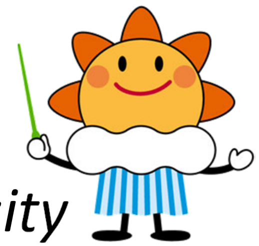
Current development status of aerosol data assimilation and forecasting system at JMA

[1)]Akinori Ogi, [1)]Takanori Matsumoto, [1)]Shokichi Yabu, [1)]Toshiyuki Kitajima
[2)]Taichu Y. Tanaka, [3)]Keiya Yumimoto, [2)]Thomas T. Sekiyama, [2)]Takashi Maki

1) Japan Meteorological Agency
2) Meteorological Research Institute
3) Research Institute for Applied Mechanics, Kyushu University



22 July 2019
11th ICAP Working Group Meeting
@ Tsukuba International Congress Center

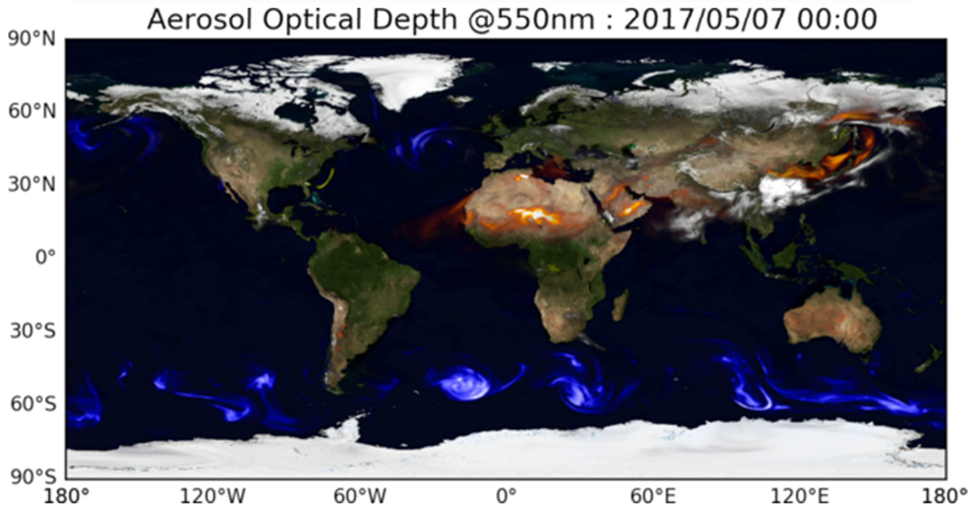
Outline

- Current development status of aerosol data assimilation and forecasting system using Himawari-8/9 data
- Verification of aerosol prediction mainly focused on Asian dust prediction
- Future development plans
- Summary

JMA Asian dust Information

JMA has been providing Asian dust information based on numerical forecasts and observations since January 2004.

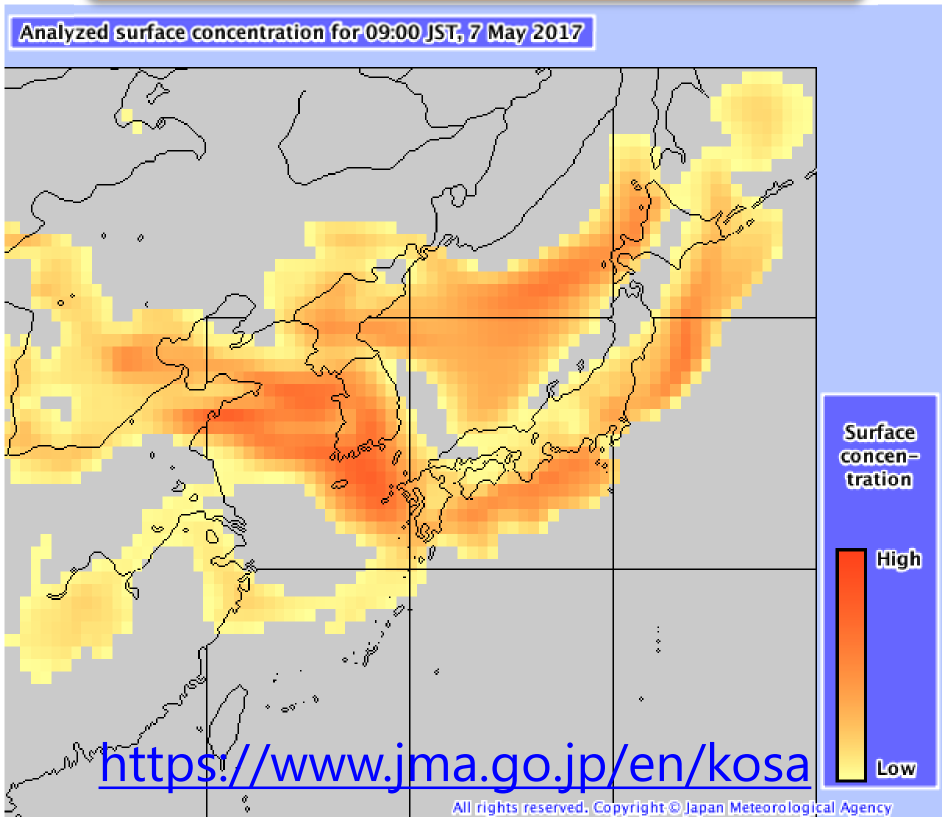
Global aerosol model MASINGAR



Research & Development in MRI/JMA

- **JAXA Himawari monitor**
- **ICAP**
- **JRAero**
- **CMIP6, CCMI …**

JMA Asian dust prediction



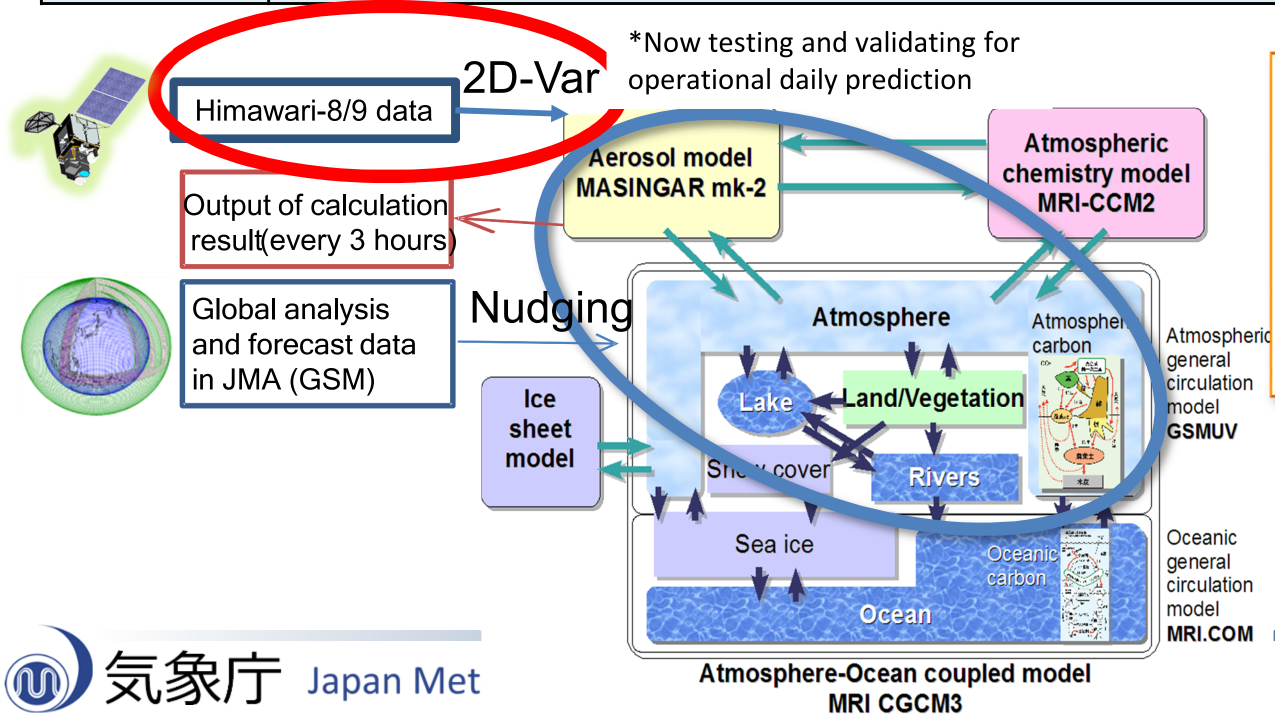
- **Asian dust advisory information**
- **WMO SDS-WAS Asian Node**

JMA also provides Asian dust prediction results (GPV : GRIB2 format) for private weather services via the Japan Meteorological Business Support Center (JMBSC).

Outline of the current global aerosol forecast model (MASINGAR mk-2)

Resolution	TL479L40 Horizontal 40km, Vertical 40 layers (Surface – 0.4hPa)
Types of aerosols	10 bins of dust (0.2 - 20μm), 10 bins of sea salt (0.2 – 20μm), Sulfate, Organic carbon, Black carbon
Dust emission process	depend on Particle size, Vegetation, Surface condition (Soil moisture, Snow depth etc..) and Surface wind speed
Dust deposition Process	Gravity (Dry deposition), Removal due to clouds and rain (Wet deposition)
Dynamical model	MRI-AGCM3 (GSMUV)
Calculation interval	Once a day (12UTC initial)
Forecast period	5 days (120 hours)

The **MRI-ESM** aims to improve climate change projection reliability and contribute to the understanding of the climate system. We apply this system to the daily aerosol prediction in JMA.



In our daily forecasting system, we're combining the atmospheric general circulation model (GSMUV) with the global aerosol forecast model (MASINGAR mk-2).

Dust emission flux
Function of the surface friction velocity

Current development status of Himawari-8/9 aerosol data assimilation

- Near Real-Time 2D-Var AOD data assimilation
  - We plan to introduce 2D-Var aerosol data assimilation method (Yumimoto et al., 2017) for operational dust prediction.
  - We're using Himawari-8/9 AOD data by JAXA/EORC retrieval method (L2:Ver.2.1, L3:Ver.3) (Yoshida et al., 2018, Kikuchi et al., 2018) as observation data.
  - Various QA/QC of observation data (e.g., coast mask, Angstrom Exponent, etc.) have been applied.

- Investigations of the observation and background errors for the AOD data assimilation
  - We have calculated the statistical errors by comparing Himawari-8/9 and MODIS AOD data to estimate the observation errors.

Aerosol data assimilation method based on 2D-Var

In AOD assimilation, we define the cost function with AOD (2D-Var)

$$J(\tau)=\frac{1}{2}(\tau-\tau^f)^T\mathbf{P}^{-1}(\tau-\tau^f)+\frac{1}{2}(\mathbf{H}\tau-\tau^o)^T\mathbf{R}^{-1}(\mathbf{H}\tau-\tau^o) \quad (1')$$

$\boldsymbol{\tau}^f$: first guess $\quad$ $\boldsymbol{\tau}^o$: observation

$$\Delta\tau=\tau^a-\tau^f=\mathbf{PH}^T\left(\mathbf{R}+\mathbf{HPH}^T\right)^{-1}\left(\tau^o-\mathbf{H}\tau^f\right)=\mathbf{K}\left(\tau^o-\mathbf{H}\tau^f\right) \quad (4')$$

P: background error covariance $\quad$ **R**: observation error covariance

$\Delta\boldsymbol{\tau}$: increment of AOD $\quad$ $\boldsymbol{\tau}^a$: analysis

1) Increment of AOD → Increment of AOD of each aerosol component

$$\Delta\tau_{DS01}=\Delta\tau\frac{\tau^f_{DS01}}{\tau^f}$$

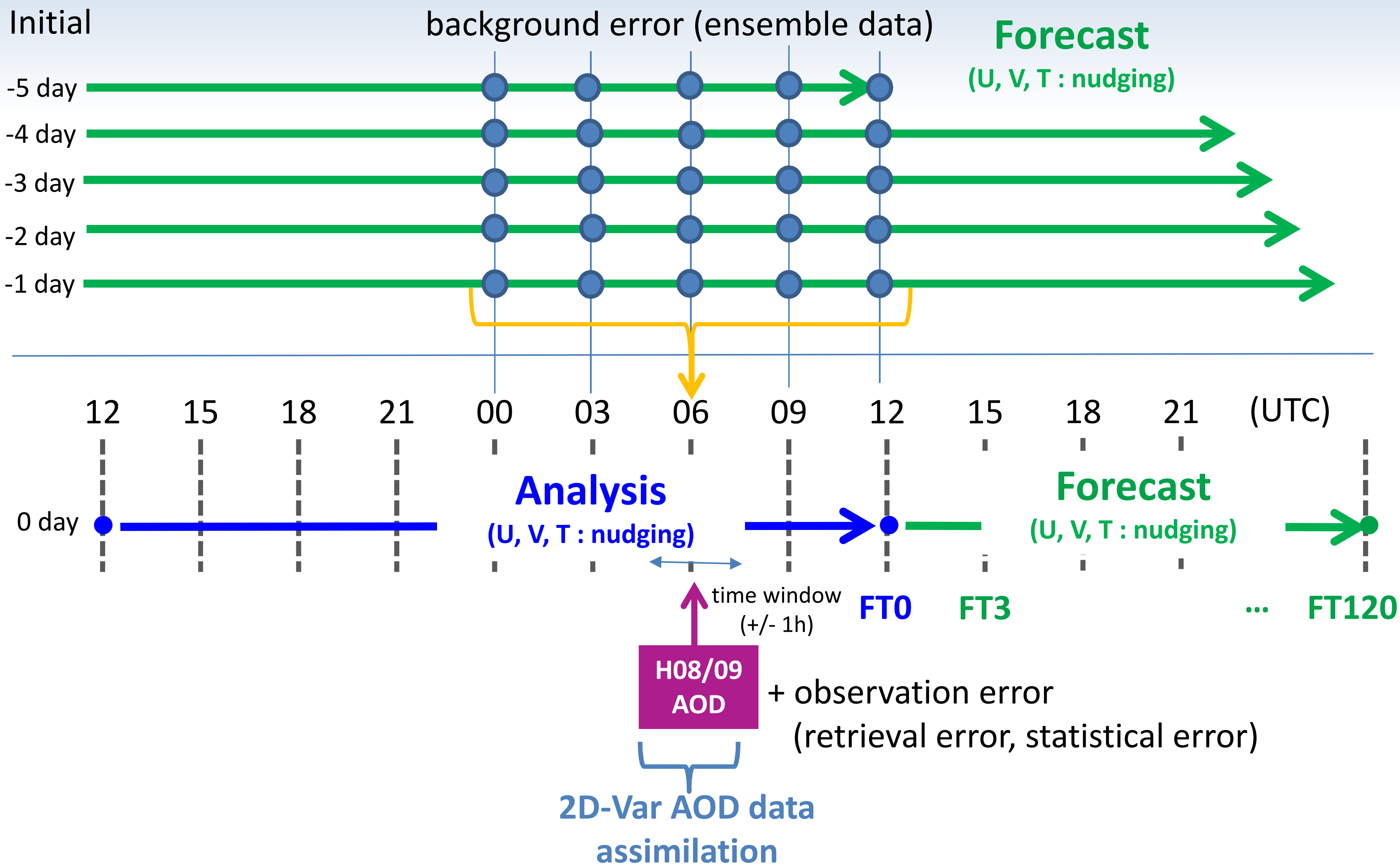
2) Increment of AOD of each aerosol → Increment of EXT of each aerosol component

3) Increment of EXT of each aerosol → Increment of mass of each aerosol component

$$\Delta x_k=\frac{x_k^f}{\alpha_k^f}\Delta\alpha_k=\frac{x_k^f}{\alpha_k^f}\frac{\alpha_k^f}{\tau^f}\Delta\tau \qquad \left(\Delta\alpha_k=\frac{\alpha_k^f}{\tau^f}\Delta\tau\right)$$

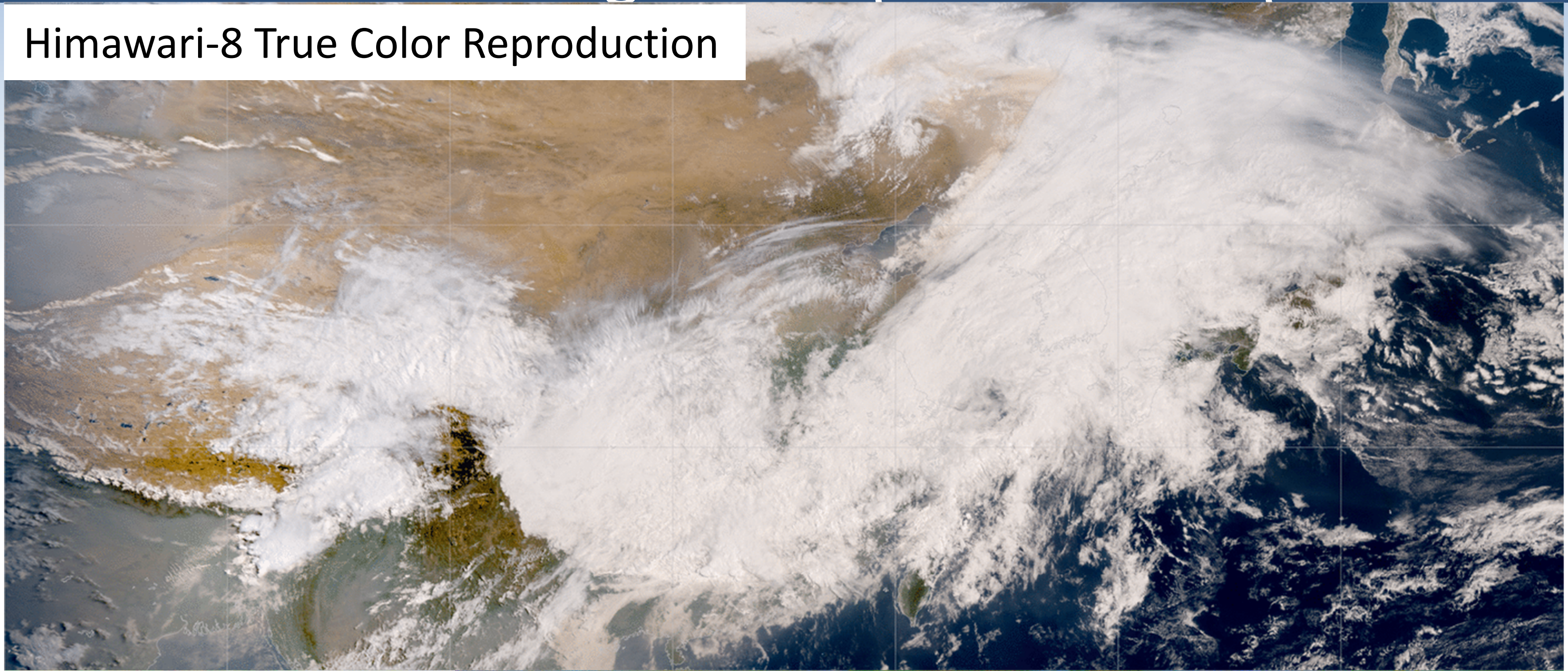
$\boldsymbol{\alpha}^f$: first guess (extinction) $\quad$ $\mathbf{x}^f$: first guess (mass mixing ratio)

Aerosol data assimilation and forecasting system

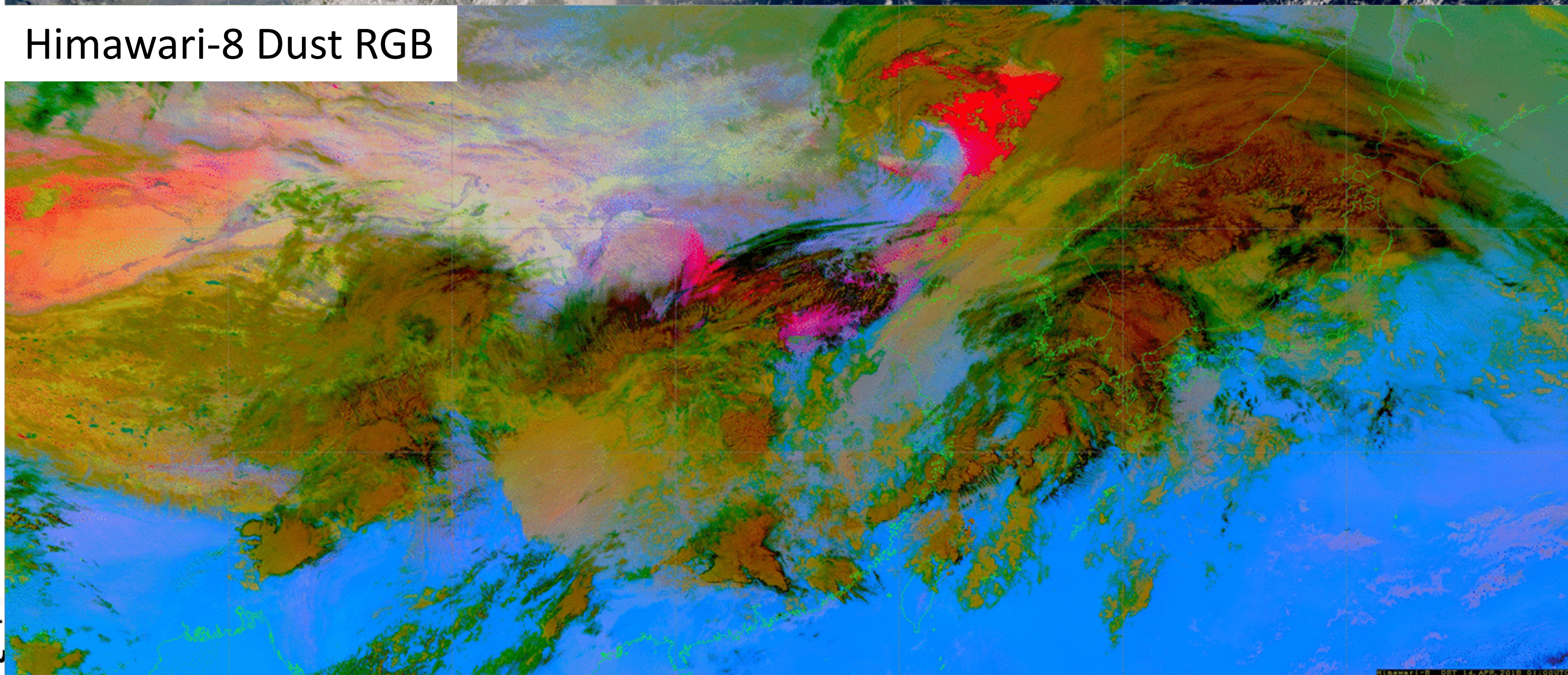


Asian dust flowing over Japan: 14-16 Apr. 2018

Himawari-8 True Color Reproduction

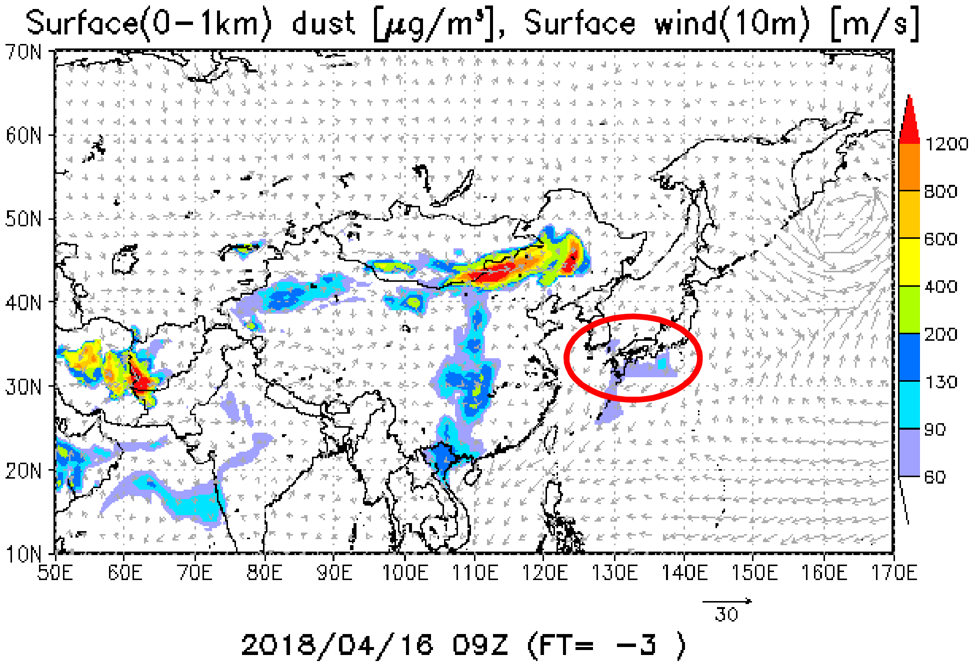


Himawari-8 Dust RGB

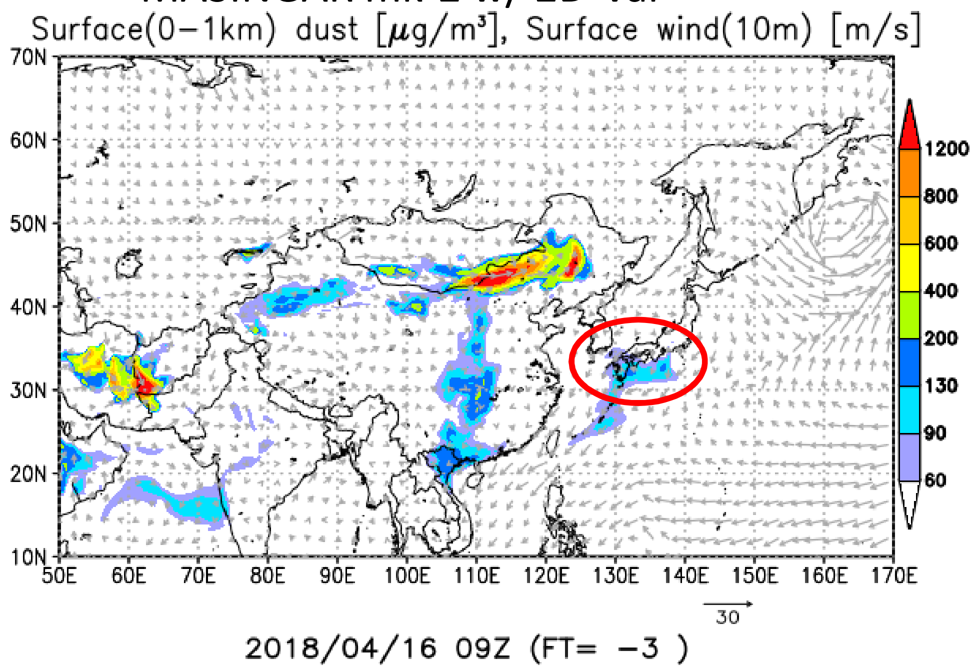


Case study for verification of dust prediction (20180416 09Z)

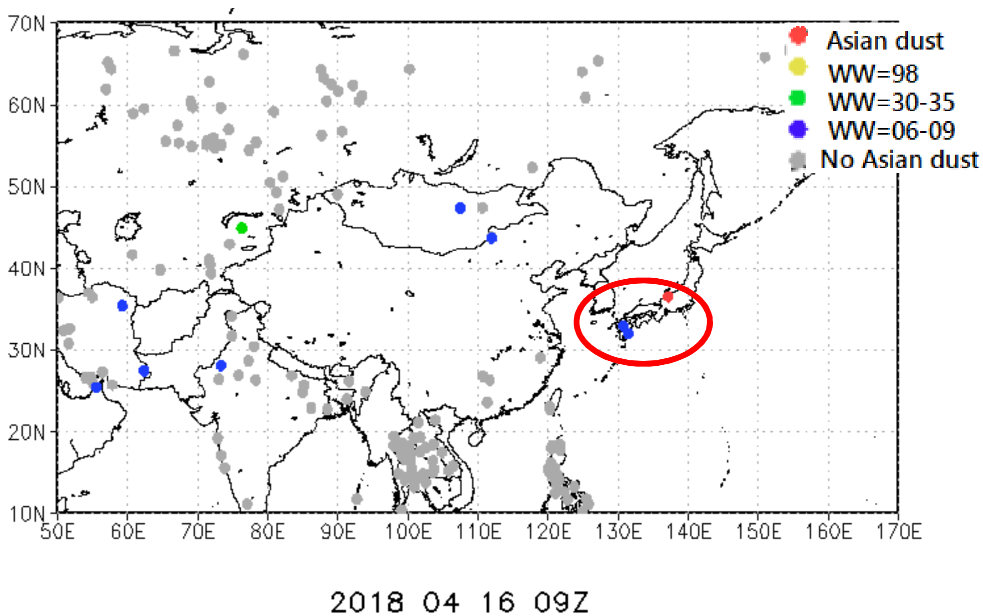
MASINGAR mk-2



MASINGAR mk-2 w/ 2D-Var

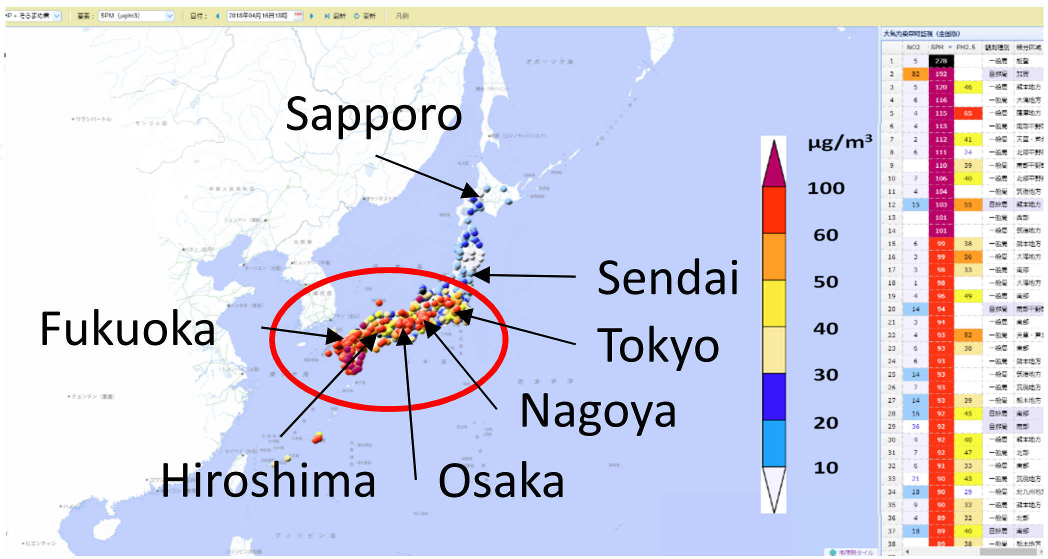


SYNOP



2018 04 16 09Z

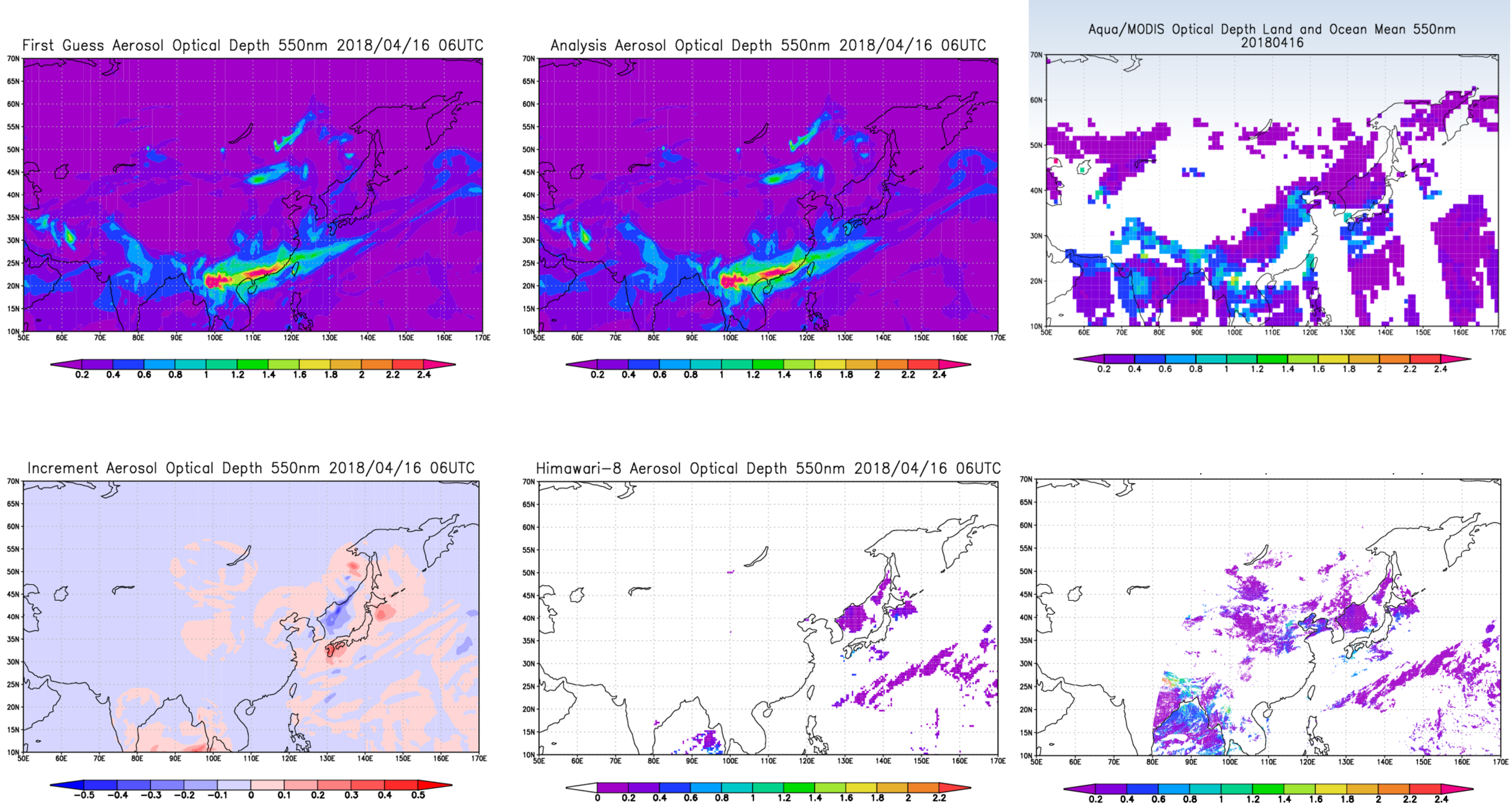
SPM(Suspended Particulate Matter)



2018.04.16 09Z

Atmospheric Environmental Regional Observation System : AEROS

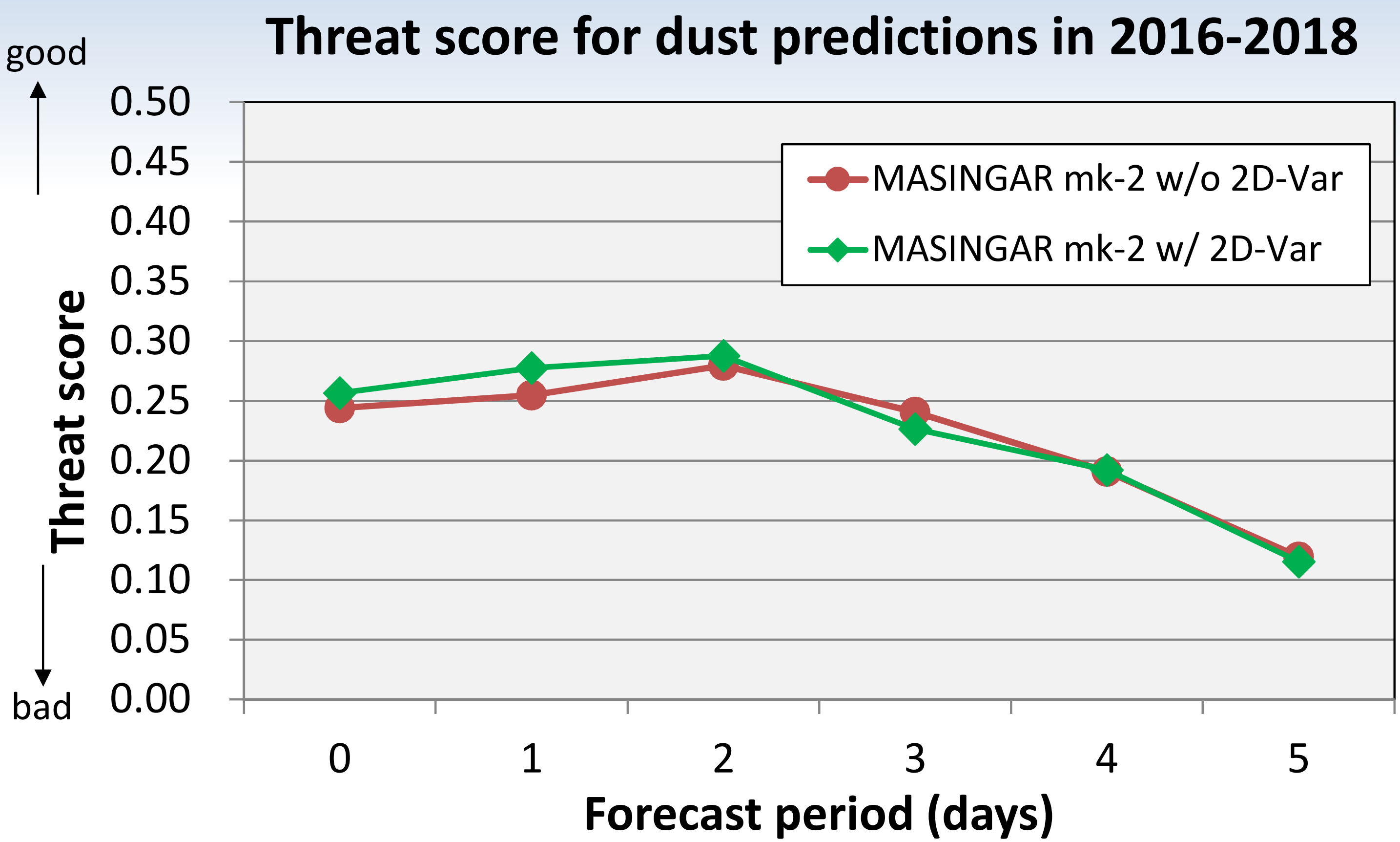
Case study for verification of dust prediction (Assimilation date and time : 20180416 06Z)



(QA/QC and regridded data) (raw data)

The assimilation result is consistent well with the MODIS AOD distribution.

Statistical verification for dust predictions against SYNOP observations



$$\text{Threat Score} = \frac{FO}{FO + FX + XO}$$

$$\text{Hit Rate} = \frac{FO}{FO + XO}$$

$$\text{False Alarm Ratio} = \frac{FX}{FO + FX}$$

$$\text{Percent Correct} = \frac{FO + XX}{FO + XO + FX + XX}$$

* Forecast threshold : 90 μg/m^3

Hit Rate	MASINGAR mk-2 w/o 2D-Var	MASINGAR mk-2 w/ 2D-Var
0 day	0.597	0.597
1 day	0.612	0.642
2 day	0.672	0.657
3 day	0.567	0.537
4 day	0.433	0.433
5 day	0.358	0.358

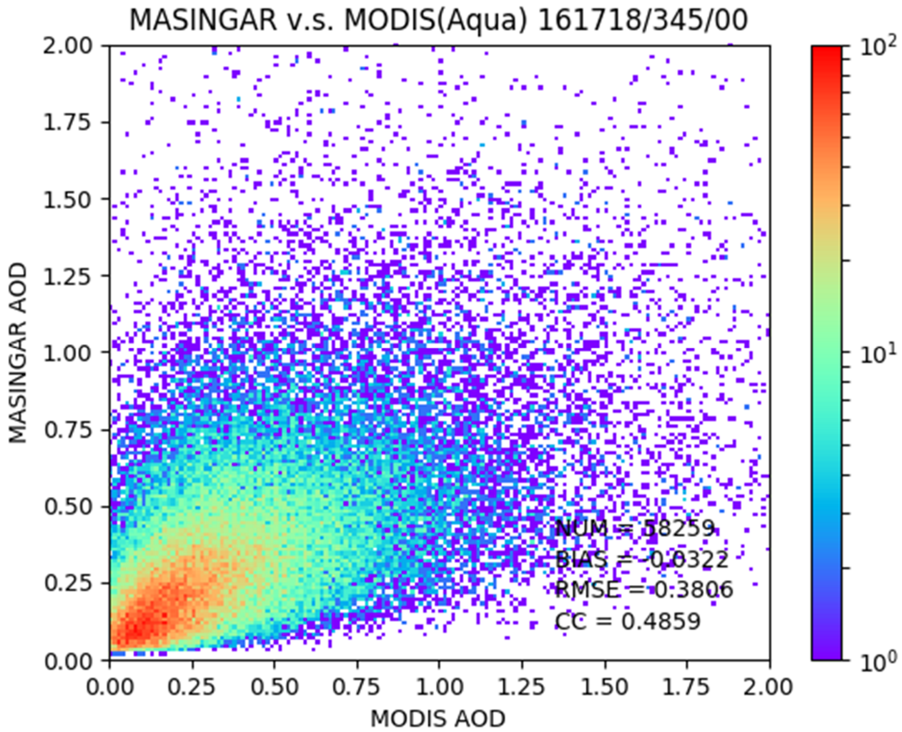
False Alarm Ratio	MASINGAR mk-2 w/o 2D-Var	MASINGAR mk-2 w/ 2D-Var
0 day	0.708	0.690
1 day	0.696	0.672
2 day	0.676	0.662
3 day	0.705	0.719
4 day	0.746	0.743
5 day	0.848	0.855

Percent Correct	MASINGAR mk-2 w/o 2D-Var	MASINGAR mk-2 w/ 2D-Var
0 day	0.979	0.981
1 day	0.980	0.981
2 day	0.981	0.982
3 day	0.980	0.980
4 day	0.980	0.980
5 day	0.971	0.969

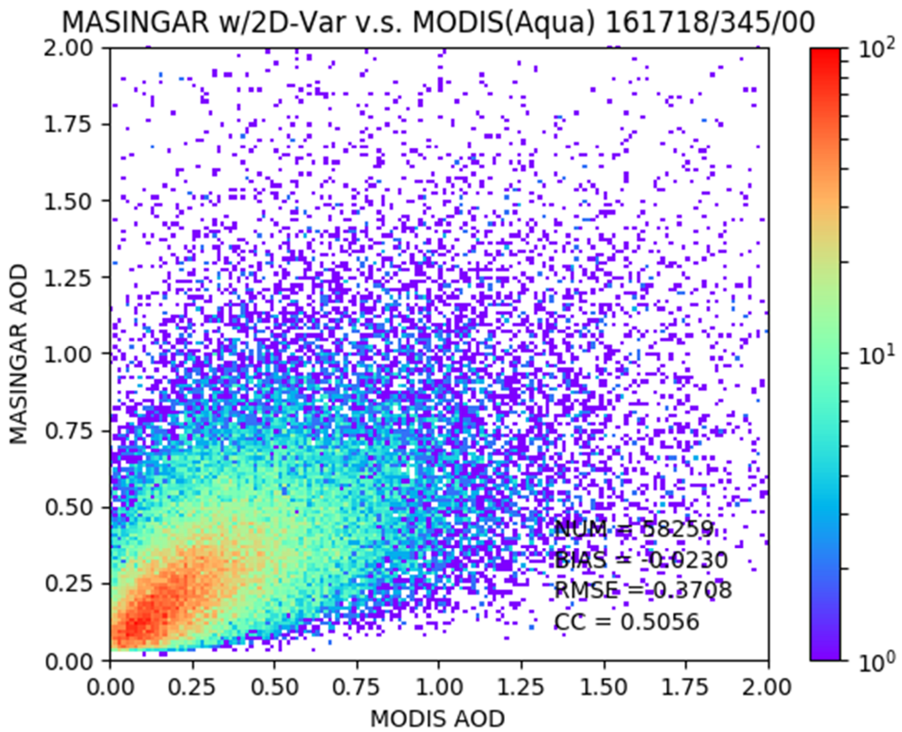
Model AOD predictions against MODIS observations

Land : Year 2016-2018, Month 03-05, 20-50°N, 110-150°E

w/o DA



w/ DA



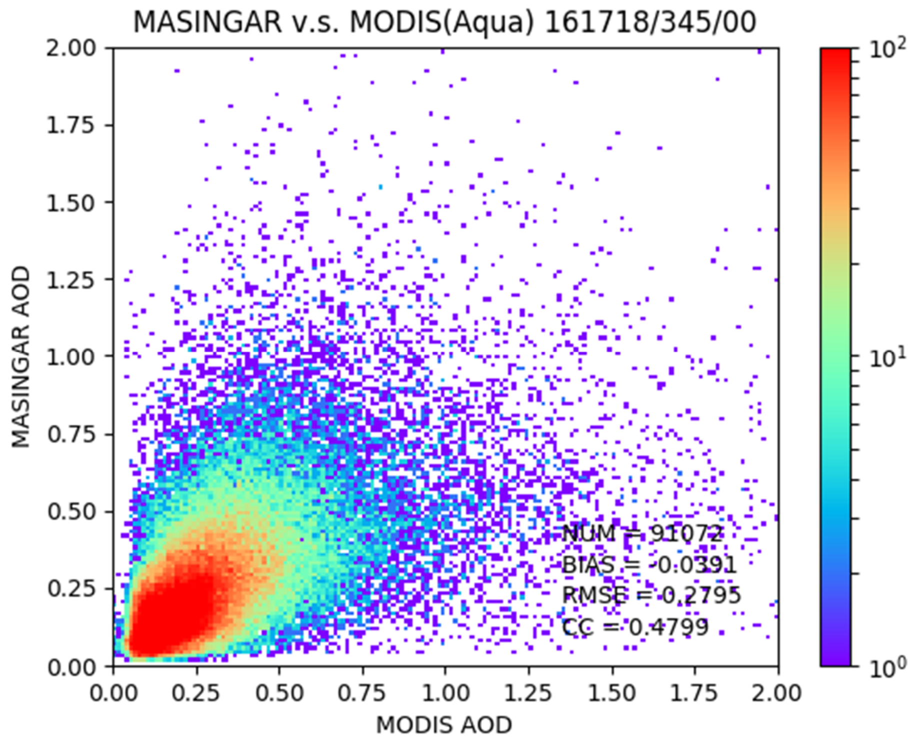
No data assimilation	Spring (Mar.-May.)	March	April	May
NUM	58259	14269	18790	25200
BIAS	-0.0322	-0.1481	-0.0071	0.0148
RMSE	0.3806	0.3761	0.3821	0.3820
CC	0.4859	0.5919	0.5327	0.4121

Data assimilation	Spring (Mar.-May.)	March	April	May
NUM	58259	14269	18790	25200
BIAS	-0.0230	-0.1326	0.0021	0.0204
RMSE	0.3708	0.3686	0.3778	0.3667
CC	0.5056	0.5996	0.5424	0.4391

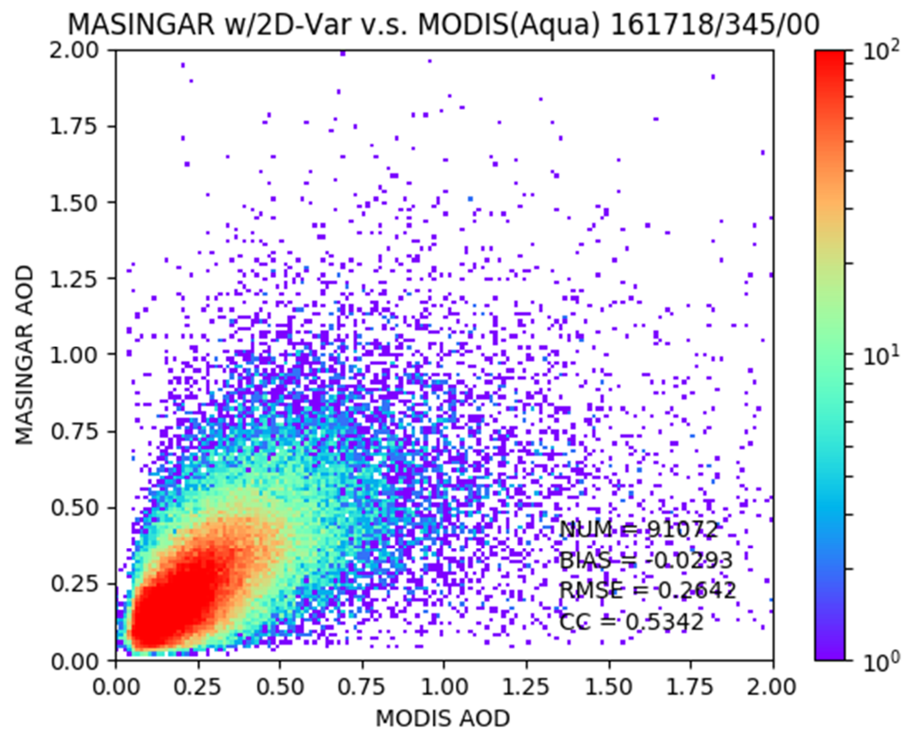
Model AOD predictions against MODIS observations

Ocean : Year 2016-2018, Month 03-05, 20-50°N, 110-150°E

w/o DA



w/ DA

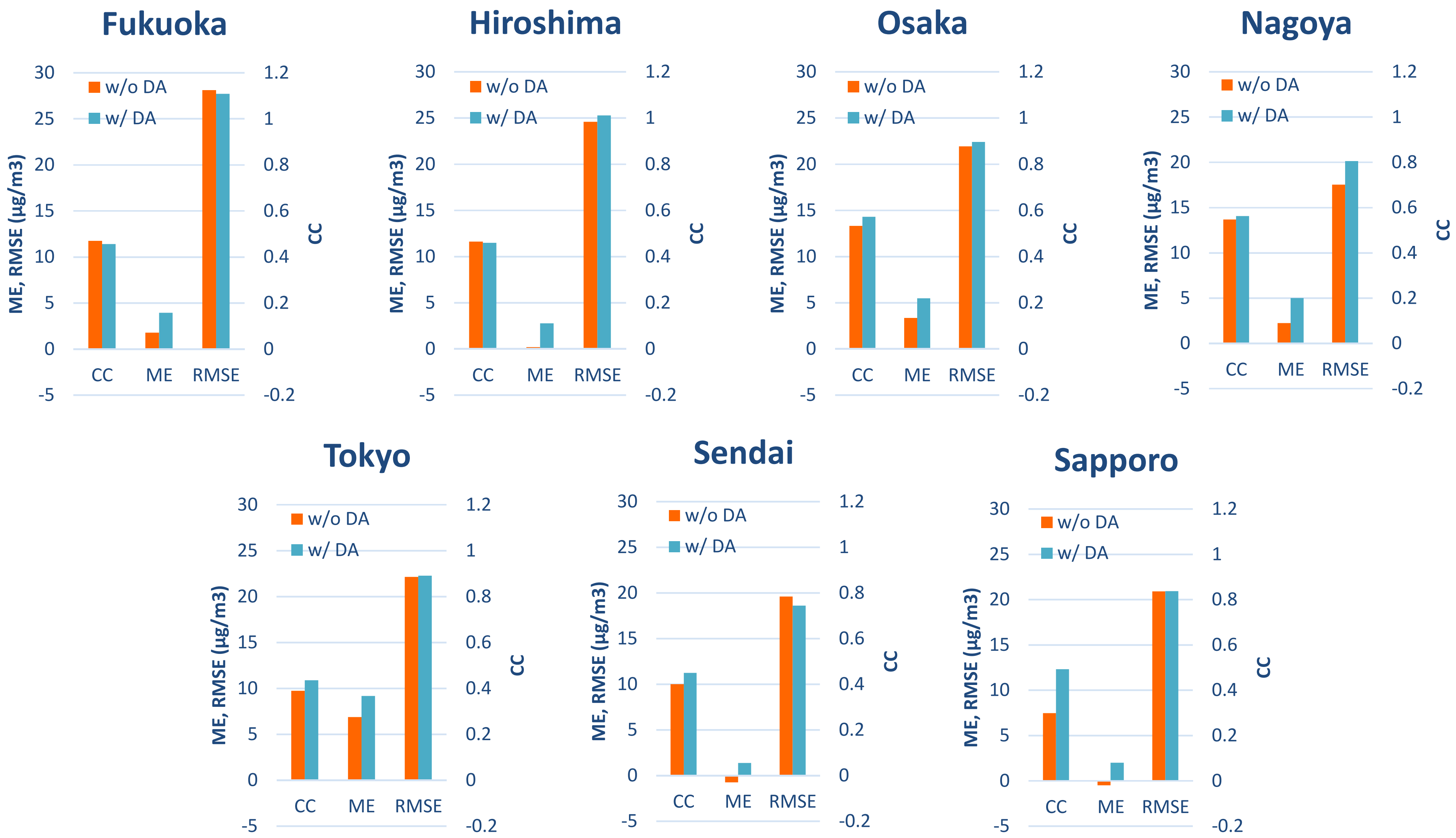


No data assimilation	Spring (Mar.-May.)	March	April	May
NUM	91072	35599	28233	27240
BIAS	-0.0391	-0.0982	-0.0046	0.0025
RMSE	0.2795	0.2755	0.3044	0.2567
CC	0.4799	0.5743	0.4448	0.4618

Data assimilation	Spring (Mar.-May.)	March	April	May
NUM	91072	35599	28233	27240
BIAS	-0.0293	-0.0773	-0.0030	0.0064
RMSE	0.2642	0.2621	0.2828	0.2465
CC	0.5342	0.6047	0.5066	0.5011

Modeled surface SPM concentrations against observations

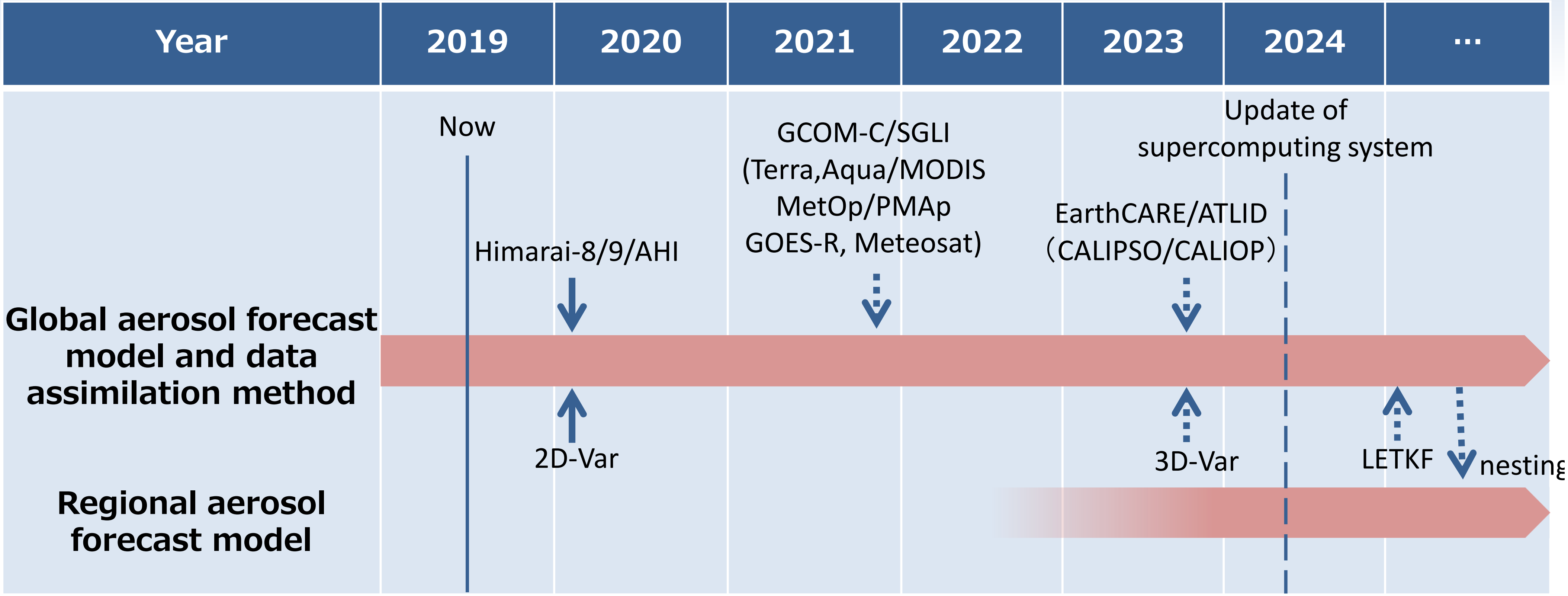
Average（Year:2016-2017, Month:03-05）



- CC values are improved at almost all of the stations.
- ME and RMSE values are slightly deteriorated at some stations.

*AEROS data are provided by Dr. Hayasaki.

Future development plans



- Next we’re planning to use GCOM-C data with Himawari-8/9 data to our aerosol data assimilation and forecasting system in few years.
- After that, we’re going to use EarthCARE data to improve forecast accuracy in the vertical direction applying 3D-Var or LETKF data assimilation method.

Summary

- The current global aerosol forecast model (MASINGAR mk-2 with TL479L40) has been used for operational dust prediction.

- JMA/MRI has been developing a 2D-Var aerosol data assimilation method using Himawari-8/9 data for operational dust prediction and we have evaluated its prediction accuracy.

- The statistical verification results show dust prediction is slightly improved by introducing the assimilation method and it can predict dust distributions better than the current system.

- The comparisons between the AOD, SPM observations and the model predictions indicate good performances.

- We are now testing the improved system so that we can upgrade the operational dust prediction hopefully from early 2020.

That is all for my presentation.
Thank you very much for your kind attention!