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The PM Module in the New Canadian Operational AQ Forecast Model GEM-MACH15: Current Status and Future Plans

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Talk Outline

- Short overview of GEM-MACH15
- Description of current PM module
- Some evaluation statistics
- Future plans

Terminology

- **What is GEM?**
  - *Environment Canada's operational global/medium-range and regional/short-range weather forecast model*
- **What is GEM-MACH?**
  - *GEM with on-line chemistry from AURAMS CTM*
- **What is GEM-MACH15?**
  - *operational limited-area configuration of GEM-MACH with 15-km horizontal grid spacing; went operational on 18 Nov. 2009*

Acronym “GEM-MACH” Stands For

modèle **G**lobal **E**nvironnemental **M**ulti-échelle –**M**odélisation de la qualité de l'**A**ir et de la **CH**imie

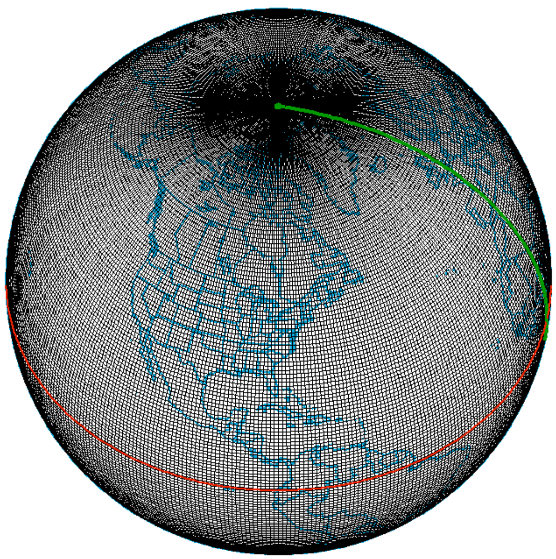
et / and

Global **E**nvironmental **M**ultiscale model – **M**odelling **A**ir quality and **CH**emistry

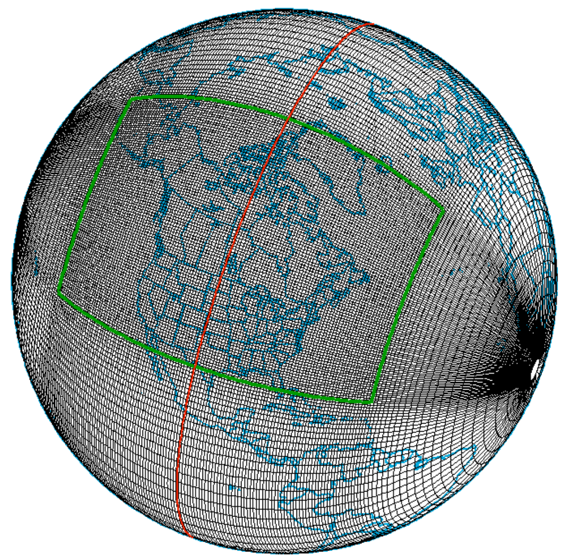
GEM Characteristics

- rotated latitude-longitude horizontal grid
- three different grid configurations
  - global uniform model (used for 10-day forecasts)
  - global variable model (used for 2-day regional forecasts)
  - limited area model (LAM: selected for GEM-MACH15)
- hybrid vertical coordinate
- semi-Lagrangian advection
- hydrostatic and non-hydrostatic options
- four-dimensional data assimilation
- extensive physics library

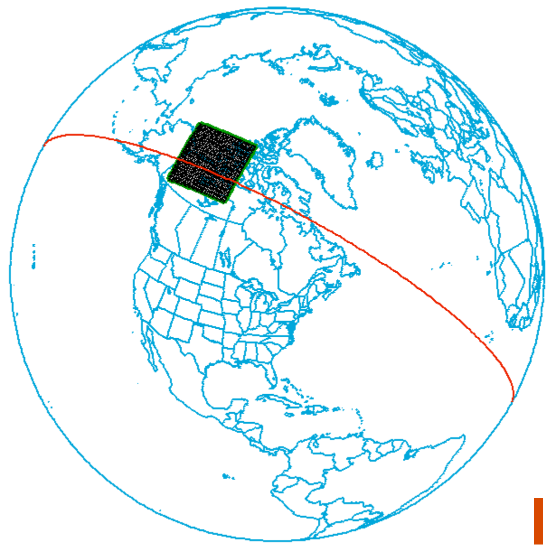
"Multiscale" Examples:
Three GEM Grid Configurations



global



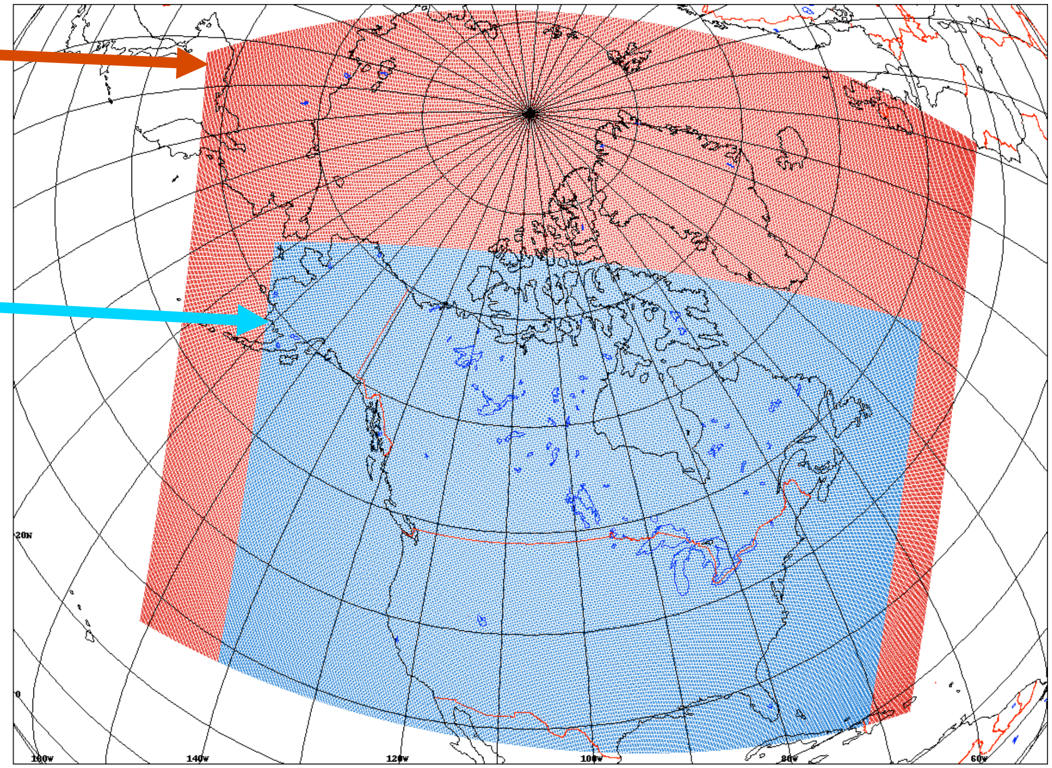
regional



limited area

GEM15 and GEM-MACH15 Grids

- **GEM15** employs a variable grid, but uniform core has 15-km spacing
- **GEM-MACH15** employs a limited-area grid (LAM), also with 15-km spacing and co-located with GEM15 grid points
- **GEM15** supplies meteorological initial conditions and hourly lateral boundary conditions to LAM



GEM15 core grid (red) ; GEM-MACH15 grid (blue)

Process Representations in GEM-MACH15

PROCESS	DESCRIPTION
PM Composition and Size Distribution	2 size bins: $PM_{2.5}$, PM_c 9 chemical species: SO_4, NO_3, NH_4, EC, pOC, sOC, CM, SS, H_2O
Emissions	$PM_{2.5}$ and PM_c emissions speciated to 7 species by primary source type (major point, minor point, area, mobile); 17 gas-phase species emitted
Gas-Phase Chemistry Mechanism	ADOM-2 mechanism (Stockwell and Lurmann, 1989): 1) 42 species, 114 rxns; p-SO_4 replaced by H_2SO_4+p-SO_4 2) N_2O_5 + H_2O "heterogeneous nitrate formation" rate enhancement off
Aqueous-Phase Chemistry	ADOM aqueous-phase chemistry (20 species, 20 rxns)
Heterogeneous Chemistry	HETV (Makar et al., 2003), based on ISORROPIA
Aerosol Dynamics	Sedimentation, nucleation, condensation, coagulation, swelling, activation (S. Gong et al., 2003)
Secondary Organic Yields	IAY scheme based on Jiang (2003, 2004); 5 lumped VOC species form SOA
Dry Deposition	Zhang et al. (2001) scheme (land-cover- and size-dependent)
Wet Deposition	Transfer of tracers from cloud to rain water based on precipitation production. In-cloud and below-cloud scavenging of soluble gases and particles (size-dependent) (W. Gong et al., 2003).
Chemical Boundary Conditions	Climatological profiles with Davies lateral boundary conditions

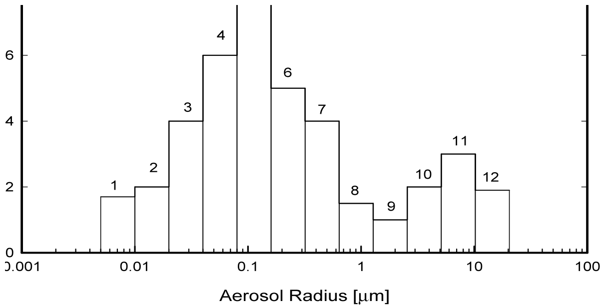
Simplifications to GEM-MACH15 for Operational Use (1)

- Perform meteorological calculations every time step (450 s) but AQ calculations every 2nd time step (900 s)
- Used 58 vertical levels to 0.1 hPa rather than 80 levels to 0.1 hPa used by GEM15
- Used metastable option in heterogeneous chemistry
- Switched from 12-bin to 2-bin representation of PM size distribution [reduces number of advected tracer fields by 80 from 137 to 57, i.e., by ~60%]

Simplifications to GEM-MACH15 for Operational Use (2)

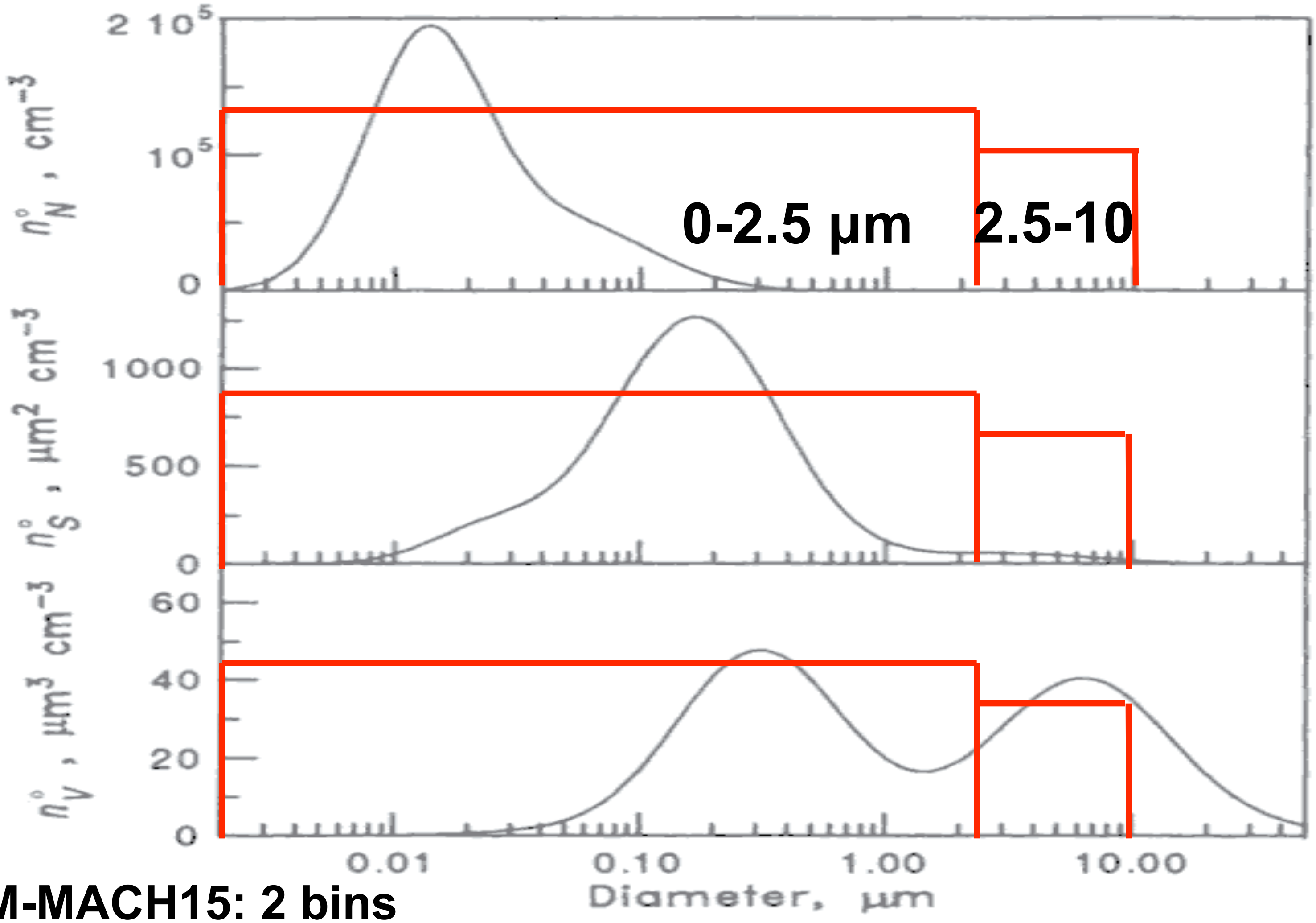
- Several other AQ models have used a simplified 2-bin sectional representation of PM size distribution (DAQM, CHRONOS, CAMx)
- In case of CHRONOS, PM processes were added selectively and no mass transfer assumed between bins
- In case of GEM-MACH15, we started with a full treatment of PM dynamics designed for a multi-sectional representation, including mass transfer between bins, then reduced number of bins to two
- Had to implement new sub-bin calculations to account for size dependence in some PM processes (sea-salt emissions, dry deposition, intersectional transport)

Particulate Matter : AURAMS Sectional Representation of PM Volume Size Distribution



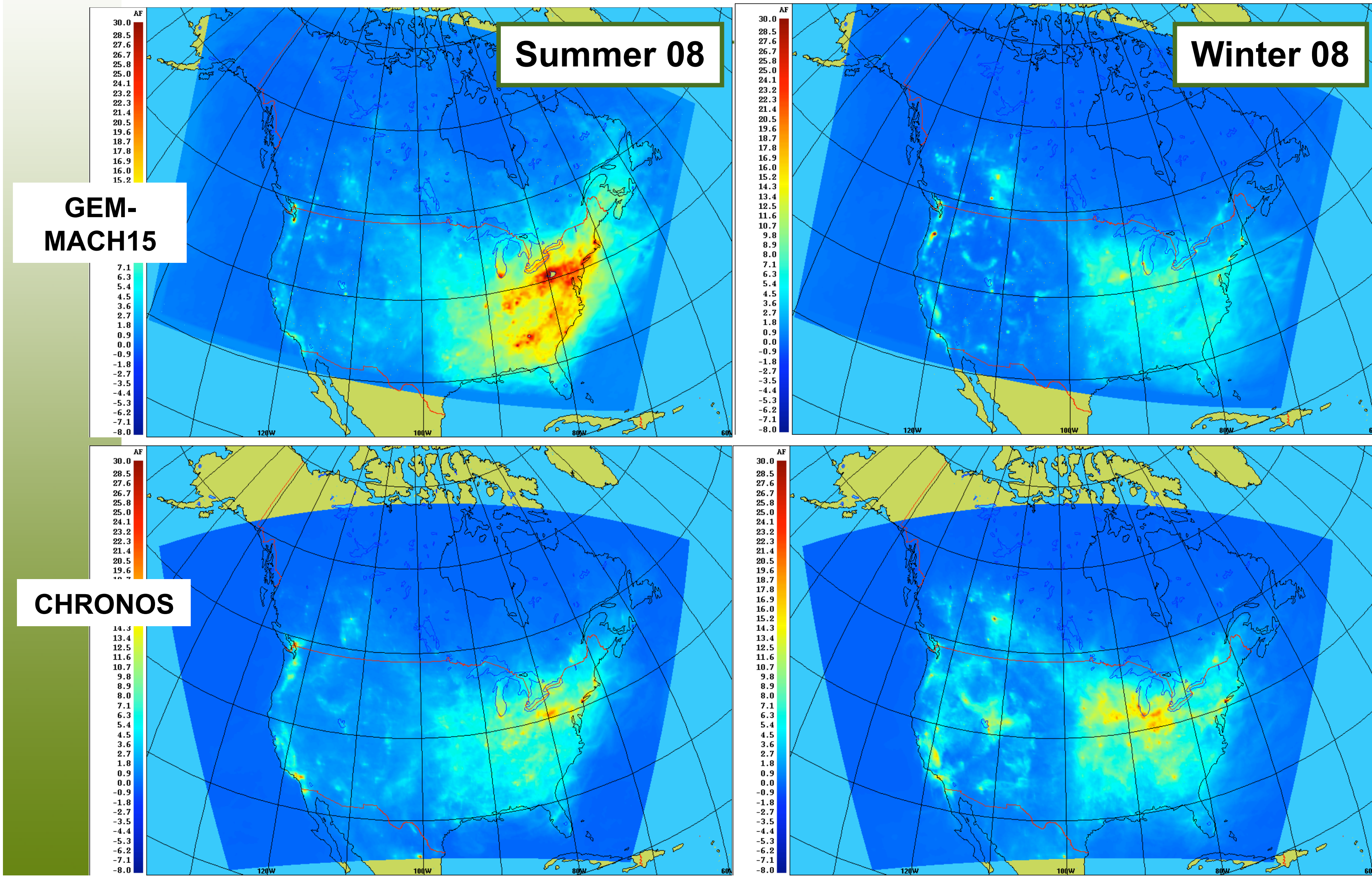
AURAMS: 12 bins

Particulate Matter: Simplified 2-Bin Sectional PM Size Representation

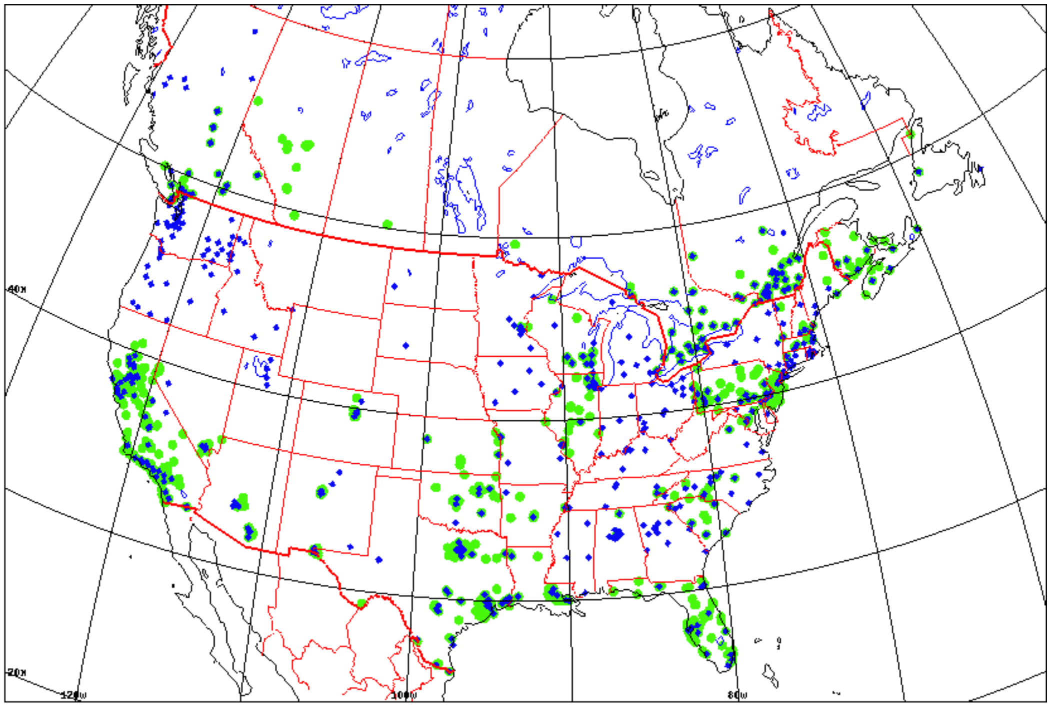


GEM-MACH15: 2 bins

General Overview: Average $PM_{2.5}$ Field at 20 UTC



Summer 2008 $PM_{2.5}$ Monitor Locations and Winter 2008 O_3 Monitor Locations

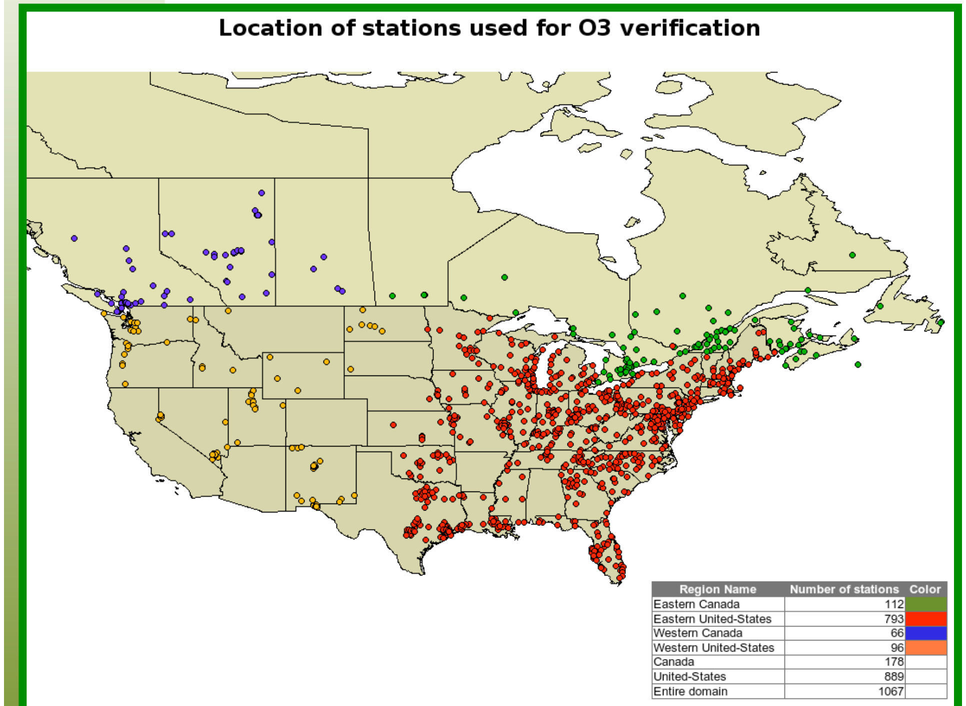


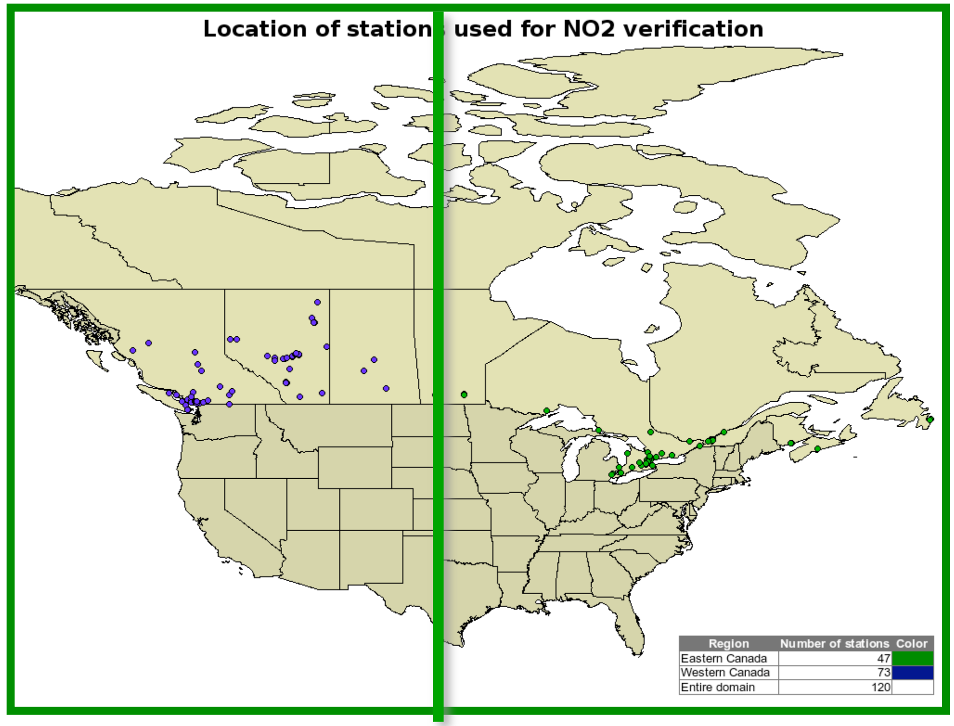
$PM_{2.5}$ monitors – blue

Winter O_3 monitors - green

- Canadian data: real-time data from ADE system (provincial and federal real-time transmission)
- U.S data: real-time data from SonomaTech / EPA real-time feed (ftp.airnowdata.org)

Summer 2008 O_3 and NO_2 Monitor Locations





Comparison Between CHRONOS and GEM-MACH15 Evaluation Scores by Region

Metric	North Am	Cda	E Cda	W Cda	US	E US	W US
Summer 2008	North Am	Canada	Est Can	Ouest Can	US	Est US	Ouest US
PM2.5 R	**0.30/0.40**	**0.20/0.30**	**0.21/0.27**	**0.20/0.20**	**0.34/0.42**	**0.32/0.40**	**0.09/0.07**
PM2.5 MB	**-2.08/0.69**	**-0.07/0.62**	**-1.38/1.22**	**1.82/-0.24**	**-2.86/0.71**	**-2.99/1.76**	**-2.50/-2.06**
PM2.5 RMSE unbiased	**12.8/13.5**	**14.2/13.9**	**15.9/16.7**	**11.0/8.2**	**11.9/13.3**	**12.5/14.1**	**10.1/10.5**
Winter 2008							
PM2.5 R	**0.26/0.22**	**0.13/0.12**	**0.29/0.22**	**0.06/0.06**	**0.38/0.31**	**0.39/0.37**	**0.26/0.23**
PM2.5 MB	**0.86/-0.18**	**2.21/1.76**	**1.55/1.36**	**3.15/2.34**	**0.34/-0.86**	**0.55/-1.84**	**-0.22/1.74**
PM2.5 RMSE unbiased	**14.1/15.9**	**19.5/21.1**	**12.30/17.2**	**26.7/25.7**	**11.3/13.6**	**11.6/11.4**	**10.6/17.8**

GEM-MACH better **48% red**

CHRONOS better **50% blue**

Not statistically significant (bootstrapping) **2 % yellow**

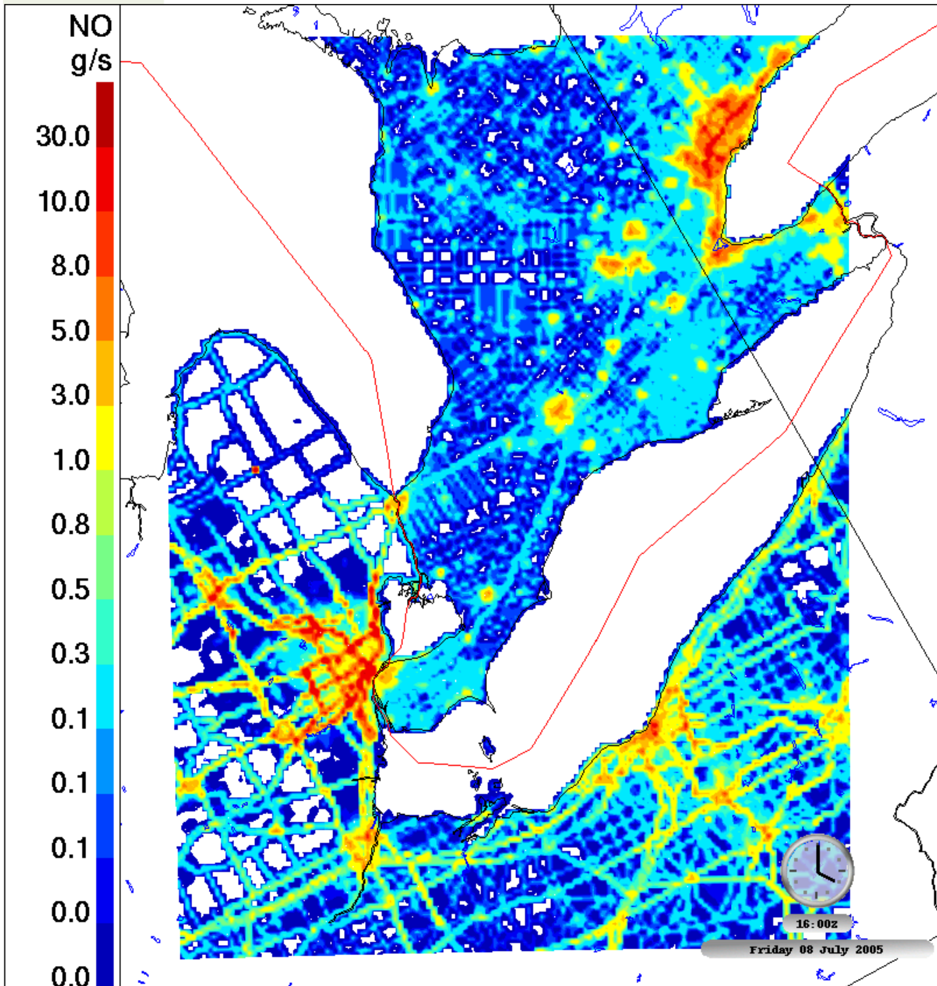
Future Plans – Model Processes

- improve vertical diffusion scheme, including UHI influence
- update SOA scheme to include contributions from benzene, monoterpenes, sesquiterpenes, and IVOCs
- implement new gas- and aqueous-phase chemistry solvers
- implement subgrid-scale convective vertical tracer transport
- add cloud ice-phase and mixed-phase chemistry
- add treatment of plume rise for non-point sources
- add time-dependent chemical lateral boundary conditions

Future Plans – Emissions

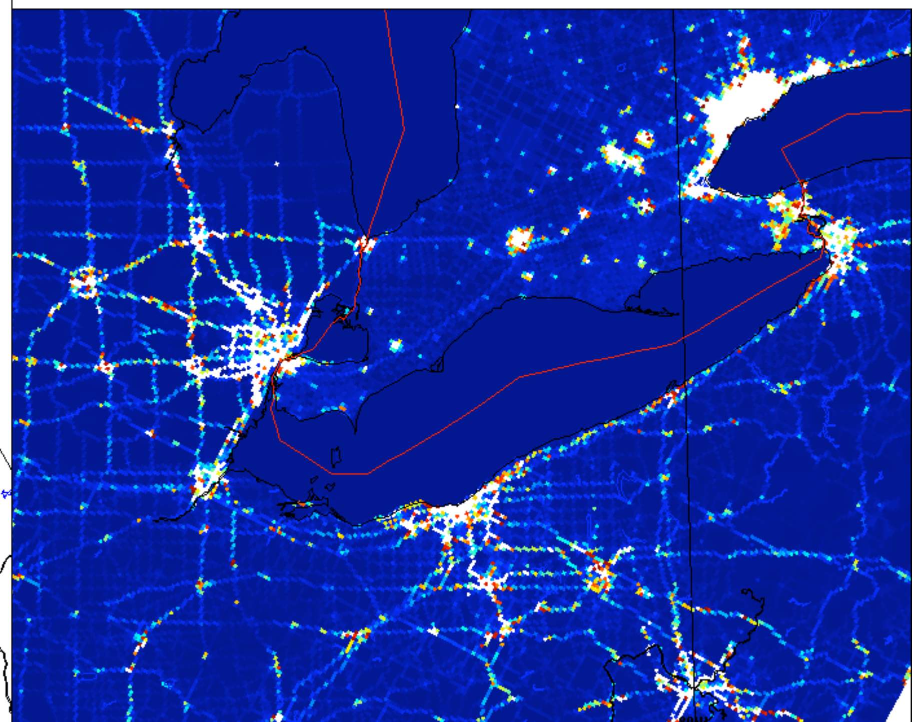
- improve processing of anthropogenic emissions, including spatial and temporal disaggregation and chemical speciation
- implement projection of base-year inventory emissions to current forecasting year
- implement wind-blown dust emissions
- implement real-time wildfire emissions
- improve biogenic emissions, including phenology
- implement lightning-generated NOx emissions

Current Emissions Processing Example: Cross-Border Differences in Spatial Distribution of Emissions from Light-Duty Gasoline Vehicles



Logarithmic scale

- **U.S. – highways stand out**
- **Ontario – population centres & full road network evident**



Linear scale

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Thank you for your attention!