standard approach using a single urban category (right) implemented in the WRF model.

3.2 WRF Simulations

To assess the impact of urban parameterizations, we conducted a series of sensitivity simulations for one year (2020) exploring different options for representing the urban environment in the WRF model.

3.2.1 Model configuration

For the simulations we applied an one-way nested domain approach. The outer domain covers the entire Europe with ~12 km resolution (412X424 grid points) while the inner domain is centred over Paris and covers most of France with a higher ~3 km resolution (252x236 grid points). In the vertical dimension, 60 levels are used with enhanced resolution in the boundary layer.

The simulations use the ERA5 reanalysis data (Hersbach et al. 2020) as initial and boundary conditions at 6 hourly intervals, while sea surface temperatures (SSTs) were updated per 24 hours from the same dataset. The ERA5 is produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), and it is based on the Integrated Forecasting System (IFS) Cy41r2 with horizontal resolution of 31 km, 137 vertical layers and hourly output. The ERA5 is available from the Copernicus Climate Change Service (C3S) (Thepaut et al. 2018) at a horizontal grid-spacing of 0.25^ox 0.25^o (latitude-longitude).

All simulations use the same set-up and parameterizations and differ only in the treatment of the urban environment. The Noah-MP (Niu et al., 2011; Yang et al., 2011) was used as a land surface model, while the Thompson microphysics scheme (Thompson et al., 2008) was employed for the representation of microphysical processes. Furthermore, longwave and shortwave radiation were represented by the RRTMG schemes (Iacono et al., 2008), and the BouLac PBL scheme (Bougeault and Lacarrere, 1989) was used, since it is the PBL scheme that has been tested most extensively with BEP-BEM. These parameterizations were used for all simulations and both domains, while for the outer domain (d01), the sub-grid-scale convection was parameterized by the Kain–Fritsch scheme (Kain, 2004) and for the shallow convection in the inner domain (d02) GRIMS shallow convection scheme was used (Hong and Jang, 2018).

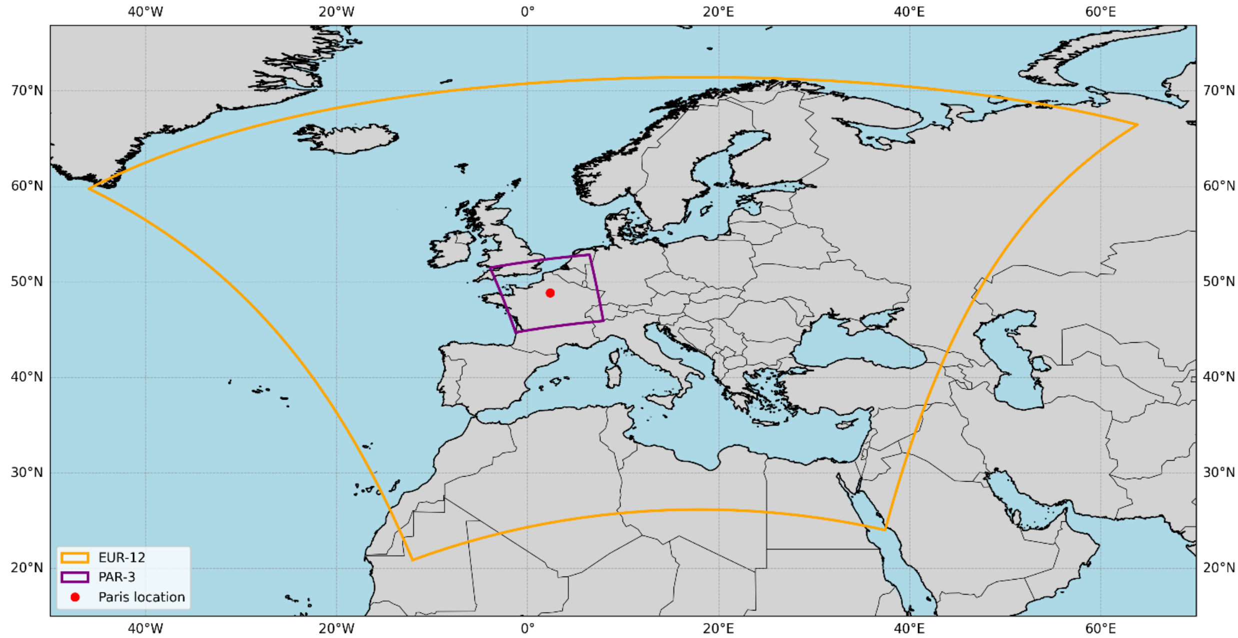

Figure 3. The outter domain (yellow) and inner nested domain (purple) of the simulations conducted.

3.2.2 Urban sensitivity experiments

We have performed five simulations exploring various urban options in WRF, listed in Table 1. More in detail, we performed the following simulations.

1. **No-urban:** no urban scheme & no urban land use. This option does not have an urban land use category at all: The geo_em file has been modified in a way that he urban environment has been replaced by the category with the next higher land use fraction in each grid point. All other simulations have urban land categories in their domain.
2. **Bulk**: no urban scheme – land model deals with urban land cover. This approach does not use an urban model. The urban environment is treated by the land surface model as another land use category, without receiving special treatment.
3. **BEP-BEM CTRL**: Activation of the BEP-BEM model with the use of Local Climate Zones. The BEP-BEM CTRL simulation uses the BEP-BEM state-of-the-art urban canopy model, incorporating Local climate Zones and WRF default data of urban form.
4. **BEP-BEM PARIS**: BEP-BEM scheme, Local Climate Zones using tailored data for Paris. The BEP-BEM PARIS simulation uses the BEP-BEM state-of-the-art urban scheme, Local climate Zones and tailored data for the city of Paris, as produced in D4.10.
5. **BEP-BEM Paris A/C Switch:** BEP-BEM scheme, Local Climate Zones using tailored data for Paris, A/C units work only limited hours. The BEP-BEM Paris A/C Switch has the same features as BEP-BEM PARIS, except for the working hours of the A/C units that have been reduced. In the default BEP-BEM configuration, A/C systems are assumed to operate non-stop, 24 hours a day. To perform a sensitivity test of A/C use during the heatwave event the A/C schedule was modified for August 2020, from 9UTC to 21UTC. This effectively halves operating hours and restricts A/C use to daytime, when it is more realistic for such systems to be active.

Table 1: Simulations conducted and their main characteristics

Simulation	Urban land Category	Urban Parameterization	Local Climate Zones	Additional urban related options	Duration
No-urban	No	No	No	-	6 months
Bulk	Yes	No	No	-	1 year
BEP-BEM CTRL	Yes	BEP-BEM	Yes	-	6 months
BEP-BEM PARIS	Yes	BEP-BEM	Yes	Tailored Paris urban form dataset	1 year
BEP-BEM Paris A/C Switch	Yes	BEP-BEM	Yes	A/C during only limited hours	1 month

3.2.3 WRF output variables

The raw output data of all simulations has been extensively post-processed to produce a number of climate variables that cover all aspects of the climate system in easy to access form. In total, 36 variables are available in NetCDF format for both the outer (d01) and the inner (d02) domains. All variables are available on monthly resolution while also hourly, six-hourly or daily resolution is available depending on the given variable (Table 1). The total amount of data for all simulations is approximately 560 G. The data are stored in the Aristotelis Data Center of AUTH, in the following path "/mnt/meteo_i/Urban" and are available upon request (mailto: katragou@geo.auth.gr). In the Appendix, we present the structure of a typical NetCDF file.

Table 2: List of all extracted variables for the performed simulations

Output variable name	units	long_name	Frequency
clt	%	Total Cloud Cover Percentage	1hr
evspsbl	kg m^{-2} s^{-1}	Evaporation Including Sublimation and Transpiration	1hr
hfls	W m^{-2}	Surface Upward Latent Heat Flux	1hr
hfss	W m^{-2}	Surface Upward Sensible Heat Flux	1hr

hurs	%	Near-Surface Relative Humidity	1hr
huss	1	Near-Surface Specific Humidity	1hr
pr	kg m^{-2}	Precipitation	1hr
prc	kg m^{-2}	Convective Precipitation	1hr
ps	Pa	Surface Air Pressure	1hr
psl	Pa	Sea Level Pressure	1hr
rlds	W m^{-2}	Surface Downwelling Longwave Radiation	1hr
rsds	W m^{-2}	Surface Downwelling Shortwave Radiation	1hr
rsdt	W m^{-2}	TOA Incident Shortwave Radiation	1hr
sfcWind	m s^{-1}	Near-Surface Wind Speed	1hr
tas	K	Near-Surface Air Temperature	1hr
ts	K	Surface Temperature	1hr
uas	m s^{-1}	Eastward Near-Surface Wind	1hr
vas	m s^{-1}	Northward Near-Surface Wind	1hr
ua50m	m s^{-1}	Eastward Near-Surface Wind at 50m	1hr
va50m	m s^{-1}	Northward Near-Surface Wind at 50m	1hr
zmla	m	Height of Boundary Layer	1hr
ta **at various pressure levels***	K	Air Temperature at level	6hr
ua **at various pressure levels***	m s^{-1}	Eastward Wind at level	6hr

va **at various pressure levels***	m s^{-1}	Northward Wind at level	6hr
zg **at various pressure levels***	m	Geopotential Height	6hr
tasmax	K	Daily Maximum NearSurface Air Temperature	day
tasmin	K	Daily Minimum NearSurface Air Temperature	day
orog	m	Surface Altitude	-
sftlf	%	Percentage of the Grid Cell Occupied by Land	-

*Available pressure levels: 1000, 925, 850, 700

4 References

Ban, Nikolina, Cécile Caillaud, Erika Coppola, et al. 2021. “The First Multi-Model Ensemble of Regional Climate Simulations at Kilometer-Scale Resolution, Part I: Evaluation of Precipitation.” Climate Dynamics 57 (1): 275–302. https://doi.org/10.1007/s00382-021-05708-w.

Bougeault, P. and Lacarrere, P.: Parameterization of Orography-Induced Turbulence in a Mesobeta--Scale Model, https://doi.org/10.1175/1520-0493(1989)117%3C1872:POOITI%3E2.0.CO;2, 1989.

Demuzere, M., Kittner, J., Martilli, A., Mills, G., Moede, C., Stewart, I. D., Van Vliet, J., & Bechtel, B. (2022). A global map of local climate zones to support earth system modelling and urban-scale environmental science. Earth System Science Data, 14(8), 3835–3873. https://doi.org/10.5194/essd-14-3835-2022

Fita, Lluís, Jan Polcher, Theodore M. Giannaros, et al. 2019. “CORDEX-WRF v1.3: Development of a Module for the Weather Research and Forecasting (WRF) Model to Support the CORDEX Community.” Geoscientific Model Development 12 (3): 1029–66. https://doi.org/10.5194/gmd-12-1029-2019.

Hersbach, Hans, Bill Bell, Paul Berrisford, et al. 2020. “The ERA5 Global Reanalysis.” Quarterly Journal of the Royal Meteorological Society 146 (730): 1999–2049. https://doi.org/10.1002/qj.3803.

Hong, S. Y. and Jang, J.: Impacts of Shallow Convection Processes on a Simulated Boreal Summer Climatology in a Global Atmospheric Model, Asia Pac J Atmos Sci, 54, 361–370, https://doi.org/10.1007/s13143-018-0013-3, 2018.

Iacono, Michael J., Jennifer S. Delamere, Eli J. Mlawer, Mark W. Shephard, Shepard A. Clough, William D. Collins. 2008. “Radiative Forcing by Long-Lived Greenhouse Gases: Calculations with the AER Radiative Transfer Models.” Journal of Geophysical Research

113 (D13): D13103. https://doi.org/10.1029/2008JD009944.

Kain, John S. 2004. “The Kain–Fritsch Convective Parameterization: An Update.” Journal of Applied Meteorology and Climatology. Journal of Applied Meteorology and Climatology, January 1, 170–81.

Katragkou, E., M. Garciá-Diéz, R. Vautard, et al. 2015. “Regional Climate Hindcast Simulations within EURO-CORDEX: Evaluation of a WRF Multi-Physics Ensemble.” Geoscientific Model Development 8 (3): 603–18. https://doi.org/10.5194/gmd-8-603-2015.

Katragkou, E., S. P. Sobolowski, C. Teichmann, et al. 2024. “Delivering an Improved Framework for the New Generation of CMIP6-Driven EURO-CORDEX Regional Climate Simulations.” Bulletin of the American Meteorological Society. Bulletin of the American Meteorological Society 1 (aop). https://doi.org/10.1175/BAMS-D-23-0131.1.

Niu, Guo-Yue, Zong-Liang Yang, Kenneth E. Mitchell, et al. 2011. “The Community Noah Land Surface Model with Multiparameterization Options (Noah-MP): 1. Model Description and Evaluation with Local-Scale Measurements.” Journal of Geophysical Research 116 (D12): D12109. https://doi.org/10.1029/2010JD015139.

Salamanca, F., & Martilli, A. (2010). A new Building Energy Model coupled with an Urban Canopy Parameterization for urban climate simulations-part II. Validation with one dimension off-line simulations. Theoretical and Applied Climatology, 99(3–4), 345–356. https://doi.org/10.1007/s00704-009-0143-8

Thepaut, J.-N., Pinty, B., Dee, D., Thepaut, J.-N., Pinty, B., & Dee, D. (2018). The Copernicus Programme and its Climate Change Service (C3S): A European Response to Climate Change. Cosp, 42, A0.4-15-18

Thompson, Gregory, Paul R. Field, Roy M. Rasmussen, and William D. Hall. 2008. “Explicit Forecasts of Winter Precipitation Using an Improved Bulk Microphysics Scheme. Part II: Implementation of a New Snow Parameterization.” Monthly Weather Review 136 (12): 5095–115. https://doi.org/10.1175/2008MWR2387.1.

Yang, Zong-Liang, Guo-Yue Niu, Kenneth E. Mitchell, et al. 2011. "The Community Noah Land Surface Model with Multiparameterization Options (Noah-MP): 2. Evaluation over Global River Basins." Journal of Geophysical Research 116 (D12): D12110. https://doi.org/10.1029/2010JD015140.

APPENDIX

```
netcdf           tas_PARIS-3_ERA5_evaluation_r1i1p1f1_AUTH-MC_WRF451R-CTRL_v1-fpsurbrcc-s0r1_1hr_2020030100-2020090100 {
dimensions:
        x = 236 ;
        y = 252 ;
        height = 1 ;
        time = UNLIMITED ; // (4417 currently)
variables:
        double lon(y, x) ;
                lon:standard_name = "longitude" ;
                lon:long_name = "Longitude" ;
                lon:units = "degrees_east" ;
                lon:_CoordinateAxisType = "Lon" ;
        double lat(y, x) ;
                lat:standard_name = "latitude" ;
                lat:long_name = "Latitude" ;
                lat:units = "degrees_north" ;
                lat:_CoordinateAxisType = "Lat" ;
        char crs ;
                crs:grid_mapping_name = "lambert_conformal_conic" ;
                crs:longitude_of_central_meridian = "9.700012f" ;
                crs:latitude_of_projection_origin = "49.f" ;
                crs:false_easting = "0." ;
                crs:false_northing = "0." ;
                crs:earth_radius = "6370000.f" ;
                crs:standard_parallel = "30.f,60.f" ;
        double height(height) ;
                height:standard_name = "height" ;
                height:long_name = "Height" ;
                height:units = "m" ;
                height:positive = "up" ;
                height:axis = "Z" ;
        double time(time) ;
                time:standard_name = "time" ;
                time:long_name = "Time" ;
                time:units = "days since 1949-12-01T00:00:00Z" ;
```

```
                time:calendar = "standard" ;
                time:axis = "T" ;
        float tas(time, y, x) ;
                tas:standard_name = "air_temperature" ;
                tas:long_name = "Near-Surface,Air,Temperature" ;
                tas:units = "K" ;
                tas:cell_methods = "time: point" ;
                tas:coordinates = "lon lat height" ;
                tas:grid_mapping = "crs" ;
                tas:missing_value = 1.e+20f ;
                tas:_FillValue = 1.e+20f ;

// global attributes:
                :Conventions = "CF-1.4" ;
                :contact = "Eleni Katragkou, katragou@geo.auth.gr" ;
                :creation_date = "2024-08-16-T12:11:44Z" ;
                :experiment = "Control run with reanalysis forcing" ;
                :experiment_id = "stage0" ;
                :driving_experiment = "reanalysis simulation" ;
                :driving_model_id = "ERA5" ;
                :driving_model_ensemble_member = "r1i1p1f1" ;
                :driving_experiment_name = "evaluation" ;
                :frequency = "1hr" ;
                :institution = "Aristotle University of Thessaloniki, Dept. of
Meteorology & Climatology, Thessaloniki, Greece" ;
                :institute_id = "AUTH-MC" ;
                :model_id = "AUTH-MC_WRF451R-CTRL" ;
                :rcm_version_id = "v1-fpsurbrcc-s0r1" ;
                :project_id = "FPS-URB-RCC" ;
                :CORDEX_domain = "PARIS-3" ;
                :product = "model-output" ;
                :references = "" ;
                :tracking_id = "b3d07ec4-5bc8-11ef-9b29-6cae8b08caaf" ;
                :title = "AUTH-MC-WRF451R model output prepared for CORDEX FPS-
URB-RCC stage0, ERA5 reanalysis forcing, control run" ;
                :comment = "postprocessing: WRF_CMORizer.f90 v0.4; excl. 10
grid point boundary relaxation zone" ;
                :institute_run_id = "" ;
                :conventionsURL = "" ;
```

```
:source = "" ;
:nesting_levels = "" ;
:comment_nesting = "" ;
:comment_1stNest = "" ;
```