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

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Environment Canada

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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, PM₂.₅ forecast program
- As of today, forecasts are communicated in most areas as an Air Quality Health Index (AQHI)

\[
\text{AQHI} = \left(\frac{10}{10.4}\right) \times 100 \times \left[\exp\left(0.000871 \times \text{NO}_2\right) - 1\right] + \left[\exp\left(0.000537 \times O_3\right) - 1\right] + \left[\exp\left(0.000487 \times \text{PM}_{2.5}\right) - 1\right]
\]
Overview of the Canadian AQ Forecast Program – Public Forecasts

http://weather.gc.ca

Air Quality
Find the latest local air quality forecasts and information.

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$_{2.5}$/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
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 = Regional Air Quality Deterministic Prediction System
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 (O₃, NO₂, PM₂.₅) in 2010
  - Equations are recalculated four times a month
Products: **Air Quality Health Index**

Used for public forecasts:
- Multi-pollutant index
- Triggers warnings

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

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 (O₃, PM₂.₅, NO₂), 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 (AQMAQ)

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

In case of problems, refer to this document | Français

Forecast Report
Select month

Active Notices
No active notices available

Notice Archive

Surface Field Maps
GEM-MACH
- NO2
- CO
- PM10
- PM2.5
- AQHI 5
- AQHI 10

Objective Analysis
- AQHI
- NO
- NO2
- CO
- PM10
- PM2.5
- SC10

Observation Maps
- AQHI
- Hourly
- British Columbia
- Vancouver

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

AQHI observation availability for the last 6 months

<table>
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<tr>
<th>Site / Month</th>
<th>2015-02</th>
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The target for minimum availability of the AQHI at any site is at least 85%

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

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

- **GEM-MACH**
  - Ozone forecast (GEM MACH model)

- **OA**
  - Objective ozone analysis

- **Analysis Increments**
  - Difference analysis objective - forecast difference

- **Observations**
  - Ozone based on surface observations
  - 1089 stations
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$_{2.5}$/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
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

Observed hourly PM$_{2.5}$ up to 250 µg/m$^3$
Products: FireWork Forecaster Resource Site

FIREWORK-GEHMACH SITE

Forecast Report

- Select month
- Nunavut
  - Iqaluit (CATP)
  - Iqaluit (25300)
- Northwest Territories
  - Inuvik (CATP)
  - Inuvik (51900)
  - Yellowknife (CLAMAC)
  - Yellowknife (121000)
- Unassociated stations
  - Tuktoyaktuk (123001)
- Alberta
  - Calgary (AQICN)
  - Calgary Central (10320)
  - Calgary Northeast (10322)
  - Calgary Southeast (10320)
  - Cold Lake (AQICN)
  - Cold Lake South (10301)
  - Drumheller Valley (AQICN) & Spokane (SAPM)
  - Edmonton (50101)
  - Medicine Hat (50101)
  - Medicine Hat (50101)
- Edmonton (AQICN)
  - Edmonton Central (10301)
  - Edmonton East (9821)
  - Edmonton South (9821)
- Woodcroft (50133)

Active Notices

No active notices available

Notice Archive

Surface Field Maps

- PM2.5
- PM10
- AQHI
- AQHI 2.5

Difference Plots

- PM10 surface
- PM2.5 surface
- PM2.5 column
- PM10 column

PM2.5 Difference Summary / Différence de PM2.5 Semaine

Observation Maps

- AQHI
  - Alberta
  - Baffin Island
  - Northwest Territories
  - Southeast

Observation availability for the last 6 months

- AQHI

- 24-hour observation summaries
- FireWork-GEHMACH summaries for next 24 hours
- Monitoring of incoming air quality observations (Not operational)
- Troubleshooting Guide: Procedures for SPs
- Current CWF II hotspot map
- Recent CWRF hotspot map
- FireWork-GEHMACH output in CSV format

17 – 23 septembre 2015
FireWork forecasts available as WMS/KML layers

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:
**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
VAQUM Products

**Daily Maximums Statistics**

- Per observation value bin graphs
- Per station statistics

**In Areas Time Series**

- rmse

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**Table:**

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<th>Pollutant</th>
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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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