Comparisons of CMAQ and AURAMS modelling runs over complex terrain of coastal British Columbia

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INTRODUCTION

The meteorology of coastal British Columbia, particularly the Greater Vancouver Regional District (GVRD) is complex: land-sea breezes from the Strait of Juan De Fuca, the urban heat island of the city of Vancouver, and the topography of the surrounding Coast Range mountains combine to create complex flow patterns. Additional complexity is added to the system through the emissions: particulate sea-salt may be carried inland from the ocean, urban anthropogenic emissions are released from the city, significant agricultural emissions of ammonia occur further inland on the valley floor, and biogenic emissions on the surrounding mountains have pronounced elevation dependence, in response to altitude-dependant changes in vegetation. All of these factors combine to make this region a good test-bed for meteorological and air-quality models. Here, we discuss work in progress towards comparing the results of two air-quality models in this region, the Community Multiscale Air-Quality modelling system (CMAQ) and A Unified Regional Air-quality Modelling System (AURAMS). A feature of this study is a concerted effort to minimize differences in the model inputs, hence allowing a focus on differences between the chemical transport models themselves.

Model setup

Aim: Evaluate both models for this region, while harmonizing as many model inputs as possible.

Model versions: CMAQ 4.6, AURAMS 1.4.2

Horizontal projection system (same for both models): polar stereographic, 93 x 93 gridpoints, 12-km resolution.

Emissions data: both models use same emissions database (2006 Canadian, 2005 US, processed by the Sparse Matrix Operating Kernel Emissions system (SMOKE). The chemical speciation differs between the two models (AURAMS uses ADOM-II for the gas-phase chemistry, while CMAQ is configured here for SAPRC-99). The two models use different methodologies for primary particulate speciation and size disaggregation.

Driving meteorology: both models are driven by the same driving meteorology, provided by the Canadian Global Environmental Multiscale model (GEM, v3.2.2), in turn driven by Canadian Meteorological Centre 00Z operational analyses, 30 hour simulations with the first 6 hours discarded as spin-up.

Simulation periods: Jan. 28th to Feb. 28th, 2005

July 15th to Aug. 15th, 2005

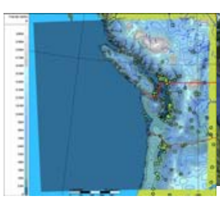

Figure 1: The common AURAMS and CMAQ 12km model domains showing all stations.

Figure 2: The Lower Fraser Valley; locations of stations used for the time series may be found here.

The area from Vancouver east towards and south of Pitt Meadows is primarily urban, with farmland more predominant further east and south. The valley sides are steep with mainly coniferous forest.

AURAMS, CMAQ, vs Observations

The table below compares the overall statistics for the domain of Figure 1 for the **summer** 2005 period.

Statistic	Ozone			PM2.5		
	Obs.	AURAMS	CMAQ	Obs.	AURAMS	CMAQ
Number of pairs		41846	41789		8657	8646
Mean	22.67	31.24	39.79	7.44	10.81	4.82
Maximum	100.00	100.78	100.48	49.00	70.06	44.49
Minimum	0.00	0.00	1.26	0.00	0.22	0.00
Y intercept (of obs vs model)		15.37	31.11		5.51	3.47
Slope (of obs vs model)		0.70	0.38		0.71	0.18
Correlation coefficient (R)		0.64	0.58		0.36	0.26
Mean Bias		8.56	17.11		3.37	-2.62
Root Mean Square Error		16.24	21.25		9.19	5.52
Normalized Mean Bias (%)		37.77	75.42		45.36	-35.20
Normalized Mean Error (%)		55.55	81.63		82.99	55.82

Table 1: Statistical comparison between observations for the 12-km resolution domain measurement sites vs AURAMS or CMAQ for the summer 2005 period.

O_3: AURAMS had better performance for ozone than CMAQ for all measures. Some of these differences were quite substantial – e.g. AURAMS had roughly half the ozone intercept, half the mean bias and normalized mean bias of CMAQ. Both models were bias high for ozone.

$PM_{2.5}$: CMAQ outperformed AURAMS for all except two statistics, the slope and the correlation coefficient. AURAMS $PM_{2.5}$ was biased positive, CMAQ negative.

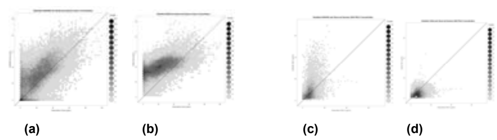

Figure 3: Model O_3 versus Observation scatter plots, for AURAMS (a) and CMAQ (b); Model $PM_{2.5}$ versus Observations scatter plots for AURAMS (c) and CMAQ (d)

Figures 3 (a) and (b) show scatter plots of modelled versus observed ozone concentrations for the summer 2005 period. 3(b) shows that at least some of the higher bias values for CMAQ are due to the overprediction of minimum values; the CMAQ intercept is higher than AURAMS. Figures 3 (c) and (d) show the corresponding scatter plots for $PM_{2.5}$, with AURAMS positive bias extending over the range of observed values.

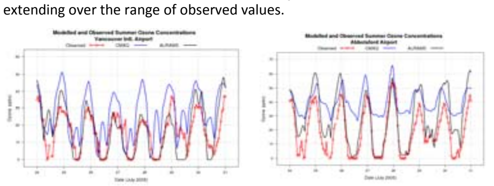

Figure 4: Model O_3 versus Observation time series for Vancouver Int'l Airport (left) and Abbotsford Airport (right) for the period July 24-31, 2005.

Figure 4 shows time series of O3 at Vancouver International Airport, and further up the Fraser Valley, Abbotsford airport. In urban Vancouver (4a), CMAQ overpredicts the maximum O3, and also predicts a secondary maximum during the night, when O3 titration by NOx might otherwise be expected. At Abbotsford, the absence of nighttime titration in the CMAQ simulations is more pronounced, with nighttime overpredictions on the order of 30 ppbv. Figure 5 (below) shows the PM2.5 time series at Vancouver International Airport and Hope (further up the valley). AURAMS positive bias seems to be confined to the urban center (5a), while both models have negative biases further up the valley (5b). Some of the negative biases in (5b) may be due to forest fire smoke, observed in the vicinity of Hope during the simulation period, and absent from the model emissions.

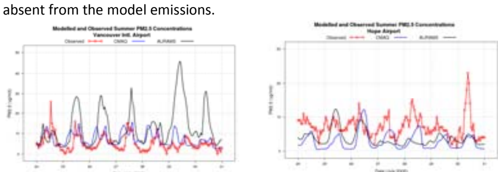

Figure 5: As in Figure 4 but for $PM_{2.5}$.

During the winter (see Table 2, next column), the differences between the two models is more pronounced, with the CMAQ bias being attributable once again to overpredictions at low O_3 concentrations (at night). With the longer and stronger surface inversions expected during the winter period, CMAQs difficulties with nighttime titration are amplified.

While the observed PM2.5 concentrations are higher in the winter (compare Tables 1 and 2), the positive bias for AURAMS has become worse in the winter simulation. CMAQ once again has a smaller magnitude, negative mean bias. CMAQs statistics for the winter simulations are better than AURAMS for all measures except slope and correlation coefficient, but the relative improvement for AURAMS for these two statistics is less than in the summer.

The table below compares the overall statistics for the domain of Figure 1 for the **winter** 2005 period.

Statistic	Ozone			PM2.5		
	Obs.	AURAMS	CMAQ	Obs.	AURAMS	CMAQ
Number of pairs		29546	29509		8457	8477
Mean	14.24	15.05	39.35	6.21	15.09	3.96
Maximum	52.00	44.17	54.28	65.00	218.20	86.43
Minimum	0.00	0.00	0.00	0.00	0.04	0.00
Y intercept (of obs vs model)		8.44	34.78		5.91	1.98
Slope (of obs vs model)		0.46	0.18		1.48	0.32
Correlation coefficient (R)		0.51	0.28		0.35	0.32
Mean Bias		0.82	23.11		8.88	-2.26
Root Mean Square Error		12.05	26.45		24.51	7.14
Normalized Mean Bias (%)		5.75	162.20		142.84	-36.35
Normalized Mean Error (%)		63.69	165.24		196.44	76.84

Table 2: Statistical comparison between observations for the 12-km resolution domain measurement sites vs AURAMS or CMAQ for the winter 2005 period.

Several sensitivity studies using the summer period were performed in order to determine the cause of the differences in model performance. Figure 6(a) shows the vertical layer structure of the two models, with CMAQ having a coarser resolution near the surface than AURAMS. Figure 6(b) shows the effect of running CMAQ at a vertical resolution approaching AURAMS: relatively minor change to O_3, $PM_{2.5}$, and NO_x (solid lines are base case, dashed are sensitivity run): relatively little impact on model results.

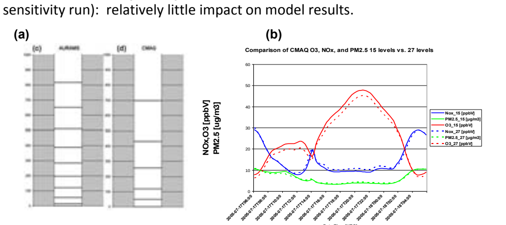

Figure 6: Comparison of model layers, and sensitivity of CMAQ to layer structure.

Figure 7 shows the effect of running AURAMS with CMAQ's lower limit on vertical diffusivity (1 m^2s^{-1}): a very significant impact, with the AURAMS results becoming more like those of the base case CMAQ simulation:, with lower $PM_{2.5}$ values, and night time overpredictions of O_3. The use of this lower limit allows CMAQ to achieve better $PM_{2.5}$ biases, but

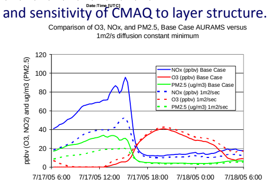

Figure 7: Effect of using CMAQ lower diffusivity limit in AURAMS.

at the expense of decreasing the accuracy of the ozone simulation. The chosen limit is also somewhat arbitrary. The predicted PM speciation in the vicinity of Vancouver was examined: in both models, the primary particulate matter contributes the bulk of the mass. The emissions of PM are thus a key factor in determining PM concentrations where the largest AURAMS overpredictions in $PM_{2.5}$ occur. A detailed examination of the SMOKE spatial disaggregation and temporal allocation fields for primary PM was carried out. Figure 8(a) shows the diurnal time series for different sources of primary PM on the Canadian side of the model domain. Certain sources have constant emissions (despite the type of source being known to be diurnally varying (e.g. residential charcoal grilling). Others have diurnal signatures that still allow significant emissions in the early morning hours (e.g. agricultural tractors). Figure 8(b) shows an error in spatial disaggregation: a erroneous hole in the map occurs between Abbotsford and Hope. Emissions being distributed over the domain will therefore be overestimated in Vancouver, but underestimated between Abbotsford to Hope.

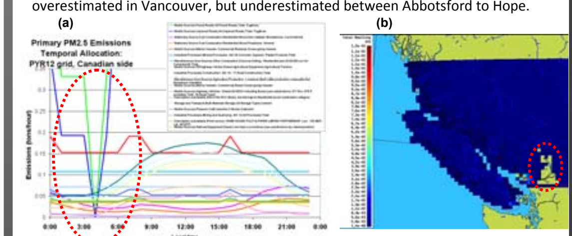

Figure 8: (a) Primary PM temporal allocation; (b) Spatial allocation: dwellings.

Next Steps:

The above work suggests that the use of a lower cut-off in diffusivity of 1 m^2s^{-1} may account for much of the differences between the two models – but that the use of this cut-off may mask other problems in the model setup. The identification of the above emissions errors in this study has led to a review of the Canadian emissions temporal and spatial allocation factors (M. Moran, J. Zhang, Q. Zheng). New emissions are being generated which will hopefully improve the $PM_{2.5}$ predictions. Other investigations have examined AURAMS operator splitting methodology. These improvements will be used in a second comparison of the models in the near future.