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A new Canadian operational air quality forecast model: GEM-MACH15

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GEM-MACH team: The success of this project is based on the scientific expertise and technical skills provided by several sections inside Environment Canada.

- Air Quality Models Applications Section (AQMAS) (Québec)
- Air Quality Research Division (AQRD) (Québec, Ontario)
- Meteorological Research Branch (MRB) (Québec)
- Analysis and Prognosis (A&P) (Québec)
- Implementation and Operational Services division (CMOI) (Québec)
- Environment Canada Regional Offices

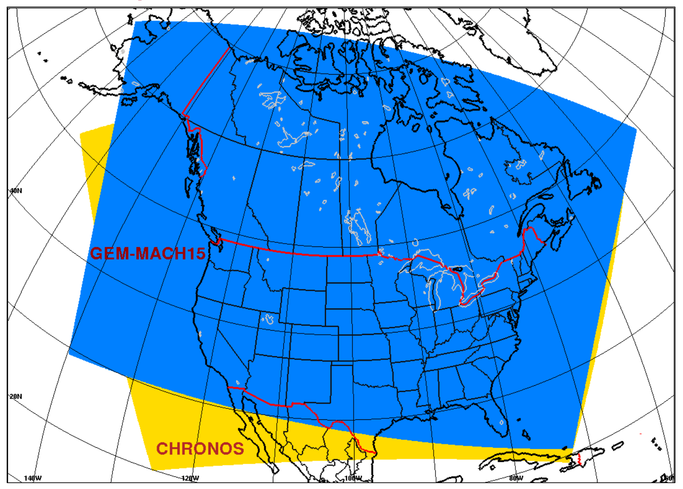
Abstract

Operational AQ forecasting began in Canada in 2001 with the implementation by Environment Canada (EC) of a continental-scale, 21-km, ozone-only version of the off-line CHRONOS chemical transport model (CTM). The meteorological driver used was the regional configuration of EC's operational GEM weather forecast model. Operational CHRONOS forecasts of PM2.5 and PM10 using a simple 2-bin sectional representation of the PM size distribution followed in 2003.

Work to develop a new EC operational AQ forecast model called GEM-MACH15 began in 2006. This new model is an on-line chemical transport model embedded within GEM. A number of AQ process representations from EC's AURAMS off-line CTM have been implemented in GEM-MACH15, including gas-phase, aqueous-phase, and heterogeneous chemistry and aerosol processes. Like CHRONOS, GEM-MACH15 uses a 2-bin sectional representation of the PM size distribution, but PM chemical composition is treated in more detail and additional processes affecting PM concentrations have been included. The SMOKE emissions processing system is used to produce anthropogenic input emission files on the GEM-MACH15 rotated latitude-longitude grid based on the 2006 Canadian and 2005 U.S. national inventories. Biogenic emissions are estimated on-line using the BEIS v3.09 algorithms.

In late 2009, GEM-MACH15, a 15-km limited-area version of GEM-MACH, was implemented by EC as the replacement to CHRONOS after evaluation of both models' performance for a summer 2009 parallel run. This poster will provide an overview of GEM-MACH, and a description of the specific domain and grid configuration chosen for GEM-MACH15. Results of performance evaluations of GEM-MACH15 against CHRONOS forecasts and O3, NO2, and PM2.5 measurements will be presented, and the use of GEM-MACH15 forecasts to support EC's new national Air Quality Health Index will be shown.

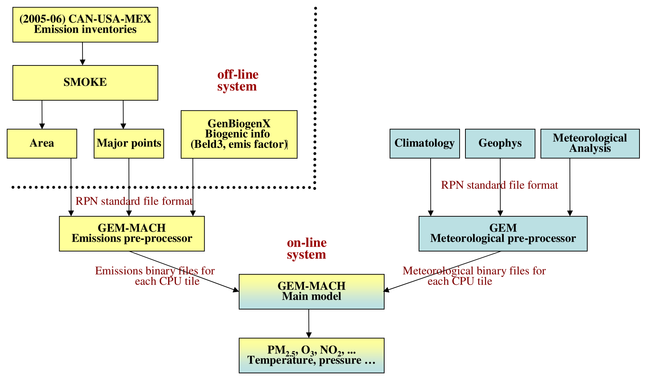
Operational GEM-MACH15 Model Domain



Operational GEM-MACH15 Model Configuration

Grid configuration	Limited Area Model over North America (LAM)
Grid projection	Rotated Latitude-Longitude
Grid dimensions	348 x 465 x 58
Model horizontal spacing	15 km
Vertical coordinate	58 Hybrid Levels
Model top	0.1 hPa (~60 km)
Model time step	450 s for meteorology 900 s for chemistry
Anthropogenic Emissions	Canada 2006, US 2005, Mexico 1999
Parallelism	MPI + OpenMP
Number of CPU used	384
Execution time	34 minutes for a 48 hour forecast
Model output	Meteorology & Chemistry (gases and particles)

GEM-MACH15 dataflow



References

GEM-MACH: http://cmascenter.org/conference/2009/slides/moran_status_new_2009.ppt

AQHI: http://www.ec.gc.ca/cas-aqhi/

GEM: http://www.msc-smc.ec.gc.ca/cmc/op_systems/index_e.html
http://web-mrb.cmc.ec.gc.ca/mrb/rpn/eng/gemdm/gemdm.html

CHRONOS: http://www.msc-smc.ec.gc.ca/aq_smog/chronos_e.cfm
Pudykiewicz J., A. Kallaur, and P. K. Smolarkiewicz, 1997: Semi-Lagrangian modelling of tropospheric ozone. *Tellus*, **49B**, 231-248.

AURAMS: Gong, W. et al., 2006: Cloud processing of gases and aerosols in a regional air quality model (AURAMS). *Atmos. Res.*, **82**, 248-275.

SMOKE: http://cf.unc.edu/cep/empd/products/smoke/index.cfm

BEIS3: http://www.epa.gov/asmdnerl/biogen.html

NPRI: http://www.ec.gc.ca/pdb/npri **US EPA**: http://www.epa.gov

GEM-MACH15 Chemistry Package

Initialization of chemistry	Fixed initial conditions based on climatological background values ("cold start") or extracted from previous run ("warm start")
Chemical boundary conditions	Lateral & upper climatological vertical species profiles
Advection	Semi-Lagrangian method (Côté et al, 1993)
Vertical Diffusion	Based on prognostic equation for turbulent kinetic energy (TKE)
Emissions	PM2.5 and PMc emissions speciated to 7 species and size disaggregated to 2 bins by primary source type (major and minor point, area, mobile); 17 gas-phase species emitted
Major point sources treatment	Plume rise formulation based on Briggs (1984)
Gas-Phase Chemistry Mechanism	ADOM-2 mechanism (Stockwell and Lurmann, 1989) with 1) **p-SO_4 replaced by H_2SO_4,** 2) **N_2O_5 + H_2O "heterogeneous nitrate** formation" rate enhancement **switch=off,** 3) 42 gas species and 114 reactions
Gas-Phase Chemical Solver	Vectorized version of Young and Boris (1977): Makar (1995)
Photolysis	Table lookup
Cloud (Physical) Processes	Cloud attenuation and enhancement photolysis rates, based on ADOM algorithm. 1) Aerosol activation (based on Jones et al., 1994) 2) Droplet scavenging of interstitial aerosol
Sub-grid Convective Mixing	Not included
Aerosol Dynamics	Nucleation, Condensation, Coagulation, Sedimentation, Swelling
PM Composition Representation	9 species: SO_4, NO_3, NH_4, EC, pOC, sOC, CM, SS, H_2O
PM Size Distribution Representation	Sectional method (flexibility to allow different number of size bins (2-12) based on Canadian Aerosol Module) (Gong et al., 2003)
Aqueous-Phase Chemistry Mechanism	Based on ADOM mechanism (Young and Lurmann, 1984); nucleation scavenging reactions replaced by explicit particle activation; 20 reactions, 7 gas and 13 aqueous species (Gong, 2001)
Aqueous-Phase Solver	Vectorized Young & Boris (based on Makar, 1995)
Heterogeneous Chemistry	HETV (vectorized inorganic heterogeneous chemistry based on the [halogens excluded] ISORROPIA). (Makar et al., 2003, *Atmos. Environ.*, **37**, 2279-2294)
Secondary Organic (SOA) Yields	IAY scheme, Jiang et al., 2003, *Atmos. Environ.*, **37**, 5439-5444
Dry Deposition	Gases: New scheme based on multiple resistance approach and single-layer "big leaf" approach (mostly based on work of Wesely (1989,1996), Zhang et al. (2002), and Robichaud, (1991, 1994)) Particles: size-segregated model (Zhang et al., 2001); 15 land-use categories
Wet Deposition	Transfer of tracers from cloud to rain water based on precipitation production. In-cloud and below-cloud scavenging of particles and gases based on size and solubility, respectively. (Gong et al., 2003, *J.Geophys. Res.*, 108(D1))

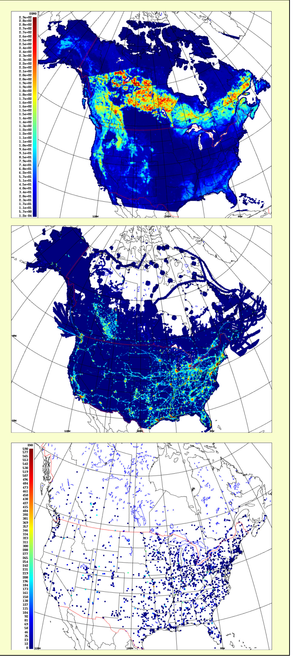
Emissions Processing

Time-dependent gridded and un-gridded (major point sources) emissions fields are prepared in advance with the SMOKE emissions processing system. Emissions files are read by the model at every model chemistry time step.

Biogenic emissions
- Calculated with the Biogenic Emission Inventory System (BEIS3) v3.09.
- 230 soil and vegetation types come from the Biogenic Emission Landuse Database (BELD3) and the 2000 Canadian National Forest Inventory.
- Meteorological dependency on solar radiation, cloud cover, and 10m air temperature.
- Emitted species: Isoprene, Monoterpenes, NO, and other VOCs.

Anthropogenic emissions
- Prepared with the SMOKE modelling system (version 2.4).
- Data from Canadian, U.S., and Mexican criteria-air contaminant emissions inventories (mostly based on 2005-06 inventories).
- 17 primary gas species emitted.
- Particulate matter speciation for sulfate (SO_4), nitrate (NO_3), ammonium (NH_4), crustal material, elemental carbon, organic carbon, and sea-salt.
- Season-day-specific mobile, non-mobile, and area emissions.

Major point source emissions
- Prepared with the SMOKE modelling system (version 2.4).
- More than 10,000 sources.
- Month-day-specific.



Air Quality Health Index (AQHI)

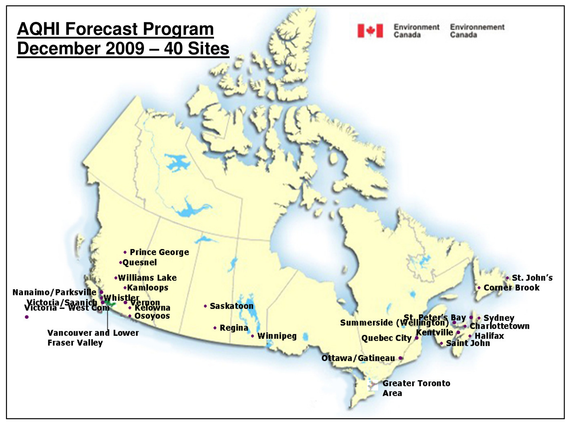
Motivations
- Current AQ indices do not reflect current scientific evidence, in terms of low-level exposure and multiple pollutant exposure
- Uneven application of current AQIs across Canada, in terms of formulations, thresholds, and health messaging
- Preference for a greater emphasis on health

Objectives
- Create a national, simplified communications tool for AQ observations and forecasts, with the ultimate goal to empower individuals to take action to protect their health
- Promote personal action to reduce air pollution

Plan
- Phased in approach, gradually replacing AQI by AQHI
- Expand to cover largest metropolitan areas in Canada, followed by rural regions

Partners
- Environment Canada, Health Canada, provincial & municipal governments, and NGOs

AQHI Forecast Program December 2009 – 40 Sites

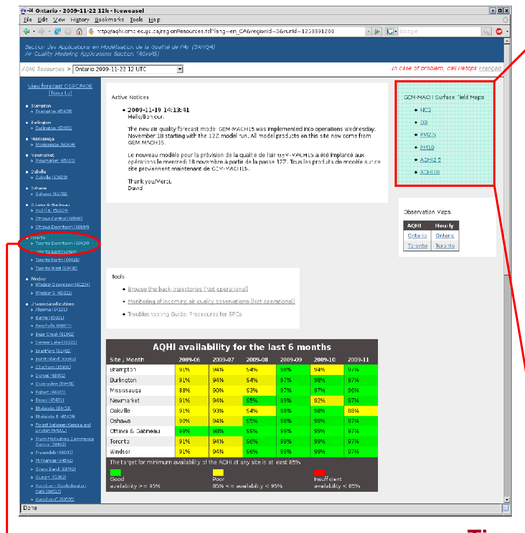


Formulation
- Formulas are statistically derived from studies of short-term health effects on morbidity/mortality for major Canadian cities
- Inputs are 3-hr rolling averages of pollutants
- Science is peer-reviewed and published

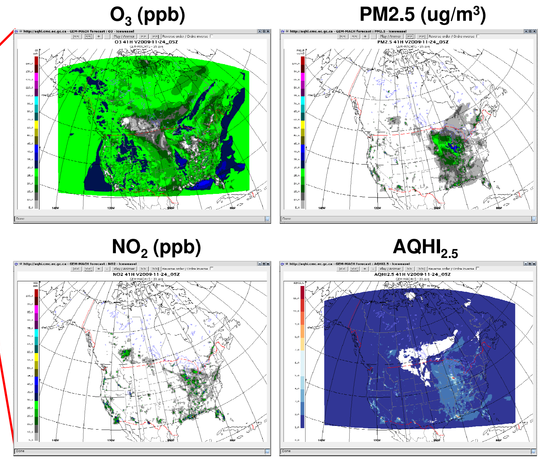
$$AQHI_{2.5} = \frac{10}{10.4} * [100 * ((e^{0.000871 * NO_2} - 1) + (e^{0.000537 * O_3} - 1) + (e^{0.000487 * PM\,2.5} - 1))]$$

$$AQHI_{10} = \frac{10}{11.7} * [100 * ((e^{0.000871 * NO_2} - 1) + (e^{0.000537 * O_3} - 1) + (e^{0.000297 * PM\,10} - 1))]$$

AQHI Forecaster Resource Web Site (Internal)



Surface Maps (3-hr rolling avg)



Time Series

Observed (left) & GEM-MACH15 (right)