Demonstration of Satellite-Chemical Transport Model Framework to Estimate Near-Real-Time $PM_{2.5}$ Composition

Tessa Clarizio[1], Hannah Marie Horowitz[1], Vishal Verma[2], and Lei Zhao[1]

[1]University of Illinois at Urbana-Champaign
[2]University of Illinois at Urbana Champaign

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Abstract

The Global Burden of Disease attributes millions of premature deaths to ambient air pollution each year, making it one of the largest environmental health risks faced by society. This mortality is largely due to exposure to fine particulate matter ($PM_{2.5}$). In the United States, the Environmental Protection Agency estimated that 50.5 million people lived in counties with $PM_{2.5}$ concentrations above the level of the National Ambient Air Quality Standards in 2020. $PM_{2.5}$ levels can be derived from satellite aerosol optical depth (AOD) measurements providing comprehensive spatial and temporal coverage. However, the chemical composition of $PM_{2.5}$ affects the mechanisms by which adverse health effects occur, and thus there is a pressing need for linking satellite data with high-resolution atmospheric modeling of $PM_{2.5}$ composition. In order to better inform public health policy and decision-making, we aim to estimate near-real-time (NRT) surface $PM_{2.5}$ composition informed by satellite AOD measurements and chemical transport modeling for the first time. Here, we demonstrate this framework for hindcast estimates in year 2021. NRT AOD is collected from multi-source remote sensing data including Moderate Resolution Imaging Spectroradiometer (MODIS; Aqua and Terra), the Visible Infrared Imaging Radiometer Suite (VIIRS; Dark Target and Deep Blue), and Multi-Angle Imaging SpectroRadiometer (MISR). The data obtained from these products are combined into daily, 10-km AOD estimates and used to scale simulated total $PM_{2.5}$. GEOS-Chem (v13.1.2) nested regional simulations are run over North America with GEOS-Forward Processing (FP) assimilated meteorology at resolution 0.25° lat. x0.3125° lon. (approximately 20-30km) to simulate daily AOD and get an initial estimate of $PM_{2.5}$ composition. This estimate is interpolated into the 10-km grid and multiplied with the satellite-adjusted total $PM_{2.5}$ composition to produce concentrations of each $PM_{2.5}$ species. This satellite-constrained chemical transport model framework estimates of $PM_{2.5}$ will ultimately be evaluated against observations and compared to estimates using standard satellite products to inform future use of this framework to predict ambient air pollution health risks in true near-real-time.

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Tessa Clarizio (tessac2@illinois.edu), Dr. Hannah Horowitz, Dr. Vishal Verma, Dr. Lei Zhao
Session Number: A45P-2059; Abstract ID: 897910
Department of Civil & Environmental Engineering, Grainger College of Engineering, University of Illinois at Urbana-Champaign

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

MOTIVATION

Improve forecasting of particulate matter air pollution health risks in true near-real-time.

RESEARCH OBJECTIVE

Establish a link between near-real-time satellite AOD measurements and chemical transport modeling to predict $PM_{2.5}$ composition.

BACKGROUND

- Air pollution causes millions of premature deaths each year globally.
- Air pollution mortality is largely due to particulate matter (PM) exposure.
- Fine PM (diameter <2.5 microns, $PM_{2.5}$) pose the greatest risk to health because they can travel deeper into the lungs.
- $PM_{2.5}$ can be composed of different chemicals such as sulfate, nitrate, ammonium, black carbon and organic aerosol.
- $PM_{2.5}$ chemical composition can affect adverse health impacts.
- $PM_{2.5}$ levels (but not composition) can be estimated from satellite aerosol optical depth measurements (AOD).
- Atmospheric chemical modeling tools can be used to predict $PM_{2.5}$ composition.

STEP 3: MET FIELD SENSITIVITY ANALYSIS

In order to carry out research task #3, first must carry out a **sensitivity analysis** between the different meteorological fields available in GEOS-Chem: MERRA-2 & GEOS-FP.

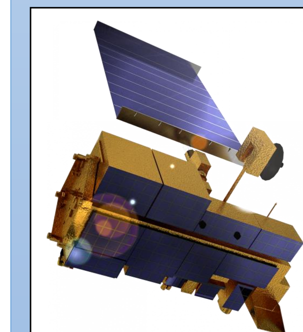
MERRA-2	GEOS-FP
The Modern-Era Retrospective analysis for Research and Applications, Version 2	Uses most recent validated GEOS system, "forward processing"
Reanalysis	Operational
0.5° x 0.625°	0.25° x 0.3125°

Main $PM_{2.5}$ Components Simulated in GEOS-Chem

- Fine Sea Salt Aerosol (SALA)
- Ammonium (NH_4)
- Black Carbon Aerosol (BC)
- Inorganic Nitrates (NIT)
- Dust Aerosol (DST)
- Sulfate (SO_4)
- Organic Aerosol (OA)
- Secondary Organic Aerosol (SOA)

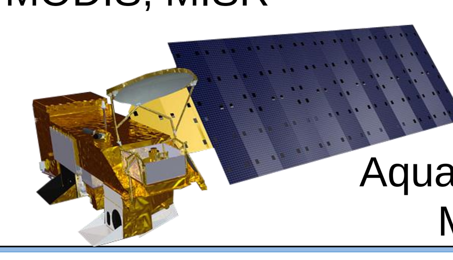
→ $PM_{2.5}$

METHODS



Terra Satellite – MODIS, MISR

Suomi NPP Satellite – VIIRS



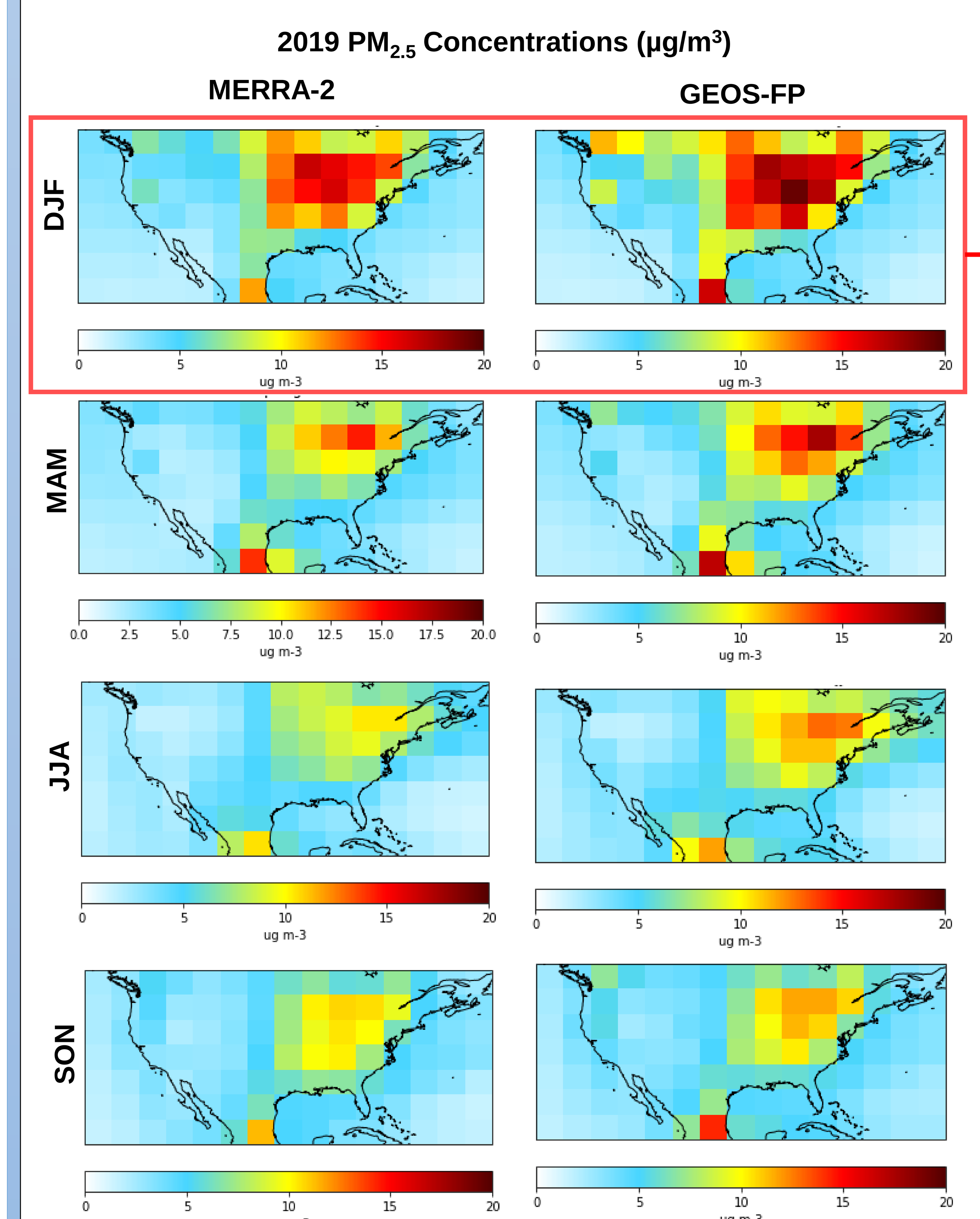
Aqua Satellite – MODIS

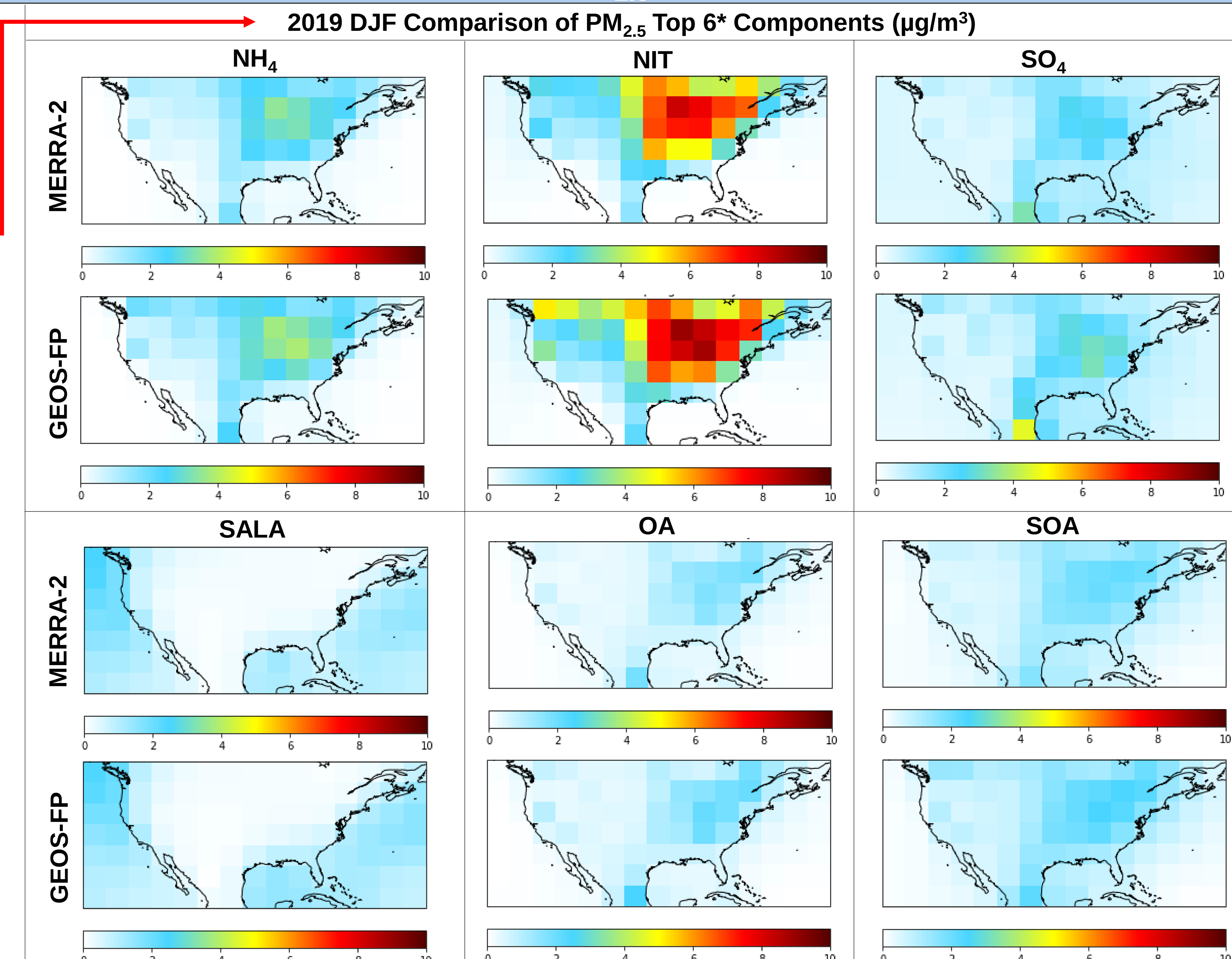
1. Collect NRT satellite data
2. Combine satellite AOD products
3. Use combined products and chemical transport model to get initial estimate of $PM_{2.5}$ composition
4. Interpolate the model estimates to a 10km grid
5. Multiply satellite-adjusted total $PM_{2.5}$ to get chemical concentrations of each species

GEOS Chem

$PM_{2.5}$ Components

STEP 3: SAMPLE GEOS-CHEM OUTPUT – 2019 SEASONAL $PM_{2.5}$ AVERAGES

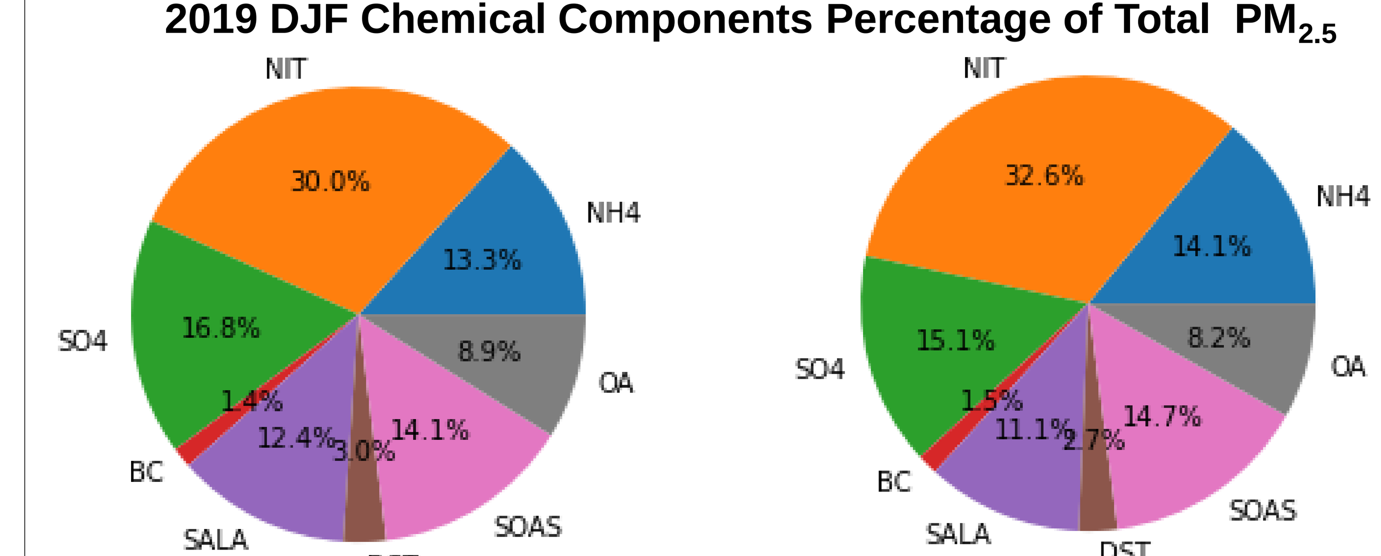




*DST and BC are not plotted above due to their low concentrations

- Overall, using GEOS-FP results in higher $PM_{2.5}$ concentrations at all locations compared to MERRA-2.
- The spatial distribution of $PM_{2.5}$ concentrations are similar for both MERRA-2 and GEOS-FP.
- Winter (DJF) had the highest $PM_{2.5}$ concentrations. Therefore, the 8 main $PM_{2.5}$ components were examined to see how different species contributing to $PM_{2.5}$ differ between MERRA-2 and GEOS-FP.
- Future work will examine differences between the remaining seasons.

2019 DJF Chemical Components Percentage of Total $PM_{2.5}$



SUMMARY

- NIT, SO_4 and NH_4 were the largest contributors to $PM_{2.5}$.
- GEOS-FP resulted in higher concentrations of all $PM_{2.5}$ components compared to MERRA-2.
- MERRA-2 and GEOS-FP had similar chemical component fractions, demonstrating consistency on the relative amount of each aerosol species across both met fields.