An evaluation of trends and variability in aerosol optical depth over the Northern Hemisphere simulated by CMAQv5.3.2 for the EQUATES project

Rebecca Miller[1], Christian Hogrefe[2], Rohit Mathur[2], Jonathan Pleim[2], and Kristen Foley[2]

[1]ORAU NSSC, on assignment to U.S. Environmental Protection Agency, Research Triangle Park, NC, USA

[2]U.S. Environmental Protection Agency, Research Triangle Park, NC, USA

*Corresponding Author: Rebecca Miller | miller.rebecca@epa.gov

www.epa.gov

Background

Air quality models are important tools for studying atmospheric trace gases and aerosols. Their outputs are often used to quantify adverse impacts of air quality on human health and the environment. Model simulations were performed for 2002–2017 using CMAQv5.3.2 and WRFv4.1.1 over the Northern Hemisphere (NH). Emissions were represented by a 2002–2017 emissions dataset developed for EPA's Air QUAlity TimE Series (EQUATES) project. In this presentation, we compare these simulations with monthly average aerosol optical depth (AOD) data from satellite and surface observations to assess the model's ability to capture observed variability and trends in the tropospheric aerosol burden.

Data & Methods

- AOD and total precipitation from CMAQ and WRF simulations, as described above. Monthly average AOD is calculated for the daily hours 0900–1500 LST to match satellite observations.
- Monthly average AOD from the Moderate Resolution Imaging Spectroradiometer (MODIS; MOD08_M3, Platnick et al., 2015) onboard the NASA Terra satellite is used to assess modeled AOD. The MODIS Deep Blue Dark Target product is used to have a complete picture of the NH and is interpolated to the model grid.
- AERONET ground based AOD observations are also used. Model AOD values are matched with site location and observation hour. These hourly observations are used to calculate the monthly average for each site, with a minimum of one observation required for the calculation. Not all AERONET sites provide a complete set of hourly observations for the entire time period. To further analyze the representativeness of the available observations, monthly average model AOD for each site for the entire 2002–2017 time series is used for comparison.
- Annual linear trends for each grid point are calculated from the annual average of the monthly average AOD values. Trends not tested for statistical significance.

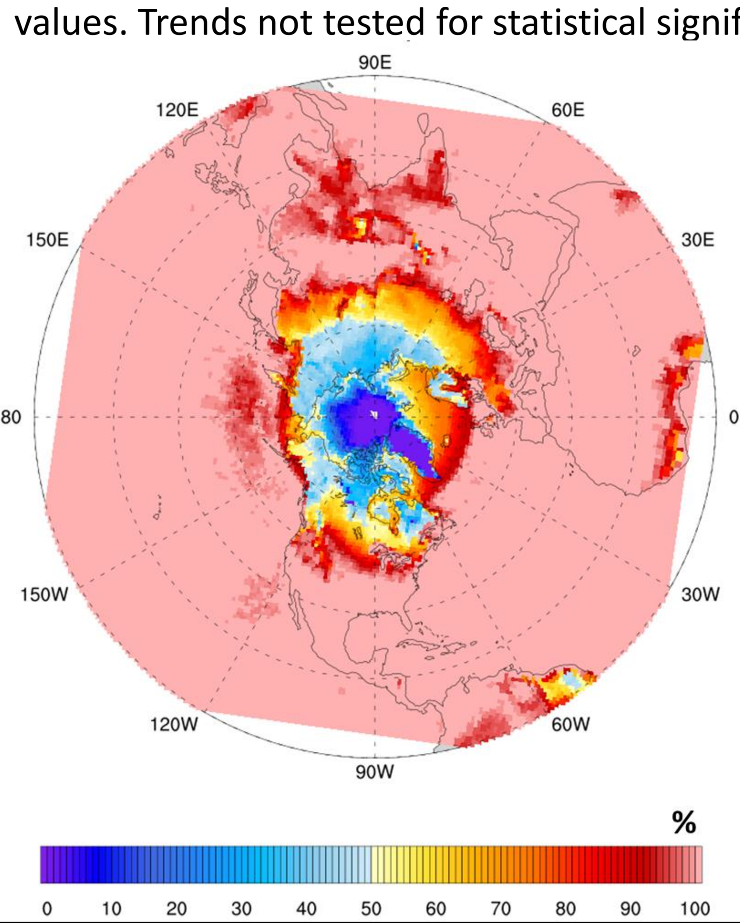

Figure 1. Percentage of monthly average AOD values available from MODIS (MOD08_M3) satellite Deep Blue Dark Target product for 2002–2017 (192 months).

How does model derived AOD compare with MODIS satellite observations?

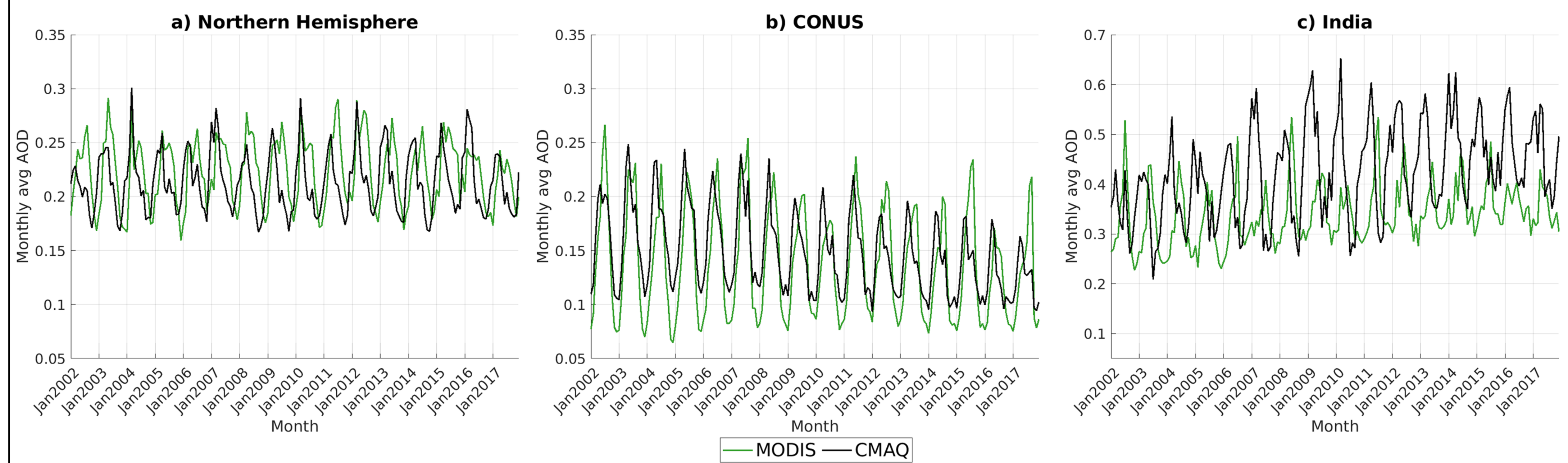

Figure 2. Monthly average AOD values for H-CMAQ (black) and MODIS satellite observations (green). Regional averages are calculated over a) Northern Hemisphere, b) CONUS, and c) India.

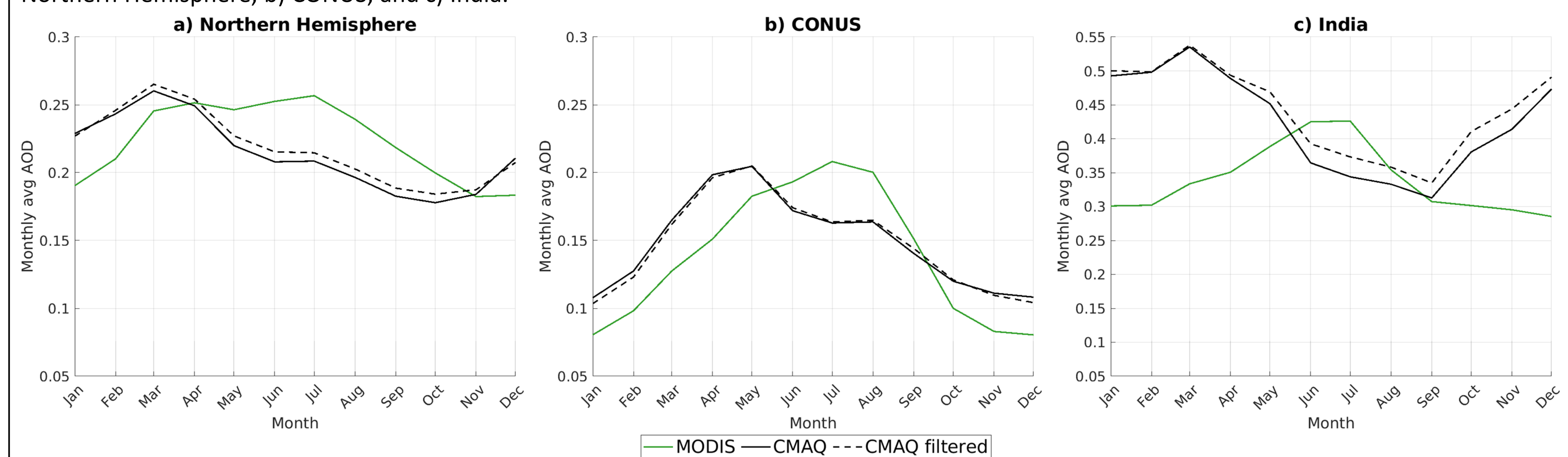

Figure 3. Annual AOD cycles averaged over 2002–2017 for H-CMAQ (black) and MODIS satellite observations (green) for regions a) Northern Hemisphere, b) CONUS, and c) India. H-CMAQ AOD is filtered (black dashed line) with the 70th percentile total precipitation.

Figs. 2 and 3 compare monthly average AOD values between MODIS satellite observations and HCMAQ model values averaged over select regions. The model overestimates winter and spring AOD and underestimates summer AOD for all regions. The NH and CONUS show a similar annual cycle with a different annual peak, where the model begins to decrease earlier. For India, the annual cycle is opposite between the model and observation, where the observation increase to a mid-year peak and then decreases, and the model decreases to a mid-year minimum and then increases.

One hypothesis as to why the model summertime AOD is underestimated is the inclusion of high precipitation days in the computation of the model monthly averages. Such days, which may be characterized by lower aerosol concentrations due to rainout, are not included in the satellite product due to cloud cover. To test this, we filter model high precipitation days by removing AOD values for days that exceed the 70th percentile of the grid point total precipitation. These filtered model AOD values are shown in Fig. 3 (black dashed line). The change in AOD values with the precipitation filter is minimal. Therefore, excluding high precipitation day AOD values does not explain why the model underestimates summertime AOD values compared with satellite observations.

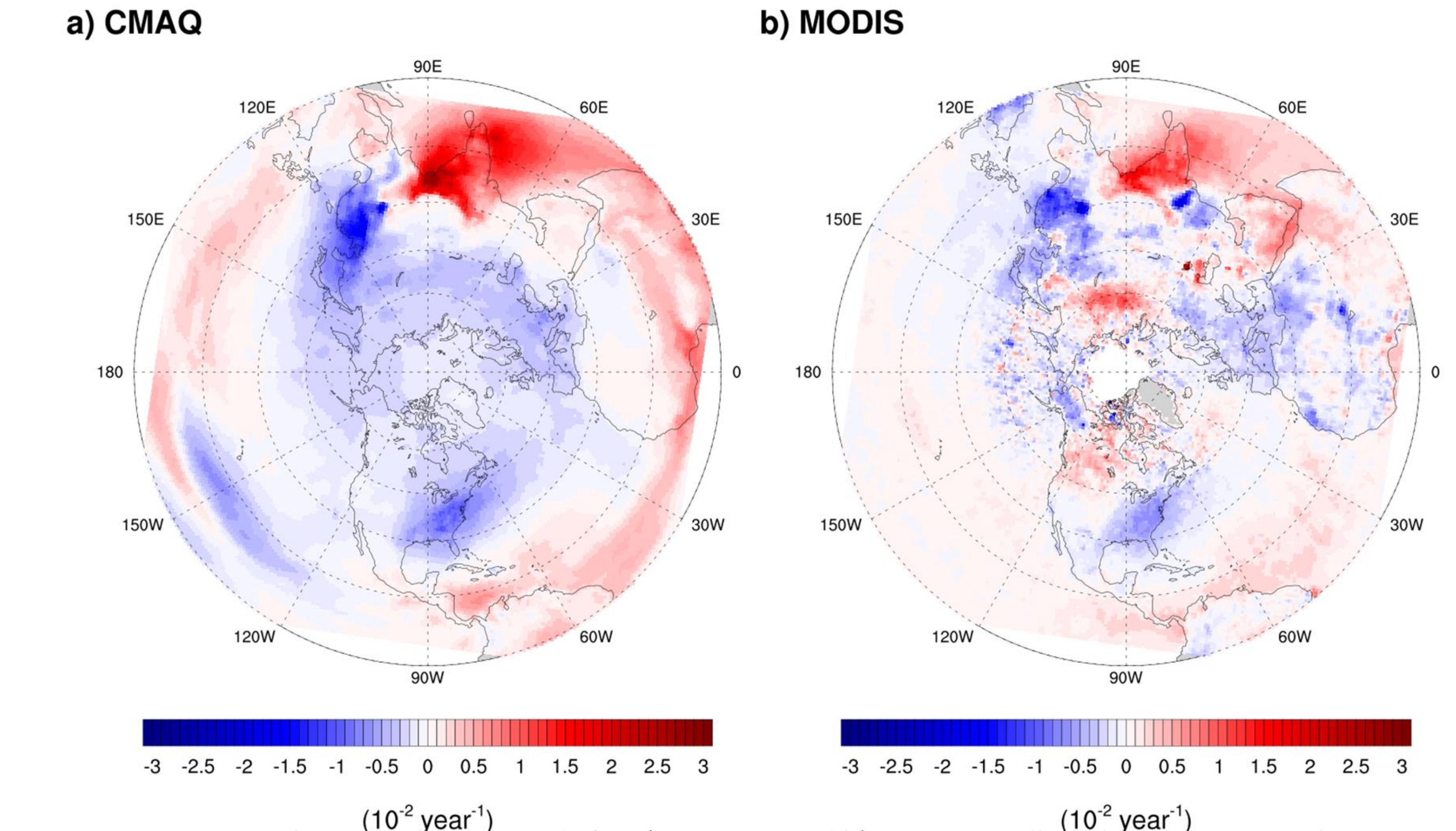

Figure 4. AOD annual average linear trends for a) H-CMAQ and b) MODIS satellite observations. Analyzing trends in AOD provides insights into the effects of emission changes over this time period on the tropospheric aerosol burden.

While the time series highlight differences between the annual cycles of modeled and observed AOD values, the spatial patterns of linear trends in annual average values are quite similar. There is a positive trend in AOD over India and the Indian Ocean. For the model, south of 15°N is a band of positive trends, except for an area of negative trends in the SE Pacific that is not observed in the satellite observations. North of 30°N are regions of negative trends, namely the Eastern US, Europe, Russia, and China. MODIS shows a region of positive trends over central Russia and NW Canada that is not shown in the model trends, suggesting possible missing emissions from growth in sectors such as oil and gas exploration.

How does model derived AOD compare with AERONET ground-based observations?

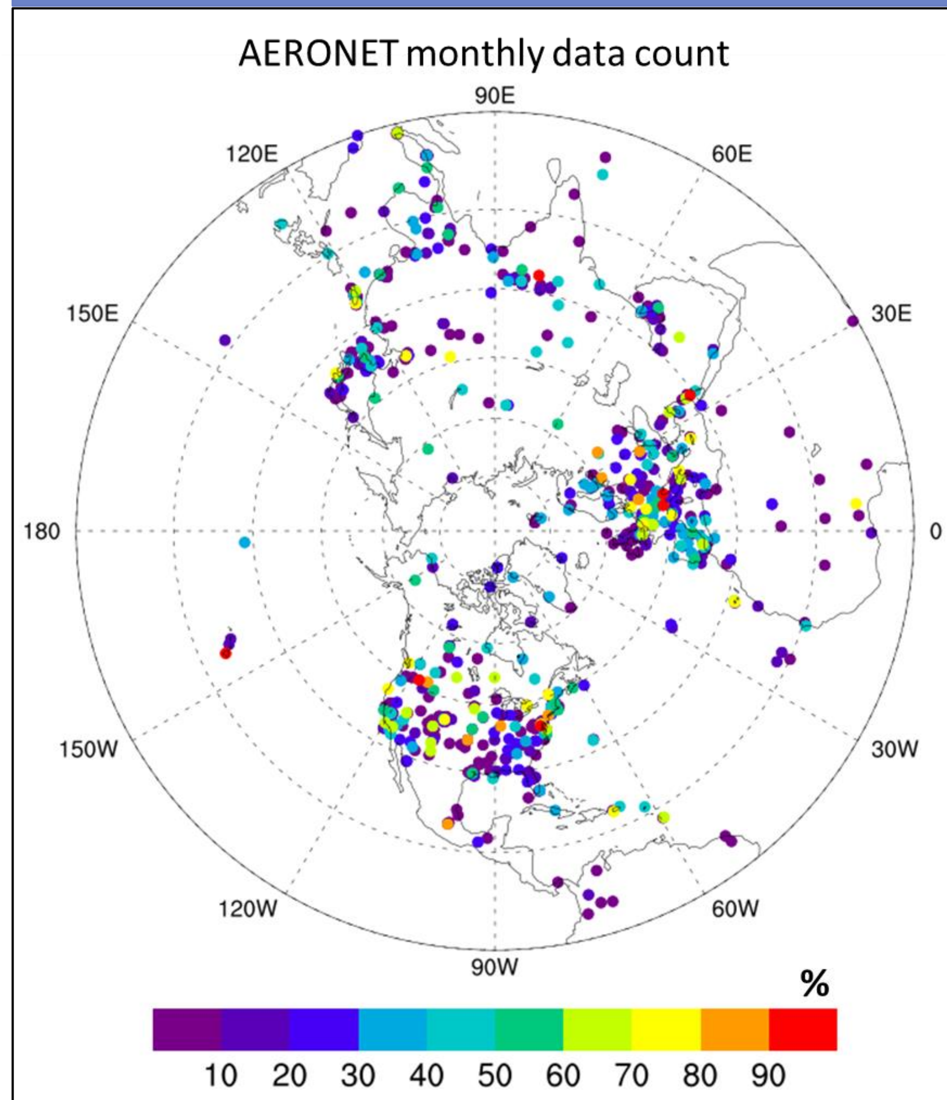

Figure 5. AERONET site locations (791 sites) with monthly average AOD values for 2002–2017 (192 months).

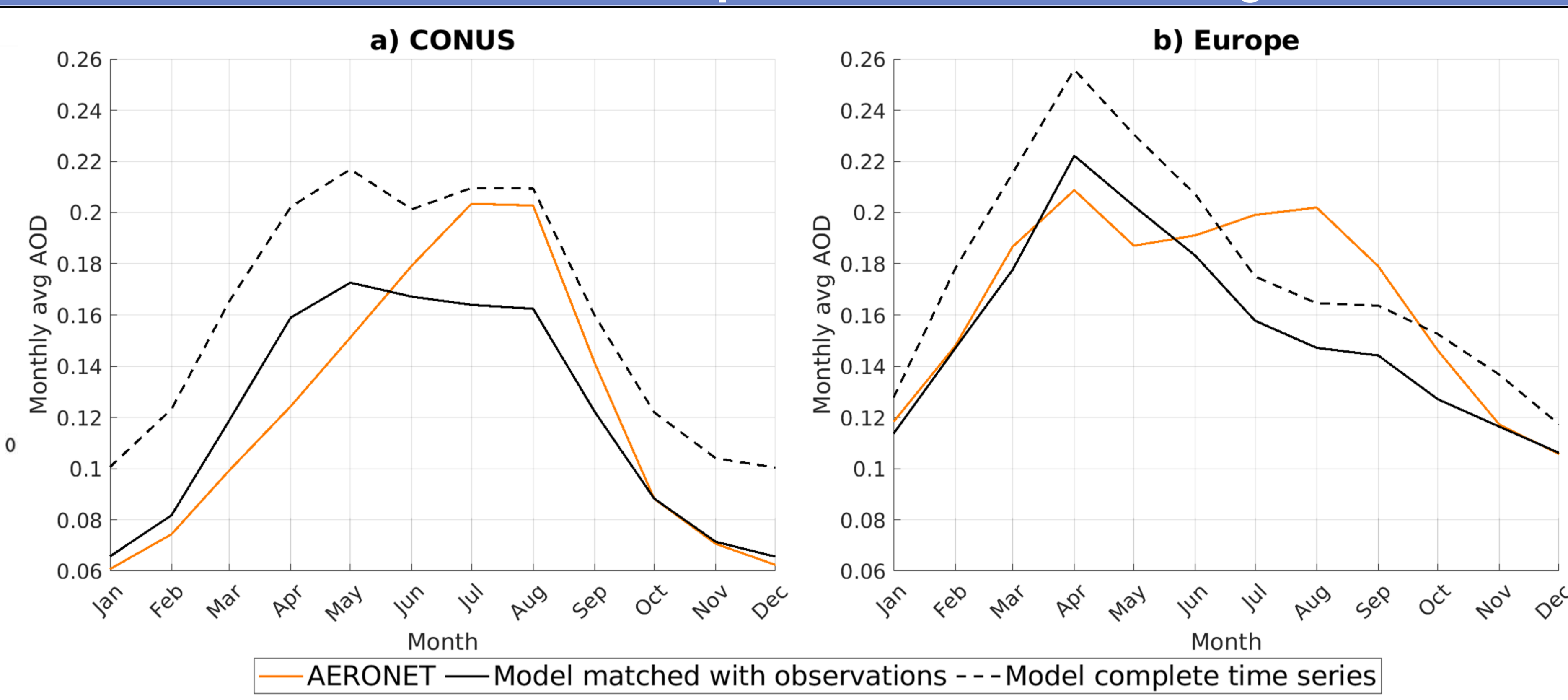

Fig. 6 (above) displays the annual cycle of monthly average AOD values for all AERONET sites in the specified region. The model (black) AOD values are again underestimated in summer months compared with observations (orange) for both CONUS and Europe. Comparing the available observation times with a complete time series of hourly data from the model (black dashed line), the annual cycle of the observations is smaller in magnitude than that derived from the entire time series. This is not observed for all years in the time period or for all regions (not shown).

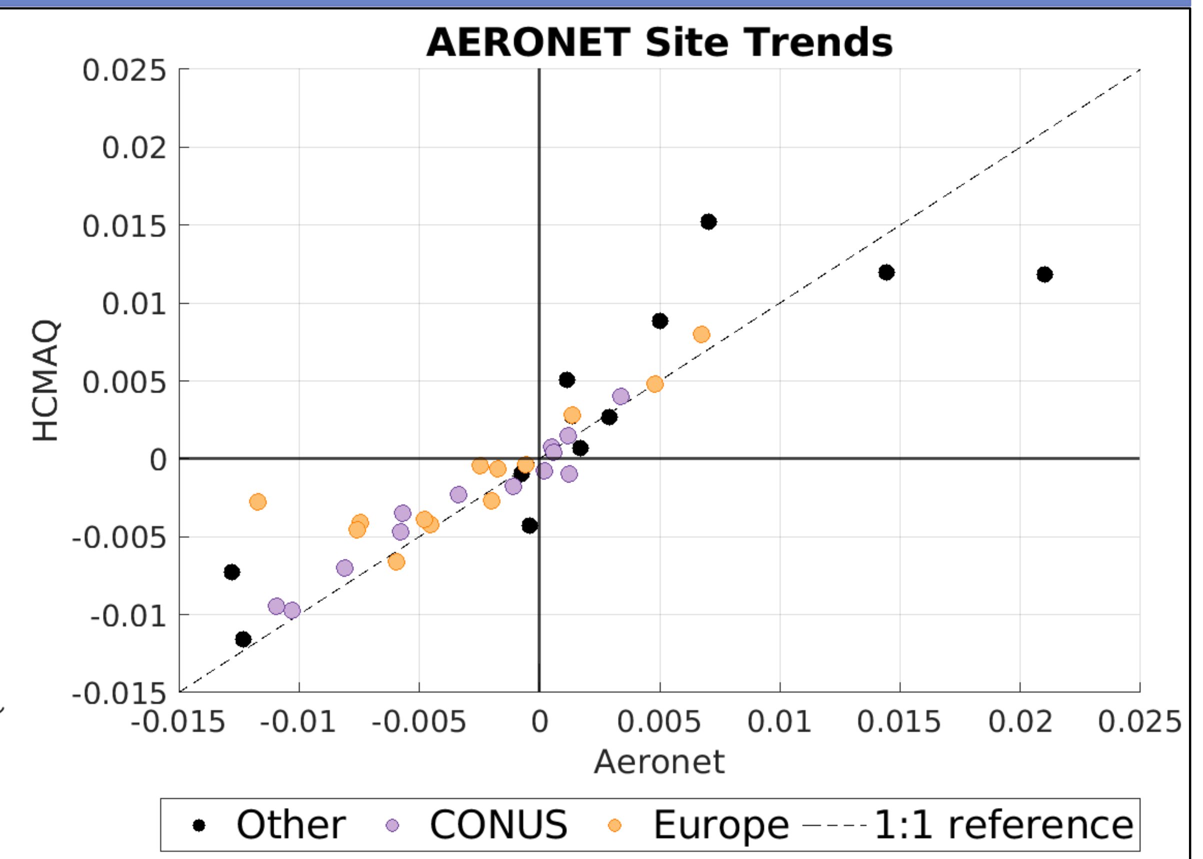

Fig. 7 (above) compares linear trends for AERONET sites between the site observations and the modeled values. Linear trends are calculated from the annual average for 39 sites which had at least 70% data availability for the monthly values during 2002–2017. 13 sites are in CONUS (purple) and 14 are in Europe (orange). Most of the site trends, including all sites in CONUS, are similar between the observation and the modelled AOD value. Most sites observe a negative trend or a trend near zero.

Conclusions

- Modelled AOD trends are similar in magnitude and location compared with observed trends from both satellite and ground-based observations.
- H-CMAQ modelled AOD is underestimated in summer months compared with both MODIS satellite observations and AERONET ground-based observations.
- The exclusion of modelled AOD days with high precipitation does not account for this bias.

Future Work

- Continue to investigate the model's underestimation of summertime AOD.
- Continue to analyze trends.
- Analysis of PM2.5.
- Analysis of the effects of MODIS retrievals and AERONET uncertainty.

Reference:
Platnick, S., et al., 2015. MODIS Atmosphere L3 Monthly Product. NASA MODIS Adaptive Processing System, Goddard Space Flight Center, USA: http://dx.doi.org/10.5067/MODIS/MOD08_M3.061