# Assessment of Meteorological Models for Air Pollution Transport: Analysis between Mexico and Puebla Metropolitan Areas

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***Abstract-*** *This poster presents the results of research in the metropolitan areas in Mexico and Puebla valleys. The objective is assess and conduct a sensitivity analysis of meteorological conditions that could influence air pollutant transport between both valleys. The simulations were performed with CALMET v6.4 and WRF v.3.5, latter performed in the Mare Nostrum III super computer in the BSC-CNS; six days simulations considered statistically by Spearman correlations were selected in March and May months in 2012 year. It was found that WRF presented better results in domains to 9, 3 and 1 km in contrast to CALMET, considering wind speed and temperature variables.*

## I. Introduction

Urban development and air pollution in last 50 years, has brought a lot of problems, these consequences are just beginning to be recognized [1]. In accordance with World Health Organization (WHO), one way of assess air quality is measuring the concentration of criteria air pollutants (PM, $O_3$, $SO_2$, $NO_2$ y CO) [2]. Furthermore, there have been multiple studies using mathematic models, with the aim of to know the transport and influence between urban zones. Currently, air quality models constitute a complementary approach to monitor and characterize air pollution [3].

The Mexico City Metropolitan Area (MCMA) lies in an elevated basin at an altitude of 2240 m.a.s.l. (Meters above sea level) and 780 hPa mean atmospheric pressure (data from Mexico City International Airport). The MCMA's large population, industries, 5 million vehicles, complex topography, and meteorology cause high pollution levels. The mountains together frequent thermal inversions trap pollutants within the basin. The high elevation and intense sunlight also contribute to photochemical processes that create $O_3$ [4]. Some previous research suggests that air pollution emitted by MCMA is transported to cities near of this as Toluca and Cuernavaca [5][6]. However, it should be mentioned that the MCMA is a receptor of air pollution, e.g. from the Tula Metropolitan Area as a result of the emissions of industrial complexes in that area [7], there is few information related with the transport between MCMA and Puebla Metropolitan Area.

Usually air quality modelling systems (AQMS) require detailed information about topography, meteorological and pollutants emissions. Atmosphere is the place where are carried out the transport phenomena, therefore is need to obtain reliable and validated data to achieve accurate results for meteorological modelling as well as in air quality modelling.

The objectives in this work are threefold. First, to analyse synoptic and meso meteorology in the study area to find meteorological variables that impulse the air pollutants transport between both MCMA and Puebla Metropolitan Area (PMA); second, to assess the sensitivity of meteorological models (WRFv3.5 and CALMETv6.4); and the third is generate 3D weather information for use in an AQMS.

## II. Methods

### *II.1 Study zone and selection of days for modelling*

The study area was defined as a rectangular grid projection. The left corner reference coordinates of Southwest are latitude 18.603864°N, longitude -99.104269°W. The grid has 115 per 115 (*x,y*), with 1 km of spacing. The Metropolitan Areas within study area are: Mexico City, Puebla-Tlaxcala and Cuernavaca. There are three important elevations that creates a particularly situation: in the centre the "Popocatepetl" and "Iztaccihuatl" volcanoes, and northeast "La Malinche" volcano with 5500 m, 5220 m and 4420 m.a.s.l. respectively. The days selection, was performed by statistics analysis of measuring air pollutants data between 2001 and 2013 from SIMAT (Sistema de Monitoreo Atmosférico de la ciudad de México, spanish acronym) in MCMA and REMA (Red Estatal de Monitoreo Atmosférico, spanish acronym) in PMA, (2001-2013), this database must fulfil the criteria on the 75 % minimum. The third stage calculated the maximum mixing height layer with Holzworth method [8]. This calculation is aimed at getting to know in which days the heights exceeds volcanoes elevation, and was realized using information from radiosounding from International Airport "Benito Juárez" in Mexico City (BJIA, English acronym). Finally, was performed a Spearman correlation of measuring air pollutants data between MCMA and PMA to select days most correlated.

### *II.3 CALMET configuration*

CALMET as a diagnostic meteorological model uses meteorological measurement, orography and land use data, for CALMET v6.4 configuration was used local meteorological data observations from different institutions, SIMAT, BUAP (Benemérita Universidad Autónoma de Puebla, Spanish acronym) and SMN (Servicio Meteorológico Nacional de

México, Spanish acronym), this study used 16 meteorological stations datasets; the vertical meteorological information was obtained from BJIA radio sounding. The key configuration are z levels: 0., 20., 40., 80., 160., 300., 600., 1000., 1500., 2200., 5000, and maximum mixing height is 5000 m.a.s.l.

*II.2 WRF configuration*

The Weather Research Forecasting (WRF v3.5) is a mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting, configuration in this work considered the domains: 27 (D0), 9 (D1), 3 (D2) and 1 (D3) km, centered on the coordinates 19.124º N, -98.556º W, with geographical resolutions of 10 m, 5 m, 2 m and 30s; GRIB2 files (6 hourly files) in 1º x 1º resolution were downloaded from the NCEP data base ds083.2 [9]; according to the procedure of preprocessing in WPS, the geogrid, ungrib and metgrid for each domain corresponding files were generated, being D0 the parent domain and D1, D2, and D3 nesting domains. It was considered in the parameterization 50 eta-levels, and mp_physics 4 value (D0, D1) and 5 (D2, D3). The execution was performed in the super computer MNIII, with 128 processors and 7:00 hours for each day simulated.

*III.4 Sensitivity assessment*

The sensitivity assessment considered only the meteorological variables wind-speed and temperature; the BIAS (1) and MSRE (2) equations were calculated with METAR observations of BJIA (METAR MMMX) in the days of this evaluation, the WRF domains D1, D2, D3 and CALMET domain. $\Phi_i$ is forecast value for i cell, $\Phi_{obs}$ is observation for i cell and N is the number of analysed values. The selection of these variables was the lack of information in other meteorological variables as relative humidity or wind-direction.

$$BIAS = \sum_{i=1}^{N} \frac{(\phi_i - \phi_{iobs})}{N} \quad (1)$$

$$RMSE = \sqrt{\sum_{i=1}^{N} \frac{(\phi_i - \phi_{iobs})^2}{N}} \quad (2)$$

## III. Results

The database year concentration of air pollutants with better performance than satisfy the 75% sufficiency criteria was 2012. The calculation of the estimate of the maximum mixing layer height (MMLH) used the BJIA radio survey, calculating in March, April and May months, MMLH higher than 3250 m (minimum height between the volcanoes), therefore these months were selected by Spearman correlation, obtaining the six days with higher correlation: 14, 19, 30 and March; 18 and May 27, 2012.

CALMET v6.4 and WRF v 3.5 simulations were calculated in different geopotential heights; a qualitative analysis of the behavior of synoptic and meso-scale meteorology was performed with wind-speed, wind direction, temperature, planetary boundary layer (WRF: PBLH) and mixing layer height (CALMET: MLH) variables; Figure 1 shows an example of these results. In sensitivity assessment were compared hourly values of temperature and wind speed between modelled results and observations from MMMX stations in selected days at 00 - 23 (00 UTC-6). Tables 1 and 2 shown wind speed magnitude at z500 height, pressure at 500 hPa and the geopotential height in D1. It can be observed conditions for possible pollutants transport. The temperature modeled in CALMET v6.4 presented better BIAS results between -0.45 and 2.33, however, the RMSE did not.

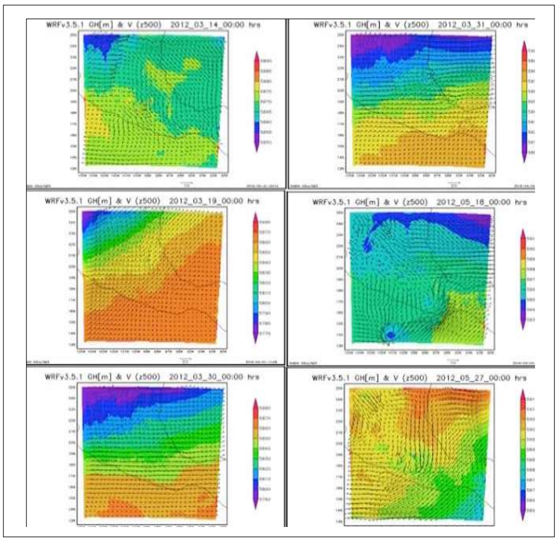


Fig. 1. Wind-speed, wind-direction at z500 (500 hPa) and geopotential height for domain (D1) in selected days for simulation.

Table 1. Sensitivity assessment results in Temperature (ºK).

| Temperature [ºK] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Day | BIAS | | | | RMSE | | | |
| | CM | $WD_1$ | $WD_2$ | $WD_3$ | CM | $WD_1$ | $WD_2$ | $WD_3$ |
| 1 | 0.01 | 1.42 | 2.03 | -0.87 | 3.33 | 2.30 | 1.42 | 2.76 |
| 2 | 2.33 | 1.42 | 1.30 | 1.46 | 3.53 | 1.58 | 1.14 | 1.65 |
| 3 | -0.06 | 1.16 | 1.20 | 1.32 | 2.58 | 2.55 | 1.10 | 2.58 |
| 4 | 0.03 | 1.31 | 1.46 | 1.61 | 2.69 | 2.13 | 1.21 | 2.37 |
| 5 | -0.45 | 1.71 | 1.75 | 2.07 | 3.00 | 2.02 | 1.38 | 2.25 |
| 6 | 0.08 | 1.65 | 1.66 | 1.64 | 3.33 | 1.85 | 1.29 | 1.88 |

**CM:** CALMET. **WD1**: WRF dominium 1. **WD1**: WRF dominium 2. . **WD1:** WRF dominium 3.

Table 2.- Sensitivity assessment results in wind speed (m/s).

| Wind speed [m/s] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Day | BIAS | | | | RMSE | | | |
| | CM | $WD_1$ | $WD_2$ | $WD_3$ | CM | $WD_1$ | $WD_2$ | $WD_3$ |
| 1 | 2.05 | 1.72 | 1.69 | 1.71 | 2.55 | 2.07 | 2.09 | 2.11 |
| 2 | 1.45 | 1.73 | 1.29 | 1.22 | 2.17 | 2.39 | 2.21 | 2.23 |
| 3 | 3.09 | 2.02 | 2.10 | 2.08 | 3.82 | 2.93 | 3.05 | 3.14 |
| 4 | 2.81 | 2.34 | 2.19 | 2.07 | 3.60 | 3.16 | 3.17 | 3.19 |
| 5 | 2.54 | 1.65 | 1.60 | 1.58 | 3.32 | 2.08 | 2.08 | 2.04 |
| 6 | 2.03 | 1.83 | 1.82 | 1.73 | 2.87 | 2.49 | 2.52 | 2.44 |

**CM:** CALMET. **WD1**: WRF dominium 1. **WD1**: WRF dominium 2. . **WD1:** WRF dominium 3.

Wind speed modeling WRF v3.5 presented better performance in Wind-speed BIAS values of 1.22 (minimum) and 2.34 (maximum) at different domains (D1, D2 and D3) and RMSE values of 2.04 (minimum) and 3.19 (maximum) corresponding at D3.

## IV. Conclusions

According to the sensitivity analysis performed on selected days (14.03, 19.03, 30.03, 18.03 and 27.05, 2012), it concluded that:

Meteorology for selected days was analyzed, concluding that could exist conditions for air pollution transport between these metropolitan areas.

Modelling in WRF v.3.5 reflected better sensitivity to temperature and wind speed, although CALMET v.6.4 model is influenced by the surface meteorological information provided by only 16 stations.

WRF Outputs model generated datasets for their use in an AQMS in selected days in MCMA and PMA; it is necessary to confirm the air transport of pollutants between both metropolitan areas.


## Acknowledgment

Thanks to the Barcelona Supercomputing Center – Centro Nacional de Superomputación (BSC-CNS) for the support in this mobility project and the facilities for the stay in the Earth Sciences Department, thanks to CONACyT for the "Beca mixta" support and the Mobility Department in UNAM.


## References


[1] Baldasano, J., Valera, E., & Jiménez, P. (2003). Air quality data from large cities. *The Science of the Total Environment, ELSEVIER*, 141-165.

[2] WHO. (2014, Marzo). *World Health Organization. Ambient (outdoor) air quality and healt.* Retrieved 2015, from Fact sheet N°313: http://www.who.int/mediacentre/factsheets/fs313/es/

[3] Valverde. (2016). Characterization of atmospheric pollution dynamics in Spain by means of air quelity modelling,. *Ph.D.Thesis*. Barcelona, Cataluña, España: UPC-BSC (Universidad Politécnica de Cataluña-Barcelona Supercomputing Center-Centro Nacional de Supercomputación).

[4] Molina, L., & Molina, M. (2004). Megacities and Atmospheric Pollution. *ISSN 1047-3289. Air & Waste Management Association. 54*, 644-680.

[5] Chuquer, D. (2014). Transporte de contaminantes atmosféricos entre la Zona Metropolitana del Valle de México y la Zona Metropolitana del Valle de Toluca. Ciudad de México, México: Tesis de maestría, UNAM.

[6] Luna, C. (2015). Estudio de calidad del aire de la Zona Metropolitana de Cuernavaca y la posible aportación de contaminación proveniente de la Zona Metropolitana del Valle de México. Ciudad de México, México: Tesis de maestría, UNAM.

[7] García, J., García, J., Jazcilevich, A., & Ruiz, L. (2014). The influence of the Tula, Hidalgo complex on the air quality of Mexico City Metropolitan Area. *Atmósfera, Vol. 27, N° 2*, 215-225.

[8] Holzworth, G. C. (1972). *Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. AP-101. U.S. Environmental Protection Agency, Research Triangle Park, NC.*

[9] National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce (2000), NCEP FNL Operational Model Global Tropospheric Analyses, continuing from July 1999, http://dx.doi.org/10.5065/D6M043C6, Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory, Boulder, Colo. (Updated daily.) Accessed† 07 03 2016.