NASA GEOS Aerosol Modeling and Assimilation Activities

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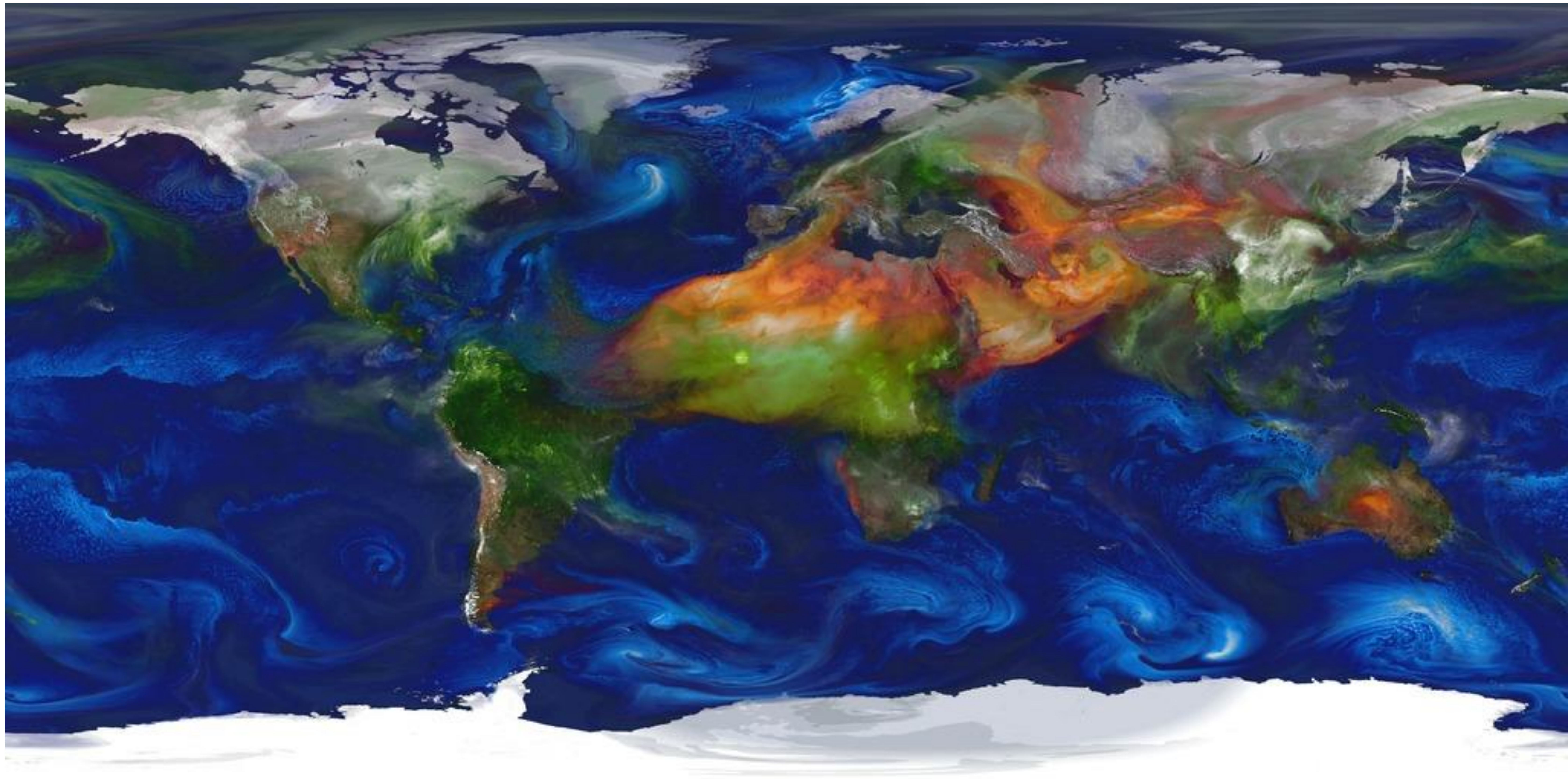
Outline

- ○ *Model Architecture*
- ○ *Model Status*
- ○ *Science Highlights*
- ○ *Aerosol Assimilation and OSSE*
- ○ *Field Campaign Support*
- ○ *Summary*



GEOS Model Architecture

GEOS is a hierarchy of ESMF components

- *An infrastructure for building GEOS applications:*
  - Standardized component interfaces
  - Low level data containers for data sharing
  - Grid classes for the physical domain
  - Parallel communication
  - Others: Regridding, Logging, Calendar

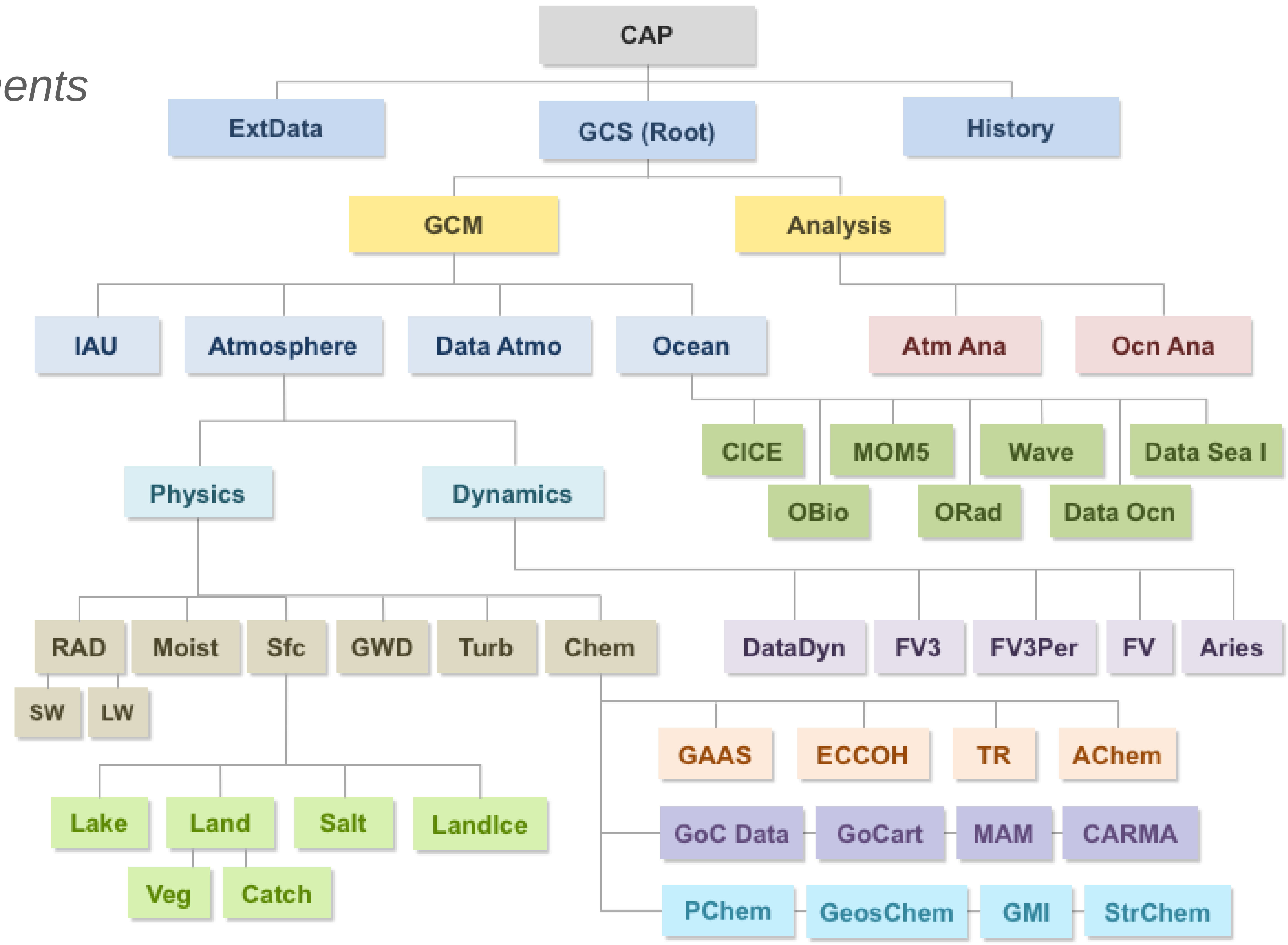
The MAPL layer interface to ESMF

- *Provides an abstraction of software issues including:*
  - Generic Initialize/Finalize/Run
  - Simplified hierarchy (creation of child components)
  - IO Layers (Asynchronous file server output)
  - Regridding transforms (grids and tiles)
  - Profiling (Performance and Memory)
  - Input (ExtData) / Output (History)

Architecture permits flexibility

- NWP configuration
- S2S configuration (seasonal, w/coupled ocean)
- CCM configuration (advanced chemistry)
- CF configuration (full chemistry NRT forecasting)
- NR configuration (high resolution for OSSEs)
- CTM configuration (offline met fields)

All these use the same core model components



GEOS Comprehensive Architecture

GEOS Model Architecture – Forward Processing Configuration

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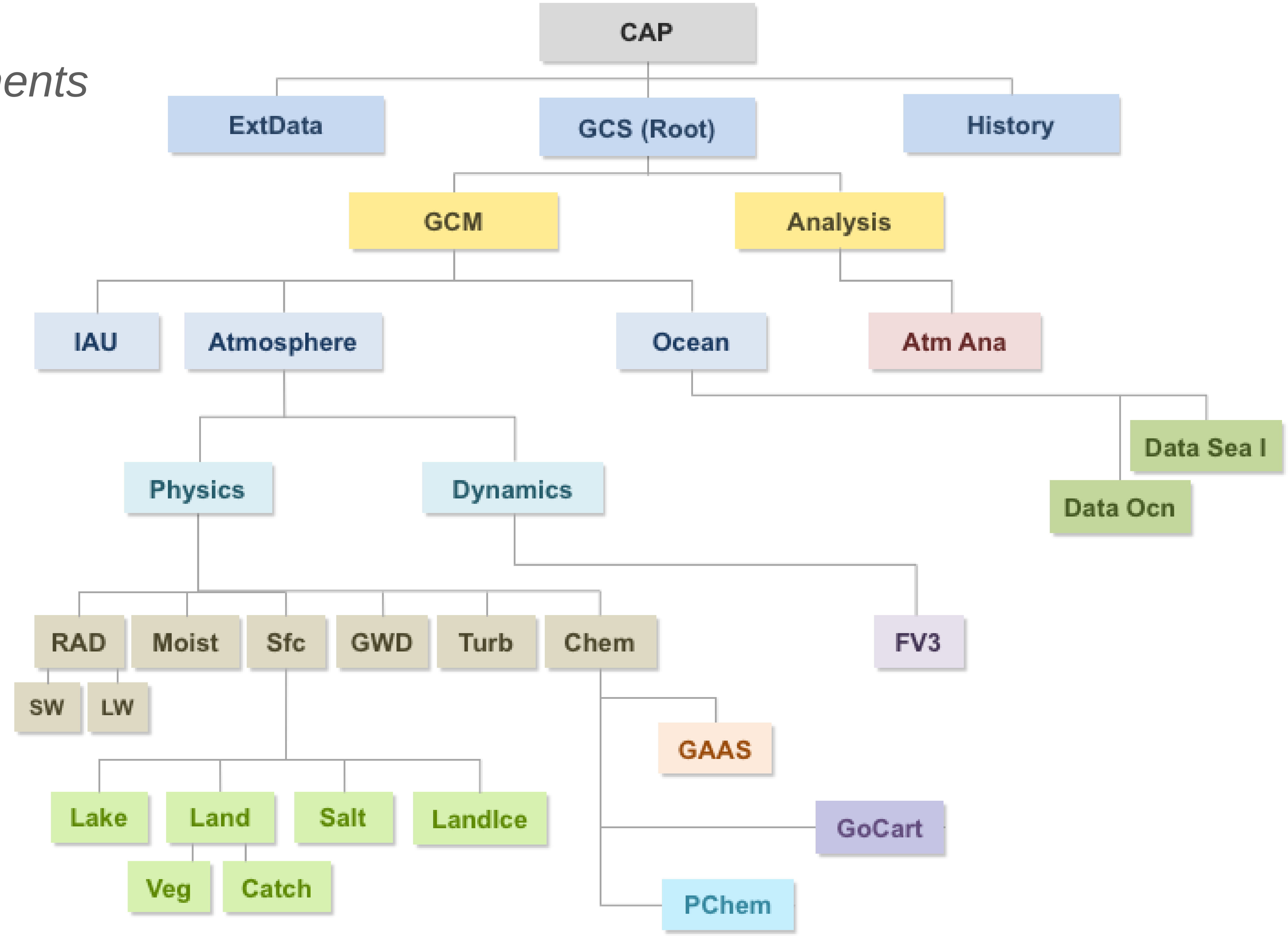
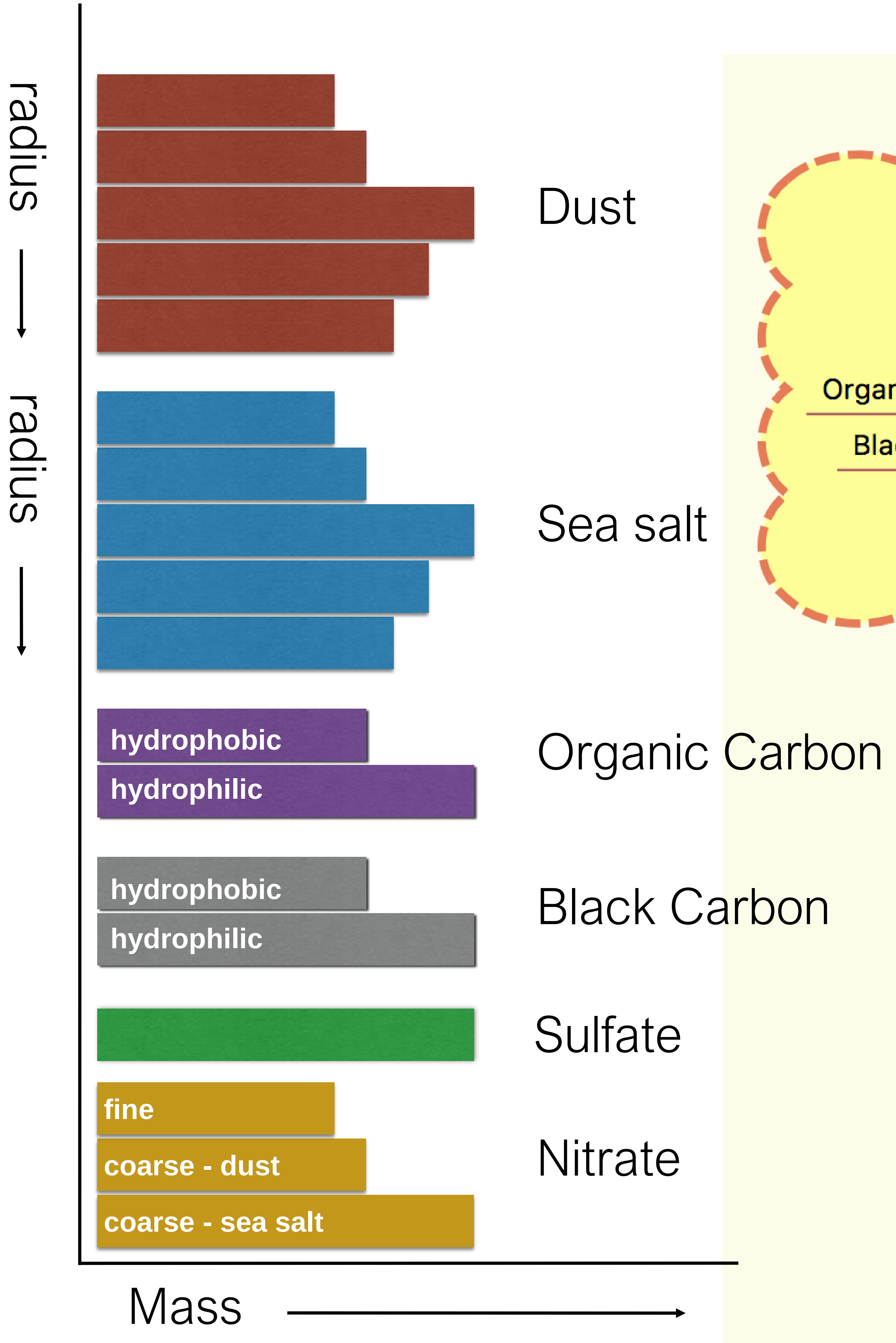
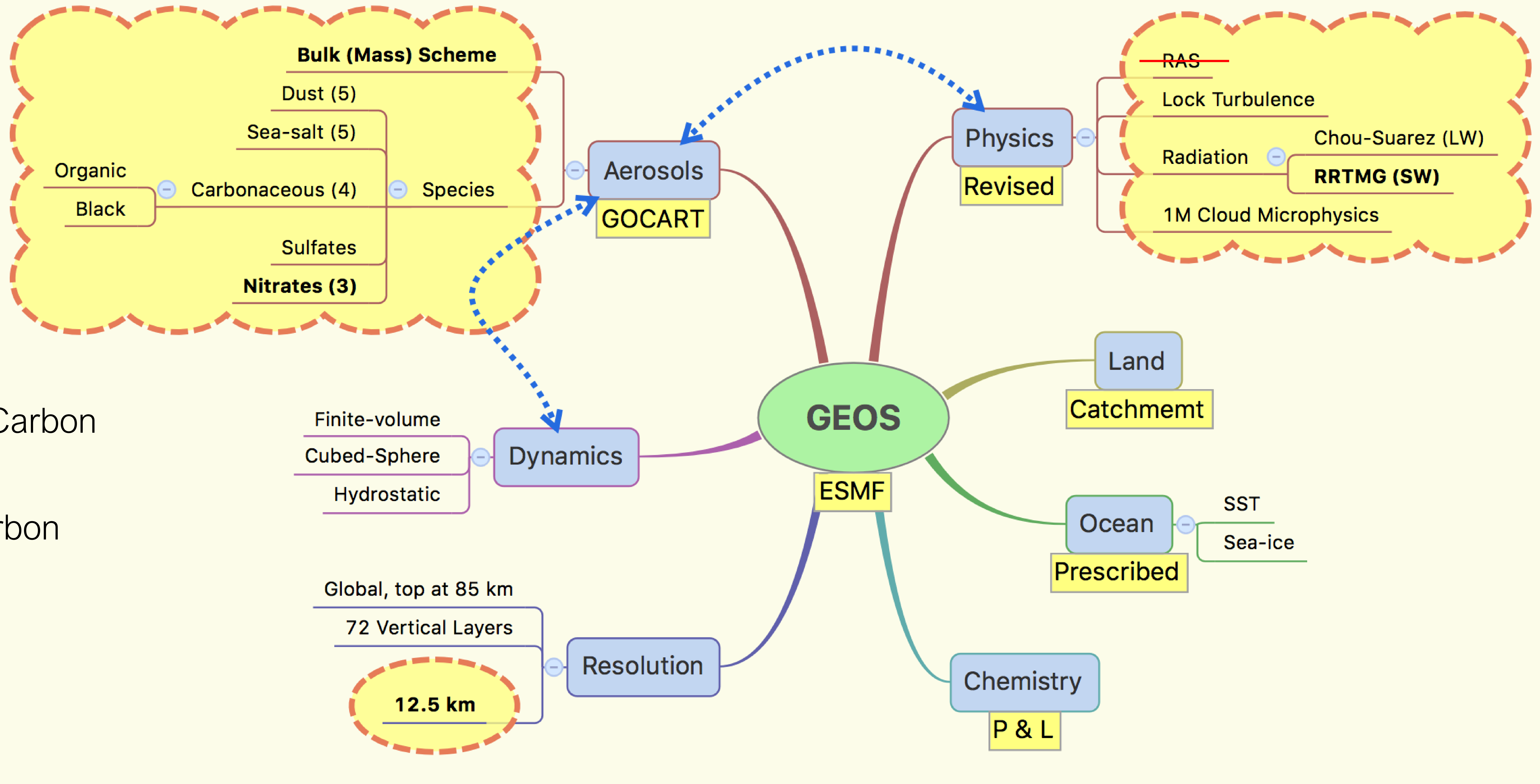


GEOS Current NWP Configuration (March 2019)

Grell-Freitas Deep, Bretherton-Park Shallow

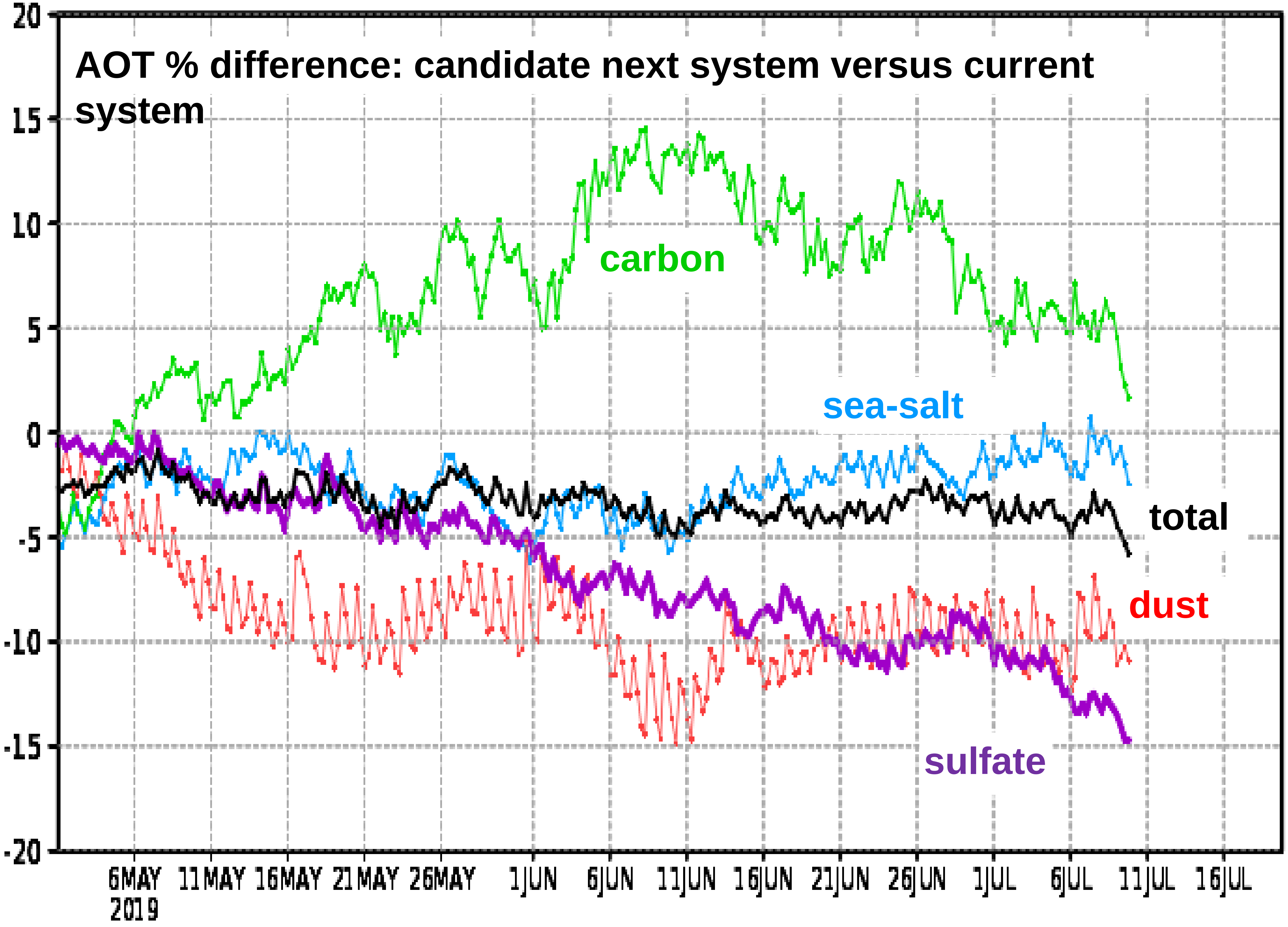
- Scale aware
- Increased shallow convection (RAS underestimate)
- Aerosol Coupling: droplet formation and rainfall depend on CCN at base of cloud





NASA Goddard SPACE FLIGHT CENTER

GEOS Next NWP Configuration (summer 2019)



- *Candidate for next NRT system introduces new moist physics scheme*
- *Aerosol assimilation leaves the total AOD largely unchanged*
- *Aerosol wet removal is affected by change in moist physics, and behaves differently across species simulated*
- *Detailed comparisons against airborne data will help adjust parameterizations to increase composition fidelity with respect to observations*

Courtesy of G. Partyka

GEOS Future NWP Configuration (notionally by next ICAP…)

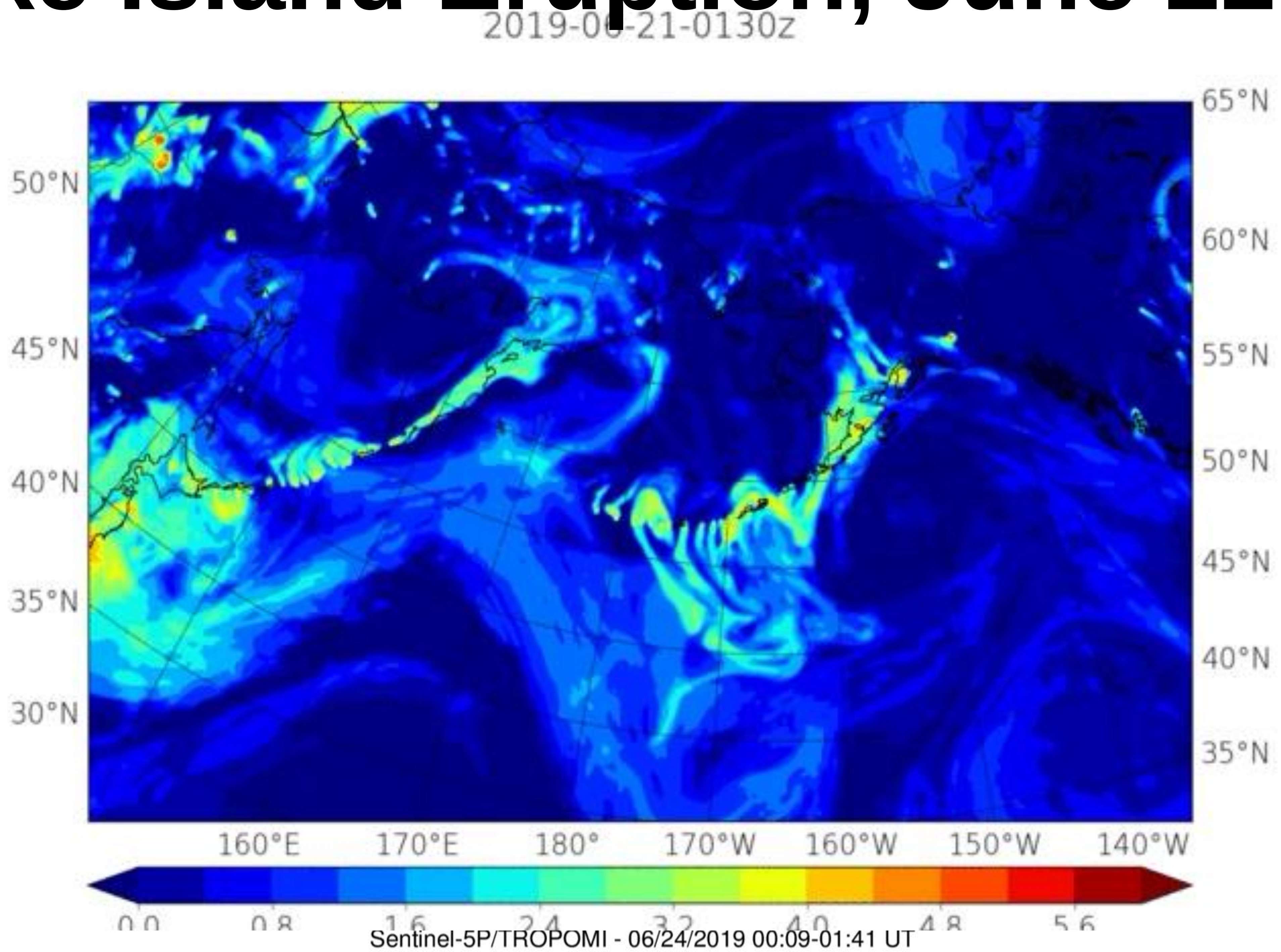
- Prognostic SOA from anthropogenic and biomass burning VOCs
- Biogenic SOA updated to newer version of dynamic MEGAN

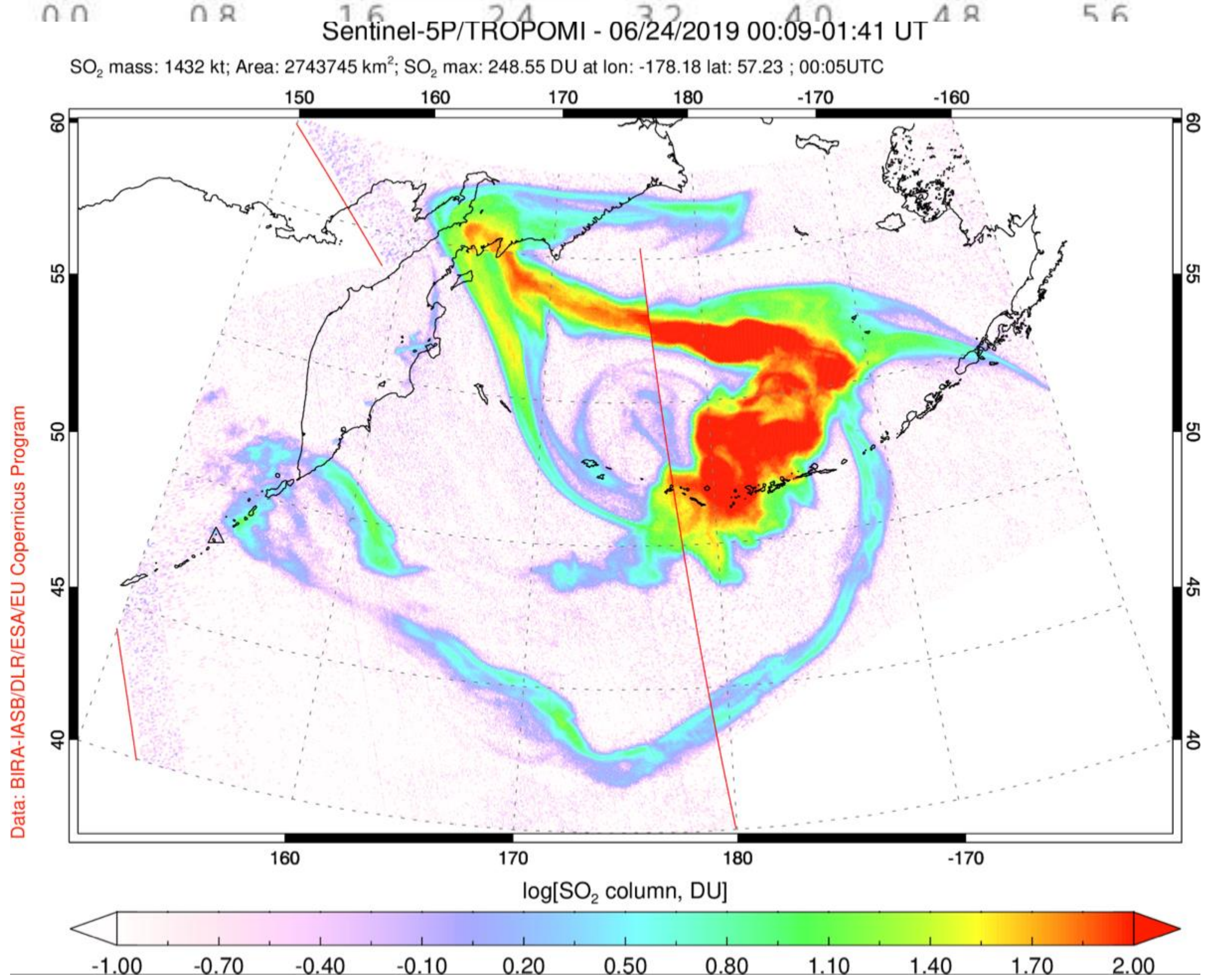
Science Highlights

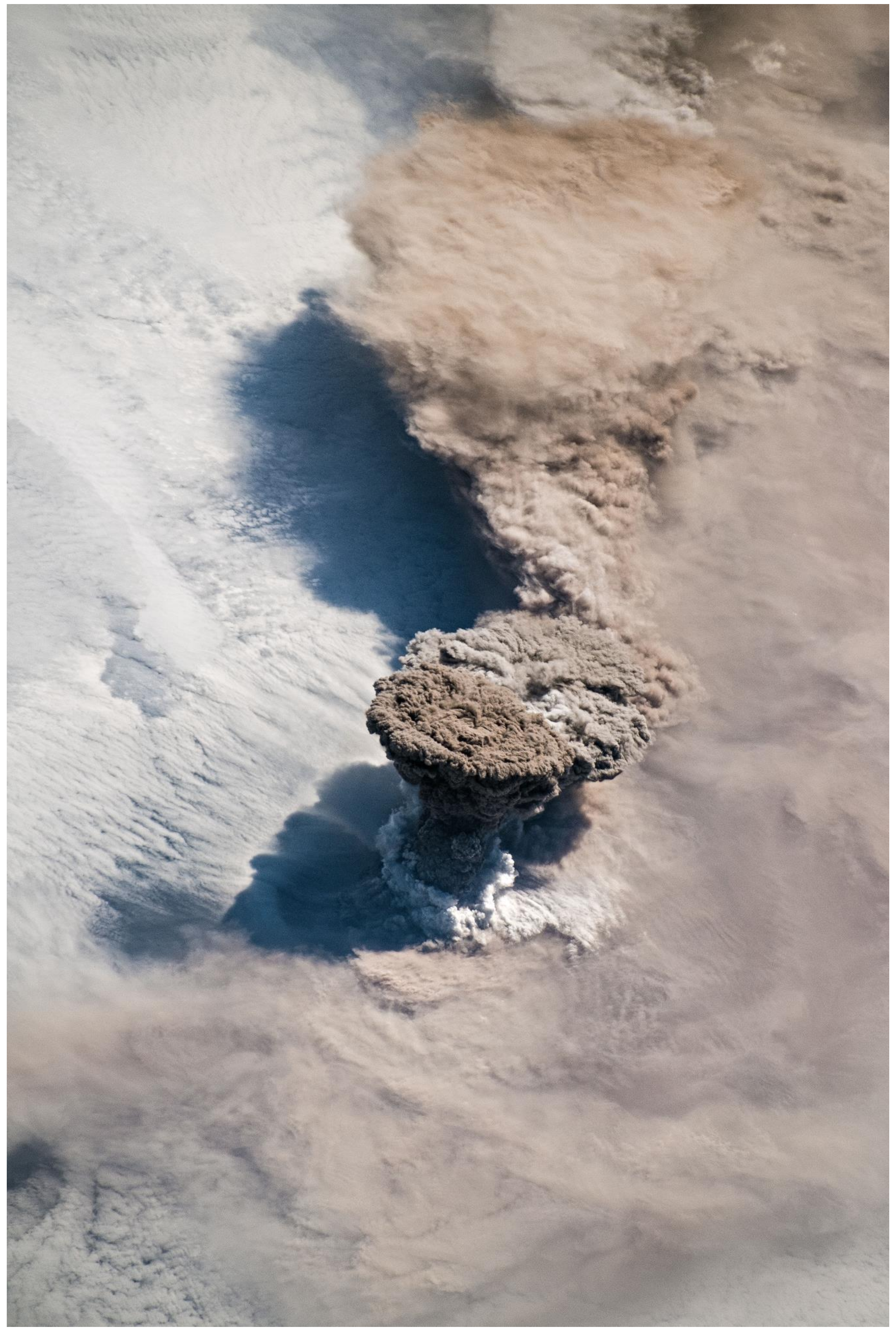
Raikoke Island Eruption, June 22, 2019

Approach to entrain NRT observations of exceptional events not captured (well) in nominal modeling system

- *example: volcanic events*
- *inputs: satellite derived injection amounts and altitudes*
- *but the effort to do in NRT needs some refinement…*



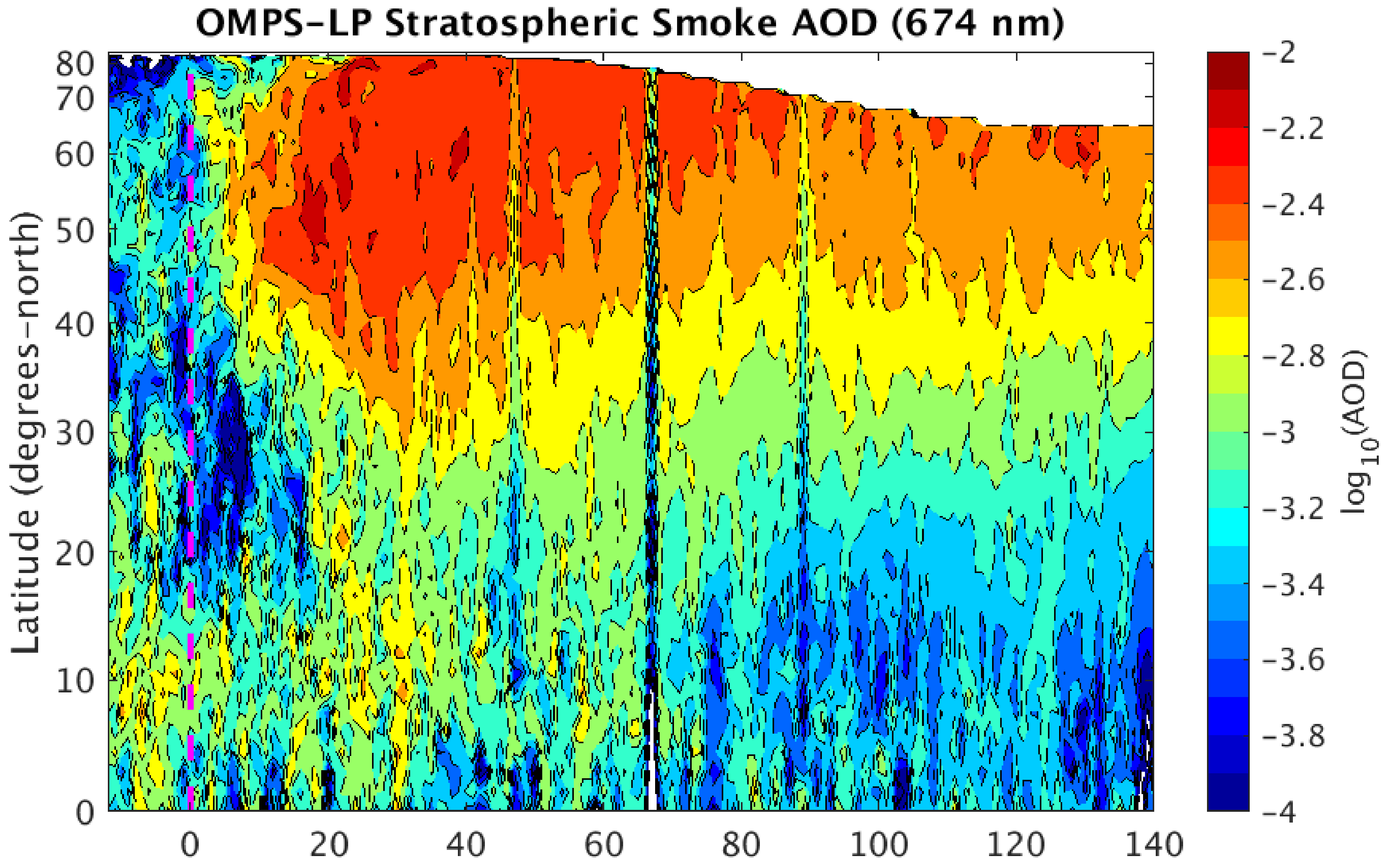




Work on Pyro-CB Events

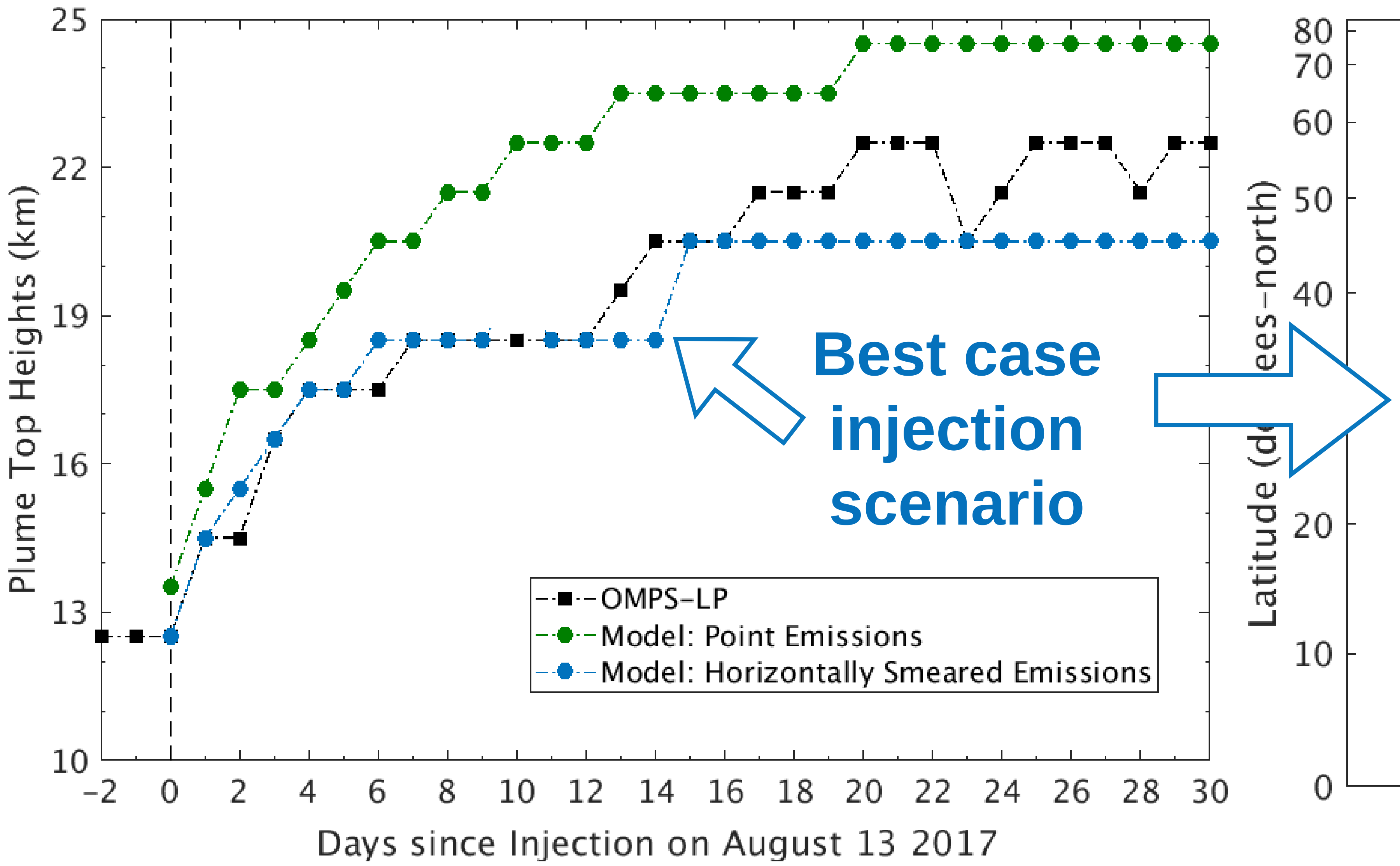
Assimilation system can't cope with oddball stratospheric injections like those from volcanic and pyro-cb events

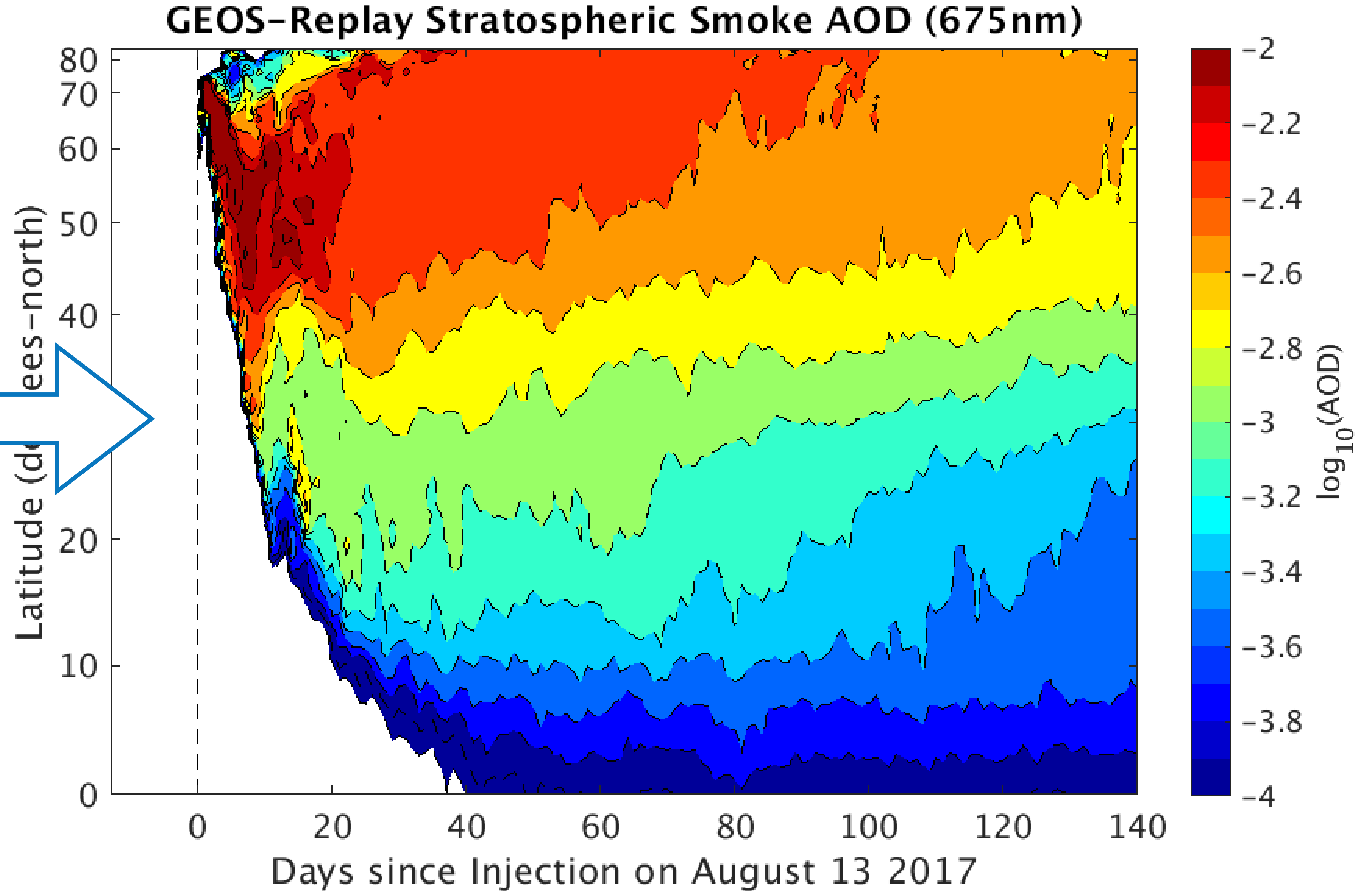
- *missing source functions (e.g., volcanoes)*
- *even where satellite derived emissions are present (e.g., fires) for things like pyro-cb events we don't place correctly*



Detailed investigation of August 2017 Canadian pyro-cb event

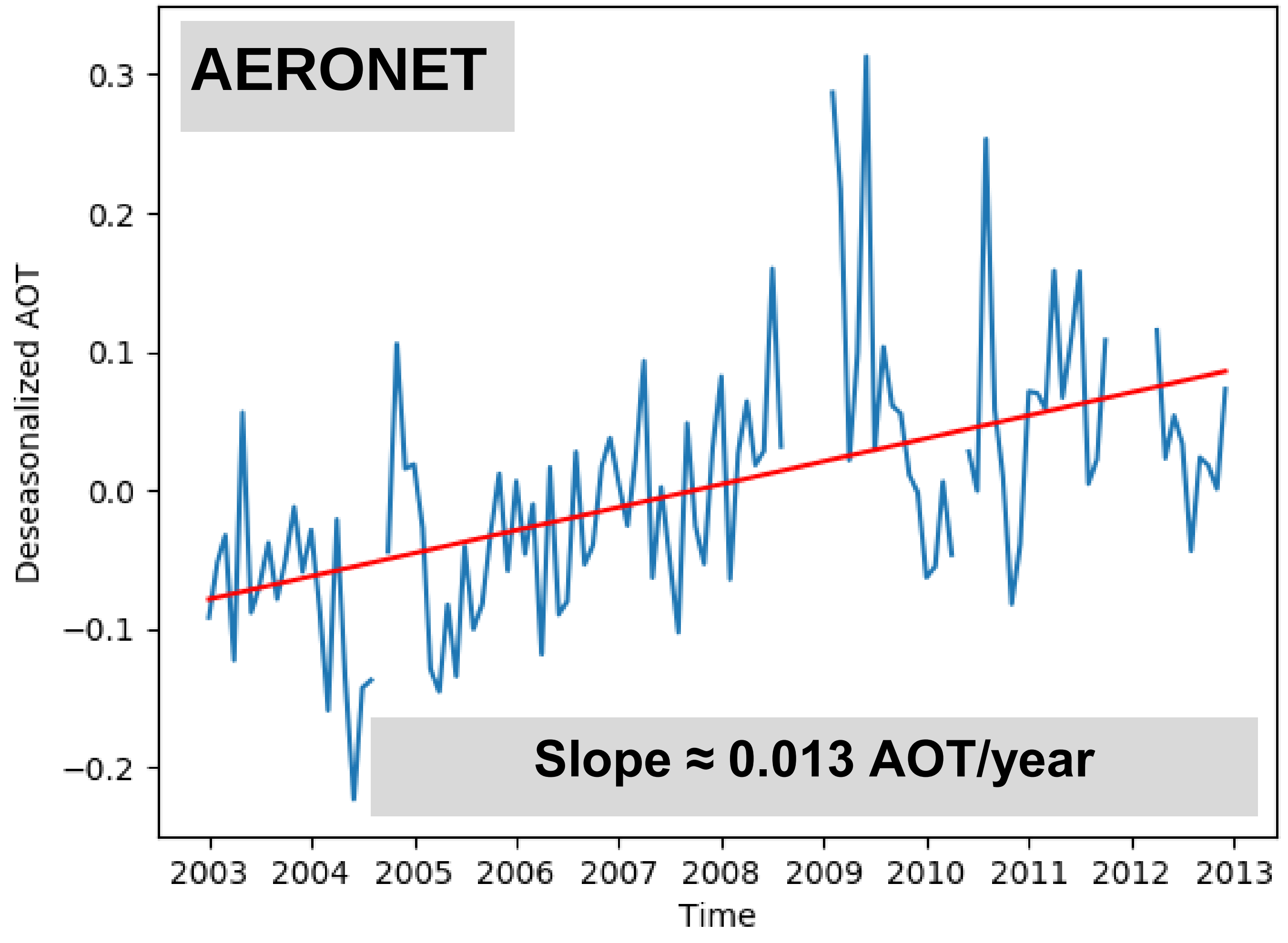
Comparisons with OMPS-LP observations shows reasonable representation of smoke vertical profile and long-term evolution of stratospheric smoke loading

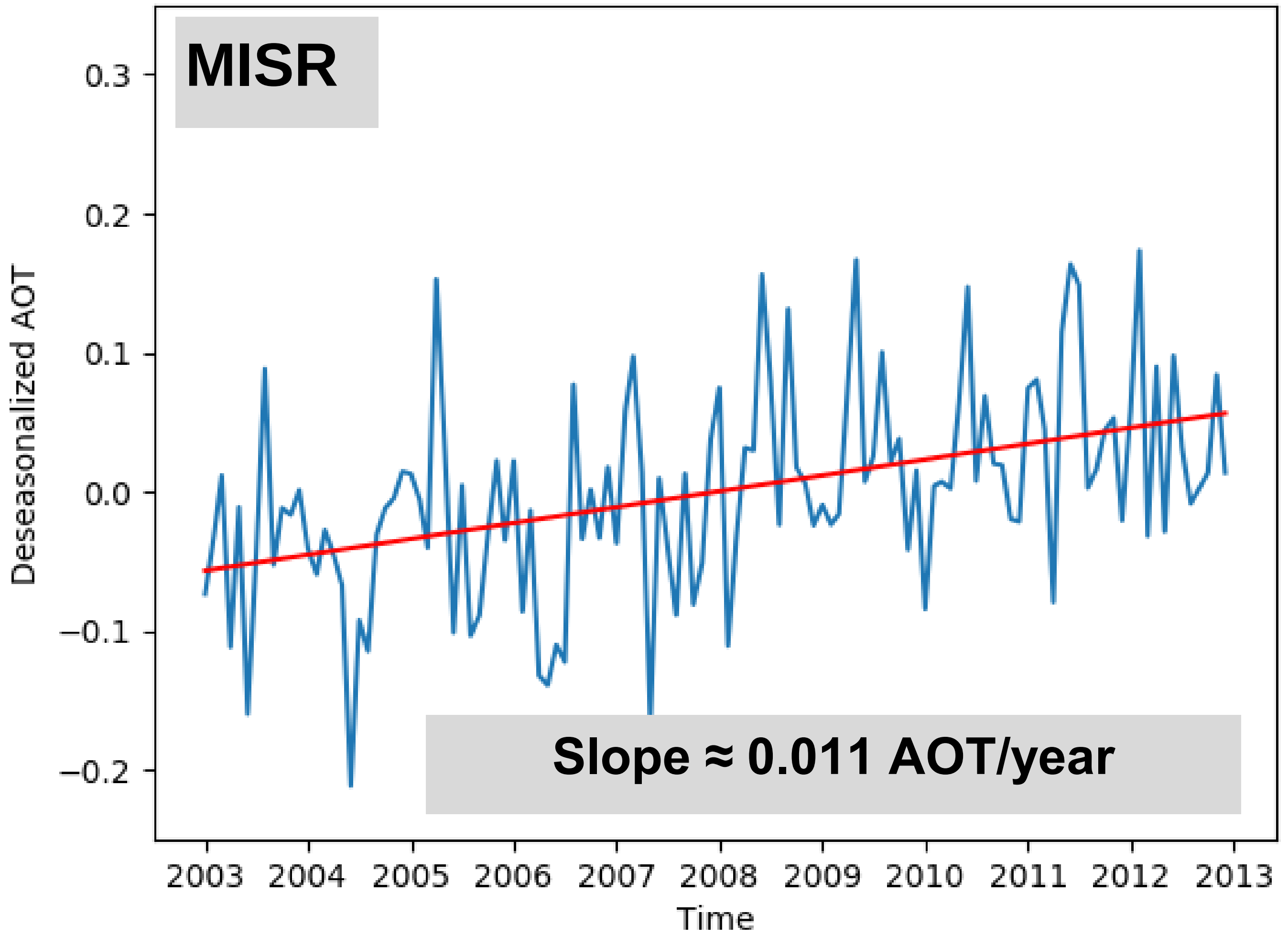


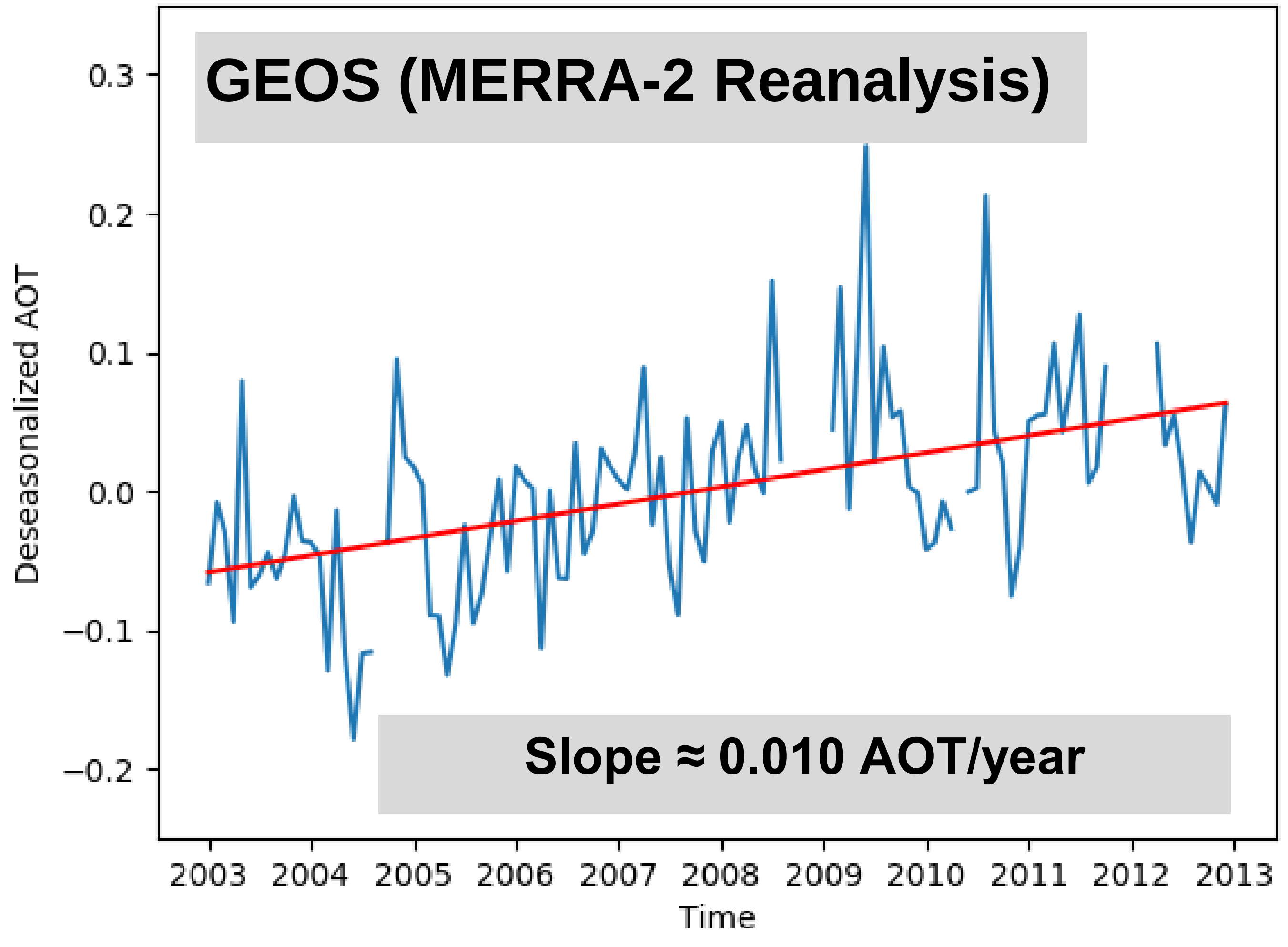


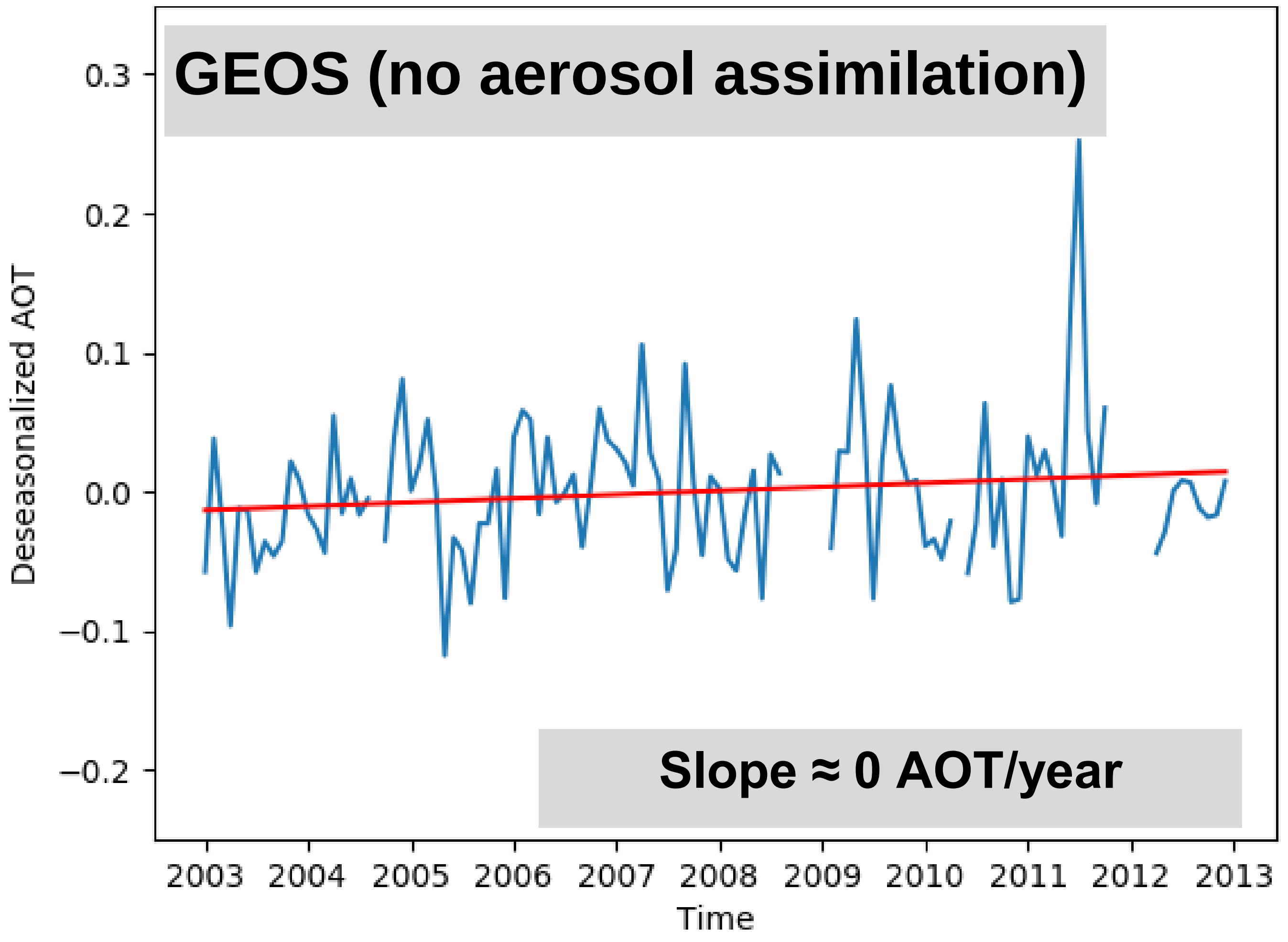
Das et al. in preparation 2019

Recent Variability of Middle Eastern Dust AOT in Observations and Models

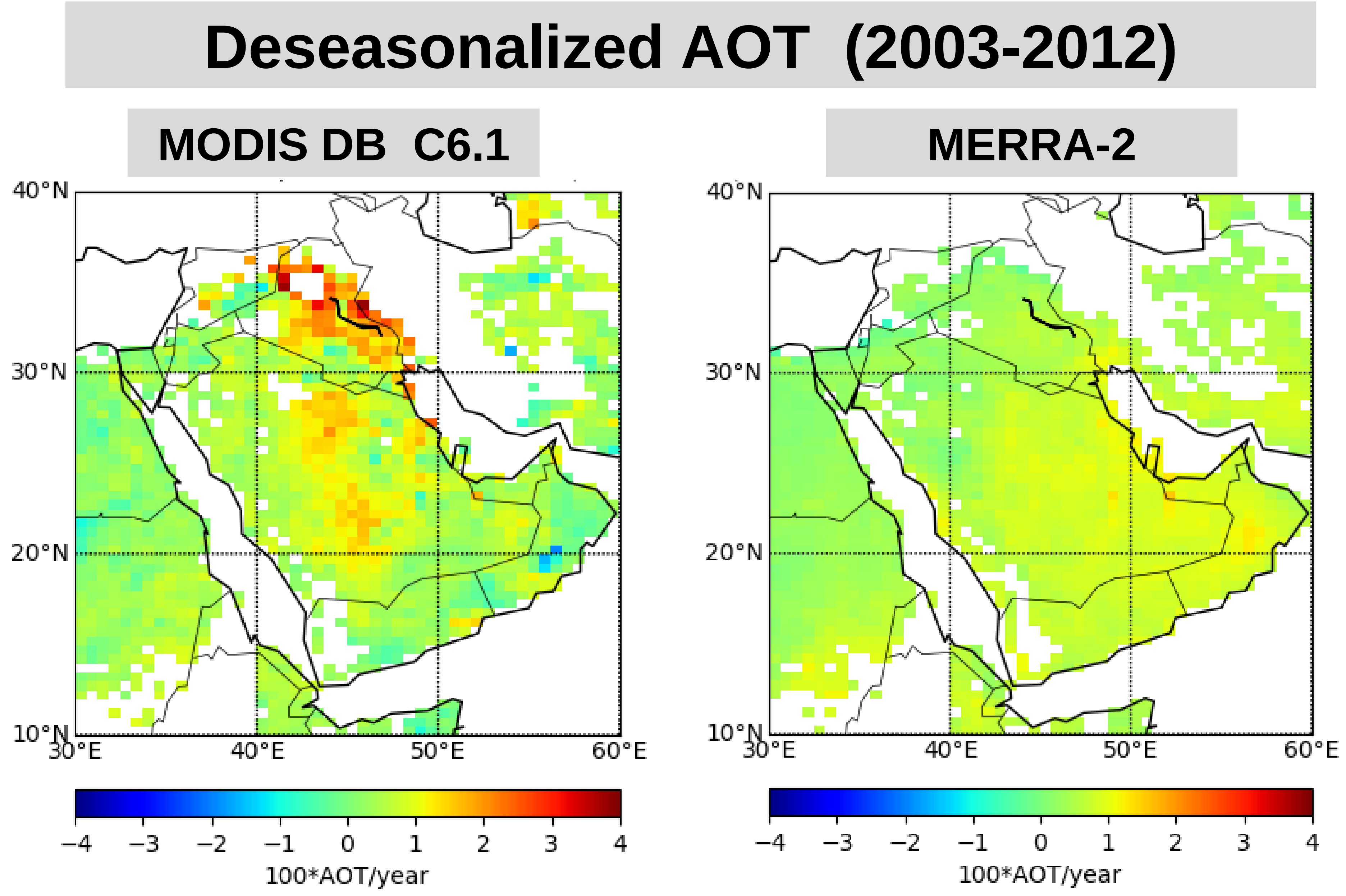


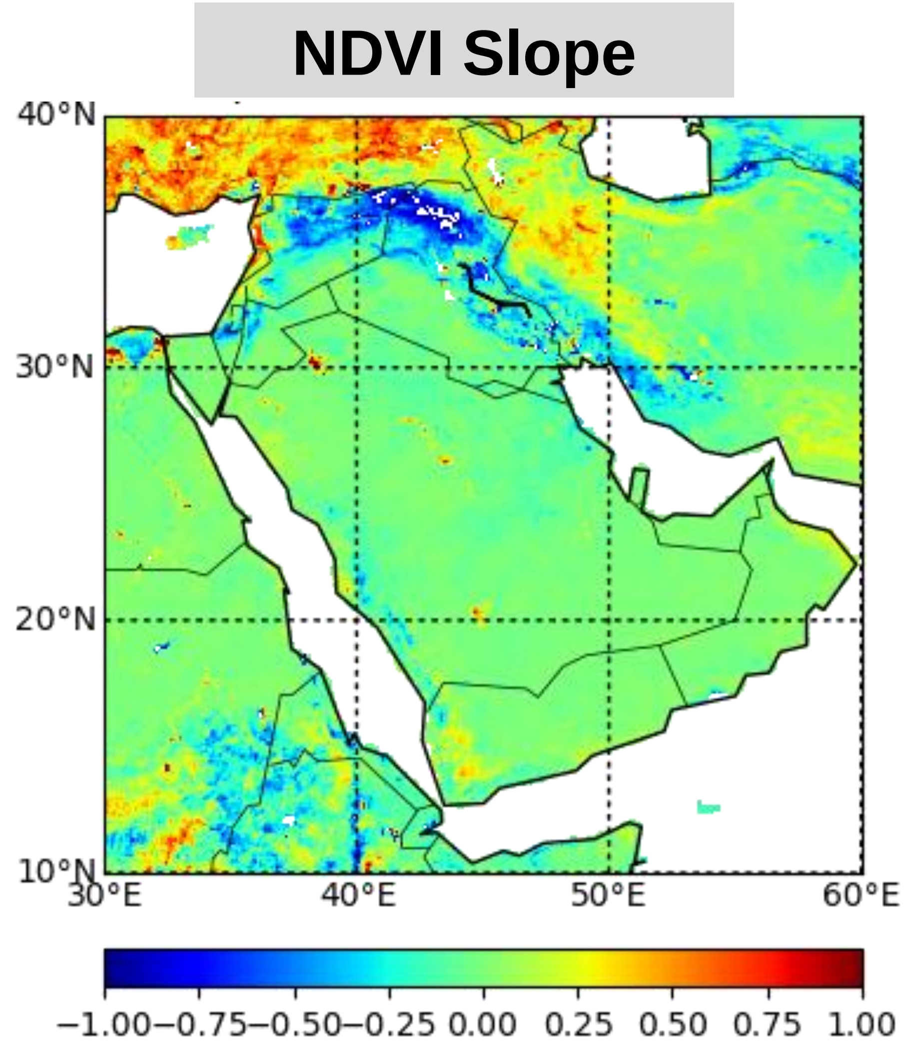






Observed slope in Middle Eastern dust-related AOD (AERONET-Solar Village, MISR) is evident in GEOS simulations with aerosol data assimilation (MERRA-2) but not in simulations without.

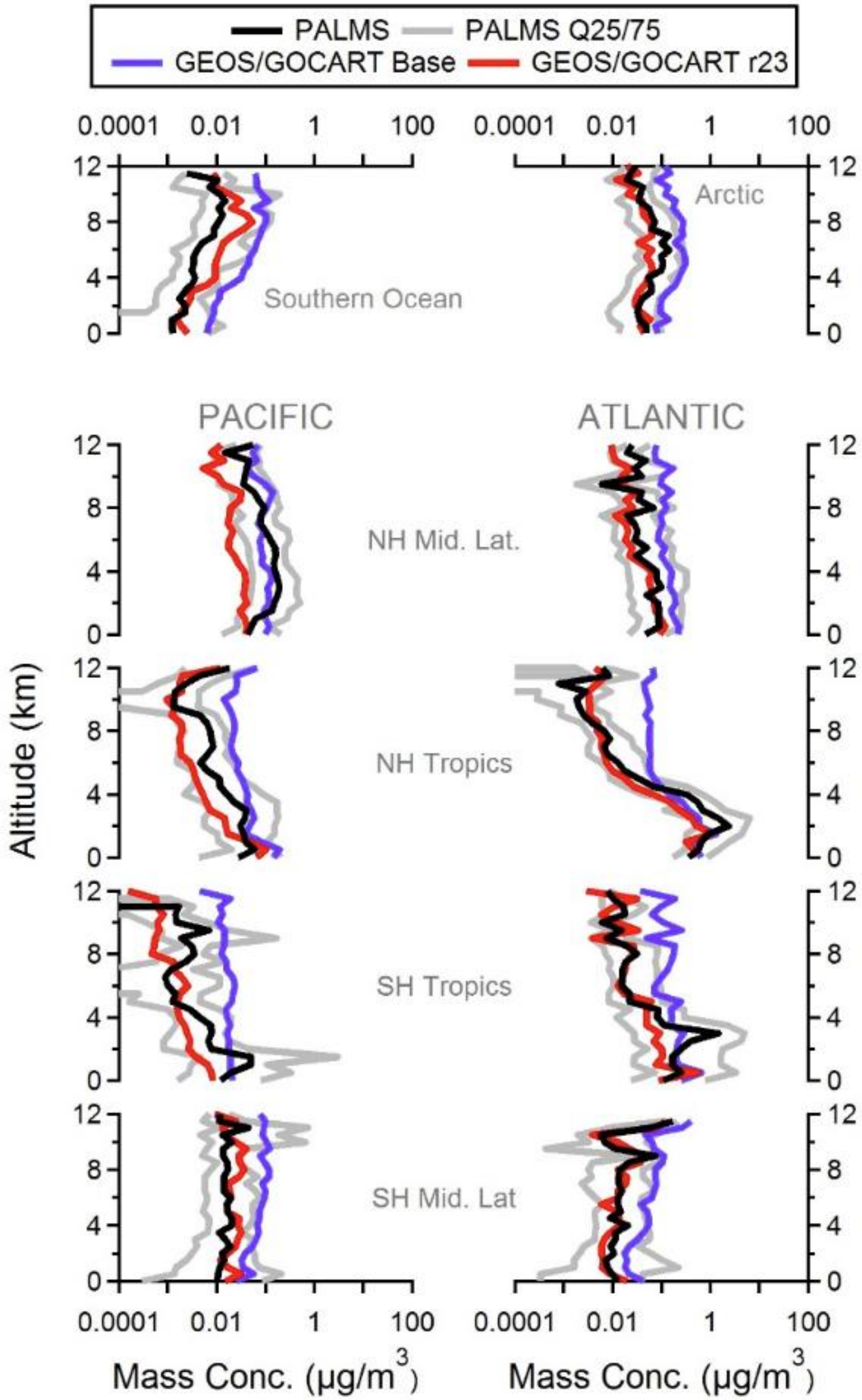




Dust AOD variability seems to be associated with trend in vegetative cover (NDVI) across Syria and Iraq. New dust production scheme will be sensitive to this variability.

Rocha Lima et al. in preparation 2019

Airborne Observations Informing Treatment of Aerosol Scavenging

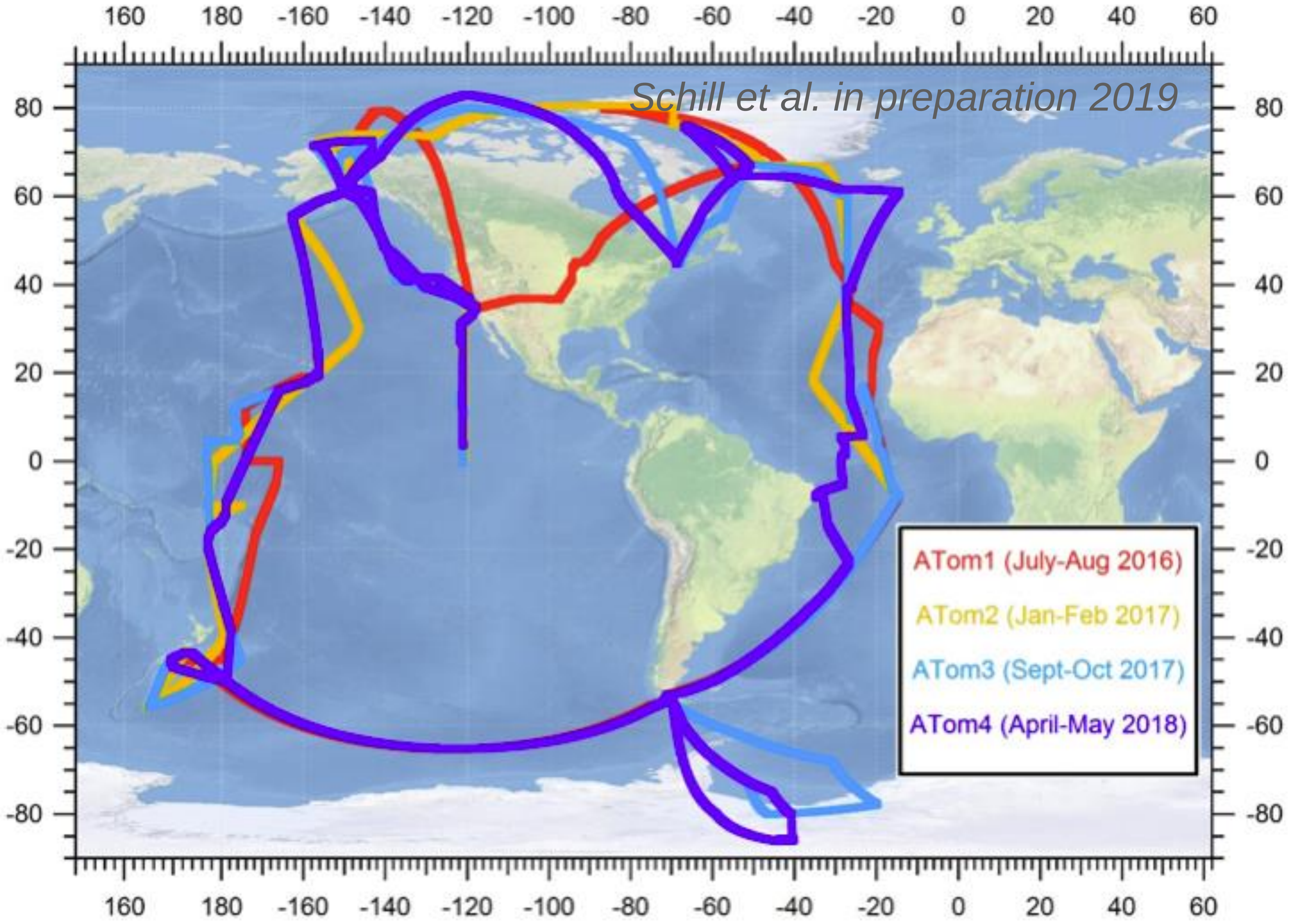


NASA Atmospheric Tomography mission (ATom) flew profiles with DC-8 in remote oceans during four seasons

PALMS single particle mass spectra reveal the ubiquity of biomass burning particles in remote troposphere

25% of aerosol mass in remote troposphere is BB aerosol!

GEOS simulations ***greatly improved by incorporating cold-cloud scavenging processes***

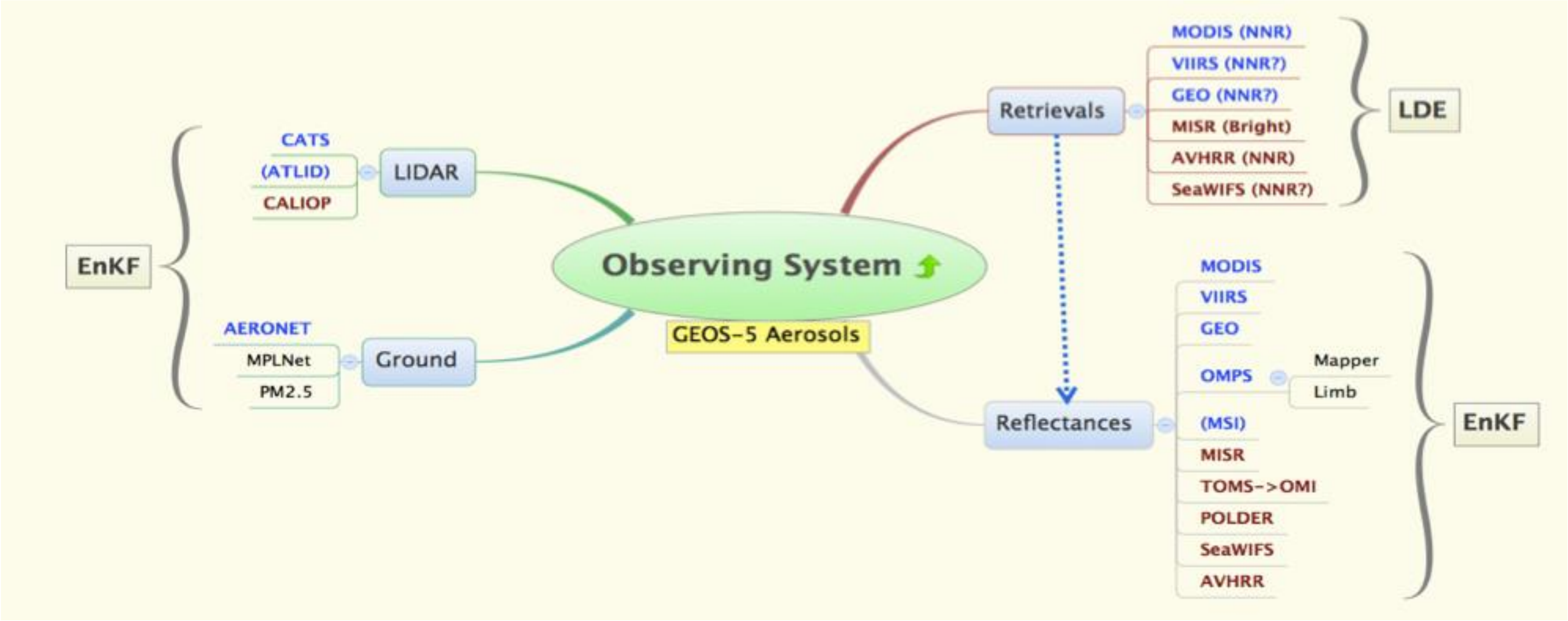


Assimilation and OSSE Activities

Aerosol Observing System

Aerosol Optical Depth (AOD) is the most commonly available observable

- Vertically integrated mass weighted by extinction coefficient, summed over multiple species: ***low observability***



Radiance assimilation:

- Vector scattering calculations needed for UV-VIS measurements are **computationally demanding**
- Surface BRDF characterization is a challenge

Surface PM 2.5

- Single level
- Often plagued by ***representativeness errors***

Lidar measurements provide vertical info

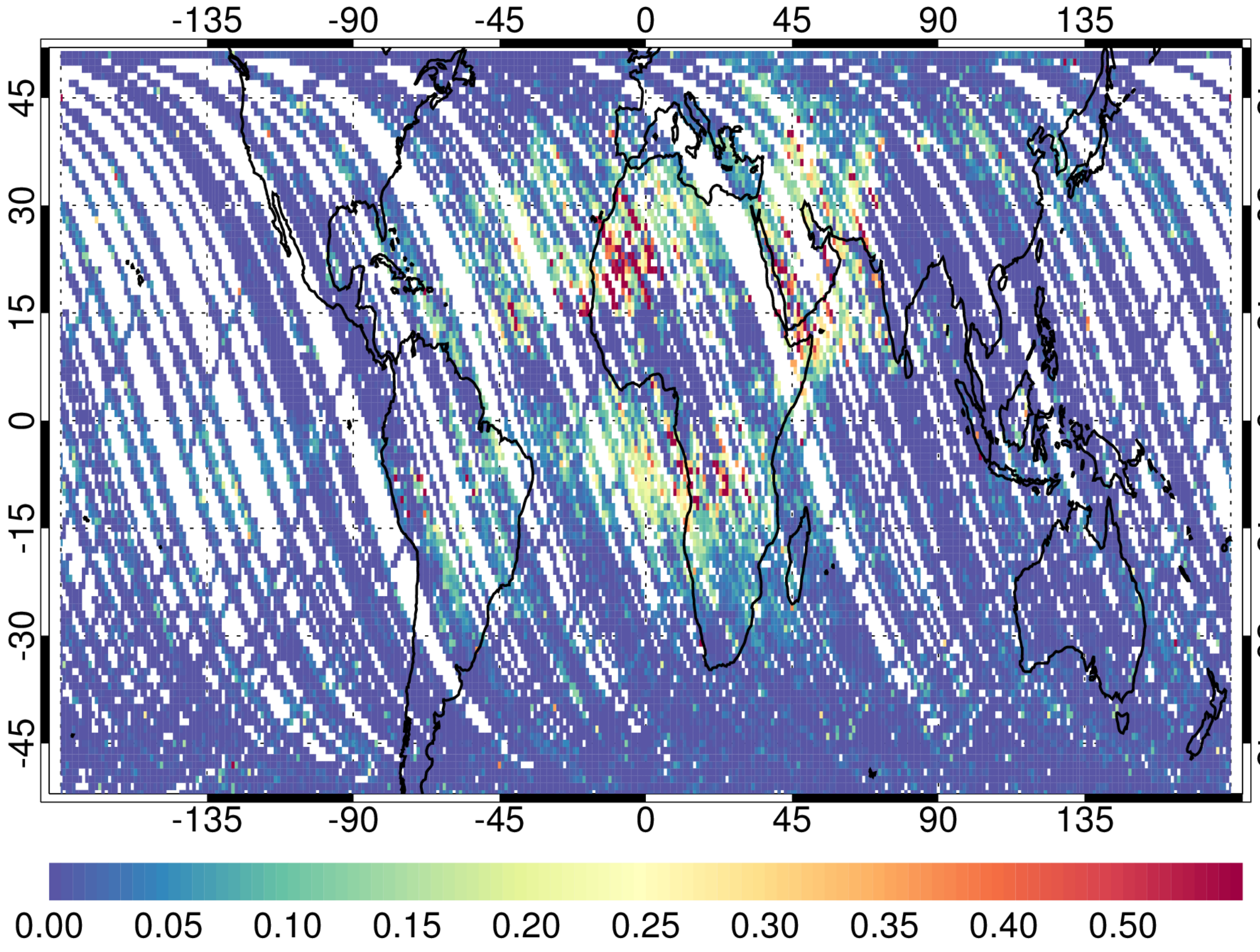
- Spatial **coverage is poor** (pencil thin)
- Attenuated backscatter again requires optical assumptions which are not directly measured
  - ✓ HSRL concept is promising

1-D EnsVar GEOS/Lidar Retrievals

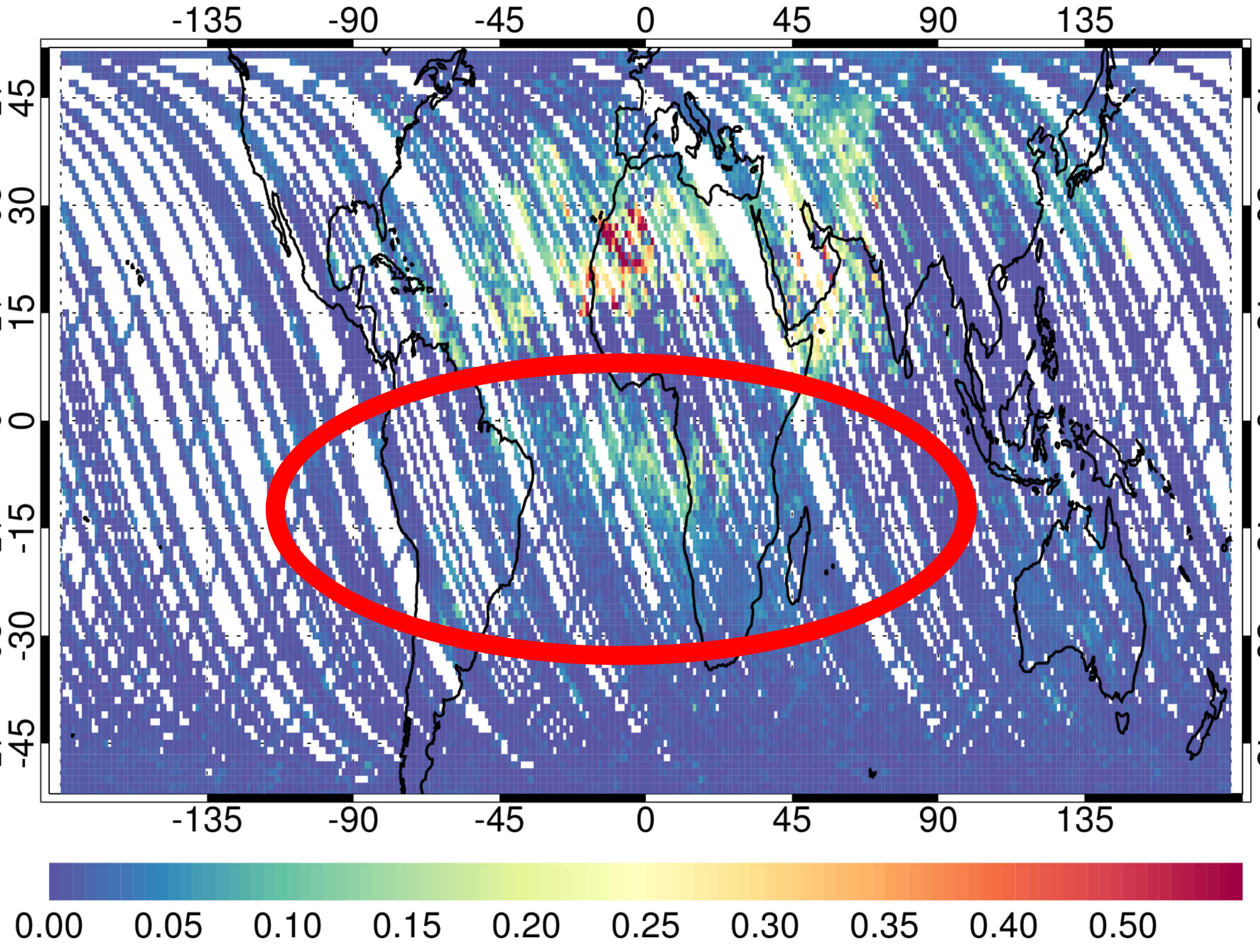
Using vertical profiles of total attenuated backscatter from the CATS lidar on the ISS, a 1-D ensemble based variational (1-D EnsVar) retrieval approach has been developed using model priors from GEOS:

- *The approach is flexible and can be used to retrieve speciated aerosol optical quantities and mass concentration*
- *Currently, retrievals are being made for the entire CATS data record (2015– 2017)*

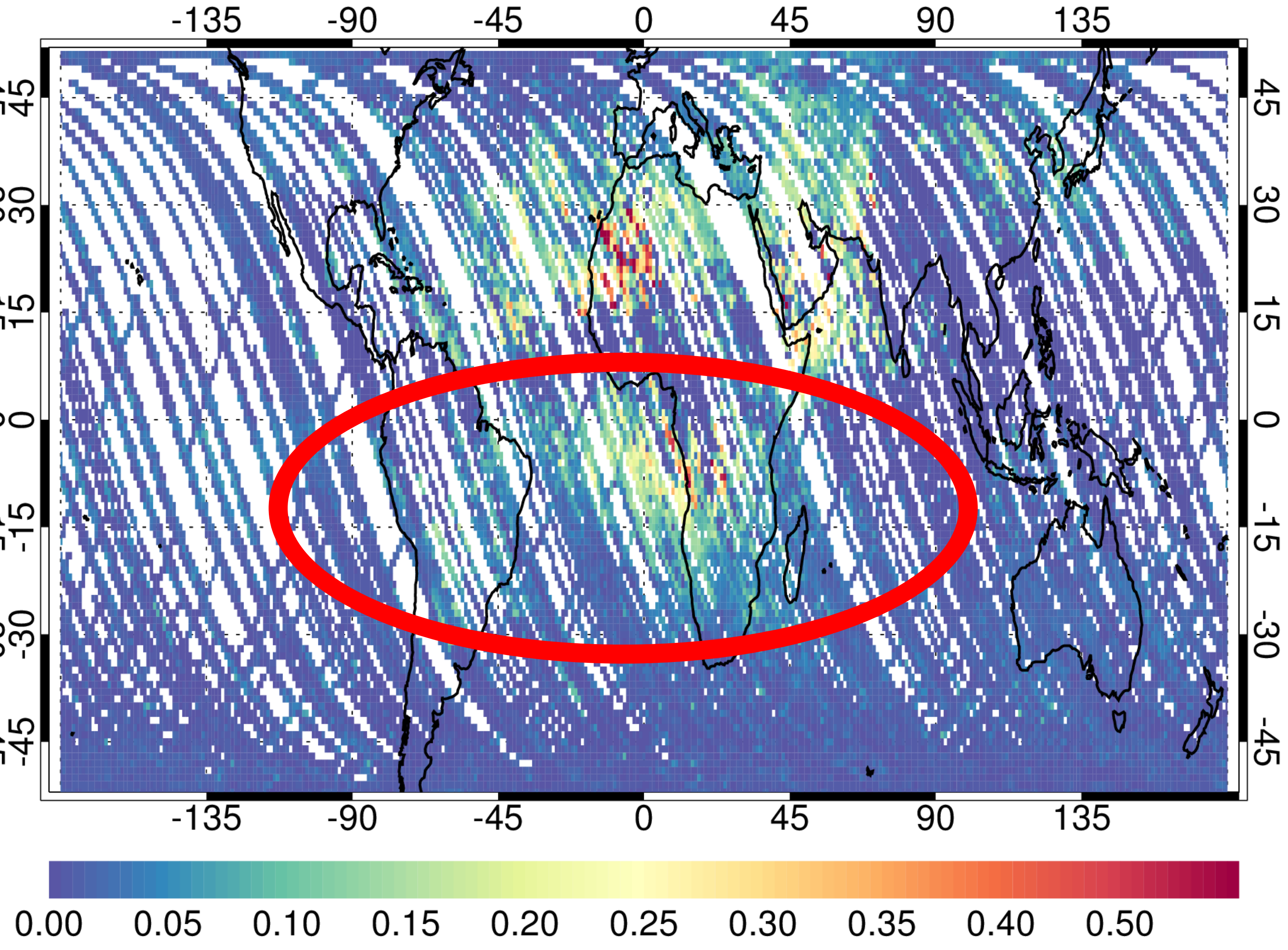
CATS:
1064 nm AOD



GEOS Background:
1064 nm AOD

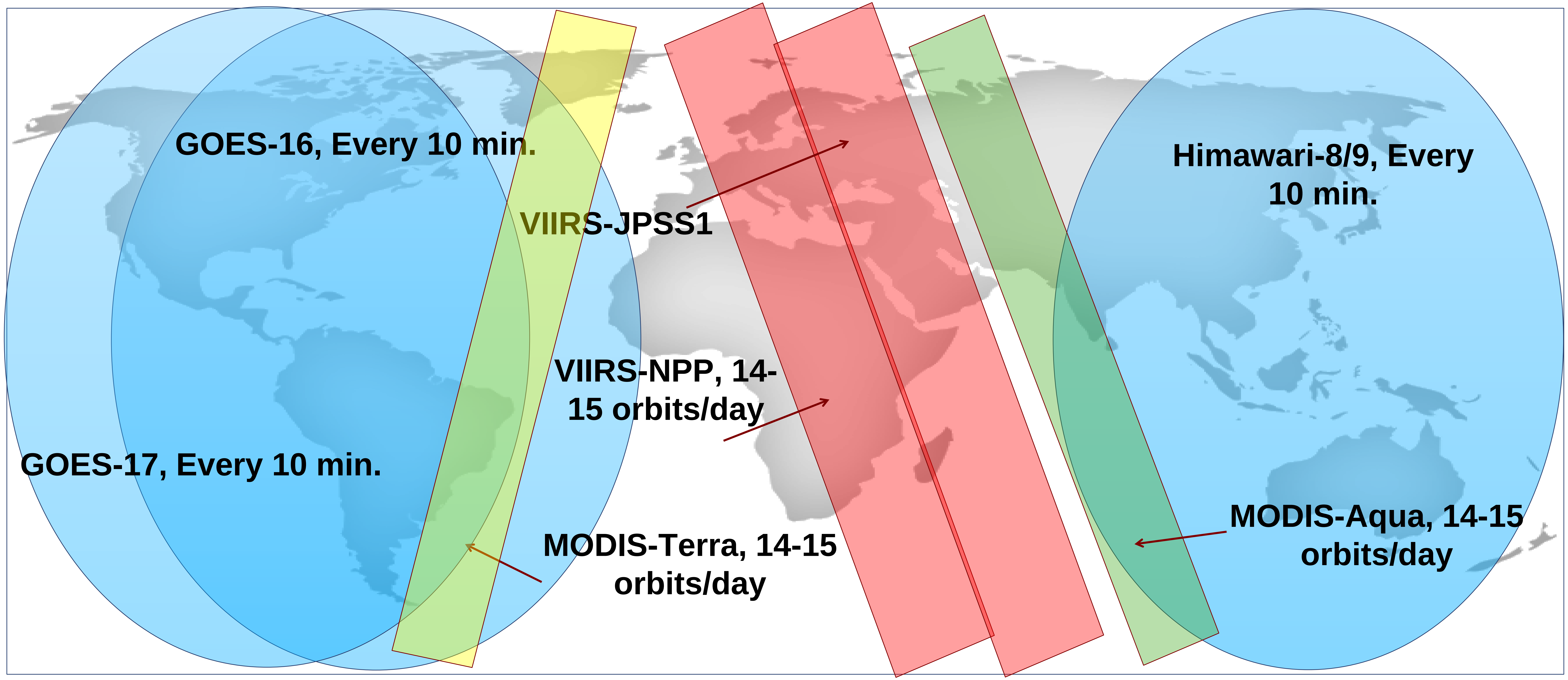


CATS/GEOS Retrieval:
1064 nm AOD



Observations from CATS enhance the AOD over central Africa and South America during the August 2016 biomass burning season

Dark Target Combined LEO & GEO



- *Dark Target Algorithm is implemented on all 6 sensors*
- *Aerosol product is created for the 6 sensors for one month*
- *Data integration and validation is on-going*

Dark Target (DT) ABI Aerosol Retrievals

Algorithm is adapted from MODIS-DT and VIIRS-DT

- Uses wavelengths in VIR, NIR, and SWIR for aerosol retrieval and TIR for cloud masking
- Accounts for wavelength shifts and gas absorption
- Retrieves in NxN boxes of native resolution pixels to get ~10 km resolution products
- Like MODIS-DT retrieves:
  - AOD at 550 nm
  - Spectral AOD
  - Diagnositics and QA flags

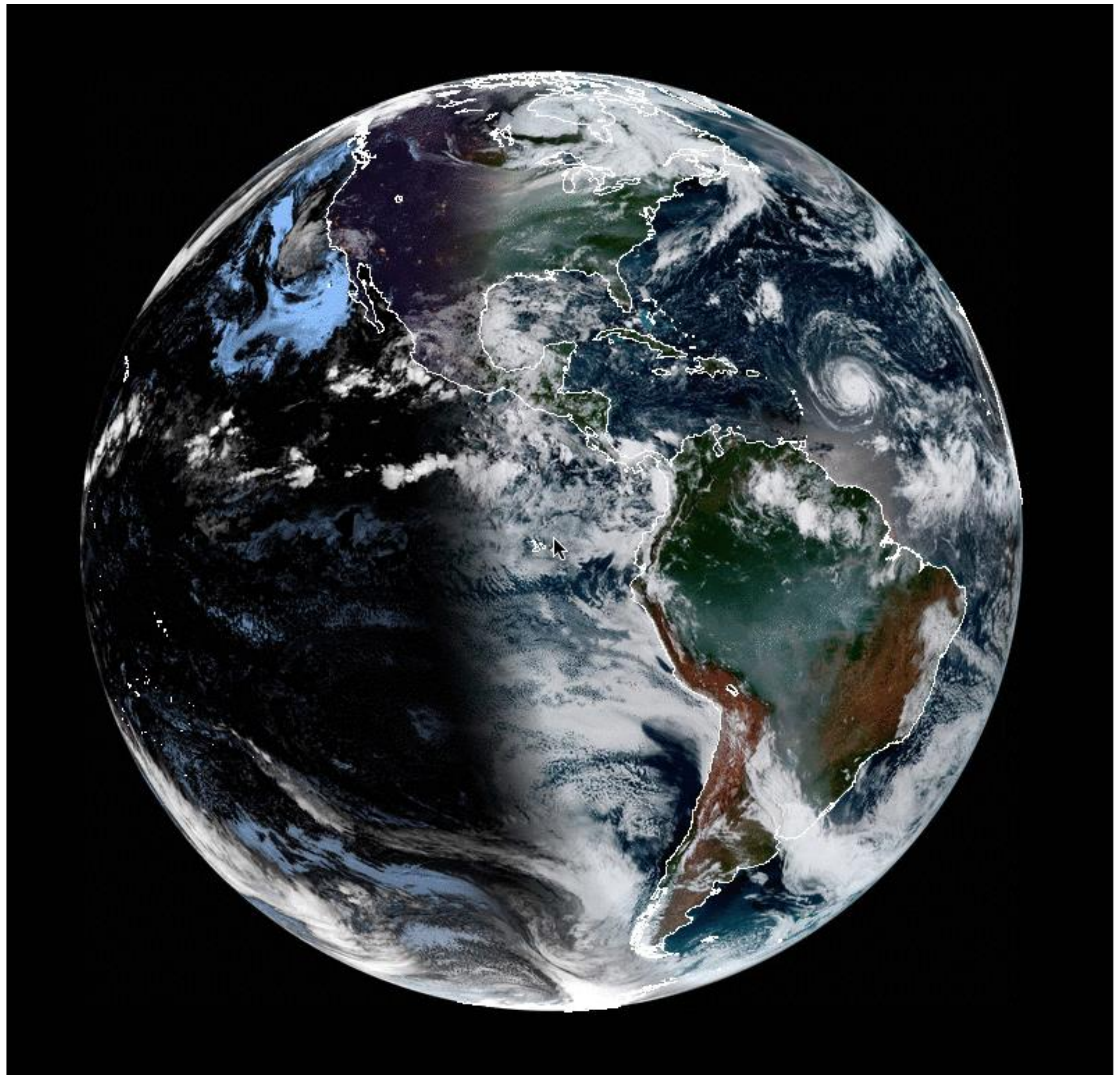
Sensor wavelengths/native pixel resolution

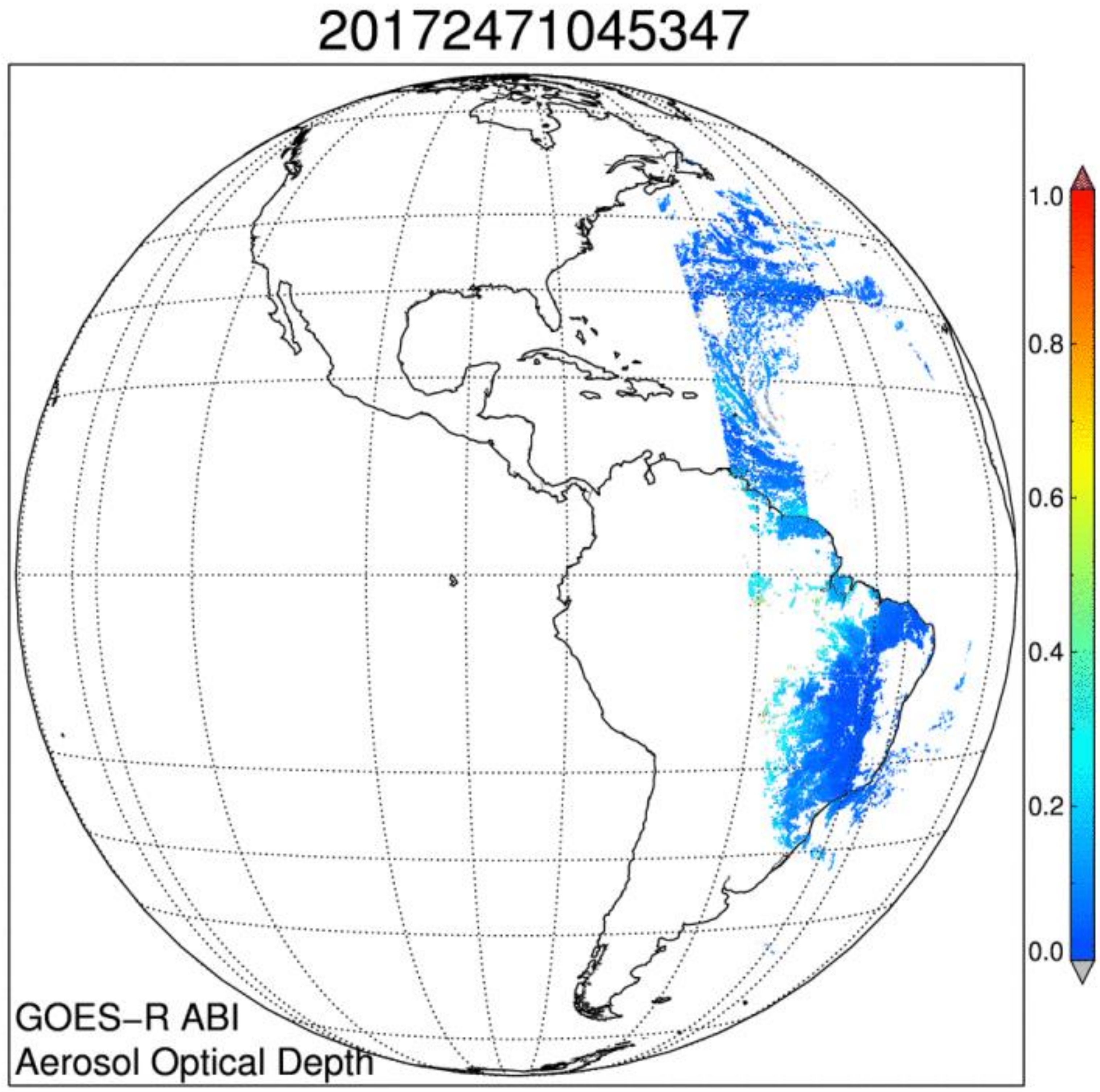
	MODIS	VIIRS	ABI
Blue	0.47/0.5	0.49/0.75	0.47/1.0
Green	0.55/0.5	0.55/0.75	
Red	0.66/0.25	0.67/0.75	0.64/0.5
NIR	0.86/0.25	0.86/0.75	0.86/1.0
NIR	1.24/0.5	1.24/0.75	
Cirrus	1.38/0.5	1.38/0.75	1.38/2.0
SWIR	1.61/0.5	1.61/0.75	1.61/1.0
SWIR	2.11/0.5	2.25/0.75	2.25/2.0

Dark Target (DT) ABI Aerosol Retrievals

ABI-DT Product very useful for GEOS assimilation

- Provides "cloud-cleared" data
- Variables names are the same as MODIS
- Product files are NetCDF format
- Currently processing ABI on GOES-16 and AHI on Himawari-8, plan is to eventually process entire 5+ years of AHI and 2+ years of ABI
- Observations of diurnal aerosol!





Additional Data Screening for Data Assimilation

Cloud Screening

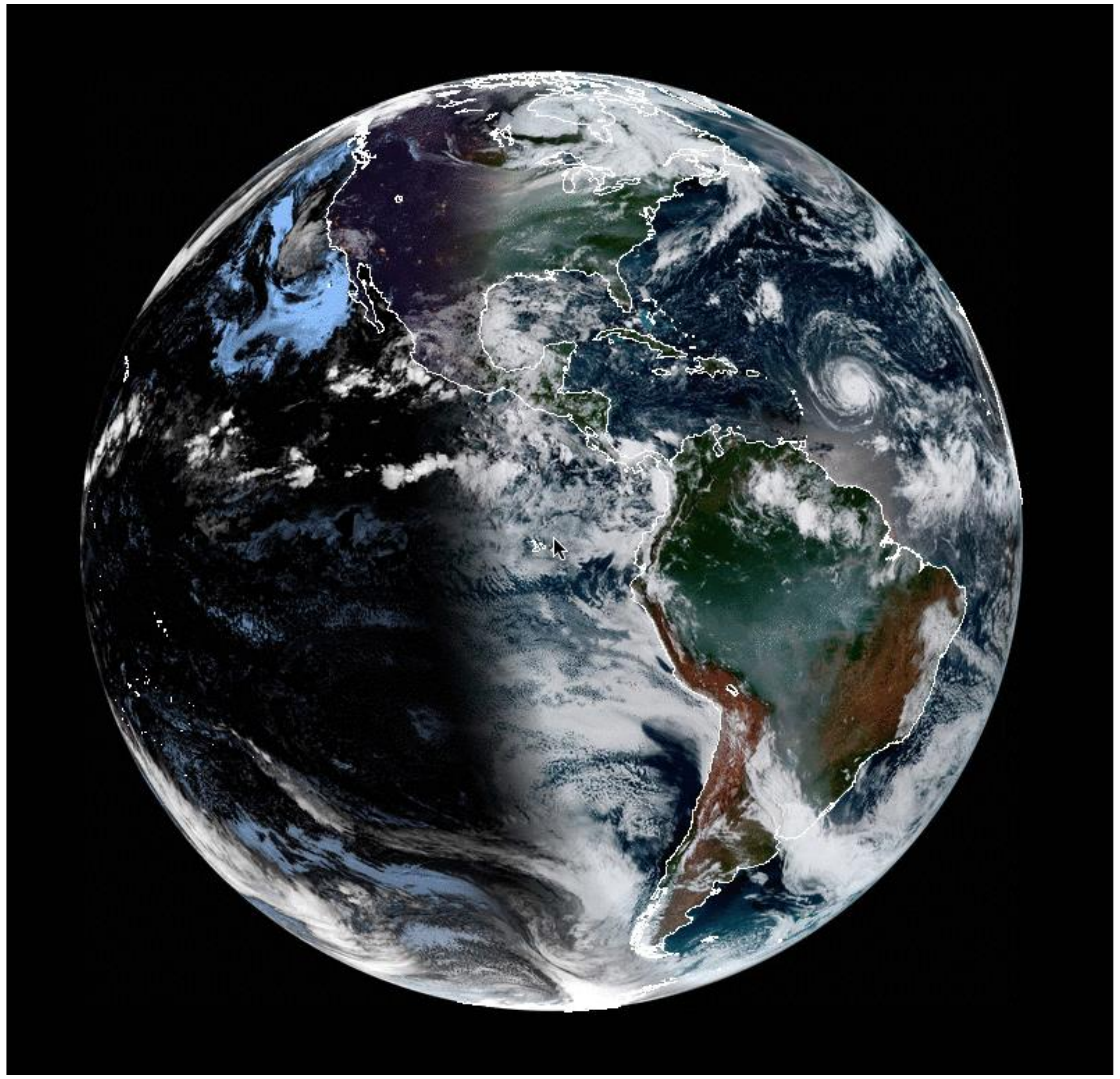
- Cloud fraction <0.7 for AOD>2
- Cloud fraction <0.25 for AOD<2

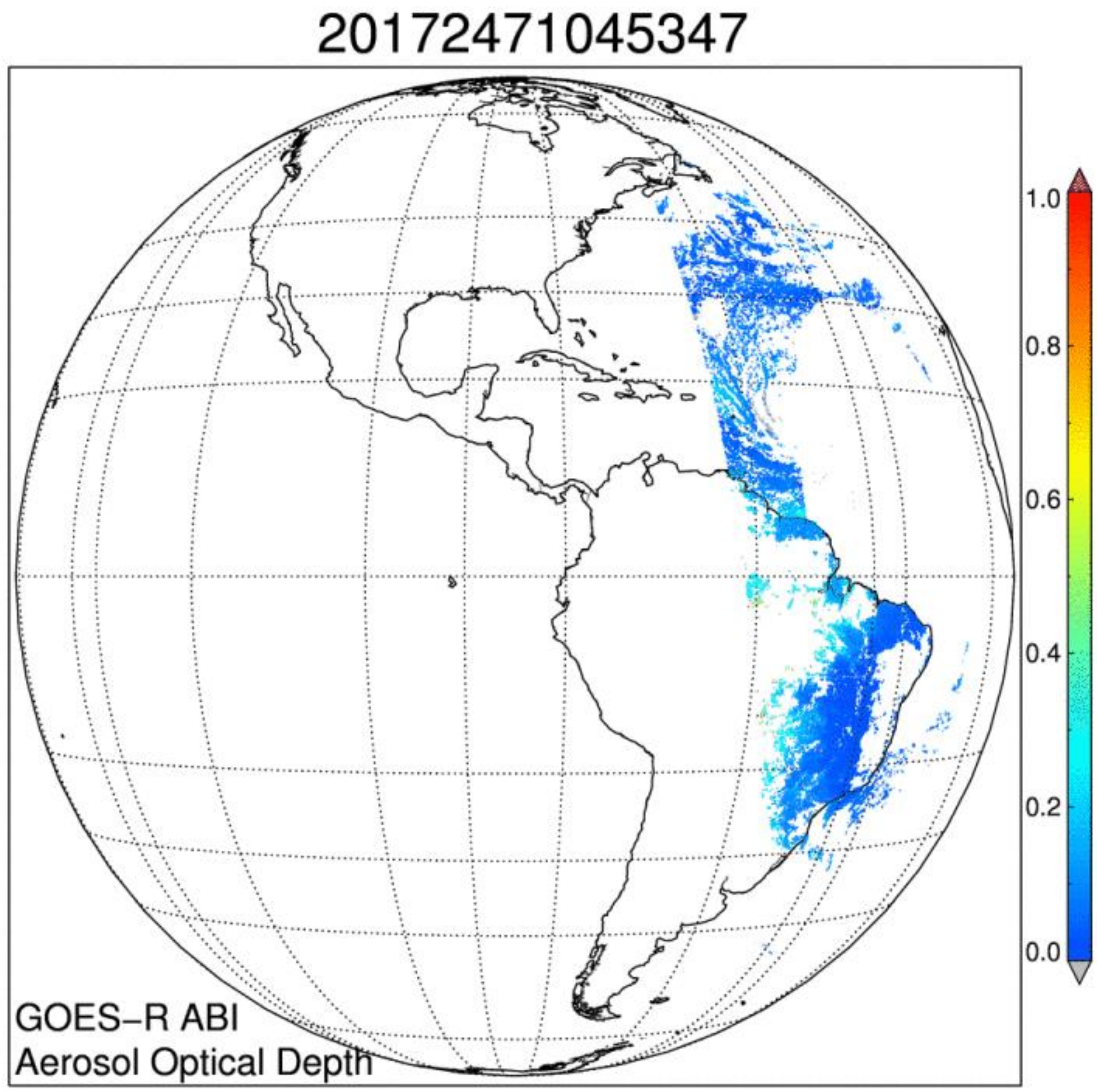
Geometry

- SZA < 60
- Ocean: Glint Angle > 70, Scattering Angle < 170

QA

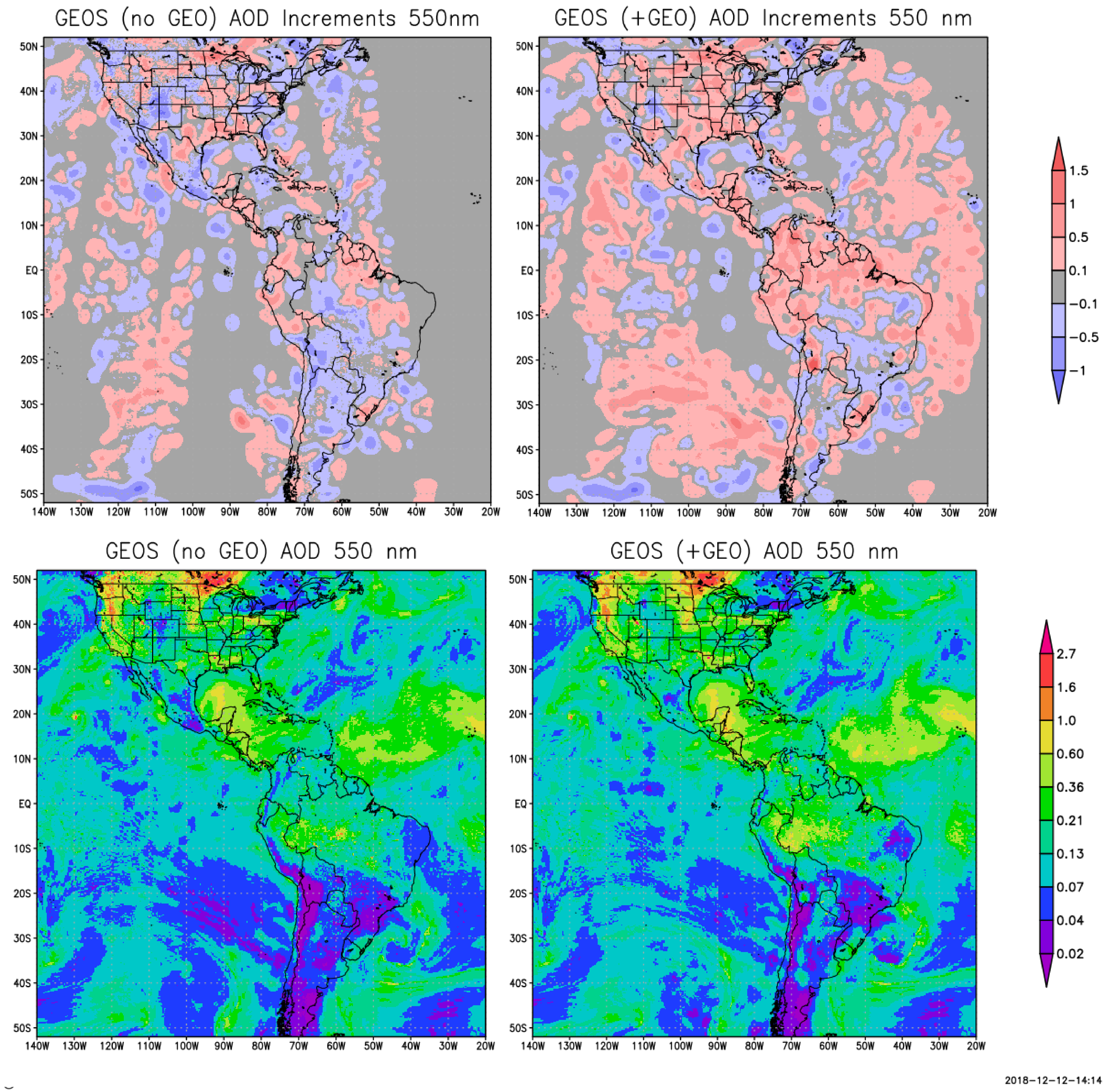
- Land: BEST quality flag
- Ocean: Non-Zero quality flag





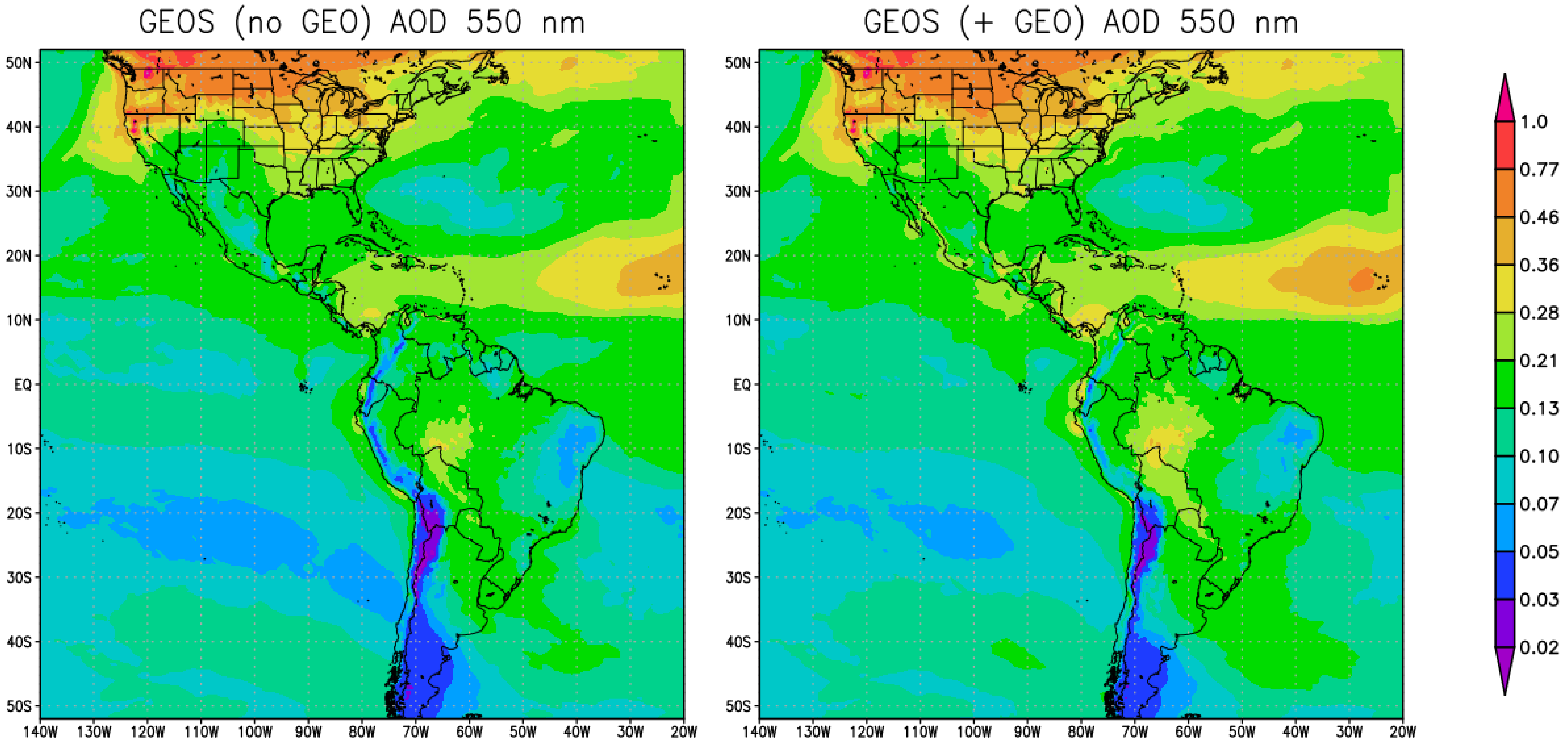
Impact of ABI on AOD Analysis

18Z August 10, 2018



Impact of ABI on AOD Analysis

Monthly Mean August, 2018



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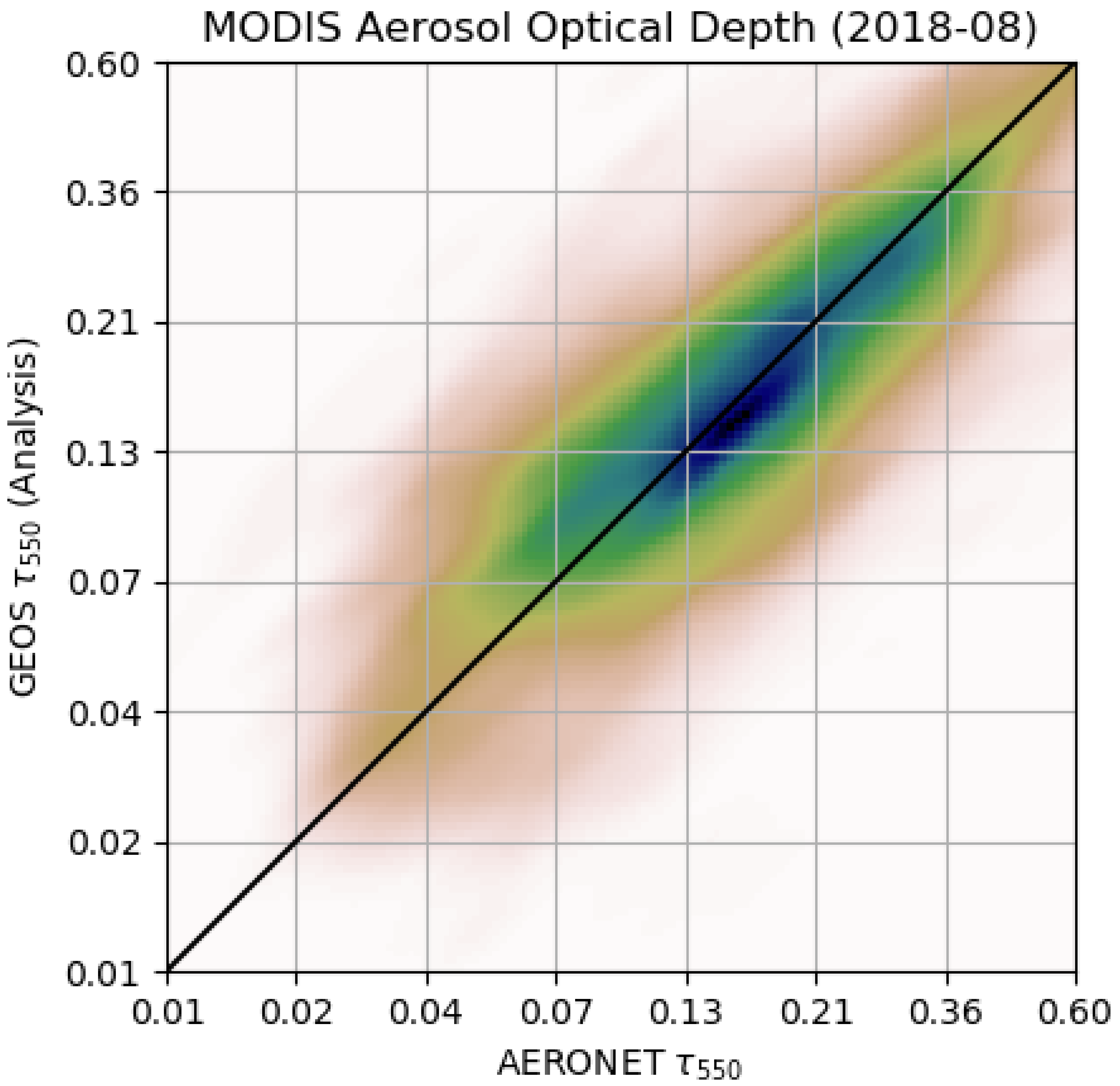
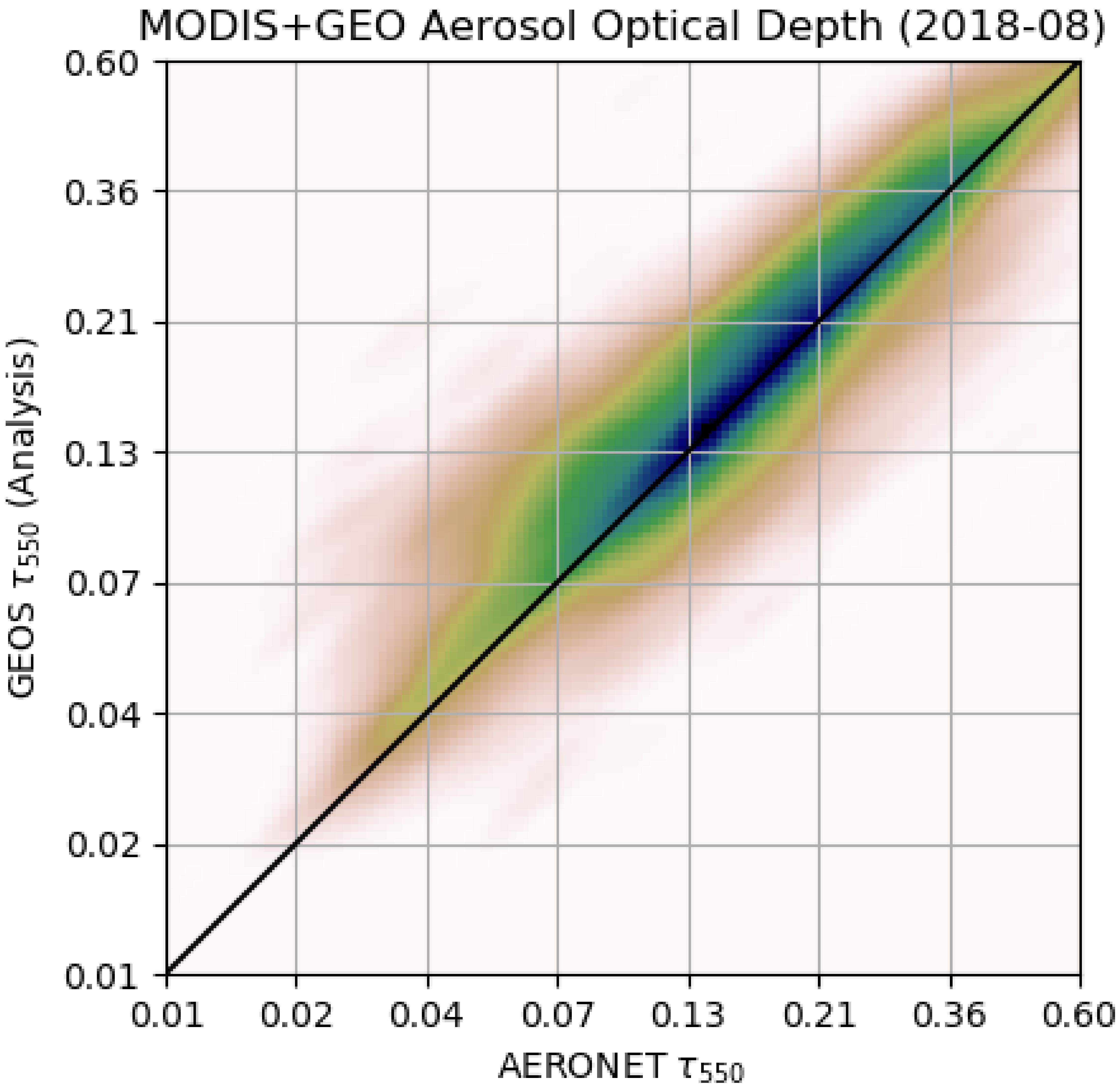
AERONET Verification: August 2018





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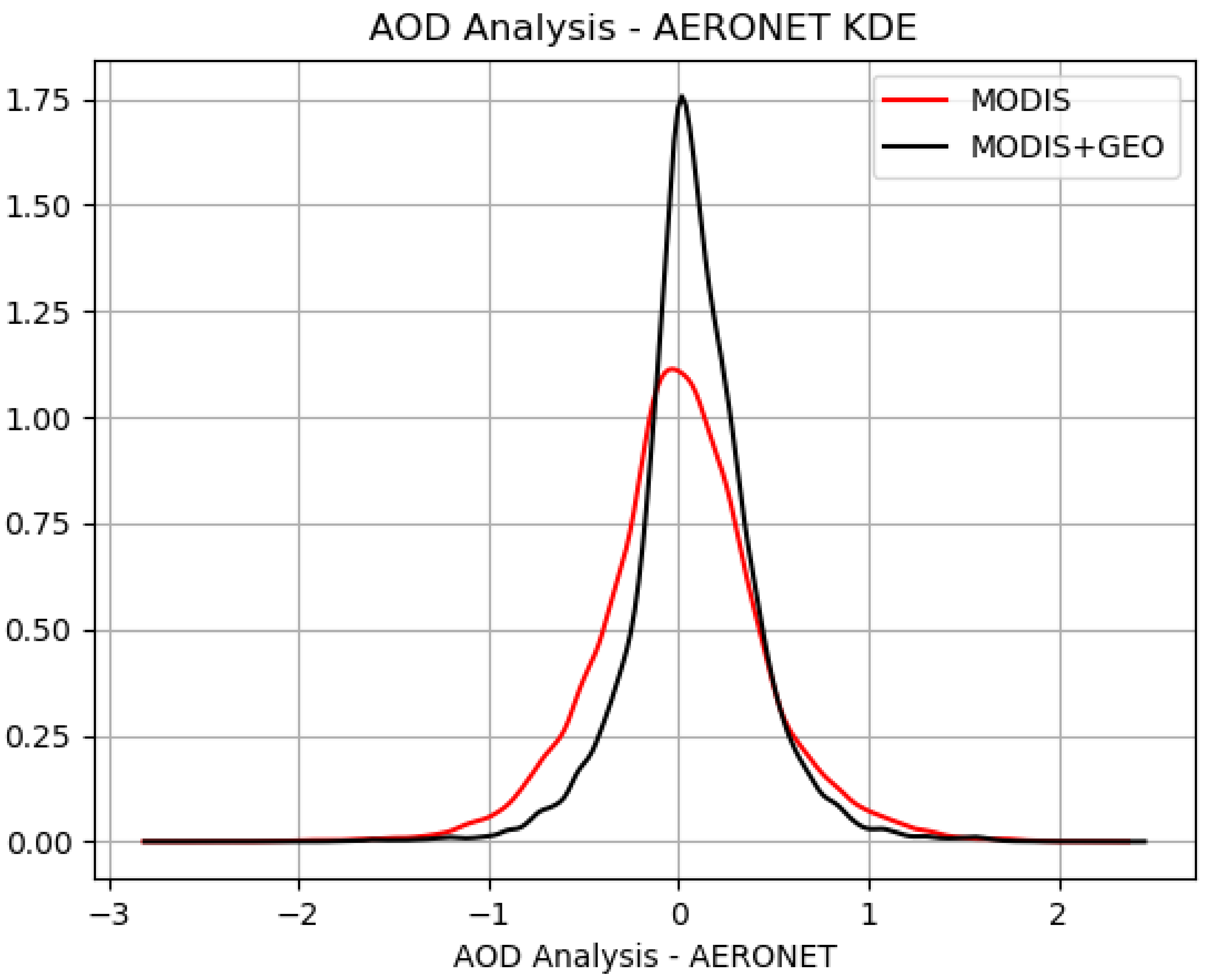
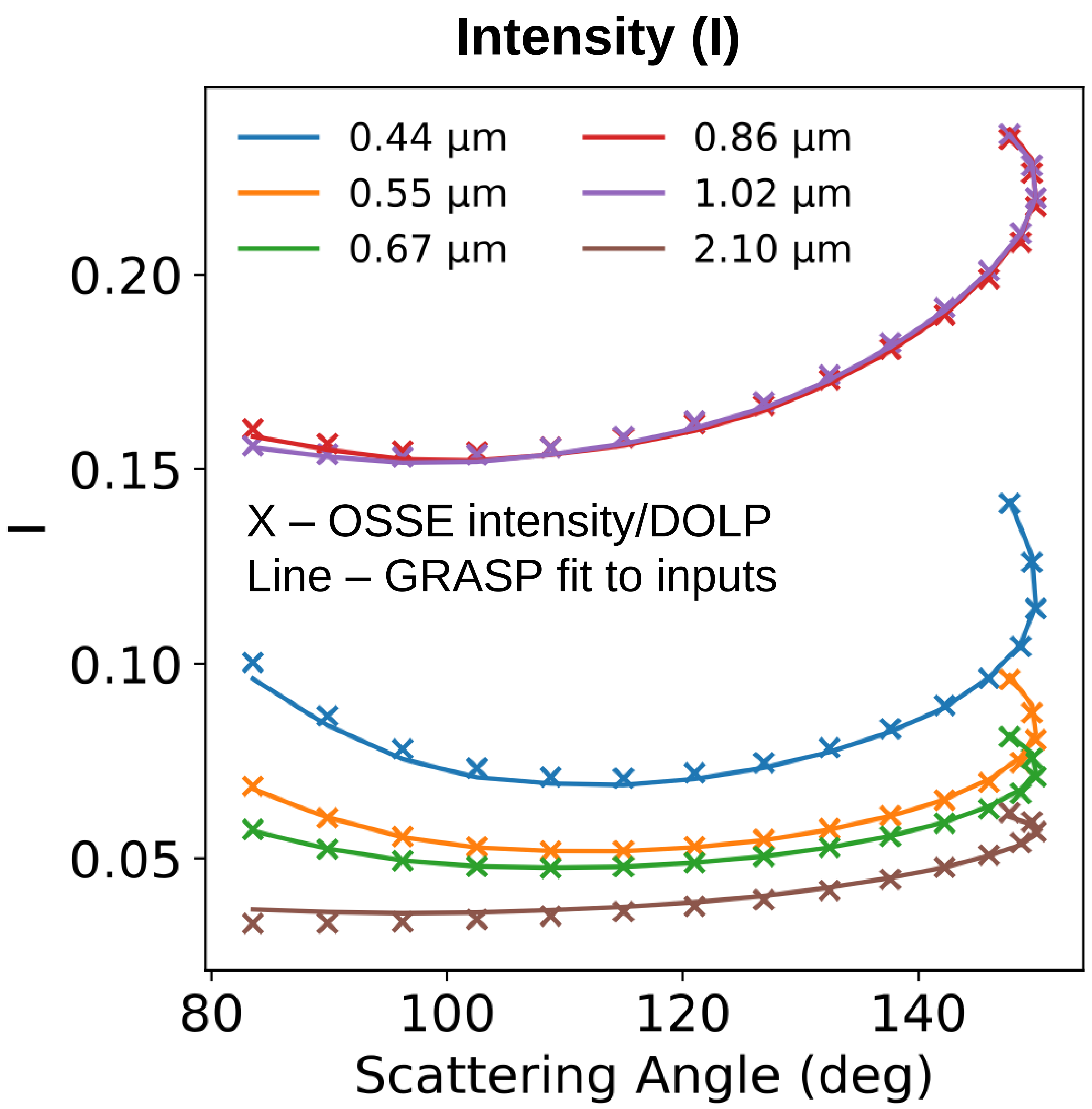
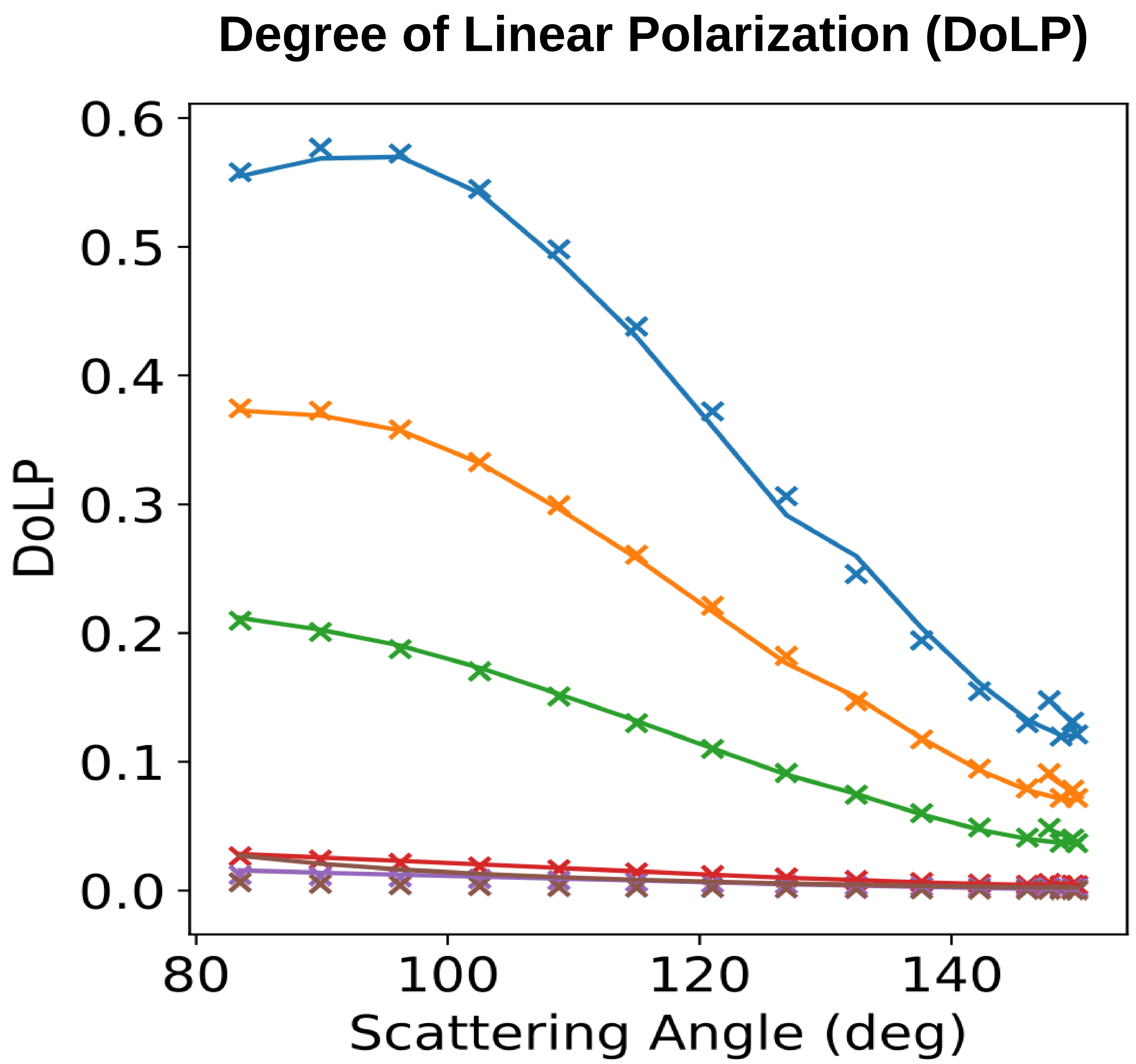


OSSE Work to Support NASA Decadal Survey Study





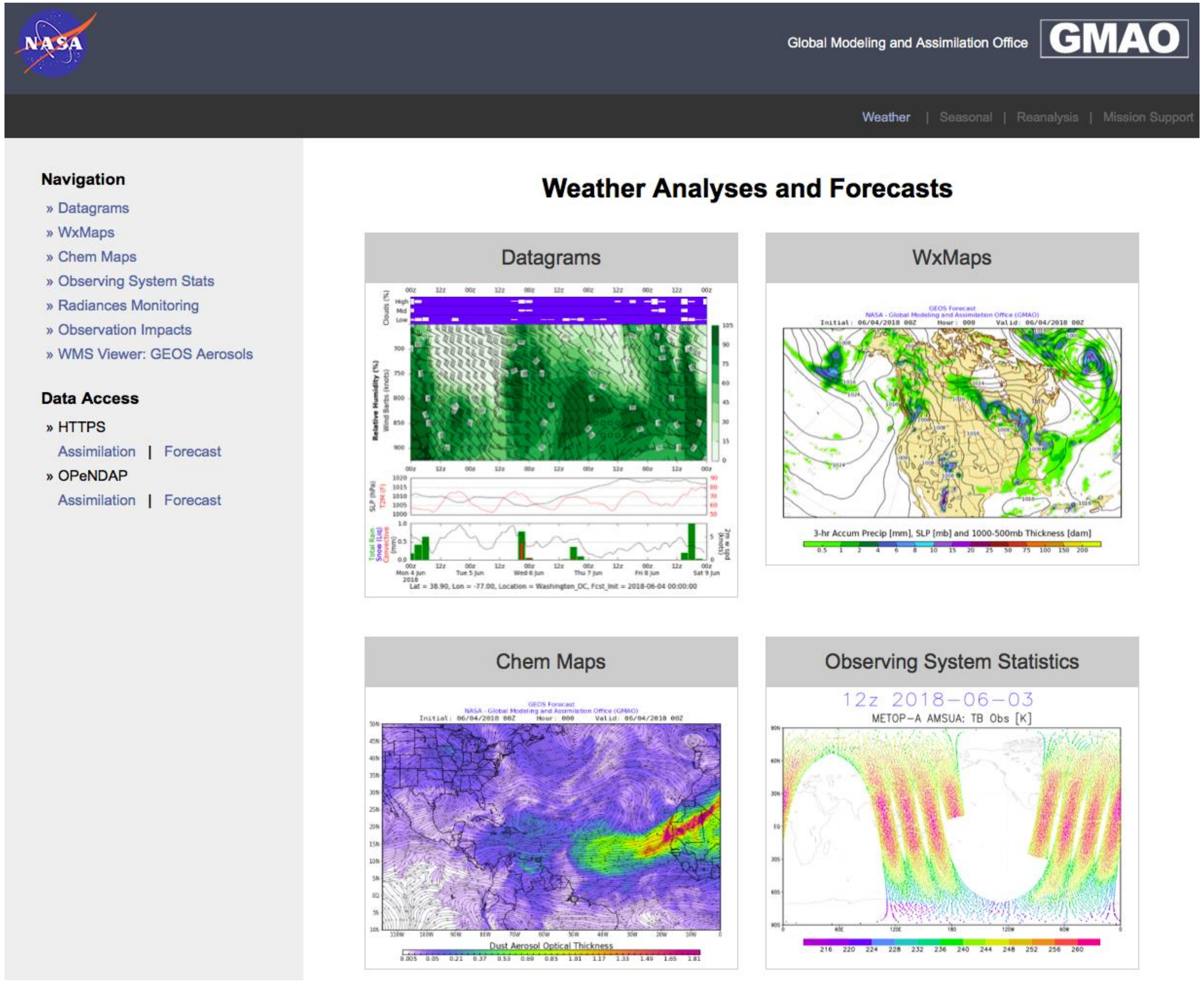
- *GEOS global 6 km Nature Run (G5NR) provides a known ("true") atmosphere and aerosol state*
- *VLIDORT is run with G5NR inputs to generate synthetic observations in order to explore observation and retrieval parameter space*
- *The example shown here is a simulation of the intensity and degree of linear polarization for a HARP-like multi-angle/multi-spectral aerosol polarimeter, and a GRASP retrieval fit to the "observations"*
- *This is groundwork toward performing architecture studies supporting the NASA Earth Science Decadal Mission study for future aerosol space missions*

Field Campaign Support

Field Campaign Support

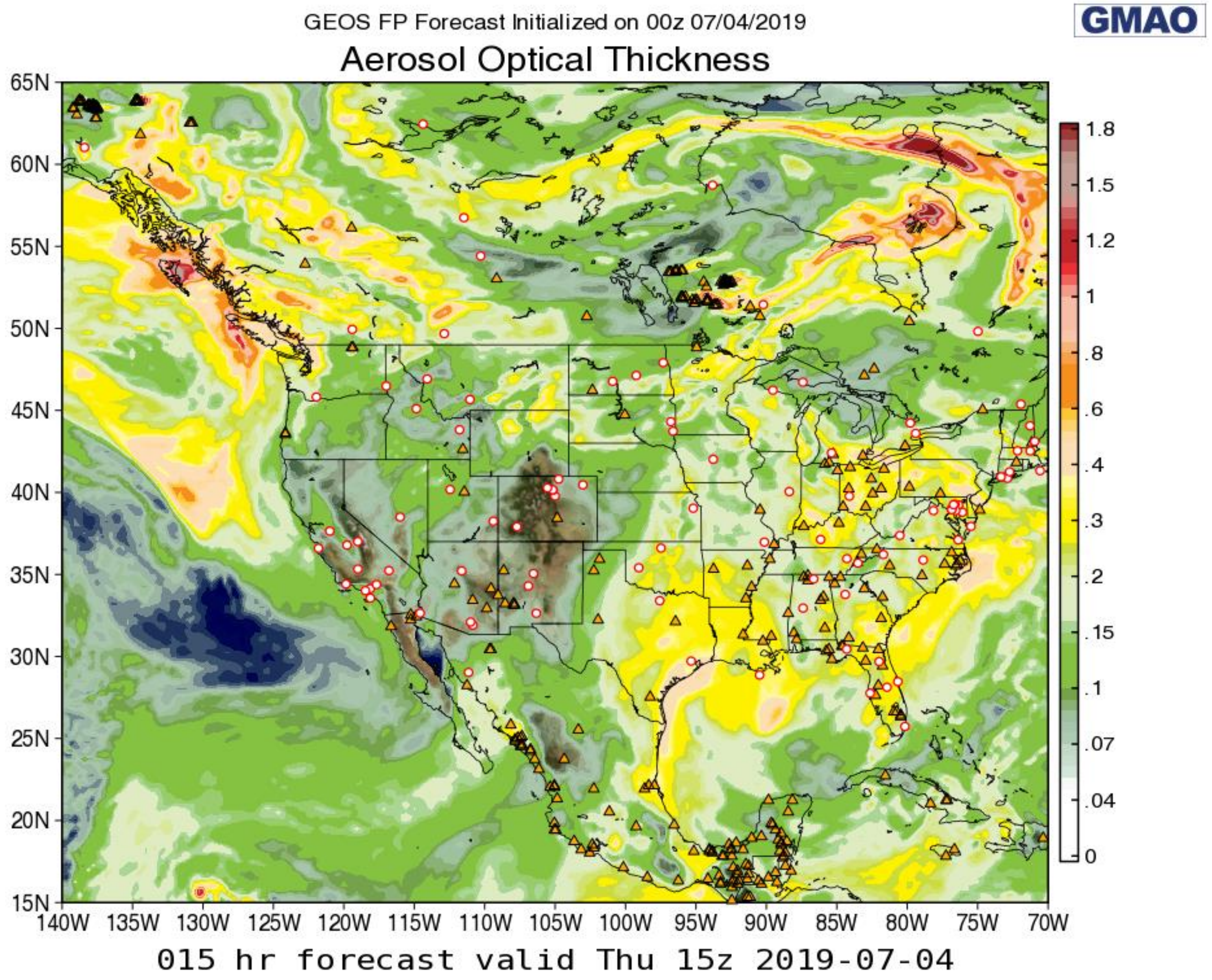
Global chemical forecasts

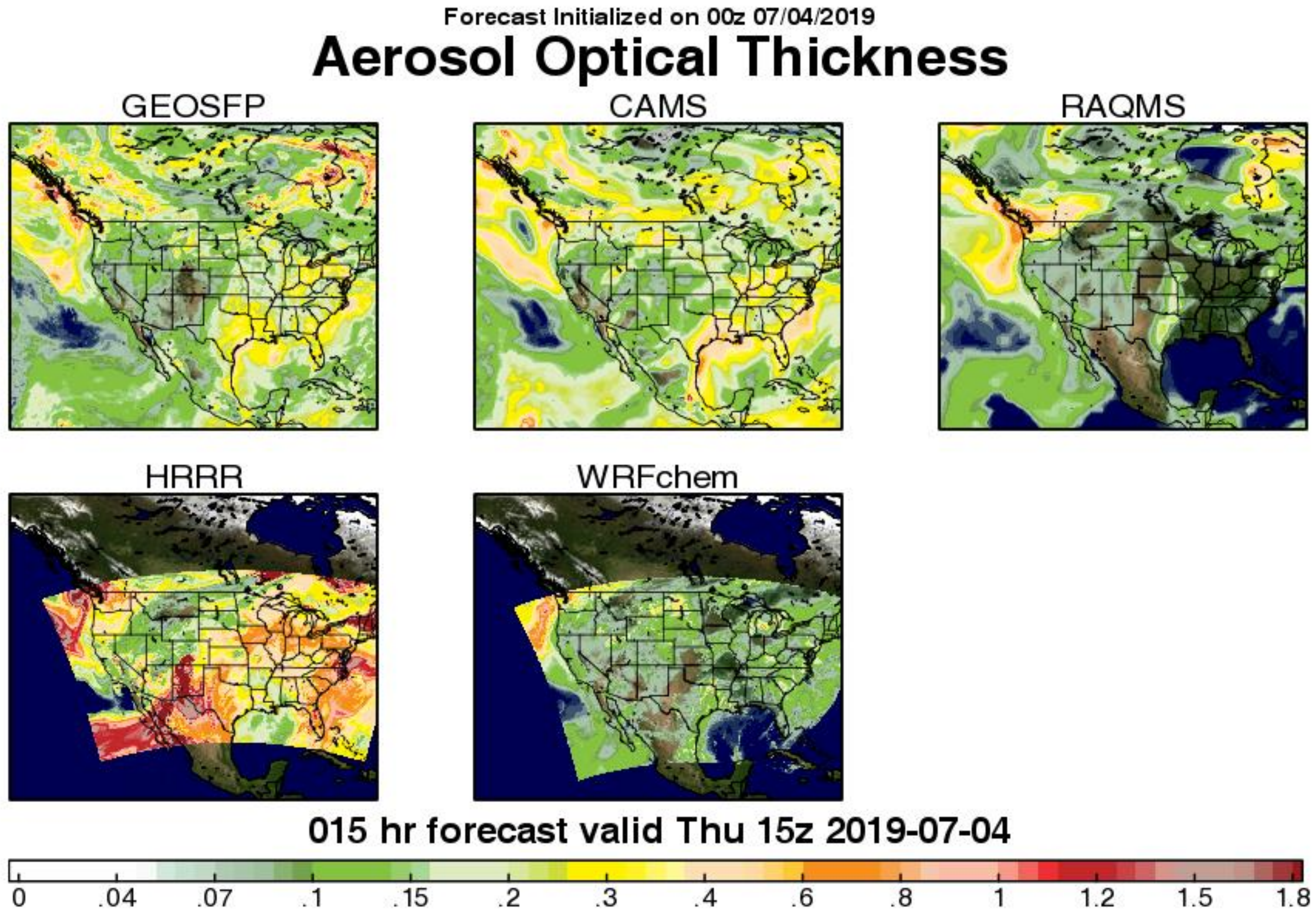
- O_3, aerosols, CO, CO_2, SO_2
- Constituents transported on-line, radiatively interactive
- Nominally 12.5 km
- 10-day forecast (0z)
  5-day forecast (12z)



https://fluid.nccs.nasa.gov/weather

Field Campaign Support

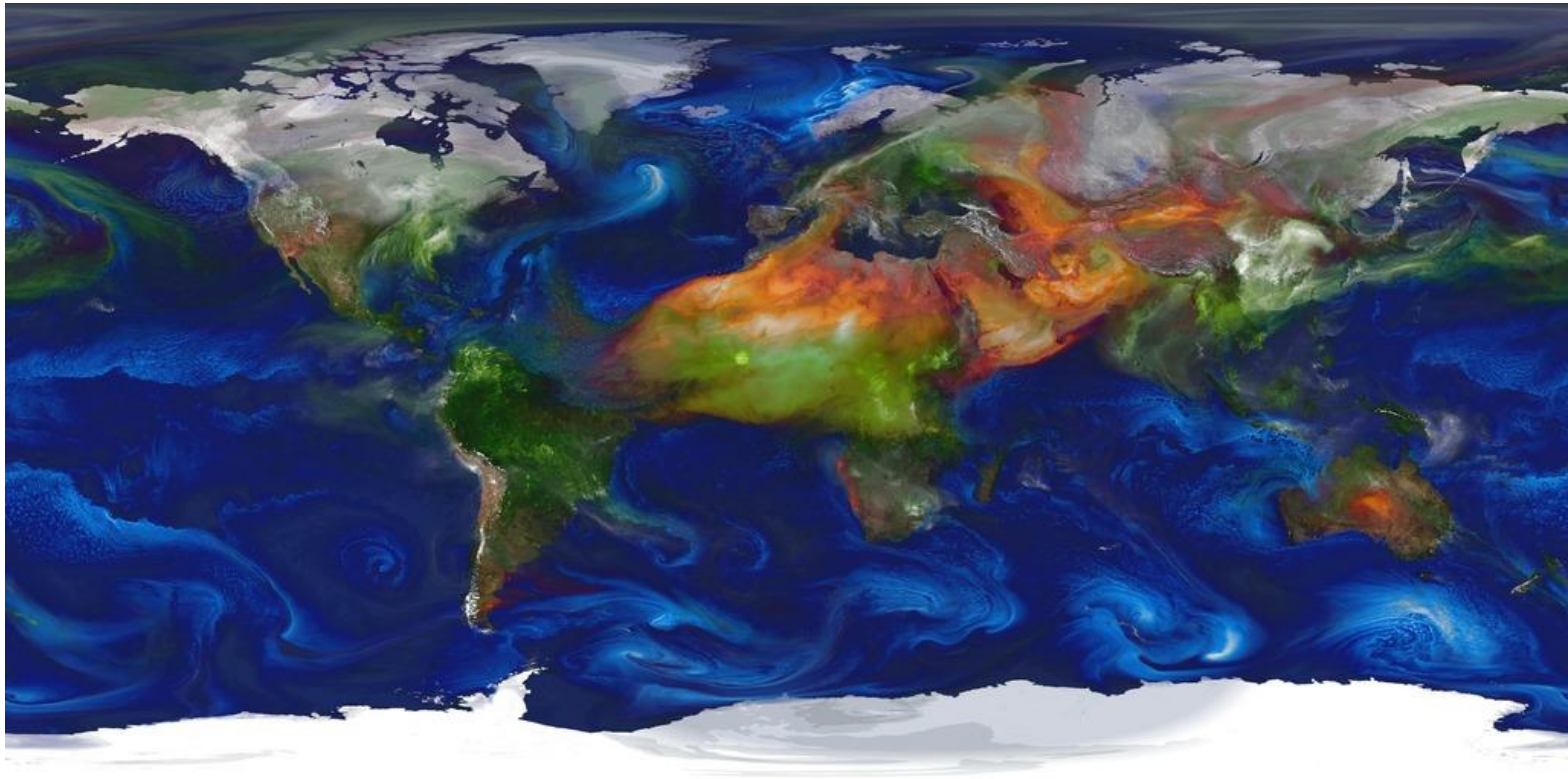




https://fluid.nccs.nasa.gov/weather

Summary

- *New scale-aware convection includes coupling between aerosols and cloud droplet size and rainfall*
- *Significant aerosol updates coming in next FP (prognostic SOA, NDVI based Dust, Brown Carbon)*
- *Adopting DT aerosol retrievals based on MODIS-heritage algorithms from Rob Levy's group*
  - *AERONET validation shows clear benefits of assimilating ABI aerosol*
- *Aerosol analysis migrating to EnKF based system*
  - *New observables: multi-spectral AOD, attenuated backscatter*



Backup/Redundant Slides

Aerosol Analysis: Splitting

2D AOD Analysis

- Observable is 550 nm AOD
  - Constraints column average optics
  - Cannot constrain speciation of vertical distribution
- Analysis in observation space:

$$\tau^a \equiv Hq^a = H\left(q^b + \delta q^a\right)$$
$$= \tau^b + \delta\tau^a$$

Going from 2D to 3D

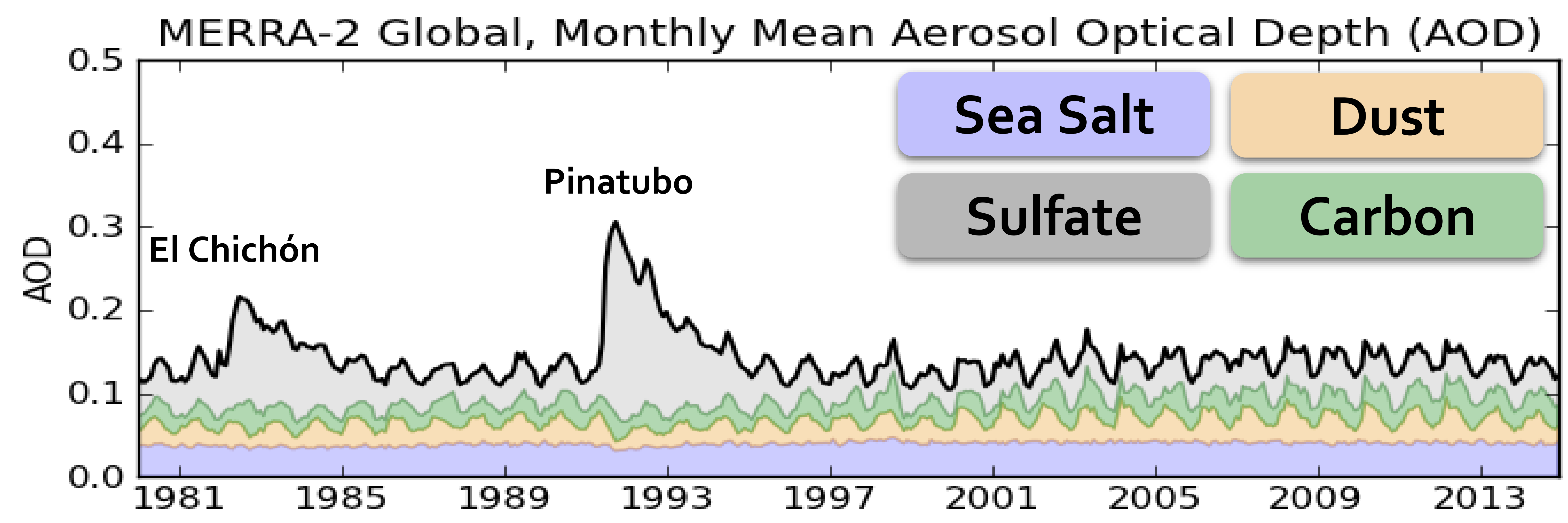
- Using ensemble perturbations:

$$\delta q^a = XY^T\left(YY^T\right)^{-1}\delta\tau^a$$

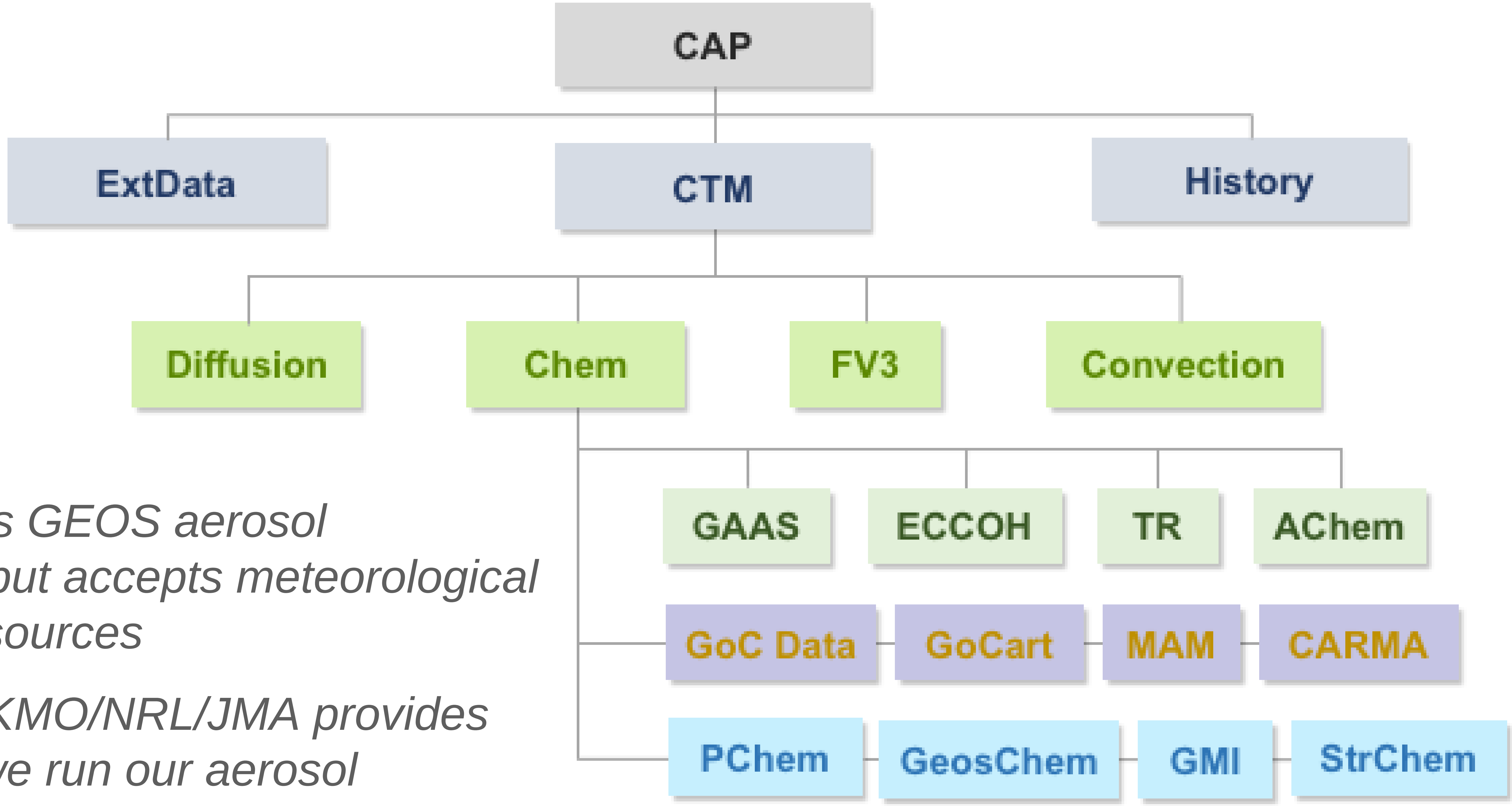
- Current GEOS uses Local Displacement Ensembles (LDE) in 1D

MERRA-2 Global Mean AOD Analysis: 1980 - Onward

- Unique amongst its peers, the MERRA-2 reanalysis now includes an aerosol reanalysis for the modern satellite era (1980 – onward).
- Aerosols are ***coupled*** to the meteorological reanalysis (both radiatively and through emissions/loss processes).



GEOS-CTM Framework

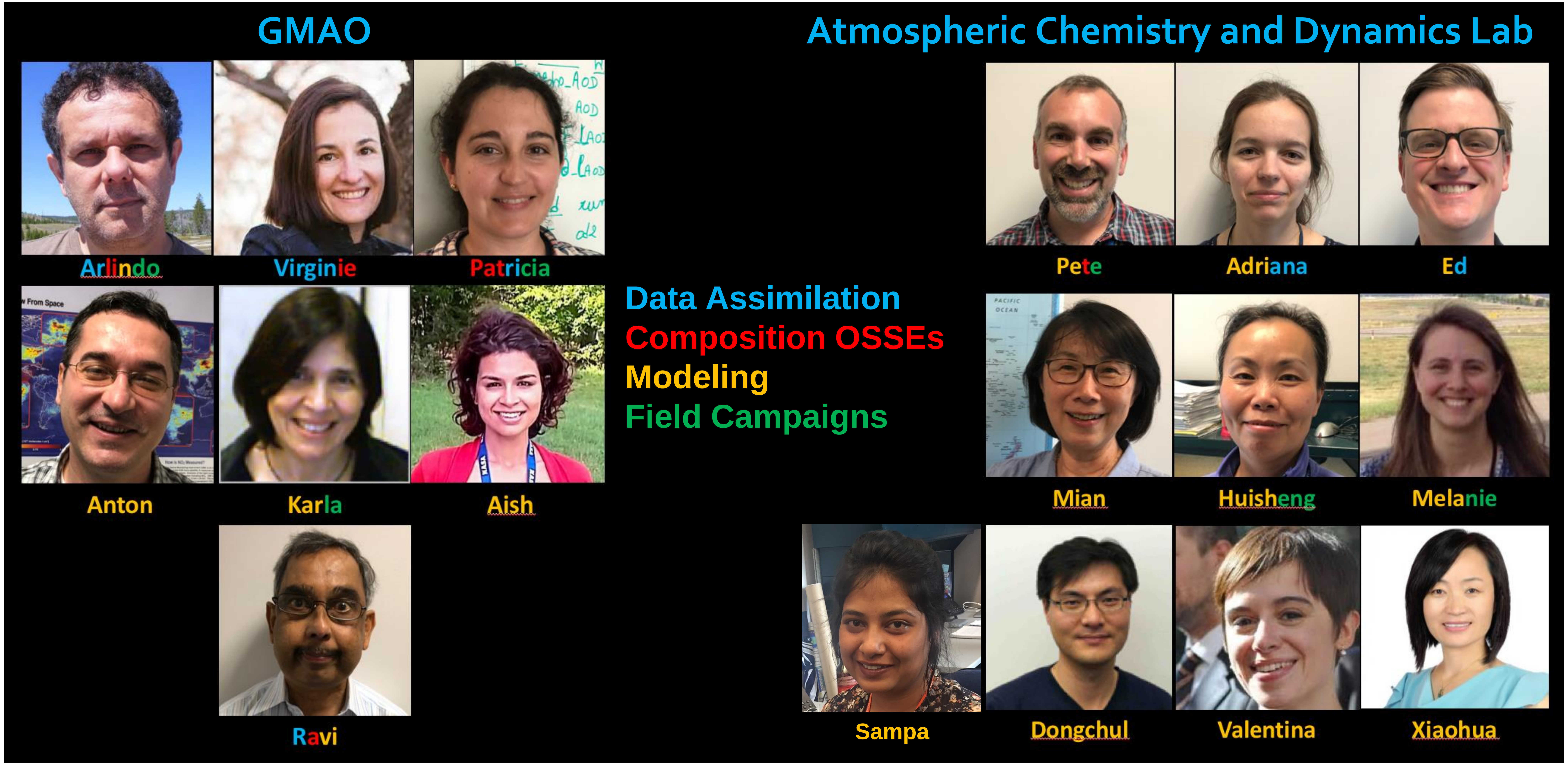


GEOS-CTM exercises GEOS aerosol (chemistry) modules but accepts meteorological inputs from arbitrary sources

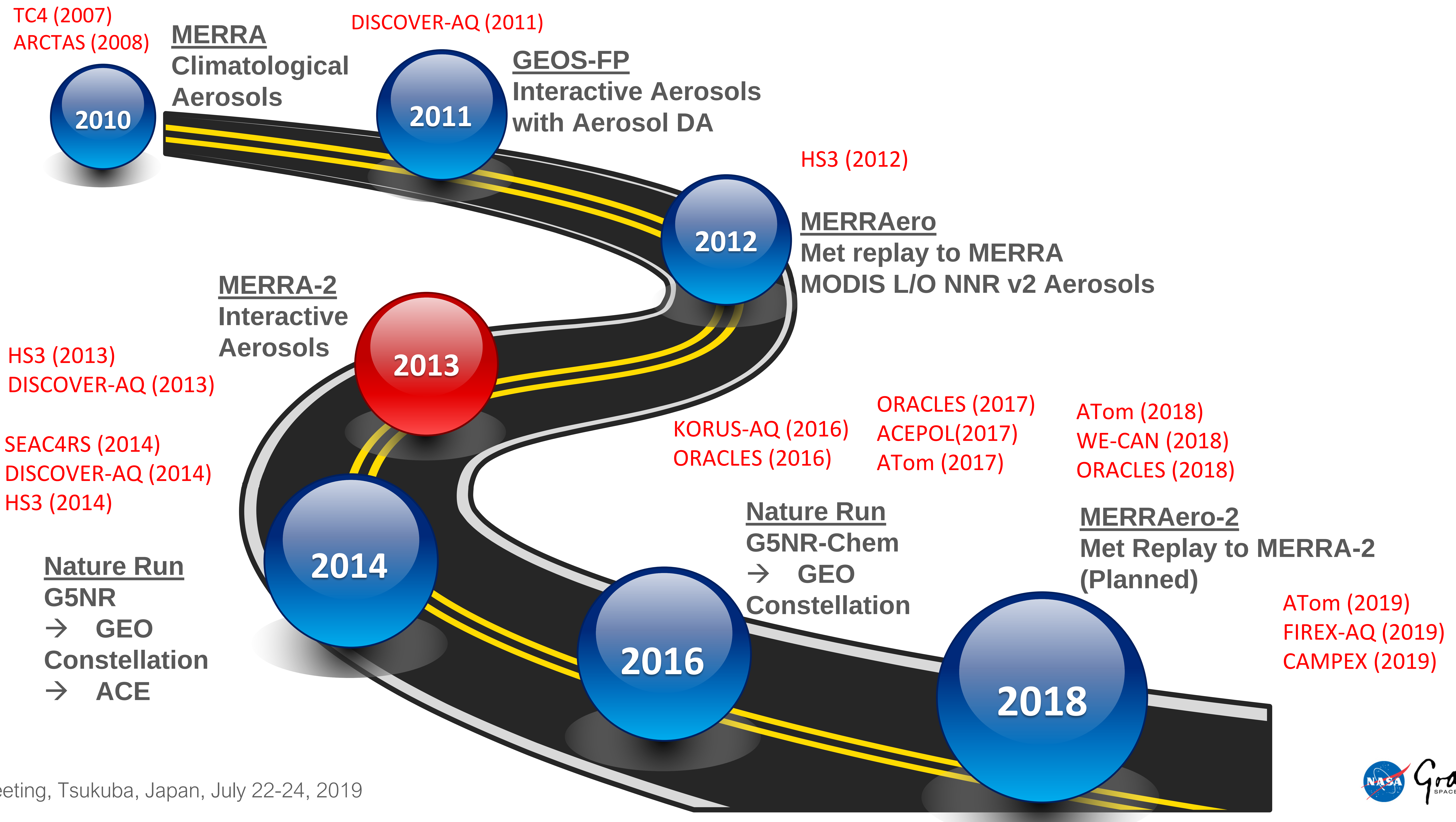
Example: ECMWF/UKMO/NRL/JMA provides its meteorology and we run our aerosol packages we can quantify simulation errors resulting from meteorology

Alternative: Provide your aerosol algorithms and we run against GEOS meteorology

The Goddard Aerosol Team



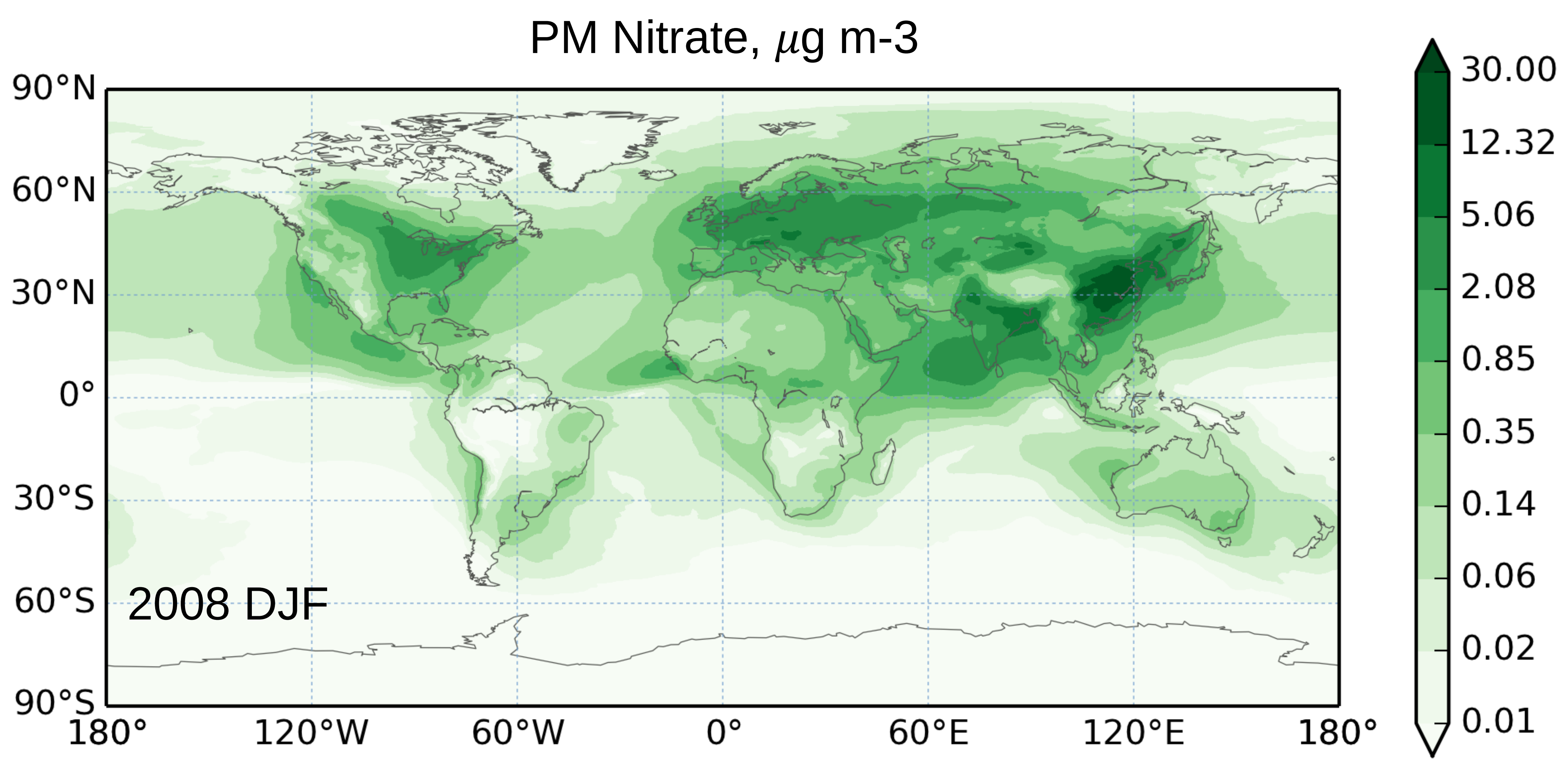
Aerosol Milestones in GEOS

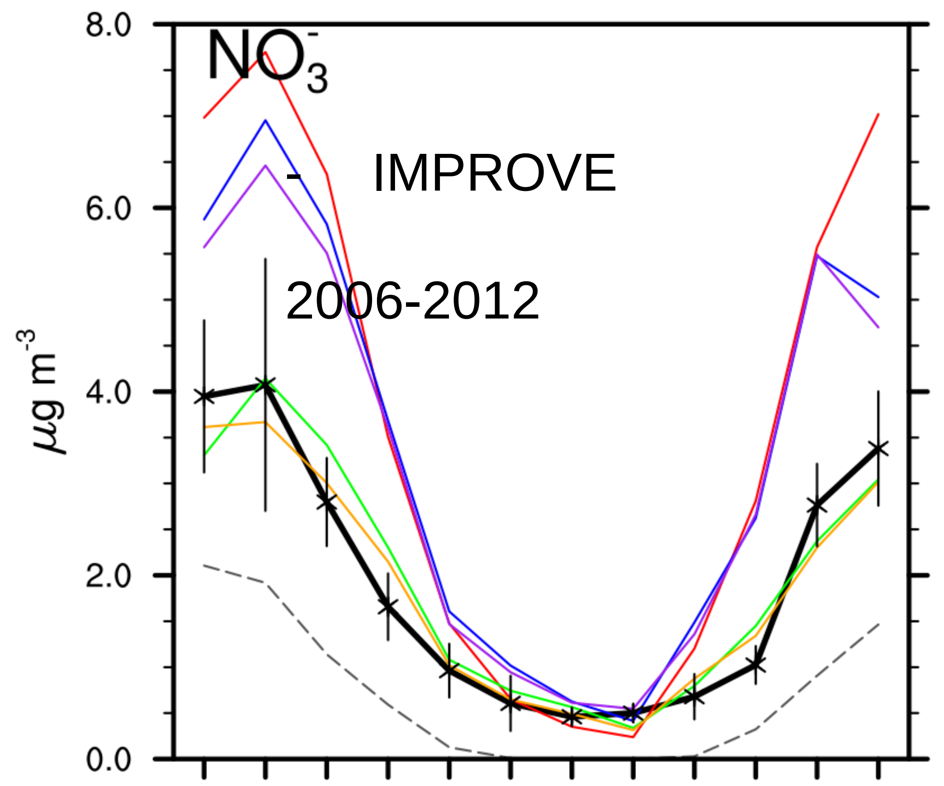


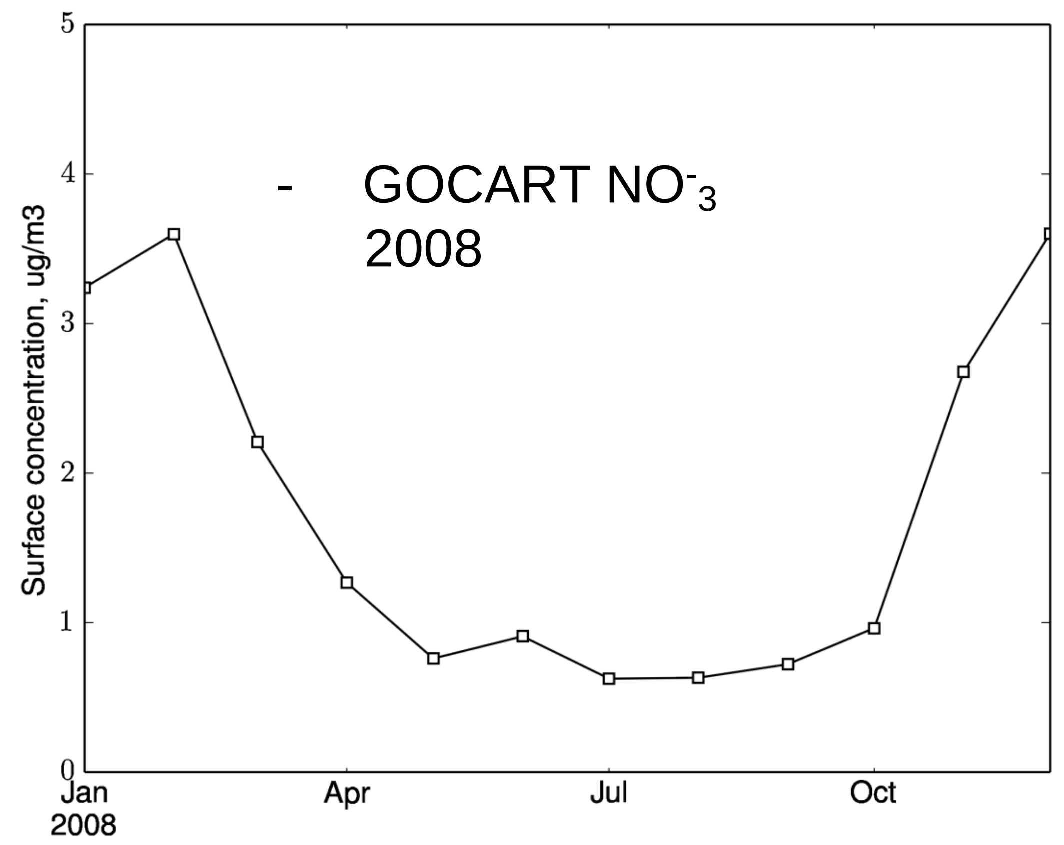
Aerosol Model Development

Prognostic Nitrate Aerosols

- *5 tracers added (NH3, NH4, aerosol nitrate/NO3an: 0-0.5 μm, 0.5-4 μm, 4-10 μm)*
- *RPMARES aerosol thermodynamics (SO_4-NO_3-NH_4-H_2O)*
- *Heterogeneous reactions on dust and sea salt particles*
- *Nitric acid (HNO_3) is from monthly GMI output*
- *Refractive indices of NH_4NO_3 from Lacis et al. (1997)*







Measured (Paulot et al., 2016) and modeled GEOS/GOCART particulate nitrate concentrations in Bondville.

Aerosol Model Development

Prognostic Nitrate Aerosols

- *5 tracers added (NH3, NH4, aerosol nitrate/NO3an: 0-0.5 μm, 0.5-4 μm, 4-10 μm)*
- *RPMARES aerosol thermodynamics (SO_4-NO_3-NH_4-H_2O)*
- *Heterogeneous reactions on dust and sea salt particles*
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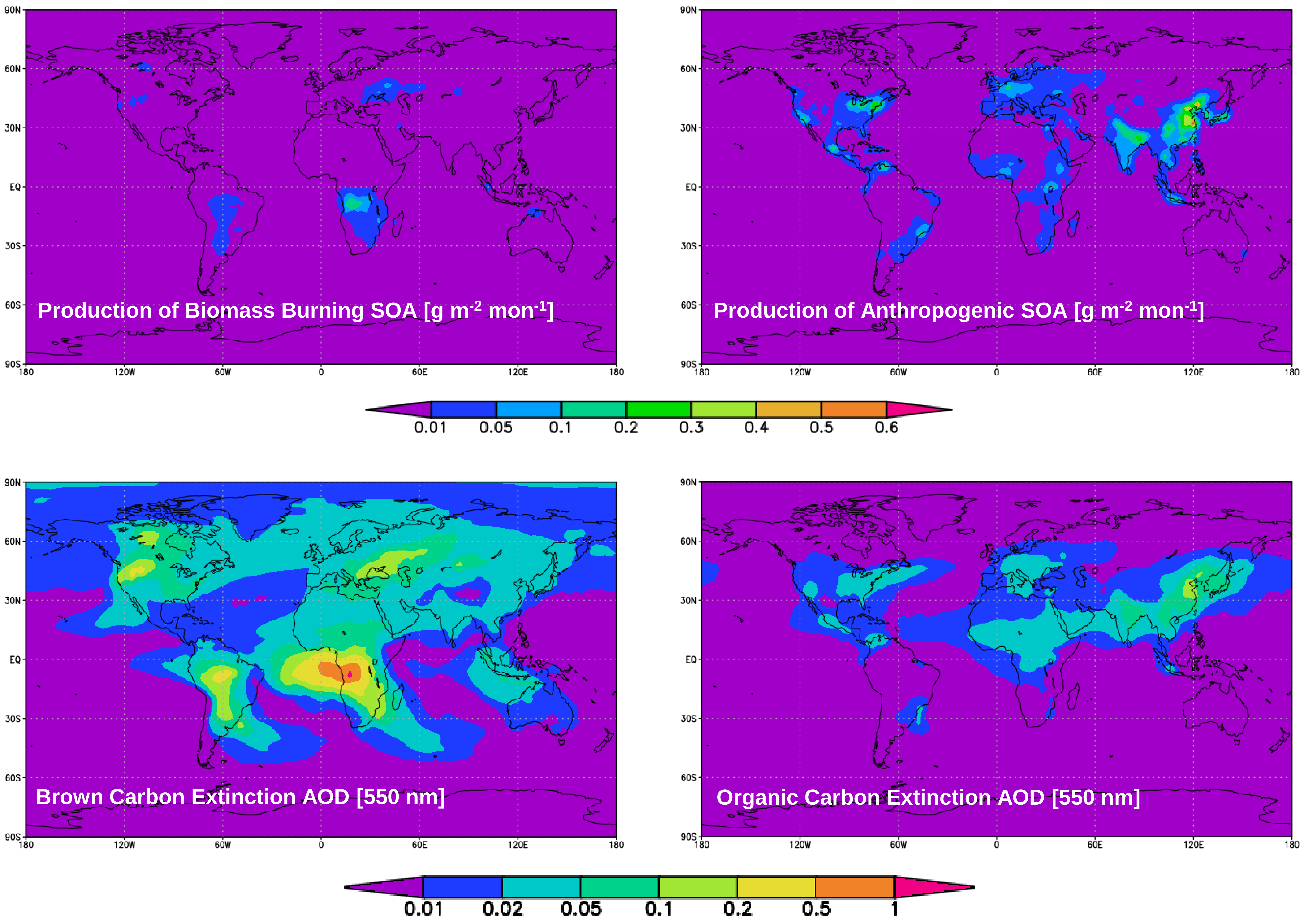
Updates to Carbonaceous Aerosols

- *Anthropogenic SOA from oxidation of VOC emissions scaled from anthropogenic and biomass burning CO emissions (after Hodzic and Jimenez 2011)*
- *Biogenic SOA from online MEGAN provided by HEMCO component*
- *Re-tuning of OA:OC ratio based on ATom observations*
- *2 tracers added from brown carbon (hydrophilic and hydrophobic)*

August 2008



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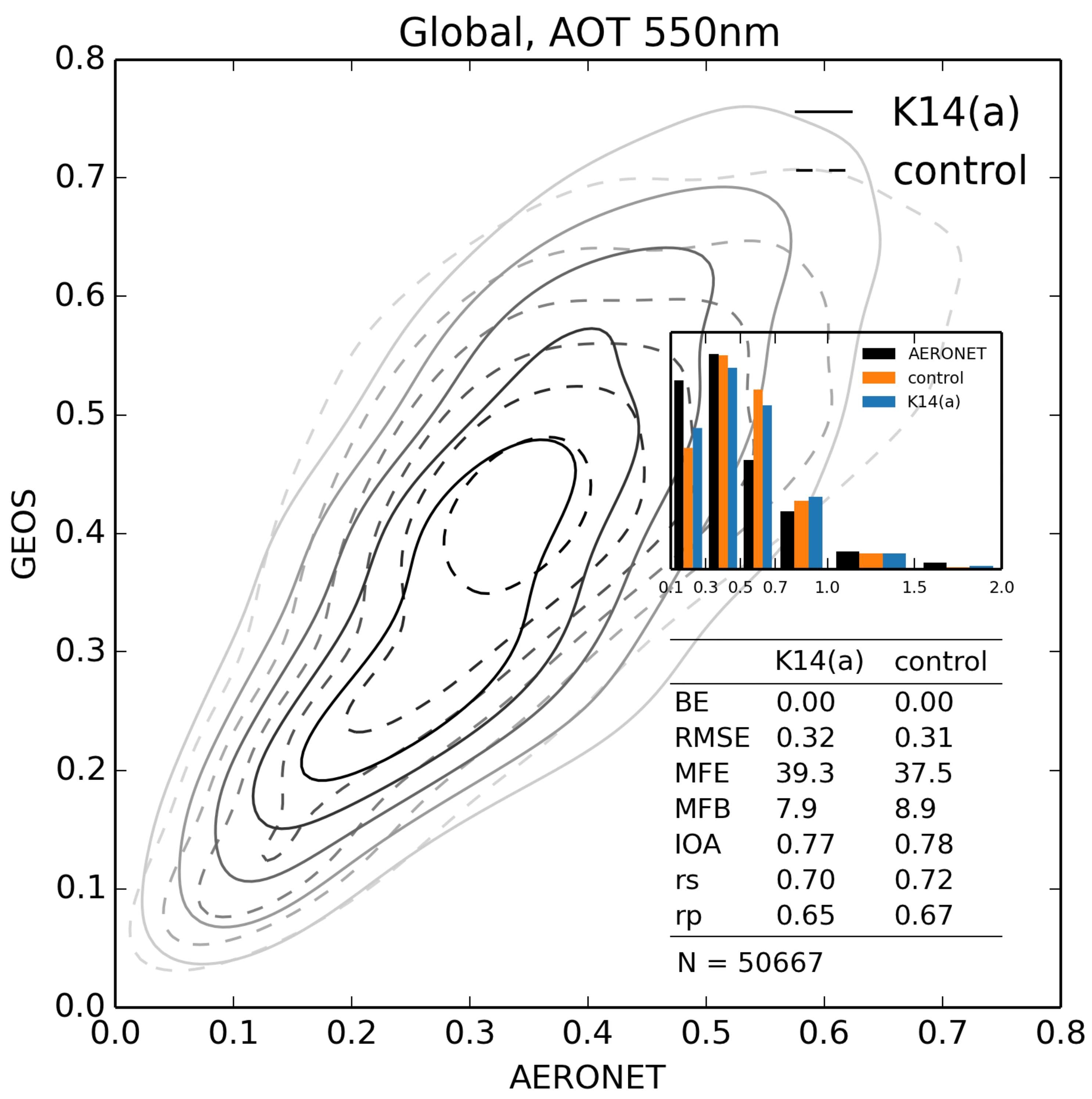
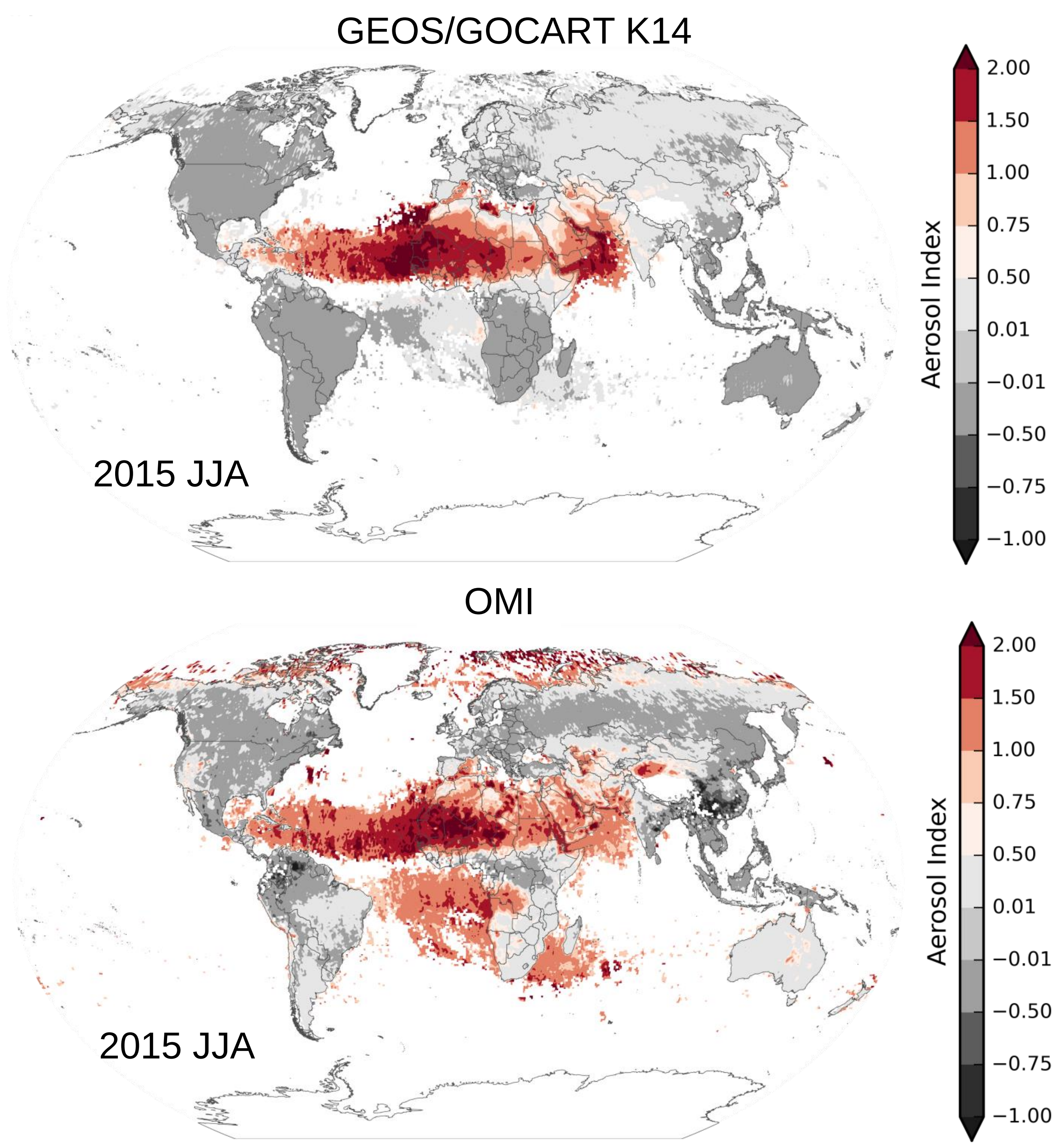
Physically-based Dust Emissions

- *Roughness, soil-texture, and vegetation cover aware scheme after Kok (2014)*
- *Implement Kok (2011) initial particle size distribution*
- *Scheme is found to perform well in GEOS system*





Aerosol Model Development

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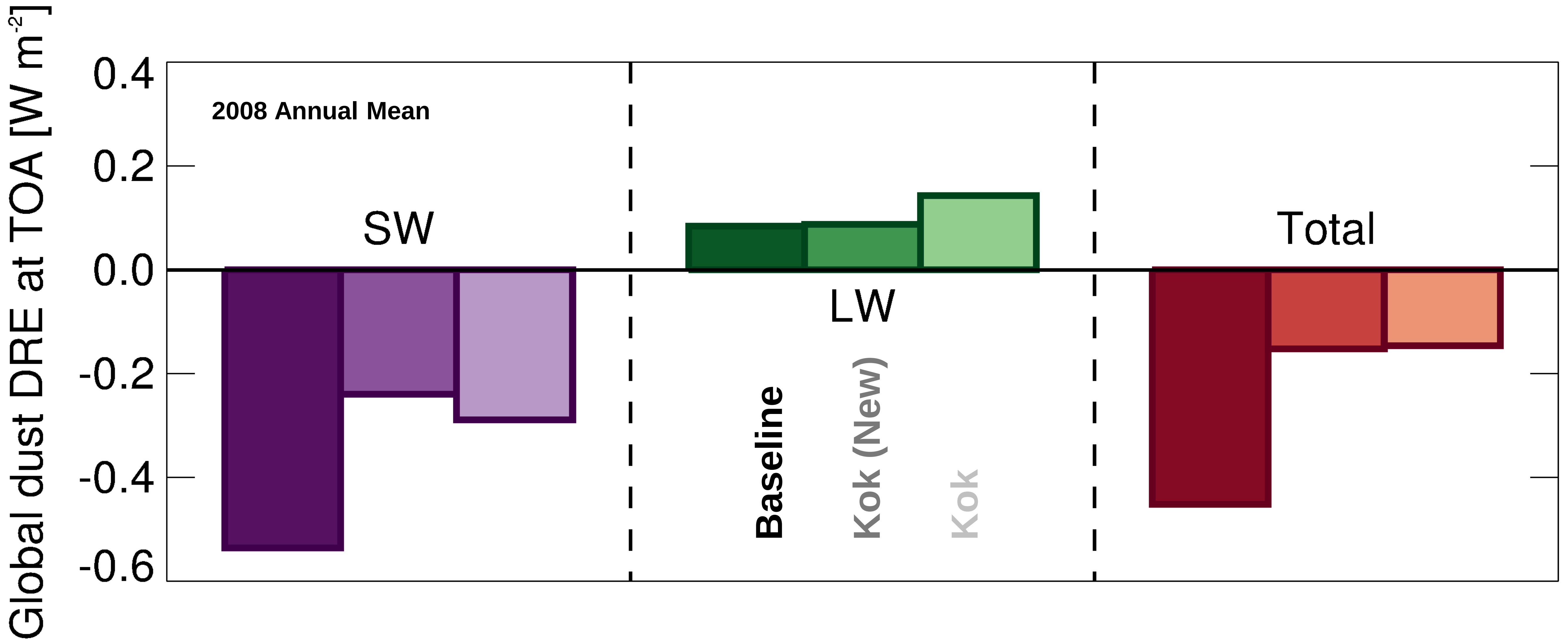
- *Roughness, soil-texture, and vegetation cover aware scheme after Kok (2014)*
- *Implement Kok (2011) initial particle size distribution*
- *Scheme is found to perform well in GEOS system*
- *Developing new dust optical properties*

Global Dust Direct Radiative Effect at TOA



- **Baseline** - Default GOCART initial particle size distribution
- **Kok** - New dust particle size distribution
- **Kok (New)** - New dust particle size distribution with candidate new optical properties

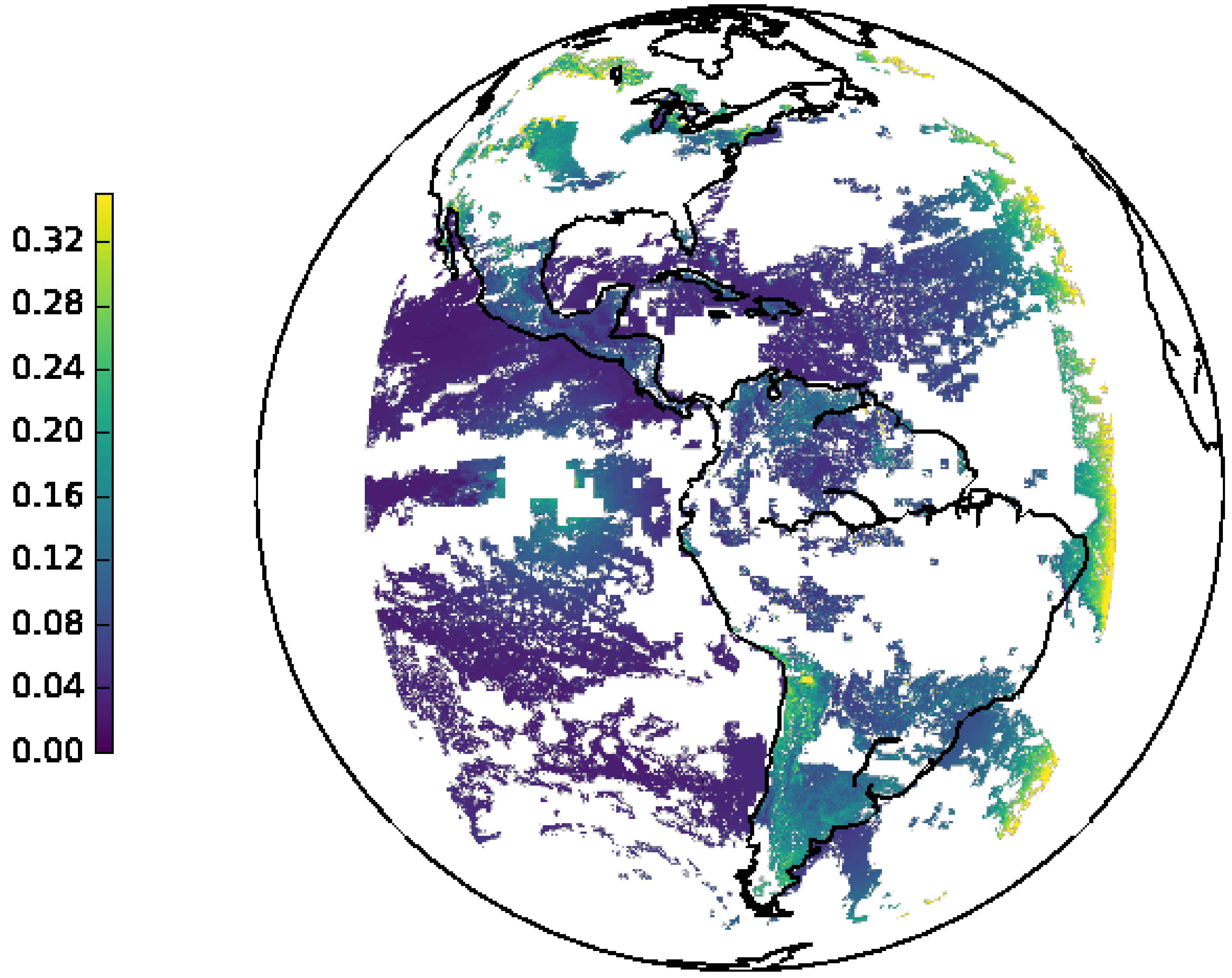
From LEO to GEO: Calibration Transfer

NRT SatCORPS cloud cleared GOES-16 and AHI-8 TOA reflectances
- ➢ Provided by NASA Langley SatCORPS Group (R. Palikonda, W. Smith)
- ➢ 1 full disk scan per hour

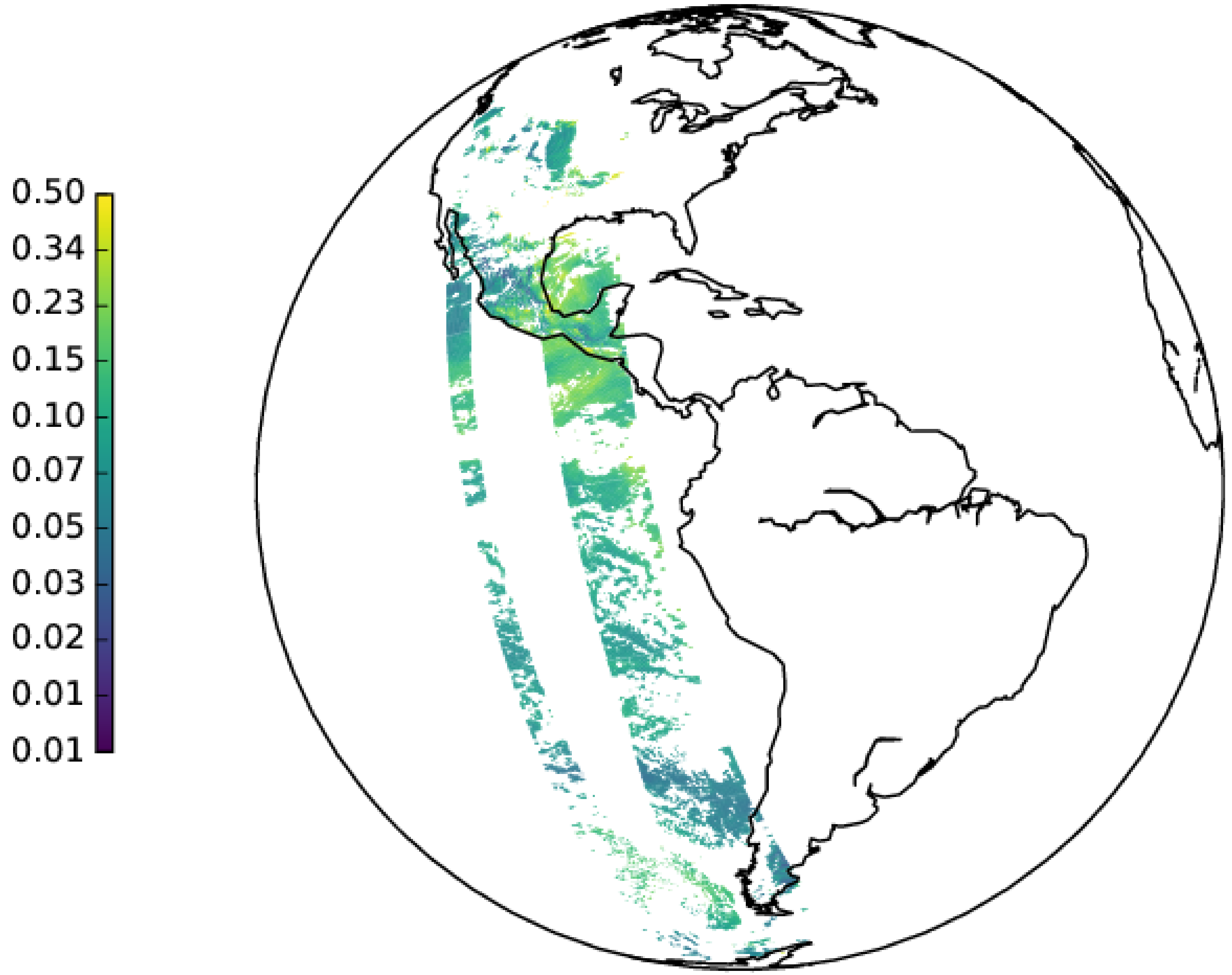
Use MODIS-NNR AOD as targets for training GEO Reflectance observations

INPUTS → **TARGETS**

GOES-16 TOA 640 Reflectance 2018-03-11 20Z



MODIS Aqua NNR AOD 2018-03-11 20Z



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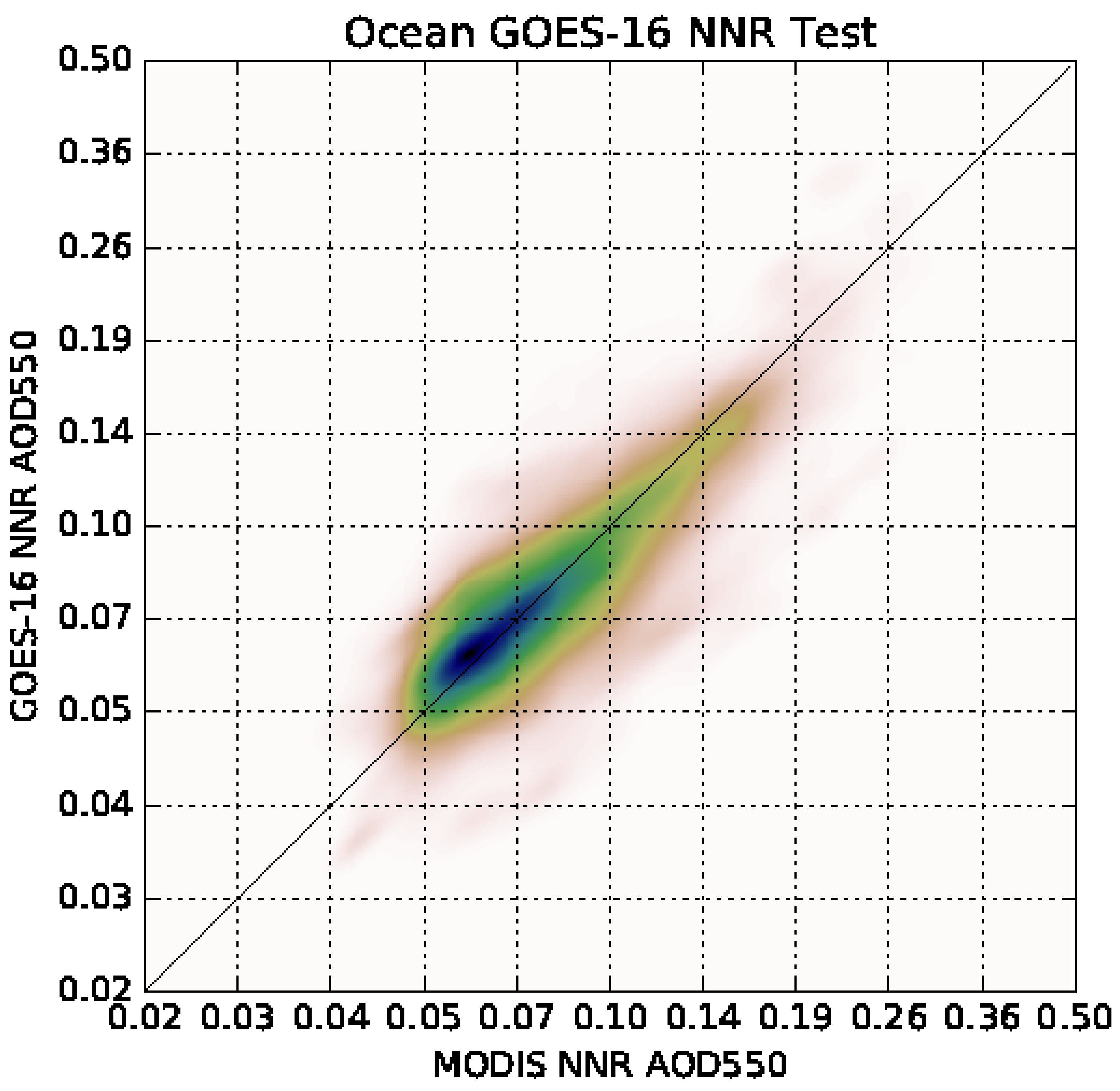


Preliminary Test with Ocean Data

- Trained NNR with 2-months of MODIS/GOES-16 collocated observations
- ~100K data points
- Currently only 640, 860, and 1600 nm channels provided
- No water vapor correction

High priority for going to ops (notionally Fall 2018)

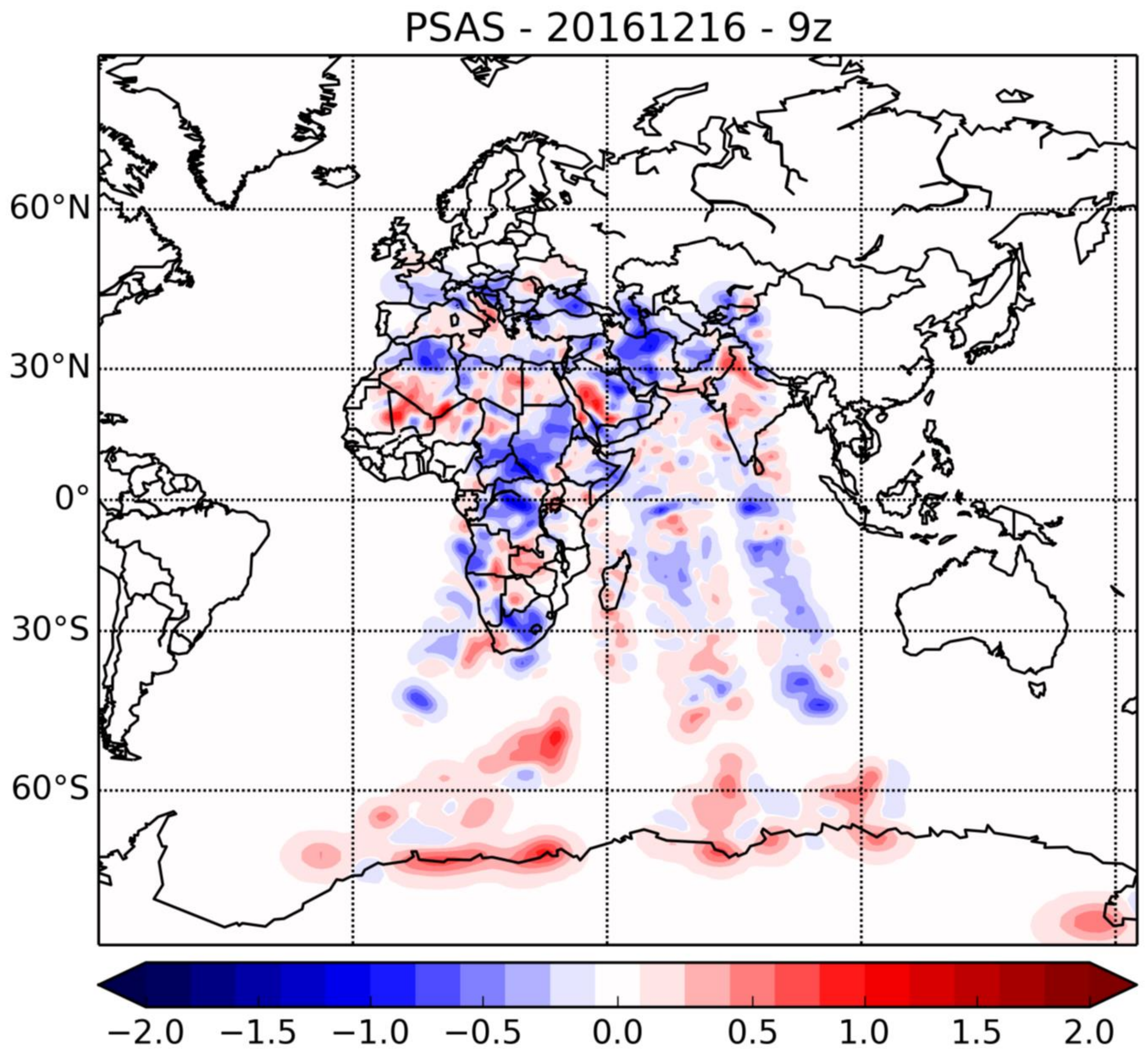
Aerosol EnKF

As part of GMAO's hybrid system, aerosol ensemble members are produced as a matter of routine

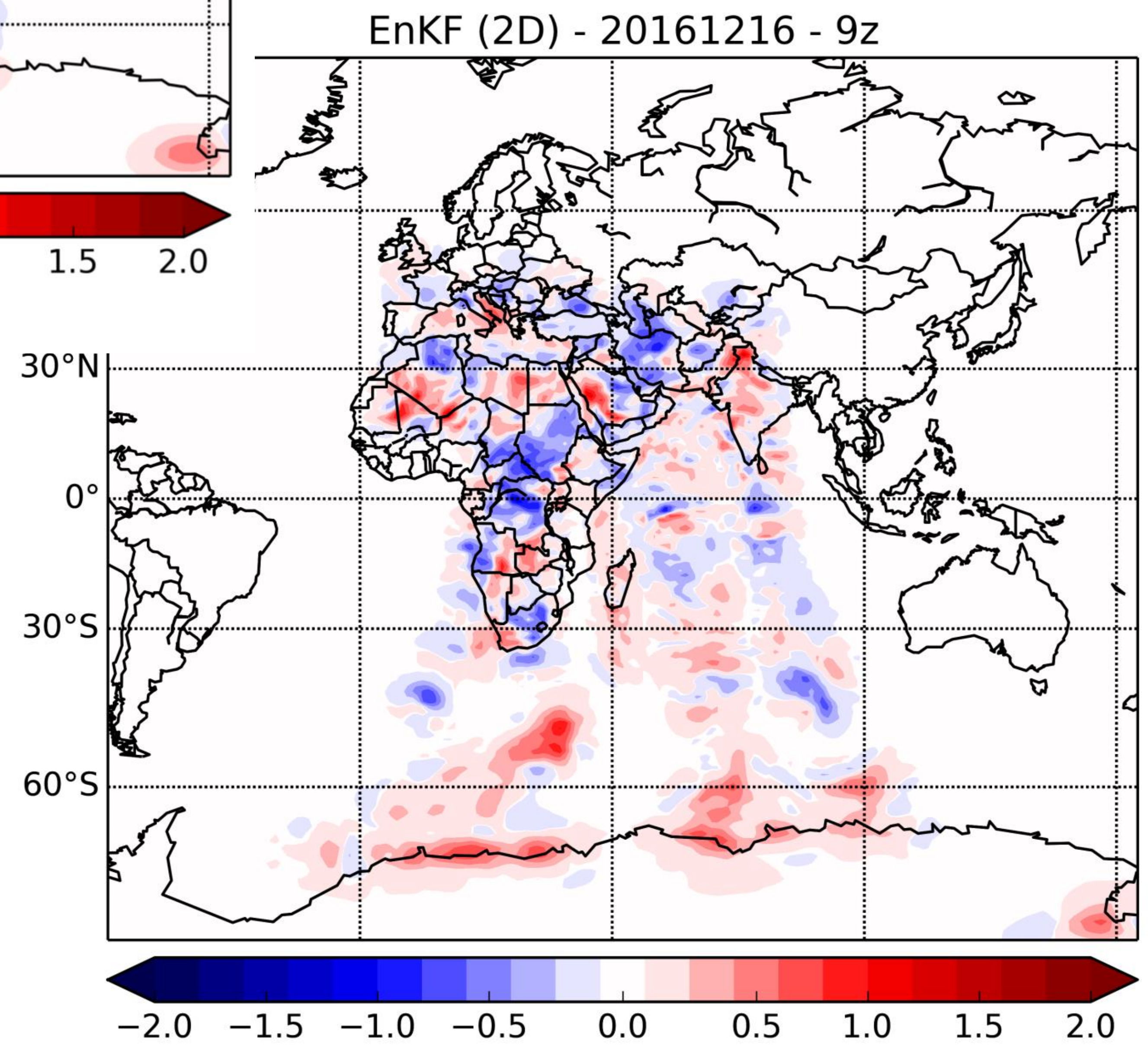
The same Whitaker-Hamill EnKF used for the hybrid Meteorological assimilation has been adapted for aerosols

Target observation systems

- Multi-spectral AOD: 470, 550 and 870 nm
- Lidar attenuated backscatter
- Sensors: MODIS, VIIRS, GEO, CATS/CALIOP, TropOMI



Current PSAS Based Analysis



Ensemble Mean EnKF Analysis