Canadian Meteorological Centre Smoke Forecasting System: Firework 2014

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2014-10-10

Meteorological Service of Canada
Canadian Centre for Meteorological and Environmental Prediction
Canadian Meteorological Centre Operations

Summary

- Impact of forest fire emissions on air quality
- How FireWork was developed and how it works
- Accessing FireWork products
- How FireWork is used by MSC meteorologists
- Performance & Limitations
- Next steps

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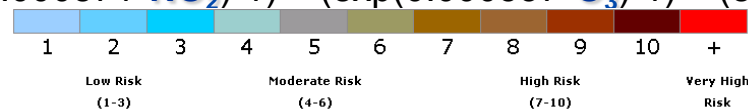Environment Canada

Forest Fires and Air Quality

- Forest fires can greatly affect air quality
  - Even far away from sources
- Emissions: primarily aerosols, VOCs, NO_x and CO_x
  - Affecting mainly $PM_{2.5}$
- Forest fires have been identified as an important factor for summertime air quality in Canada
  - National air quality program wants to take them into account, to improve forecast
  - Some AQHI program partners (provinces) requested that the health index includes the effect of wild fire smoke
  - FireWork is EC's response to these requests
- Modelling forest fire emissions is also important for climate studies

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FireWork Objectives

- Include near-real-time biomass burning emissions into Environment Canada's operational air quality forecast system (RDAQPS, based on GEM-MACH model)
  - Interim goal: an « alternate » AQ forecast
- Forecasts from FireWork can also serve as an input for the operational Air Quality Health Index (AQHI*)
  - AQHI+FF is produced
- Some other information can also be provided
  - Smoke dispersion
  - Visibility

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

1	2	3	4	5	6	7	8	9	10	+

Low Risk (1-3)	Moderate Risk (4-6)	High Risk (7-10)	Very High Risk

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Timeline of FireWork Development

- **2011**
  - Developed fire emissions method for GEM-MACH (based on Bluesky);
  - Processed fire information from Canada and USA for historical cases
  - Established a case study for a 2010 wildfire in British Columbia
- **2012**
  - The model was run for the entire summer (May-October) at 15-km grid spacing; the new wildfire version of GEM-MACH is named "FireWork"
- **2013**
  - The model was run for the entire summer with operational settings at 10-km grid spacing.
  - Gathering feedback from AQ forecasters
- **2014**
  - FireWork is run by Canadian Meteorological Centre operations in experimental mode (includes partial 24/7 support)

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BlueSky Canada & FireWork

- EC a
  - In
  - Us
    -
    -

- FireW   3
  the B   ler
  - Re
  - Le
- FireW
  - Fu
  - Co   tem

From www.bcairquality.ca/bluesky

Smoke Forecast Issued at: Thursday, July 4, 2013, 6:08 PDT

Currently showing forecast image for: Thursday, July 4, 2013, 12:00 PDT

| << Rewind | < | Pause || | > | Forward >> |

Play speed: | − | | + |
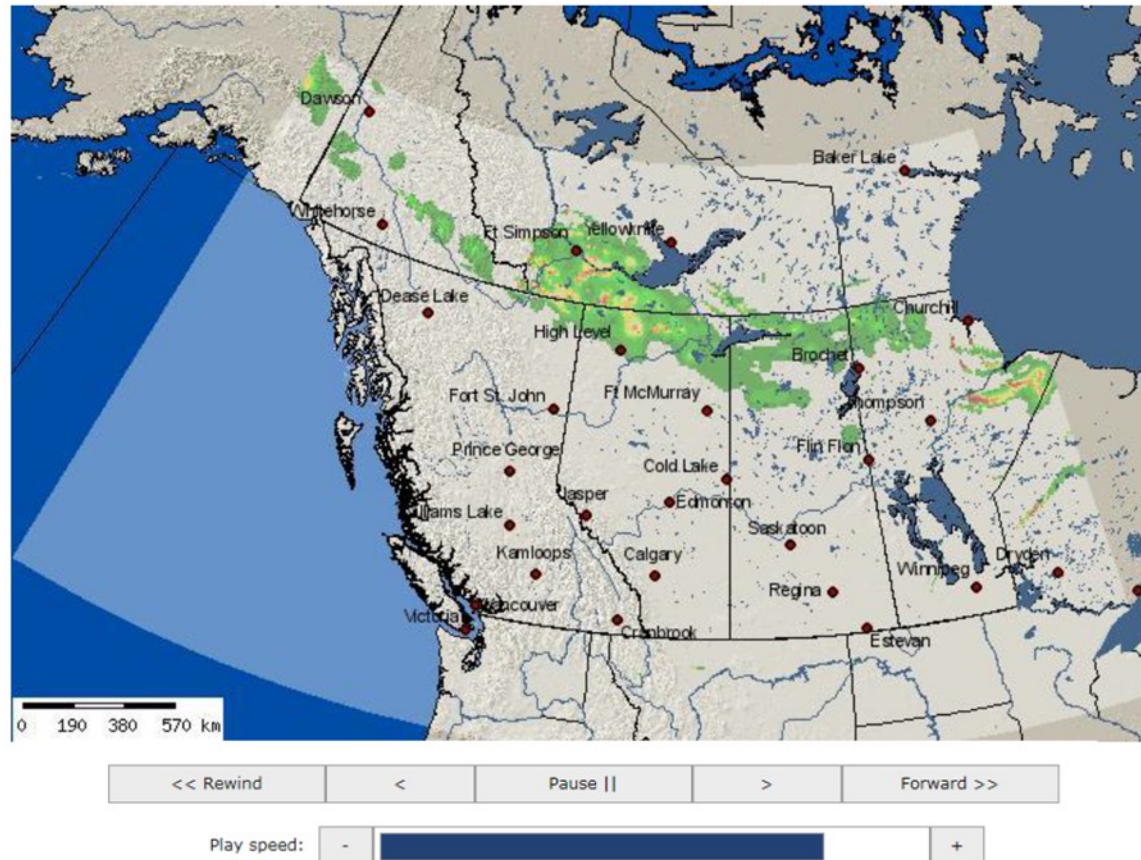
Figure 2 Western Canada Forecast Output (forecast area shown in grey shade)
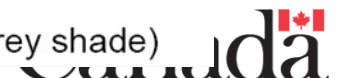
Current FireWork Modelling Strategy

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

- Run in parallel with wildfire emissions:
  - Run twice a day (initiated at 0 UTC and 12 UTC)
  - Available approximatively at the same time as operational model

- Additional products
  - Alternate AQHI with FireWork (products calculated as for OPS)
  - PM2.5 maps and animations based on the difference (FireWork – OPS) to isolate plumes
  - Total column PM10 and PM2.5 concentrations

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FireWork = RAQDPS + Forest Fires

Emissions:
- Anthropogenic
- Biogenic
- (Forest fires)

Config, landuse, etc.

Real time AQ obs

Real time DB

Verif DB

RAQDPS = Regional Air Quality Deterministic Prediction System

Weather BCs from global model

AQ piloting from global model

Operational environment and systems

AQ initial conditions

UMOS-AQ

Products:
- AQHI
- Specialized
- Custom

= Not yet

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Wildfire Emissions Data

FireWork framework
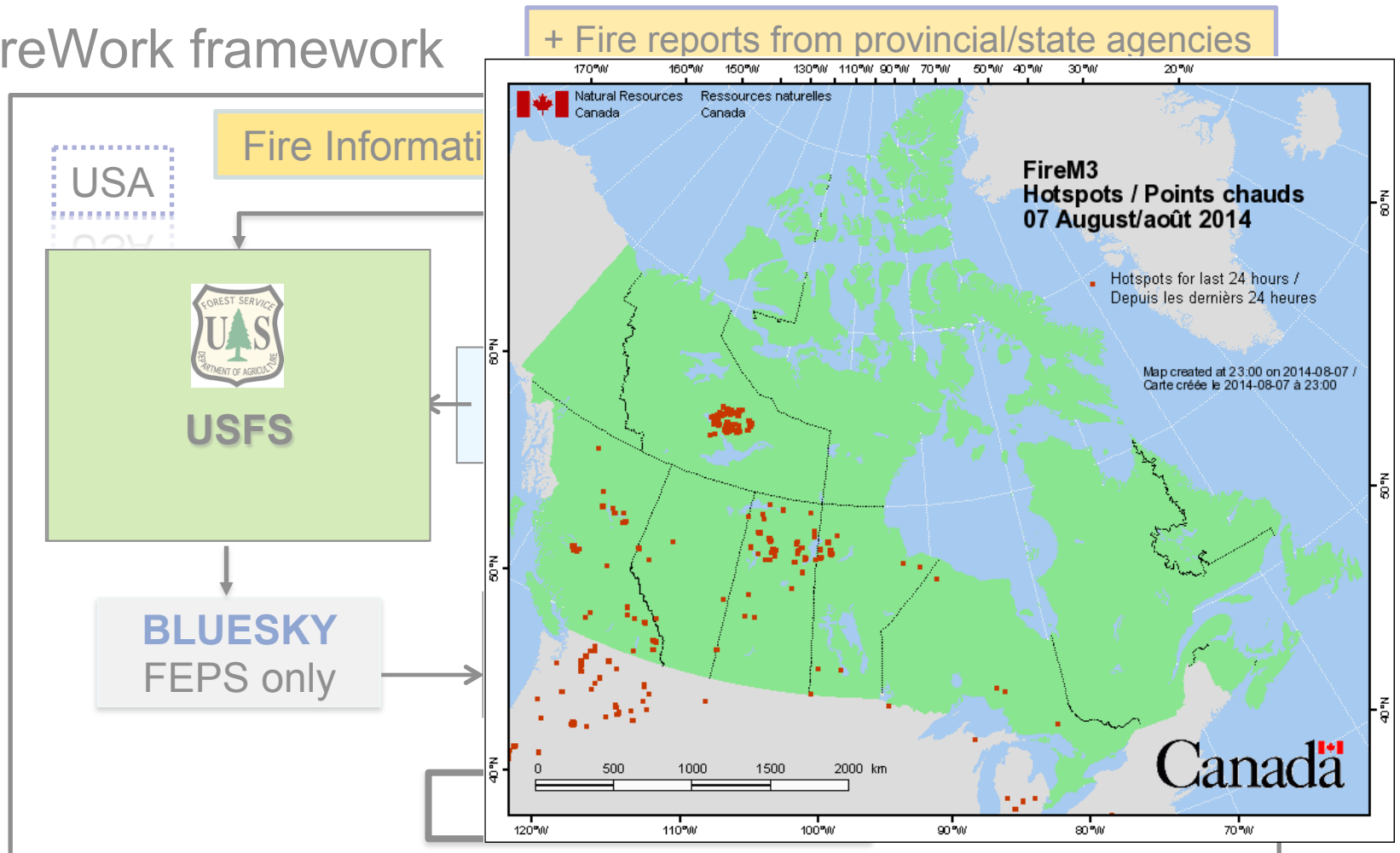
Model-Ready Wildfire Emissions

- Fire information for Canadian/USA sources
  - Data contains previous day's fire locations by lat/lon and CWFIS estimated fuel type/consumption
  - BLUESKY is used to estimate total emissions using the FEPS module. Emissions are generated as "Daily Total" per fire hotspot
  - No fire behavior is modeled (persistence assumed)
- Emission processing with SMOKE software
  - Use diurnal profile to convert daily total wildfire emissions into hourly values
  - Convert VOC, NOx, PM into explicit model species
  - Merge with other major anthropogenic point sources
- Some assumptions on emitted species, e.g:
  - $PM_{2.5}$ ➜ 56% organic carbon, 34% Crustal material, 9% elemental carbon, 1% sulfates
  - Organic gas ➜ 19% Ethene, 9% Propane, 6% Alkene, 1% Alkane.

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External access to FireWork, 2014

http://collaboration.cmc.ec.gc.ca/cmc/air/FireWork-GEMMACH/ (firework, FFForecast!)

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

Produits de FireWork-GEMMACH / Products from FireWork-GEMMACH

AVERTISSEMENT / WARNING
Produits expérimentaux de recherche et développement. Cliquez ici pour plus d'information

Experimental research and development products. Click here for further information

Présentation sur FireWork-GEMMACH aux partenaires externes (anglais seulement):
FireWork-GEMMACH presentation to external partners:

Présentation FireWork-GEMMACH / FireWork-GEMMACH Presentation

Pour les besoins de réponse aux urgences, le SMC diffuse les produits de dispersion suivants pour les feux de forêts :
For emergency response applications, MSC provides the following forest fire dispersion modeling :

Sorties du modèle MLDP0 pour les feux de forêt / Output from the MLDP0 model for forest fires

Date de la passe / Run date : 2014-10-09 00:00:00

- Carte des points chauds / Maps of the hotspots

- $PM_{2.5}$ à la surface attribués aux émissions de feux de forêt
  Surface level $PM_{2.5}$ attributed to forest fire emissions

- $PM_{2.5}$ sur toute la colonne attribués aux émissions de feux de forêt
  Total vertical column $PM_{2.5}$ attributed to forest fire emissions

- PM_{10} à la surface attribués aux émissions de feux de forêt
  Surface level PM_{10} attributed to forest fire emissions

- PM_{10} sur toute la colonne attribués aux émissions de feux de forêt
  Total vertical column PM_{10} attributed to forest fire emissions

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Access to FireWork Products

AQHI FireWork external web page:

http://collaboration.cmc.ec.gc.ca/cmc/air/FireWork-GEMMACH/

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

Produits expérimentaux de FireWork-GEMMACH / Experimental products from FireWork-GEMMACH

AVERTISSEMENT : TOUS LES PRODUITS LIÉS CI-DESSOUS SONT EXPÉRIMENTAUX!
Information complémentaire

WARNING : ALL THE PRODUCTS LINKED BELOW ARE EXPERIMENTAL!
Additional information

Pour les besoins de réponse aux urgences, le SMC diffuse les produits de dispersion suivants pour les feux de forêts :
For emergency response applications, MSC provides the following forest fire dispersion modeling :

Sorties du modèle MLDP0 pour les feux de forêt / Output from the MLDP0 model for forest fires

Date de la passe / Run date : 2014-06-18 00:00:00

- Carte des points chauds / Maps of the hotspots

- $PM_{2.5}$ à la surface attribués aux émissions de feux de forêt
  Surface level $PM_{2.5}$ attributed to forest fire emissions

- $PM_{2.5}$ sur toute la colonne attribués aux émissions de feux de forêt
  Total vertical column $PM_{2.5}$ attributed to forest fire emissions

- PM_{10} à la surface attribués aux émissions de feux de forêt
  Surface level PM_{10} attributed to forest fire emissions

- PM_{10} sur toute la colonne attribués aux émissions de feux de forêt
  Total vertical column PM_{10} attributed to forest fire emissions

username = firework
password = FFForecast!

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Forecasted forest fire emissions contribution to total PM$_{2.5}$ concentration: July 23-26, 2014

AT SURFACE
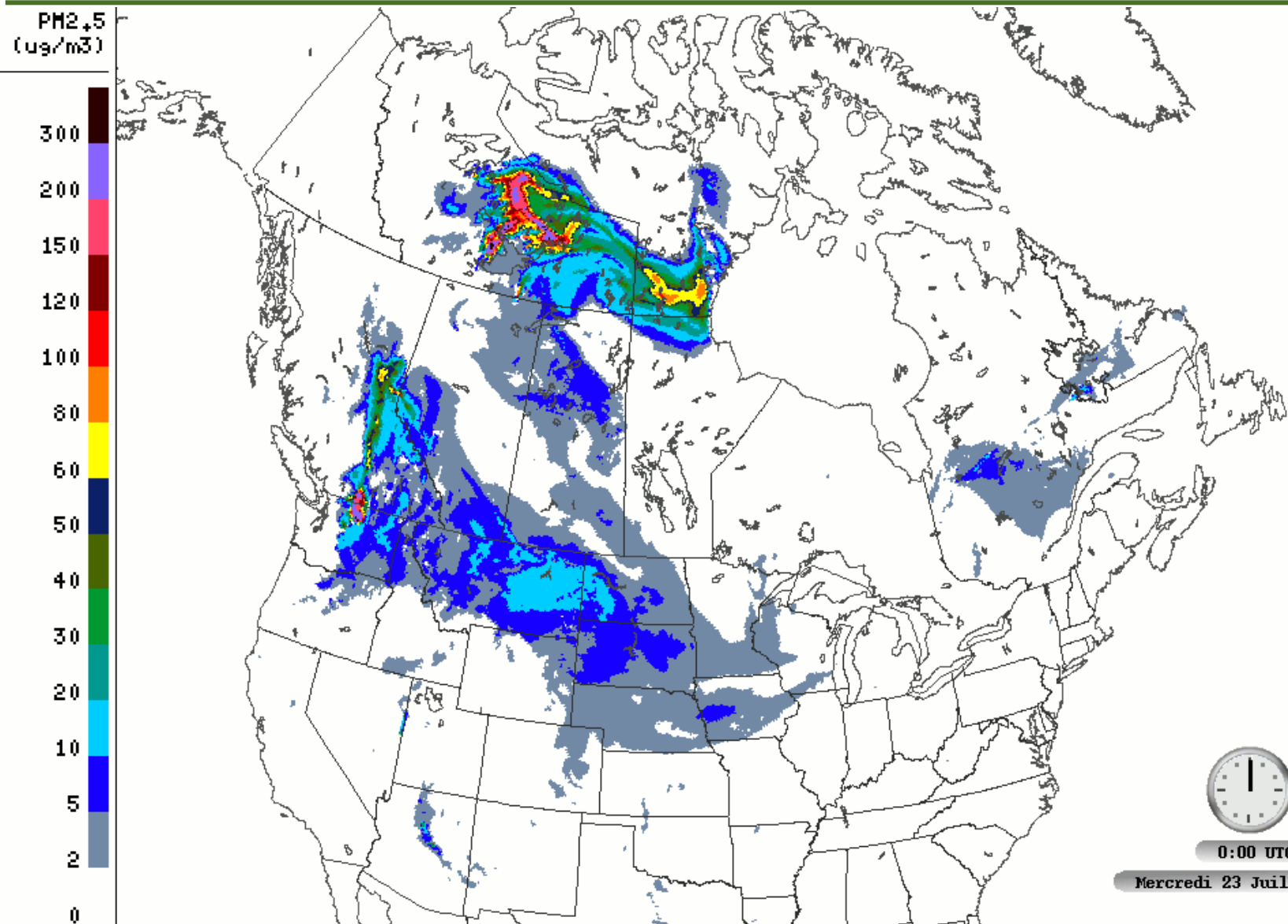
Publishing FireWork layers as WMS/KML

- Documentation

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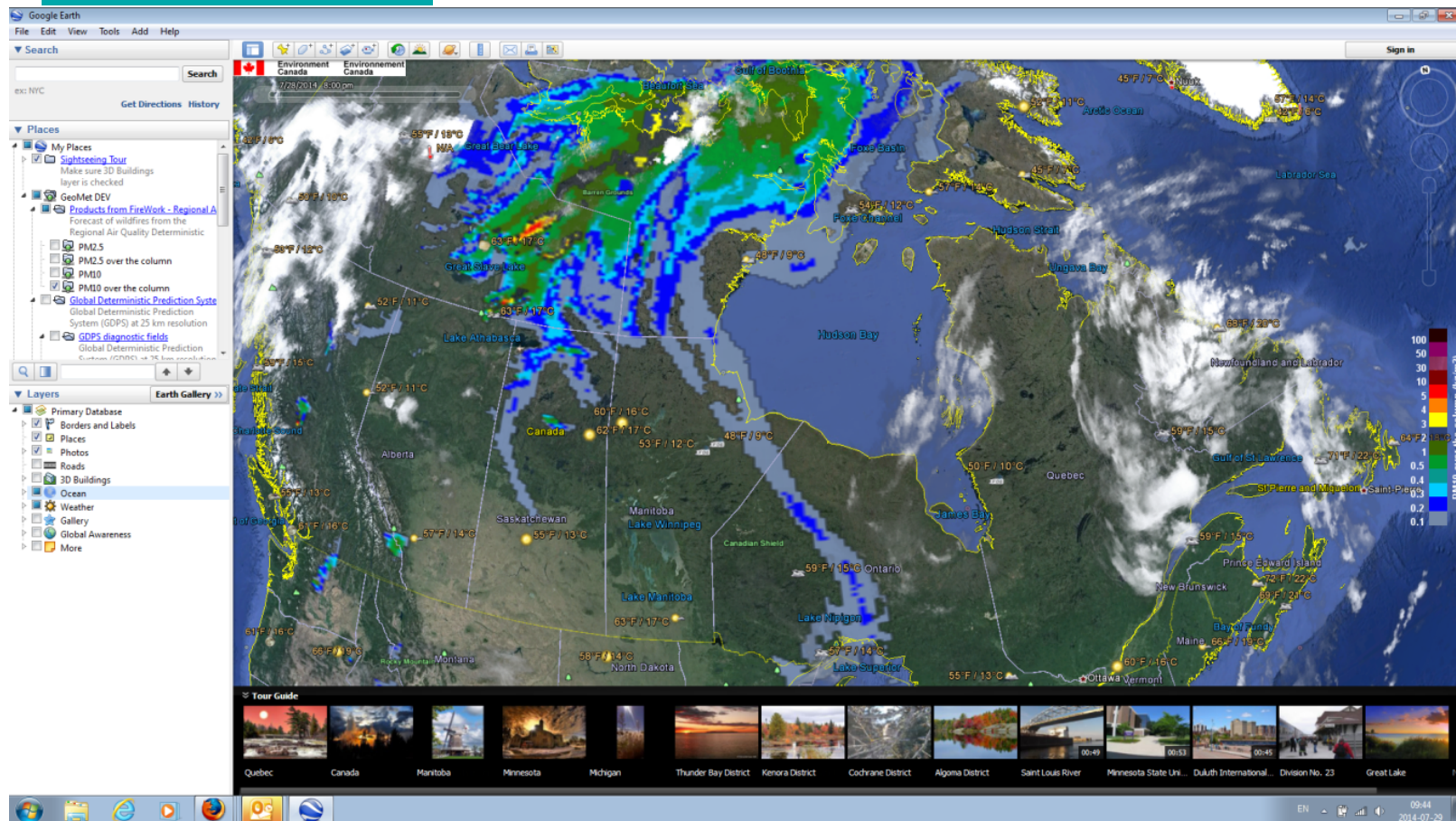
Meteorologist get a lot more

- Forecaster desk (Scribe)

AQHI

Chemistry

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AQHI Internal web site

Example of additional products

AQHI FireWork Web Page (internal)

Early test runs

GEM-MACH OPERATIONNEL   FIREWORK   FIREWORK UMOS/MIST
=OPS AQ/MIST – GM-OPS + FIREWORK

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Long-range impact of Fires (July 25-26)
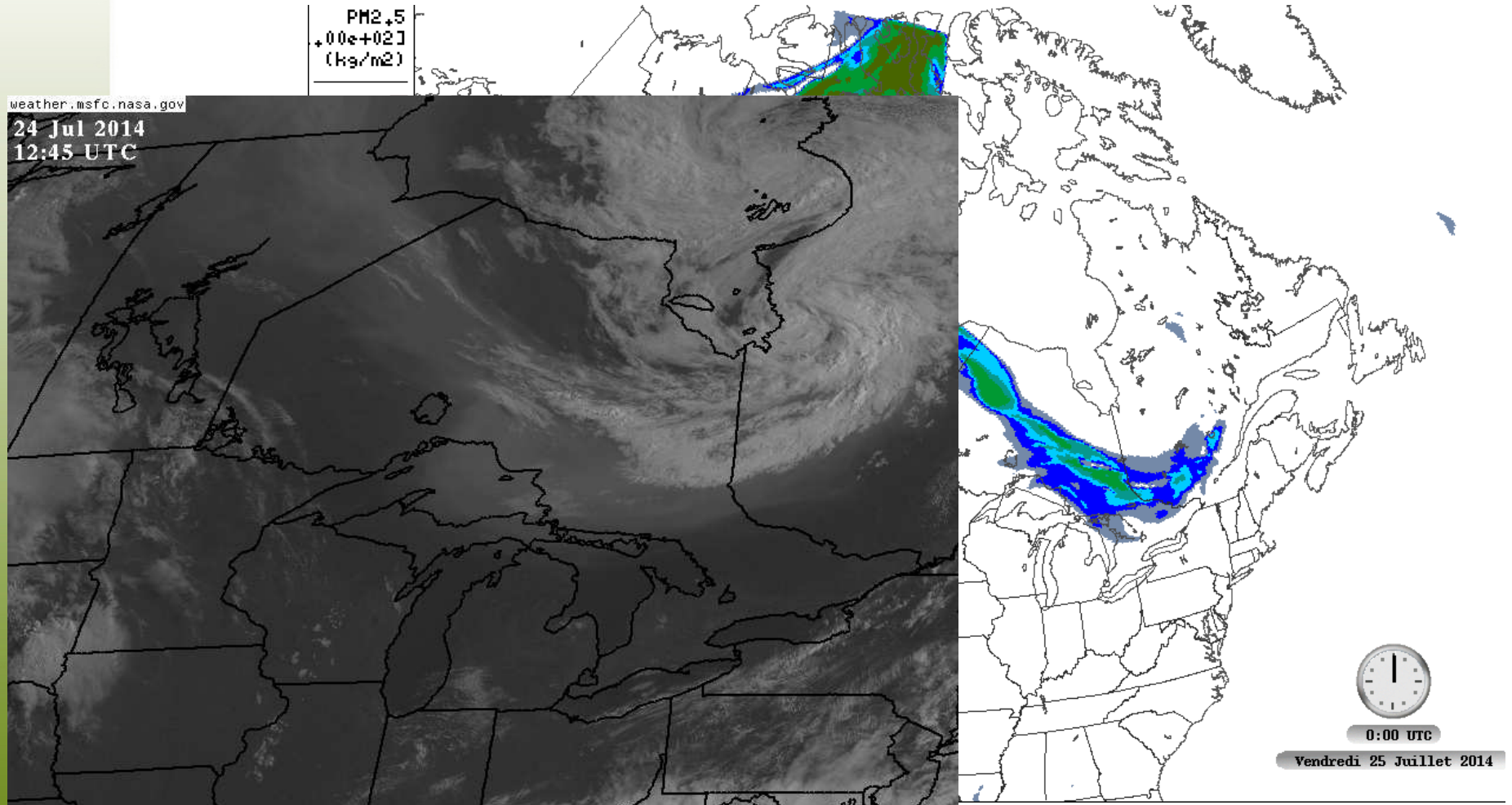
Keep in mind: Current Limitations

- Sensitivity to hotspot algorithms
  - Ac...
  - Re...
- No mo...
  - fire...
  - fire...
  - Im...
- Fire si...
- Basic

- Some fires can be missing (new, undetected)
- Emission estimates can be wrong (e.g. wrong fuel type)
- Fire may evolve very differently (as opposed to reproducing yeasterday's behaviour)
- Plume rise may be insufficient

- Predictability remains limited

- Operational considerations: reliability and timeliness of remote sensing data

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FireWork performance: verification

- Verification against observations
  - Used NAPS & AirNow networks for verification
  - Used summer of 2013 & 2014 observations
  - Looked at objective scores, categorical scores

- Case studies
  - Examined performance during major fire events

- Main conclusions:
  - In general, Firework has a better performance than OPS model in forecasting $PM_{2.5}$ in Canada
  - However, model bias may worsen in some areas
  - Case studies show good performance when emission sources are well defined
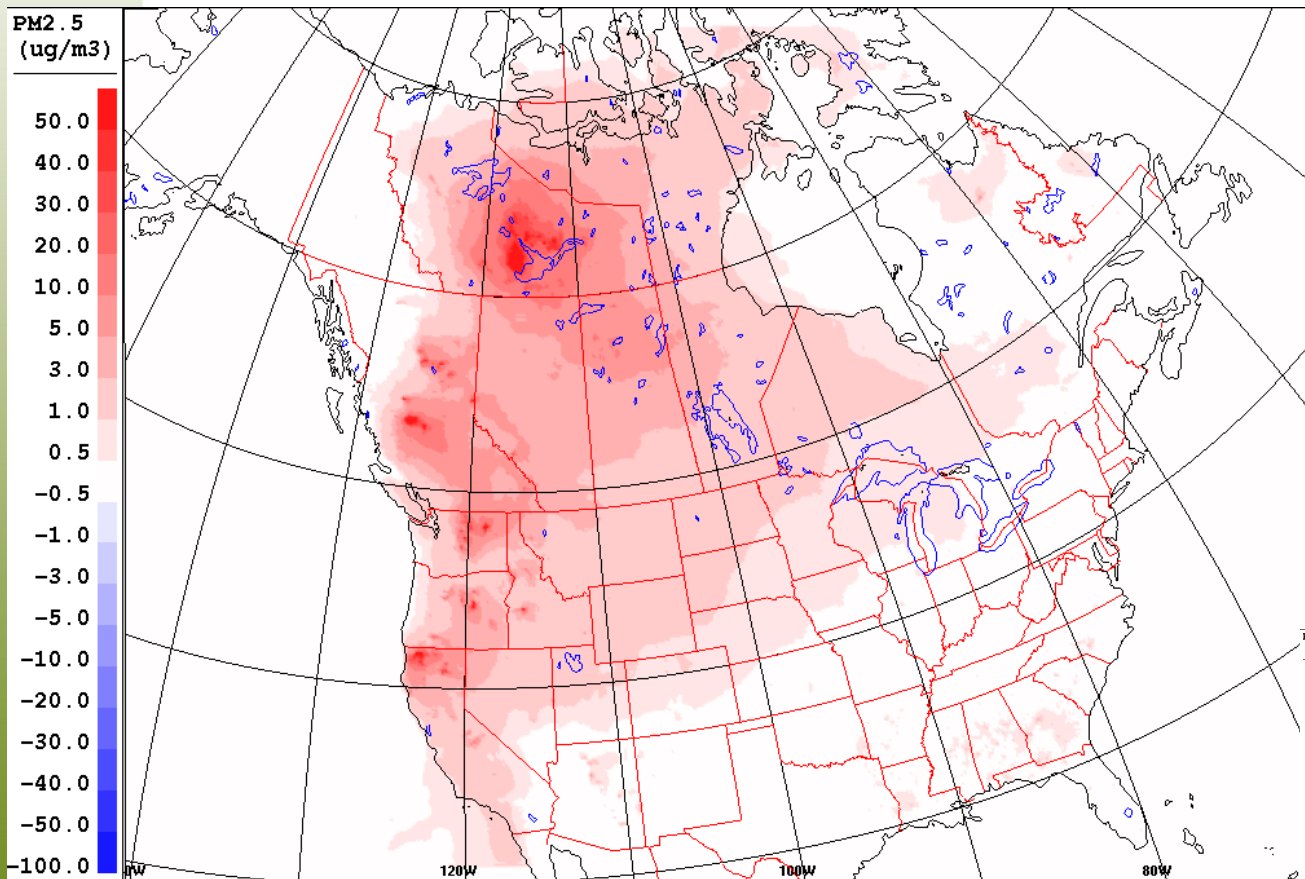
Environment Canada Environment Canada

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Results for Summer 2014 (June – August)
Average PM$_{2.5}$ Concentrations and Differences

Wildfire emissions contribution to average summertime PM$_{2.5}$ concentrations

Difference: FireWork - GEM-MACH

AVG FireWork forecast

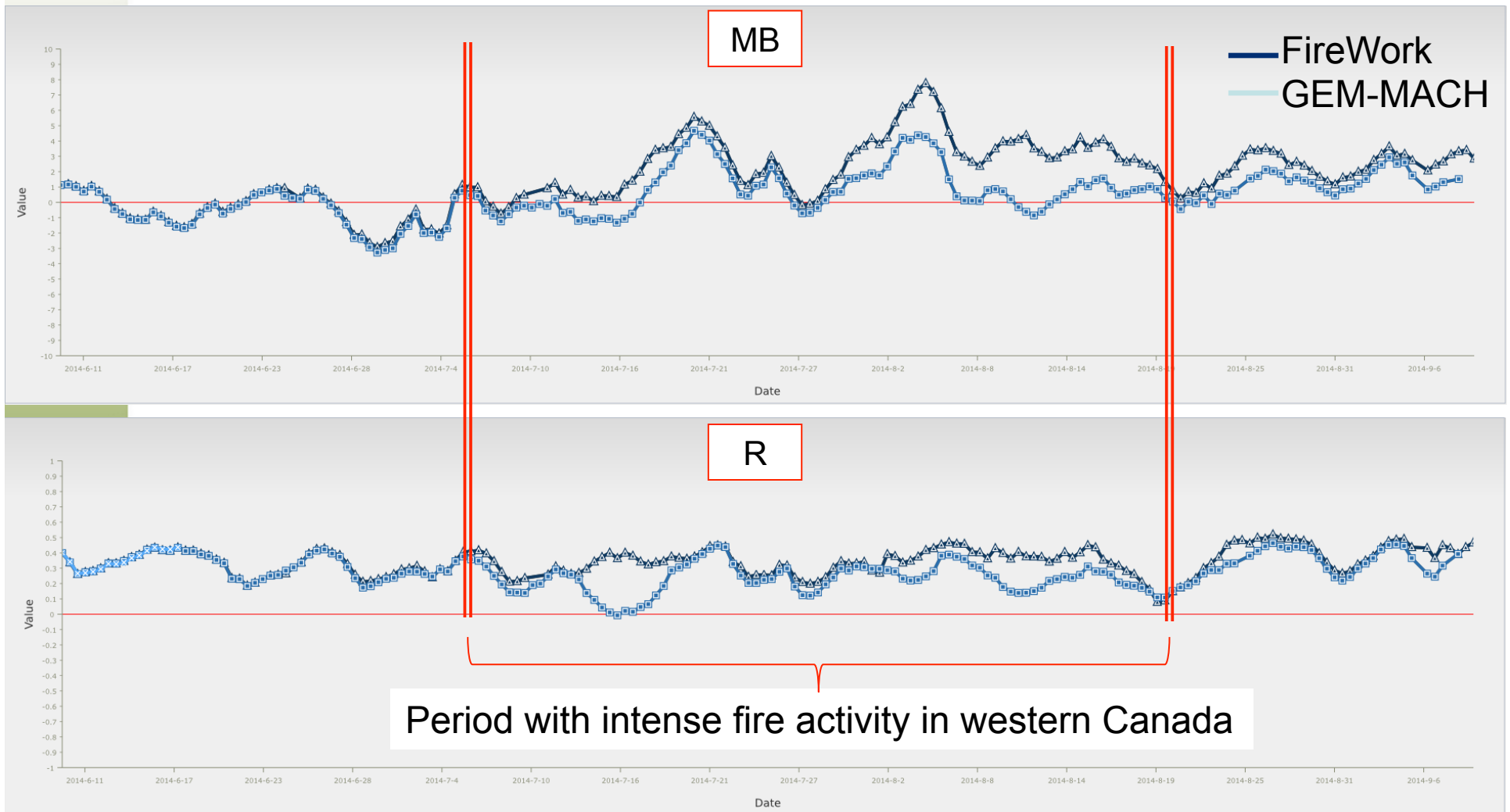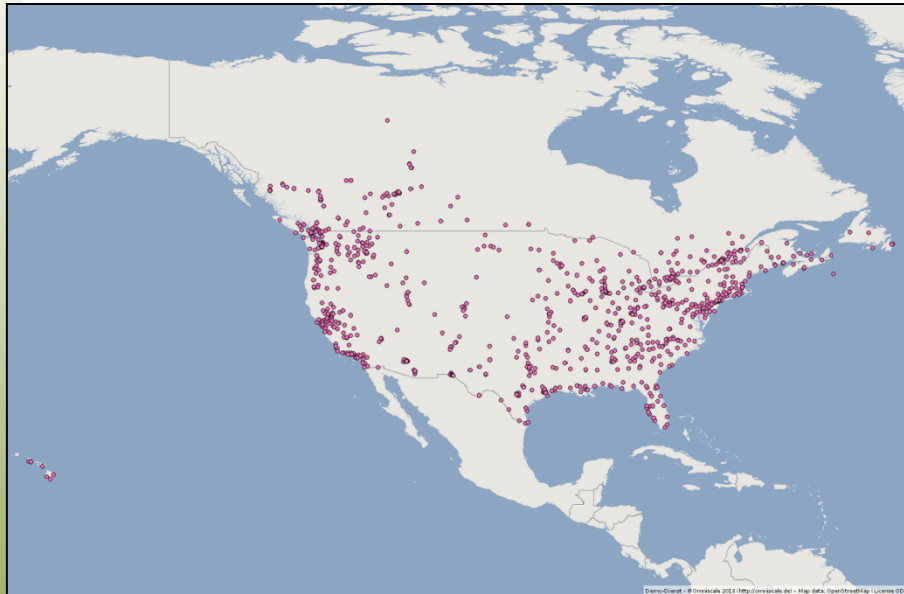Page 21 – 15 October 2014
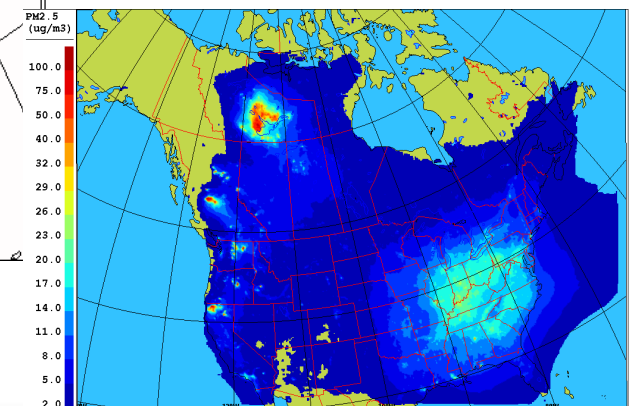
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Evolution of **MB** and **R** statistics over time: FireWork vs GEM-MACH

Period with intense fire activity in western Canada

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Objective Scores

Available PM$_{2.5}$ monitoring stations across Canada and U.S. used for model performance evaluation

	Number of stations
Canada	197
USA	573

BOOTSRAPPING		Canada		W Canada		E Canada	
Polluant	Statistic	OPS	FireWork	OPS	FireWork	OPS	FireWork
PM$_{2.5}$	MB	-2.32	-0.27	-6.52	-2.72	1.08	1.72
	R	0.13	0.36	**0.03**	**0.41**	0.38	0.40
	URMSE	13.90	13.04	15.99	15.04	10.82	10.75

Legend	
OPS G-M better	
G-M with Forest Fires better	
Statistically not significant	

Periode: June 10th – Septembre 17th
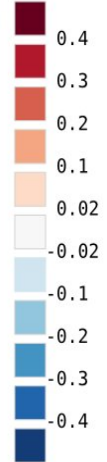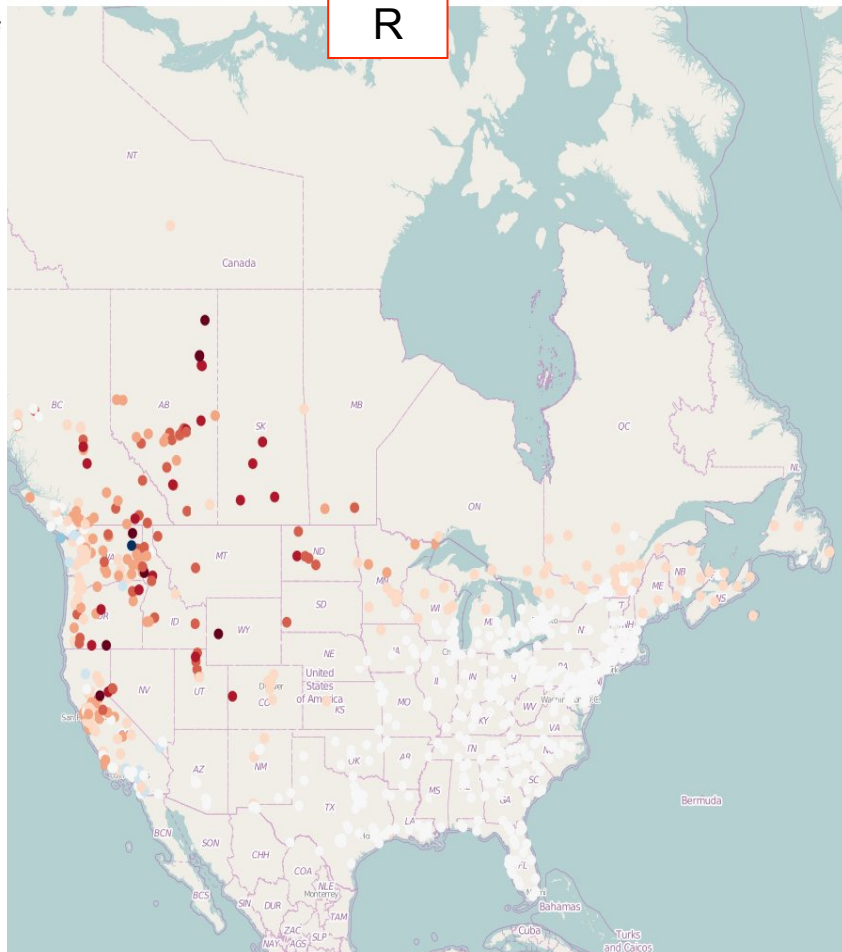
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Statistics by Station

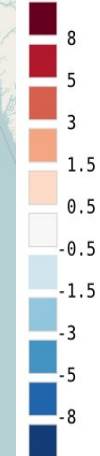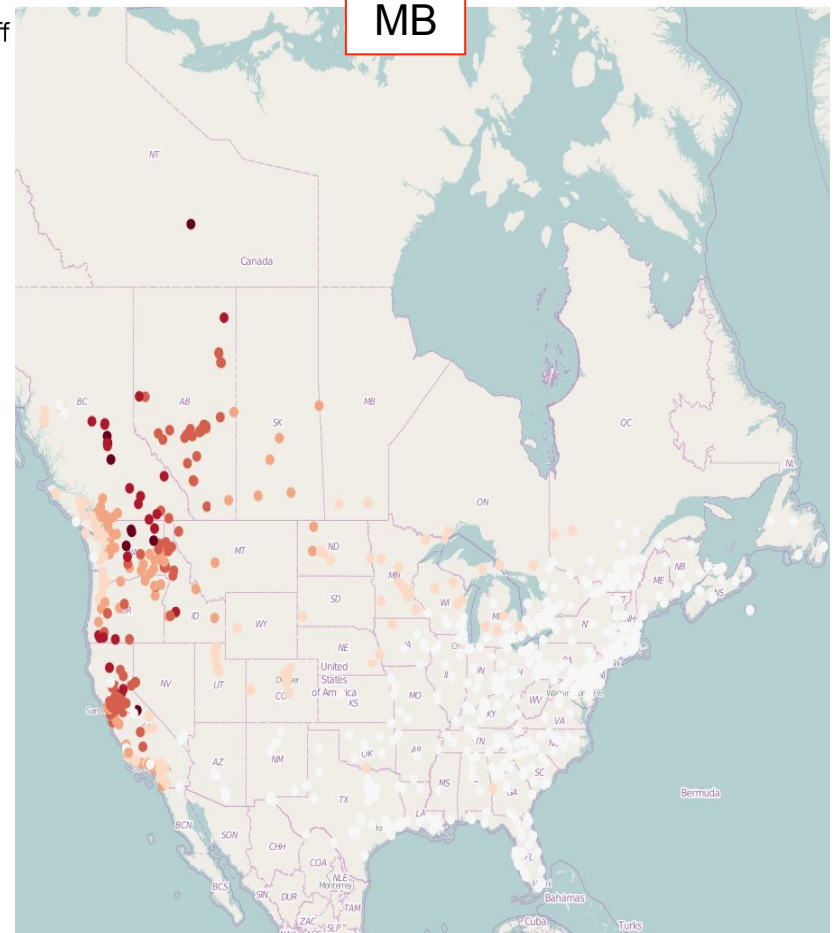Correlation coefficients improved by FireWork

Difference: FireWork - GEM-MACH

Firework application
(Yellowknife forest fires, summer 2014)

25 JULY 2014
Wildfire Smoke Reaches New York and Ontario
Posted by Dan Satterfield

N.W.T. experiencing one of its worst fi...
Officials have logged 123 fires in 2014, most caused by lightning, but some through bu...
CBC News   Posted: Jul 03, 2014 7:38 AM CT | Last Updated: Jul 03, 2014 2:52 PM CT

PHOTOS | Fire in the sky: 'Apocaly...

Smoke from N.W.T. fires re...
Fire conditions remain extreme in the regions north and sout...
CBC News   Posted: Jul 09, 2014 9:04 AM CT | Last Updated: Jul 09, 2014 9:46 AM C...

Smoke hovers in the sky near Kakisa, N.W.T. The community of about 50 people w...
Smoke from the 137 forest fires burning in the territory is now travelling as far as Sa...

Margaret Munro, Postmedia News | August 4, 2014 5:45 PM ET

- Massive smoke clouds from Canadian wildfires are up to 15 km high and visible all the way to Portugal

"It's a major event in the life of the earth system to have a huge set of fires like what you are seeing in Western Canada," says Douglas Morton, an earth scientist at NASA
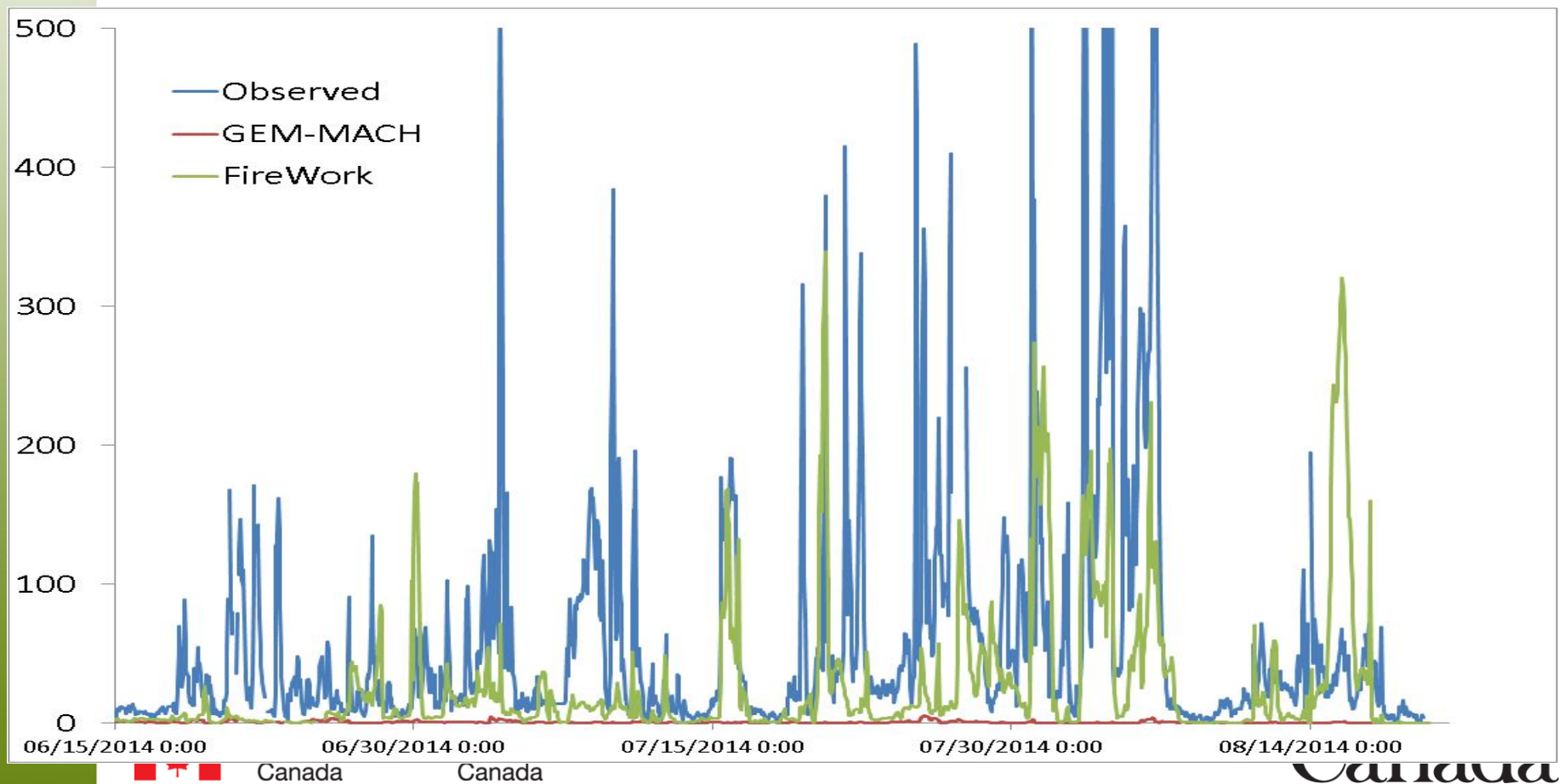
Handout/NWT Fire

Canada

GOES VIS showing long range transport from NWT to Atlantic

Courtesy of A&P, Canadian Meteorological Centre
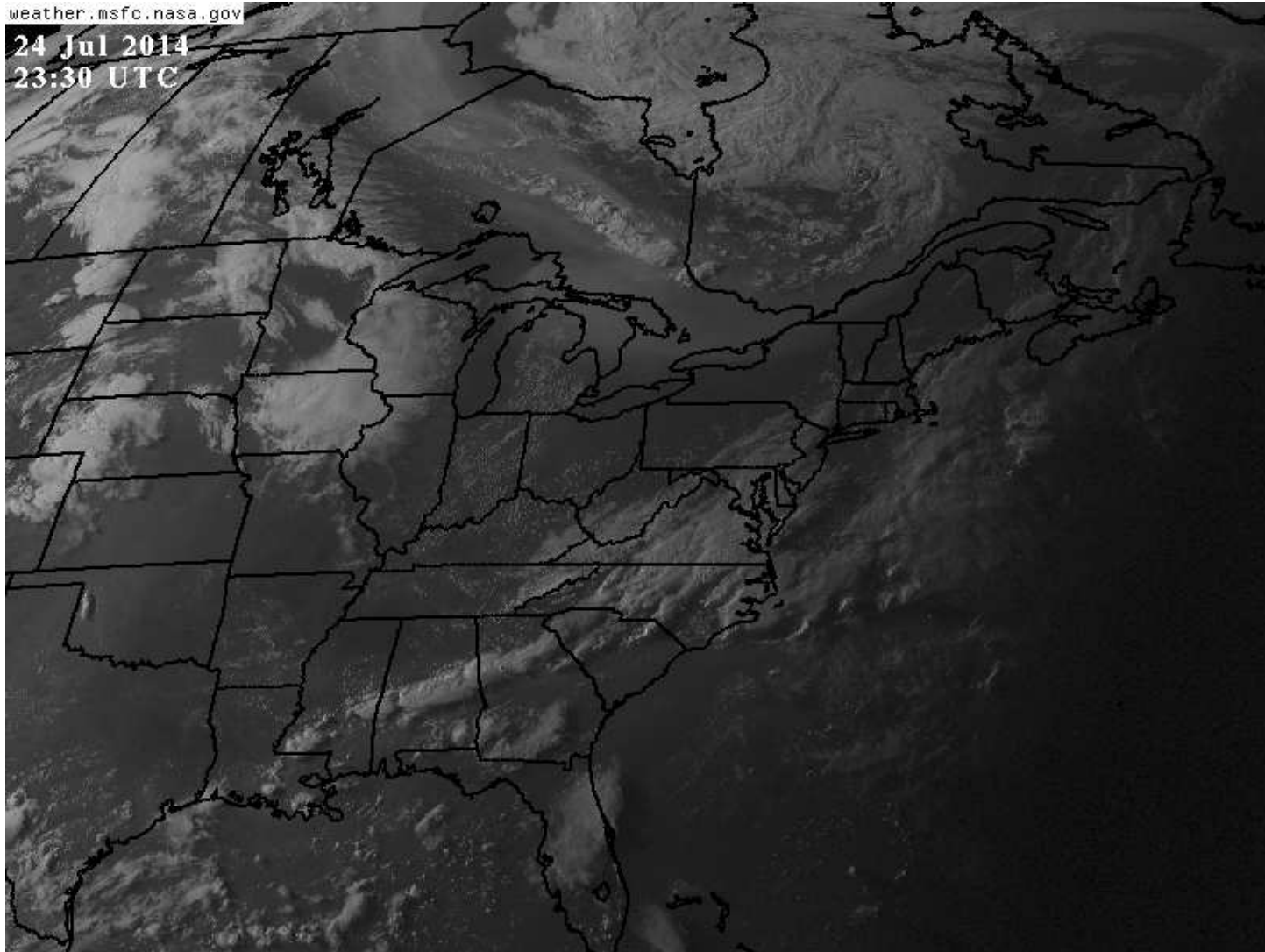
Station 129003 (Yellowknife): Observed and forecasted PM$_{2.5}$ (ug/m^3) concentrations

	ug/m3
Observed	54.5
GEM-MACH	0.8
FireWork	25.2

Analysis for Selected Stations in Alberta

Correlation Coefficient		
StationID	OPS	FireWork
90806	0.09	0.32
90801	0.08	0.37
90701	0.06	0.39
90702	0.09	0.45
91801	-0.10	0.80
91501	0.21	0.42
92001	0.33	0.47
AVG	0.11	0.46

Fort Chipewyan
Station 91801
PM$_{2.5}$ time series
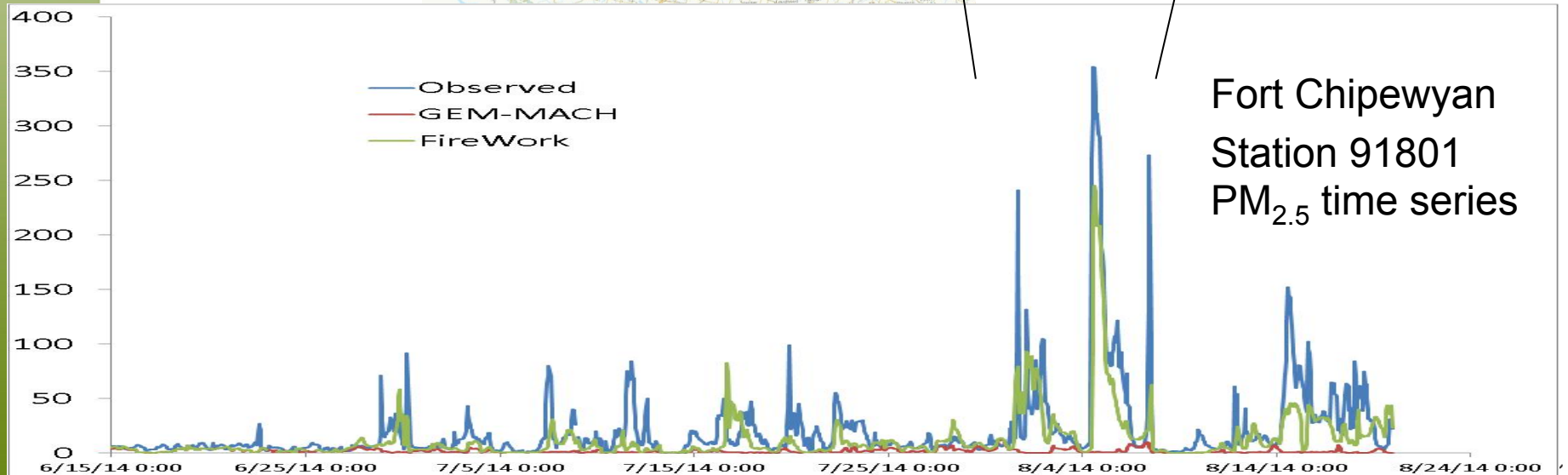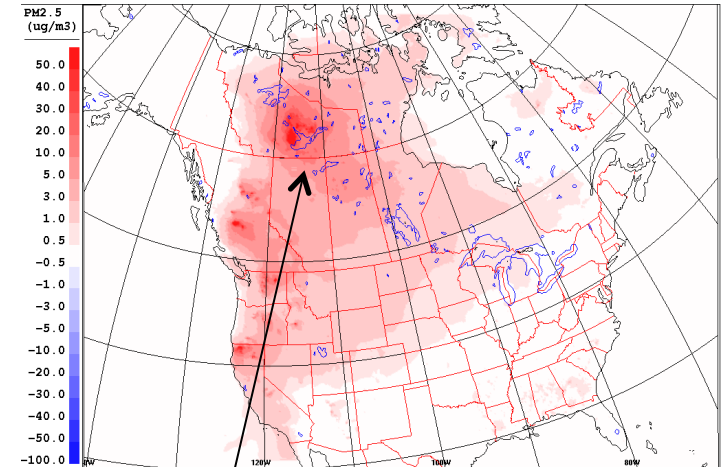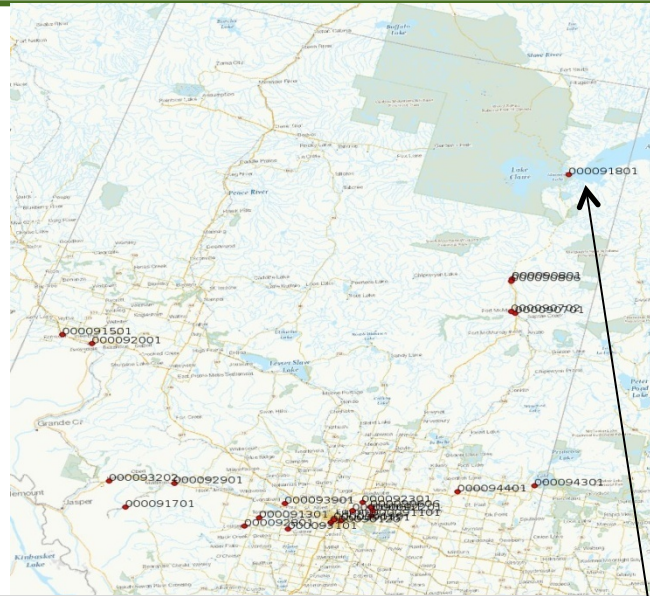
Analysis for Selected Stations in BC
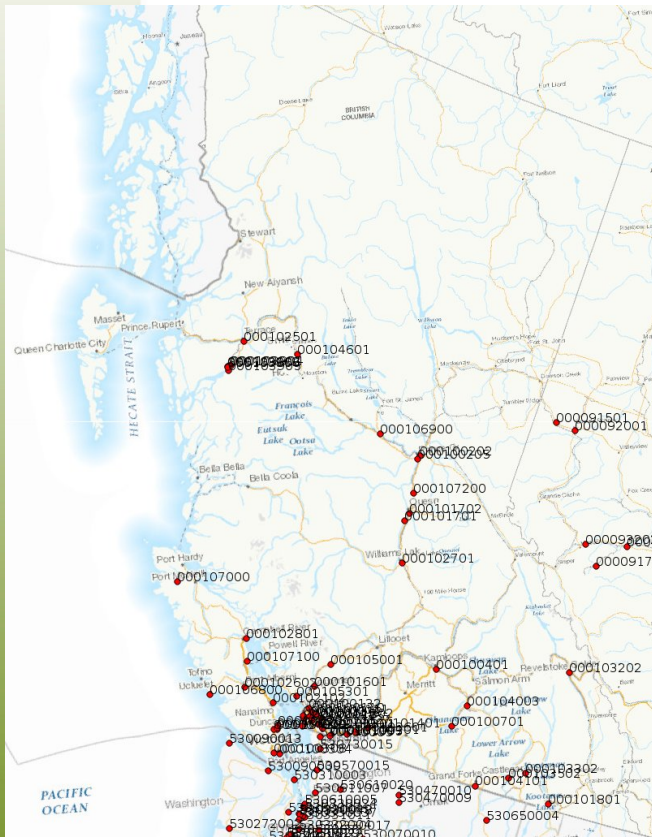
Correlation Coefficient		
StationID	OPS	FireWork
101702	0.28	0.42
107200	0.29	0.56
101701	0.19	0.43
100202	0.33	0.51
106900	0.37	0.41
104601	0.20	0.48
100205	0.28	0.32
101704	0.24	0.55
100111	0.33	0.55
102701	0.21	0.57
100401	0.31	0.51
103502	0.34	0.67
AVG	0.28	0.50

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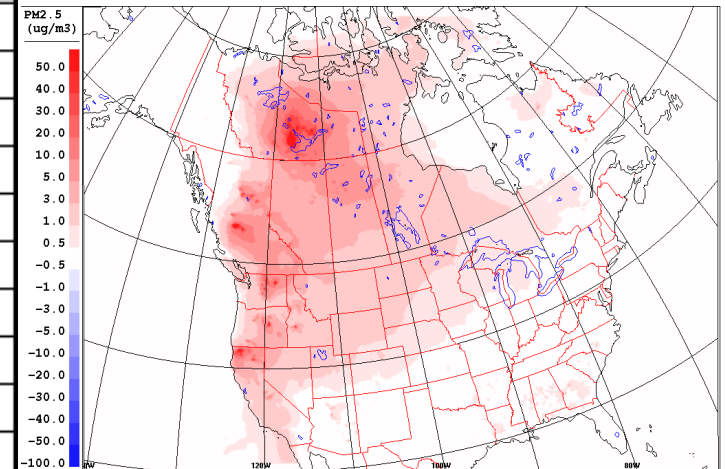
Stations 101702 and 107200: Observed and forecasted PM$_{2.5}$ (ug/m^3) concentrations
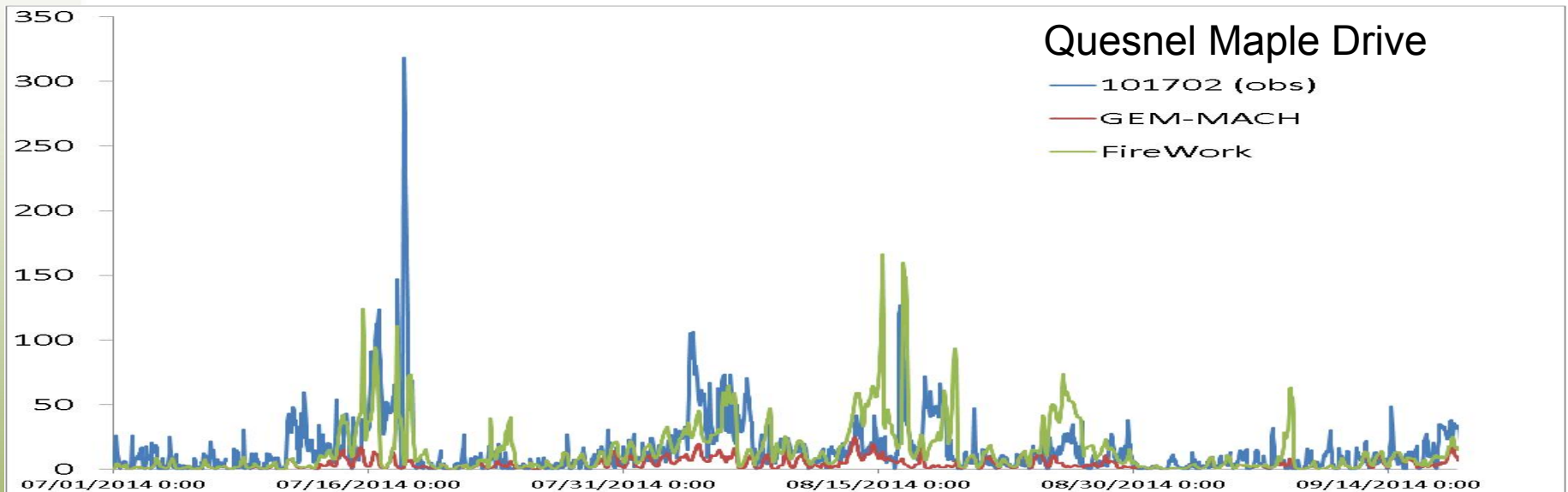
Stations 101701 and 102701: Observed and forecasted PM$_{2.5}$ (ug/m^3) concentrations
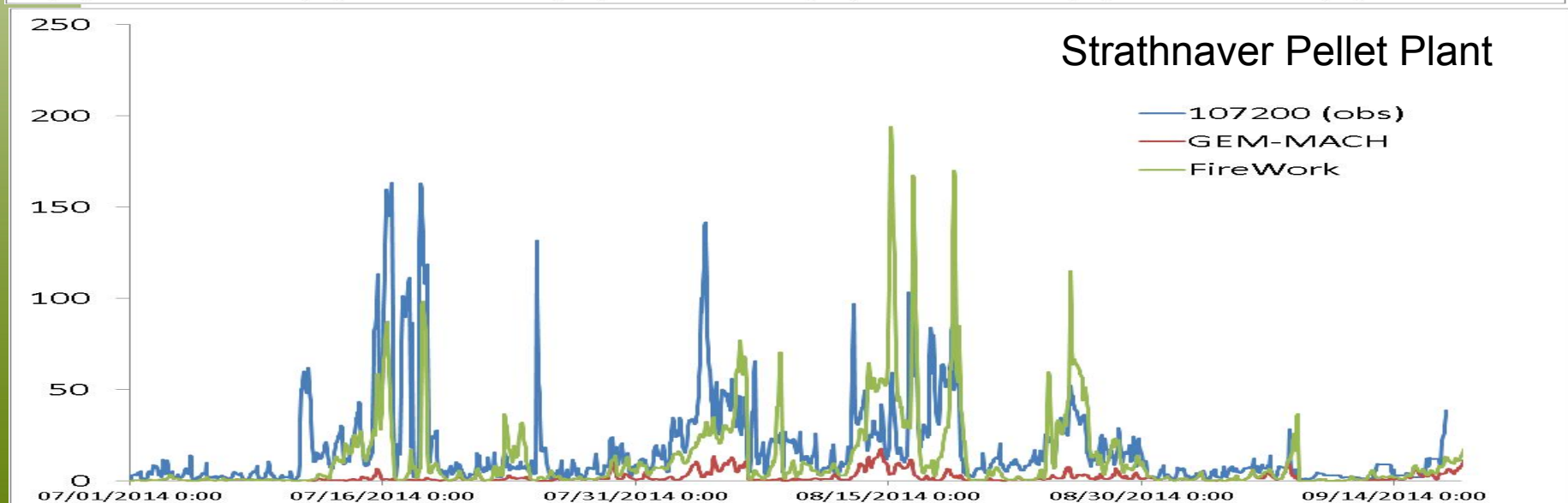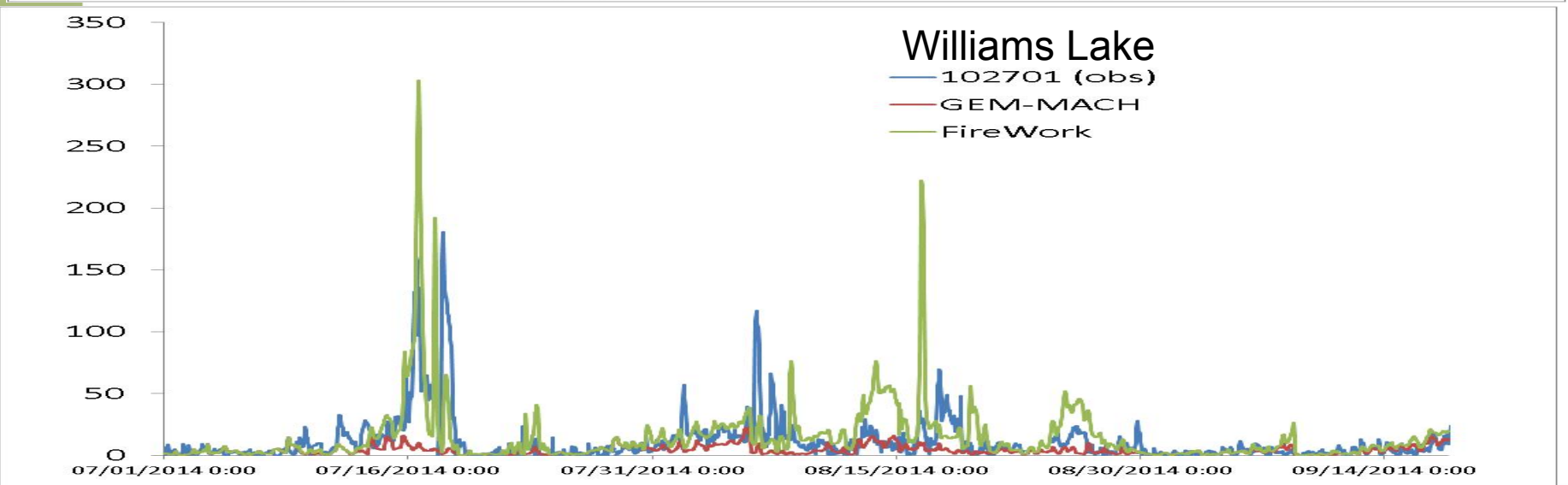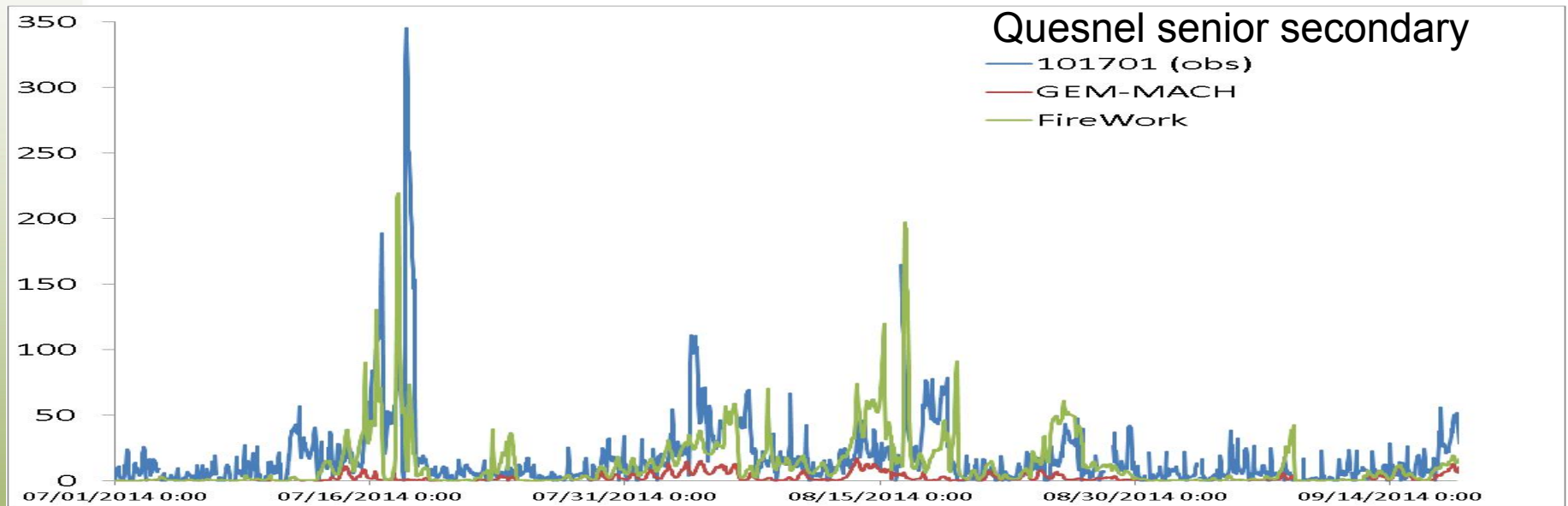
Analysis for Selected Stations in Manitoba
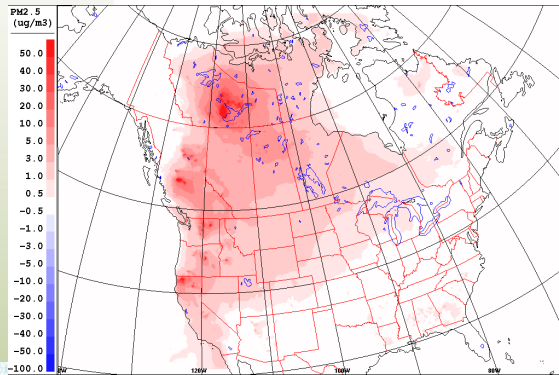
Correlation Coefficient		
StationID	OPS	FireWork
70118	0.23	0.60
70119	0.29	0.53
70203	0.17	0.47
AVG	0.23	0.53

FireWork was able to forecast long range smoke advection
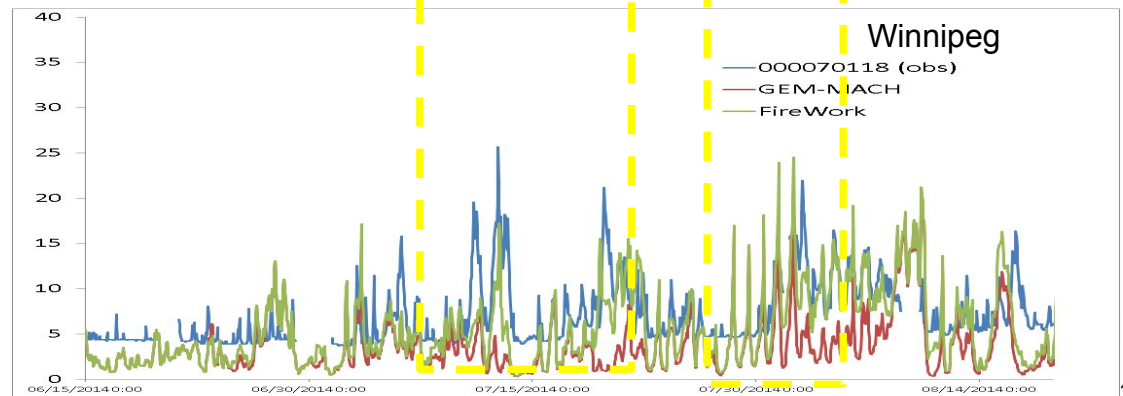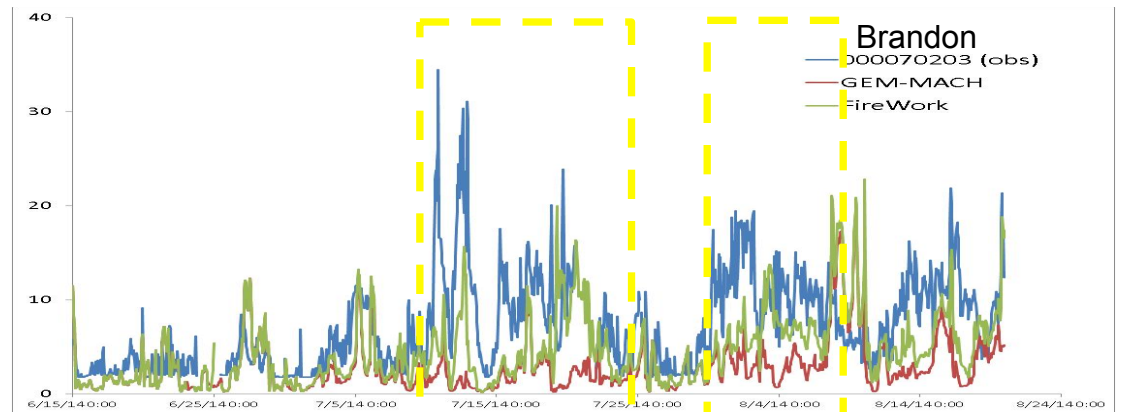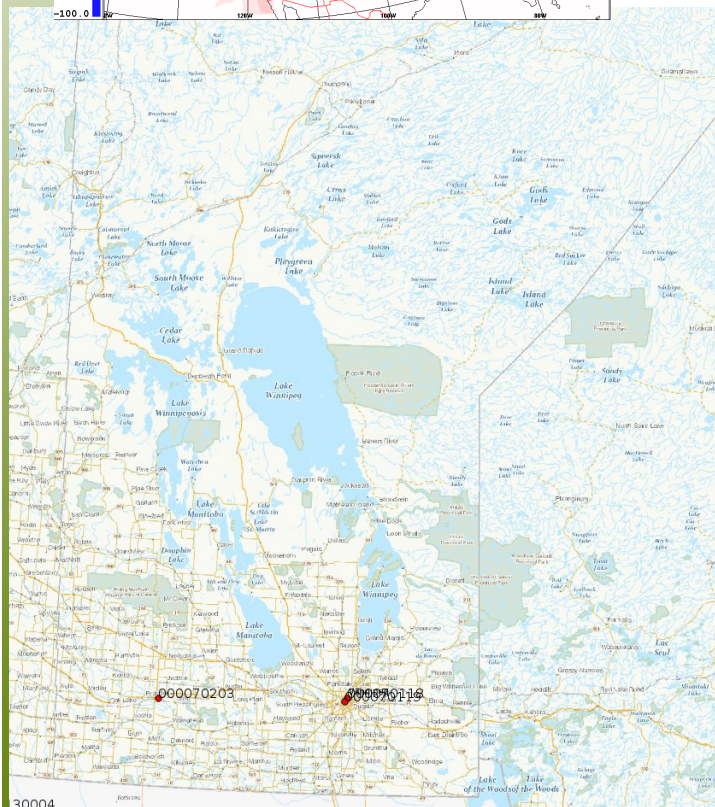
Some lessons learned

- Uncertainties in forecasted meteorology can have a significant impact
  - Example: the error of 0-30° in wind direction can affect greatly the smoke advection
  - Intense forest fires have important impact on radiative balance, convection, winds, etc.

- Need to examine if model produces too much ozone, and not enough secondary PMs
  - Ozone bias slightly worse, NO_2 scores neutral.

- Hotspot data feed from NRCan: need to raise reliability up to operational standards
  - Additionnal Q/C processes are needed along the chain

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Can FireWork be useful to your organisation?

- Using FireWork as a guidance tool in fire management (dealing with the impact of smoke)
  - Beware of limited predictability of wildland fire smoke
  - Best approach is to combine various sources of data
    - Other models (e.g. BlueSky Canada)
    - Satellite imagery
    - In-situ reports on fire evolution
    - etc

- Using FireWork for health guidance
  - FireWork can forecast a multi-pollutant health index (AQHI)
  - Health warning tresholds & messages are discussed with provincial/territorial autorities
    - Can have messages adapted to fire smoke situations

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FireWork product development

- Sharing PM animations only for now
- Possible products
  - FireWork forecast at Canadian stations, with statistical model correction – csv file
  - FireWork forecast at other locations (interpolated statistical correction: not as precise) – csv file
  - Projections on polygons (average over an area) - xls/dbf
  - Model-derived visibility (experimental)
- Cannot share observations (unless agreement with providers)
- FTP site, potential for « push » technology
  - By default, maps are shared with GRIB format (requires extension in ArcGIS)
- WMS server (also serving kml)

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Future of FireWork

- Continue improving emissions through collaboration with Natural Resources Canada, US forest Service and the Bluesky Canada community

- Implement a plume rise algorithm adapted to wildfires (testing explicit and statistical methods)

- R&D questions:
  - Can we improve on fire persistence hypothesis? (e.g. correct for weather)
    - Through a fire growth model or a statistical model?
  - Can we design an ensemble of models/emission scenarios and provide a probabilistic forecast?
  - Would a 2-way coupling with the weather model improve the forecast?

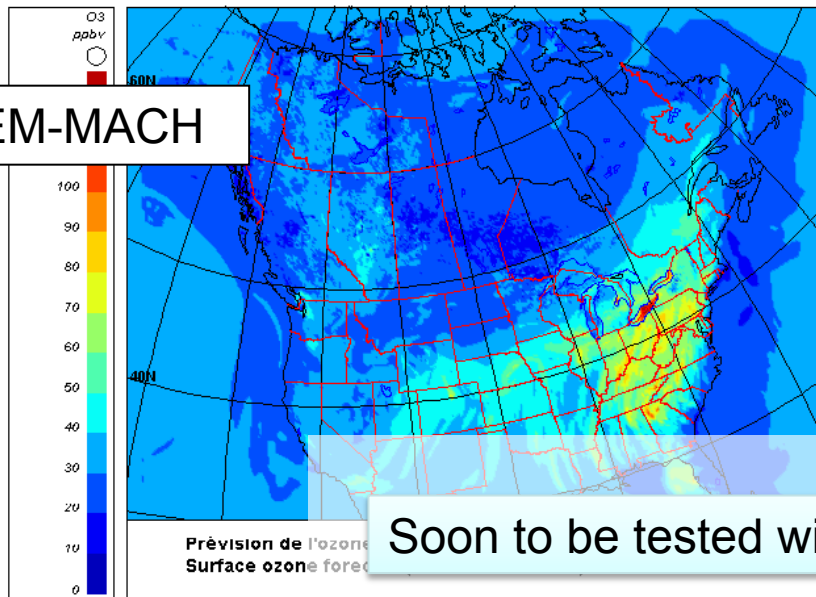Environment Canada   Environnement Canada

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OA: Objective Analysis for Surface Pollutants

- Operational as of February 2013

- Blends model forecasts with surface observations from Canadian regional networks and the U.S. EPA/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):
  - O_3 and $PM_{2.5}$ **(NO_2 to be added in 2015)**
  - **For 2015: AQHI maps** derived from individual analyses for O_3, $PM_{2.5}$, and NO_2

- 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
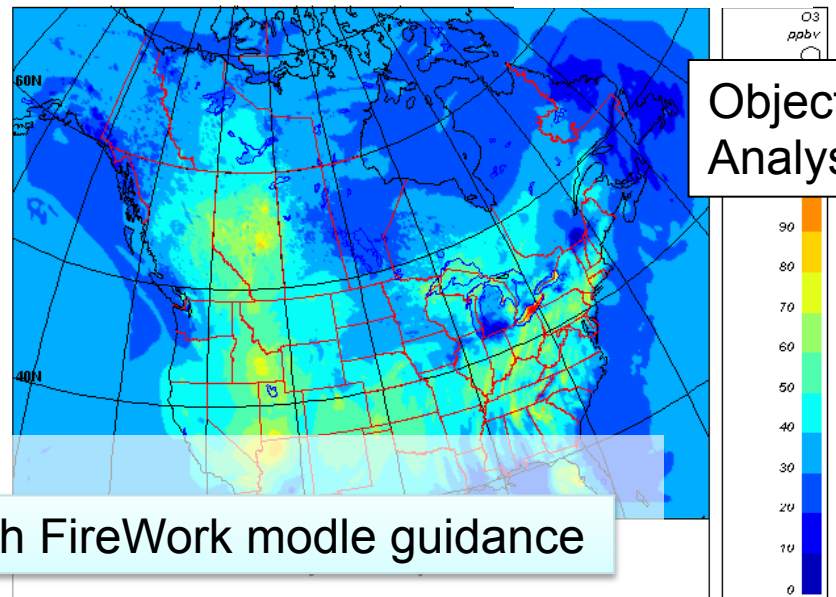 - Promising results, especially for PM (gain goes beyond 48h)

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Ozone

Dimanche 29 Mai 2011 à 23:00Z / Sunday May 29 2011 at 23:00Z (EXPERIMENTAL)

GEM-MACH

Objective Analysis

Soon to be tested with FireWork modle guidance

Prévision de l'ozone
Surface ozone forecast

Analysis Increments

Incrément d'analyse (correction au modèle)
Analysis increment (model correction)

Observations
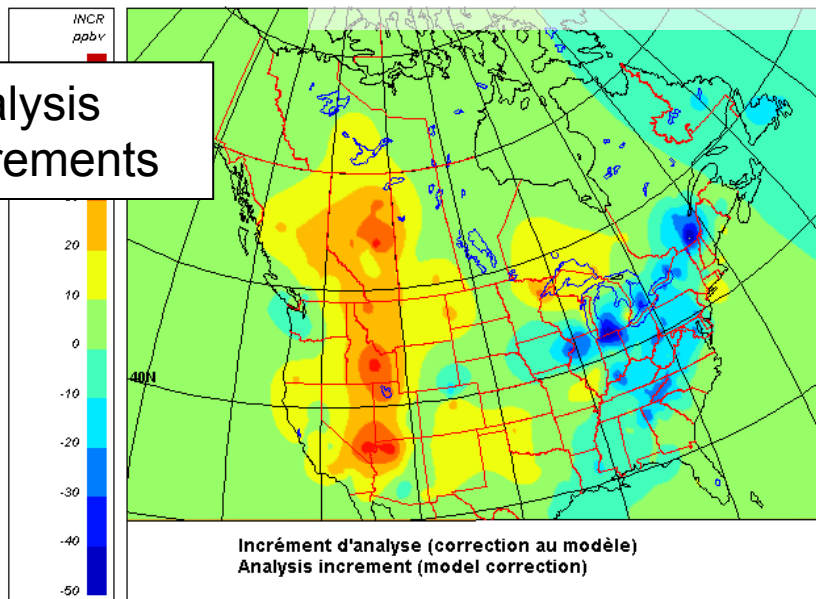
Observation d'ozone en surface
Surface ozone Observations
1235 stations
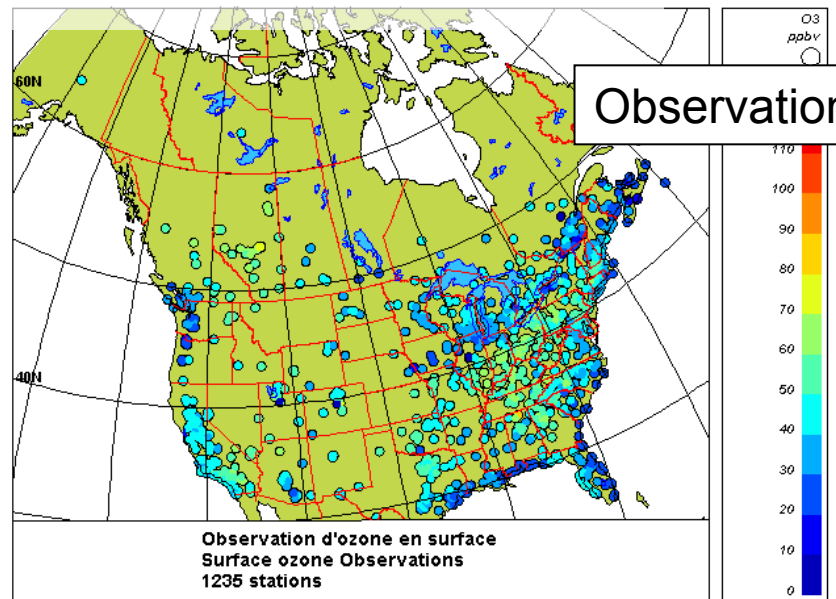
Conclusions

- Environment Canada is now operating an air quality forecast system with forest fire emissions: « FireWork »

- FireWork is primarily designed to support meteorologists in issuing AQ forecast and advisories
  - Modelling atmospheric chemistry and transport within a comprehensive air quality forecast system
  - Wildfire plume predictability is limited

- EC is willing to share additional products from FireWork with governmental agencies dealing with wildland fire management

- Your feed-back is important to us

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Environment Canada   Environment Canada

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THANK YOU