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Canada

UMOS-AQ

Updatable Model Output Statistics – Air Quality

Description, Verifications and Future developments

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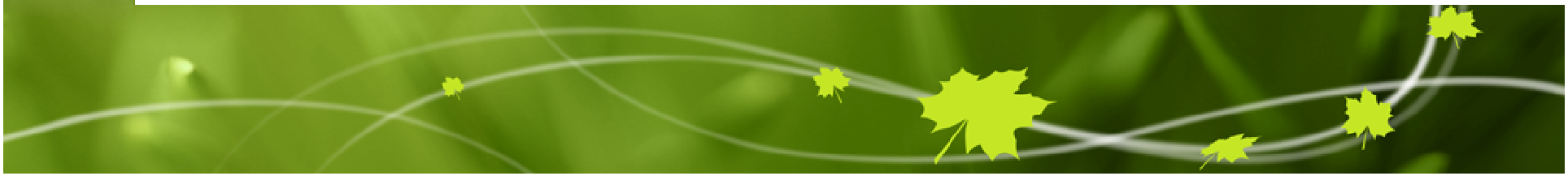

Overview

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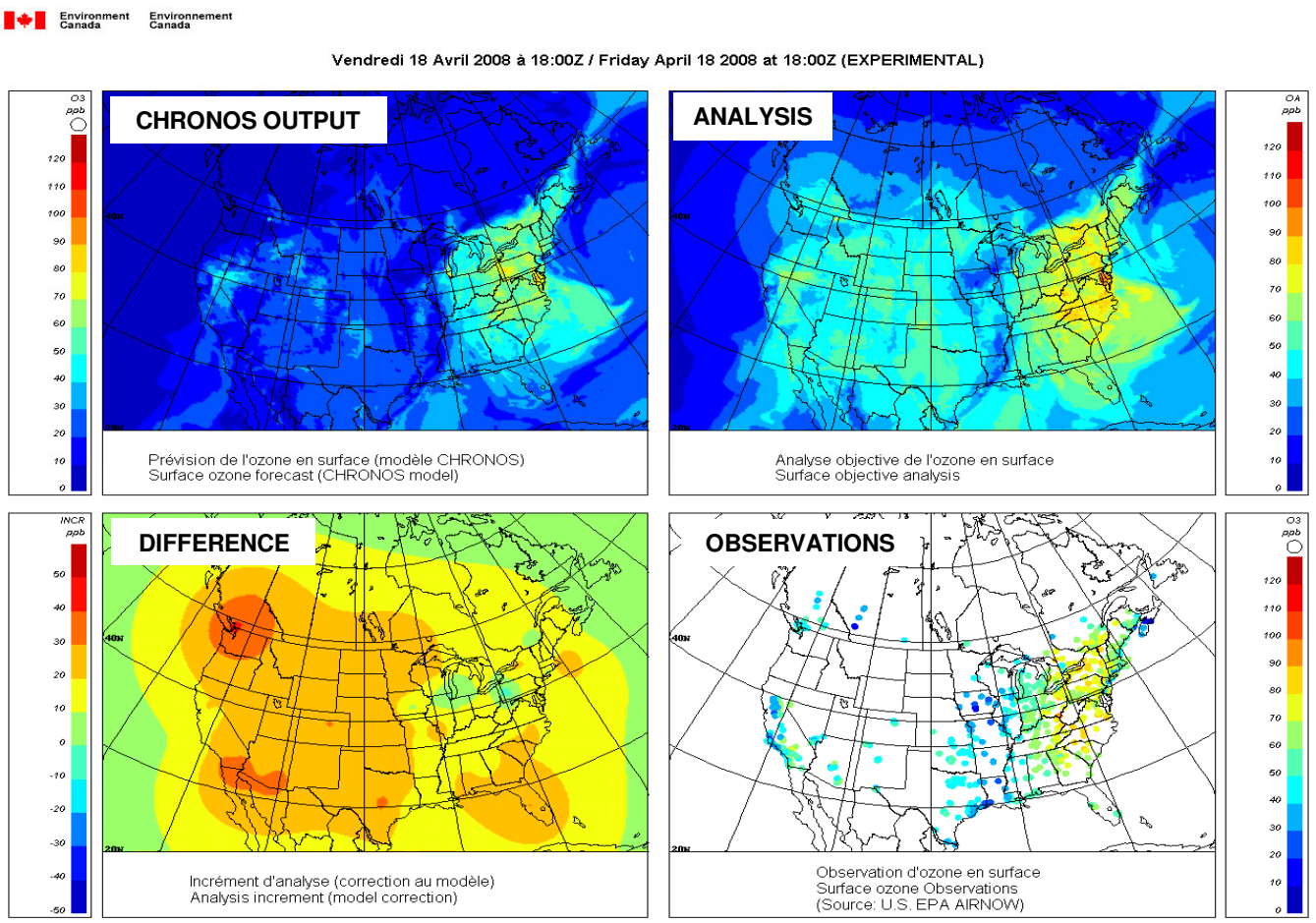
Motivation: Models have errors



Why Statistical post-processing?

- Can compensate for models' inherent systematic errors
- Take into account scales and phenomena not yet resolved by dynamical models
- Possibility of probabilistic forecasts
- Generate output (predictands) that may not exist directly in model's output (e.g. 8hrs avg. [O3], AQHI index, etc.)
- Can be used for Quality Control of direct model output
- Possibility of combining different sources of information (e.g. chemistry model, meteorological model, physical variables, etc.)

Why UMOS ?

- UMOS is a post-processing system that utilizes the model's predictors and can follow its evolution (*Updatable* MOS)
- In operational status at CMC since 1995 for meteorological predictands
- Presently forecasting: TT, POP6, POP12, Wind speed and direction, Cloud Opacity

UMOS-AQ overview

- Based on the UMOS system used for weather elements but using different driving models, predictors, predictands and observation sets
- Equations are recalculated four times a month
- Model dependent: Equations must be recalculated for every model change
- Two types of statistical techniques can be used: MLR (Multivariate Linear Regression) and MDA (Multiple Discriminant Analysis)
- Has two seasons (summer/winter) with a transitional period of approximately six weeks

Caveats

- Not very easy to modify in order to perform various experiments
- Can be time consuming to add a new predictand
- May require retraining for significant model change
- Uses linear statistics and therefore may not be ideal at forecasting extreme events (air quality episodes)

Predictands: What are we forecasting ?

Hourly concentrations of O_3, PM_{25} and NO_2

Reasons:

- Availability of observations

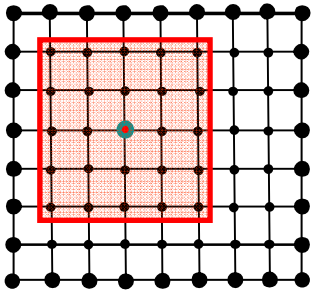
- Required for Air Quality Health Index (AQHI) calculations

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

Predictors: What do we use to forecast ?

Persistence plus a total of 84 predictors in 3 main categories:

- Meteorological:
  UU, VV, HR, GZ, ES, Calculated Mixing Height, etc., at various levels.



- Chemical:
  O3, NO2, PM25 at SFC, Max and Avg values over the lower vertical levels (~500m) and "neighbor sampling" (n=2)

- Physical parameters:
  Solar flux, Sine of Julian Day, etc.

Predictors: equations

- UMOS generates one equation per station, per pollutant, per season, per forecast hour, per run.
- In order to have stable equations we need to accumulate a minimum of 250+ cases.
- System has been calibrated so that on average there are 2-5 predictors per equation in order to avoid “over-fitting”.

Predictor selection example: Ozone Summer 2009

17843 equations with and without persistence
(~180 stations x 2 sets x 49 hrs)

Total	Element	Description
7042	015192	OZONE IN BOUNDARY LAYER (PPB)
5067	059053	DEW POINT DEPRESSION, SIGMA/ETA=1
4564	048206	O3: SPATIAL SFC SIGMA/ETA=1 (PPB)
2788	059055	DEW POINT DEPRESSION 925 HPA
2757	059124	WIND SPEED (SS(SIGMA/ETA=1))
2616	059126	WIND SPEED (SS(925))
2414	048192	O3: SFC SIGMA/ETA=1 (PPB)
2370	059183	MODEL BOUNDARY LAYER HEIGHT
2013	004211	SINE OF JULIAN DAY [(2piXJD/365)]
1629	012237	DEW POINT TEMPERATURE, SIGMA/ETA=1
1275	048208	O3: SPATIAL MAX LWR LVLS LAST 6H (PPB)
1201	059127	WIND SPEED (SS(850))
1172	059018	GEOPOTENTIAL HEIGHT, 700 HPA
1111	059045	NORTH-SOUTH WIND COMPONENT, VV700
1068	014222	DOWNWARD SOLAR FLUX

...etc.

Observations

- Observations network still in its infancy
- Difficulties collecting initial training data
- Missing observations occur often
- No rigorous quality control in place

Since July 2007:

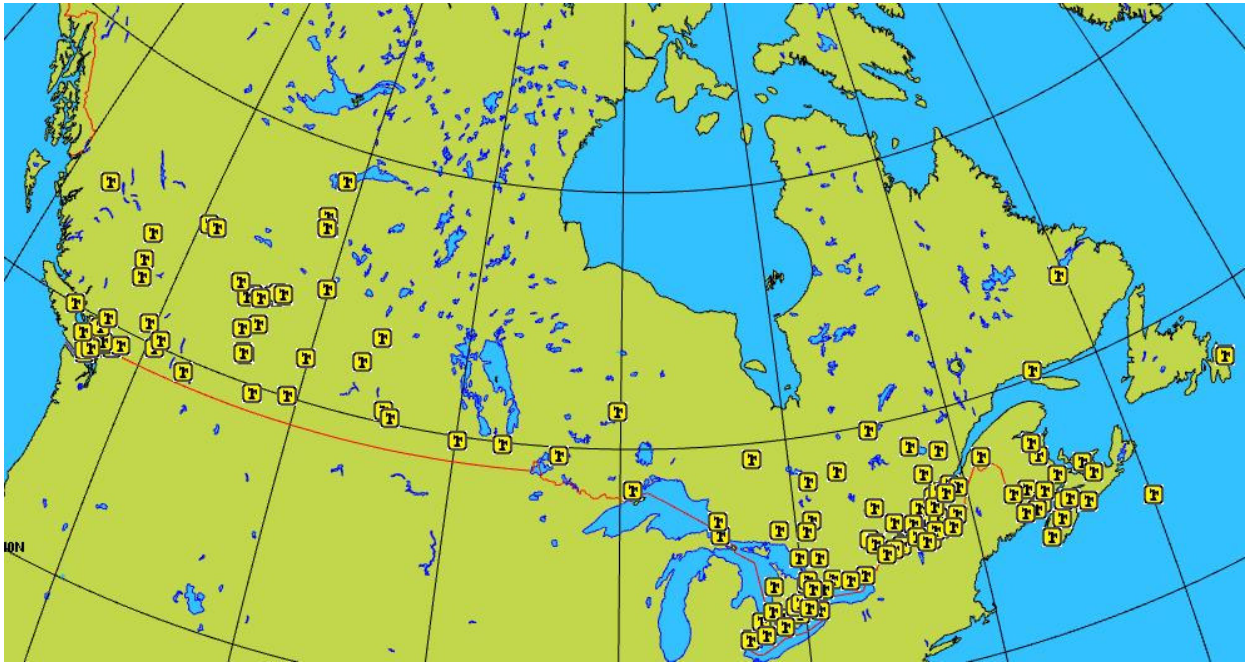
- National database
- All measuring stations are members of the National Air Pollution Surveillance Network (NAPS)
- Not all measuring stations report all predictand values
- Quality control of observations from near real-time to yearly

Observations: sites

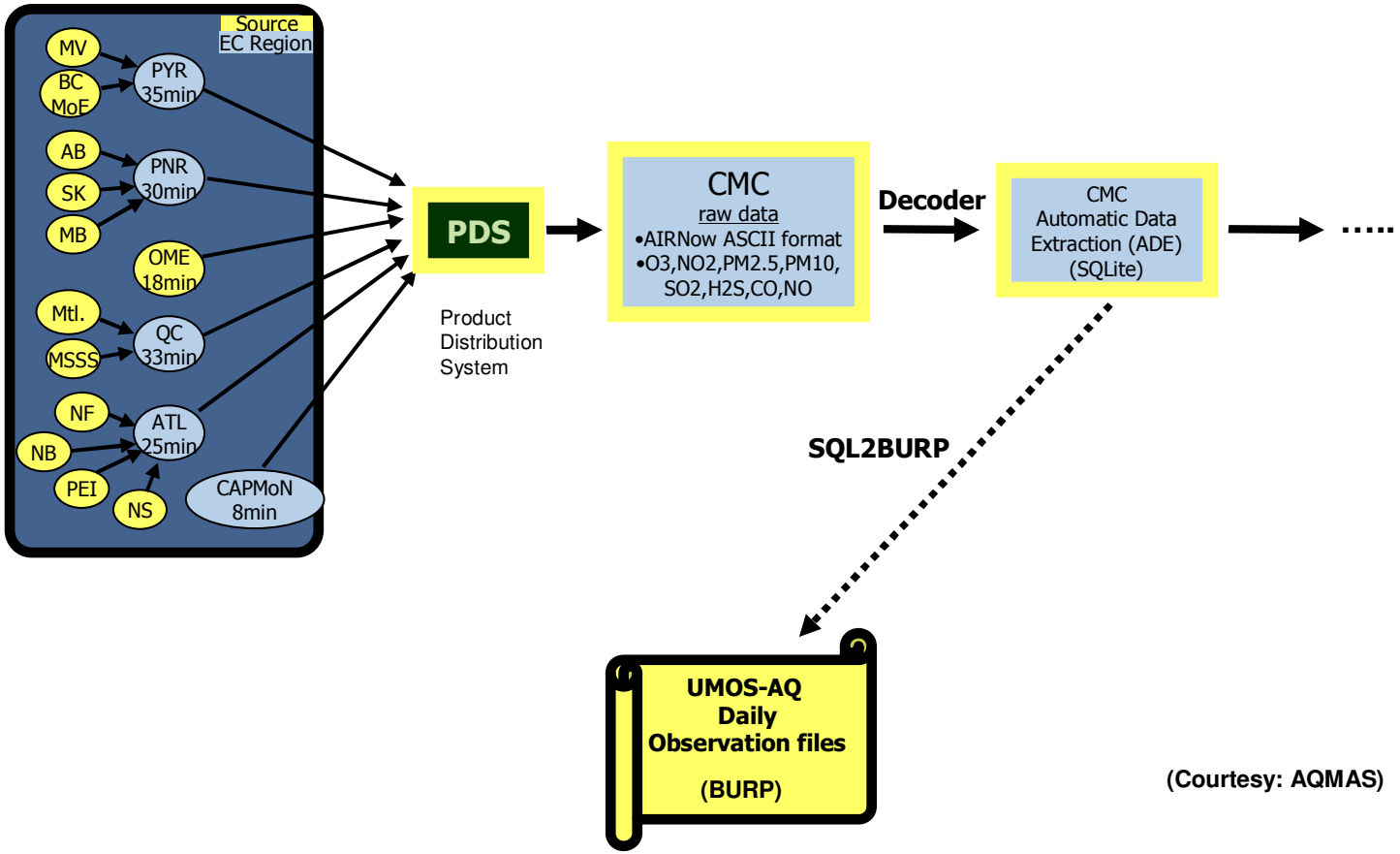
Total stations in UMOS-AQ Dictionary: **231**

- O3 is reported hourly by ~ **180** stations
- PM25 is reported hourly by ~ **170** stations
- NO2 is reported hourly by ~ **130** stations

➢ All three pollutants: ~ **85** stations

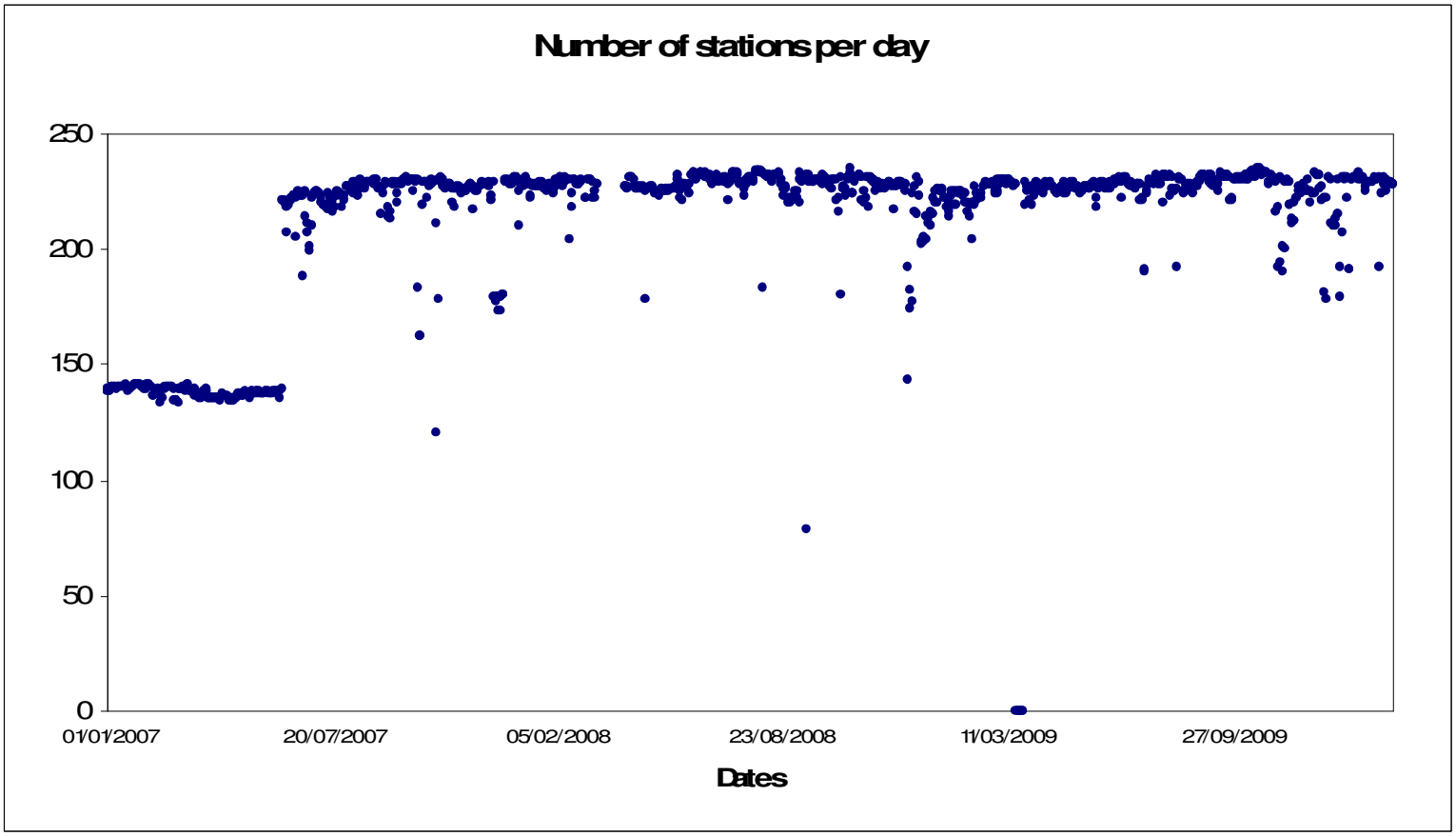


Observations: Dataflow



(Courtesy: AQMAS)

Observations: Daily distribution



Project history

Phase 1 - 2008

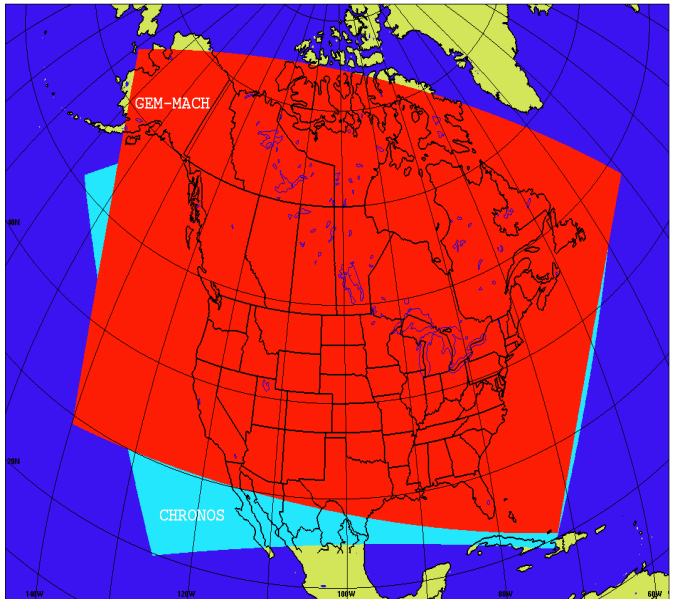
- Two predictands: [O3], [PM25]
- 3-hourly forecasts
- Two different models: CHRONOS + GEM Regional
- Two daily runs (00Z and 12Z)
- 48hrs forecast
- Database: Approx. 3 years (2007 - 2009)

Phase 2 - spring 2009

- Added [NO2] as a predictand
- Model: GEM-MACH15
- Cloned the 3-hourly SSCP matrices to produce hourly forecasts
- Performed a model switchover on July 2009 with approximately 100 hindcast cases from the new model (GEM-MACH15)

CHRONOS vs GEM-MACH15

	CHRONOS	GEM-MACH15
Resolution:	21Km	15km (45% of GEM's grid points)
Time step	3600s (Chemistry)	900s (Chemistry) and 450s (Meteorology)
Chemical Processes	Significant differences between the two models in: Emissions inventory used, Gas and Aqueous-Phase Chemistry, Aerosol dynamics, Boundary conditions, etc.	
Vertical Levels	24 Gal-Chen levels up to 6km	58 Hybrid levels up to ~60km (0.1hPa)
Meteorology	Interpolated from GEM15	Own Physics and Dynamic packages – almost identical to GEM15
Emission fields	2000 (Can) – 2001 (US) (corrected for 2005 regulations)	2005 (US) and 2006(Can)



(Courtesy: AQMAS)

- In general GEM-MACH15 performs slightly better
- **From a statistical point of view, the two models have different characteristics!**

Model switchover

- During the transition period towards a full GEM-MACH15 equation set (250 cases per season), UMOS-AQ utilizes the old model's (CHRONOS) accumulated cases in addition to the newly developed matrices (SSCP.1) from the new model.
- The total number of accumulated cases varies and depends on the station, season, predictand and forecast hour.
- On <u>average</u>, for the previous model statistics, over a 2 year period and all forecast hours we have the following:

CHRONOS Accumulated cases (SSCP.2)		
	Summer	Winter
O3	505	408
PM25	470	380
NO2	432	325

Verifications: Hourly forecasts of O3, PM25 and NO2

Periods:

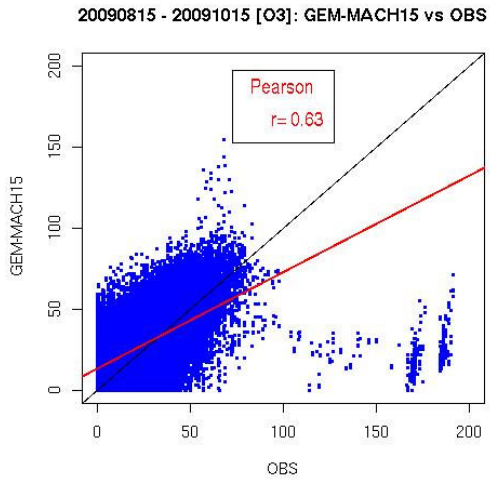
Summer (60 days):
15th August 2009 – 15th October 2009, 00Z and 12Z

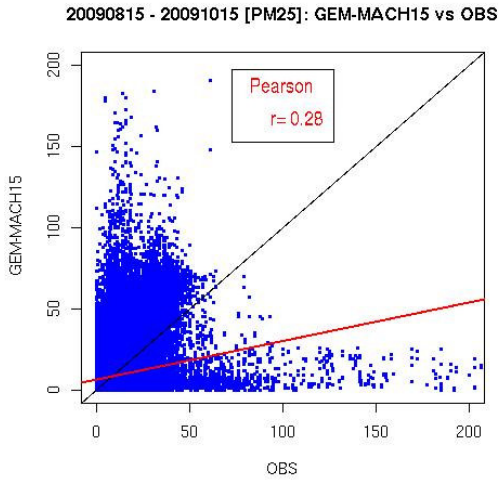
Winter (60 days):
15th December 2009 – 15th February 2010, 00Z and 12Z

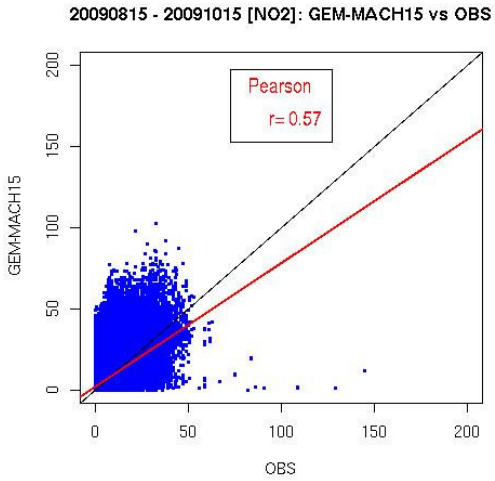
- **Verification data are based on independent samples generated on a pseudo-operational setting**

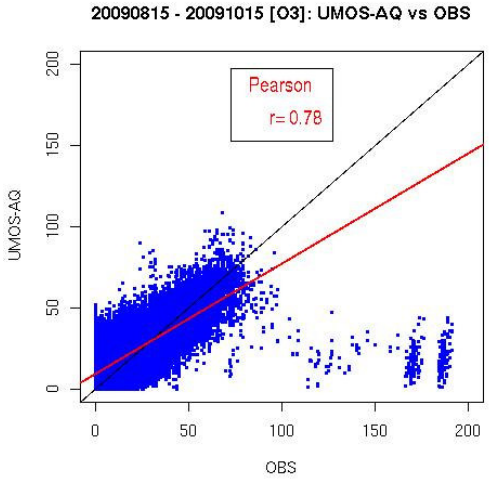
- **Scores are generated for all stations together and some individual representative ones:**
  - **Vancouver International Airport**
  - **Edmonton Central**
  - **Toronto Downtown**
  - **Aeroport de Montreal 1**
  - **Winnipeg**
  - **Halifax - Lake Major**

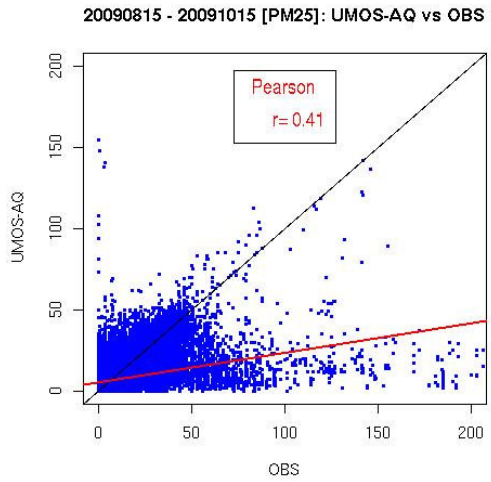
Verifications: Scatter plots – Summer 2009 (~460K cases)

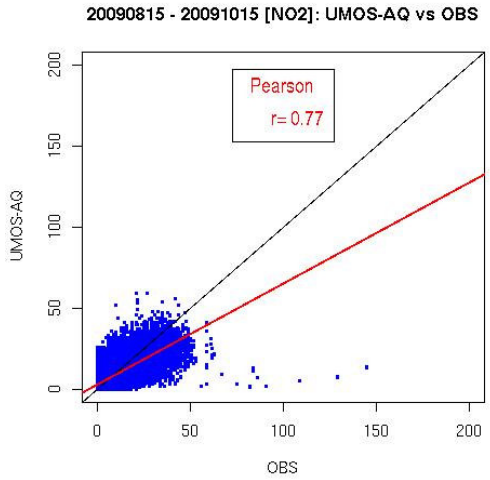












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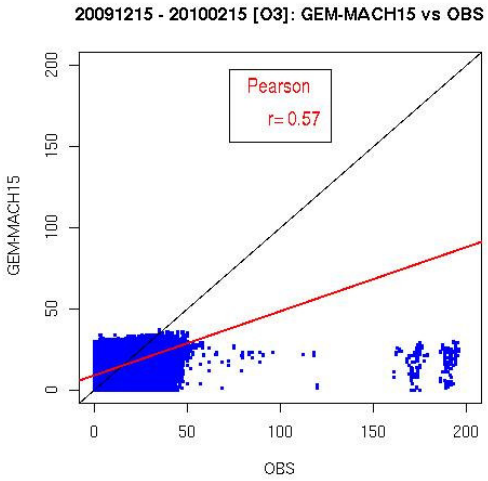
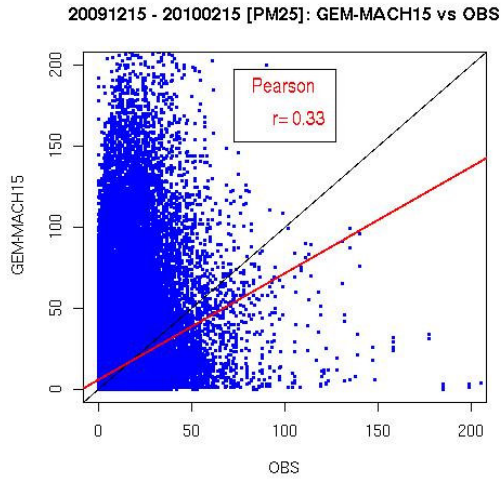
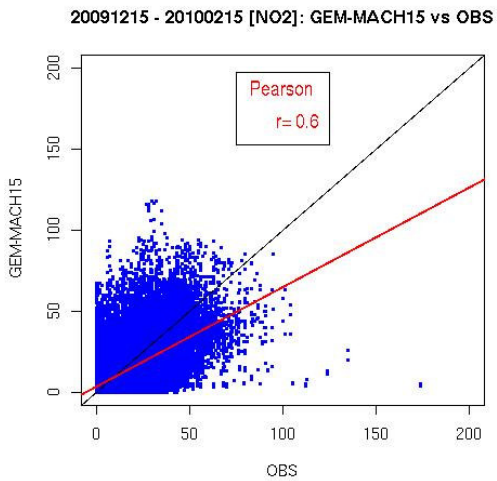
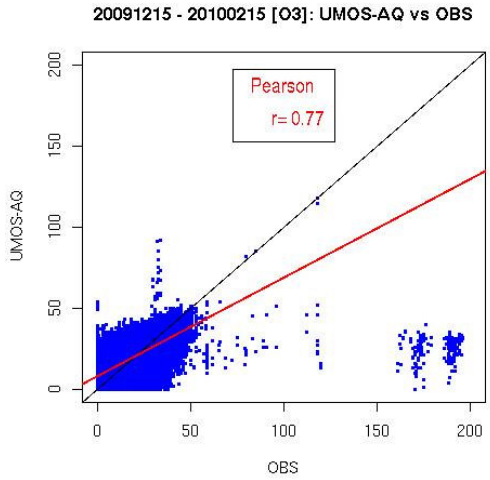
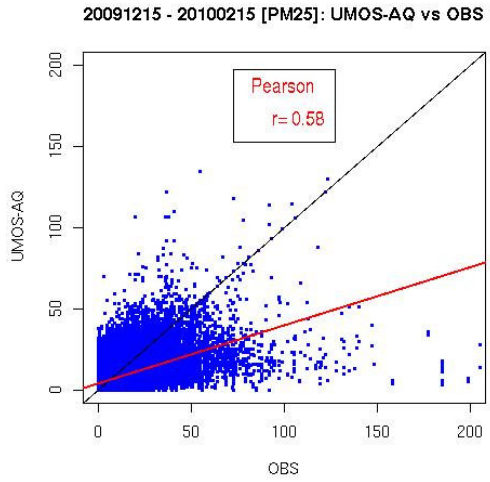
Verifications: Scatter plots – Winter 2009-2010 (~430K cases)

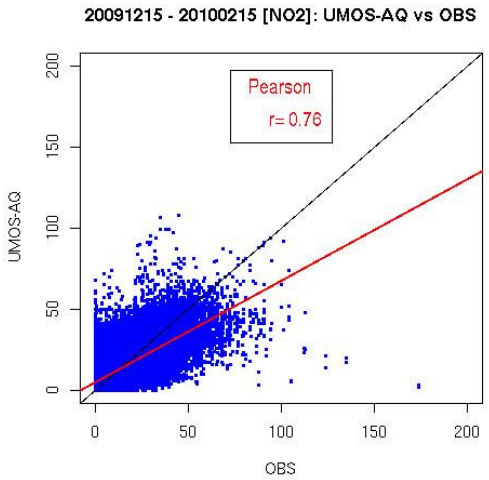












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Verifications: Scores

$$BIAS = \frac{1}{N}\left[\sum_{i=1}^{N}\left(F_i - O_i\right)\right]$$

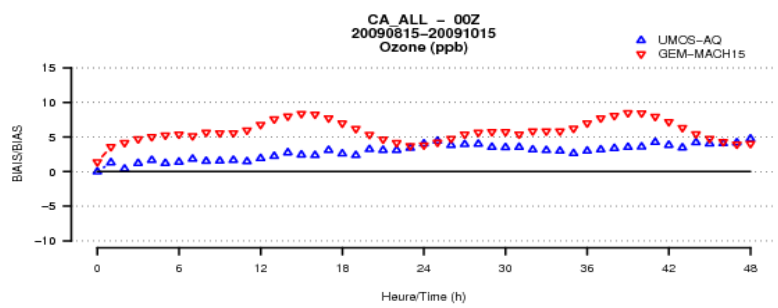
$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(F_i - O_i\right)^2\right]^{1/2}$$

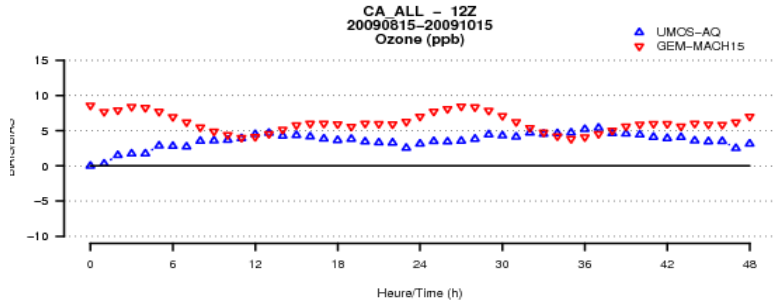
$$RV_{cmc} = \left(1 - \left[\frac{\sum_{i=1}^{N}\left(F_i - BIAS - O_i\right)^2}{\sum_{i=1}^{N}\left(\overline{O} - O_i\right)^2}\right]\right) * 100\%$$

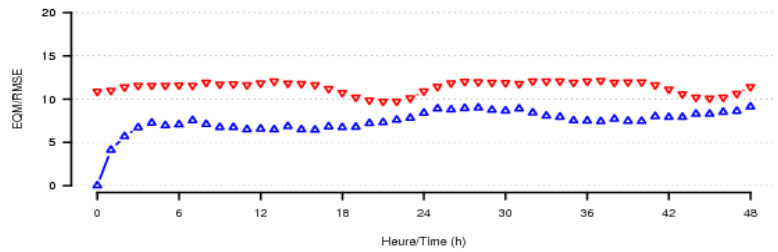
Verifications [O3], All stations

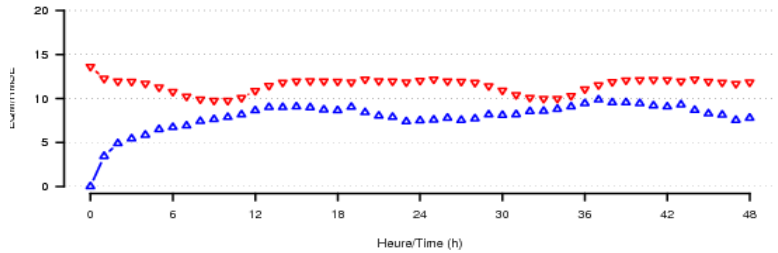
Summer, 60 days [2009-08-15, 2009-10-15]

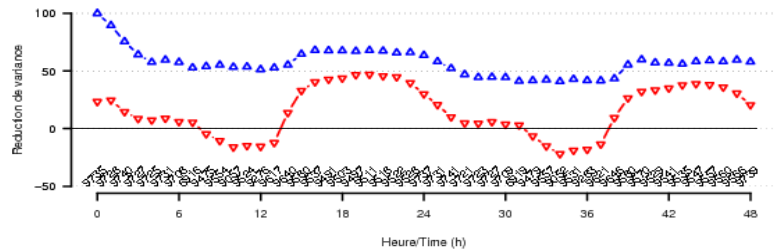
00Z and 12Z, Pseudo-operational mode

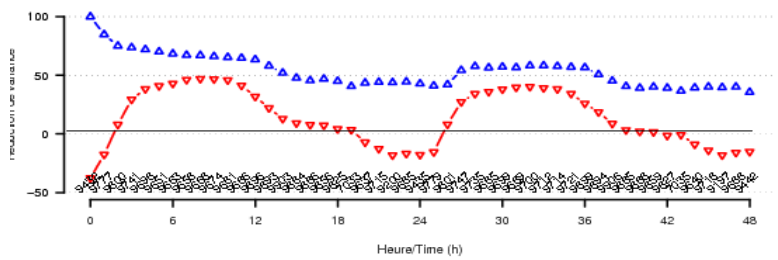










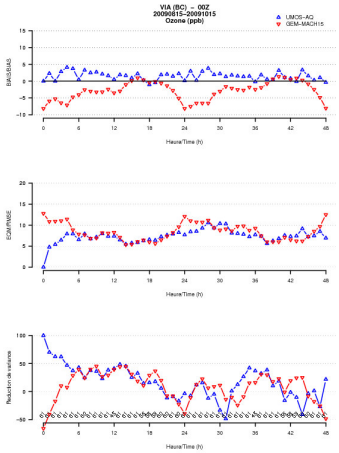


Verifications [O3] – Various stations

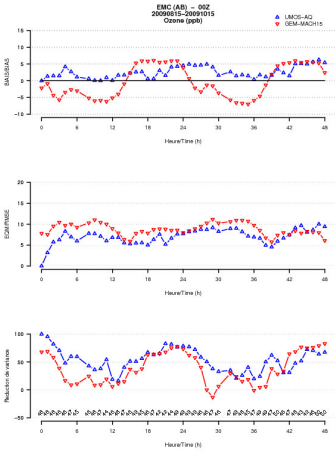
Summer, 60 days [2009-08-15, 2009-10-15]

Pseudo-operational mode

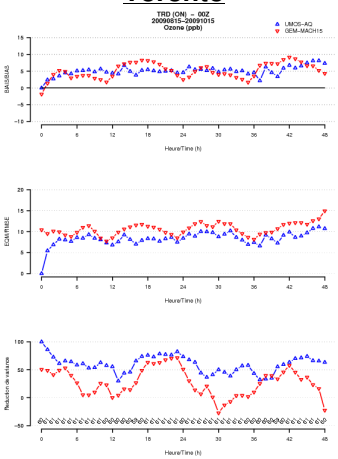
Vancouver



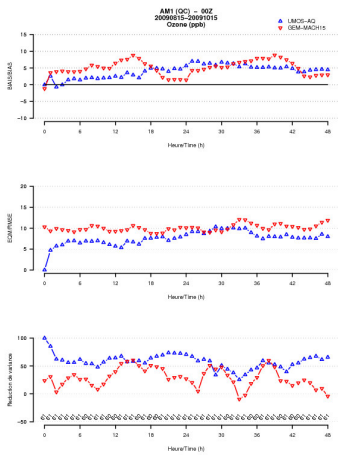
Edmonton



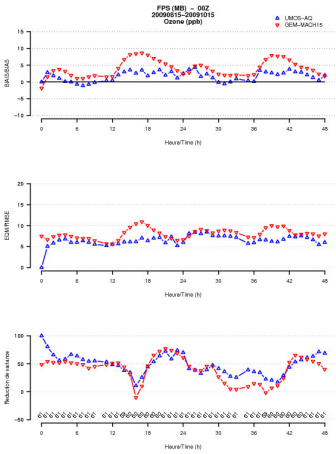
Toronto



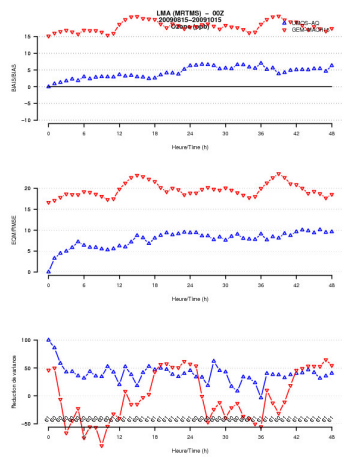
Montreal



Winnipeg



Halifax



Verifications [PM25], All stations

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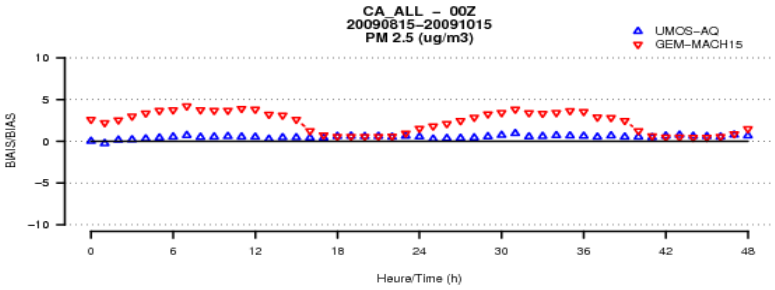
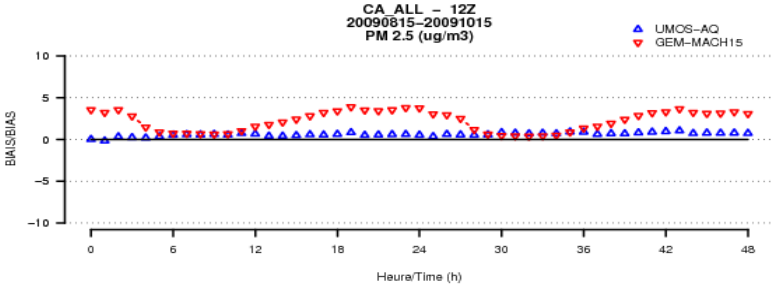
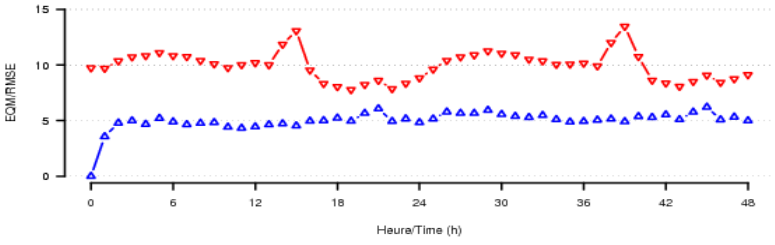
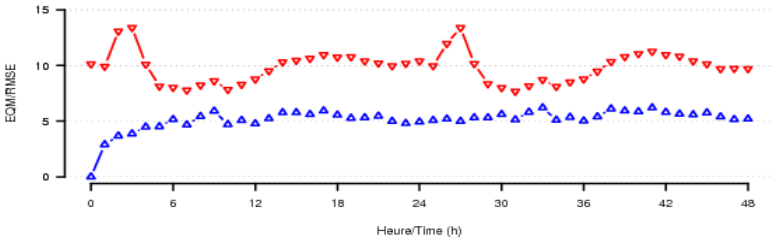
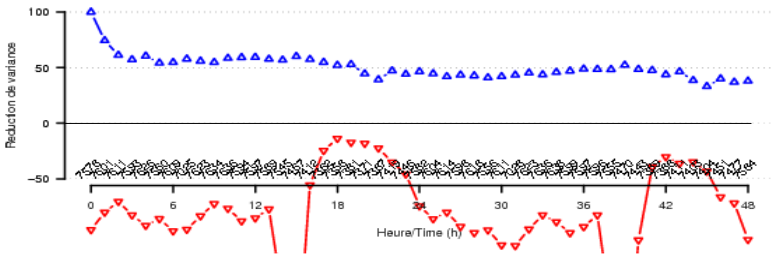
00Z and 12Z, Pseudo-operational mode

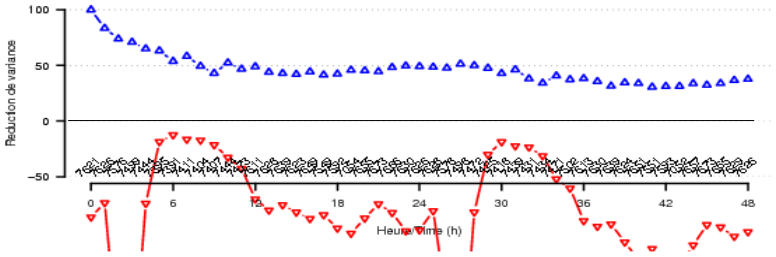












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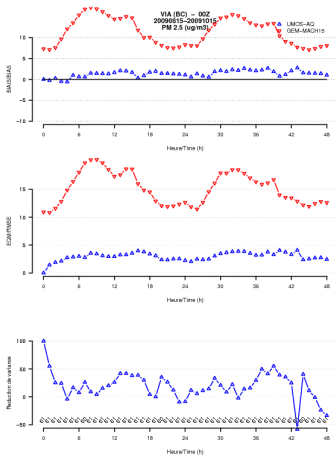
Verifications [PM25] – Various stations

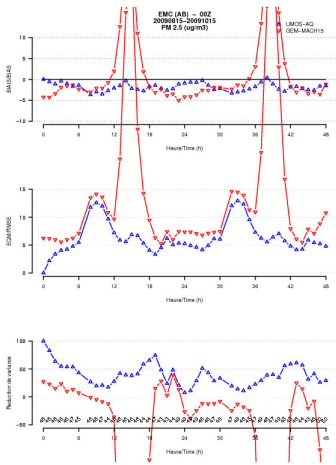
Summer, 60 days [2009-08-15, 2009-10-15]

Pseudo-operational mode

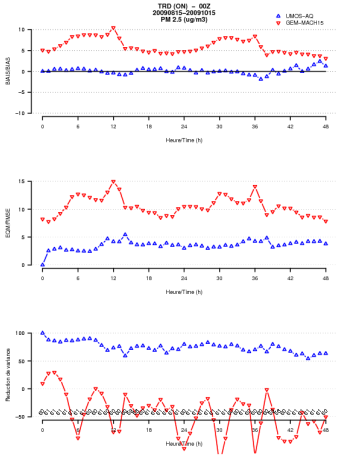
Vancouver



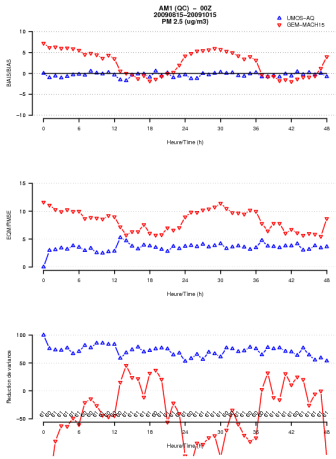
Edmonton



Toronto



Montreal



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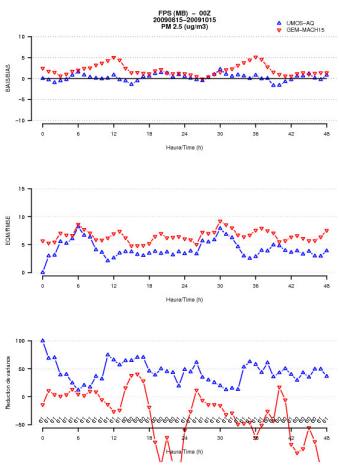
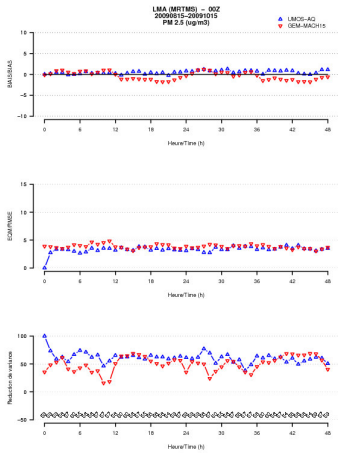


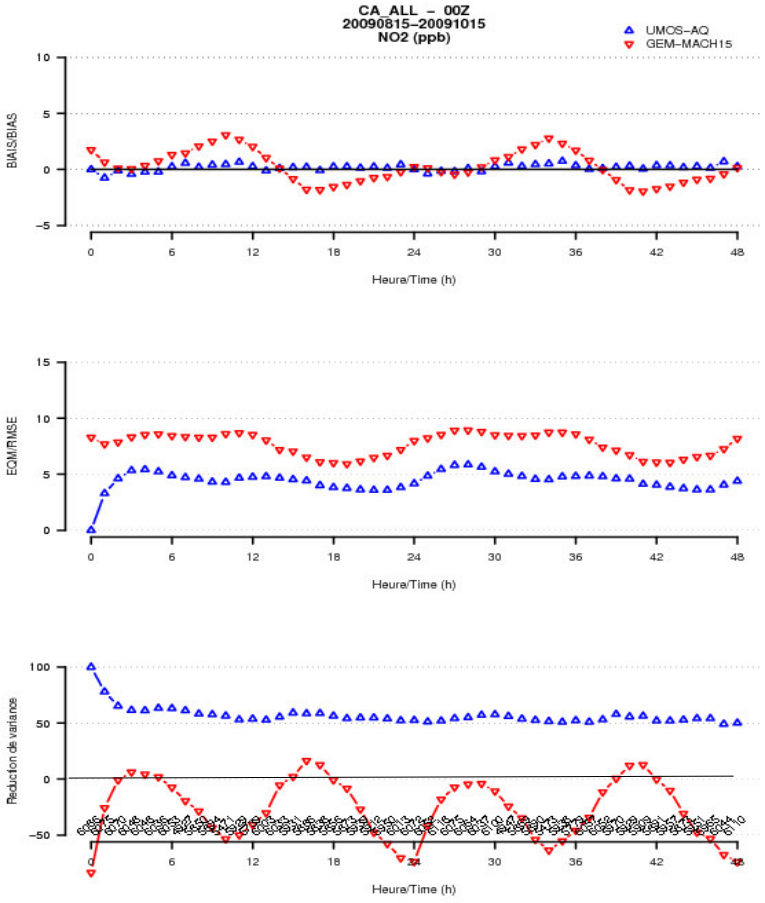
Halifax

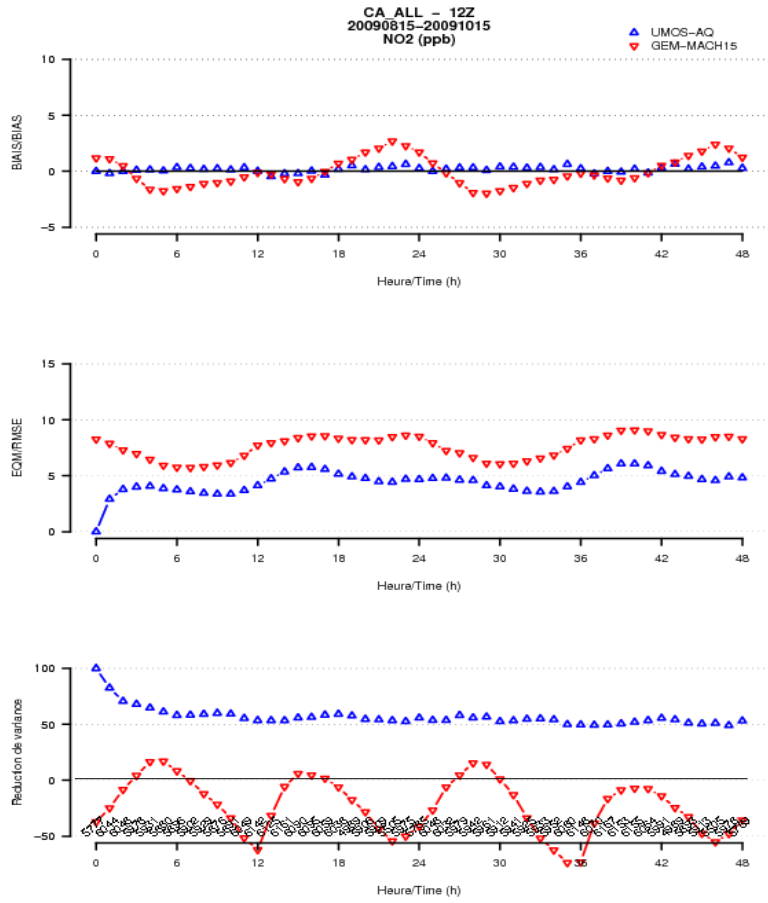


Verifications [NO2], All stations

Summer, 60 days [2009-08-15, 2009-10-15]

00Z and 12Z, Pseudo-operational mode



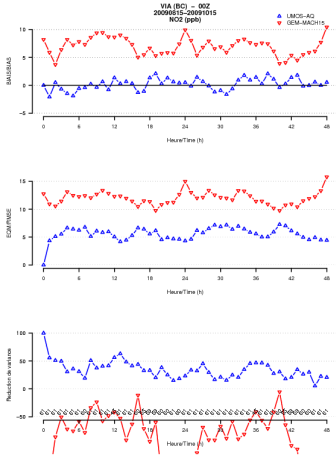


Verifications [NO2] – Various stations

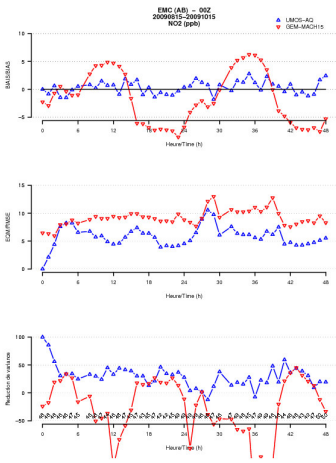
Summer, 60 days [2009-08-15, 2009-10-15]

Pseudo-operational mode

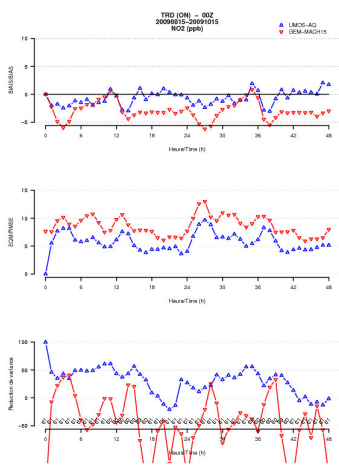
Vancouver



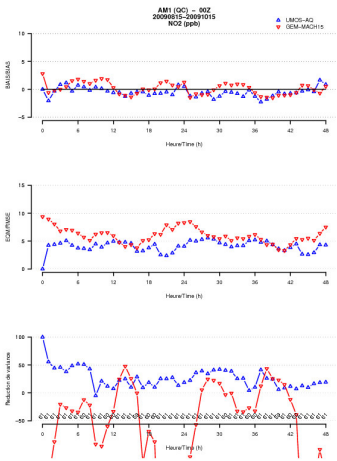
Edmonton



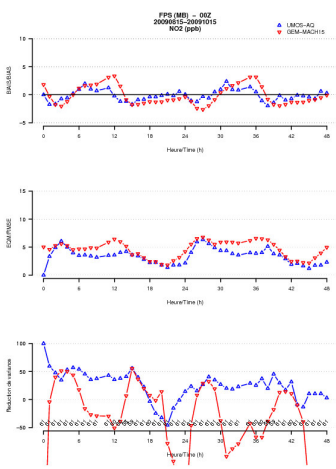
Toronto



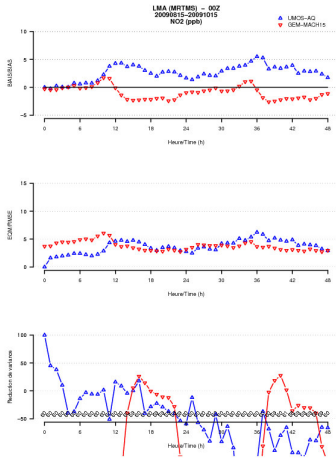
Montreal



Winnipeg



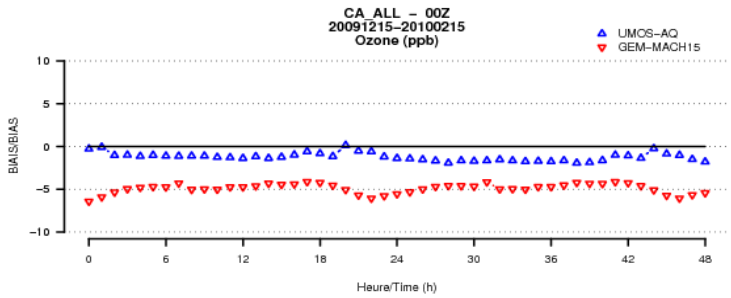
Halifax

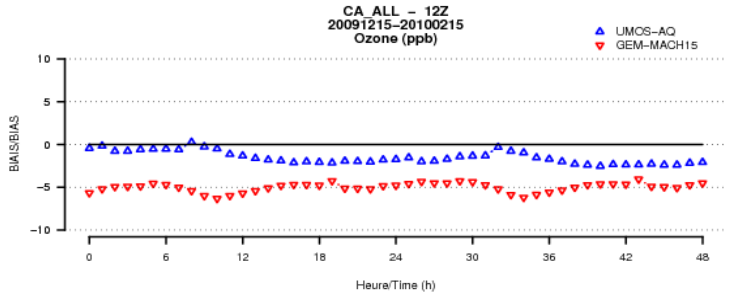


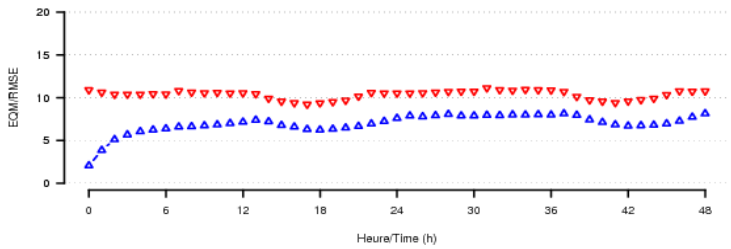
Verifications [O3], All stations

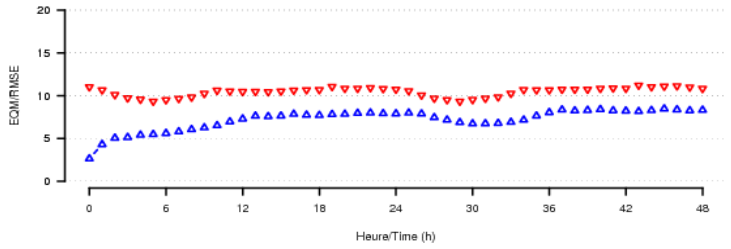
Winter, 60 days [2009-12-15, 2010-02-15]

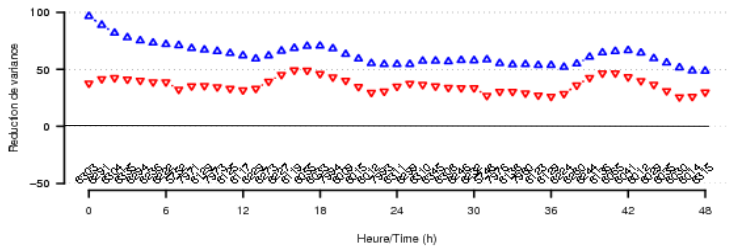
00Z and 12Z, Pseudo-operational mode

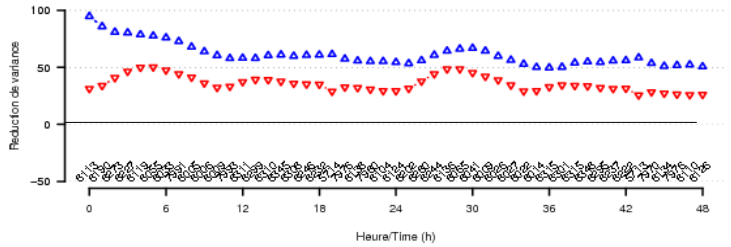












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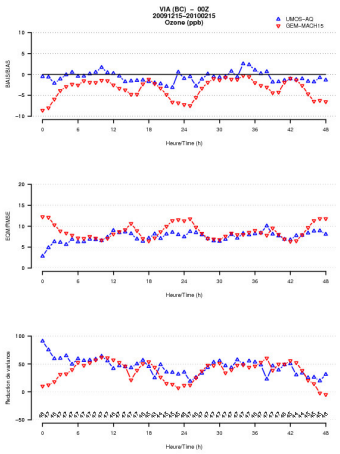
Verifications [O3] – Various stations

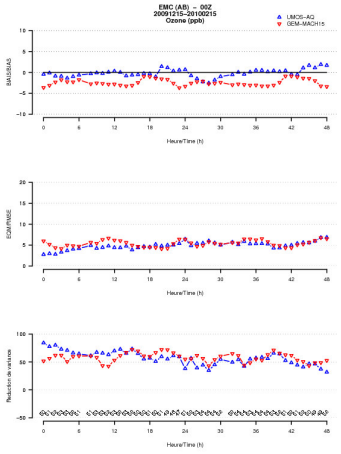
Winter, 60 days [2009-12-15, 2010-02-15]

00Z and 12Z, Pseudo-operational mode

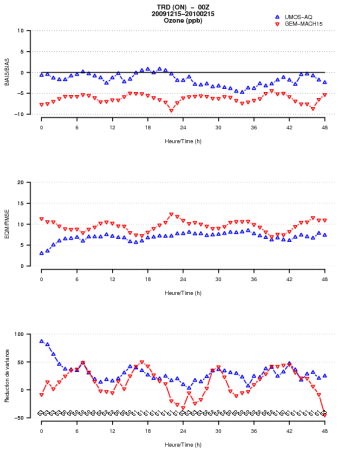
Vancouver



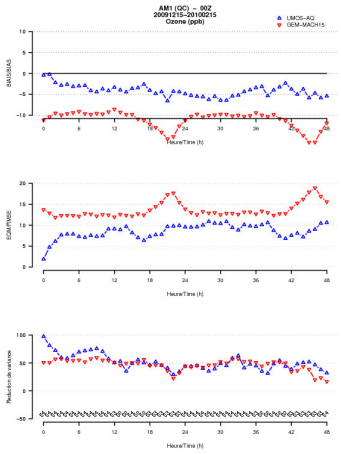
Edmonton



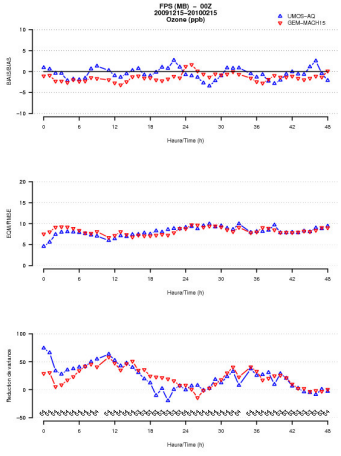
Toronto



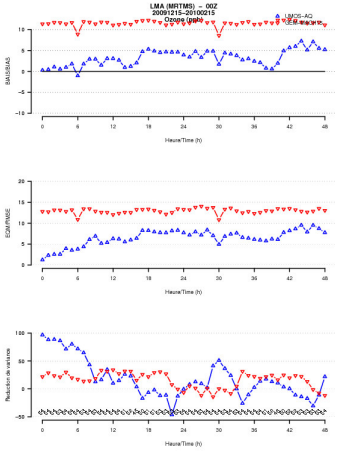
Montreal



Winnipeg



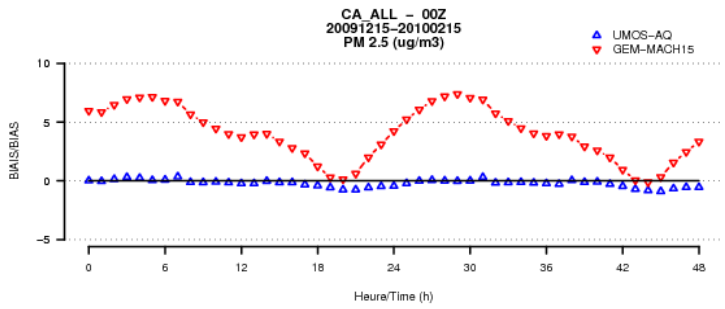
Halifax

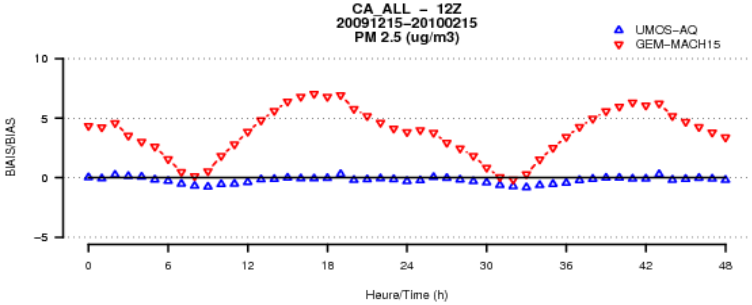


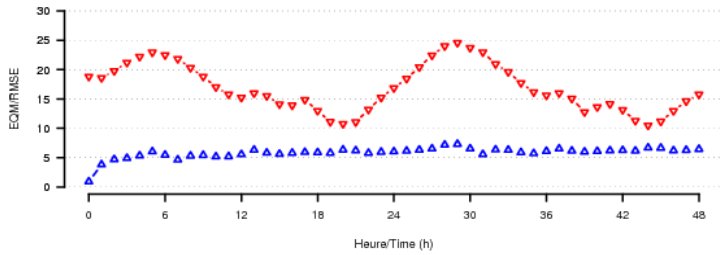
Verifications [PM25], All stations

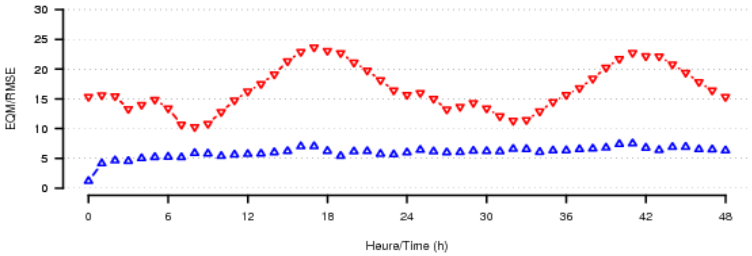
Winter, 60 days [2009-12-15, 2010-02-15]

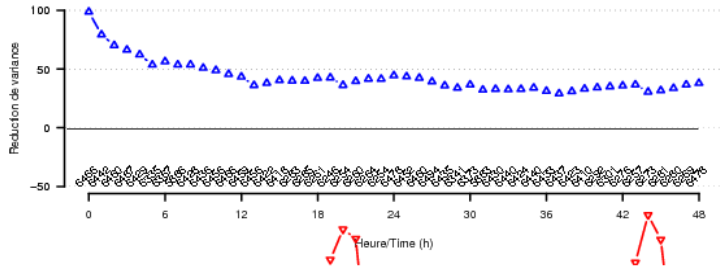
00Z and 12Z, Pseudo-operational mode

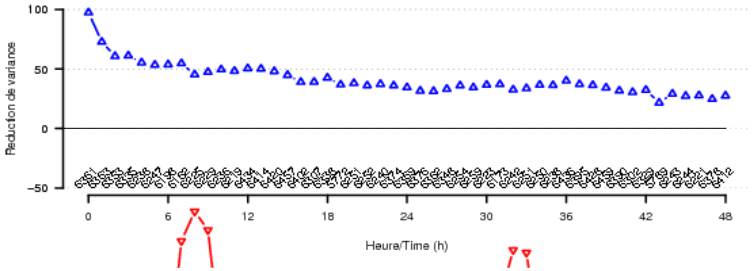










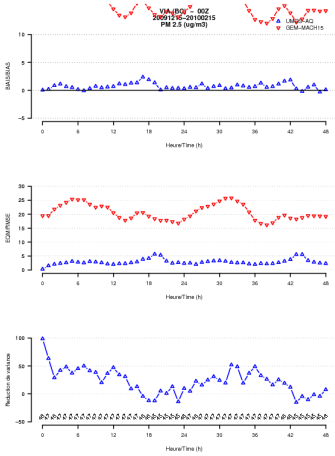


Verifications [PM25], Various stations

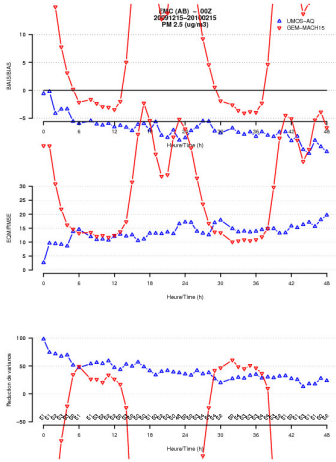
Winter, 60 days [2009-12-15, 2010-02-15]

00Z and 12Z, Pseudo-operational mode

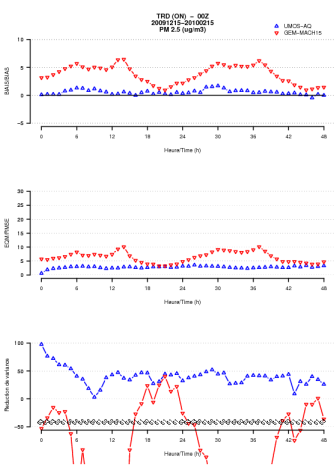
Vancouver



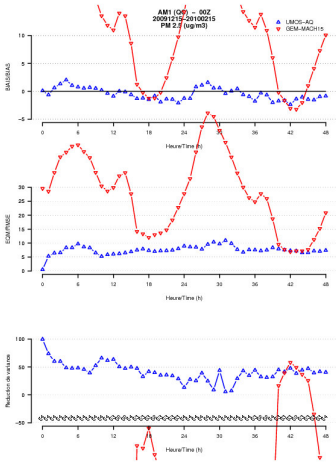
Edmonton



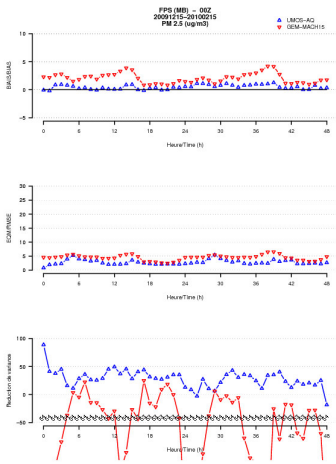
Toronto



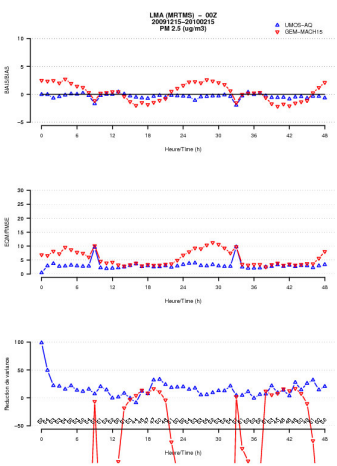
Montreal



Winnipeg



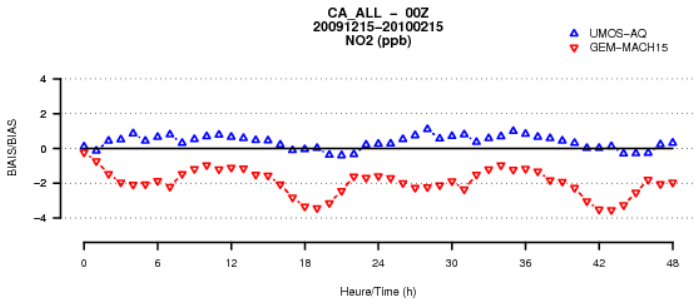
Halifax

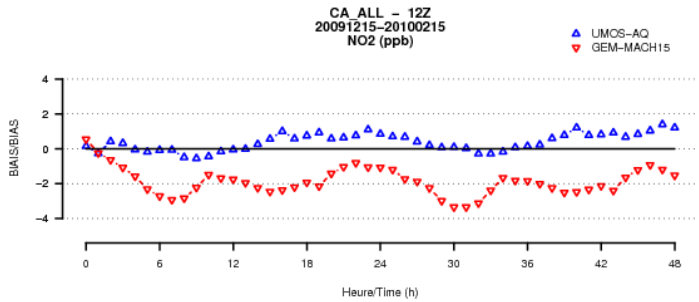


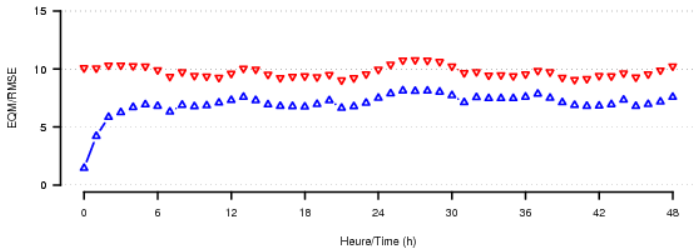
Verifications [NO2], All stations

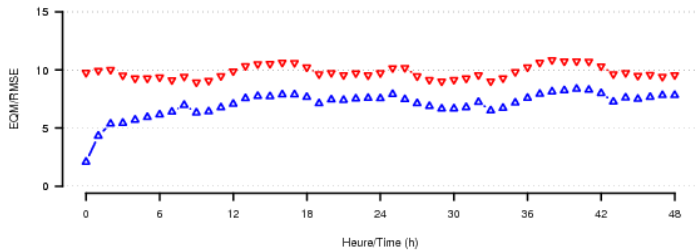
Winter, 60 days [2009-12-15, 2010-02-15]

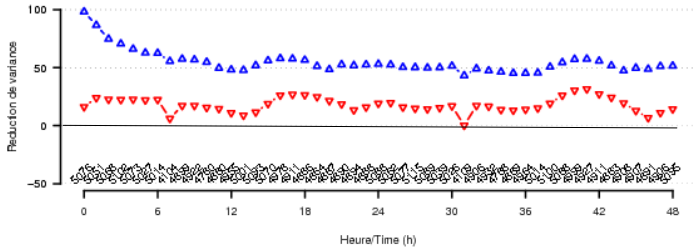
00Z and 12Z, Pseudo-operational mode

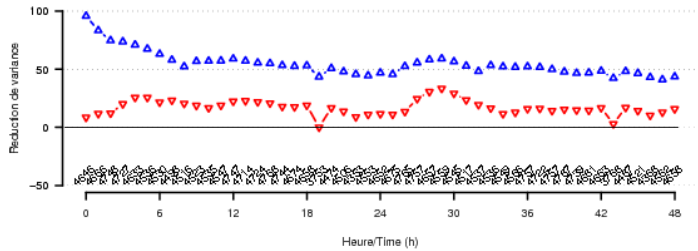












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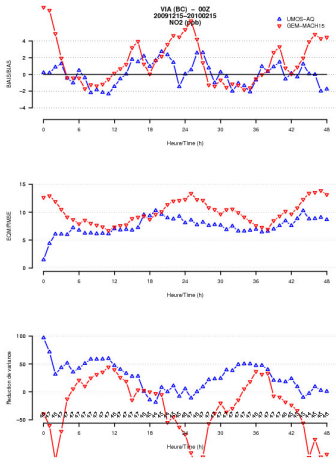
Verifications [NO2] – Various stations

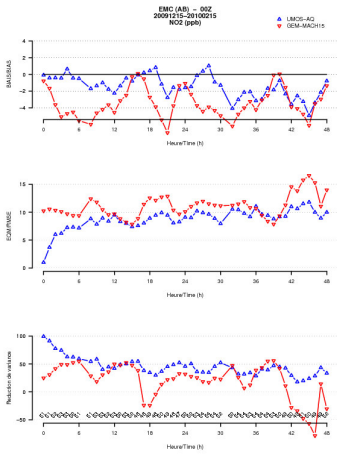
Winter, 60 days [2009-12-15, 2010-02-15]

00Z and 12Z, Pseudo-operational mode

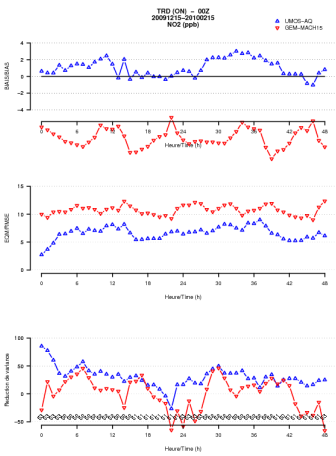
Vancouver



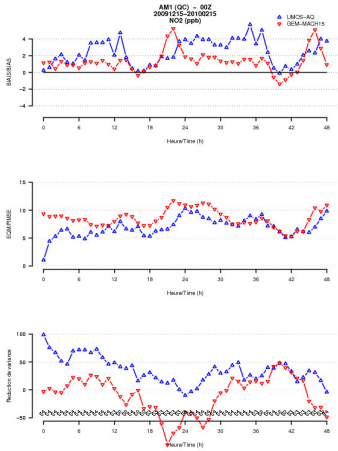
Edmonton



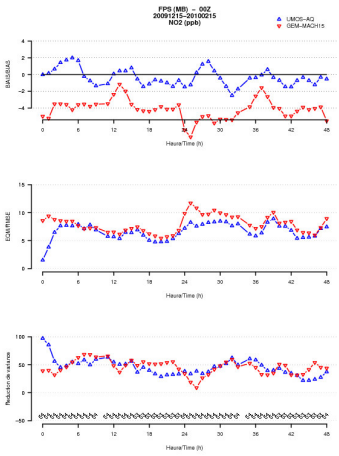
Toronto



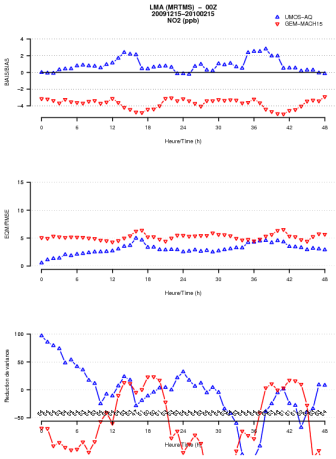
Montreal



Winnipeg



Halifax



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Contingency tables

- **Three categories used in order to evaluate performance in “low”, “medium” and “high” values.**

  O3 : [0 , 40] (40, 80] (> 80)

  PM25 : [0 , 15] (15, 30] (> 30)

  NO2 : [0 , 15] (15, 30] (> 30)

- **The scores used are:**
  - ✓ Hit Rate
  - ✓ False Alarm Ratio (FAR)
  - ✓ Critical Success Index (CSI)
  - ✓ Percent Correct (PC)
  - ✓ Heidke Skill Score (HSS)

- **All scores are almost identical between the 00Z and 12Z runs, therefore we only show the 00Z in the following tables.**

Contingency table: O3, Summer/Winter

(UMOS-AQ vs. GEM-MACH15)

O3 : 20090815-20091015 00Z, UMOS-AQ vs. GEM-MACH15

		FCST			
		[0 – 40]	(40 – 80]	> 80	Totals
OBS	[0 – 40]	**429037**	10515	4	439556
		411435	28102	19	439556
	[40 – 80]	6809	**17222**	54	24085
		7165	**16602**	318	24085
	> 80	45	51	**4**	100
		47	51	**2**	100
	Totals(um)	435891	27788	62	**463741**
	Totals(dm)	418647	44755	339	

Hit Rate	98%	72%	4%
	94%	69%	2%
FAR	2%	38%	94%
	2%	63%	99%
CSI	**96%**	**50%**	**3%**
	92%	**32%**	**0%**

PC	**96%**
	92%
HSS	**64%**
	45%

O3 : 20091215-20100215 00Z, UMOS-AQ vs. GEM-MACH15

		FCST			
		[0 – 40]	(40 – 80]	> 80	Totals
OBS	[0 – 40]	**383758**	1163	3	384924
		384924	0	0	384924
	[40 – 80]	8068	**1563**	0	9631
		9631	**0**	0	9631
	> 80	16	6	**4**	26
		26	0	**0**	26
	Totals(um)	391842	2732	7	**394581**
	Totals(dm)	394581	0	0	

Hit Rate	100%	16%	15%
	100%	0%	0%
FAR	2%	43%	43%
	2%	N/A	N/A
CSI	**98%**	**14%**	**14%**
	98%	**0%**	**0%**

PC	**98%**
	98%
HSS	**25%**
	0%

Contingency table: PM25, Summer/Winter

(UMOS-AQ vs. GEM-MACH15)

PM25 : 20090815-20091015 00Z, UMOS-AQ vs. GEM-MACH15

		FCST			
		[0 – 15]	(15 – 30]	> 30	Totals
OBS	[0 – 15]	**332146**	7537	191	339874
		296972	34062	8840	339874
	(15 – 30]	12974	**9172**	731	22877
		10890	**6229**	5758	22877
	> 30	945	2299	**1904**	5148
		1304	836	**3008**	5148
	Totals(um)	346065	19008	2826	**367899**
	Totals(dm)	309166	41127	17606	

Hit Rate	98%	40%	37%
	87%	27%	58%
FAR	4%	52%	33%
	4%	85%	83%
CSI	**94%**	**28%**	**31%**
	84%	**11%**	**15%**
PC	**93%**		
	83%		
HSS	**47%**		
	22%		

PM25 : 20091215-20100215 00Z, UMOS-AQ vs. GEM-MACH15

		FCST			
		[0 – 15]	(15 – 30]	> 30	Totals
OBS	[0 – 15]	**276610**	6449	253	283312
		245486	24195	13631	283312
	(15 – 30]	14944	**6956**	634	22534
		11900	**4431**	6203	22534
	> 30	2193	2535	**1006**	5734
		2212	1159	**2363**	5734
	Totals(um)	293747	15940	1893	**311580**
	Totals(dm)	259598	29785	22197	

Hit Rate	98%	31%	18%
	87%	20%	41%
FAR	6%	56%	47%
	5%	85%	89%
CSI	**92%**	**22%**	**15%**
	83%	**9%**	**9%**
PC	**91%**		
	81%		
HSS	**38%**		
	19%		

Contingency table: NO2, Summer/Winter

(UMOS-AQ vs. GEM-MACH15)

NO2 : 20090815-20091015 00Z, UMOS-AQ vs. GEM-MACH15

		FCST			
		[0 – 15]	(15 – 30]	> 30	Totals
OBS	[0 – 15]	**237125**	11877	45	249047
		220076	24829	4142	249047
	(15 – 30]	17602	**19351**	485	37438
		17814	**14218**	5406	37438
	> 30	381	2296	**420**	3097
		526	1034	**1537**	3097
	Totals(um)	255108	33524	950	**289582**
	Totals(dm)	238416	40081	11085	

Hit Rate	95%	52%	14%
	88%	38%	50%
FAR	7%	42%	56%
	8%	65%	86%
CSI	**89%**	**37%**	**12%**
	82%	**22%**	**12%**
PC	**89%**		
	81%		
HSS	**50%**		
	32%		

NO2 : 20091215-20100215 00Z, UMOS-AQ vs. GEM-MACH15

		FCST			
		[0 – 15]	(15 – 30]	> 30	Totals
OBS	[0 – 15]	**133086**	25989	835	159910
		134823	22511	2576	159910
	(15 – 30]	19111	**40729**	3746	63586
		32433	**24845**	6308	63586
	> 30	1380	9330	**7820**	18530
		3572	7728	**7230**	18530
	Totals(um)	153577	76048	12401	**242026**
	Totals(dm)	170828	55084	16114	

Hit Rate	83%	64%	42%
	84%	39%	39%
FAR	13%	46%	37%
	21%	55%	55%
CSI	**74%**	**41%**	**34%**
	69%	**26%**	**26%**
PC	**75%**		
	69%		
HSS	**50%**		
	34%		

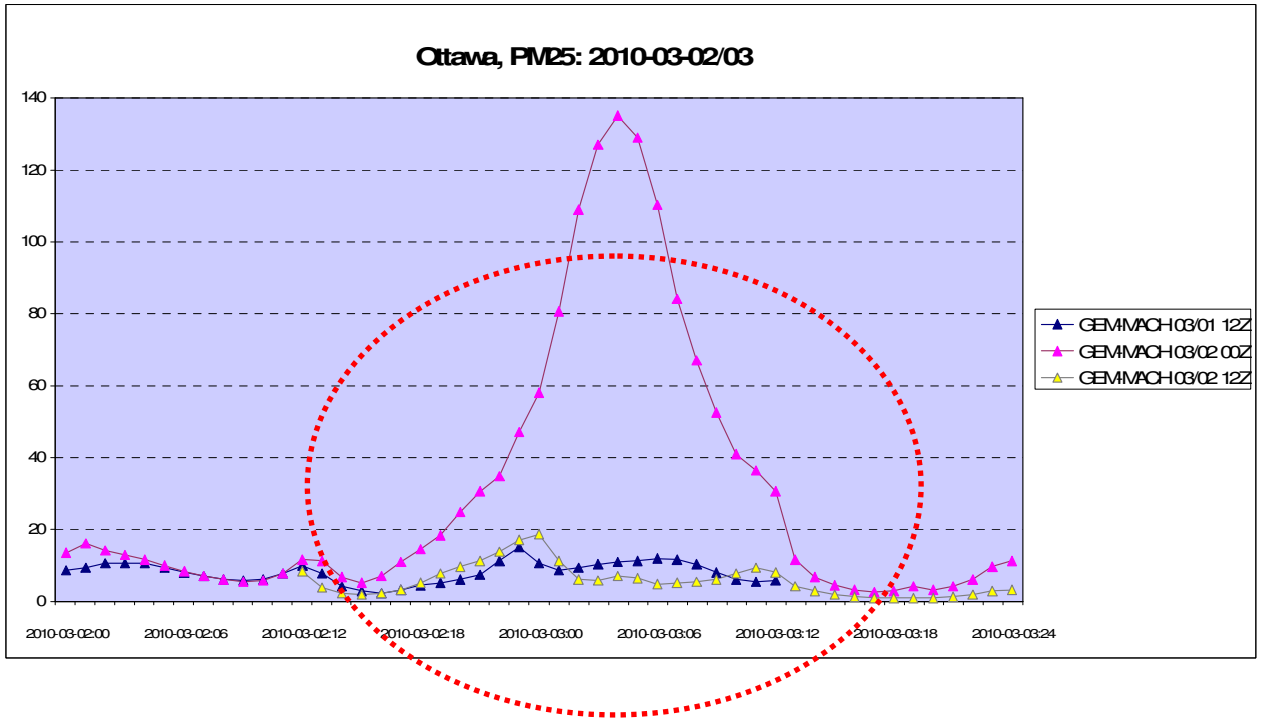
Verifications: Conclusions

- In the vast majority of forecast hours, over all stations, predictands and seasons:
  - ✓ The model's bias is reduced.
  - ✓ RMSE is reduced.
  - ✓ More than the above, we explain better the observed variance.
- Contingency tables: Significant improvement in almost all categories over all pollutants. Better skill.
- **UMOS-AQ significantly improves the model's forecast quality.**

Special case: 2010-03-02 Ottawa (PM25)

Problem:

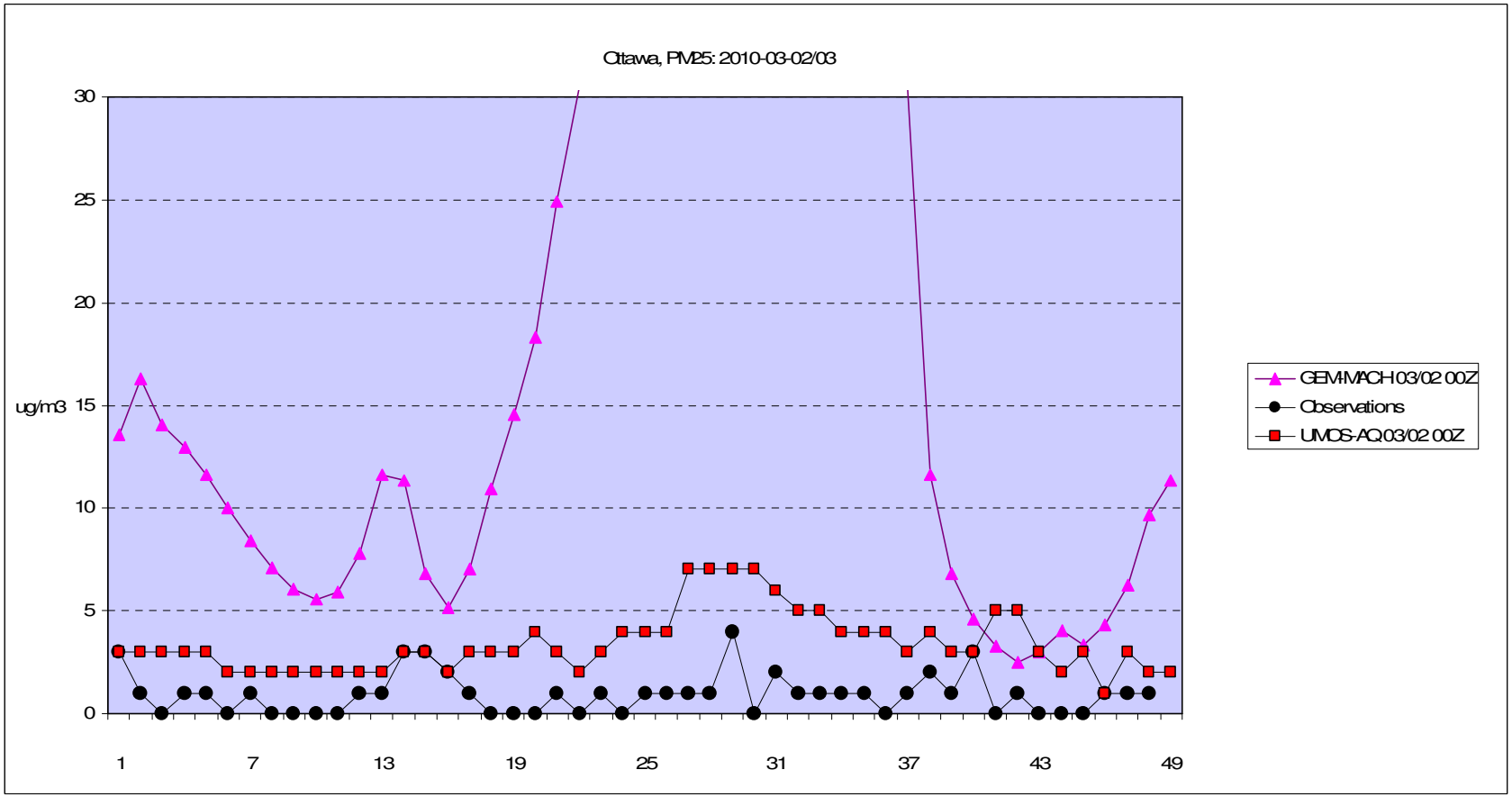
- Generally there is a general accordance and “continuity” between adjacent model runs.
- Occasionally relatively small differences in meteorology (sfc temperature, sfc wind direction, boundary layer height, etc.) can have a great impact in predicted pollutant values
- Problem occurs occasionally across Canada and is related to small changes in meteorology inside the boundary layer, which are important for air quality



Courtesy:

Radenko Pavlovic (AQMAS)

Special case: 2010-03-02 Ottawa (PM25) (cont'd)

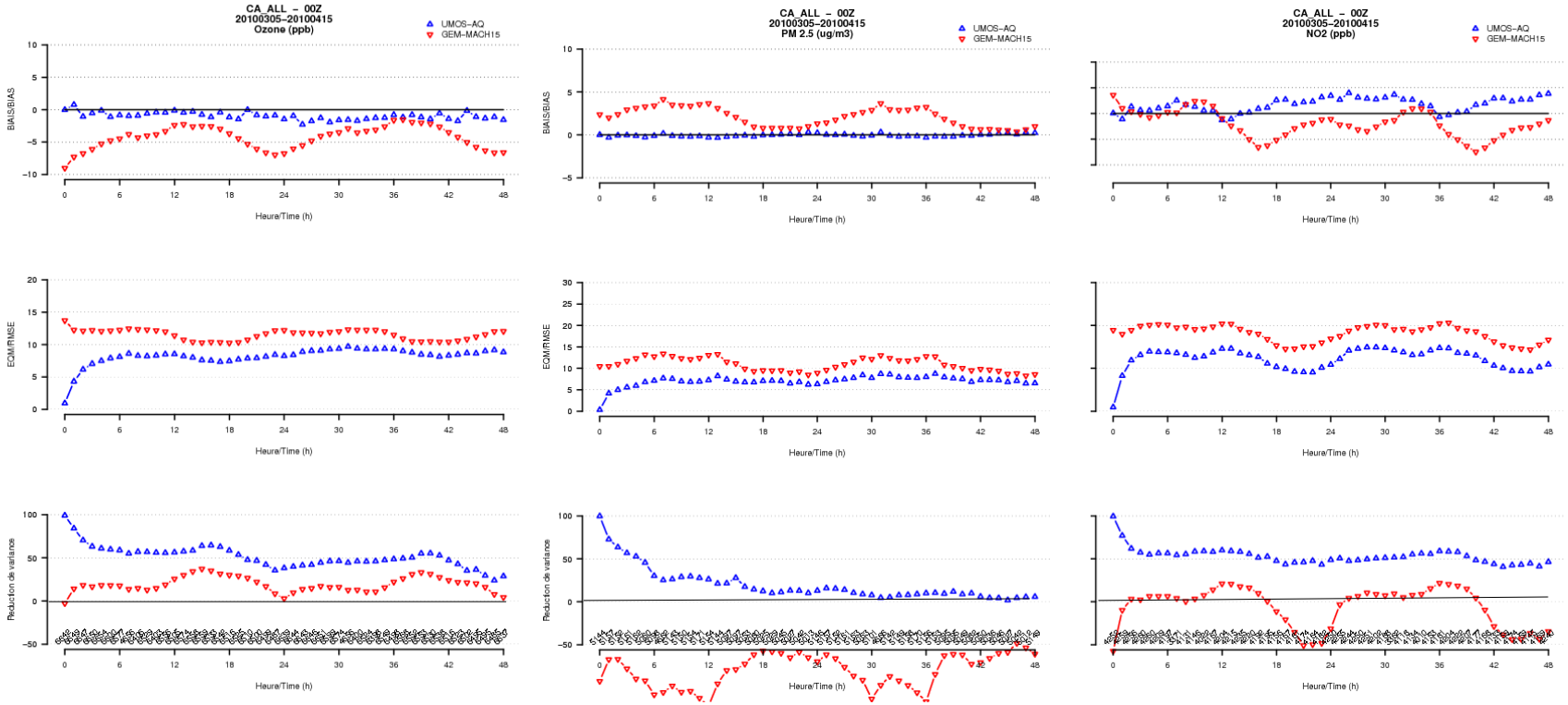


New Emissions (March 2nd 2010)

- In March 2nd 2010 (12Z) an operational implementation of a new Emissions inventory was applied to GEM-MACH15
- Due to a lack of appropriate (period and format) hindcast data we decided to not perform a switchover and let the system adapt
- A performance study for the winter season has been generated that shows a smooth transition with no significant loss in the quality of the forecasts

New Emissions - Evaluation scores

40 days [2010-03-05, 2010-04-15]



Environment Canada Environnement Canada

Canada

Forecasting extreme events (episodes)

- MLR (linear) techniques tend to “push” the forecast towards a mean value therefore making extreme event forecasting more challenging.

- Difficult to acquire extensive training data: percentage of episodes compared to “average” values is small.

- MDA approach could be more skilful in episode forecasting.

Future

- In the next CPOP a proposal will be made for an operational implementation.
- Possibility to generalize the forecasts by using MIST (Optimal interpolation) in order to produce forecast fields from irregular forecast points.
- Reduce the number of predictors and simplify the system without loss in the forecast quality.
- MDA may also be evaluated to improve extreme events forecasting.

Conclusions

- Over the last 2 years UMOS-AQ has shown a significant improvement over the direct model output for all three pollutants in both seasons. This fact has been repeatedly shown over long and short term independent verification periods.
- An abrupt model switchover along with a matrix cloning operation did not noticeably affect the quality of the forecasts which demonstrates the robustness of the system.
- UMOS-AQ can provide a high quality national guidance in AQ forecasting.
- Future improvement is expected as more cases get accumulated and a full transition to GEM-MACH15 is completed.
- UMOS has shown great potential into a different field such as AQ.

Merci / Thank you !

Questions ? – Comments ?

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