Testing simple models for street wind conditions in Barcelona

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Abstract—***Street wind speed and direction drive models to estimate air quality levels at street scale. In this study, simple models are combined with a mesoscale meteorological model to provide wind conditions at street level. Then, wind speed and direction are evaluated using observations collected during an experimental campaign in April 2013 at street level in Barcelona, Spain. Overall, models considering street geometry give better estimates for both wind speed and direction than those assuming homogeneous terrain. For light winds, models tend to produce a large amount of error estimating wind direction.***

I. Introduction

The focus of this PhD work is to develop a coupled air quality modelling system in which a regional photochemical model, a mesoscale meteorological model, an emissions model and a street scale dispersion model are coupled to give air quality estimates of street level air pollutants. This coupled modelling system is driven by surface meteorological parameters. Typically in urban air quality modelling, these parameters are generated by adapting airport measurements to local winds using empirical equations. This approach results in less precise air pollutant level estimates compared to using local wind conditions as meteorological input [1].

II. Objective

We aim to use specific wind conditions for each street segment to drive a dispersion model. In this abstract, a comparison of simple models to obtain street-specific wind conditions combined with WRF, a mesoscale meteorological model, is presented.

III. Data

Wind speed and direction estimates are evaluated using meteorological observations from an experimental campaign conducted by CSIC in April 2013 in Barcelona [2]. During the campaign, mobile laboratories placed at the parking lane of several street segments measured air quality and meteorological parameters at 3 meters (m) height. For this study, data gathered every 30 minutes at Industria Road No. 213, Industria Road No. 309 and Valencia Road No. 445 were used. Street geometries in these sites are similar: street width at Industria Road and Valencia Road is 20 m and average building height is approx. 20 m. As input for road configuration, we use HERMES emission model road links [3]. For building geometry, we use district geometry from Barcelona City Council [4].

IV. Methods

Adapting regional winds to street level using simple models can be divided in two sub-problems: adapting mesoscale wind to surface level and projecting wind flow into the street segment. In this abstract, two approaches to adapt WRF outputs to surface level using a logarithmic wind profile and taking into account atmospheric stability are evaluated: WRF surface layer parametrization (originally implemented to diagnose winds at 10 m) was adapted to estimate winds at 3 m height; and RLINE parametrization to estimate surface level winds [9]. These methods assume that terrain is homogeneous. In order to project wind into each street segment, three approaches are evaluated (sketches shown in Figure 1): a) channel, which projects wind speed into the street segment using θ, the angle between over roof wind direction and street axis. It estimates wind speed as $u_{street}(\theta) = u_{street}(\theta = 0^{\circ})\cos(\theta)$ following Soulhac et al. [5] method. Wind direction is set to either up street or down street depending on θ angle cosine value; b) OSPM, which adapts roof wind speed to surface level using a logarithmic profile and does not consider atmospheric stability [6]. For the analysed street segments, OSPM assumes that street wind direction is mirrored inside the street compared to over roof wind direction (see Sub-figure b in Figure 1); and c) H-H model, which incorporates a model for transverse wind flow in street canyons [7] and a logarithmic wind profile for along canyon flow following Canyon Plume-Box Model methodology [8].

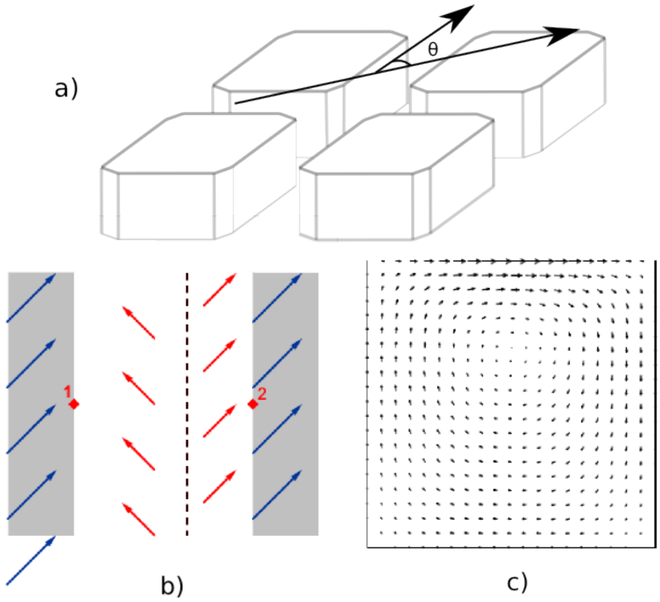

Figure 1. Tested models for street wind conditions. a) Channel, approach purposed by Soulhac et al. [5]; b) OSPM, developed by Hertel and Berkowicz [6]; c) H-H, designed by Hotchkiss and Harlow [7] for transverse flow and extended by Yamartino et al. [8] for along canyon flow.

V. Experiment Setup

Two WRF simulations were executed over the Catalonian domain at 1 km x 1 km horizontal resolution, for the entire month of April 2013. The first simulation used the current CALIOPE Air Quality Forecast System configuration in urban areas with surface roughness (z_0) equal 0.5. In the second simulation, z_0 was set to 1.0, $1/20$ of the average building height (approx. 20 m) in Eixample District. Then,

Table I
MEAN GROSS ERROR (MGE) COMPARISON OF WIND SPEED (M/S) AND DIRECTION (DEG.) FOR EACH TIME PERIOD. MODELS WITH LOWER MGE FOR EACH PERIOD ARE HIGHLIGHTED. $*$ DATA ENDS 24TH OF APRIL. $MGE = \frac{1}{n}\sum_{i=1}^{n}|Model_i - Obs_i|$

Site	Period	WRF-Open		RLINE-Open		WRF-Chan		RLINE-Chan		OSPM		H-H	
		Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.	Speed	Dir.
Industria No. 213	$3-11$	0.57	91	0.63	91	**0.51**	**51**	0.53	**51**	0.73	62	0.77	62
	$12-18$	0.40	92	0.52	92	**0.39**	**85**	0.41	**85**	0.53	104	0.59	104
	$19-24*$	0.77	114	0.86	114	**0.73**	64	0.78	64	0.98	65	1.04	**54**
Industria No. 309	$3-11$	**0.50**	81	0.54	81	0.51	56	0.51	56	0.63	57	0.66	**51**
	$12-18$	**0.37**	118	0.49	118	0.39	121	0.38	121	0.48	**82**	0.52	88
	$19-30$	0.67	91	0.88	91	**0.56**	64	0.69	64	0.86	49	1.00	**47**
Valencia No. 445	$3-11$	0.55	76	**0.52**	76	0.65	**53**	0.62	**53**	0.66	58	0.72	56
	$12-18$	0.61	93	**0.48**	93	0.81	99	0.75	99	0.72	**89**	0.82	104
	$19-30$	**0.68**	87	0.75	87	0.75	**61**	0.81	**61**	0.88	66	1.05	**61**

wind conditions at 10 m using WRF and RLINE approaches were evaluated using observations from the airport station. At urban sites, WRF simulations were combined with four street wind methods: open terrain, using either WRF surface level wind (WRF-open) or RLINE surface wind parametrization (RLINE-open); channel, combined with either WRF or RLINE surface wind (WRF-Chan and RLINE-Chan); OSPM and H-H. Both OSPM and H-H, were driven by WRF first layer wind as over roof wind (middle of the first layer at 20.23 m). Hourly wind conditions were estimated for the entire period of April 2013. Additionally, this period was subdivided into three sub-periods to evaluate model outputs under low wind speeds and high wind speeds. From the 12th to the 18th of April 2013, the slow wind speed period (e.g. airport average wind speed was 3.3 m/s), there was a high pressure system over the Iberian Peninsula that brought atmospheric stability and calm winds to Barcelona [10]. In contrast, during periods 1st to 11th of April and 19th to 30th higher wind speeds were measured (e.g. average wind speed at airport 4.3 m/s and 4.8 m/s). In this abstract, Mean Gross Error (MGE) is used for model comparison. MGE is: $MGE = \frac{1}{n}\sum_{i=1}^{n}|Model_i - Obs_i|$.

VI. RESULTS

At the airport, hourly wind speed and direction outputs from WRF $z_0 = 1$ (WRF1) simulation were compared to WRF $z_0 = 0.5$ (WRF.5) for the entire April 2013. WRF.5 produced better wind speed estimates (MGE 2.09 m/s) than WRF1 (MGE 2.38 m/s) at the airport while wind direction results were similar (both simulations approx. MGE = 105 degrees). Then, WRF1 and WRF.5 ability to simulate wind speed combined with simple models was analysed. WRF1 produced more accurate estimates. Thus, WRF1 simulation was used as input for the comparison of simple models for street wind conditions. Regarding urban sites, a preliminary data exploration showed that Valencia Road No. 445 wind speed measurements were higher (1st period average wind speed was 1.2 m /s; 2nd 1.1 m/s; 3rd 1.06 m/s) than Industria Road No. 213 (1st period average wind speed was 0.71 m/s; 2nd 0.36 m/s; 3rd 0.52 m/s) and Industria Road No. 309 (1st period average wind speed was 0.90 m/s; 2nd 0.40 m/s; 3rd 0.54 m/s). This fact may be caused by the lower height of Valencia Road No. 445 surrounding buildings compared to Industria Road sites. Model results at street segments are summarized in Table I, where lower MGE (higher accuracy) for each period is highlighted. In the table, we see that wind speed at Valencia Road calculated by WRF-Open and RLINE-Open were more precise. In contrast, for most of the sub-periods in Industria Road sites WRF-Chan and RLINE-Chan were more accurate than other approaches. Regarding wind direction, models considering street geometry produced more precise estimates in every site and period. Additionally, under low wind speed (12th to 18th) wind direction estimates were less precise than under high wind speed conditions.

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