JMA/MRI/JAXA/KU Aerosol Model Activities Overview

MAKI Takashi*, SEKIYAMA Thomas T.*, OSHIMA Naga*,

KAMADA Akane†, YAMAGUCHI Haruki†, OGI Akinori†, TANAKA Taichu Y.†, YUMIMOTO Keiya$, Hiroshi Murakami#

**Meteorological Research Institute, Japan Meteorological Agency*
†Japan Meteorological Agency
$ Research Institute for Applied Mechanics, Kyushu University
 # Earth Observation Research Center, Japan Aerospace Exploration Agency

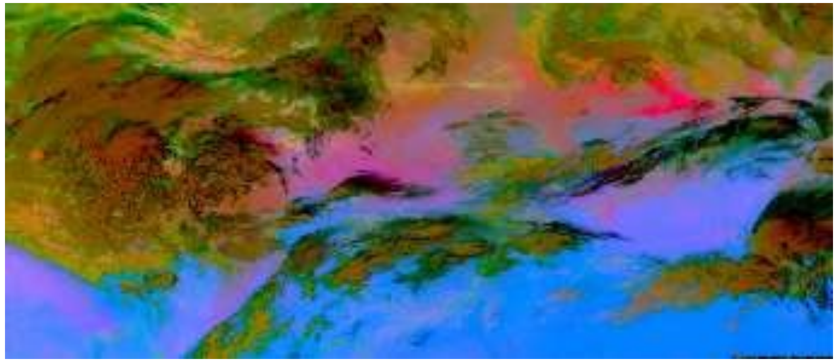
13th Technical Working Group Meeting, Darmstadt, 8 November 2023

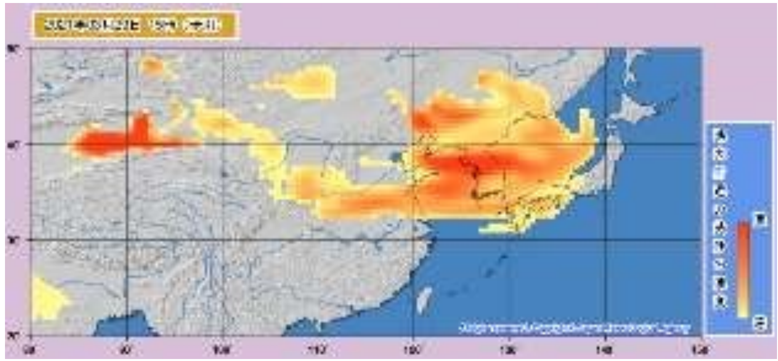
Outline

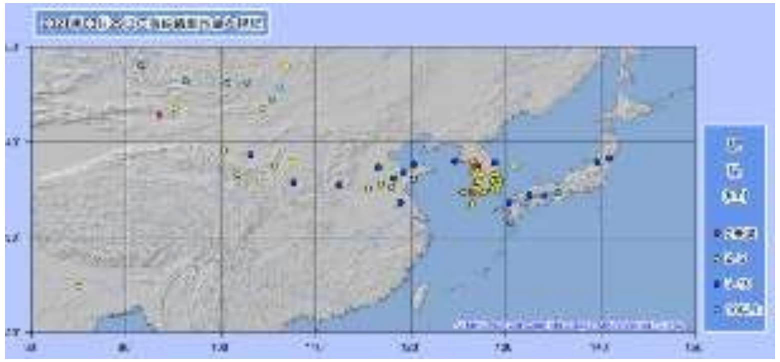
- **Updates of the JMA/MRI global aerosol model and data assimilation**
- **Integration of multiple satellite data through model assimilations with JAXA**
- **Summary**

JMA operational aeolian dust Information

JMA has been providing Aeolian dust information based on numerical forecasts and observations since January 2004 (http://www.jma.go.jp/en/kosa).





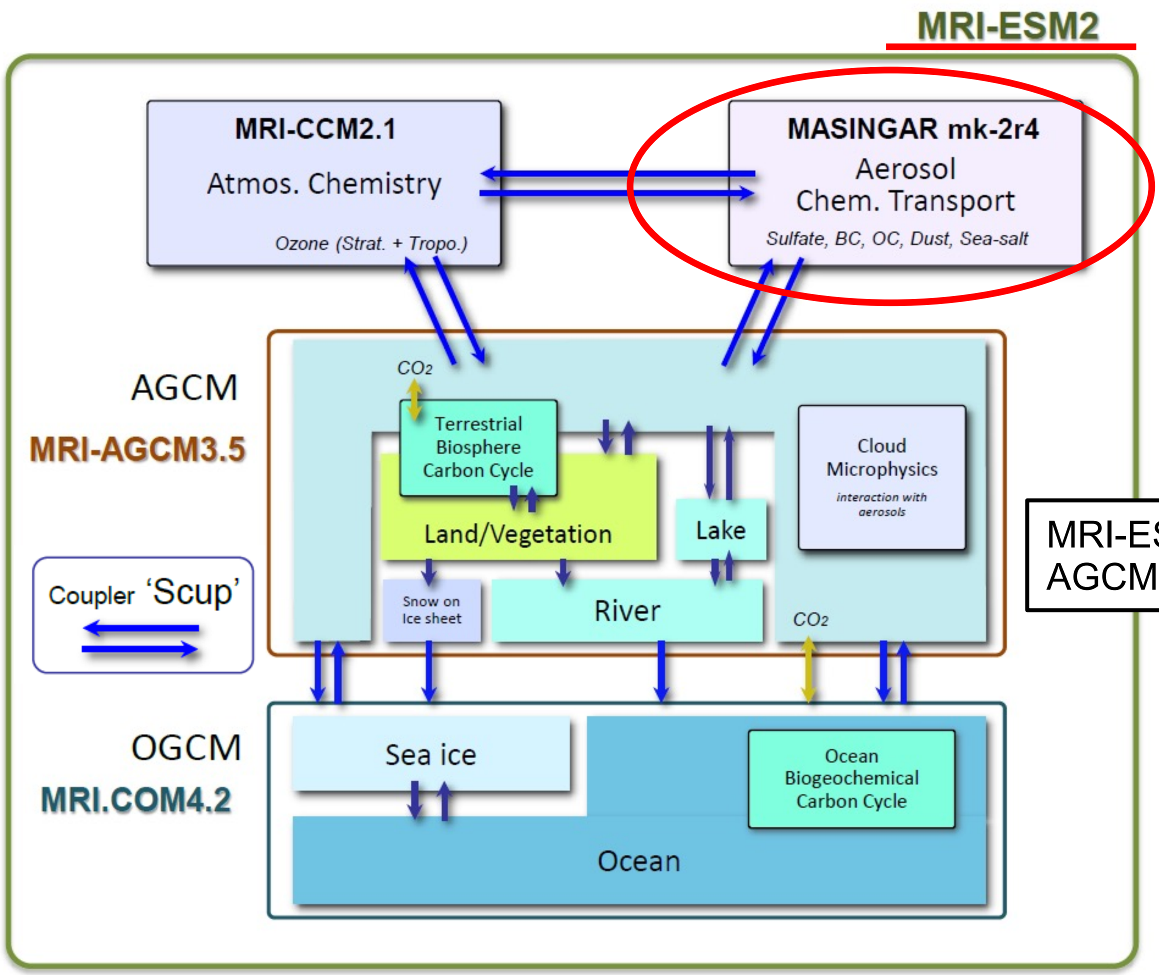


JMA operates a global aerosol model (TL479L40) for the prediction of aeolian dust.

The forecast charts up to 4 days ahead with the interval of 6 hours are updated once per day.

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

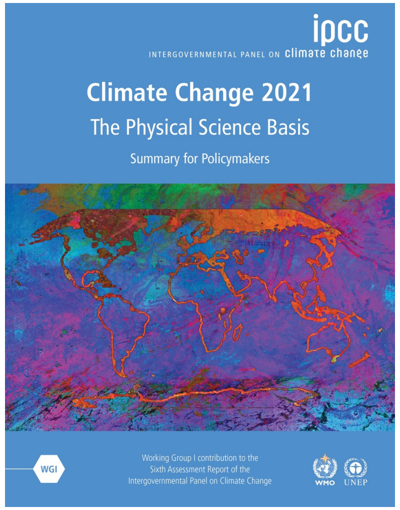
Meteorological Research Institute Earth System Model version 2.0 (MRI-ESM2.0)



MRI developed the 2nd version of Earth System Model (MRI-ESM2.0). The model consists of AGCM, OGCM, aerosol model and atmospheric chemistry model and each model is interactively coupled by Coupler, which enables an explicit representation of the effects of the gases and aerosols on the climate system. Compared to the previous version of the model, aerosols and clouds are largely improved in MRI-ESM2.0, leading to the reasonable reproducibility in global radiation budgets. MRI-ESM2.0 participated in CMIP6 (Coupled Model Intercomparison Project phase 6) and contributed to IPCC AR6.

MRI-ESM2.0, horizontal distributions;
AGCM: TL159 (110 km), Aerosol model: TL95 (180 km), Chemistry model: T42 (280 km)

- JMA operates Aeolian Dust Prediction using the aerosol model (TL479, 40km).
- JMA operates the seasonal ensemble prediction system to support a wide range of seasonal forecast products, but the aerosol climatology is used (aerosols/dust are not predicted).

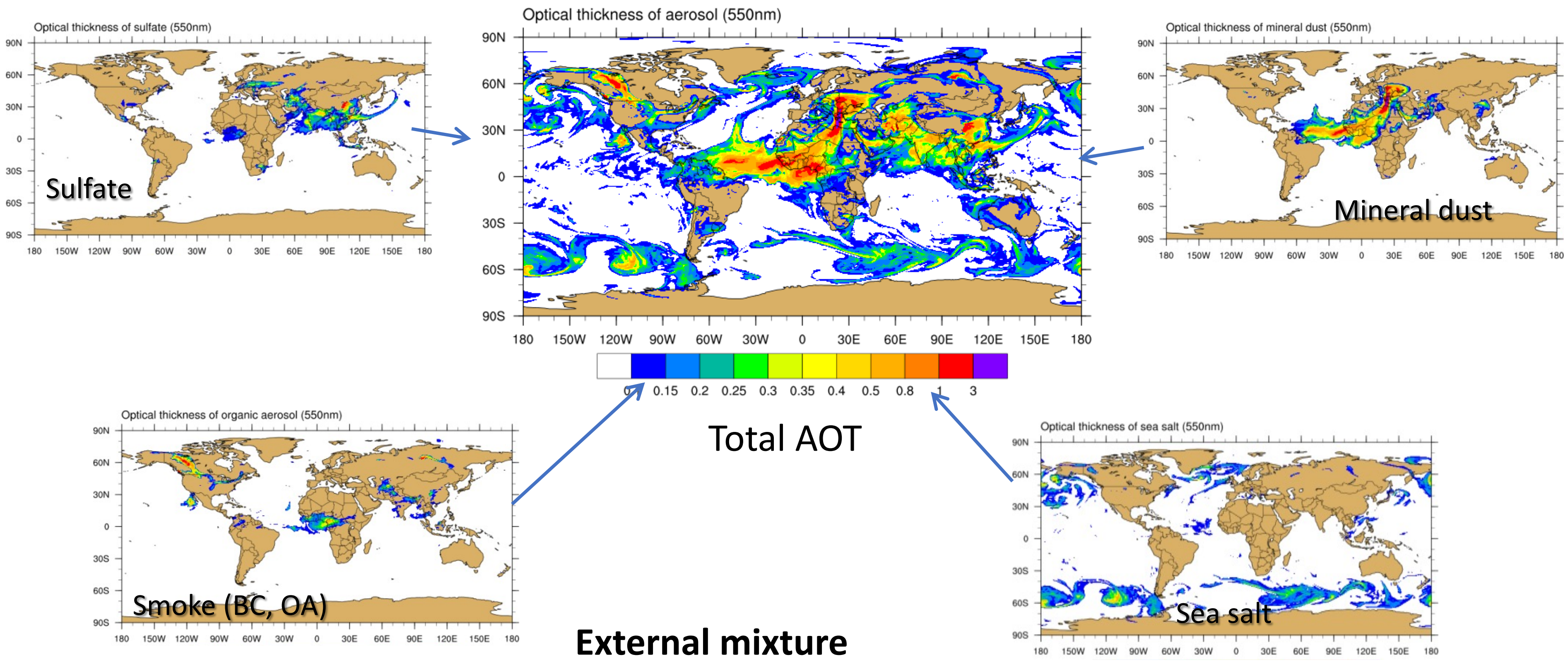


MRI-ESM2.0 papers;
[*Yukimoto et al., JMSJ,* 2019]
[*Kawai et al., GMD,* 2019]
[*Oshima et al., PEPS,* 2020]

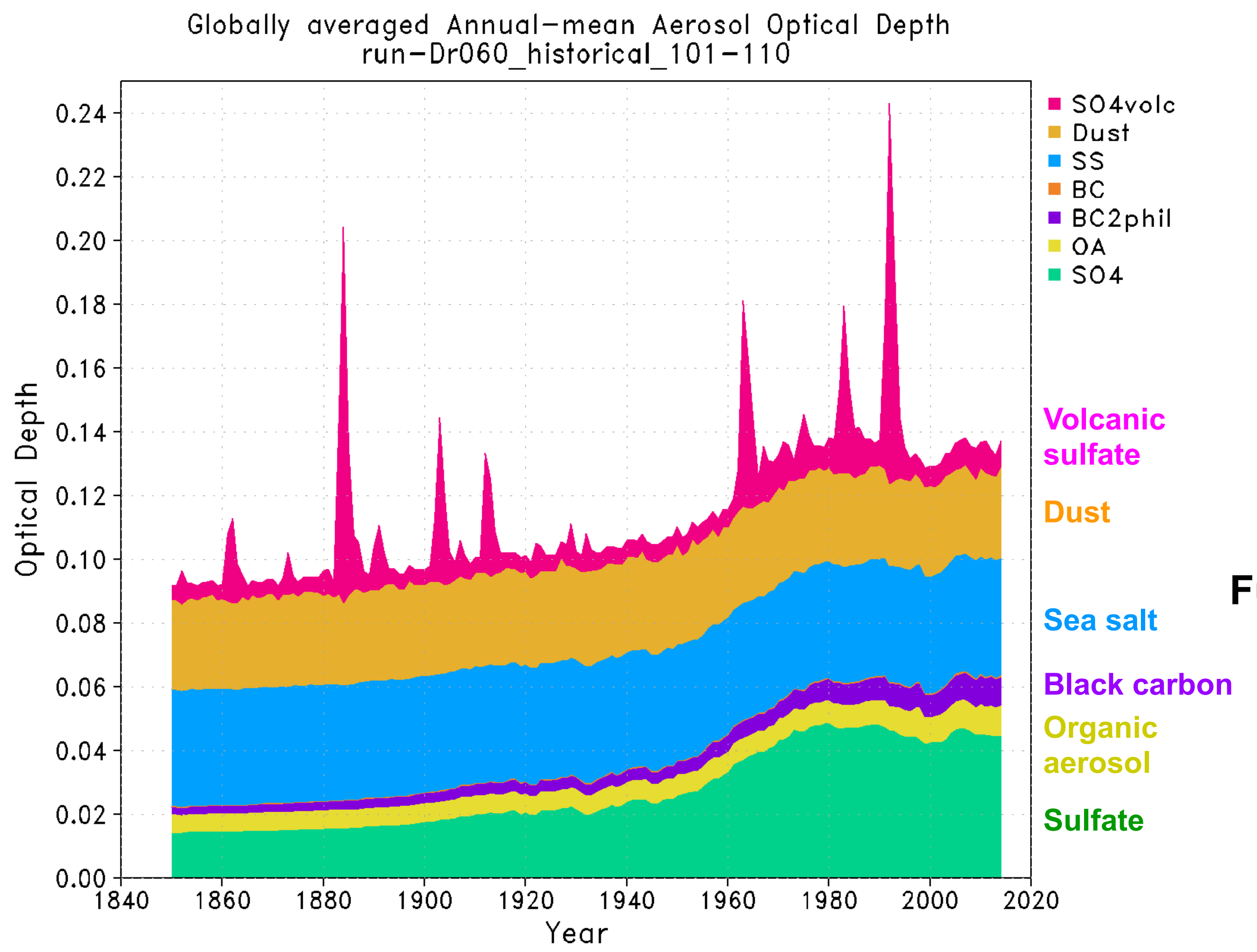
Recently, we replaced AGCM with JMA's operational numerical weather prediction model and have developed a new version of ESM (MRI-ESM3.2). We are considering the possibility of using this model for the seasonal predictions.

JMA/MRI Aeolian dust prediction model
(Model of Aerosol Species in the Global Atmosphere: MASINGAR)

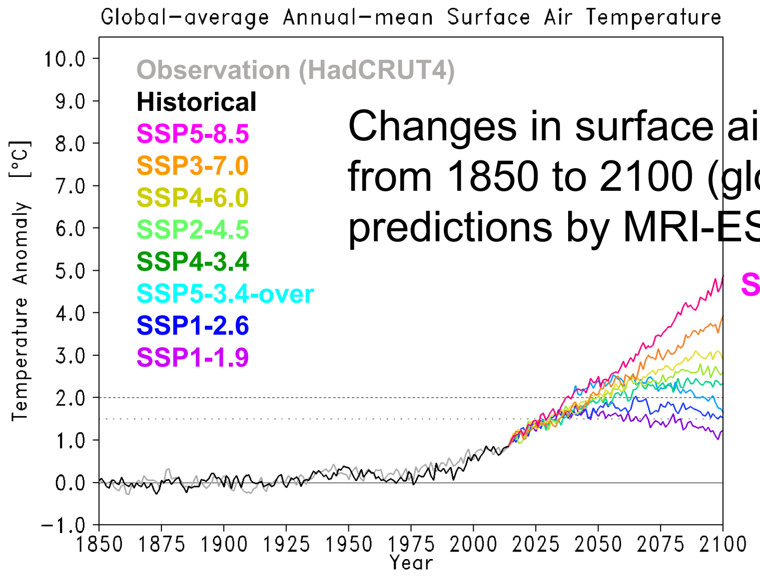
- Sulfate, black carbon, organics, sea salt, and mineral dust are included
    - The emission flux of sea-salt, mineral dust, and dimethylsulfide are predicted based on the surface properties calculated by the atmospheric model.
    - Particle size distributions of sea salt and dust are expressed by sectional approach (10-bins from 0.2 to 20 μm)



Climate Change Predictions by MRI-ESM2.0

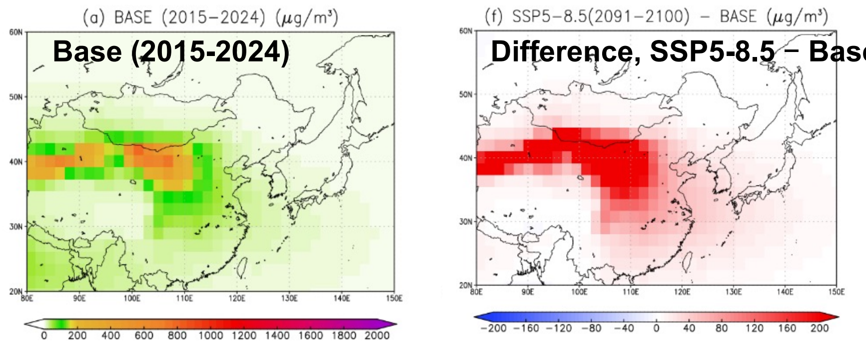


Aerosol optical depth (AOD) and contributions of each aerosol species (global averages, CMIP6 historical simulations by MRI-ESM2.0).



Changes in surface air temperature from 1850 to 2100 (global averages, predictions by MRI-ESM2.0).

Future dust emission changes in East Asia by MRI-ESM2.0

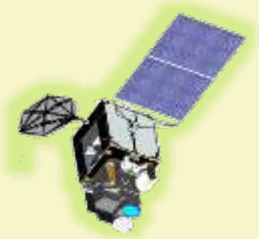


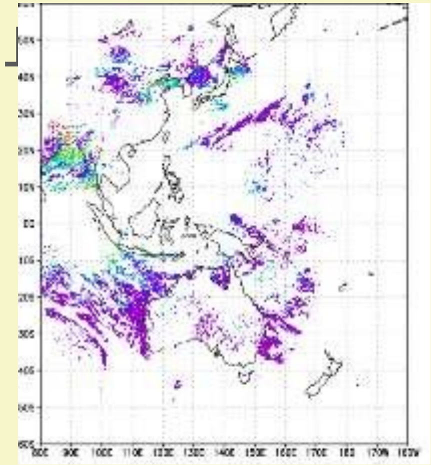
[*Maki et al., SOLA*, 2022]

Surface dust concentrations (March) in **base period (2015−2024)** and **SSP5-8.5 future (2091−2100)** scenario in East Asia. Dust emissions would increase in early spring from 2015 to 2100 in warmer scenarios (SSP5-8.5), likely due to changes in seasonal transition.

Data assimilation of the operational dust forecast

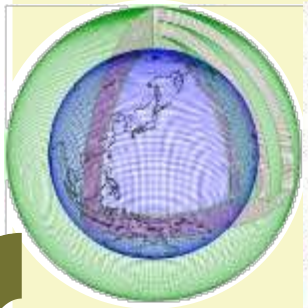
Himawari 8/9」

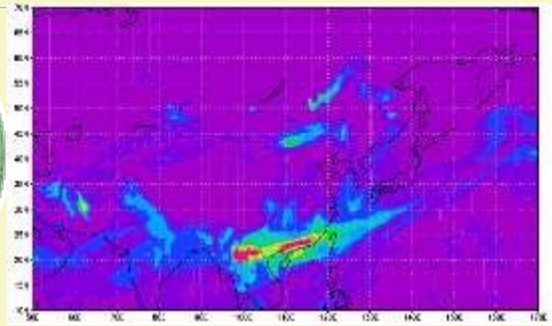




Observation

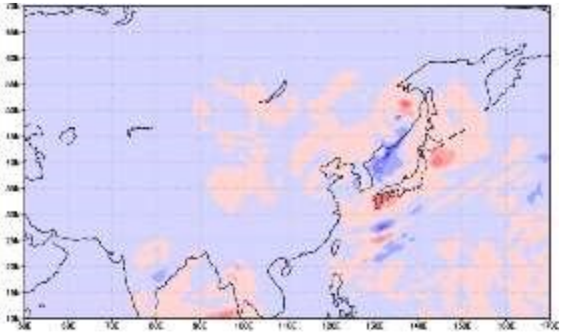
「 MASINGAR mk-2」



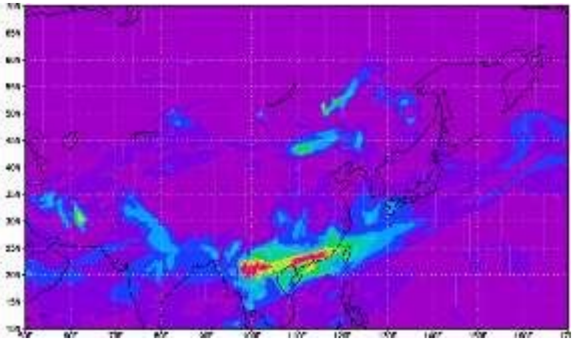


model

Data Assimilation



Increment



Analysis

Target: AOD

Frequency: Once per day

Method: 2D-Var

Area: Asia and Oceania

Aerosol data assimilation system

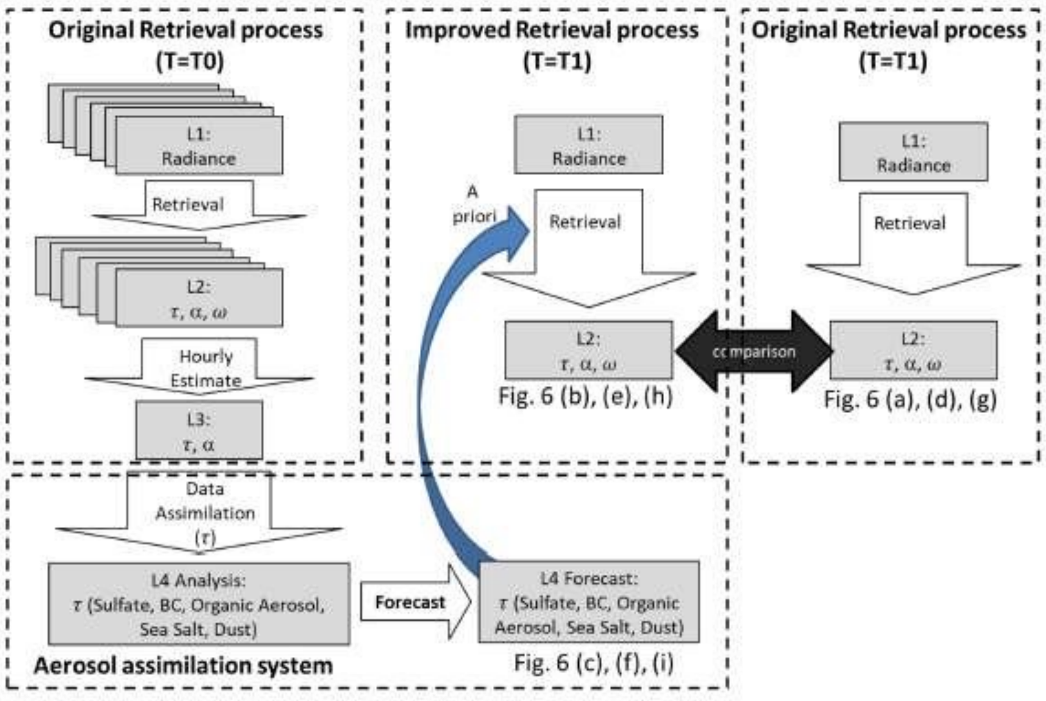
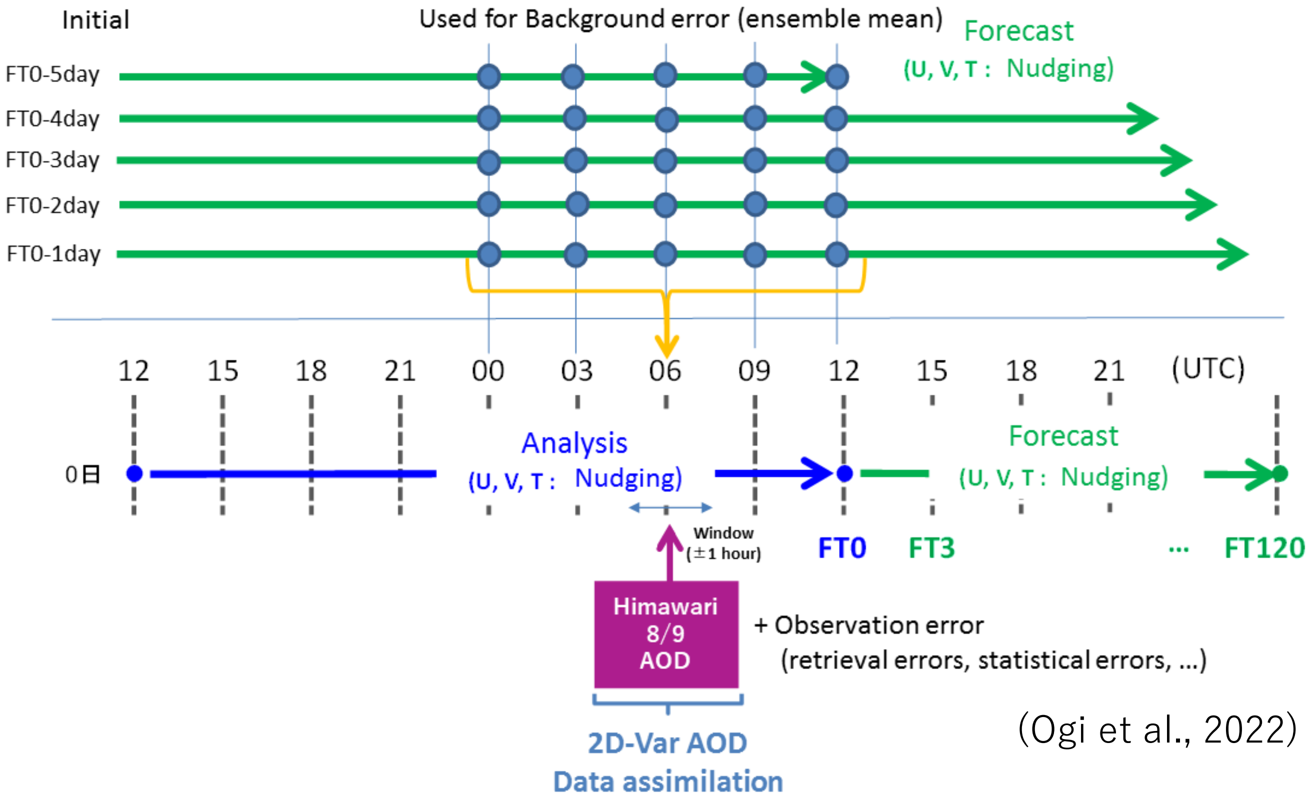


Figure 1: Flowchart of data processing for aerosol retrieval at time T1.

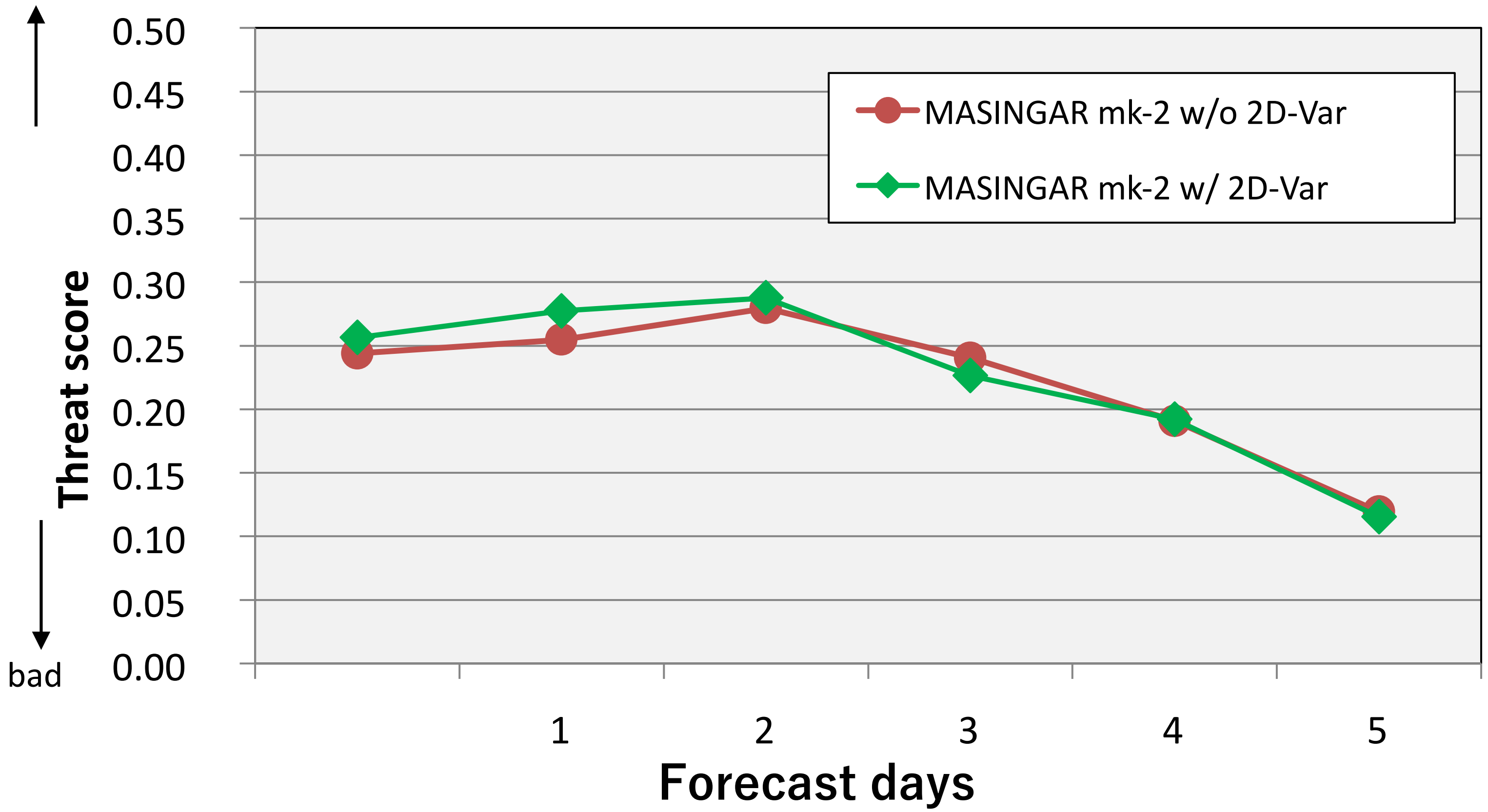
(Yoshida et al., 2020, ACP)



(Ogi et al., 2022)

We, JMA and JAXA, developed a new aerosol retrieval algorithm combining a numerical aerosol forecast. In the retrieval algorithm, the short-term forecast from an aerosol data assimilation system was used for a priori estimate instead of spatially and temporally constant values. The retrieval accuracy was improved by using the model forecast as compared with using constant a priori estimates. (Yoshida et al., 2020, ACP)

Verification for dust predictions against SYNOP observations



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

* Forecast threshold : 90 μg m^{-3}

(Ogi et al., 2022)

Dust predictions with Himawari-8 data assimilation generally resulted better threat scores.

JMA operational aerosol prediction: update

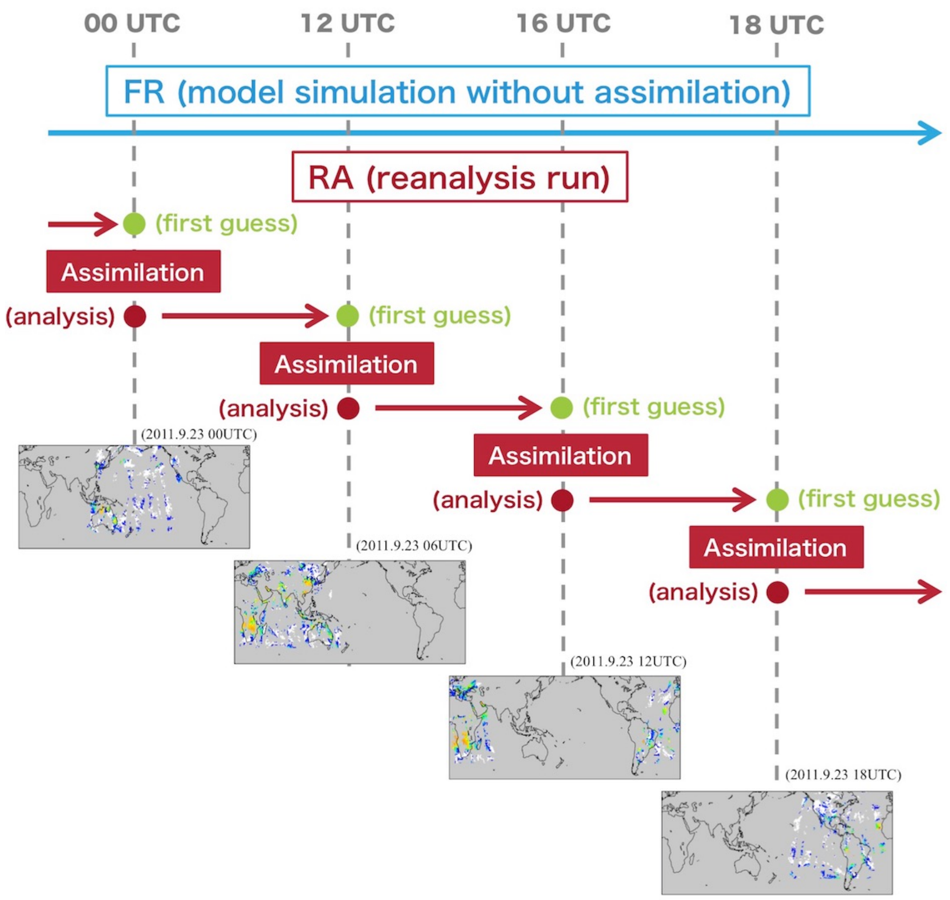
- The geostationary meteorological satellites for the AOT data assimilation of the JMA's operational aerosol forecast was switched from Himawari-8 to **Himawari-9** in December 2022.
- A feasibility study of the usability of JAXA's GCOM-C/SGLI aerosol properties has been conducted for the JMA's operational aerosol forecast.
- The JMA's supercomputing system for NWP will be replaced in March 2024.

The Japanese Reanalysis for Aerosol (JRAero)

MRI of JMA and RIAM of KU have constructed a global aerosol reanalysis (Japanese Reanalysis for Aerosol: JRAero) version 1.0 for 2011–2019.

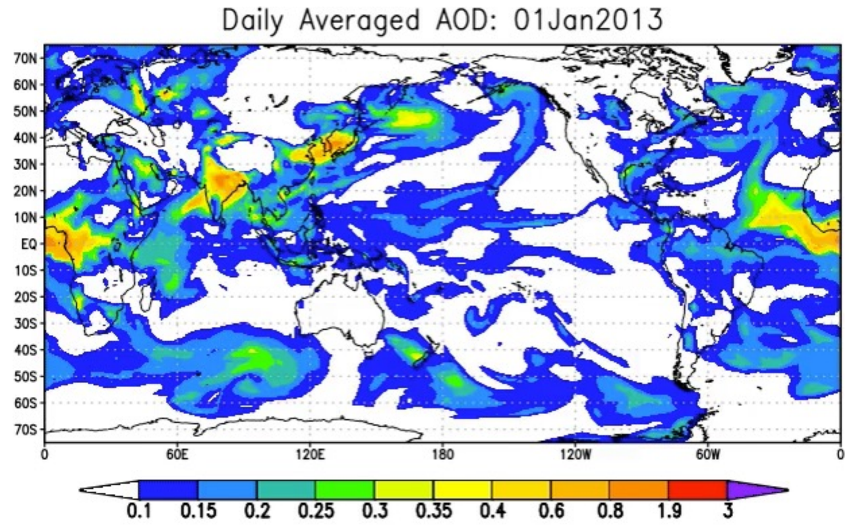
The world 4th aerosol reanalysis (ECMWF, NASA, NRL, JMA).

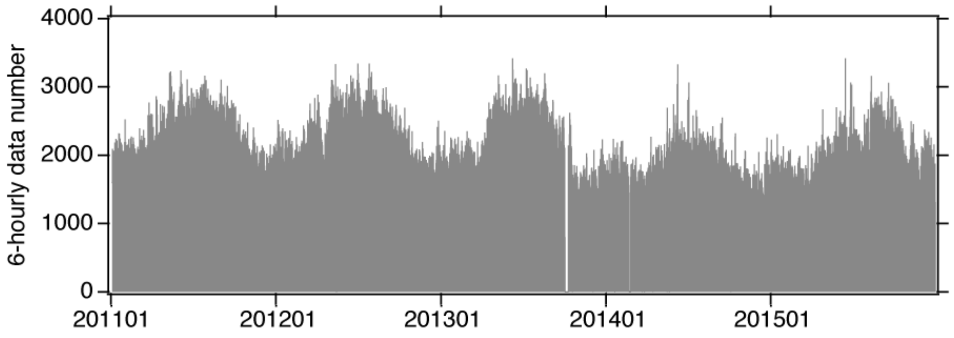
DA procedure for JRAero



←Schematic diagram of the assimilation procedure for JRAero.

Assimilating MODIS AOD ever 6 hours.
To evaluate the impact of data assimilation, aerosol fields of JRAero are compared with those from free run (model simulation without assimilation).



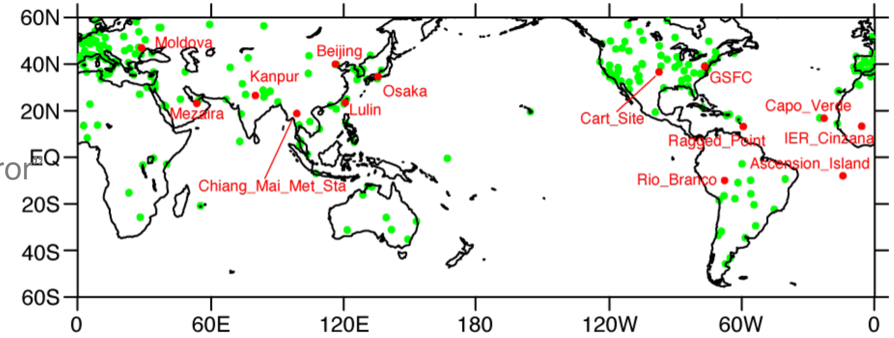


←Number of data used in JRAero.

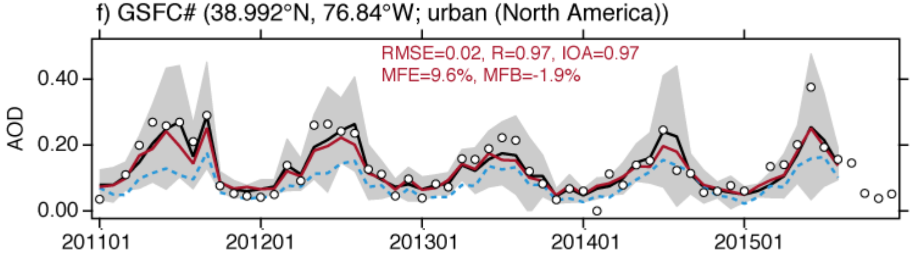
Approximately 2000–3000 MODIS AOD were assimilated in JRAero every 6 hours (Totally ca. 2,000,000-2,900,000 MODIS AOD were assimilated in each year).

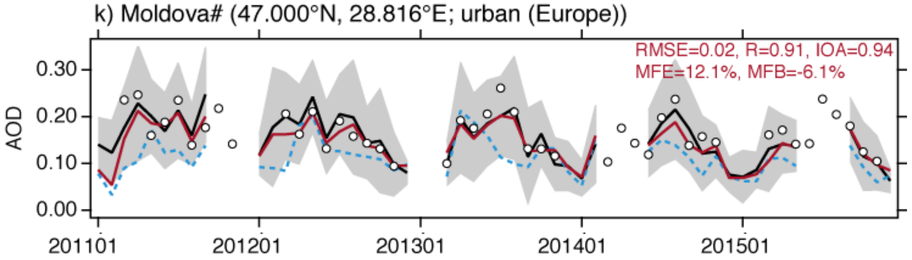
JRAero performance: vs AERONET AOD

R = ”Correlation coefficient”
RMSE = “Root Mean Square Error”
IOA = “Index of agreement”
MFE = “Mean fractional error”
MFB = “Mean fractional bias”

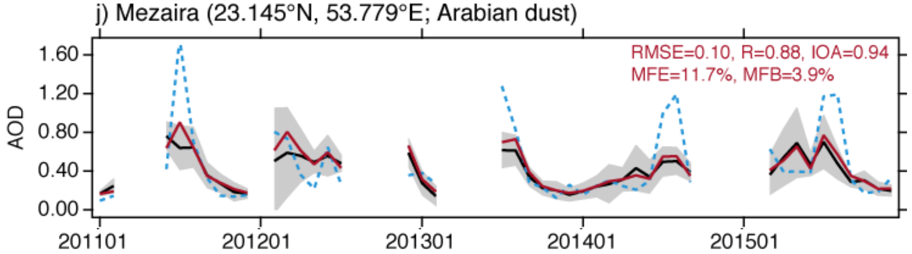


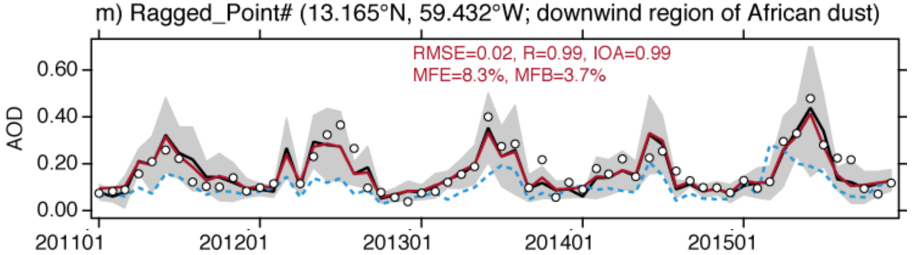
Urban sites



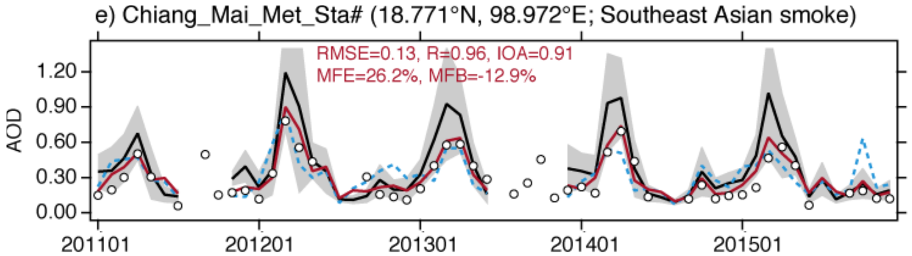


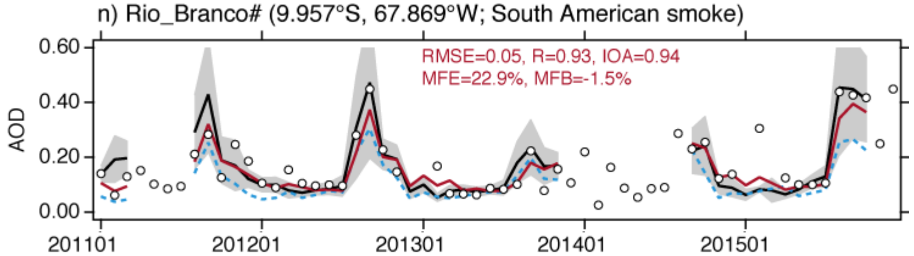
Dust





Smoke





JRAero Data distribution

JRAero products are now available through web site!

JRAero HP	: https://www.riam.kyushu-u.ac.jp/taikai/JRAero
E-mail	: jraero@mri-jma.go.jp
Horizontal resolution	: 1° x 1°
Temporal resolution	: 6-hour
Period	: Jan. 2011 – Dec. 2019
File format	: netcdf

Now, we have a plan to update JRAero for next version (V2).

Available variables

- 2D distribution of AOD (total, dust, sea salt, bc, oc, sulfate)
  → climate effect, air quality
- 2D distribution of surface conc. (PM2.5, PM10, dust, sea salt, bc, oc, sulfate)
  → air quality, human health
- 2D distribution of deposition (dust, sea salt, bc, oc, sulfate)
  → air quality, oceanography
- 2D distribution of downward radiance (short- and longwaves; all and clear skies)
  → climate effect
- 3D distribution of ext. coef. (total, dust, sea salt, bc, oc, sulfate)
  → climate effect, air quality, boundary conditions for retrieval
- 3D distribution of mixing ratio (dust, sea salt, bc, oc, sulfate)
  → boundary conditions for regional model, air quality

Integration of multiple satellite data through model assimilations with JAXA

1. Introduction: Targets of JAXA atmospheric environment monitoring group

【Background and current issues】

- Aerosols affect people's living environments, such as visibility human health, and the climate system: interaction with clouds is a major unknown factor in the global warming prediction.
- Conventional operational aerosol prediction models did not use satellite data sufficiently and did not make accurate information such as its reaching time, quantity, altitude, type and origin.
- (new) The feedback cycle from satellite observations to prediction models was not sufficiently established

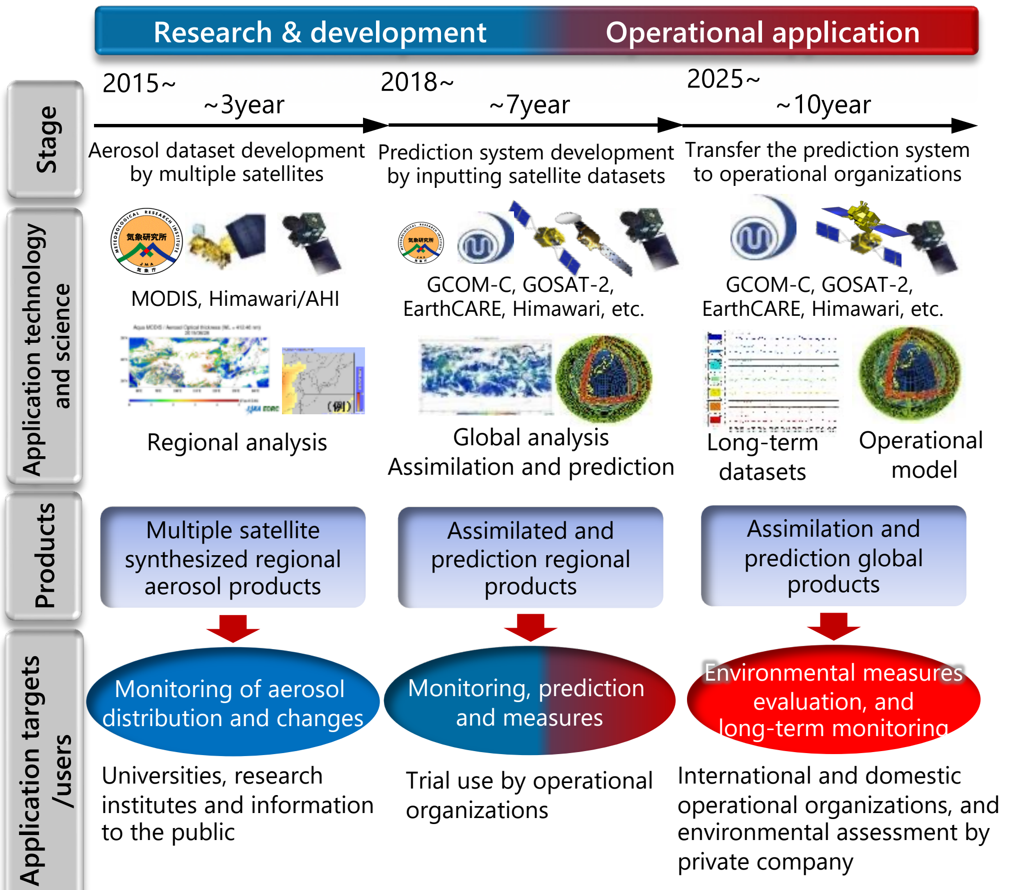
【Targets】

- Processing and distribution of integrated satellite aerosol datasets using Himawari and JAXA Earth observation satellites in near real time
- Construction of effective and stable model assimilation and prediction systems by inputting multiple satellite aerosol products
- (new) Analyze systematic differences between model predictions and satellite observations to improve the model process

【Outcome】

- Through adapting the system in operational organizations, highly reliable daily information ("when, where, what type/origin, and how much volume of aerosol it will fly") will be shared in public and contribute to air quality measures and damage reduction
- (new) Monitoring aerosol variation under climate change and environmental measures by integrating satellite observation and models, and feedback the acquired knowledge to the model prediction improvement

Development of aerosol assimilation and prediction system using satellite data



Timeline of the group goal and activity

Current key targets:

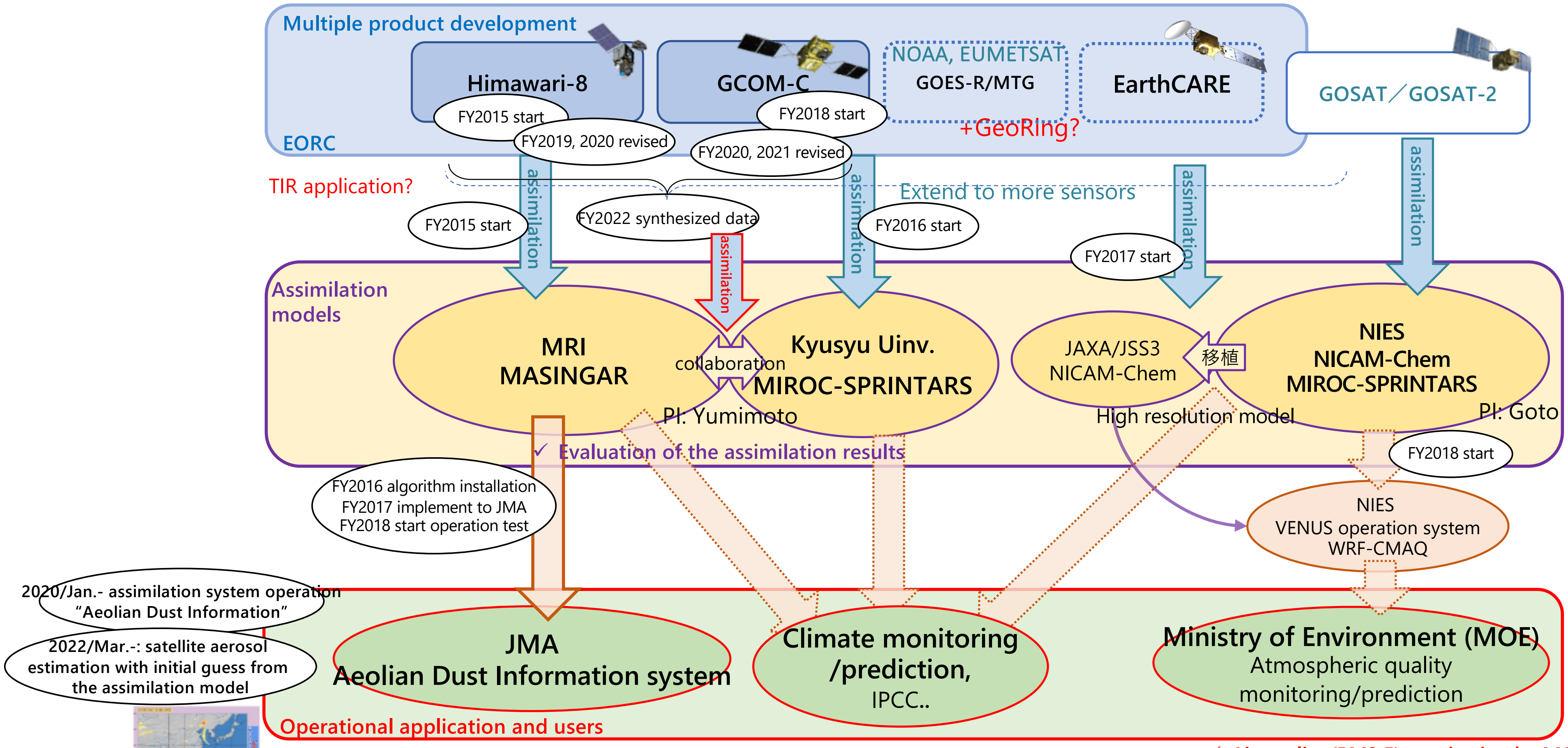
① Multiple sensor assimilation, lidar assimilation, and multivariable assimilation research in EORA3

② Development of aerosol composite data for effective assimilation of JAXA satellite aerosols

③ Analysis of assimilation model outputs/ensembles and comparison analysis with satellite observations

Introduction: Integration of multiple satellite data through model assimilations

Operational application and contribution to the climate prediction with Japanese key organizations



✓ Monitoring of aerosols associated with climate change and understanding of processes through knowledge from the satellite observation and the assimilation models

✓ Air quality (PM2.5) monitoring by MOE

MRI: Meteorological Research Institute, Japan

JMA: Japan Meteorological Agency

NIES: National Institute for Environmental Studies, Japan

MOE: Ministry of Environment (MOE)

MASINGAR: a global tropospheric aerosol chemical transport model developed by MRI

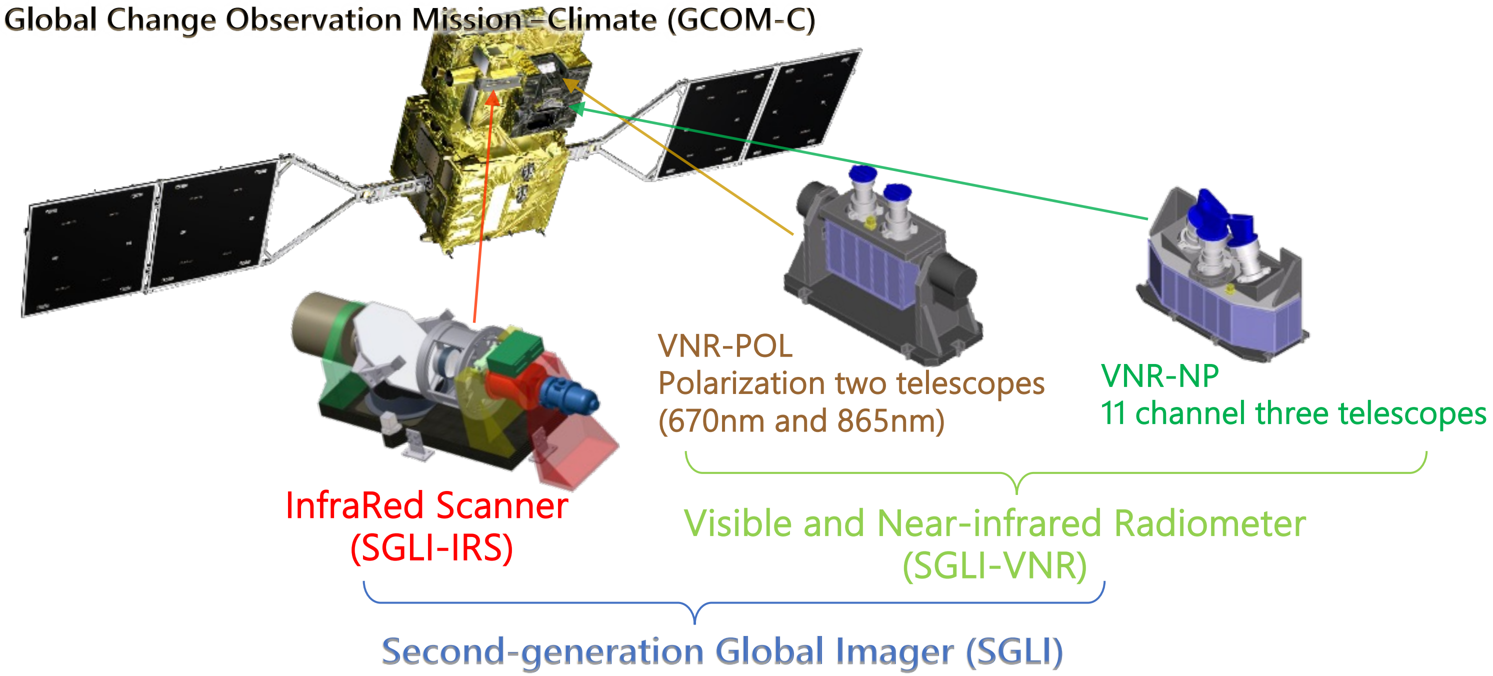
MIROC-SPRINTARS: Spectral Radiation-Transport Model for Aerosol Species, SPRINTARS with an atmosphere-ocean GCM, MIROC developed by AORI

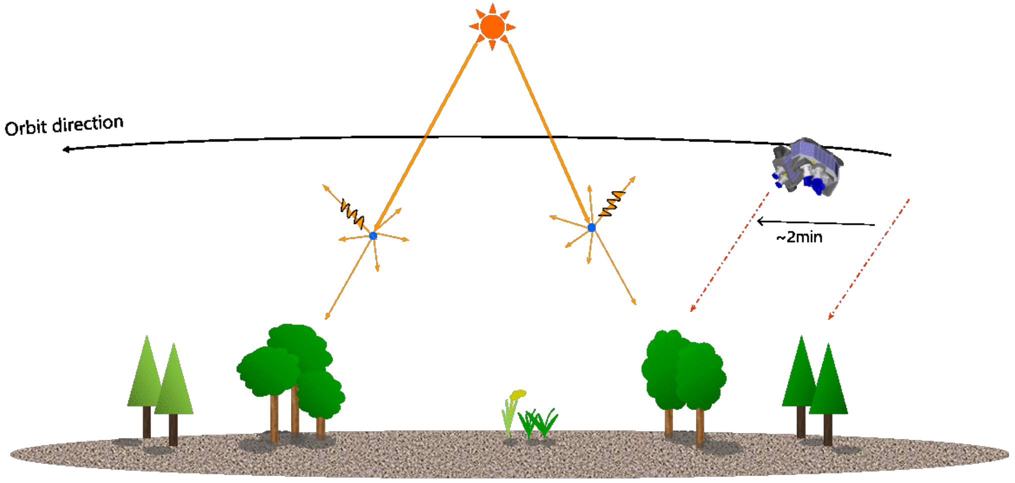
NICAM-Chem: a global cloud resolving model, Nonhydrostatic ICosahedral Atmospheric Model with chemical transport model

WRF-CMAQ: Weather Research and Forecasting Model (WRF) with Community Multiscale Air Quality model

JSS3: JAXA Supercomputer System Generation 3

Aerosol observation sensors: GCOM-C/SGLI





VNR-POL operated by along-track ±45deg tilt for polarization observation of the atmospheric scattering

GCOM-C characteristics	
Launch Date	23 Dec. 2017 (data since 1 Jan 2018)
Orbit	Sun-synchronous (descending local time: 10:30), Altitude: 798km, Inclination: 98.6deg

SGLI channel specification

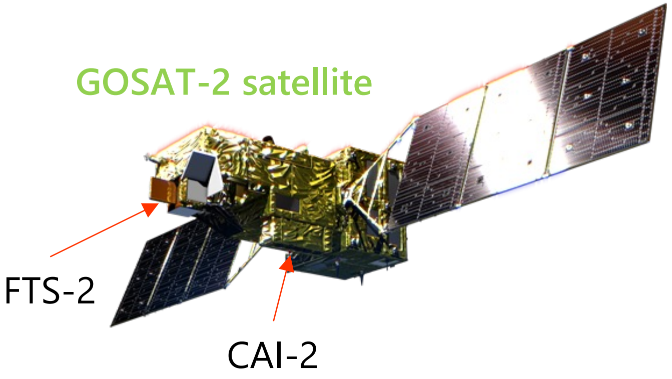
swath	CH	λ	$\Delta\lambda$	L_{std}	L_{max}	SNR@L_{std}	IFOV
km		nm		W/m^2/sr/μm K: Kelvin		- K: NEΔT	m
1150km (VNR: push-broom electric scan)	VN01	380.0	10.6	60	240-241	624-675	250 /1000
	VN02	412.5	10.3	75	305-318	786-826	250 /1000
	VN03	443.2	10.1	64	457-467	487-531	250 /1000
	VN04	489.8	10.3	53	147-150	858-870	250 /1000
	VN05	529.6	19.1	41	361-364	457-522	250 /1000
	VN06	566.2	19.8	33	95-96	1027-1064	250 /1000
	VN07	672.0	22.0	23	69-70	988-1088	250 /1000
	VN08	672.1	21.9	25	213-217	537-564	250 /1000
	VN09	763.1	11.4	40	351-359	1592-1746*	250 /1000*
	VN10	866.8	20.9	8	37-38	470-510	250 /1000
	VN11	867.1	20.8	30	305-306	471-511	250 /1000
	PL01	671.9	20.6	25	293	609	1000@nadir
	PL02	866.2	20.3	30	396	646	1000@nadir
1400km (IRS: whisk-broom)	SW01	1055	21.1	57	289.2	951.8	1000
	SW02	1385	20.1	8	118.9	347.3	1000
	SW03	1635	195.0	3	50.6	100.5	250 /1000
	SW04	2209	50.4	1.9	21.7	378.7	1000
	TI01	10793	756	300K	340K	0.08K	250/500/1000
	TI02	11956	759	300K	340K	0.13K	250/500/1000

https://suzaku.eorc.jaxa.jp/GCOM_C/data/prelaunch/index.html

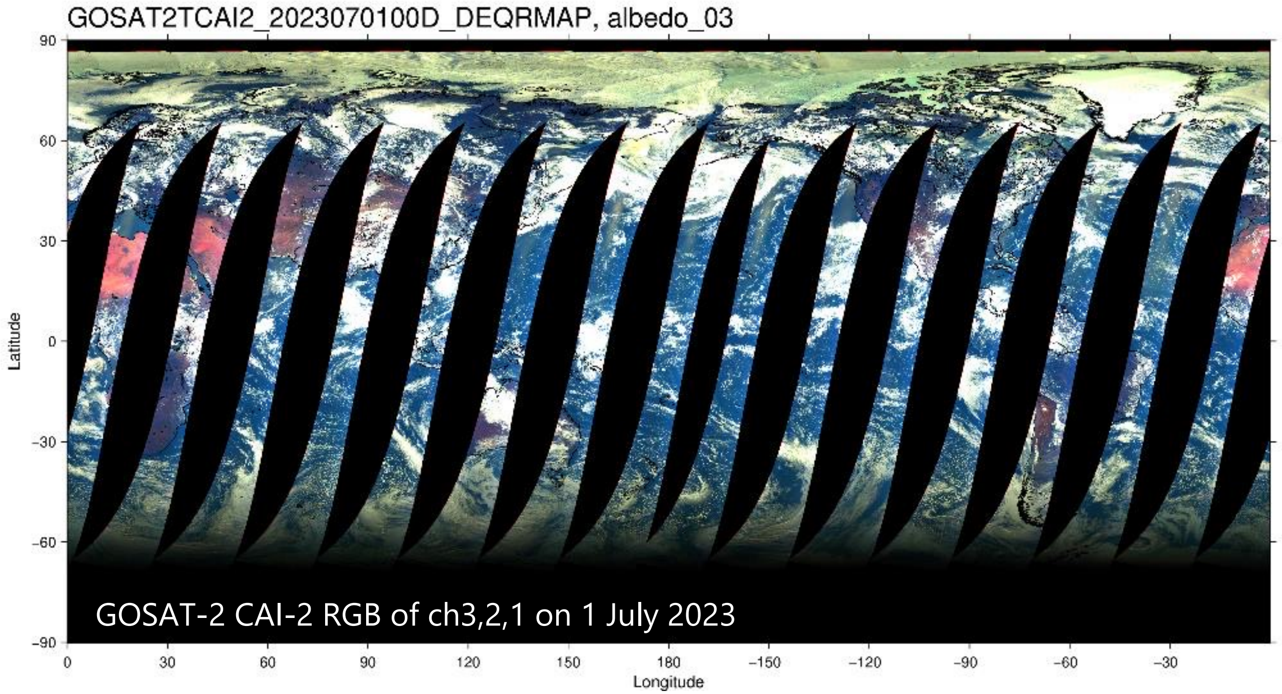
Aerosol observation sensors: GOSAT-2/CAI-2

- Greenhouse gases Observing SATellite-2 (GOSAT-2) Thermal And Near Infrared Sensor for carbon Observation - Cloud and Aerosol Imager-2 (TANSO-CAI-2)

- The CAI-2 standard aerosol product will be produced by “**the multiwavelength and multipixel method**” (Hashimoto and Nakajima JGR 2017) which uses general characteristics of heterogeneous land surface reflectance and smoothly distributed aerosol over the surfaces.



GOSAT-2	
Launch	Oct. 29 2018
Orbit type	Sun synchronous (dec 13:00 ± 0:15)
Altitude	613 km
Repeat cycle	6 days
Mass	< 2,000 kg
Power	5.0 KW

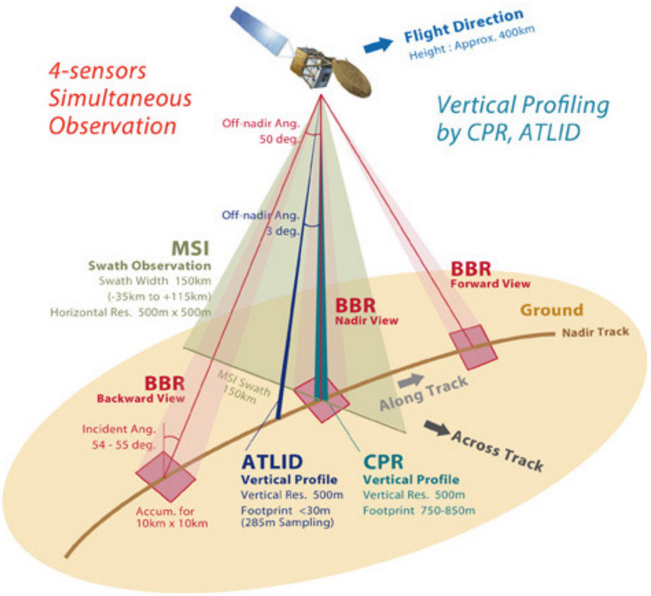


GOSAT-2 CAI-2 RGB of ch3,2,1 on 1 July 2023

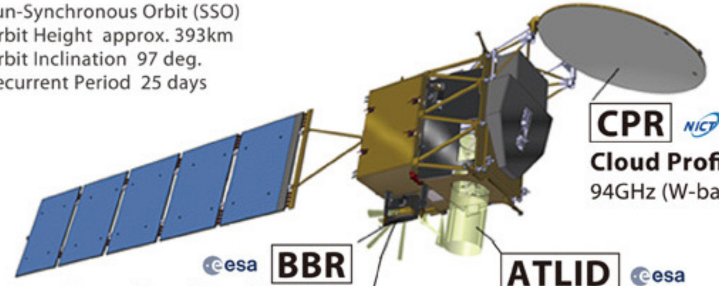
CAI-2 bands	nm	Tilt	Spatial resolution	Swath
B1	333 - 353	+20 deg. (Forward viewing)	460 m	920 km
B2	433 - 453			
B3	664 - 684			
B4	859 - 879			
B5	1585 - 1675		920m	
B6	370 - 390	-20 deg. (Backward viewing)	460 m	
B7	540 - 560			
B8	664 - 684			
B9	859 - 879			
B10	1585 - 1675		920m	

Aerosol observation sensors: EarthCARE/Cloud Profiling Radar (CPR)

- EarthCARE will observe 3D structure of clouds and aerosols, and reduce errors in climate change and weather forecast, by Japan (JAXA/NICT)-Europe (ESA) cooperation.
- CPR is the world's first W-band Doppler radar (94GHz) aboard a satellite. We can understand the vertical structure of clouds, as well as the ascending and descending movement of clouds.



- **Mission**
  - Vertical profile of clouds, aerosol
  - Interaction between clouds and aerosol
  - Cloud stability and precipitation
- **Orbit**
  - Sun synchronous (13:45)
  - Altitude 400km
- **Task sharing**
  - JAXA/NICT (CPR)
  - ESA (LIDAR, MSI, BBR, Spacecraft)
- **Launch target**
  - 2024



Synthetic data for model assimilation (bias correction and error estimation, under investigation)

AHI AOT bias correction and error estimation

(1) **AHI bias correction** (adjust to AERONET AOT)

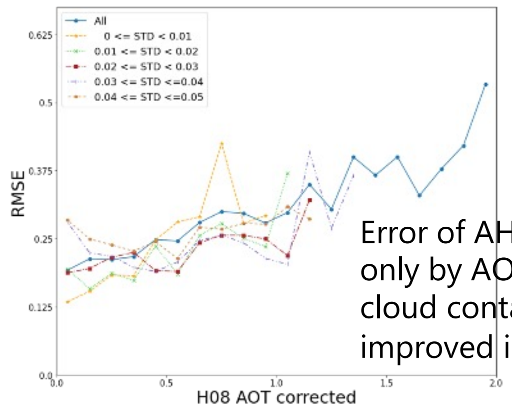
$$AOT_{\mathrm{corr}} = AOT_{\mathrm{AHI}} * (1 - \mathrm{a} * \exp(\mathrm{b} * AOT_{\mathrm{AHI}}))$$

Land area: a=-0.14, b=0

Water area: a=-12.55, b=-55.20

(2) **AHI error estimation** after correction (1)

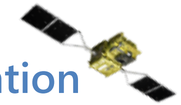
$$Err_{\mathrm{AHI}} = slope * AOT_{\mathrm{AHI}} + offset$$
$$slope_{land} = 0.15 , offset_{land} = 0.17$$
$$slope_{water} = 0.20, offset_{water} = 0.02$$



Error of AHI is modeled only by AOT range (AHI cloud contamination is improved in Level-3 QC)

AHI AOT error (RMSE from Aeronet). X-axis is AOT range and color shows standard deviation (STD) in 0.1-deg box (land area)

SGLI AOT bias correction and error estimation



(1) **SGLI bias correction** (adjust to AERONET AOT)

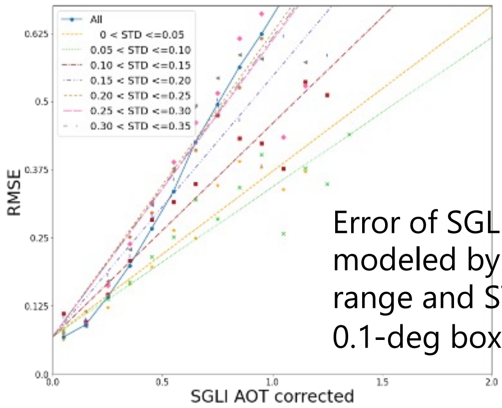
$$AOT_{\mathrm{corr}} = AOT_{\mathrm{SGLI}} * (1 - \mathrm{a} * \exp(\mathrm{b} * AOT_{\mathrm{SGLI}}))$$

Land area: a=0.70, b=-2.87

Water area: a=0.48, b=-0.51

(2) **SGLI error estimation** after correction (1)

$$Err_{\mathrm{SGLI}} = slope * AOT_{\mathrm{SGLI}} + offset$$
$$slope_{land} = \left(\frac{0.61}{1 + \exp(-9.7 * (STD_{\mathrm{SGLI}} - 0.06))}\right), offset_{land} = 0.07$$
$$slope_{water} = \left(\frac{1.61}{1 + \exp(-7.81 * (STD_{\mathrm{SGLI}} - 0.30))}\right), offset_{water} = 0.04$$

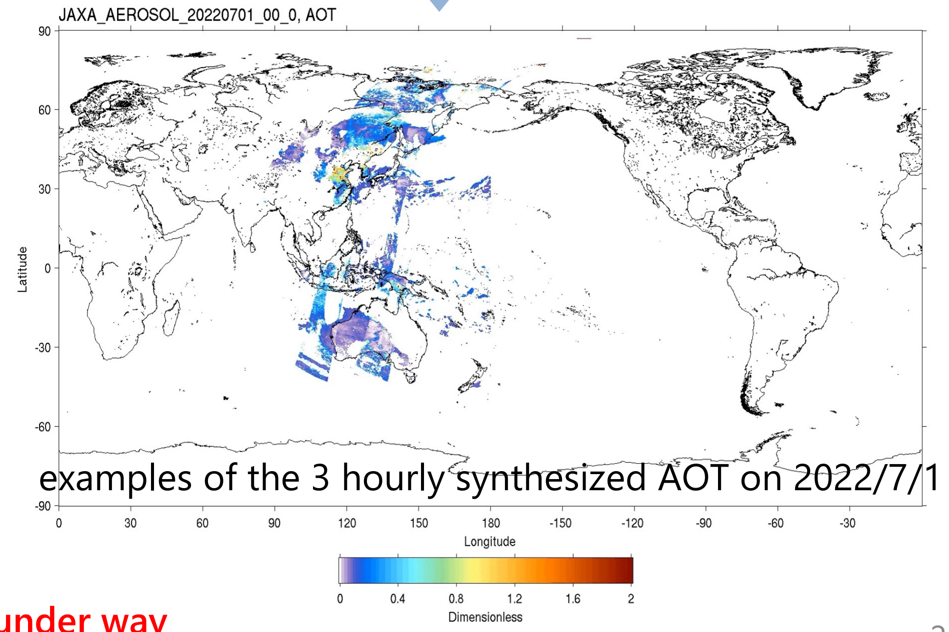


Error of SGLI is modeled by AOT range and STD in 0.1-deg box

SGLI AOT error (RMSE from Aeronet). X-axis is AOT range and color shows standard deviation (STD) in 0.1-deg box (land area)

- ✓ Bias is corrected for each sensor
- ✓ Weighted average by w=1/error^2
- ✓ Make the file for each 3 hour

Smooth addition or transition to the next sensors for assimilation system



examples of the 3 hourly synthesized AOT on 2022/7/1

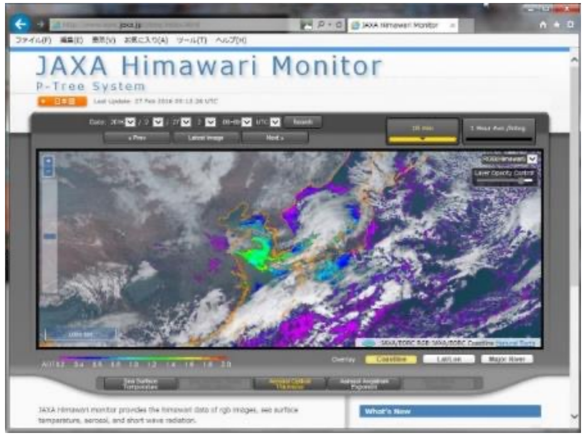
✓ **Assimilation test using the synthesized data is under way**

Data distribution

- JAXA products are distributed by FTP with simple user registration

- JAXA AHI products and MRI assimilated data are distributed via "JAXA Himawari Monitor" of P-Tree system

http://www.eorc.jaxa.jp/ptree/

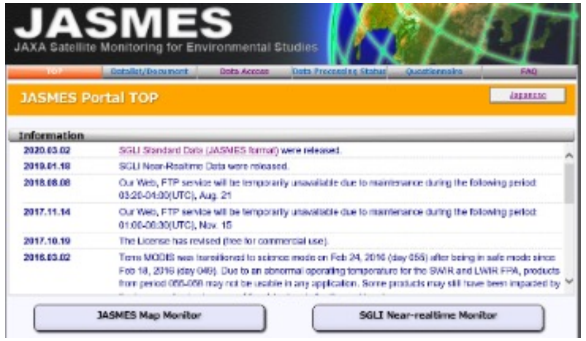


- Ver.2 standard products (Level-1, 2, and 3) have been open to the public via JAXA data portal, "G-Portal" (data search and SFTP)

https://gportal.jaxa.jp/gpr/

- Some products are open via JAXA multi-sensor data site, "JASMES"

https://kuroshio.eorc.jaxa.jp/JASMES/index.html
https://www.eorc.jaxa.jp/cgi-bin/jasmes/sgli_nrt/index.cgi



Summary

- ✓ JMA/MRI develop global aerosol model (MASINGAR) for aeolian dust prediction and climate research.
- ✓ We introduced data assimilation system using Himawari-9 AOT for JMA aeolian dust prediction.
- ✓ MRI introduced data assimilation system using Himawari-9 and MODIS AOT for JAXA, ICAP, and VFSP-WAS .
- ✓ The satellite aerosol products and outputs from MASINGAR are open to the public through the JAXA G-portal, Himawari Monitor and P-Tree system.
- ✓ MRI and Kyusyu University developed aerosol reanalysis (JRAero) using MODIS AOT data assimilation.
- ✓ JAXA has developed a common algorithm to estimate aerosol optical thickness AOT, AE, and SSA applicable to both the polar orbit satellite imager, GCOM-C/SGLI and the geostationary satellite imager, Himawari-8/AHI; the next targets will be GOSAT-2/CAI2 and EarthCARE/MSI.
- ✓ To effective use of the GEO and LEO data (including the vertical profile from EarthCARE/ATLID in the future), we are developing synthetic data.
- ✓ Monitoring aerosol under climate change by integrating satellite and model, and feedback from the acquired knowledge to the model improvement.

Acknowledgements

This study was supported by the JAXA Earth Observation Research Announcement (ER2GCN213) and Grant-in-Aid for Scientific Research B (16H02946). The following observation data were also used. We would like to thank

- SGLI standard products: JAXA G-Portal: https://gportal.jaxa.jp/
- JAXA Himawari Monitor: https://www.eorc.jaxa.jp/ptree/
- Aerosol observation data by NASA AERONET: https://aeronet.gsfc.nasa.gov/
- MODIS MCDAODHD (MODIS/Terra+Aqua L3 Value-added Aerosol Optical Depth - NRT): https://cmr.earthdata.nasa.gov/search/concepts/C1426395436-LANCEMODIS.html