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Modeling of mesoscale phenomena using WRF-BEP-BEM-CIM in a complex region

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Abstract. Because of the global warming, urban planning strategies must be investigated to reduce building energy consumption and increase thermal comfort in urban areas. It is thus proposed in this study to use a mesoscale meteorological model to study the impact of multiple urban planning scenarios in the Canton of Vaud. The Weather Research and Forecast (WRF) model is used to conduct simulations. The urban parameterizations, Building Effect Parameterization + Building Energy Model + Canopy Interface Model (BEP-BEM-CIM), developed in previous studies are already integrated in the WRF model. We demonstrate that the models perform well in plateaued regions (<10% difference) but some important deviations (20%-30% difference) are noted in particularly complex regions with complex topography. Two possible improvements will be addressed in the future: there is a need to improve the topography representation in the model itself and other scenarios including the impact of future climate will also be assessed.

1. Introduction

By 2050, two persons out of three will probably live in cities or urban areas [1]. It is expected that climate change will increase the frequency of heat waves and hence put urban dwellers at risk [2]. The presence of human activities in urban zones and the modification of the land surface also affect the climate in built areas. Moreover, in Switzerland, urban densification is promoted by the new Swiss territorial planning law's revision (LAT) voted in 2014 (ARE) along with the Swiss Energy strategy 2050 framework. With the global warming, extended heatwaves, such as those of 2003 and 2018, will become more common and the impact of the future land use on the urban climate is still unknown in these extreme conditions.

However, to correctly evaluate urban planning strategies at a regional scale, the currently used models have to be robust enough in complex regions (with lakes, mountains and urban areas) to evaluate future planning scenarios. This can have strong effects in areas where urban areas are surrounded by topographical features which can significantly influence the urban heat island [3]. Although mesoscale models have been used extensively in the recent years [4,5], it is still not clear how future land uses are going to impact the urban climate and how this will translate in terms of energy consumption at the local and city scale. It is particularly difficult to estimate the impact when land use inputs are difficult to

obtain, specifically for urban areas. In particular, the performance of such models in complex regions has not yet been assessed and the impacts of future land use are thus difficult to evaluate.

It is thus proposed in this study to assess the WRF-BEP-BEM-CIM [6] model by performing a simulation of the mixed urban/rural region of the Canton de Vaud. Simulations are performed for this domain at high resolution using a mesoscale numerical weather prediction system. The results from the simulations are compared with multiple meteorological stations located in the domain and used to evaluate the urban heat island phenomena.

The paper is structured as follows: first, we describe briefly the WRF model and the domain over which the simulations are conducted. Second, we analyse and discuss the results. Finally, we conclude and gives some perspectives for the current work.

2. Methodology

2.1. WRF model

The Weather Research and Forecast model (WRF) is an atmospheric model developed by the National Center for Atmospheric Research (NCAR)[7]. It is a set of several programs used for both research and numerical weather prediction (NWP). The version 3.6 is used in the current study.

As this is an open-source software developed by the scientific community, a wide-ranging selection of physics and dynamics options are available. The current settings have been previously used by Mauree et al., [6]. The Monin-Obukhov Similarity Theory [8] and the Noah Land Surface Model [9] were selected for this study. Additionally, we have chosen to use the BEP-BEM parameterization [10,11] to simulate the buildings effects on the long wave and short wave radiation (shadow effects and multi-reflexion) and the surface fluxes of momentum and heat.

2.2. Simulations setup

Figure 1. Domains used in the WRF simulations (left), location of the Dole, Payerne and Aigle stations in the inner most domain (right)

The WRF model is run over four domains with a respective resolution of 45km, 15km, 3km and 1km centred over the coordinates 46.5N and 6.6E (see **Figure *1***) and a time step of 270s is chosen for the coarser domain.

For the purpose of this study, simulations were conducted for one month from 15th of July 2003 to 14th August 2003. The wind speed and the air temperature were compared for three meteorological stations located in the area:

- La Dôle : simulated as rural area in WRF, weather station located at the top of a mountain.
- Payerne : simulated as rural area in WRF, weather station located in a rural area, without obstacles.

- Aigle : simulated as rural area in WRF, weather station located in a rural area at the bottom of a valley.
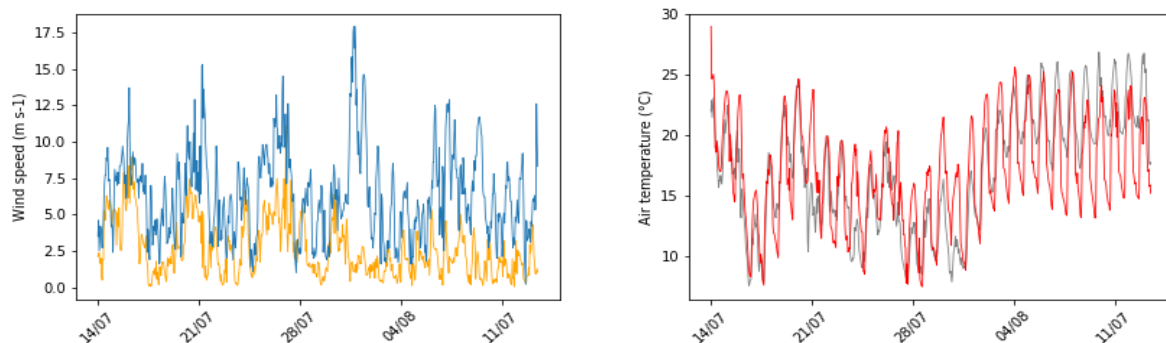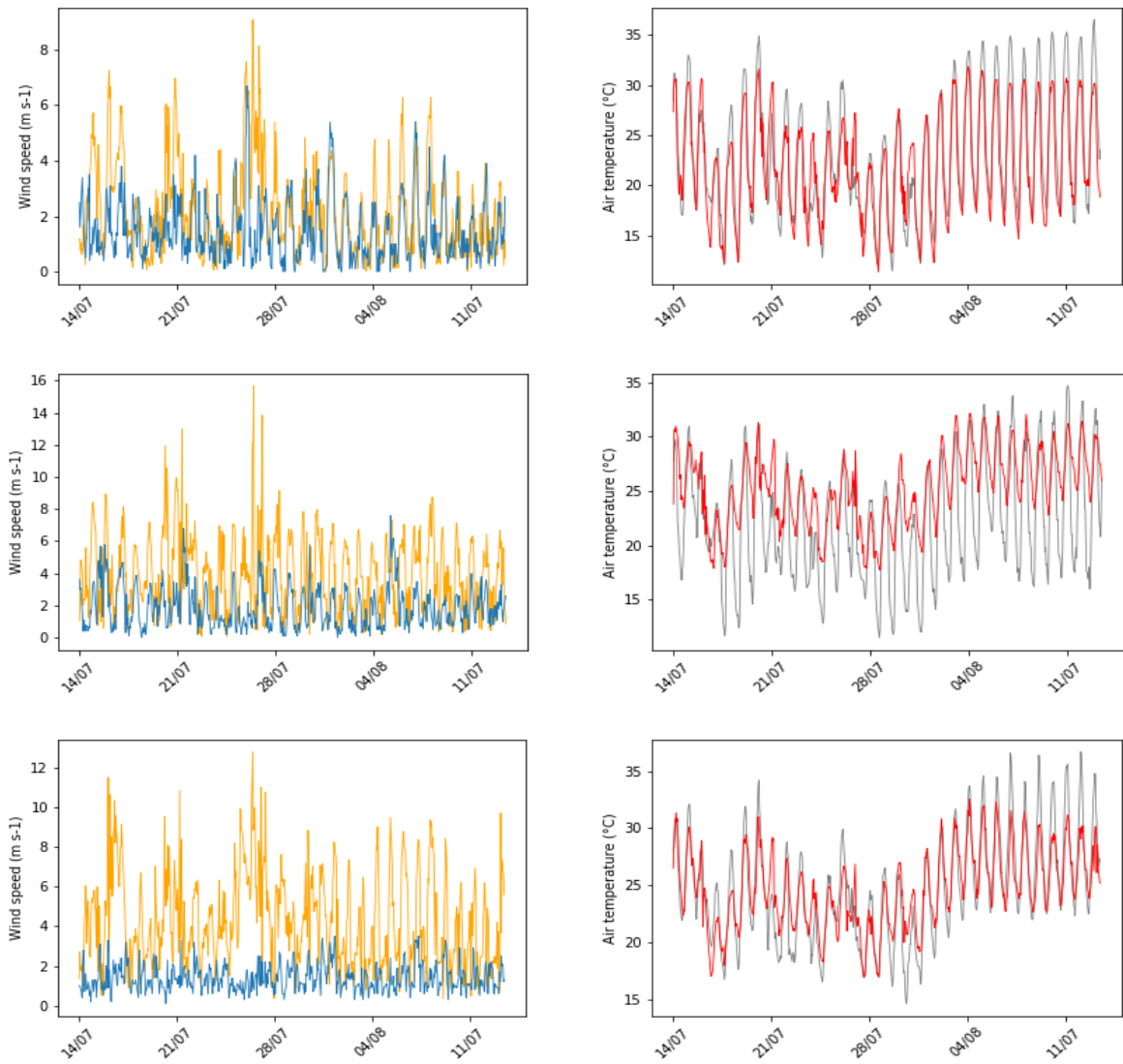
3. Results and Discussions

Simulations were conducted for one month from 15th of July 2003 to 14th August 2003. The measured and simulated air temperature at 2m above ground and the wind speed at 10m above ground are compared in **Figure 2**.

In rural areas, the morphology of the terrain significantly impacts the accuracy of the model. From the simulation of Aigle, it can be noted that the maximum temperature looks coherent with the measurement but during the night the temperatures do not fall by the same extent as in the observations (by up 7°C) (see **Figure 2**). It is possible that the "urban signature" of the temperature is due to an urban plume that is generated from a neighbouring cell, which propagates to the actual cell where the values were taken. Another reason for this might be the lower wind speeds as the model tends to perform imperfectly in complex and mountainous regions [12]. Similarly, the mountainous region of La Dôle, does not show a very good agreement. However, the results from the simulation show that at the beginning of the simulation there is a better correspondence with the observations with a reproduction of the daily dynamics (maxima and minima) that tends to worsen in the last days of August. In Payerne, a considerably better correspondence between measured and simulated data is obtained even if the simulated temperatures are lower during the days (by approximatively 1°C to 5°C). These results reflect studies [12] that suggest that WRF simulates temperatures for non-complex areas better than areas located near obstacles such as mountains that can create strong turbulences and complex airflow.
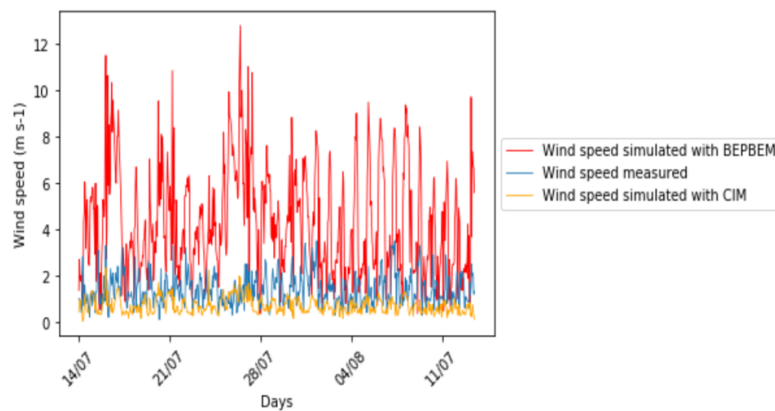
The simulated wind speeds for the Payerne station show a very good agreement with the measured wind speed (see Figure 2.) This can be explained by the fact that this station is located over a flat terrain with low or no vegetation. It can however be noted that the simulated wind speeds are higher in the Aigle station while they are significantly underestimated in La Dôle. These simulations give a good indication that complex terrains in WRF, such as mountainous areas, are difficult to represent and the simulation performs better for non-complex land use. Overall, the model performs well over rural areas (correlation coefficient: $r^2 = 0.81$, standard deviation: $\sigma = 0.1$ m s^{-1}), while there are significant deviations for mountainous regions (correlation coefficient: $r^2 = 0.56$, correlation coefficient: $\sigma = 0.5$ m s^{-1}).

No actual weather stations are located in the urban areas in the region. The closest one to an urban station is Pully and we show in **Figure 2** the simulated wind speeds and air temperature. It can be noted that the dynamics for the air temperature are reproduced in a satisfactory way, although at the end of the simulation there is a divergence. The wind speed is clearly overestimated and CIM can hence be used to obtain a more coherent profile (see *Figure 3*).
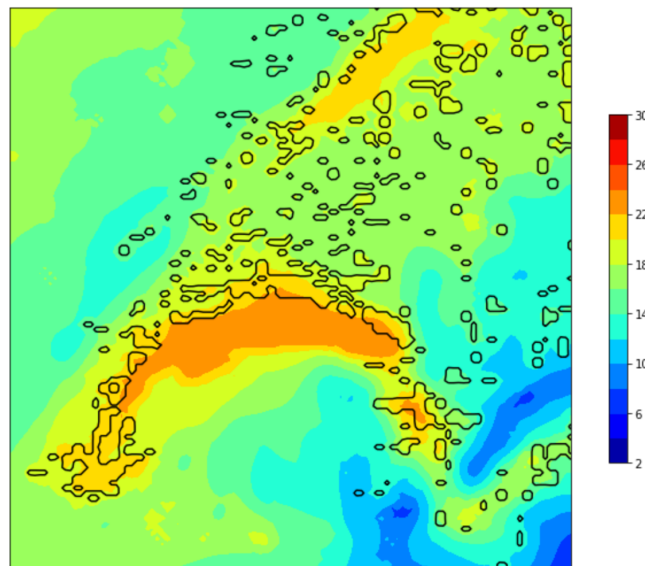
Figure 2: Left pane: Wind speed (m s^{-1}) and right pane: air temperature (°C) (top to bottom: La Dole, Payerne, Aigle and Pully)

Figure 3: Wind speed (m s^{-1}) simulated for Pully with CIM and with WRF-BEP-BEM

Additionally, it should be noted that the presence of Lake Geneva in this particular region, further influences the meteorological dynamics. It is noted, for example, that there is an accumulation of heat over the lake during summer nights. Figure 4 shows the mean monthly temperatures at 05.00 at 2m above the lake. The presence of highly urbanized areas around the lake creates an urban heat archipelago that leads to land / lake breezes and in turn to the accumulation of heat over the lake. It can thus bring some additional comfort for the urbanized areas in the summer nights.

Figure 4. Mean monthly 2m air temperature (°C) from the 14th July to the 13th of August 2003 at 05.00 in the morning

4. Conclusions and Perspectives

Heatwaves will become more frequent in the future due to climate change. Within the framework of Swiss Energy Strategy 2050 and the 2014 legislation on planning, Switzerland is promoting the densification of urban areas. The combined effect of future land uses and of climate change on urban areas, especially on the intensity of urban heat island has not yet been addressed at the cantonal scale in Switzerland. The aim of this study was hence to assess the performance of a meteorological model in a complex region including mountainous regions and a lake. The objective in the future is to use such types of models to evaluate the impact of the future urban planning scenarios on the urban climate, in particular during strong heatwaves.

It was shown that the WRF model performed very well over rural areas in particular when no obstacles were present. However, when the simulations were compared with measurements from two different stations (one in the Jura and one of the North side of the Alps), they did not give satisfactory results. This could be due to the representation of the mountainous regions themselves in the model and to the resolution used in the model (inner-most domain with a resolution of 1km). Studies have yet to be conducted on the impact of the urban areas on the Leman Lake. In particular, the lack of decrease in the temperature over the lake needs to be better understood as it has and will have a significant implication for the aquatic life of the lake. Furthermore, the WRF model itself needs to be improved to better represent the meteorological phenomena in particularly complex regions. This can be done for example with the use of models such as the Canopy Interface Model [13] which could be adapted to improve the representation of mountainous regions.

Acknowledgements

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