Bias-adjustment method for street-scale air quality models

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EXTENDED ABSTRACT

Air quality (AQ) is a growing concern, especially in urban areas where high-density populated regions are exposed to frequent exceedances of regulated pollutants. To take action in reducing citizen exposure to pollution, a reliable assessment of the pollutants' ambient concentrations across the city is required.

Street-scale AQ models are designed to capture the typical spatial variability that pollutants exhibit in the urban morphology. Such urban models are generally nested to regional AQ models and use the information of traffic emissions, together with meteorological conditions, and a geometric description of the building's layout, to provide an estimation of the dispersion of target pollutants at the street scale. However, results of urban AQ models are subjected to uncertainties, mainly due to the multiscale behavior of the phenomenon and to the challenges of characterizing the wind flow within street-canyons, which encompasses multiple emission sources and the downscaling of meteorological variables.

To minimize these uncertainties, we present a data-fusion method that combines the model results, obtained using the CALIOPE-Urban [1] model, with publicly available observations from the official monitoring network in Catalonia (XVPCA). This method is derived to preserve the spatial variability of the urban model. As a test case, we then present annual bias-corrected results of the NO_2 levels across the city of Barcelona for the year 2019. Results correspond to the legislated annual mean and the 19th daily maximum value of the year.

A. Observational data

The observational data used for the data-fusion method are obtained from the 7 urban monitoring stations of the XVPCA that measure NO_2 within the Barcelona municipality.

B. Model data

The spatial distribution of NO_2 is obtained using the CALIOPE-Urban [1] model. CALIOPE-Urban computes the dispersion of pollutants emitted by the traffic sector [2] at the street-scale using a Gaussian dispersion model. Background concentrations, used as an input in the urban model, are provided by the regional AQ model CALIOPE. In this work, the urban model computes hourly NO_2 concentrations at a resolution of 50 m x 50 m, while the regional model uses nested domains of resolutions: 1km x 1km for the region of Catalonia, 4 km x 4km for the Iberian Peninsula, and 12 km x 12 km for the European Union region.

C. Data fusion methodology

Data fusion methodologies aim to correct systematic errors of the model at the entire computational grid using the available observations. In contrast with the commonly data-fusion methods used in the regional-AQ models (such as CALIOPE) that are based on the distance to the observational sites; in this work, we derive a method that preserves the spatial variability estimated by the urban model.

For this purpose, linear regressions for the daily mean concentration and the daily variability are fitted using all available data pairs of model-observation. Using these regressions, model results are corrected in terms of daily mean and daily variability, relying solely on the model output. The post-processing models are refitted every day to account for the dependency of the systematic errors on the meteorological conditions.

D. Results

Leave-One-Out-Cross-Validation (LOOCV) has been performed to assess the validity of the present data fusion method. This validation consists in performing the bias-adjustment considering all observational data except one, which is used to cross-validate the results. In Table I, raw results from the urban model are compared with the bias adjustment and the cross validation (LOOCV) results. In average, locations for which there are no available observations are expected to have a correlation coefficient of r^2=0.62 and a fraction of predictions within a factor of two FAC2=0.80.

TABLE I
CROSS VALIDATION RESULTS OF THE BIAS CORRECTION FOR 2019

Station name	Raw model		Bias adjustment		LOOCV	
	FAC2	r^2	FAC2	r^2	FAC2	r^2
Sants	0.67	0.42	0.80	0.61	0.79	0.60
Eixample	0.82	0.53	0.91	0.69	0.87	0.66
Ciutadella	0.69	0.53	0.78	0.64	0.76	0.63
Palau Reial	0.71	0.47	0.76	0.62	0.75	0.61
Gràcia	0.81	0.54	0.87	0.69	0.85	0.65
Poblenou	0.72	0.58	0.84	0.70	0.82	0.68
Valld'Hebron	0.65	0.46	0.74	0.57	0.72	0.54

The corrected annual average map of NO_2 concentrations is shown in Fig.1. In the regions close to the main roads of the city, where the traffic is more intense, as well as the area close to the port (at the south region), the legislated threshold of 40 $\mu g/m^3$ (established in 2008/50/CE) is exceeded.

Model results of the NO_2 annual average at the observational sites are compared with measurements in Table II. The corrected model results are in good agreement with the observed annual mean, being that the larger relative difference is 10.6% (positive values of the relative difference stand for model over-predictions and vice-versa).

TABLE II
MODEL RESULTS AND OBSERVATIONS OF ANNUAL MEAN NO_2 FOR 2019

Station name	**Model mean** ($\mu g/m^3$)	**Obs. mean** ($\mu g/m^3$)	**Relative diff. (%)**
Sants	30.49	30.81	-1.06
Eixample	46.65	48.67	-4.33
Ciutadella	35.49	31.73	10.60
Palau Reial	29.66	27.46	7.40
Gràcia-St.Gervasi	40.37	42.78	-5.97
Poblenou	33.17	36.02	-8.58
Vall d'Hebron	27.62	28.45	3.02

The daily hourly maximum limit of NO_2, defined in the 2008/50/CE as the 19^{th} daily maximum of the year, corresponds to a threshold of 140 $\mu g/m^3$. Figure 2 shows the 19^{th} daily maximum NO_2 concentration across the city of Barcelona, again some exceedance of the legal limit can be observed in heavily trafficked streets. Looking at the NO2 19^{th} daily maximum concentrations in Table III, model exceedances are observed at the traffic monitoring sites of Eixample and Gràcia.

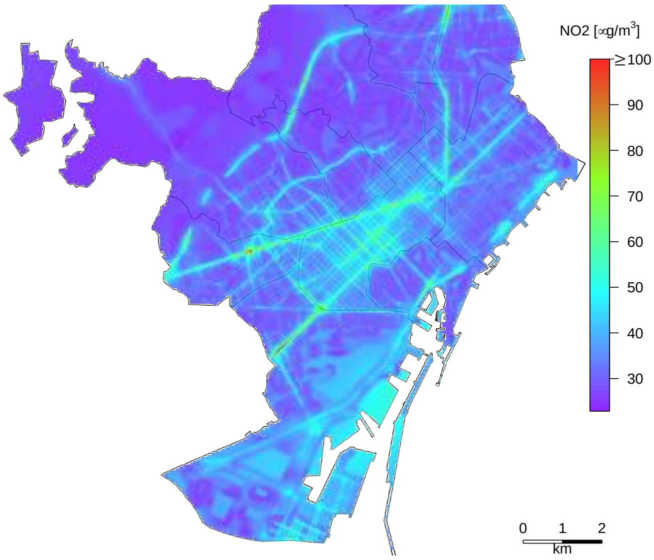

Fig. 1 Annual mean NO2 concentration levels at the municipality of Barcelona for 2019.

TABLE III
MODEL RESULTS AND OBS. OF THE 19^{TH} DAILY MAX. OF NO_2 FOR 2019

Station name	Model 19^{th} max. ($\mu g/m^3$)	Obs. 19^{th} max. ($\mu g/m^3$)	Relative diff. (%)
Sants	131.70	111.05	15.68
Eixample	149.91	137.58	8.22
Ciutadella	123.98	107.12	13.60
Palau Reial	131.31	115.96	11.69
Gràcia St.Gervasi	133.98	156.26	-16.62
Poblenou	120.82	114.97	4.83
Vall d'Hebron	124.54	114.99	7,68

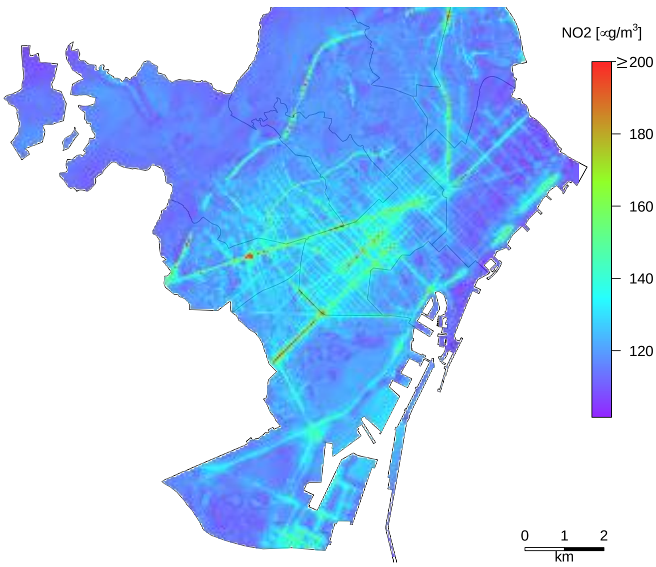

Fig. 2 19^{th} daily maximum NO2 concentration levels at the municipality of Barcelona during 2019.

E. Conclusion and Future Enhancement

The presented bias-adjustment methodology permits to perform reliable diagnosis of the annual NO2 levels. The diagnosis of Barcelona for 2019 puts in evidence that the NO_2 annual mean is systematically exceeded in many locations of the city, especially in the *Eixample* central district, and the region close to the port. On the other hand, the legislated hourly 19^{th} daily maximum (140 $\mu g/m^3$) is exceeded in some heavily trafficked regions.

As future works, we plan to apply other state-of-the-art data fusion methodologies, such as Universal Kriging, to compare their performance with the present methodology. The future goal is to improve data fusion methodologies in the urban context to perform better reanalyzes which are key for health impact studies.

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Author biography

Jan Mateu Armengol holds a Bachelor degree in Industrial Engineering from the Universitat Politècnica de Catalunya (Spain, 2013). He obtained a MSc. degree in numerical heat transfer and fluid flow by the Universidade Estadual de Campinas (Brazil, 2015). After receiving his joint-PhD degree in mechanical engineering from both the Universidade Estadual de Campinas and the École Centrale Paris (France, 2019), he collaborated with L'École Polytechnique (France, 2020) as a postdoctoral researcher working on Bayesian inference and uncertainty quantification on reduced chemical schemes. In 2020, he obtained a postdoctoral funding at the BSC from the STARs program (Marie-Sklodowska-Curie Action COFUND program) to join the Atmospheric composition group, as well as the Earth System Services group, to apply uncertainty quantification and data assimilation methodologies to urban air quality simulations.