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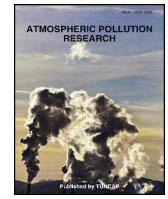


# Performance studies of planetary boundary layer schemes in WRF-Chem for the Andean region of Southern Ecuador

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## ABSTRACT

In tandem with emissions, the dynamics of the Planetary Boundary Layer (PBL) strongly define the concentration of pollutants in the atmosphere. The PBL parameterization schemes of numerical models need to be assessed to identify which one provides the best performance. We simulated the meteorology and transport of pollutants in Cuenca (Andean region of Southern Ecuador, 2400 masl) during September 2014, using the *Carbon Bond Mechanism Z* (CBMZ) for gaseous species and the *Model for Simulation Aerosol Interactions and Chemistry* (MOSAIC) for aerosol, from the Weather Research & Forecasting with Chemistry (WRF-Chem) model. Simulations were done under 6 PBL schemes: 1 Yonsei University, YSU; 2 Mellor-Yamada-Janjic, MYJ; 3 Hong and Pang, GFS; 4 Mellor-Yamada Nakanishi and Niino Level 2.5, MYNN2; 5 Mellor-Yamada Nakanishi and Niino Level 3, MYNN3; 6 Asymmetric Convective Model PBL, ACM2. The MYJ (local, 1.5 order of closure) and YSU (nonlocal, first order of closure) schemes showed on average the best skill, with capturing 81% and 78% of short-term air quality observations. For the MYJ scheme, the inclusion of direct effects between aerosol and meteorology increased the percentage of capturing of short and long-term air quality by 5% and 13% respectively, in comparison with modeling without feedbacks. In the future it is necessary to explore the effects in modeling of direct and indirect feedbacks, in combination with other parameterizations and aerosol-chemical mechanisms.

## 1. Introduction

Interactions between air pollutant emissions and meteorology define air quality levels. Among the meteorological components, the dynamics of the Planetary Boundary Layer (PBL) strongly influence the concentration of pollutants.

The PBL is the bottom part of the atmosphere, which is influenced directly by the Earth's surface, and responds with a timescale of one hour or less (Stull, 1988). It experiences a daily cycle of temperature, humidity, wind and pollution variation (Stull, 2000). The PBL depth can vary from a few tens of meters early in the day to several kilometers by midday (Stensrud, 2007), producing a changing volume of atmosphere to disperse pollutants.

Turbulence is the dominant mechanism that transmits surface forcing throughout the PBL. Because turbulence causes mixing, the PBL becomes homogenized (Stull, 2000). Turbulence operates on scales that cannot be explicitly represented on grid scales and time steps used in most weather mesoscale models (Cohen et al., 2015). Hence, its effects are expressed in modeling through PBL parameterization schemes.

There are two major components by which turbulence is represented in numerical weather models: 1) the order of turbulence closure, 2) the use of a local or nonlocal mixing approach.

The representation of PBL schemes decomposes the variables of the equation of motion into mean and perturbation components. The mean components show the time-averaged conditions of the background atmosphere. The perturbation components show turbulent fluctuations from the background mean state. Equations representing turbulence contain unknown terms, and these are always one order above the known terms. For this reason, turbulence closure requires empirically relating the unknown terms of moment $n+1$ to lower-moment known terms. This is referred to as $n^{th}$-order turbulence closure, where n is an integer (Stensrud, 2007). Some schemes present a 1.5-order of closure because they use second-order moments for some variables, and first-order moments for others.

Moreover, local schemes consider the influence only of the adjacent layers to a given cell and neglect the influence of large eddies; and nonlocal schemes use multiple vertical layers to a given cell, considering the superposition of both large and small eddies.

The influence of PBL schemes has been studied mainly in simulating meteorology (e.g. Cohen et al. (2015), Banks et al. (2016), Dimitrova et al. (2016)) and air quality in a lesser extent (e. g. Cuchiara et al. (2014), Banks and Baldasano (2016)).

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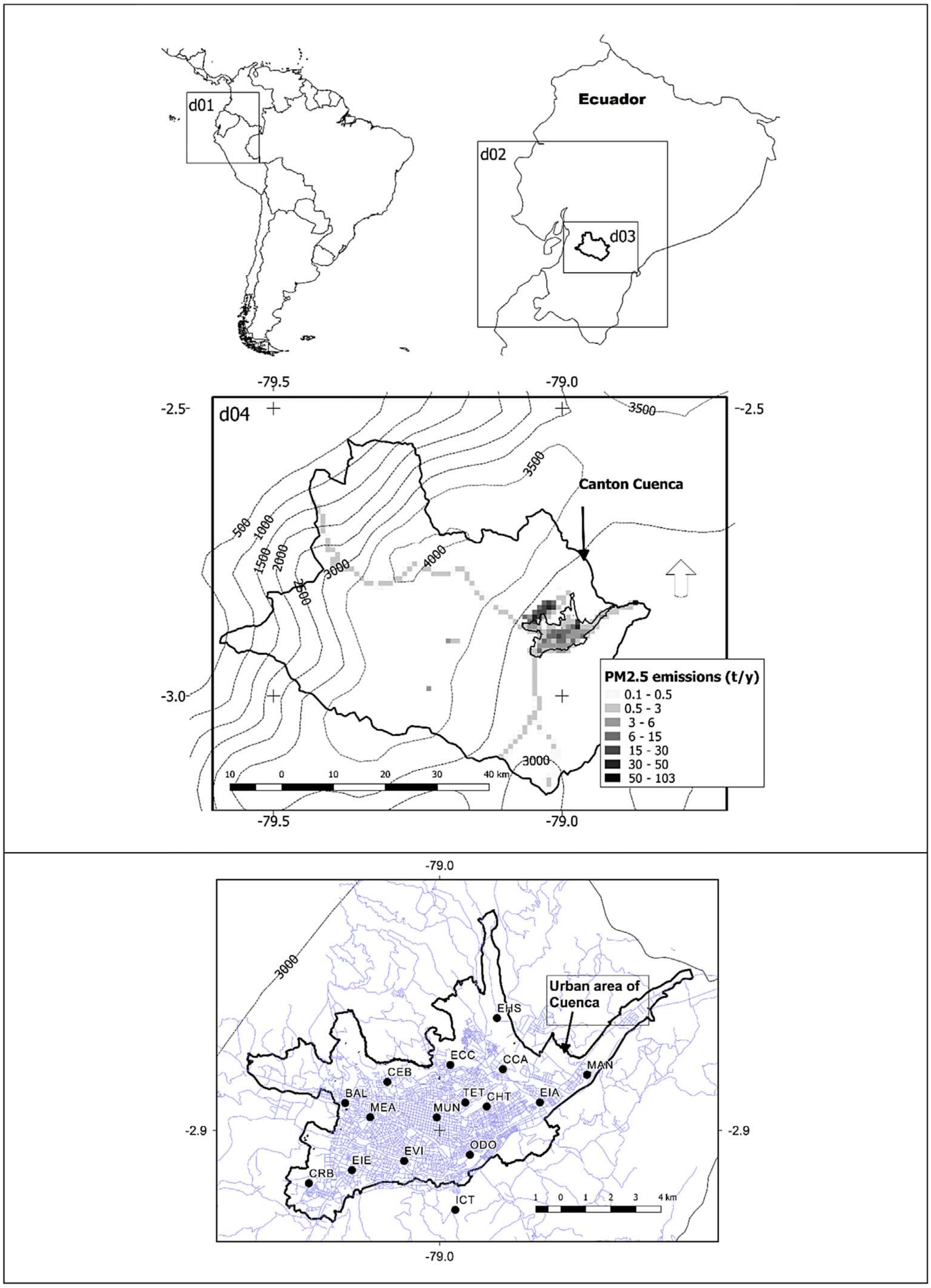


**Fig. 1.** Location of Cuenca (Andean region of Southern Ecuador). Legend shows the $PM_{2.5}$ emissions during the year 2014 (t/y) (EMOV EP, 2016a). Dashed lines depict topography (masl). Black dots indicate the air quality stations from Cuenca. MUN station (Historic Center, 2500 masl) provides meteorology and short-term air quality levels. The others are passive stations which monitor monthly-mean air quality concentrations. Master domain for modeling (d01): 70 × 70 cells, 27 km. First subdomain (d02): 52 × 52 cells, 9 km. Second subdomain (d03): 61 × 43 cells, 3 km. Third subdomain (d04): 100 × 82 cells, 1 km.

Coupling of atmospheric dynamics, pollutant transport, chemical reactions and atmospheric composition is of interest, since recent research has shown that meteorological and chemical feedbacks are important in the context of research areas such as meteorology and air quality modeling (Baklanov et al., 2014).

The effects of aerosol feedbacks can be explained in terms of direct and indirect effects. Direct effects are related with the scattering and absorbing of solar radiation. Indirect effects produce changes as the modification of vertical temperature profile, relative humidity, cloud formation, cloud properties and atmospheric stability (Boucher, 2015).

The main objective of this assessment is to identify the PBL scheme which provides the best performance in modeling both meteorology and the transport of air pollutants in the Canton Cuenca (Andean region of Southern Ecuador, Fig. 1). Also we want to explore the benefits in this region of modeling with direct effects of aerosol, in comparison with no aerosol feedbacks.

### 1.1. *Emission inventory from Cuenca*

Air pollutant emission inventories provide the information required both for environmental policy and modeling issues (Van Aardenne, 2002). Inventories for modeling demand spatial distribution and time resolution of both natural and anthropogenic emissions, which are required for the simulation of transport of air pollutants (Baklanov et al., 2014).

The Municipality of Cuenca currently has more than a half million inhabitants. It has a complex topography, with altitudes ranging from 1000 to 4000 masl (Fig. 1), showing strong changes of relief, climate and vegetation in a relatively small geographic area.

The last emission inventory from Cuenca correspond to 2014

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