

# Recent Upgrades to the Operational Air Quality Forecasting Systems in Canada: Description and Performance Analysis



D. Davignon<sup>1</sup>, R. Pavlovic<sup>1</sup>, M. D. Moran<sup>2</sup>, P. A. Beaulieu<sup>1</sup>, S. Gilbert<sup>1</sup>, S. Gravel<sup>2</sup>, H. Landry<sup>1</sup>, A. Lupu<sup>2</sup>, R. Munoz-Alpizar<sup>1</sup>, and V. Savic-Jovcic<sup>2</sup>

<sup>1</sup>Air Quality Modeling Applications Section, ECCC  
<sup>2</sup>Air Quality Research Division, ECCC  
**Corresponding Author:** : *Didier Davignon* ([didier.davignon@canada.ca](mailto:didier.davignon@canada.ca))

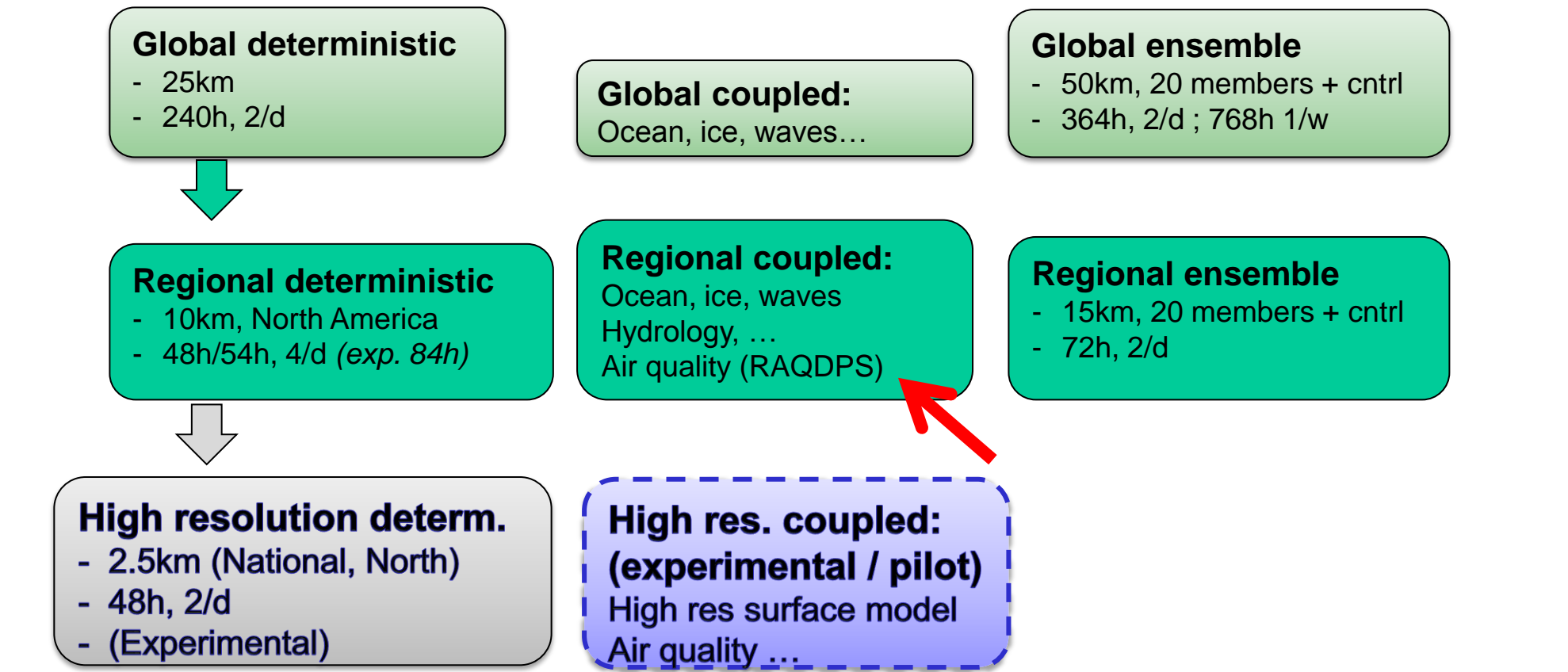
## Abstract

In 2016, Environment and Climate Change Canada introduced major upgrades to its Regional Air Quality Deterministic Prediction System (RAQDPS), operated by the Canadian Meteorological Centre Operations (CMCO). At the heart of the RAQDPS is still the GEM-MACH model, an on-line coupled meteorology–chemistry model, but upgrades were made both to the GEM (weather) and the MACH (chemistry) modules. The spatial configuration still includes a rotated uniform North American grid at 10-km horizontal grid spacing and with 80 vertical levels, but with a modified orientation, and now using a new vertical coordinate (log-hydrostatic-pressure hybrid) with discretization on a staggered vertical grid of the Charney-Phillips type. Various improvements were made to the weather module, notably including the introduction of a mass-conserving semi-Lagrangian advection scheme for tracers. The CHEM module has additional changes that include an improved treatment of surface fluxes and vertical diffusion, leaf-area scaling in the gas-phase dry deposition scheme, and three-dimensional seasonal chemical lateral boundary conditions.

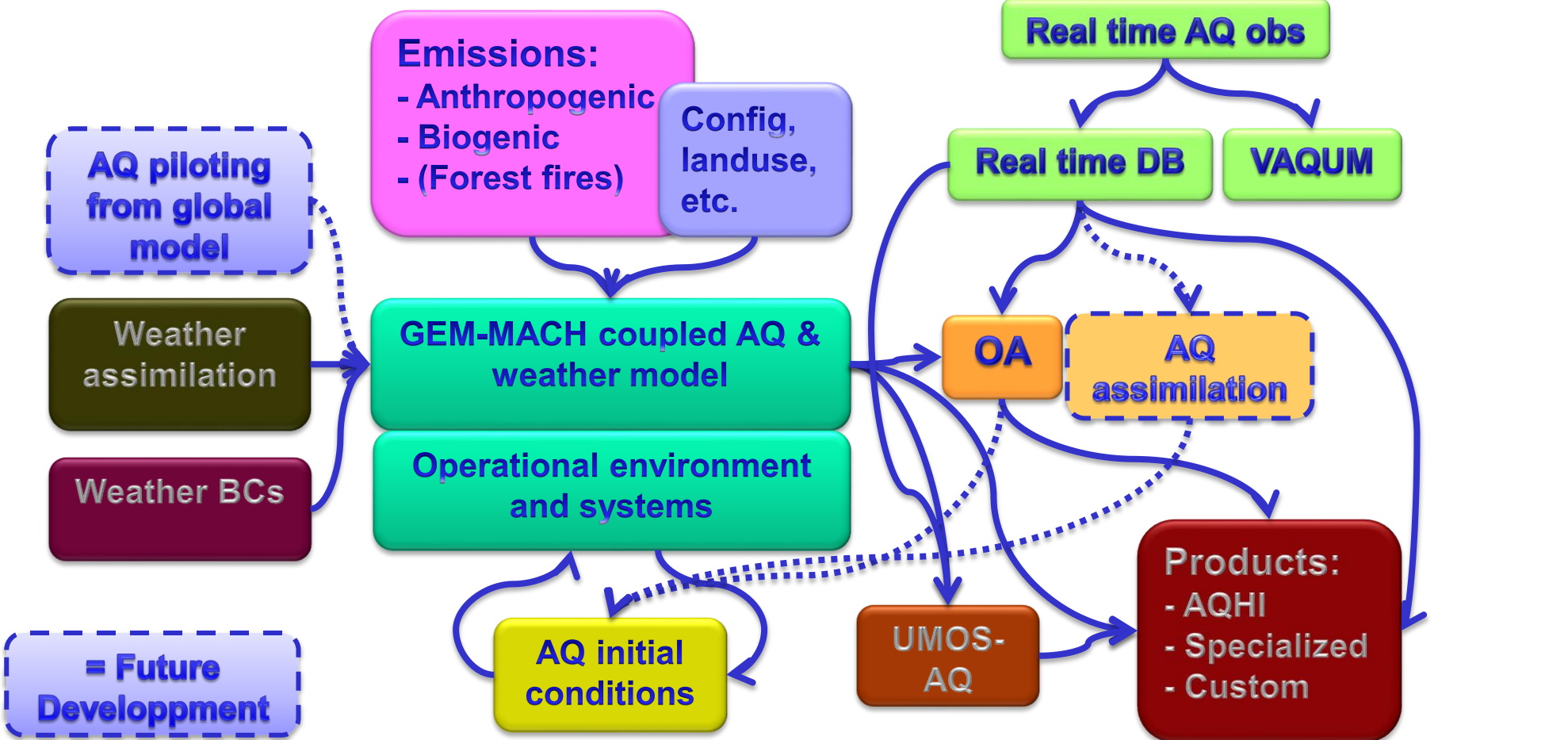
This suite of changes impacted both the RAQDPS forecast and the wildfire smoke forecast from the cloned FireWork system. Recent RAQDPS and FireWork system performance is summarized, with a discussion on the benefits of the various changes mentioned above.

## RAQDPS overview

### Numerical modelling at the Meteorological Service of Canada

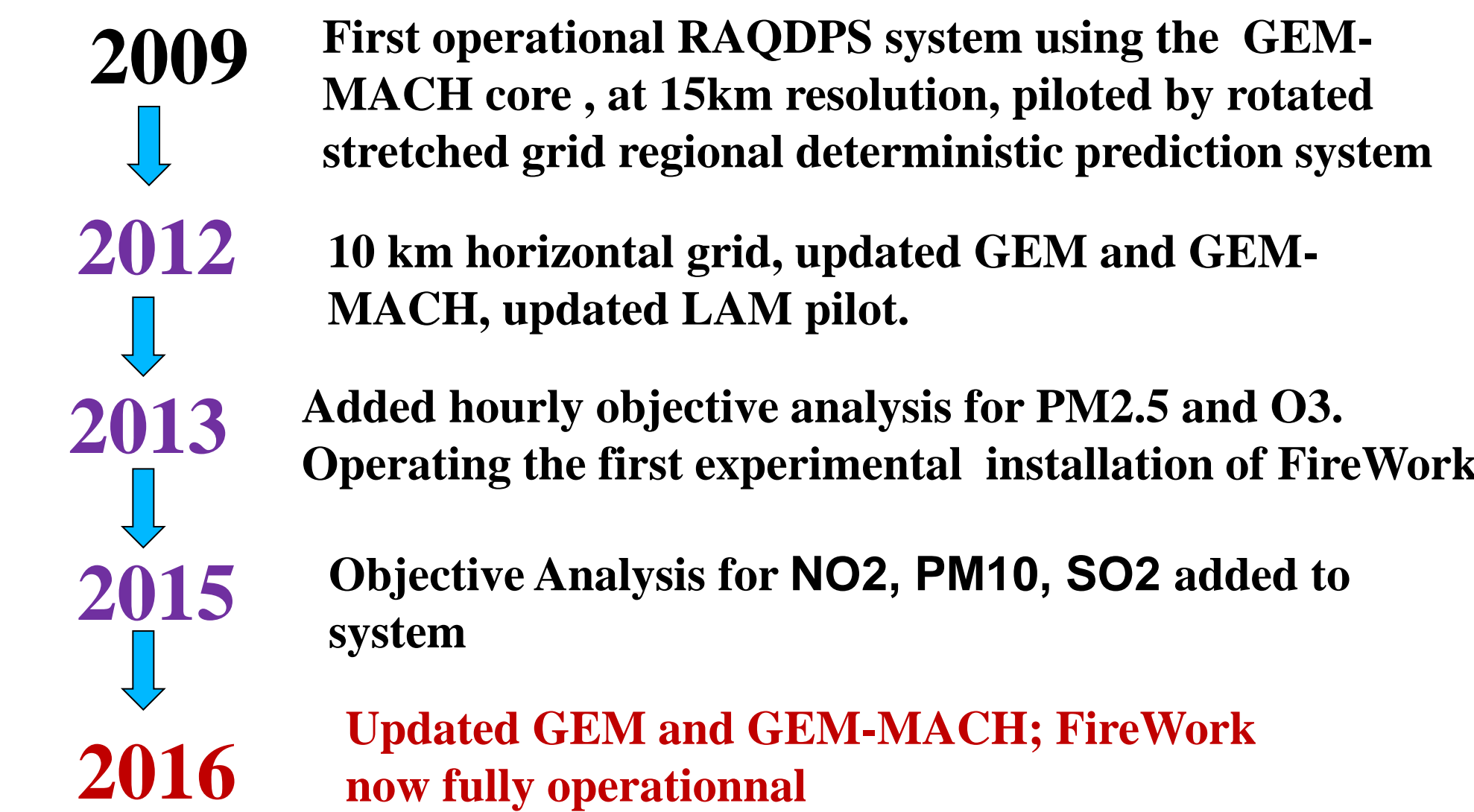


### RAQDPS components

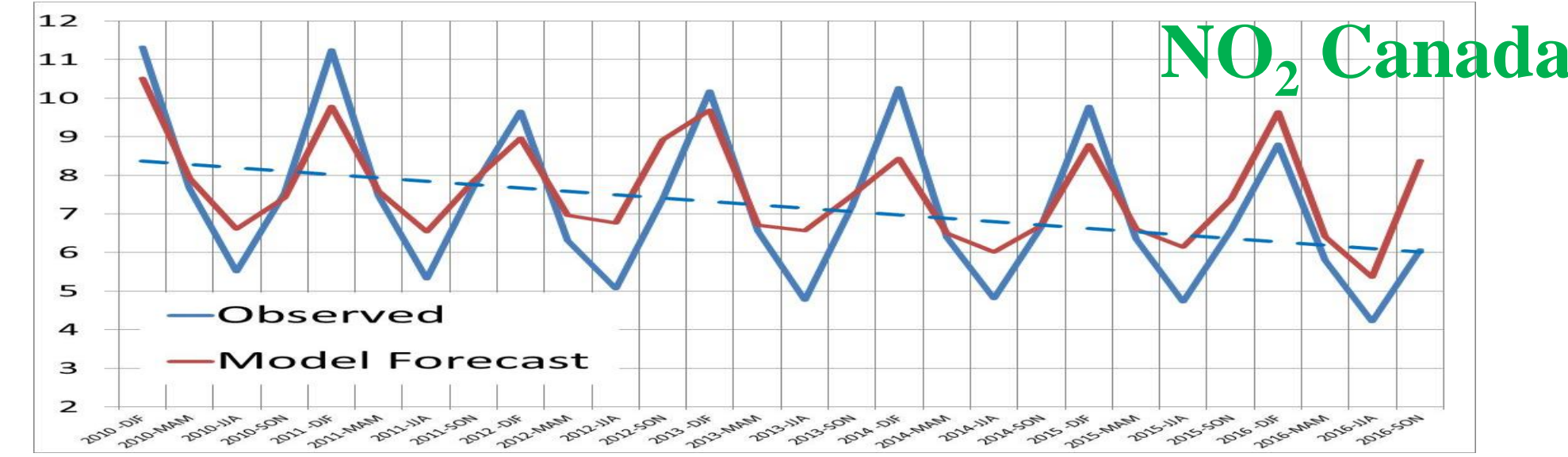


Component	Short description
OA	Objective Analysis available for O <sub>3</sub> , PM <sub>2.5</sub> , PM <sub>10</sub> , SO <sub>2</sub> , NO, NO <sub>2</sub> and AQHI
Emissions	Anthropogenic emission inventory based on: 2010 for Canada, 2011 for USA and 1999 for Mexico
UMOS-AQ	Operational Statistical Air Quality Post-Processing Package
AQHI	Air Quality Health Index $AQHI = (10/10.4) \cdot 100 \cdot [(exp(0.000871 \cdot NO_2) - 1) + (exp(0.000537 \cdot O_3) - 1) + (exp(0.000487 \cdot PM_{2.5}) - 1)]$
Forest fires emissions	Near-Real-Time biomass burning emissions are provide to FireWork AQ system
VAQUM	Verification of Air QUality Models System essential tool to assess the performance of development and operational AQ forecasting systems
AQ initial conditions	12h forecast from previous run are used as initial conditions

## RAQDPS implementation timeline



## Observed Pollution Trends



## Upgrades to the GEM-MACH dynamics and chemistry module

GEM = Global Environmental Multiscale  
MACH = Modelling Atmospheric Chemistry

### Regional grid :

- 10 km horizontal grid spacing
- 80 vertical levels with lid at 0.1 hPa (~10 levels in 1<sup>st</sup> km above surface)

### Schedule:

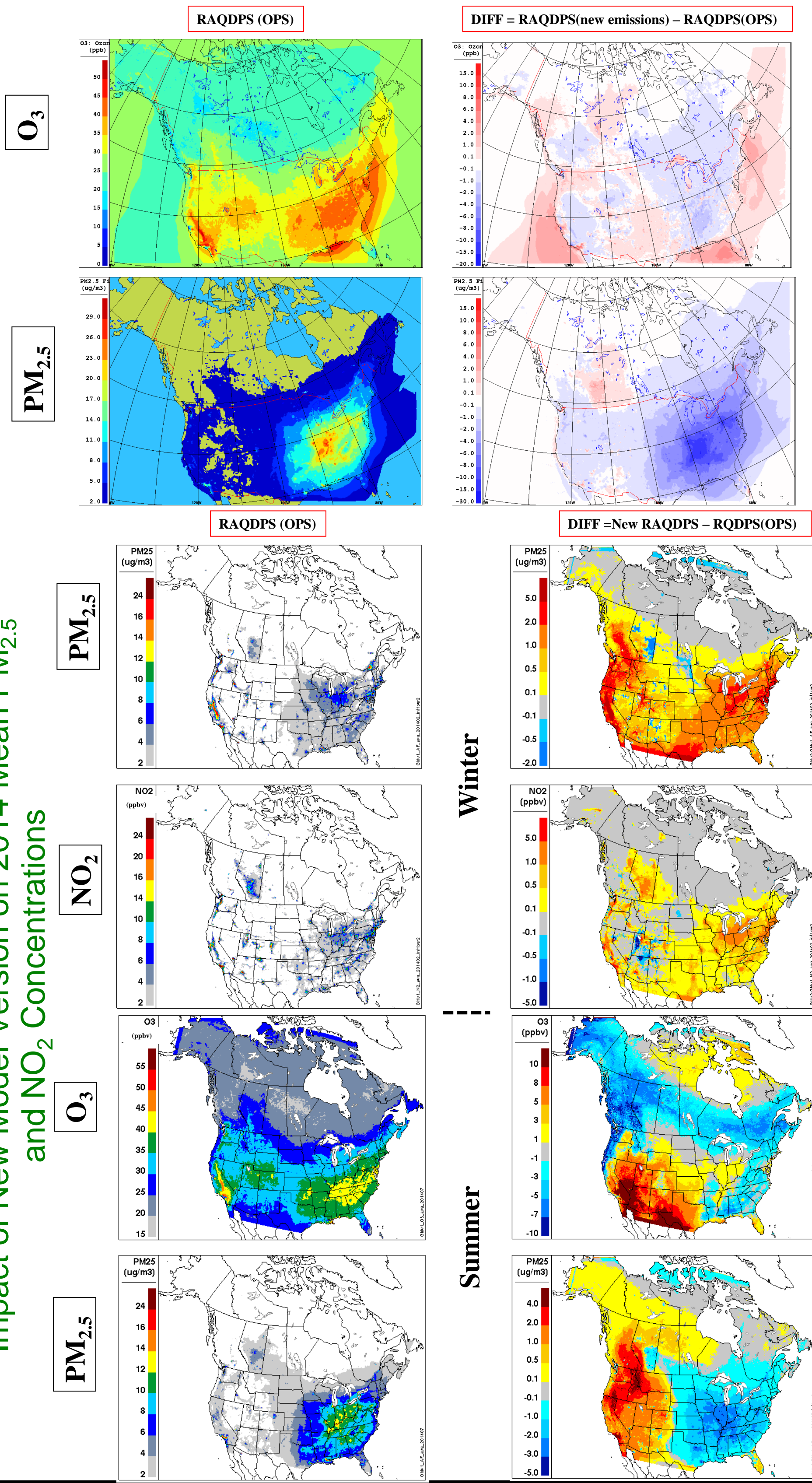
- 48 hour forecast, 00 and 12 UTC.
- Recycling tracers from 12h forecast



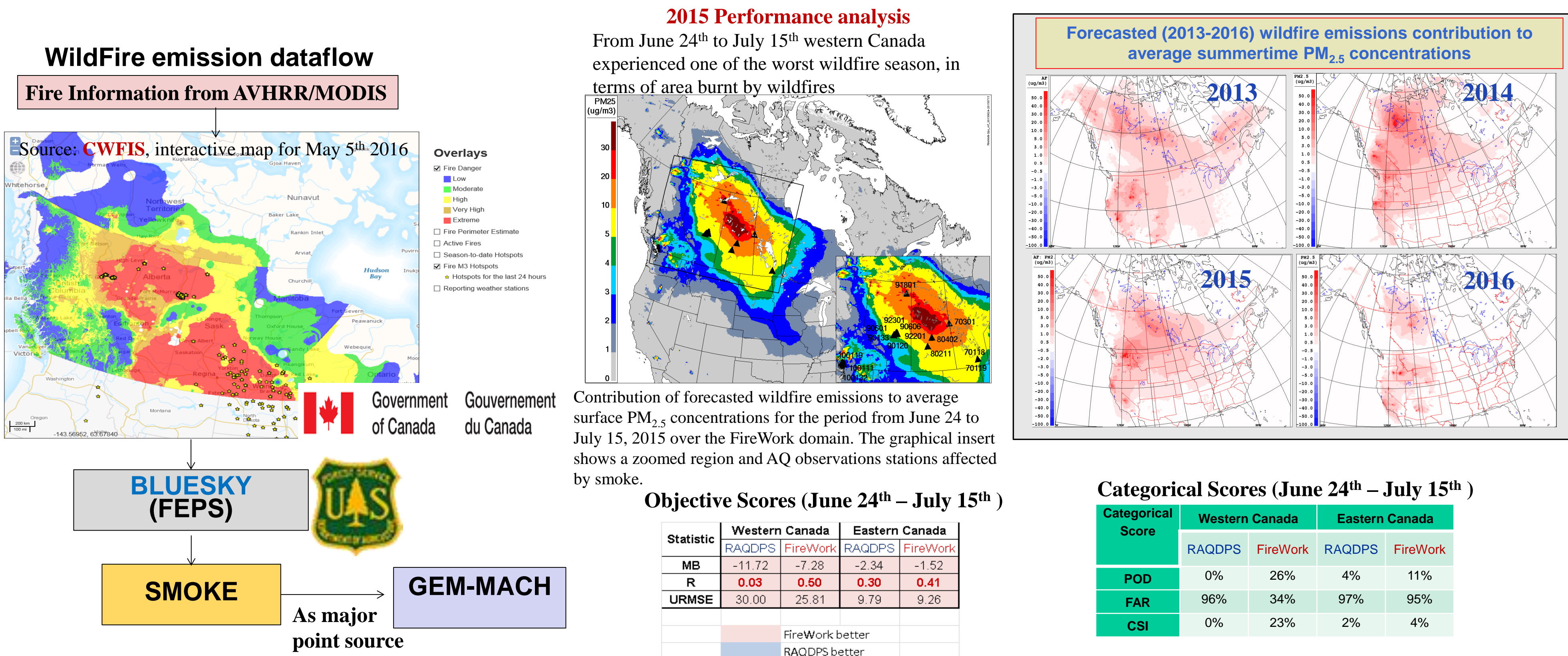
New domain shown in green

Process / aspect	Change
Vertical coordinate	hybrid in log-hydrostatic-pressure staggered vertical discretization
vertical discretization	Charney-Phillips staggering Lowest layer depth is now 40m (was 20m) Surface level defined at 20m (was 0m)
Horizontal Grid	LAM aligned to a global Yin-Yang grid (was rotated lat-lon)
Physics	Modified PBL moist TKE scheme Modified orographic blocking scheme
Vertical diffusion of tracers	Following GEM native diffusion for thermodynamical quantities
Advection	Introduced GEM's algorithm for mass conservation for tracers, designed for LAM
Chemical boundary	New climatology seasonal 3D mean fields from MOZART4 (was 1D vertical profiles)
Tracer deposition	Gas-phase dry deposition with improved LAI scaling
Emissions	Corrections to area and sea salt emissions New Canadian population and dwelling spatial surrogates based on 2011 census replaced older versions based on 2006 census New Canadian spatial surrogates for residential wood combustion, on-road mobile sources, airports, marine pleasure craft, and others Land-use-dependent transportable fraction used to scale fugitive dust emissions for near-source capture in place of simple 0.25 factor New temporal profiles for major point sources New library of PM speciation profiles and addition of some VOC speciation profiles Removal of emissions from closed facilities Impact of emission changes: Summertime: Mixed results with slightly deteriorated NO <sub>2</sub> scores Wintertime: remarkable improvements to NO <sub>2</sub> , PM <sub>2.5</sub> and O <sub>3</sub> statistics

### Impact of Revised Emissions on Summer 2014 Mean O<sub>3</sub> (ppbv) and PM<sub>2.5</sub> (µg/m<sup>3</sup>) Concentrations

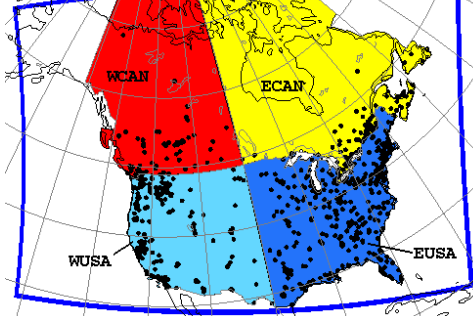


## FireWork Modelling Framework Description



## Performance summary

### Objective Scores (MB, R, URMSE) for Hourly Forecasts (NO<sub>2</sub>, O<sub>3</sub>, PM<sub>2.5</sub>)



#### WINTER 2014

W Canada	E Canada	W Canada	E Canada
GMV1	GMV2	GMV1	GMV2
1.34	0.79	1.42	1.10
0.63	0.52	0.54	0.60
7.51	6.85	6.84	6.13
2.06	2.30	2.06	2.30
0.62	0.68	0.70	0.73
11.45	11.12	10.09	10.18
-5.49	-5.48	-1.48	-3.06
0.10	0.06	0.36	0.36
15.97	15.85	8.62	8.05

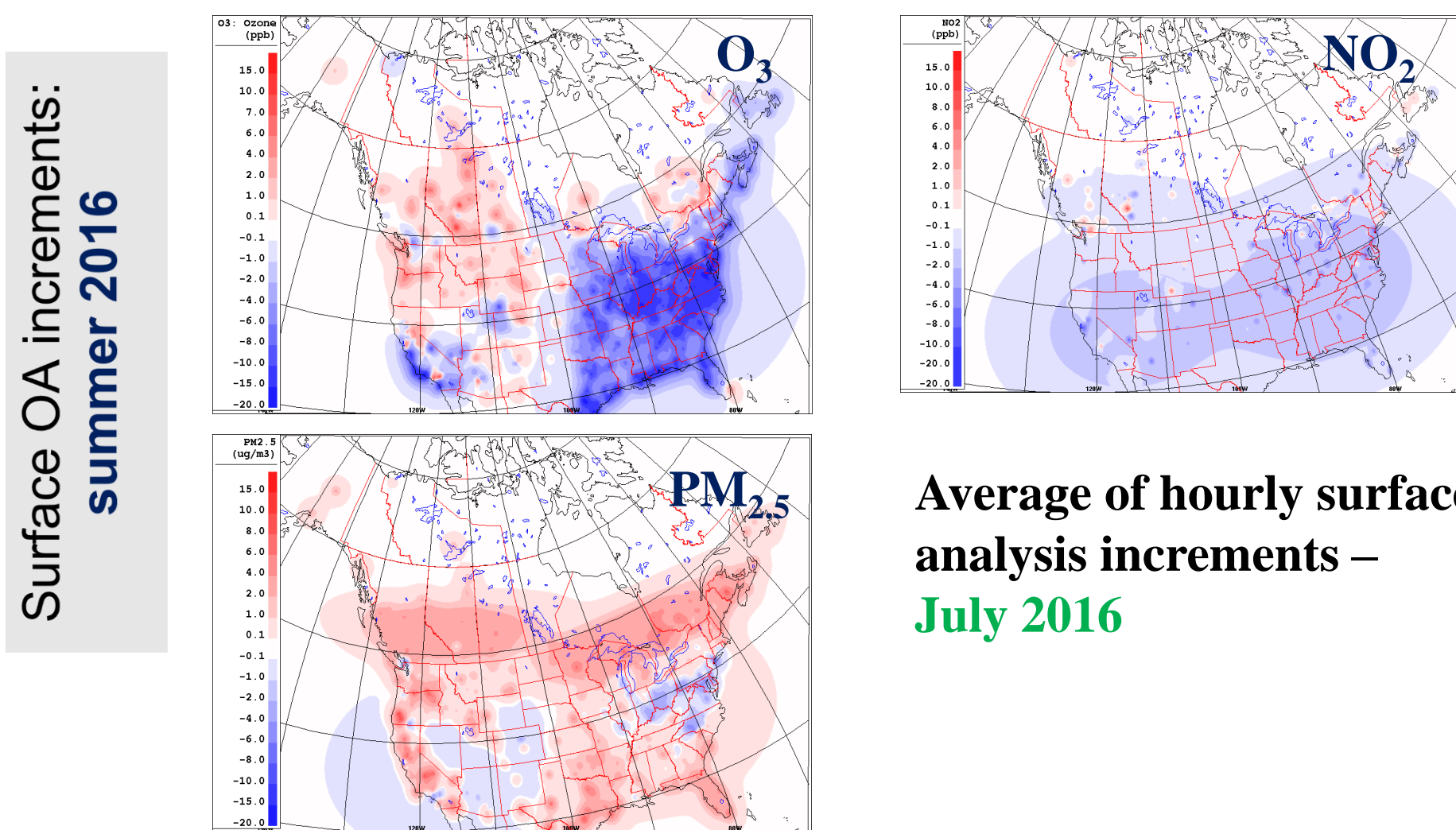
#### SUMMER 2014

W Canada	E Canada	W USA	E USA
GMV1	GMV2	GMV1	GMV2
1.34	0.79	1.42	1.10
0.63	0.52	0.54	0.60
7.51	6.85	6.84	6.13
2.06	2.30	2.06	2.30
0.62	0.68	0.70	0.73
11.45	11.12	10.09	10.18
-5.49	-5.48	-1.48	-3.06
0.10	0.06	0.36	0.36
15.97	15.85	8.62	8.05

Legend	All scores	Canada	USA
Operational RAQDPS (GMV1) is better	35%	26%	33%
New RAQDPS (GMV2) is better	65%	49%	50%

In both winter and summer, statistics for Canada and the U.S.A. were improved with the new RAQDPS.

## Objective Analysis Performance



Objective analysis increments provide information about model performance. For the summer 2016:  
NO<sub>2</sub> : over-forecasted in Canada and U.S.(occurs mostly at night)  
O<sub>3</sub> : over-forecasted in eastern and south-western U.S. (daytime), under-forecasted in western Canada and north-western U.S.  
PM<sub>2.5</sub> : under-forecasted in Canada, with mixed results in the U.S.A.

## Conclusions

The ECCC operational RAQDPS has been updated 17 times since 2009. One major update in 2015 introduced new input emissions. In 2016 the GEM-MACH chemical weather model was upgraded: changes included new vertical discretization, new mass-conserving semi-Lagrangian advection scheme, updated gas-phase dry deposition scheme, new tracer vertical diffusion scheme, new chemical lateral boundary conditions, and correction of surface emissions error.

In the near future the following upgrades to the operational ECCC's AQ systems are planned:

**RAQDPS:** 1) Extended forecast to 72h; 2) Update emission inventories; 3) Expansion of AQHI program; 4) Update surface analysis with non-homogenous and non-isotropic horizontal error correlations 5) Implement experimental global ozone assimilation; 6) incorporate data assimilation into forecast cycle; 7) piloting by global weather model and 8) high AQ resolution modelling.

**FireWork:** 1) Improve plume-rise algorithm applied to wildfire emissions; 2) Improve wildfire emissions estimates; 3) Make injection height as a function of fire intensity; and 4) fire spread and growth forecast.