THE CANADIAN AIR QUALITY MODELLING PLATFORM FOR POLICY EMISSION REDUCTION SCENARIOS: YEAR 2010 CONFIGURATION

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1. INTRODUCTION

The Air Quality Modelling and Applications Section (AQMAS) of Environment Canada (EC) has developed an Air Quality Modelling Platform (AQMP) for 2010 to assist in the development of the Canadian air quality regulations and policies. This platform constitutes an update to the previous 2006 AQMP (Chen et al., 2010), with substantial improvements including the latest available emissions data and methods.

The 2010 AQMP consists of emissions inventories and ancillary data files used to produce model-ready emissions, as well as meteorological, initial and boundary conditions files needed to run the AURAMS (A Unified Regional Air-quality Modelling System) off-line chemical transport model.

Being able to assess the air quality response to changes in emissions and/or meteorology, for a current period, is mandatory when managing future emissions regulatory purposes. This document will first provide an overview of the 2010 policy AQMP, followed by the evaluation results of a 2010 base case. Comparison with the 2006 AQMP will be also presented. Finally, a conclusion and future work on the 2010 AQMP will be given.

2. AIR QUALITY MODELLING PLATFORM

The 2010 AQMP includes three major components: the Global Environmental Multiscale Model meteorological driver (GEM), the Sparse Matrix Operator Kernel Emissions processor system (SMOKE) and the air quality model AURAMS. Next subsections briefly describe each of these components depicted in blue in Fig 1.

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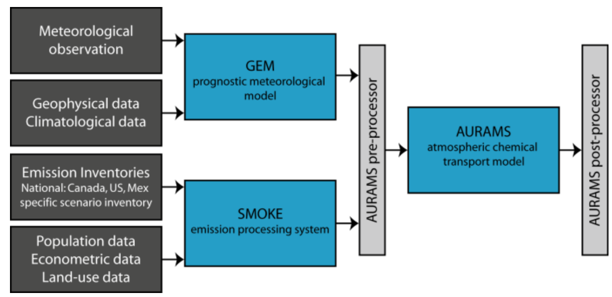

Fig.1 Schematic data flow diagram of the 2010 AQMP

2.1 Meteorology

The GEM model is the EC integrated weather forecasting system for short- and medium-range weather forecasts (Côté et al., 1998). It is based on the fully compressible Euler equations that are solved by implicit and semi-Lagrangian method. The parameterization of the physical processes used in this study includes Kuo deep convection, ISBA (Interactions Soil-Biosphere-Atmosphere) surface scheme, and Sundqvist stratiform condensation scheme. Unlike the 2006 AQMP, the 2010 AQMP includes the urban heat island scheme in order to account for subgrid- scale effects at this scale. The selected modelling domain covers North America with a horizontal resolution of 15-km and 80 hybrid vertical levels increasing with height from surface to 0.1hPa.

For the annual simulation, GEM was run in series of 30-hr segments with each segment initialized from analyses fields. The first 6 hours of each segment were discarded as spin-up. Model results from GEM were interpolated as inputs to the AURAMS model.

2.2 Emissions

Hourly anthropogenic emissions for the 2010 platform were prepared using the SMOKE emission processor version 3.5. Input emissions inventory includes: 2010 Canadian Criteria Air Contaminants (CAC) emission inventory, 2008 United States National Emission Inventory (NEI) and 2008 Mexican inventory. The CAC inventory is based on the EC National Pollutant Release Inventory (NPRI) (http://www.ec.gc.ca/inrp-npri), whereas the NEI and Mexican inventories were obtained from the EPA emissions clearinghouse (http://www.epa.gov/ttn/chief/emch).

In addition, biogenic emissions for the annual simulation were estimated online by AURAMS using the BEIS version 3.09 algorithms and adjusted with hourly surface temperature and solar fluxes. Wildfires emissions were not considered in both 2006 and 2010 AQMPs. Comparisons between the emissions inventories for both 2006 and 2010 AQMPs are shown in Table 1.

Table 1: Emission inventories sources and features for 2006 and 2010 AQMPs.

Sources types		2006	2010
Mobile	**On-road**	MOBILE6.2C[1] only	- MOVES[2] for heavy duty diesel and gasoline vehicles - MOBILE6.2C[1] for other
Point	**Stack information**	Mean characteristics	Detailed facility-characteristics
Point	**Individual VOC speciation temporal profiles**	Based on source category code (SCC)	Facility-specific
Point	**Allocation of oil sand fleet emissions**	Over the whole province	Facilities' geographic location
Area	**Spatial allocation of agricultural NAESI[3] emissions**	4 surrogates	54 surrogates
Area	**Fugitive dust emissions**	Average sector-based transportable fraction (TF)	Estimates based on gridded land use transportable fraction (TF)

[1]Vehicles emissions modelling software
[2]MOtor Vehicle Emissions Simulator
[3]National Agri-Environmental Standards Initiative

2.3 Chemical Transport Model

AURAMS is a multi-pollutant off-line air quality model designed to simulate the formation of ozone, particulate matter (PM) and acid depositions (Gong et al., 2006 and reference therein). The model uses a sectional approach to represent the size distribution of airborne particles: 12 size bins from 0.01 to 40.96 µm in diameter and 9 PM species (sulphate, nitrate, ammonium, elemental carbon, primary organic aerosol, secondary organic aerosol, crustal material, sea salt, and aerosol water)

The model also includes gas-phase chemistry and aerosol dynamics process such as: tropospheric gas-phase oxidative chemistry, absorptive formation of secondary organic aerosols (SOA), inorganic heterogeneous chemistry, particle microphysics (nucleation, condensation, coagulation, etc.), cloud-aerosol interaction, advection, vertical diffusion, and gas and particle emissions and deposition.

The AURAMS modelling domains and settings for both 2006 and 2010 AQMPs are shown in Fig. 2 and Table 2, respectively. Grid points for the coarser and higher resolution grids were co-located to minimize interpolation errors.

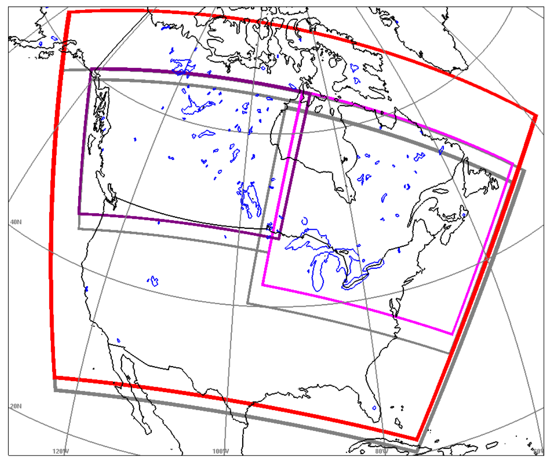

Fig. 2 AURAMS domains for 2006 (in grey) and 2010 AQMPs (45-km (red), 15-km Western (purple) and Eastern (fuchsia) grids)

Table 2: AURAMS settings for 2006 and 2010 AQMPs.

	Horizontal resolution (km)	Coverage	Number of grid points	Vertical resolution
2006	45	North America	143x107	28 terrain-following levels from surface to 29 km
2006	22.5	West	124x93	
2006	22.5	East	145x123	
2010	45	North America	141x120	
2010	15	West	193x135	
2010	15	East	201x180	

3. MEASUREMENTS DATA

In order to evaluate the AURAMS model performance, 2010 hourly near-real time (NRT) pollutant measurements for Canada were acquired from several air quality monitoring networks, including provincial, territorial and municipal AQ networks. For USA, 2010 hourly NRT pollutant data were obtained from AIRNow (http://www.airnowtech.org).

For 2006 model evaluation, hourly measurements from the National Air Pollution Surveillance Program (NAPS, http://maps-cartes.ec.gc.ca/rnspa-naps/data.aspx?lang=en) for Canada, and from the US Environmental Protection Agency (EPA)-Air Quality System (AQS) for USA, were also included.

The hourly ground-level air quality model forecasts were extracted at the observation sites for each pollutant to create forecast-observation pairs. These pairs were stored in the EC's Verification for Air QUality Models (VAQUM) system (Gilbert, 2014), to produce statistical scores.

In addition, another set of archived 2010 NAPS data, available only for Canada, was used for the model evaluation, because it contains a detailed station type classification. In total, 287 stations are classified by type of location area: 191 are in densely populated areas (54 urban commercial, 137 urban residential), 75 in sparsely populated areas (29 forests, 28 agricultural, 18 undeveloped) and 21 are defined as industrial type located in variously populated areas. Furthermore, since AURAMS doesn't consider wildfire emissions, Canadian 2010 $PM_{2.5}$ archived data were filtered using the annually simulated maximum concentration.

In the next section, model evaluation only for O_3, NO_2 and $PM_{2.5}$ species is discussed. Note that other model comparisons using non-continuous Canadian (CAPMoN) and US (AIRS, IMPROVE, etc.) observations were also carried out but are not showed here.

4. MODEL EVALUATION

The seasonal ozone behavior is marked by a maximum in the spring followed by a decrease in ozone values toward the autumn minimum for Canada, and winter minimum for USA as shown by the observations in Fig 3a and 3b, respectively. In contrast, $PM_{2.5}$ concentrations are typically higher from July to September when wildfire events occurred (Fig 3 c,d).

The seasonal O_3 trend is well captured by AURAMS; however the model has a tendency to underestimate during the cold period and slightly overestimate during the summer season. For $PM_{2.5}$, on the other hand, the modelled values are underestimated for all the seasons. This might be attributed, among others factors, to the dilution of emissions given the coarse grid resolution. It is expected that $PM_{2.5}$ underestimation could be reduced at higher resolutions over the Western and Eastern 15-km domains.

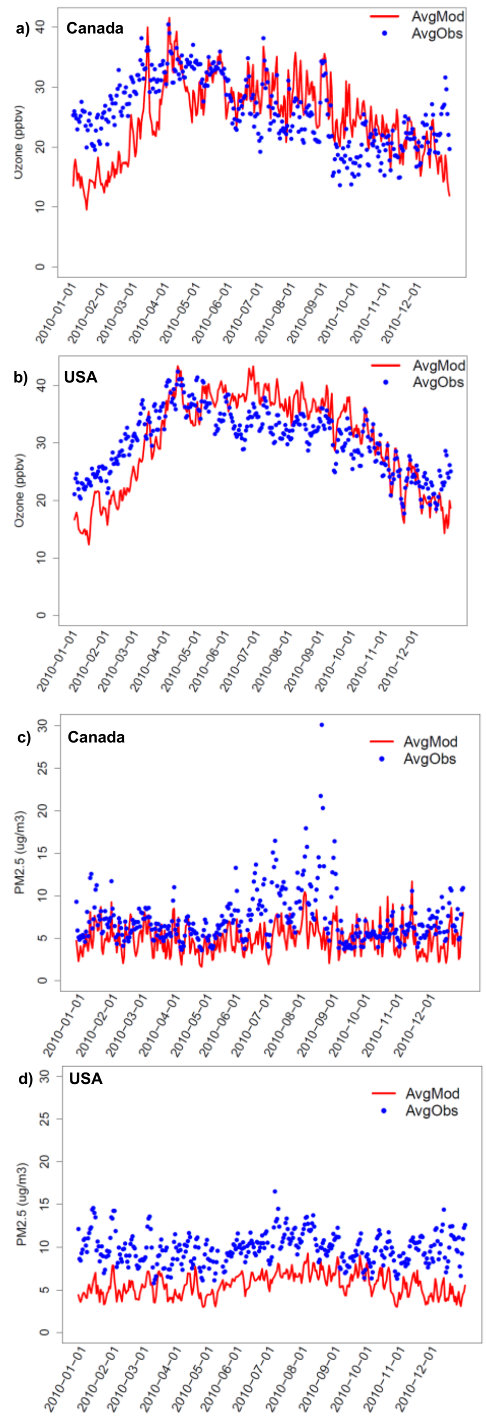

Fig. 3: Comparisons of modelled versus observed O_3 (a, b) (ppbv) and $PM_{2.5}$ (c, d). (μg/m^3) daily average time series for Canada and USA

Annual and seasonal statistics for O_3, $PM_{2.5}$ and NO_2 are shown in Table 3. For O_3, model performance is slightly better for 2010 than 2006 for summer, similar for autumn and less good for spring and winter. Annually, the model performance for both years is overall acceptable with low Normalised Mean Bias (NMB) for both 2010 and 2006. For $PM_{2.5}$, the model performance is generally poor with a significant under-prediction for both years: the lowest NMB for 2010 (-0.54) and 2006 (-0.44) are for USA in winter. Also, model skills for $PM_{2.5}$ for 2010 are weaker than 2006 and this issue is currently under investigation.

There is a general tendency for under-predicting NO_2 concentrations by AURAMS for both years for Canada. However, the model shows a relatively better performance in spring and summer for 2010 than for 2006. In addition, it captures reasonably well the high NO_2 levels in winter and fall.

Table 3: Model performance statistics by season and annually for O_3, $PM_{2.5}$ and NO_2. The statistics are: Average Modelled (AvgMod) and Observed (AvgObs) values, correlation coefficient (R), Normalised Mean Bias (NMB) and Normalised Mean Error (NME).

		DJF		MAM		JJA		SON		YEAR	
O_3		2006	2010	2006	2010	2006	2010	2006	2010	2006	2010
CAN	AvgObs	22.10	24.68	32.13	32.86	26.19	25.97	18.86	20.08	24.88	25.98
	AvgMod	19.43	16.55	29.81	29.57	30.66	28.93	24.25	23.7	26.12	24.78
	R	0.44	0.40	0.45	0.49	0.54	0.46	0.66	0.60	0.55	0.51
	NMB	-0.12	-0.33	-0.07	0.29	0.18	-0.10	0.17	0.11	0.05	-0.05
	NME	0.40	0.47	0.32	0.48	0.40	0.31	0.36	0.35	0.38	0.37
USA	AvgObs	23.23	24.77	35.85	36.35	36.31	32.97	26.24	28.64	31.68	31.38
	AvgMod	23.67	18.92	37.40	35.56	41.32	37.70	31.56	30.72	35.12	32.24
	R	0.52	0.47	0.61	0.62	0.65	0.58	0.67	0.66	0.67	0.64
	NMB	0.02	-0.24	0.04	0.20	0.07	-0.02	0.14	0.14	0.11	0.03
	NME	0.41	0.43	0.29	0.42	0.35	0.29	0.35	0.35	0.35	0.47

		DJF		MAM		JJA		SON		YEAR	
$PM_{2.5}$		2006	2010	2006	2010	2006	2010	2006	2010	2006	2010
CAN	AvgObs	6.70	7.03	6.42	6.36	8.39	9.92	6.66	5.93	7.06	7.36
	AvgMod	5.07	4.94	5.26	4.68	6.36	5.42	6.48	5.06	5.80	5.03
	R	0.32	0.24	0.38	0.14	0.36	0.13	0.33	0.22	0.34	0.16
	NMB	-0.24	-0.30	-0.18	-0.26	-0.24	-0.45	-0.03	-0.15	-0.18	-0.32
	NME	0.73	0.82	0.69	0.77	0.63	0.72	0.75	0.81	0.69	0.77
USA	AvgObs	10.60	10.28	10.25	9.06	13.31	10.82	10.85	9.18	11.27	9.85
	AvgMod	5.92	4.77	5.80	5.18	8.67	6.72	7.71	5.69	7.05	5.60
	R	0.38	0.32	0.34	0.31	0.40	0.31	0.36	0.31	0.38	0.31
	NMB	-0.44	-0.54	-0.43	-0.43	-0.35	-0.38	-0.29	-0.38	-0.37	-0.43
	NME	0.63	0.70	0.63	0.67	0.58	0.63	0.60	0.66	0.61	0.67

		DJF		MAM		JJA		SON		YEAR	
NO_2*		2006	2010	2006	2010	2006	2010	2006	2010	2006	2010
CAN	AvgObs	13.85	11.90	10.85	8.29	8.14	6.15	10.73	8.43	10.88	8.71
	AvgMod	7.40	6.58	5.85	5.10	5.01	4.15	6.80	5.10	6.26	5.24
	R	0.36	0.38	0.34	0.35	0.33	0.35	0.38	0.38	0.36	0.38
	NMB	-0.47	-0.45	-0.46	-0.38	-0.38	-0.33	-0.37	-0.40	-0.42	-0.40
	NME	0.66	0.68	0.73	0.76	0.74	0.76	0.70	0.73	0.70	0.72

* NO_2 NRT observations are not available for USA

Spatial distributions of r for O_3, $PM_{2.5}$ and NO_2 for 2010 are shown in Fig. 4. Relatively high r values for O_3 in Eastern USA, along the Western coast as well as in Southern Ontario and Alberta are observed. NMB (not shown here) is generally low at the stations where r is high. For $PM_{2.5}$, r is lower than for O_3 (Fig. 4b), whereas NMB and NME at the stations are higher for $PM_{2.5}$ than for O_3. NO_2 r values (Fig. 4c) are lower for Maritime Provinces and this might be due to emissions levels and meteorological conditions in a costal environment.

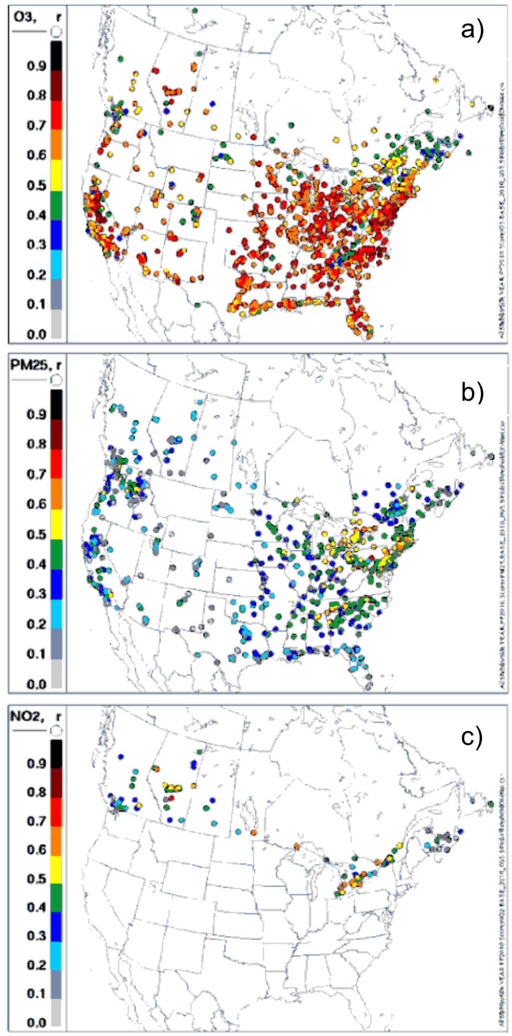

Fig. 4: Correlation coefficient for a) O_3, b) $PM_{2.5}$ and c) NO_2

Taylor diagrams (Fig. 5) and conditional quantiles (Fig. 6) plots for O_3, $PM_{2.5}$ and NO_2 were used to verify the model's performance. The plots were generated only for Canada using the Openair package (http://www.openair-project.org).

Taylor diagrams simultaneously depict correlation coefficient (r), ratio of modeled to observed standard deviation (SD), and centered root mean square error (CRMSE). Together these statistical parameters provide a quick outline of the degree of pattern correspondence between observations and modelled values (Fig. 5). Conditional quantiles plots show the distribution of the observed (gray) and modelled (blue) counts, as well as, the median (red) values of the forecast. Estimates of the 25/75th and 10/90th percentiles (yellowish) were also calculated for each size bin of the distribution and included in the plots (Fg. 6)

The results for O_3 shows that the model performs well for all station types and seasons, with better values for r (~ 0.5-0.8), CRMSE (~ 0.7-1.0) and SD (comparable to observations) in summer (Fig. 5a). On the other hand, the model's skill to simulate $PM_{2.5}$ (Fig. 5b) is relatively low for all seasons. For NO_2 (Fig. 5c), the model performance varies considerably by station type and season, except in winter.

The overall performance for O_3 is good for most of the concentration values, except for higher winter values, as seen from the divergence of the red line from the blue line (perfect model) in Fig. 6a. The overall performance for $PM_{2.5}$ (Fig. 6b) is slightly better in the range of low concentrations during summer (< 10 μg/m^3). The overall performance for NO_2 (Fig. 6c) is better in winter than for other seasons for concentrations values lower than ~30 ppbv. Furthermore, the percentile shading shows that the predictions become increasingly worse as the concentration for all pollutants increases, as shown by their broadening, particularly for NO_2.

The results show that the AURAMS model do well in capturing O_3 concentrations across the full range of observed values, and do better performance for lower concentrations for all pollutants. Additionally, the results also show that there is a tendency for the model to overestimate $PM_{2.5}$ and NO_2, and to a much less extent O_3, for higher concentrations, but the number of these observed and modelled cases is small, hence less statistically significant.

5. FUTURE WORK

Further analyses are in preparation to refine the 2010 AQMP evaluation. It will include higher resolution runs at 15 km, evaluation of precipitation chemistry, and particulate matter chemical components. In order to assess the model sensitivity, cross modelling runs will be performed by interchanging meteorology and emissions with those of 2006.

GEM meteorological data for 2010 will be compared against measurements data as well as against GEM outputs of 2006.

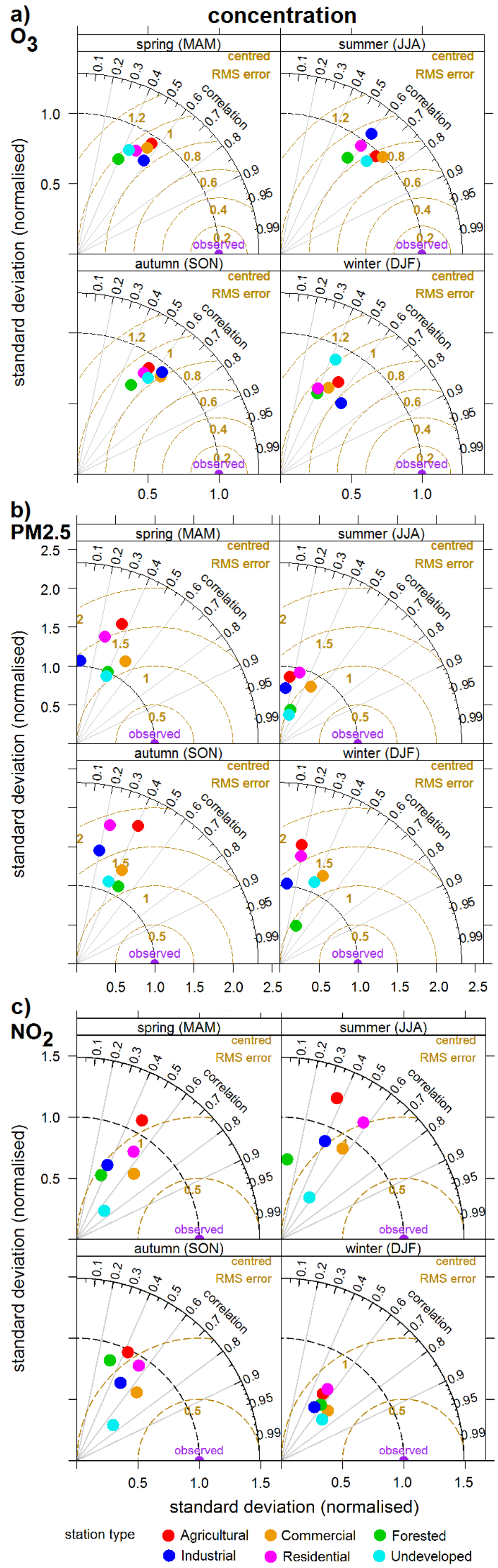

Fig. 5: Taylor diagram of concentration for: a) O_3 (ppbv), b) $PM_{2.5}$ (μg/m^3) and c) NO_2 (ppbv) by season and station type only for Canada.

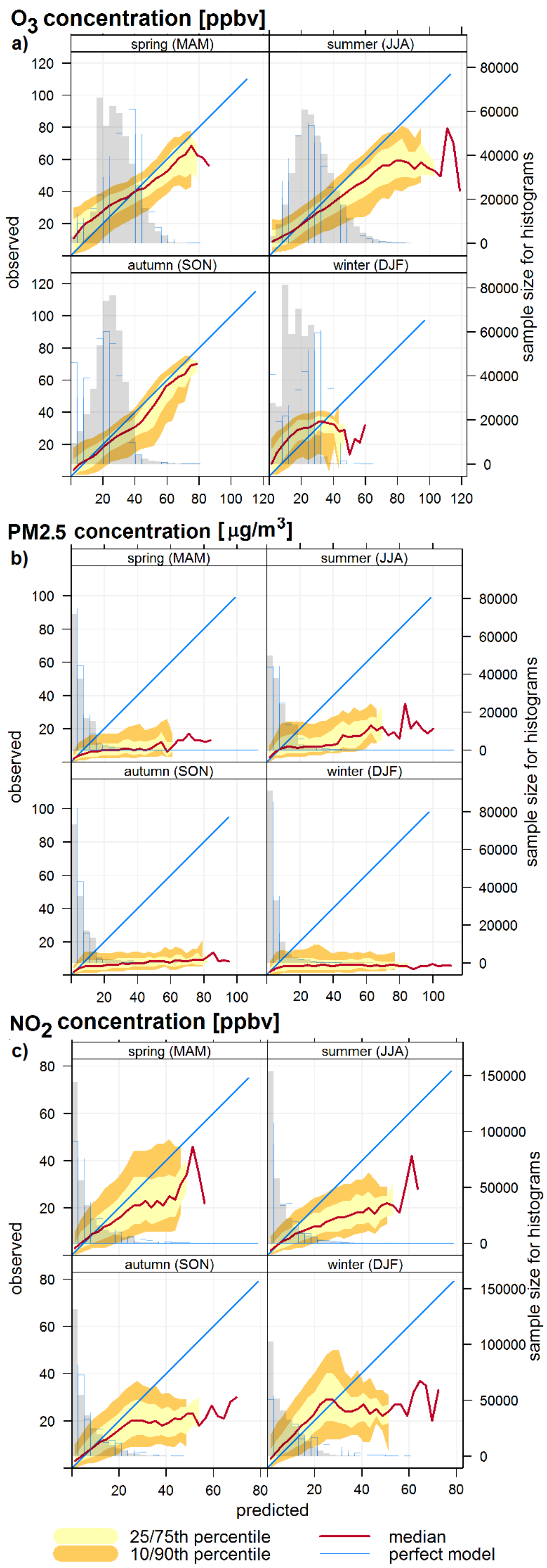

Fig. 6: Seasonal conditional quantiles plots of concentration for a) O_3 (ppbv), b) $PM_{2.5}$ ($\mu g/m^3$) and c) NO_2 (ppbv), only for Canada.

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