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The impact of GEM and MM5 meteorology on CMAQ results in eastern Canada and the northeastern US

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Outline

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- Impact of meteorology on emissions
- Impact of meteorology on CMAQ results
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Introduction

- Compare and evaluate
  - selected MM5 and GEM meteorological fields
  - the emission fields generated using GEM and MM5 meteorology in SMOKE
  - the impact of GEM and MM5 meteorology on CMAQ results

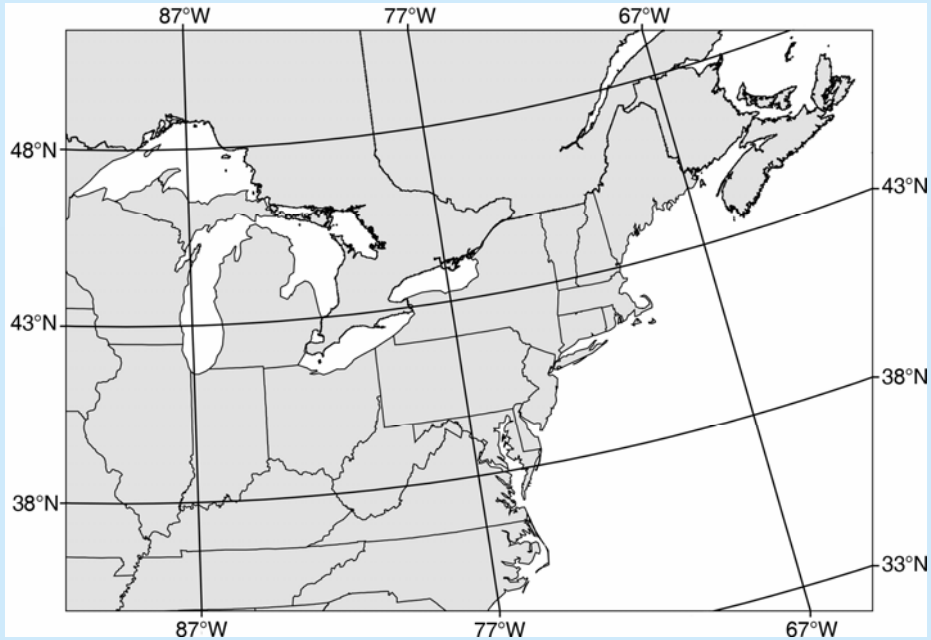
- Performance evaluation of each model against measurement data completed but not presented

Modelling Systems

- Meteorological Models
  - GEM v3.1.1
  - MM5 v3.3
  - GEM-MCIP
    - Extension of MCIP to work with both GEM and MM5 met fields
- Emissions
  - SMOKE v2.0
  - Canadian emissions:
    - 1995 CAC emissions inventory from EC; 1999 VMT data from SENES; MOBILE6.2C; GEM and MM5 meteorology
  - U.S. emissions:
    - 1999 NEI v3; 1999 VMT data from NEI; MOBILE6.2; GEM and MM5 meteorology

Modelling Systems (cont.)

- Air Quality
  - CMAQ v4.3
    - Radm2; aero2; NRC PMx CMAQ post-processor
- Modelling Domain and Simulation Period
  - 0000 UTC 11 July 1999 to 2300 UTC 19 July 1999 (9 days)
  - 68×49 grid with 36-km resolution
  - 15 vertical sigma layers



Model Comparison Metrics

Comparison Metric	Definition
Mean Difference (MD)	$MD = \frac{1}{n}\sum_i \left(GEM_i - MM5_i\right)$
Normalized Mean Difference (NMD)	$NMD = \frac{\sum_i \left(GEM_i - MM5_i\right)}{\sum_i MM5_i} \times 100\%$
Normalized Absolute Difference (NAD)	$NAD = \frac{\sum_i \left\|GEM_i - MM5_i\right\|}{\sum_i MM5_i} \times 100\%$

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Comparison of GEM and MM5 Meteorology

- Moderate difference in temperature between GEM and MM5
- Relative humidity (RH) shows largest NMD of meteorological variables investigated
  - Affects $PM_{2.5}$ and PM_{10} concentrations
- Wind speed has largest NAD

model results	pressure (hPa)		temperature (°C)		wind speed (m s^{-1})		RH (%)	
	GEM	MM5	GEM	MM5	GEM	MM5	GEM	MM5
n	719,712	719,712	719,712	719,712	745,200	745,200	719,712	719,712
mean	996.6	995.6	21.4	22.7	4.6	4.0	78.7	67.5
standard deviation	21.4	21.6	4.5	4.8	2.6	2.1	13.4	18.2
comparison statistics								
MD	1.0 hPa		**-1.3°C**		0.6 m s^{-1}		**11.2 %**	
NMD	0.1 %		**-5.6%**		15.0 %		**16.6 %**	
NAD	0.2 %		10.1%		35.9 %		21.5 %	

Impact of Meteorology on Emissions

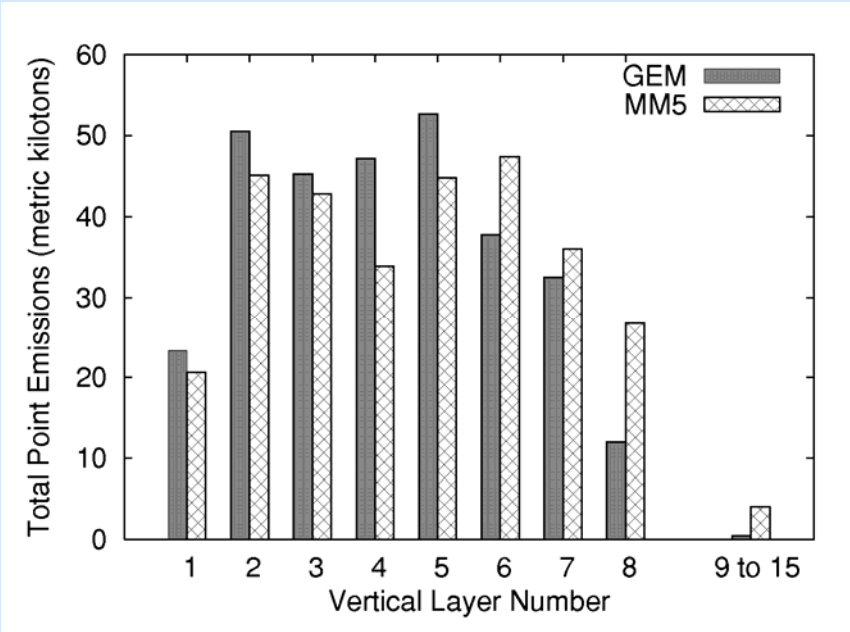
- Largest impact on Biogenic emissions
  - Biogenic emission correction factors based on temperature except ISO which is also based on photosynthetically active radiation (PAR)
  - Therefore differences mainly due to variations in temperature between the models

pollutant	on-road mobile emissions (metric kilotons)			biogenic emissions (metric kilotons)			total emissions (metric kilotons)		
	GEM	MM5	RD[a] (%)	GEM	MM5	RD (%)	GEM	MM5	RD (%)
CO	837.4	836.7	0.1	-	-	-	1269.0	1268.4	0.1
VOC	85.5	88.4	-3.3	**880.5**	**1056.1**	**-16.6**	1090.9	1269.4	-14.1
NOx	121.6	122.0	-0.3	**8.1**	**9.2**	**-11.8**	248.6	250.1	-0.6
TPM	3.0	3.0	0	-	-	-	74.4	74.4	0
NH3	3.3	3.3	0	-	-	-	45.9	45.9	0
SOx	4.1	4.1	0	-	-	-	178.4	178.4	0
TOTAL	1062.9	1065.4	-0.2	888.6	1065.3	-16.6	2948.2	3127.4	-5.7

[a] Relative Difference (RD) = (GEM – MM5) / MM5 × 100%

Vertical Distribution of Point Source Emissions

- Layers 1 through 5
  - Larger in GEM-based results
- Layers 6 through 15
  - Larger in MM5-based results



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Impact of Meteorology on CMAQ Results

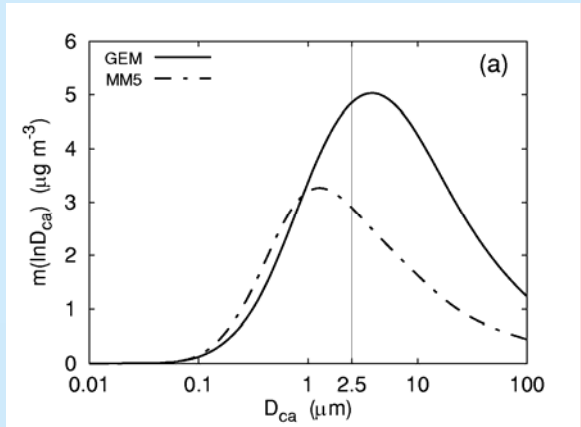
- Moderate difference in average ozone concentrations
- Larger difference between average PM_{10} concentrations than average $PM_{2.5}$ concentrations
  - Due to effect of RH on PM mass distributions

model results	O_3 (ppb)		PM_{10} (μg m^{-3})		$PM_{2.5}$ (μg m^{-3})	
	GEM	MM5	GEM	MM5	GEM	MM5
mean	44.4	45.2	13.6	9.6	6.9	6.5
standard deviation	17.7	15.9	17.6	11.5	8.1	7.4
comparison statistics						
MD	-0.8 ppb		4.0 μg m^{-3}		0.4 μg m^{-3}	
NMD	-1.7 %		**41.2 %**		**6.0 %**	
NAD	15.9 %		68.7 %		44.4 %	

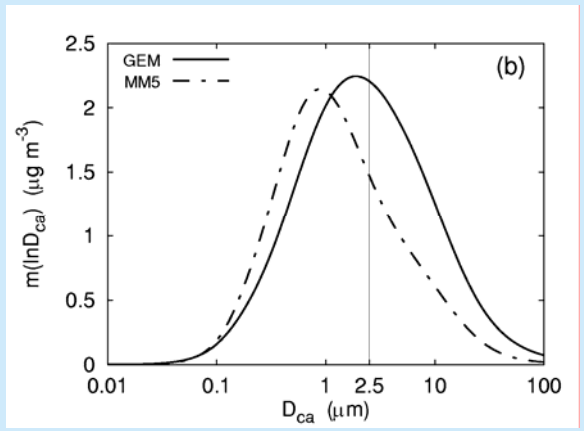
Influence of RH on PM Size and Mass Concentration

- As shown previously:
  - Avg. GEM RH – 78.7%
  - Avg. MM5 RH – 67.5%
- Higher RH in the GEM model causes shift towards larger particle diameters
- Effect seen even when AH2O is excluded from the average mass distribution curve

Avg. PM Mass Distribution w/ AH2O



Avg. PM Mass Distribution w/o AH2O



Speciated PM

- Larger differences in speciated PM_{i+j} concentrations of those species involved in thermodynamic equilibrium (ASO4/ANO3/ANH4)
  - Due to differences in RH between GEM and MM5
- Large relative difference in AH2O concentrations

	PM_{i+j} (μg m^{-3})			$PM_{2.5}$ (μg m^{-3})			PM_{10} (μg m^{-3})		
	GEM	MM5	RD (%)	GEM	MM5	RD (%)	GEM	MM5	RD (%)
ASO4	**3.92**	**2.86**	**37.1**	1.75	1.96	-10.7	3.07	2.62	17.3
ANO3	**0.331**	**0.180**	**83.9**	0.136	0.119	14.2	0.244	0.162	50.7
ANH4	**1.08**	**0.849**	**27.2**	0.508	0.615	-17.4	0.871	0.797	9.28
AORGPA	0.182	0.177	2.82	0.091	0.133	-31.7	0.150	0.168	-10.6
AORGA	0.250	0.234	6.83	0.130	0.177	-26.8	0.205	0.221	-7.23
AORGB	0.537	0.665	-19.2	0.312	0.523	-40.2	0.459	0.630	-27.1
AEC	0.153	0.146	4.79	0.076	0.110	-31.3	0.126	0.139	-9.35
A25	0.784	0.737	6.38	0.383	0.552	-30.5	0.643	0.701	-8.27
AH2O	**13.1**	**5.74**	**128**	3.44	2.25	52.7	7.37	3.76	95.9

Sensitivity Tests

- RH Sensitivity Test

  Base Case: GEM-based model simulation

  Sensitivity Case: 25% reduction in water vapour mixing ratio (corresponding reduction of ~25% in RH)

  – produced similar conclusions regarding affect of RH difference on PM concentrations

- CMAQ Configuration

  Reran using CMAQ v4.4 with radm2, aero3

  – decreases in PM concentrations and changes in statistics but overall conclusions were the same

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Summary and Conclusions

- Differences between investigated GEM and MM5 meteorological fields were moderate with RH having the largest NMD of 16.6%
- Moderate difference in temperature (1.3°C) had large impact on biogenic emissions
- Moderate difference in average ground level ozone concentrations between the two CMAQ results (NAD of 15.9%)
- For aerosol concentrations, the most influential meteorological variable was RH that affected $PM_{2.5}$ and PM_{10} concentrations due to the shift towards larger diameters at higher RH
- Overall, the study showed that the use of GEM meteorology produces CMAQ results comparable to those generated using MM5 meteorology

S. Smyth, D. Yin, H. Roth, W. Jiang, M.D. Moran, L.-P. Crevier, 2005. The impact of GEM and MM5 meteorology on CMAQ air quality modeling results in eastern Canada and the northeastern United States. *Journal of Applied Meteorology*. (Submitted)

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  - performing the MM5 simulations
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  - 1995 Criteria Air Contaminants emissions inventory
- U.S. EPA and CMAS
  - U.S. emissions data, SMOKE, CMAQ, MCIP

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Performance Statistics: Meteorology

measurement site statistics	pressure (hPa)		temperature (°C)		wind speed (m s^{-1})	
no. sites	10		10		10	
n	129		128		124	
measured mean	997.4		23.0		3.5	
standard deviation	11.6		5.6		2.1	
performance statistics	GEM	MM5	GEM	MM5	GEM	MM5
modelled mean	994.8	992.4	22.0	24.9	4.0	3.4
standard deviation	7.7	8.6	4.6	5.0	1.9	1.6
MB	-2.5	-4.9	-1.0	2.0	0.57	-0.10
NMB (%)	-0.25 %	-0.49 %	-4.4 %	8.6 %	16.4 %	-2.9 %
ME	4.7	5.9	2.2	2.6	1.5	1.4
NME (%)	0.47 %	0.59%	9.4 %	11.3 %	43.6 %	41.8 %

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Performance Statistics: Air Quality

measurement site statistics	O_3 (ppb)		PM_{10} (μg m^{-3})		$PM_{2.5}$ (μg m^{-3})	
no. sites	640		37		33	
n	133 639		7499		6764	
measured mean	40.0		38.6		21.9	
standard deviation	24.8		29.3		16.5	
performance statistics	GEM	MM5	GEM	MM5	GEM	MM5
modelled mean	47.7	48.4	29.6	21.0	14.4	13.9
standard deviation	20.4	20.2	23.8	15.7	14.2	13.6
MB	7.7	8.3	-9.0	-17.7	-7.5	-8.0
NMB (%)	19.1 %	20.8 %	-23.4 %	-45.7 %	-34.4 %	-36.4 %
ME	16.1	16.2	18.3	21.2	12.5	13.0
NME (%)	40.2%	40.3 %	47.3 %	54.8 %	57.1 %	59.2 %