Environment Canada Environnement Canada

Canada

# 15 YEARS OF AIR QUALITY FORECASTING: ACHIEVEMENTS AND OUTLOOK

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**Chair, GURME – GAW URban Meteorology and Environment Project**

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

# Overview

- Early years and Ramp-up :  ~2000 – 2007
- Growth: ~2008 – 2014
- 2015 onwards

  Research outlook towards the next generation of models and services

# Disclaimer

**PERSONAL OVERVIEW OF THE EVOLUTION OF AIR QUALITY FORECASTING PROGRAMS BIASED TOWARDS MAJOR NMHS (NOAA, EC, ECMWF), NORTH-AMERICAN ACTIVITIES AND IN PARTICULAR CANADIAN ONES.**

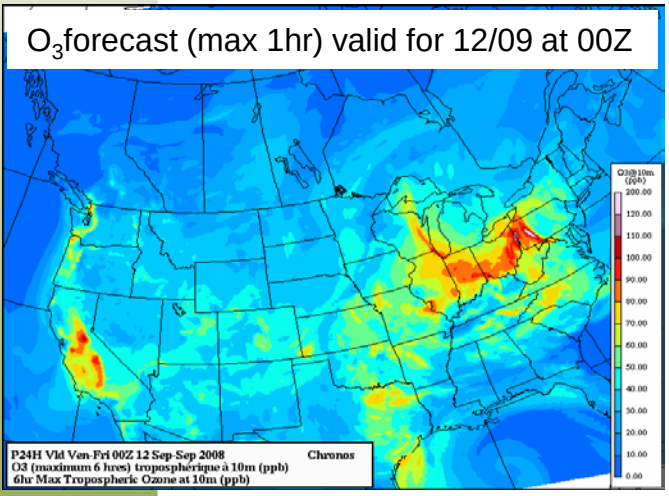
**AIR QUALITY FORECASTING IS STRONGLY TIED TO RESEARCH IN THE HEALTH IMPACTS OF AIR POLLUTION. THIS ASPECT IS NOT COVERED IN THE PRESENTATION.**

# Early years: 1995 - 2000

- 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)

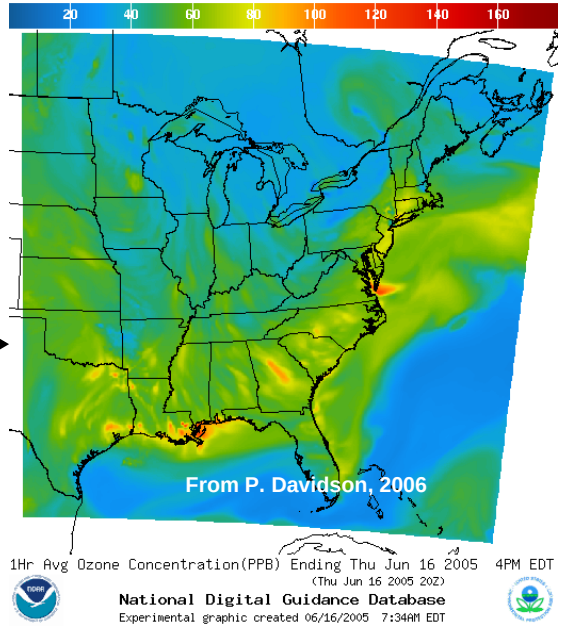
# First generation forecast models

- 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

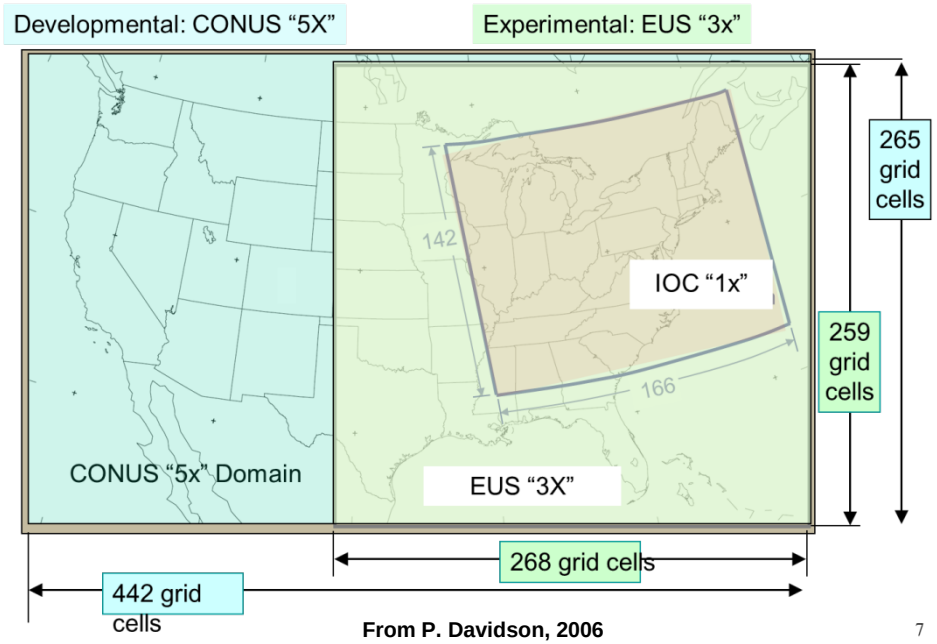
**Environment Canada**

- **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

# Some key initiatives in AQF development

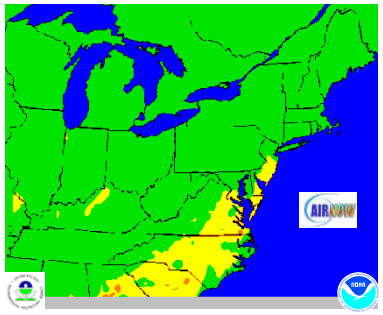
**AQHI observation availability for the last 6 months**

| 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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Car

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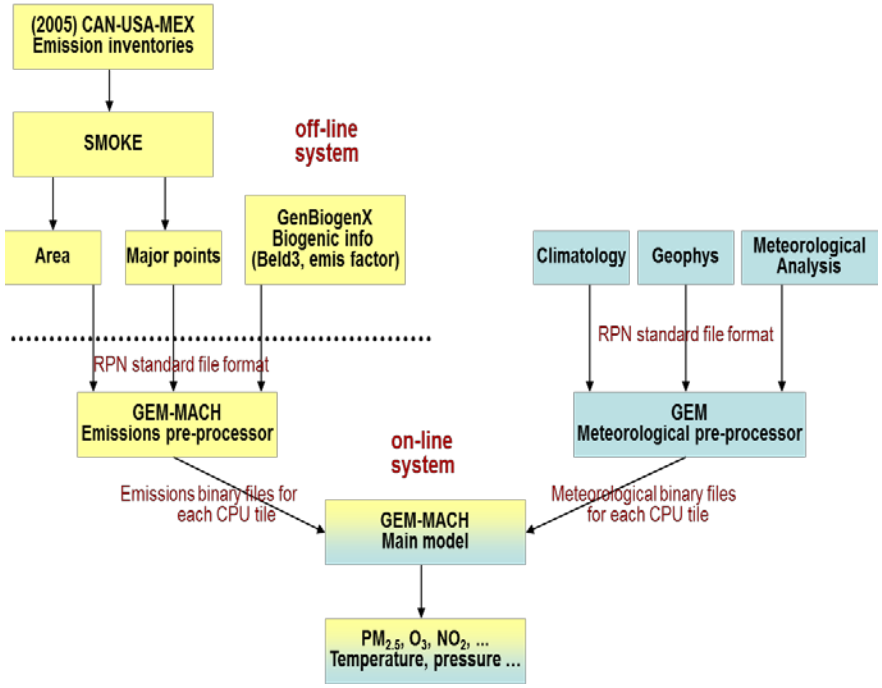
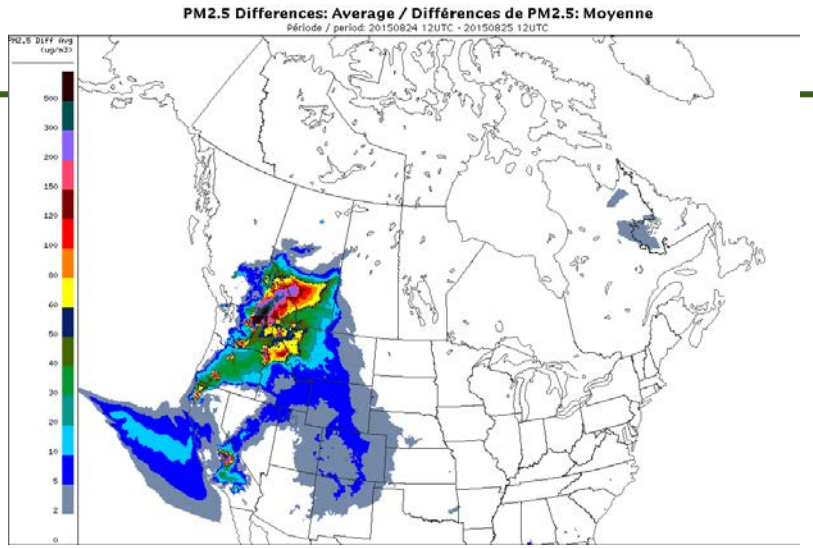
# Turning point: in Canada, new MPI based HPC

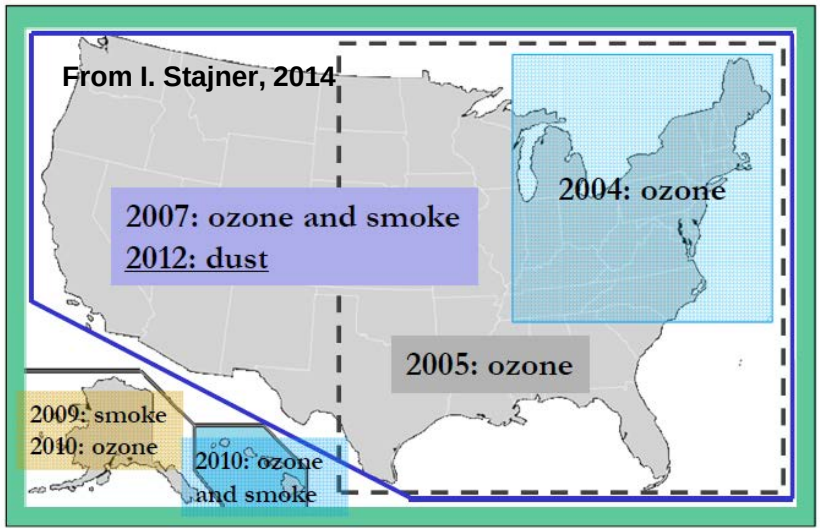
- **Summer 2004:** major hardware change with MPI capability
  - Started a 5 year development period towards on-line model
- **Summer 2009:**
  - Operational implementation of second generation of AQ forecast model: on-line GEM-MACH (1-way interaction)
- Marks operational uptake of research on on-line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



# Growth since ~2007

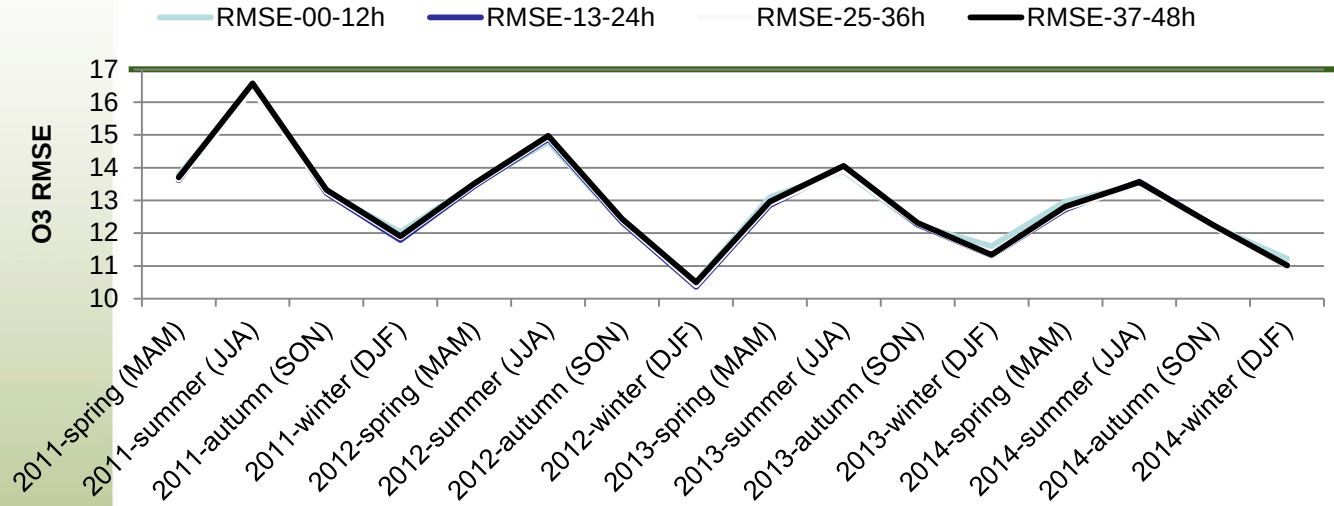



- Environment Canada:
  - Chemical /emission modules
    - 2 bins representation of PM
  - Resolution: 21 to 15 to 10km
    - Driven by met model changes
  - Smoke (Fireworks)
  - Operational objective analysis and post-processing

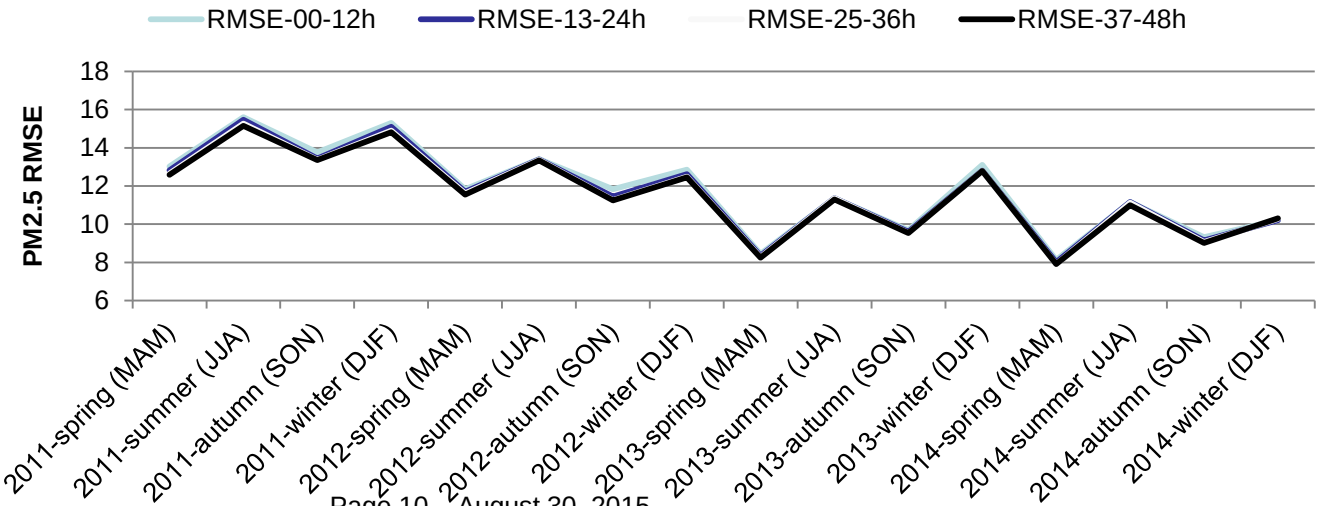



- NOAA:
  - Chemical /emission modules
    - Smoke and Dust
    - Experimental PM over CONUS
  - CONUS to all U.S. states
  - Post-processing

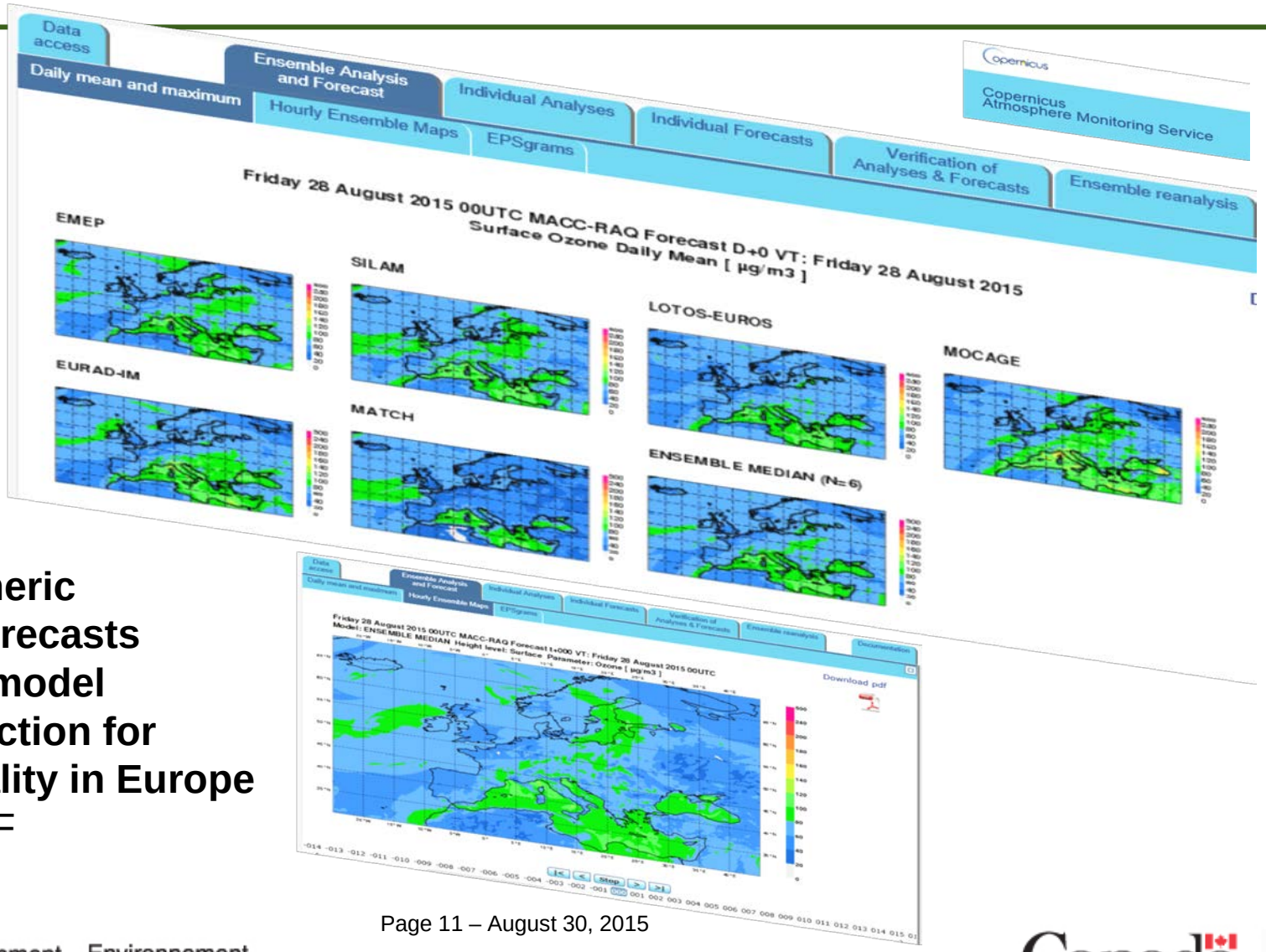
# Performance is steadily improving




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



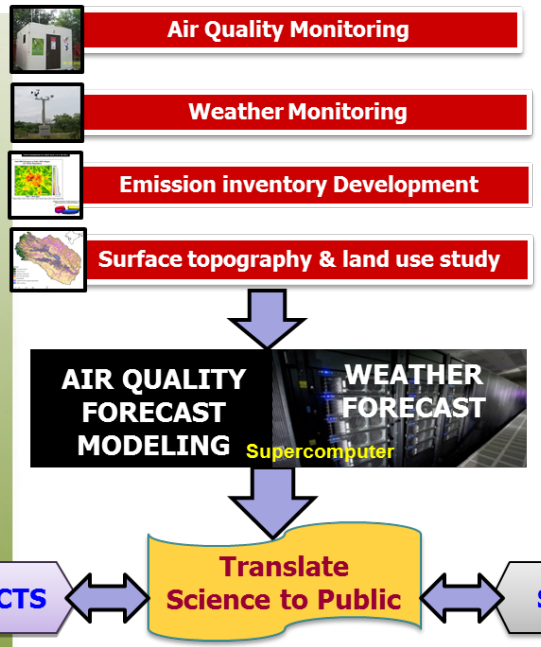
# European effort: GEMS/MACC/Copernicus



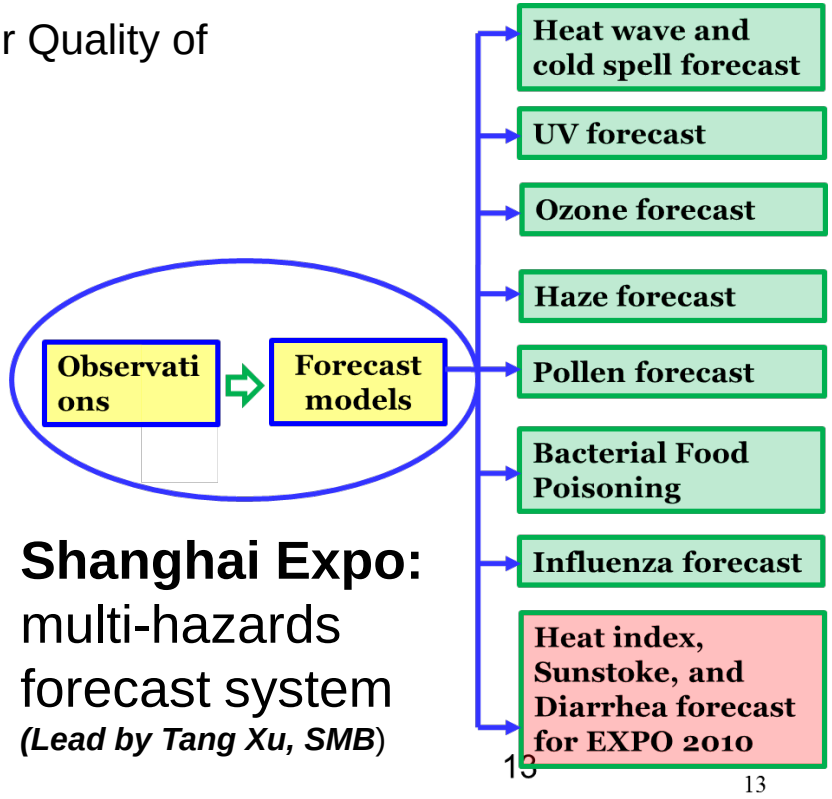

**Global atmospheric composition Forecasts driving a Multi-model ensemble prediction for regional air quality in Europe**
GEMS – ECMWF

# 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)***

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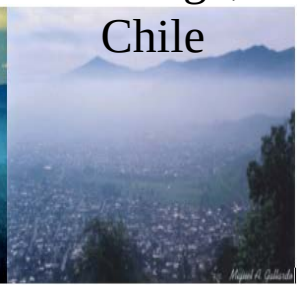
Sao Paulo, Brazil

Mexico City, Mexico

Santiago, Chile



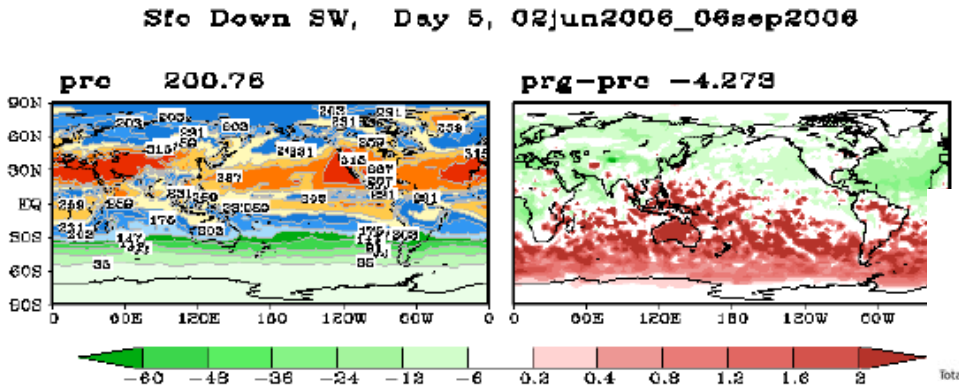
**Latin American cities**

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

# Effect of aerosols on weather

**Impact of aerosols on medium range weather forecasts: Comparisons between forecasts**

- T126 L64 GDAS experiments (2006-06-01 to 2006-09-07)
- Aerosol scheme configuration: PRC (climatology) and PRG (GEOS4-GOCART)
- The experimental aerosol treatment only impacts the model results via its direct effect on the radiative forcing of the atmosphere



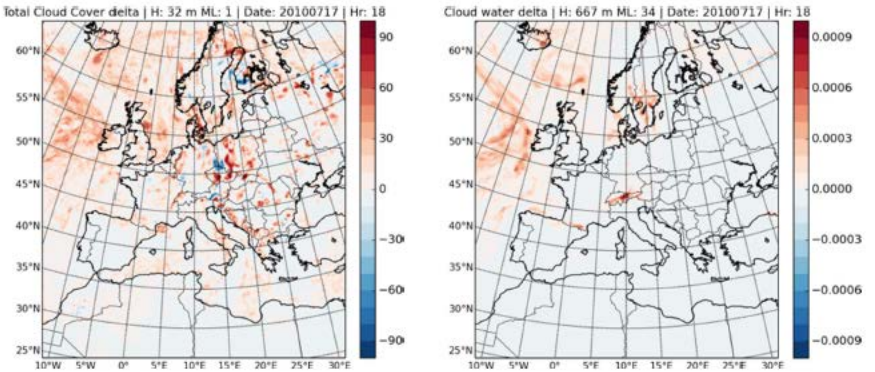

Surface downward SW fluxes are reduced due to higher aerosol attenua
Cooler near surface temperature and suppressed PBL depth are foun

*International Workshop on Air Quality Forecasting Research, Boulder, CO, Dec 2-3, 2009*

**S. Lu, IWAQFR, 2009**

**A. Baklanov, WWOSC, 2014**

**Enviro-HIRLAM Applications for NWP:**
aerosol–cloud interactions




(Enviro-HIRLAM – REF-HIRLAM )
Change in total cloud cover [%] (left) and cloud water content [kg/kg] (right) due to aerosol–cloud interactions

*Nuterman et al, 2014*

# Effect of aerosols on weather

- **WGNE – Aerosol exercise (S. Freitas):**
  - How important are aerosols for predicting the physical system as distinct from predicting the aerosols themselves?
  - How important is atmospheric model quality for air quality forecasting?
  - What are the current capabilities of NWP models to simulate aerosol impacts on weather prediction?

| Institution<br>Model | Domain<br>Resolution | Aerosol Species | A & BB Emissions | Aerosol Physics | Cloud Physics | Aerosol Assimilation |
|---|---|---|---|---|---|---|
| CPTEC<br>BRAMS LAM+CCAT | Regional<br>10 km | BC, Sea-Salt, OC, $SO_4$ | EDGAR 4. 3BEM | bulk | 2-mom | no |
| JMA<br>MASINGAR | Global<br>TL319L40 | Dust, Sea-Salt, BC, OC, $SO_4$ | MACCity GFAS 1.0 | 2-mom | 2-mom | no |
| ECMWF<br>Global | Global<br>T511L60 | | | Bulk | Bulk | yes |
| Météo-France<br>ALADIN + ORILAM | Regional<br>7.5 km | Dust | DEAD model | 3-mom log-no normal | Bulk | no |
| ESRL/NOAA<br>WRF | Regional<br>cloud res. | (many) | EDGAR 4. 3BEM | Bulk and Modal | 2-mom | no |
| NASA/GSFC<br>GEOS-5+GOCART | Global<br>25 km | Dust, Sea-Salt, BC, OC, $SO_4$ | EDGAR 4.1 QFED 2.4 | Bulk<br>modal | Bulk or<br>2-mom MG | yes |
| NCEP<br>NGAC+GOCART | Global<br>T126 | Dust, Sea-Salt, BC, OC, $SO_4$ | Climatological Aerosols | Bulk | Bulk | no |
| Barcelona SC | regional | dust | BSC-dust model | 8 dust size bins | Same as in WRF | no |

**Participating models**

**Website**
http://meioambiente.cptec.inpe.br/wgne-aerosols/

**From A. DaSilva/S. Freitas, WWOSC, 2014**

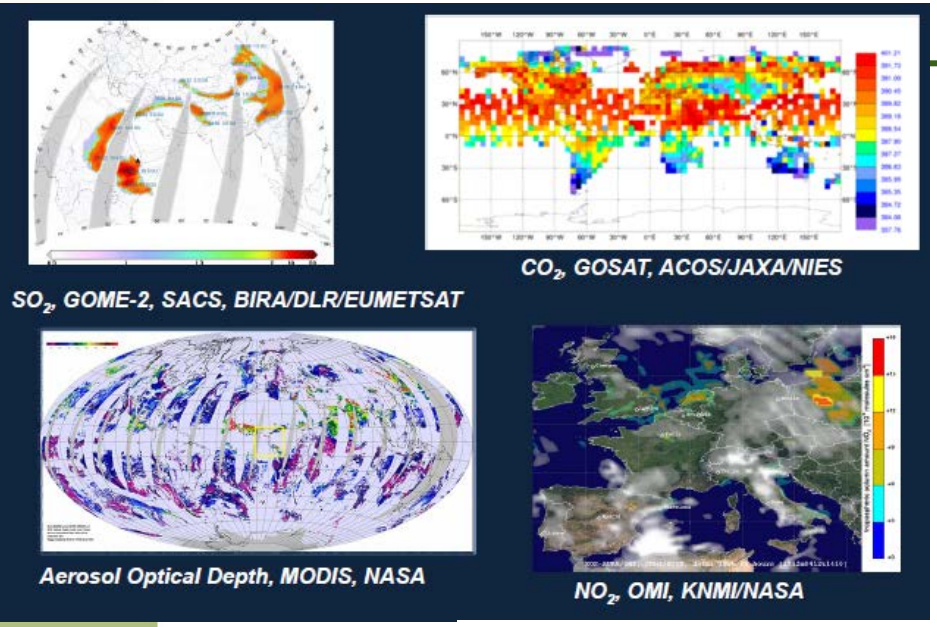
# Chemical Data Assimilation

**(courtesy V.H Peuch, WWOSC 2014)**

- Austin, **1992**: Nudging in a stratospheric CTM (simplified chemistry)
- Fisher and Lary, **1995**: 4D-Var in trajectory box model (reduced strato. chemistry)
- Elbern and Schmidt, **1999**: 4D-Var in a regional Air Quality CTM
- Khattatov et al., **2000**; Ménard et al., **2000**; Errera and Fonteyn, **2001**;...: Kalman filter or 4D-var in global stratospheric CTMs (homogeneous and heterogeneous chemistry)
- Elbern et al., **2007**: Emission rate and chemical state estimation by 4-dimensional variational inversion in a regional Air Quality CTM
- Zhang et al., **2008**; Benedetti et al., **2009**;...: 3D- or 4D-var AOD assimilation
- Semane et al., **2009**: impact on (UTLS) winds from ozone profile observations
- Sekiyama et al. **2010** : EnKF assimilation of lidar data (aerosol)
- Engelen and Bauer, **2011**: use of composition information ($CO_2$) for improving IR radiance assimilation
- ...

*(sorry for all the pioneering work not mentioned in this short anthology!)*

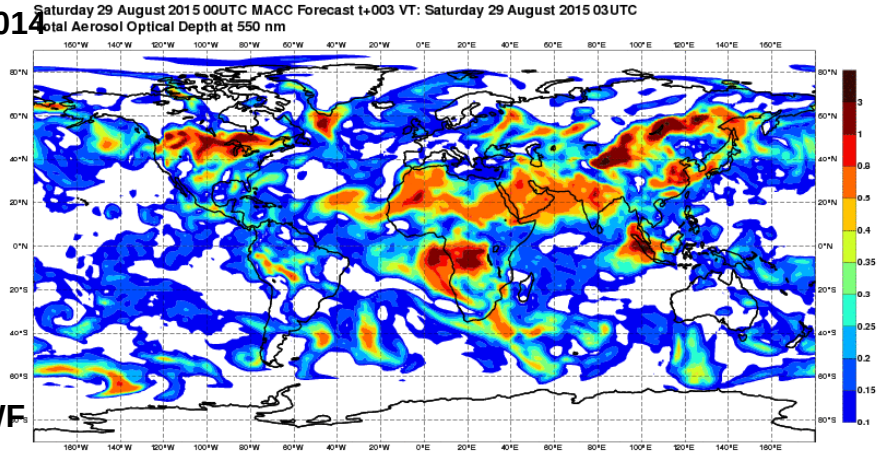
# Chemical Data Assimilation

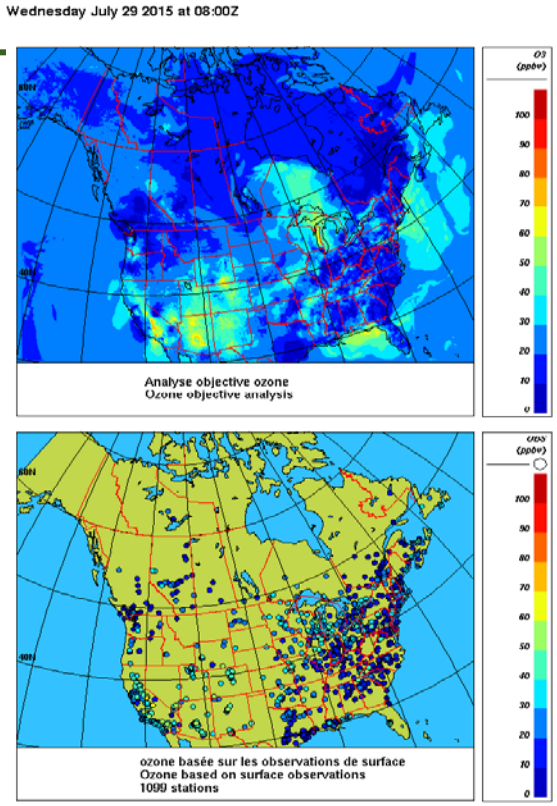



From VH. Peuch, WWOSC, 2014

**From satellite to chemical analyses** (from Copernicus, Sat Aug 29)

Courtesy VH. Peuch, ECMWF




Courtesy A. Robichaud, EC

**From ground stations to objective analyses** (EC, July 29, 2015)

# IWAQFR workshop series

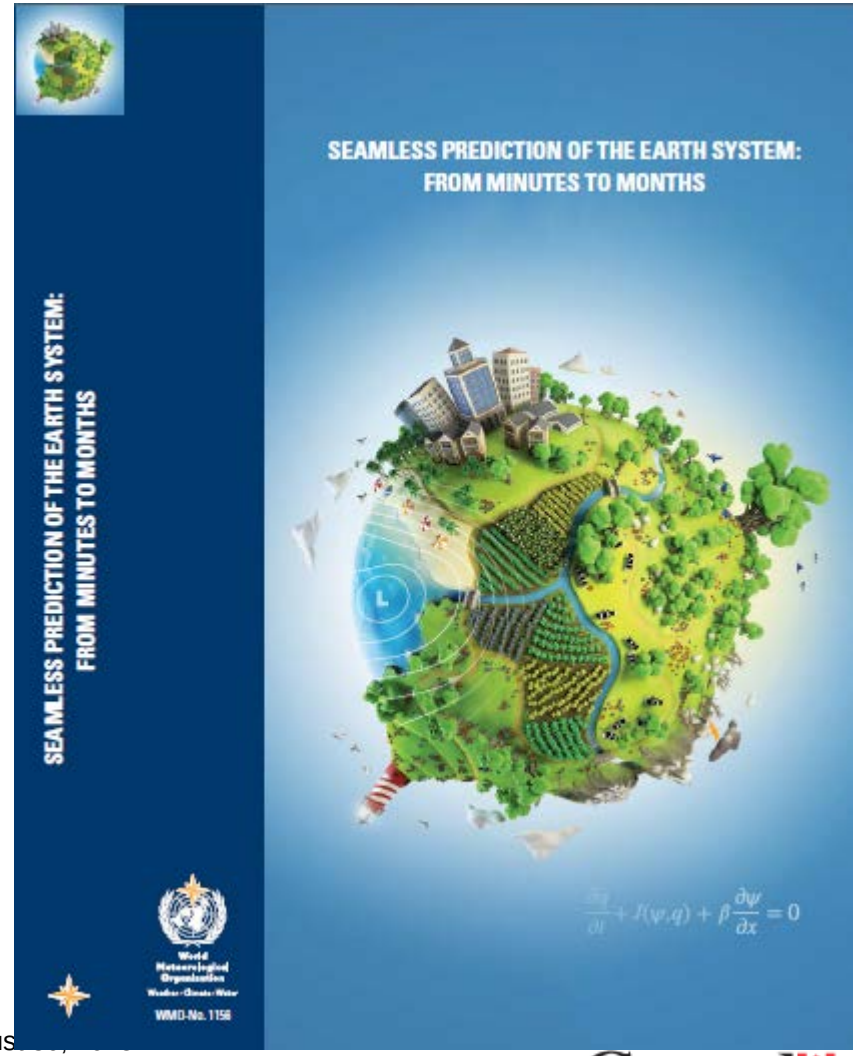
- 2009: Boulder, Co
- 2010: Quebec City, Canada
- 2011: Potomac, Maryland
- 2012: Geneva, Switzerland
- 2013: Santiago, Chile
- 2014: Montreal, Canada in conjunction with WWOSC
- 2015: College Park, Maryland


# Working closer with NWP scientists

- **Recommendation from IWAQFR-5:**
  - Establish closer working collaborations with NWP scientists
  - WWOSC 2014

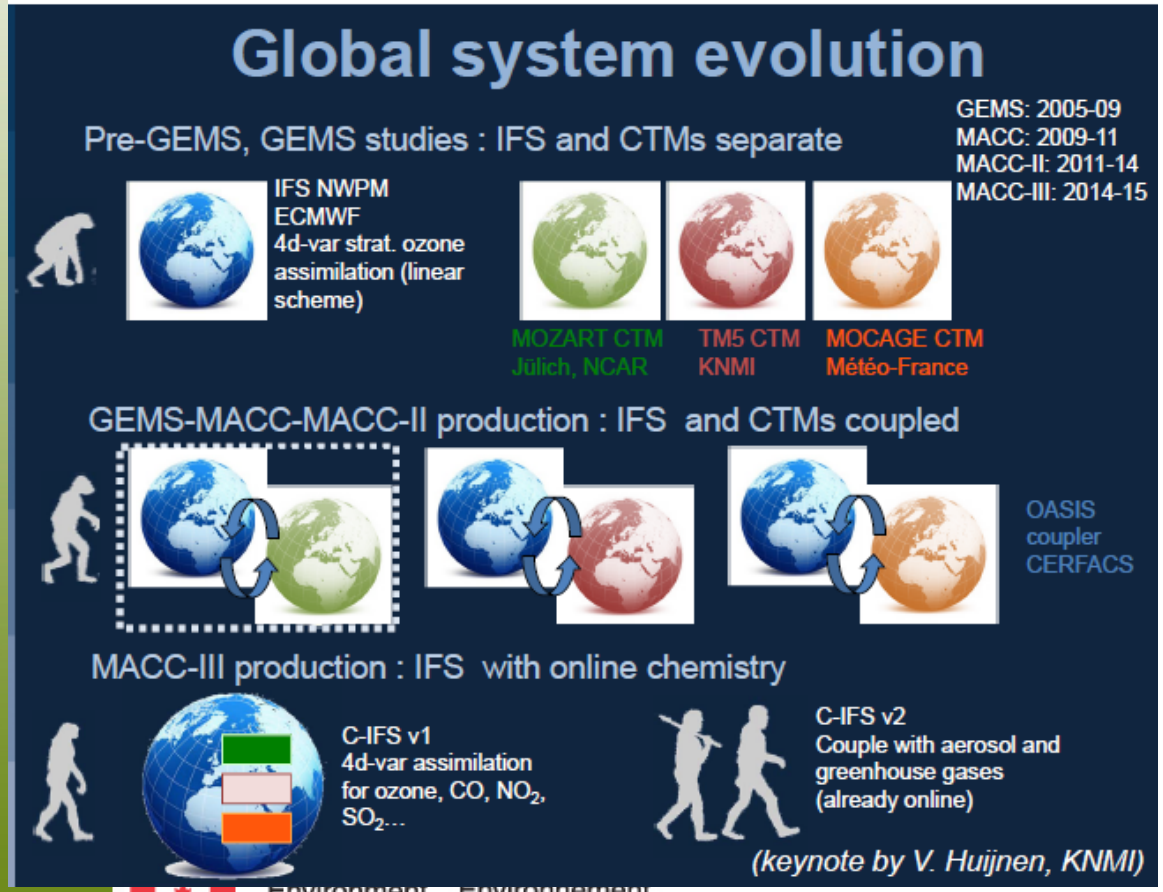
WWOSC 2014
MONTRÉAL, CANADA

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



# Seamless meteorology-composition models

- **Chapter 12: *Seamless meteorology-composition models: challenges, gaps, needs and future directions*** (A. Baklanov et al, 2015)




From VH. Peuch, WWOSC, 2014

- Evolving from separate to seamless met/composition models to address limitations in weather, climate and atmospheric composition fields whose interests, applications and challenges are now overlapping
- Support creation of new environmental prediction services
- Seamless at the process-scale and temporal/spatial scale
- CCMM symposium (Feb, 2015)

# Key challenges in seamless models

- **What are the interacting processes and feedbacks that are needed?**
  - PM/Radiation/Cloud Microphysics - … - Land surface: need to further the understanding of the various mechanisms
  - **Which ones are important, at what scale and for what application?**
    - For AQ forecasts: How much does it affect the forecast over 48-72hr ?
- **How much integration is needed to get it right?**
  - **How complex the representations?**
  - **Consistency across scales**
    - Would the representation in the global met/chem models be compatible with regional/urban AQ forecast? (met forecasts, boundary conditions)
  - **Efficiency and affordability**
- **How to evaluate them**
  - International test beds for global to urban scales (ex: AQMEII ++)
  - Evaluation methodologies including for operational context
  - Broadening of variables measured and evaluated (chem/met/feedbacks)

# Urban-scale systems

- **Chapter 18: *Urban-scale environmental prediction systems*** (C.S. Grimmond et al, 2015)
  - Urban environments are particularly sensitive to weather, air quality and climatic conditions and their variability, for:
    - Safety and services,
    - Human health and well-being
    - Economic activities and innovation
  - They have a huge potential to benefit from smarter models, data and services given population growth and continuing urbanization.
- Paper addresses urban weather, urban air quality and urban hydrology
- **WMO: EC-66:**

  "The active interaction between the meteorological, environmental and climate communities is required to ensure the development of new generation coupled chemistry – meteorology models and their applications for numerical weather prediction, atmospheric pollution and climate studies".





**From VH. Peuch, WWOSC, 2014**

# Key challenges for Urban-scale systems

**(Chap 18, C.S.Grimmond et al, 2015)**

- Development of high-resolution coupled environmental prediction models that include realistic city-specific processes, boundary conditions and fluxes
- Enhanced observational systems to support (force, constrain, evaluate) these models to provide high quality forecasts for new urban services
- New targeted and customized delivery platforms using modern communication techniques, developed with users to ensure that services, advice and warnings result in appropriate action
- Development of new skill and capacity to make best use of technologies to deliver new services in complex, challenging and evolving city environments.

# Key challenges for Urban-scale systems

**(Chap 18, C.S.Grimmond et al, 2015)**

- Resolution required to provide suitable descriptions of urban effects for different applications
  - Corollary: simplifications appropriate for use at different scales (time/space) – building grey zone
- Methods to routinely gather and continuously update dynamically changing land cover, ingesting the spatially explicit parameters appropriate to models
- Advance coupled models that simulate the feedback between human activities and urban environmental conditions (and multi-scale modelling systems)
  - Understand the AQ/weather feedbacks at urban scales and the sensitivity of the predictability to the representation of these feedback
- Data assimilation methods to support coupled prediction systems.

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

# PanAm 2015 Environmental Prediction Systems

**All these systems have been successfully run during the Pan Am Games**

*Weather (GEM), 2.5km, 1km, and 0.25km*

*Air quality model (GEM MACH), 2.5km*

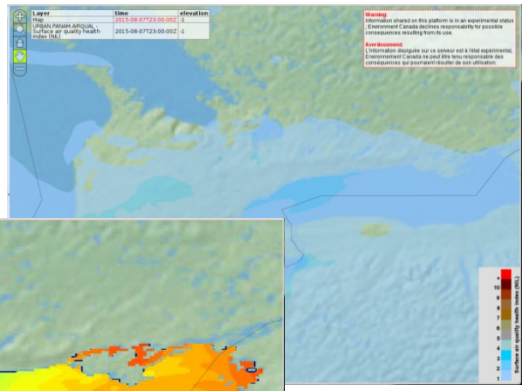
*3D Lake model (NEMO), 2km*

*Particle tracing*

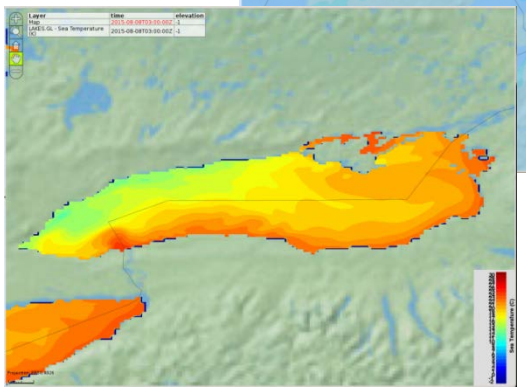
*Water level forecasting*

*Wave forecasts (WW3), 1km deterministic, 2.5km ens.*

*Precipitation analysis and streamflow prediction*

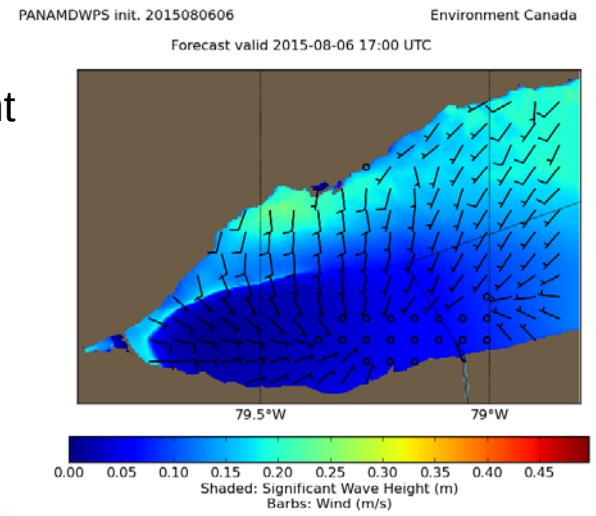


Air quality index



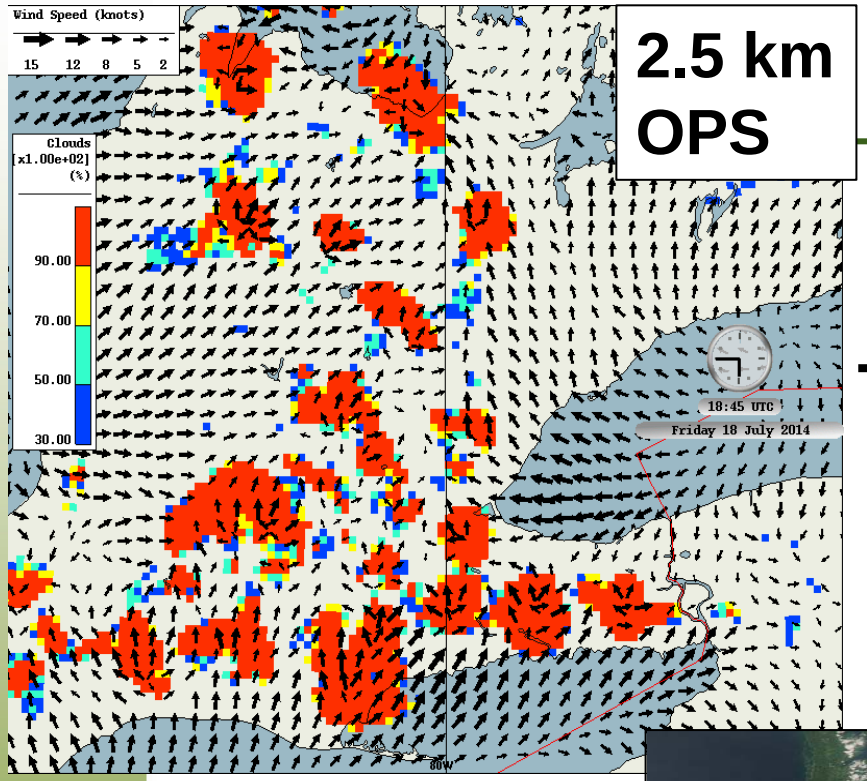
Lake surface temperature

Wave height

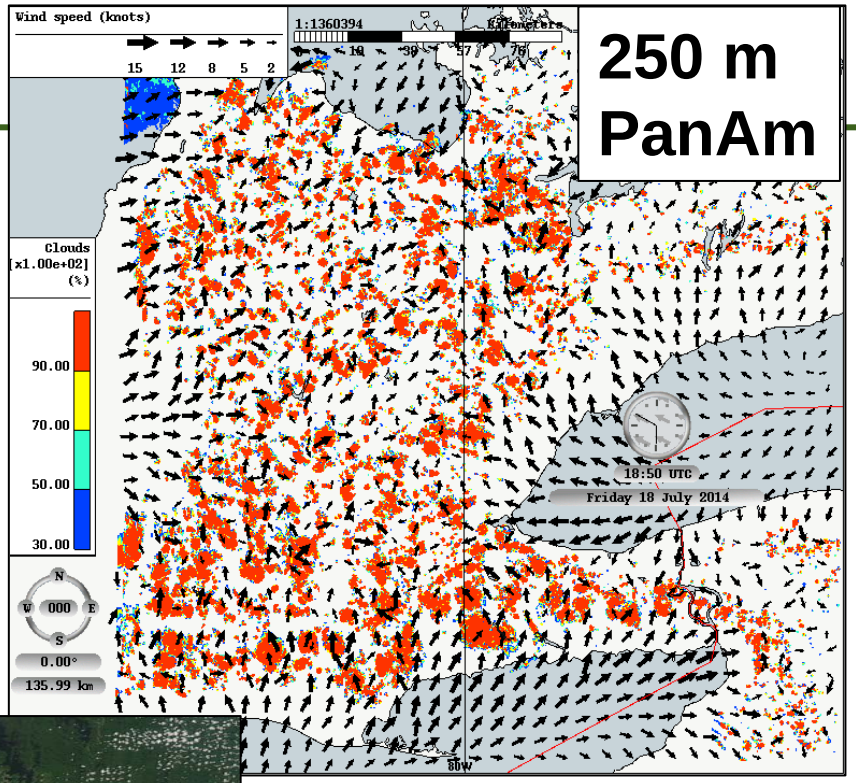



*Recent forecasts 6-7 August 2015*

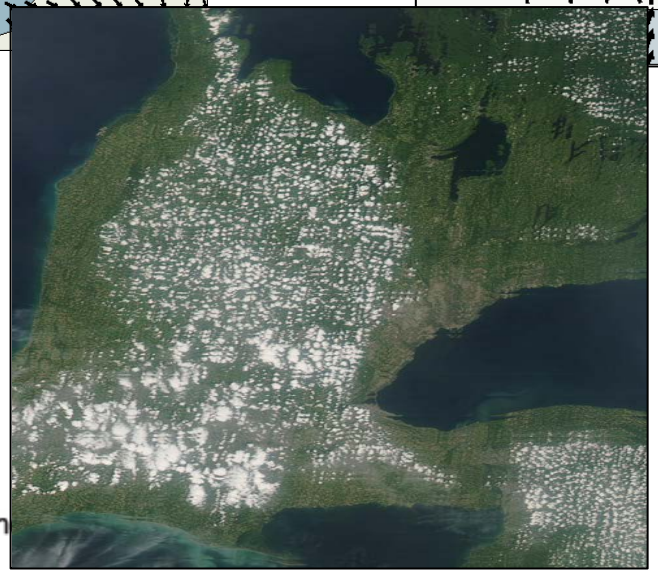
# Improvements with increasing resolution




2.5 km OPS




250 m PanAm



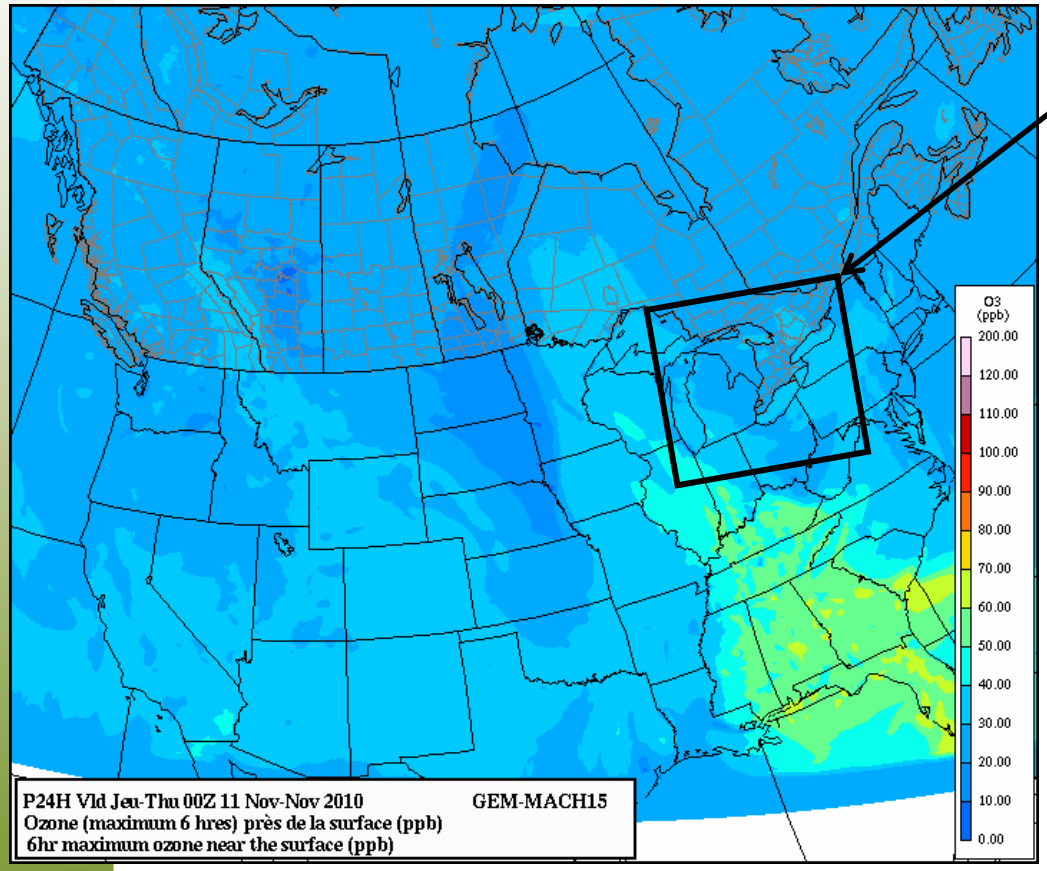
***Cloud coverage and near-surface winds Valid at 1850 UTC 18 July 2014***

***MODIS (Aqua satellite)***

ronnem Canada

Canada

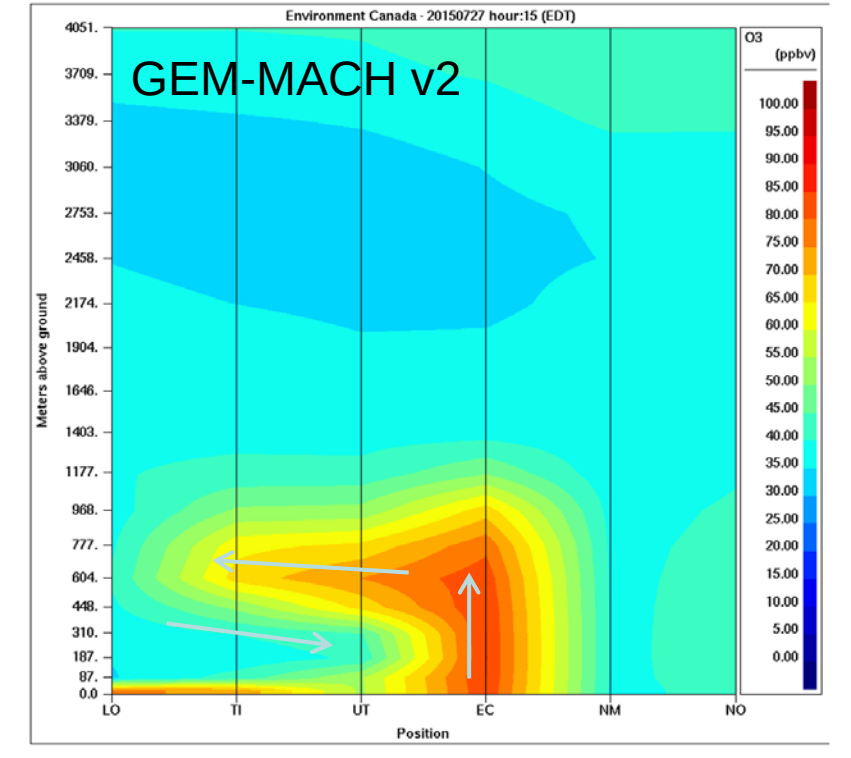
# GEM-MACH v2 Model Setup for Pan Am Games (Craig Stroud, Sylvie Gravel)




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





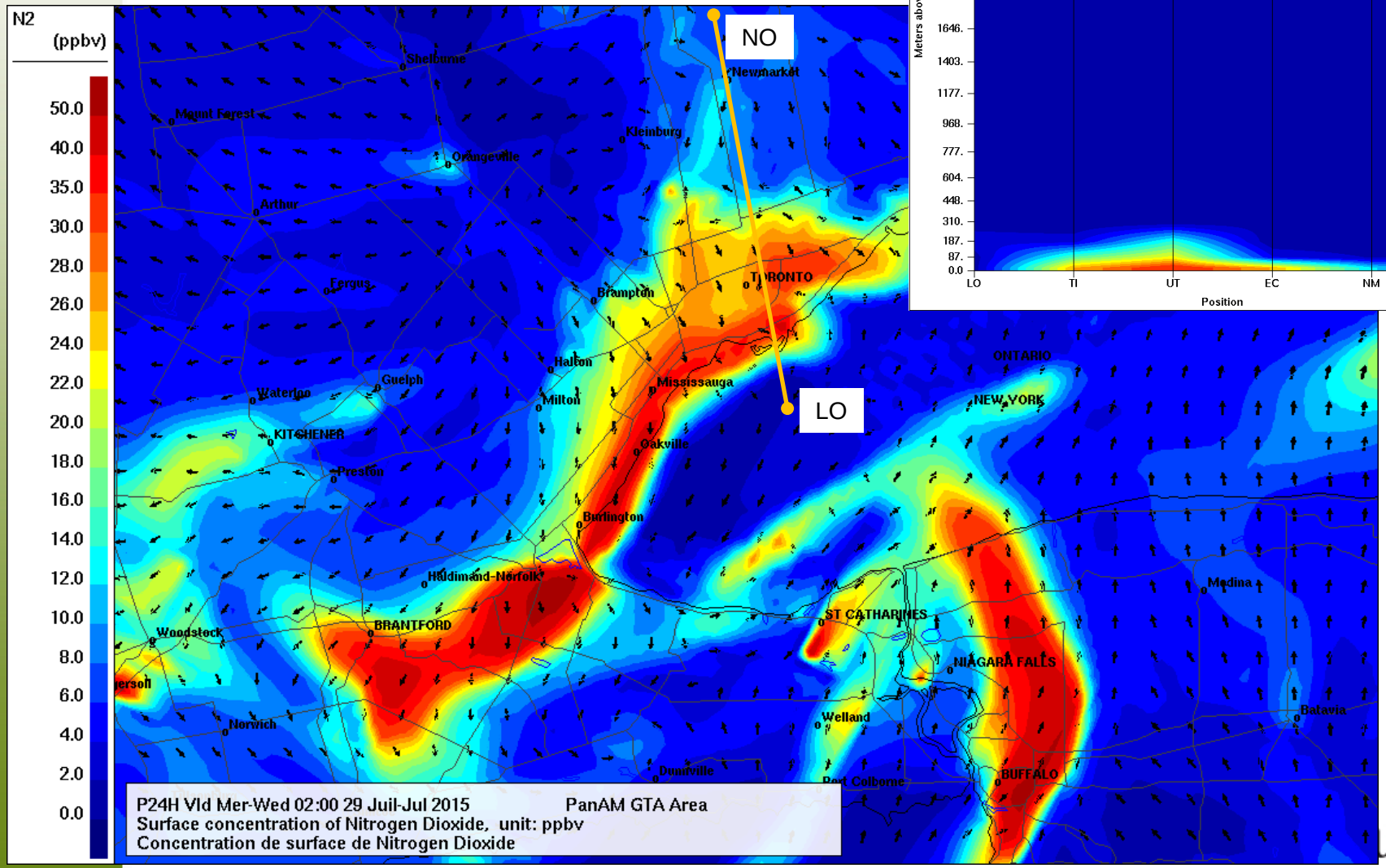


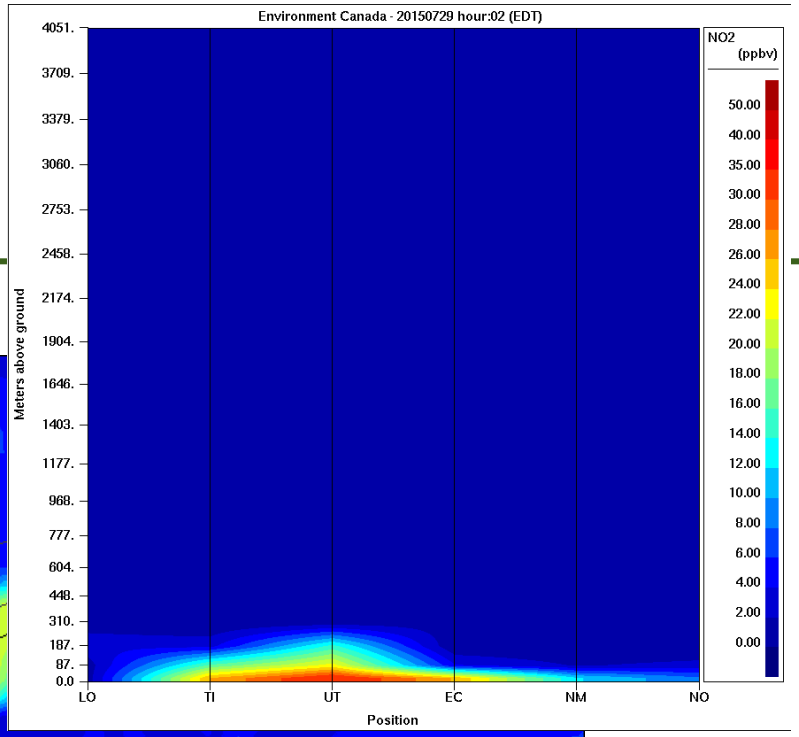
Note the GEM-MACH grid spacing

## 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 Heat Island



# PERFORMANCE AND RESOLUTION: 2.5km vs 10km

## GEM-MACH Model Evaluation (Bootstrapping method)

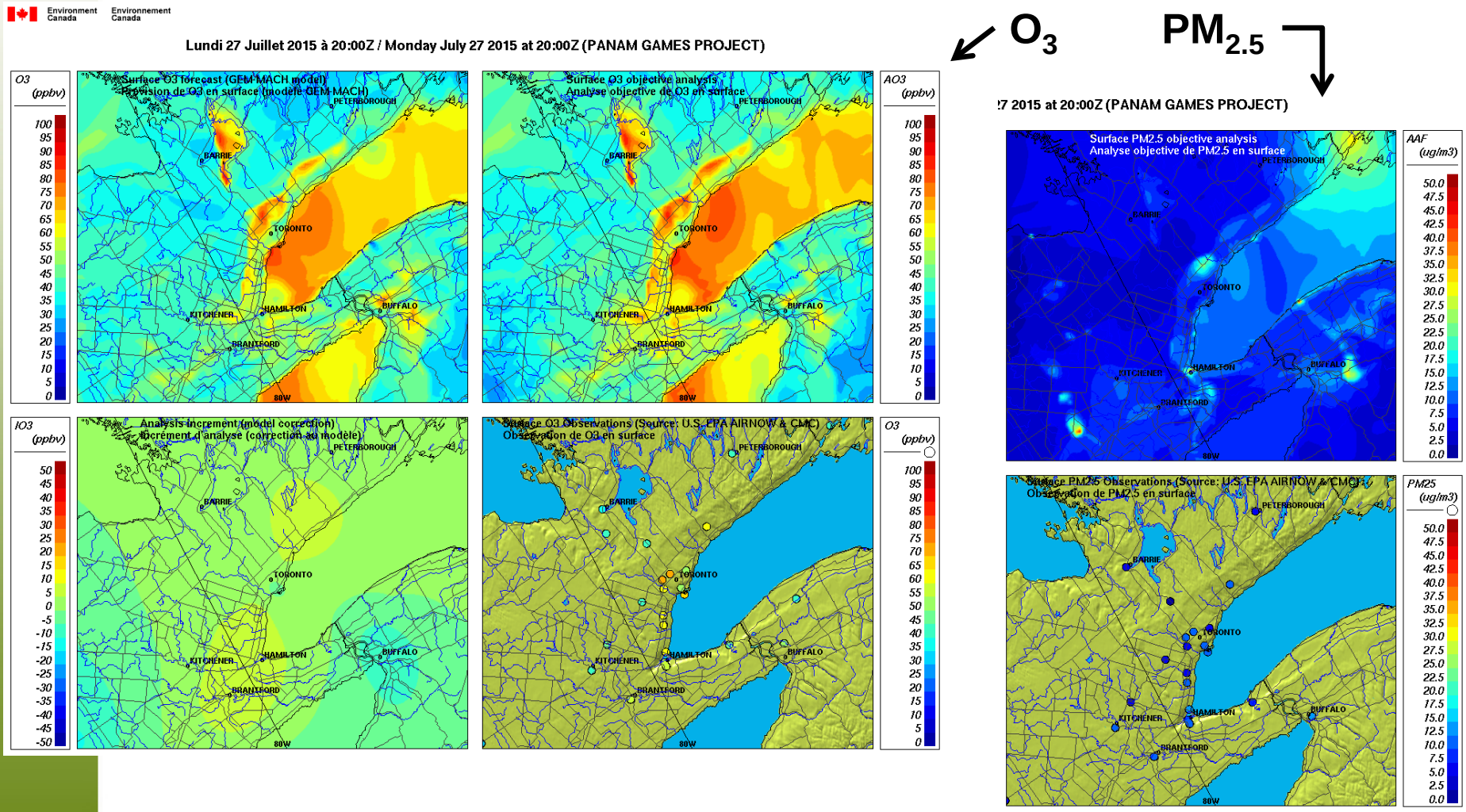
| | O3 | | NO2 | | PM2.5 | |
|---|---|---|---|---|---|---|
| | HRDPS vs OBS | RDPS vs OBS | HRDPS vs OBS | RDPS vs OBS | HRDPS vs OBS | RDPS vs OBS |
| R | 0.39 | 0.25 | 0.81 | 0.87 | 0.56 | 0.42 |
| MB | -3.25 | 3.99 | 1.68 | 2.62 | -1.55 | 1.47 |
| RMSE | 5.05 | 6.50 | 3.52 | 4.35 | 3.20 | 4.10 |
|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

# Chemical Objective Analysis for Ozone and $PM_{2.5}$ (Alain Robichaud)



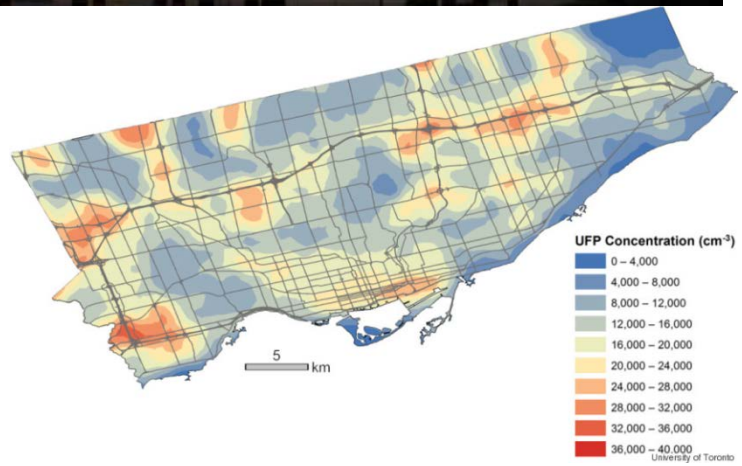



Environment Canada Environnement Canada

Canada

# Pan AM Demonstration of Urban Scale Air Quality

- Requirements for more urban scale **services**
- Partnerships and Technology
  - Modelling
  - Monitoring
  - Mapping applications

# Pan Am Weather And Health Portfolio

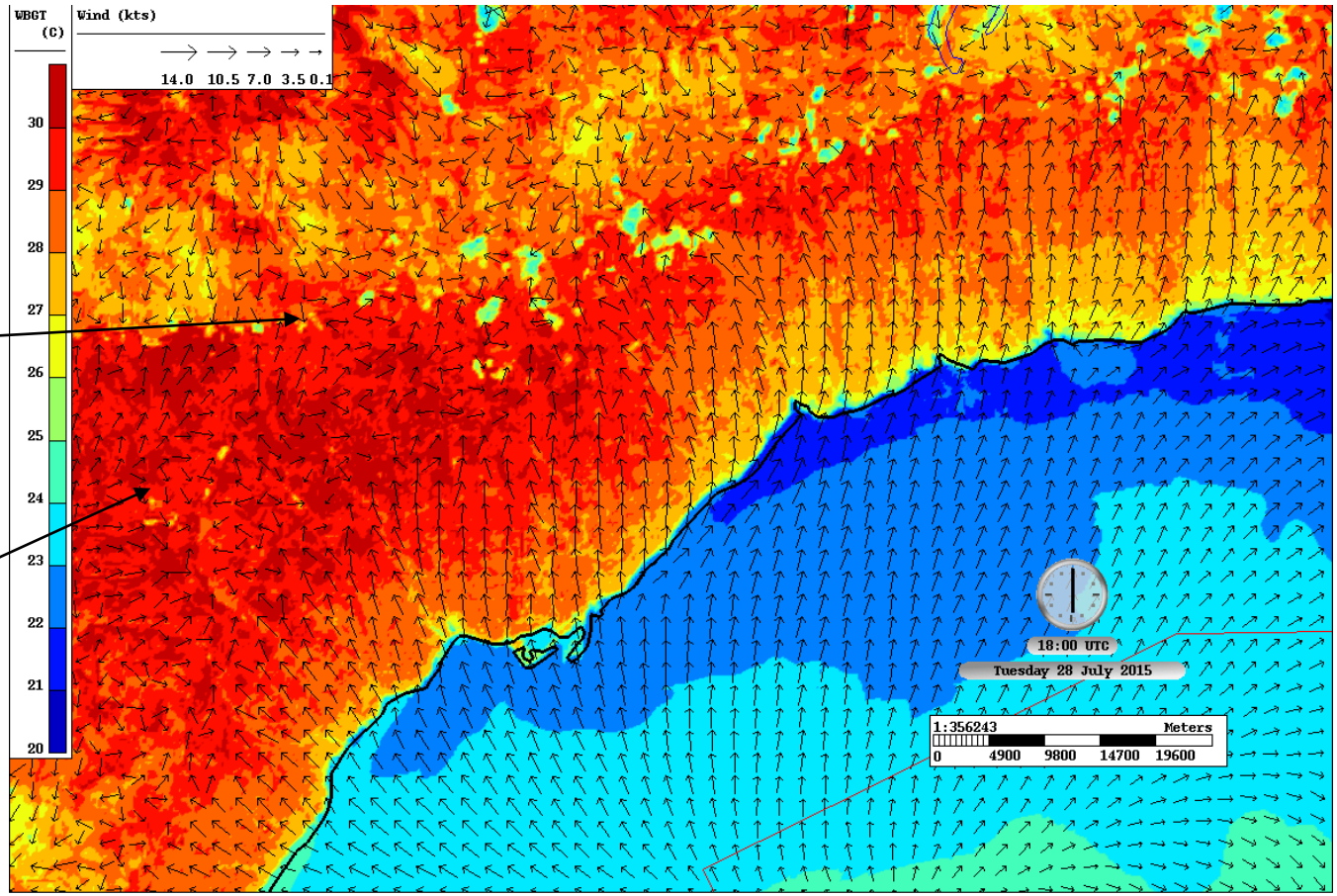
| Theme | Activity |
|---|---|
| Air Quality | **Increase number of AQHI locations and provision of hourly forecasting for all locations and communities**<br>**Enhancing AQHI model resolution (GEM-MACH 2.5 km)**<br>**Firework: forest fire smoke modeling maps**<br>**Air Sensors for Chemicals in the Environment (AirSENCE)**<br>**Near Roadside Ultrafine Monitoring Study**<br>Web-based mapping for traffic related air pollution and route planning<br>**AQHI implementation in Ontario … Pan Am driven** |
| Heat | **Multi-parameter weather monitoring network (mesonet)**<br>**Urban-scale heat, humidity and stress indices predictions**<br>**Urban Heat Island/Population vulnerability mapping**<br>**Implementation of new health-based-criteria for Heat Warnings** |
| UV | **Enhanced and geospatially presented UV forecasts**<br>**Investigation of cost-effective, real-time UV monitors**<br>**Pilot warning with health stakeholders** |
| West Nile Virus | **Weather prediction to improve modelling estimates of risk** |
| Education | **OAGEE Pan Am Summer Institute on Weather and Health** |
| Dissemination | Weather Active - Heat and AQ smart phone application<br>**Weather.GC.CA, EC Alert Me WISDOM** |
| Decision Support | **Heat Alert and Response Table Top Exercise**<br>**Weather health Information System for Decision Optimization Management (WISDOM)** |

# 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

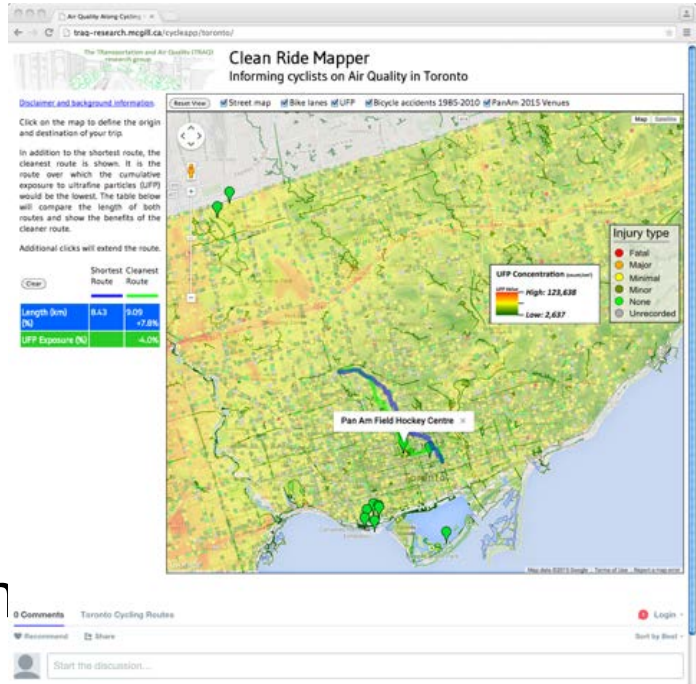
"Hot" zone: effect of city and lake breeze




Valid 2:00 pm on July 28, 2015

# Clean Ride Toronto

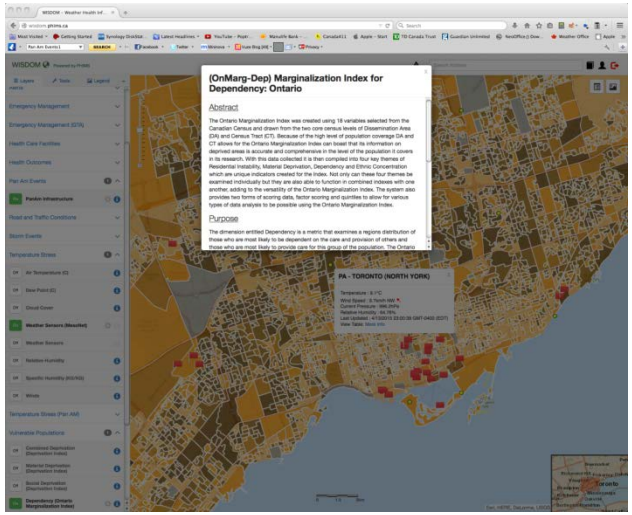
- The cycling app for Toronto was developed by McGill University and Health Canada
  - http://traq-research.mcgill.ca/cycleapp/toronto/
- New features
  - Improved navigation
  - More data (e.g. Pan Am Venues)
  - Ultrafine Particle Surface
- Toronto District School Board
  - Eco-schools
  - Summer School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



# WISDOM

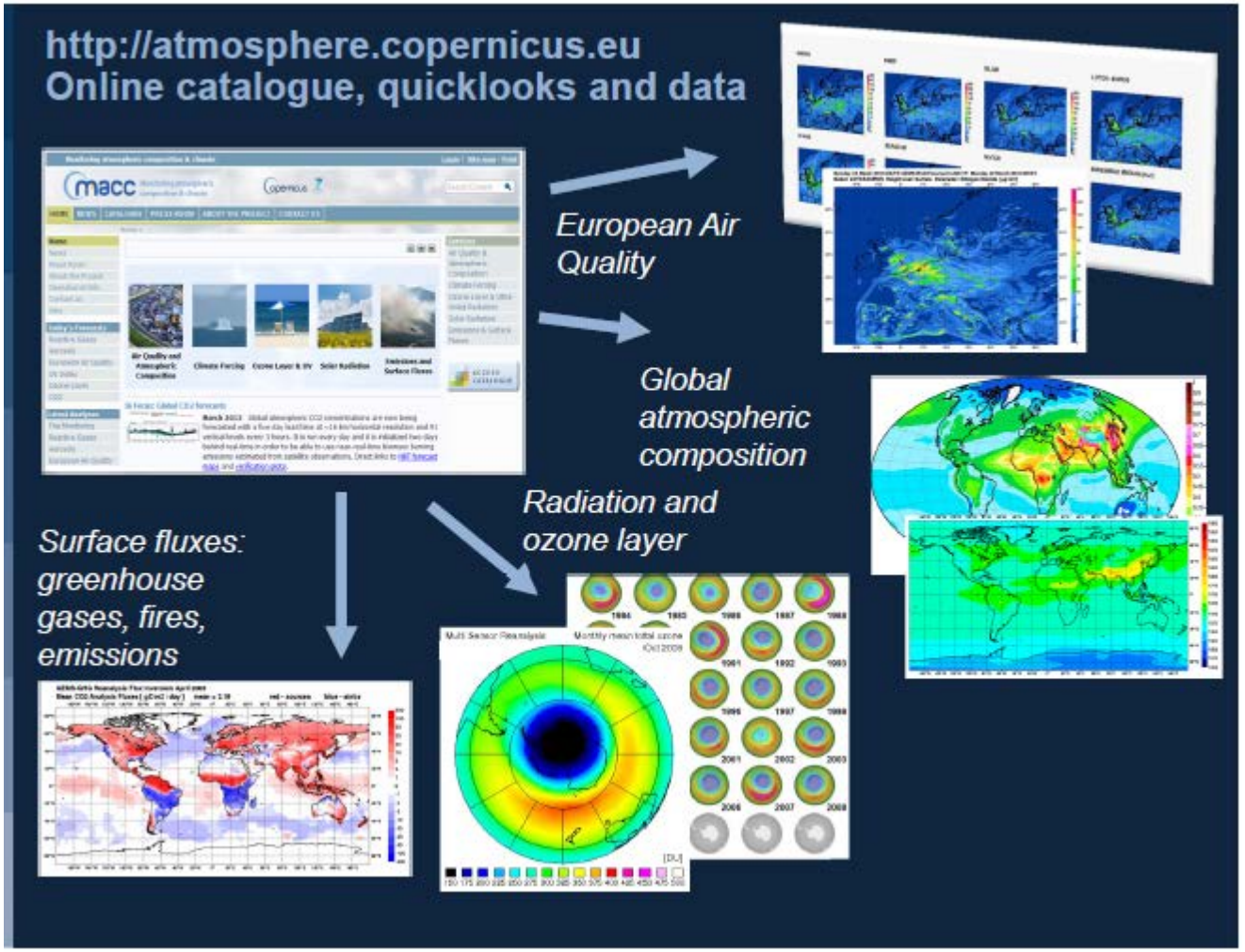
## Weather and health Information System for Decision Optimization and Management

- 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

# Key Challenges in Data Assimilation




From VH. Peuch, WWOSC, 2014

# Key Challenges in Data Assimilation

- **Capacity for chemical assimilation is increasing steadily, as well as the availability of observations in RT (both ground-based and satellite) - Numerous challenges:**
  - DA of chemical constituents:
    - Impacts vary with species, primary/secondary nature of species
    - Analyses (initial conditions) versus emissions field adjustments
    - How to handle correlated/secondary species?
    - Combination of all sources of information (ground, satellite, sondes, lidar…)
  - Deterministic models are more and more integrated, DA systems aren't
    - Will require sustain efforts over sustained period
    - Human capacity to advance DA for chemical constituents remains limited
  - Composition and Weather: what are currently the impact of assimilating data in the absence of aerosol
    - Parallel efforts starting on environmental prediction (coupled atmosphere/ ocean/ice assimilation) that will develop methodologies for coupled assimilation
  - Urban scale and assimilation: what is needed? What is feasible?

# Key Challenge for operational forecasts

- Addressing uncertainties and uncertainty of emission information in particular?
  - More unknown in PM emissions: speciation for many sources, intermittent nature of some sources, lag of inventories, primary vs secondary…..
  - Likely that there will always remain some unknown
- Multi-ensembles have shown fairly consistently improvements over deterministic AQ forecast
  - MACC, ICARTT/TEXAQ experiments
- Are Ensembles feasible in a forecasting context? What type?
  - MACC: Real-time regional multi-ensemble
  - North-America equivalent? Investment in global forecasts?

# Emissions: Where to?

Atmospheric Environment

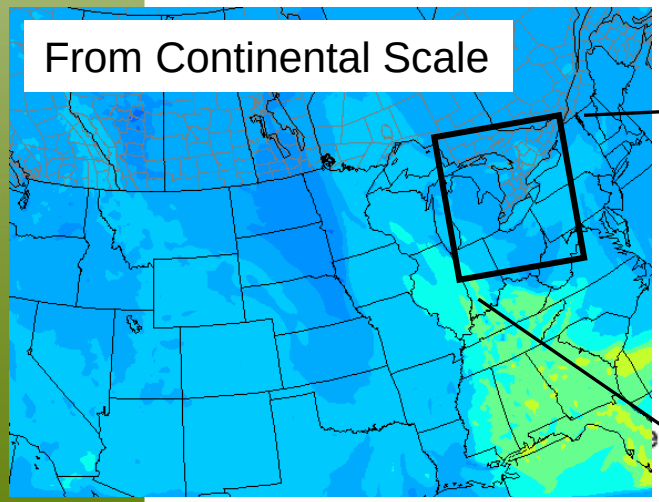
Volume 116, September 2015, Pages 320–322

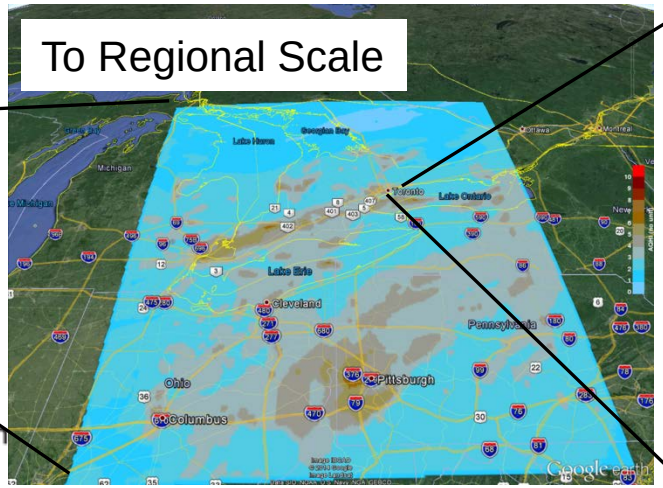

## Operational forecasting of source impacts for dynamic air quality management

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




# ADDITIONAL SLIDES

# Summary from IWAQFR-6 Open Discussion

- The assembly identified that a first task ahead would be to gather what is known and available to model/forecast at the urban scale, its limitation as well as what is required to address the urban scale. For example:
- Remote sensing does not necessarily have the resolution to go to the street scale
- Soil moisture is critical yet model representation has limitation as it can take 1 year to spin up
- A number of processes can be considered constant on a 1-2 week timescale
- A number of databases of interest were mentioned and there would be value in an effort to identify them and centralize the information on how to access them. The ones mentioned included:
- Initiative to create databases for cities all over the world, complemented with crowd sourcing information (Valery Mason)
- Measures of traffic flow combined with census information in the UK and also in Finland
- There would be similar needs for emission forecasts for AQ, maps of evaporation ….
- Emission forecasts should be revisited by the community: emission fields that are weather dependant have already be incorporated as part of the forecast system/are forecasted on their own (ex: fire, dust…). The community should reflect on what emission forecasts are needed and foster activities in that area.
- The topic was proposed as an action item for inclusion as topic in the next IWAQFR meeting.
- Test beds: the legacy of efforts such as the London Olympics and upcoming PanAm2015 in the context of urban weather and air quality was discussed. There was support to sharing data and provide guidance for future activities. The catalyst power of such efforts in weather forecasts has been evident in particular in association with winter Olympics. Considerations were given to the potential of a special effort aligned with the 2020 summer Olympics in Japan.
- The assembly discussed the state of observations and whether they are adapted to the urban scale. It was clearly expressed that an effort is needed to define/design the observation networks that are required to model and possibly assimilate at the urban scale. Some of the questions that could help forge that thinking included:
- What would be the specific requirements for data assimilation in the urban environment, beyond weather forecasts? (including for chemical components) Would the rapidly evolving city dynamics be an impediment as well? What are all the variables available and are there some more useful than others (ex: soil moisture versus surface temperature)

# Summary from IWAQFR-6 Open Discussion – Cnt'

- What is currently the skill of models versus observations? (a required step to DA)
- What have we learned from analyses of chemical constituents and are those feasible at the urban scale?
- What are "local" stations? (as per the new definitions being worked on by WMO)
- Issues and requirement with real-time transmission
- What are the requirements on the measurements themselves to be useful? (ex: need to be above buildings level to be reliable at the neighborhood scale; canopy is critical for chemical constituents…)

**Discussion on initiatives to address ODA for chemical components gaps (A. DaSilva)**

- The ICAP (International Cooperation fore Aerosol Prediction) effort was introduced to the assembly. This is a real-time intercompariason of global models with aerosol representation. A multi-model ensemble is also derived using the NRL, NCEP, NASA, ECMWF, JMA and UKMO models. The data are provided to the main satellite agencies (ESA, EUMETSAT, JAXA, NASA, NESDIS, UKMO).
- The assembly identified that there was a link between ICAP and AQMEII as AQMEII is looking at including global models in Phase 3. There was also discussion of a possible extension to ICAP at the regional scale, for the North American portion where it does not overlap with MACC.
- The WGNE aerosol project was also discussed extensively in terms of extending the intercomparison to regional models since some of the cases are well adapted to the regional scale.
- The WGNE aerosol project lead was receptive to the possibility which would be well received within WMO as an example of cross-activity.
- Funding would be required to facilitate participation in the meetings.
- Next step for the current WGNE project is to bring a lot of in-situ data; again the air quality community felt it could contribute significantly to that aspect as well on the existing cases.
- A question that remains open is: what are currently the impact of assimilating data in the absence of aerosol in the modelling and DA system. This is another avenue that WGNE could investigate.

# Summary from IWAQFR-6 Open Discussion – Cnt'

**Discussion on initiatives to address Integrated met-chemistry models gap (A. Baklanov)**

- The assembly identified a number of shortcomings on the integrated met-chemistry systems when it comes to DA:
- While the deterministic models are more and more integrated, the DA system is not
- In order to achieve some progress in DA, the community will need to focus on a few areas and sustain that effort for long periods of time.
- Efforts are starting on coupled environmental assimilation (ex: wind and ocean parameter) which could be informative for weather/chemistry
- The human capacity to advance DA for chemical constituent remains thin
- Building on the tools and studies on-going at different scales right now, the communities (weather/chemistry/AQ/Climate) is very interested to see some recommendations on the level of application awareness that are required at different scales given the cost of chemistry in models. Likewise, prioritazation guidance on what is feasible in what timeframe and within the context of regional issues (ex: China vs Europe/NA AQ levels) would also be very valuable.
- There are currently a number of satellites set for launch in the next few years that present a lot of interest for AQ and chemical forecasts: TEMPO, Sentinel 4, GEMS…. There was a consensus that expectations are building in term of the use of the satellite information that will be produced and that we, as a community, may have a lot of work ahead to be ready in time.
- It was proposed to reflect this issue/concern in the DA white paper.
- Ensemble forecasting was not addressed in the integrated met-chemistry white paper as of yet and would need to be added.