Environment Canada Environnement Canada

Canada

ASP Colloquium:

AIR QUALITY FORECASTING - CANADA

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Chair, GURME – GAW URban Meteorology and Environment Project

With contribution from R. Pavlovic , M. Moran, C. Stroud, D. Henderson, S. Belair, S. Leroyer, I. Stajner, G. Carmichael and GURME SAG

Overview

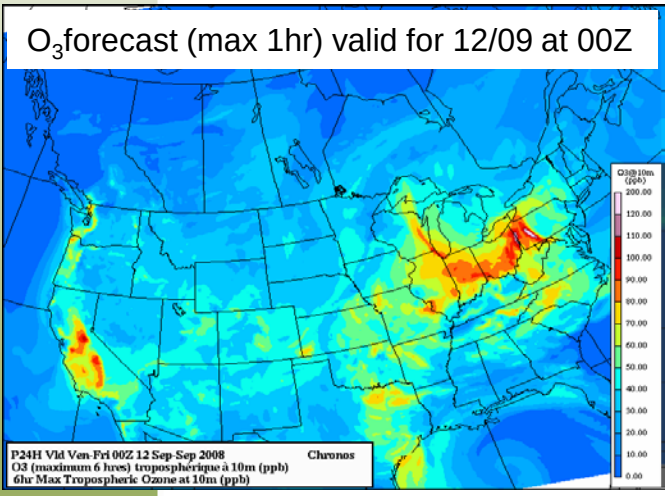
- Historical perspective ~ 2000 – 2014
  - Early years, Ramp-up and Growth to today's system
- The Canadian Air Quality Forecasting System
  - Operational system & model
- Air Quality Forecasting in general
  - Important ingredients
- Research outlook towards the next generation of models and services
  - A Canadian perspective

Early years: 1995 – 2000 (North America)

- Revisiting of association between urban air pollution and mortality
  - **Harvard six cities study**: *An association between Air Pollution and Mortality in Six U.S. Cities*, Dockery, Pope et al., 1993, The New England Journal of Medicine.
  - **Canadian study**: *The Effect of the Urban Ambient Air Pollution Mix on Daily Mortality Rates in 11 Canadian Cities*, Burnett, Cakmak and Brook,1998, Canadian Journal of Public Health.
- Looking at feasibility of AQ forecasting as mitigation
- Merging of air quality modelling and NWP capacity
  - High-Performance Computing in Meteorological Centres (NMHS)

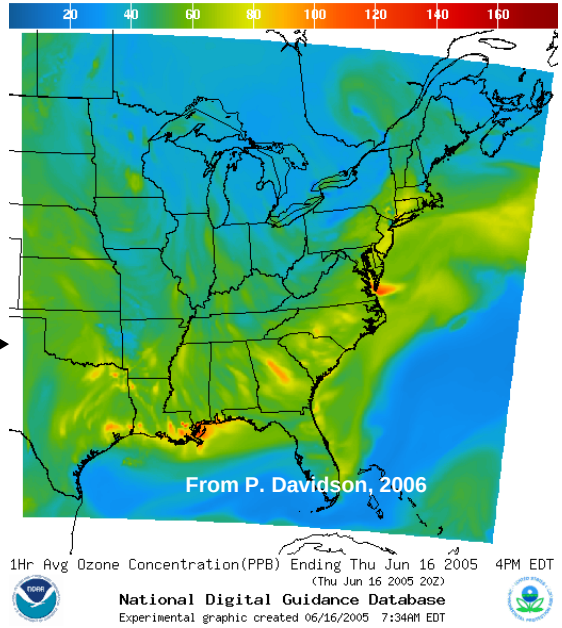
First generation forecast models (NA)

- Chemical transport models driven off-line by regional weather prediction models



Canadian CHRONOS (21km)

U.S. CMAQ (12km)



- 48hr forecasts, twice a day (00 and 12 UTC)
- Gaseous species (O_3) in all, some with bulk $PM_{2.5}$
- Coarser horizontal and vertical resolutions than NWP, but regional-scale

Rapid ramp-up focused on coverage, resolution and species (NA)

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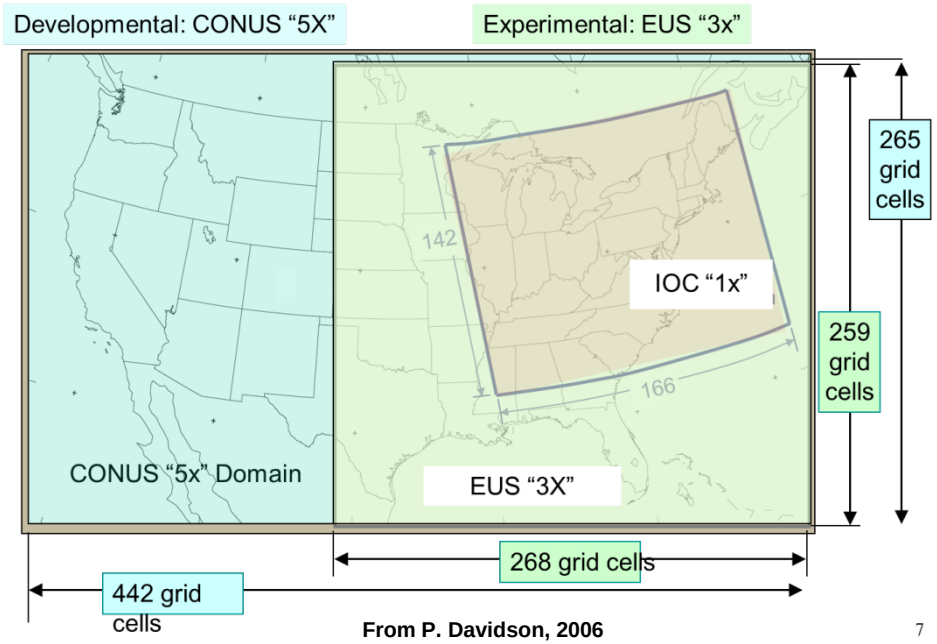
- **Summer 1999:** First pilot for eastern Canada – CHRONOS (O_3 only, 21km res)
- **Summer 2001:** Prediction Program extended to all subarctic Canada (O_3)
- **Summer 2002:** Introduction of bulk aerosol scheme in experimental version
- **Summer 2003:** bulk aerosol scheme in operational CHRONOS version (public)
- **Summer 2004 to 2007:** Year-long forecasts of O_3 and PM (op)

One of the main constraints at the time: what could be afforded on the computing infrastructure in the forecast window (~1h)

NOAA operational AQ forecasts from 2004 to 2007:

- From North-Eastern domain to CONUS (O_3)
- From 24h to 48h forecasts
- From O_3 to O_3 & smoke



From P. Davidson, 2006

July 22, 2016

Some key initiatives in AQF development

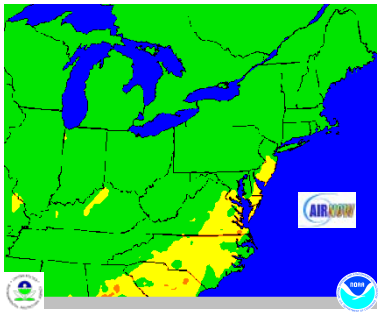
AQHI observation availability for the last 6 months

Site / Month	2014-11	2014-12	2015-01	2015-02	2015-03	2015-04
Barrie	99%	99%	99%	99%	93%	98%
Brampton	99%	98%	99%	99%	95%	98%
Burlington	98%	99%	99%	98%	95%	98%
Dorset	99%	97%	98%	99%	95%	98%
Hamilton	99%	99%	99%	99%	95%	98%
Hamilton Downtown	0%	65%	99%	99%	94%	98%
Hamilton Mountain	0%	64%	99%	97%	94%	98%
Hanlan's Point	0%	65%	98%	99%	95%	98%
Kingston	99%	99%	98%	99%	95%	98%
London	99%	99%	99%	99%	94%	98%
Mississauga	99%	98%	99%	98%	92%	98%
Newmarket	98%	98%	99%	99%	94%	98%
Oakville	99%	93%	99%	95%	89%	98%
Oshawa	97%	99%	95%	99%	95%	98%
Ottawa & Gatineau	99%	100%	99%	99%	99%	100%
Peterborough	99%	99%	95%	99%	95%	98%
Sault Ste. Marie	99%	99%	99%	97%	95%	98%
St. Catharines	99%	99%	99%	98%	95%	70%
Toronto	99%	99%	99%	99%	95%	98%
Toronto Downtown	0%	65%	99%	99%	95%	98%
Toronto East	0%	65%	99%	98%	95%	98%
Toronto North	0%	65%	99%	98%	94%	98%
Toronto West	0%	65%	99%	99%	92%	98%
Windsor	99%	99%	99%	99%	95%	98%
York University	0%	65%	99%	97%	95%	98%

The target for minimum availability of the AQHI at any site is at least 85%

Good availability >= 95% | Poor 85% <= availability < 95% | Insufficient availability < 85%

6-month running statistics (Canada EC's observation monitoring system)



- Real-time AQ data transmission
  - Air*NOW*
  - Canadian networks

Institute, model, horiz. resolution	$PM_{2.5}$, log-transformed, statistics				O_3 standard statistics			
	r coeff.	Mod/Obs ratio	RMSE (factor)	Skill (%)	r	bias (ppbv)	RMSE (ppbv)	Skill (%)
NOAA FSL, WRF/CHEM-1, 27km	0.42	1.17	2.19	33	0.67	14.3	20.9	24
NOAA FSL, WRF/CHEM-2, 27km	0.64	0.81	1.97	64	0.73	3.4	11.6	61
NOAA FSL, WRF/CHEM-2, 12km	0.54	0.64	2.38	40	0.67	11.9	16.6	31
MSC Canada, CHRONOS, 21km	0.65	0.77	2.14	50	0.68	17.0	23.2	16
MSC Canada, AURAMS, 42km	0.46	0.85	2.16	59	0.54	5.9	16.2	27
U of Iowa, STEM, 12km	0.63	1.12	1.97	70	0.60	26.4	31.0	2
CMAQ/ETA, 12km	0.65	0.76	2.03	60	0.63	13.4	17.9	24
6-model arithmetic ensemble	**0.73**	**0.89**	**1.78**	**76**	**0.76**	**10.2**	**15.0**	**47**
6-model geometric ensemble	**0.74**	**0.79**	**1.83**	**73**				
Persistence (previous day forecast)	0.38	1.0	2.13	50	0.48	0.0	13.7	50

[McKeen et al., JGR, 112, 2007; McKeen et al., JGR, 110, 2005]

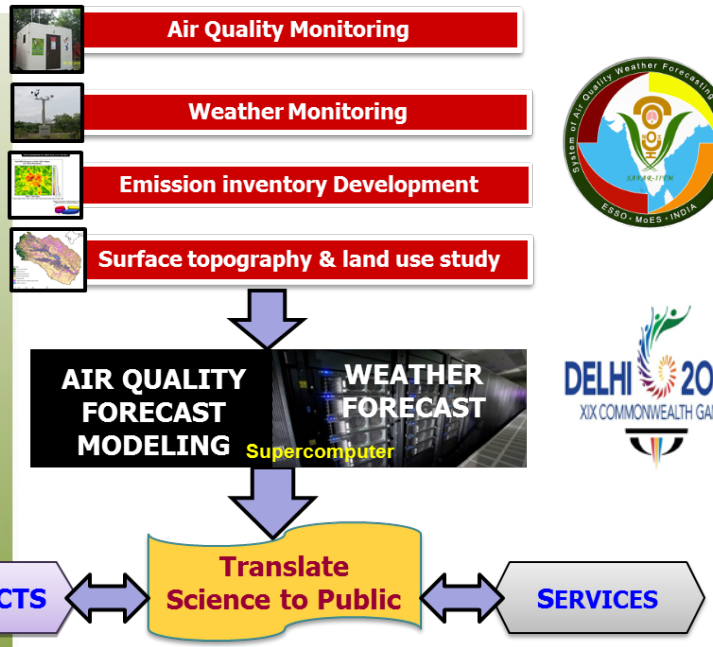
- Campaigns and Intercomparisons
  - ICARTT 2002/2004
  - TexAQ 2006
  - Beginning of multi-model ensembles in North America

Env
Car

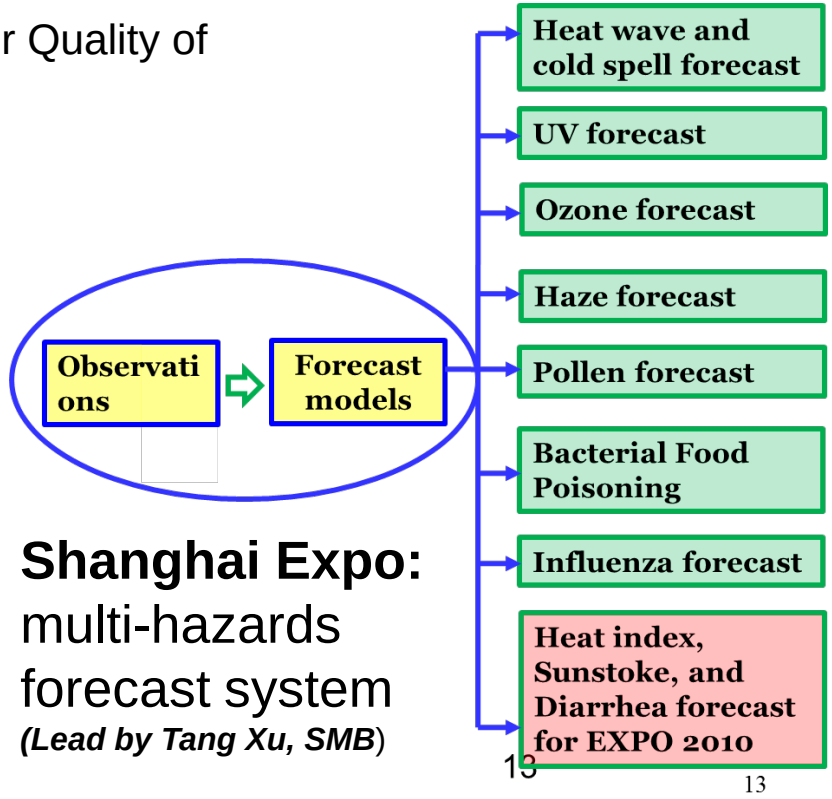
– July

GURME pilot projects

1st AQ Forecasting System in India: Forecasting Air Quality of tomorrow **SAFAR (G. Beig, IITM)**



DELHI 2010 XIX COMMONWEALTH GAMES



Shanghai Expo: multi-hazards forecast system
(Lead by Tang Xu, SMB)

13

Sao Paulo, Brazil

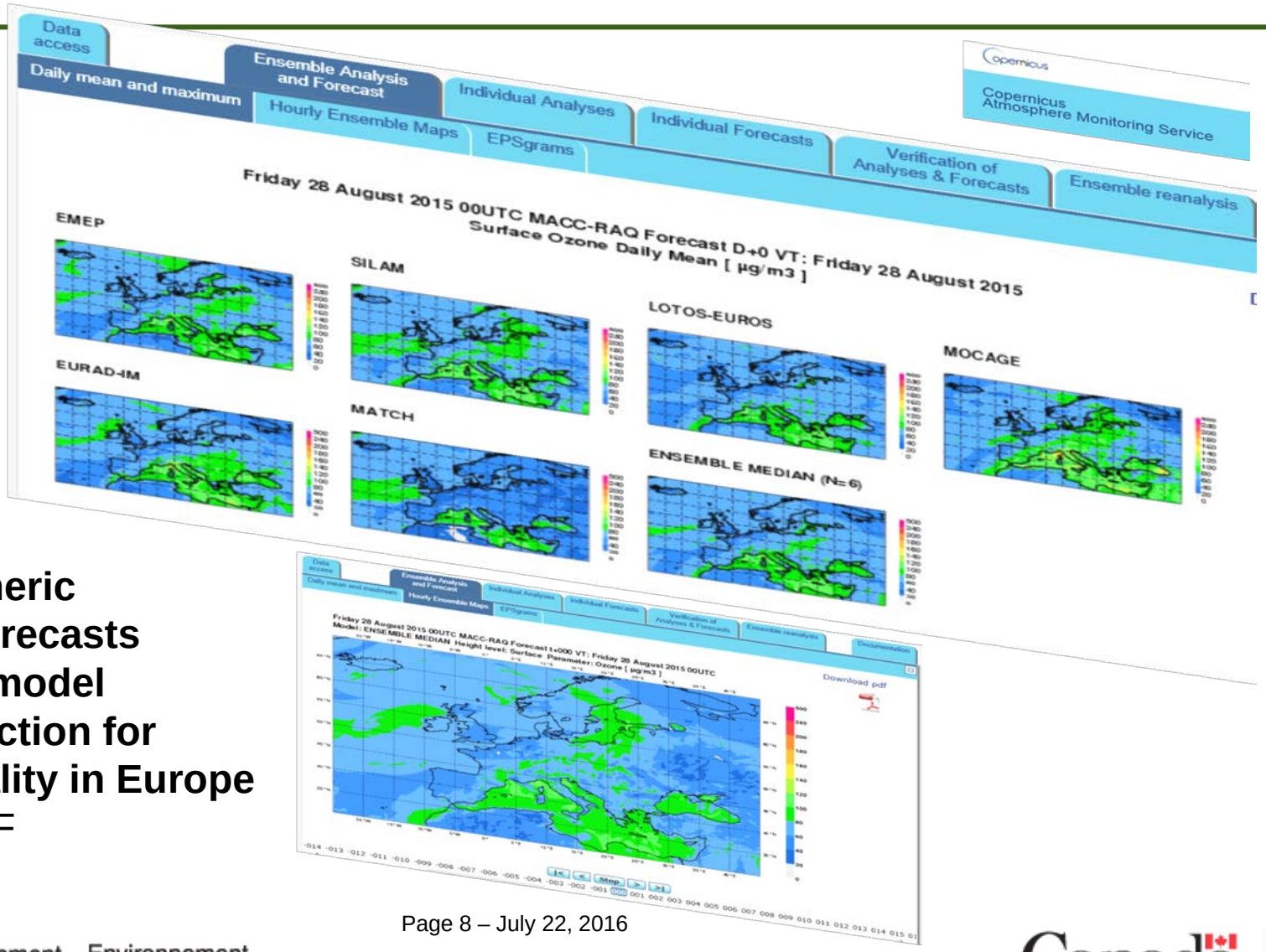
Mexico City, Mexico

Santiago, Chile

Latin American cities

Signature of MOU between Chilean Meteorological Office and UNAB to transfer AQ forecasting model to the Met Office.

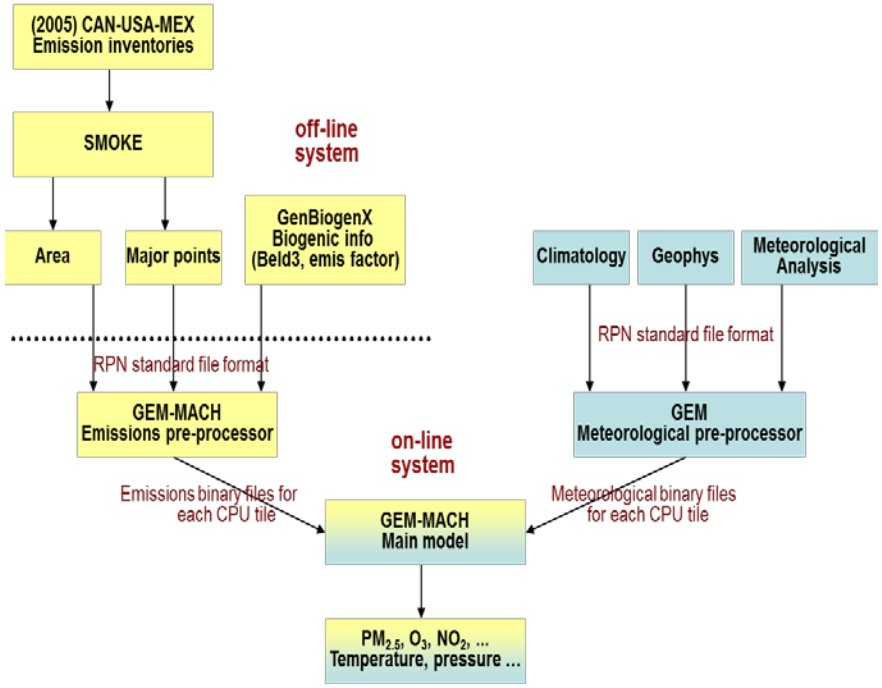
European effort: GEMS/MACC/Copernicus



Global atmospheric composition Forecasts driving a Multi-model ensemble prediction for regional air quality in Europe
GEMS – ECMWF

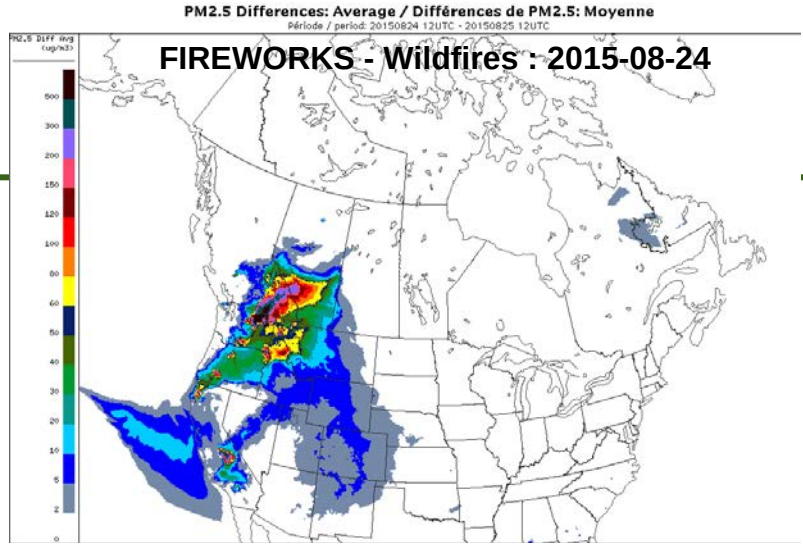
Turning point: in Canada, new MPI based HPC

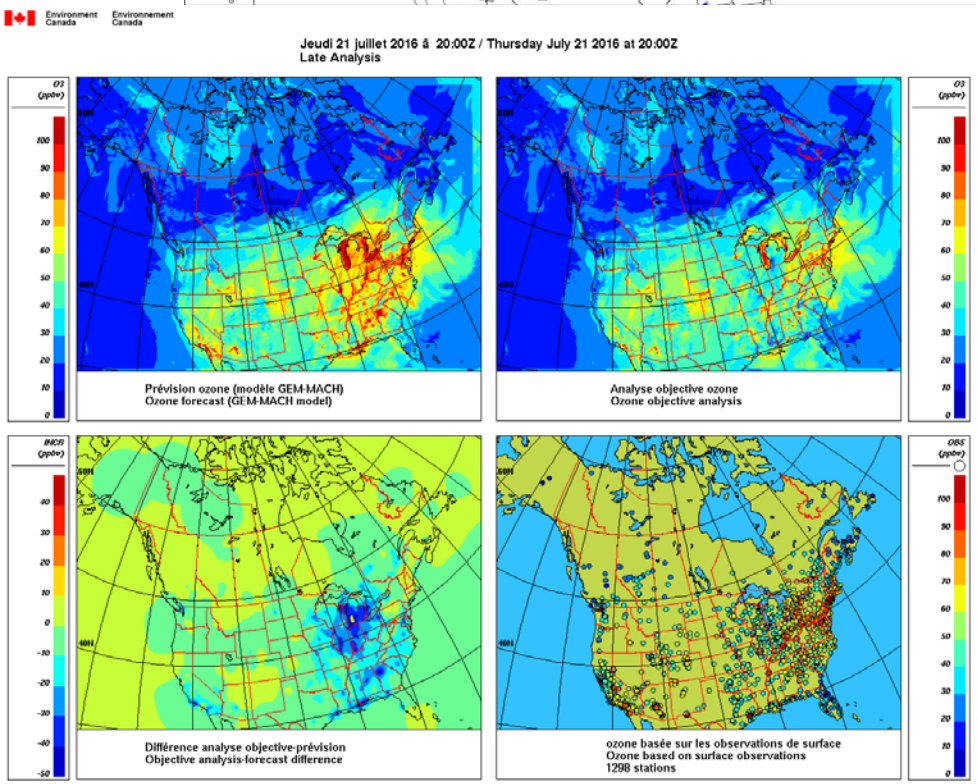
- **Summer 2004:** major hardware change with MPI capability
  - Started a 5 year development period towards on-line model
- **Summer 2009:**
  - Operational implementation of second generation of AQ forecast model: on-line GEM-MACH (1-way interaction)
- Marks operational uptake of research on on-line AQ Models (WRF-Chem, GEM-AQ, …)



Growth since ~2007

- Environment Canada:
  - Chemical /emission modules
    - 2 bins representation of PM
  - Resolution: 21 to 15 to 10km
    - Driven by met model changes
  - Smoke (Fireworks)
    - http://weather.gc.ca/firework/index_e.html
  - Operational objective analysis and post-processing





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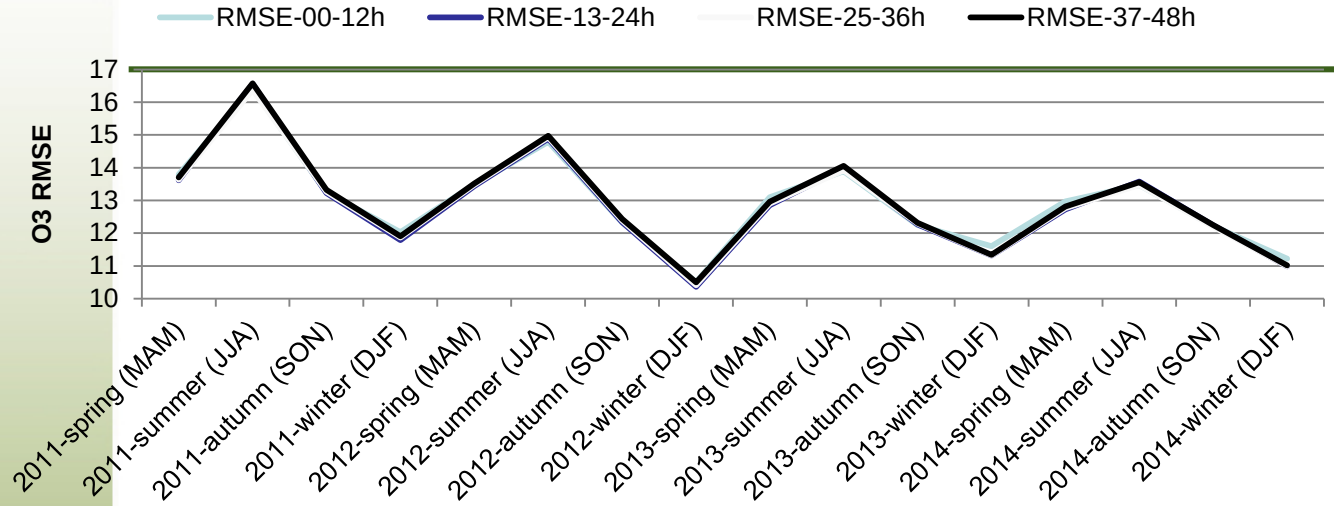
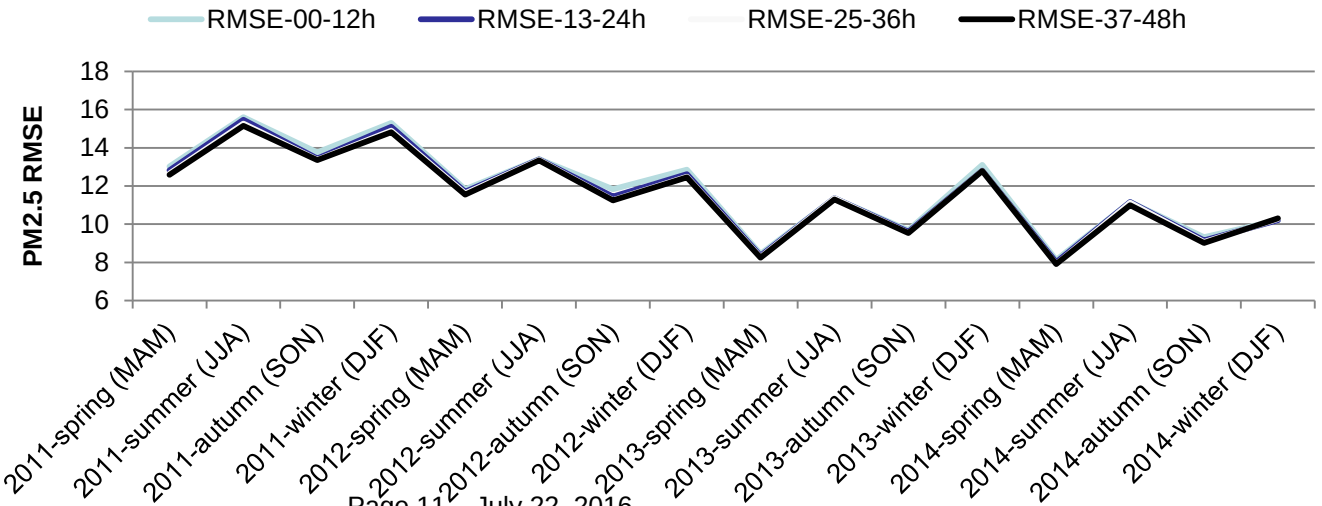
Performance is steadily improving



O3 & PM2.5 Root Mean Square Error (RMSE) by Season, 2011-2014 (courtesy M. Moran, J. Zhang)



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Operational Air Quality Forecasting in Canada: Current Status

Radenko Pavlovic
Meteorological Service of Canada
Environment Canada

Authors:
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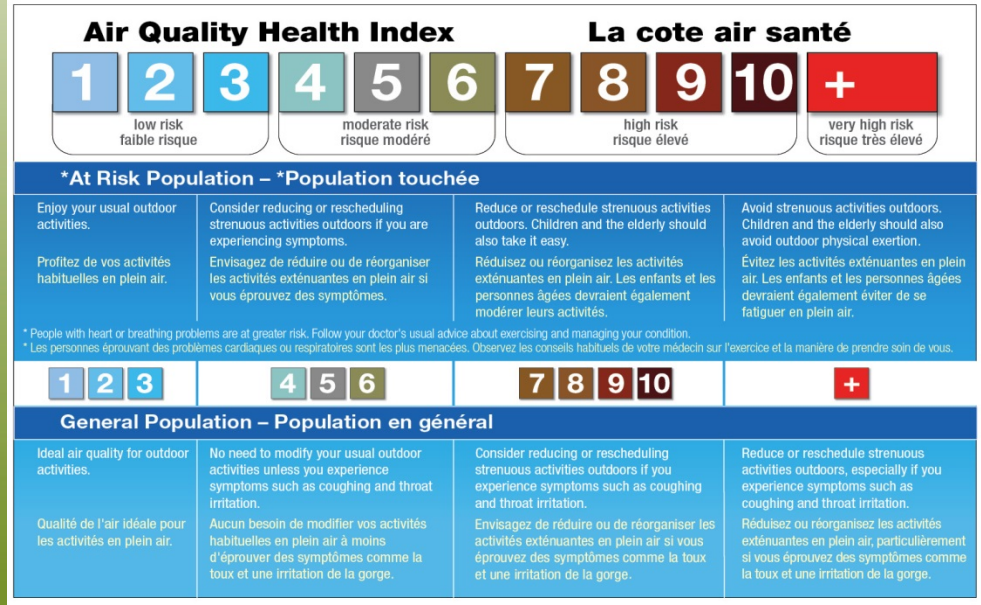
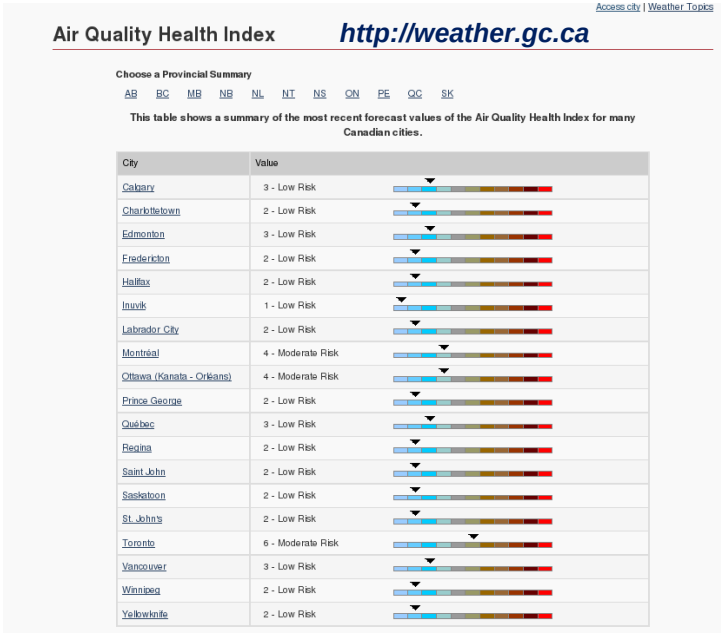
Canada's Air Quality Health Index

- 15-year-old program that has evolved from an O_3-only forecast programe in eastern Canada to a Canada-wide O_3, NO_2, $PM_{2.5}$ forecast program
- As of today, forecasts are communicated in most areas as an Air Quality Health Index (AQHI)





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

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

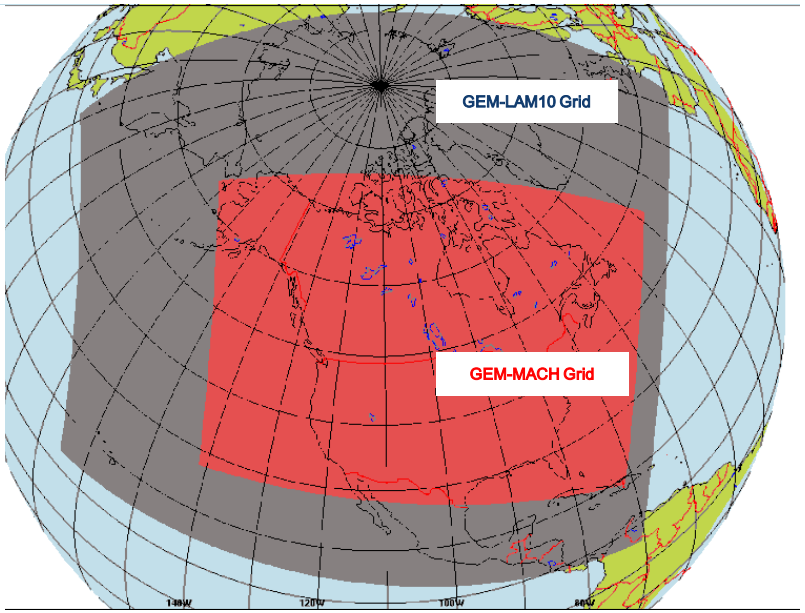
- Quebec INFO-SMOG

Canadian Air Quality Forecast System

- **RAQDPS** (**R**egional **A**ir **Q**uality **D**eterministic **P**rediction **S**ystem)
  - 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)
- **RDAQA** (**R**egional **D**eterministic **A**ir **Q**uality **A**nalysis System)
- Experimental AQ system versions (ex: GEM-MACH on 2.5km for PanAm games)
- **VAQUM** (**V**erification of **A**ir **QU**ality **M**odels) System

GEM-MACH, Operational Version (v1.5.4)

- GEM-MACH is ECCC'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

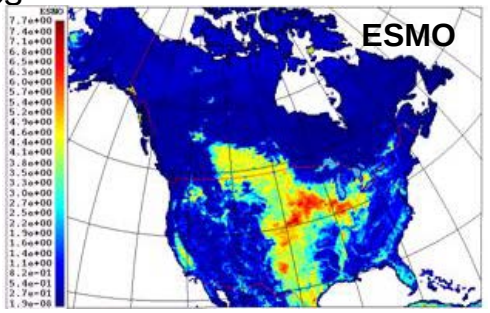


  - Full process representation of oxidant and aerosol chemistry:
    - gas-, aqueous- & heterogeneous chemistry mechanisms
    - aerosol dynamics
    - dry and wet deposition (including in- and below-cloud scavenging)

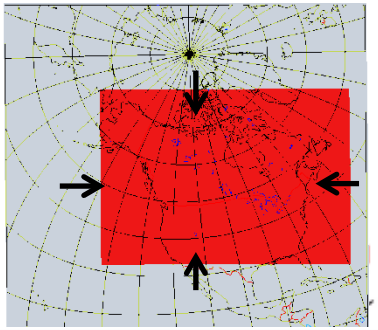
Emissions & Boundary Conditions

- 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



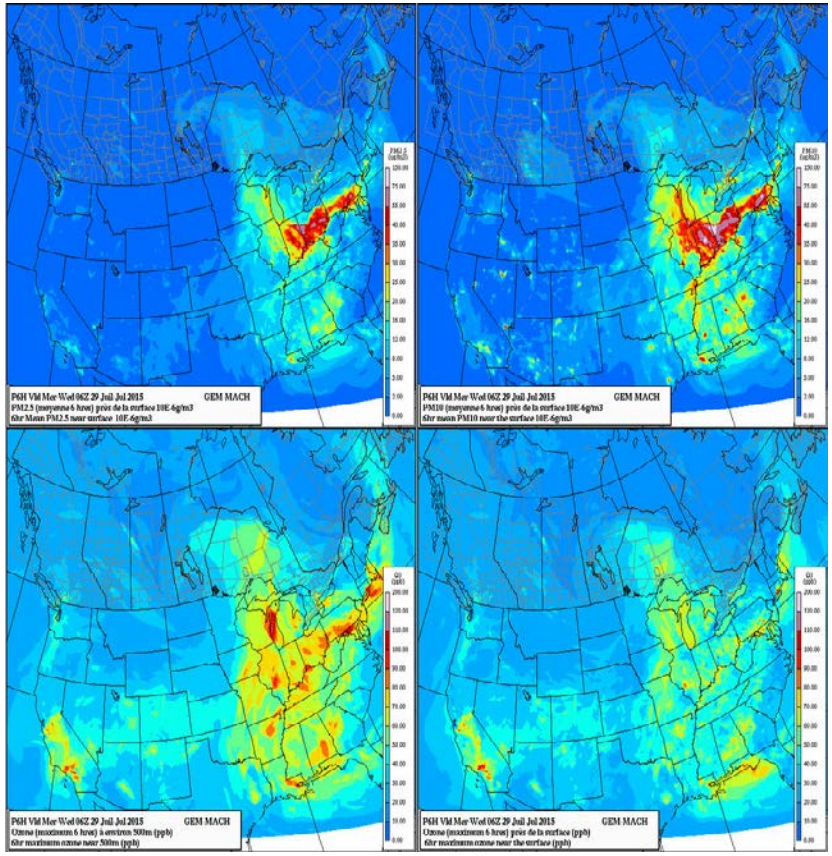
- Initial and Boundary Conditions
  - Using previous 12h forecast as initial AQ conditions
  - Using the operational weather analysis as initial weather conditions
  - Weather “piloting” from the operational weather runs (which are on a larger domain)
  - AQ piloting: using a chemical climatology at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

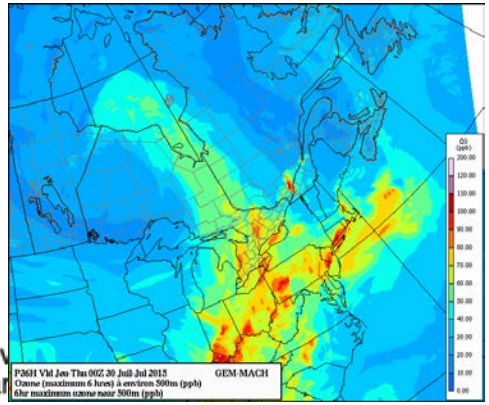


Overview of the Canadian AQ Forecast Program – Model Charts

- Maximum **ozone** near the surface, at 50m and 500m over a 6-hour interval
- **$PM_{2.5}$/PM_{10}** near the surface - 6-hour mean
- **4-panel maps** ($PM_{2.5}$, PM_{10}, O_3 near the surface, O_3 at 500 metres)

- Products are available over:
  - Eastern Canada; Western Canada and North America



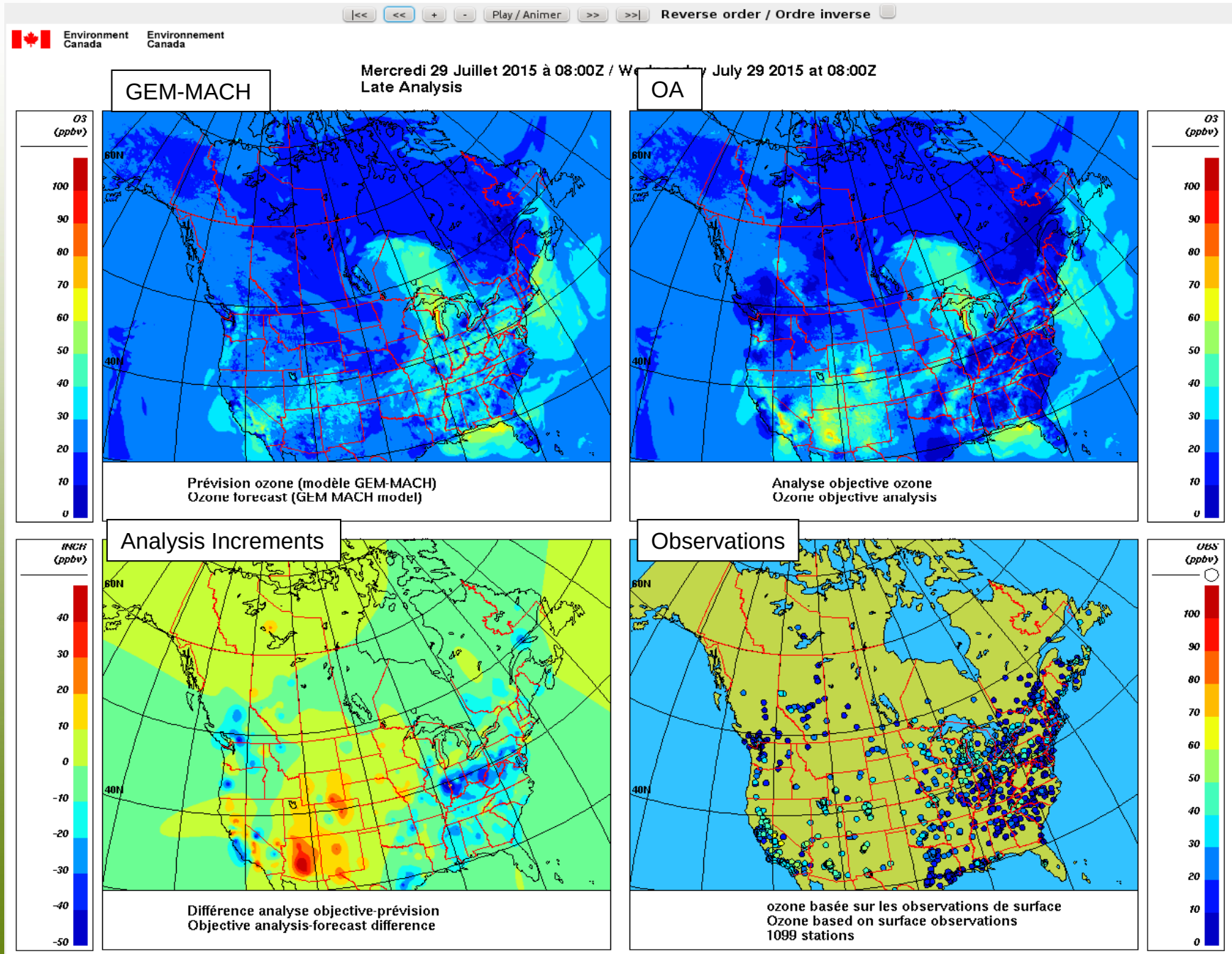


Canada

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 : **$PM_{2.5}$, O_3, NO_2, NO, SO_2, PM_{10} 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

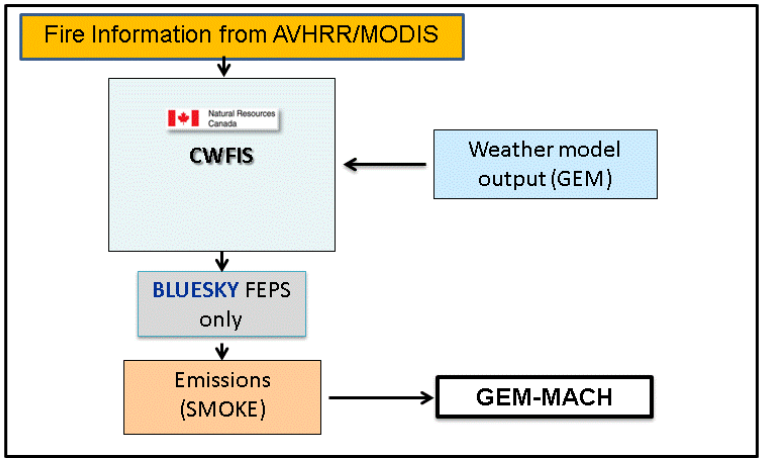


FireWork System

- 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

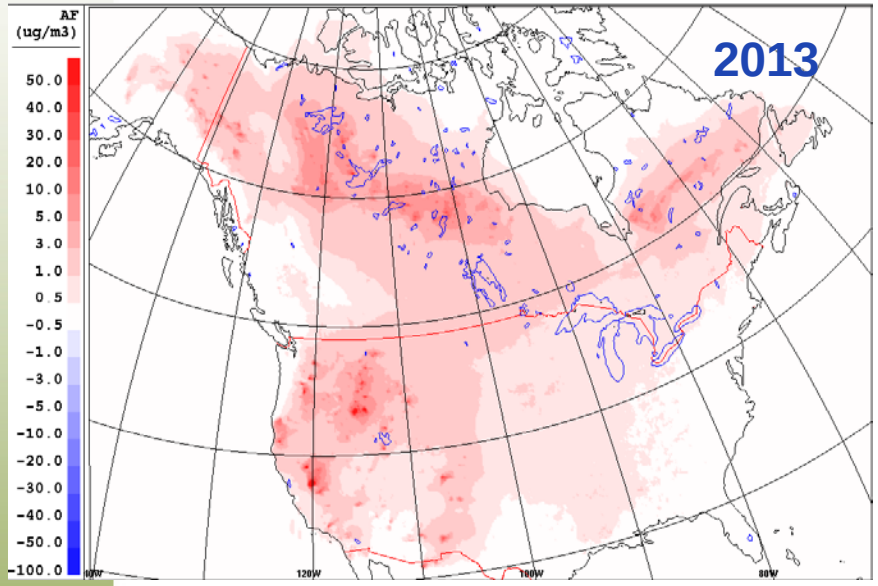
WildFire Emissions Data

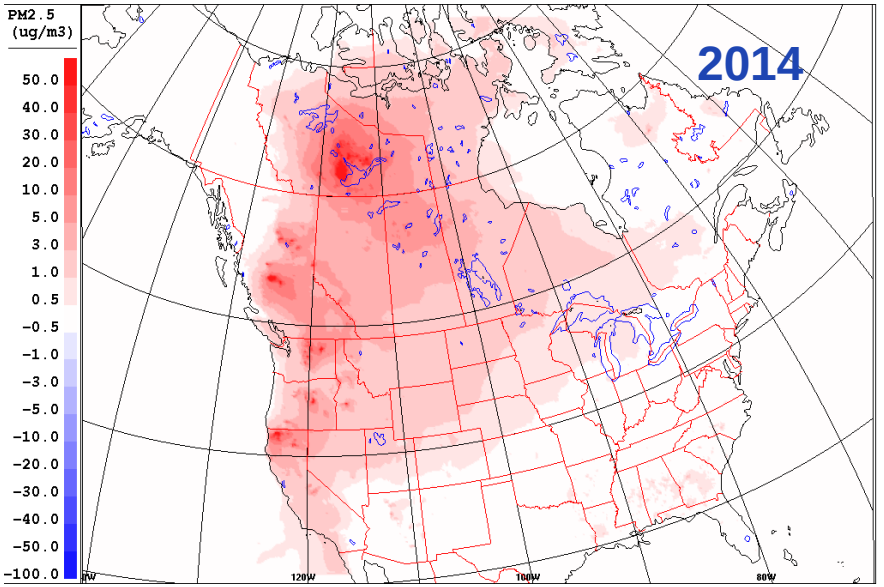


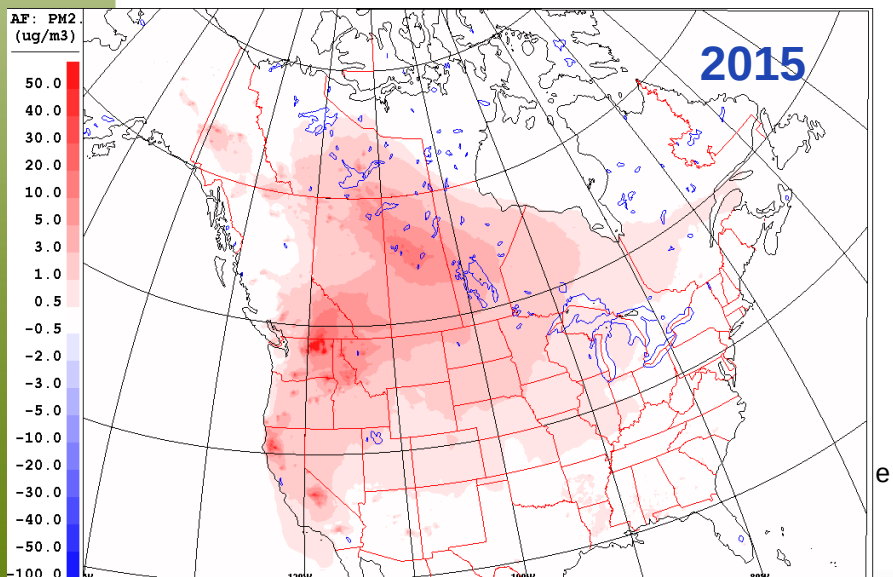
- Additional products
  - Alternate AQHI based on FireWork
  - $PM_{2.5}$/PM_{10} maps and animations based on difference fields (FireWork – GEM-MACH) to isolate plumes
  - Total column $PM_{2.5}$/PM_{10} sums
  - Other specialized products available upon request

How Important are wildfires for AQ?

Forecasted wildfire emissions contribution **to average summertime $PM_{2.5}$ concentrations**







In Canada, the impact of wildfire smoke on air quality is very significant.

Forecasted wildfire emissions contribution to the average summertime $PM_{2.5}$ concentrations (2013-2015) ranges from a few µg/m³ to ***over 30µg/m³****.*

e 22 – July 22, 2016

Canada

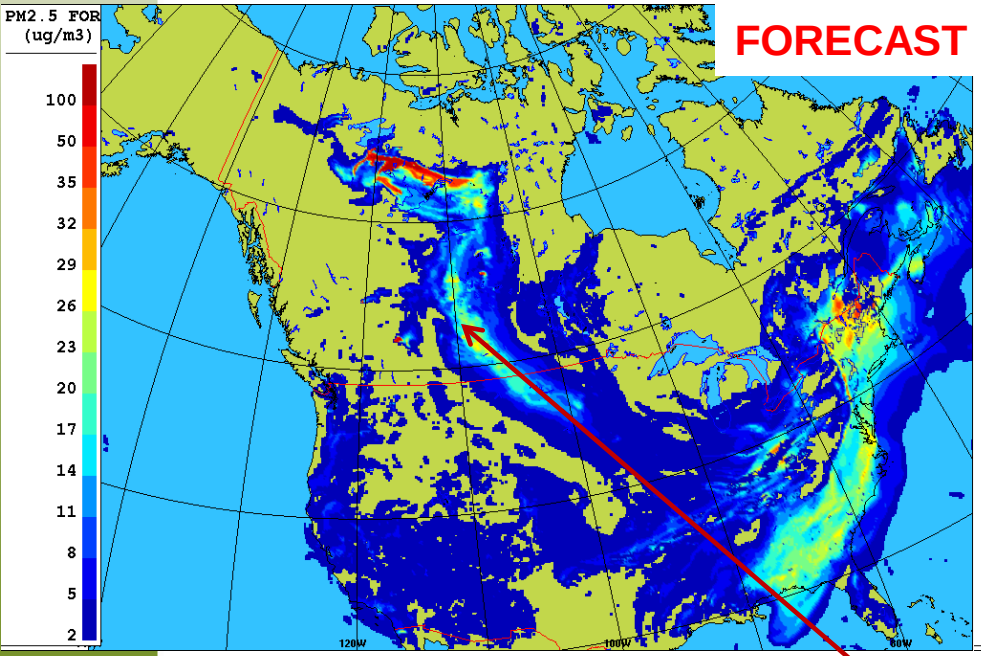
Edmonton and Vancouver Examples

Bad air quality caused by forest fires

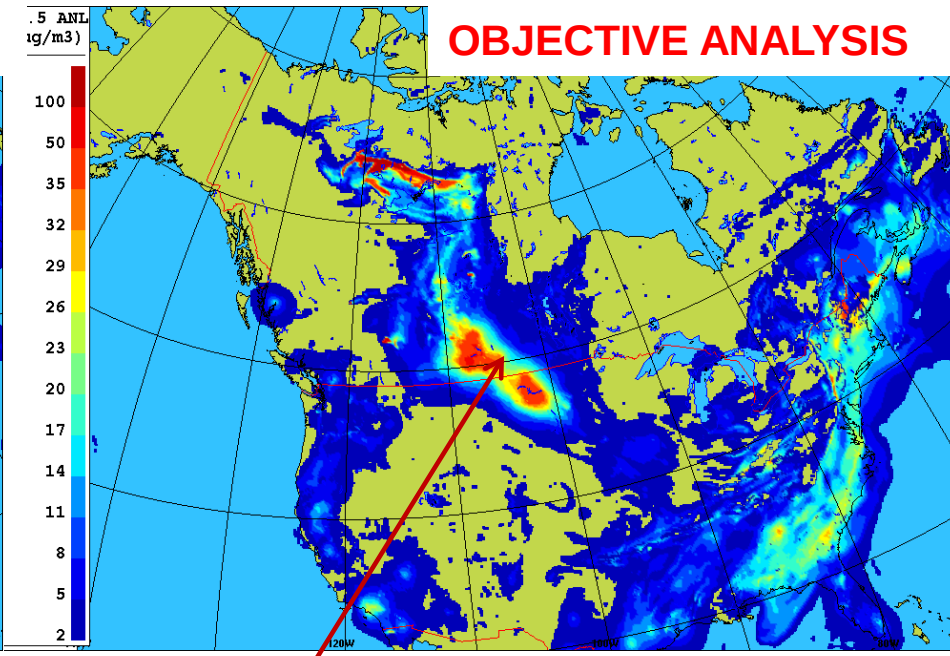
FireWork Objective Analysis

Example for 2014-07-09 00 UTC

There were extreme wildfires in NWT and pollution was advected thousands of km.



FORECAST

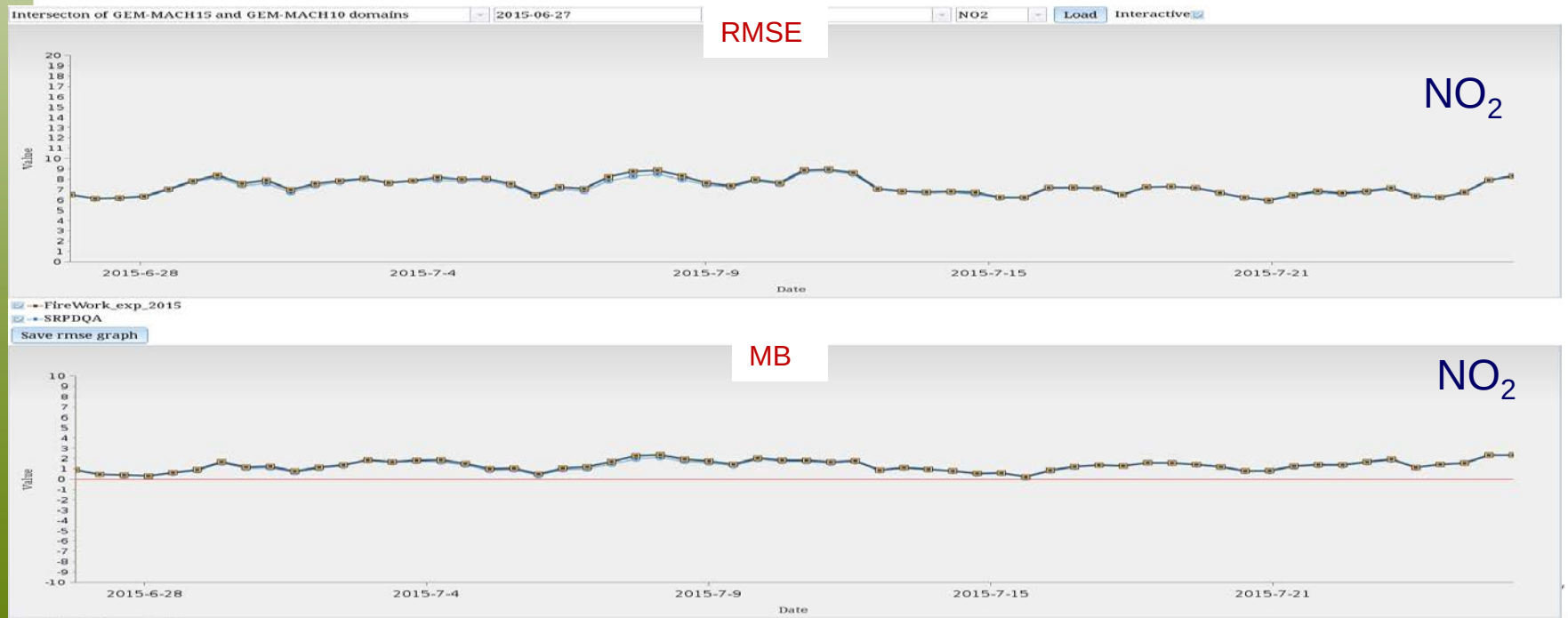


OBJECTIVE ANALYSIS

Forecasters can observe that advected pollution is **under-estimated**

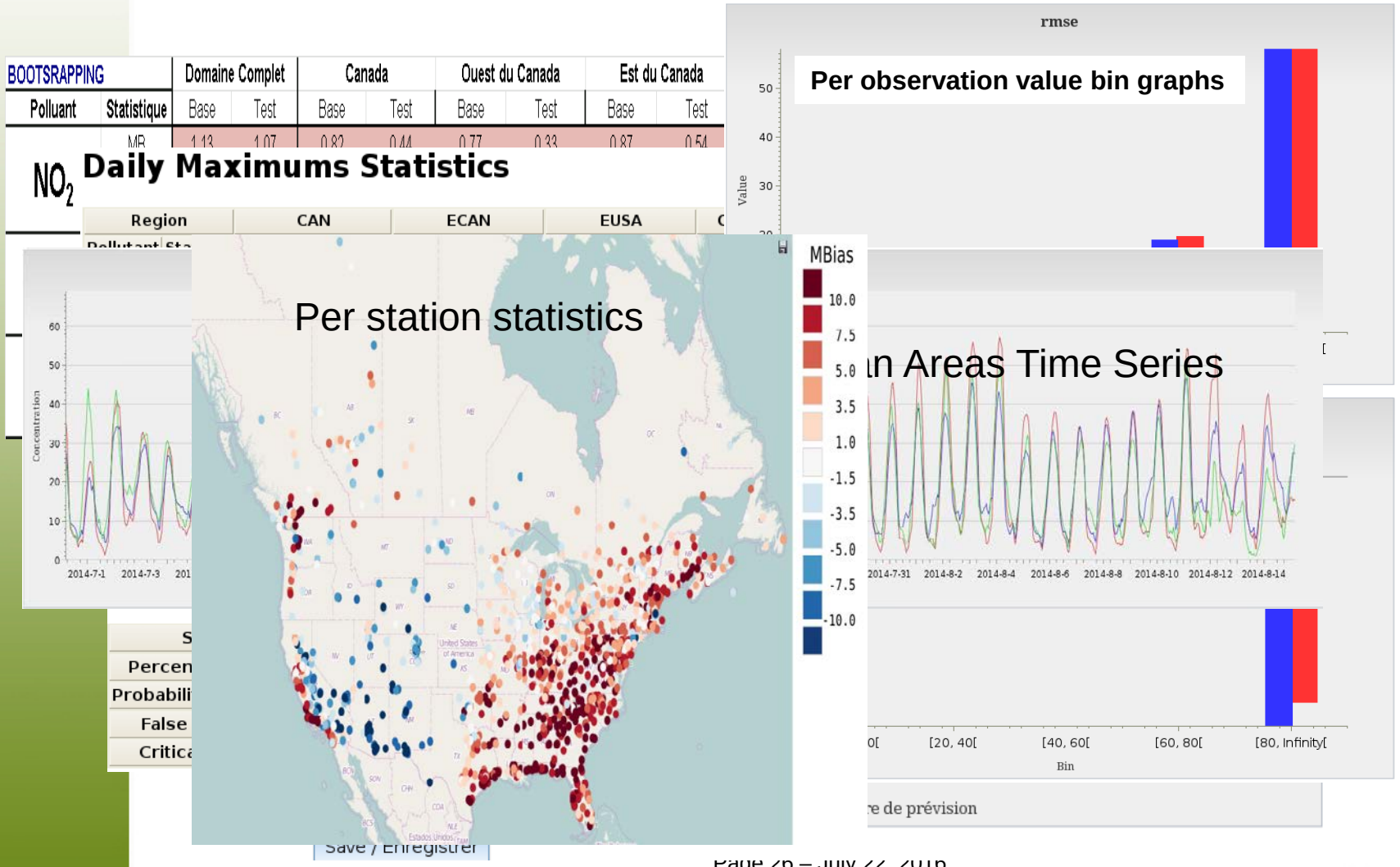
VAQUM: Verification for Air QUality Models

- 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



Automatic Operational Model Evaluation

VAQUM Products



Statistical Model: UMOS-AQ

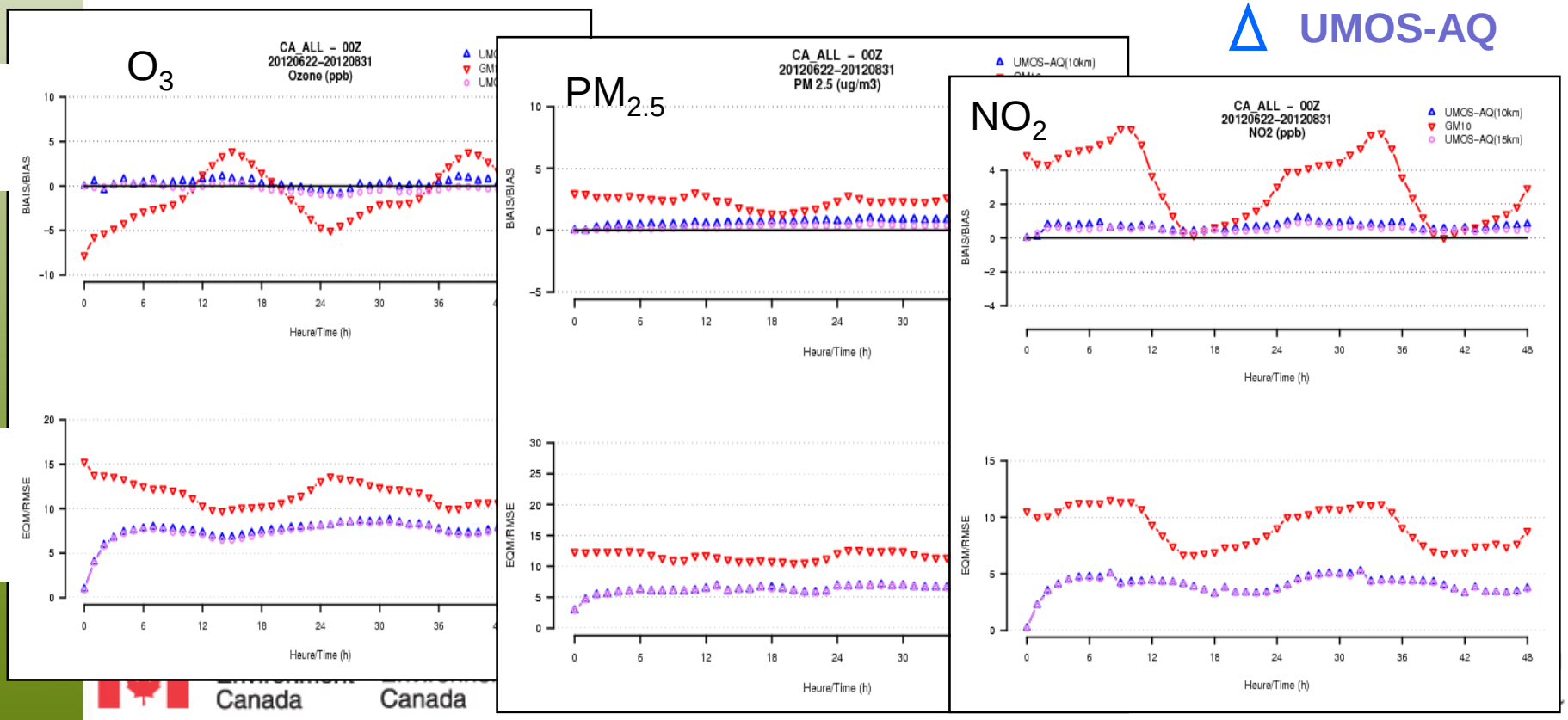
- Post-processing applied to GEM-MACH raw model output
- **Reduces model bias and model error** at point locations **with AQ monitors** through through multi-variate linear regression approach
  - Applied to meteorological variables since 2000
  - Adapted for air quality variables (O_3, NO_2, $PM_{2.5}$)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

▽ GEM-MACH

△ UMOS-AQ

BIAS

RMSE



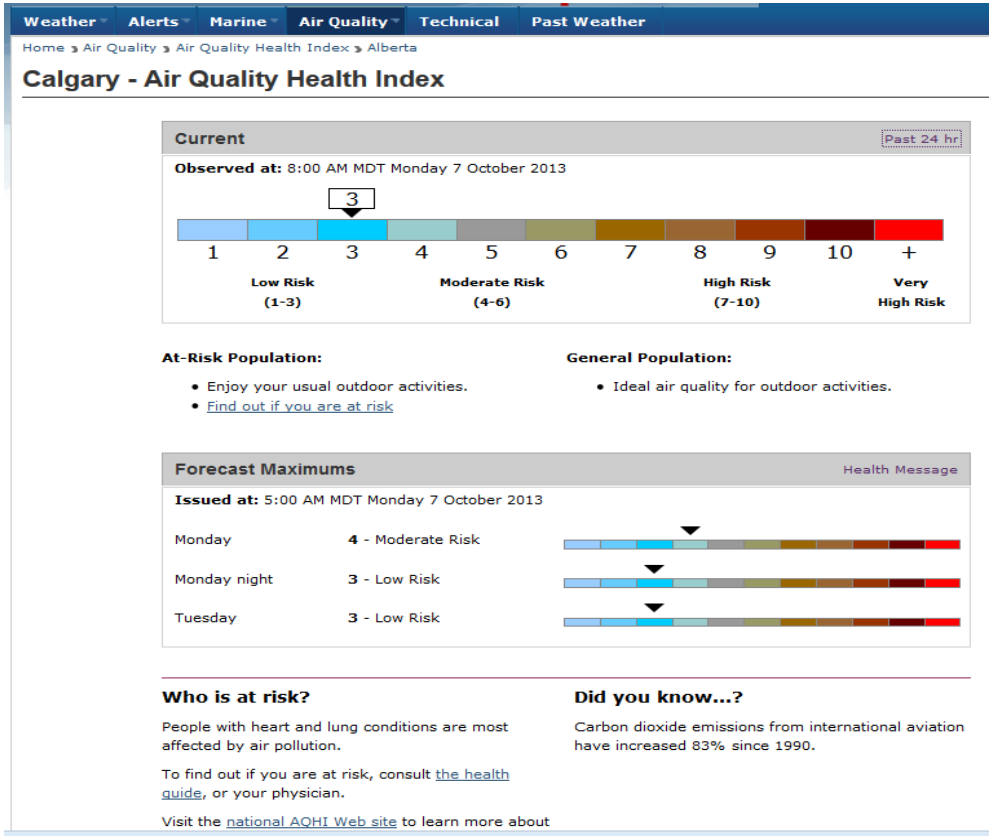
Canada Canada

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).

Products: AQHI Forecaster Resource Site

Section des Applications en Modélisation de la Qualité de l'Air (SAMQA)
Air Quality Modeling Applications Section (AQMAS)

AQHI Resources > Pacific and Yukon 2015-07-29 00 UTC

In case of problems, refer to this document | Français

Forecast Report

Select month

- Castlegar (JCAAC)
  - Castlegar Zinio Park (103502)
- Central Fraser Valley (JABNO)
  - Abbotsford Airport (101005)
  - Central Abbotsford (101003)
- Central Okanagan (JAFUV) & South Okanagan (JBHJG)
  - Kelowna College (100701)
- Comox (JCUYZ) & Courtenay (JAHJY)
  - Courtenay Elementary School (107100)
- Duncan (JBBWA)
  - Duncan Cairnsmore (104803)
- Eastern Fraser Valley (JCVCC)
  - Chilliwack Airport (101101)
  - Hope Airport (101401)
- Kamloops (JAFNW)
  - Kamloops Federal Building (100401)
- Metro Vancouver - NE (JBXHZ)
  - Coquitlam (100135)
  - Maple Ridge (101501)
  - Pitt Meadows (101202)
  - Rocky Pt. Park (100111)
- Metro Vancouver - NW (JDATF)
  - Burnaby South (100119)
  - Kensington Park (100110)
  - Kitsilano (100118)
  - Mahon Park (100132)
- Metro Vancouver - SE (JAZBU)
  - Langley Central (101301)
  - Surrey East (100127)
- Metro Vancouver - SW (JBRIK)
  - North Delta (100125)

Active Notices

No active notices available

Notice Archive

Surface Field Maps

GEM-MACH

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

Objective Analysis

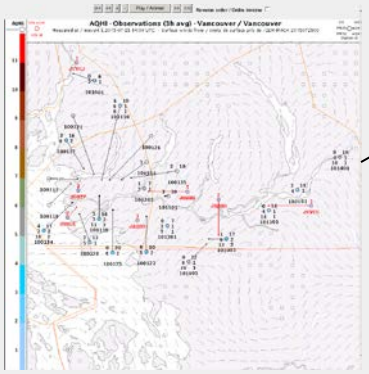
- AQHI
- NO
- NO2
- O3
- PM10
- PM2.5
- SO2

Observation Maps

AQHI	Hourly
British Columbia	British Columbia
Vancouver	Vancouver

Tools

- 24-hour observation summaries
- Monitoring of incoming air quality observations (Not operational)
- Troubleshooting Guide: Procedures for SPCs



Observation type: Hourly observations | Species: AQHI (AQHI, NO2, O3, PM10, PM2.5, CO, H2S, NO, SO2, TRS) | Domain: All locations | Location type: Communities | Submit

24-hour s… table for (AQHI) generated on: Wednesday July 29 14:55:56 (All times in UTC)

Current Conditions

Community	CGNDB	2015-07-28 15	16	…	19	20	21	22	23	2015-07-29 00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	Current Forecast	Max Obs
Castlegar	JCAAC	0.4	0.5	…	3.3	3.6	3.7	1.5	1.5	1.5	1.5	1.4	1.3	1.1	1.0	0.9	0.9	0.9	0.7	0.7	0.6	0.6	0.6	0.5	2	3.7
Central Fraser Valley	JABNO	1.4	1.6	1.6	1.7	1.7	1.7	1.7	1.8	1.9	2.0	2.1	2.1	2.0	1.8	1.8	1.8	2.0	2.1	2.1	2.1	1.9	1.9	1.7	3	2.1
Central Okanagan	JAFUV	1.4	1.5	1.5	1.6	1.6	1.6	1.6	1.6	1.7	1.8	2.0	2.0	2.0	2.0	1.9	1.9	1.6	1.4	1.3	1.3	1.3	1.2	1.2	2	2.0
Comox	JCUYZ	0.2	0.2	1.2	1.8	1.7	1.5	1.4	1.4	1.3	1.3	1.3	1.4	1.4	1.4	1.5	1.4	1.3	1.0	0.8	0.7	0.6	0.6	0.5	2	1.8
Courtenay	JAHJY	0.2	0.2	1.2	1.8	1.7	1.5	1.4	1.4	1.3	1.3	1.3	1.4	1.4	1.4	1.5	1.4	1.3	1.0	0.8	0.7	0.6	0.6	0.5	2	1.8
Duncan	JBBWA	0.7	0.7	0.9	1.1	1.4	1.5	1.7	1.8	2.1	2.3	2.5	2.5	2.3	2.0	1.8	1.6	1.6	1.3	1.0	0.9	0.8	0.7	0.6	3	2.5
Eastern Fraser Valley	JCVCC	1.2	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.2	2.1	2.1	2.0	2.0	1.9	1.9	1.7	1.6	1.4	3	2.2
Kamloops	JAFNW	1.7	1.8	1.8	1.9	1.8	1.9	1.9	1.9	1.9	2.0	2.1	2.1	2.1	2.0	2.0	2.0	2.0	1.9	1.8	1.6	1.5	1.4	1.4	3	2.1
Metro Vancouver - NE	JBXHZ	0.8	1.0	1.2	1.5	1.7	1.9	2.0	2.3	2.5	2.7	2.8	2.7	2.5	2.3	2.2	2.1	2.0	1.7	1.5	1.4	1.2	1.2	1.1	3	2.8
Metro Vancouver - NW	JDATF	1.4	1.5	1.6	1.8	2.0	2.2	2.3	2.4	2.4	2.4	2.4	2.4	2.3	2.2	2.2	2.2	2.1	2.1	2.0	1.9	1.8	1.7	1.6	3	2.4
Metro Vancouver - SE	JAZBU	1.0	1.1	1.3	1.4	1.5	1.7	1.9	2.1	2.3	2.4	2.3	2.1	1.9	1.9	2.0	2.1	1.9	1.8	1.7	1.6	1.4	1.2	1.1	3	2.4
Metro Vancouver - SW	JBRIK	1.6	1.6	1.6	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.0	2.0	2.0	2.3	2.4	2.5	2.4	2.3	2.2	2.0	1.8	1.6	1.6	2	2.5
Nanaimo / Parksville	JAQAL	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.6	1.6	1.6	1.7	1.7	1.7	1.7	1.7	1.5	1.4	1.3	1.3	1.2	1.1	1.0	2	1.7
North Okanagan	JBOAP	1.2	1.2	1.3	1.4	1.6	1.7	2.0	2.0	2.0	2.0	2.2	2.2	2.1	2.0	2.0	1.8	1.6	1.4	1.2	1.1	1.1	1.0	1.0	2	2.2
Prince George	JBLVS	1.4	1.6	1.7	1.8	1.8	1.8	1.8	1.8	–	–	–	–	2.2	2.1	1.9	1.8	1.8	1.6	1.5	1.4	1.4	1.5	1.5	2	2.2
Quesnel	JBNTS	0.8	1.1	1.2	1.2	1.1	1.0	1.1	1.3	1.4	1.5	1.6	1.6	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.4	0.3	0.4	2	1.6
South Okanagan	JBHJG	1.4	1.5	1.5	1.6	1.6	1.6	1.6	1.6	1.7	1.8	2.0	2.0	2.0	2.0	1.9	1.9	1.6	1.4	1.3	1.3	1.3	1.2	1.2	2	2.0
Squamish	JCVCJ	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.7	1.9	2.0	2.2	2.3	2.4	2.3	2.2	2.0	1.7	1.4	1.2	0.9	0.7	0.6	0.6	2	2.4
Victoria / Saanich	JBOBQ	0.9	0.9	1.0	1.1	1.3	1.7	1.8	2.0	2.0	1.9	1.6	1.3	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.8	3	2.0
WestShore	JBLXS	1.1	1.2	1.2	1.4	1.6	1.7	1.9	2.1	2.1	2.0	1.7	1.5	1.4	1.4	1.4	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	2	2.1
Whistler	JCJHI	0.5	0.7	0.9	1.1	1.2	1.3	1.3	1.4	1.4	1.4	1.5	1.5	1.5	1.6	1.4	1.3	1.1	1.0	0.9	0.7	0.6	0.5	0.5	2	1.6
Williams Lake	JBTMB	0.9	1.0	0.8	–	–	1.2	1.2	1.2	1.2	1.4	1.4	1.4	1.4	1.4	1.3	1.2	1.2	1.2	1.2	1.1	1.1	1.0	1.1	2	1.4

1 2 3 4 5 6 7 8 9 10 +

AQHI observation availability for the last 6 months

Site / Month	2015-02	2015-03	2015-04	2015-05	2015-06	2015-07
Castlegar	75%	68%	90%	90%	81%	97%
Central Fraser Valley	99%	95%	99%	97%	98%	98%
Central Okanagan & South Okanagan	32%	88%	88%	90%	86%	86%
Comox & Courtenay	77%	90%	89%	73%	85%	97%
Duncan	77%	94%	87%	95%	85%	96%
Eastern Fraser Valley	99%	95%	99%	98%	96%	98%
Kamloops	80%	91%	87%	85%	80%	89%
Metro Vancouver - NE	99%	95%	99%	93%	99%	98%
Metro Vancouver - NW	99%	95%	99%	97%	99%	98%
Metro Vancouver - SE	99%	95%	99%	97%	99%	98%
Metro Vancouver - SW	99%	95%	99%	97%	99%	98%
Nanaimo / Parksville	79%	84%	89%	78%	82%	96%
North Okanagan	68%	68%	89%	95%	84%	97%
Prince George	79%	87%	86%	91%	79%	94%
Quesnel	80%	88%	29%	68%	79%	97%
Squamish	80%	96%	90%	95%	80%	97%
Victoria / Saanich	73%	95%	90%	93%	85%	97%
WestShore	80%	91%	81%	94%	84%	95%
Whistler	74%	82%	89%	73%	86%	97%
Williams Lake	81%	77%	0%	32%	86%	81%

The target for minimum availability of the AQHI at any site is at least 85%

Good availability >= 95%

Poor 85% <= availability < 95%

Insufficient availability < 85%

Canada

Products: FireWork Forecaster Resource Site

Section des Applications en Modélisation de la Qualité de l'Air (SAMQA)
Air Quality Modeling Applications Section (AQMAS)

FIREWORK-GEMMACH SITE

AQHI Resources > Prairies and North 2015-07-29 12 UTC

Franç

Forecast Report

Select month

Nunavut
- Iqaluit (OATRP)
  - Waterlab (129303)

Northwest Territories
- Inuvik (LALNA)
  - Inuvik (129203)
- Yellow knife (LBAMG)
  - Yellow knife (129003)
- Unassociated stations
  - Snare Rapids (129501)

Alberta
- Calgary (IAKID)
  - Calgary Central (90228)
  - Calgary Northwest (90222)
  - Calgary SouthEast (90229)
- Cold Lake (IAEFD)
  - Cold Lake South (94301)
- Drayton Valley (IABOA) & Spruce Grove (IAKRM)
  - Genesee (93101)
  - Tomahawk (91301)
- Edmonton (IACMP)
  - Edmonton Central (90130)
  - Edmonton East (90121)
  - Edmonton South (90120)
  - Woodcroft (90133)

Active Notices

No active notices available

Notice Archive

Surface Field Maps

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

Difference Plots
- PM10 surface
- PM2.5 surface
- PM10 column
- PM2.5 column
- Avg over hours 24 - 48
- Sum over hours 24 - 48

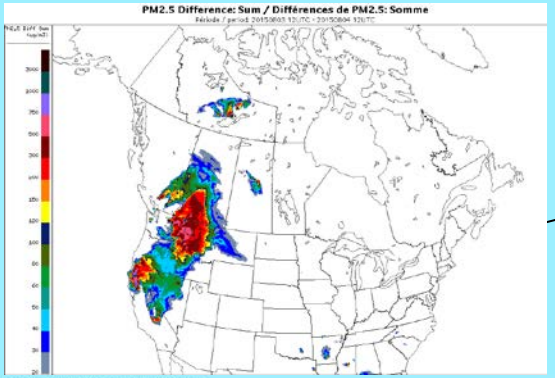
UMOS-AQ/MIST + Difference Plots
- UMOS-AQ/MIST PM2.5 surface

Objective Analysis
- PM2.5
- PM10

Observation Maps

AQHI	Hourly
Alberta	Alberta
Baffin Island	Baffin Island
Northwest Territories	Northwest Territories
Southeast PNR	Southeast PNR

Tools
- 24-hour observation summaries
- FireWork-GEMMACH summaries for next 24 hours
- Monitoring of incoming air quality observations (Not operational)
- Troubleshooting Guide: Procedures for SPCs
- Current CWFIS hotspot map
- Recent CWFIS hotspot map
- FireWork-GEMMACH output in CSV format



AQHI observation availability for the last 6 months

Site / Month	2015-02	2015-03	2015-04	2015-05	2015-06	2015-07
Brandon	87%	82%	49%	96%	51%	76%
Calgary	97%	97%	99%	98%	97%	99%
Cold Lake	73%	85%	81%	85%	78%	82%
Drayton Valley & Spruce Grove	97%	99%	99%	99%	98%	98%
Edmonton	99%	100%	99%	99%	99%	100%
Fort Chipewyan	97%	98%	96%	97%	96%	98%
Fort McKay	96%	98%	97%	98%	97%	98%
Fort McMurray	98%	99%	99%	99%	99%	99%
Fort Saskatchewan	97%	91%	90%	94%	90%	96%
Grande Prairie	74%	97%	98%	98%	96%	98%
Inuvik	95%	97%	93%	33%	76%	85%
Iqaluit	0%	0%	0%	0%	0%	0%
Lethbridge	93%	88%	95%	93%	91%	82%
Medicine Hat	40%	58%	96%	96%	98%	98%
Prince Albert	87%	86%	75%	9%	63%	85%
Red Deer	68%	87%	87%	89%	86%	89%
Regina	65%	59%	72%	83%	94%	79%

Canada

Environment Canada Environnement Canada

Canada

Operational Air Quality Forecasting in general

Generic AQ forecasting system

- **Schematic diagram of an AQ forecast system**

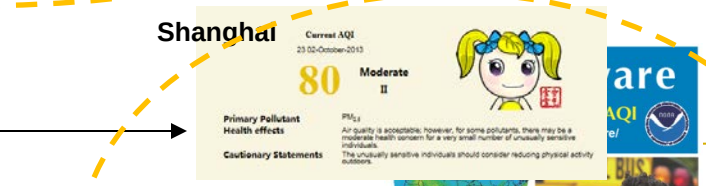
Past and present situation
- ex: Last 48hr -
Real-time observations
of O_3, $PM_{2.5}$, NO_2, …

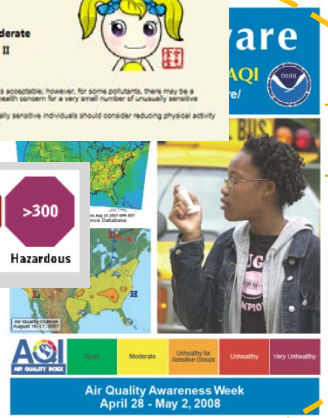
Forecasted future situation
- Next 48hr -
Modelled forecast values
of O_3, $PM_{2.5}$, NO_2

Forecaster

Processing of observations into the chosen format for
Dissemination to the public of actual conditions

Analysis and prognostic of forecasted conditions in the same chosen format for dissemination





Generic AQ forecasting system

Each part of the system has specific requirements:

- Requirements for numerical model(s): the forecast needs to be available with a certain leadtime
  - Domain size & model complexity to be balanced with computing time/power and timing of the forecast
  - Compromise with availability of met forecast/fields
- Requirements for the observations: Available in as near-real-time as possible
  - Density : As many as possible
  - Multiple sources: At forecast locations (urban/sub-urban), but also upstream and at regional and/or global scale (satellite)
  - Timing: For some systems, observations are used as input

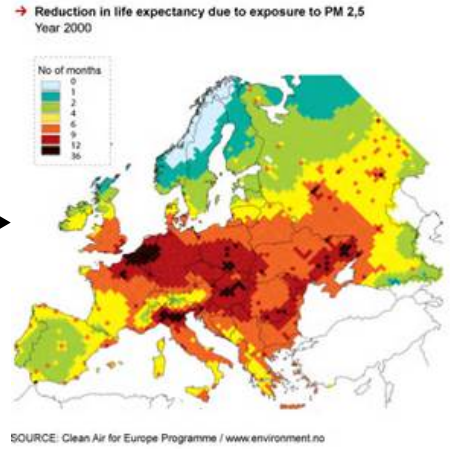
Jurisdictional challenges

- In the AQ world, observation sites can be owned and/or operated by multiple agencies ≠ met

US: Multiple Federal Agencies + State and local authorities

Canada: Shared Federal (national)/Provincial responsibility + collaboration with

Europe: Multiple countries and multiple agencies within each countries



South-America: Multiple agencies & academia

Jurisdictional challenges

- The different agencies usually have different mandates and responsibilities:
  - Regulatory mandate
  - Research, Long term background monitoring
- Real-time transmission is not always exploited if not required for mandate
  - Added complexities for extremely remote locations
  - Need to work collaboratively to upgrade networks to the benefit of all parties
    - Ex: In Canada, the Meteorological Centre supplied DRDAS® hardware and licenses for joint federal/provincial sites
- Data need to be collected centrally for forecast to access
  - Own system or one that is readily accessible

Jurisdictional challenges

- Different agencies also means:
  - Differences in instrumentation
  - Differences in mode of operation
    for PM in particular) and calibration
  - Differences in reporting schedules
- Similar considerations as for any AQ networks:
  - Homogeneity of network(s) in terms of data, format and transmission
- **But now in Real-time**
  - Consider establishing a RT monitoring system of the monitoring data (data volume, outages, corrupted data)
  - Real-time QA/QC

Jurisdictional challenges

- Environment Canada Monitoring system for observations

Monitoring de la Qualité de l'air en date du 20150406 1900Z

Nombre total d'observations reçues par région pendant la dernière heure

LÉGENDE:

>30% de la moyenne de dix jours	<30% de la moyenne de dix jours

Bonnes Données / Mauvaises Données / Données Suspectes

20150406 1800Z Retour à la page principale 20150406 2000Z

RÉGION	O3	NO2	PM2.5	PM10	SO2	H2S	TRS	CO	NO
ATLANTIQUE	25 / 0 / 1	18 / 0 / 0	18 / 0 / 0	NULL	8 / 0 / 0	NULL	NULL	NULL	7 / 0 / 0
QUÉBEC	10 / 0 / 0	10 / 0 / 0	10 / 0 / 0	NULL	1 / 0 / 0	NULL	NULL	3 / 0 / 0	1 / 0 / 0
ONTARIO	40 / 0 / 0	40 / 0 / 0	40 / 0 / 0	NULL	11 / 0 / 0	NULL	NULL	NULL	40 / 0 / 0
MANITOBA	2 / 0 / 0	2 / 0 / 0	4 / 0 / 0	3 / 0 / 0	3 / 0 / 0	NULL	NULL	2 / 0 / 0	NULL
SASKATCHEWAN	4 / 0 / 0	4 / 0 / 0	3 / 0 / 0	NULL	3 / 0 / 0	NULL	NULL	2 / 0 / 0	NULL
ALBERTA	22 / 0 / 0	27 / 0 / 0	22 / 0 / 0	1 / 0 / 0	25 / 0 / 0	2 / 0 / 0	6 / 0 / 0	8 / 0 / 0	26 / 1 / 0
BC MINISTRY OF THE ENVIRONMENT	16 / 0 / 0	16 / 0 / 0	36 / 0 / 0	18 / 0 / 0	24 / 0 / 0	NULL	12 / 0 / 0	2 / 0 / 0	17 / 0 / 0
METRO VANCOUVER	16 / 0 / 0	16 / 0 / 0	15 / 0 / 0	8 / 0 / 0	11 / 0 / 0	NULL	1 / 0 / 0	14 / 0 / 0	16 / 0 / 0
CAPMoN	6 / 0 / 0	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL
TERRITOIRES DU NORD-OUEST	2 / 0 / 0	2 / 0 / 0	2 / 0 / 0	2 / 0 / 0	2 / 0 / 0	NULL	NULL	2 / 0 / 0	2 / 0 / 0

Hourly summary across Canada

6-month running statistics for 1 region

AQHI observation availability for the last 6 months

Site / Month	2014-11	2014-12	2015-01	2015-02	2015-03	2015-04
Barrie	99%	99%	99%	99%	93%	98%
Brampton	99%	98%	98%	99%	95%	98%
Burlington	98%	99%	99%	98%	95%	98%
Dorset	99%	97%	98%	99%	95%	98%
Hamilton	99%	99%	99%	99%	95%	98%
Hamilton Downtown	0%	65%	99%	99%	94%	98%
Hamilton Mountain	0%	64%	99%	97%	94%	98%
Hanlan's Point	0%	65%	98%	99%	95%	98%
Kingston	99%	99%	98%	99%	95%	98%
London	99%	99%	99%	99%	94%	98%
Mississauga	99%	98%	98%	98%	92%	98%
Newmarket	98%	98%	98%	99%	94%	98%
Oakville	99%	93%	98%	95%	89%	98%
Oshawa	97%	99%	95%	99%	95%	98%
Ottawa & Gatineau	99%	100%	99%	99%	99%	100%
Peterborough	99%	99%	95%	99%	95%	98%
Sault Ste. Marie	99%	99%	99%	97%	95%	98%
St. Catharines	99%	99%	99%	98%	95%	70%
Toronto	99%	99%	99%	99%	95%	98%
Toronto Downtown	0%	65%	99%	99%	95%	98%
Toronto East	0%	65%	99%	98%	95%	98%
Toronto North	0%	65%	99%	98%	94%	98%
Toronto West	0%	65%	99%	99%	92%	98%
Windsor	99%	99%	99%	99%	95%	98%
York University	0%	65%	99%	97%	95%	98%

The target for minimum availability of the AQHI at any site is at least 85%

Good availability >= 95% Poor 85% <= availability < 95% Insufficient availability < 85%

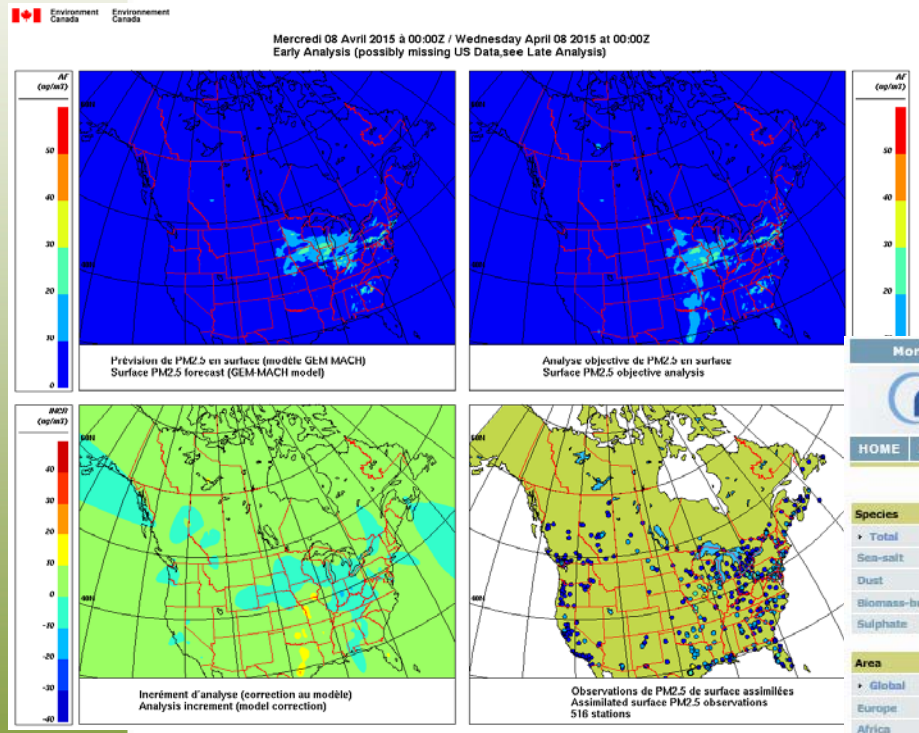
Best Effort versus Operational Systems

- System you have access to versus a system you operate?
  - How reliable is your access? How much redundancy is there?
  - How much outage can you handle at any one time?
- Within collaborative agreements, need to build real-time requirements for data exchange:
  - Ex: Environment Canada contributed to upgrade to have 24/7 data servers while Provinces agreed to increase support for outages (technician availability)
  - Data standarts: WMO/BUFR vs Airnow-like

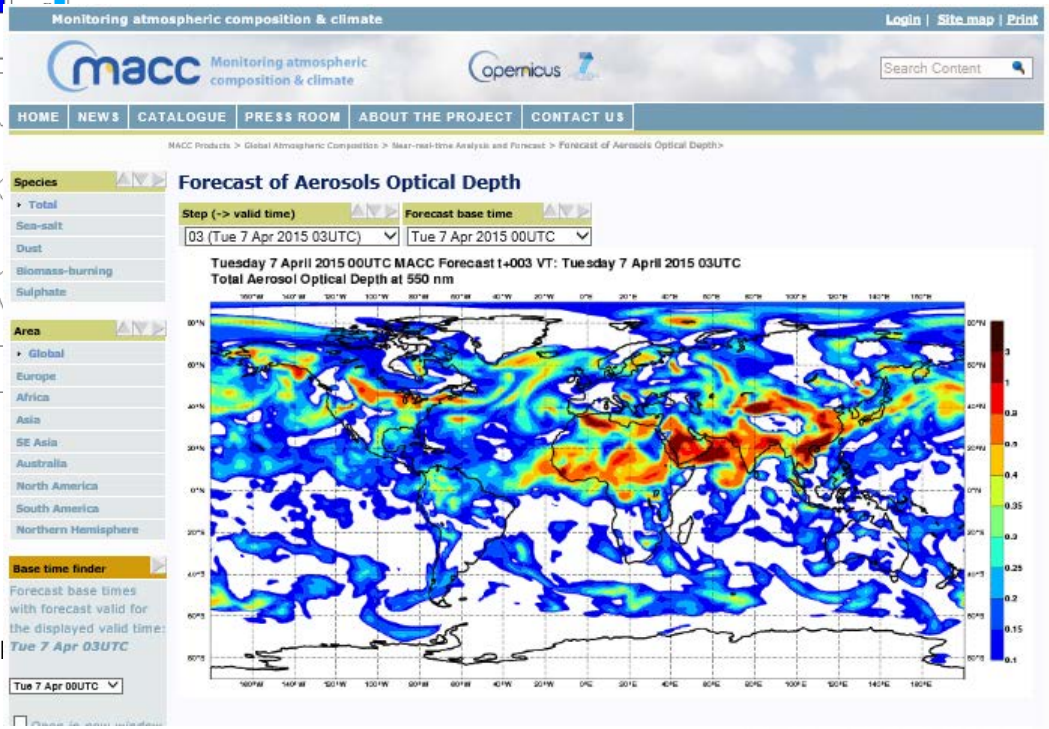
Data constraints and considerations

- Given there are often multiple agencies and mandates, there maybe some constraints on what can be accessed or done with the data
  - Intellectual Properties differences, Political sensitivities, Disagreements on the use of data, Avoid confusion, Communication best practices….
- Is your system able to adapt and manipulate the data as necessary?
- Do you have resiliency through alternative sources of data?

Alternatives elements of the forecast system



- Chemical composition analyses (ground base – Environment Canada)



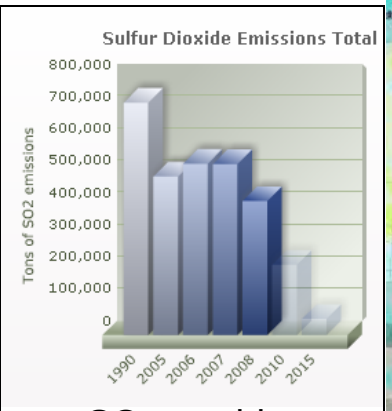
- Chemical composition analyses (Satellite – ECMWF)

Environment Canada Environnement Canada

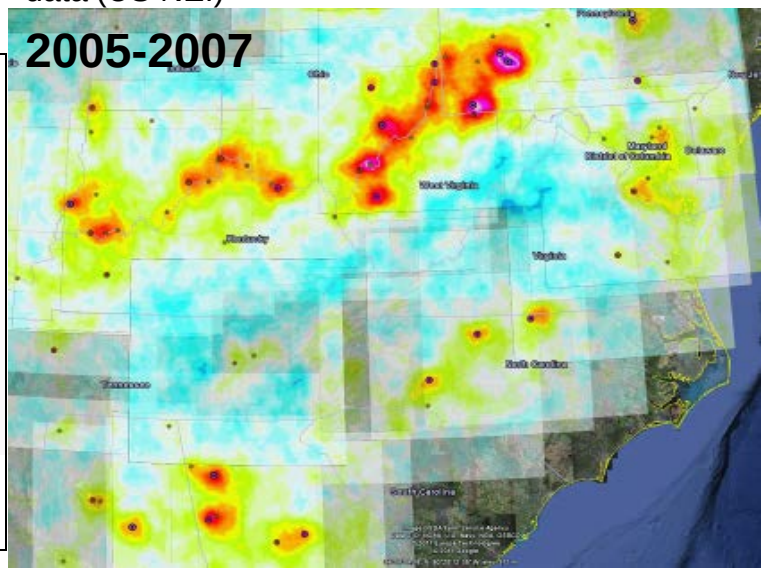
Alternatives elements of the forecast system: Satellite Monitoring: SO2 Emissions from Individual Sources (Fioletov et al., 2011, GRL)

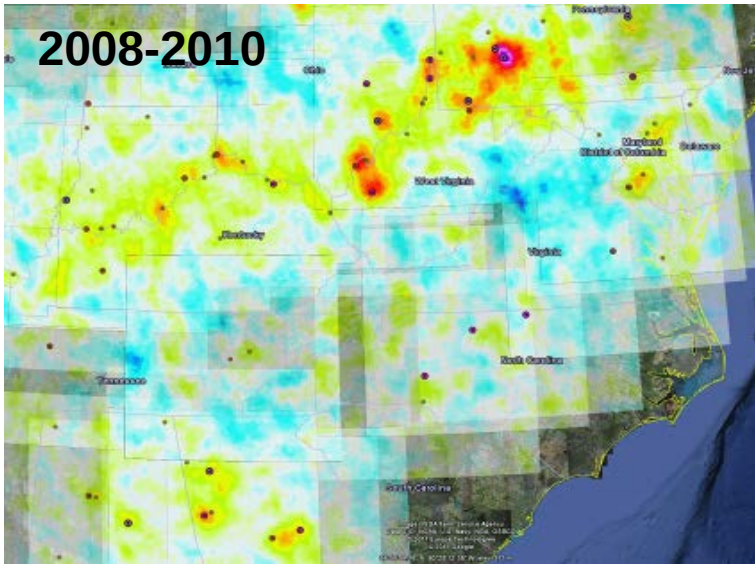
- OMI SO_2 data can be used to produce direct estimates of emissions from large individual sources (> 70kT/y)
- Methodology relies on averaging large number of individual pixels centered within a few km of the source
  1. QC – screen by track position, cloud fraction, SZA
  2. Use of spatial smoothing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

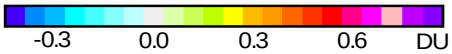
Mean OMI SO_2 values: Estimate change between two periods is 40% from OMI data; 46% from CEM data (US NEI)



SO_2 scrubbers added in 2008







Continuous Improvement

An operational system that is not sustained by continuous research and technological updates becomes irrelevant within a couple of years.

- GEM and GEM-MACH are supported by research teams within ECCC
- Innovation cycles are between 18 and 36 months.

Continuous Improvement

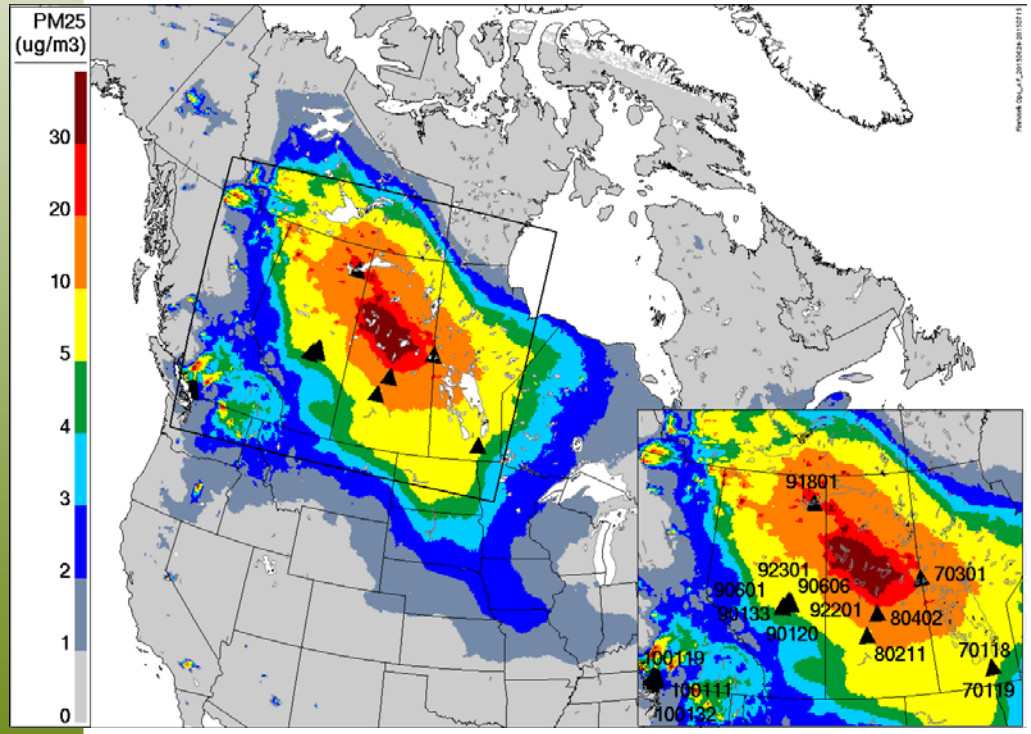
Air quality levels are changing as a result of various programs.

Snapshot of the world's AQI levels on 2016-07-22 during a heat wave in eastern NA – From https://waqi.info/

Period With Extreme Wildfires in Canada

Period: 24 June – 15 July 2015

Average wildfire emissions contribution to **total surface** $PM_{2.5}$ concentrations



Objective Scores

Statistic	Western Canada		Eastern Canada	
	RAQDPS	FireWork	RAQDPS	FireWork
MB	-11.72	-7.28	-2.34	-1.52
R	0.03	0.50	0.30	0.41
URMSE	30.00	25.81	9.79	9.26

FireWork better

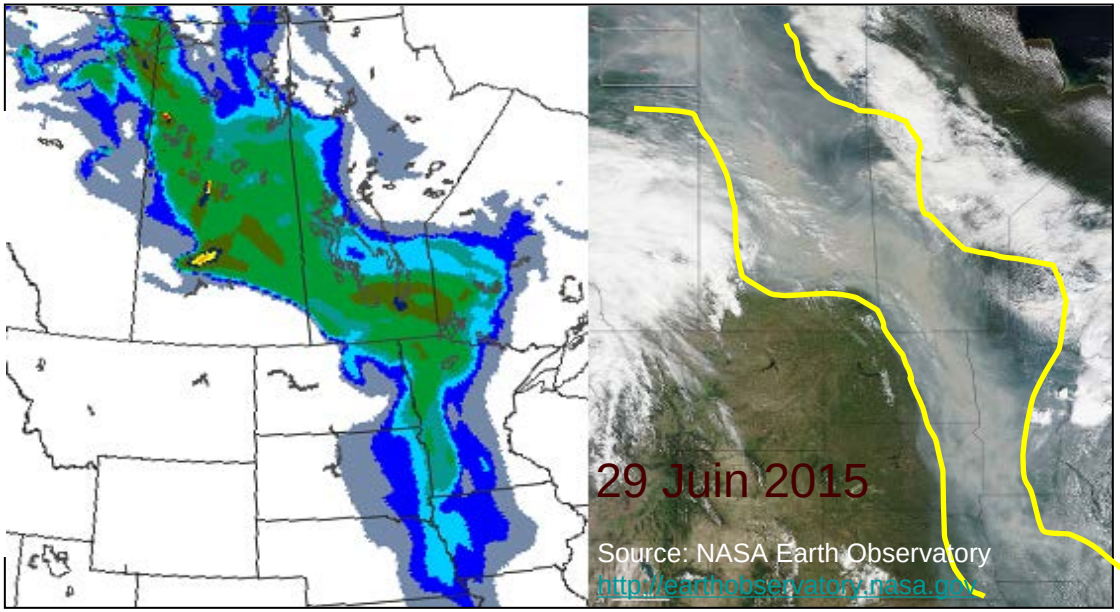
RAQDPS better

Categorical Scores

Categorical Score	Western Canada		Eastern Canada	
	RAQDPS	FireWork	RAQDPS	FireWork
POD	0%	26%	4%	11%
FAR	96%	34%	97%	95%
CSI	0%	23%	2%	4%

Period With Extreme Wildfires in Canada

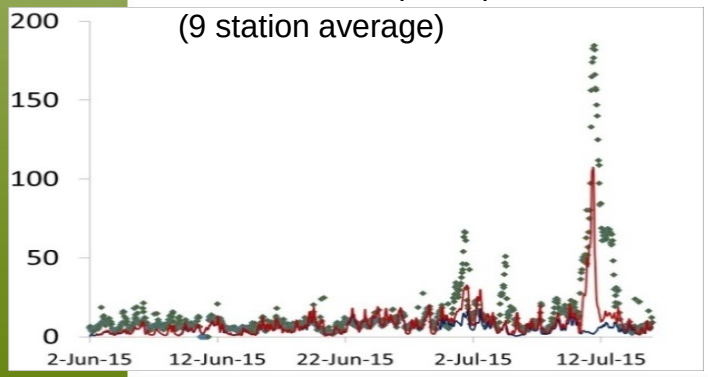
Total column $PM_{2.5}$ concentration forecasted by FireWork (2015-06-28 00UTC run), valid at June 29th 12UTC. **Forecasted 24h in advance.**



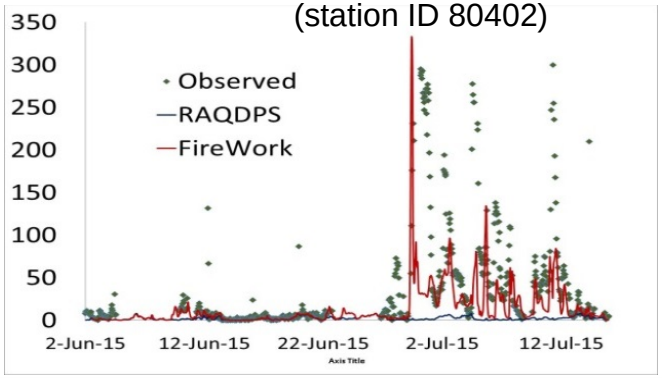
On June 29th, a dense "smoke river" from NW Canada to the central USA was observed. FireWork performed well in forecasting the affected regions.

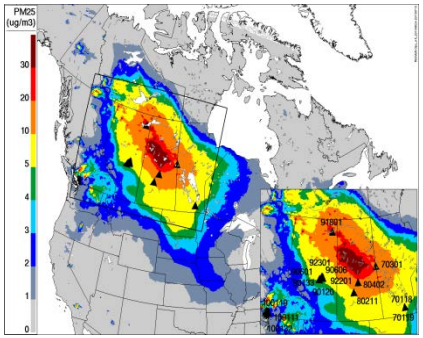
Time series

Edmonton, AL, Canada
(9 station average)



Prince Albert, SK, Canada
(station ID 80402)

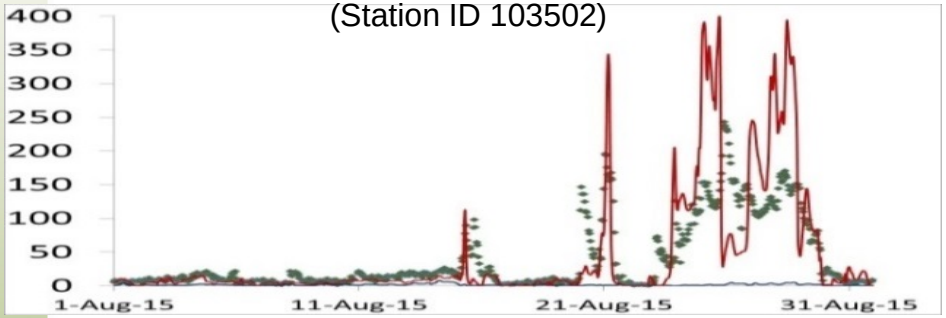




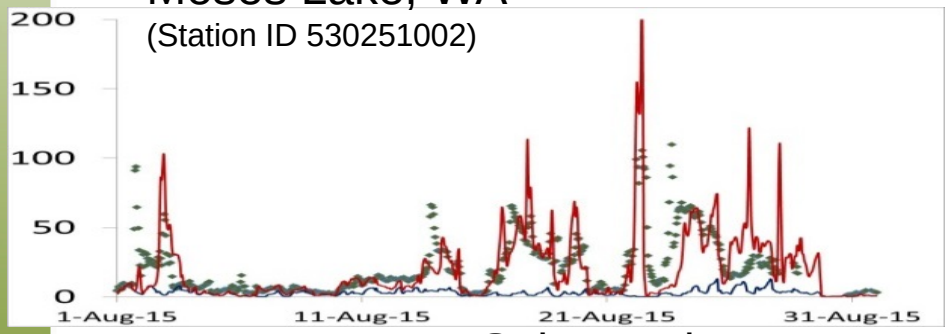
Canada

Period With Extreme Wildfires in the USA

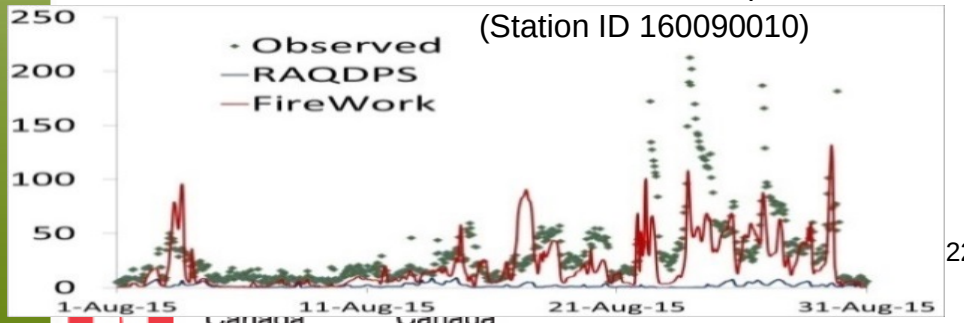
Castlegar Zinio Park, near Kelowna, BC
(Station ID 103502)



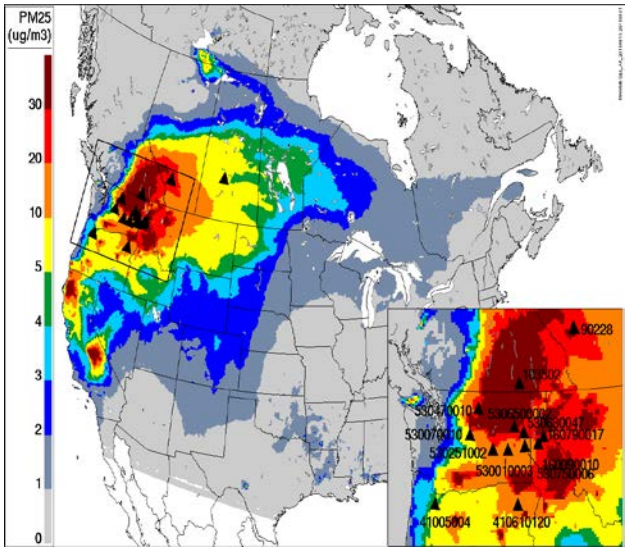
Moses Lake, WA
(Station ID 530251002)



Saint Maries, ID
(Station ID 160090010)



Time Series



Canada

Current System Limitations

- Hotspot analysis algorithms (active burning emissions vs. smoldering emissions; remote sensing is limited by cloud cover)
- No modelling of fire spread and growth nor fire suppression
- Fire size is empirically estimated
- Timeliness of remote sensing data
- Uncertainties in forecasted meteorology are affecting FireWork (Example: an error of 0-30° in wind direction can greatly impact smoke advection)
- Impact of wildfires is not taken into account by the meteorological forecast

Environment Canada | Environnement Canada

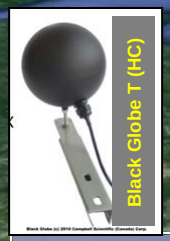
TORONTO 2015 Pan Am/Parapan Am

Canada

Environment Canada's Environment Prediction System for the Toronto 2015 Pan Am & Parapan Am Games

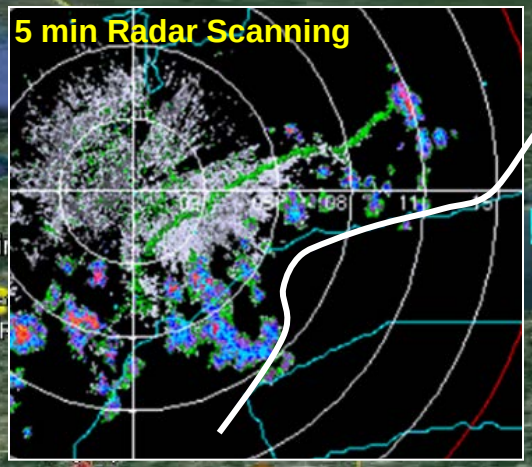
Manda
Meson


UV Monitoring




Roadside AQ


Met Sensor
3 Auto8 Legacy


5 min Radar Scanning


AQ Cruiser

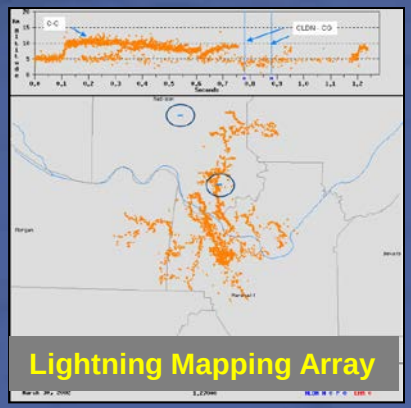

UAV – Met/AQ


X Band
Phased Array


Doppler LIDAR

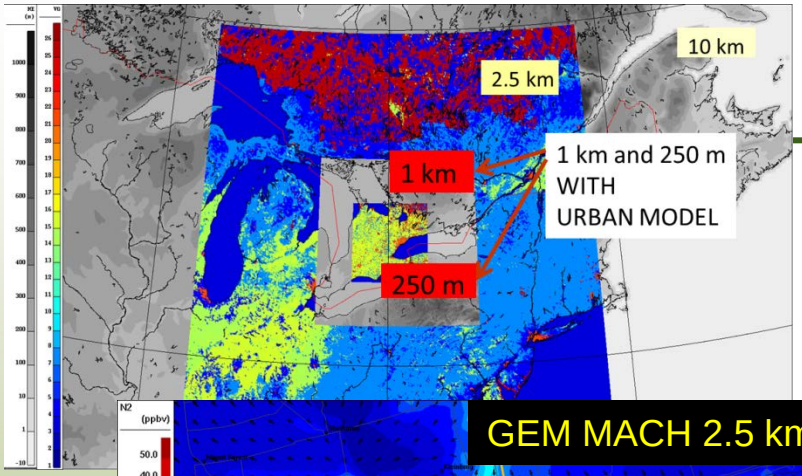

AQ Site

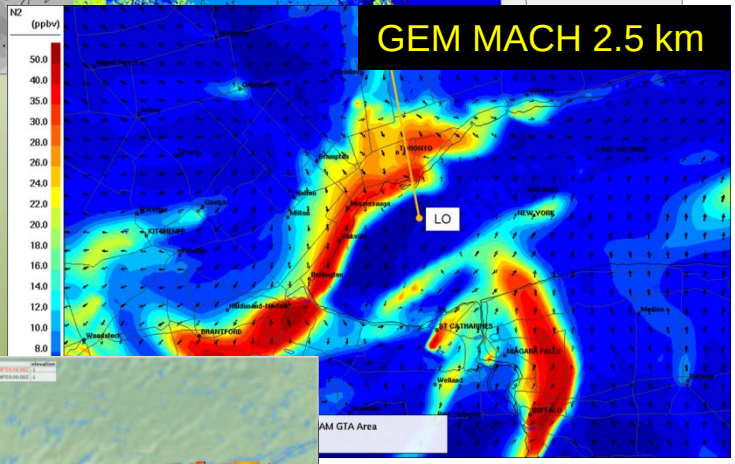

Wave Buoy
Spectra/Dir


Lightning Mapping Array

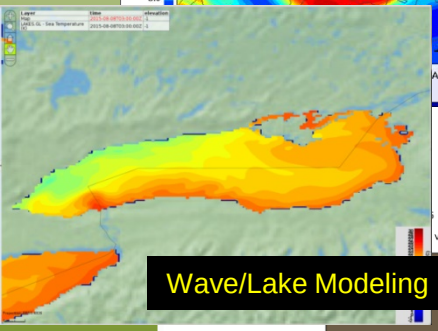
Lake Breeze

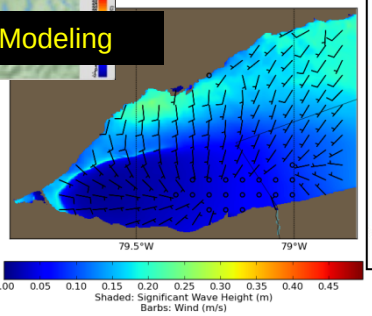
Forecast/Nowcast System

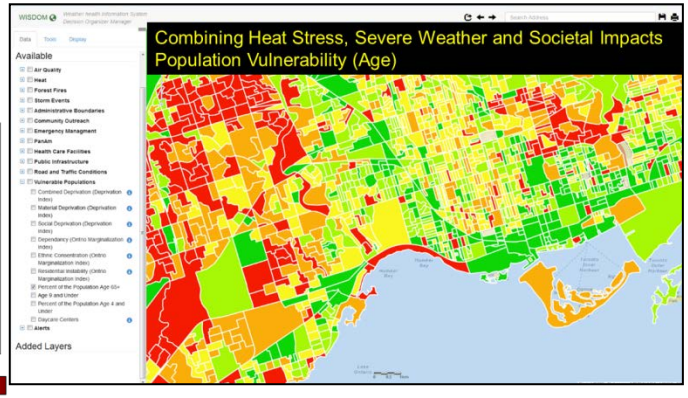


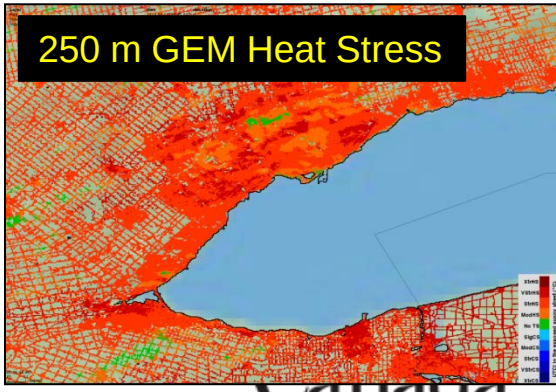


- Weather: 10km, 2.5km, 1km, 250m GEM cascade (urbanized <1km)
- AirQuality: 2.5 km GEM MACH AQ (HPC)
- Lake Model: GEM-NEMO (2km)
- Wave model :WW3 (1km deterministic)
- Heat: GEM heat stress indices
- Health Services & Societal User Impacts
- Dispersion modelling for emergency preparedness & response





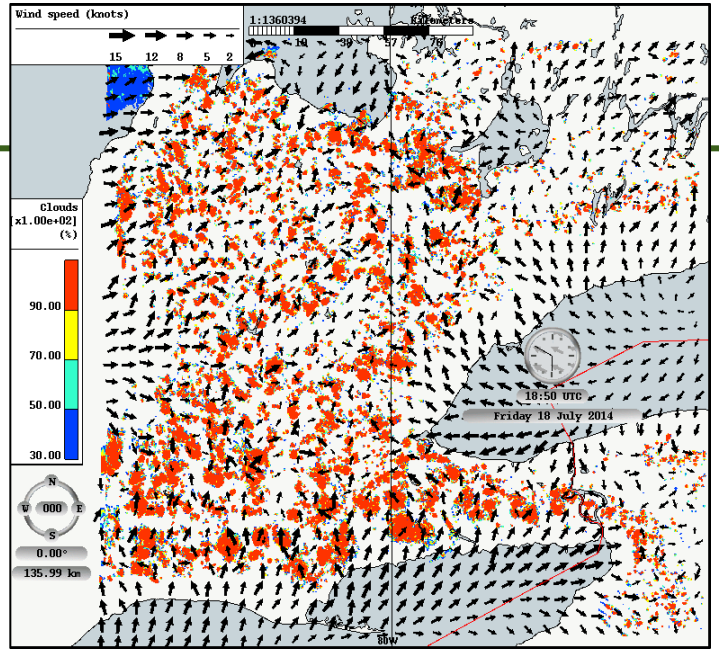




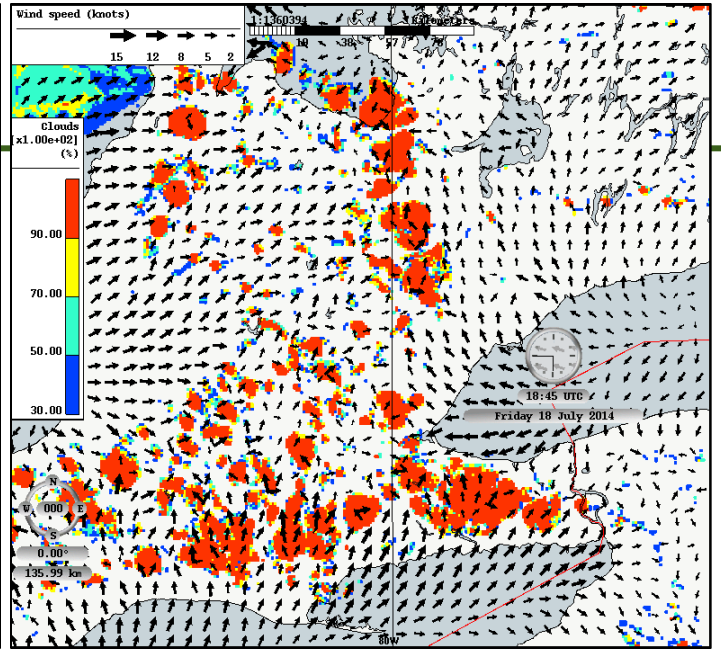
TORONTO 2015
Pan Am/Parapan Am

Cloud cover structure (18:50 UTC)

250 m

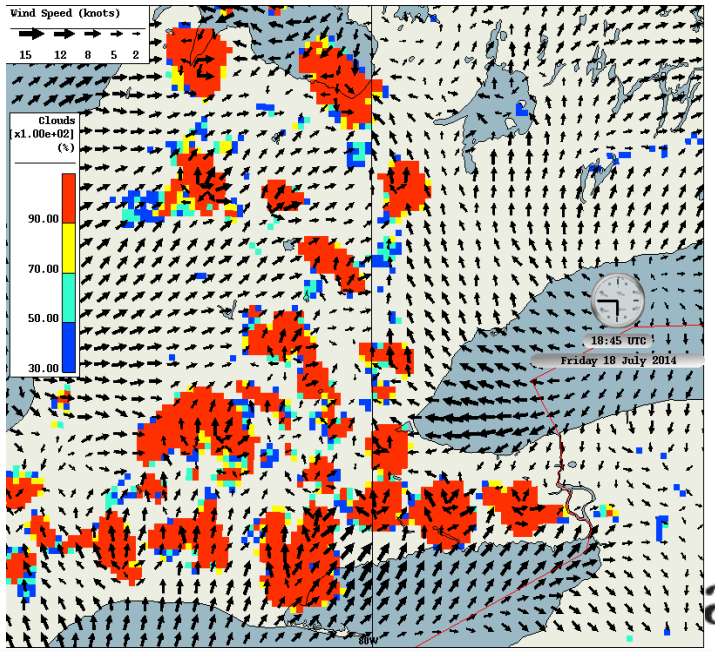


1 km

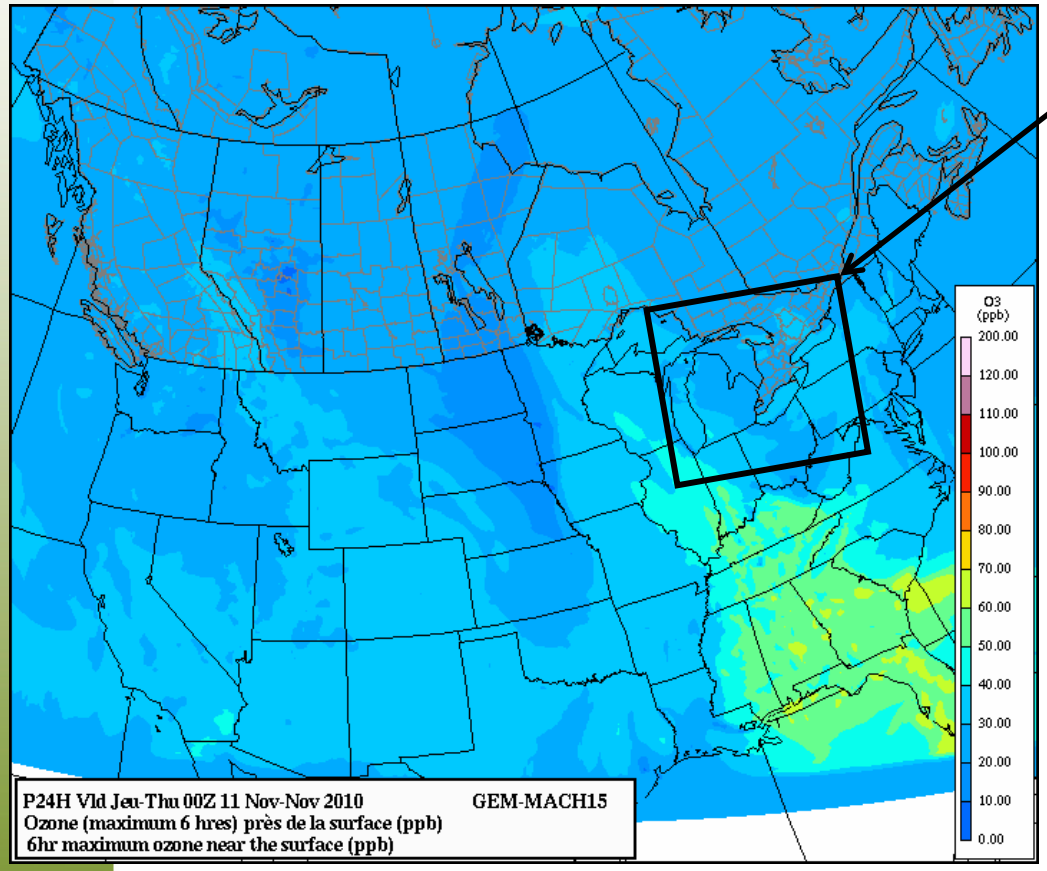


MODIS
Aqua
250 m

2.5 km



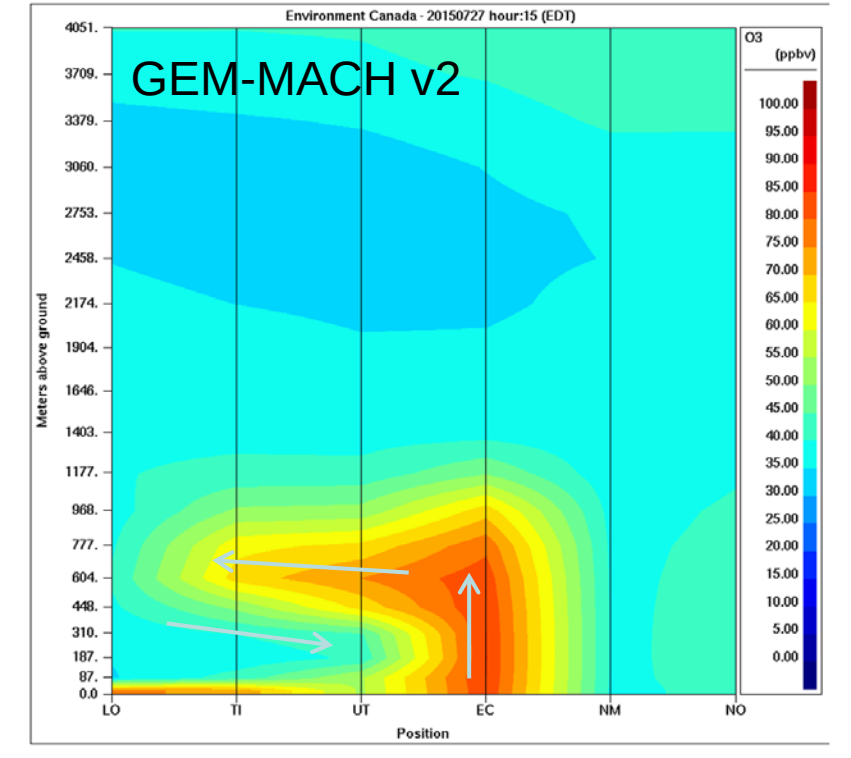
GEM-MACH v2 Model Setup for Pan Am Games (Craig Stroud, Sylvie Gravel)



GEM-MACH 10km : 48-hr forecasts started at 0Z and 12Z
GEM-MACH 2.5km : 24-hr forecasts started at 6Z

- High resolution domain, 518x418 points (2.5 km)
- Chemical species at lateral boundaries are driven by ops GEM-MACH at 10km
- Chemical species at start of each forecast are recycled from last step of previous forecast
- Met species at start of each run are from met analysis. **Cloud variables are recycled from last time step.**
- One of the objectives: Study the impact of Urban Heat Island and Lake Breeze circulations on air quality pollutant distributions

Ozone Vertical Cross Section, July 27, 15 EDT
Classic Lake Breeze Circulation

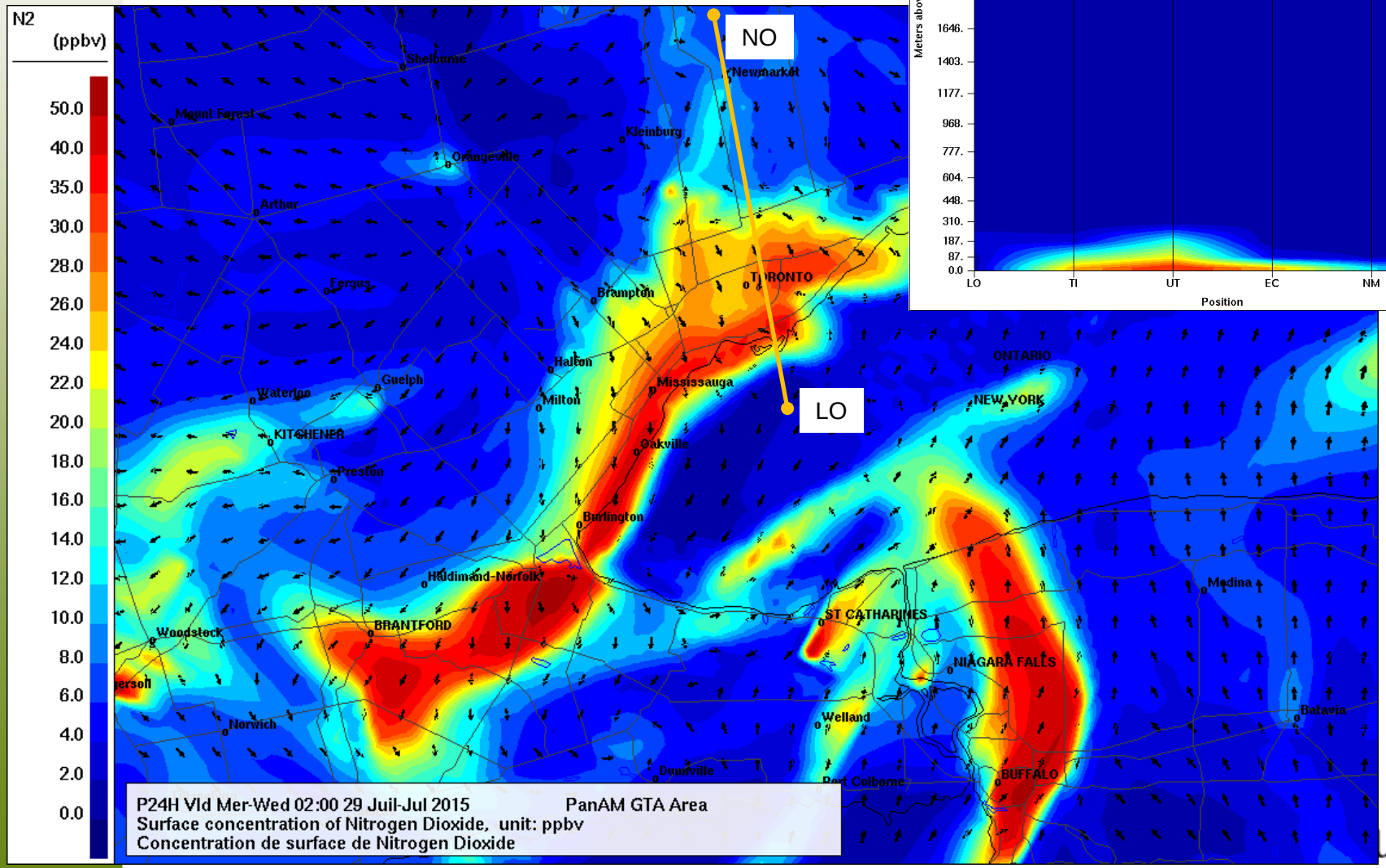


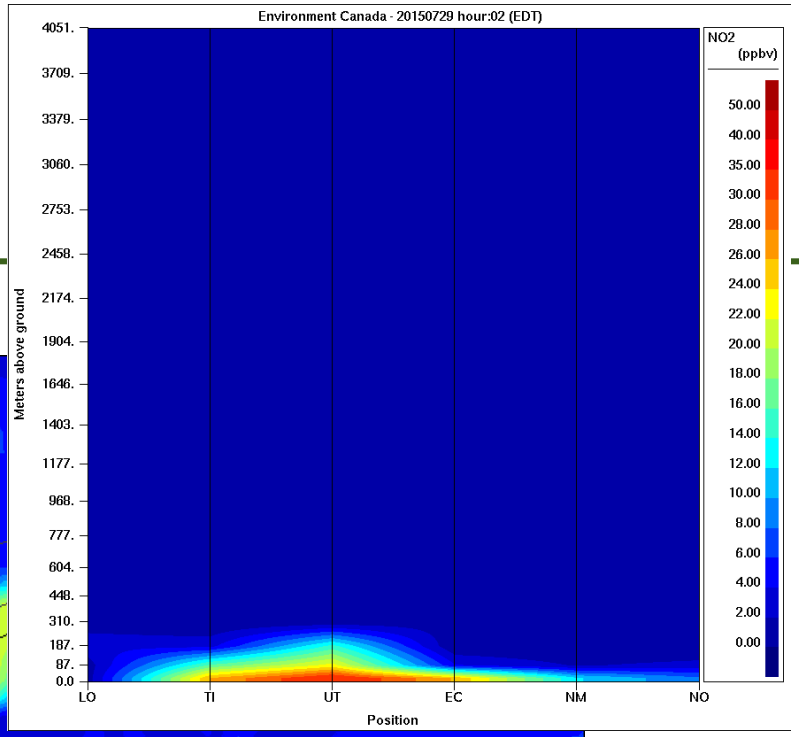
Note the GEM-MACH grid spacing

Air Quality Sites

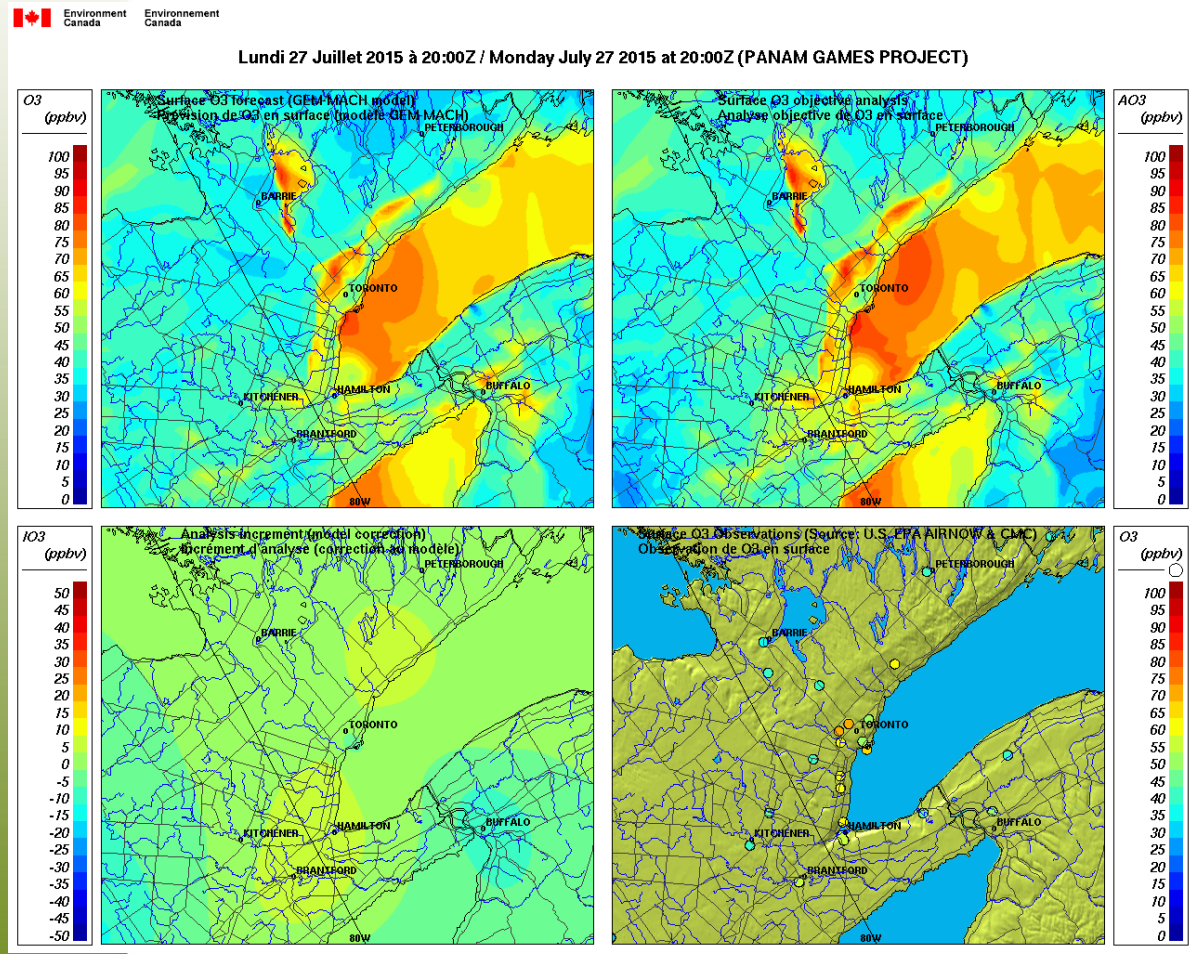
OA Oakville
MI Mississauga
PA Pearson Airport
TE Toronto East
OS Oshawa University
LO Lake Ontario
TI Toronto Island
UT University of Toronto
EC Environment Canada
NM Newmarket
NO North GTA

GEM-MACH NO_2 July 29, 02 EDT, Night Urban Effects

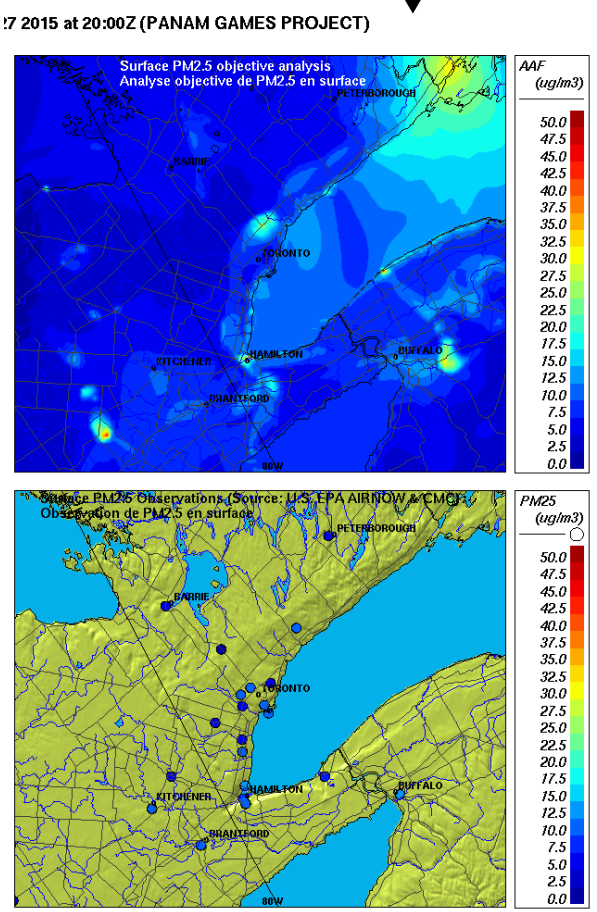




Chemical Objective Analysis for Ozone and $PM_{2.5}$ at 2.5km resolution (Alain Robichaud)



O_3 $PM_{2.5}$



Environment Canada Environnement Canada

Canada

PERFORMANCE AND RESOLUTION: 2.5km vs 10km

GEM-MACH Model Evaluation (Bootstrapping method)

	O3		NO2		PM2.5	
	HRDPS vs OBS	RDPS vs OBS	HRDPS vs OBS	RDPS vs OBS	HRDPS vs OBS	RDPS vs OBS
R	0.39	0.25	0.81	0.87	0.56	0.42
MB	-3.25	3.99	1.68	2.62	-1.55	1.47
RMSE	5.05	6.50	3.52	4.35	3.20	4.10
HRDPS TOTAL				7		
RDPS TOTAL				2		

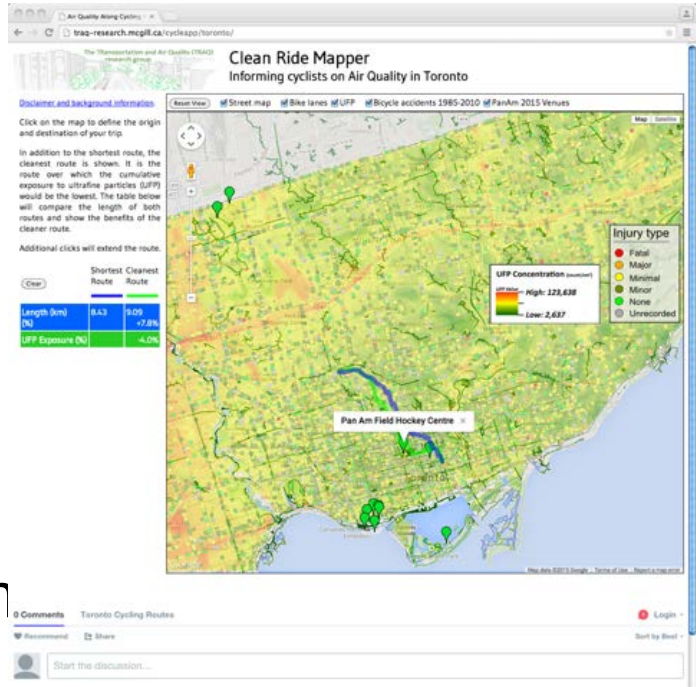
HRDPS: High Resolution AQ model – 2.5km
RDPS: Regional AQ model – OPS 10km

Next steps:

- **Rerun at 1km with urbanized version**
- **Legacy dataset for entire Pan Am period (all AQ and met obs) – WWRP HiWeather Project**

Clean Ride Toronto

- The cycling app for Toronto was developed by McGill University and Health Canada
  - http://traq-research.mcgill.ca/cycleapp/toronto/
- New features
  - Improved navigation
  - More data (e.g. Pan Am Venues)
  - Ultrafine Particle Surface
- Toronto District School Board
  - Eco-schools
  - Summer School on Wx & Health

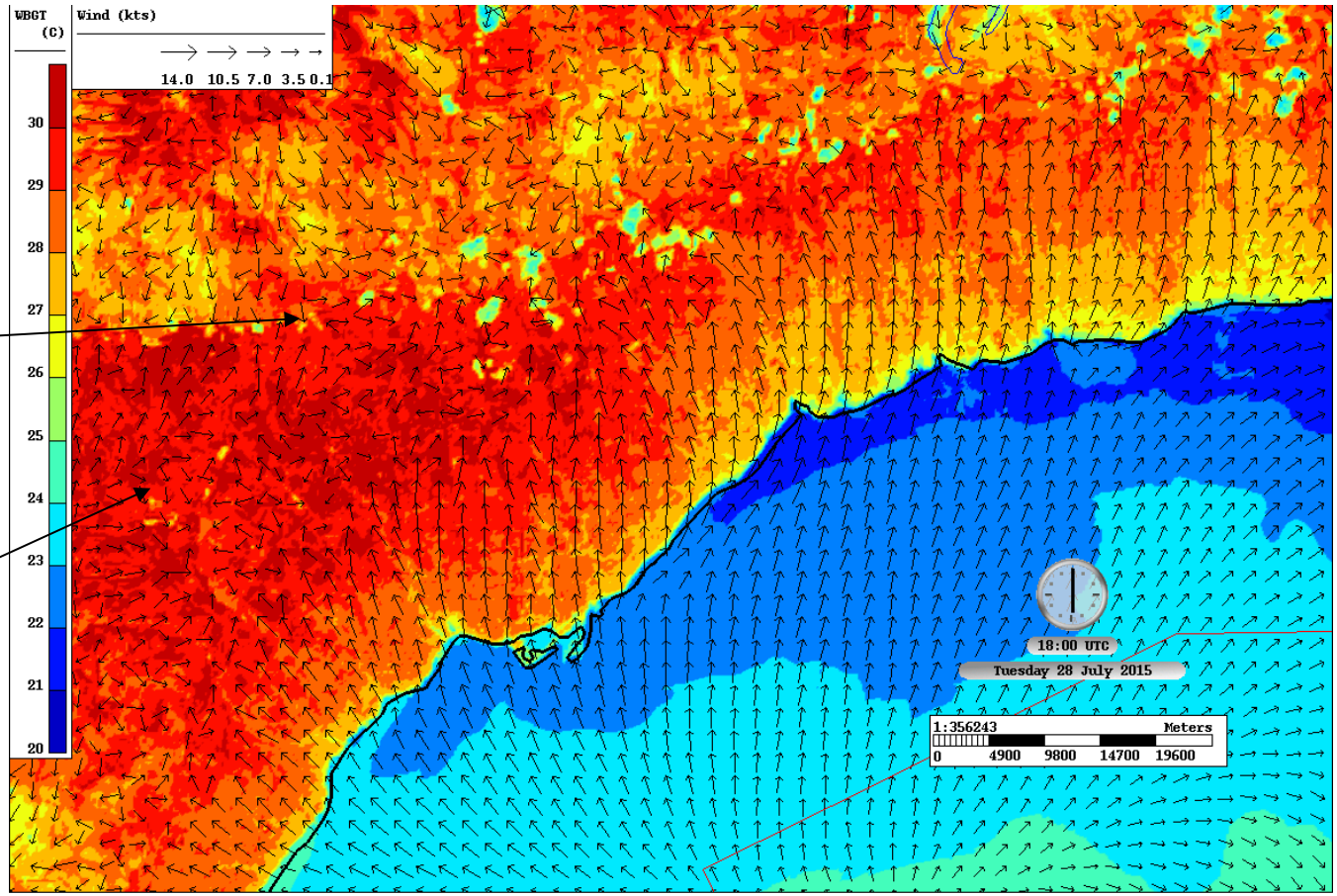


Heat event: An example of heat stress from 250-m GEM model (WBGT)

WBGT – Wet Bulb Globe Temperature

Effect of clouds, along the breeze front

"Hot" zone: effect of city and lake breeze

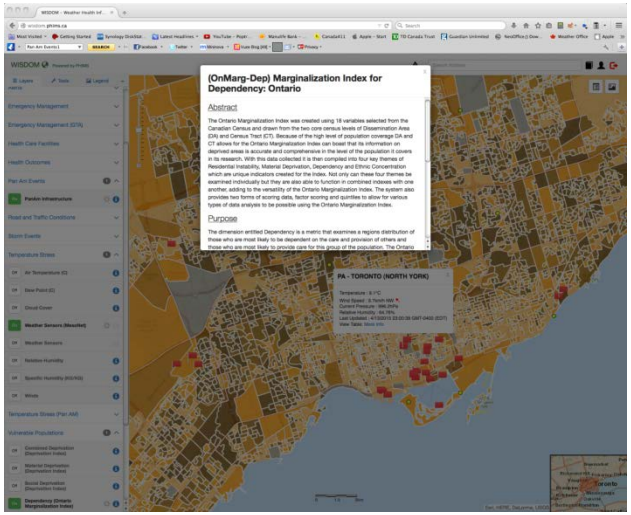


Valid 2:00 pm on July 28, 2015

WISDOM

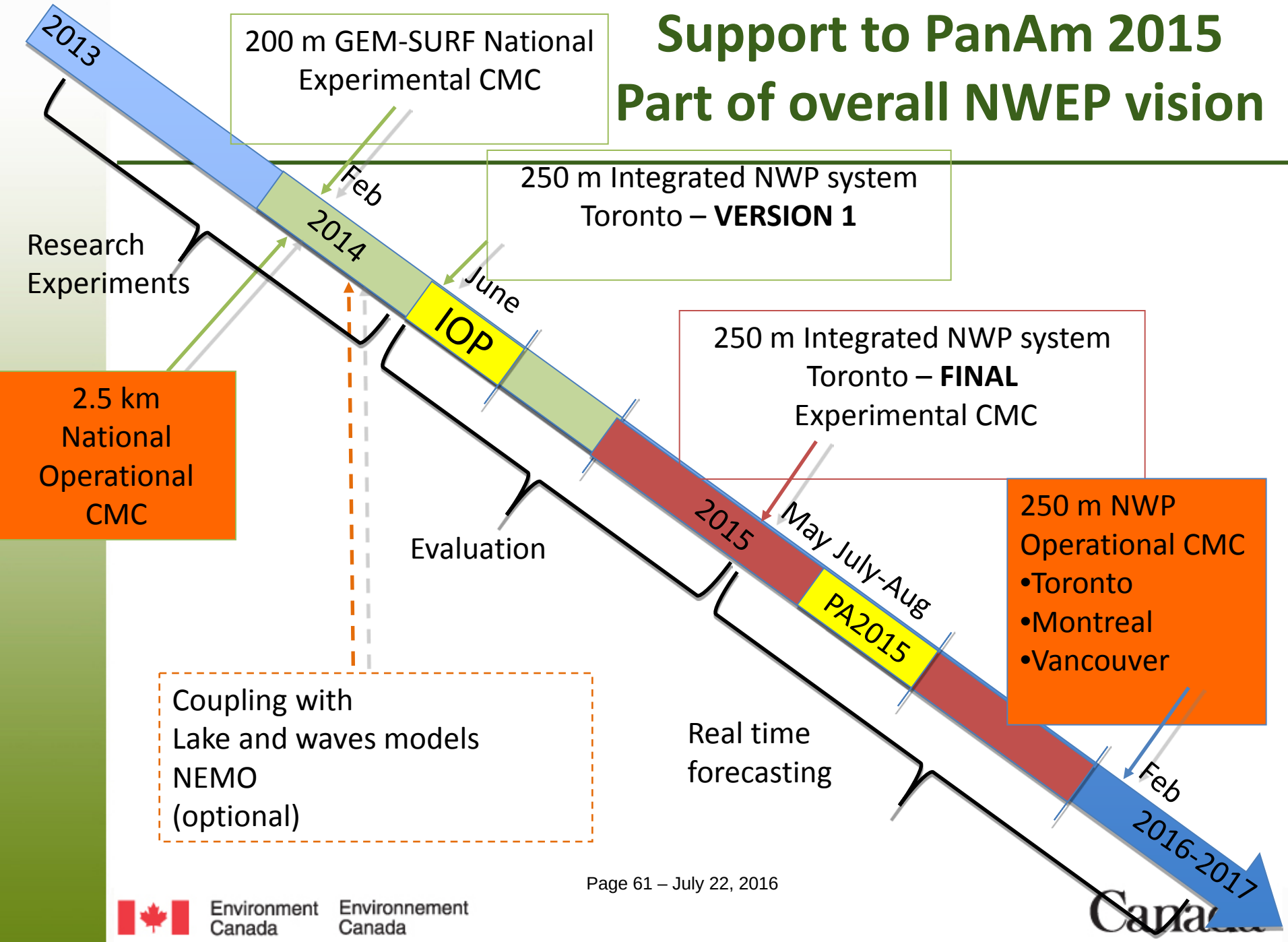
Weather and health Information System for Decision Optimization and Management

- Developed in collaboration with KFL&A Public Health
  - Based on PHIMS (Public Health Information Management System)
- Common Operating Picture – Situational awareness tool for environmental risks related to public health
  - Custom ESRI GIS platform
  - Responsive design
  - Password protected



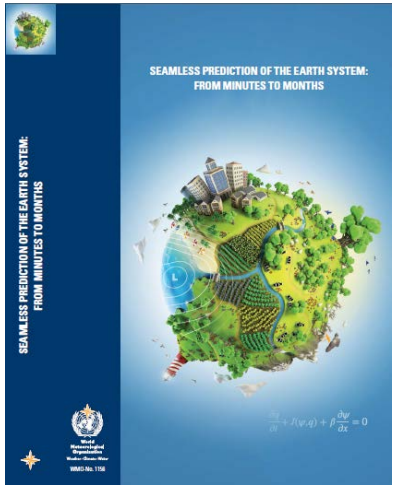
- Integration of monitoring/prediction with health outcomes in real-time
  - Socio-economic and psycho-social static data
    - To support interventions with vulnerable populations

Support to PanAm 2015
Part of overall NWEP vision



Working closer with NWP scientists

- **WWOSC2014 - Seamless prediction of the Earth system: from minutes to months** (Available online at: http://library.wmo.int/pmb_ged/wmo_1156_en.pdf)



- **Chapter 12: Seamless meteorology-composition models: challenges, gaps needs and future directions** (A. Baklanov et al, 2015)
- **Chapter 18: *Urban-scale environmental prediction systems*** (C.S. Grimmond et al, 2015)
  - Resolution to describe urban effects for different applications
  - Methods to routinely gather and continuously update dynamically changing land cover
  - Advance coupled models that simulate the feedback between human activities and urban environmental conditions
  - Data assimilation methods to support coupled prediction systems

WWOSC 2014
MONTRÉAL, CANADA

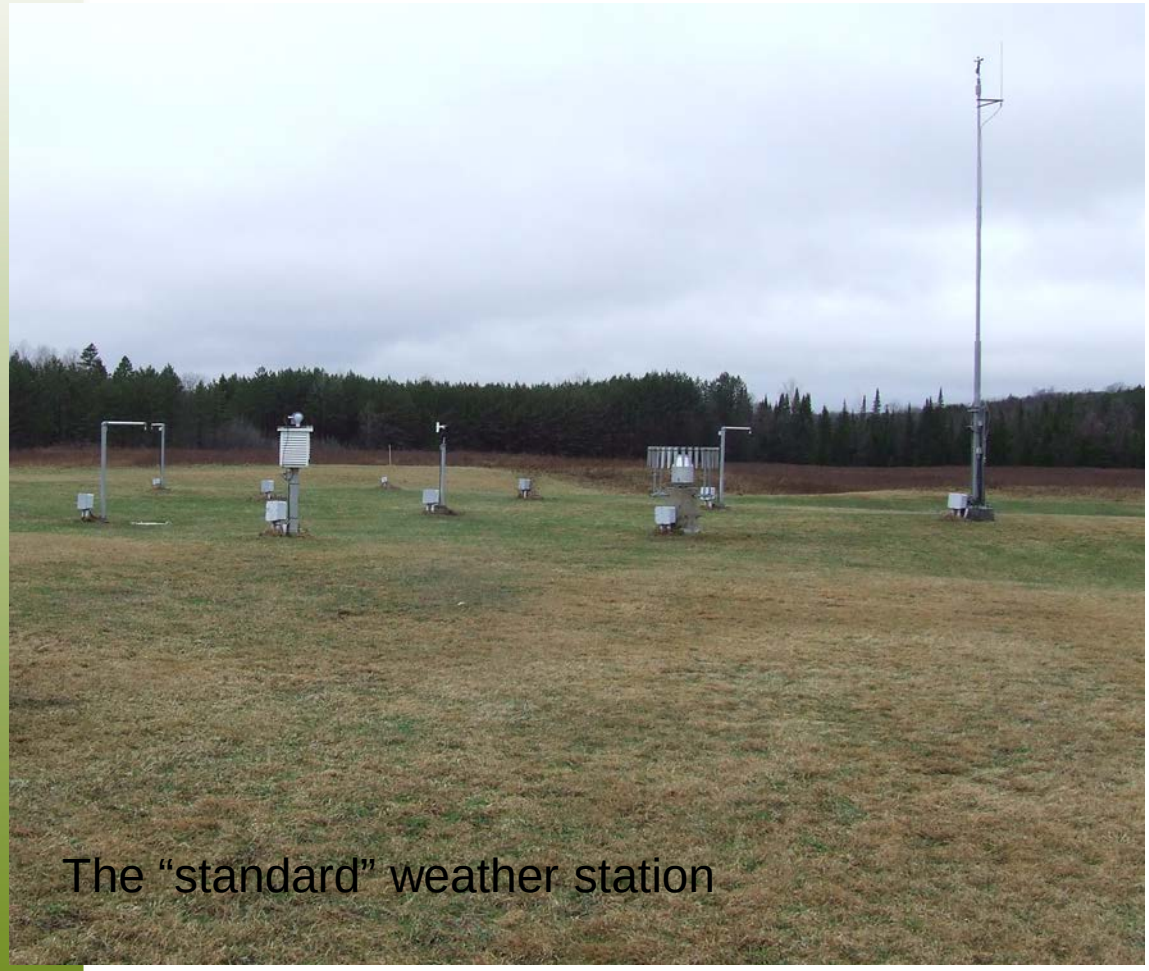
GAW Urban Research Meteorology and Environment Project (GURME)

Created under GAW in 1995:

- To enhance the capabilities of NMHSs in providing urban-environmental forecasting and air quality services of high quality, illustrating the linkages between meteorology and air quality;
- In collaboration with other WMO programmes, WHO and environmental agencies, to better define meteorological and air quality measurements focusing specifically on those that support urban forecasting;
- To provide NMHSs with easy access to information on measurement and modeling techniques;
- To promote a series of pilot projects to demonstrate how NMHSs can successfully expand their activities into urban environment issues.

mce2.org/wmogurme.org/ (hosted by L. Molina)

The Urban Challenge



Quality control of urban measurements must take into account the highly variable surface.

Emissions: Where to?

Atmospheric Environment

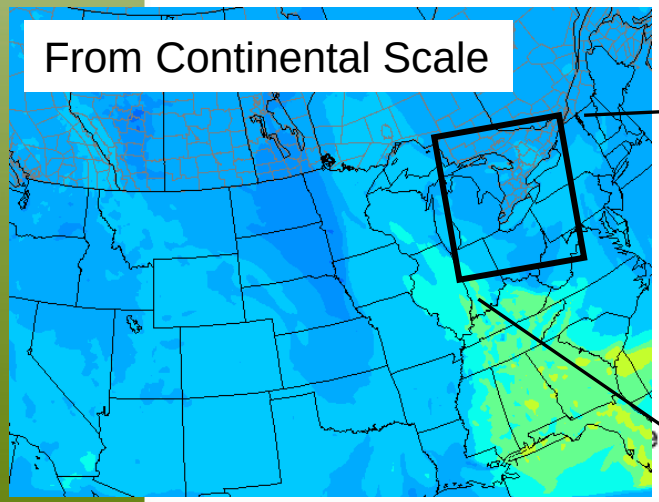
Volume 116, September 2015, Pages 320–322

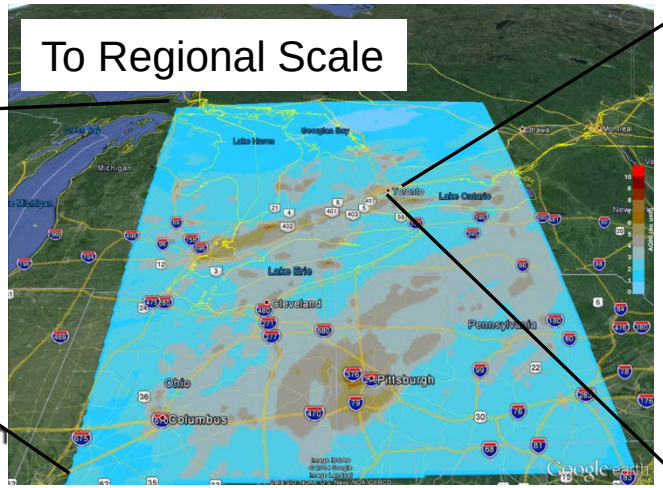
Operational forecasting of source impacts for dynamic air quality management

Yongtao Hu[a], M. Talat Odman[a], Michael E. Chang[b], Armistead G. Russell[a]

Conclusion

- Air Quality Forecasting is an integral part of Numerical Prediction and the challenges ahead will need to be addressed in a coupled ‘earth’ system approach
- Technology transfer to Operation / R2O is critical
- Urban-scale systems and services emerging rapidely
- Looking forward to the next 15 years





IWAQFR workshop series

- 2009: Boulder, Co
- 2010: Quebec City, Canada
- 2011: Potomac, Maryland
- 2012: Geneva, Switzerland
- 2013: Santiago, Chile
- 2014: Montreal, Canada in conjunction with WWOSC
- 2015: College Park, Maryland
- **January 2017: Toronto, Canada**

ADDITIONAL SLIDES

GURME Terms of Reference

- Address the research barriers to advance the predictive capacity at increasing resolutions, and in the urban context in particular: through the coordination of reviews in the current state of science in urban-scale forecasting and associated monitoring, establish activities where gaps exist.

- Develop activities on those research questions/issues that transcend disciplines and require leveraging a broader community to develop improved forecasting concepts and tools to resolve complex urban environments at increasing scales; facilitate data sharing and establishment of test beds.

- Given the integrative nature of modelling, the on-going scientific trend towards seamless predictions and the evolution of technology, actively engage other WMO advisory and working groups within WWRP, GAW and the rest of its organisation, to address this complex and multidisciplinary challenge.

- While megacities will continue to receive particular attention, orient its research to cover the full array of urban environments that are key to the broader scientific question of urban-scale modelling.

GURME Terms of Reference – cont'

- Continue to nurture its engagement with the health community as the main partner in assessing the needs, evaluating the benefits and communicating resulting services to society within these urban environments.

- Build capacity through its research projects, identifying those environments that constitute gaps in the overall directions of the GURME program and Encourage in its projects the development and testing of derived services. The products themselves would take the form of forecasts, alerts and warnings and/or real-time/NRT maps or databases.

- Forge stronger collaborations with CBS and/or individual operational centres to transition products in dissemination systems in a form that is well suited for large or targeted audiences.

- Collaborate explicitly with the Apps-SAG on projects at the interface of regional and local scales and contribute actively to facilitating data assimilation efforts focused on integrated/coupled models and at finer and finer scales.