Assimilation of GOCI AOD retrievals to improve air-quality forecasting during the KORUS-AQ period

Soyoung Ha
MMM/NCAR

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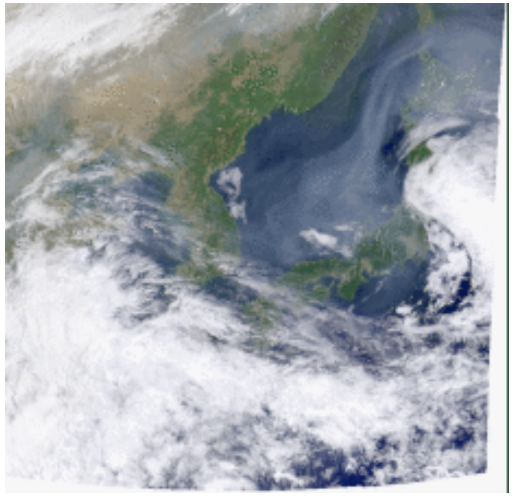

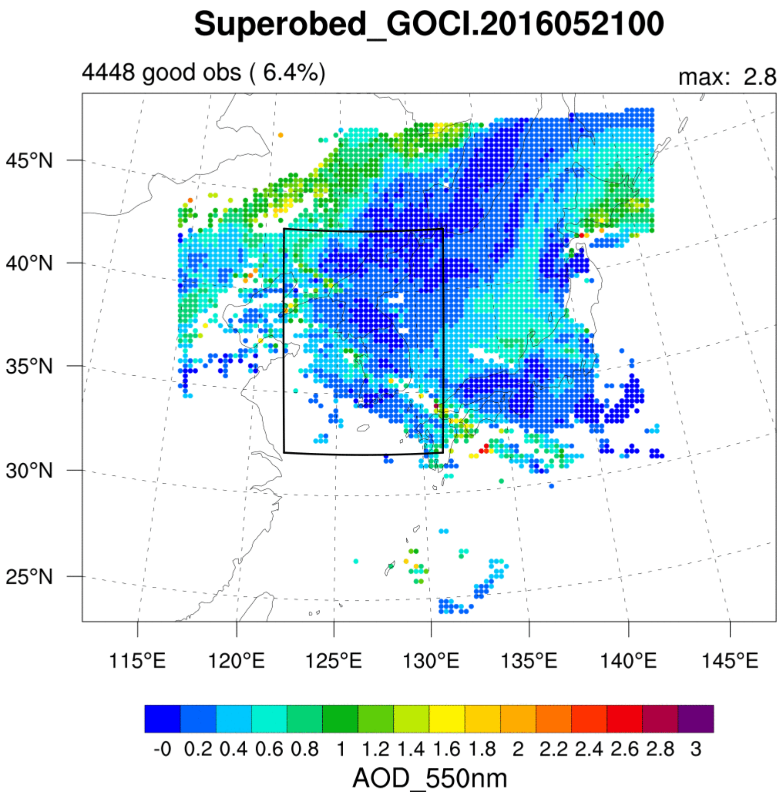

Collaborators:
Zhiquan Liu, Wei Sun (NCAR)

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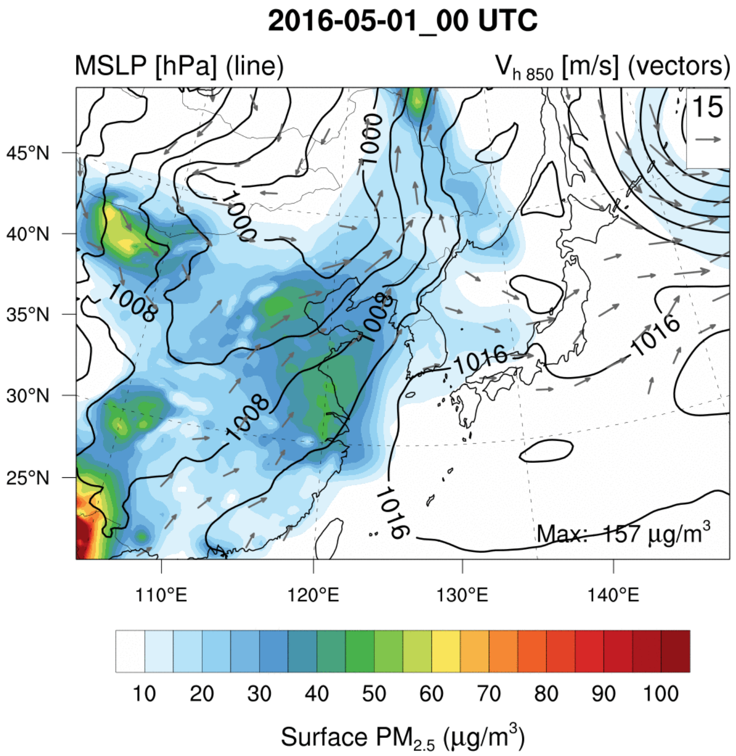
An International Cooperative Air Quality Field Study in Korea

The KORUS-AQ field study was conducted in South Korea during **May-June, 2016**. The study was jointly sponsored by **NASA** and **Korea's National Institute of Environmental Research** (**NIER**).
The primary objectives were to investigate the factors controlling air quality in Korea (e.g., local emissions, chemical processes, and transboundary transport) and to assess future air quality observing strategies incorporating geostationary satellite observations.

[» KORUS-AQ DOI: 10.5067/Suborbital/KORUSAQ/DATA01]



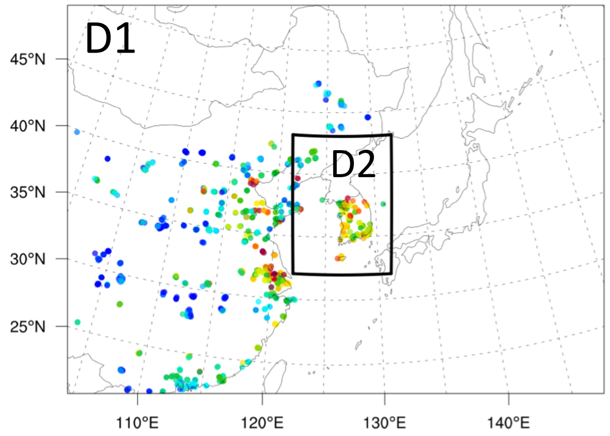
The **Geostationary Ocean Color Imager** (**GOCI**) was loaded on the Communication, Ocean and Meteorological Satellite (COMS) of South Korea which was launched in June, 2010. It acquires data in 8 spectral bands (6 visible, 2 NIR) with a spatial resolution of about 500 m around the Korean Peninsula 8 times a day until now.

Background on the AOD assimilation

- Aerosol Optical Depth (AOD) assimilation has both positive and negative impact on the forecast of surface $pm_{2.5}$ concentrations (Schwartz et al. 2012; Saide et al. 2014; Pang et al. 2018)
  - Hard to represent/match $PM_{2.5}$ concentrations at ground stations with AOD retrievals
  - Correlations between AOD and ground $PM_{2.5}$ concentrations are not very high
  - Systematic error in the AOD retrievals (errors associated with cloud contamination effects)
  - The GOCART mechanism in WRF/Chem tends to underestimate the surface $PM_{2.5}$ (due to the lack of secondary organic aerosol (SOA) formation, nitrate, and ammonium)
  - Concurrent assimilation of MODIS AOD retrievals and surface $PM_{2.5}$ improved aerosol forecasts, but still underestimated surface $PM_{2.5}$.

A forecast model – WRF-Chem V3.9.1

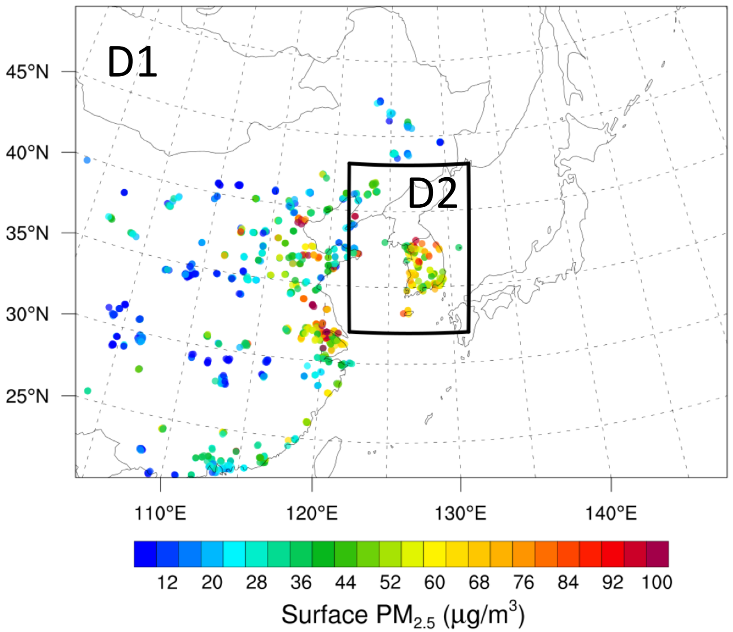
- Online coupled between meteorology and chemistry
- One-way nesting in 27- and 9-km domains
  - D1: 175 x 127 on 27 km resolution
  - D2: 97 x 136 on 9 km resolution
  - Total of 31 vertical levels up to 50hPa

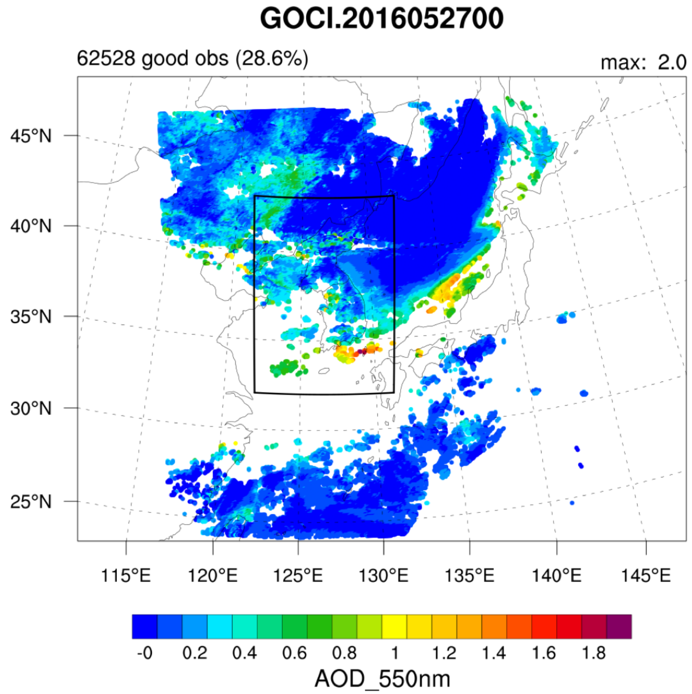


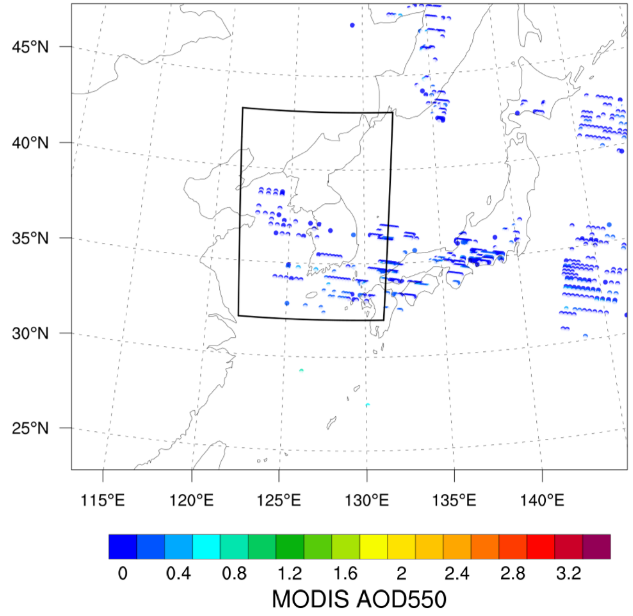
- Lin microphysics, RRTMG longwave, Goddard shortwave radiation, Noah LSM, YSU PBL, Grell-3 cumulus schemes
- MOZART chemistry and GOCART aerosol schemes
- Anthropogenic emission: EDGAR-Hemispheric Transport of Air Pollutants (HTAP) V2
- Phot_opt = 3; Madronich F-TUV photolysis
- MEGAN biogenic emissions
- The Fire Inventory from NCAR (FINN) biomass burning emissions
- Feedback from the aerosols to the radiation schemes is on

Observations

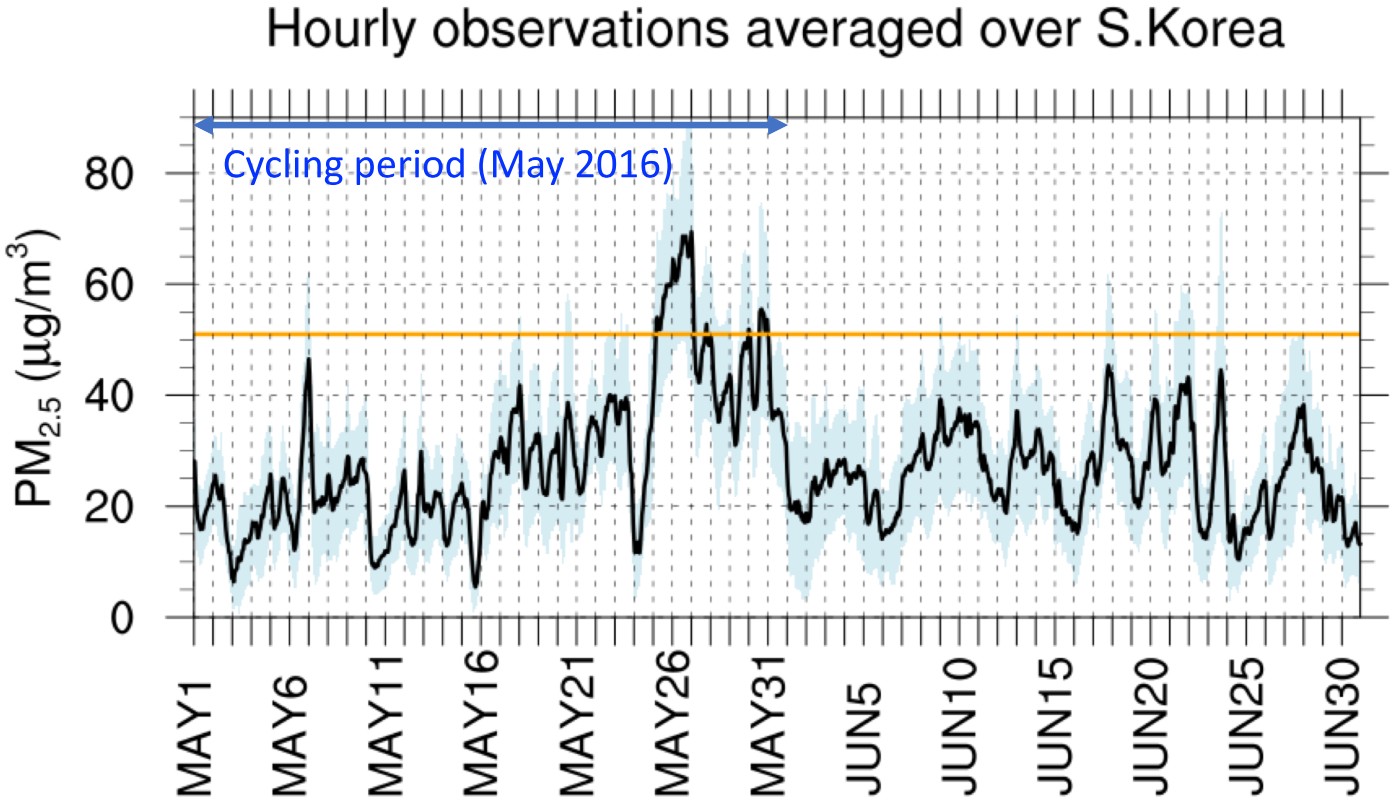
- Aerosol observations for May 1 – 31, 2016 during the KORUS-AQ period
- Surface data: Hourly surface particulate matter ($PM_{2.5}$) concentrations over Korea (AirKorea; 361 stations) and China (CNEMC;~950 stations)
- Satellite data: Aerosol optical depth (AOD) retrievals from Moderate Resolution Imaging Spectroradiometer (MODIS) AQUA and TERRA, and Geostationary Ocean Color Imager (GOCI) Level II data at 550 nm wavelength

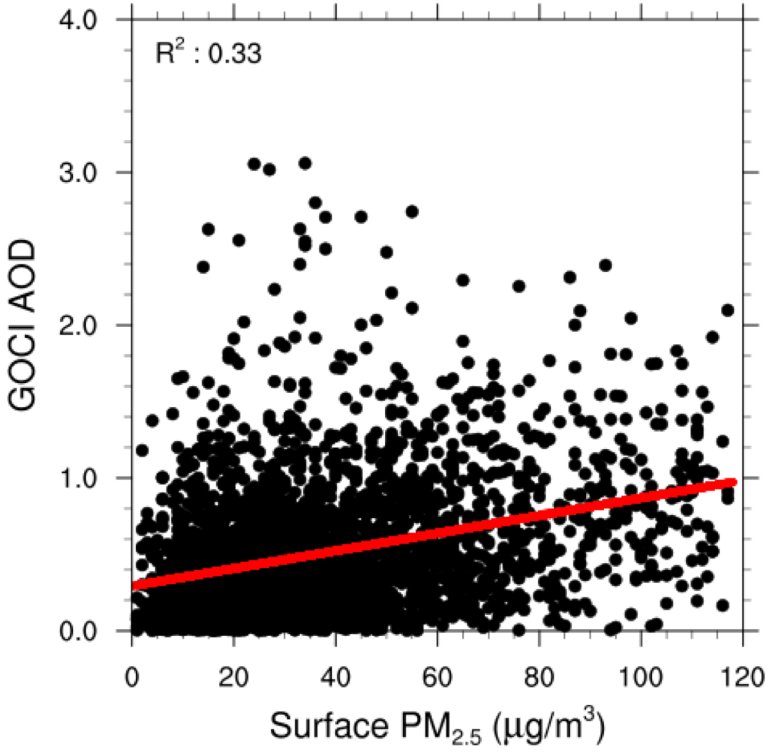






Surface PM observations vs. GOCI AOD retrievals

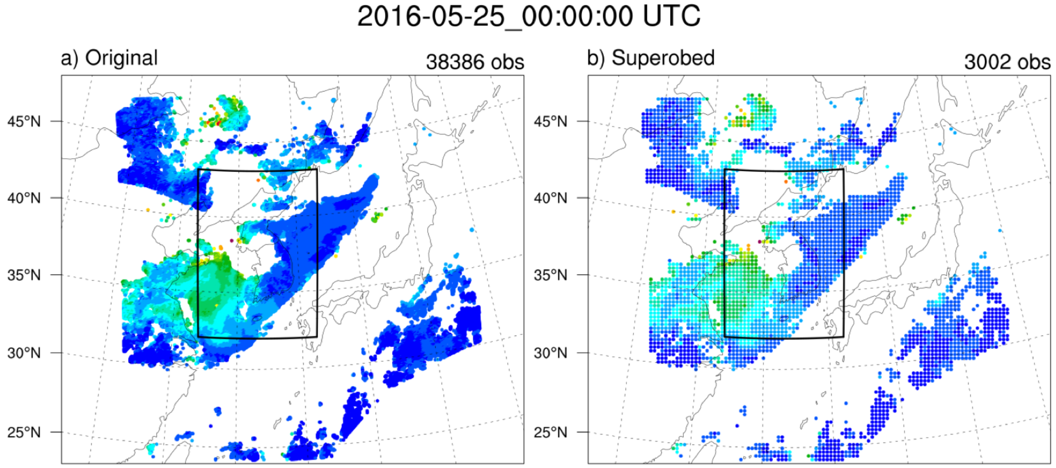


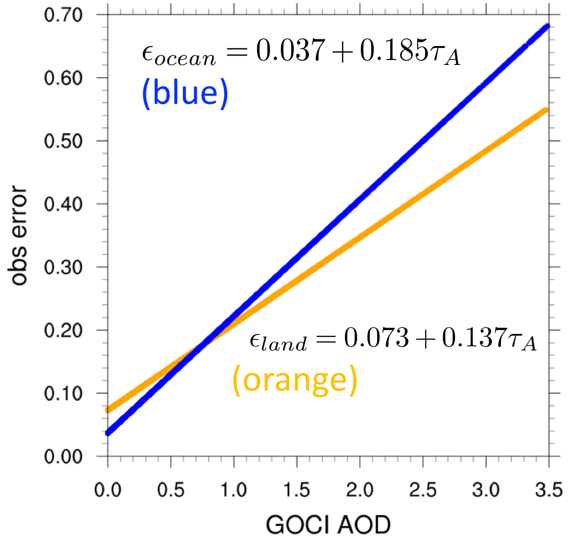


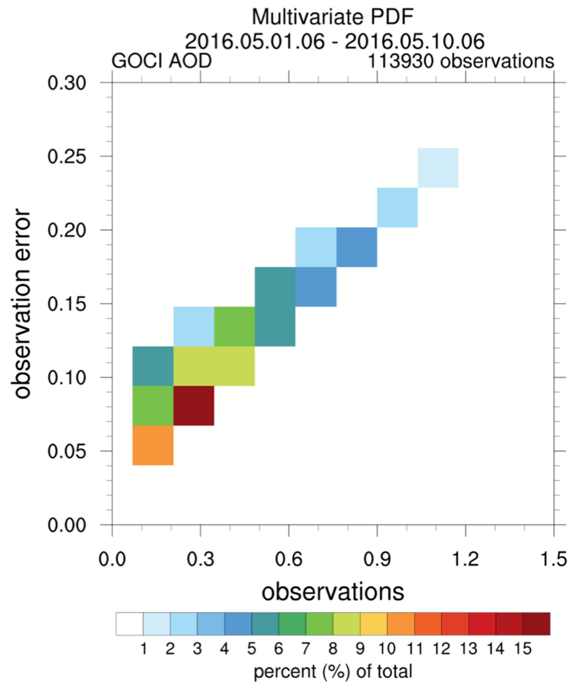
GOCI AOD retrievals

- Monitoring the East Asian region hourly from 00 to 08 UTC every day
- Level II data @ 6 km resolution

  => preprocessed over 27-km grids – GSI became 25x faster than thinning
- Observation error assignment based on Choi et al. (Atmos. Meas. Tech., 2018)







An analysis system – GSI 3DVAR (Version 3.5)

- Given the model variable (x) for the corresponding observation y, the cost function *J(x)* is minimized w.r.t. the initial condition x_0.

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \mathbf{x_b})^{\mathbf{T}}\mathbf{B}^{-1}(\mathbf{x} - \mathbf{x_b}) + \frac{1}{2}[H(\mathbf{x}) - \mathbf{y}]^{\mathbf{T}}\mathbf{R}^{-1}[H(\mathbf{x}) - \mathbf{y}]$$

Observation operator, *H*(x), for AOD data, is based on the community radiative transfer model (CRTM), as in Liu et al. (2011).

Schwartz et al. 2014 (JGR-A)

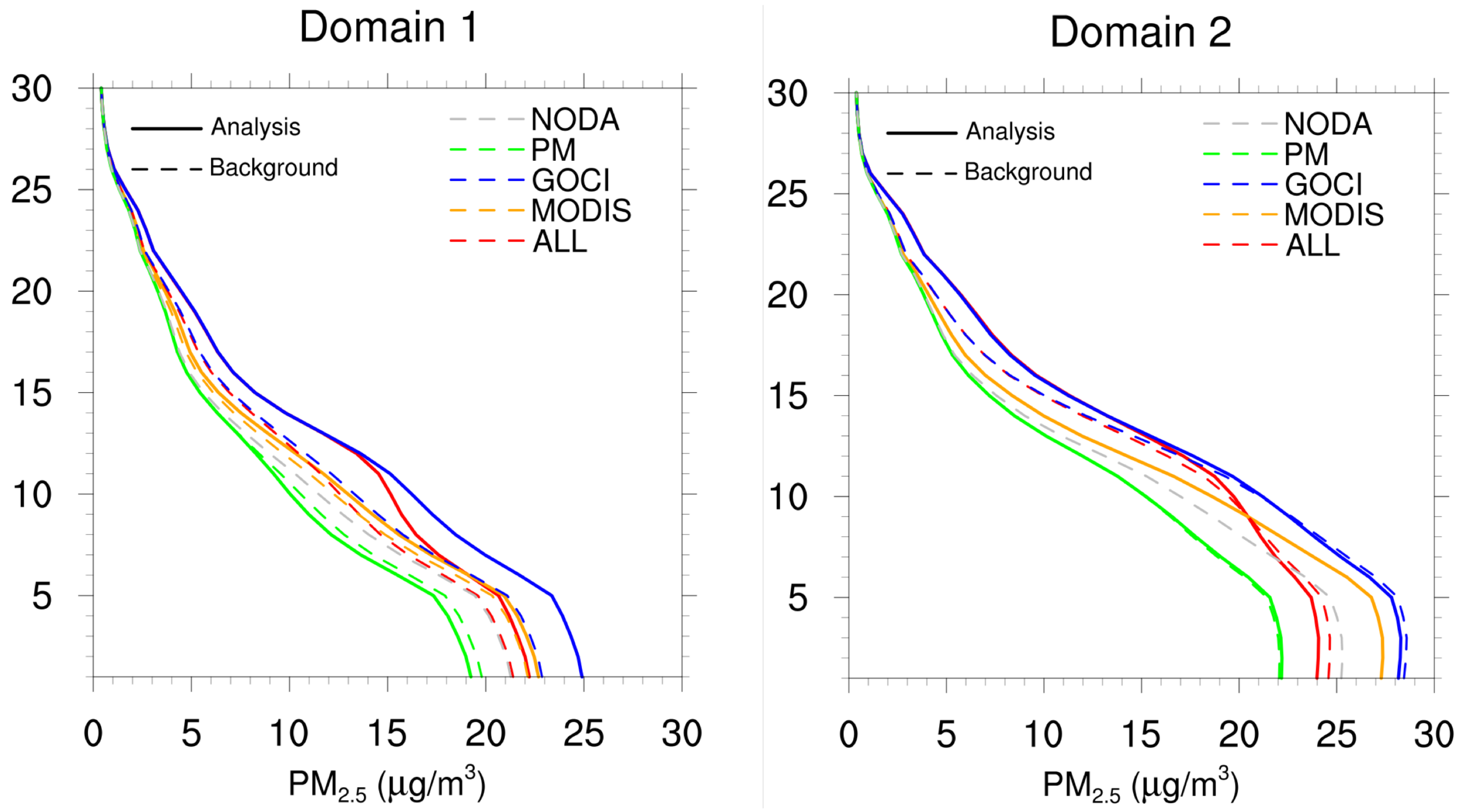
Table 1. Descriptions and Abbreviations of the 15 GOCART Aerosol Variables Considered in This Study

Description	Abbreviation Used in Figures 9 and 10
Sulfate	Sulfate
Hydrophobic organic carbon	OC1
Hydrophilic organic carbon	OC2
Hydrophobic black carbon	BC1
Hydrophilic black carbon	BC2
Sea salt with effective radius 0.3 μm for dry air	SeaSalt1
Sea salt with effective radius 1.0 μm for dry air	SeaSalt2
Sea salt with effective radius 3.25 μm for dry air	SeaSalt3
Sea salt with effective radius 7.0 μm for dry air	SeaSalt4
Dust with effective radius 0.5 μm	Dust1
Dust with effective radius 1.4 μm	Dust2
Dust with effective radius 2.4 μm	Dust3
Dust with effective radius 4.5 μm	Dust4
Dust with effective radius 8.0 μm	Dust5
Unspeciated contributions to $PM_{2.5}$	P25

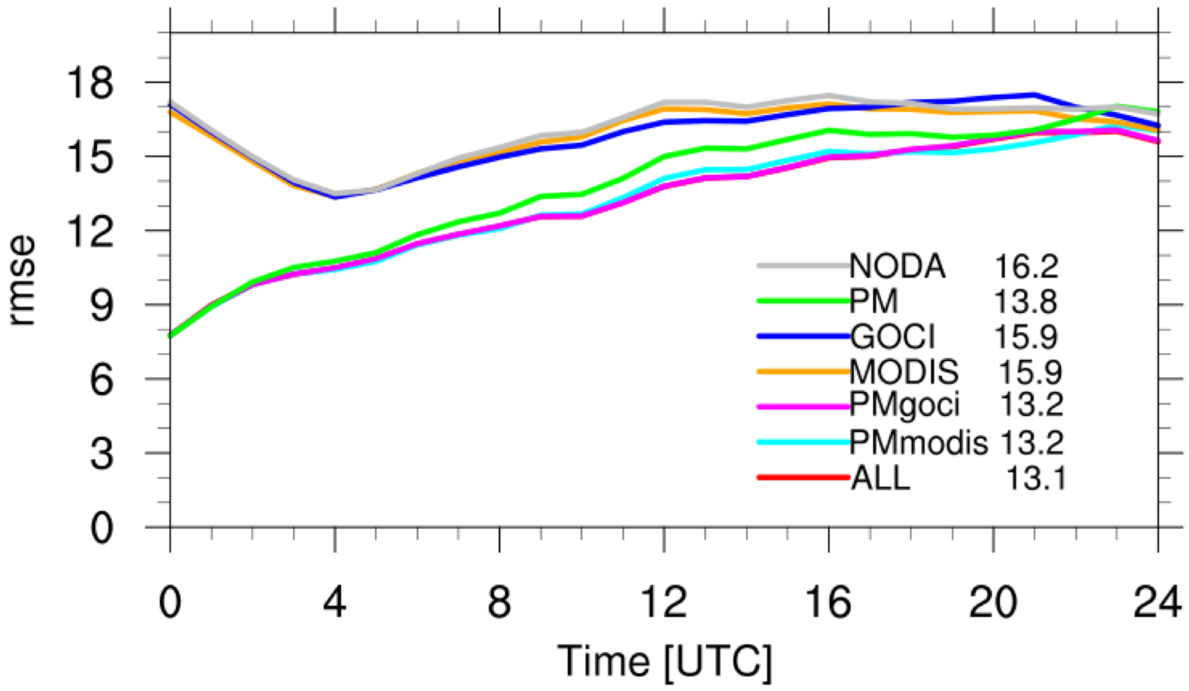
Analysis/forecast cycling

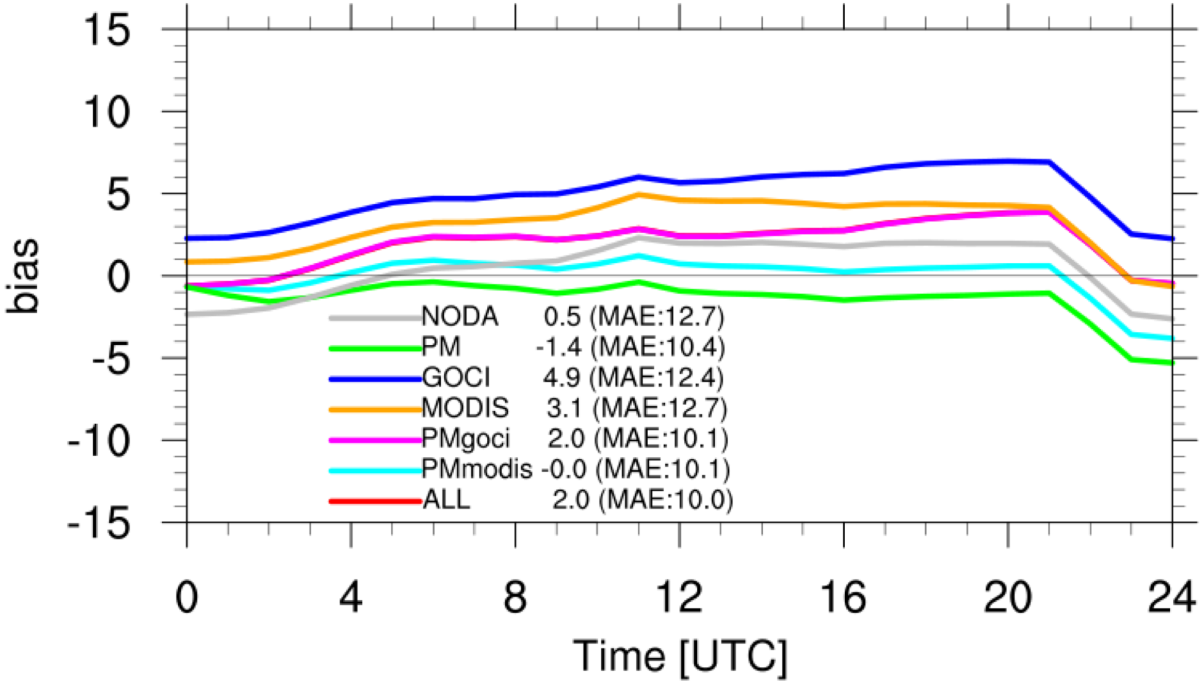
- Regional cycling using WRF-Chem/GSI 3DVAR analysis w/ ± 1h assim. window
- KORUS-AQ period (May 1 – 31, 2016) cycling every 6h
- One-way nesting in 27- and 9-km domains (for both analysis and forecast)
- Meteorological initial and lateral boundary conditions from UM forecasts
- Chemical initial and boundary conditions from MOZART-4 output (mozbc)
- Static background error covariance estimates using 48-24h forecast error (the NMC method; Parrish and Derber, 1992); univariate error covariance for 15 GOCART aerosol species
- 24h forecasts from the 00 UTC analysis every day

Observation impact on the analysis of $PM_{2.5}$



Impact of aerosol data assimilation (rmse/bias for all events in May 2016)





- Initialized from the 00Z analysis every day, for the period of May 3 – 31, 2016.
- The assimilation of ground PM observations tends to underestimate the surface PM forecasts.
- AOD assimilation alone overestimates surface PM.
- When assimilated with surface PM observations, however, GOCI and MODIS AOD retrievals are effective in improving surface PM forecasts for 24h.

Impact of aerosol data assimilation (categorical forecasts)

Concentration ($\mu g/m^3$, hourly)	Good	Moderate	Unhealthy	Very Unhealthy
PM_{10}	0-30	31-80	81-150	> 150
$PM_{2.5}$	0-15	16-50	51-100	> 100

Category		Forecast			
		Good	Moderate	Unhealthy	Very Unhealthy
Observation	Good	a1	b1	c1	d1
	Moderate	a2	b2	c2	d2
	Unhealthy	a3	b3	c3	d3
	Very Unhealthy	a4	b4	c4	d4

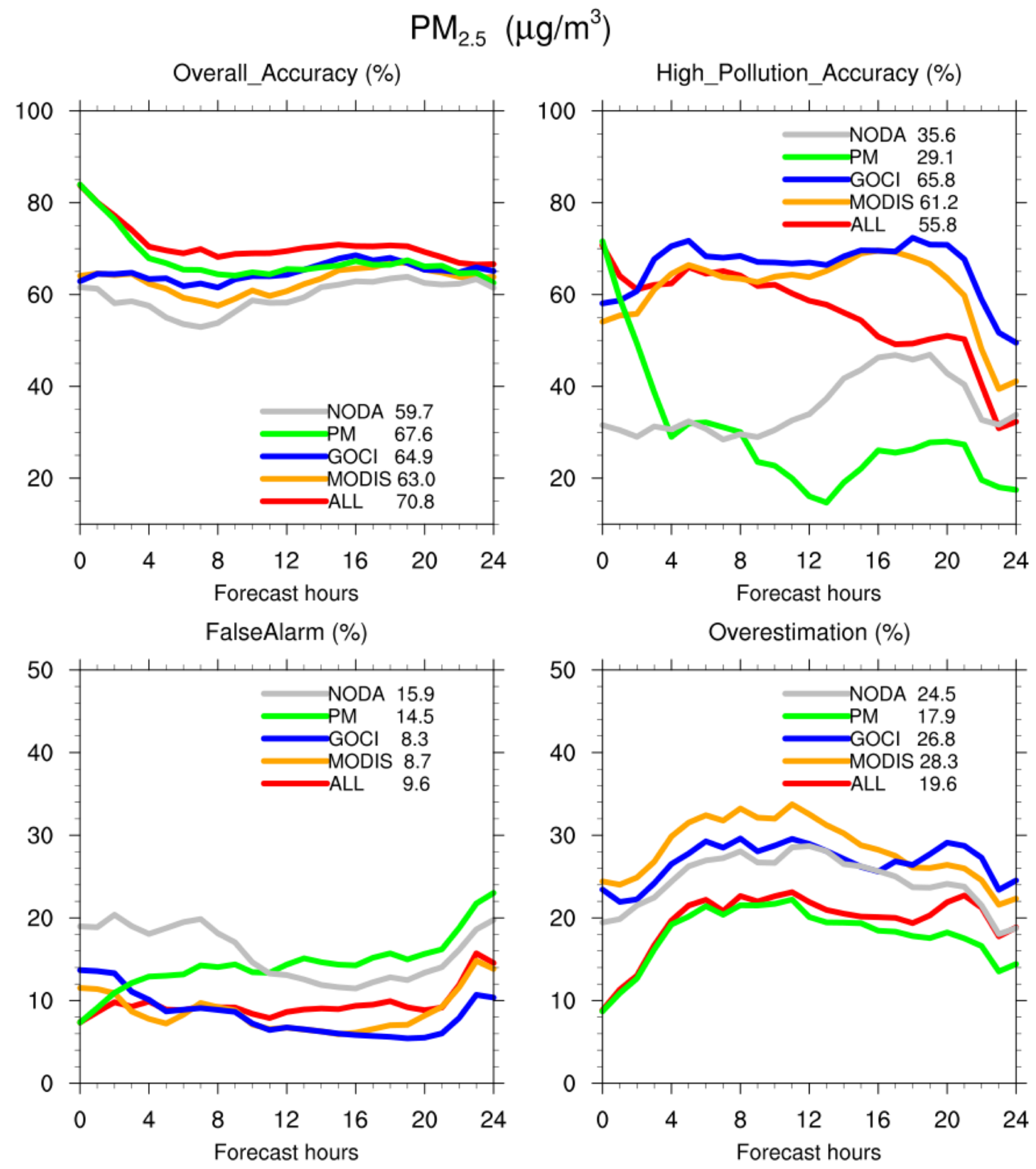
I, II, III, IV

$$Overall\_Accuracy(\%) = \frac{a1 + b2 + c3 + d4}{N} \times 100$$

$$High\_Pollution\_Accuracy(\%) = \frac{c3 + d4}{III + IV} \times 100$$

$$False\_Alarm(\%) = \frac{II}{II + IV} \times 100$$

$$Overestimation(\%) = \frac{b1 + c1 + c2 + d1 + d2 + d3}{N} \times 100$$



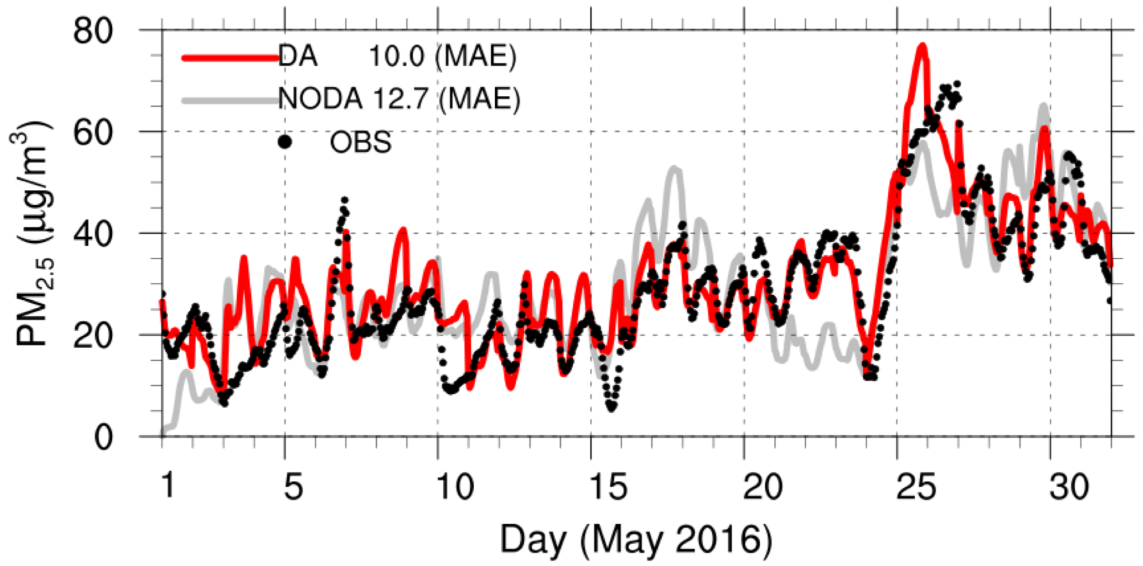
Summary

❖GOCI AOD retrievals are preprocessed and assimilated in WRF-Chem/GSI 3DVAR using MOZART/GOCART schemes during the KORUS-AQ period (May 2016).

❖GOCI AOD retrievals help improving surface $PM_{2.5}$ forecasts up to 24h when assimilated with ground PM observations.

❖GOCI AOD is particularly helpful for predicting heavy polluted events.

❖Aerosol assimilation improves air-quality forecasting over Korea with the mean absolute error (MAE) of 24h forecasts reduced by ~21% in surface $PM_{2.5}$.

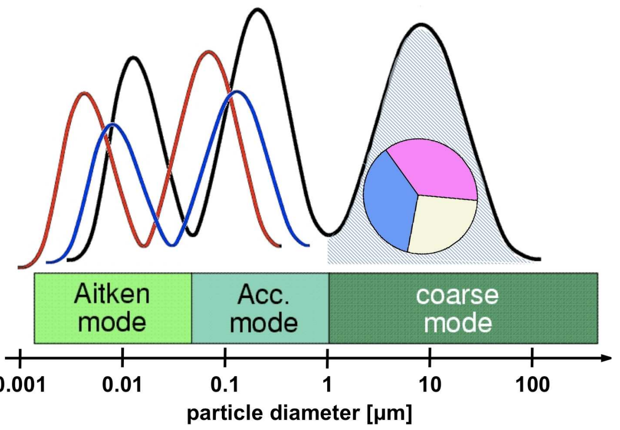


Future plan

Switching to WRFDA, we develop new observation operators **H(x)** for surface PM and chemical observations (such as O_3, SO_2, CO, NO_2) for new chemistry/aerosol schemes.

	Current GSI	WRFDA_2019
Gas phase chemistry	MOZART	RACM Regional Atmospheric Chemistry Mechanism
Aerosol chemistry	Bulk GOCART	MADE Modal Aerosol Dynamics Model for Europe
Gas phase/particle partitioning	No Secondary Organic Aerosol (SOA)	VBS Volatility Basis Set

Aquila et al. (GMD 2011)



MADE simulates the evolution of the coarse mode independently of the sub-micrometer modes