Toward synergistic use of geostationary satellite observations, atmospheric measurements, and models for air quality research and applications

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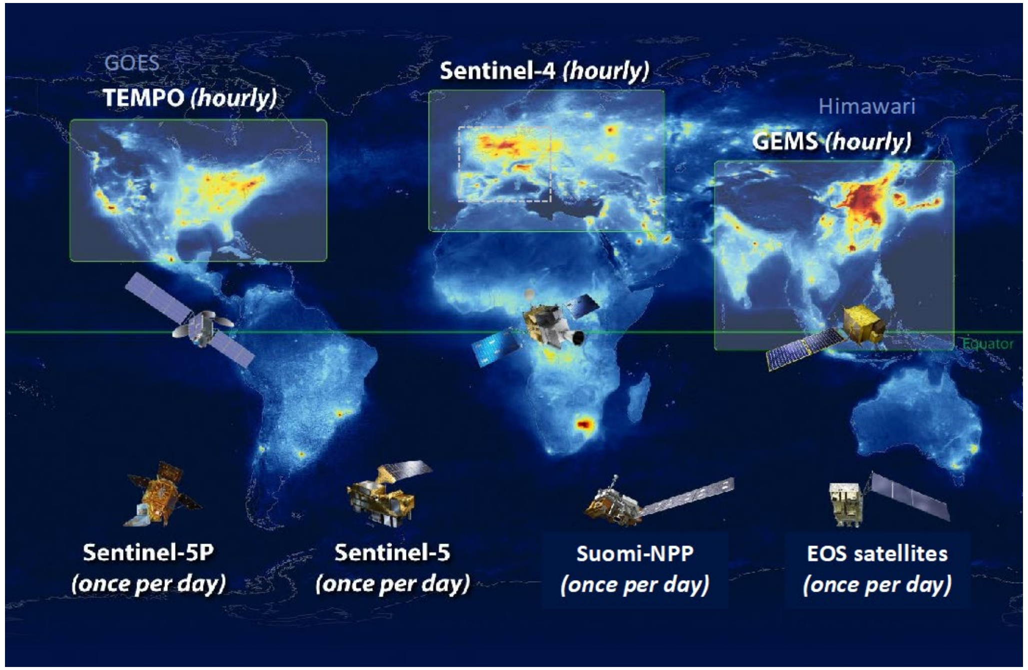

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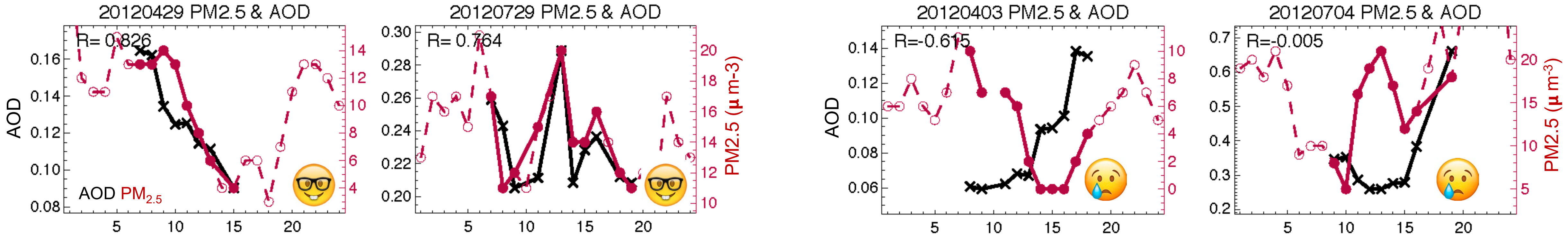
Introduction

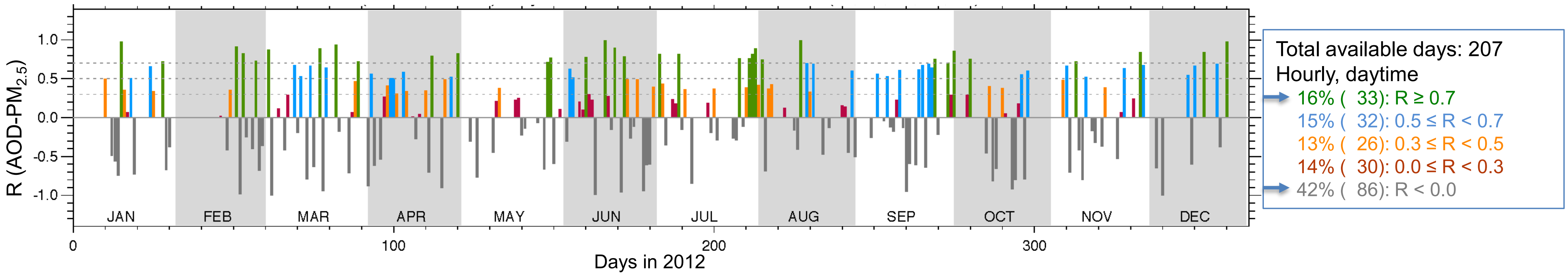
- Aerosol is a major pollutant determining air quality, e.g., $PM_{2.5}$. However, there are many areas with few or no surface $PM_{2.5}$ monitoring sites to sufficiently assess the health risk for large fraction of the world population
- Monitoring $PM_{2.5}$ from space has been made possible in the past two decades using satellite retrieved column aerosol optical depth (AOD) for its extensive spatial coverage. Still, fundamental challenges remain, because the AOD-$PM_{2.5}$ relationship varies spatially and temporally depends on many factors
- Inspired by the emerging constellation of geostationary satellite observations of major pollutants on diurnal time scales, we use the ground-based observations and the NASA GEOS model simulations to examine:
  - **How is AOD and $PM_{2.5}$ correlated on the diurnal time scale?**
  - **What are the major controlling factors determining the AOD and $PM_{2.5}$ relationship?**
  - **What are the implications of using geostationary satellite AOD for PM2.5 application?**

On diurnal time scale, observed AOD and $PM_{2.5}$ can exhibit quite different variability, affected by both mesoscale and synoptic scale processes – example at GSFC, MD with AERONET AOD and EPA $PM_{2.5}$

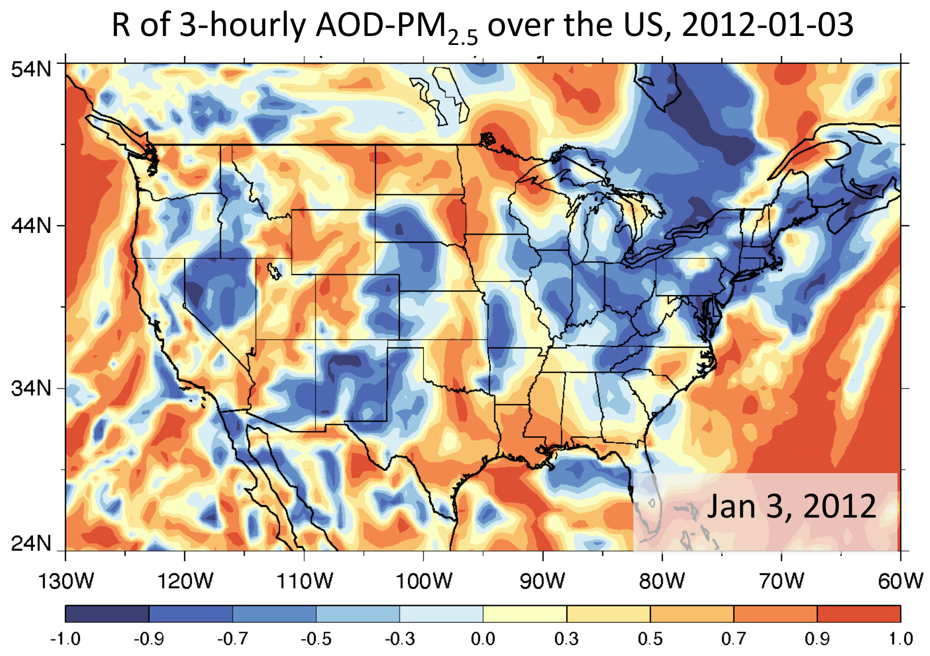
Daytime hourly correlation at GSFC in 2012: examples of “good” and “bad” correlation days

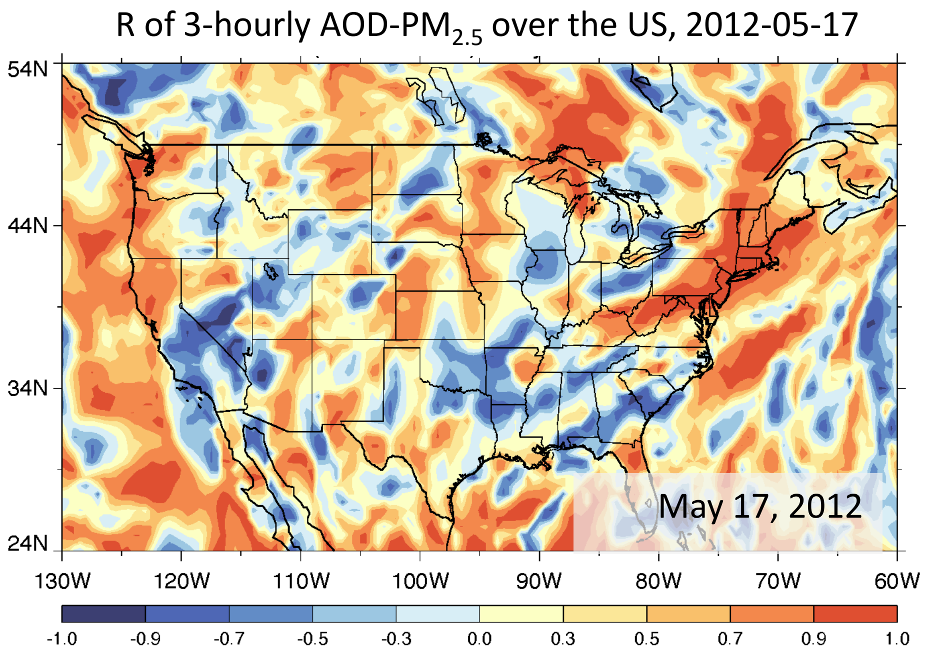


Correlation coefficients of observed hourly AOD-$PM_{2.5}$



The GEOS model simulations also show highly variable AOD-$PM_{2.5}$ correlations with time and locations

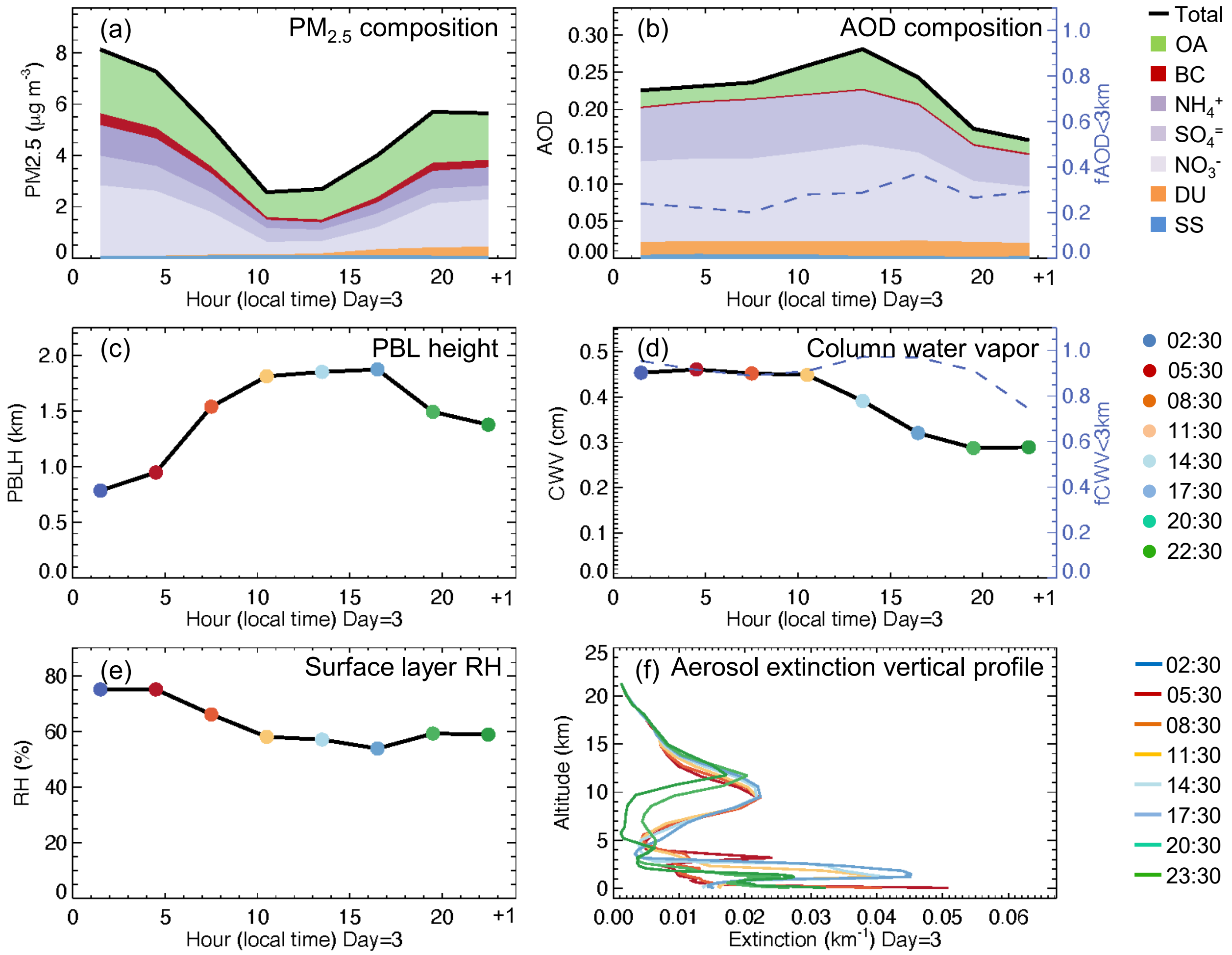




- There is a high spatial inhomogeneity of AOD-$PM_{2.5}$ co-variability at sub-daily time scales such that the hourly AOD cannot be directly used to estimate hourly $PM_{2.5}$ for AQ applications
- We choose two days in 2012 when model simulated 3-hourly AOD and $PM_{2.5}$ are either strongly negatively correlated or positively correlated to examine the reasons for different correlations

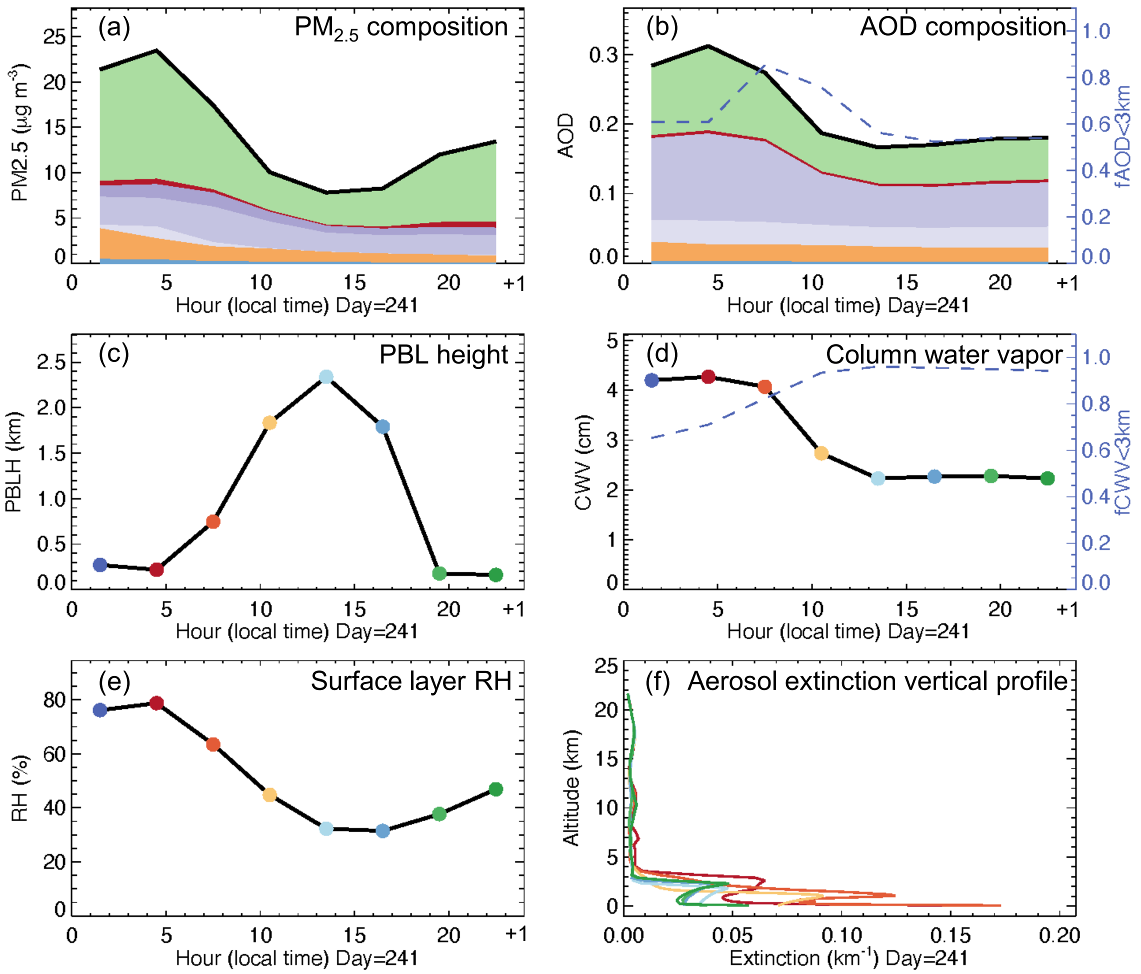
Examination of GEOS-simulated aerosol compositions, vertical profiles, and some meteorological fields to explain the AOD-$PM_{2.5}$ relationship in two different days

1. GSFC, 2012-01-03 ($R_{AOD-PM2.5}$= -0.90)



- **Aerosol compositions of $PM_{2.5}$ and AOD are quite different**
- **~30% of total AOD below 3 km with different temporal variation from aerosols aloft -> AOD variations are not in-sync with $PM_{2.5}$**

2. GSFC, 2012-08-29 ($R_{AOD-PM2.5}$= +0.98)



- **Aerosol compositions of $PM_{2.5}$ and AOD are similar**
- **55-80% of AOD below 3km -> both AOD and $PM_{2.5}$ temporal variations are controlled by the aerosol below 3 km**

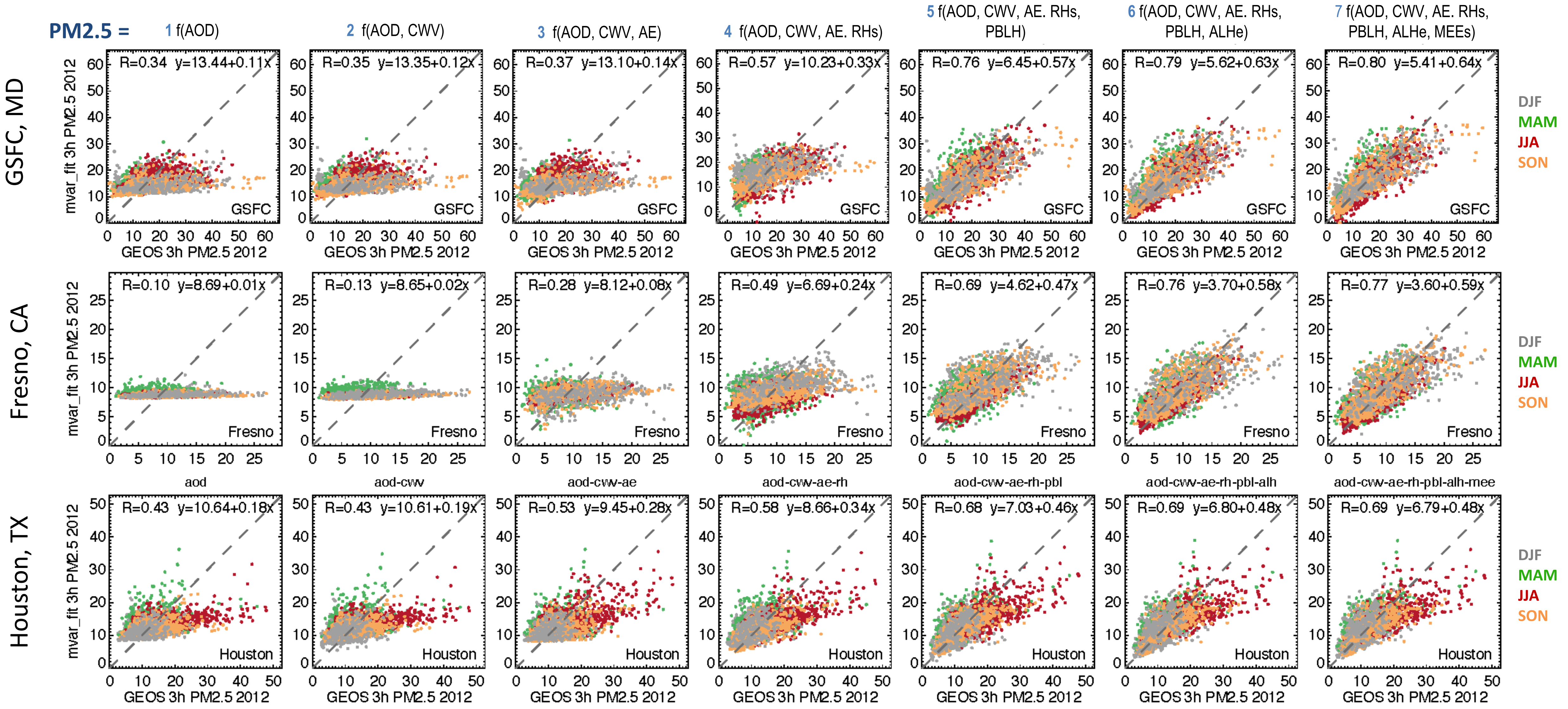
We use the GEOS model simulations of AOD, $PM_{2.5}$, aerosol extinction vertical profiles, and relevant meteorological fields to explain the diurnal variations of AOD and $PM_{2.5}$ at various locations

- Select several key "observable" variables from the GEOS model for multi-variable regression to estimate the 3-hourly $PM_{2.5}$ concentrations from model simulated AOD and compare them to the "true" model calculated $PM_{2.5}$ values at different places

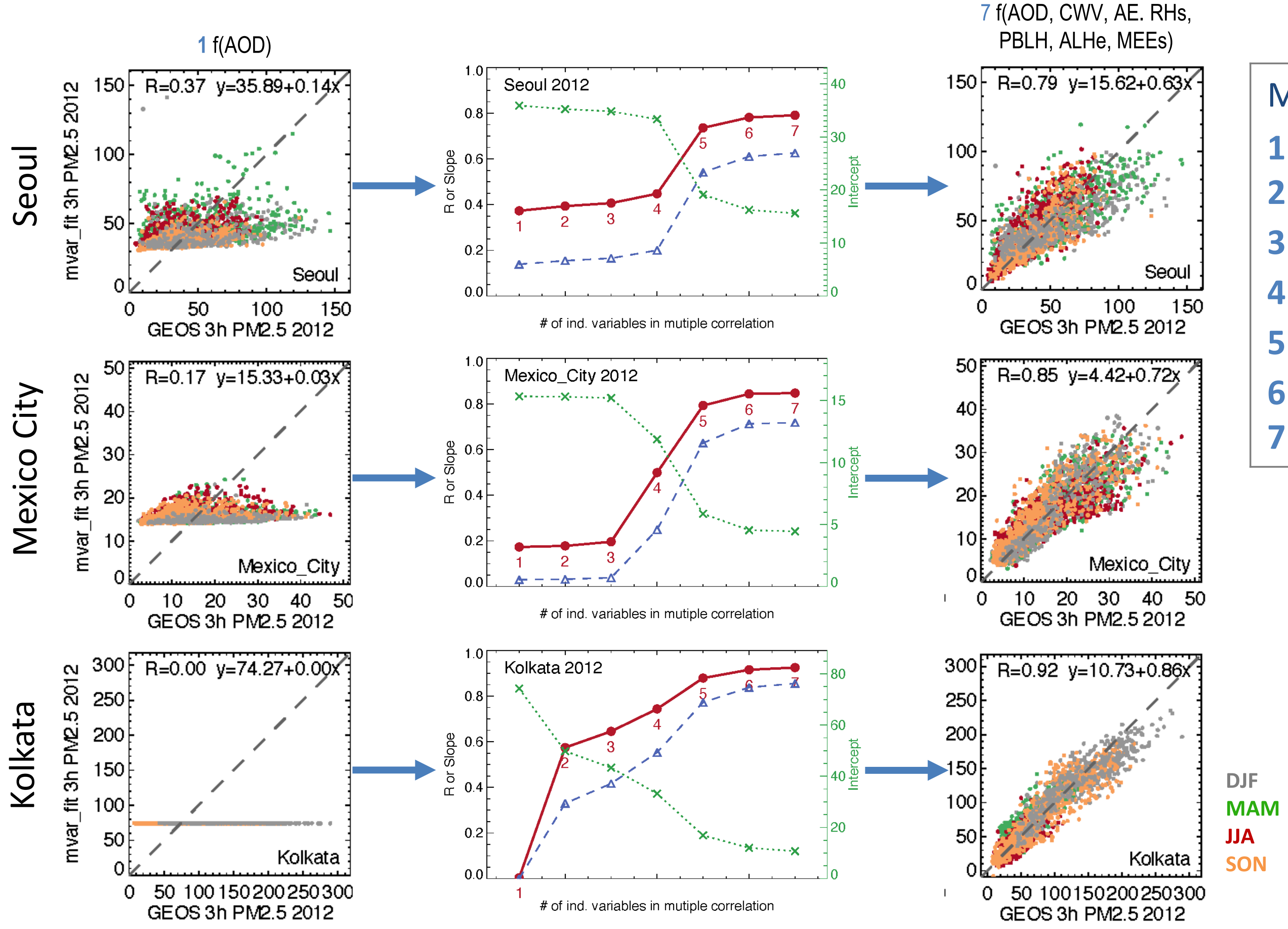
Variable	Effects	Observability
1 Aerosol optical depth (AOD)	Basic quantity for estimating PM2.5	Satellite & AERONET
2 Column water vapor (CWV)	Affecting AOD	Some satellite & AERONET
3 Angstrom Exponent (AE)	Indication of particle size	Some satellite & AERONET
4 Surface RH (RHs)	Affecting surface aerosol extinction	Surface weather station
5 PBL height (PBLH)	Controlling surface PM2.5	Ceilometer, lidar, balloon, etc.
6 Aerosol eff. layer height (ALHe)	Indication of aerosol vertical location	Limited satellite retrieval, lidar
7 Sfc. mass extinction efficiency (MEEs)	Information of aerosol composition	Rarely observable

Observability decrease

Estimated $PM_{2.5}$ from multi variable regression vs. "true" GEOS-calculated $PM_{2.5}$ at 3 US sites



Estimated $PM_{2.5}$ from multi variable fitting vs. “true” GEOS-calculated $PM_{2.5}$ at 3 other pollution sites

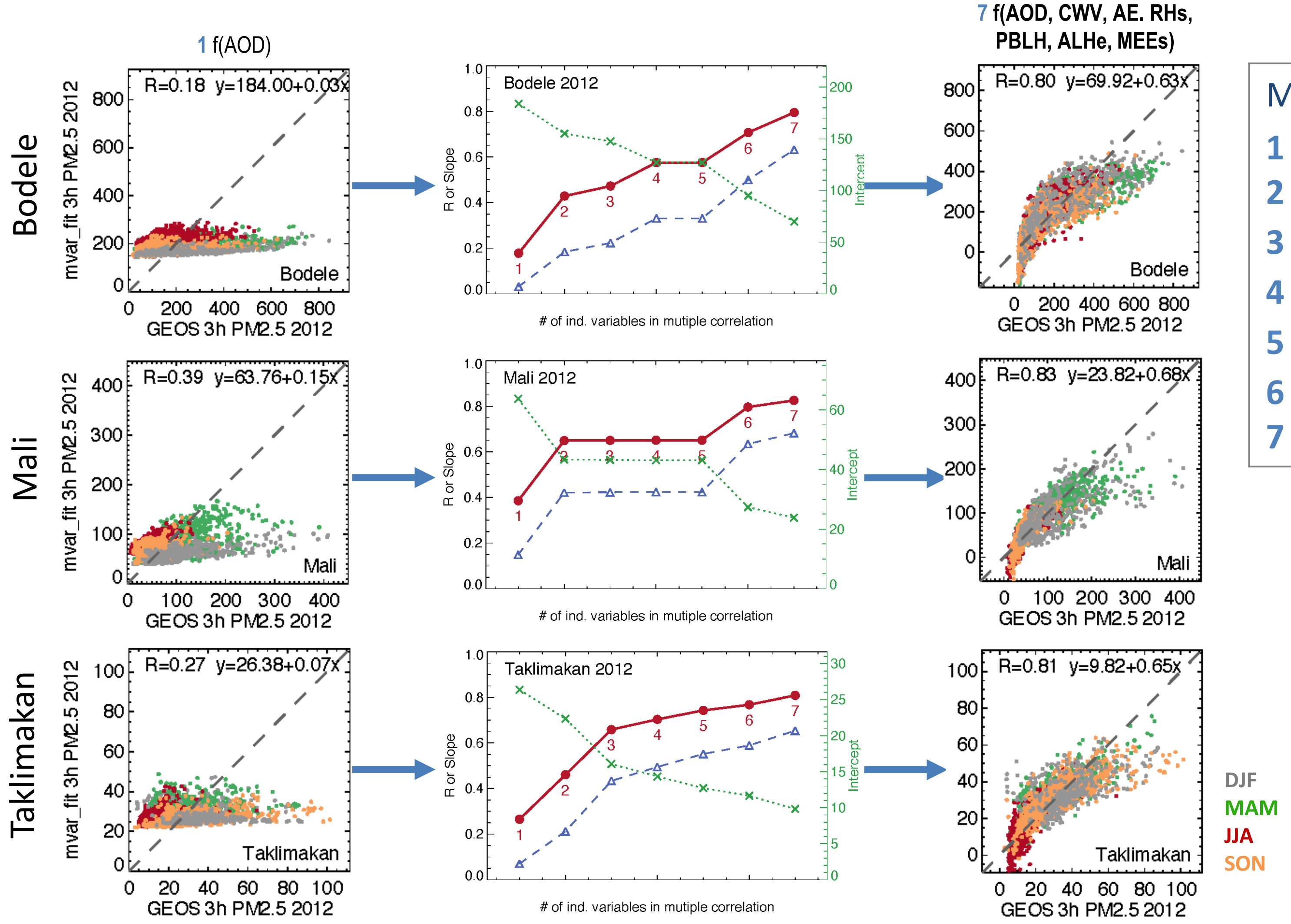


Multivariable regression of 3-hour GEOS output:

1. $PM_{2.5} = f\,(AOD)$
2. $PM_{2.5} = f\,(AOD, CWV)$
3. $PM_{2.5} = f\,(AOD, CWV, AE)$
4. $PM_{2.5} = f\,(AOD, CWV, AE, RHs)$
5. $PM_{2.5} = f\,(AOD, CWV, AE, RHs, PBLH)$
6. $PM_{2.5} = f\,(AOD, CWV, AE, RHs, PBLH, ALHe)$
7. $PM_{2.5} = f\,(AOD, CWV, AE, RHs, PBLH, ALHe, MEEs)$

The multi-variable regression fitting is generally robust over polluted regions, although sensitivities to different variables vary

Estimated $PM_{2.5}$ from multi variable fitting vs. "true" GEOS-calculated $PM_{2.5}$ at 3 dust dominated sites



Multivariable regression of 3-hour GEOS output:

1. $PM_{2.5} = f\,(AOD)$
2. $PM_{2.5} = f\,(AOD, CWV)$
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5. $PM_{2.5} = f\,(AOD, CWV, AE, RHs, PBLH)$
6. $PM_{2.5} = f\,(AOD, CWV, AE, RHs, PBLH, ALHe)$
7. $PM_{2.5} = f\,(AOD, CWV, AE, RHs, PBLH, ALHe, MEEs)$

Over the dust source regions, additional factors (e.g., non-linear relationship with surface winds) need to be included

Conclusions

- Observations from collocated AOD and $PM_{2.5}$ measurements shows that it is not feasible to directly convert observed diurnal AOD to diurnal $PM_{2.5}$
- Our modeling analysis suggests that it is possible to "retrieve" diurnal $PM_{2.5}$ from diurnal AOD data with much improved accuracy if additional ancillary variables are included in the retrieval (e.g., CWV, AE, RHs, PBLH, ALHe, and possibly MEEs)
- Such method seems to be temporally and spatially robust across seasons over pollution dominated regions, although sensitivity to different variables varies
- For dust regions, additional parameters (e.g., surface wind speed) need to be included (work in progress)
- We are in the process of developing a physically-based machine learning model (trained with GEOS parameters) that will be tested with GOES and Himawari geostationary satellite AOD data to retrieve the surface PM2.5