Routine Multi-model Performance Analysis over North America for Six Operational Air Quality Forecast Systems

Mike Moran[1], Patrick Manseau[2], Si Jun Peng[2], Ivanka Stajner[3], Johannes Flemming[4], Youngsun Jung[5], Jeff McQueen[3], Rick Saylor[6], Miha Razinger[4], Christoph Keller[7,8], Emma Knowland[7,8], Rostislav Kouznetsov[9], Mikhail Sofiev[9], and Radenko Pavlovic[2]

[1]Air Quality Research Division, Environment and Climate Change Canada (ECCC), Toronto, Ontario, Canada
[2]Canadian Meteorological Centre, ECCC, Montreal, Quebec, Canada
[3]U.S. National Weather Service, National Oceanic and Atmospheric Administration (NOAA), College Park, Maryland, U.S.A.
[4]Copernicus Atmosphere Monitoring Service (CAMS), European Centre for Medium-range Weather Forecasts (ECMWF), Reading, United Kingdom
[5]U.S. National Weather Service, NOAA, Silver Spring, Maryland, U.S.A.
[6]Air Resources Laboratory, NOAA, Oak Ridge, Tennessee, U.S.A.
[7]Universities Space Research Association, Columbia, Maryland, U.S.A.
[8]Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.
[9]Finnish Meteorological Institute, Helsinki, Finland

10th International Workshop on AQ Forecasting Research (Virtual)   *20-22 Oct. 2021*

Environment and Climate Change Canada   Environnement et Changement climatique Canada

Canada

INTRODUCTION

- Seven groups (now 9) in Europe making operational regional AQ forecasts have shared and compared their forecasts since 2009 under the MACC-I, -II, and -III and CAMS projects

- In North America, while operational regional AQ forecasts have been made for over a decade in both Canada and the U.S., no comparable routine side-by-side evaluation and comparison of forecasts had taken place until quite recently

- ECCC, NOAA, and ECMWF began to exchange operational AQ forecasts for North America in 2017, and ECCC has built an automated verification system to receive, ingest, and compare these forecasts

- Two more AQ forecast systems from NASA and FMI have joined this multi-model evaluation project in the past year

PARTICIPATING AQ FORECAST SYSTEMS

System	AQ Model	Country (Agency)	Grid Type	Grid Size (km)	Lowest Vertical Layer Thickness (m)	Wildfire Emissions	Chemical Data Assimilation	Forecast Starts	Forecast Duration/ Availability
RAQDPS	GEM-MACH	Canada (ECCC)	Regional	10	20	No	No	00Z,12Z	72-hr / Hourly
FireWork	GEM-MACH	Canada (ECCC)	Regional	10	20	Yes	No	00Z,12Z	72-hr / Hourly
NAQFC	CMAQ	U.S.A. (NOAA)	Regional	12	38	Yes	No	06Z,12Z	72-hr / Hourly
IFS-CAMS	CAMS	Europe (ECMWF)	Global	40	20	Yes	Yes	00Z,12Z	120-hr / 3-hourly
GEOS	GEOS-CF (GCC)	U.S.A. (NASA)	Global	25	138	Yes	No	12Z	120-hr / Hourly
IFS-SILAM	SILAM	Finland (FMI)	Global	20	20	Yes	No	00Z	120-hr / Hourly

All systems share O_3, NO_2 and $PM_{2.5}$ forecasts except NOAA NAQFC, which does not share NO_2 forecasts. The integrations starting at 12 UTC are chosen as the "common ground" for the comparison of these systems. For any system with forecasts starting at 00 UTC only, the forecasts with a lead time of 12 h and more will be used as a synthetic 12 UTC integration.

AQ Measurement Stations Reporting in Near-Real Time
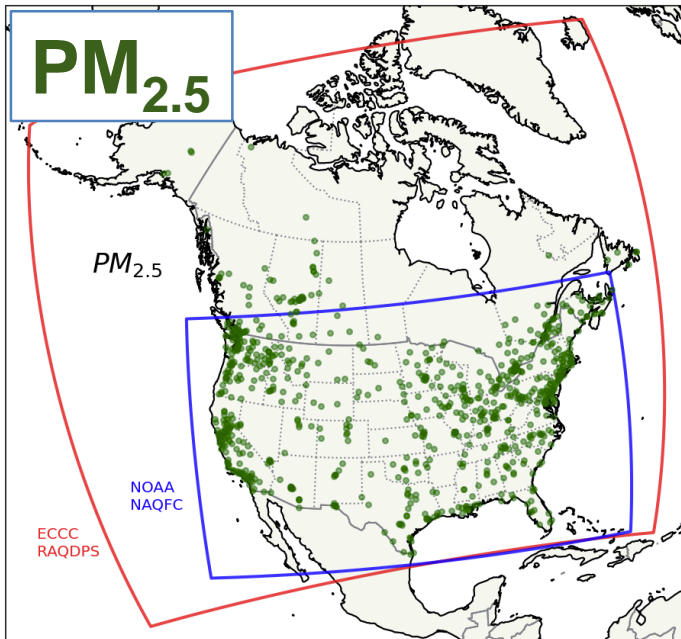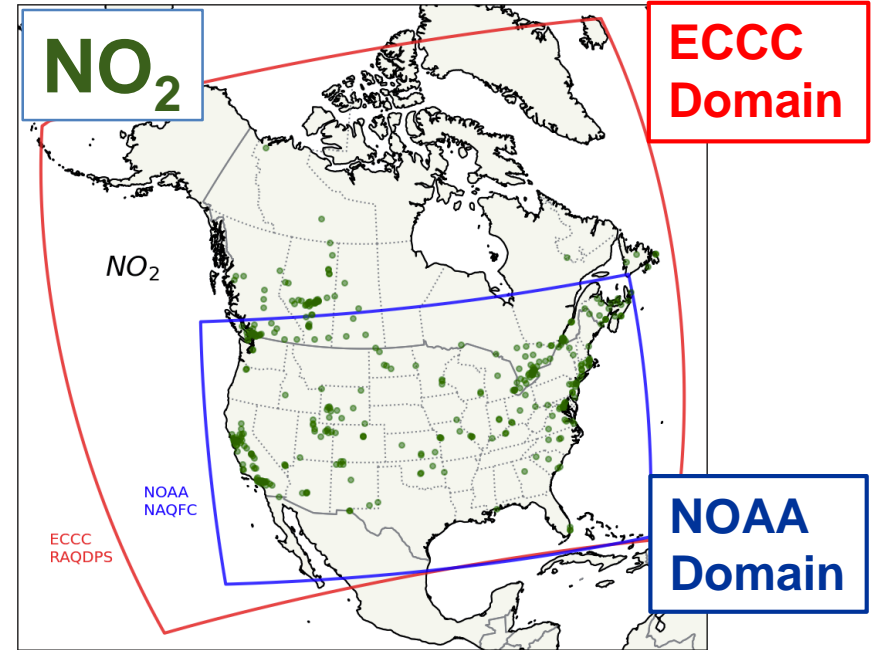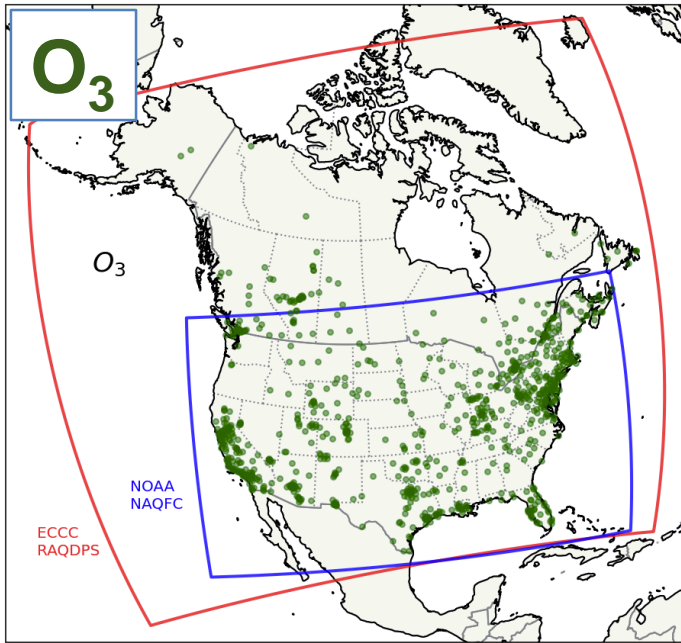
Number of stations by pollutant that reported at least 75% of all hourly observations in 2020

O₃	**917**
NO₂	**379**
PM₂.₅	**877**

Two NRT AQ measurement data feeds are U.S. EPA AIRNow system and ECCC ADE system

AUTOMATED VERIFICATION SYSTEM

- **Monthly** evaluation statistics for each AQ modelling system are calculated automatically early in the following month for **7 regions** (domain, Canada, U.S., WCAN, ECAN, WUSA, EUSA)

- Statistics are calculated for forecast **O_3**, **NO_2**, and **$PM_{2.5}$** for the **12 UTC** runs

- Since AQ episodes and acute health impacts are of greatest concern, most monthly statistics are calculated based on observed and predicted *daily maximum* **values** (paired by day but not necessarily by hour)

- The standard statistics are *n, Ȳ, MB, MFB, NMB, R, FAC2, NMGE, RMSE, URMSE, sigma Y, and var Y* (where *n* is the number of model-measurement pairs and *Y* is the predicted species concentration)

- A new non-dimensional summary statistic, **AQPI** (AQ Performance Index), which is based on 3 standard non-dimensional statistics (FAC2, R, MFB), is also calculated, where AQPI = 100 * [**FAC2** + **R** + (1-ABS(**MFB**/2))] / 3

- **Hour-of-day**-specific statistics are also calculated for every *third* hour (to align with IFS-CAMS outputs) to examine the variation of model errors by time of day

Q2 2021 MULTI-MODEL AQPI SCORES

Domain: NAQFC–RAQDPS intersection (southern Canada and continental USA)

Agency	System	O_3			NO_2			$PM_{2.5}$		
		Apr	May	Jun	Apr	May	Jun	Apr	May	Jun
ECCC	RAQDPS	88	89	89	72	71	68	48	51	49
ECCC	RAQDPS-FW	88	89	89	72	71	68	50	53	54
NOAA	NAQFC	88	92	89	-	-	-	58	63	62
ECMWF	IFS-CAMS	87	89	86	65	63	63	60	64	64
NASA	GEOS-CF	87	86	81	65	61	61	37	46	47
FMI	IFS-SILAM	87	87	87	69	67	67	53	60	61

Legend	AQPI (%)
Excellent	[90,100]
Very good	[80,90[
Good	[70,80[
Acceptable	[60,70[
Poor	[50,60[
Very poor	<50

- **O_3** : All systems had very good performances. NAQFC reached the "excellent" category in May

- **NO_2** : RAQDPS has the best performance.

- **$PM_{2.5}$** : IFS-CAMS has the best performance.

AQPI[O_3,NO_2,$PM_{2.5}$]= 100*AVG [**FAC2** , **R** , (1-ABS(**MFB**/2))]

MONTHLY MEAN 48-H DIURNAL CONCENTRATION TIME SERIES
(DOMAIN: NAQFC–RAQDPS INTERSECTION)
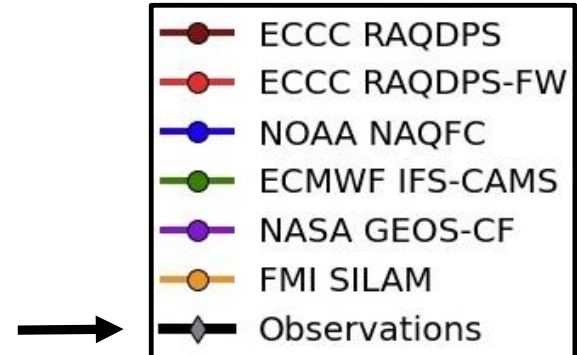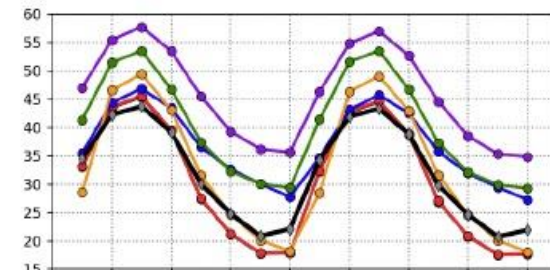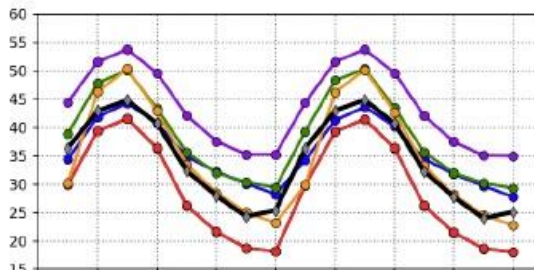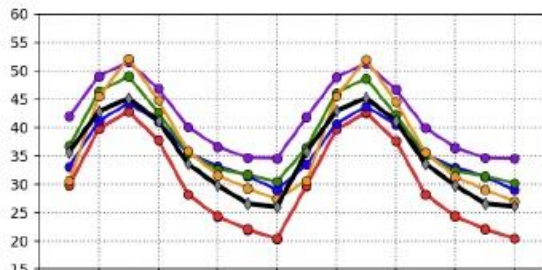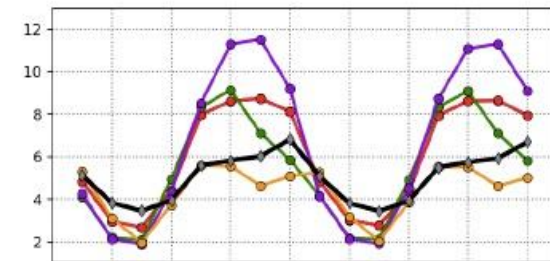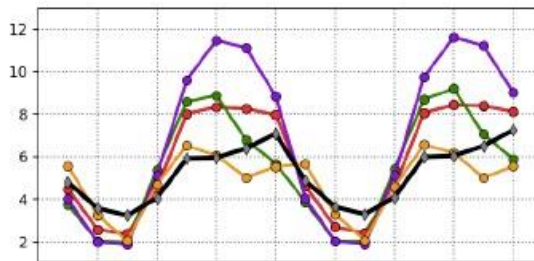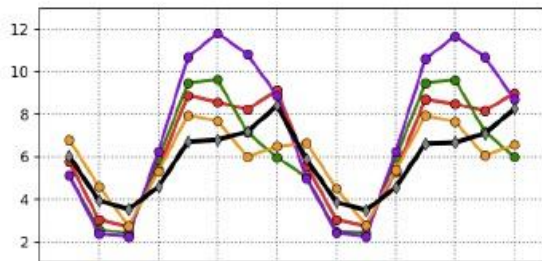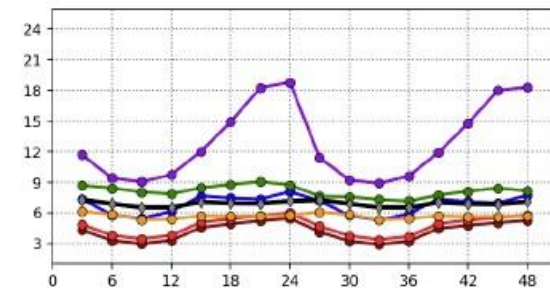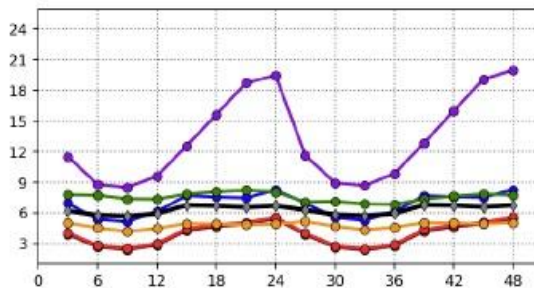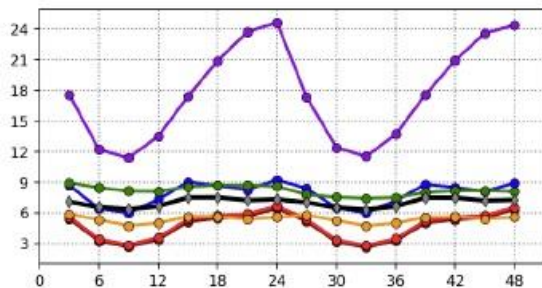
MONTHLY AQPI (LAST 15 MONTHS)

O$_3$

NO$_2$

PM$_{2.5}$

Domain:
NAQFC–RAQDPS
intersection

Legend:
- ECCC RAQDPS
- ECCC RAQDPS-FW
- NOAA NAQFC
- ECMWF IFS-CAMS
- NASA GEOS-CF
- FMI SILAM
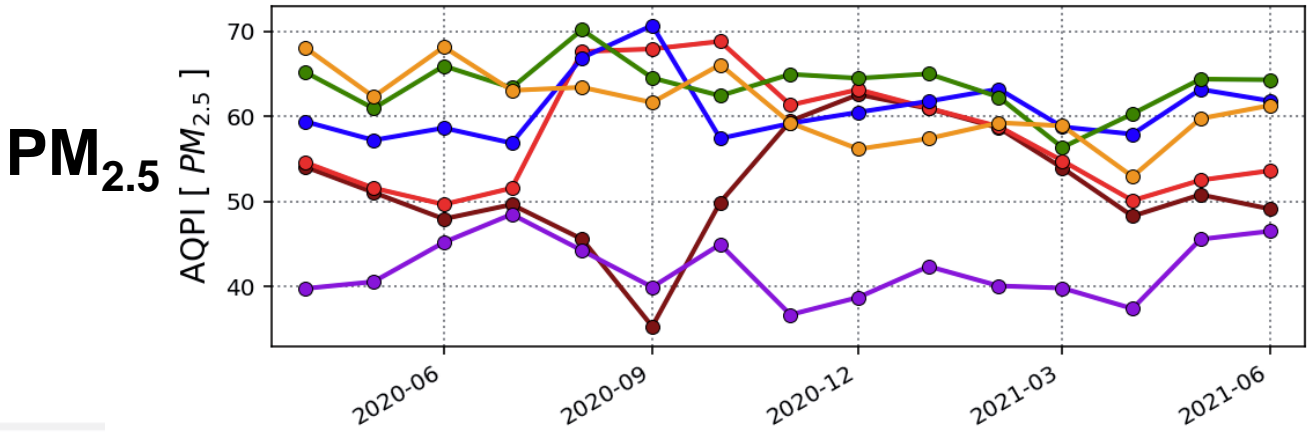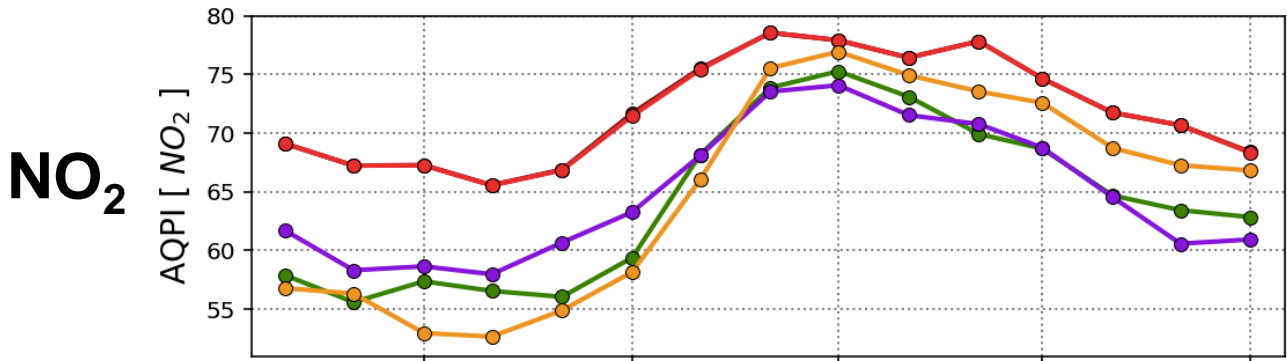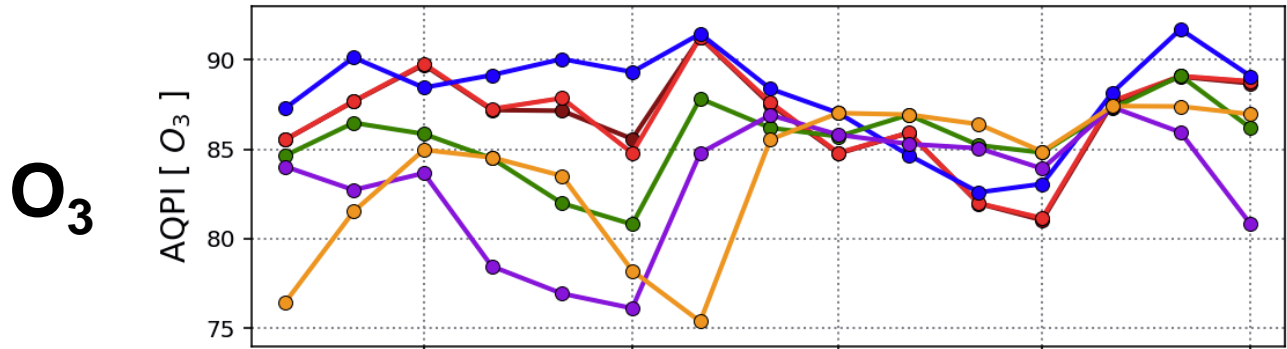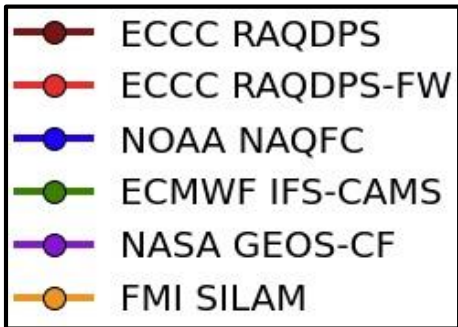
AQPI[O$_3$,NO$_2$,PM$_{2.5}$]= 100*AVG [**FAC2** , **R** , (1-ABS(**MFB**/2))]

MONTHLY FAC2
(FACTOR-OF-2
FRACTION)
(LAST 15 MONTHS)

O₃

NO₂

PM₂.₅

Domain:
NAQFC–RAQDPS
intersection

Legend:
- ECCC RAQDPS
- ECCC RAQDPS-FW
- NOAA NAQFC
- ECMWF IFS-CAMS
- NASA GEOS-CF
- FMI SILAM

FAC2 = fraction of data satisfying the criterion $0.5 \leq P_i/O_i \leq 2$

MONTHLY _R_
(CORRELATION COEFFICIENT)
(LAST 15 MONTHS)

O_3

ECCC RAQDPS
ECCC RAQDPS-FW
NOAA NAQFC
ECMWF IFS-CAMS
NASA GEOS-CF
FMI SILAM

NO_2

$PM_{2.5}$

Domain:
NAQFC–RAQDPS
intersection

$$R = \sum (O_i - \overline{O})(P_i - \overline{P}) / \sqrt{\sum (O_i - \overline{O})^2 \sum (P_i - \overline{P})^2}$$

MONTHLY MFB
(MEAN FRACTIONAL BIAS)
(LAST 15 MONTHS)

O$_3$

NO$_2$
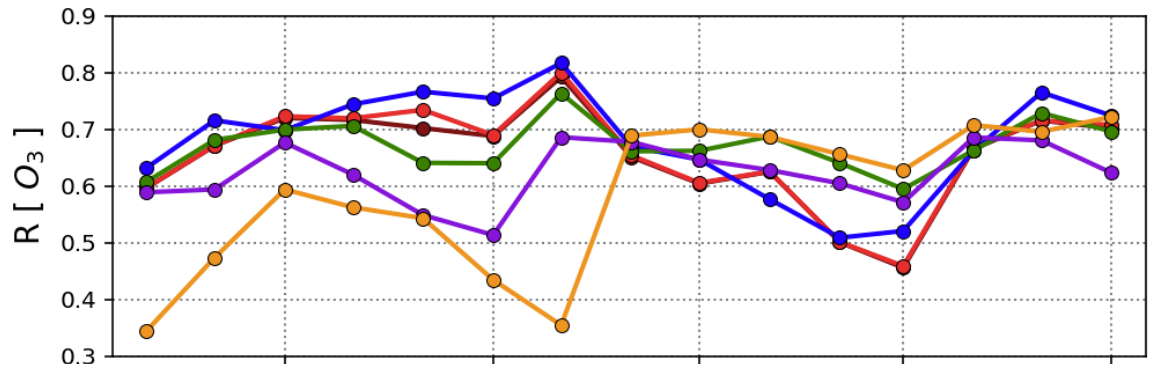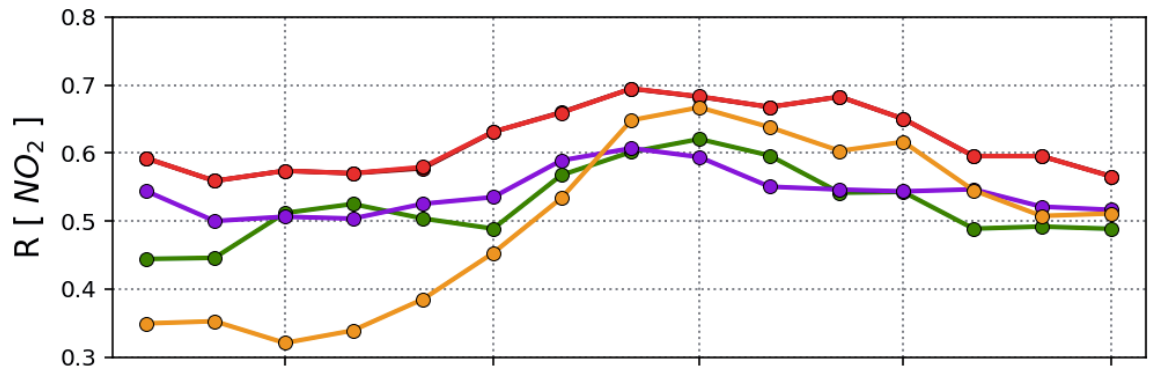
PM$_{2.5}$
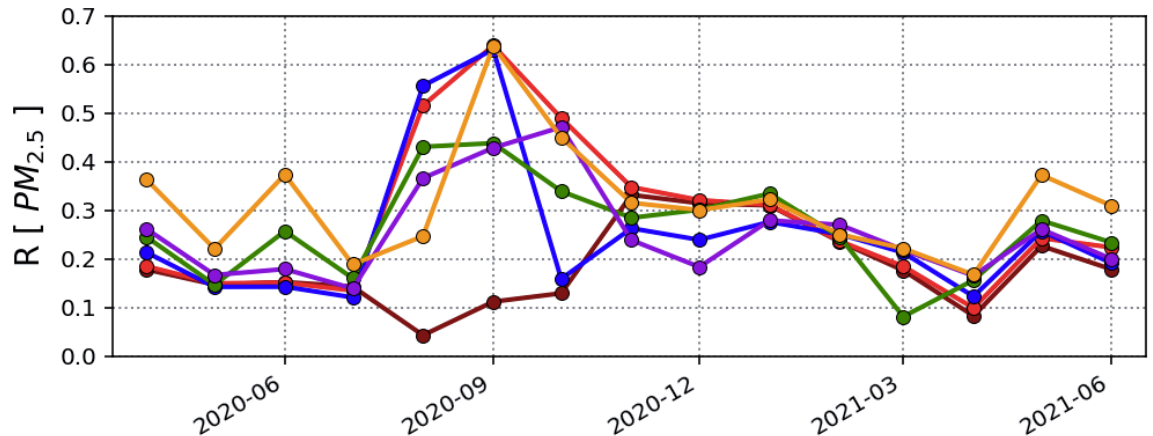
Legend:
- ECCC RAQDPS
- ECCC RAQDPS-FW
- NOAA NAQFC
- ECMWF IFS-CAMS
- NASA GEOS-CF
- FMI SILAM
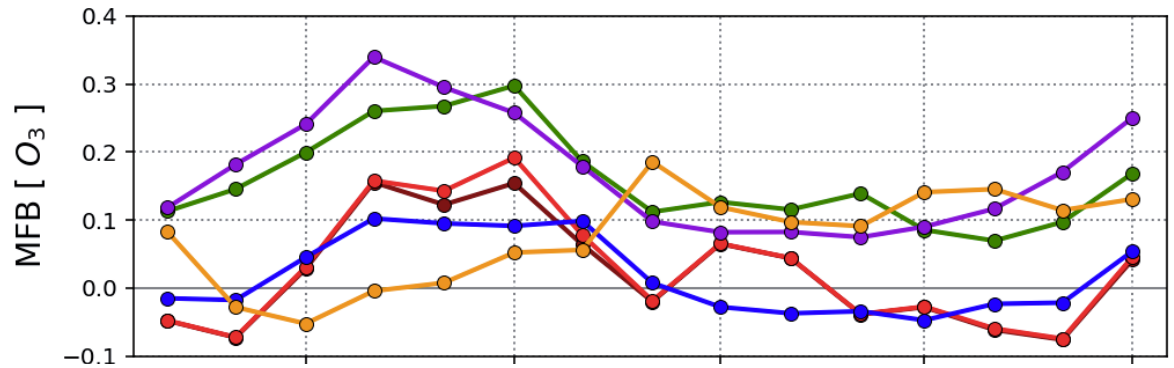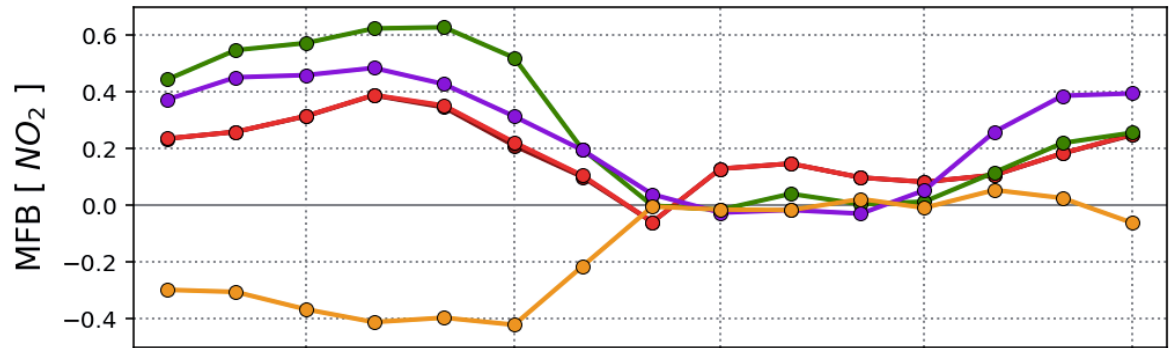
Domain:
NAQFC– RAQDPS
intersection
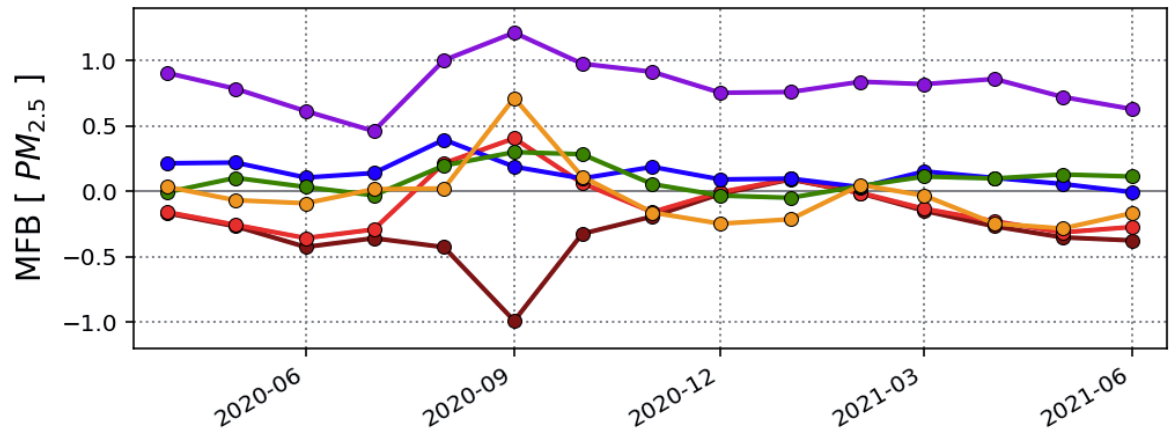
$$\mathbf{MFB} = 2\sum(P_i - O_i) / \sum(P_i + O_i)$$

SUMMARY AND CONCLUSIONS

Operational AQ forecasts for North America from 3 regional AQ forecast models and 3 global AQ forecast models are now being exchanged and compared for 3 pollutant species: O_3, NO_2, and $PM_{2.5}$

We can use this new evaluation database to examine and compare the performance of these 6 AQ forecast systems for multiple statistics from multiple perspectives, including:

- Multi-year time trends
- Time of year and time of day performance variations
- Regional differences (e.g., west vs. east) [not shown]
- Urban vs. rural differences [not shown]
- Impacts of modelling system upgrades [implicit]

Thank You for Your Attention