

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 2025

Project Title: WRF-based high resolution simulations to improve the resilience of the Italian Energy System

Computer Project Account: spitric2

Principal Investigator(s): Bonanno Riccardo

Affiliation: RSE S.p.A. Ricerca sul Sistema Energetico

Name of ECMWF scientist(s) collaborating to the project
(if applicable) Collino Elena, Sperati Simone, Viterbo Francesca, Lacavalla Matteo

Start date of the project: 01/01/2025

Expected end date: 31/12/2027

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)			50000000	48276343
Data storage capacity	(Gbytes)			50000	8000

Summary of project objectives (10 lines max)

This report details the structure and preliminary testing of the new MERIDA URB meteorological reanalysis, which is a high-resolution 2 km product for the Italian peninsula with WRF version 4.7. One of the primary objectives is to predict heat waves in urban areas, which necessitates the inclusion of the Single Layer Urban Canopy Model (SLUCM). The configuration was optimised through sensitivity studies, which led to the selection of the Noah-MP LSM and the Mellor-Yamada-Janić (MYJ) PBL scheme. Additionally, a new soil initialisation technique has been implemented and tested using Noah-MP to address the underestimation of 2-metre temperature in the Po Valley. Preliminary validation showed that MERIDA URB provided better localisation of convective precipitation peaks and effectively highlighted heat islands in major cities. The configuration was also successfully tested in forecast mode, producing 600 m offline downscaling offline over the Milan urban area.

Summary of problems encountered (10 lines max)

None

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

In the coming year, verification will be carried out to assess the performance of the new soil moisture and temperature initialisation in the runs conducted in 2025. Further case studies will be analysed to improve the reanalysis configuration in light of the verification results. Simulations will be performed over a longer period to enable a more robust assessment of temperature and precipitation performance. The high-resolution (600 m) heatwave forecasting system for Milan will be operational in summer 2026. If available, downscaling tests will be conducted using ERA6 reanalysis to evaluate differences compared to downscaling with ERA5.

List of publications/reports from the project with complete references

F. Viterbo, S. Sperati, R. Bonanno, F. D'Amico, B. Vitali, F. Cavalleri, G. Decimi e M. Lacavalla, Ricostruzione modellistica atmosferica tramite l'utilizzo di rianalisi meteorologica per la quantificazione delle minacce atmosferiche rilevanti per il sistema elettro-energetico, Ricerca di Sistema, RSE, n. 25009777, 2025.

R. Bonanno, M. Lacavalla, S. Sperati, B. Vitali, F. D'Amico, G. Quinteri, A. Lanza, E. Golinelli e D. Bartalesi, «Indagine su sistemi innovativi di previsione e monitoraggio delle minacce meteorologiche per la gestione resiliente del sistema elettro-energetico,» Ricerca di Sistema, RSE, n. 25009780, Milano, 2025.

F. Viterbo, S. Sperati, B. Vitali, F. D'Amico, F. Cavalleri, R. Bonanno e M. Lacavalla, «MERIDA HRES: A new high-resolution reanalysis dataset for Italy,» *Meteorological Applications*, vol. 31, n. 6, p. e70011, 2024.

R. Bonanno, M. Lacavalla e S. Sperati, «A new high-resolution Meteorological Reanalysis Italian Dataset: MERIDA,» *Quarterly Journal of the Royal Meteorological Society*, vol. 145, n. 721, pp. 1756-1779, 2019.

Summary of results

This document summarizes the structure, configuration, and preliminary tests related to a new high-resolution meteorological reanalysis of the Italian peninsula and describes the implementation of the product in an urban operational forecast context. The new MERIDA URB reanalysis is a meteorological reanalysis product that differs from existing reanalyses in that it has a higher spatial resolution, increasing from 4 km in MERIDA HRES to 2 km. For the development of this product, the WRF atmospheric model has been updated to version 4.7 (compared to version 3.9 used in previous reanalyses). A primary objective of the new reanalysis is the prediction of heat waves in urban areas, which required the inclusion of appropriate urban parameterization: the Single Layer Urban Canopy Model (SLUCM). The initial conditions (IC) and boundary conditions (BC) for the MERIDA URB simulations come from the ECMWF's ERA5 global reanalysis.

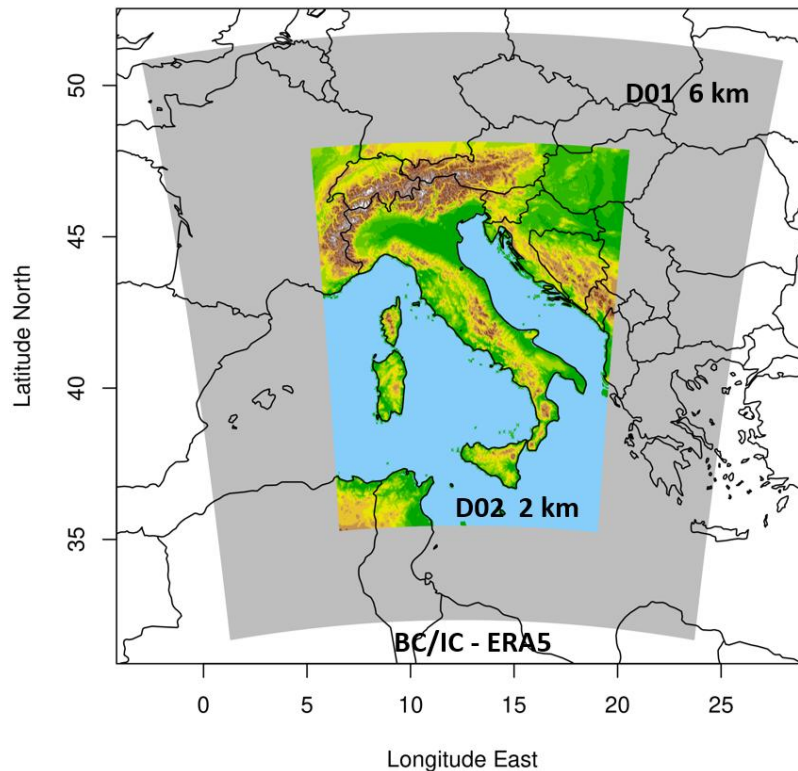


Figure 1: Domain of the new meteorological reanalysis over the Italian peninsula. The domain has two grids (d01 and d02) with resolutions of 6 and 2 km, respectively, of which the final MERIDA URB product represents the one on the innermost d01 grid.

The increase in spatial resolution and the new WRF modelling suite made it necessary to conduct a new sensitivity study of the configurations that can be selected in WRF 4.7. Furthermore, given the aim of accurately describing soil variables, particularly in urban contexts, it was decided to use more detailed soil type and land use datasets than the default global WRF datasets. The European Soil Database (ESDB) was selected for soil type classification instead of the default FAO, while the MODIS dataset was adopted for land use instead of USGS, thus maintaining methodological consistency between the representation of land use and the vegetative component (green fraction and Leaf Area Index - LAI).

To define the optimal model configuration, sensitivity studies were conducted, focusing on the parameterizations that most influence the 2-meter temperature fields, namely the Land Surface Model (LSM) and the Planetary Boundary Layer (PBL). With regard to the LSM, the Noah-MP model, successor to the Noah model used in MERIDA, was adopted due to its greater accuracy in describing phenomena such as snow on the ground and vegetation, and due to its customization. Several Noah-MP options were tested against configurations suggested in the literature on a significant number of case studies of heat waves affecting the Italian peninsula.

Once the Noah-MP configuration was set, the sensitivity of the PBL was analysed by comparing the Mellor-Yamada-Janić (MYJ), Mellor-Yamada-Nakanishi-Niino (MYNN), and Yonsei University (YSU) schemes.

The MYJ provided the best estimates of temperature at 2 meters for the summer case study, while the others tended to overestimate the temperature field, especially over the Po Valley. The activation of urban parameterization in MERIDA URB made it possible to highlight heat islands in the main cities of northern Italy.

During the configuration phase, a problem emerged regarding the underestimation of the 2m temperature, particularly in some areas of the Po Valley. This anomaly was attributed to excessive soil moisture inherited from the ERA5 driver ICs, where moisture tends to remain too constrained by initial conditions due to inertia greater than that of the atmosphere.

A new initialization methodology has been proposed to generate soil conditions (temperature and humidity) that are more consistent with the WRF settings in MERIDA URB. This new initialization led to a better representation of the thermal field over the Po Valley. Test simulations were run to compare these methodologies over a longer time period. Specifically, two years were simulated using ERA5 initialization of temperature and humidity fields, and another two years using the Noah-MP methodology with HRLDAS. The years chosen for the test are 2022 and 2023, the former being particularly dry and the latter more standard but also characterized by flooding events such as the one that occurred in Emilia Romagna in May 2023. Performance checks on these configurations, mainly on the 2m temperature estimate, will be carried out at the end of the runs in 2026.

A preliminary assessment, albeit qualitative, of the final configuration of MERIDA URB was conducted on several case studies of extreme events to verify the model's ability to reproduce various physical processes. With regard to heat waves, a case study of a heat wave that occurred in summer 2023 has been analysed. Figure 2 shows the 2 m temperature estimated by the new reanalysis, which considers the initialisation of soil temperature and moisture directly from the ERA5 reanalysis, as well as that processed by the Noah MP-HRLDAS. This last initialization shows a better agreement with the observed 2 m temperature fields, which were interpolated from Italian meteorological stations.

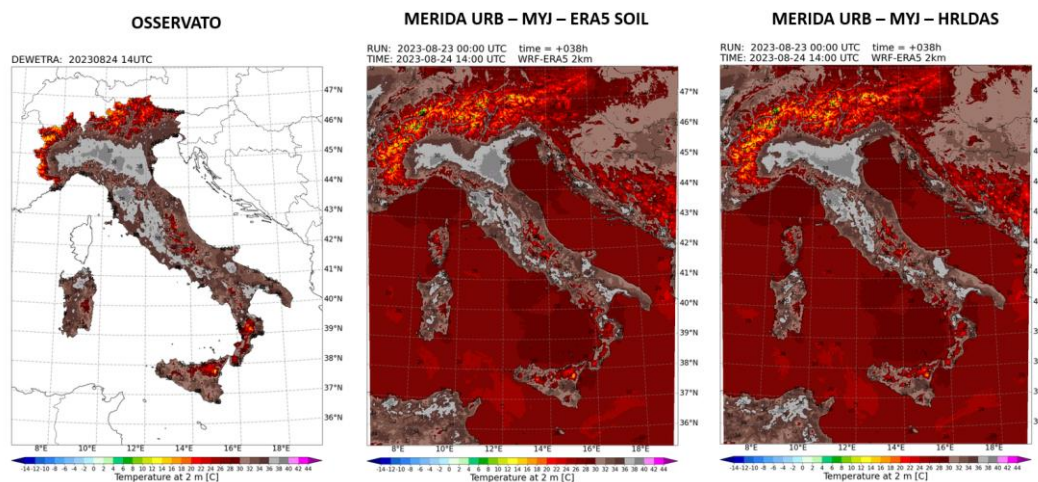


Figure 2: 2 m temperature maps referring to the case study of 24-08-2023, 14UTC. On the left is an estimate of the temperature field at 2 m spatially interpolated from data from meteorological stations located throughout Italy; in the center are the temperature fields relating to soil moisture initialization from ERA5, and on the right are those relating to initialization using the new methodology based on HRLDAS and ERA5 Land.

With regard to convective precipitation, MERIDA URB showed good localization of extreme precipitation peaks compared to existing reanalyses (MERIDA, MERIDA HRES, AEOLIAN), which tended to shift or overestimate the peaks. For synoptic precipitation (Emilia flood, May 2023), reanalysis datasets were fairly consistent in their localization; however, MERIDA URB appeared to be more consistent with observations in the most affected area of the Emilian Apennines, although it showed some underestimations in other areas (Marche, lower Veneto). As for strong winds (Storm Vaia, October 2018), despite the use of PBL MYJ (which does not include the *topo_wind* parameterisation present in YSU, used in AEOLIAN and MERIDA HRES),

the higher resolution of MERIDA URB allowed for better reproduction of wind intensity peaks in the presence of relief, although with an overestimation in valley floor and flat areas, a problem known to the WRF model.

The configuration tested in reanalysis mode was also tested in forecast mode for the summer of 2025, producing daily 2 km forecasts with further offline downscaling to 600 m over the Milan urban area.

In particular, the activation of SLUCM required the configuration of static parameters, the most important of which is Local Climate Zones (LCZ), a standardized classification system that describes the thermal and morphological characteristics of the urban landscape. The LCZ categories were entered into WRF Land Use using the Python script WUDAPT-TO-WRF (W2W).

The key static parameters, in addition to the LCZ, were the Urban Fraction (UF), building height, and street width. The UF was obtained from ESA's WorldCover dataset, while building height was obtained from the Global Human Settlement built-up height (100m resolution).

For the operational forecast run, WRF version 4.7 with 6 km and 2 km nesting was also used, forced by ECMWF IFS data. An additional run at sub-kilometer resolution (approximately 600 m) on the Milan urban area is performed offline. In this regard, the outputs of the 2 km run are post-processed (interpolation on regular grid and isobaric levels) to serve as IC and BC for this very high-resolution dynamic downscaling.

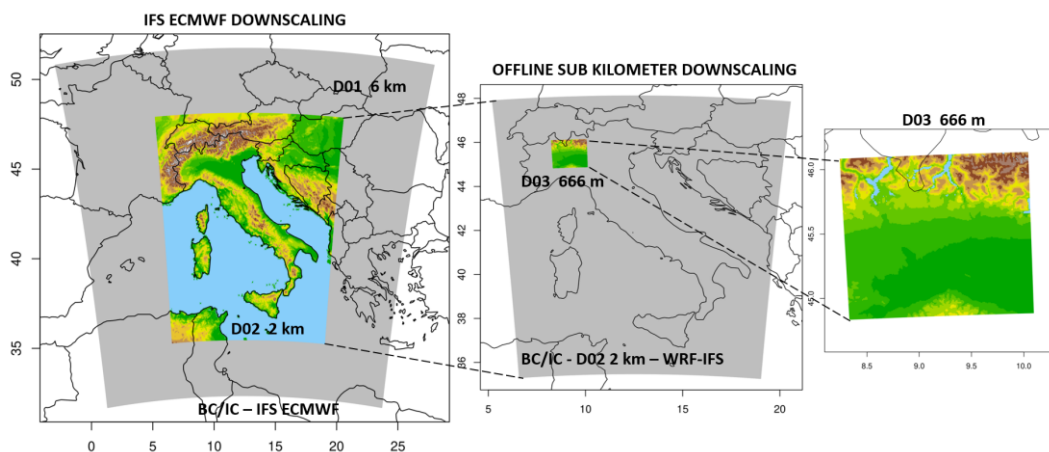


Figure 3: Schematic representation of WRF grids for IFS-ECMWF downscaling on the Italian domain at 2k and for offline downscaling for sub-kilometer simulation on a generic area within the 2km domain (the Lombardy-Milan area in this example).

For the qualitative verification of temperatures in urban environments, the Netatmo amateur network was used, which offers widespread coverage in Milan.

The case studies of forecasts for summer 2025 showed that the model (2 km and 666 m) is able to intercept the spatial distribution of the urban heat island, which is particularly evident in the evening hours (Figure 4). Variable biases were found, for example, an overestimation of about 1 degree in a case study from June 2025. Over the next year, work will be done to further refine this configuration in order to try to further reduce model biases on temperature.

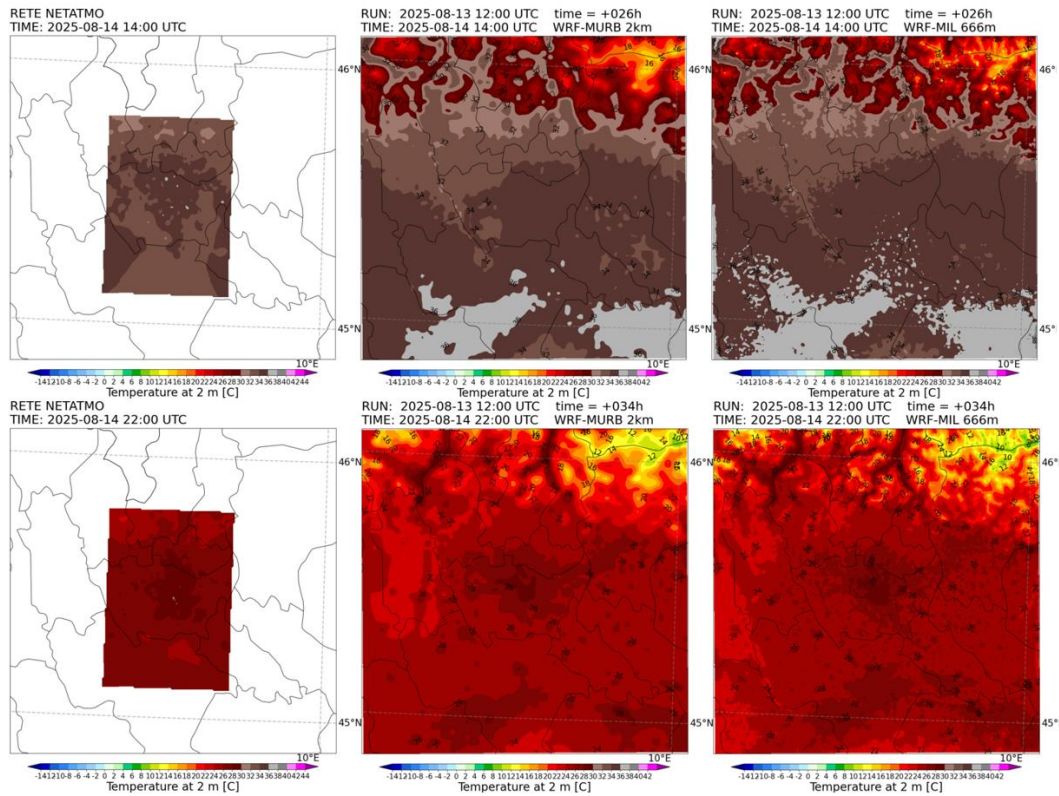


Figure 4: 2 m temperature for the case study of August 14, 2025, at 14:00 UTC (top) and 22:00 UTC (bottom). On the left are the Netatmo network temperatures, validated and bilinearly interpolated on a regular 1 km grid. The central figures represent the 2 km forecast run (WRF-MURB), while those on the right represent the offline downscaling run at 600 m spatial resolution (WRF-MIL).

Finally, the computing resources planned for this year were used to extend the AEOLIAN dataset for the years from 2022 to 2024.