Environment Canada Environnement Canada

Canada

Canada's Air Quality Forecasting System: Operations and Research

Véronique Bouchet

Manager, Air Quality Modelling Research Section,

Science & Technology Branch, Environment Canada, Canada

ARQI and AQMAS teams

3rd International Workshop on Air Quality Forecasting Research

Potomac, Maryland, 29 November-1 December 2011

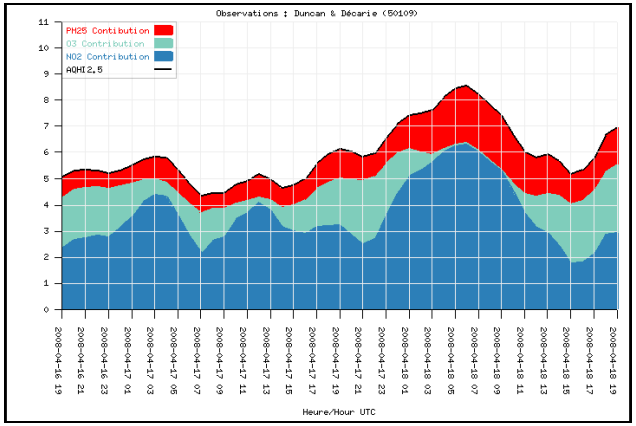
Talk Outline

- Overview of Canadian AQ Forecast Program
- Canadian AQ Forecast System
  - GEM-MACH15 Overview
  - Operational Post-processing (UMOS-AQ)
  - Objective analysis and data assimilation
- Possible Features of Next Version
- Recent research development using satellite observations

Overview of the Canadian AQ Forecast Program

- Evolution from an O_3-only forecast in Eastern Canada in 2001 to a Canada-wide O_3, NO_2, $PM_{2.5}$ forecast program
- Forecast is communicated in most areas as an Air Quality Health Index (AQHI): hourly, multi-pollutant, additive, no-threshold, health-based

$$\mathbf{AQHI = 10/10.4*100*[(exp(0.000871*NO_2)-1) +(exp(0.000537*O_3) -1)+(exp(0.000487*PM_{2.5}) -1)]}$$



- 10-point scale that links air quality to the health risk associated with exposure to a 3-pollutant mixture

- Developed by Health Canada (Stieb et al., 2008, JA&WMA) from Canadian multi-city mortality/morbidity studies of short term health effects and AQ data from the Canadian National Air Pollution Surveillance Network (NAPS)

Overview of the Canadian AQ Forecast System

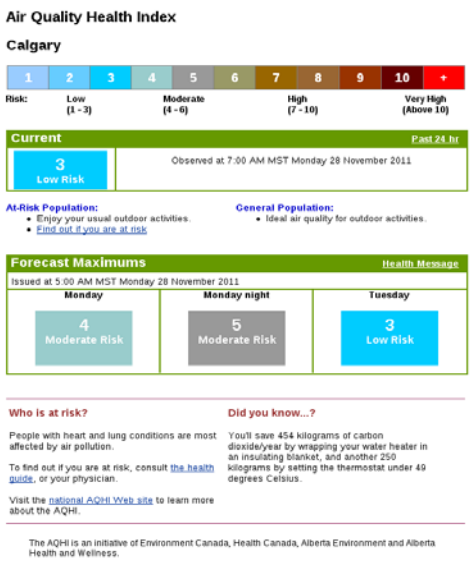
- **Schematic diagram of an AQHI forecast**

Past and present situation
- Last 48hr -
Real-time observations
of O_3, $PM_{2.5}$, NO_2

Numerical forecast
- Next 48hr -
GEM-MACH15
UMOS-AQ

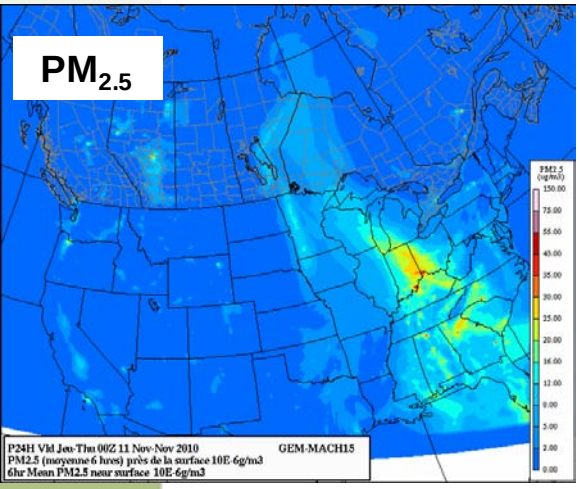
Forecaster
(1 desk/forecast region)

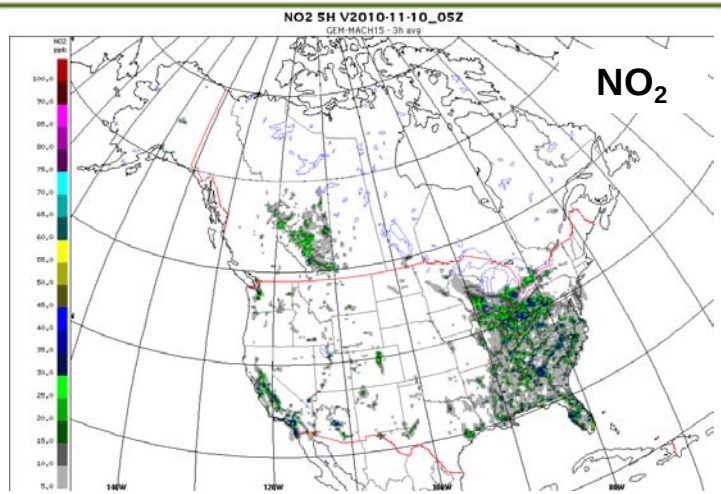
$$AQHI = 10/10.4*100*[(\exp(0.000871*NO_2)-1)+(\exp(0.000537*O_3)-1)+(\exp(0.000487*PM_{2.5})-1)]$$

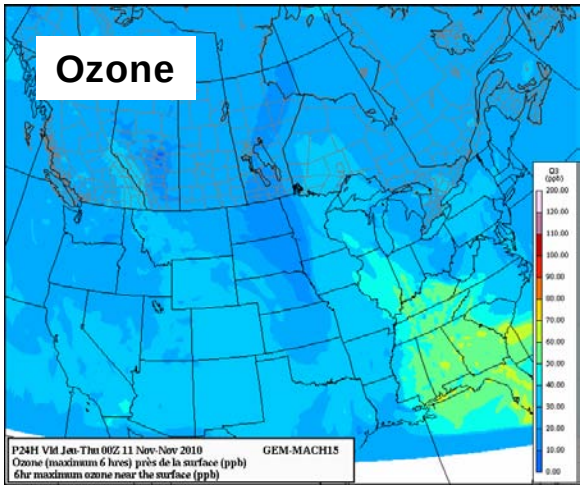


$$AQHI = 10/10.4*100*[(\exp(0.000871*NO_2)-1)+(\exp(0.000537*O_3)-1)+(\exp(0.000487*PM_{2.5})-1)]$$

Canadian Operational Air Quality Forecast Model: GEM-MACH15



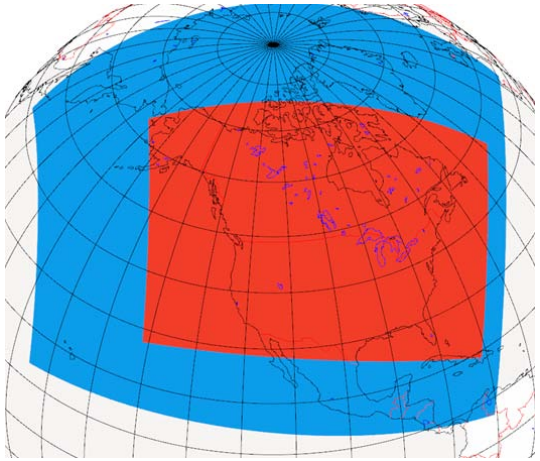




- Model forecasts are based on GEM-MACH15: multi-scale chemical weather forecast model composed of dynamics, physics, and **in-line** chemistry modules
- 3D, continent-wide, hourly forecasts of $PM_{2.5}$, O_3 and NO_2, twice a day (00 and 12 UTC), for the next 48 hours
  - Publicly accessible at http://www.weatheroffice.gc.ca (Analyses & Modelling)
- Weather forecast suite is not merged with air quality forecast suite:
  - AQ runs are launched after completion of weather forecast with repeat of meteorology

Canadian Air Quality Forecast Model: Operational Configuration

- GEM-MACH options are chosen to meet EC's operational AQ forecast needs; key characteristics include:
  - limited-area (LAM) configuration where grid points are co-located with operational met-only **GEM** which supplies initial conditions and lateral boundary conditions for **GEM-MACH15**
  - 15-km horizontal grid spacing, 58 vertical levels to 0.1 hPa
  - 2-bin sectional representation of PM size distribution (i.e., 0-2.5 and 2.5-10 µm) with 9 chemical components
    - Some processes resolved with increased number of sub-bins



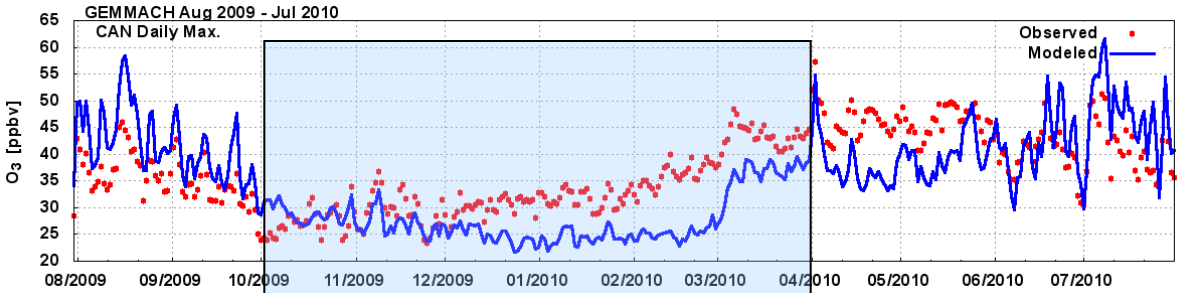
GEM-15 grid (blue) ; GEM-MACH15 grid (red)

- Full process representation of oxidant and aerosol chemistry:
  - gas-, aqueous- & heterogeneous chemistry mechanisms
  - aerosol dynamics
  - dry and wet deposition (including in- and below-cloud scavenging)
- Emissions: Canada (2006), US (2012 projection of NEI), Mexico (1999)

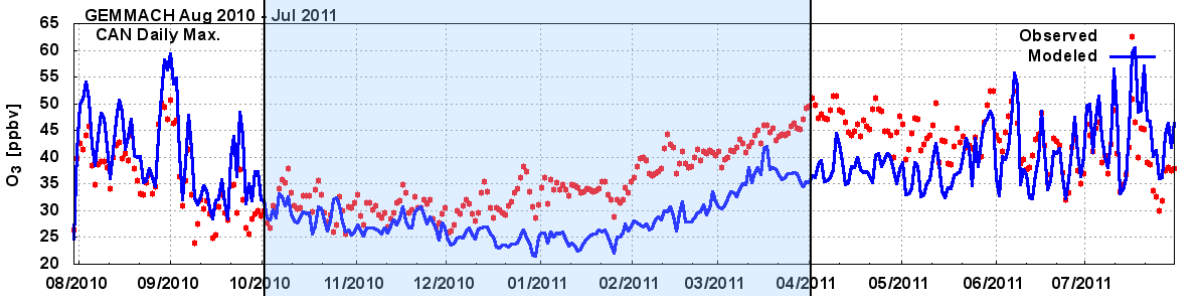
Canada

Year 1 & Year 2 Annual Time Series Of National-Average Daily Maximum 1-h O_3 Concentrations At Canadian & U.S. Stations

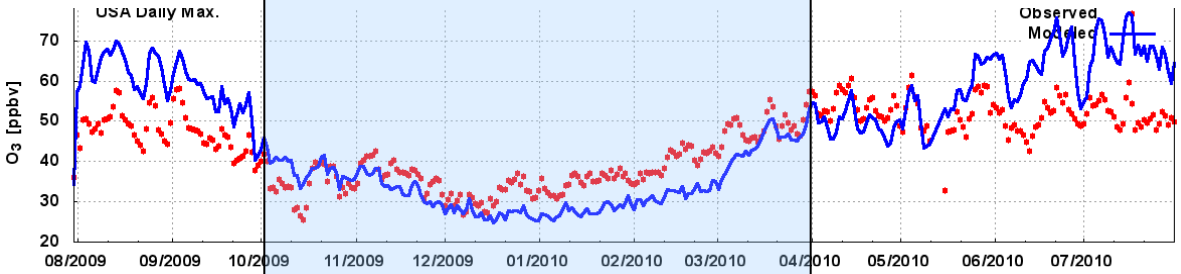
CAN Year 1



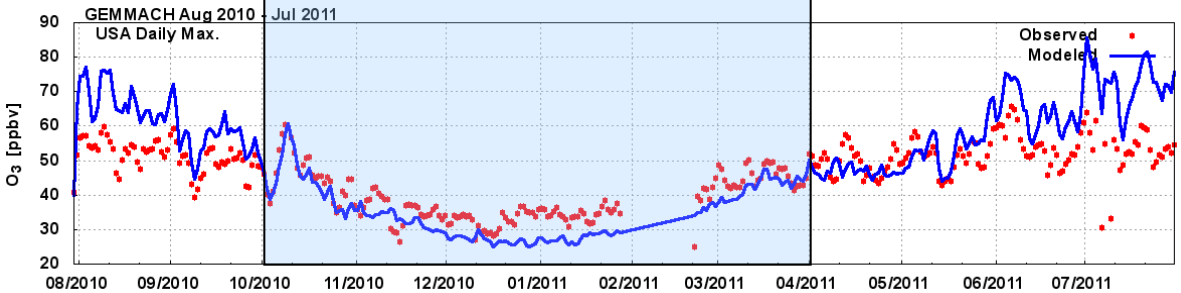
CAN Year 2



U.S. Year 1



U.S. Year 2



Envi
Can

Canada

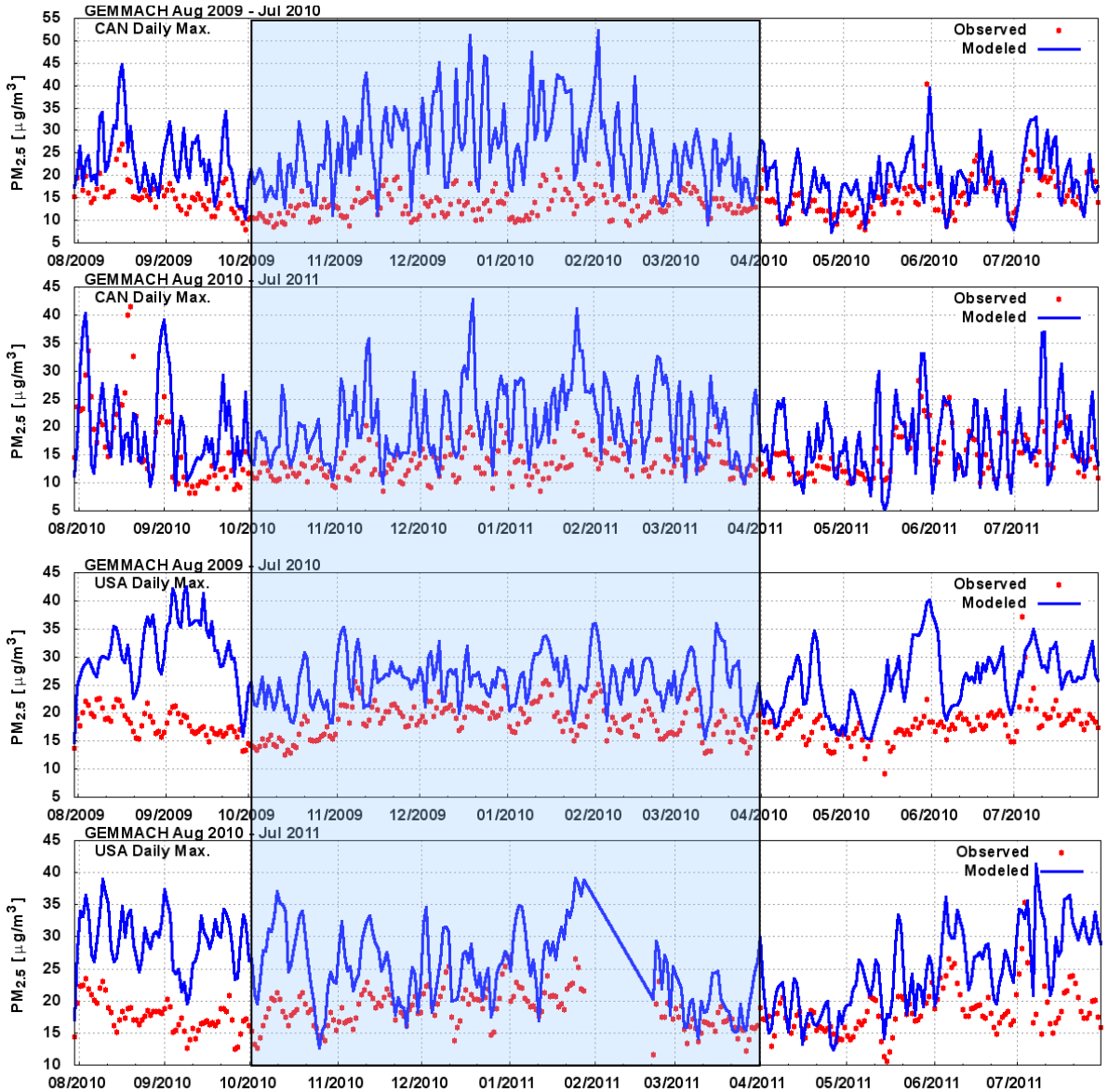
Year 1 & Year 2 Annual Time Series Of National-Average Daily Max'm 1-h $PM_{2.5}$ Concentrations At Canadian & U.S. Stations

CAN Year 1

CAN Year 2

U.S. Year 1

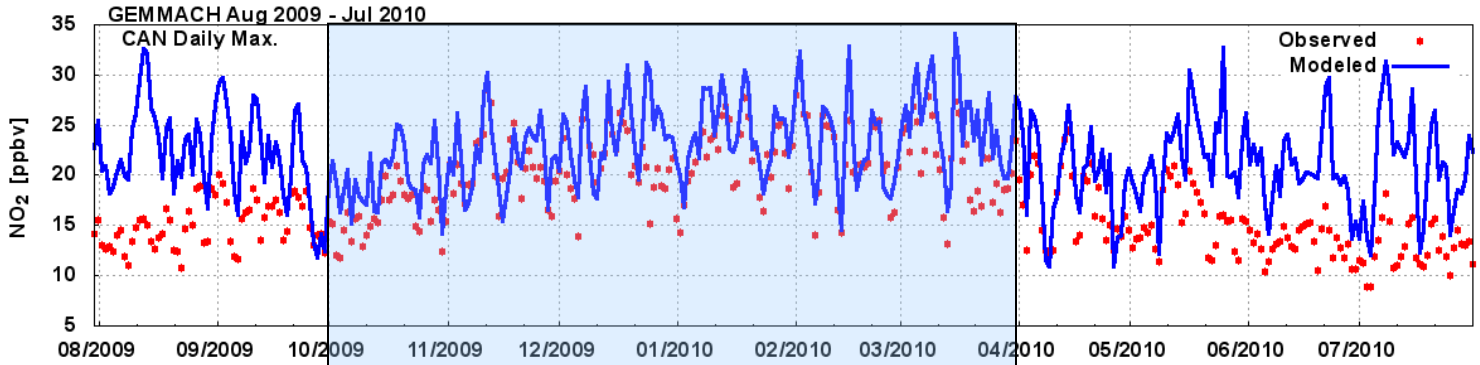
U.S. Year 2



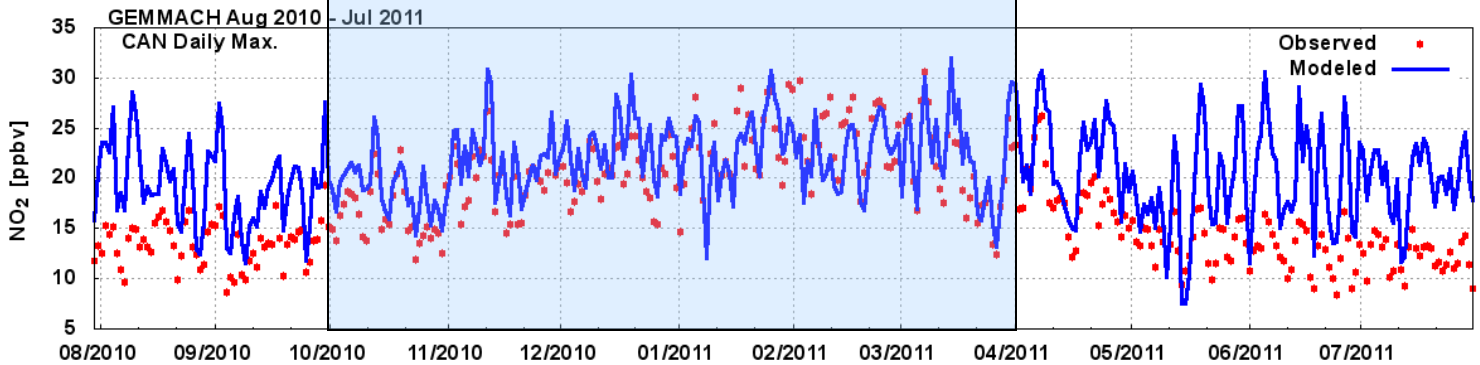
Canada

Year 1 & Year 2 Annual Time Series Of National-Average Daily Maximum 1-h NO_2 Concentrations At Canadian Stations

CAN Year 1

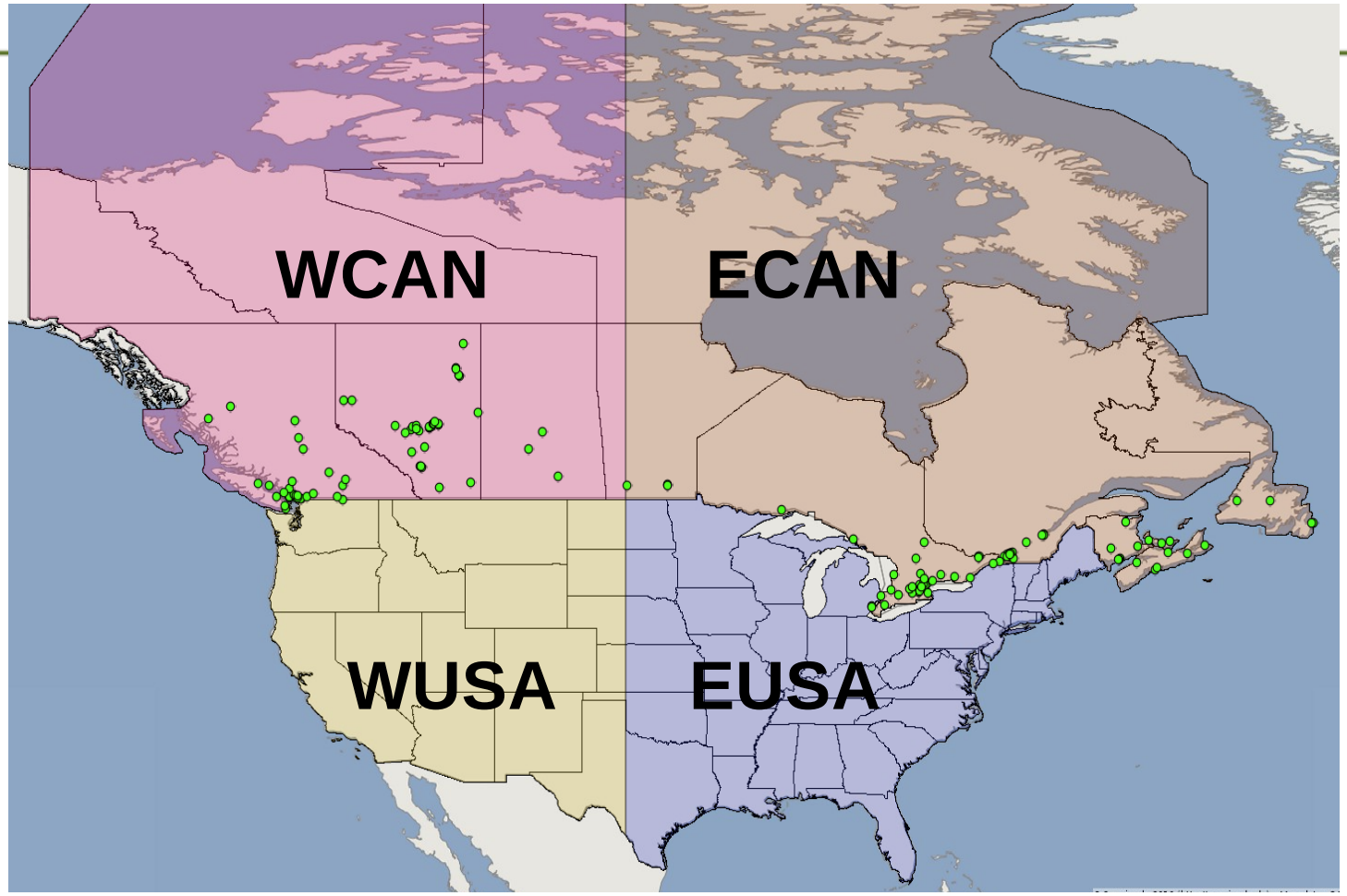


CAN Year 2

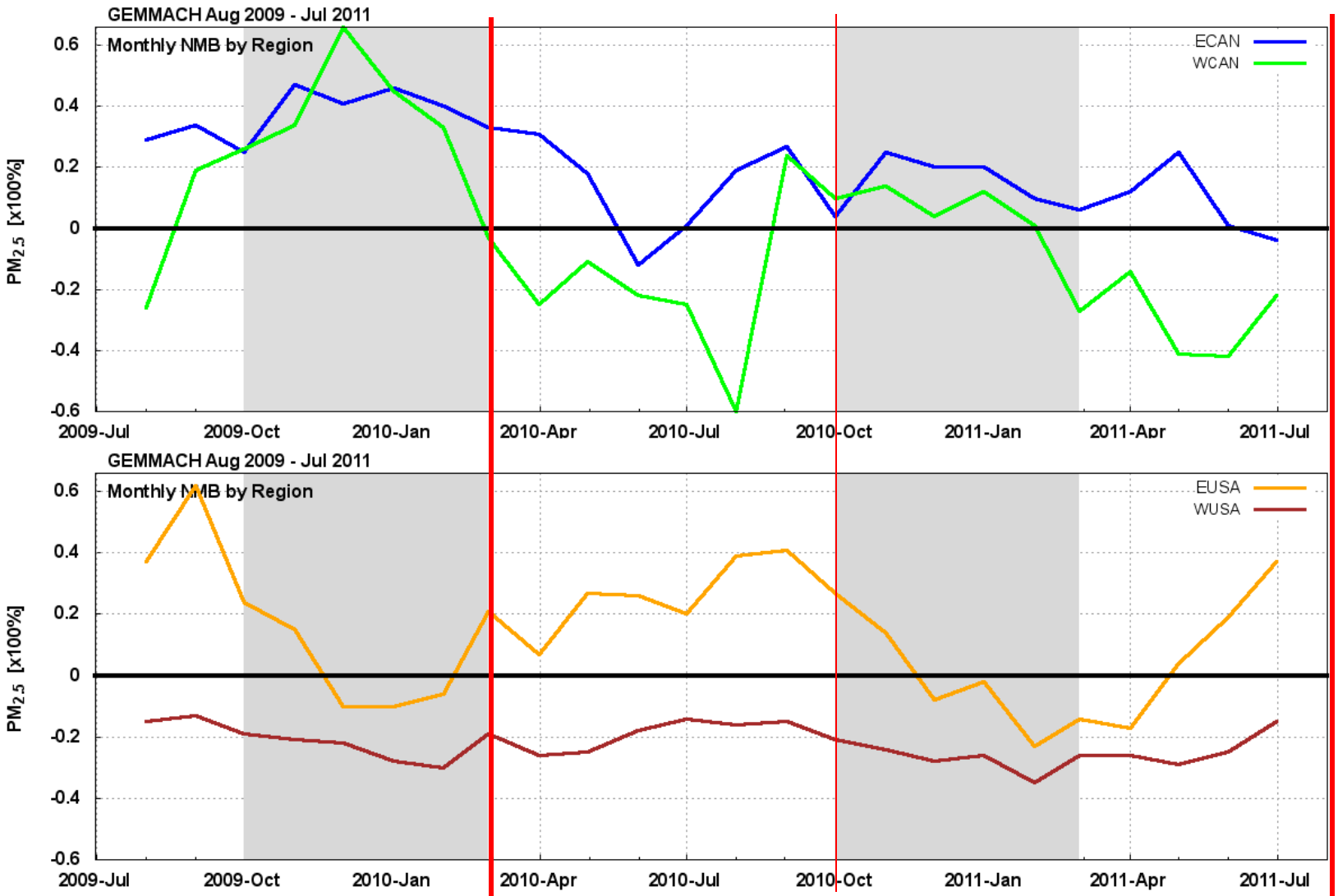


See poster by R. Pavlovic

Regions for Model Evaluation



Monthly Variation Of Regional Mean NMB For Daily Maximum $PM_{2.5}$ For 4 Regions For Full 2 Years



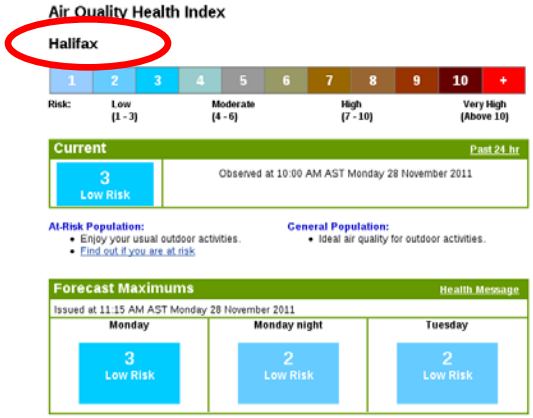
Correction to $PM_{2.5}$ primary emissions spatial allocation

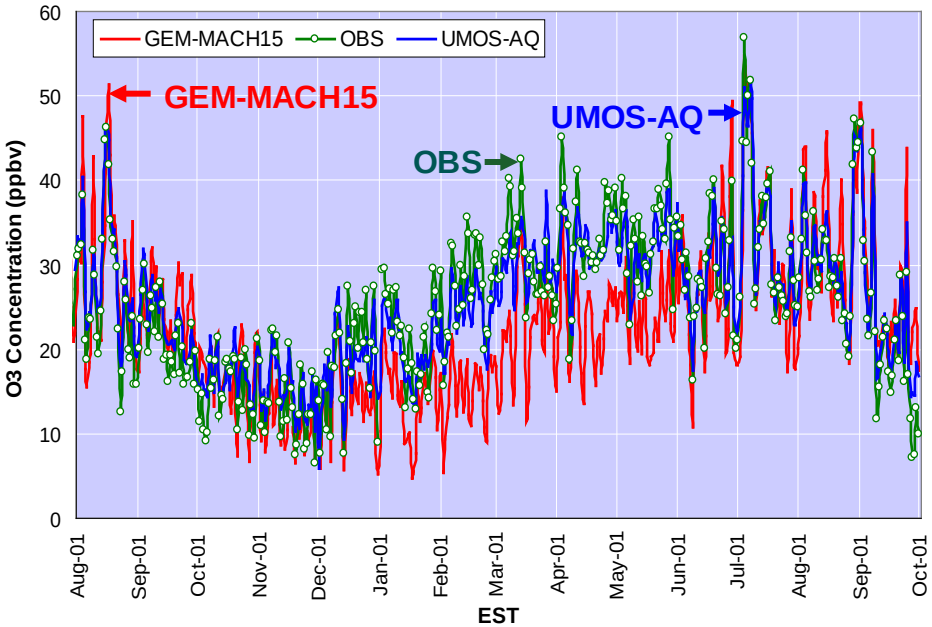
Addition of regional assimilation to met boundary conditions

Update to US inventory (2012 projection)

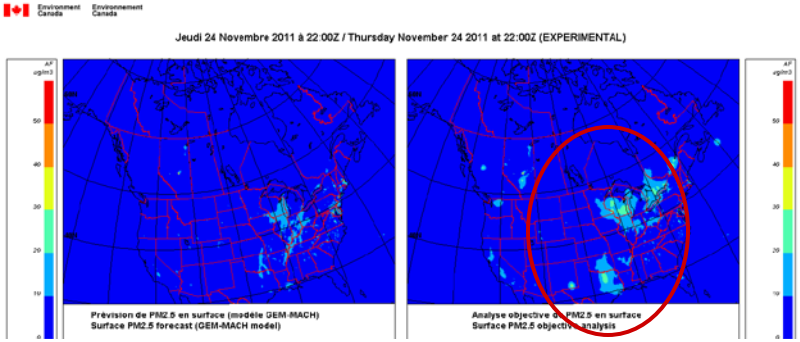
Canadian Air Quality Forecast Suite: Post-Processing Using UMOS-AQ

- AQHI forecasts issued publicly are actually point forecasts at prescribed locations
- Updatable Model Output Statistics (UMOS) post-treatment system developed at CMC/CMDW
  - To downscale GEM-MACH15 forecast to individual locations
  - Also provides means to correct local biases
- Methodology
  - Statistical approach using Multiple Linear Regression (MLR)
  - Predictors:
    - Persistence (observations) plus 84 meteorological and chemical variables from GEM-MACH15
  - Forecast values/Predictands: hourly O_3, NO_2, and $PM_{2.5}$ for AQHI formula
  - Successful at correcting model biases for all 3 species, lower success rate for peak values
  - Investigating non-linear statistical approaches (XM Tool presentation)
  - Evolution towards UMOS-AQ/MIST





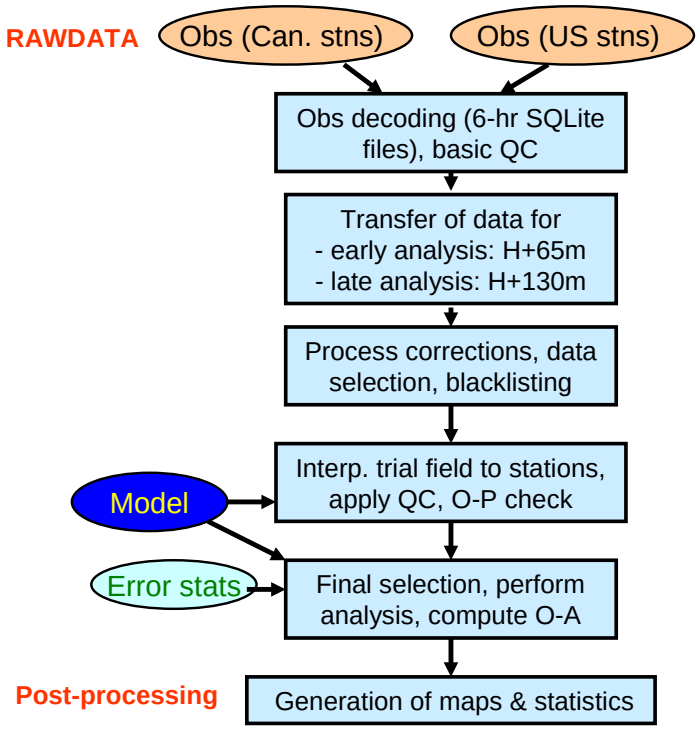
Pending operational transfer: Objective Analysis

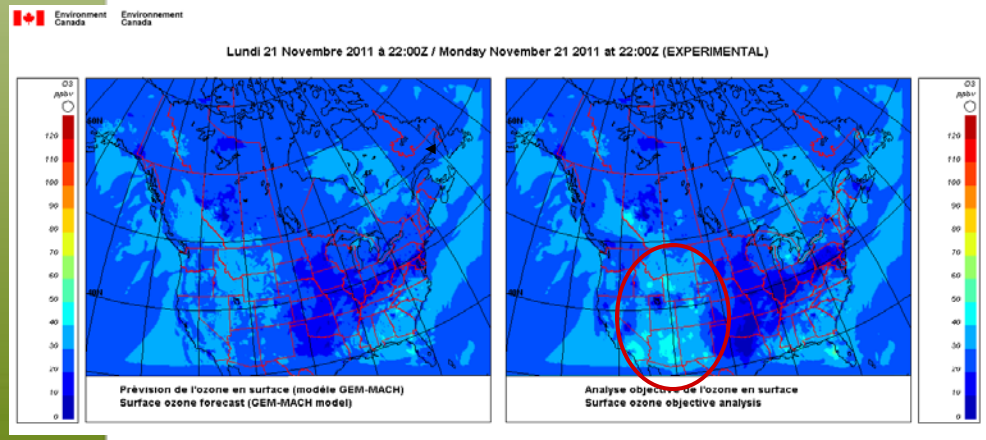


$PM_{2.5}$ objective analysis

- Advancements towards full operational status
  - OA for O_3 **and $PM_{2.5}$**
  - New observation sources (Canada, AIRNow Gateway)
  - New error statistics (GEM-MACH15)
  - Concept of Early and Late analyses (for 80%, 95% of avail. obs, respectively)
  - Code installed in the operational sequencer
  - Target: April 2012

- Future R&D:
  - Investigate impact of initializing model with analyses
  - Develop NO_2 product (augment with satellite obs?)





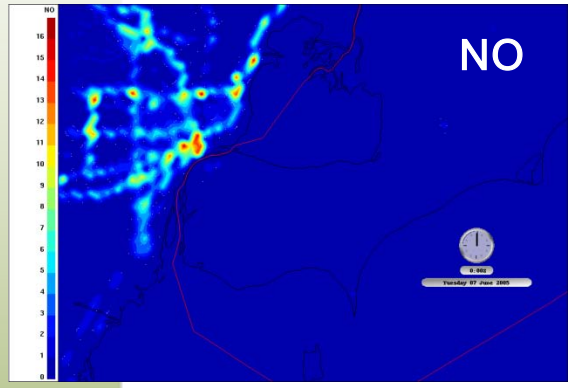
O_3 objective analysis

See poster by Y. Zaitseva

Features being considered for upcoming GEM-MACH op versions

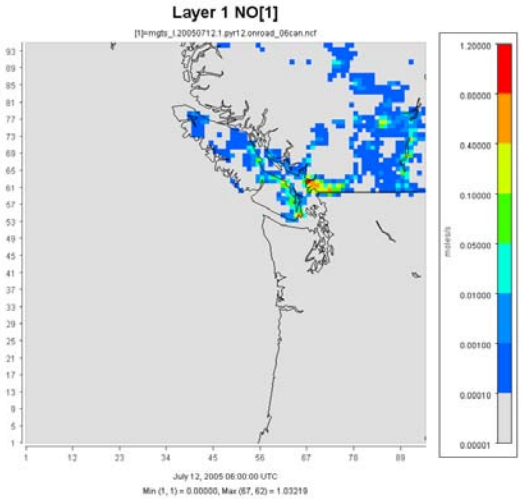
- Reduced grid spacing (15 km → 10 km?)
- Further improvements to emissions files
  - Use of inventory projections (e.g., year 2012 for Canada)
  - Improved spatial surrogate fields (e.g., Cdn mobile)
  - Improved temporal profiles (onroad mobile, agriculture)
- Improved process representations
  - Account for meteorological dependence of fugitive PM emissions
  - Chemistry of organic aerosols
- Improved initialization using objectively-analyzed model-measurement fields
- Migration to new version of GEM (v4)
  - New vertical staggered; piloting at upper troposphere lid

Spatial distribution of mobile emissions

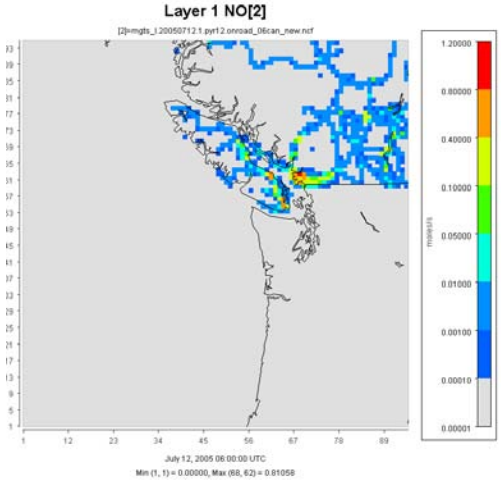


On-road mobile NO emissions for a Tuesday in June in Detroit/Windsor area. Where is the Canadian road network?

- Moving from 1 spatial surrogate (based on road network and population density) to 6 surrogates (with specific identification and weighting of rural and urban road networks)



NO emissions (old surrogate)



NO emissions (new composite surrogate)

Chemistry Development Projects

Gas-Phase Chemistry Modules in Development:

- ADOM-II gas chemistry package with additional species representing intermediate volatility organic compounds (IVOCs), monoterpenes, sesquiterpenes (implemented in Stroud, C. A., Makar, P. A., Moran, M. D., Gong, W., Gong, S., Zhang, J., et al. (2011). Impact of model grid spacing on regional- and urban- scale air quality predictions of organic aerosol. ACP, 11(7), 3107-3118).
- SAPRC-CS07A gas chemistry package (140 reactions)
- SAPRC-07 detailed version (525 reactions)

Secondary Organic Aerosol Modules in Development:

- Traditional SOA yield module
  - Updated SOA yields for monoterpenes: Hao et al., 2011
  - Updated SOA yields for isoprene: Carlton et al., 2010
  - Updated SOA yields for anthro alkanes and alkenes: Ziemann papers
- Developed a module for uptake of gasoline combustion organic gases into aqueous sulfate aerosol (published in Li, S., Liggio, J., Graham, L., Lu, G., Brook, J., Stroud, C., et al. (2011), ACP, 11(19)).
- Developed a module for uptake of water-soluble organic gases to cloud phase (*Gong et al.* presentation in *Theme* 1)
- 2D-basis set module is under development as a framework for representing both lower volatility and water soluble organic species and their partitioning to the organic and aqueous particle phase.

See poster by C. Stroud

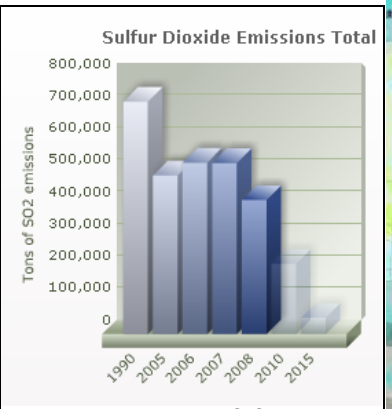
Program development & Research

- Renewed funding for AQHI Program with specific focus on:
  - Expansion of the forecast window beyond 48 h
  - Incorporation of intermittent sources from forest fires (see S. Gravel presentation
  - Expansion outside urban areas
- Intensification of Research and Innovations over the next 5 years associated with surface/remotely sensed (aloft and satellite) data and ingestion/integration in numerical models

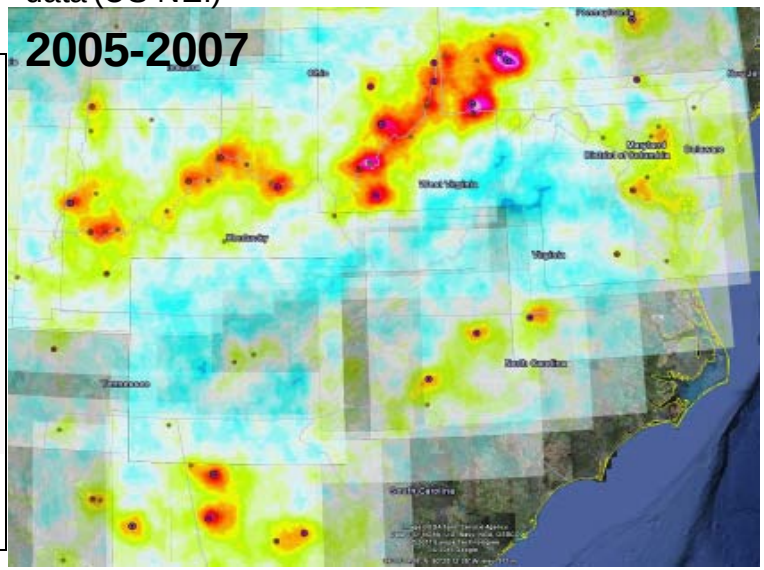
Satellite Monitoring: SO_2 Emissions from Individual Sources (Fioletov et al., 2011, GRL)

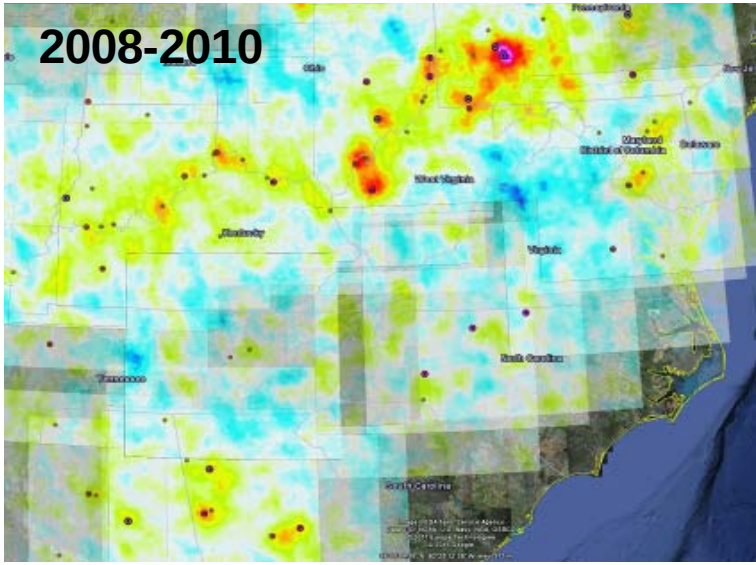
- OMI SO_2 data can be used to produce direct estimates of emissions from large individual sources (> 70kT/y)
- Methodology relies on averaging large number of individual pixels centered within a few km of the source
  1. QC – screen by track position, cloud fraction, SZA
  2. Use of spatial smoothing
  3. Local bias correction – high-pass filter to remove effects of remaining ozone signal

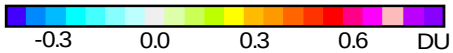
Mean OMI SO_2 values: Estimate change between two periods is 40% from OMI data; 46% from CEM data (US NEI)



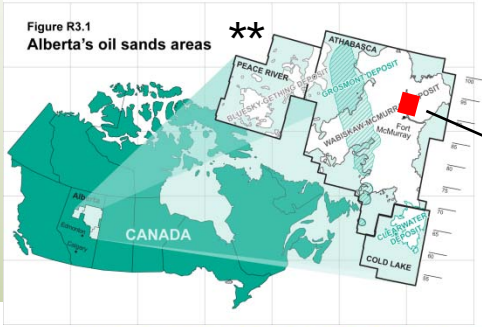
SO_2 scrubbers added in 2008



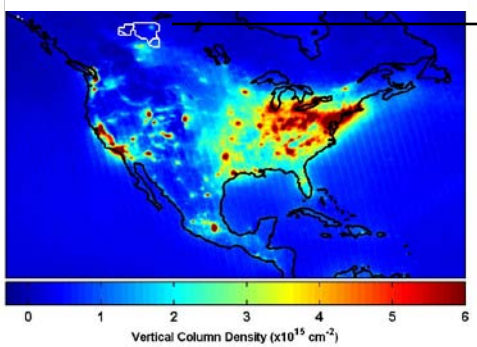




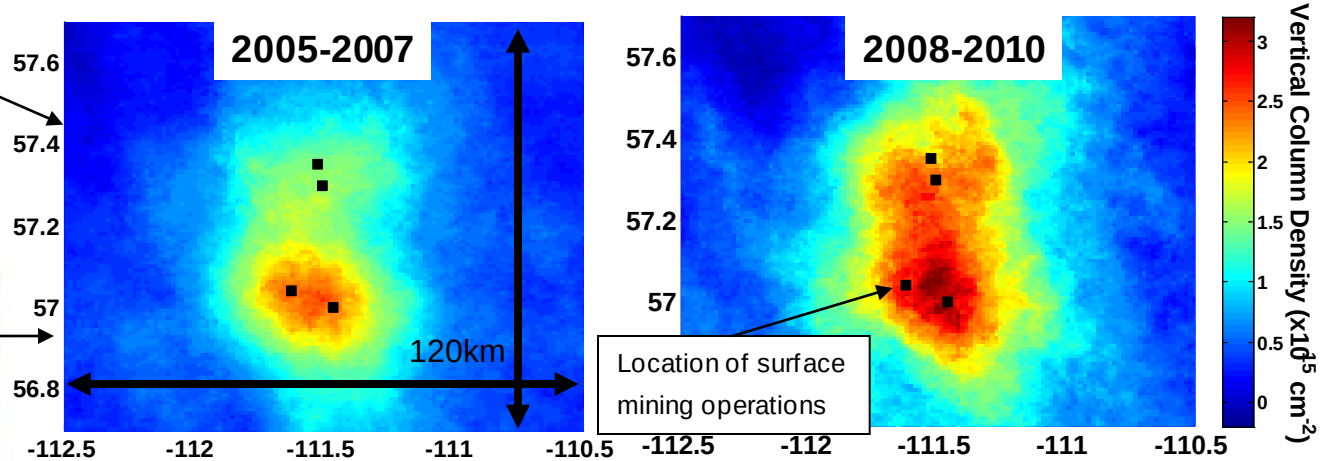
Satellite Monitoring: NO_2 Emissions from Individual Sources – Alberta oil sands



OMI annual mean, 2005-2010



OMI annual mean NO_2 tropospheric vertical column density over oil sands



	2005-2007	2008-2010	Change
Annual mean NO_2 mass (t) [from OMI]	4.55	6.83	+40%
Emission (kt[NO_2]/yr) [from NPRI*]	25.4	25.8	+2%
Bitumen Production (10^6 barrels/day)**	1.35	1.63	+19%

Satellite sees rapid increase in NO_2 over oil sands, in contrast with reported emissions
Possible reasons? Construction or transportation – sectors not reported to NPRI*

* National Pollutant Release Inventory
** Alberta Energy Resources Conservation Board (2011)

Summary

- Short-term developments
  - Continuous improvements of GEM-MACH as operational model
    - Emissions (including forest fires)
    - Chemical processes
    - Dynamic and architecture evolution
  - Continuous improvement of post-processing techniques and forecaster tools
- Mid/Long-term developments
  - R&D associated with new sources of data and their use in numerical models
    - Direct assimilation
    - Boundary condition information (lateral and lid)
    - Emission information and trends
  - Continued use of on-line approach