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Development of atmospheric pollutant prediction model by assimilating aerosol data from SGLI and others

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Objectives: This project is aimed at development of an integrated system of numerical modeling and satellite observation of air pollution for its reliable monitoring and prediction. Specially, an atmospheric air pollution transport model (NICAM-Chem) with a data assimilation technique using atmospheric aerosol products retrieved from GCOM-C/SGLI is developed as a prototype for the next generation forecast system in NIES. As a result, the system can reproduce much realistic air pollutions than ever before.

Introduction: Our history of aerosol data assimilation using NICAM

Model	Grid size	Satellite				Reference
Target		Name	Param.	Target	T-window	
Global	GL05 (223km)	MODIS-NRL	AOT	Global	1 day	Dai et al. (2014); Yin et al. (2016)
Global	GL05 (223km)	AHI	AOT	Regional	1 hr	Dai et al. (2019)
Global	GL05 (223km)	AHI, CALIPSO	AOT, C_{ext}	Global	1 hr	Cheng et al. (2019)
Regional	GL06 (>50km)	AHI	AOT	Regional	1 hr	Dai et al. (in prep)
Global	GL07 (56km)	SGLI	AOT	Global	1 day	Cheng et al. (2021)

$$\tau(x,y) = \int_{z=surface}^{z=top} C_{ext}(x,y,z)\,dz$$

AOT: Aerosol Optical Thickness
C_{ext}: Aerosol Extinction Coefficient

CALIPSO: 3-dimensional C_{ext}
SGLI, AHI, MODIS: 2-dimensional AOT

Methodology: LETKF (Localized Ensemble Transform Kalman Filter by Hunt et al., 2007)

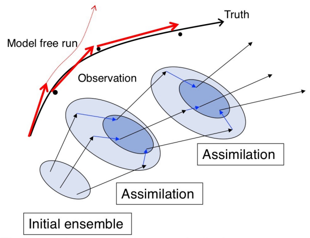

Figure 1: Image of data assimilation system

$$\begin{cases} x^a = x^f + P^a H^T R^{-1}(y - Hx^f) \\ P^a = (I + P^f H^T R^{-1} H)^{-1} P^f \end{cases}$$

[Rodgers, 2000]
a: analyzed state
f: forecast state
y: actual values
Hx^f: simulated values

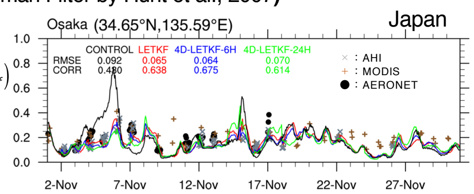

Figure 2: Temporal variation of aerosol optical thickness (AOT) at Osaka. The aerosol assimilation reduce 20% of RMSE and improve correlation by 0.3. This results are shown in Dai, Cheng, Suzuki, Goto et al. (2019)

Experiments Design

Resolution	56 x 56 km (GL7 in NICAM)
Time Period	2018 23 March – 2018 31 March
Region	Global scale, but focused on East Asia
Nudging Technique	UV wind speed
Assimilation technique	LETKF
Assimilation Time Window	24-hours
Localization Length	200 km
Ensemble Member	20
Perturbation	100% of emission uncertainty

name	note
FR (Free Run)	Single deterministic forecast without aerosol data assimilation
DA (Data Assimilation)	Assimilation with the GCOM-C/SGLI gridded 6-hourly AOTs (forecast length is set at 6 hours)

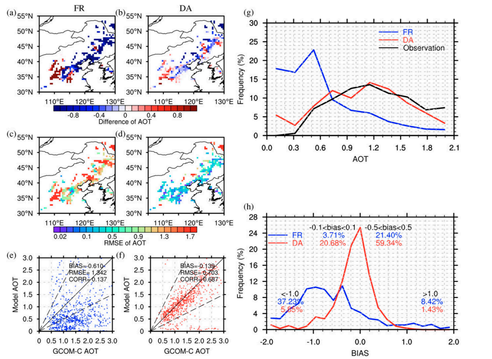

Figure 3:Spatial distributions of the biases and RMSEs between simulated and SGLI-retrieved AOTs at 500 nm from 28 to 31 March 2018.

Quality control of SGLI observation

QA Flag options used in the original package
- AOT confidence flag: only uses "very good"
- No coastal, No cloud, No cloud shadow possibility, …
- Uncertain surface reflectance flag (Turbid water, snow/ice covered surface or Rtoa_obs <Rtoa_Rayleigh): No

Our further quality control (Cheng et al., 2019)
- Regrid the original data into NICAM grid (56x56 km)
- Exclude the following data;
  - The observation points out of range (mean-stddev, mean+stddev) in one grid
  - The grid with observation number less than 20%, i.e., (56km x 56km)/(4km x 4km)*0.2=40
  - The grid with stddev/mean>0.5

(stddev: standard deviation)

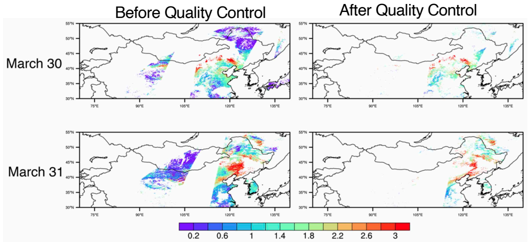

Figure 4: Spatial distributions of the SGLI-retrieved AOTs before and after quality control procedures on March 30 and 31 in 2018.

Results: Assimilation with GCOM-C/SGLI aerosol optical thickness

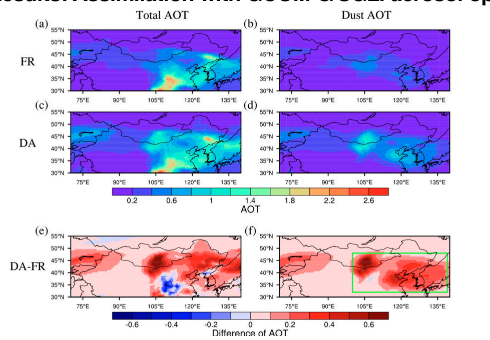

Figure 5: Spatial distributions of total AOTs and dust AOTs averaged from 28 to 31 March 2018 over East Asia for (a,b) FR and (c,d) DA experiments. (e,f) Differences in AOTs between the two experiments.

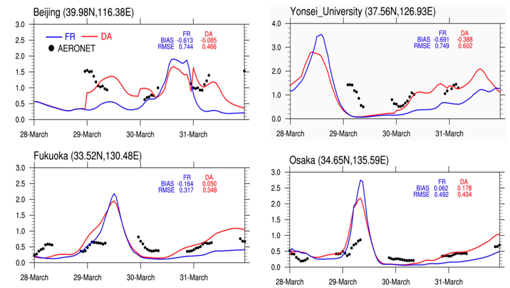

Figure 6: Temporal variation of simulated AOTs at 440 nm for two experiments (FR in blue and DA in red) and AERONET-retrieved AOTs (dots in black) at 440 nm over Asian four sites (Beijing in China, Yonsei University in Korea, Fukuoka in Japan and Osaka in Japan). *The remarkable improvements from 30-31 March are seen.*

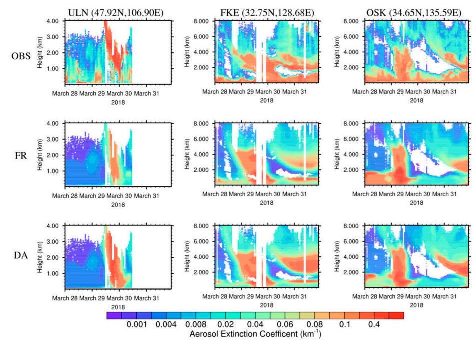

Figure 7: Comparison of total observed aerosol extinction coefficients from NIES/AD-Net and simulated coefficients for FR and DA experiments from 28 to 31 March at these selected sites (ULN: Ulaanbaatar; FKE: Fukue; OSK: Osaka)

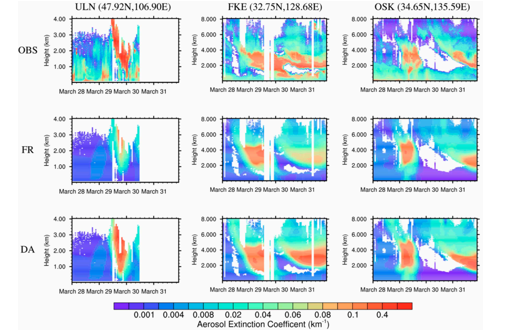

Figure 8: Same as Figure 7, but for dust extinction coefficients. *The strong peaks in the 1-5km heights are mainly dust aerosols. The DA results are closer to the AD-net, but the underestimation in dust is found in 0-1 km heights, which may be caused by a bias of dust particle size distribution in NICAM.*

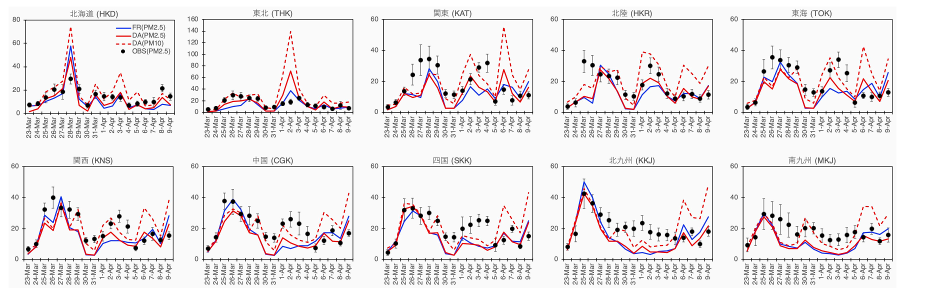

Figure 9: Temporal variation of PM2.5 at Japanese 10 regions from 23 March to 9 April in 2018. The 10 regions are classified according to Japanese Meteorological Agency (JMA). These are (a) 北海道 (HKD) including 21 sites, (b) 東北 (THK) including 65 sites, (c) 関東 (KAT) including 323 sites, (d) 北陸 (HKR) including 49 sites, (e) 東海 (TOK) including 119 sites, (f) 関西 (KNS) including 171 sites, (g) 中国 (CGK) including 53 sites, (h) 四国 (SKK) including 31 sites, (i) 北九州 (KKJ) including 119 sites, and (j) 南九州 (MKJ) including 20 sites. Generally, the aerosol data assimilation with column aerosol optical thickness provides closer results of the assimilated PM2.5 at the surface to the AEROS observation. However, there are positive biases of the simulated/assimilated PM2.5, which may be caused by a bias of the particle size distribution of the dust in NICAM.

Summary: The first assimilation study of the AOTs at 500 nm observed by this new satellite is performed to investigate a severe dust storm in spring over East Asia for 28 March to 9 April 2018. The aerosol observation assimilation system is an integration of 4D-LETKF and the NICAM-Chem. Through verification with the independent observations from the AERONET and the AD-Net, the results demonstrate that the assimilation of the GCOM-C aerosol observations can significantly enhance Asian dust storm simulations. The dust characteristics over the regions without GCOM-C observations are better revealed from assimilating the adjacent observations within the localization length, suggesting the importance of the technical advances in observation and assimilation, which are helpful in clarifying the temporal-spatial structure of Asian dust and which could also improve the forecasting of dust storms, climate prediction models, and aerosol reanalysis.

These results are mainly referred from Y. Cheng, T. Dai, D. Goto, H. Murakami, M. Yoshida, G. Shi and T. Nakajima (2021) Enhanced simulation of an Asian dust storm by assimilating GCOM-C observations, Remote Sensing, 13, 2020, https://doi.org/10.3390/rs13153020