Efficacy of dust aerosol forecasts for East Asia using the adjoint of GEOS-Chem with ground-based observations

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Examine the efficacy of the data assimilation (DA) system for daily dust storm forecasts based on the adjoint model and ground-based observations

GEOS-Chem Adjoint Model (v8-02-01)
- Driven by assimilated GEOS-5 meteorological fields from the NASA GMAO
- Spatial resolution of 2°x2.5°, 47 vertical levels

Case studies for dust forecast
1. overestimation case (May 2007)
2. underestimation case (March 2011)

Observations
- Surface PM$_{10}$: API (China), NIER (Korea), EANET (Japan)
Simulated PM$_{10}$ concentrations with a priori dust source in surface air

1. overestimation case (May 2007)

- May 22-23, a severe dust storm occurred in the Gobi Desert.
- The a priori model seems to capture the temporal evolution of dust aerosol transport.
- But the model tends to overestimate the surface PM$_{10}$ concentrations.

[Jeong and Park, 2018]
Flowchart of the proposed adjoint framework

1. Dust emission scaling factors
2. Forward model (GEOS-Chem)
3. Observation ($\text{PM}_{10}$ in surface air)
4. Difference between model vs. observation
5. Gradient calculation (GEOS-Chem adjoint)
6. Update dust emission scale factor
To reduce the high bias of simulated dust concentrations, we applied the adjoint model with observed daily surface PM$_{10}$ concentrations in East Asia.

The a priori dust sources yield 7.7 Tg in the whole domain. However, the optimized dust emission based on the adjoint model calculation is 2.6 Tg.
Simulated PM$_{10}$ concentrations with the optimized dust source in surface air

1. overestimation case (May 2007)

The model with optimized dust sources better agrees with the observations, remarkably reducing the large bias.

Successfully reproduces the spatial and temporal distributions of PM$_{10}$ concentration observations, especially in downwind regions.

[Jeong and Park, 2018]
1. overestimation case (May 2007)

- The forecasts reproduce the high PM$_{10}$ concentrations in downwind regions in Korea and Japan on May 25–27.
- The spatial pattern of the forecasted PM$_{10}$ concentrations is similar to that of the observations, even when based on the surface observations up to the previous day.

[Jeong and Park, 2018]
1. overestimation case (May 2007)

- Model with optimized dust sources significantly reduces the high bias.
- DA system successfully forecasts the time evolution of observed peak PM$_{10}$ concentrations in Korea.

[Jeong and Park, 2018]
A clear severe dust storm signal was observed in Northwest China on March 17; the dust storms moved southeastward following the low-pressure system.

On March 18 a considerable dust signal was detected over eastern China approaching the western part of the Korean Peninsula.
PM$_{10}$ concentrations simulated with a priori dust source and forecast in surface air

2. underestimation case (Mar 2011)

- The model with a priori dust sources does not show high concentrations at all.
- The forecast successfully reproduces the observed surface PM$_{10}$ concentrations.

[Jeong and Park, 2018]
The PM$_{10}$ concentrations simulated with a priori sources are much lower than the observations (by a factor of 5), especially on March 19.

The DA system generally captured the time evolution of observed PM$_{10}$ concentrations including the core and tail of the severe dust storm.
The adjoint model constrained by observations showed better agreement with the spatial and temporal distributions of the observed PM$_{10}$ concentrations through improved dust emissions in source regions.

The forecast results successfully captured the spatial and temporal variations of ground-based observations in downwind regions, indicating that the data assimilation system with ground-based observations effectively forecasts dust storms, especially in downwind regions.

Further work is necessary to improve the dust storm forecast by developing the DA system combining available hourly updated ground- and satellite-based aerosol data.
Thank You !
Sensitivity simulation for 4°×5° horizontal resolution on May 2007

1. overestimation case (May 2007)

- simulated with a priori dust sources

24 May 2007

26 May 2007

25 May 2007

27 May 2007

[Jeong and Park, 2018]
Sensitivity simulation for 4°x5° horizontal resolution on May 2007

1. overestimation case (May 2007)

- forecasted with daily modified initial fields at 0000 UTC

24 May 2007

26 May 2007

25 May 2007

27 May 2007

[μg m⁻³]

[Jeong and Park, 2018]
Statistics of the PM$_{10}$ concentrations between model and observations in surface air

<table>
<thead>
<tr>
<th>Case</th>
<th>Resolution</th>
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<th>NMB (%)</th>
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