UPDATES ON THE INTERNATIONAL COOPERATIVE FOR AEROSOL PREDICTION MULTI-MODEL ENSEMBLE (ICAP-MME) AND SURFACE PM VERIFICATIONS

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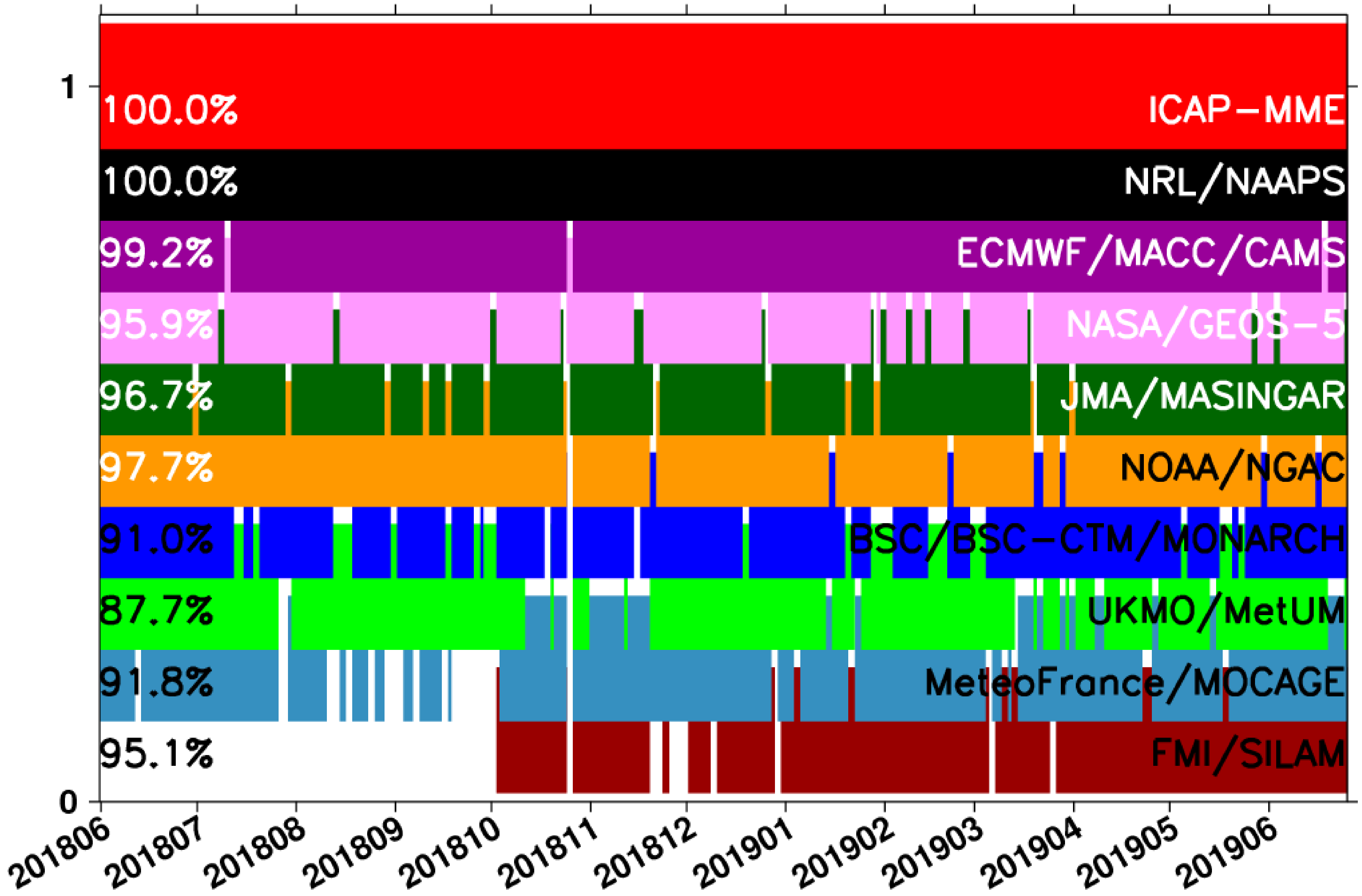
CURRENT ICAP OPERATIONS - as of June 2019

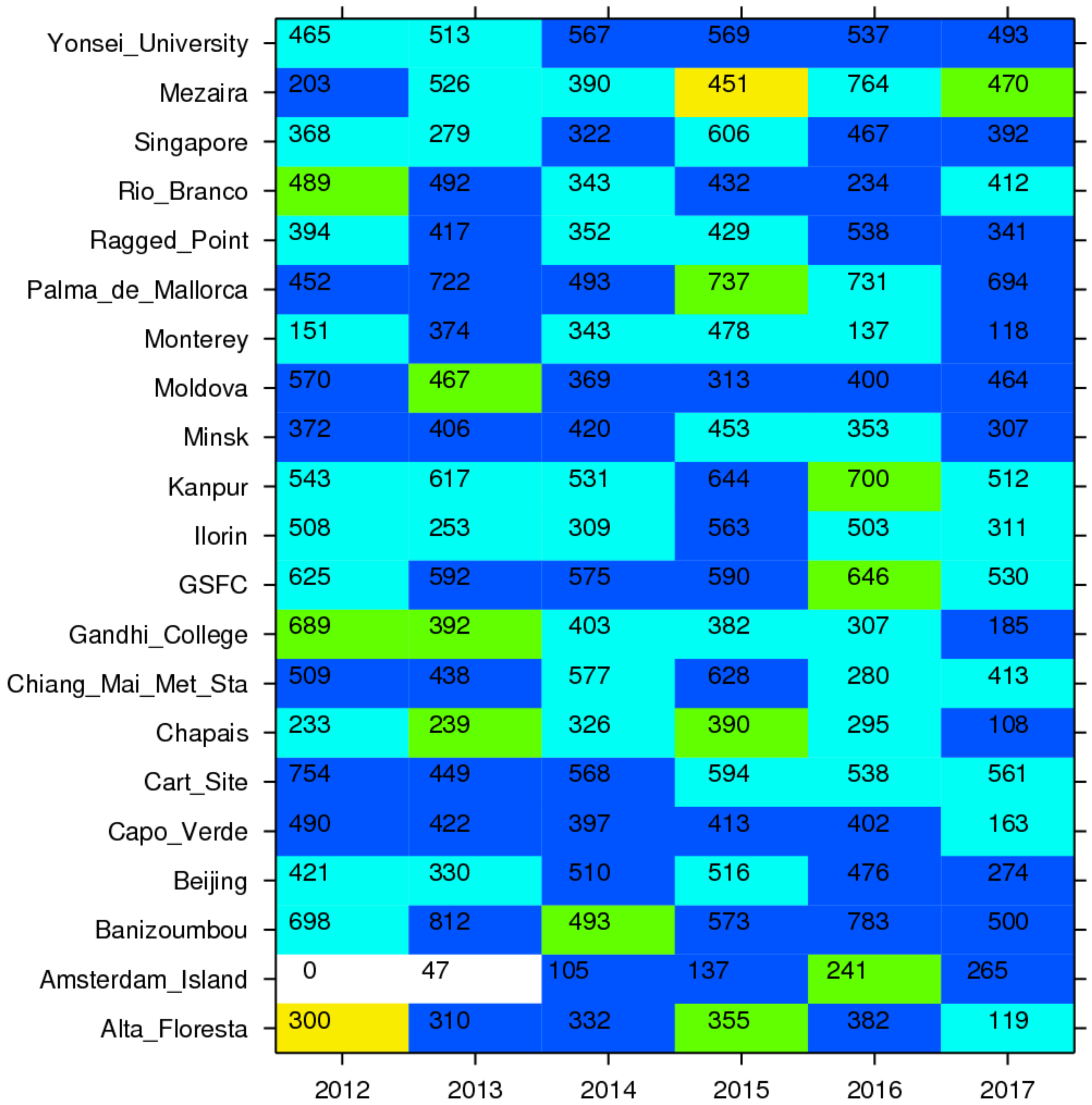
Organization	BSC	Copernicus/ ECMWF	JMA	Meteo France	NASA	US Navy	NOAA	FMI	UKMO
Model	MONARCH	CAMS	MASINGAR	MOCAGE	GEOS-5	NAAPS	NGAC/FV3GFS-Chem	SILAM	MetUM
Status	QO	O-24 hrs	QO	O	QO	O	O	O	O
Meteorology	Inline NMMB	Inline IFS	inline AGCM	Offline ARPEGE	Inline GEOS-5	Offline NAVGEM	Inline GFS/FV3GFS	Offline IFS	Inline UM
Resolution	1.4x1 (0.7x0.5)	0.4x0.4	0.375x0.375	1x1	0.125x0.15	0.33x0.33	1x1/0.25	0.5x0.5	0.35x0.23
levels	24 (48)	~~60~~ 137	40	47	72	60	64	60	70
DA	LETKF[p]	4DVar	2DVar LETKF[p]	2018	2DVar +LDE	2DVar 3DVar, EnKF[p]	NA	3Dvar[p], 4Dvar[p], EnKF[p]	4DVar
Assimilated Obs	DAQ MODIS+DB	DAQ MODIS DT+DB PMAp	MODIS L3, AHI[p], CALIOP[p]	NA	Neural Net MODIS	DAQ MODIS, AVHRR[p] VIIRS[p] CALIOP[p]	NA	NA	MODIS Dust AOT
Species	Dust, Sea Salt BC (POA,SOA)bio Sulfate (POA, SOA)anthro	BC, OC Dust, Sea Salt Sufate, Nitrate, Ammonium	BC, OC Dust Sea Salt Sulfate	BC, OC Dust Sea Salt Sulfate, Nitrate, Ammonium	BC, OC Dust Sea Salt Sulfate Nitrate	Anthro+bio B. B. Smoke Dust Sea Salt	Dust BC, OC Sea Salt Sulfate	BC, Dust, OC, Sea Salt, Sulfate, Nitrate, B.B. Smoke	Dust
Size Bins	8 (dust, salt) bulk for others	3 (dust, salt), bulk for others	10 (dust, salt), bulk for others	6	5 (dust, SS), 2(BC, OC), 3(NI*), bulk sulfate	bulk	5 (dust, SS), 2(BC, OC), bulk sulfate	4 (dust), 5 (SS), 3 (B.B. Smoke), 2 (sulfate), bulk for others	2
Antho. & Biogenic Emission	HTAPv2.1 (anthro), MEGANv2.04 (biogenic)	MACCity (anthro), MEGAN (biogenic)	MACCity	MACCity (anthro.) MEGAN-MACC (biogenic)	EDGAR V4.1/4.2, AeroCom Phase II, GEIA	MACCity, BOND, POET	EDGAR V4.1+CEDS AeroCom Phase II, GEIA	MACCity, STEAM, MEGANE, HTAP(Coarse PM)	NA
Bio. Burn. Emissions	GFAS	GFAS	GFAS	GFAS	QFED	FLAMBE	GBBEPxV2	GFAS, IS4FIRES	NA

- The ICAP-MME is run daily w/ 1x1 deg res at 00Z for 6 hrly fcasts out to 120 hrs w/ a 1-day latency.
- Modal AOT (550nm) and dust AOT (550nm) data in NetCDF is available publically.
- Green means proposed. Red means changes occurred last year. "p" means prototype.

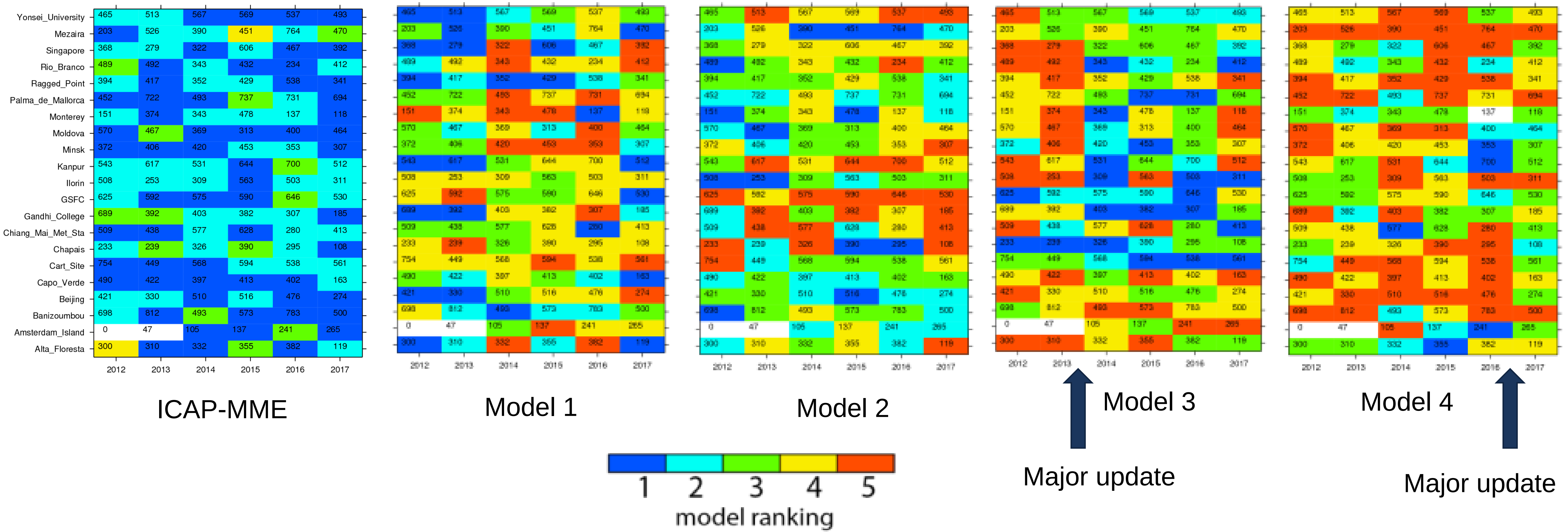
ICAP Model Data Flow since last meeting



Key results from the recent ICAP paper (Xian et al., 2019) Ranking of ICAP-MME in terms of total AOD RMSE for 72-hr fcst over 2012-2017



Ranking of all models in terms of total AOD RMSE for 72-hr fcst over 2012-2017



- ICAP-MME performance is stable and reliable over the years compared to individual models.
- AOD RMSE of the ICAP-MME is not always the lowest for a given species, site or year, but it is relatively low and stable.
- Consensus MME wins in the long run because of its averaging of independent models.

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Evolution of ICAP-MME performance over 2012-2017

Number inside each block is yearly mean modal AOD.

Fine-mode AOD RMSE

	2012	2013	2014	2015	2016	2017
Yonsei_University	0.33	0.34	0.41	0.30	0.32	0.30
Mezaira	0.12	0.11	0.11	0.11	0.12	0.13
Singapore	0.31	0.30	0.37	0.56	0.19	0.18
Rio_Branco	0.13	0.07	0.10	0.17	0.16	0.21
Ragged_Point	0.03	0.03	0.03	0.03	0.03	0.04
Palma_de_Mallorca	0.08	0.06	0.07	0.06	0.06	0.06
Monterey	0.03	0.04	0.03	0.03	0.23	0.08
Moldova	0.11	0.11	0.11	0.08	0.10	0.09
Minsk	0.10	0.10	0.10	0.10	0.10	0.08
Kanpur	0.32	0.44	0.42	0.39	0.42	0.43
Ilorin	0.27	0.27	0.30	0.23	0.30	0.31
GSFC	0.10	0.08	0.09	0.09	0.07	0.07
Gandhi_College	0.39	0.42	0.34	0.44	0.38	0.38
Chiang_Mai_Met_Sta	0.36	0.50	0.35	0.31	0.47	0.24
Chapais	0.07	0.07	0.06	0.06	0.06	0.03
Cart_Site	0.08	0.06	0.06	0.07	0.05	0.08
Capo_Verde	0.06	0.05	0.06	0.06	0.07	0.11
Beijing	0.51	0.41	0.48	0.45	0.36	0.33
Banizoumbou	0.11	0.09	0.10	0.11	0.12	0.11
Amsterdam_Island	NaN	NaN	0.05	0.03	0.01	0.02
Alta_Floresta	0.16	0.08	0.12	0.20	0.11	0.40

0.02 0.06 0.10 0.14 0.18 0.22 0.26 0.30 0.34 0.38 0.42 0.46 0.50

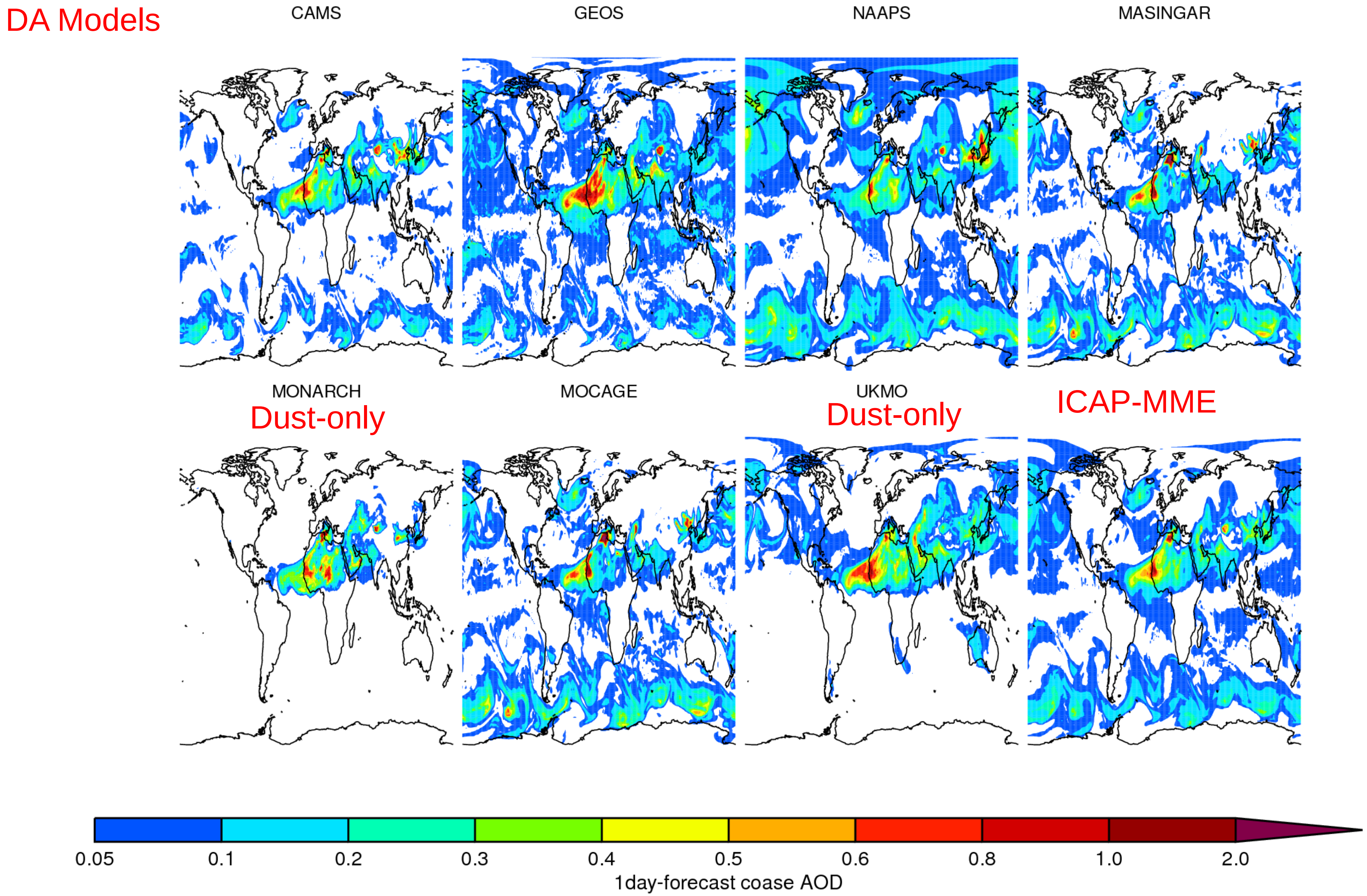
Coarse-mode RMSE

2012	2013	2014	2015	2016	2017
0.14	0.12	0.14	0.12	0.13	0.12
0.42	0.25	0.22	0.28	0.22	0.22
0.13	0.12	0.14	0.16	0.11	0.10
0.06	0.04	0.06	0.07	0.07	0.06
0.14	0.12	0.13	0.16	0.12	0.16
0.10	0.05	0.09	0.07	0.07	0.07
0.04	0.03	0.03	0.04	0.05	0.05
0.07	0.06	0.06	0.05	0.06	0.07
0.06	0.06	0.06	0.05	0.05	0.06
0.30	0.22	0.21	0.23	0.22	0.22
0.48	0.27	0.35	0.44	0.45	0.46
0.05	0.04	0.04	0.04	0.04	0.04
0.25	0.19	0.24	0.20	0.20	0.26
0.11	0.12	0.10	0.10	0.13	0.10
0.05	0.04	0.03	0.04	0.03	0.03
0.05	0.04	0.05	0.04	0.03	0.05
0.29	0.23	0.25	0.31	0.29	0.33
0.20	0.18	0.19	0.16	0.16	0.15
0.43	0.32	0.27	0.44	0.44	0.38
NaN	NaN	0.10	0.08	0.05	0.06
0.07	0.05	0.07	0.08	0.06	0.12

0.02 0.06 0.10 0.14 0.18 0.22 0.26 0.30 0.34 0.38 0.42 0.46 0.50

- A general tendency for model improvements in fine-mode AOD, especially over Asia for 2012-2017.
- No significant improvement in coarse-mode AOD is found overall for this time period.

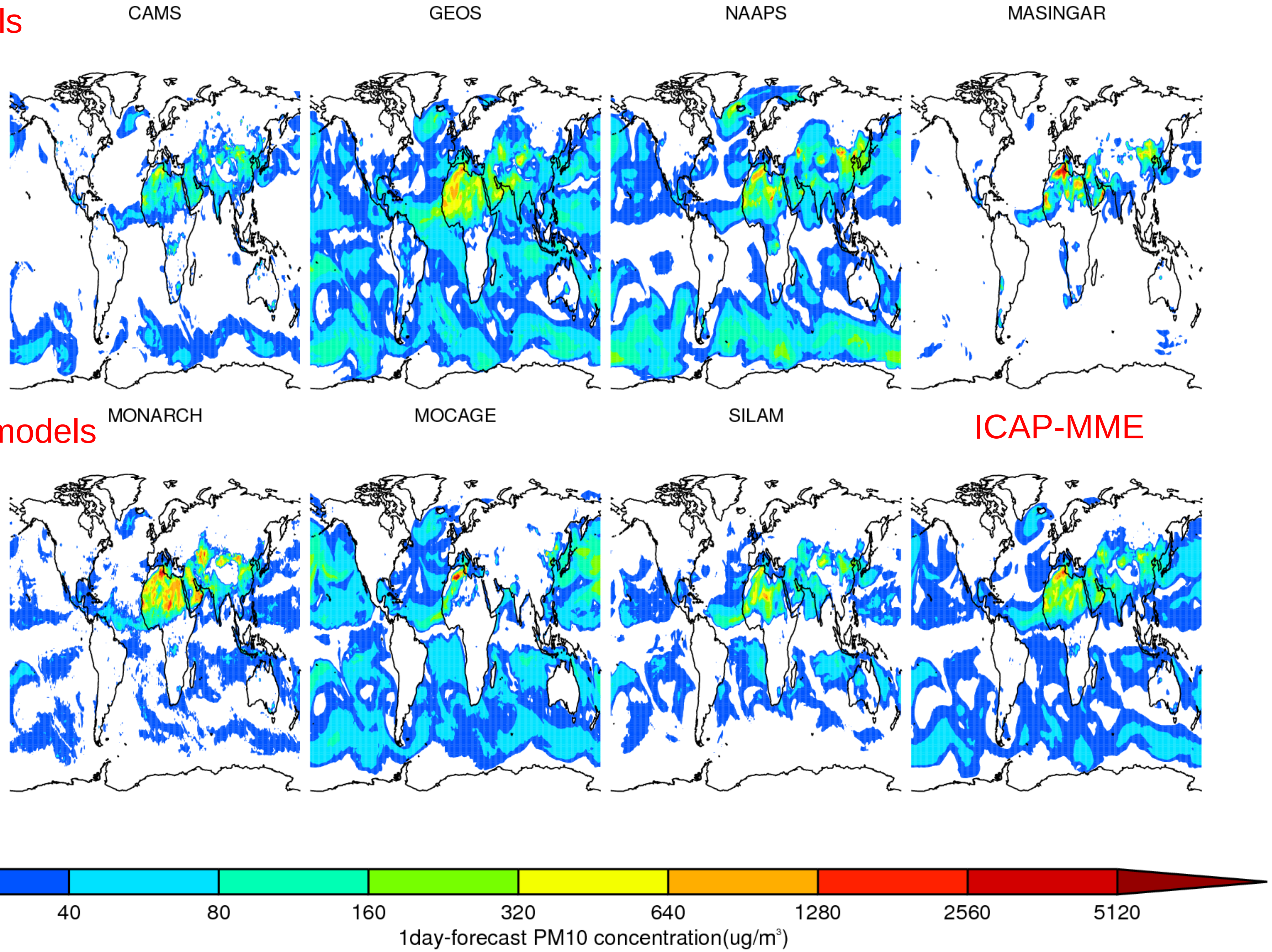
Model coarse-mode AOD --- a snapshot for 20170511



Model Surface PM10 --- a snapshot for 20170511

DA Models

Non-DA models



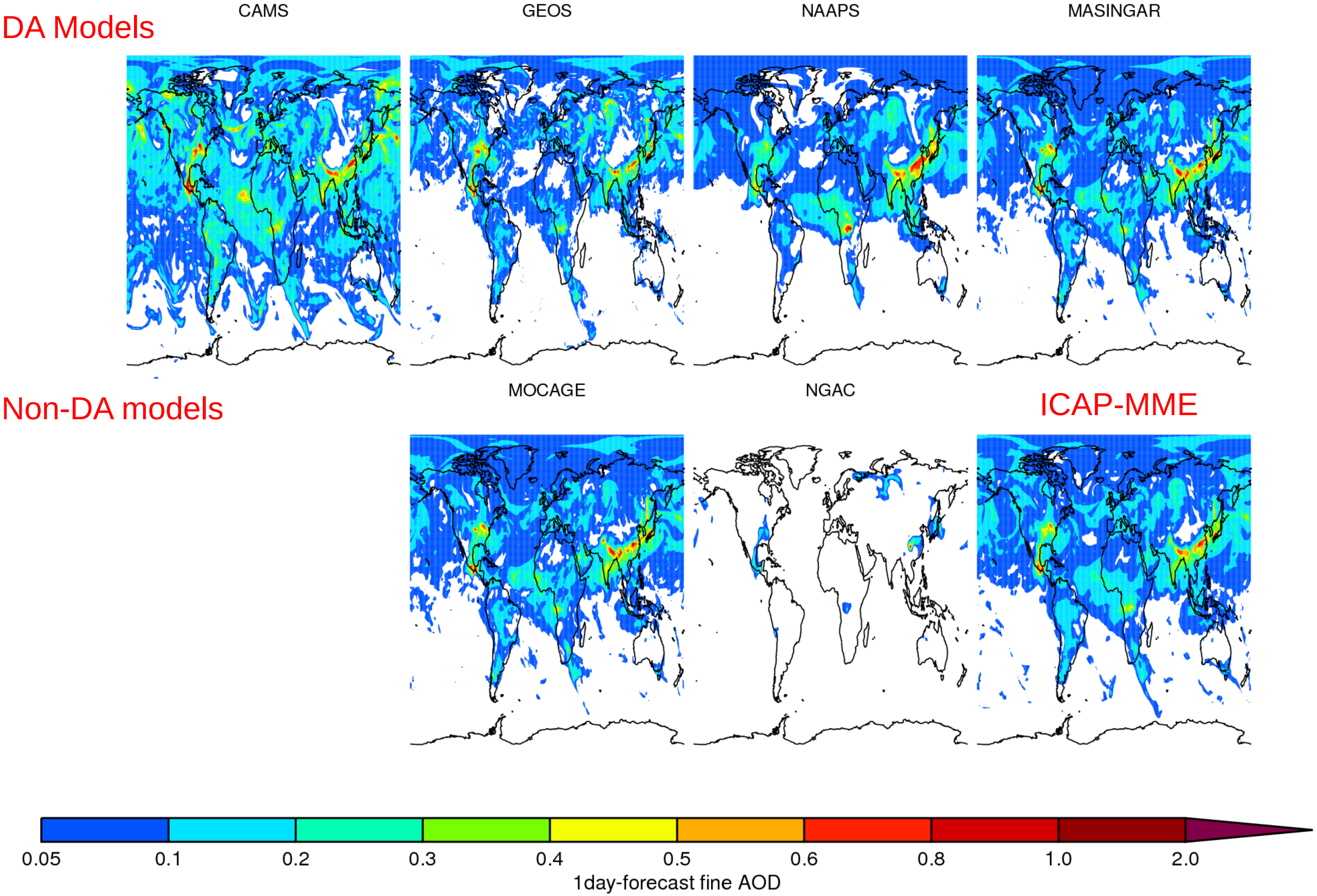
Large diversity among models, including the AOD-DA models, over dust influenced regions and sea salt production regions.

DA models have similar coarse-AOD, e.g., over ocean, but their PM10 can be a few factors/order of magnitude different, due to possible differences in aerosol optical properties, vertical distributions, hygroscopic growths, meteorology etc.

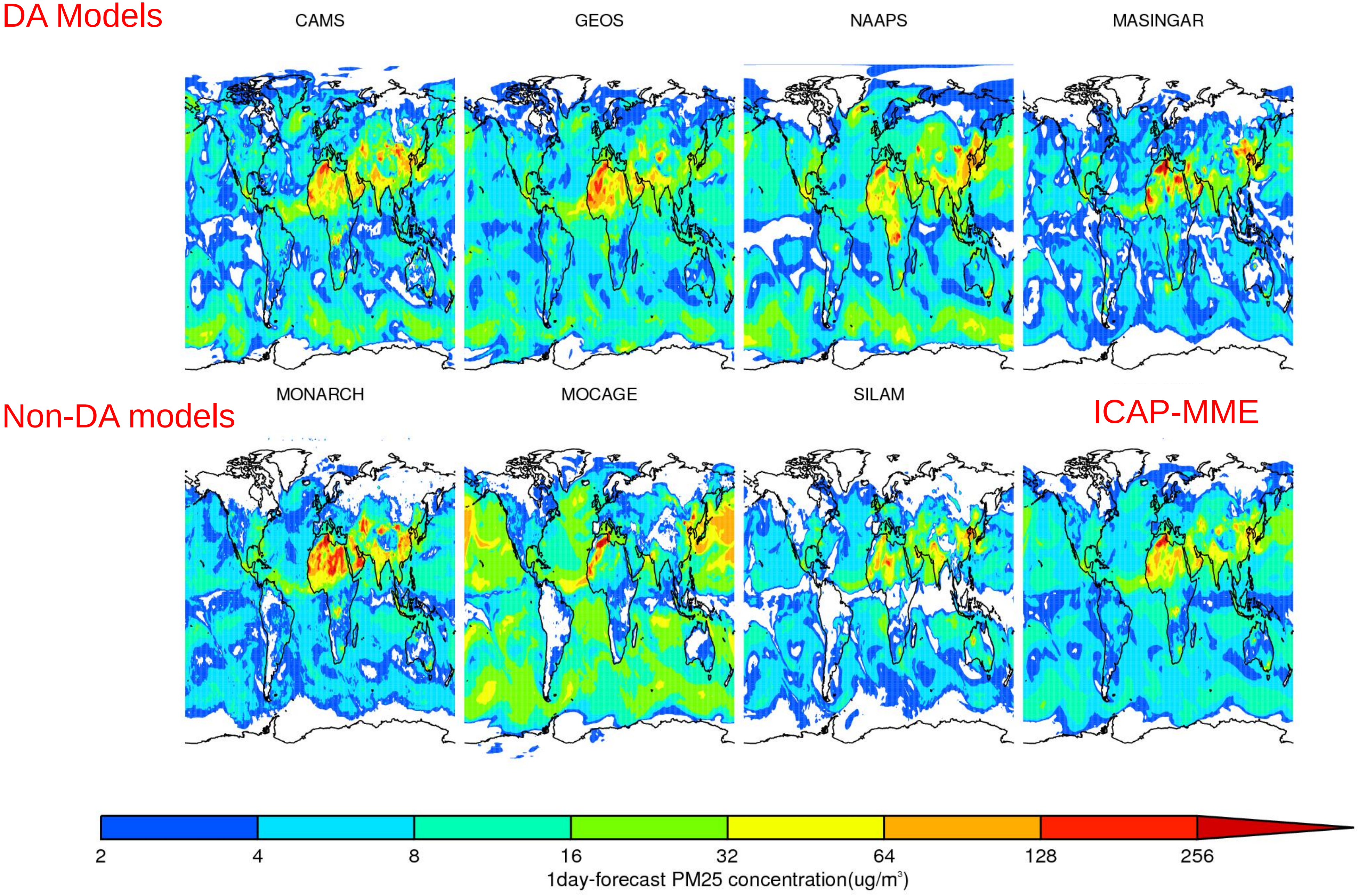
Model fine-mode AOD--- a snapshot for 20170511

DA Models

Non-DA models



Model surface PM2.5 ---- a snapshot for 20170511



There are some differences among models in fine-mode AOD, but there are larger differences in PM2.5.

Optical properties, vertical distributions, chemistry, hygroscopic growths, size-bins (fine dust, sea salt), meteorology all matter.

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Surface PM Measurements

openAQ.org

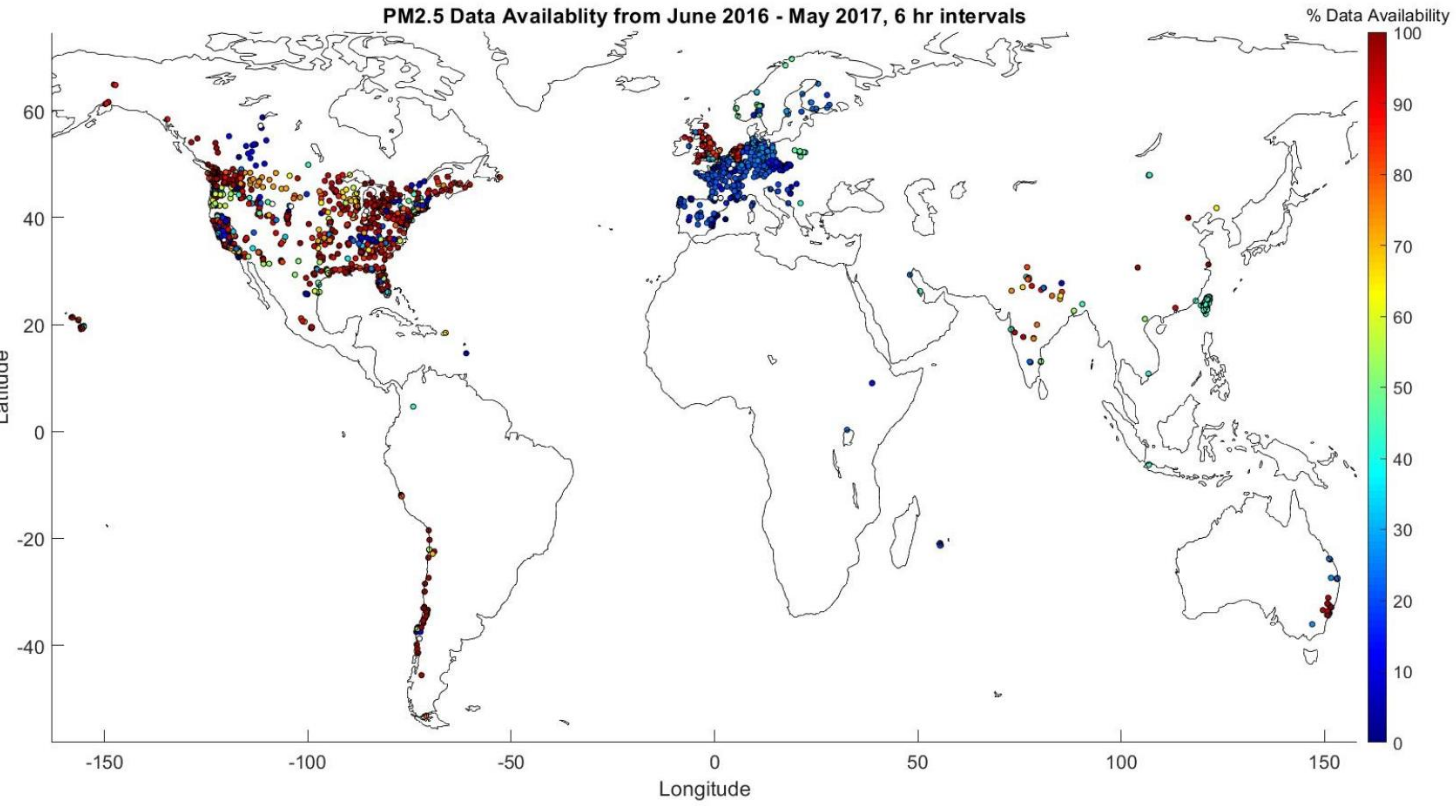
~34.8 million surface particulate matter (PM) measurements for 2016-2017

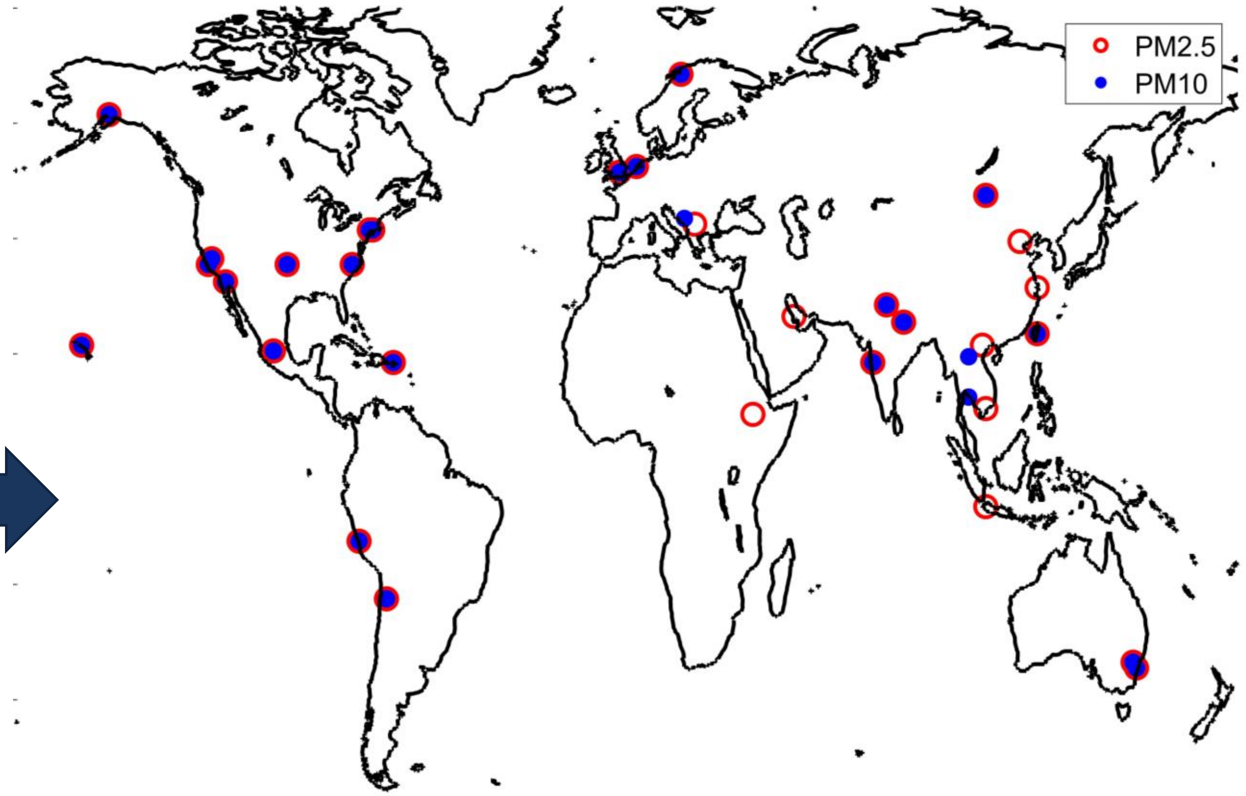
34825084x10 table

	1 location	2 city	3 country	4 utc	5 parameter	6 value	7 unit	8 latitude	9 longitude	10 attribution
1	US Diplomatic Post: Jakarta South	Jakarta	ID	"2016-01-03T18:00:00.000Z"	pm25	61	Âµg/mÂ³	-6.2366	106.7933	[{"name":"EPA AirNow DOS","url":"http://airnow.gov/index.cfm?action=airnow.global_summary"}]
2	US Diplomatic Post: Jakarta Central	Jakarta	ID	"2016-01-03T18:00:00.000Z"	pm25	45	Âµg/mÂ³	-6.1824	106.8341	[{"name":"EPA AirNow DOS","url":"http://airnow.gov/index.cfm?action=airnow.global_summary"}]
3	US Diplomatic Post: Ulaanbaatar	Ulaanbaatar	MN	"2016-01-03T18:00:00.000Z"	pm25	64	Âµg/mÂ³	47.9284	106.9302	[{"name":"EPA AirNow DOS","url":"http://airnow.gov/index.cfm?action=airnow.global_summary"}]
4	US Diplomatic Post: Hanoi	Hanoi	VN	"2016-01-03T18:00:00.000Z"	pm25	-999	Âµg/mÂ³	21.0218	105.8190	[{"name":"EPA AirNow DOS","url":"http://airnow.gov/index.cfm?action=airnow.global_summary"}]
5	US Diplomatic Post: Hyderabad	Hyderabad	IN	"2016-01-03T18:30:00.000Z"	pm25	61	Âµg/mÂ³	17.4435	78.4749	[{"name":"EPA AirNow DOS","url":"http://airnow.gov/index.cfm?action=airnow.global_summary"}]
6	US Diplomatic Post: Chennai	Chennai	IN	"2016-01-03T18:30:00.000Z"	pm25	28	Âµg/mÂ³	13.0524	80.2519	[{"name":"EPA AirNow DOS","url":"http://airnow.gov/index.cfm?action=airnow.global_summary"}]

PM data were processed to remove errors and then aggregated into 1x1 degree “grids”

Surface PM Measurements sites





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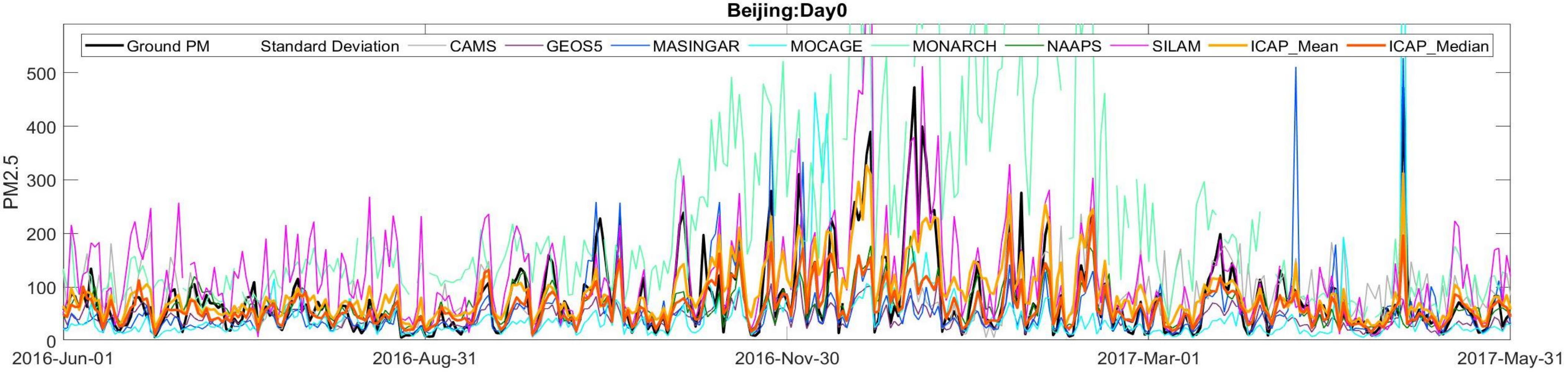
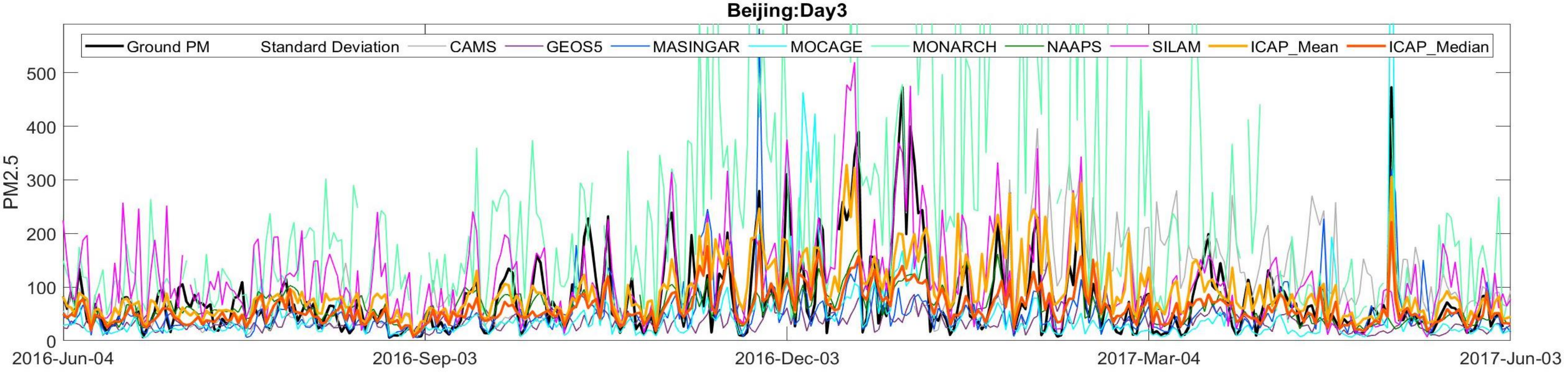
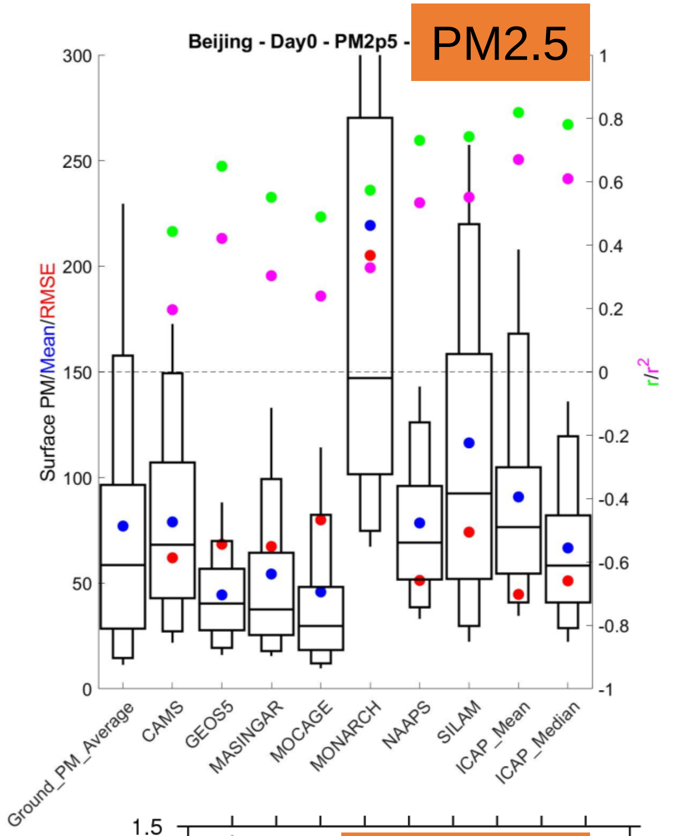
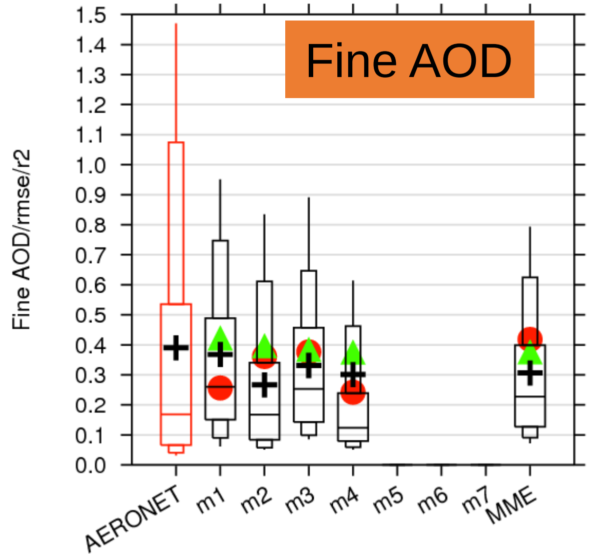
Preliminary verification result on PM2.5, June 2016-May 2017 Beijing



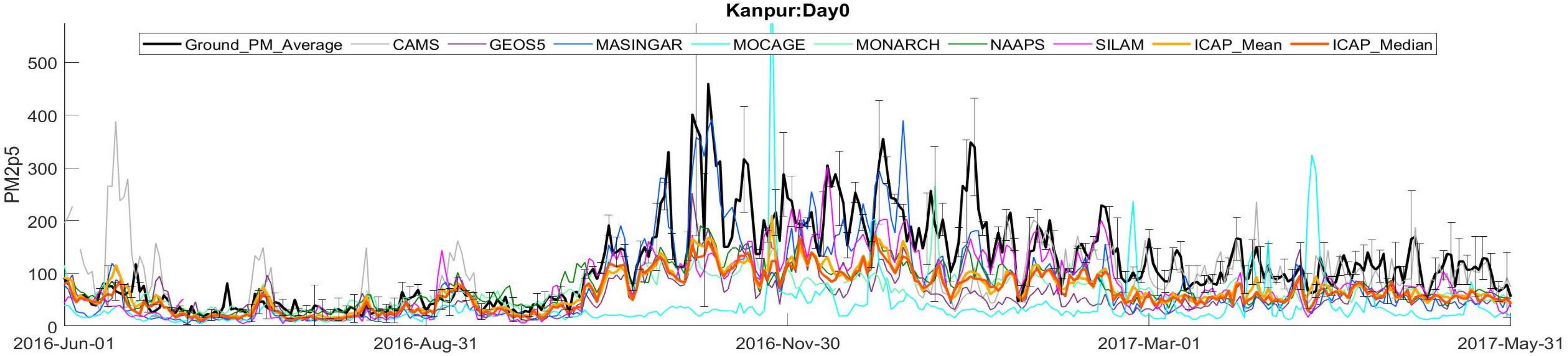


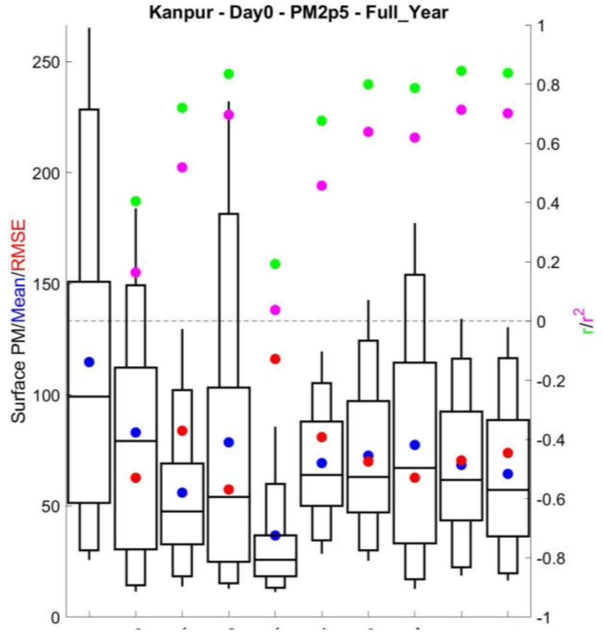


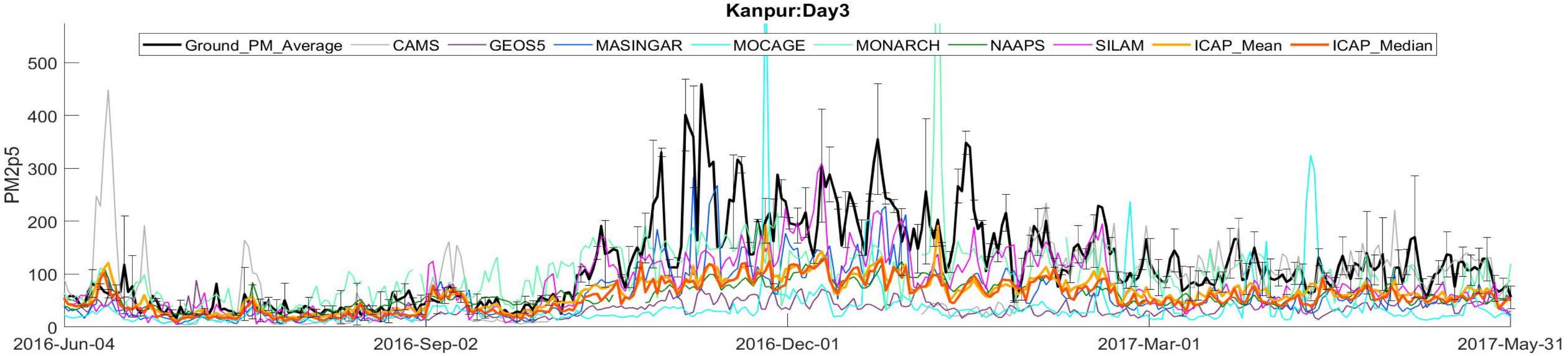


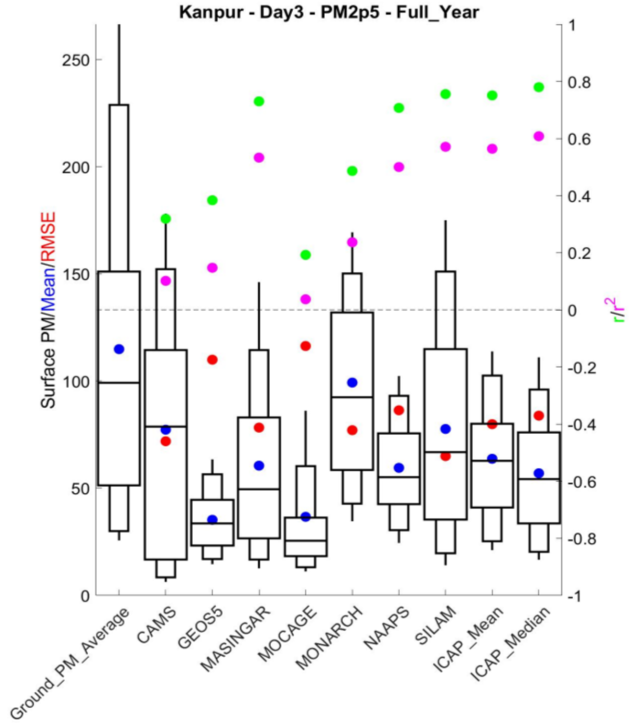
- ➢ Compared to AOD, PM2.5 has a larger diversity among models.
- ➢ ICAP-MME still performs the best compared to individual models as for PM2.5.

Preliminary verification result on PM2.5, June 2016-May 2017 Kanpur



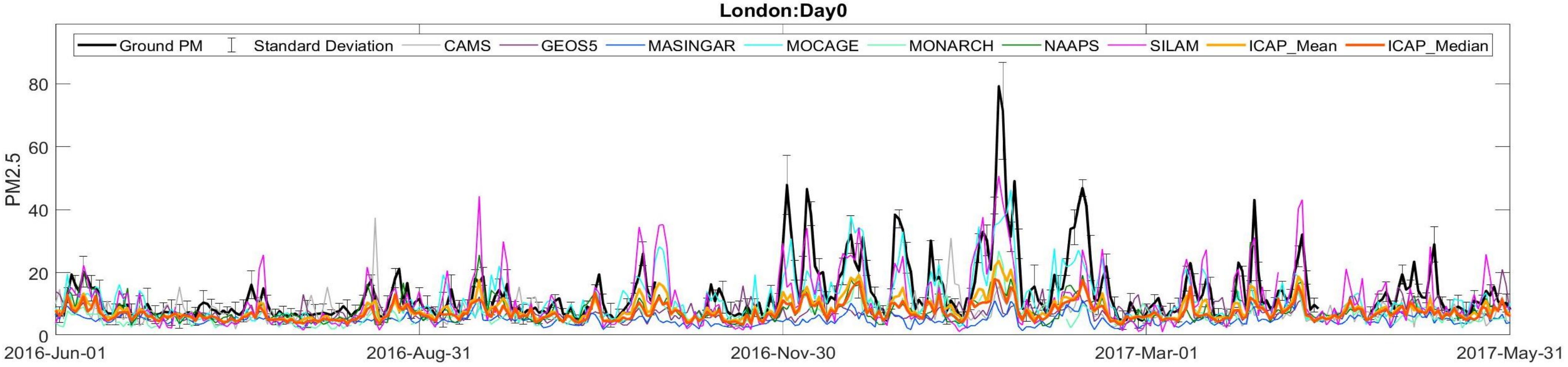


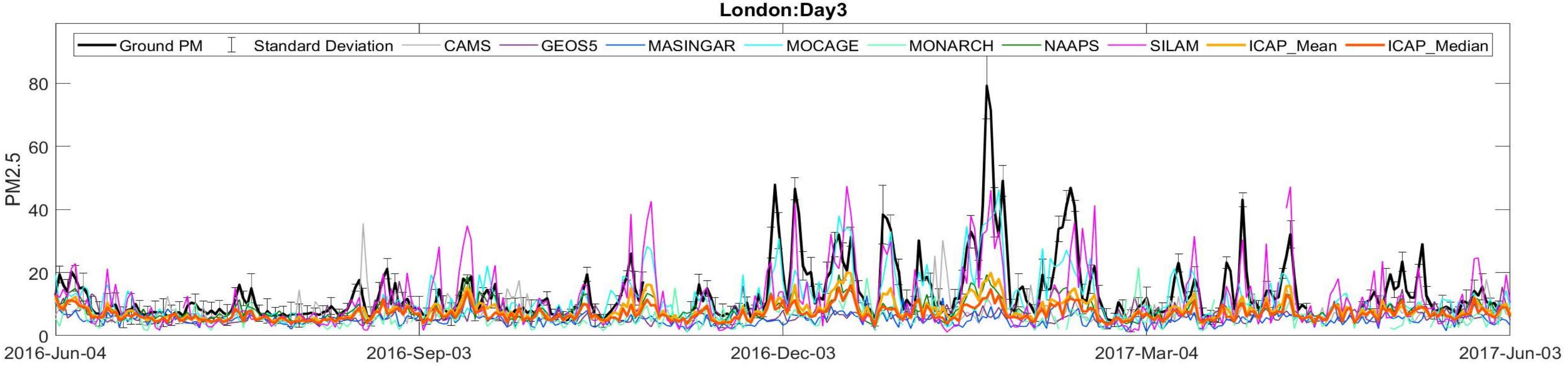


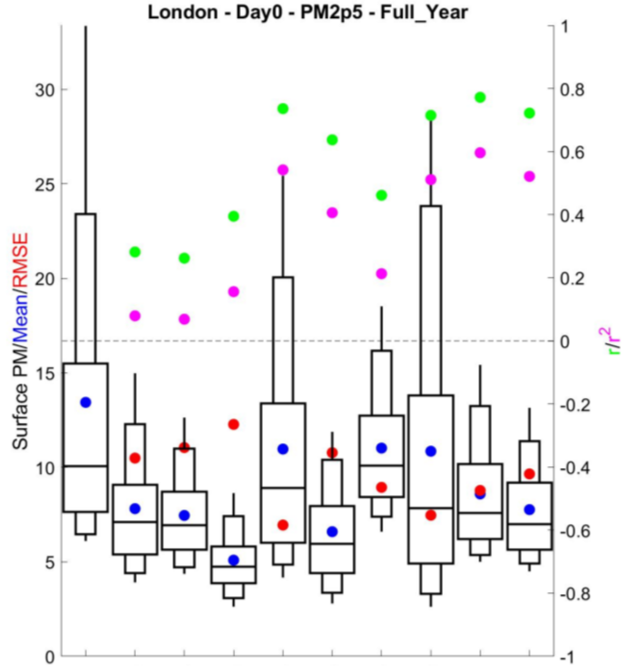


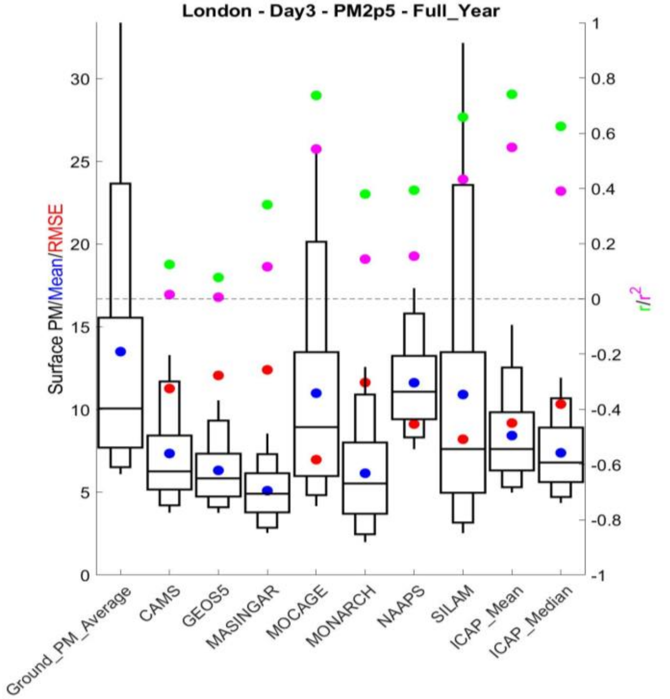
- ICAP-MME still performs the best compared to individual models.
- DA models don't necessarily perform better than non-DA models.
- Consistent large low biases among all models for winter time.

Preliminary verification result on PM2.5, June 2016-May 2017 London

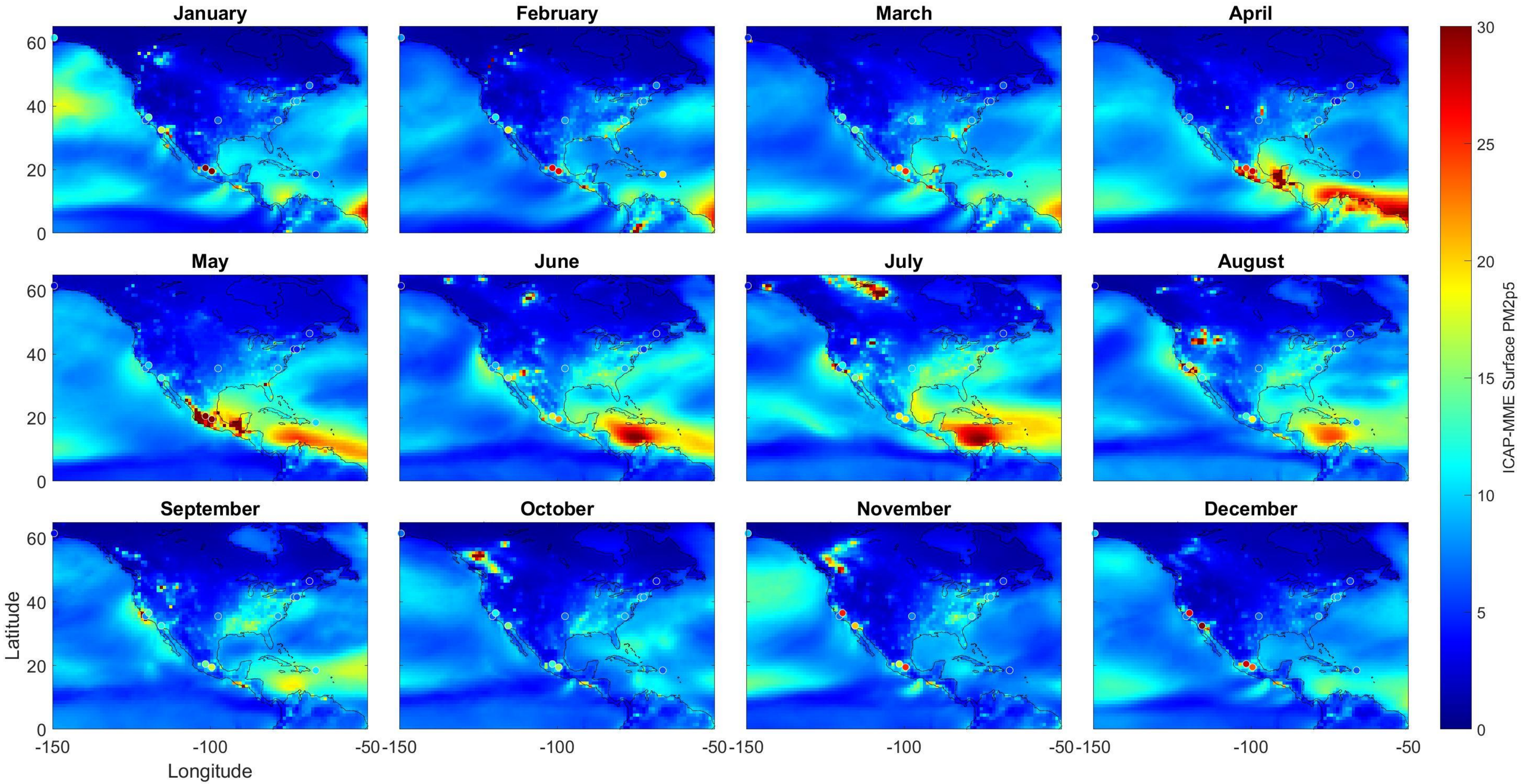




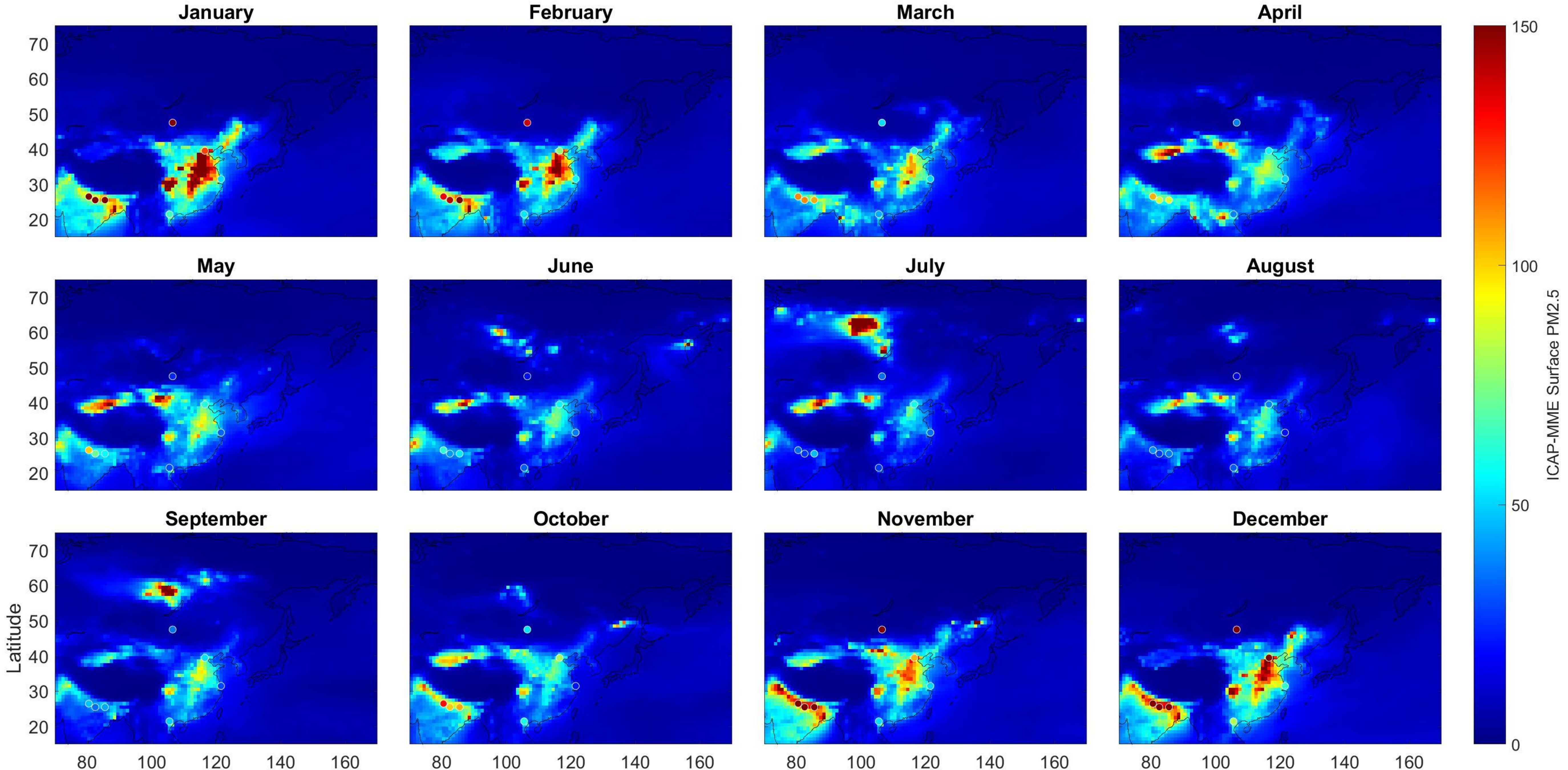




Annual cycle of PM2.5



Annual cycle of PM2.5



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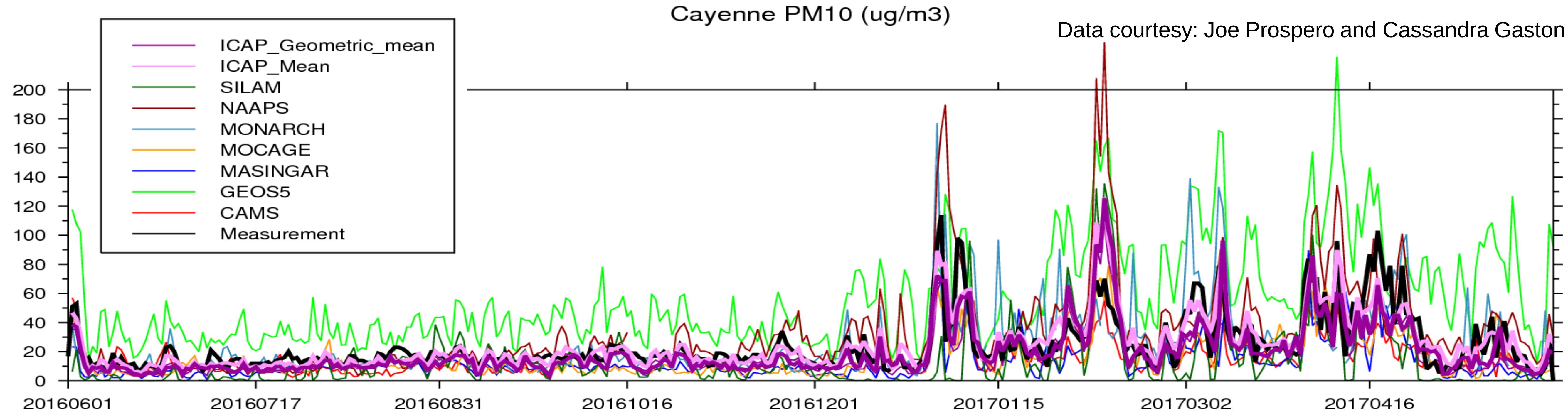
Preliminary verification result on PM10: receptor site of African Dust in NNE coast of S. America

Data courtesy: Joe Prospero and Cassandra Gaston



One-day forecast

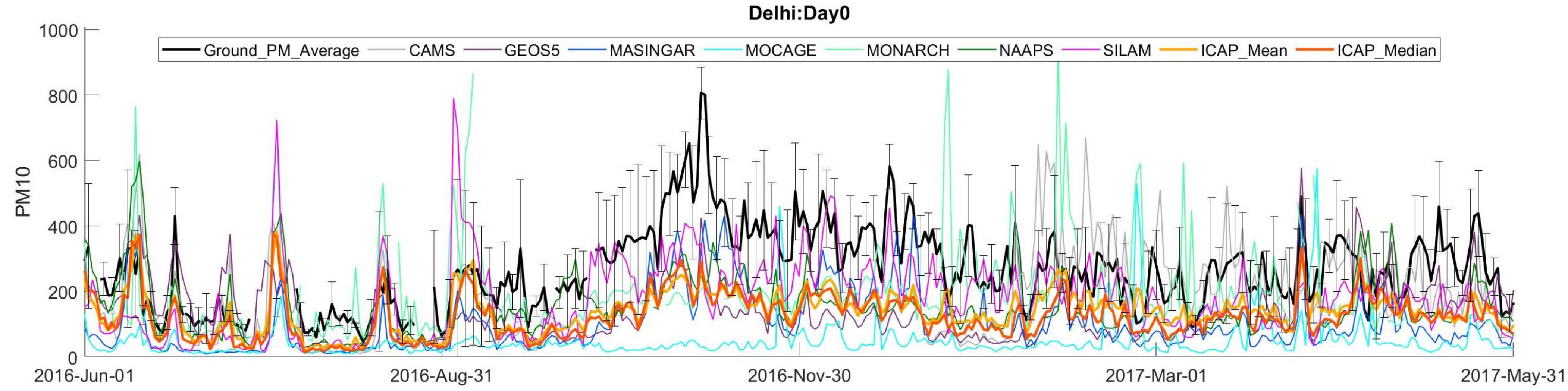
CAMS	bias=	-10.6rmse=	16.3r2=	0.65
GEOS5	bias=	32.7rmse=	41.5r2=	0.49
MASINGAR	bias=	-9.0rmse=	16.0r2=	0.54
MOCAGE	bias=	-8.2rmse=	15.2r2=	0.54
MONARCH	bias=	0.9rmse=	18.3r2=	0.41
NAAPS	bias=	8.2rmse=	23.8r2=	0.51
SILAM	bias=	-10.5rmse=	20.8r2=	0.35
ICAP_Mean	bias=	0.9rmse=	10.8r2=	0.69
ICAP_Medianbias=		-4.6rmse=	12.7r2=	0.62
ICAP_Geomebias=		-5.9rmse=	12.5r2=	0.66

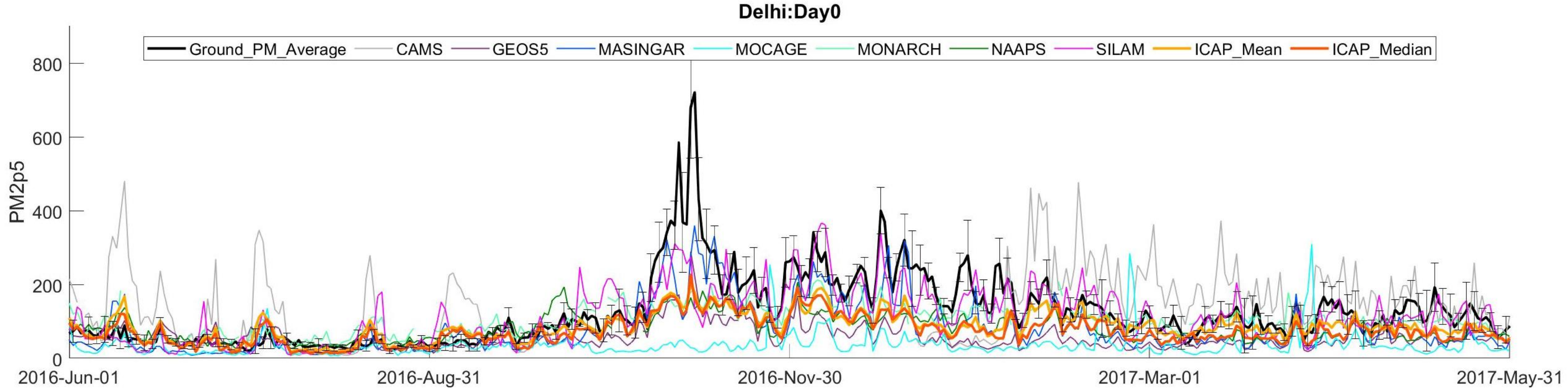
3-day forecast

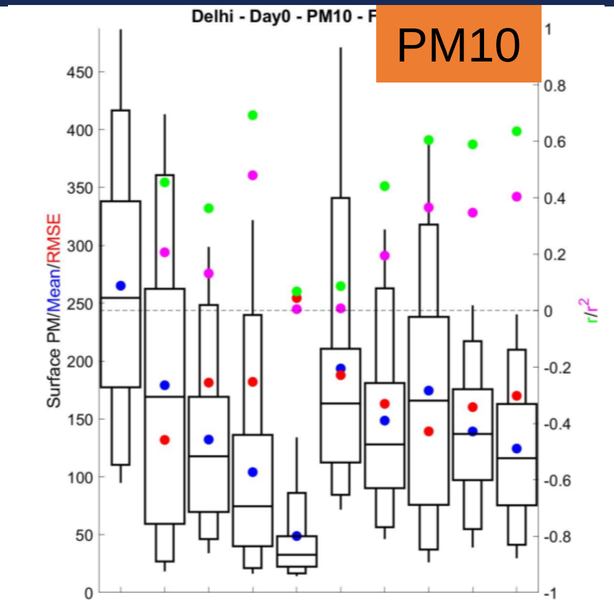
CAMS	bias=	-15.5rmse=	23.3r2=	0.28
GEOS5	bias=	33.2rmse=	44.7r2=	0.46
MASINGAR	bias=	-9.2rmse=	20.8r2=	0.24
MOCAGE	bias=	-8.5rmse=	18.1r2=	0.31
MONARCH	bias=	9.1rmse=	51.5r2=	0.07
NAAPS	bias=	1.9rmse=	21.1r2=	0.33
SILAM	bias=	-11.4rmse=	24.9r2=	0.16
ICAP_Mean	bias=	0.4rmse=	15.8r2=	0.41
ICAP_Medianbias=		-6.2rmse=	17.8r2=	0.32
ICAP_Geomebias=		-7.9rmse=	16.7r2=	0.40

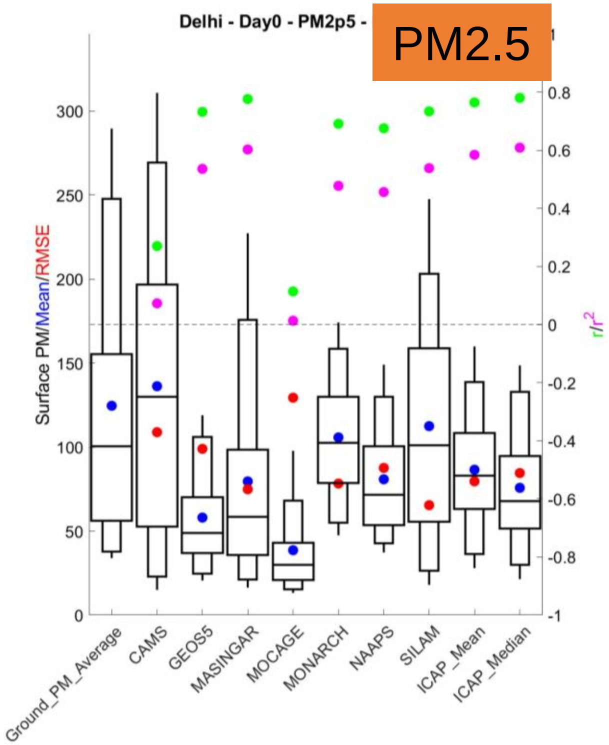
- ➢ Models capture the annual variations and magnitude of PM10 to various extent.
- ➢ ICAP MME consensus ranks the 1st.

Preliminary verification result on PMs
Delhi, India : mixed dust and pollution









- Consistent low bias for winter pollutions.
- Seemingly too much fine dust in some model.

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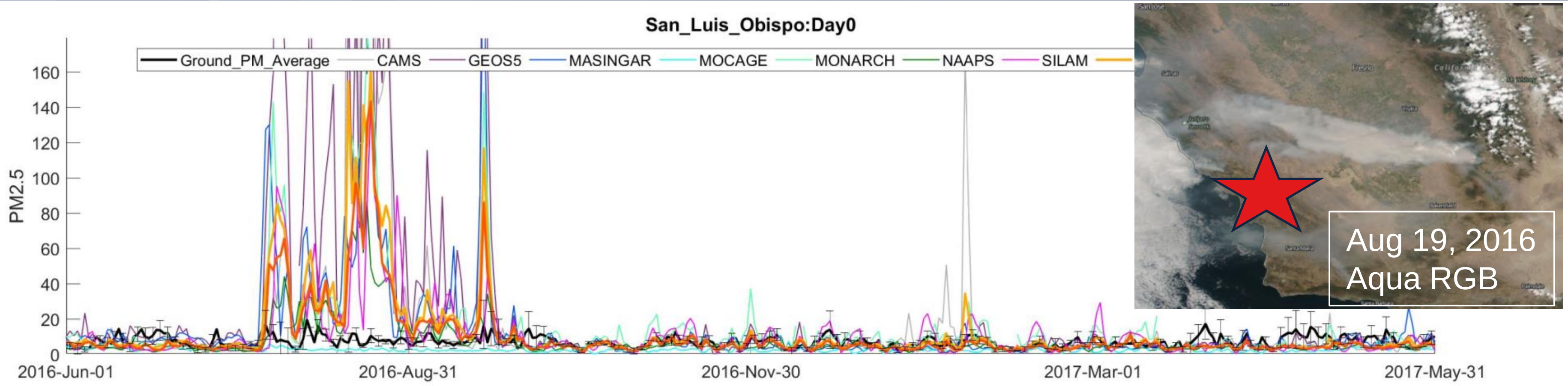
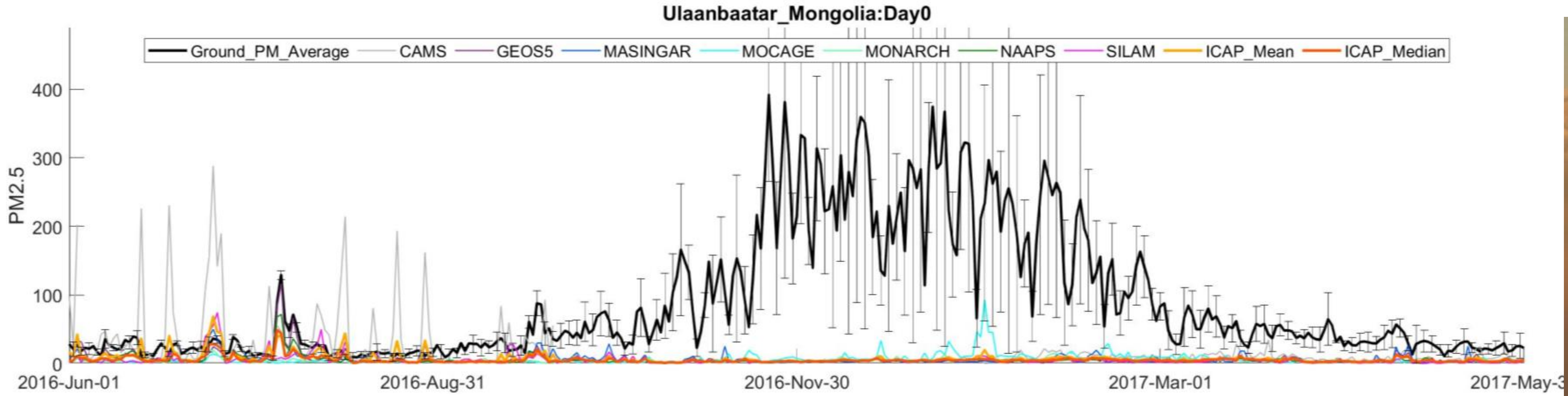
Challenges for models in surface PM simulation

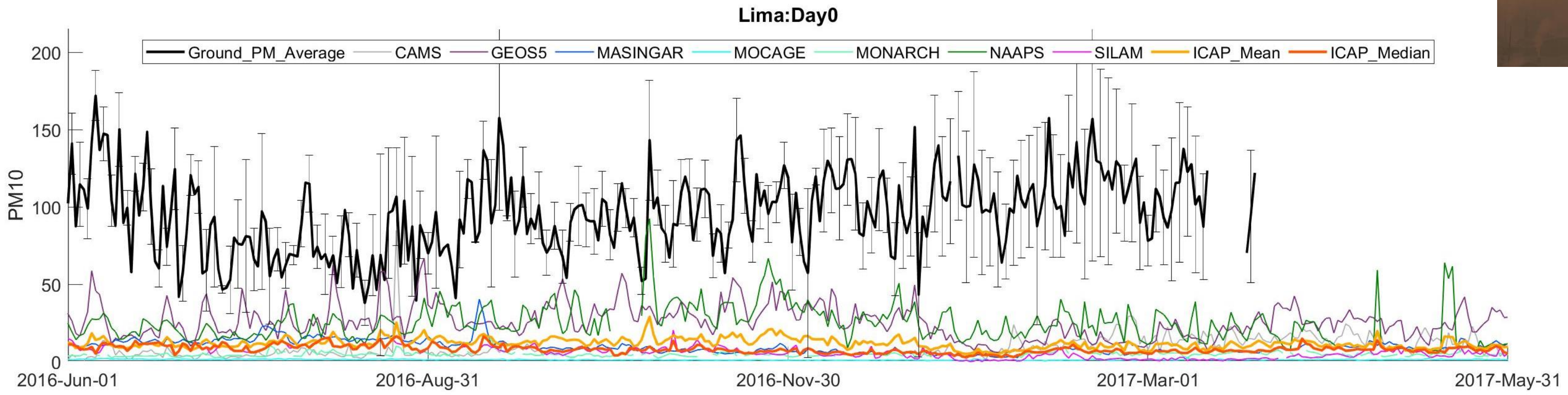


Models put too much biomass-burning smoke into the boundary layer and surface.

Challenges in simulating PBL processes and PBL height, inversion, topography effects. Also very possible of high biased biomass-burning emission and incorrect emission height.



Lack of anthropogenic emissions in emission inventories.



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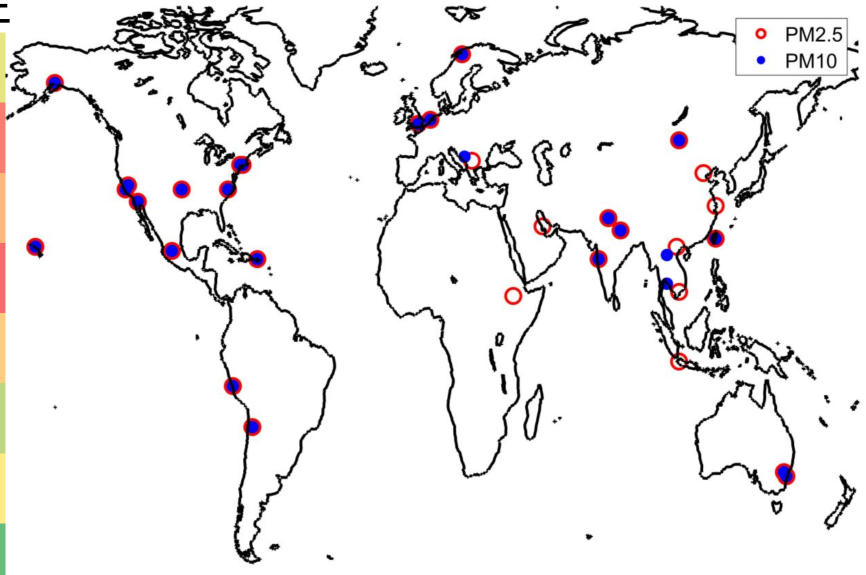
Rankings of all models in terms of PM2.5 and PM10 RMSE

MODELS	ranking w.r.t. RMSE of PM2.5 3-day forecst																														AVE
CAMS	4	9	8	6	6	1	2	8	7	8	9	6	8	9	8	3	7	2	8	7	2	8	8	8	1	7	4	8	8	8	1	6.1
GEOS5	7	7	2	8	3	6	6	4	5	9	4	8	7	8	7	9	5	4	7	8	9	5	4	7	6	8	3	7	4	3	5	6.0
MASINGAR	8	8	1	4	2	3	5	9	4	4	7	9	9	5	4	8	9	8	5	4	4	4	3	6	7	5	7	4	9	9	7	5.8
MOCAGE	9	5	9	5	9	5	4	7	9	1	8	1	1	6	5	4	8	7	9	9	8	6	6	4	2	6	9	6	2	6	8	5.9
MONARCH	3	3	3	3	8	9	9	5	8	7	1	7	6	7	2	6	6	9	6	2	3	9	9	9	8	9	8	9	5	5	9	6.2
NAAPS	1	4	7	9	1	7	7	1	1	2	2	3	3	3	9	2	1	6	1	6	7	7	1	1	3	3	5	3	7	7	4	4.0
SILAM	6	6	5	7	7	8	8	6	6	5	6	2	4	1	6	1	4	3	4	1	1	2	7	5	9	4	6	5	3	4	6	4.8
ICAP_Mean	2	1	6	2	4	4	3	2	3	6	3	4	2	2	1	5	3	5	2	3	5	3	5	3	4	2	1	2	6	2	2	3.2
ICAP_Median	5	2	4	1	5	2	1	3	2	3	5	5	5	4	3	7	2	1	3	5	6	1	2	2	5	1	2	1	1	1	3	3.0

Green is better.

MODELS	ranking w.r.t. RMSE of PM10 analysis																									AVE
CAMS	6	4	5	2	5	9	3	3	4	5	6	9	9	7	1	4	2	1	1	5	9	1	4	9	7	4	4.8
GEOS5	2	8	2	7	9	8	4	9	8	2	8	2	8	9	9	5	8	6	8	8	6	3	8	3	9	6	6.3
MASINGAR	9	3	4	1	7	6	9	4	2	7	9	7	6	1	7	6	6	7	7	7	5	7	6	6	1	8	5.7
MOCAGE	8	6	9	4	8	3	8	8	9	9	2	8	5	4	5	7	9	9	9	6	4	8	3	7	4	9	6.6
MONARCH	3	7	8	9	6	7	6	7	1	8	5	4	4	3	8	9	5	8	6	3	1	9	7	4	3	1	5.5
NAAPS	1	9	1	6	2	1	1	5	7	1	7	1	7	8	2	2	4	4	3	1	8	2	9	8	8	2	4.2
SILAM	7	5	7	8	4	4	7	6	6	3	1	6	1	5	4	8	7	2	2	9	2	6	5	5	6	7	5.1
ICAP_Mean	4	2	3	5	1	5	2	1	3	4	3	3	2	6	3	1	1	3	4	2	7	4	1	1	5	3	3.0
ICAP_Median	5	1	6	3	3	2	5	2	5	6	4	5	3	2	6	3	3	5	5	4	3	5	2	2	2	5	3.7

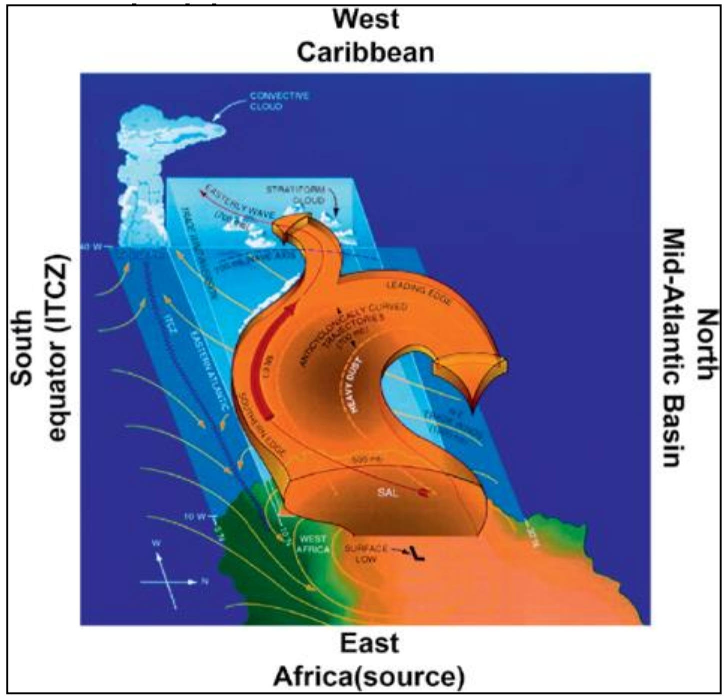
sites of interest



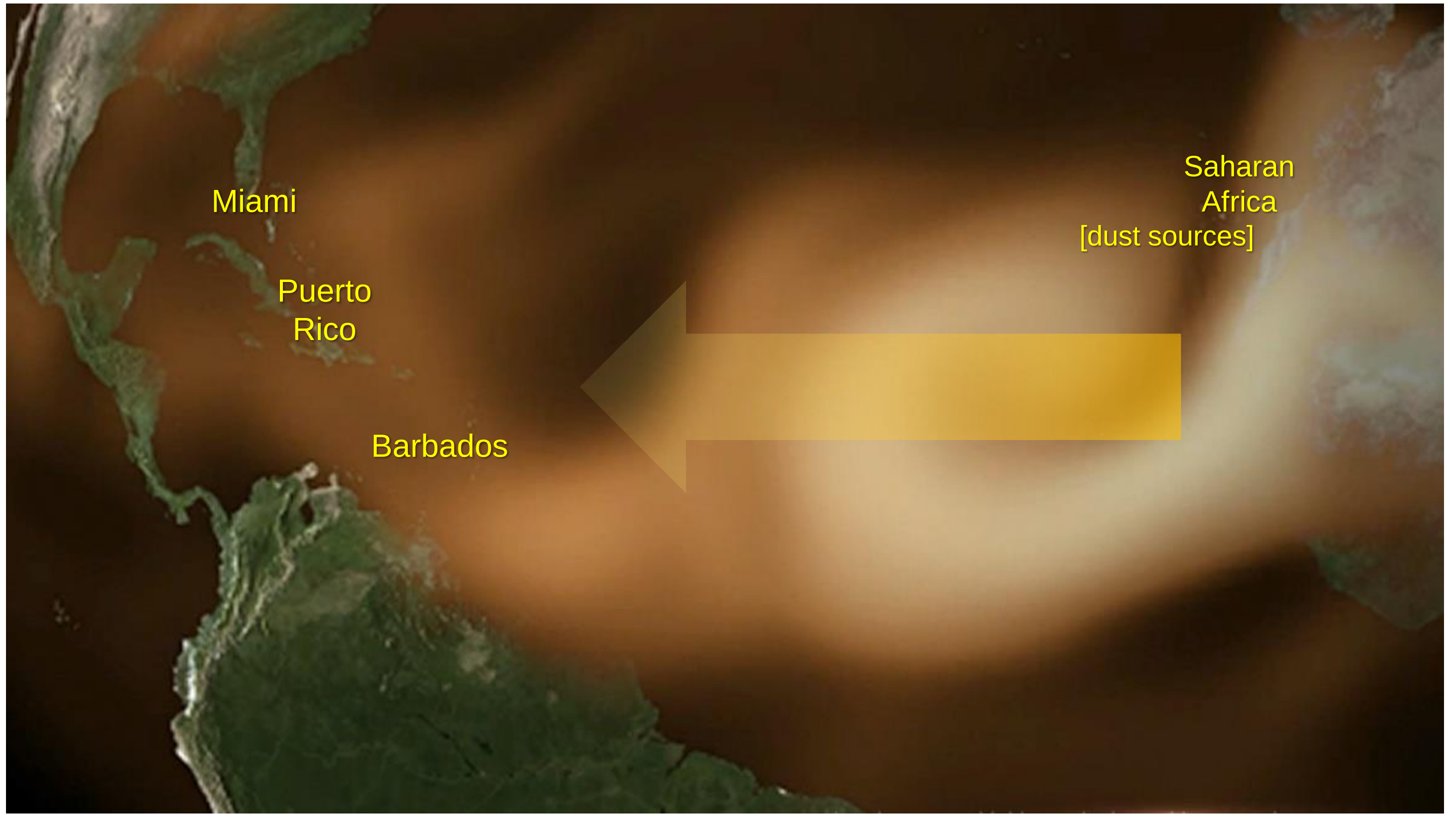
ICAP supporting 3 year NRL African dust project over the Greater Caribbean

Potential ICAP support for the Caribbean communities

- Provides skillful depictions and predictions of African dust transport over the tropical Atlantic basin
- Potentially valuable resource for air quality & fire hazard prediction throughout Caribbean
- Recently requested by Hurricane Research Division (HRD), Miami and WFOs throughout



courtesy: Karyampudi and Carlson (1988)



ICAP applications for CY 2019:

- Saharan Air Layer/African dust forecasting at NWS, San Juan, PR
  - ongoing training webinars to NWS WFOs in FL and Caribbean
- WMO Pan American Sand and dust storm Warning Advisory and assessment system
  - Caribbean node
- GOES-16, JPSS and GEONETCast Americas Satellite Workshop & training, Barbados, July 2019
- NASA-ROSES project : African dust, health and air quality

Summary

- ICAP now includes 8 multi specie and 1 dust only models.
- ICAP-MME AOD update paper published on QJRMS, 2019. Key results: https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/qj.3497
  - ICAP-MME performance is stable and reliable over the years compared to individual models. Consensus MME wins in the long run because of its averaging of independent models.
  - ICAP-MME performance in terms of modal AOD RMSEs of the 21 regionally representative sites over 2012-2017 suggests a general tendency for model improvements in fine-mode AOD, especially over Asia. No significant improvement in coarse-mode AOD is found overall for this time period.
- Preliminary verification on PM2.5 and PM10 shows
  - More challenges in surface PM than column AOD simulations for the ICAP models.
  - Compared to AOD, PM2.5 and PM10 have larger divergence among the models, including the AOD-DA models.
  - Regarding PM2.5 and PM10, ICAP-MME is still the top performer among all models.

Extra slide : PM2.5 RMSE of models at analysis time

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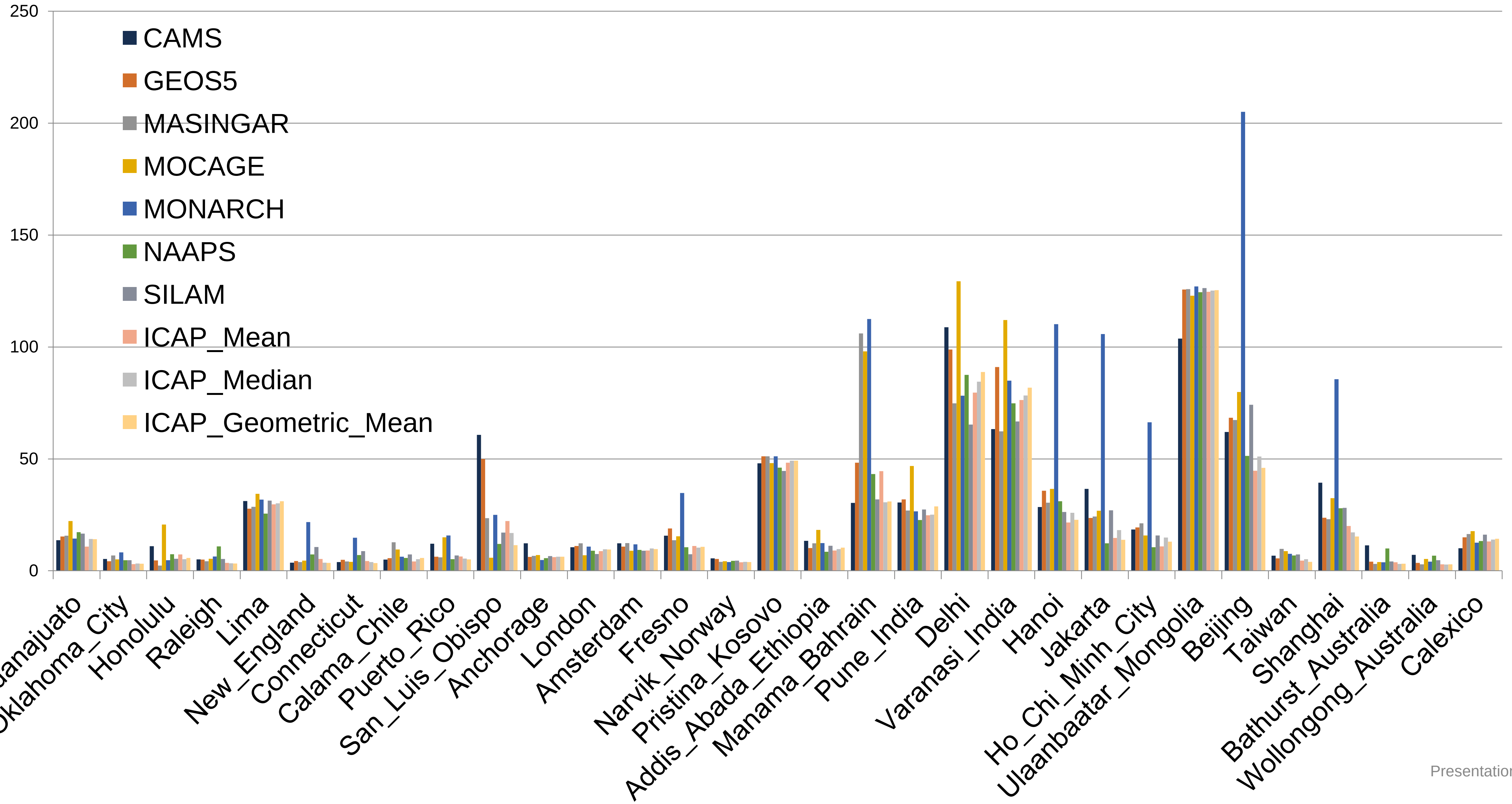
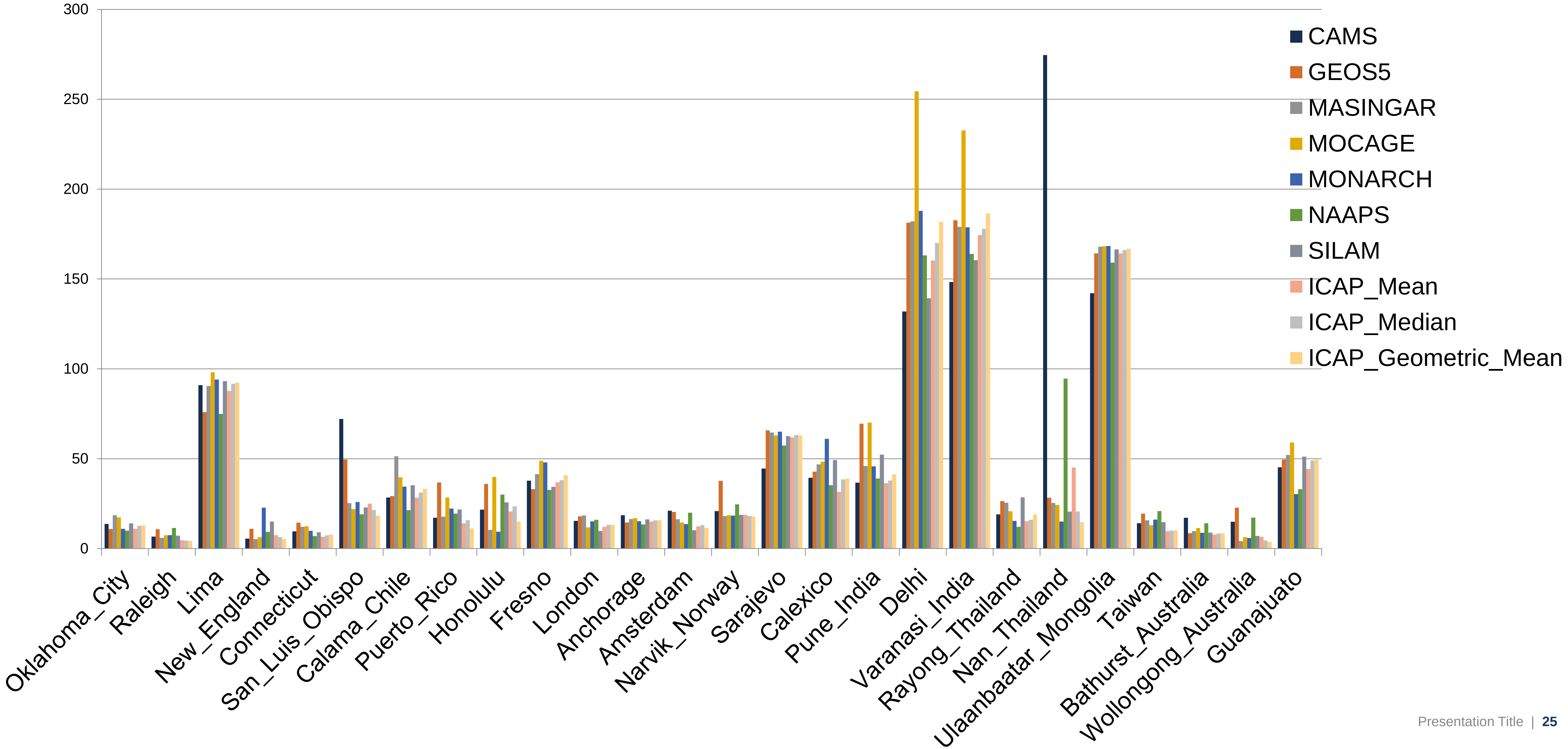


PM10 RMSE of models at analysis time



PM data availability from models for the study period