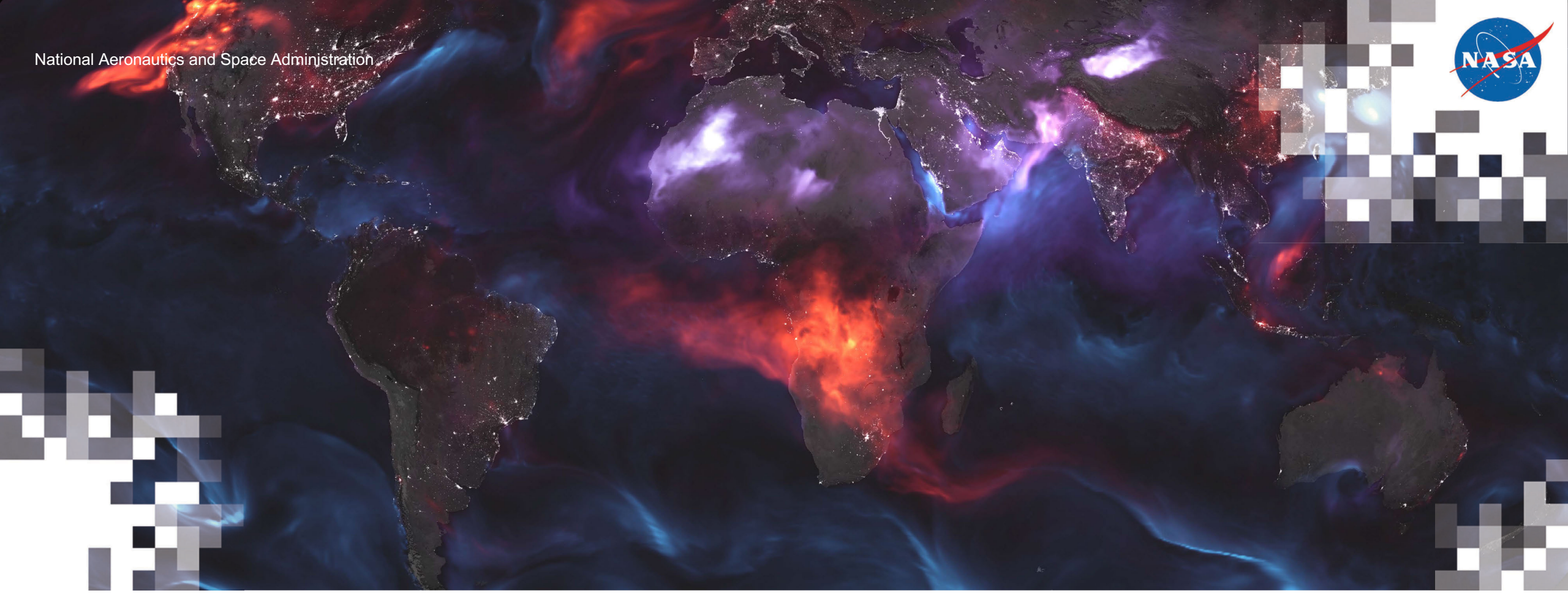


Tools for Analyzing NASA Air Quality Model Output

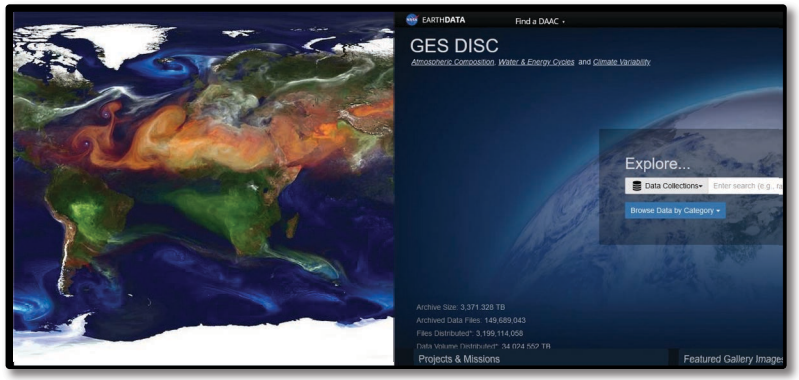
Interpreting Model Output for Air Quality Assessment

Sarah Strode, Pawan Gupta, Melanie Follette-Cook

March 1, 2021

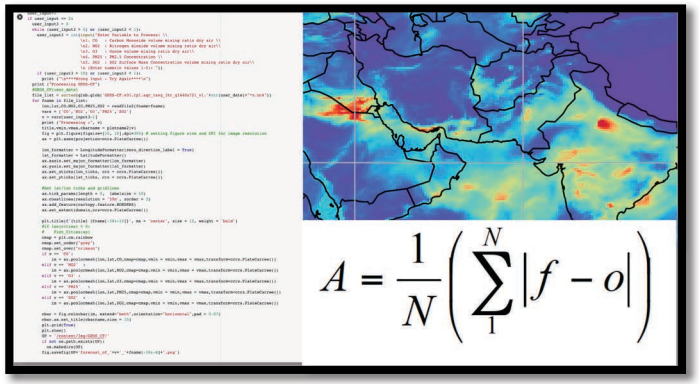
Training Outline

Part 1: February 22, 2022



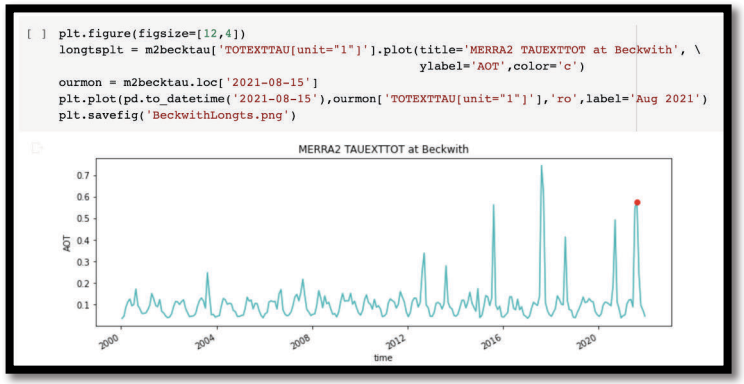
Review of NASA Air Quality Forecasts and Reanalysis

Part 2: February 24, 2022



Introduction to Python Tools for Visualization and Analysis

Part 3: March 1, 2022



Interpreting Model Output for Air Quality Assessment

Sarah Strode

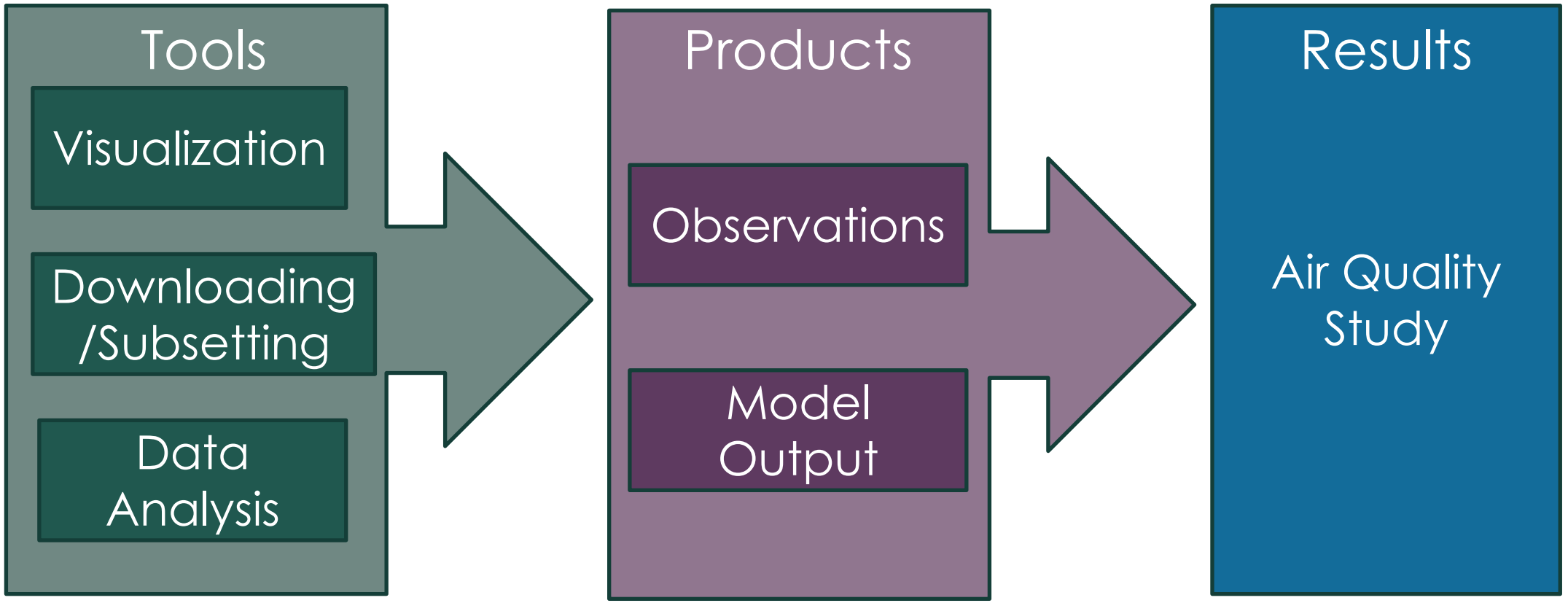
Melanie Follette-Cook

Pawan Gupta

Part 3 Learning Objectives

- Apply the tools discussed in Sessions 1 and 2 to recent air quality events
- Analyze NASA model output along with observations to visualize the impact of fires and smog on air quality

Part 3 Learning Objectives



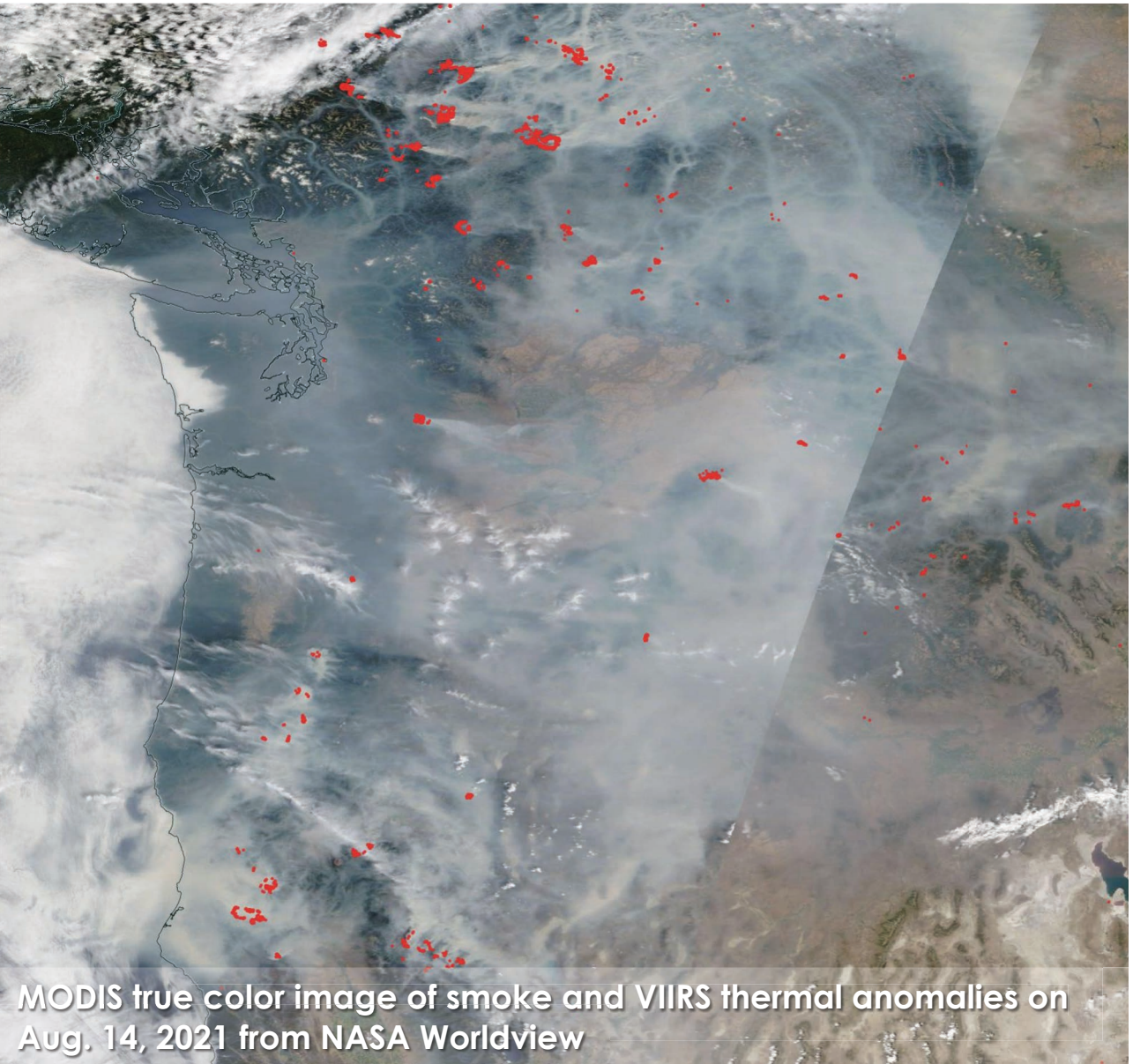
Part 3 Outline

- Presentation of 1st Case Study: August 2021 Wildfires in the Western United States
- Jupyter Notebook Demonstration of Case Study 1 Plots
- Presentation of 2nd Case Study: December Haze in Northeast India
- Jupyter Notebook Demonstration of Case Study 2 Plots

Note:

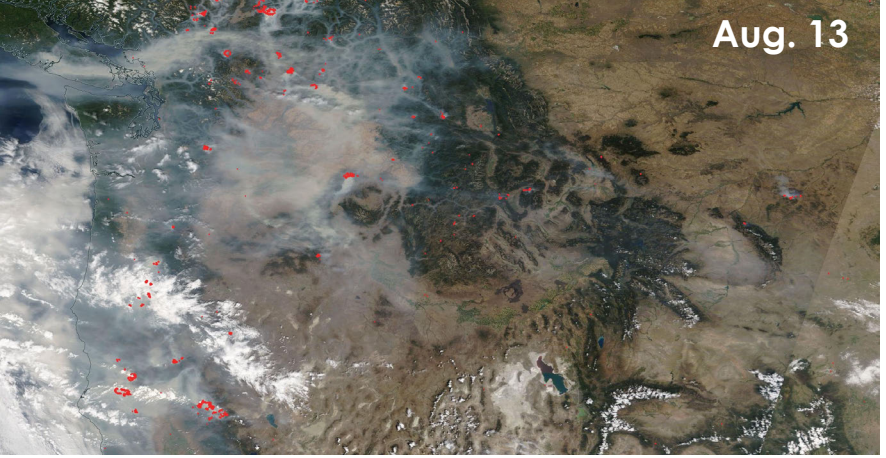
Please download the Part 3 data and notebooks to your own Google Drive if you want to follow along with the demonstrations. See instructions on the training page: https://appliedsciences.nasa.gov/join-mission/training/english/arset-tools-analyzing-nasa-air-quality-model-output

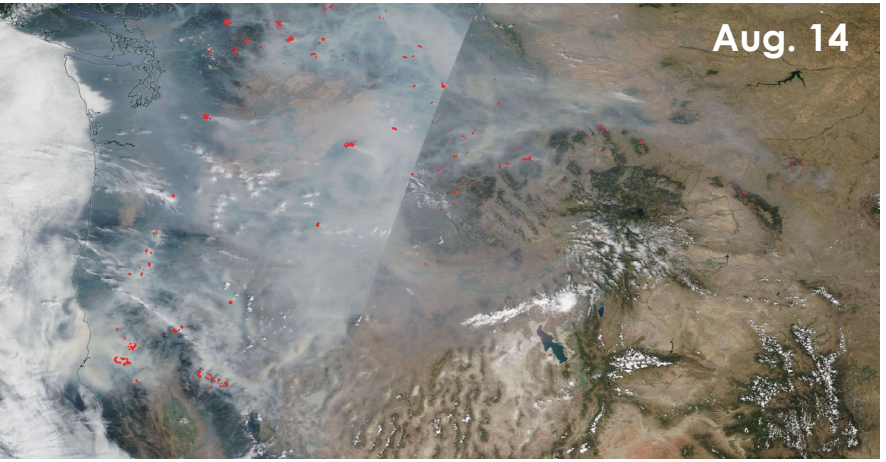
Case Study 1: August 2021 Wildfires in the Western United States

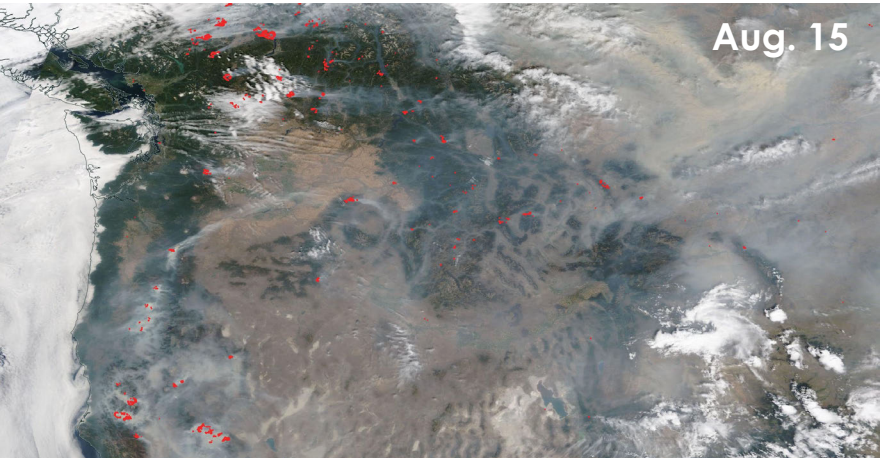


MODIS true color image of smoke and VIIRS thermal anomalies on Aug. 14, 2021 from NASA Worldview

- How did smoke influence air quality in the western United States in Aug. 2021, locally and in regions downwind?
- How did air quality change over the course of the month?
- How did this month compare with previous months and years?

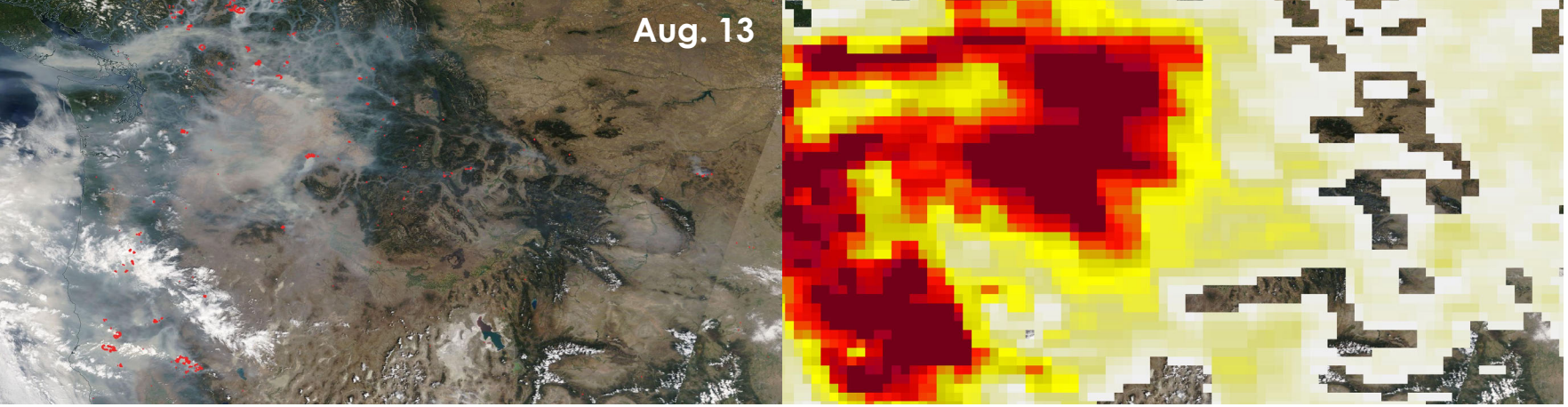


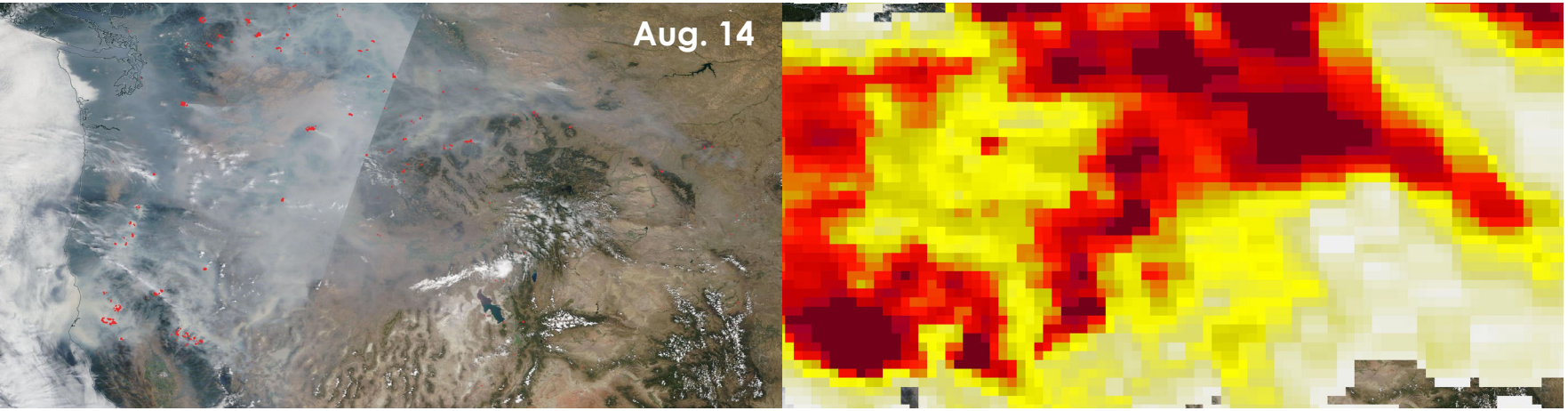


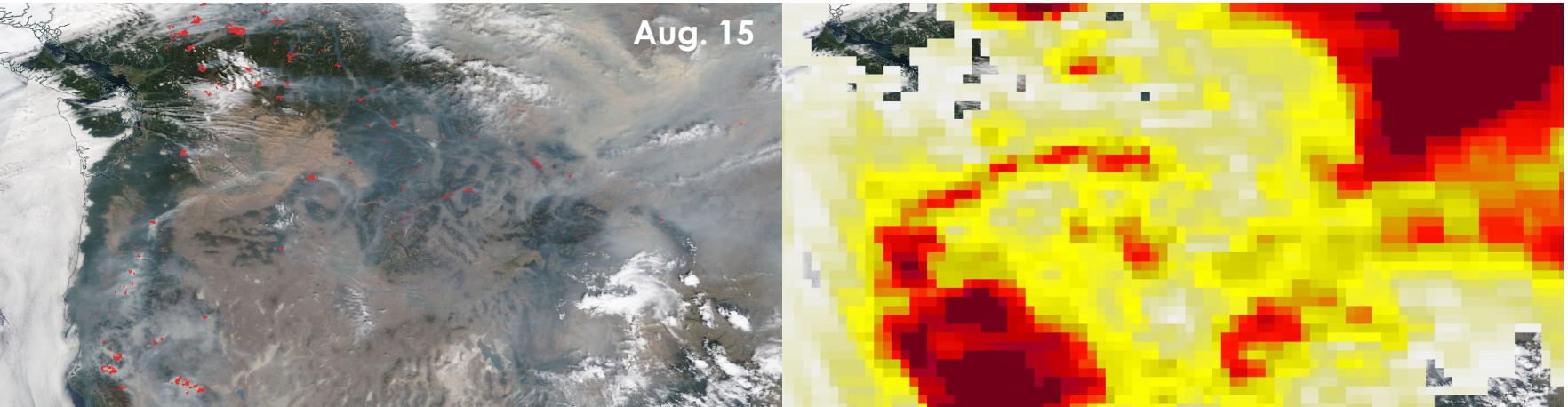


How did fires influence air quality in the western United States in Aug. 2021?

- Thermal anomalies from VIIRS (red dots) indicate the presence of fires.
- Smoke is transported far downwind from the fire source and can be seen across much of the northwestern United States.
- The position and extent of the smoke changes daily, such as the eastward shift between Aug. 14 and 15.
- Images generated using NASA's Worldview website: https://worldview.earthdata.nasa.gov/

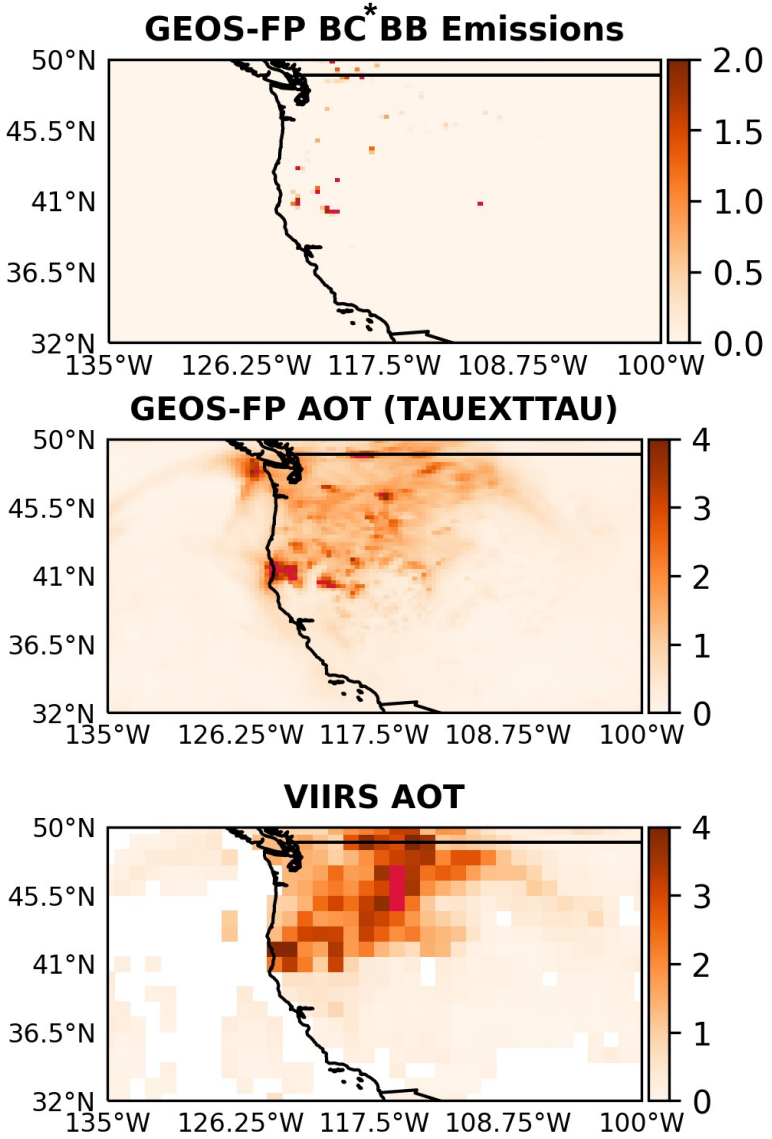






- The aerosol index (AI) from the Ozone Mapping and Profiler Suite (OMPS) instrument (right column) also shows the transport of smoke across the region.
- Positive values of AI indicate the presence of absorbing aerosols (e.g., dust or smoke).
- These plots were generated using Worldview.

How does GEOS see this event?

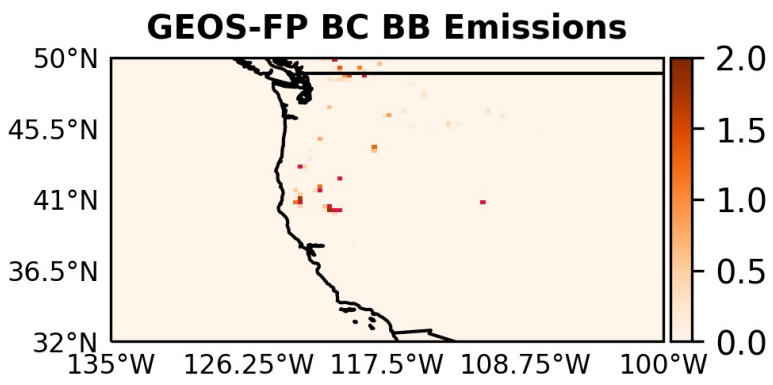


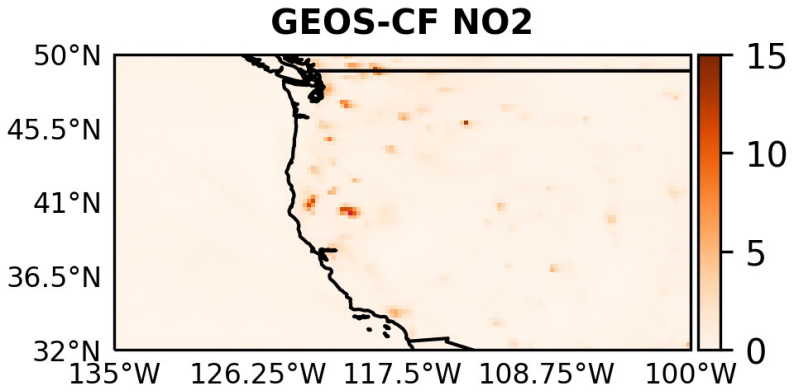
* BC = Black Carbon

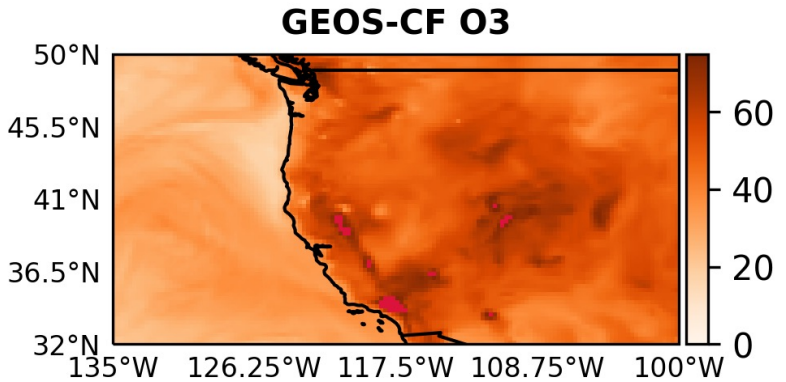
- Emissions from biomass burning (BC) come from the Quick Fire Emissions Dataset Version 2 (QFEDv2) inventory, which is based on satellite observations of fire radiative power.
  - More details available in the ARSET training "Introduction and Access to Global Air Quality Forecasting Data and Tools"
- MERRA-2 and GEOS-FP also include data assimilation of aerosol optical thickness (AOT)
- On Aug. 14, AOT from GEOS-FP (variable name: TOTEXTTAU) shows a similar spatial pattern to that observed by the VIIRS instrument (Level 3 product), with high AOT values over the emission hotspots.
  - For details on using VIIRS Level 2 data, see the ARSET training on "MODIS to VIIRS Transition for Air Quality Applications"
- We will show how to generate these plots in a Jupyter Notebook.

How are other pollutants affected?

- GEOS-CF simulates the concentration of pollutants such as NO_2 and O_3 as well as aerosols.
- Concentrations of NO_2 in the lowest model level are high in the high emission regions.
- Ozone (O_3) concentrations are locally reduced in many of these emission hotspots. However, ozone production may occur downwind.

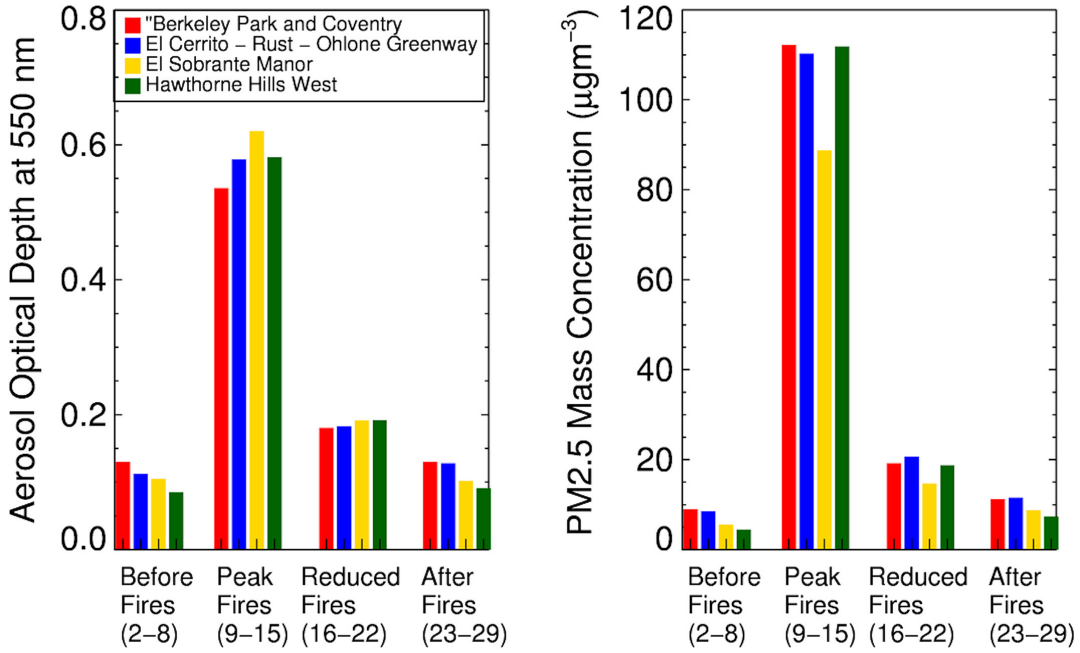






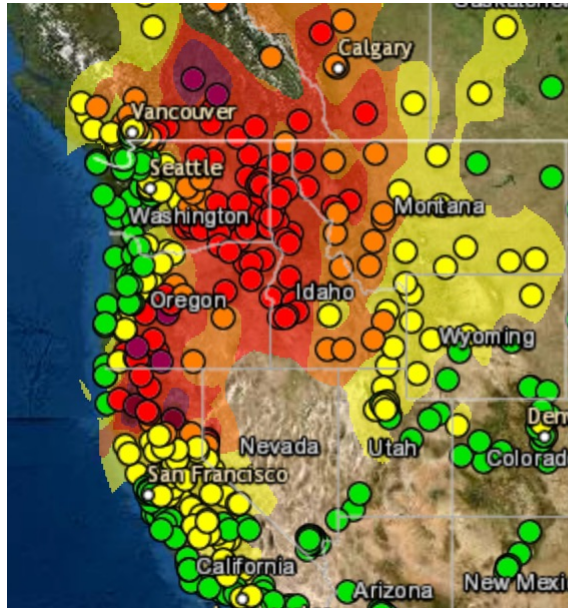
Impact on Surface Air Quality

- Published studies demonstrate that wildfire smoke adversely affects air quality in the western United States.
- EPA's AirNOW surface observations show high PM2.5 on Aug. 14.



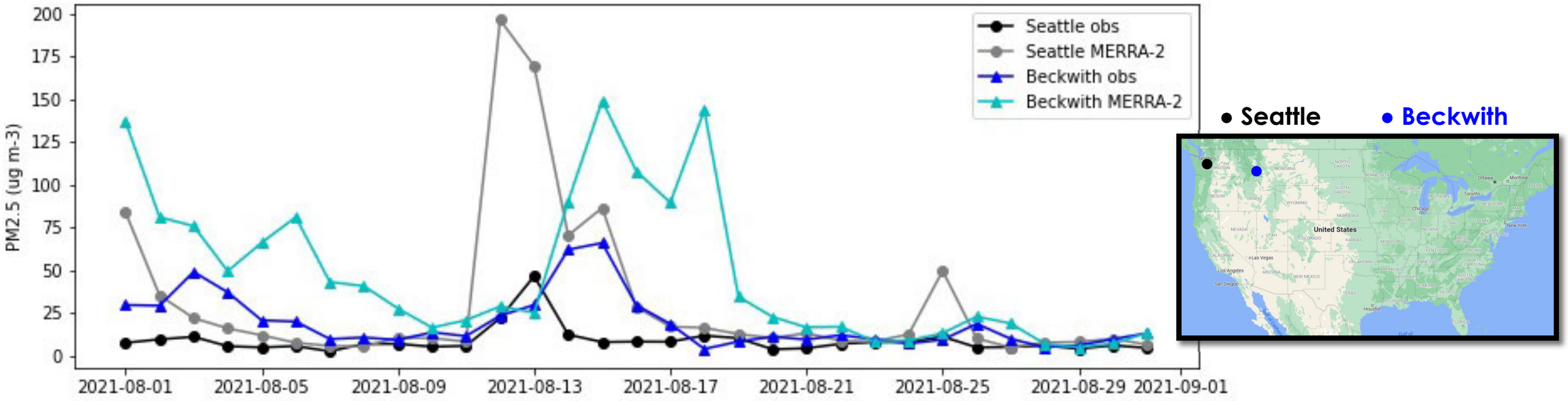
Gupta et al (2018), GeoHealth, DOI: 10.1029/2018GH000136

Aug. 14, 2021 PM2.5 from AirNOW (https://gispub.epa.gov/airnow/)



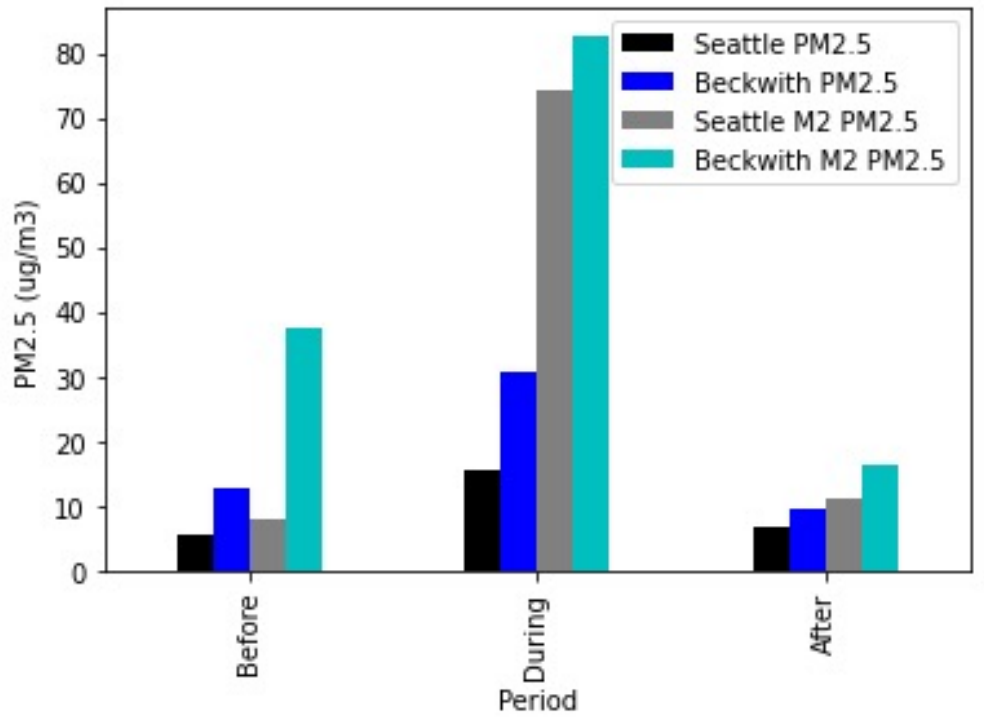
How does MERRA-2 PM2.5 compare with AirNOW observations?

- Since we saw earlier that the smoke moves eastward over time, we will compare a more western station (Seattle, WA: 122°W, 47.6°N) with a station further east (Missoula, MT, Frenchtown-Beckwith Station: 114°W, 47.0°N).
- MERRA-2 overestimates PM2.5 compared to the observations, but both MERRA-2 and observations show the later arrival of the plume at Beckwith vs. Seattle.



How did PM2.5 change before, during, and after the fires?

- We can average PM2.5 for the periods before (Aug. 6-10), during (Aug. 11-18), and after the event (Aug. 19-24) to visualize the enhancement in PM2.5.

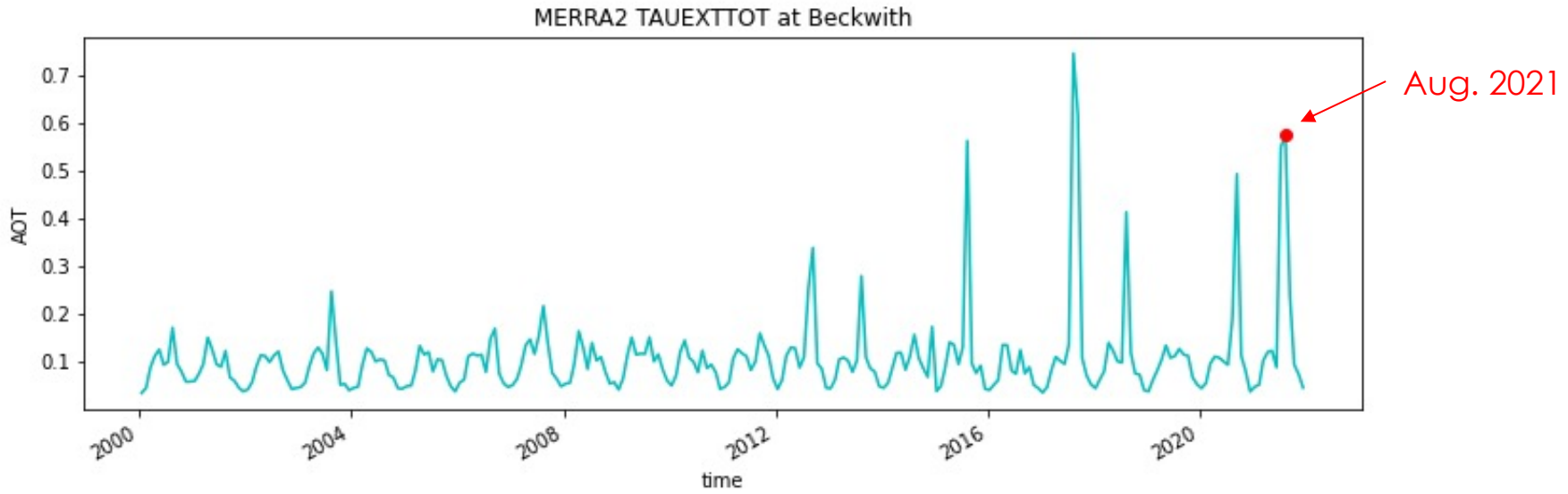


- Several factors can contribute to mismatches between models and observations, including:
  - Grid box average vs. single point
  - Vertical distribution of aerosol

MODIS true color image from NASA Worldview shows strong variability between locations within the plume and just outside it.

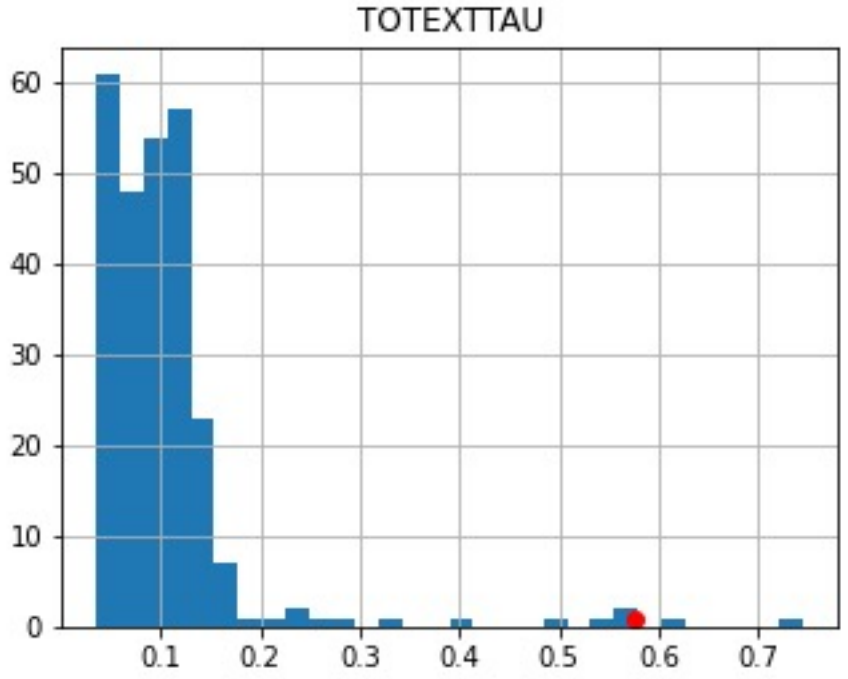
How did Aug. 2021 compare to previous months?

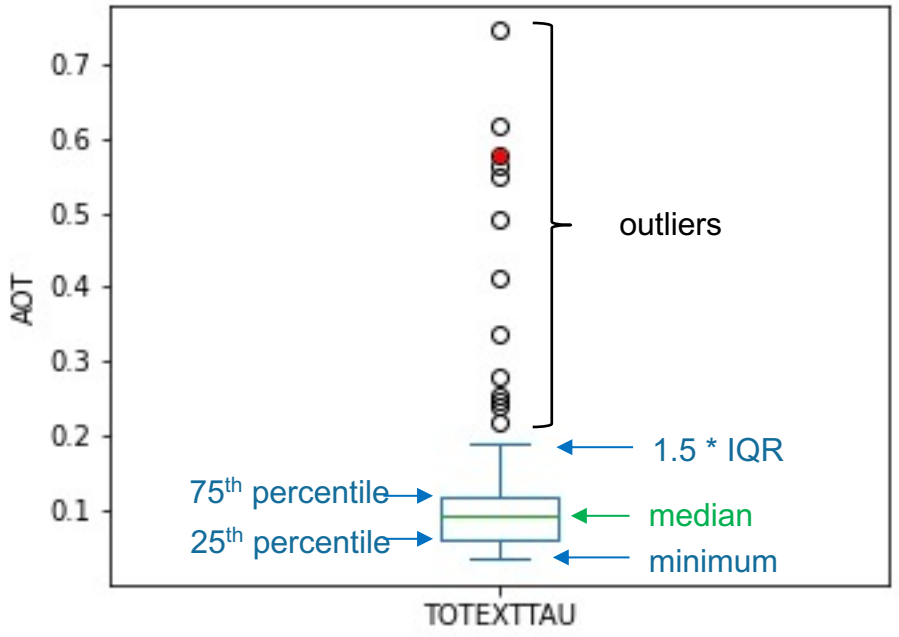
- In Part 1, we saw a timeseries of MERRA-2 PM2.5 fire-season averages for California generated in Giovanni.
- Here, we examine AOT (TAUEXTTOT variable) from MERRA-2 at the Beckwith site with plots generated in our Jupyter Notebook.
- Aug. 2021 was much higher than usual, but not the highest month since 2000.



How did Aug. 2021 compare to previous months?

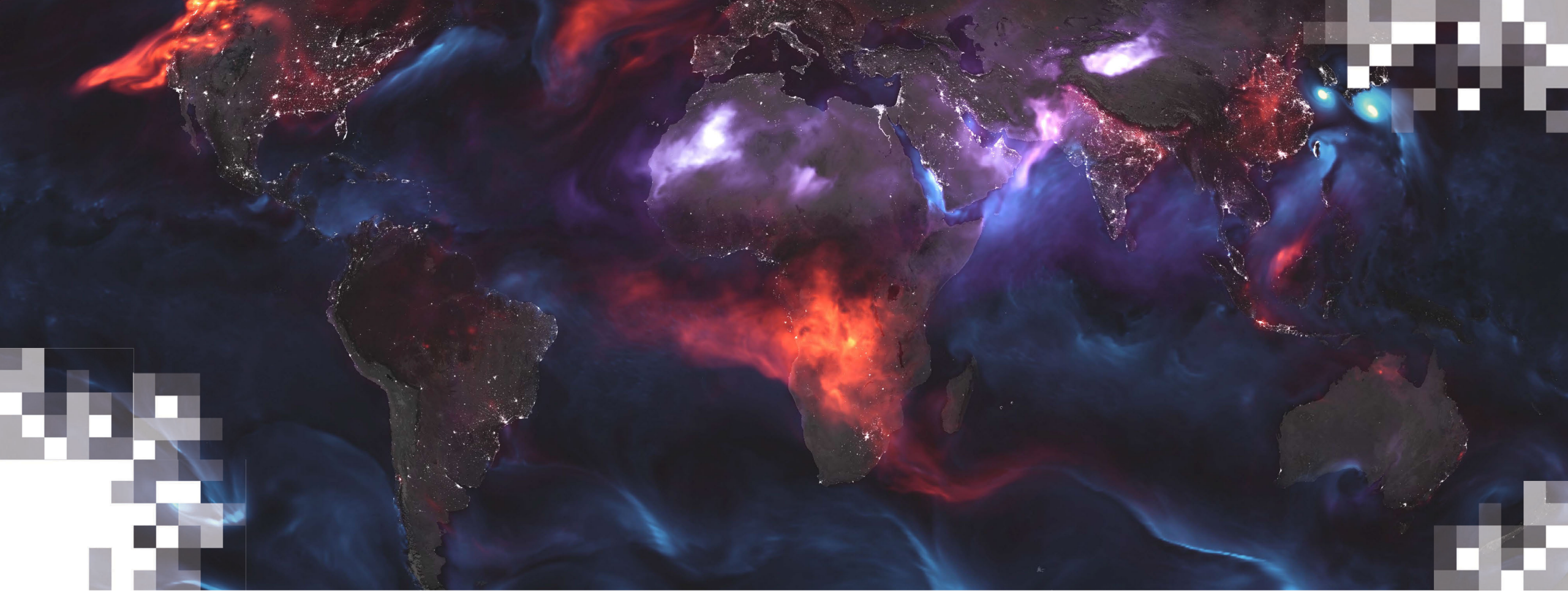
- We can also use a histogram or box plot to visualize Aug. 2021 (red dot) in the context of the last 20+ years.
  - Histogram shows how frequently values fall in each AOT bin
  - Box plot shows range and interquartile range (IQR) of data
- Only 2 previous months since Jan. 2020 had higher AOT at this site in MERRA-2





Case Study Summary

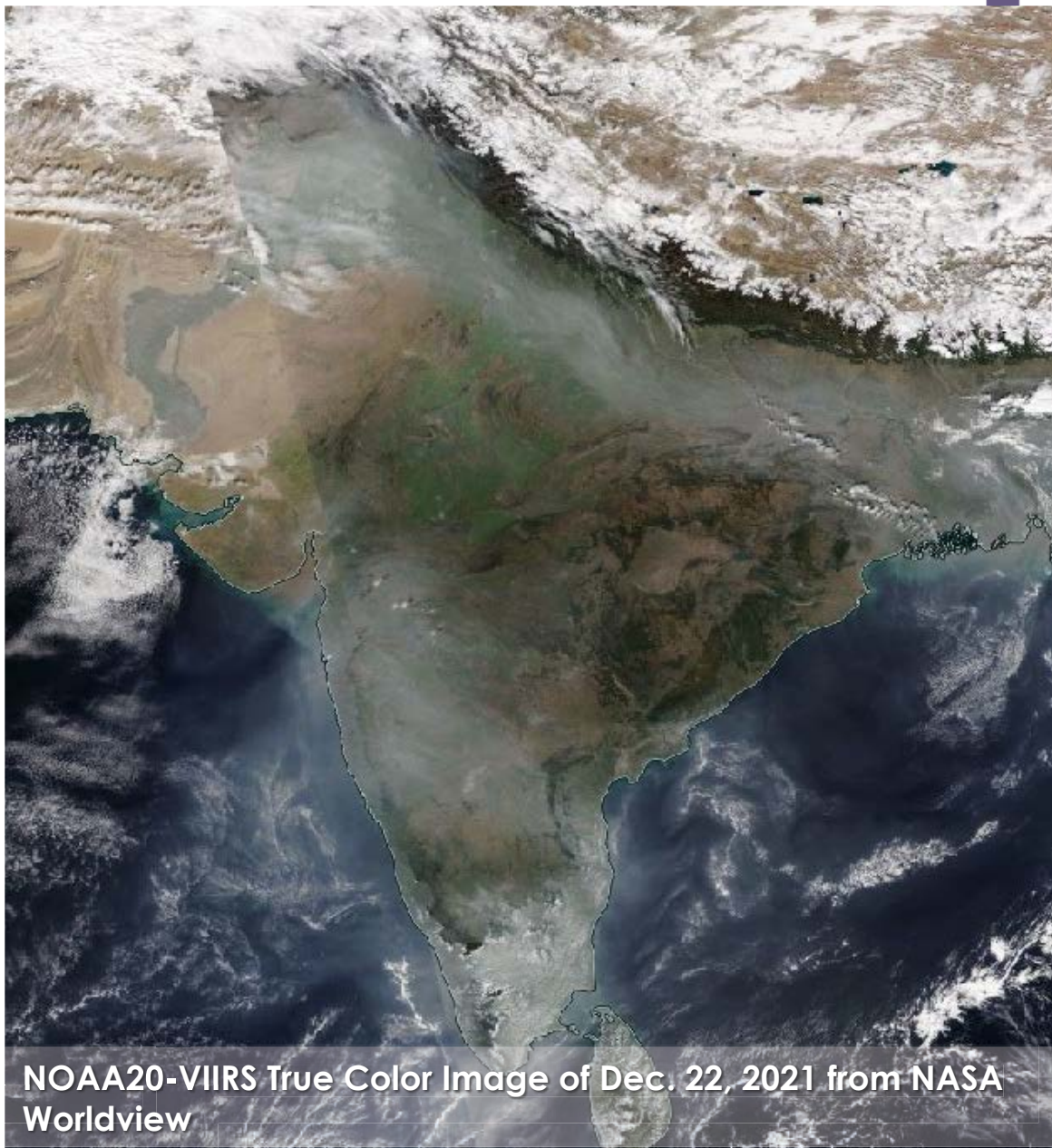
- Wildfire smoke affected a large region of the western United States during Aug. 2021.
- The impact is seen in GEOS products as well as surface and satellite observations.
- Aug. 2021 had the 3rd highest AOT since 2000 in MERRA-2 output for the Missoula Frenchtown-Beckwith location.
- Next, we will walk through a Jupyter notebook that can be used to create many of the plots used in this case study.



Case Study 1 Notebook Demonstration

Case Study 2: December Haze in Northeast India

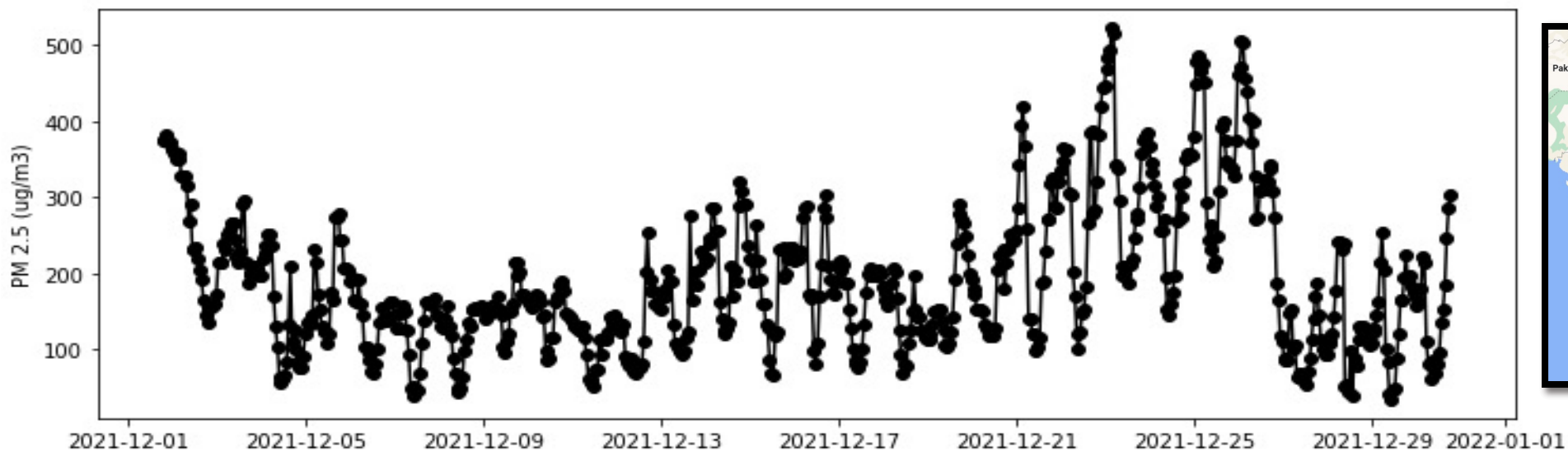
- Can models simulate or forecast the particulate pollution levels over Delhi in December 2021?
- How do PM2.5 concentrations vary on hourly or daily timescales?
- How do aerosol levels change seasonally?



NOAA20-VIIRS True Color Image of Dec. 22, 2021 from NASA Worldview

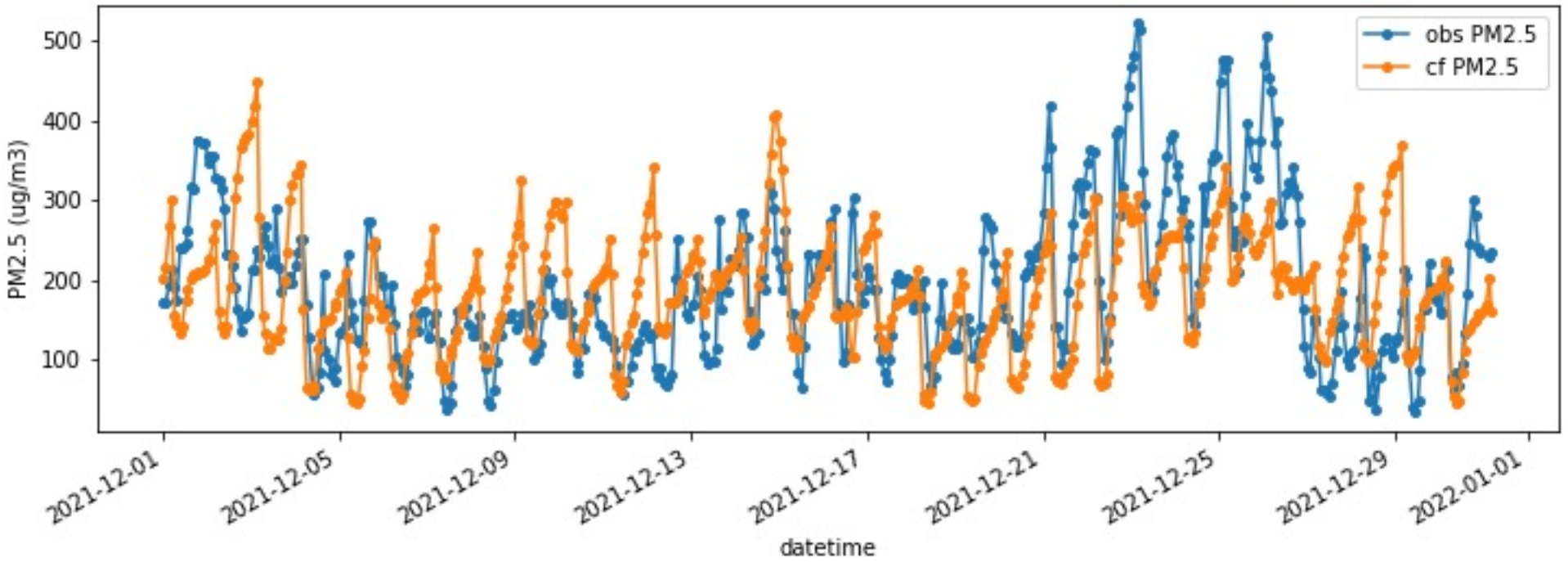
Surface PM2.5 in Delhi

- Observations from a surface site "US Diplomatic Post: New Delhi", downloaded from OpenAQ, show high levels of PM2.5 in Dec. 2021.
- Both diurnal and day-to-day variability are evident in the time series.
- Concentrations rise after Dec. 19, then fall on Dec. 27.



Comparison to GEOS-CF

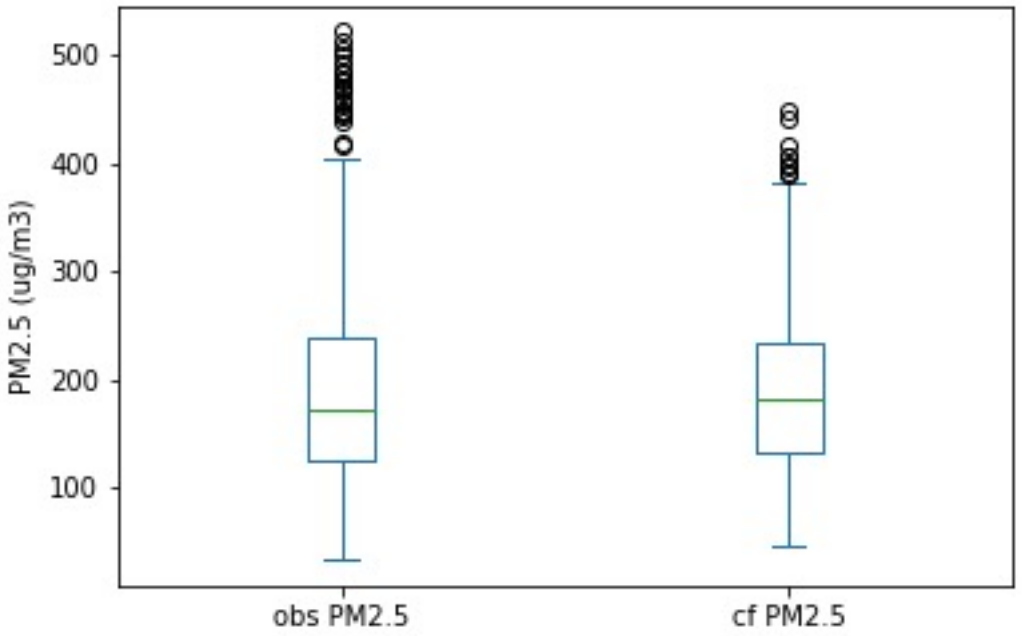
- How well does the GEOS-CF PM2.5 follow the observations for this month?



Compare Some Statistics for Dec. 2021

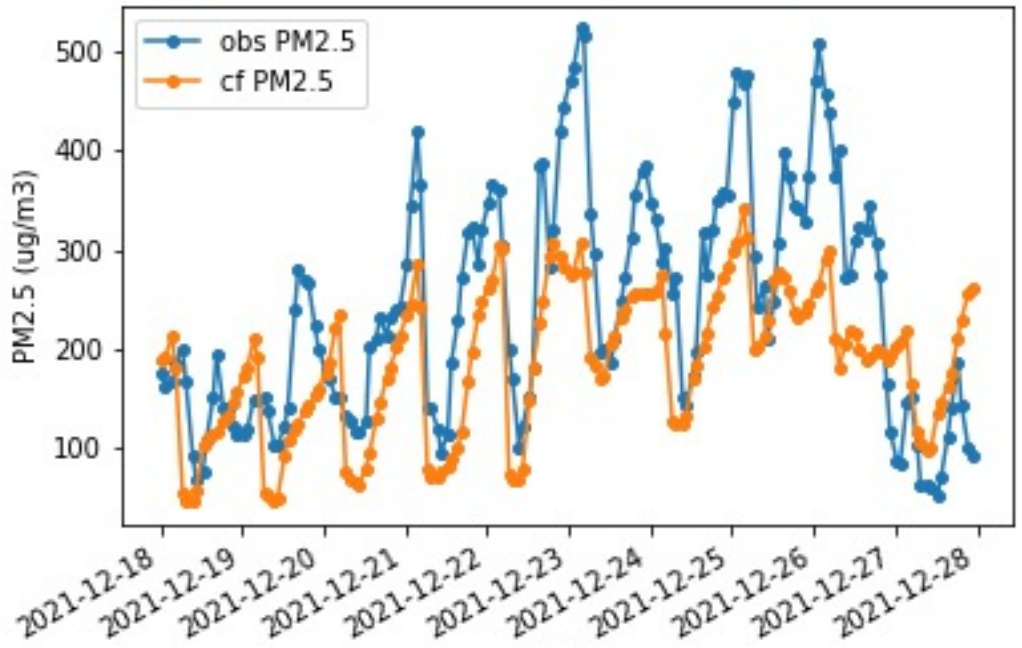
- GEOS-CF mean PM2.5 is ~3% lower than the observed mean.
- The median is slightly higher in GEOS-CF, but the maximum values are lower.

	obs PM2.5	cf PM2.5
count	723.000000	725.000000
mean	192.163209	186.050476
std	94.457782	75.595910
min	34.000000	46.149803
25%	125.500000	132.117750
50%	172.000000	181.873930
75%	239.500000	233.162630
max	522.000000	448.115200

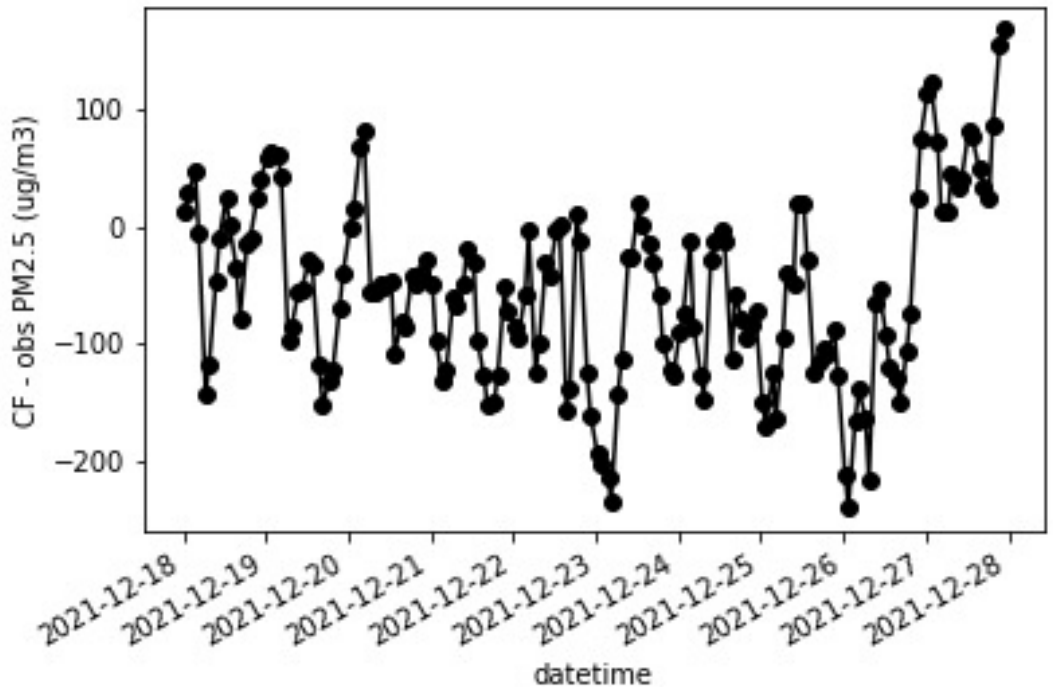


Zoom in on the Dec. 18 – Dec. 27 Event

- PM2.5 levels rise and the decline over this period in both the observations and GEOS-CF.
- GEOS-CF underestimates the peak values and overestimates the post-decline values.

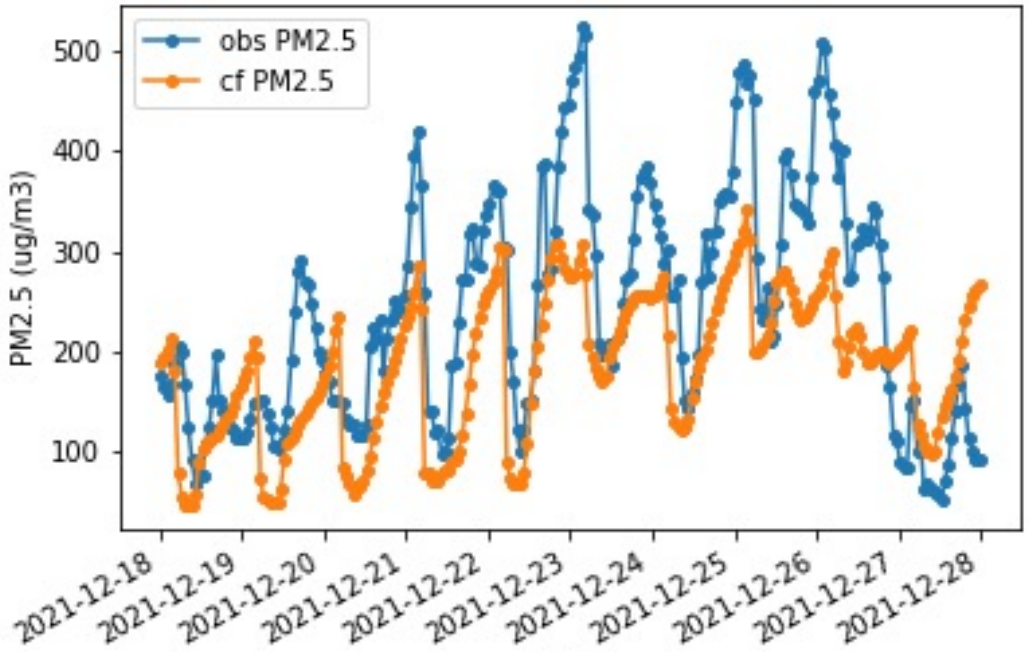


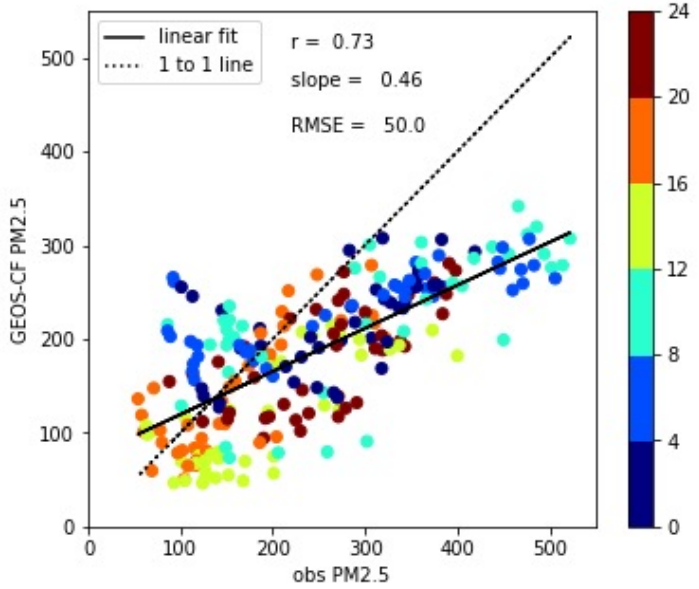
GEOS-CF PM2.5 – Observed PM2.5



Zoom in on the Dec. 18 – Dec. 27 Event

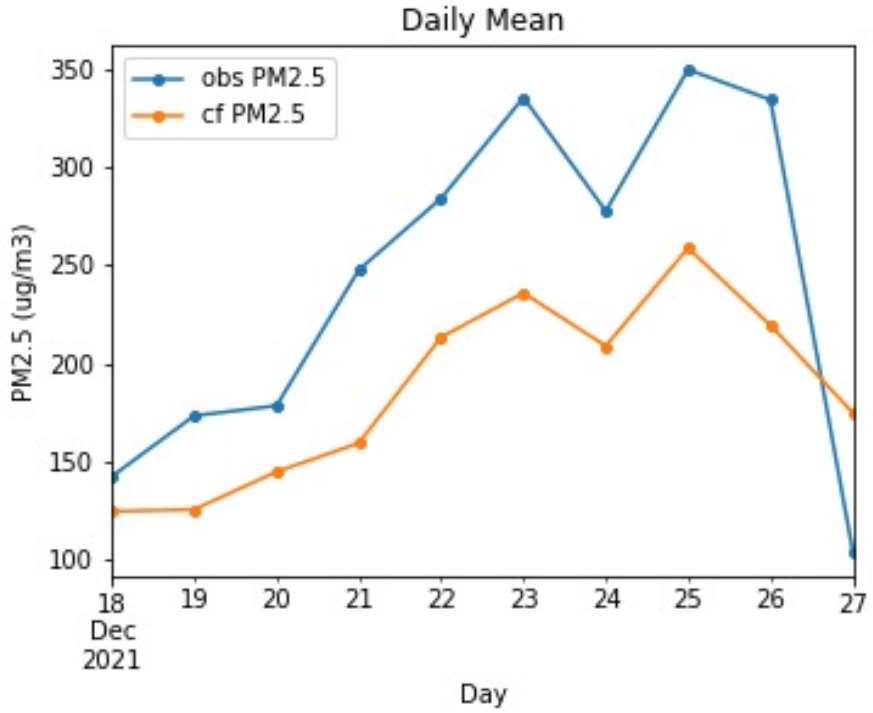
- GEOS-CF captures over 50% of the variance for this period (r^2=0.53).
- Some hours appear to show more over or under-estimates than others.
- Both daily and hourly variability are considered here. Next, we will treat them separately.

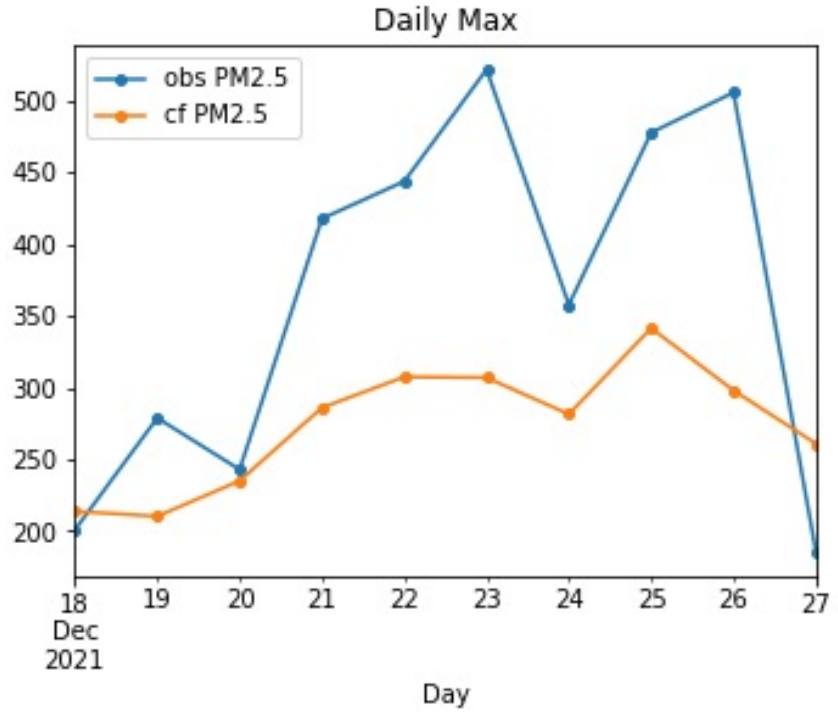




Daily Variability

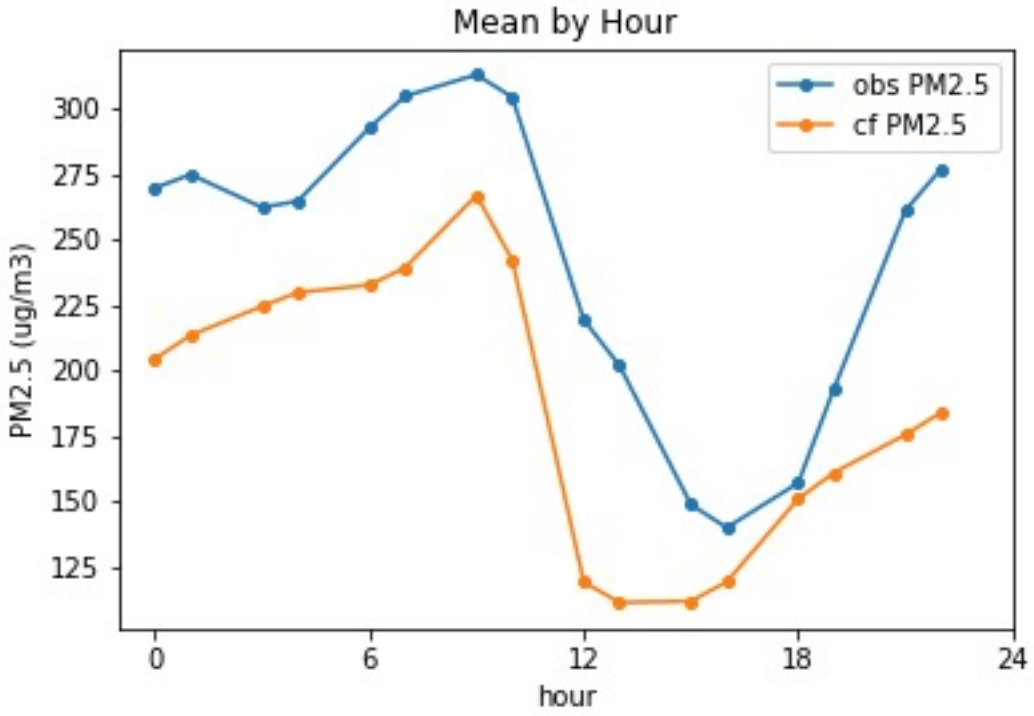
- We can remove the diurnal variations and consider only the daily means or maximum daily values.
- The model underestimate is larger for the daily max than the daily mean.
- GEOS-CF reproduces the timing of the increases and decreases well.





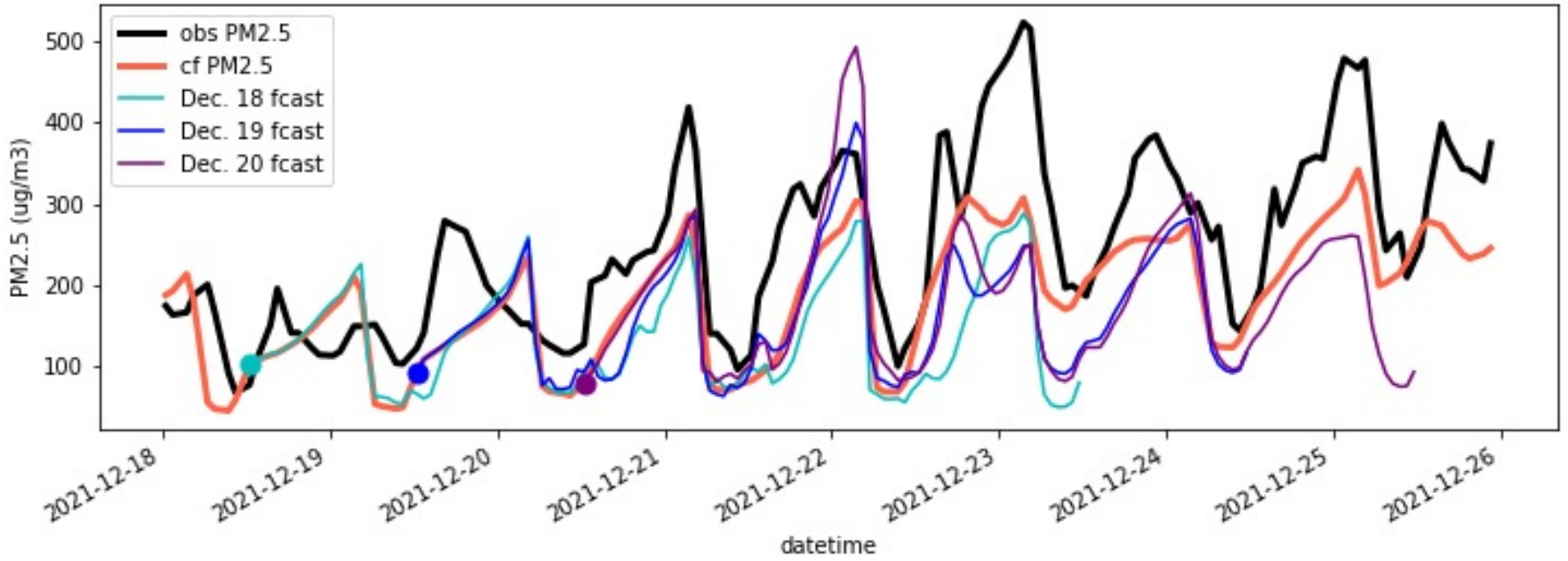
Diurnal Variability

- We can also consider the diurnal cycle, averaged over the days of this period.
- Amplitude (max – min):
  - Observations: 173 $\mu g/m^3$
  - GEOS-CF: 156 $\mu g/m^3$



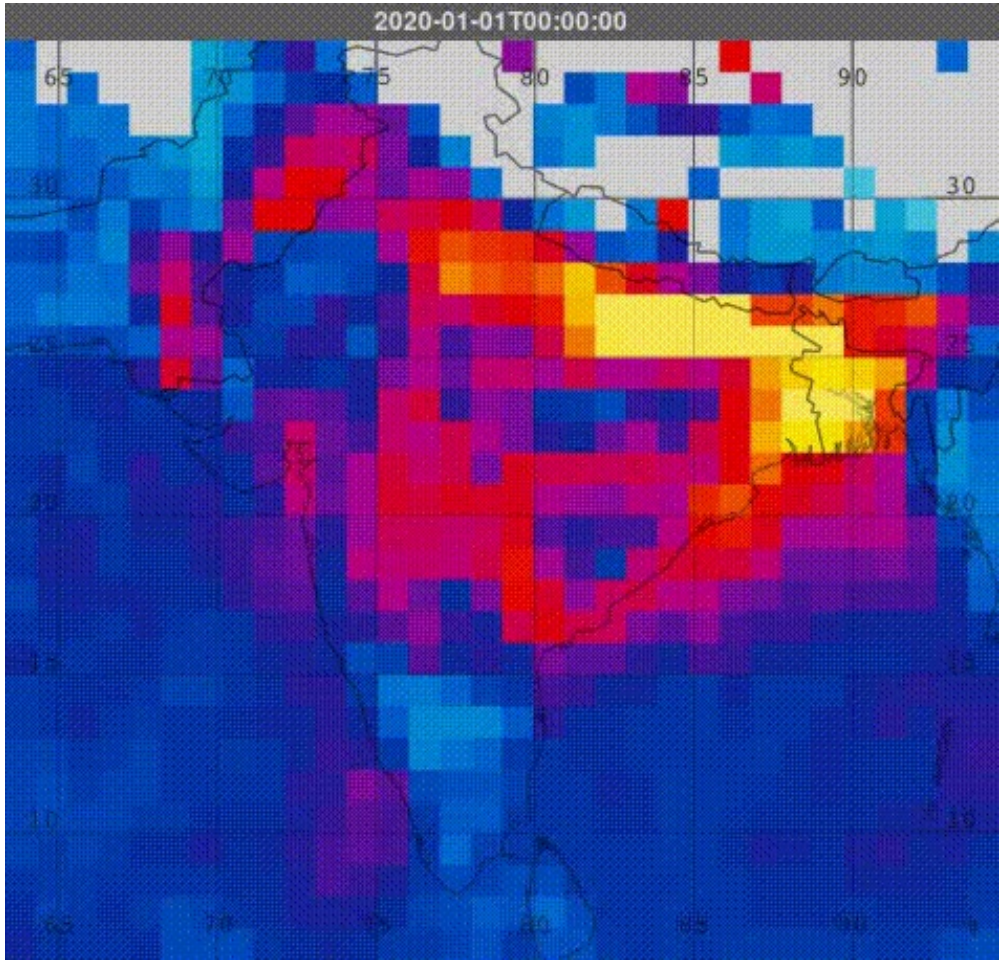
How does the forecast change over time?

- So far, we have considered the GEOS-CF replay (see Part 1).
- GEOS-CF also produces a new 5-day forecast each day.
- We can see how the forecast changes each day.
- Extensive evaluation of GEOS-CF hindcasts and forecasts available in Keller et al (2021), JAMES, doi: 10.1029/2020MS002413



Zoom Out to Seasonal Variability

- MODIS AOT shows strong seasonal variability.
- Region of maximum shifts with the season.
- What types of aerosols contribute to the seasonal cycle in different areas?



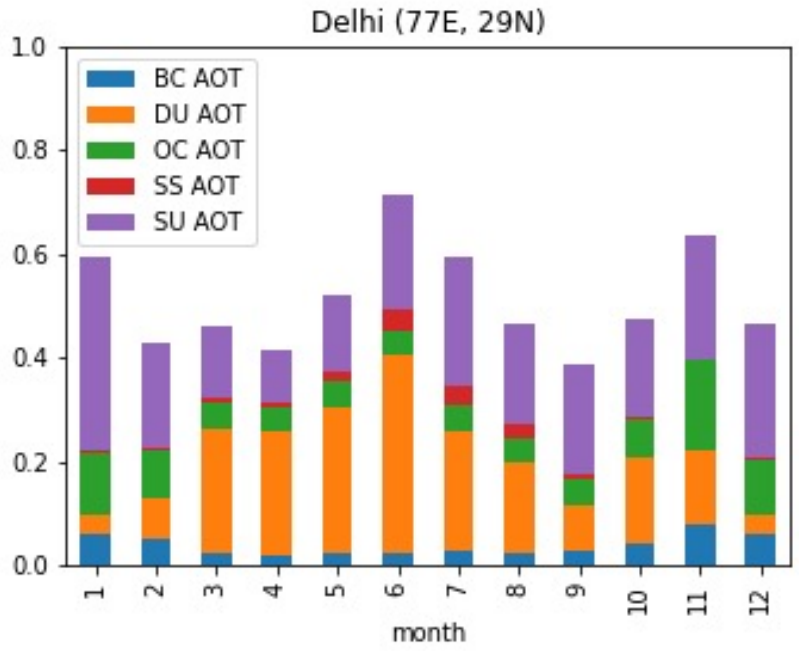
Giovanni animation of monthly mean MODIS AOT for 2020-2021
MYD08_M3_6_1_AOD_550_Dark_Target_Deep_Blue_Combined

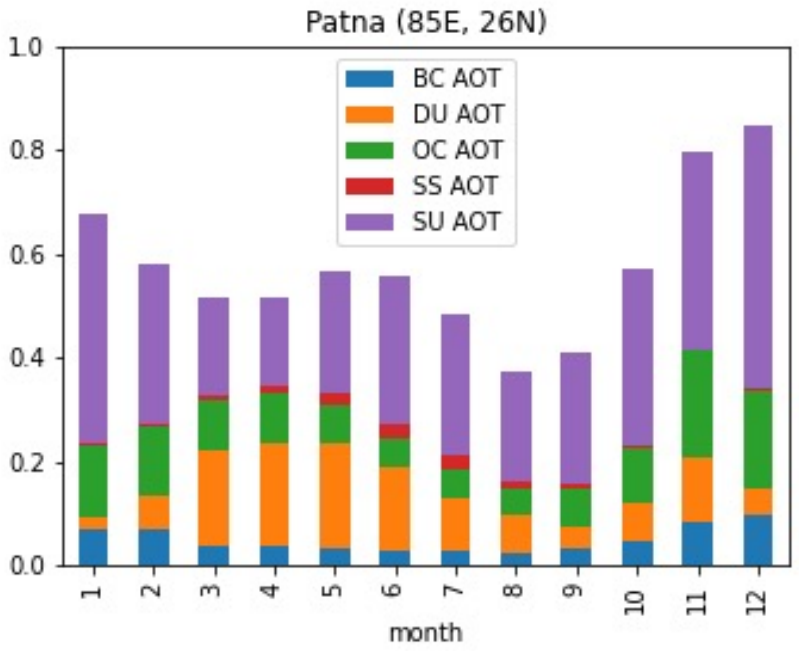
MERRA-2 AOT by Component

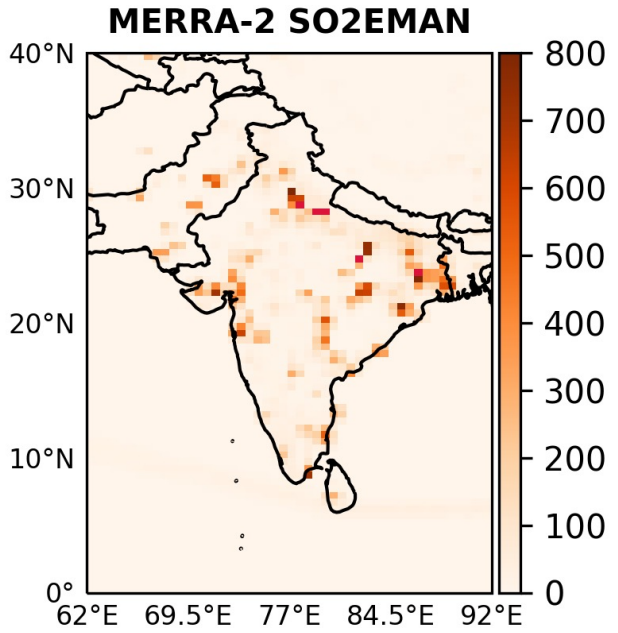
- MERRA-2 provides AOT by aerosol component in addition to the total.
- Since we saw regional variability in the seasonality of MODIS AOT, we plot MERRA-2 time series for different locations: 77.3E, 28.6N (Delhi) and 85.1E, 25.6N (Patna).

MERRA-2 AOT by Component

- Total AOT is assimilated but partitioning between components is from the model
- Delhi shows dust contribution driving June maximum
- Patna show peak in Dec. driven by sulfate aerosol
- Plot of MERRA-2 anthropogenic SO_2 emissions (SO2EMAN) shows source locations

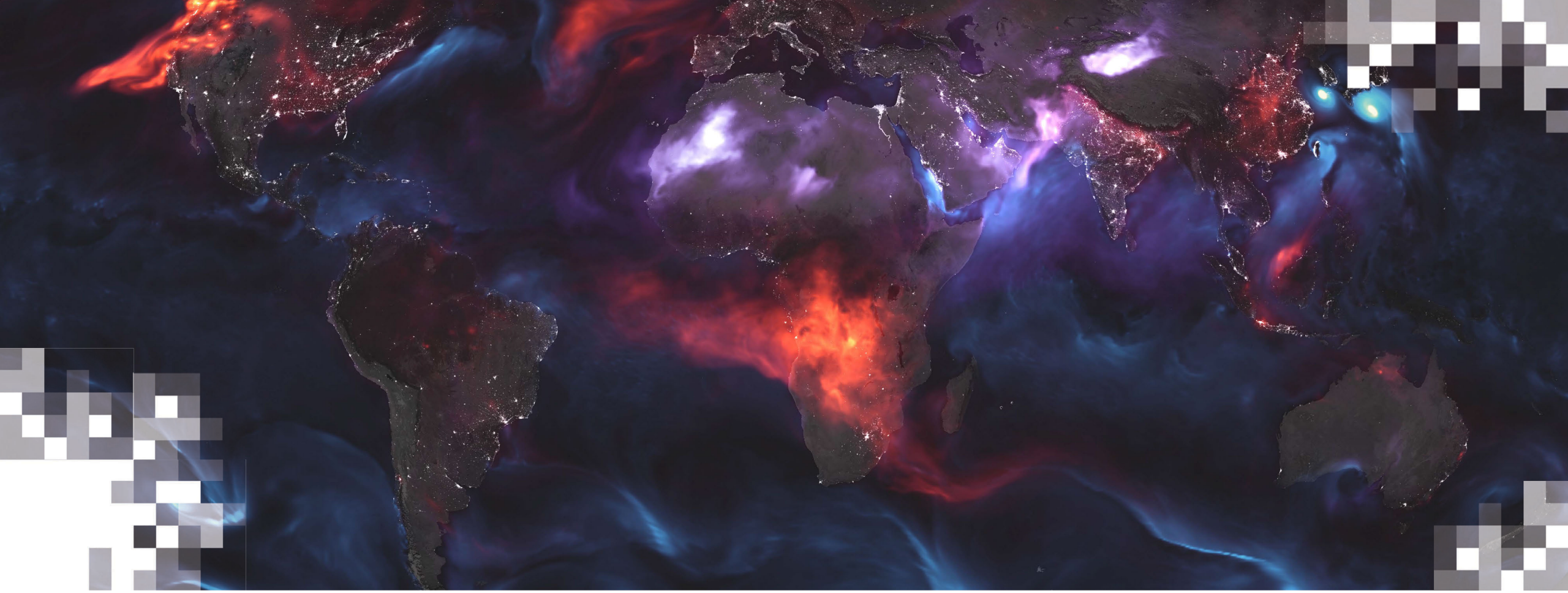






Case Study 2 Summary

- We analyzed the daily and hourly variability of PM2.5 at a surface station compared to GEOS-CF output, focusing on an episode of enhanced PM2.5.
- GEOS-CF captured important aspects of the temporal variability, although some biases were present.
- Meteorological data from GEOS and other NASA products could be used to further interpret this comparison (not shown here).
- We used the MERRA-2 time series to compare the seasonality of two different sites in NE India and the contributions of different aerosols.
- We will next step through a Jupyter Notebook to show how many of these plots were created.
- These routines are examples only. Users must check for accuracy and can modify for to fit their specific analysis needs.



Case Study 2 Notebook Demonstration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TRAIN - EMPOWER - ADVANCE

Thank You!