Verification Tools for Air Quality Models

Samuel Gilbert[1], Radenko Pavlovic[1], Hugo Landry[1], Paul-André Beaulieu[1] and Michael D. Moran[2]

[1]Air Quality Modeling Applications Section, EC, Montreal, Quebec, Canada; [2]Air Quality Research Division, EC, Toronto, Ontario, Canada ; Questions: *Radenko Pavlovic (radenko.pavlovic@canada.ca)*

Environment Canada Environnement Canada

Environment Canada's VAQUM (**V**erification of **A**ir **QU**ality **M**odels) system was built to evaluate the performance of air quality model forecasts. It is based on PostgreSQL, an open-source object-relational database management system, and PostGIS, which adds support for geospatial data. This system has been under development since 2008 . The solid infrastructure has enabled the rapid development of new model evaluation products in recent years.

Air quality model forecasts are extracted at the surface level from output files at specific locations where air quality observations are available. Similarly, observations are added to the database. The system is then able to produce a variety of regional or global analyses with georeferenced data pairs of observations and forecasts that are coupled when needed. Some of the verification products now available from VAQUM include statistics based on hourly forecasts and daily maximum forecasts, categorical scores, statistics per forecasted hour, statistics by observed value category, maps of per-station statistics, and metropolitan area time series. This poster presents examples of some of the VAQUM products used for the evaluation of Environment Canada's air quality forecast systems. Current developments and future plans will also be described.

VAQUM Project History

The project **started in 2008**.

VAQUM was designed with the following goals :

- **Reproducibility**
- **Automation of the process**
- **High maintainability**
- **Extensibility**
- **User friendliness**

To meet these goals, a geospatial relational database was chosen to become the core of the system. Since it was one of the best performers, and also free open-source software, PostGIS was an obvious choice.

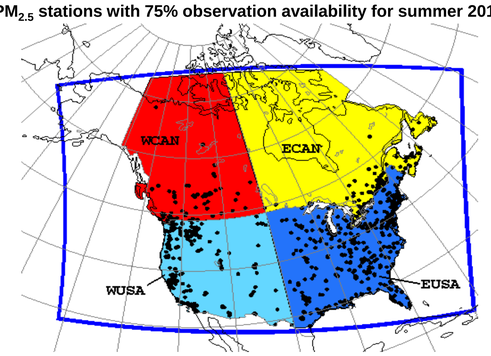
Besides SQL, VAQUM was programmed using TCL which is widely used in the Direction of Canadian Meteorological Centre Operations. However, over time, TCL was replaced with PHP since the latter is more appropriate for the development of Web applications.

Some processes where high performance is required, such as extracting forecasts from model output files or performing re-sampling to compute statistical distributions, were programmed in C++. To develop highly interactive Web applications, JavaScript with the Dojo toolkit was also used.

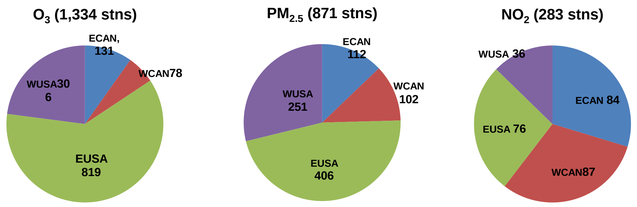
Some Features

- Assessment of model performance: Near-Real-Time or historical cases
- Results are viewable as graphs with the Web application.
- Completely geo-enabled.
- Statistics can be computed on any domain
- Online automated products:
  - Statistics of hourly forecasts
  - Statistics of daily maximums
  - Contingency tables (PC, POD, FAR and CSI)
  - Interactive maps of per station statistics
  - Per hour average charts
  - Per observation value bin charts
  - Metropolitan area time series (13 in Canada)
- Results are available in standard geospacial formats which can be viewed with off-the-shelf software
- When performing hourly objective scores comparison, VAQUM uses the bootstrap re-sampling method to perform statistical tests and determine if differences between sets of forecasts are significant
- Observation are stored in separate datasets. This was done to store both near real-time observations and validated observations that become available at a latter time. When configuring a comparison, users can choose which dataset to use for each region and variable.
- Stations coordinates are updated periodically. To enable fair comparison of forecasts, VAQUM supports multiple station snapshots to extract forecasts at the exact same locations even if the extraction processes for the two sets of forecasts occur at different dates.

$PM_{2.5}$ stations with 75% observation availability for summer 2015



Number of stations with available observations within GEM-MACH's domain



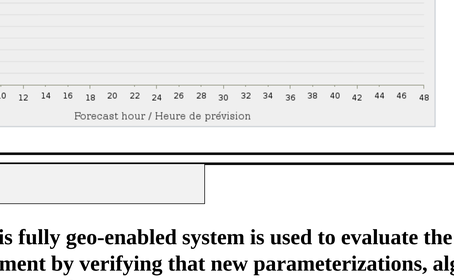
Examples of VAQUM Products

Statistics of hourly forecasts

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

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

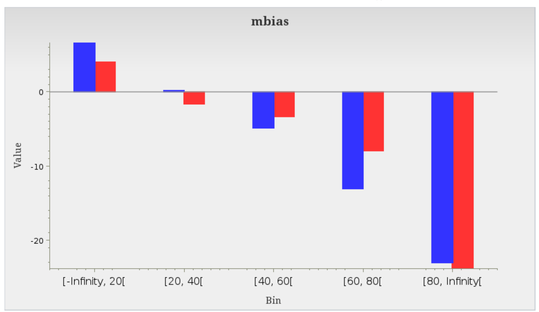
ARY vs GMv2_462CPOP_ete O3, ECAN



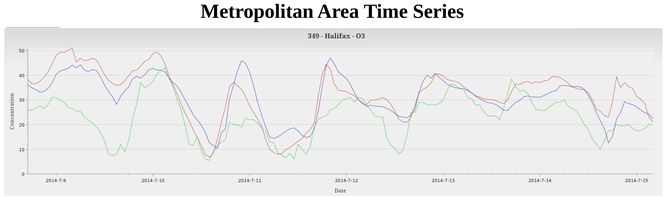
To determine if the differences are significant, distributions of the statistics are built by applying the bootstrap re-sampling method with 95% confidence intervals

Example of VAQUM Products (continued)

Per Observed Value Bin Graphs



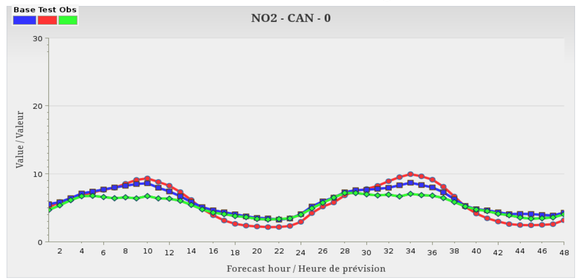
Metropolitan Area Time Series



Daily Maximums Statistics

Region		CAN		ECAN		EUSA		GEM-MACH10		USA		WCAN		WUSA	
Pollutant	Statistic	Base	Test	Base	Test	Base	Test	Base	Test	Base	Test	Base	Test	Base	Test
NO2	mbias	0.851658	0.887598	1.42757	1.62696	5.85944	5.02936	2.4419	2.54786	4.99072	5.20891	0.234901	0.0958077	3.36245	5.54546
	corr	0.621972	0.617226	0.667844	0.689528	0.661724	0.658085	0.634719	0.626666	0.662268	0.650762	0.570138	0.528294	0.6599	0.638102
	urmse	9.32518	9.46016	9.03059	9.19345	12.0587	11.4099	10.4978	10.5697	11.7009	11.6549	9.5924	9.67523	10.8125	12.0937
O3	mbias	0.406938	1.40909	1.31495	2.35594	6.82215	13.6694	4.56243	11.8534	5.35008	13.8302	-1.15189	-0.216415	1.21558	14.2818
	corr	0.606078	0.683014	0.606358	0.699477	0.590005	0.638582	0.588627	0.658288	0.558122	0.633716	0.619093	0.659111	0.512391	0.591534
	urmse	11.9728	11.2217	10.3902	10.3327	13.3593	13.868	14.2682	15.5901	14.5327	15.517	14.1515	12.4355	16.7313	19.4062
PM2.5	mbias	-9.52863	-10.766	-2.45803	-4.80065	-4.60125	-6.76001	-5.54164	-6.2696	-4.13275	-4.6807	-18.087	-17.9865	-3.31603	-1.05593
	corr	0.031504	0.0287779	0.191199	0.196224	0.192209	0.178612	0.100204	0.0803565	0.194008	0.166945	0.0513569	-0.00661349	0.0780834	0.189236
	urmse	23.2472	22.9821	15.6505	14.5534	11.7383	10.9277	15.979	15.7231	12.1234	11.7586	27.6468	28.5642	12.7258	12.2656

Per Forecast Hour Averages



Contingency Tables

EUSA - O3 - Pivot = 65

Forecast	No		Yes		Observation Total	
observation	Base	Test	Base	Test	Base	Test
No	338120 (95.00%)	323162 (90.79%)	10978 (3.08%)	25936 (7.29%)	349098 (98.08%)	349098 (98.08%)
Yes	3541 (0.99%)	1459 (0.41%)	3294 (0.93%)	5376 (1.51%)	6835 (1.92%)	6835 (1.92%)
Forecast Total	341661 (95.99%)	324621 (91.20%)	14272 (4.01%)	31312 (8.80%)	355933 (100.00%)	355933 (100.00%)

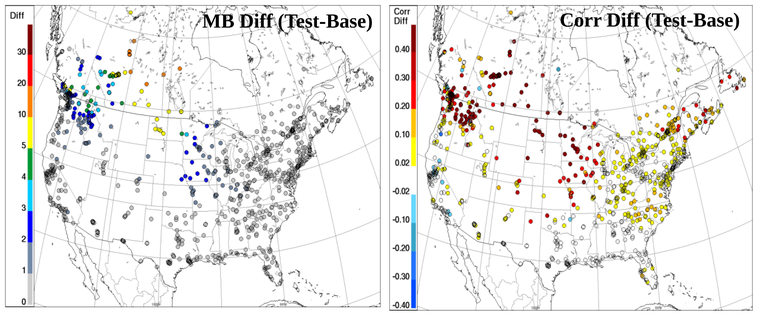
Statistic	Base	Test
Percentage Correct	95.92 %	92.30 %
Probability of detection	48.19 %	78.65 %
False Alarm Ratio	76.92 %	82.83 %
Critical Skill Index	18.49 %	16.40 %

EUSA - PM2.5 - Pivot = 30

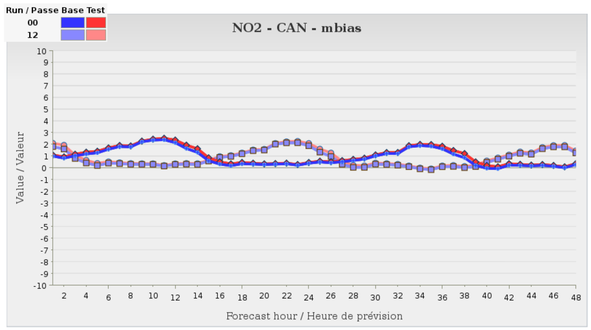
Forecast	No		Yes		Observation Total	
observation	Base	Test	Base	Test	Base	Test
No	154785 (97.20%)	155576 (97.69%)	1399 (0.88%)	608 (0.38%)	156184 (98.07%)	156184 (98.07%)
Yes	2960 (1.86%)	3020 (1.90%)	108 (0.07%)	48 (0.03%)	3068 (1.93%)	3068 (1.93%)
Forecast Total	157745 (99.05%)	158596 (99.59%)	1507 (0.95%)	656 (0.41%)	159252 (100.00%)	159252 (100.00%)

Statistic	Base	Test
Percentage Correct	97.26 %	97.72 %
Probability of detection	3.52 %	1.56 %
False Alarm Ratio	92.83 %	92.68 %
Critical Skill Index	2.42 %	1.31 %

Per Station Statistics



Per Hour Statistics



4. Planned Improvements

Improved quality control of received observations

New products such as

- Statistics based on population density
- Urban vs rural stations and related statistics, etc.

Improved Web application to give more flexibility to configure performance evaluation

5. Conclusions

Environment Canada's VAQUM system was built to evaluate the performance of air quality model forecasts. This fully geo-enabled system is used to evaluate the performance of EC's operational AQ forecast model which is launched twice daily. It is also used to guide model development by verifying that new parameterizations, algorithms, inputs, or configurations lead to better AQ forecasts. So, far system enables performance evaluation for 10 pollutants over more than 7 years.

The Canadian Meteorological Centre Operations Division will continue to work on improving our VAQUM AQ verification tool to meet increasing demands in AQ model performance analysis.