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ADAPTATION OF METEOROLOGY AND R-LINE TO STREET CANYON MICRO-CLIMATES: APPLICATION IN BARCELONA CITY SPAIN

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1. INTRODUCTION

Roadway dispersion models, such as R-LINE (Snyder et. al. 2013), are used to estimate air quality and human health impacts at the street level in urban environments. Traditionally, meteorological measurements taken at airport stations are used as input data for modelling the dispersion of traffic-related pollutants within street canyons due to the lack of measurements within the city. However, depending on the airport location, uniformity of the urban landscape, and source location, this meteorology (e.g. wind speed and wind direction) may not be representative of the dynamics observed in the street canyons.

Inaccurate meteorology can lead to uncertainties when modelling the dispersion of pollutants, especially in complex urban environments such as street canyons. The use of mesoscale meteorological models to provide gridded meteorological values for each street can be seen as an alternative to the aforementioned methodology.

In this study we first explore the appropriateness of airport and grid-based meteorology to an urban built environment. Then we explore techniques to adjust grid- and airport-based meteorology to mimic wind fields of an urban street canyon. This meteorology is then used as input to a roadway dispersion model, R-LINE, to simulate dispersion of roadway pollutants within the city. Effects of micro-climate meteorology on near-source dispersion estimates are evaluated using a measurement campaign in Barcelona city (Spain) for April 2013.

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2. METHODOLOGY

We examine the feasibility of using a grid-based meteorology model to approximate local meteorology. Then we adapt the local meteorology within the R-LINE model to account for features of the micro-climates within street canyons in an urban area.

2.1 WRF vs. Single-Point Measurement

Traditionally, dispersion models such as R-LINE use single point meteorology, typically at an airport, to estimate dispersion from all sources in large domains. There are concerns with the applicability of single point meteorology especially where there exist highly-urbanized areas and sub-urban areas within the same domain.

WRF was run over Europe at a 12 km × 12 km horizontal resolution using NCEP initial/boundary conditions. Then WRF was run at 4 km × 4 km horizontal resolution over the Iberian Peninsula, with a nesting over the European domain. Finally, WRF was executed at 1 km × 1 km over Barcelona domain using one-way nesting. In the vertical, WRF is configured with 38 sigma layers up to 50 hPa, where 11 correspond to the planetary boundary layer. In this study, WRF setup utilizes the rapid radiation transfer model for long-wave radiation and Dudhia for short-wave. It uses the Kain–Fritsch cumulus parameterization (Kain and Fritsch, 1990), the single-moment 3-class microphysics scheme, and the Yonsei University PBL scheme. Furthemore, the Noah land-surface model is applied, based on the CORINE land-use data from the year 2006.

In addition, WRF provides the possibility of forecasting localized meteorology, which is not possible with a single-point measurement. This will be advantageous when these localized meteorological adaptations are incorporated in the CALIOPE-Urban system (presented by Jaime Benavides in this conference with title CALIOPE-Urban: coupling R-LINE with CMAQ for urban air quality forecasts over Barcelona).

2.2 R-LINE local meteorology

We have identified two aspects of the urban topography that we believe greatly affect the dispersion of roadway emissions within the city. These two aspects are (1) when the wind is profiled below the average building height; and (2) the wind direction within the city is greatly affected by the orientation of the buildings and the streets between them.

We believe that the wind profile within the city does not accurately capture the wind speed below the building height due to the increased surface roughness from the existence of the buildings. We have developed a methodology to increase the surface roughness based on the average building height, building density, and the building height to street width ratio. The theory here is that the surface roughness should increase with an increase in average building height, building density, and building height to street width ratio. Once the surface roughness is adjusted the displacement height, u*, w*, mixing height, and Monin-Obukov length are re-calculated (Cimorelli et al 2005). The increase in surface roughness generally leads to a larger displacement height, u*, w*, and mixing height. Therefore, the Monin-Obukov length is less stable and more convective atmospheric conditions. Ultimately, these adjustments have an effect on the way the winds are profiled and the rate of dispersion of the roadway emissions within the urban area.

In addition to the surface roughness adjustment, we adjust the wind speed and direction to more closely represent the winds blowing down the street and constrained by the buildings. This leads to local wind being “channeled” down the street canyons. We have adapted R-LINE to incorporate the orientation of roadways with respect to the wind direction based on Soulhac et al. (2008). We have adapted the wind direction to mostly (90%) follow the street direction, with the remaining wind in the perpendicular direction. This leads to a recalculation of the wind direction and speed before roadway emissions are dispersed within a city.

2.3 Observations

In this study observations from an experimental campaign conducted in April 2013 in Barcelona (Amato et al., 2014) are used to evaluate simulated wind conditions. During the campaign, mobile laboratories placed at the parking lane of several street segments measured air quality parameters at 3 meters (m) height and meteorological parameters at 5.5 m. For this study, data gathered every 30 minutes at Industria Street No. 213, Industria Street No. 309 and Valencia Street No. 445 are used. These streets present a marked canyon pattern where building height to street width ratio is approximately 1.

3. RESULTS

Figure 1 compares the single-point airport measurement and the WRF grid cell that approximates the meteorology in the grid-cell containing the airport.

We can see from Figure 1 that the WRF gridded meteorology is performing with a less than 10% underprediction to approximate the airport measured meteorology. There is a slight bias in the WRF wind speed, but this on average is less than 10%.

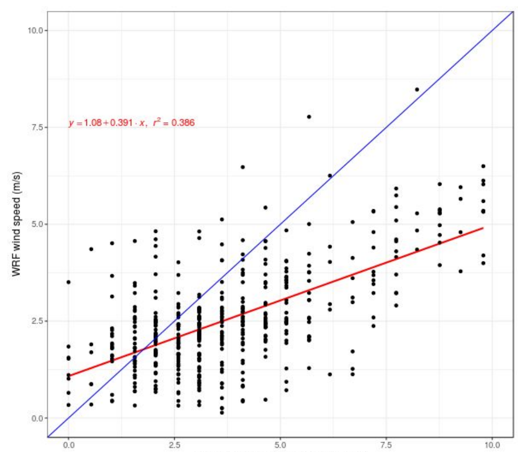

Fig.1 WRF wind speed compared to airport observations both at 10 meters matched in time and space for April 2013. The BLUE line represents 1:1 and the RED line is a regression fit to the data.

Next in Figure 2, we compare the diurnal pattern of WRF wind speeds at the airport with those at a location within the city. The highest wind speeds occurs in the middle of the day and the lowest wind speeds occur in the morning in hours eight and nine. However, we see that WRF predicts a lower wind speed at the location inside the city for all hours.

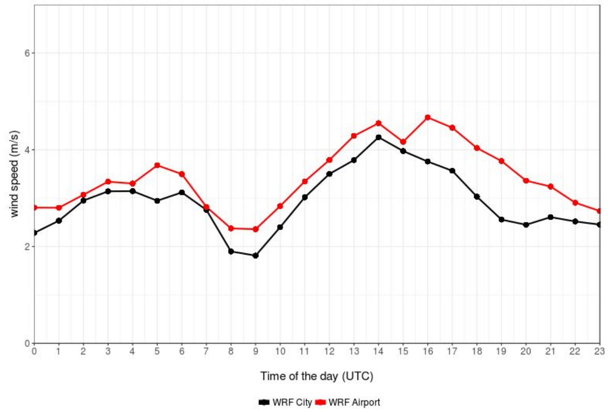

Fig.2 WRF bottom layer (mid point at 20.23 m height) wind speed by time of the day at airport (RED) and at Industria Street No. 309 (BLACK) in the city from 4th to 23rd April 2013.

This emphasizes the need to provide local meteorology throughout the city, and that a single-point measurement may not be completely representative through a city with variable topography. Also, this analysis provides confidence that we can use WRF meteorology throughout the city to approximate the localize meteorology.

The input wind speed as we have examined in the previous figures, which considers the turbulence and roughness of the specific grid cell, is then profiled to the desired height within the R-LINE model. We examine the diurnal pattern of profiled wind speed at the measurement height, 5.5 meters, during a field campaign in April 2013. Figure 3 uses WRF wind speed and compares the profiled wind speed using the standard R-LINE profiled winds (red line; R-LINE), then the profiled winds after adjustments are made to recalculate the wind speed (blue line; R-LINE local) as compared to the observed wind speed value.

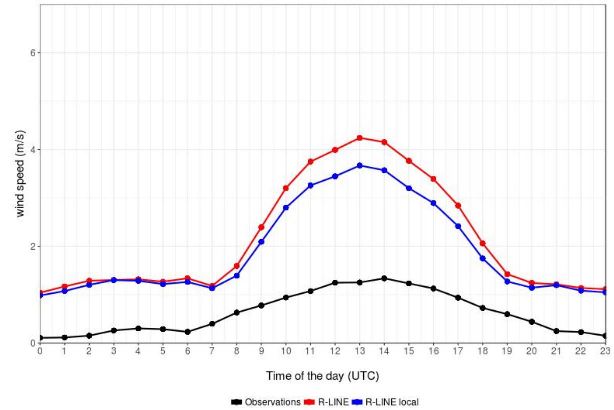

Fig.3 Average wind speed by time of the day at Industria Street No. 309 (4th to 23rd April 2013). Observations shown in BLACK, R-LINE without adjustment in RED, and R-LINE with local wind speed adjustment in BLUE.

As Figure 3 shows, the R-LINE local adjustments more closely matches the observed wind speed. However, there is still room for improvement to better match the measured wind speeds.

Next, we show effects of the wind direction and speed adjustments to show the influence of buildings to “channel” the winds along the streets within an urban area. We select the 8am hour of April 9, 2013, which has a u*=0.5 m/s, w*=1.1 m/s, zi=430.5 m, L = -108.4 m, z0 = 1.0 m, and U = 1.5 m/s. Figure 4 shows spatially how R-LINE estimates the dispersion of NO_2 within the urban area before accounting for the influence of the buildings.

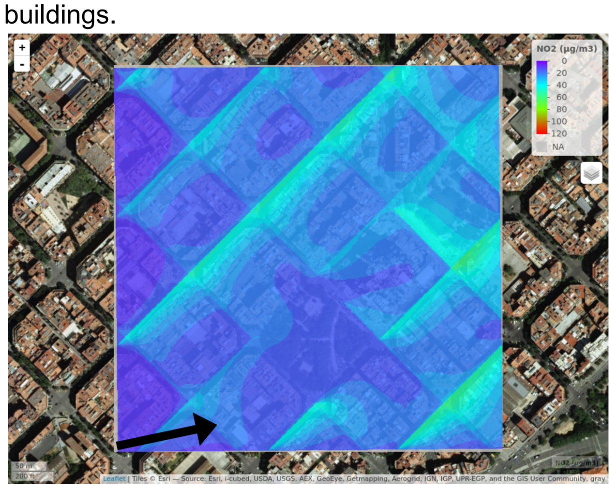

Fig.4 R-LINE before local meteorology adjustments: NO_2 concentrations in a specific 1km x 1km grid cell over Barcelona city at 8 am (UTC) on 9th April 2013. WRF wind direction is shown by the BLACK arrow at the bottom left corner of the spatial modeling domain.

Once we take into account the effect of the buildings to channel the meteorology and increase the surface roughness the surface meteorological parameters are recalculated. These recalculated parameters are u*=0.6 m/s, w*=1.5 m/s, zi=1005.2 m, L = -717.8 m, z0 = 1.2 m, and U = 2.8 m/s. The increase in wind speed is due to the new wind speed profile below the building height. The spatial concentration field is shown in Figure 5.

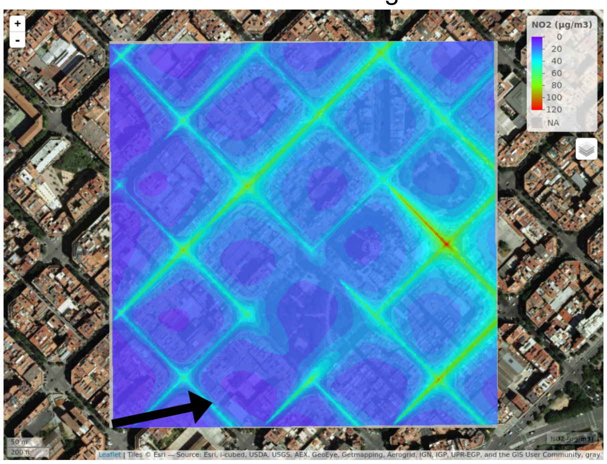

Fig.5 R-LINE local meteorology: NO_2 concentrations in a specific 1km x 1km grid cell over Barcelona at 8 am (UTC) on 9th April 2013. WRF wind direction is shown by the BLACK arrow at the bottom left corner of the spatial modeling domain.

Comparison of Figures 4 and 5 shows increased NO_2 concentrations within the street canyons created by the buildings. This also shows that the dispersion from the roadways is more contained within the street canyon where the emissions occur. We believe this better represents the "channeling" effect that the buildings have on the dispersion of the roadway emissions within the street canyons in the urban area.

4. CONCLUSION

Air quality within urban areas is difficult to represent due to the complex atmospheric dynamics caused by the local topography. We have coupled a grid-based meteorological model with a roadway dispersion model with local meteorological adjustments to better represent these complex atmospheric dynamics and lead to improved modeling of air quality in an urban area.

We began by comparing a grid-based meteorological model, WRF, to the meteorological parameters measured at an airport. Next, we showed the difference between the wind speed predicted at the airport and within the city. This shows the representativeness and power of using WRF-based meteorology as a starting point for the localized meteorology within the city.

Next, we demonstrated the improved wind speed in R-LINE when incorporating the adjustments for increased surface roughness and the corresponding profiled wind speed at the measurement height. This step shows a better representation of the micro-meteorological conditions within the city.

We take a final step to adjust the wind direction based on the street and building orientation. This adjustment shows increased impact of roadway emissions within the street canyons and a decrease in influence of one street canyon on another.

We believe in totality that the use of WRF meteorology, the increased surface roughness, and the "channeling" of the wind adjustments provide a more representative picture of the complex dynamics occurring within the urban street canyon microclimate and will lead to increased model performance when predicting localized urban air quality.

This methodology is implemented as part of the CALIOPE-URBAN project. Additional results will be presented in CALIOPE-URBAN: COUPLING R-LINE WITH CMAQ FOR URBAN AIR QUALITY FORECASTS OVER BARCELONA by Jaime Benavides at 9:10am on Wednesday 10/25/2017.

Disclaimer

The results presented here are part of ongoing research and should not be used or referenced until the research is complete and published. If you wish to use results from this extended abstract please contact the corresponding author (Michelle Snyder : michellesnyder@unc.edu)

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