Numerical forecasts of the planetary boundary layer by means of the WRF model: the Bologna case study

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Introduction

Urbanization, one of the main issue of modern society, has profound effects on all the components of the Earth system, including the atmosphere. At present, it is therefore increasingly necessary to understand and quantify the effect of the global increase of the urban population on various atmospheric processes, especially those of the planetary boundary layer. Urban models compete with different spatial scales: if the processes related to a single building or an urban neighbourhood are well represented with the microscale's own methods, the city as a whole influences the mesoscale which is a domain typical of numerical weather prediction models.

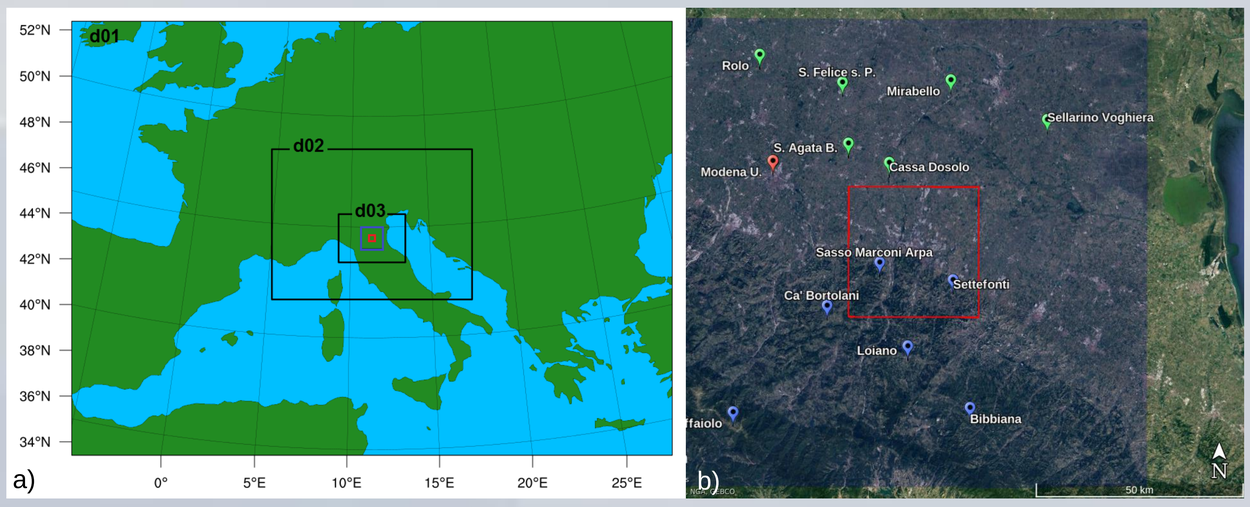

Figure 1: a) Nested domains used in WRF. b) Domain n. 5 highlighted in red and ARPAE meteorological rural stations.

Numerical Model and Settings

Various urban parameterizations, characterized by a various degrees of sophistication, have been developed within the community of the mesoscale forecasting model WRF (Weather Research and Forecasting). Although in recent years these parameterizations have found various applications, the scientific literature focuses mainly on large cities. In addition to the minor impact that small cities have on the atmosphere compared to large cities, the representation of the spatial structure of cities in urban parametrizations is based on the hypothesis of spatial regularity (e.g. buildings arranged in a normal chessboard or the whole cell of the grid occupied by a road canyon, etc.) that are hardly satisfied for a city with a limited extension and with an historical center characterized by an irregular geometry. This work aims at evaluating different parameterizations of the planetary boundary layer used in the WRF model, choosing a real summer case in August 2017 in the city of Bologna (Italy; 44 ° 30 'N, 11 ° 21'E). In particular, the evaluation is carried out by comparing the meteorological observations of air and wind temperature in urban and rural stations of the Bologna area with the numerical results obtained varying the urban parameterizations.

Parameterization

-Bulk Parametrization is a very simple parameterization which parameterizes the city as a surface with different thermal and geometric properties with respect to the surrounding area.

- Single-Layer Urban Canopy Model is a simplified model of urban "canopy" that synthesizes the city as a set of urban "canyons" where the radiative balance is calculated taking into account the presence of shadows, radiative "trapping" and solar inclination.

-Building Effect Parameterization (BEP) (Martilli et al., 2002), a model that, unlike the previous two, simulates buildings as parallelepipeds separated by roads whose geometric characteristics depend on the different urban classes into which the city is divided. It takes into account the friction exerted by buildings on the wind, the turbulent flows of sensible and latent heat, the production of turbulent kinetic energy and the effects of radiative shadow and trapping inside urban street canyons.

- Building Energy Model (BEM) (Salamanca et al., 2010; Salamanca and Martilli, 2010), estimates the contribution of buildings in terms of heat exchange with the atmosphere. The buildings are in fact considered as a set of rooms having a characteristic temperature which exchange heat with the outside according to the time, the presence of air conditioning systems, the number of windows, and even the number of occupants in the room.

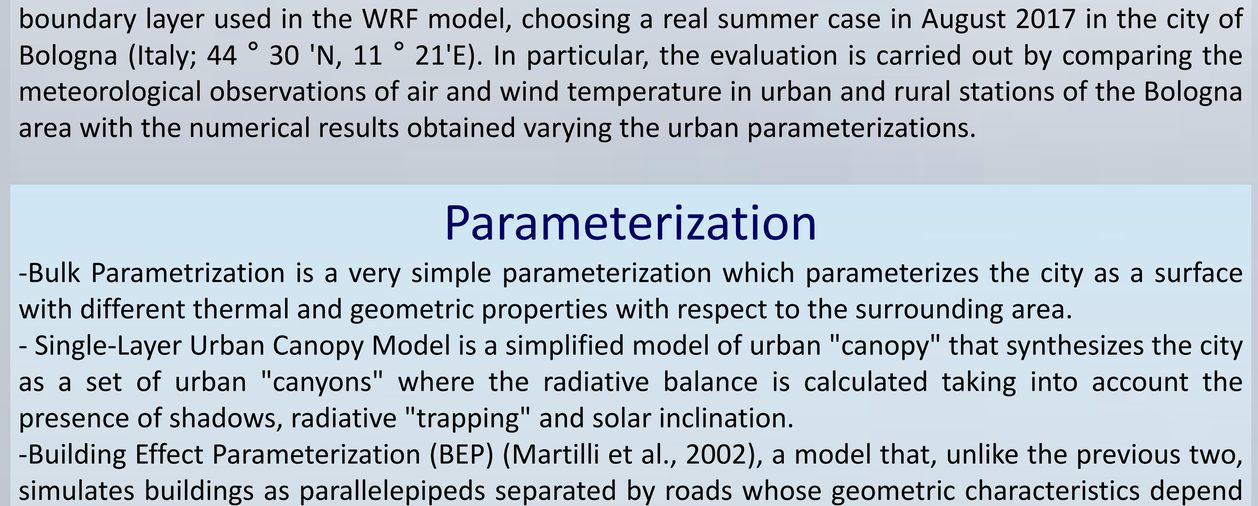

Figure 2: Time series and scatter plot of observed and simulated temperature with different urban parameterizations in the urban weather station located in Via Laura Bassi Veratti.

Results

The comparison between the measured data and the simulations of the WRF model with the different parameterizations was carried out by selecting the days 22 and 23 August 2017 corresponding to an intensive thermographic campaign conducted by the University of Bologna within the H2020 iSCAPE project ("Improving the Smart Control of Air Pollution in Europe "). The two days chosen were characterized by the absence of a stable high pressure on the Emilia-Romagna region and by the presence of a slight breeze.

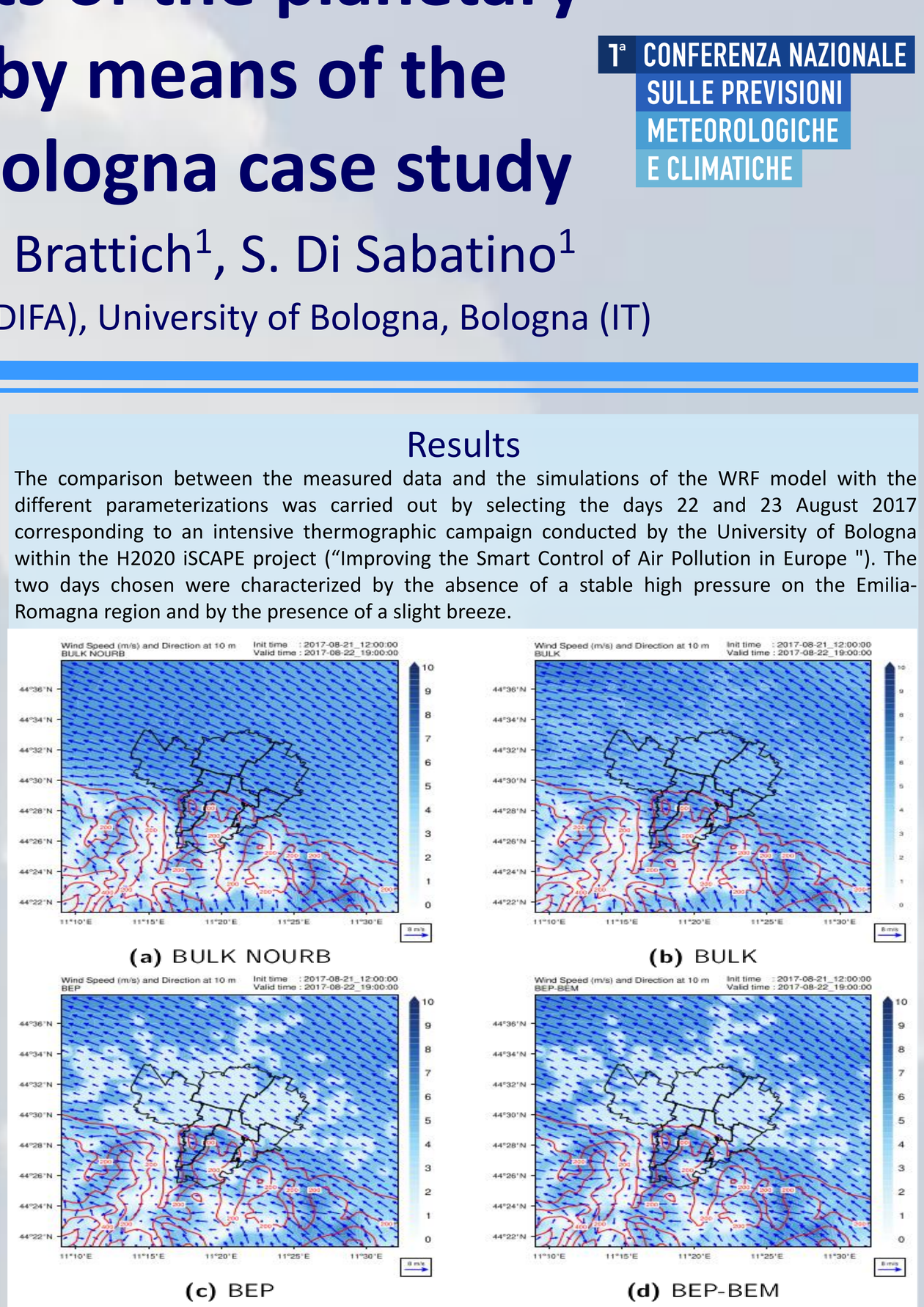

Figure 3: Wind speed (contour plot) and direction (vectors) at 19:00 on 22 August 2017 obtained with the 4 different parameterizations. Black lines represent the boundary of the districts of Bologna and the red lines the topography.

The comparison of the model outputs with the observations from weather stations shows a good agreement and emphasizes the model's ability to reproduce the diurnal cycle, albeit with an overestimation of the temperature of about one and a half degree over all the urban domain with all the parameterisations (see Fig.2).

The best performance in terms of representation of the urban heat island (UHI) and wind speed at the city of Bologna is obtained with the BEP and BEP-BEM parameterizations which, despite the complexity of the orography around the city, are able to simulate a decrease in wind intensity in correspondence of the urban center (Fig.3).

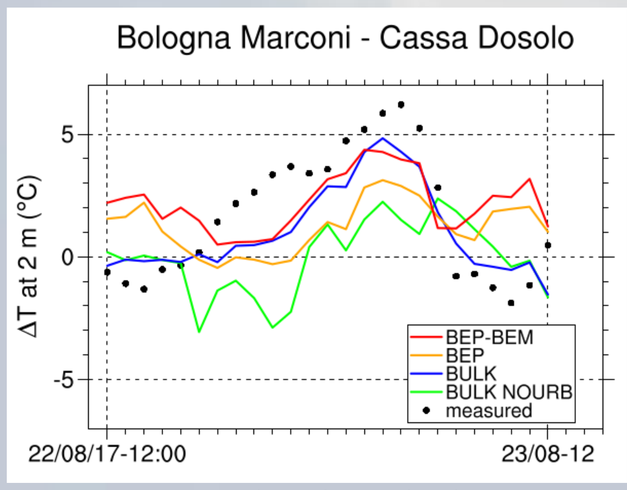

Figure 4: Measured and simulated temperature difference at 2 m above the surface in the two stations located respectively in an urban street canyon (Marconi St.) and in the rural area (Cassa Dosolo).

All the parameterizations used in this work reproduce the evolution of the UHI only during the night (Fig. 4), when this effect is most pronounced. During the day, a negative temperature difference between the urban and rural stations was measured, a phenomenon reproduced only by the BULK parameterization. The analysis of the results obtained with different parameterizations (Fig. 5) shows that in the afternoon of 23th August the BEP parameterization simulates a lower temperature inside the city compared to the BULK while the BEP-BEM simulates a warmer temperature with respect to that obtained with the BEP parameterization. Such effects might depend on the different representation of radiative and thermal fluxes in the BEP module compared with the BULK one.

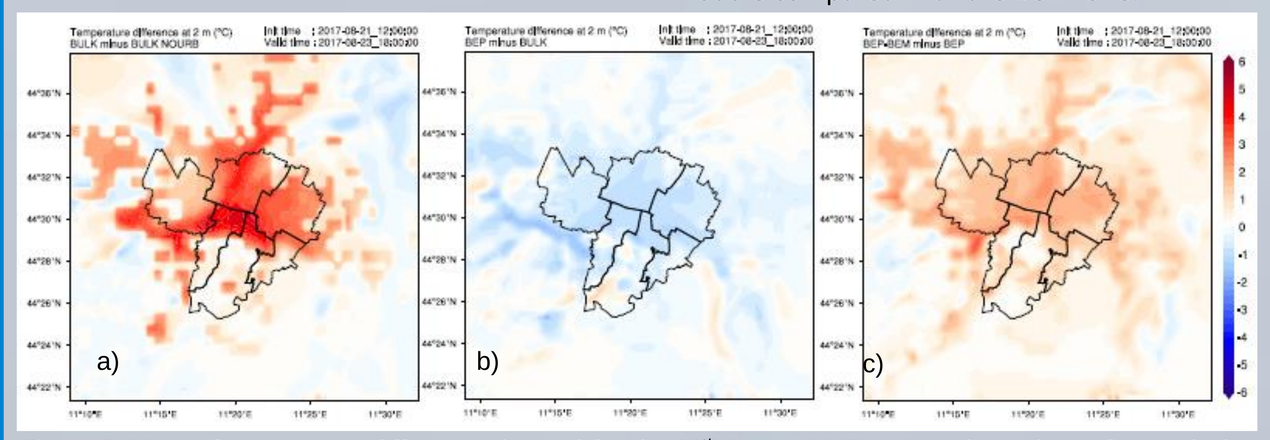

Figure 5: Maps of temperature difference obtained for the 23th August 2017 at 2 m above the surface with the different parameterizations: a) BULK in the absence of cities minus BULK with the city b) BEP minus BULK, c) BEP-BEM minus BEP.

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