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Operational Air Quality Forecasting in Canada: Current Status and Future Developments

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Scope and AQHI

- 15-year-old program that has evolved from an O₃-only forecast program in eastern Canada to a Canada-wide O₃, NO₂, PM_{2.5} forecast program
- As of today, forecasts are communicated in most areas as an Air Quality Health Index (AQHI)



Air Quality Health Index						La cote air santé				
1	2	3	4	5	6	7	8	9	10	+
low risk faible risque			moderate risk risque modéré			high risk risque élevé			very high risk risque très élevé	
*At Risk Population – *Population touchée										
Enjoy your usual outdoor activities. Profitez de vos activités habituelles en plein air.		Consider reducing or rescheduling strenuous activities outdoors if you are experiencing symptoms. Envisagez de réduire ou de réorganiser les activités exténuantes en plein air si vous éprouvez des symptômes.		Reduce or reschedule strenuous activities outdoors. Children and the elderly should also take it easy. Réduisez ou réorganisez les activités exténuantes en plein air. Les enfants et les personnes âgées devraient également modérer leurs activités.		Avoid strenuous activities outdoors. Children and the elderly should also avoid outdoor physical exertion. Évitez les activités exténuantes en plein air. Les enfants et les personnes âgées devraient également éviter de se fatiguer en plein air.				
<small>* People with heart or breathing problems are at greater risk. Follow your doctor's usual advice about exercising and managing your condition. * Les personnes éprouvant des problèmes cardiaques ou respiratoires sont les plus menacées. Observez les conseils habituels de votre médecin sur l'exercice et la manière de prendre soin de vous.</small>										
1	2	3	4	5	6	7	8	9	10	+
General Population – Population en général										
Ideal air quality for outdoor activities. Qualité de l'air idéale pour les activités en plein air.		No need to modify your usual outdoor activities unless you experience symptoms such as coughing and throat irritation. Aucun besoin de modifier vos activités habituelles en plein air à moins d'éprouver des symptômes comme la toux et une irritation de la gorge.		Consider reducing or rescheduling strenuous activities outdoors if you experience symptoms such as coughing and throat irritation. Envisagez de réduire ou de réorganiser les activités exténuantes en plein air si vous éprouvez des symptômes comme la toux et une irritation de la gorge.		Reduce or reschedule strenuous activities outdoors, especially if you experience symptoms such as coughing and throat irritation. Réduisez ou réorganisez les activités exténuantes en plein air, particulièrement si vous éprouvez des symptômes comme la toux et une irritation de la gorge.				

Air Quality Health Index <http://weather.gc.ca>

Choose a Provincial Summary

AB BC MB NB NL NT NS ON PE QC SK

This table shows a summary of the most recent forecast values of the Air Quality Health Index for many Canadian cities.

City	Value
Calgary	3 - Low Risk
Charlottetown	2 - Low Risk
Edmonton	3 - Low Risk
Fredericton	2 - Low Risk
Halifax	2 - Low Risk
Inuvik	1 - Low Risk
Labrador City	2 - Low Risk
Montréal	4 - Moderate Risk
Ottawa (Kanata - Orleans)	4 - Moderate Risk
Prince George	2 - Low Risk
Québec	3 - Low Risk
Regina	2 - Low Risk
Saint John	2 - Low Risk
Saskatoon	2 - Low Risk
St. John's	2 - Low Risk
Toronto	6 - Moderate Risk
Vancouver	3 - Low Risk
Winnipeg	2 - Low Risk
Yellowknife	2 - Low Risk

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

Overview of the Canadian AQ Forecast Program – Public Forecasts

Air Quality

Find the latest local air quality forecasts and information.

<http://weather.gc.ca>



AQHI

Air Quality Health Index

- [Canada](#)
- [Alberta](#)
- [British Columbia](#)
- [Manitoba](#)
- [New Brunswick](#)
- [Newfoundland and Labrador](#)
- [Northwest Territories](#)
- [Nova Scotia](#)
- [Ontario](#)
- [Prince Edward Island](#)
- [Quebec](#)
- [Saskatchewan](#)
- [Guide to Forecasts](#)

Text Bulletins

- [Alberta](#)
- [British Columbia](#)
- [Manitoba](#)
- [New Brunswick](#)
- [Newfoundland and Labrador](#)
- [Northwest Territories](#)
- [Nova Scotia](#)
- [Ontario](#)
- [Prince Edward Island](#)
- [Quebec](#)
- [Saskatchewan](#)

Ventilation

- [Alberta](#)
- [Manitoba](#)
- [Northwest Territories](#)
- [Nunavut](#)
- [Saskatchewan](#)

Charts

- [Air Quality Forecast Model](#)

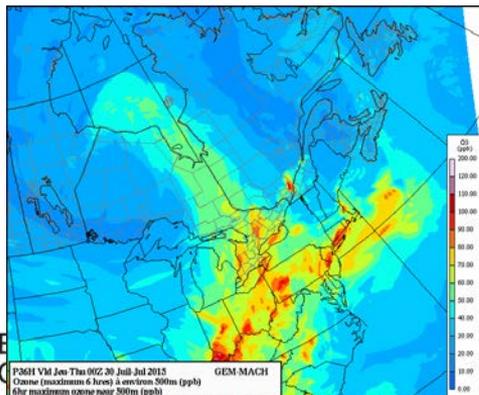
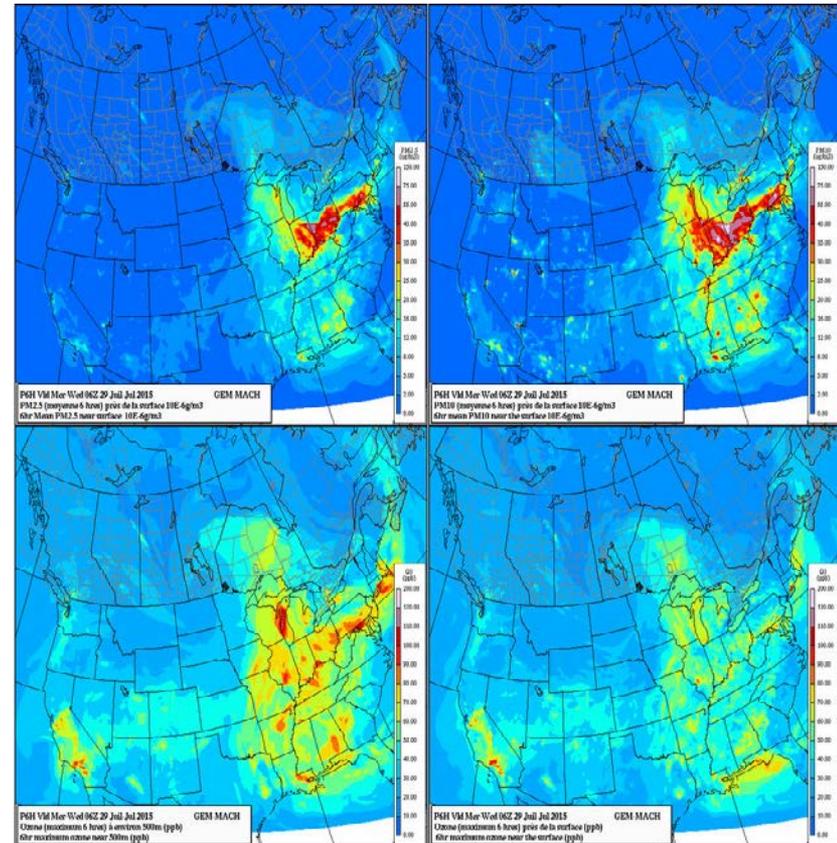
Air Quality Index

- [Quebec INFO-SMOG](#)



Overview of the Canadian AQ Forecast Program – Model Charts

- Maximum **ozone** near the surface, at 50m and 500m over a 6-hour interval
- **PM_{2.5}/PM₁₀** near the surface - 6-hour mean
- **4-panel maps** (PM_{2.5}, PM₁₀, O₃ near the surface, O₃ at 500 metres)
- Products are available over:
 - Eastern Canada; Western Canada and North America

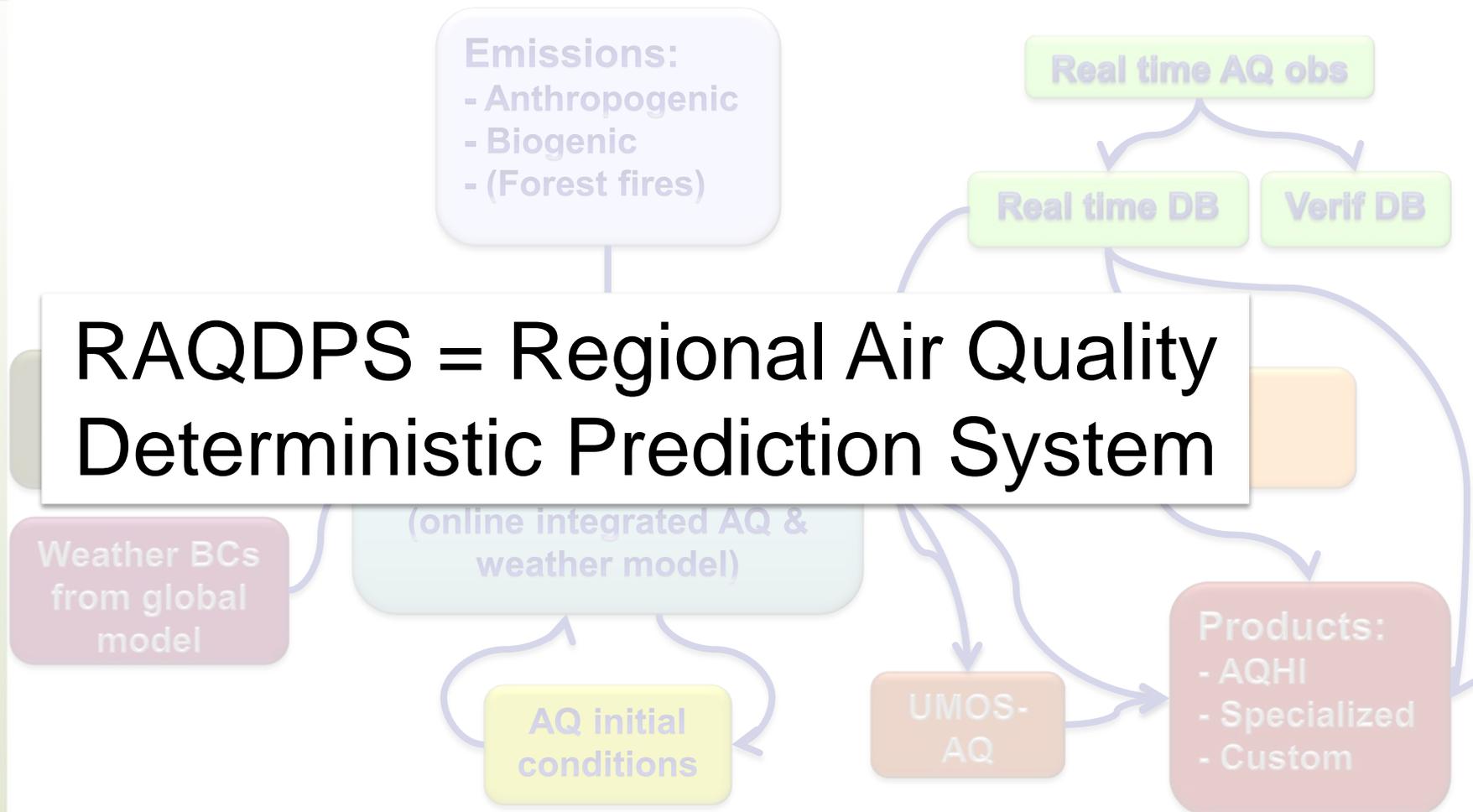


Canadian Air Quality Forecast Systems

- **RAQDPS (Regional Air Quality Deterministic Prediction System)**
 - GEM-MACH
 - Emissions & boundary conditions
 - Statistical model (UMOS-AQ)
 - Products
 - Regional Deterministic Air Quality Analysis (RDAQA)
- **FireWork (RAQDPS with wildfire emissions)**
 - Emissions
 - Statistical model (UMOS-AQ)
 - Specialized Products
 - Regional Deterministic Air Quality Analysis connected to FireWork (RDAQA-FW)
- Experimental AQ system versions (ex: GEM-MACH on 2.5km for PanAm games)
- **VAQUM (Verification of Air Quality Models) System**

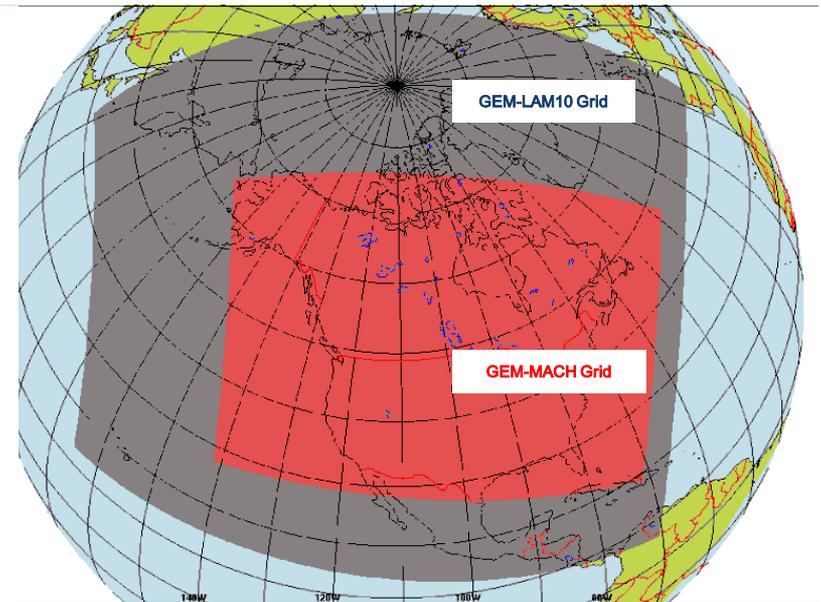


RAQDPS: Components



GEM-MACH, Operational Version (v1.5.4)

- GEM-MACH is EC's operational AQ model. Here are some essential characteristics:
 - limited-area (LAM) configuration with co-located grid points with operational met-only **GEM**, which supplies initial conditions and lateral boundary conditions for **GEM-MACH**
 - 10-km horizontal grid spacing, 80 vertical levels to 0.1 hPa
 - One-way coupling (meteorology affects chemistry)
 - 2-bin sectional representation of PM size distribution (i.e., 0-2.5 and 2.5-10 μm) with 8 chemical PM components



- 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 & Boundary Conditions

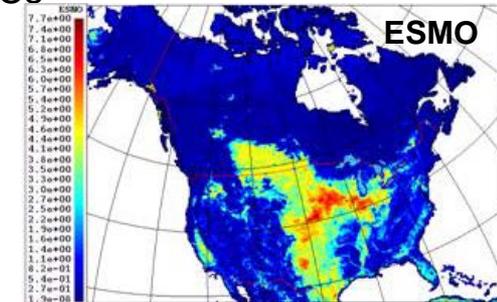
- National emissions inventories processed with SMOKE

- Canada 2010, USA 2011, Mexico 1999
- Processing area sources, point sources, mobile sources
 - Over 10 000 major points, processed individually in the model



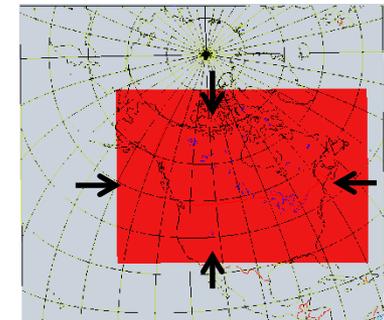
- Biogenic emissions

- Four emission factors: NO, isoprene, monoterpenes & other VOCs
- Using BEIS system with BELD3 vegetation database (231 categories), + Canadian National Forest Inventory
- Adjust emissions rates online according to meteorology
 - Solar radiation, cloud cover, 10m temperature



- Initial and Boundary Conditions

- Using previous 12h forecast as initial AQ conditions
- Using the operational weather analysis as initial weather conditions
- Weather “piloting” from the operational weather runs (which are on a larger domain)
- AQ piloting: using a chemical climatology at the boundaries
 - Varies according to month of the year



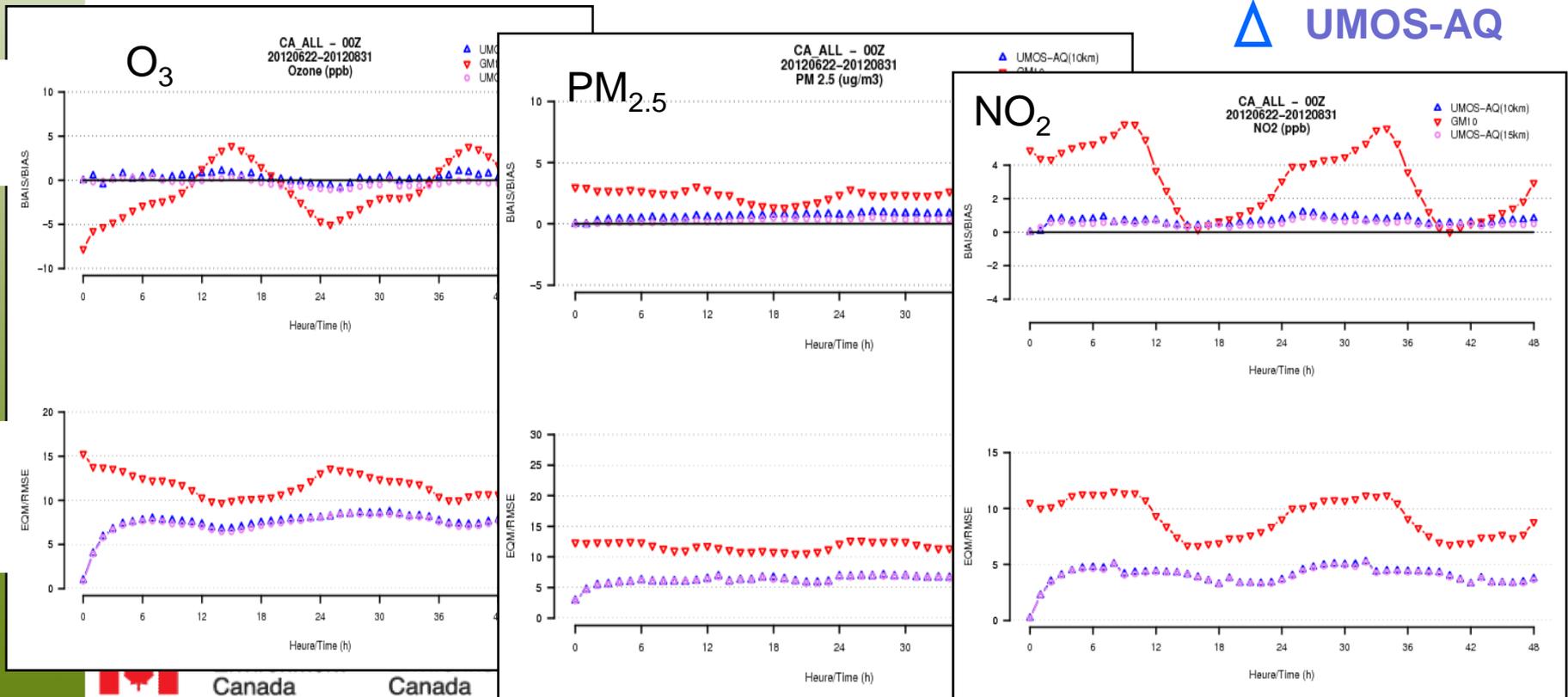
Statistical Model: UMOS-AQ

- Post-processing applied to GEM-MACH raw model output
- **Reduces model bias and model error at point locations with AQ monitors** through multi-variate linear regression approach
 - Applied to meteorological variables since 2000
 - Adapted for air quality variables (O_3 , NO_2 , $PM_{2.5}$) in 2010
 - Equations are recalculated four times a month

▽ GEM-MACH
△ UMOS-AQ

BIAS

RMSE

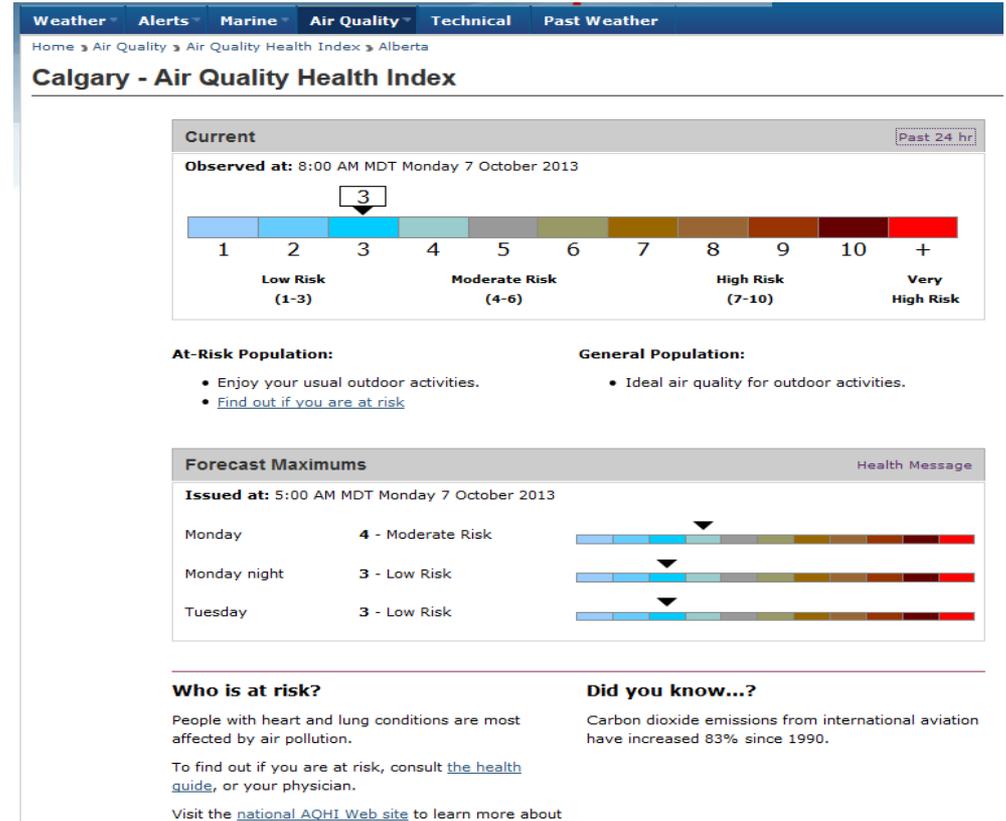


Products: Air Quality Health Index

Used for public forecasts:

- Multi-pollutant index
- Triggers warnings

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



Different messaging for at-risk population vs. general population



Products: Forecaster Tools

- Air quality forecast is prepared for each AQHI community
- Forecasters examine time series of
 - Recent observations
 - Hourly forecasts for the 3 AQHI pollutants (O_3 , $PM_{2.5}$, NO_2), with a 3h running average
 - *From UMOS-AQ*
 - Resulting AQHI
- Additional products are made available to forecasters
 - Internal website with all monitoring sites observations & forecasts
 - Allow investigation of special situations (smoke episode, trans-boundary pollution advection, wildfire smoke dispersion, etc).



OA: Objective Analysis for Surface Pollutants

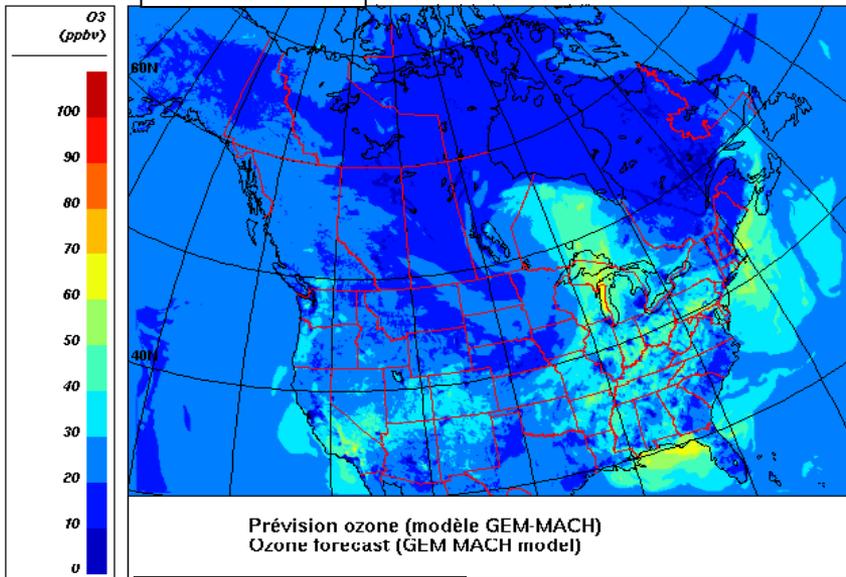
- Operational as of February 2013, called RDAQA
- Blends model forecasts with surface observations from Canadian regional networks and the U.S. EPA's AIRNow observation network
 - Using an optimal interpolation approach
 - Knowledge of the errors of model and observation data is applied to weight each input accordingly
- Products available hourly (2x = early and late analyses):
 - Available for : **PM_{2.5}, O₃, NO₂, NO, SO₂, PM₁₀ and AQHI**
 - Analyses are not yet used to initialize GEM-MACH
 - Tests have been made, applying a correlation factor to spread information at the surface into the vertical dimension
 - Results show an improvement in the short-term forecast



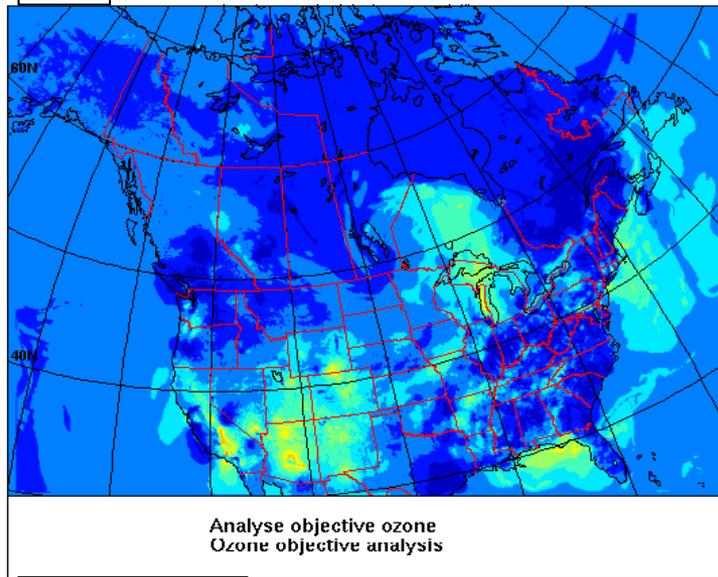
Example of 4-Panel OA Summary for Wed. July 29, 2015, 08 UTC

Mercredi 29 Juillet 2015 à 08:00Z / Wednesday July 29 2015 at 08:00Z
Late Analysis

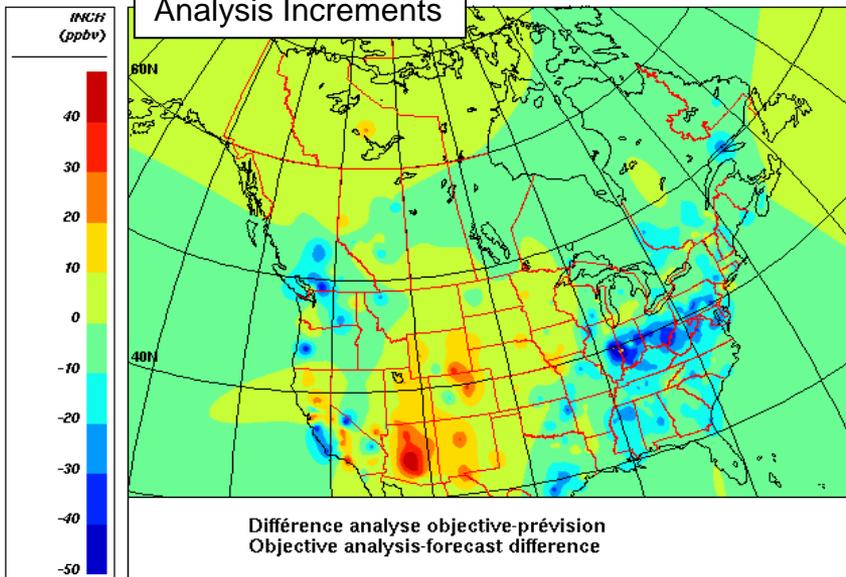
GEM-MACH



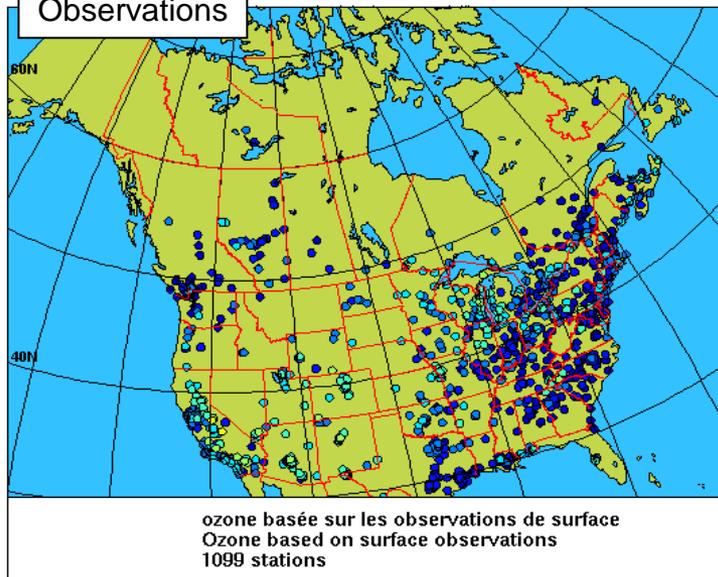
OA



Analysis Increments



Observations



FireWork System

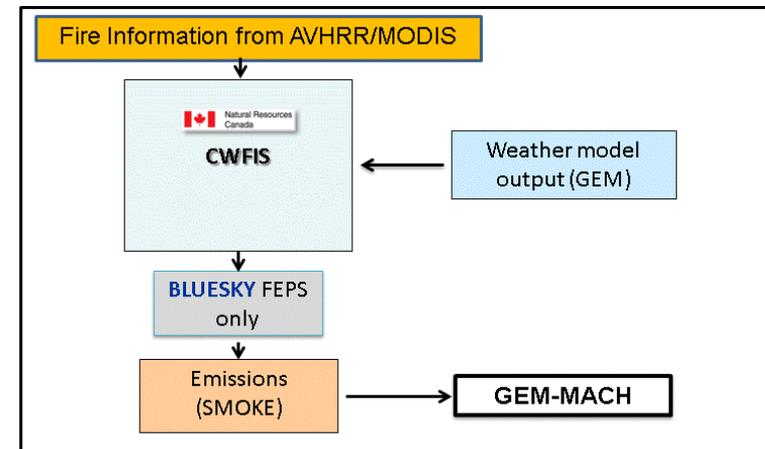


- FireWork has the same configuration as GEM-MACH, the operational AQ model. The only difference is the inclusion of the near-real-time wildfire emissions

- FireWork:
 - Run twice daily (initiated at 00 UTC and 12 UTC)
 - Available at approximately at the same time as the operational model

- Additional products
 - Alternate AQHI based on FireWork
 - PM_{2.5}/PM₁₀ maps and animations based on difference fields (FireWork – GEM-MACH) to isolate plumes
 - Total column PM_{2.5}/PM₁₀ sums
 - Other specialized products available upon request

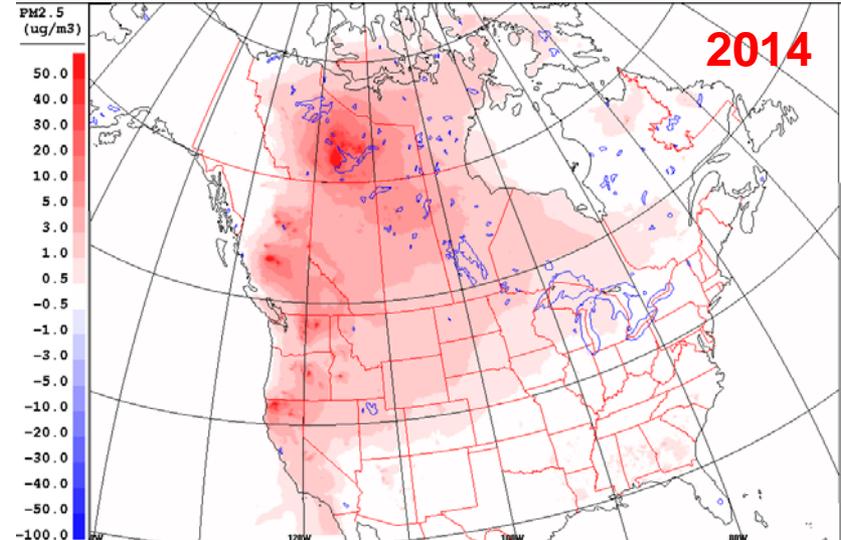
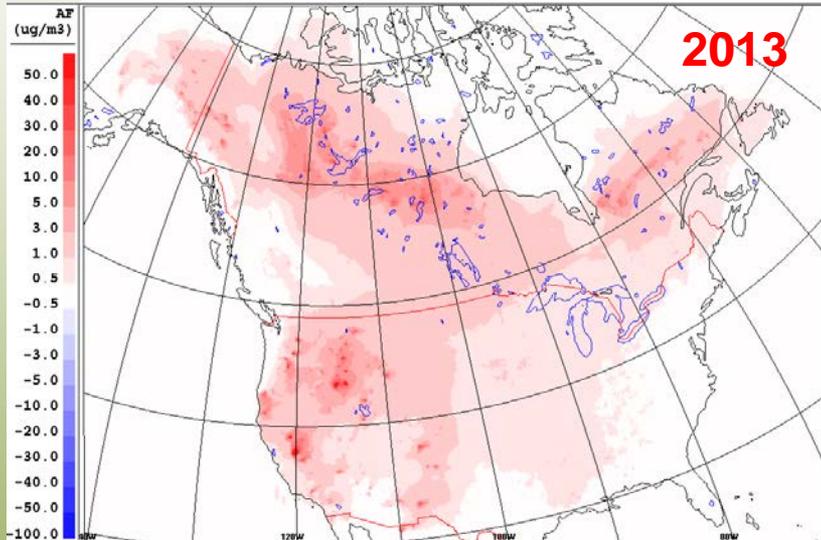
WildFire Emissions Data



Why are Wildfire Emissions Important?

Wildfire emissions contribution to average summertime $PM_{2.5}$ concentrations

Difference: FireWork – GEM-MACH

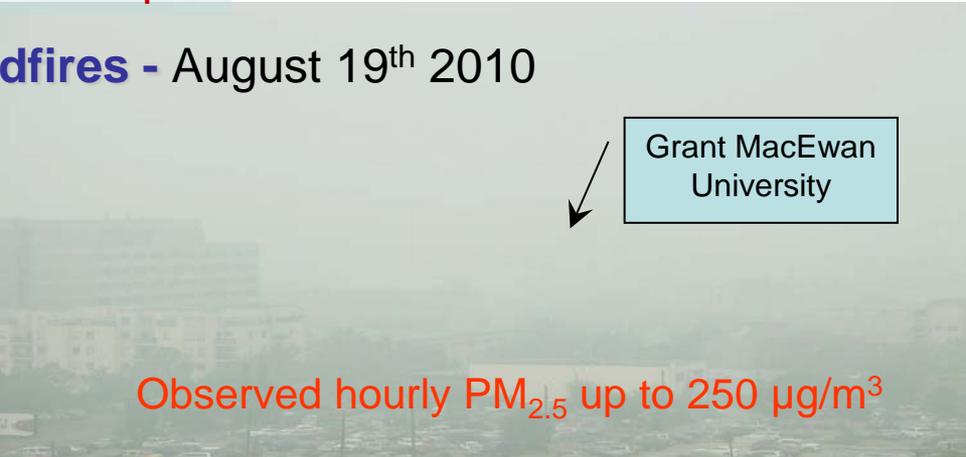


Edmonton Example

Bad air quality due to wildfires - August 19th 2010



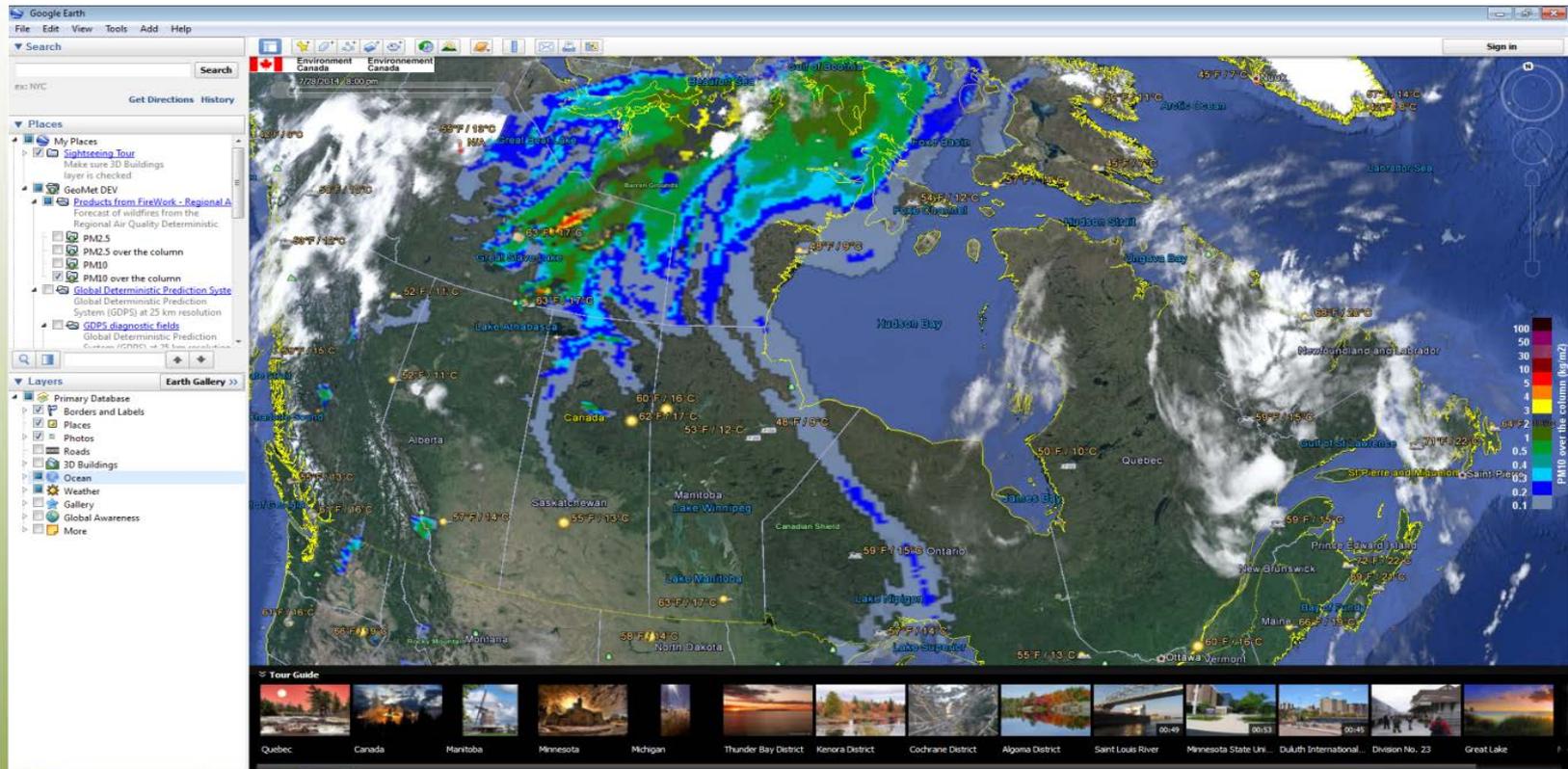
Grant MacEwan
University



Grant MacEwan
University

Observed hourly $PM_{2.5}$ up to $250 \mu g/m^3$

FireWork forecasts available as WMS/KML layers



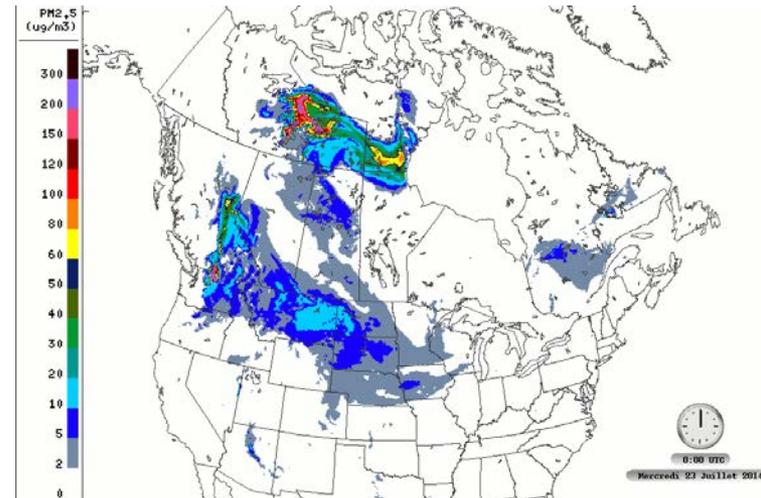
AQHI FireWork external web page: <http://collaboration.cmc.ec.gc.ca/cmc/air/FireWork-GEMMACH>

Date de la passe / Run date : 2015-07-30 00:00:00

- Carte des points chauds / Maps of the hotspots
- Sorties PM_{2.5} de FireWork-GEMMACH en format geotiff pour l'Alberta et la Colombie Britannique
FireWork-GEMMACH PM_{2.5} output in geotiff format for Alberta and British Columbia
- PM_{2.5} à la surface attribués aux émissions de feux de forêt
Surface level PM_{2.5} attributed to forest fire emissions
 - o Animation en un seul fichier
Single file animation
 - o Moyenne sur 24 heures
Average over 24 hours
 - o Somme sur 24 heures
Sum over 24 hours
- PM_{2.5} sur toute la colonne attribués aux émissions de feux de forêt
Total vertical column PM_{2.5} attributed to forest fire emissions
 - o Animation en un seul fichier
Single file animation
- UMOS-AQ/MIST + PM_{2.5} à la surface attribués aux émissions de feux de forêt
UMOS-AQ/MIST + Surface level PM_{2.5} attributed to forest fire emissions
- Analyse objective de PM_{2.5} issue de FireWork-GEMMACH
PM_{2.5} objective analysis from FireWork-GEMMACH
- PM₁₀ à la surface attribués aux émissions de feux de forêt

Summary of FireWork Experience

- Environment Canada developed the capability of including wildfire emissions into air quality forecasts
- FireWork is primarily designed to support meteorologists in issuing AQ forecast and advisories
- EC is willing to share products from FireWork with governmental agencies dealing with wildland fire management
- Based on 2013/2014/2015 FireWork results, we have seen :
 - A significant improvement of $PM_{2.5}$ forecasts
 - That FireWork is capable of forecasting long range pollution transport from wildfires



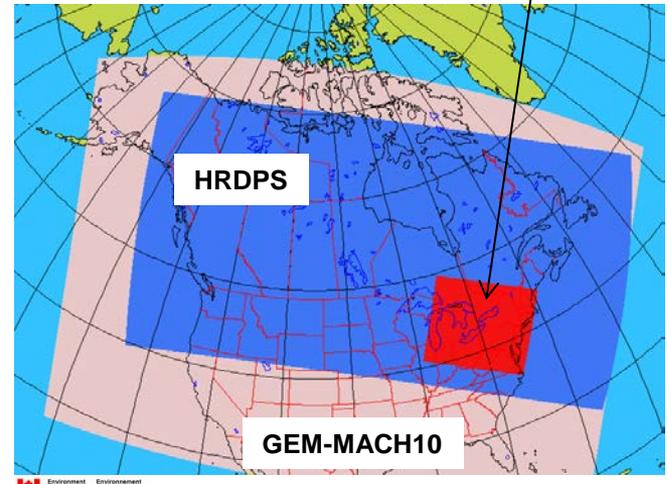
Fine-Scale AQ Systems: GEM-MACH on 2.5-km Grid for 2015 Toronto PanAm Games

GEM-MACH run at 2.5 km run (June to August 2015) by EC Operations for PanAm games:

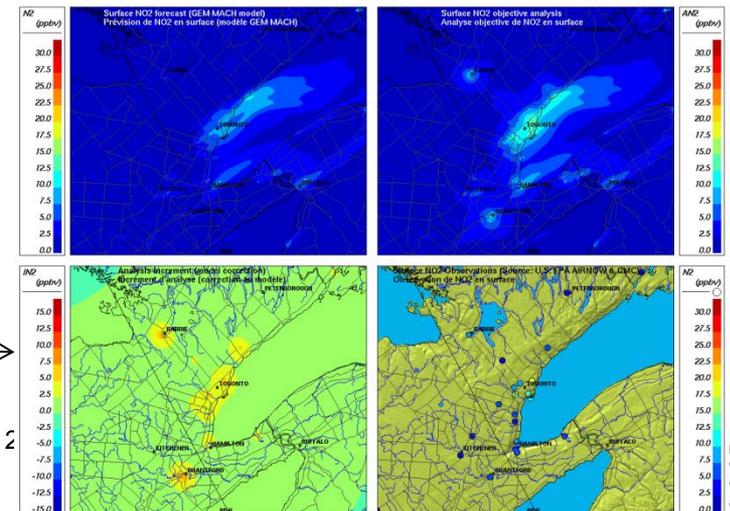
- HRDPS - used as pilot model for meteorology
- GEM-MACH10 - used as pilot model for chemistry

Products:

GEM-MACH2.5



Jeu 30 Juillet 2015 à 13:00Z / Thursday July 30 2015 at 13:00Z (PANAM GAMES PROJECT)



Forecast Report

Active Notices: No active notices available

Surface Field Maps:

- NO2
- O3
- PM10
- PM2.5
- AQHI2.5
- AQHI10

Observation Maps:

- NO2
- O3
- PM10
- PM2.5
- AQHI2.5
- AQHI10

Tools:

- 24-hour observation summaries
- Monitoring of incoming air quality observations (real operational)
- Real-time/online Ozone Procedures for 2015
- Old Toronto PanAm Games Dashboard (English only)

AQHI observation availability for the last 6 months

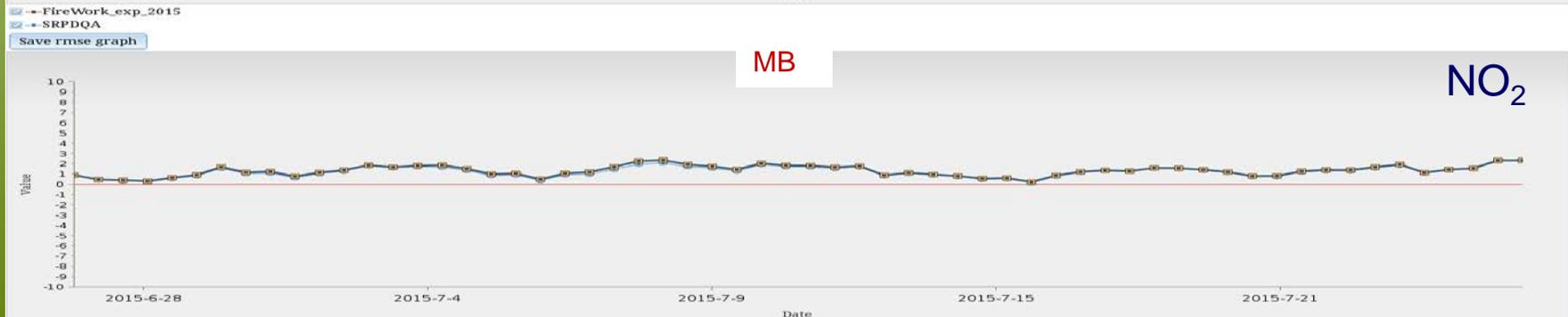
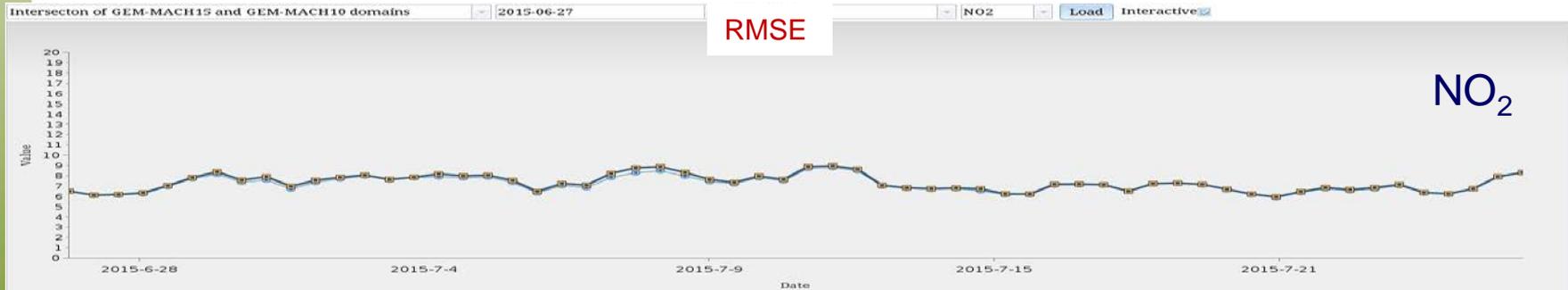
Site / Month	2015-02	2015-03	2015-04	2015-05	2015-06	2015-07
Barrie	98%	82%	98%	98%	98%	100%
Burlington	98%	98%	98%	98%	98%	100%
Burlington	98%	98%	98%	98%	98%	98%
Corbin	98%	98%	98%	98%	98%	98%
Hamilton	98%	98%	98%	98%	98%	100%
Hamilton Downtown - Elgin and Kelly	98%	94%	100%	98%	98%	100%
Hamilton Mountain - Vickers and E. 18th	97%	94%	94%	97%	98%	98%
Kingston	98%	98%	98%	98%	98%	100%
London	98%	94%	98%	98%	98%	98%
Mississauga	98%	82%	98%	98%	98%	94%
Newmarket	98%	98%	98%	98%	98%	100%
Oakville	98%	98%	98%	98%	98%	98%
Oshawa	98%	98%	98%	98%	98%	98%
Ottawa & Gatineau	98%	98%	100%	98%	98%	100%
Peterborough	98%	98%	94%	98%	98%	98%
Sault Ste. Marie	97%	98%	98%	98%	98%	98%
St. Catharines	98%	98%	92%	98%	97%	98%
Toronto	98%	98%	98%	98%	98%	100%
Toronto Downtown - Bay and Wellesley	98%	98%	98%	98%	98%	100%
Toronto East - Kennedy and Lawrence	98%	98%	98%	98%	98%	100%
Toronto Island - Harbord's Point	98%	98%	98%	98%	98%	100%
Toronto South - Yonge and Finch	98%	94%	98%	98%	98%	100%
Toronto West - Islington and 401	97%	98%	98%	98%	98%	100%
Windsor	98%	98%	98%	98%	98%	100%
York University - Keele Campus	97%	98%	98%	98%	98%	100%

Legend:

- Green: Full availability = 95%
- Yellow: 82% <= availability < 95%
- Red: Full Event availability < 82%

VAQUM: v erification for Air Q Uality M odels

- Designed a PostGIS database to store AQ observations and corresponding model outputs
 - Can ingest both real time and QC'ed historical datasets
 - Allows to produce various statistics & categorical scores
 - About **1730 stations** (265 CAN, 1465 USA)
 - Collecting data since 2007
- Essential tool to assess the impact of model updates
- Also used to monitor the performance of the operational system

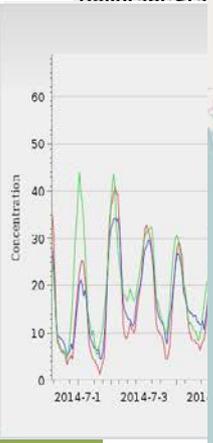


VAQUM Products

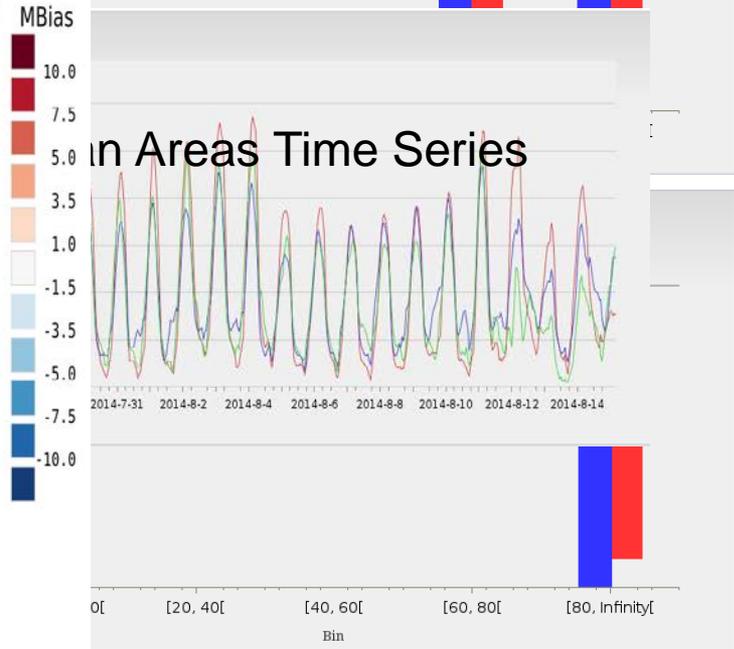
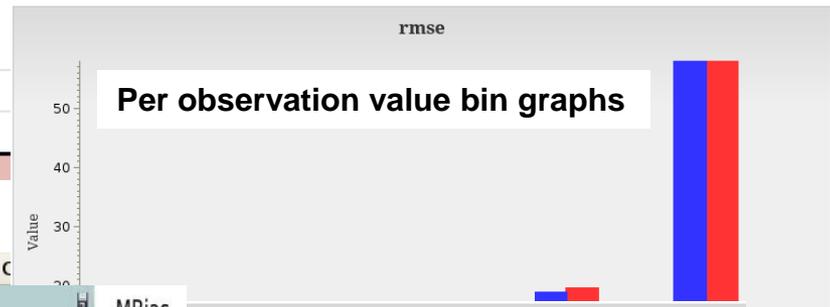
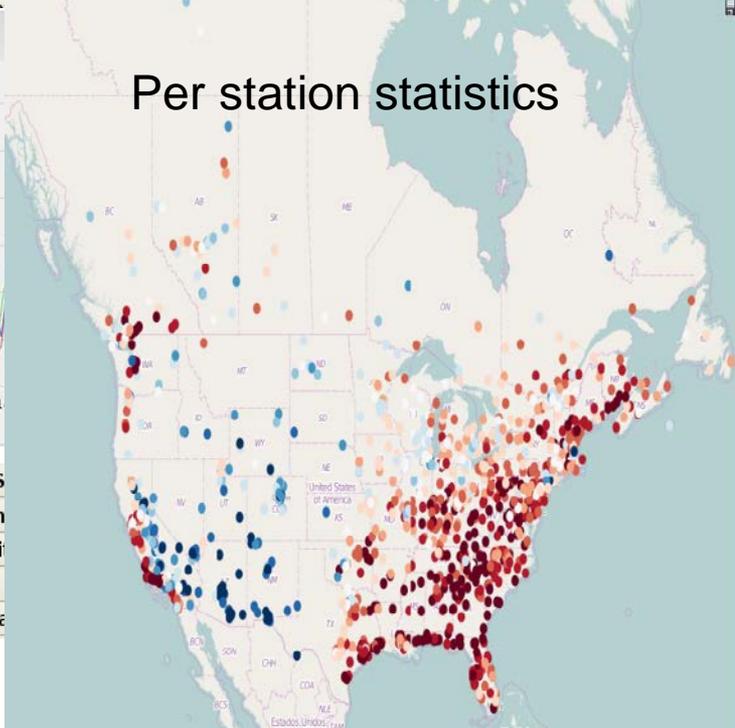
BOOTSTRAPPING		Domaine Complet		Canada		Ouest du Canada		Est du Canada	
Polluant	Statistique	Base	Test	Base	Test	Base	Test	Base	Test
NO ₂	MR	1.13	1.07	0.82	0.44	0.77	0.33	0.87	0.54

NO₂ Daily Maximums Statistics

Region	CAN	ECAN	EUSA	C
Polluant				



Per station statistics



Short-term Planned Updates of the Canadian AQ Forecast Program

- RAQDPS

- 1) Piloting by [global model](#)
- 2) [72h forecasts](#)
- 3) New, [improved GEM](#) version, with mass conservation of tracers
- 4) Updated emissions inventories for Canada, U.S. and Mexico
- 5) Expansion of AQHI program
- 6) Introduction of AQHI+ values in some provinces

- FireWork

- a. Same as 1-4 for RAQDPS
- b. [Status change](#) from experimental to operational or parallel
- c. [Improved plume-rise algorithm](#) applied to wildfire smoke dispersion
- d. Improved wildfire emissions estimates



Possible Future Directions

- Updated or new AQ process representations
- Improved chemical lateral boundary conditions from global GEM-MACH
- Chemical data assimilation to initialize GEM-MACH?
- Benefits of higher-resolution deterministic AQ systems?
 - Tested for 2.5 km for PanAm Games
- Ensemble AQ systems?
- Activating AQ feedbacks to meteorology? (longest term)

So in the next few days....

We are looking forward to exchanges on all these issues and others



Thank you!

Authors:

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