Environment Canada Environnement Canada

Canada

The New Air Quality Forecast Model GEM-MACH15

- Description and Evaluation -

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RPN Seminar Series

CMC, Dorval

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Talk Outline

- Background
- GEM-MACH: General description
- GEM-MACH15: Configuration
  - Piloting strategy
  - Timings
- GEM-MACH15: Performance evaluation
- Schedule for implementation
- Future developments

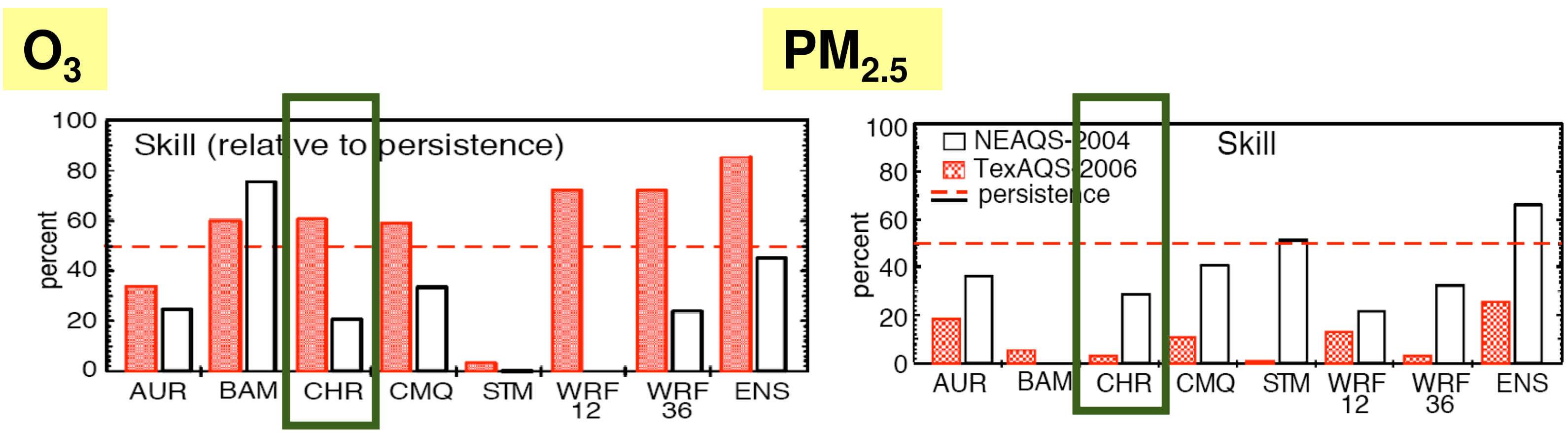
GEM-MACH Background

Global Environnemental Multi-échelle - Modélisation de la qualité de l'Air et de la CHimie

Global Environmental Multiscale – Modelling Air quality and CHemistry

Motivations for GEM-MACH development (1)

- CHRONOS science needs to be upgraded to improve performance



Skill over persistence - ICARTT 2004 and TEXAqS2006 AQFM intercomparison results – Courtesy S. McKeen, JGR, In press.

- Possible avenues for improvements:
  - Add new or improve existing processes
  - Add chemical data assimilation

Motivations for GEM-MACH development (2)

- Technical limitations:
  - Following move to an MPI-capable machine, CHRONOS code is OpenMP'ed but is not MPI'ed
    - At one point, it exceeded operational window
    - Temporary respite due to new nodes on IBM (16 CPUs)
  - Increasing amount of data that needs to be exchanged between meteorological and air quality models
    - I/O issues
  - Interpolation between GEM and CHRONOS grids is time-consuming and introduces errors

- Chosen solution:
  - Use GEM as host model and include chemistry module on-line through a set of interfaces

GEM-MACH "Team"

ARQI

- Mike Moran
- Paul Makar
- Wanmin Gong
- Sunling Gong
- Sylvie Gravel
- Alexander Kallaur
- Balbir Pabla
- Craig Stroud
- Ping Huang (contractor)
- Alain Robichaud
- Didier Davignon
- Jean de Grandpré

AQMAS

- Véronique Bouchet
- Sylvain Ménard
- Donald Talbot
- Hugo Landry
- Mourad Sassi
- Stéphane Gaudreault
- Louis-Philippe Crevier
- David Anselmo
- Paul-André Beaulieu

RPN

- Michel Desgagné
- Vivian Lee

Other groups/people involved

- CMDN (Alain Patoine), CMDW (Stavros Antonopoulos)
- CMOI, A&P, AQ regional forecasters and science groups

Objective for air quality *forecasting*

- To replace CHRONOS, the current EC operational off-line regional AQ forecast model for O_3, NO_2, $PM_{2.5}$, and PM_{10}, with a new GEM-based on-line operational AQFM that includes a science package equivalent to the one in AURAMS

- Documentation: http://aq.cmc.ec.gc.ca
  - Project: GEM-MACH

Objectives for air quality *modelling*

- To develop an initial chemical library and interfaces to GEM that could be expanded upon by other AQ projects instead of having to « reinvent the wheel» each time.
  - GEM-MACH framework can support AQ / chemical weather modelling
  - **GEM v3.3.0 released May 2007**: First official version of GEM to include the new chemistry interface needed by GEM-MACH

- To develop a model that evolves in step with the rest of the EC atmospheric models
  - Formalize the role of the GEM chemistry librarian

GEM-MACH15
General description

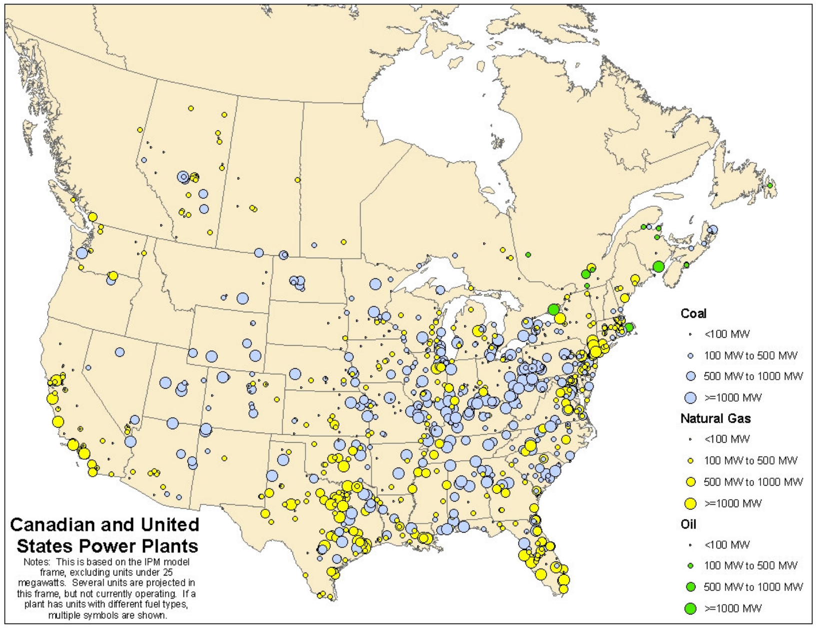
GEM-MACH Primary Components

- To model air quality ("chemical weather"), three primary components must be represented:
  1. Emissions of pollutants or their precursors
  2. Meteorology and transport & diffusion
  3. Transformation and removal processes

- Components 2 and 3 can either communicate off-line (through I/O exchange) or on-line
  - On-line means:
    - on GEM grid and time step
    - provides access to all GEM fields
    - avoids need for interpolation to another model grid
    - provides better framework for chemical data assimilation
    - potential (in future) for chemical feedback to meteorology (e.g., radiation, clouds)
  - Drawback: Increases complexity of the single model (though not of the overall AQ modelling system)

Emissions of Pollutants and Precursors (1)

- Primary source types and examples:
  - Point sources
    - Power plants, smelters, factories, incinerators, …
  - On-road mobile sources
    - Car, trucks, motorcycles, buses
  - Off-road mobile sources
    - Construction, agriculture, and mining equipment, locomotives, marine vessels, pleasure craft, aircraft, snowmobiles, …
  - Area sources
    - Small point sources (e.g., houses, lawnmowers, BBQs), painting, fertilizer application, road-paving, crop harvesting, …
  - Natural sources
    - biogenic, biomass burning, geogenic, volcanic, oceanic, lightning



- Critical component of air quality models (chemical forcing) but also important source of model uncertainty
- Difficult to quantify:
  - Strong dependence on human activity (*i.e.,* socioeconomics, geography, legislation, …)
  - Some dependence on meteorology
  - Must be comprehensive: i.e., all sources must be identified and quantified

- Analogous to a set of day-specific, time-varying (hourly!) geophysical fields

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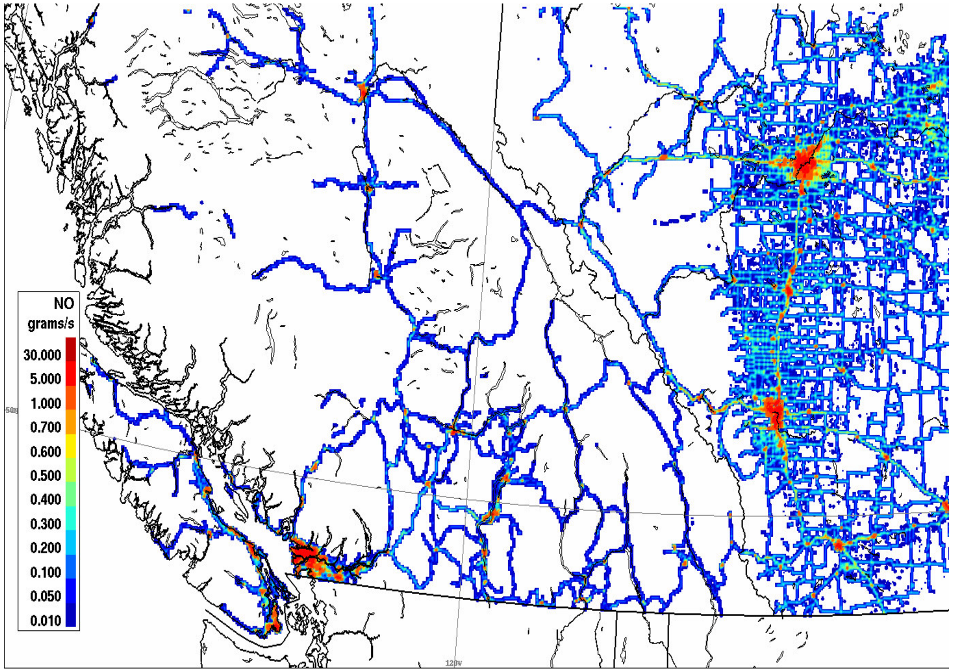

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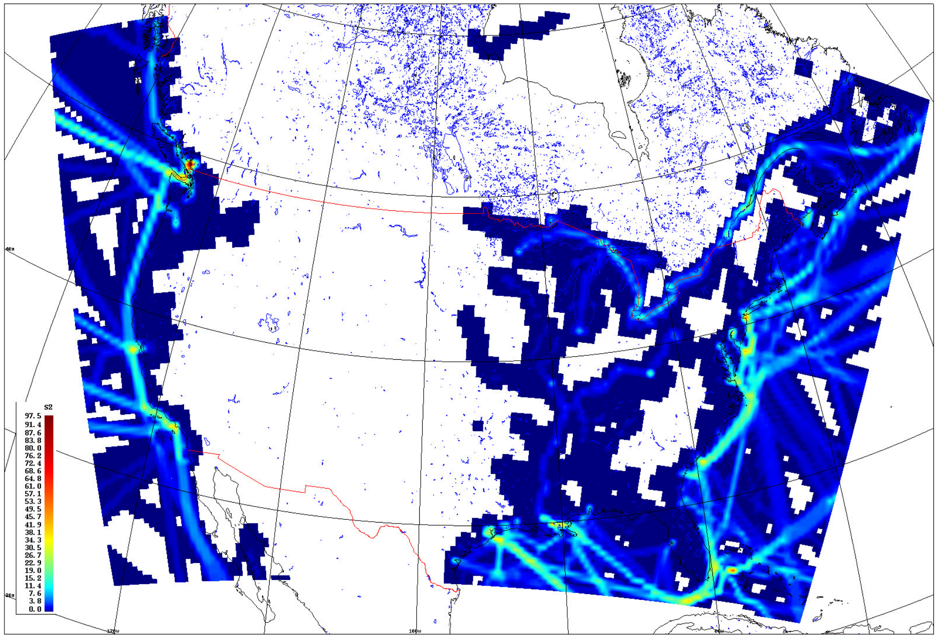

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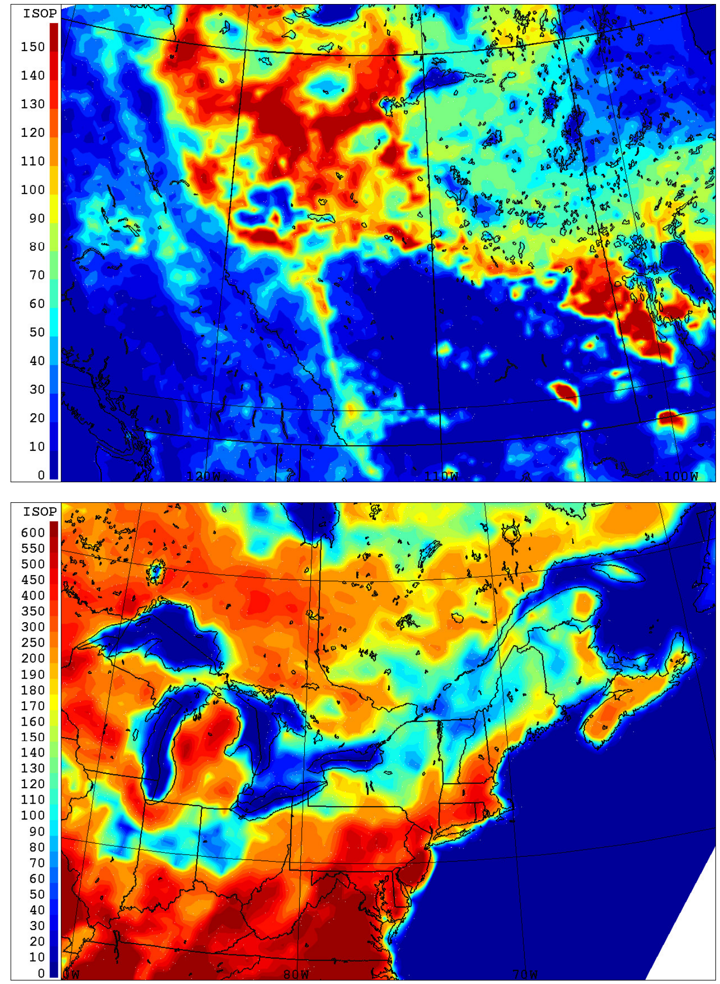


Isoprene

Emissions of Pollutants and Precursors (2)

- GEM-MACH emissions entry program:
  - Emissions information is provided to GEM-MACH on an **hourly basis**
  - Files of gridded emissions fields are first created off-line using an emissions processing system (SMOKE)
  - Emissions entry program splits emissions fields into BMF files according to model topology and run parameters
  - During GEM-MACH execution, BMF files are read at appropriate time steps
  - GEM-MACH now has capacity to read non-gridded data for major point sources (Y-grid); also split between tiles, input hourly

Implementation of Chemical Transport, Diffusion, Transformation, and Removal (1)

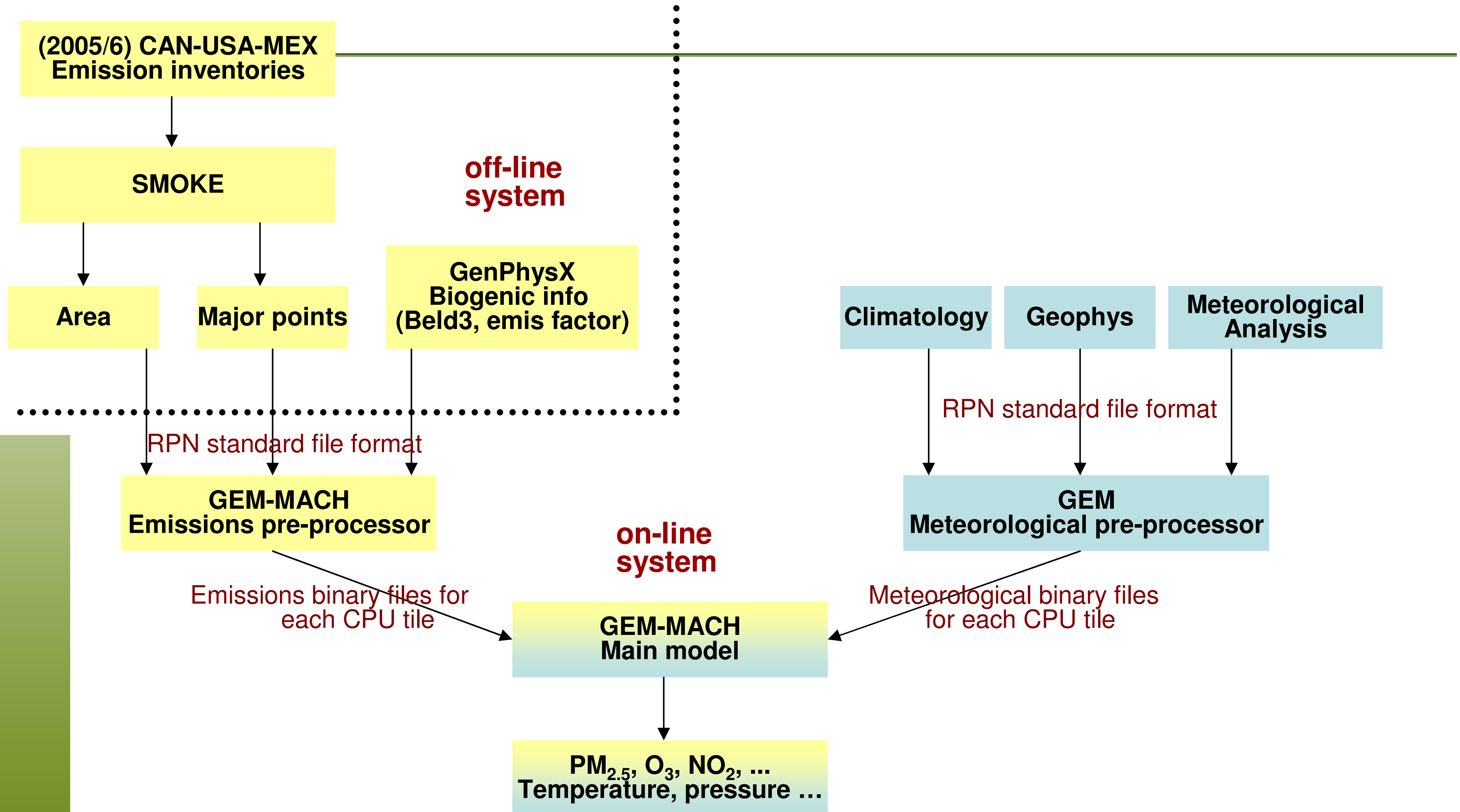
GEM with chemistry connections

- Chemistry interface
  - Design follows GEM physics interface very closely
    - development was a collaborative effort between AQRD, AQMAS, and GEM developers (M. Desgagné, V. Lee)
  - Consists of four chemistry data buses: dynamics, permanent, volatile, entry
  - Chemical species abundance fields ("chemistry tracers") are assigned to chemistry dynamics bus
    - advection is handled automatically by GEM (like GEM dynamics bus)
  - Chemical initial and cycling conditions (when chm_model_s = MACH)
  - Chemical boundary conditions (when chm_model_s = MACH)
  - Call to chemistry follows call to physics

Implementation of Chemical Transport, Diffusion, Transformation, and Removal (2)

- **Call to chemistry**
  - Vertical diffusion of chemical species
  - Dry deposition of gaseous species and particles
  - Wet deposition of gaseous species and particles
  - Gas-phase chemistry (ADOM-II mechanism)
  - Plume rise for major points sources emissions
  - Biogenic emissions calculation (BEIS scheme)
  - Secondary organic aerosol formation (IAY scheme)
  - Aqueous-phase chemistry (ADOM scheme)
  - Heterogeneous inorganic chemistry (HETV scheme)
  - Variable number of PM size distribution "bins"
  - PM size-dependent processes: natural emissions, nucleation, condensation, coagulation, activation, dry deposition, wet deposition
  - Output of chemical variables

GEM-MACH Data Flow



What's new since May 2008?

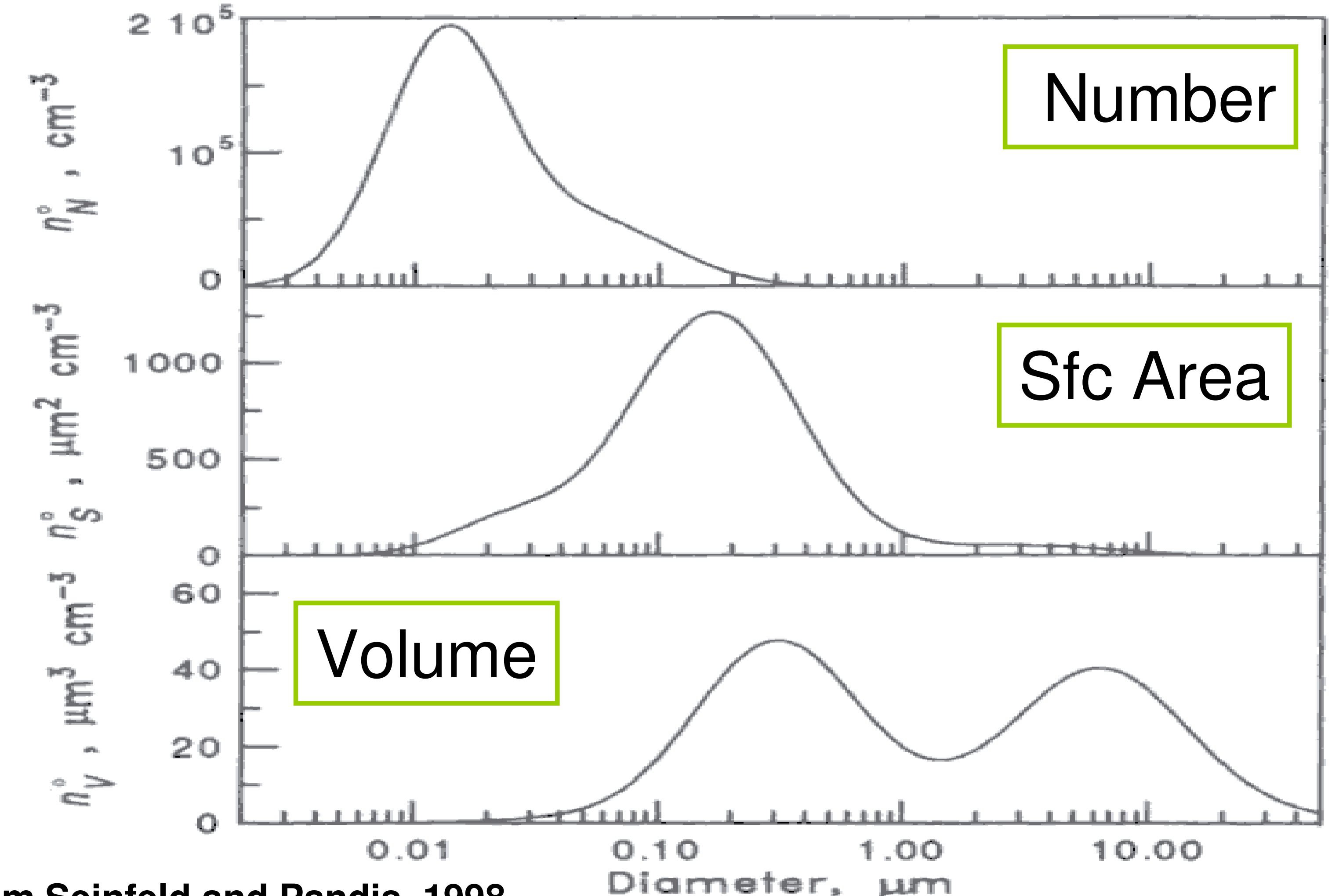
- June 2008:
  - Experimental run of GEM-MACH15 for O_3 and NO_2 (mid-July to Oct 2008)
- Fall 08 / Winter 09
  - Corrections to treatment of gas-phase dry deposition
  - Implementation and testing of particulate matter routines
- Winter 2009
  - Changes in the GEM-Regional grid
    - Switch to new IPY grid
  - Beginning of GEM-regional-strato parallel implementation
    - Decision taken to change piloting strategy to have GEM-MACH15 compatible with new GEM15 lid

Particulate Matter Representation

Particulate Matter: Differences in Chemical Processes in CHRONOS vs GEM-MACH15

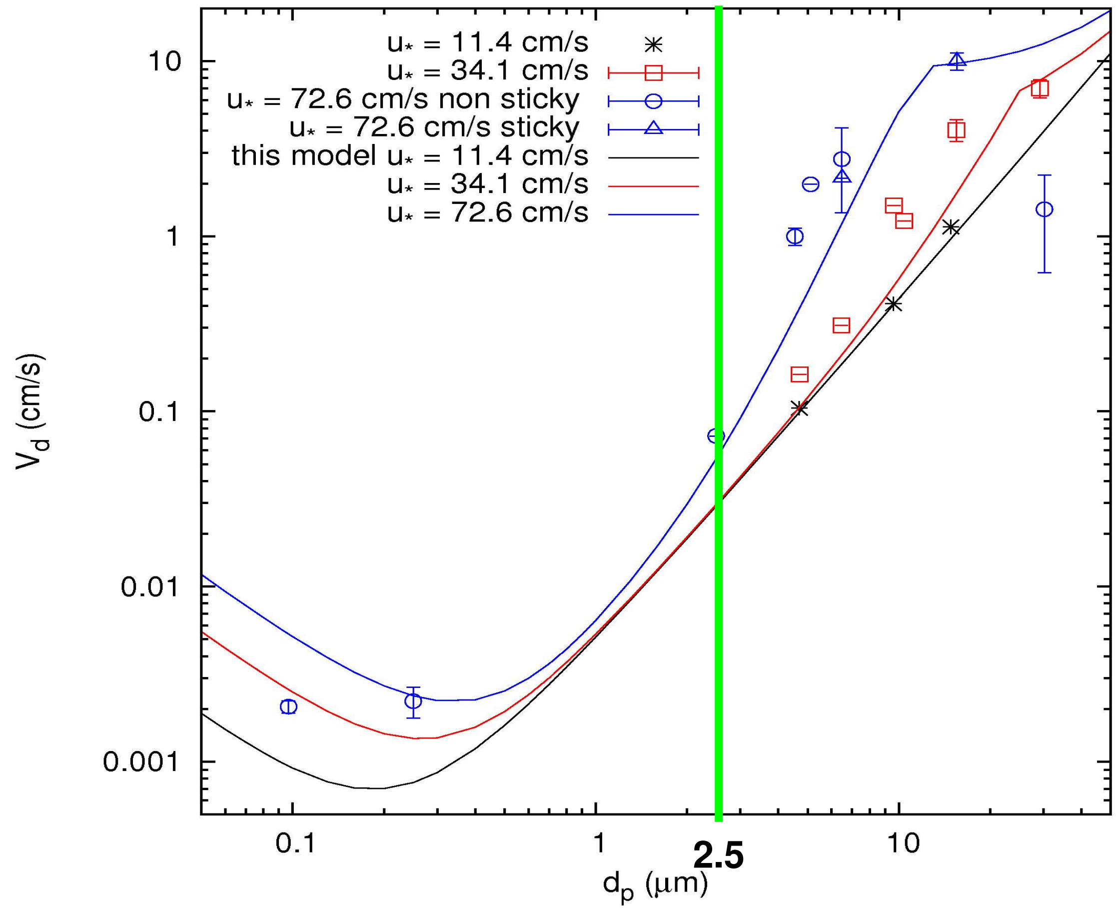
PROCESS	CHRONOS	GEM-MACH15
Emissions	$PM_{2.5}$ and PM_c primary emissions are assumed to be bulk emissions; 17 gas-phase species emitted	$PM_{2.5}$ and PM_c emissions **speciated to 7 species** by primary source type (point, area, mobile); 17 gas-phase species emitted
Gas-Phase Chemistry Mechanism	ADOM-2 mechanism (Stockwell and Lurmann, 1989); 47 advected species	ADOM-2 mechanism (Stockwell and Lurmann, 1989) with **1) p-SO_4 replaced by H_2SO_4+p-SO_4** 2) **N_2O_5 + H_2O** "heterogeneous nitrate formation" rate enhancement **switch=off.**
Aqueous-Phase Chemistry	None	**ADOM aqueous-phase chemistry**
PM Composition and size distribution	2 size bins: $PM_{2.5}$, PM_{10} 4 chemical species: sSO_4, sOC, H_2O, primary PM	2 size bins: $PM_{2.5}$, PM_{10} **8 chemical species**: SO_4, NO_3, NH_4, EC, pOC, sOC, CM, SS
Aerosol Dynamics	Sedimentation	Sedimentation, **Nucleation, Condensation, Coagulation**
Secondary Organic (SOA) Yields	Based on Pandis et al. (1992)	**IAY scheme** Based on Jiang (2004)
Wet Deposition	Distribution of LWC is used to calculate the wet scavenging term by applying Sundqvist formulae for the rate of release of precipitation	Transfer of tracers from cloud to rain water based on **precipitation production. In-cloud and below-cloud scavenging of soluble gases and particles (size-dependent) .**
Chemical boundary conditions	Zero-gradient inflow, open-boundary out-flow	**Climatological profiles** with Davies lateral boundary conditions

Particulate Matter: Idealized Size Distributions for PM Number, Surface Area, and Volume



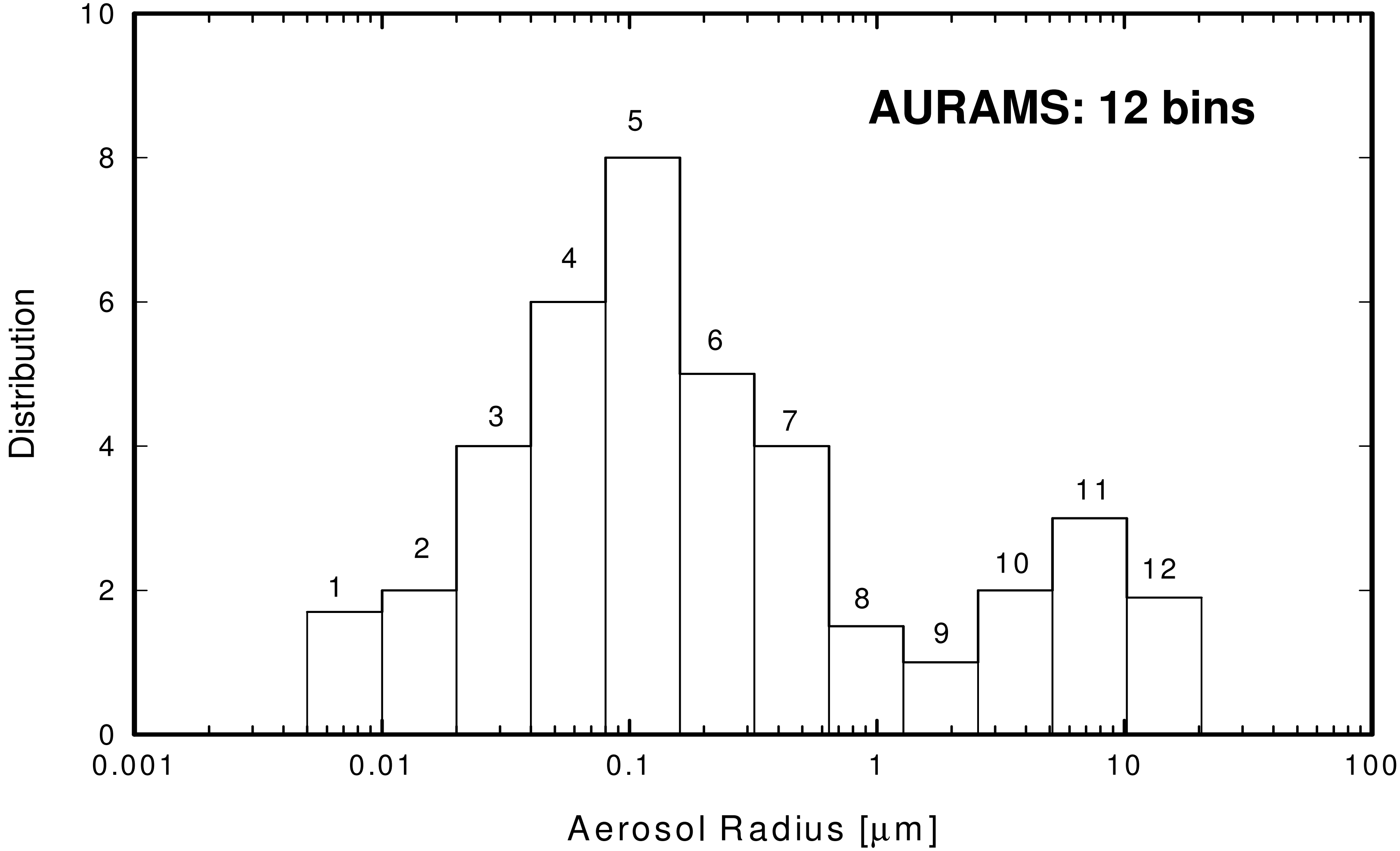
from Seinfeld and Pandis, 1998

Particulate Matter: Example of Dependence of Particle Dry Deposition Velocity on Particle Size

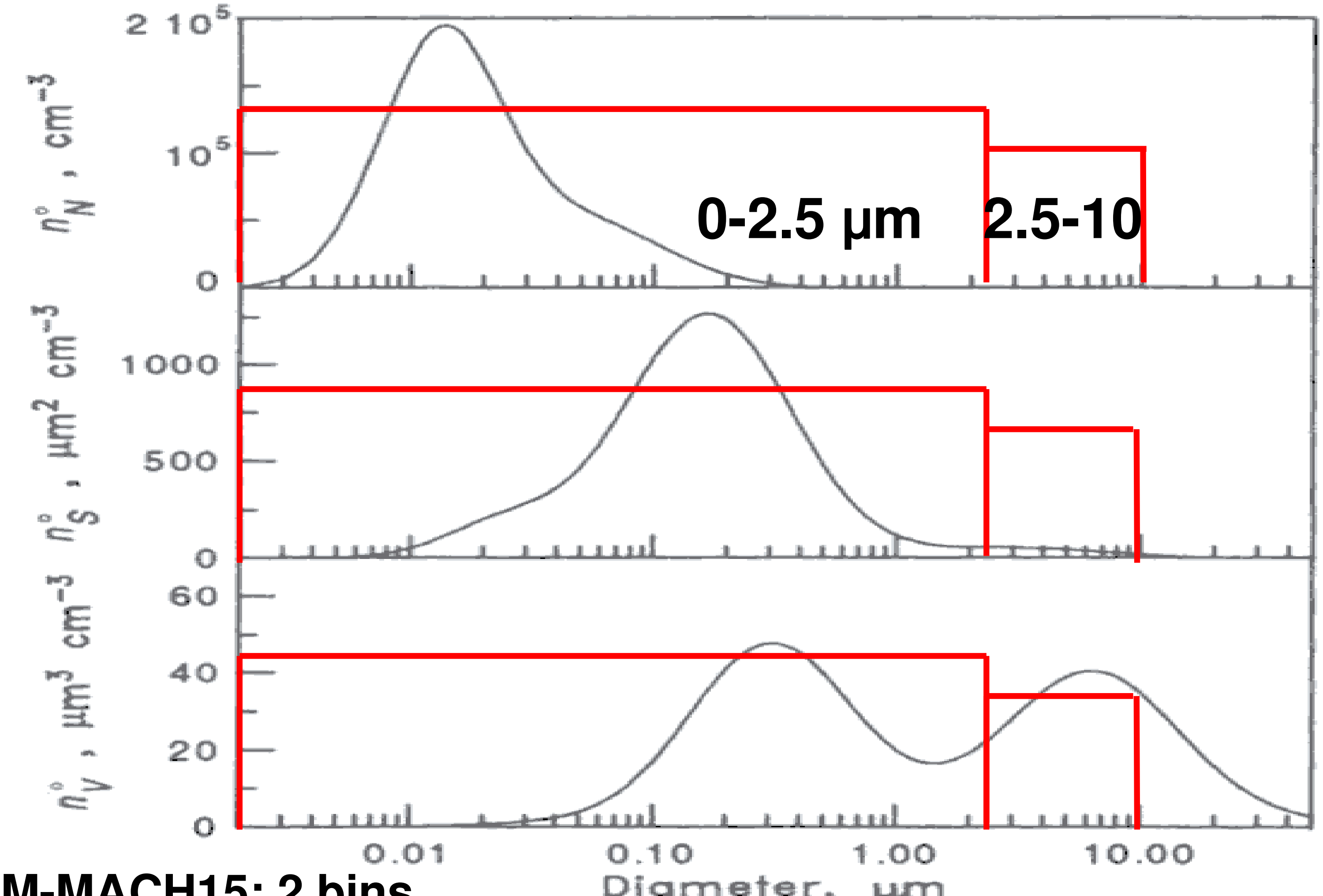


- Particle dry deposition velocity over bare soil (Courtesy of L. Zhang, AQRD)

Particulate Matter : AURAMS Sectional Representation of PM volume Size Distribution



Particulate Matter: Simplified 2-Bin Sectional PM Size Representation



GEM-MACH15: 2 bins

Particulate Matter: Modifications to AURAMS Treatment of PM Processes

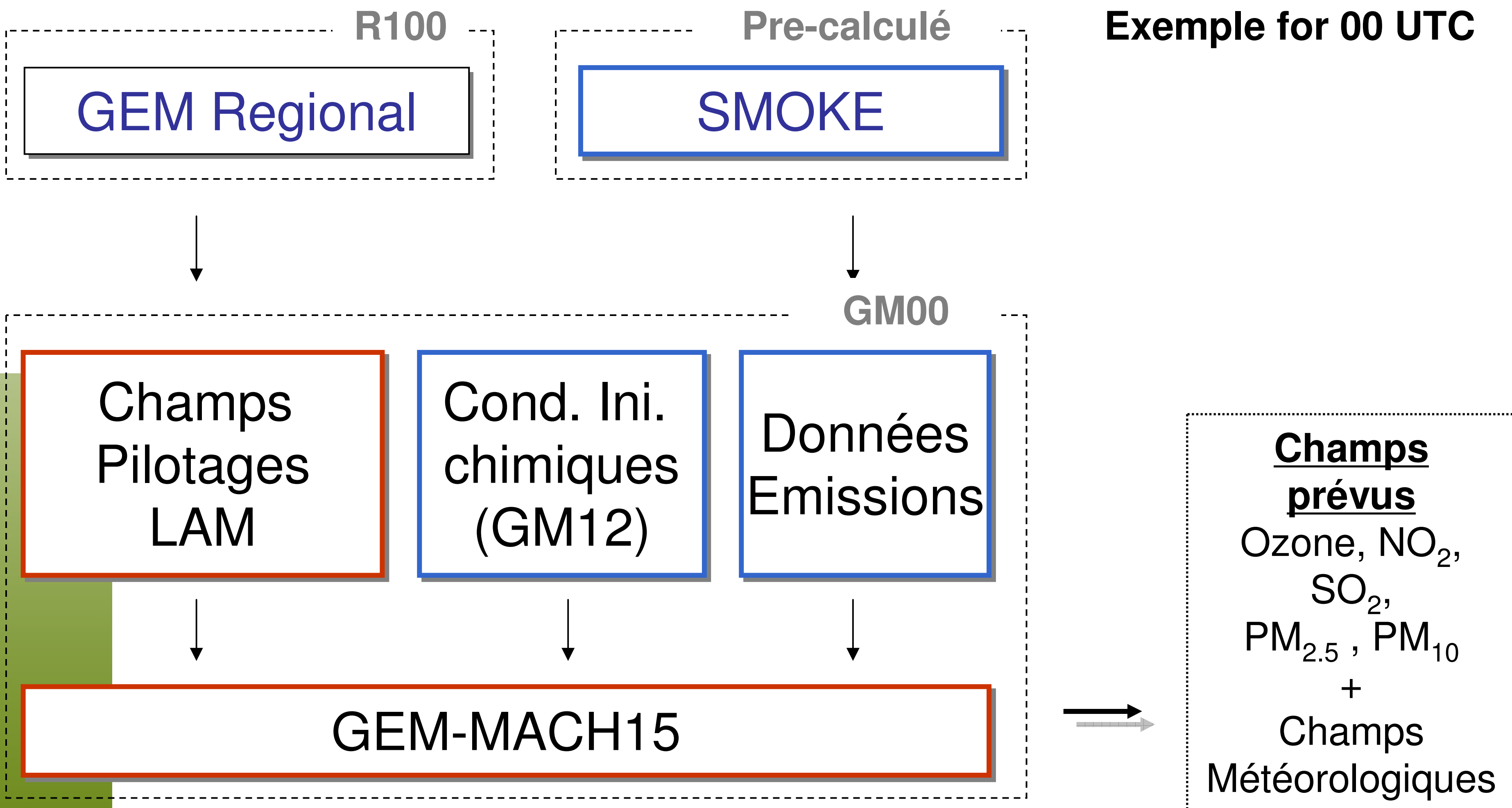
- Switched from 12-bin to 2-bin representation of PM size distribution (reduces number of advected tracer fields from 137 to 57, i.e., by ~60%)
- Implemented sub-bin calculations to account for size dependence in some processes (sea-salt emissions, particle dry deposition, intersectional transport)
- Modified some process calculations to avoid problems with
  - (a) round-off errors at very small concentrations
  - (b) parameterization boundaries for extreme temperatures and humidities

GEM-MACH15

Configuration

Système proposé pour GEM-MACH15

Exemple for 00 UTC



Configuration du GEM-MACH15 (1)

- Dynamique et physique:
  - GEM v3.3.0, Physique 4.5 (flxsurf3 corrigée)
    - reproduit GEM15-strato (3.3.2 – 4.7)
- Configuration LAM
    - Hzd_type_S= EXPLICIT pour le LAM (HO pour GEM15)
    - Vspng_nutop = 2. pour le LAM (Vspng_mf=10 pour GEM15)
    - Vspng_nk =3 pour le LAM (Vspng_nk = 6 pour GEM15)
    - Pas d'éponge équatoriale
- Initialisation:
  - Météorologie initialisée avec les champs prognostiques 00h du GEM15
  - Champs de surface tirés des analyses
  - Champs chimiques cyclés à partir du T+12h de la prévision précédente

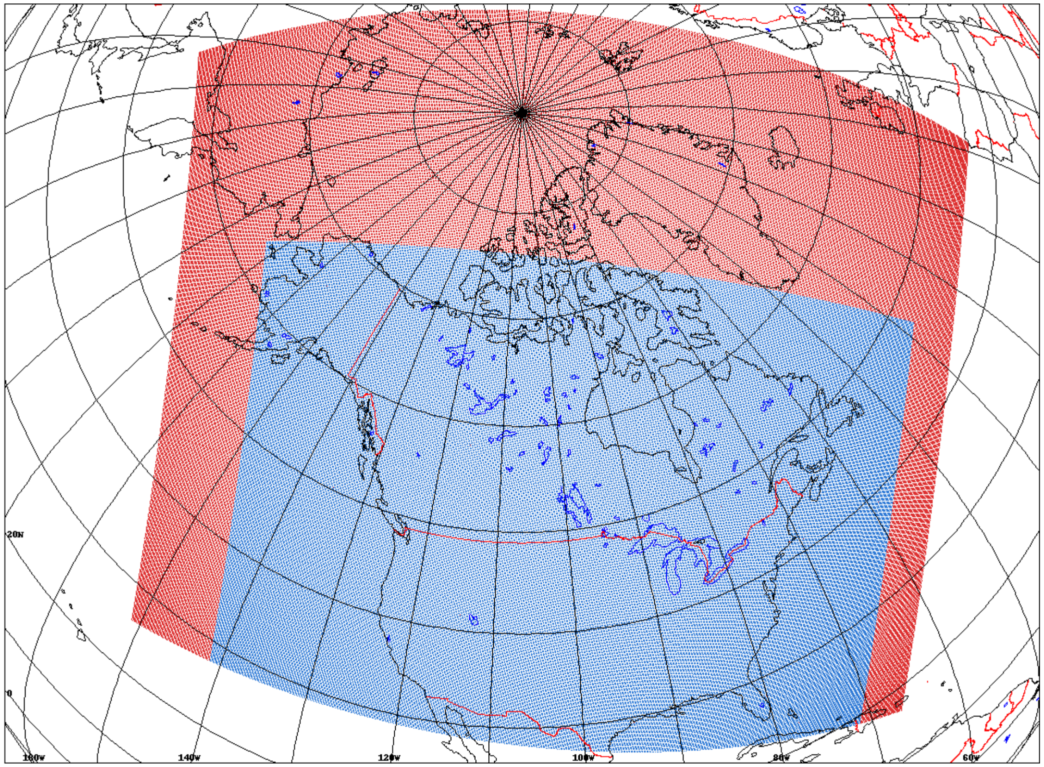
Configuration du GEM-MACH15 (2)

- Options chimiques:
  - Chimie gazeuse:ADOM-II
  - PM:
    - approche avec 2 catégories de taille et 9 composantes chimiques
    - chimie aqueuse: ADOM
    - chimie hétérogène: HETV (option métastable)
    - Formation organiques secondaires: schème IAY
  - Conditions frontières: climatologie
- Emissions:
  - Canada: inventaire 2006; U.S.: inventaire 2005
- Set-up:
  - Pilotage météorologiques aux heures
  - Pas de temps: 450s pour météo & 900s pour chimie
  - Résolution horizontale: 15km
  - Résolution verticale: 58 niveaux, 0.1hPa

La grille de GEM-MACH15

- Configuration LAM à la même résolution (15km)
  - ~approximativement 38% des points du GEM15

- Points sont colocalisés avec ceux du cœur du modèle régional



Grille GEM-MACH15 (bleu) ; Coeur GEM15 (rouge)

Le Pilotage: Génération des champs

- **Problème :**
  - préparation des champs de pilotage pour passer de la grille GV à celle du LAM
    - Processus à 1 CPU seulement
    - Exécution très longue : près de 60 minutes

- **Solution** :
  - Avant de lancer GEM-MACH15, on extrait le sous-domaine de GEM-MACH15 de la grille GV
  - UT1, VT1, TT, GZ, HU, QC, P0, HY aux heures
  - Pas d'interpolation horizontale dans l'entrée :
    - 13 minutes pour un 48h

- Travail en collaboration avec Sylvie Gravel

Le Pilotage: Stratégie pour GEM-MACH15

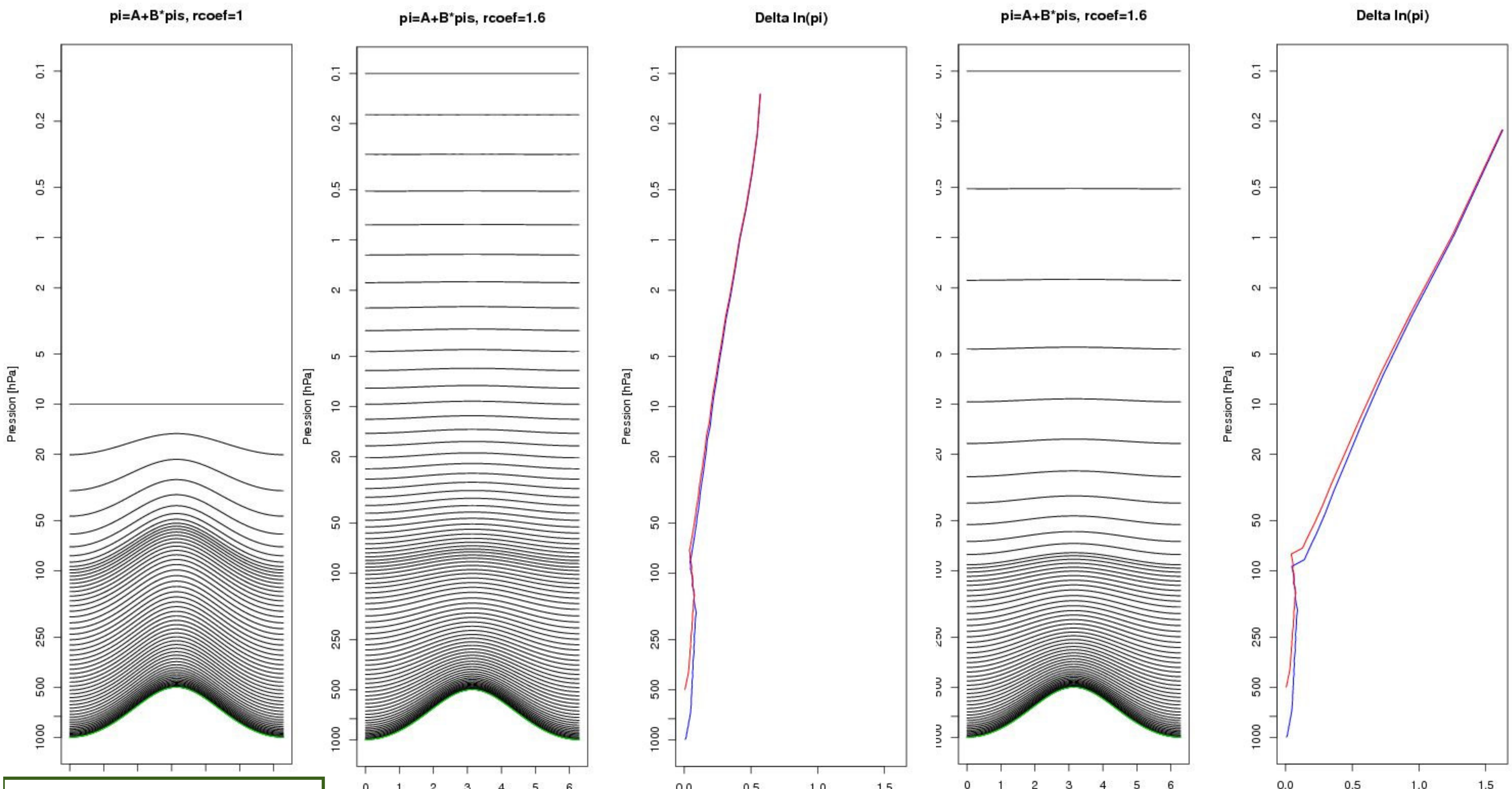
- **Problème**:
  - Avec 60 traceurs actifs, il serait très coûteux d'utiliser 80 niveaux hybrides
- **Contraintes**:
  - On essaie d'éviter toute interpolation du 00h GEM15 vers GEM-MACH15 pour avoir d'aussi bonnes prévisions pour les scores Arcad et de QPF
  - Dans les standards CPOP, on se contraint d'être le plus près possible du GEM15
- **Solution retenue** (en consultation avec CMDN):
  - 58 niveaux hybrides avec toit à 0.1hPa
  - une sous-sélection des 80 niveaux hybrides du GEM15-strato/GLB-strato

    1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 **16** 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 …
  - on retire les 22 niveaux supplémentaires sinon l'entrée cherche 80 niveaux pour les traceurs du cyclage alors qu'il n'y en a que 58

Le Pilotage: Autres Options ?

- Conservation des 58 niveaux eta avec un toit à 10hPa tel que proposé pour les LAM2.5 n'est pas une possibilité:
  - On ne peut avoir dans le 00h des niveaux **eta** provenant du cyclage de la chimie de GEM-MACH15 et des niveaux **hybrides** provenant du pilote GEM15-strato
  - La base de données du GEM15-strato dont les niveaux hybrides sont interpolés sur les niveaux eta pourrait dégrader les prévisions de la météo

Le Pilotage: Positionnement des niveaux verticaux (images de A. Plante)

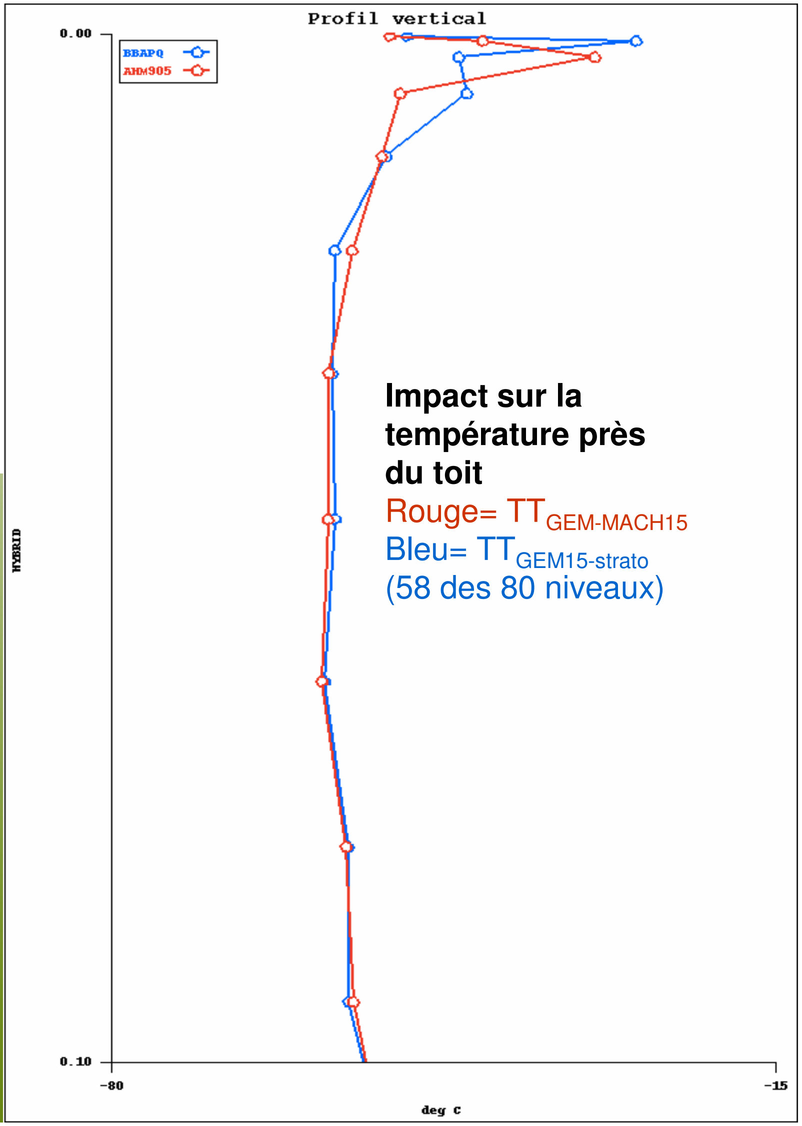


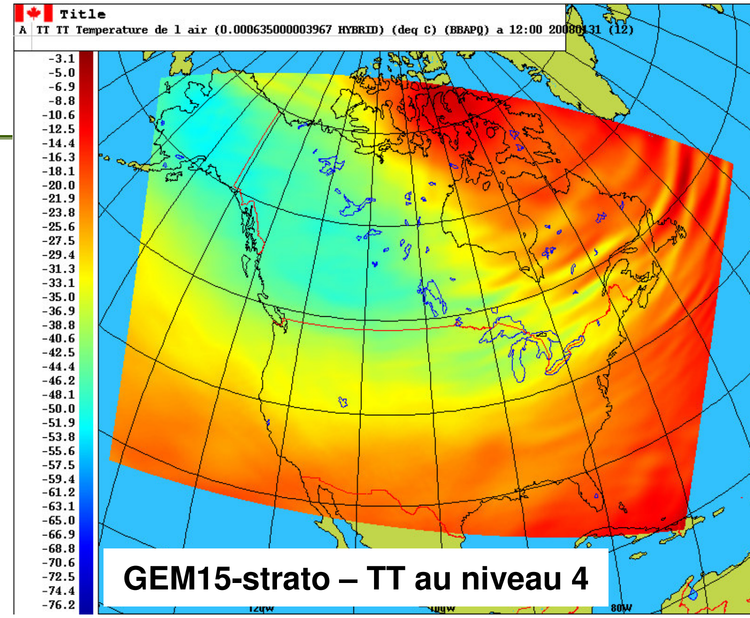
Anciens GEM15
58 niveaux eta, toit à 10 hPa

GEM15-strato: 80 niveaux hybrides, toit à 0.1hPa

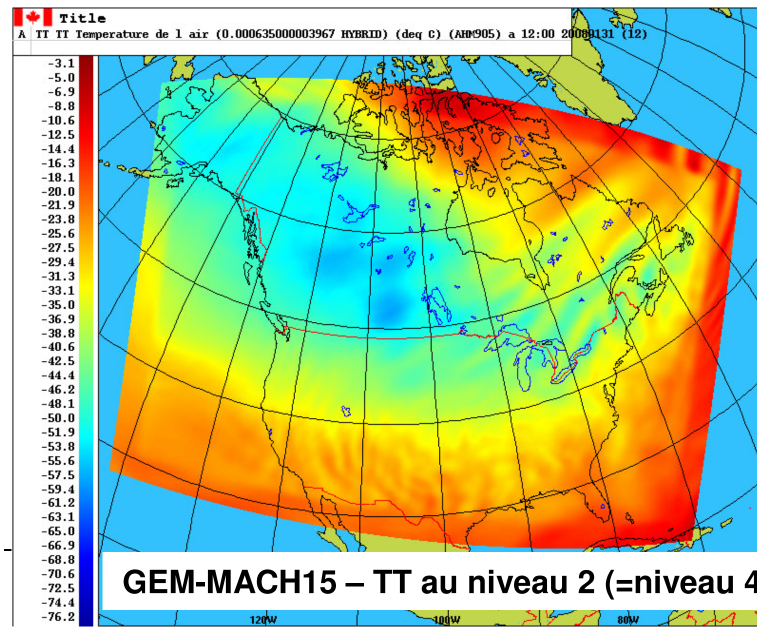
GEM-MACH15: 58 niveaux hybrides, toit à 0.1hPa

Le Pilotage: Comportement près du toit





GEM15-strato – TT au niveau 4



GEM-MACH15 – TT au niveau 2 (=niveau 4 du strato)

Le Pilotage: Traitement des vents forts dans la stratosphère

- Ajustements sur la taille de la zone de pilotage pour assurer la stabilité de l'option choisie:
  - Avec un toit à .1hPa, vents maximum observés dans les cas étudiés sont de 400 KT
  - Zone de pilotage augmentée de 12 à 14 points
    - On maintient FFT (fast Fourier transform)
    - Vitesse maximale du vent que GEM-MACH15 peut traiter est de 540KT

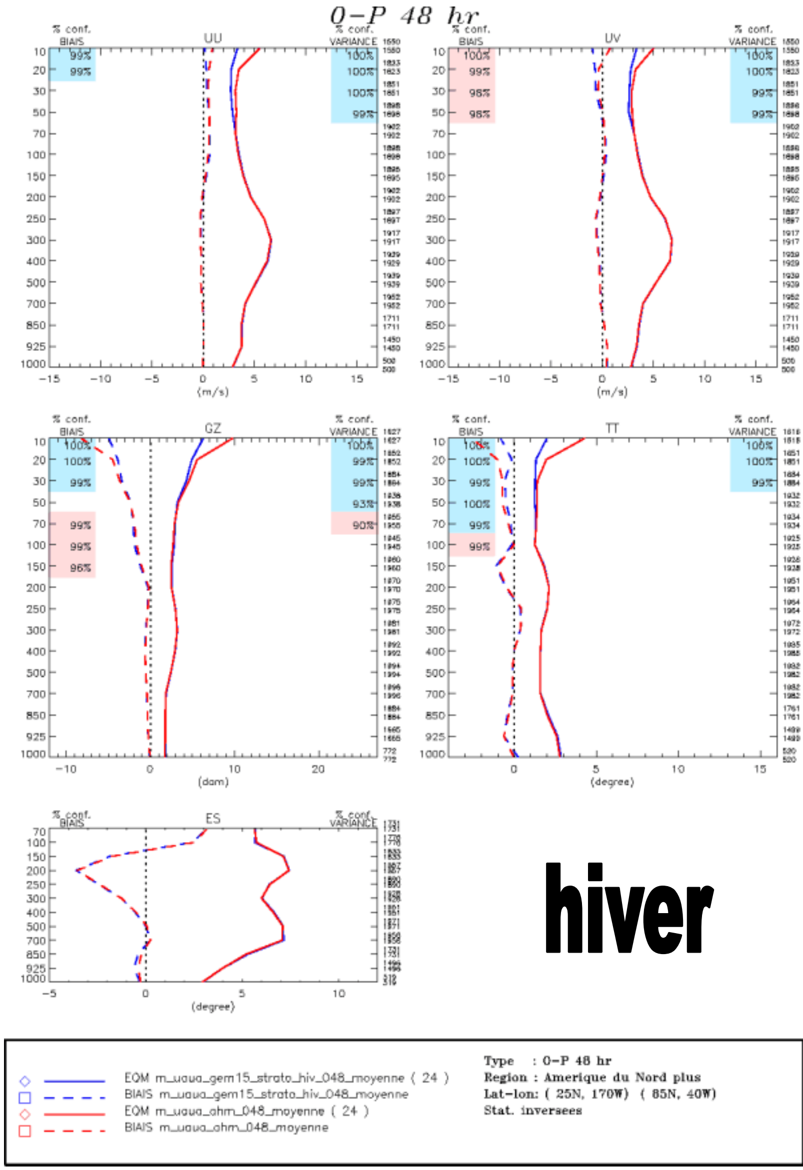
- Confirmation pour le nombre de Courant:
  - Pour faire l'advection, l'interpolation cubique a besoin de 5 points en amont (staggering+destaggering du côté droit)
  - nb de Courant maximum = 14 – 5 = 9
  - nb de Courant observé dans nos séries:
    - d'hiver : 8
    - d'été : 7

Le Pilotage: Évaluation des sorties météorologiques de GEM-MACH15 pour les séries hiver et été 2008

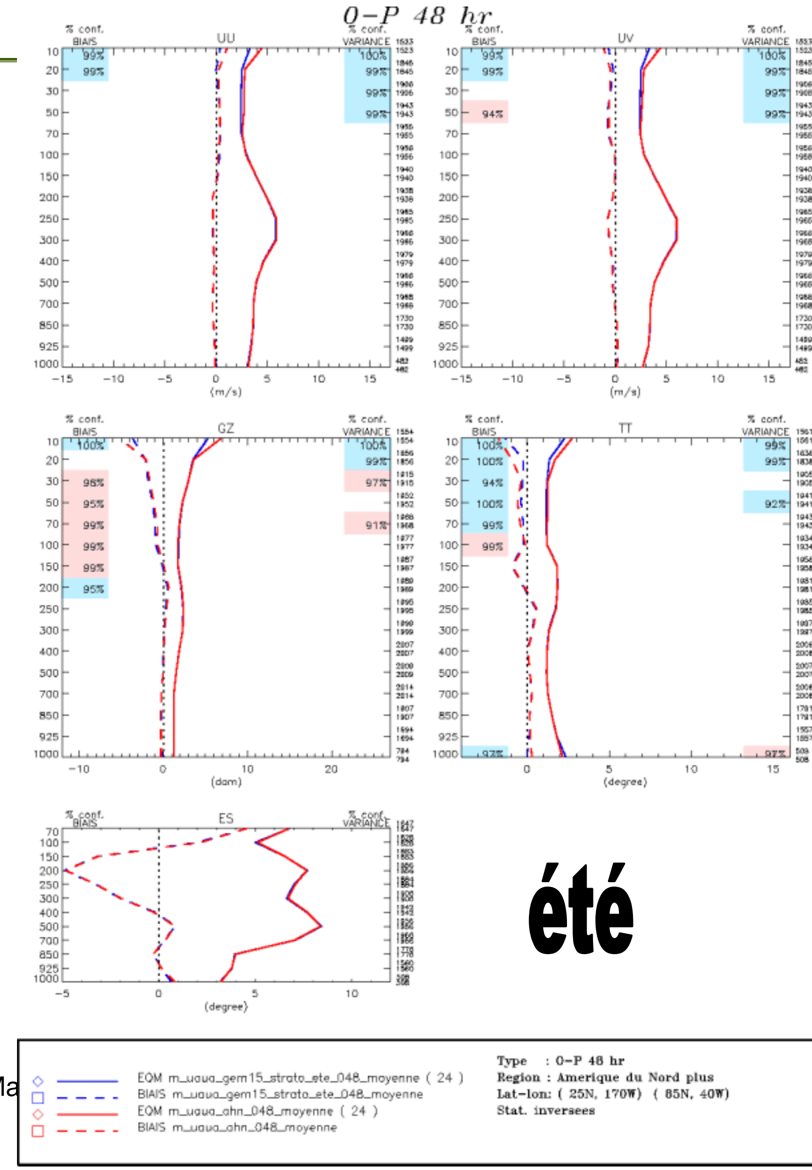
- Séries :
  - succession de 103 progs de 12h pour le cyclage
  - Séries de 24 cas de 48h à tous les 36h (en éliminant 2 premières semaines car commence avec un cold start de la chimie)
    - donc 12 cas de 00Z et 12 de 12Z
    - Hiver : 2008012900 à 2008032000
    - Été : 2008060300 à 2008072400

- Merci à Alain Patoine pour avoir produit le pilotage strato

Le Pilotage: Scores arcad UA à 48h

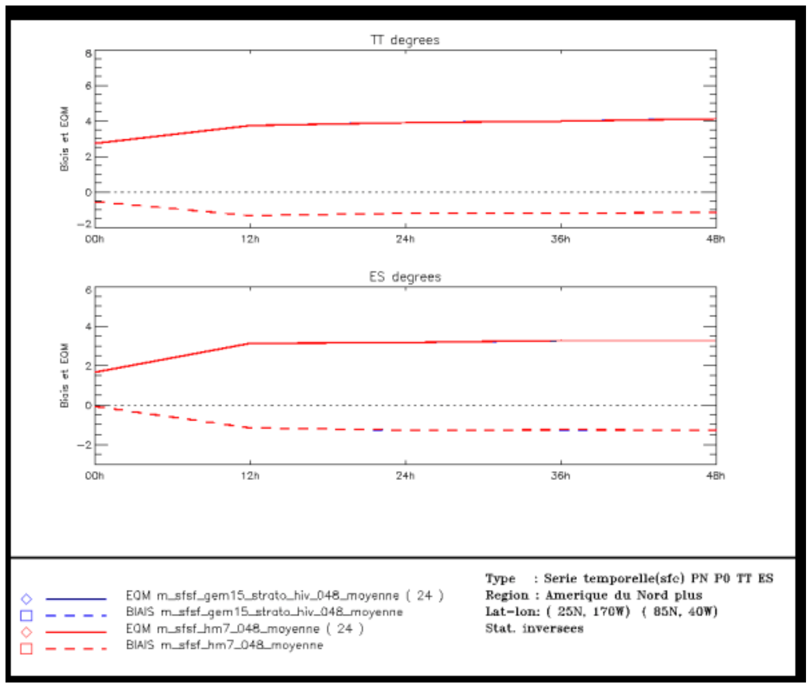


hiver



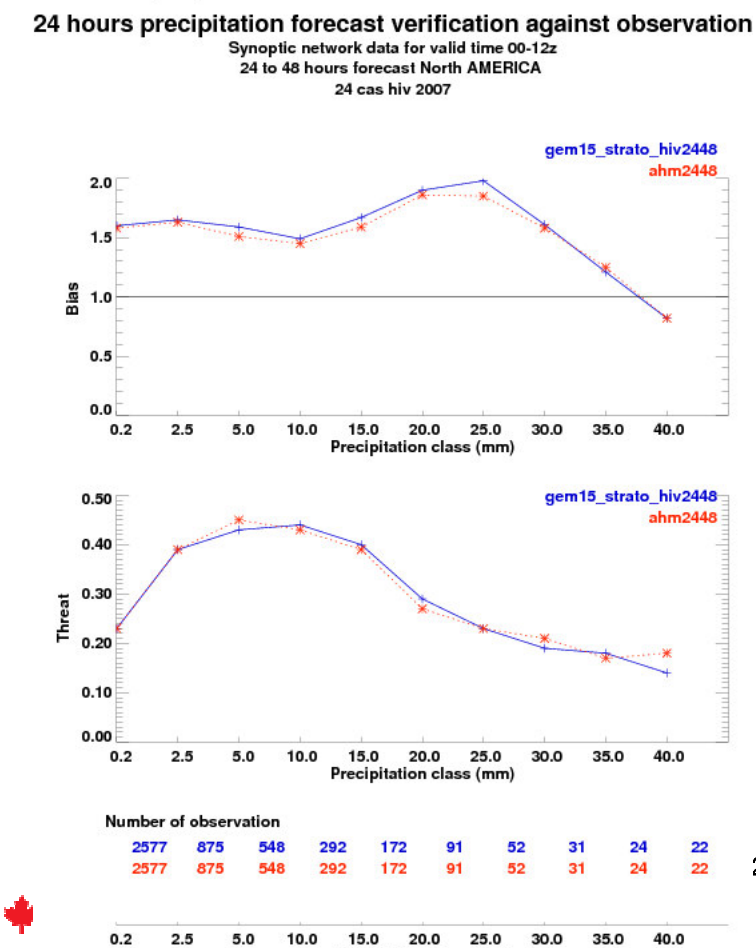
été

Le Pilotage: Scores arcad sfc hiver

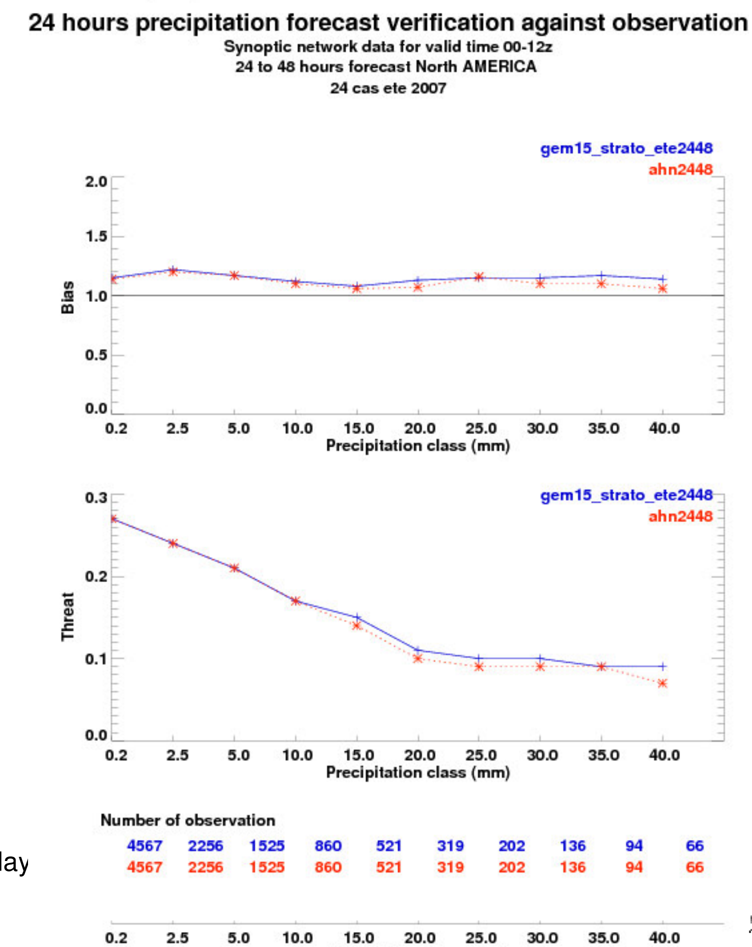


Le Pilotage: Scores de qpf

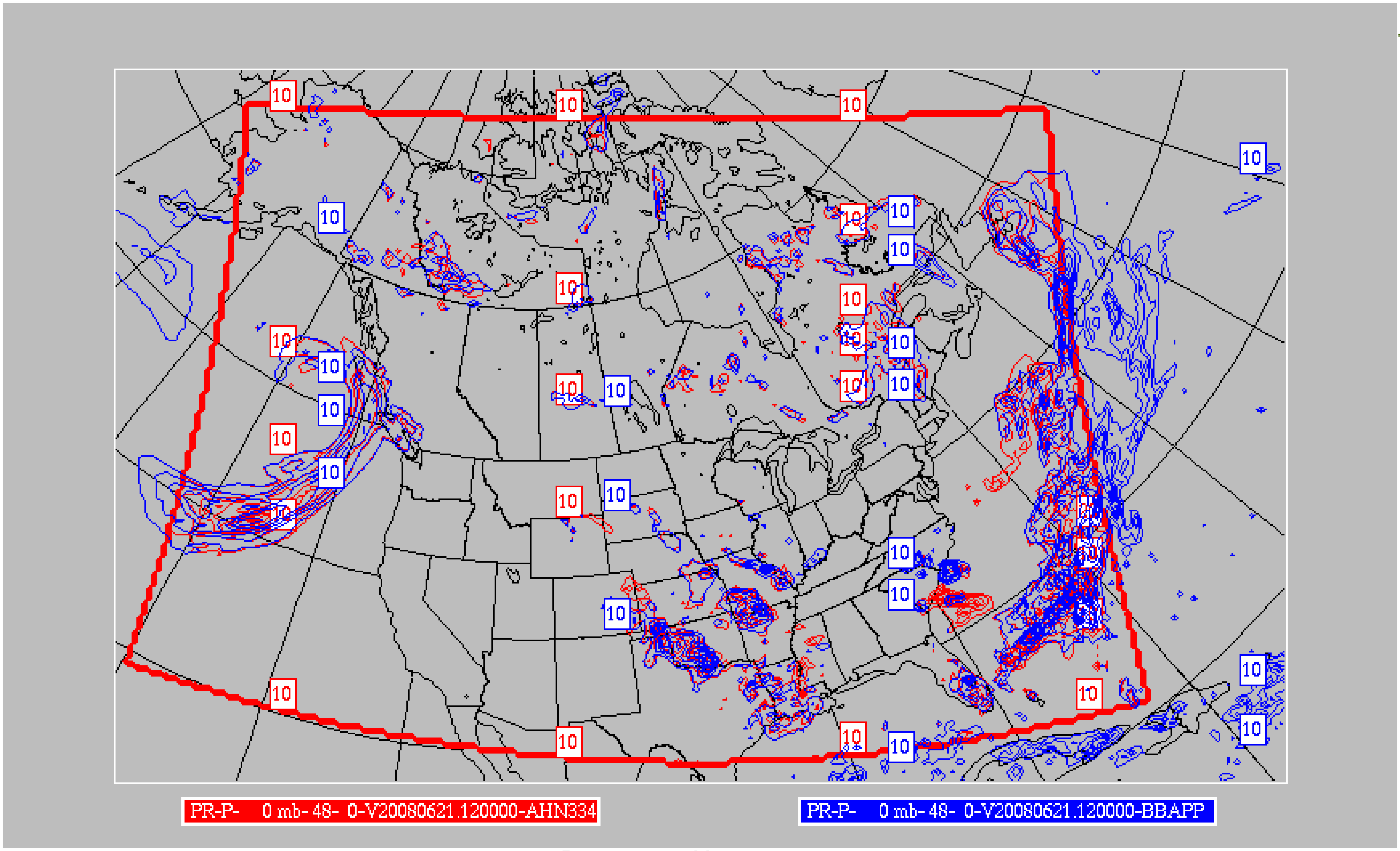
Hiver



Été



Le pilotage: Différence de qpf entre GEM15-strato et GEM-MACH15



Le Pilotage: Évaluation de la météo dans GEM-MACH15

- La prévision des champs météorologiques par un LAM plutôt que par une grille variable tel que dans GEM15-strato se compare-t-elle ?
  - arcad :
    - UA moins bons près de 10hPa
    - surface sont pareils
  - qpf : équivalents
- Solution acceptable jusqu'à là transition au pilotage par le toit dans DYN4.0

Timings

Timings de GEM-MACH15 pour prévision de 48h

- Caracteristiques de GEM-MACH15
  - Pas de temps: 450s pour météo & 900s pour chimie
  - Résolution horizontale: 15km
  - Résolution verticale: 58 niveaux, 0.1hPa
  - Durée de la prévision: 48-h, deux fois par jour

- Timings pour un 48h pour GEM-MACH15:
  - cas d'été, configuration 450s météo/900s chimie
    - 96 cpu : **105** min (CHRONOS **75** min à 16 cpu)
    - 384 cpu : **32** min (temps de mur)

- Cout des différentes composantes (tests à 96 CPUs):
    - Météo seulement **18** min
    - Météo + advection 57 traceurs: **31** min
    - Météo + advection + chimie: **105** min

GEM-MACH15
Performance evaluation

Objectives for air quality forecasting (1)

- Performance evaluation database:
  - Summer series: 2008/06/03 to 2008/07/24
  - Winter series: 2008/01/29 to 2008/03/20
  - Each series was initiated from a cold start and allowed a 2-week spin-up
  - Each series consisted of 72 cases of 48h forecast initiated every 12h (00 & 12)

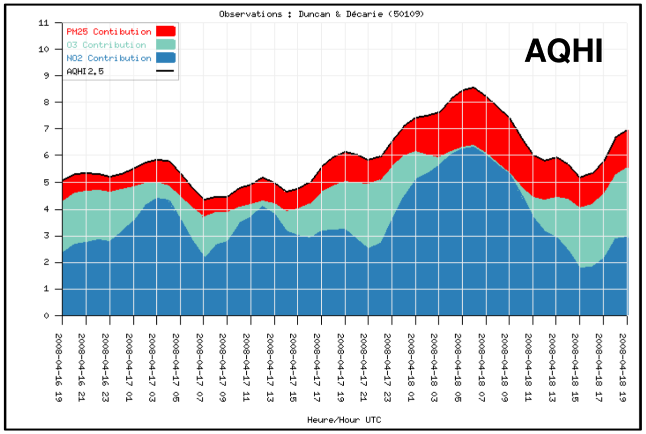
- Performance objective:
  - Equivalent or better than CHRONOS for the 3 pollutants of interest: O_3, $PM_{2.5}$, NO_2

- What are the forecasted quantities?
  - Maximum AQHI (Air Quality Health Index) within forecast window
    - $AQHI = 10/10.4*100*[(\exp(0.000871*NO_2)-1) + (\exp(0.000537*O_3) -1) + (\exp(0.000487*PM_{2.5}) -1)]$
  - Previous air quality forecast program
    - Maximum O_3
    - Maximum $PM_{2.5}$, PM_{10}

Objectives for air quality forecasting (2)

- AQHI: ~ wind-chill factor
  - Risk factor used to communicate the health risk associated with exposure to a mix of pollutants
  - Not a physical quantity
    - Forecast of single pollutants is key (O_3, $PM_{2.5}$, NO_2)
    - AQHI is a sum: hourly evolution is important to correctly identify the maximum

- What are the statistics of interest?
  - Hourly statistics
    - Capacity to capture continuous behaviour
  - Statistics on daily maxima
    - Capacity to capture events and extremes
  - Mainly summer for O_3, all year for $PM_{2.5}$ and NO_2



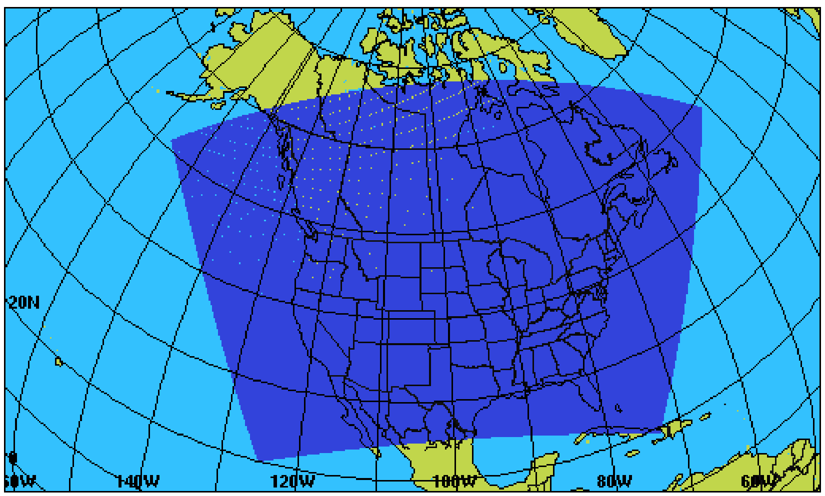
CHRONOS and GEM-MACH15 Setups

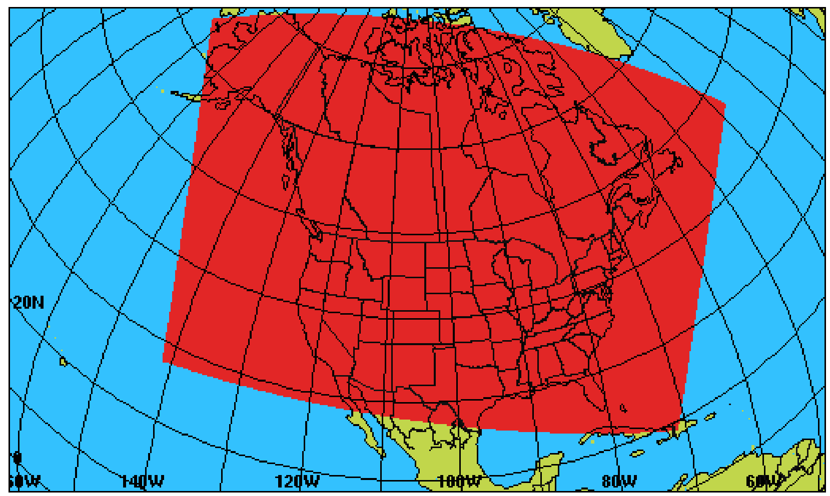
CHRONOS

- 350 x 250, PS
- résolution horizontale **21 km**
- **24** niveaux Gal-chen ~ **6km**
- Δt = **3600** s
- Emissions: 2000 Canada & 2001 US
with adjustments to 2007 EGU levels

GEM-MACH15

- 348 x 465, grille Z tournée
- résolution horizontale **15 km**
- Δt = **450** x 2 = 900 s pour la chimie
- Δt = **450s** pour la météo
- Emissions: 2006 Canada & 2005 US



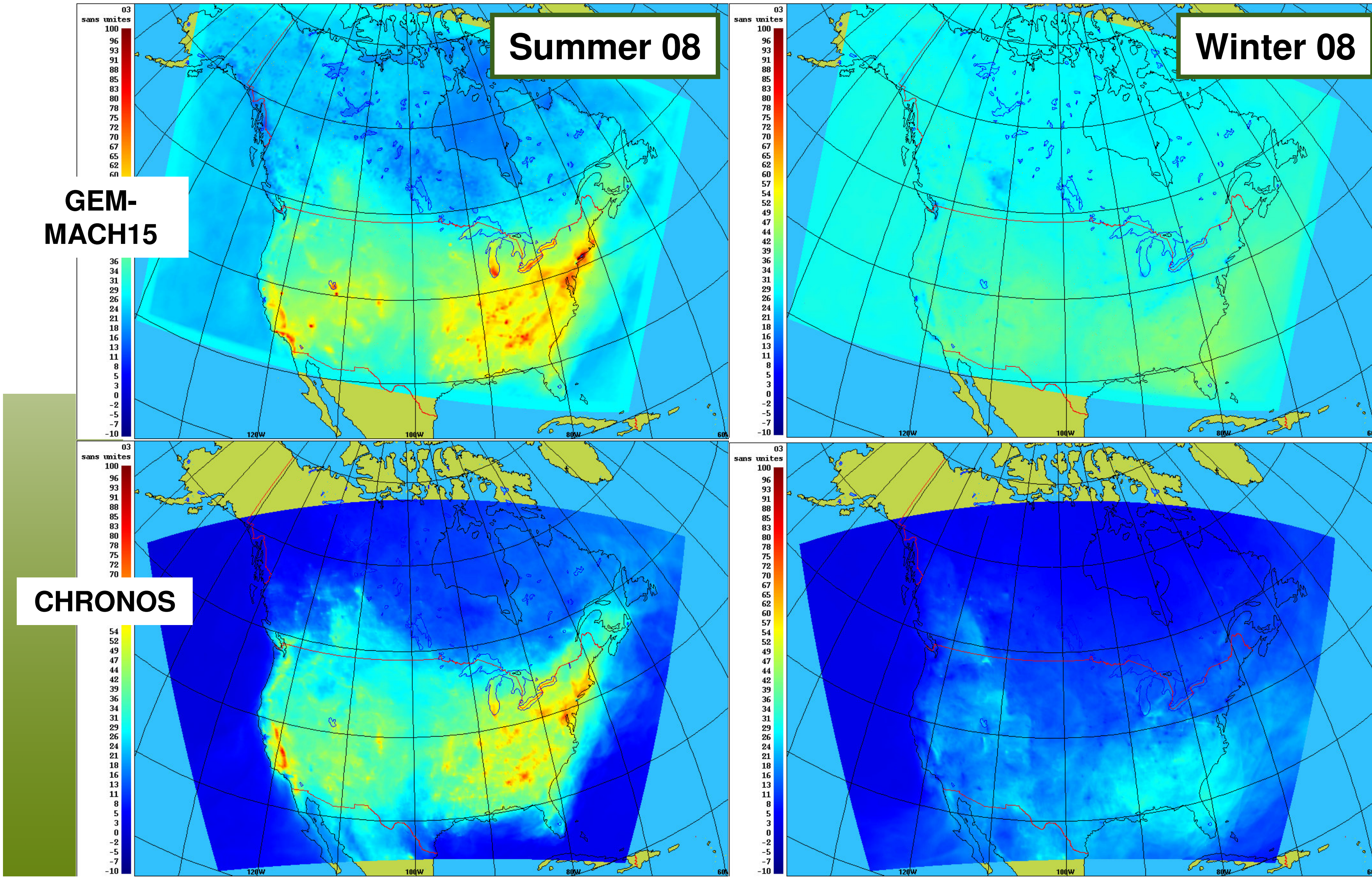


Evaluation of summer 2008 experimental run (O_3 & NO_2 only)

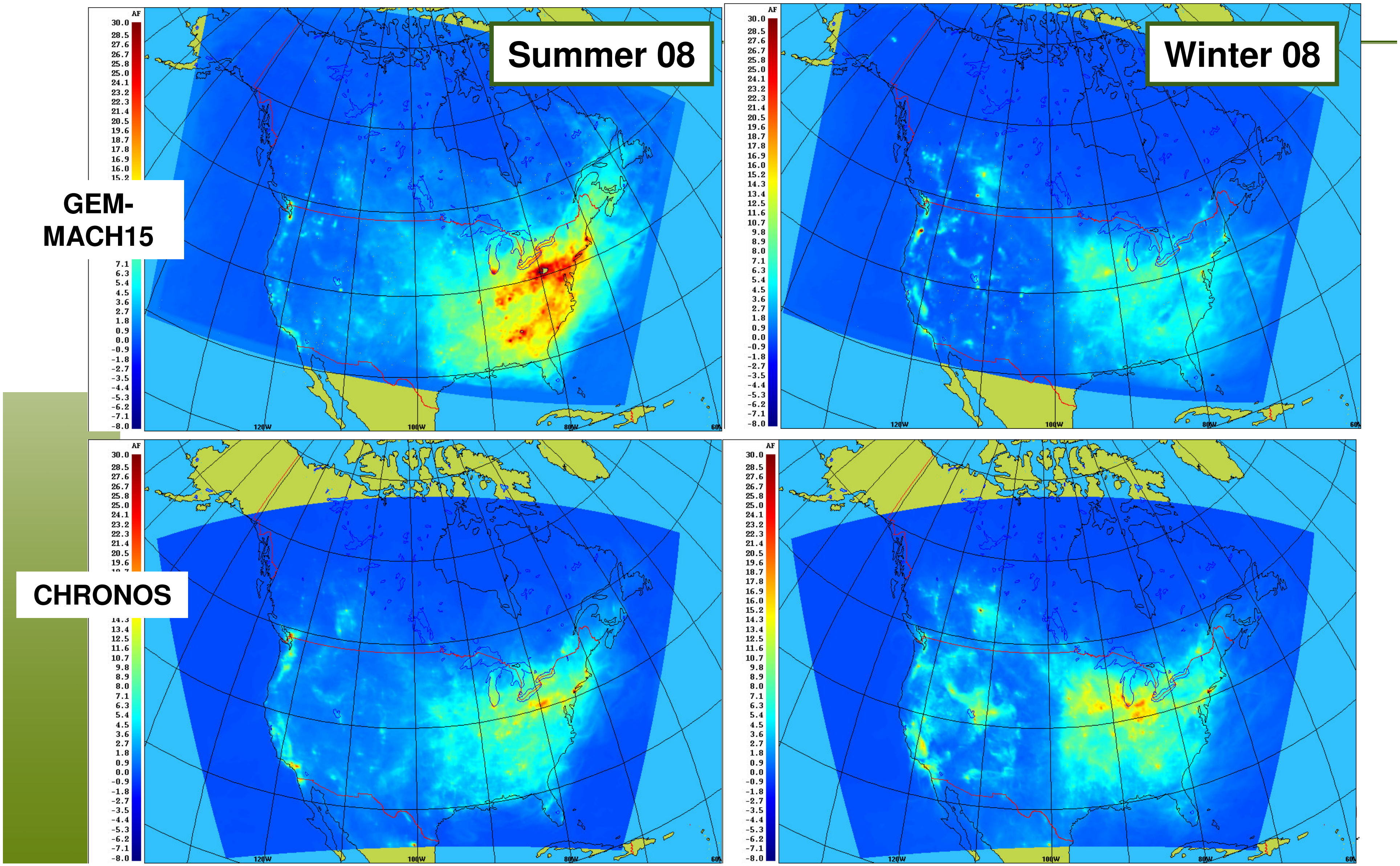
- **Subjective Analysis**
  - Participation of: PYR, PNR, OR, QR, AR, A&P
  - Areas where GEM-MACH15 performed better:
    - Overall, GEM-MACH15 slightly better than CHRONOS (considering available pollutants, all domains)
    - Large improvements in background values (due to new boundary conditions)
    - GEM-MACH15 tended to be more accurate for O_3 and NO_2 – less over-forecasting
    - GEM-MACH15 was identified as being more realistic during rainy/cloudy conditions
    - New emissions led to better guidance, especially in PNR
  - Areas where GEM-MACH15 performed less well:
    - General over-forecasting has been reduced considerably, though, GEM-MACH15 now under-forecasts in some areas
    - GEM-MACH15 tends to be more realistic at low values, but sometimes misses higher value episodes (PNR)
- **Objective Scores**
  - General improvements to bias and RMSE scores
  - Depending on region, determination coefficient not always improved

Evaluation of 2009 version for summer and winter 2008

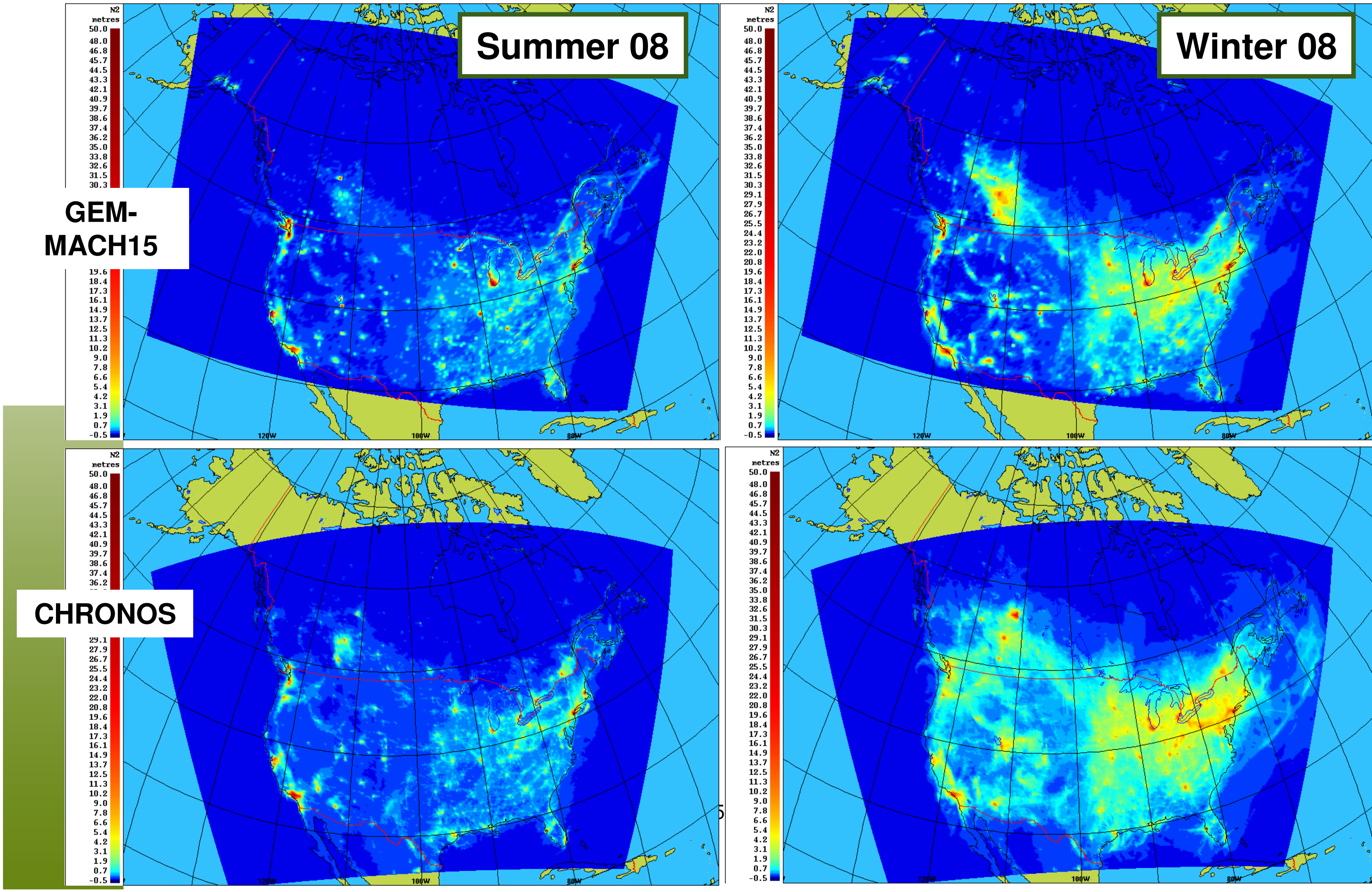
General Overview: Average O_3 Field at 20 UTC



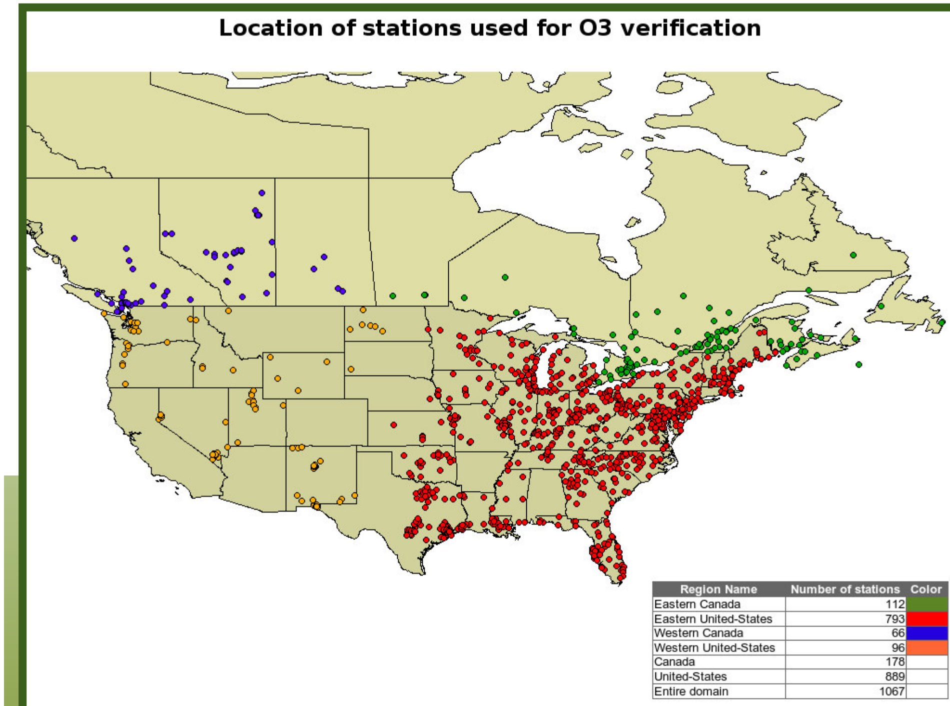
General Overview: Average $PM_{2.5}$ Field at 20 UTC

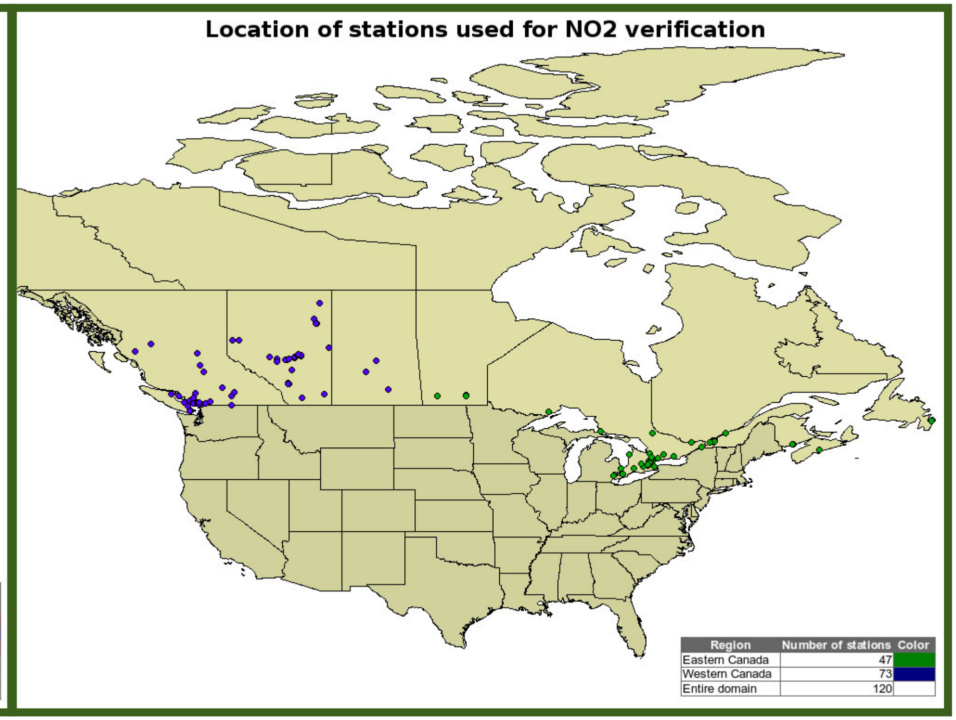


General Overview: Average NO_2 Field at 20 UTC



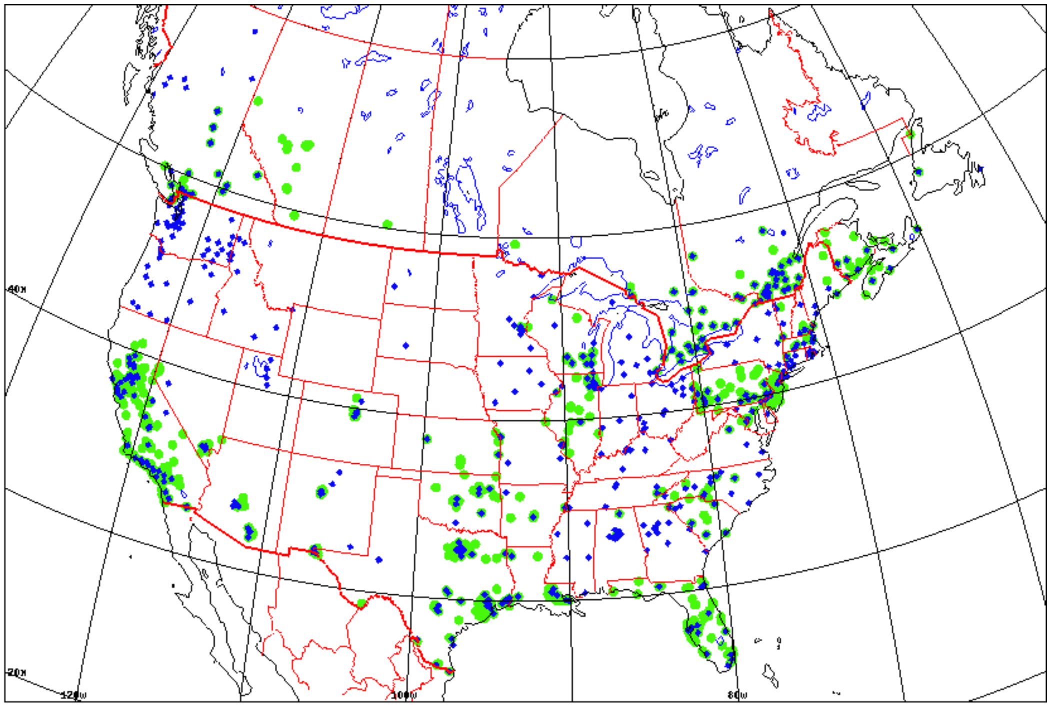
Summer 2008 O_3 and NO_2 Monitor Locations





- Canadian data: Real-time data from ADE system (provincial and federal Canadian real-time transmission)
- U.S data: real-time data from SonomaTech / EPA real-time feed (ftp.airnowdata.org)

Summer 2008 $PM_{2.5}$ Monitor Locations and Winter 2008 O_3 Monitor Locations



$PM_{2.5}$ monitors – blue
Winter O_3 monitors - green

- Canadian data: Real-time data from ADE system (Provincial and federal canadian real-time transmission)
- U.S data: real-time data from SonomaTech / EPA real-time feed (ftp.airnowdata.org)

Full-Domain Statistics (Hourly) for New Version of GEM-MACH15

O3	Persistence	CHRONOS	GEM-MACH
r	0,67	0,68	0,68
bias	0,18	-4,31	2,49
RMSE	14,74	15,94	15,47
PM2.5			
r	0,33	0,30	0,40
bias	-0,08	-2,05	0,69
RMSE	12,67	12,91	13,44
NO2			
r	0,57	0,47	0,46
bias	-0,03	2,18	0,82
RMSE	6,37	9,93	8,83

Summer 2008

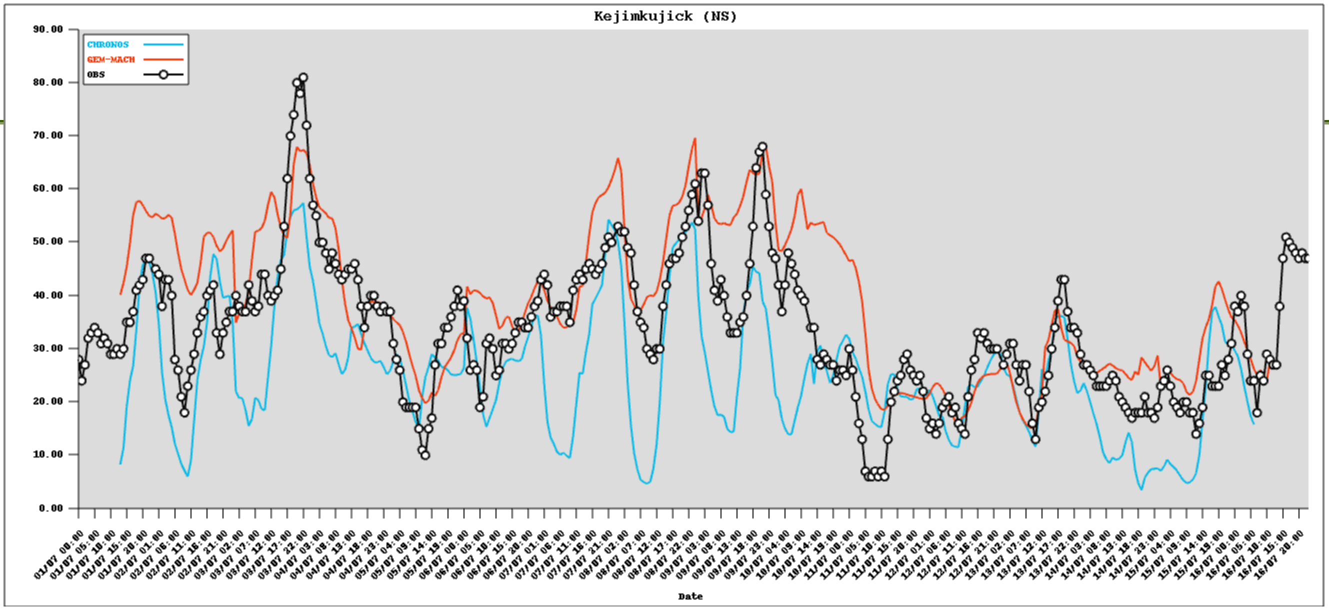
O3	Persistence	CHRONOS	GEM-MACH
r	0,50	0,46	0,58
bias	-0,46	-19,81	-5,46
RMSE	14,16	23,59	13,30
PM2.5			
r	0,21	0,26	0,22
bias	0,10	0,85	-0,20
RMSE	14,04	14,05	15,81
NO2			
r	0,41	0,48	0,59
bias	0,31	-2,99	-1,90
RMSE	13,30	12,13	11,42

Winter 2008

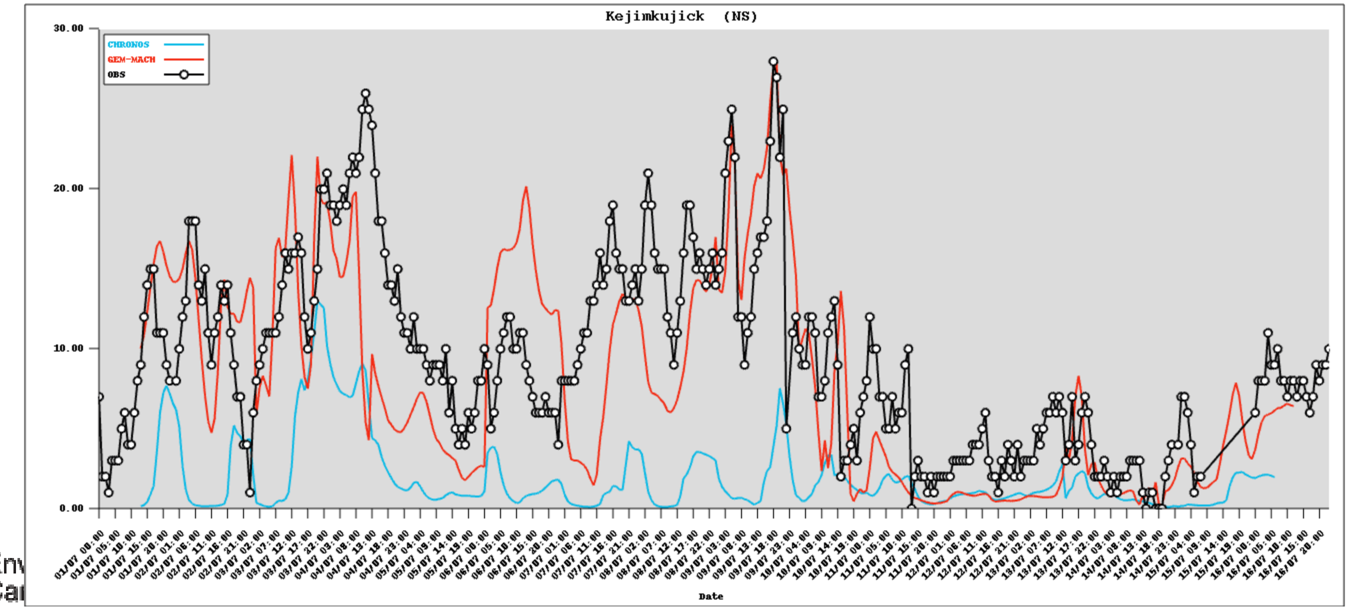
O_3 & $PM_{2.5}$ Time Series, 1-16 July 2008 (1)

Kejimkujik, Nova Scotia

O_3



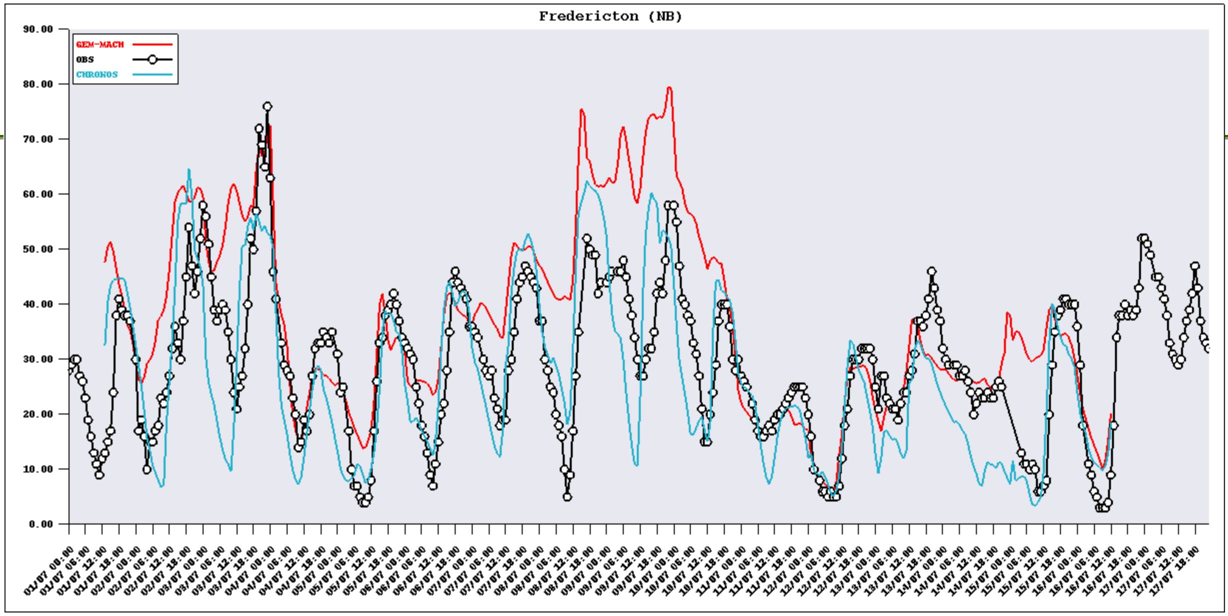
$PM_{2.5}$



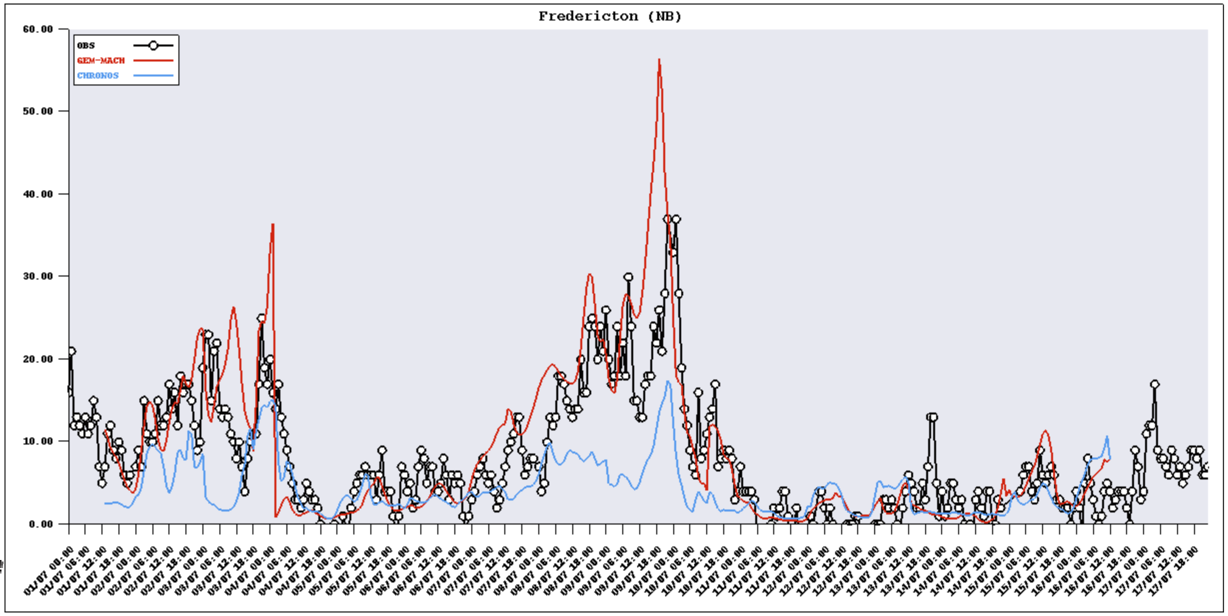
O_3 & $PM_{2.5}$ Time Series, 1-16 July 2008 (2)

Fredericton, New Brunswick

O_3



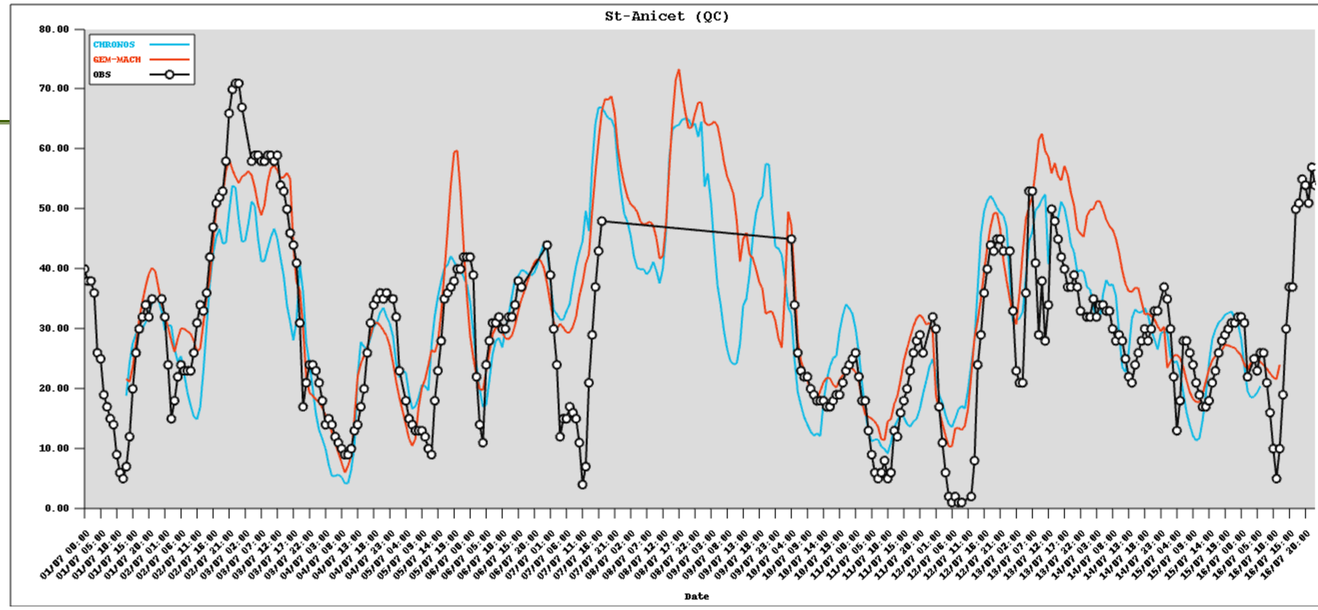
$PM_{2.5}$



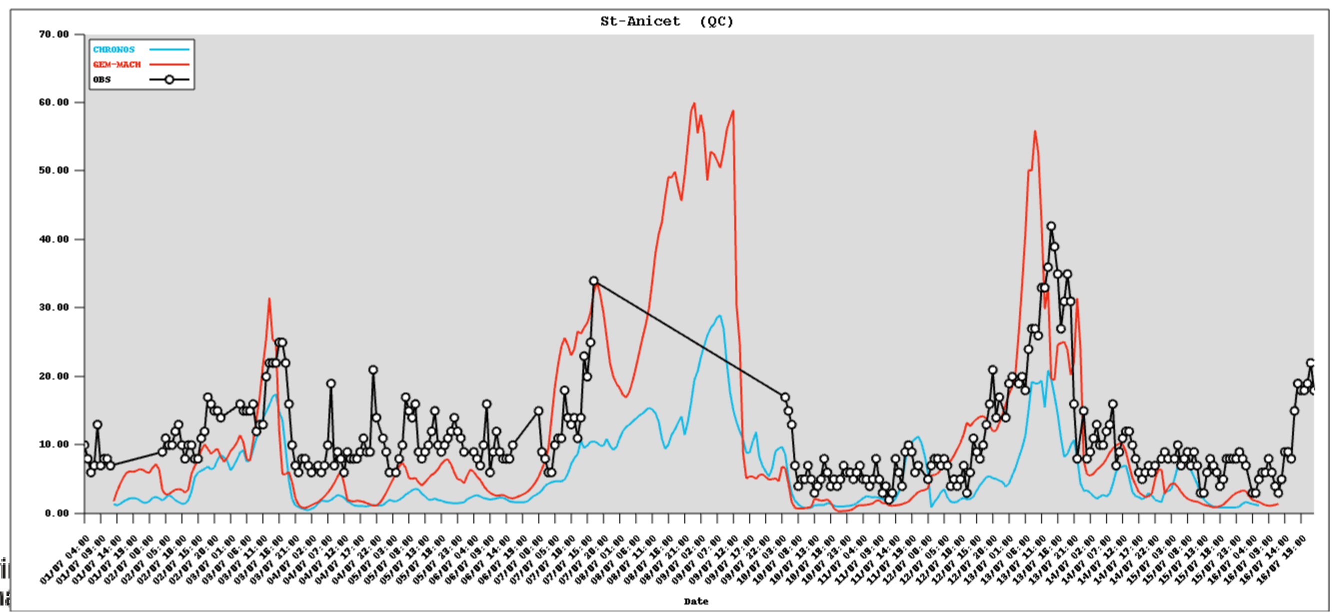
O_3 & $PM_{2.5}$ Time Series, 1-16 July 2008 (3)

St. Anicet, Quebec

O_3



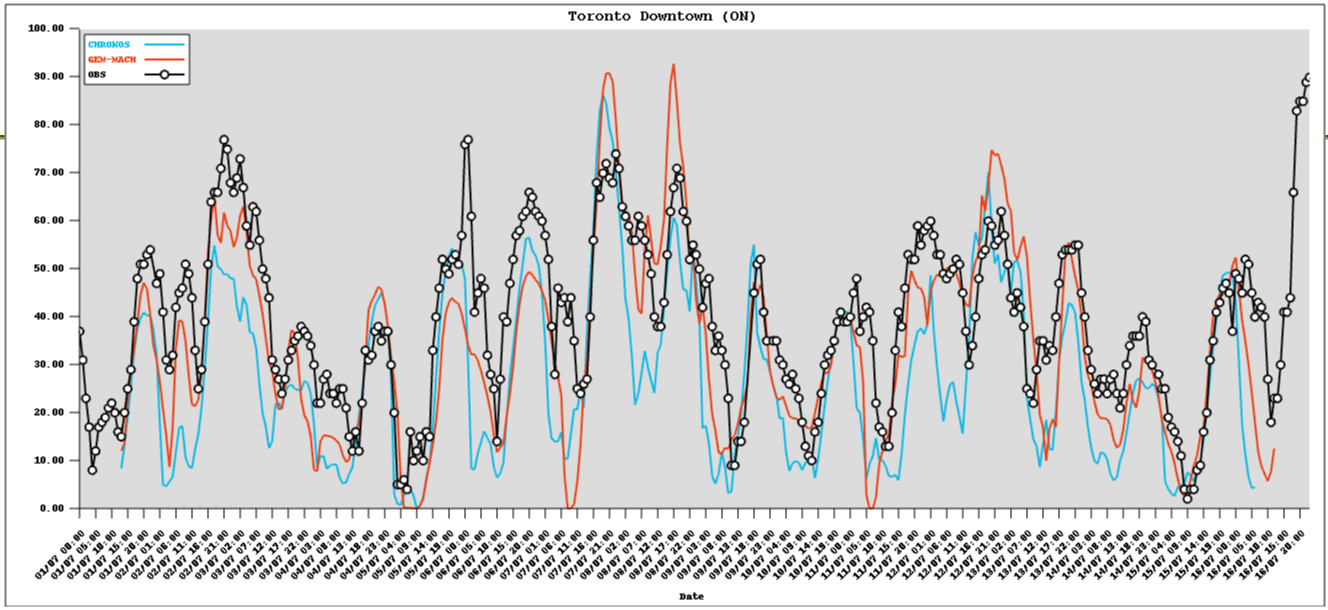
$PM_{2.5}$



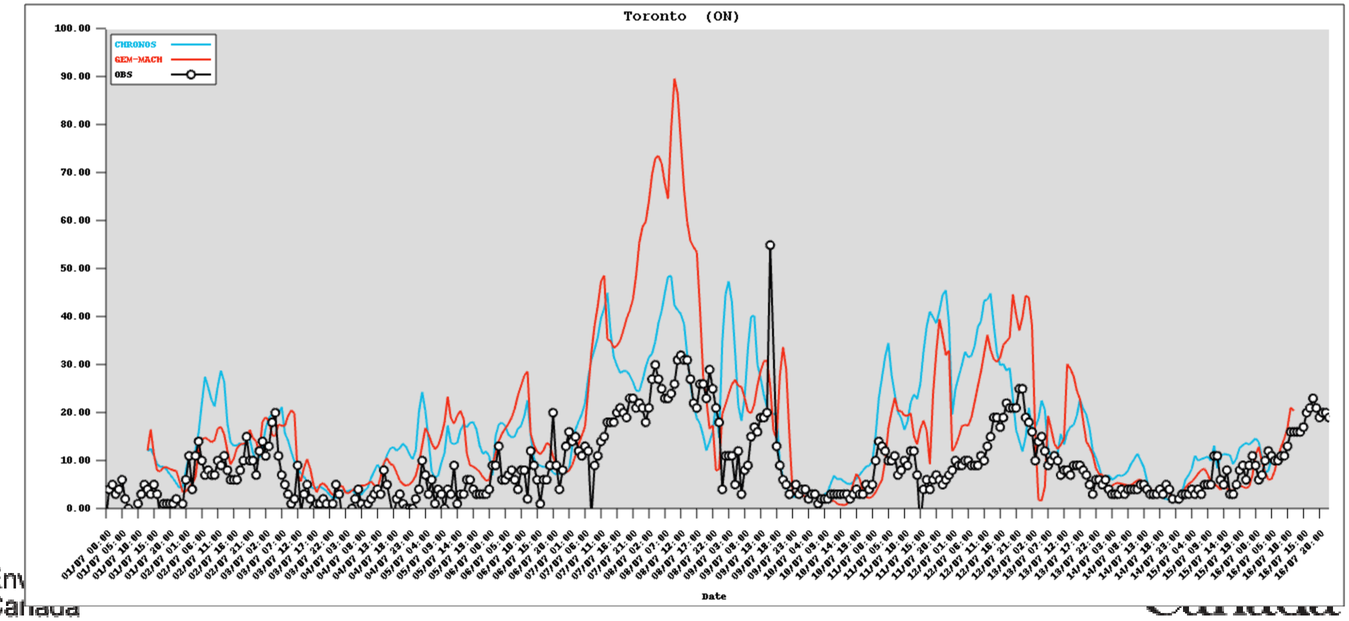
O_3 & $PM_{2.5}$ Time Series, 1-16 July 2008 (4)

Toronto, Ontario

O_3



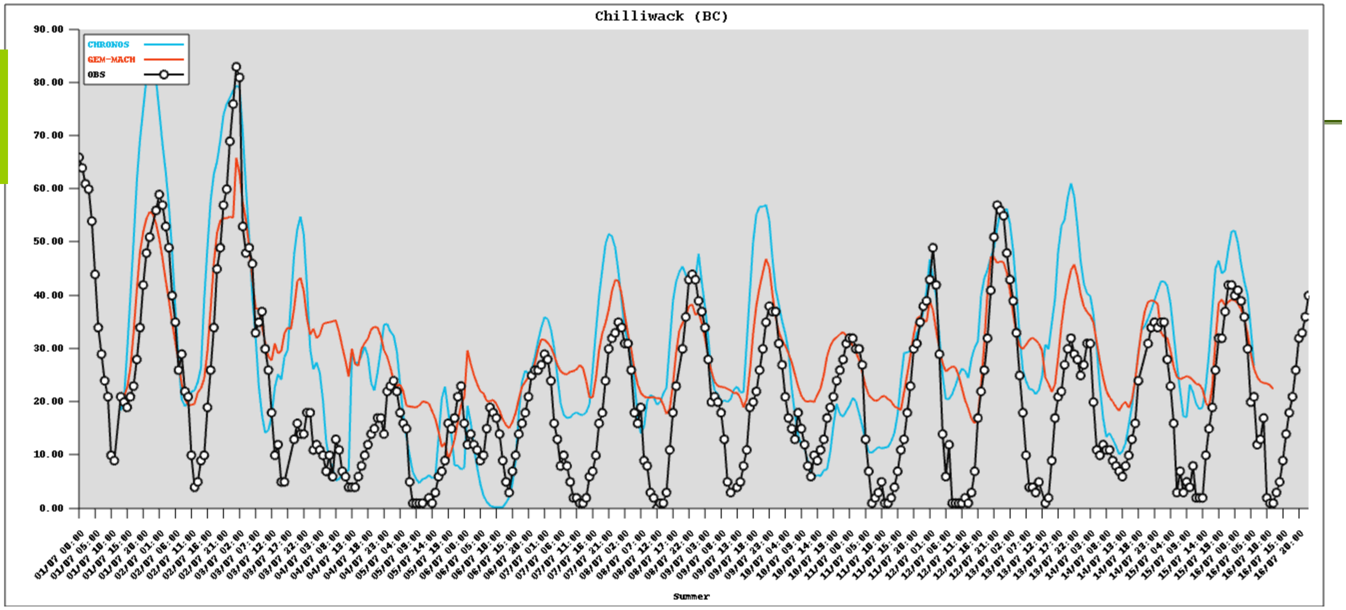
$PM_{2.5}$



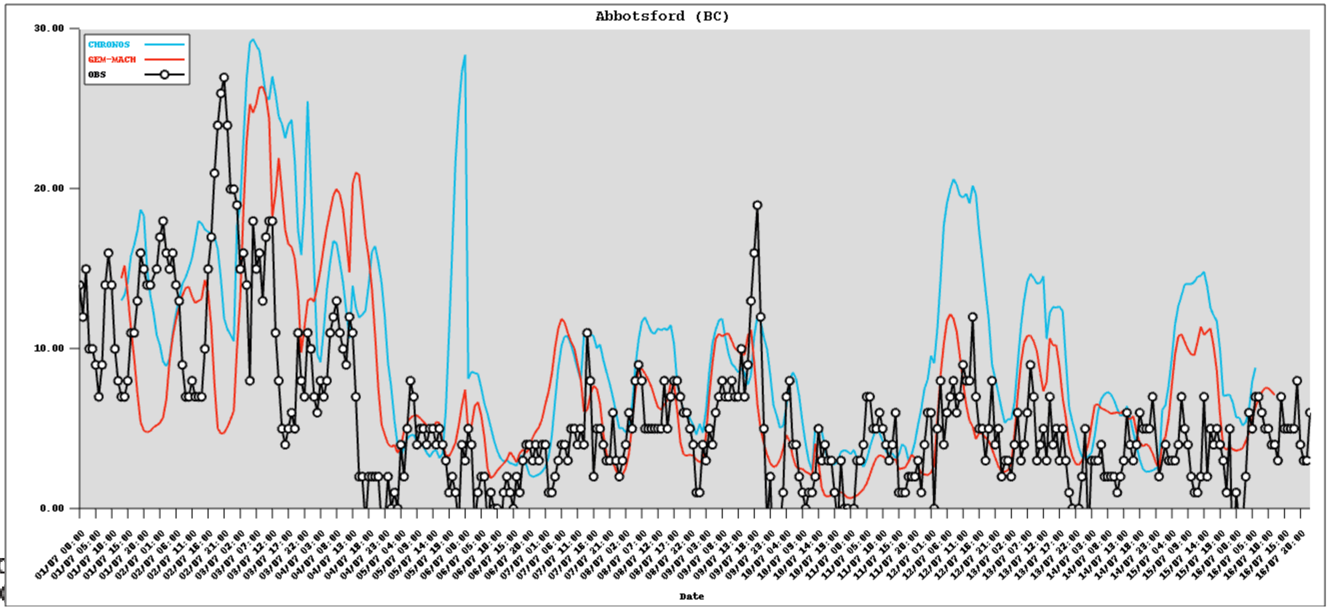
O_3 & $PM_{2.5}$ Time Series, 1-16 July 2008 (5)

Chilliwack – Abbotsford British Columbia

O_3



$PM_{2.5}$

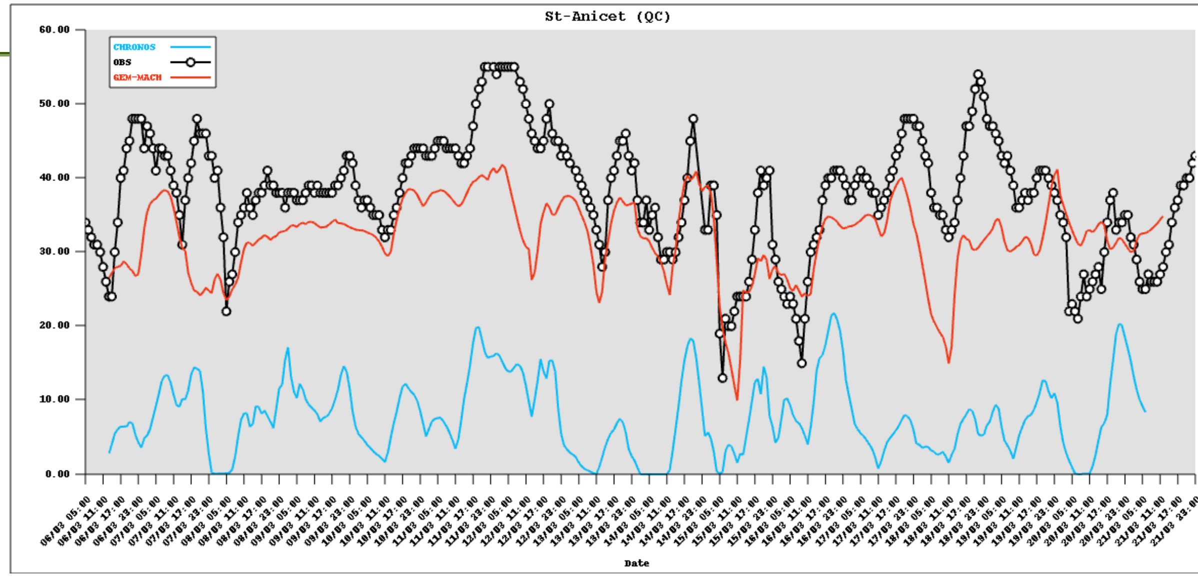


Environment Canada
Environnement Canada

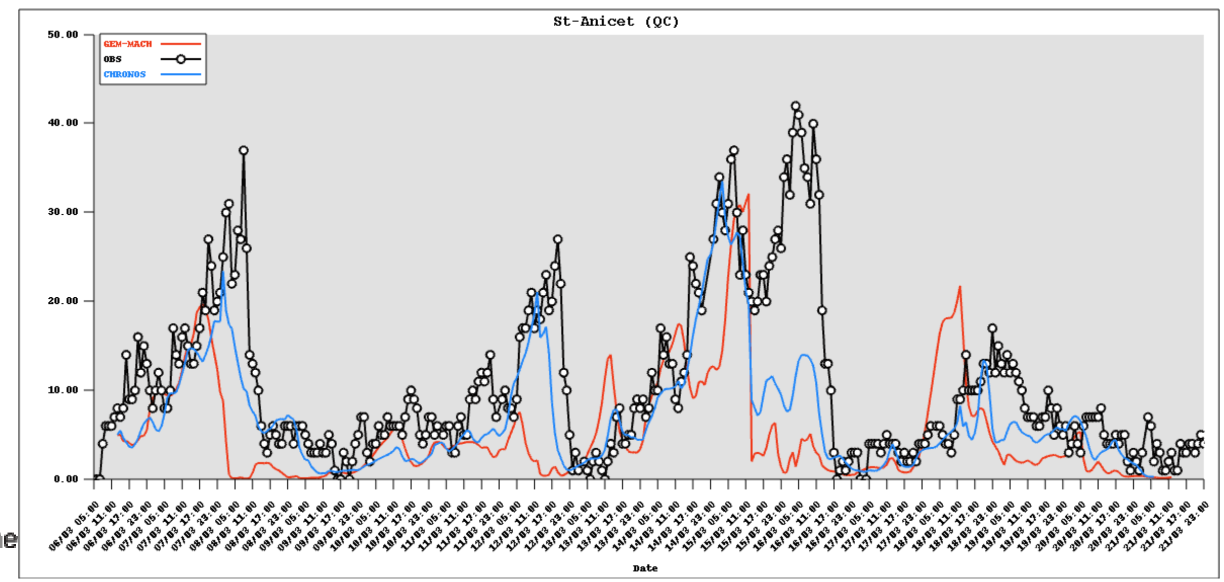
O_3 & $PM_{2.5}$ Time Series, 6-21 March 2008 (1)

St. Anicet, Quebec

O_3



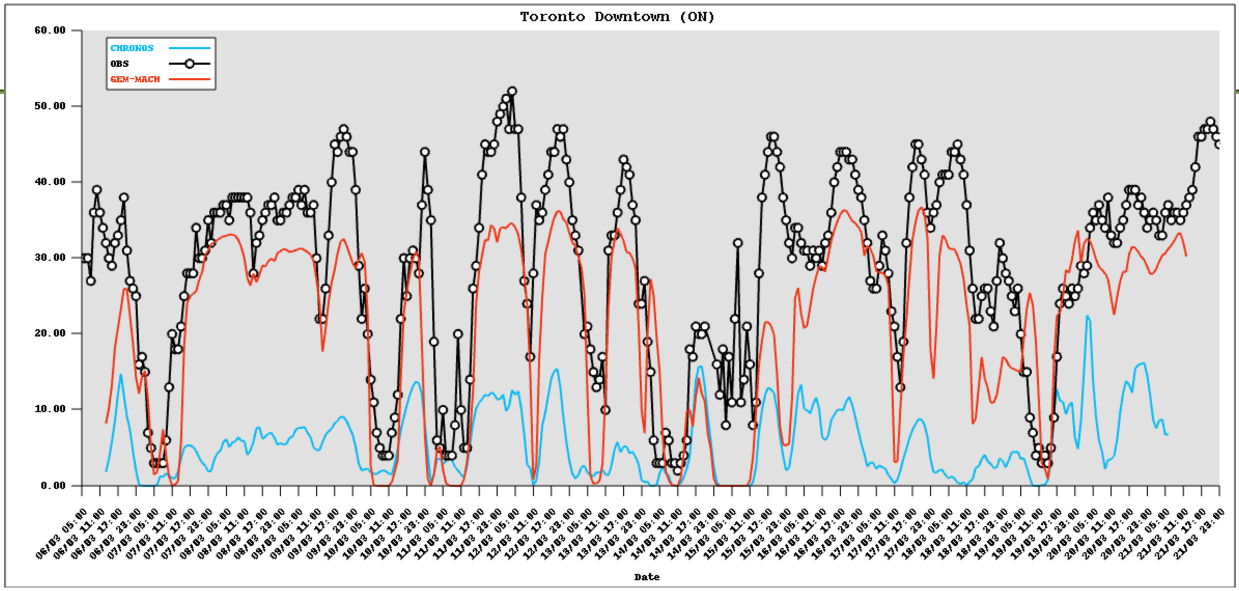
$PM_{2.5}$



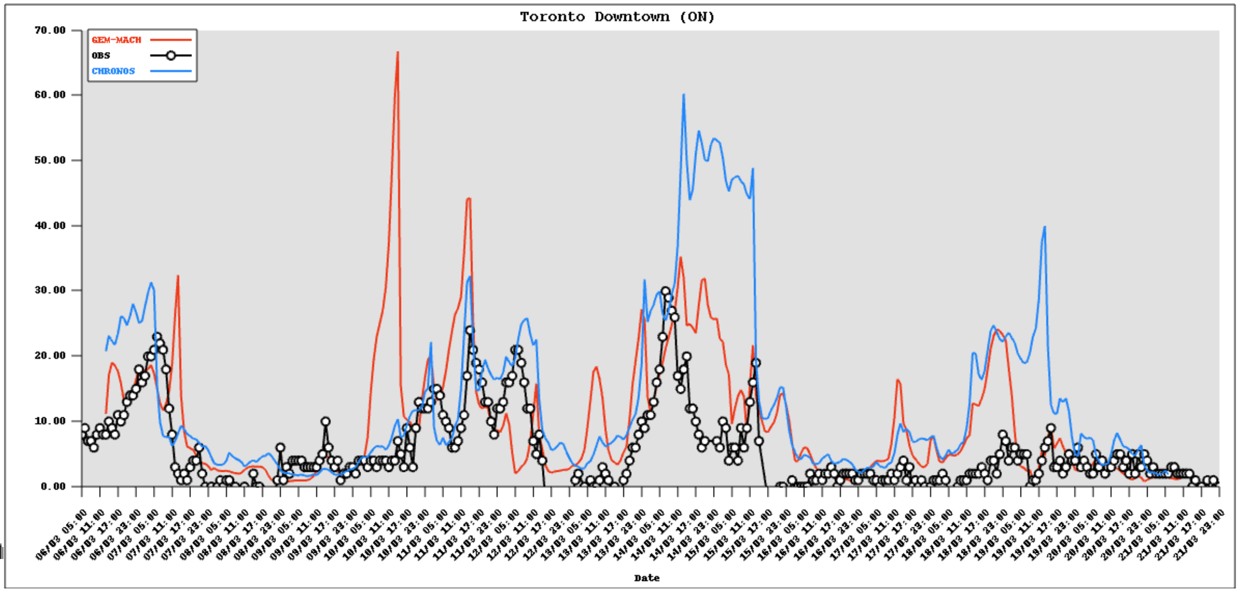
O_3 & $PM_{2.5}$ Time Series, 6-21 March 2008 (2)

Toronto, Ontario

O_3

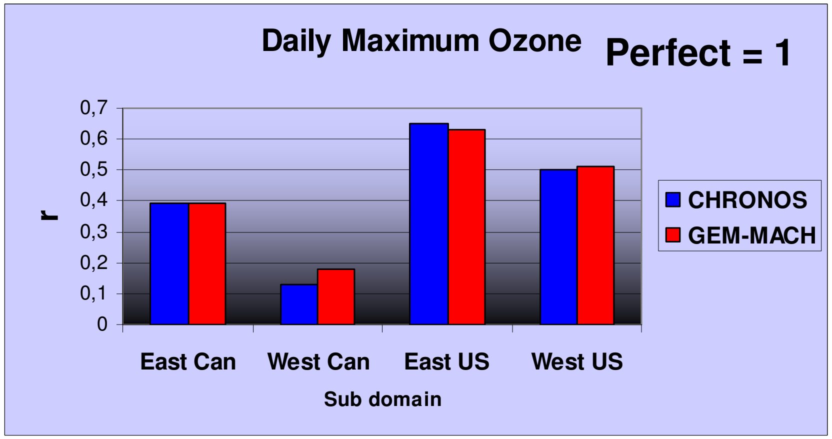


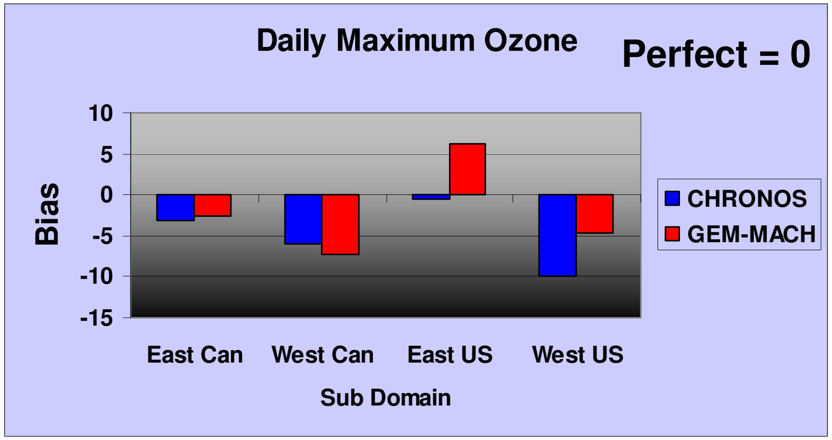
$PM_{2.5}$

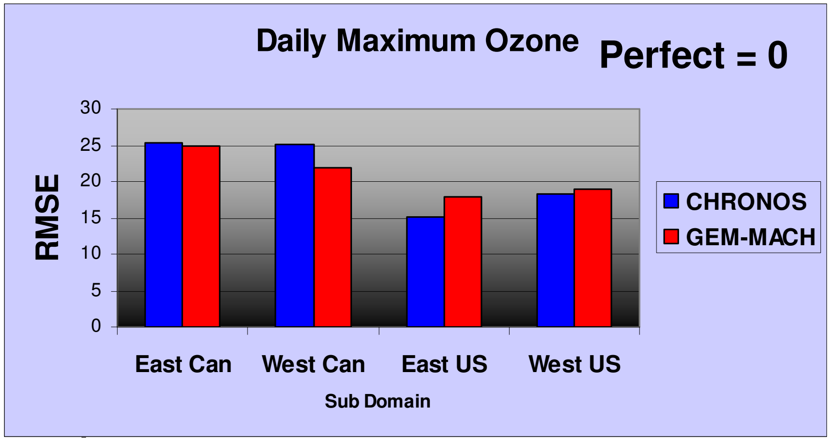


Daily Maximum O_3 (Summer 2008 series)

r, Bias, RMSE by Sub Domain

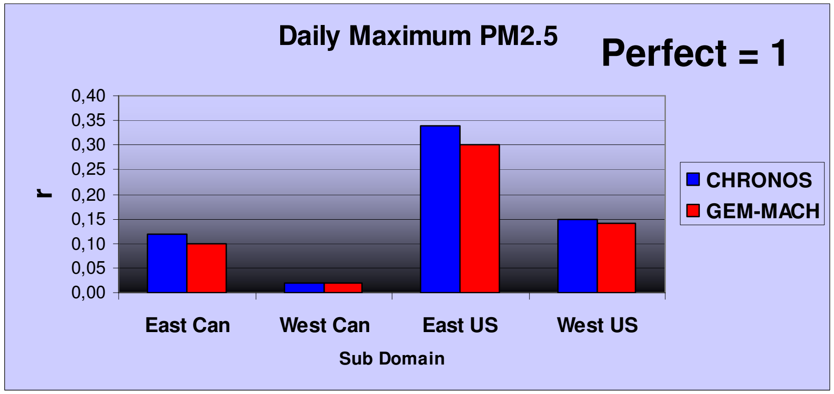


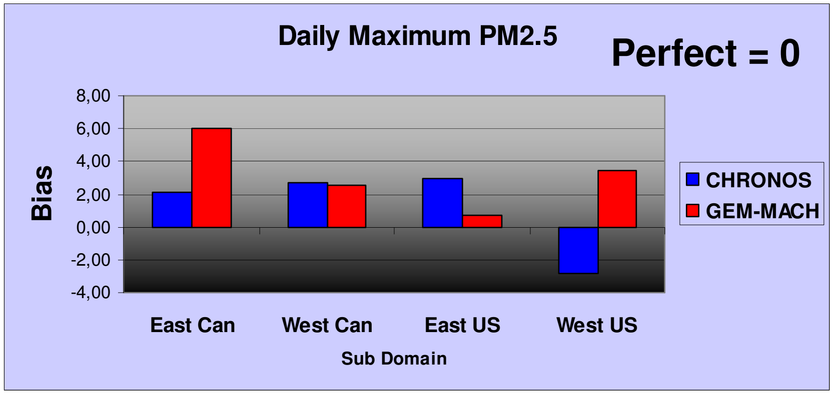


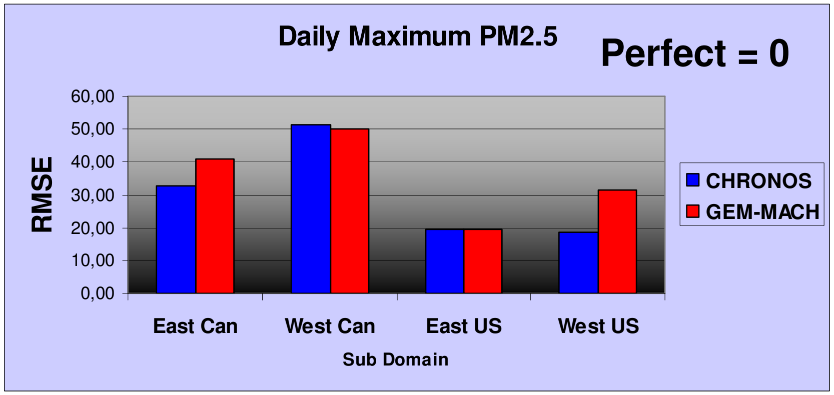


Daily Maximum $PM_{2.5}$ (Summer 2008 series)

r, Bias, RMSE by Sub Domain

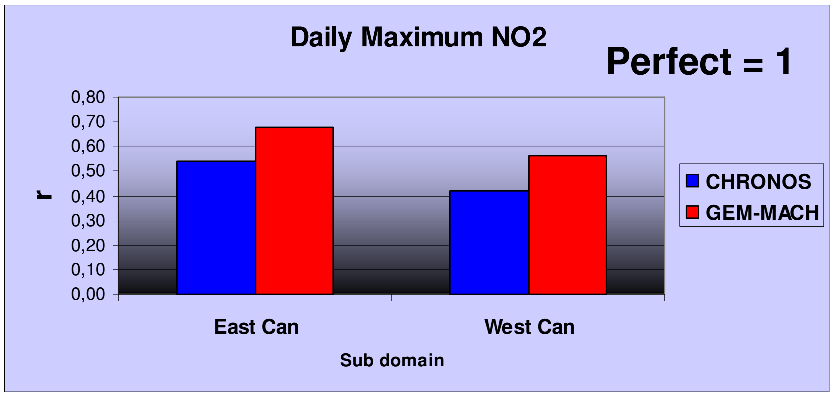


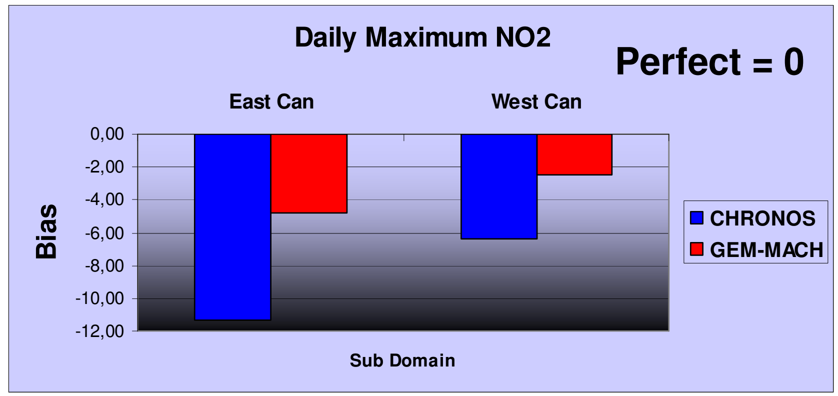


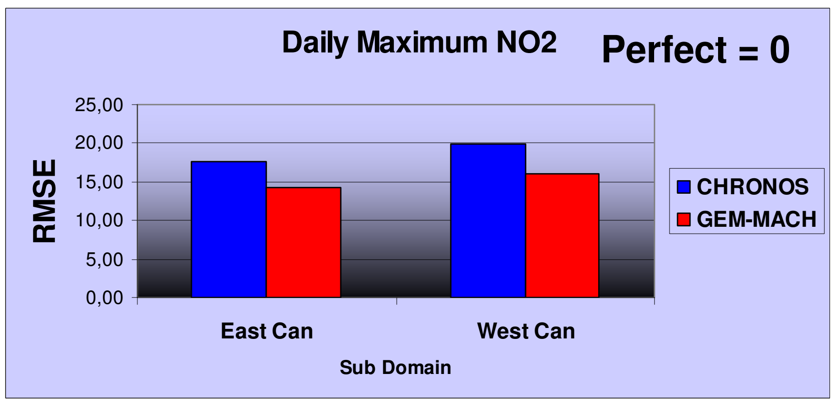


Daily Maximum NO_2 (Summer 2008 series)

r, Bias, RMSE by Sub Domain

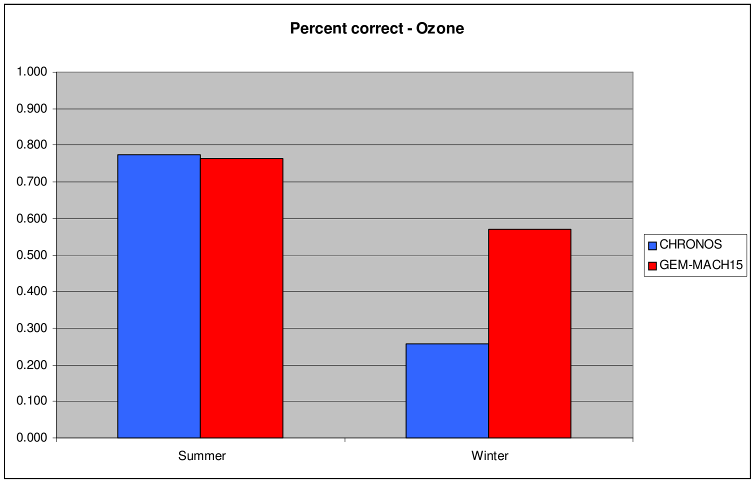




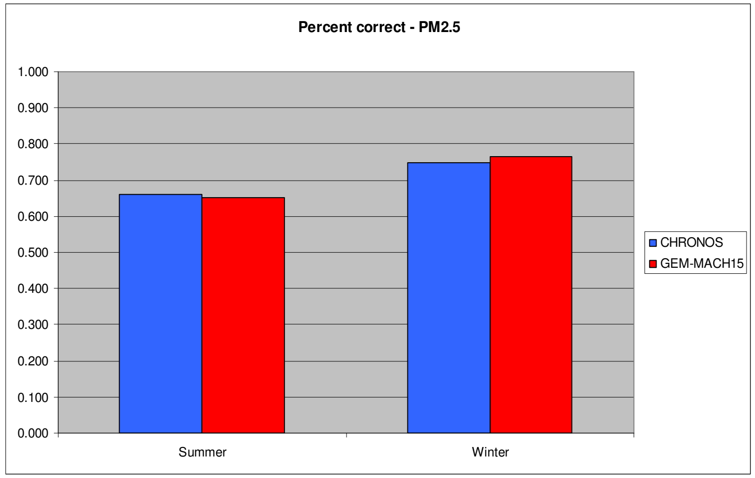


Percent Correct for Hourly O_3 and $PM_{2.5}$ for 1-16 July 2008 and 6-21 March 2008

Ozone

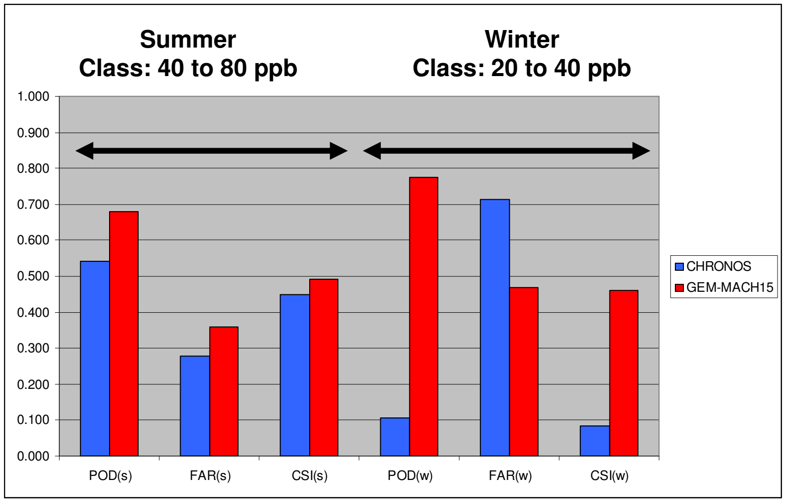


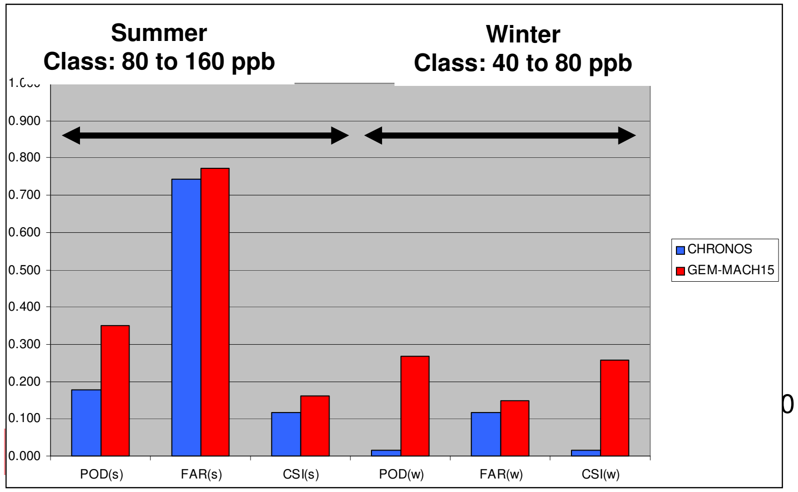
$PM_{2.5}$



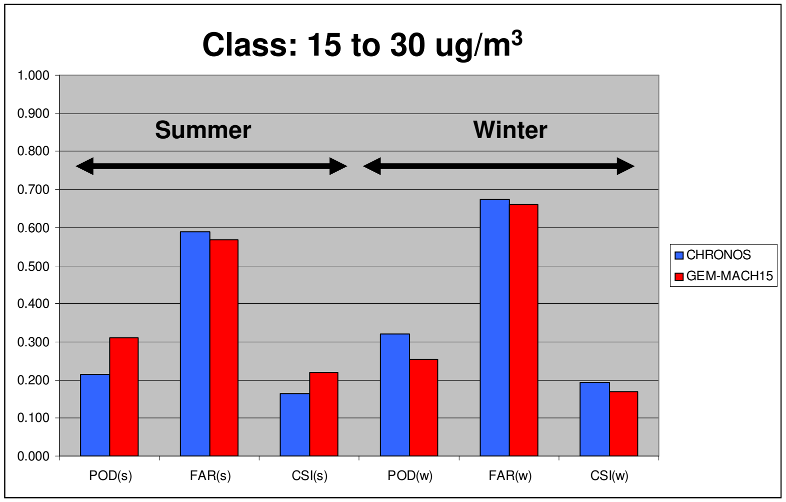
Other Categorical Statistics for Hourly O_3 and $PM_{2.5}$ for 1-16 July and 6-21 March 2008

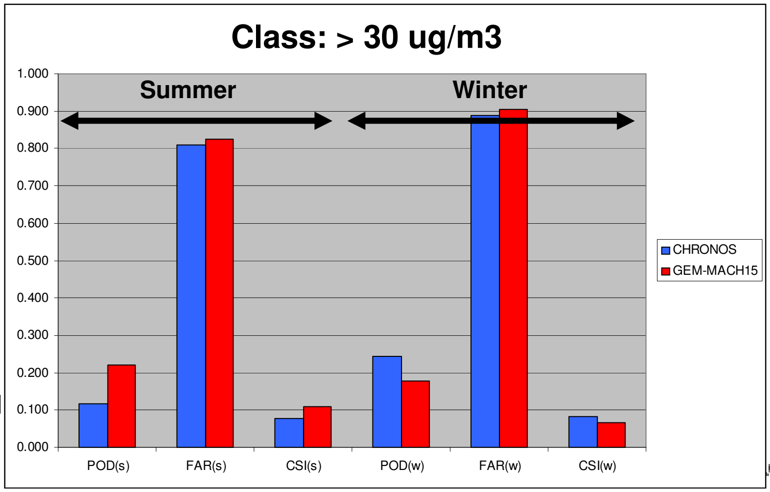
Ozone





$PM_{2.5}$





Summary Comparison of CHRONOS and GEM-MACH15 Hourly Objective Scores by Region

	GEM-MACH15 Better
	CHRONOS Better
	Effective Tie
	No Data

	Region						
Metric	North Am	Cda	E Cda	W Cda	US	E US	W US
Summer							
O3 R							
O3 MB							
O3 RMSE							
PM2.5 R							
PM2.5 MB							
PM2.5 RMSE							
NO2 R	NA						
NO2 MB	NA						
NO2 RMSE	NA						
Winter							
O3 R							
O3 MB							
O3 RMSE							
PM2.5 R							
PM2.5 MB							
PM2.5 RMSE							
NO2 R							
NO2 MB							
NO2 RMSE							

GEM-MACH15
Schedule for implementation

Schedule for Implementation

- Based on the results from the summer and winter series, GEM-MACH15 has a performance level that meets the objectives

- Schedule for operational deployment:
  - Proposal for parallel run to CPOP – May 12
  - If accepted:
    - Parallel run – mid-May to end of June
    - Proposal for operational implementation – end of June
    - Operational implementation – late July
      - CHRONOS driven by eta database from GEM15-strato in mean time

GEM-MACH15
Future developments

Main Thrusts for Air Quality Forecasting

- optimize GEM-MACH15 code and configuration further (balancing accuracy-speed trade-off)
- keep up with changes to operational version of regional GEM (e.g., v3.3.2, v4, …)
- update and improve emission inputs
- continue to pursue case studies and other diagnostic evaluations (including use of field-study and research-network data sets and peer models)
- add new or upgrade current process representations (see next slide)

Candidate Process Representations

- improved treatment of secondary organic aerosol formation
- subgrid-scale convective vertical transport
- wind-blown dust emissions
- North American wildfire emissions
- urban heat island influence on near-surface vertical mixing
- enhanced gas-phase chemistry (incl. CH_4, C_2H_6?)
- improved vertical diffusivity parameterizations
- updates to inorganic heterogeneous chemistry & dry deposition
- cloud ice-phase chemistry
- improved biogenic emissions, including seasonality

- global anthropogenic emissions, including marine vessels
- global biomass burning, wildfires, and volcanoes
- global lightning-generated NOx
- global oceanic emissions (e.g., DMS)
- time-dependent chemical lateral boundary conditions

Merci – Thank you

Questions?