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ASSESSMENT OF THE DISPERSIVE CAPACITY OF NEIGHBOURHOODS BASED ON LOCAL CLIMATE ZONES CLASSIFICATION

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Abstract: NO_x dispersion simulations of a winter period were performed with the Weather Research and Forecasting model (WRF) coupled with an urban canopy scheme (BEP-BEM) in Vitoria-Gasteiz, a small size city in the north of the Iberian peninsula. Road traffic and residential heating were considered as emission sources and NO_x was treated as an inert gas, with no deposition. Comparison with observations across three urban air quality stations shows that the model is able to reproduce time and space variability. NO_x is normalized by the emission in each grid cell in order to represent the dispersion capacity of the urban canyons and results are analysed based on the Local Climate Zone (LCZ) classification. The dispersive capacity is found to be influenced by urban morphology. LCZs show different dispersion capacity, with LCZ 2 and 3 showing higher normalized concentration values than the rest. On the other hand, horizontal transport of NO_x is found to hinder the analysis and further understanding of urban winds is needed. This study shows the potential of the LCZ classification for air quality management, providing a fast screening method for cities, in order to prioritize the areas to be improved from the air pollution perspective.

Key words: *Urban air quality, mesoscale model, BEP-BEM, dispersion capacity, Local Climate Zones.*

INTRODUCTION

Air quality represents a problem for human health, being especially important in urban areas, where most of the population live. Pollutant concentration in urban street canyons mainly depends on two factors, i.e. pollutants emission and their dispersion within the canyon. Emission is mostly associated here with traffic and residential sector (e.g. boilers, cooking), which is specific for each street and can only be controlled through technological improvement (i.e. cleaner motor vehicles) or policy restrictions (i.e. low emission zones). On the other hand, dispersion depends on meteorological factors (i.e. atmospheric stability, wind speed) and the morphology or structure of the canyon, which affects wind speed and turbulence and shapes the exchange of air with higher atmospheric levels. The latter is also specific for each street canyon and could be ideally modified or smartly designed in the construction stage.

Local Climate Zones (LCZ) classification was introduced by Stewart and Oke (2012) to characterize neighbourhoods in terms of their interaction with the atmosphere, based on their fabric, land cover, structure, and metabolism. This classification has been widely used in urban climate, primarily as model input (Brousse et al. 2016), but also as a useful guidance for climate impact assessment or the need of design interventions analysis.

On the other hand, urban canyon structure is directly related with its dispersion capacity and hence LCZ classification could theoretically be used to identify potentially polluted neighbourhoods, if high emissions occur. However, this connection hasn't been documented yet.

In this work we investigate the capacity of the LCZ classification to characterize the dispersion capacity of different neighbourhoods. This is the capacity to disperse the pollutants released. For this task, a high pollution episode is simulated with the Weather and Forecasting Model (WRF, Skamarok et al. 2008), where city morphology is characterized based on the LCZ classification.

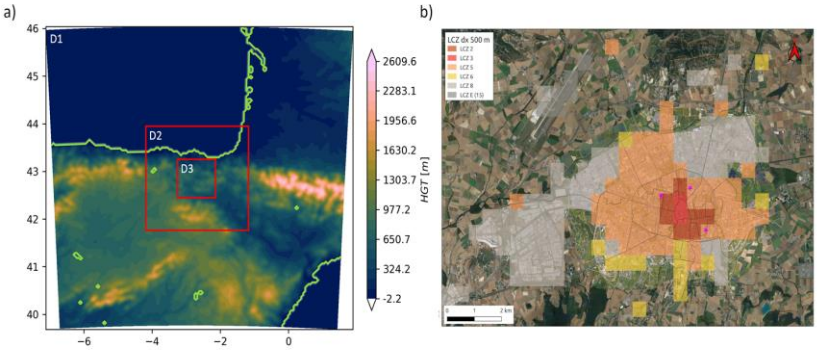

Figure1: a) Configuration of the three domains used for the simulations with 4.5 km (D1), 1.5 km (D2) and 500 m (D3) resolution, respectively. b) LCZ map for Vitoria-Gasteiz (VG) used in the simulations. The pink stars represent the measurement stations: Av. Gasteiz (West), 3 de Marzo (North) and Judimendi (South).

METHODOLOGY

In this study, the WRF model, coupled with the urban canopy parameterization BEP-BEM (Martilli et al. 2002; Salamanca et al. 2010), is used to simulate a high pollution episode in Vitoria-Gasteiz (VG), a small size city located in the north of the Iberian Peninsula (42°50′48″N 2°40′23″O). BEP-BEM is used here to account for the impact of the urban morphology on the pollutant emission and dispersion.

Three nested domains with 4.5 km, 1.5 km and 500 m resolution, respectively, are used in this study, with the smaller domain covering the city of VG (Figure 1a). The period simulated corresponds with the first week (1^{st} – 6^{th}) of January 2017, with the first day considered as spin – up. High pollution levels where registered between the 3^{rd} and 5^{th} days, making this period an interesting case study.

The LCZ map of VG was created with the *LCZ-Generator* tool (Demuzere et al. 2021), based on the WUDAPT methodology for Level 0 data (www.wudapt.org), followed by manual correction (Figure 1b). The LCZ classification is used here to assess its ability to characterize the dispersion capacity of different neighbourhoods. Next, urban morphology is characterized by calculating the average street and building width and building height for each LCZ. These parameters are required by BEP-BEM to parameterize the impact of the urban canopy on the atmosphere, and hence on pollutant dispersion.

Finally, the *wudapt-to-wrf* tool (Demuzere et al. *In preparation*) is used to convert the LCZ map into the input binary file readable by WRF. In this process, the original LCZ map with a resolution of ~50 m is averaged into the 500 m resolution grid used by WRF. Hence, due to the heterogeneity of the city, the final urban morphology parameters in each grid cell are the result of such average, being mostly a combination of different LCZs.

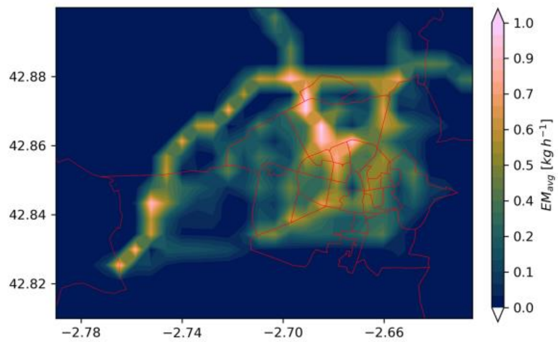

Figure 2: Mean hourly emission in kg $h^{-1.}$

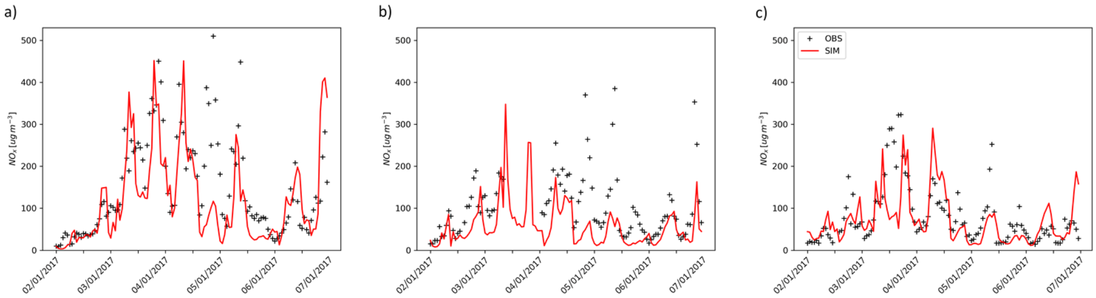

Figure 3: Observed (black crosses) and simulated (red line) hourly NO_x in the three air quality stations: a) Av. Gasteiz, b) 3 de Marzo and c) Judimendi.

NO_x dispersion is considered by activating the passive tracer variable already defined in WRF. Hence, NO_x dynamics are represented with the same diffusion coefficients than other scalars, being the ones from Bougeault and Lacarrere (1989) (Martilli et al. 2022).

Only traffic and residential emissions are considered, as they are the main contributors within the city area. This information, taken from the Air Quality Action Plan of the municipality of VG, is summed in each grid cell and introduced in the model (Figure 2), considering its diurnal variability.

The main difficulty when characterizing the dispersion capacity of a specific LCZ (or grid cell) is the advection of pollution between neighbour canyons. More pollution than what is emitted can therefore be found in an urban canyon, making difficult to assess its real dispersion capacity. To minimize this problem, two approximations are considered. First, the analysis is focused on the first vertical layer, considering emission sources and inmission levels in the first model level only. Second, to maximize the local impact on pollutant dispersion, only low wind conditions are considered. Hence, hourly situations with spatially averaged wind speed above the 50th percentile are neglected. The area used for the spatial averages extends from -2.76º to -2.63º and from 42.8º to 42.9º in longitude and latitude, respectively.

Normalized *NOx*

Pollution sources are highly heterogeneous in urban areas. Hence, to fairly evaluate the dispersion capacity of each LCZ, NO_x concentrations are normalized by the emission in each grid cell as:

$$NOx|_{NORM} = \frac{[NO_x]}{EM_{NO_x}} \tag{1}$$

where $NO_x|_{NORM}$ is the normalized NO_x concentration and $[NO_x]$ end EM_{NOx} are NOx concentration and emission, respectively, in kg h^{-1}.

This parameter represents the amount of NO_x remaining in the canyon, respect to what is emitted, and hence we define it as the inverse of the dispersion capacity.

RESULTS

Results are compared with measurements from 3 stations managed by the Basque Government (Figure 3). The model is able to qualitatively represent the increase of NO_x values observed between the 3rd and 5th of January, although it fails to reproduce the second peak observed on the 4th in Av. Gasteiz and 3 de Marzo. In addition, it captures the qualitative differences observed between the three stations, with higher values found in Av. Gasteiz, followed by 3 de Marzo and Judimendi.

Hourly averaged wind field and $NO_x|_{NORM}$, calculated as the grid cell average between all the hourly situations with spatially averaged wind speed below the 50th percentile are shown in Figure 4. Maximum values are not located where emission is higher, probably due to the different capacity to disperse pollutants in each area and the action of the wind, which shows convergence towards the area where NOx$|_{NORM}$ is maximum.

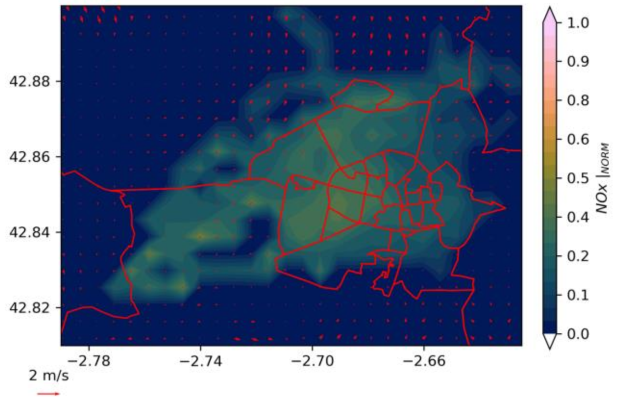

Figure 4: Mean hourly $NO_x|_{NORM}$ and wind vectors (red arrows), calculated as the average hourly $NO_x|_{NORM}$ and wind, respectively, with spatially averaged wind speed below the 50th percentile situations. The area with longitudes between -2.76º and -2.63º and latitudes between 42.8º and 42.9º is considered for the spatial average.

Box plots of $NO_X|_{NORM}$ for each LCZ are used to further study the dispersive capacity (Figure 5). Each box consists of the time median in each grid cell belonging to the correspondent LCZ. Even though averaging in time reduces the sample, it also helps minimizing inmission variability, mostly related to horizontal transport. As seen, the highest median and lower dispersion capacity is found in LCZ 3, followed by LCZ 2, LCZ 5, LCZ 8 and LCZ 6, however the differences are not big. It is important to note the high spread of the results, pointing out the complexity of avoiding non local effects and the fact that due to model resolution, morphological parameters differ between cells with the same LCZ.

Finally, the diurnal cycle of the median of $NO_X|_{NORM}$ for each LCZ is shown in Figure 6. LCZ 3 shows lower dispersion capacity during daytime (hence higher $NO_x|_{NORM}$), when the highest emission occurs, although higher during night-time. LCZ 2, with higher dispersion capacity than LCZ 3, but lower than the others, shows higher night-time $NO_{x|NORM}$ values. This is also observed for LCZ 5. This can be especially important during high pollution episodes, where pollution remains high during the night, despite the lower emission.

The shape of the curves in Figure 6 reminds such of the emission, again pointing out the difficulty to isolate the impact of advection. In addition, the decrease seen between 0900 and 1800 UTC could be a consequence of the higher wind speed during this time period.

CONCLUSIONS

The dispersive capacity of different neighbourhoods is studied by simulating NO_x dispersion in a small sized town. A normalized NO_x is defined for each grid point, previously classified by its morphology following the LCZ classification.

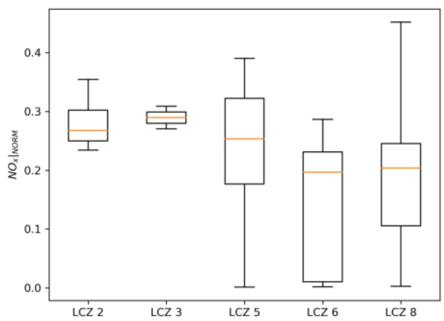

Figure 5: Box plots of $NO_x|_{NORM}$ for each LCZ. Values per box are the time mean in each point belonging to a specific LCZ. The box defines the region between 25 to 75 percentile, horizontal red lines represent the median, and the whiskers are extended to the minimum and maximum values.

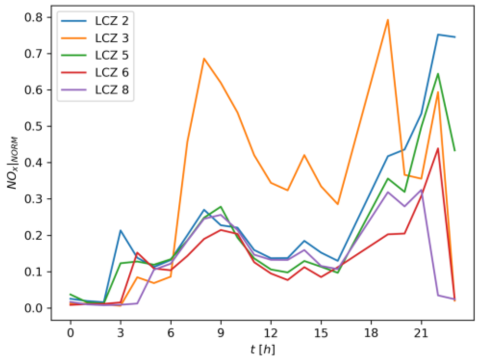

Figure 6: Diurnal cycle of the median of $NO_x|_{NORM}$ for each LCZ.

Results show that LCZ 2, 3 and 5 have the lowest dispersion capacities, tending to accumulate pollutants. In the case of Vitoria – Gasteiz, LCZ 3 has almost no traffic, making the emission, and inmission, relatively low. On the other hand, higher emissions are normally found in LCZ 2 and 5, making the accumulation of pollutants a problem, exacerbated by the fact that these LCZs are where most of the people live.

This study shows that LCZs disperse pollutants differently, making LCZ a useful classification for dispersion capacity characterization. This work points out the difficulties to avoid horizontal transport of pollutants, which could worsen the air quality in a specific area, despite its emission. The impact of such transport would also depend on the dispersive capacity of both the source and receptor of pollution.

A potential impact of wind convergence has also been hypothesized in this study. More research on pollutants dynamics and its dependency on urban morphology or urban heat island circulation would be needed. Understanding the dynamics inside urban areas and the capacity to disperse of different neighbourhoods would help optimizing traffic and hence designing cities as healthier places.

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