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WRF-CAMX APPLICATION TO THE PEARL RIVER DELTA REGION

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Abstract: The Pearl River Delta (PRD) is located in the southern coast of China and it is the second largest delta of the country. In 2014, several exceedances to the chinese limit-values, for nitrogen dioxide (NO_2) and ozone (O_3), were recorded in the PRD. To implement measures for air quality improvement in this region, it is necessary to understand the spatial distribution of air pollution. Therefore, the present work aims to study air pollution patterns, focusing on O_3 and NO_2, over the PRD region by the application of the WRF-CAMx regional air quality modelling system. The WRF-CAMx system was applied, with its nesting capabilities, to one winter and one summer 7-day periods of the year 2014 and was validated with data from several air quality monitoring stations distributed along the southern coast of China. The results for the higher resolution domain showed a reasonable performance of the model. The WRF-CAMX tends to overestimate and underestimate the O_3 and NO_2 concentrations, respectively. The analysis of temporal and spatial variability of simulated concentrations pointed to the need to improve the emission inventory with further information on the temporal and spatial distribution of local sources.

Key words: *Pearl River Delta, WRF-CAMx, NO_2, O_3.*

INTRODUCTION

The Pearl River Delta (PRD) is one of the largest industrialized regions in China. It is located in the southern coast and it comprises nine municipalities (Guangdong province) and two special administrative regions (Macao and Hong Kong). In the last decades, the region recorded a rapid development resulting in the increase of the energy consumption, atmospheric emissions and degradation of the air quality. Guangdong province and Hong Kong have implemented measures to reduce the air pollution. Between 2006 and 2014, the annual averaged NO_2 and O_3 concentrations changed from 46 to 37 and 48 to 57 $\mu g.m^{-3}$, respectively. According to “Pearl River Delta Regional Air Quality Monitoring Network” for 2014, this region continues to record several exceedances for NO_2 and O_3. Except ozone which is formed through photochemical reactions enhanced by solar radiation, the highest pollution concentrations are recorded in winter (SO_2, PM10, PM2.5, NO_2 and CO) and are associated with the northeast air mass trajectories crossing the China-Taiwan strait region. Therefore, the PRD region may be affected by the transboundary pollution besides its local emissions. Typically O_3 concentrations are higher in summer months (May, June, July, August and September) and minimum in winter months (November, December, January and February). Chemical transport modelling could be an useful tool to provide scientific advice on emission reduction strategies and air quality management.

Wu *et al.* (2012) evaluated the performance of three air quality models (including CAMx) over PRD for November 2006. The authors concluded that models have different behaviours at different spatial locations. Lu *et al.* (2016) applied CAMx and ozone source apportionment techniques to several months of 2011 to study the NO_X different emissions source contributions over southern China, and observed that heavy duty diesel vehicles, light duty gasoline vehicle, industrial and marine sources are the main sources of NO_X emissions.

In this work, the performance of WRF-CAMx was evaluated for two seasons (winter and summer) in PRD, by its application to two 7 day episodes. The selection of the episodes was based on the analysis of air pollution concentrations recorded at different air quality monitoring stations across PRD. In 2014, the highest and lowest concentrations for almost all pollutants (excluding ozone) were observed in winter and summer season, respectively. The WRF-CAMx capability to simulate NO_2 and O_3 air pollution levels was based on data from 11 air quality monitoring stations selected by their location (spread over the study region) and type. The pollutants - NO_2 and O_3 - were chosen as they are the most concerned in terms of air quality in the region.

MODELLING SETUP AND CONFIGURATION

The WRF-CAMx modelling system, composed by the Advanced Research Weather Research and Forecasting (WRF-ARW) and the Comprehensive Air quality Model with extensions (CAMx), was selected to study the air pollution patterns that characterize the PRD by its application over the southeast coast of China. The WRF-ARW (version 3.6.1) (Skamarock *et al.*, 2008) was built over a coarse domain covering east Asia, Indian subcontinent, part of the southeastern Asia and middle east (at 81 km^2 horizontal resolution) and three nested domains with resolutions of 27×27 km^2, 9×9 km^2 (southeast coast of China) and 3×3 km^2 (over the PRD region). The global meteorological fields from the National Centre for Environmental Prediction, with 1° by 1° spatial resolution and 6 hours temporal resolution , were used to initialize the meteorological simulation. The WRF-ARW simulation considered the following physical options: Ferrier scheme, rapid radiative transfer model, Goddard shortwave, Monin-Obukhov similarity scheme, Noah land surface model, Kain-Fritsch scheme and Yonsei University scheme. WRF results were validated against observation at 27 meteorological stations, selected according to their spatial distribution, revealing a good performance for temperature and a reasonable agreement for wind speed and direction.

CAMx is an 3D Eulerian photochemical dispersion model that can be applied for different scales ranging from sub-urban to global. It simulates the emissions, dispersion, chemical reactions and removal of pollutants in the troposphere by solving the Eulerian continuity equation for each chemical species on a system of nested three-dimensional grids (ENVIRON, 2015). CAMx (version 6.20) was applied to the two smaller WRF domains - a coarse domain covering southeast coast of China (9 km^2 horizontal resolution) and a nested domain with 3×3 km^2 resolution (over the PRD region) (Figure 1. Simulation domains used by CAMx: parent grid (D1, 9x9km^2 resol) and nested domain (D2, 3x3km^2 resol).
). The horizontal diffusion and chemistry were calculated using Piecewise Parabolic Method (PPM) and Euler Backward Iterative (EBI) method, respectively. The WESELY89 dry deposition option was used to define surface ultraviolet albedo, surface resistances for dry deposition calculations, and to set seasonal default surface roughness lengths and leaf area index values. For more information about CAMx see (ENVIRON, 2015).

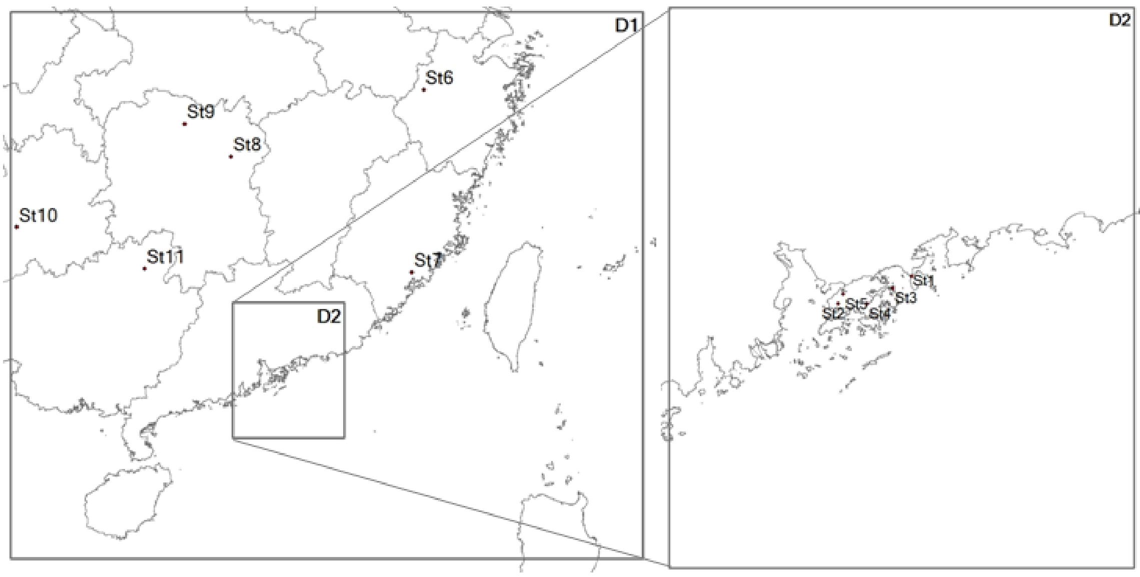

Figure 1. Simulation domains used by CAMx: parent grid (D1, 9x9km^2 resol) and nested domain (D2, 3x3km^2 resol).

The initial and boundary conditions were taken from the MOZART4 model outputs at every 6 hours. Regarding anthropogenic emissions, the 2008 Regional Emission inventory for Asia was adapted to generate temporally and spatially disaggregated emissions to the CAMx coarser domain (D1). This inventory includes monthly emissions at 0.25 degrees horizontal resolution for several pollutants (PM, SO_2, NO_2, *etc.*) distinguishing the activity sectors road transport, domestic, industrial sources, power plants, *etc*. (Kurokawa *et al.*, 2013). A literature review was performed aiming to find the most suitable speciation and temporal profiles for China and chinese chemical speciation profiles were used for road transport (Cai and Xie, 2009; Dai *et al.*, 2015; Li *et al.*, 2011), domestic (He *et al.*, 2004) and solvents (Yuan *et al.*, 2010). For the remaining sectors, the SPECIATE database from the United States Environmental Protection Agency was used. Monthly, weekly and daily variability of emissions was also considered. For road transport, temporal profiles were derived from the hourly variation of carbon monoxide concentrations at 4 urban air quality monitoring stations (1 in Macao and 3 in Hong Kong). The daily profile for the domestic sector was based on the author´s living experience. For the other sectors, the European temporal profiles were considered (Gon *et al.*, 2011). Gridded emissions for the CAMx smaller domain (D2) were interpolated from D1 emissions using the flexi nesting CAMx capability.

AIR POLLUTION MODELLING EVALUATION

The WRF-CAMX system was applied to one winter (20 to 26 January) and one summer (10 to 16 July) 7-day periods and was validated with data from 11 air quality monitoring stations over the simulation domains (Figure 1). The evaluation of the WRF-CAMx performance for NO_2 and O_3 was done by computing the following statistical parameters: correlation coefficient (r), BIAS and root mean squared error (RMSE) (Borrego *et al.*, 2008). Table 1 and Table 2 present the statistical analysis results for O_3 and NO_2 respectively. Simulated concentrations for CAMx D1 (9 km resolution) and D2 (3 km resolution) were compared with observations from St1 to St11 stations, as indicated in the tables.

Table 1. Statistical parameters obtained for ozone at the 11 selected air quality monitoring stations.

			winter episode			**summer episode**		
Stations		**Domain**	**r (-)**	**BIAS (µg/m³)**	**RMSE (µg/m³)**	**r (-)**	**BIAS (µg/m³)**	**RMSE (µg/m³)**
Guangdong province	St1	D1	0.31	-44.02	54.88	0.64	51.72	58.66
		D2	0.34	-0.26	25.89	0.08	77.30	84.33
Hong Kong	St2	D1	0.21	15.64	41.42	0.50	51.49	65.93
		D2	0.39	36.18	43.09	0.16	54.94	54.94
	St3	D1	0.35	-54.36	58.44	0.72	41.20	46.12
		D2	0.46	-11.56	27.98	0.15	69.73	69.86
	St4	D1	0.50	-24.11	40.28	0.49	51.46	56.92
		D2	0.63	11.60	33.12	0.04	70.01	70.85
	St5	D1	0.27	-12.36	39.75	0.64	58.18	63.43
		D2	0.53	26.24	35.04	0.14	72.10	72.97
Zhejiang province	St6	D1	0.64	34.83	45.59	0.56	19.93	41.18
Fujian province	St7	D1	0.66	6.68	17.51	0.54	78.91	128.05
Hunan province	St8	D1	0.35	40.04	45.11	0.38	68.87	86.31
	St9	D1	0.49	83.54	101.70	0.06	79.89	89.50
Guizhou province	St10	D1	0.53	15.66	36.13	0.36	17.50	30.69
Guangxi province	St11	D1	0.17	1.15	40.97	0.43	23.18	32.74

Globally, for the correlation coefficient a better agreement between O_3 observed and simulated concentrations was obtained for the winter period (higher correlation coefficients). Furthermore, the winter episode simulation led to lower biases and RMSE at almost all the stations. Comparing the results for D1 and D2 for the station St1 to St5, it is noticeable a better performance of the model for D2 with higher resolution, in the winter period, and in summer the opposite is verified. For D1, the correlation coefficient ranges between 0.17-0.66 in winter and 0.06-0.72 and in summer episodes. In general, the stations located in the south (St1-St2-St3-St5-St8-St11) returned the highest correlation coefficients in summer and the ones in southeast of China (St6-St7) the best correlations in winter. The BIAS range between -54.36 and 83.54 and 17.50 to 79.89 µg/m^3 in winter and summer episodes, respectively.. The magnitude errors range between 17.51 and 101.70 in the winter episode and 30.69 to 128.05 µg/m^3 in the summer episode. In general, the highest magnitude errors are recorded in the summer episode. All stations, except St1 to St5 in winter episode, tend to overestimate the O_3 concentrations (positive biases).These results, together with the analysis of the spatial and temporal variations of simulated concentrations (not presented) revealed that, in summer, the model reproduces reasonably well the O_3 concentration variability and magnitude, for the lower resolution simulation domain but not for the higher resolution. For the winter period, characterized by lower O_3 levels, the model performance is generally higher at higher resolution.

Table 2. Statistical parameters obtained for nitrogen dioxide at the 11 selected air quality monitoring stations.

			winter episode			summer episode		
Stations		**Domain**	**r (-)**	**BIAS (µg/m³)**	**RMSE (µg/m³)**	**r (-)**	**BIAS (µg/m³)**	**RMSE (µg/m³)**
Guangdong province	St1	D1	-0.02	14.14	21.27	0.01	15.09	19.90
		D2	0.26	-8.97	9.61	0.24	-6.85	7.49
Hong Kong	St2	D1	0.23	-50.11	55.73	0.11	15.07	33.41
		D2	0.22	-80.93	80.93	0.04	-25.90	26.05
	St3	D1	-0.17	21.50	23.88	0.08	32.47	32.78
		D2	0.08	-6.06	6.42	0.12	-0.55	1.91
	St4	D1	0.40	-21.17	33.84	0.25	15.20	28.75
		D2	0.50	-54.92	54.92	0.11	-33.79	33.99
	St5	D1	0.18	-20.42	40.76	0.12	18.48	36.78
		D2	0.26	-66.11	68.98	0.06	-32.40	32.79
Zhejiang province	St6	D1	0.35	-4.95	6.87	0.04	-0.38	4.80
Fujian province	St7	D1	0.58	-1.76	7.92	0.15	7.04	13.76
Hunan province	St8	D1	0.07	-51.37	59.52	0.06	-7.80	11.38
	St9	D1	0.40	-0.18	2.56	0.23	-12.46	13.86
Guizhou province	St10	D1	0.03	-15.79	23.17	0.20	3.52	9.77
Guangxi province	St11	D1	0.11	-9.63	12.29	0.00	2.20	4.70

The overall performance of the model for NO_2 is much lower than for O_3, with a maximum correlation coefficient of 0.58 in the winter episode. Notwithstanding, slightly better results are obtained for the summer period (lower biases and RMSE). For St1 and St3, in the winter episode, a negative correlation coefficient was obtained, revealing the inability of the model to reproduce NO_2 variability at these stations. In general, the model tends to underestimate the NO_2 concentrations. In general, the highest magnitude errors are recorded in winter episode. However, there is not clear evidence of a better performance of the model for one of the domains (
Table **2**).

CONCLUSIONS

The model exhibited a reasonable performance for both pollutants. For ozone, the WRF-CAMx showed a better performance in the winter episode. However, the model tends to overestimate the O_3 concentrations. For nitrogen dioxide, the WRF-CAMx results revealed a lower performance for this pollutant, with a better agreement between observations and modelled concentration in winter and an overall better performance for summer (lower biases and error).This preliminary analysis of the WRF-CAMx capacity to simulate the air pollution patterns in the region revealed some weaknesses of the global modelling setup, namely regarding emissions temporal and spatial allocation. The results pointed to the need to improve the NO_2 emission inventory, focusing on the temporal and spatial distribution of local sources.

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