Update on the NASA GEOS Aerosol Modeling Activities

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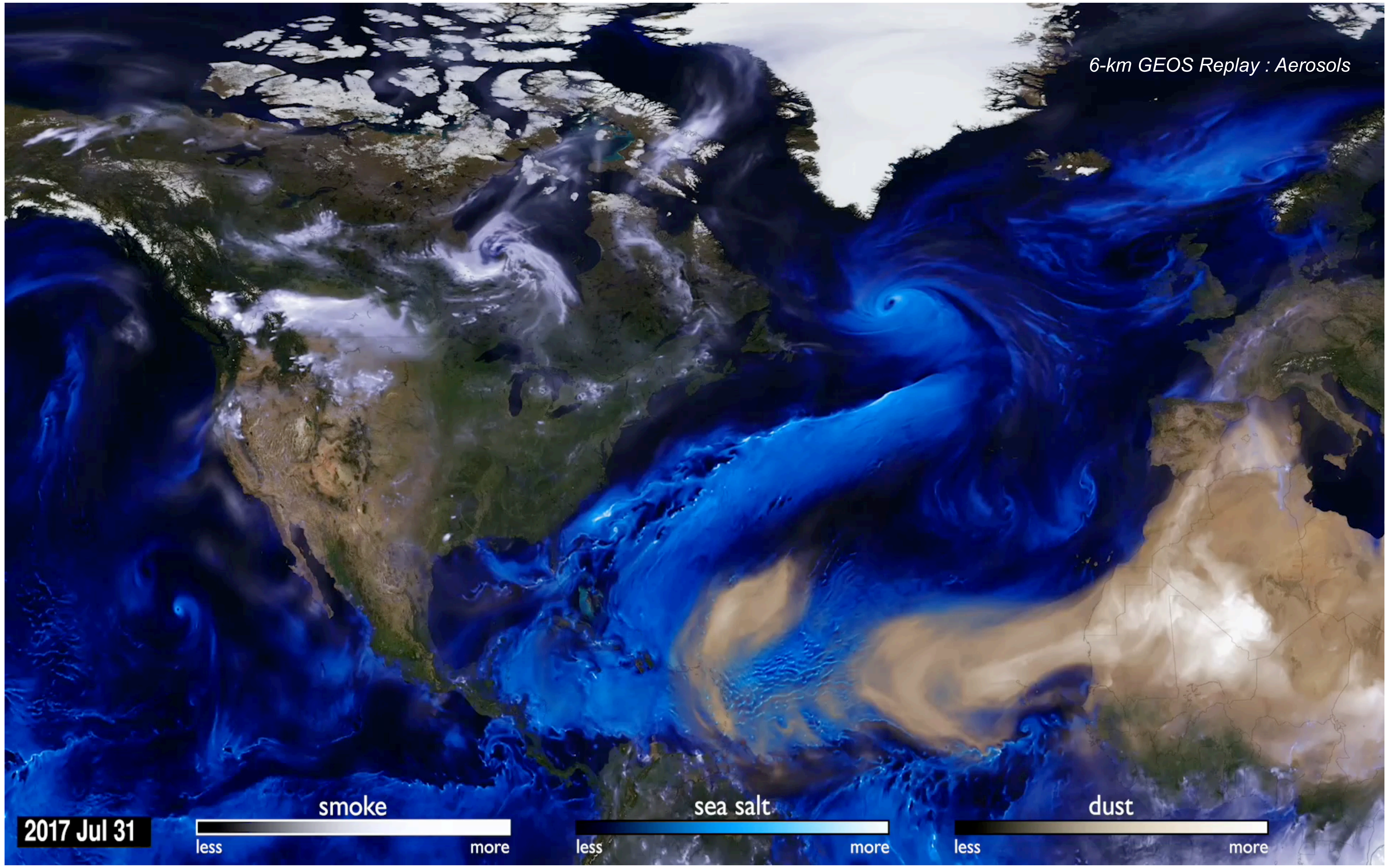
with contributions from:
Arlindo da Silva, Patricia Castellanos, Anton Darmenov, Virginie Buchard (GMAO)
Huisheng Bian, Sampa Das, Ed Nowottnick, Adriana Rocha Lima (ACDL)
Valentina Aquila (American University)

ICAP Meeting, Exeter, UK, June 6-8, 2018

Outline

- *Group: Who we are*
- *Roadmap: Where we've been*
- *Model Architecture and Status*
- *Aerosol Module Development and Plan*
- *Aerosol Assimilation*
- *Field Campaign Support*
- *Reanalysis*
- *Dessert?*

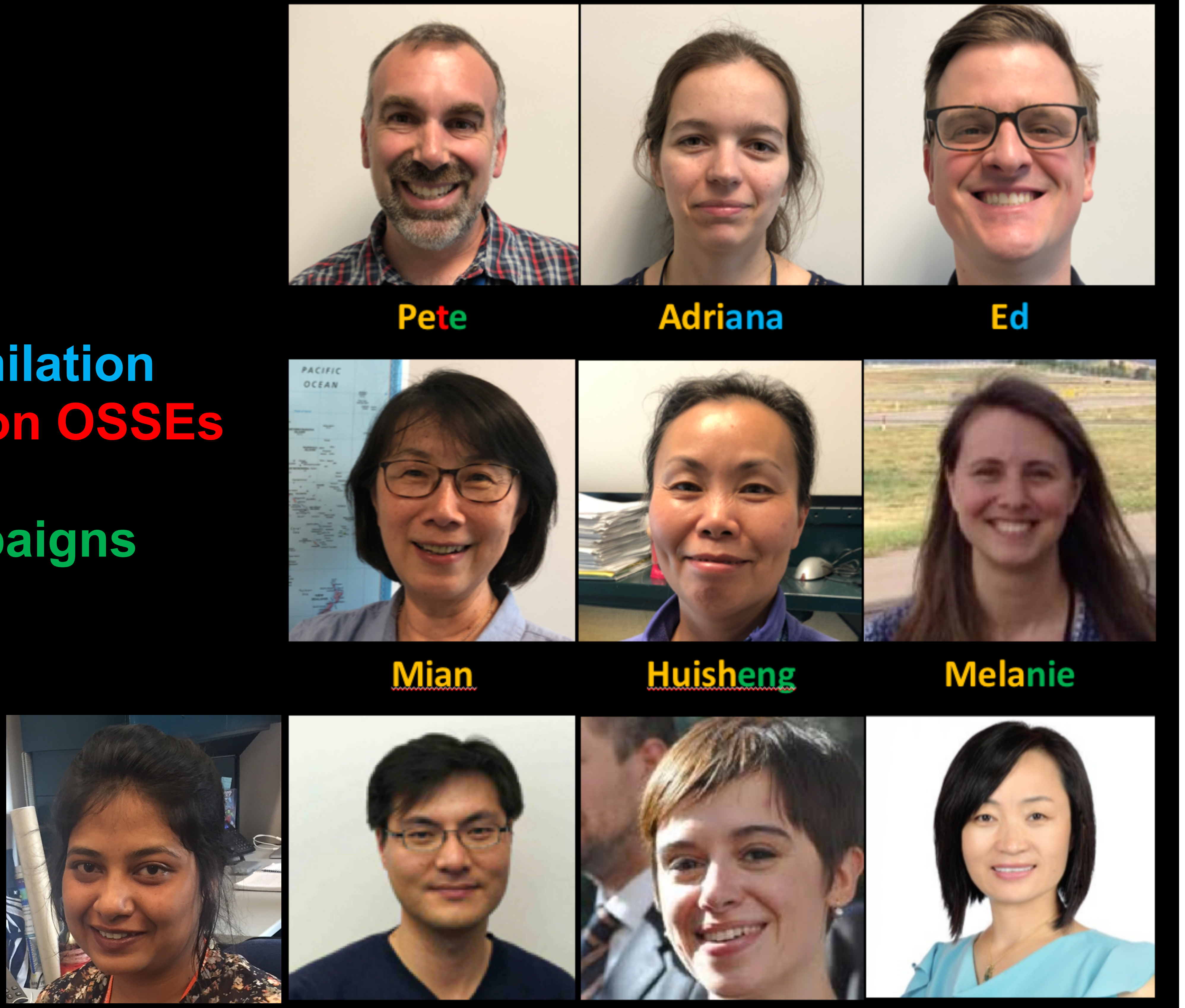


The Goddard Aerosol Team

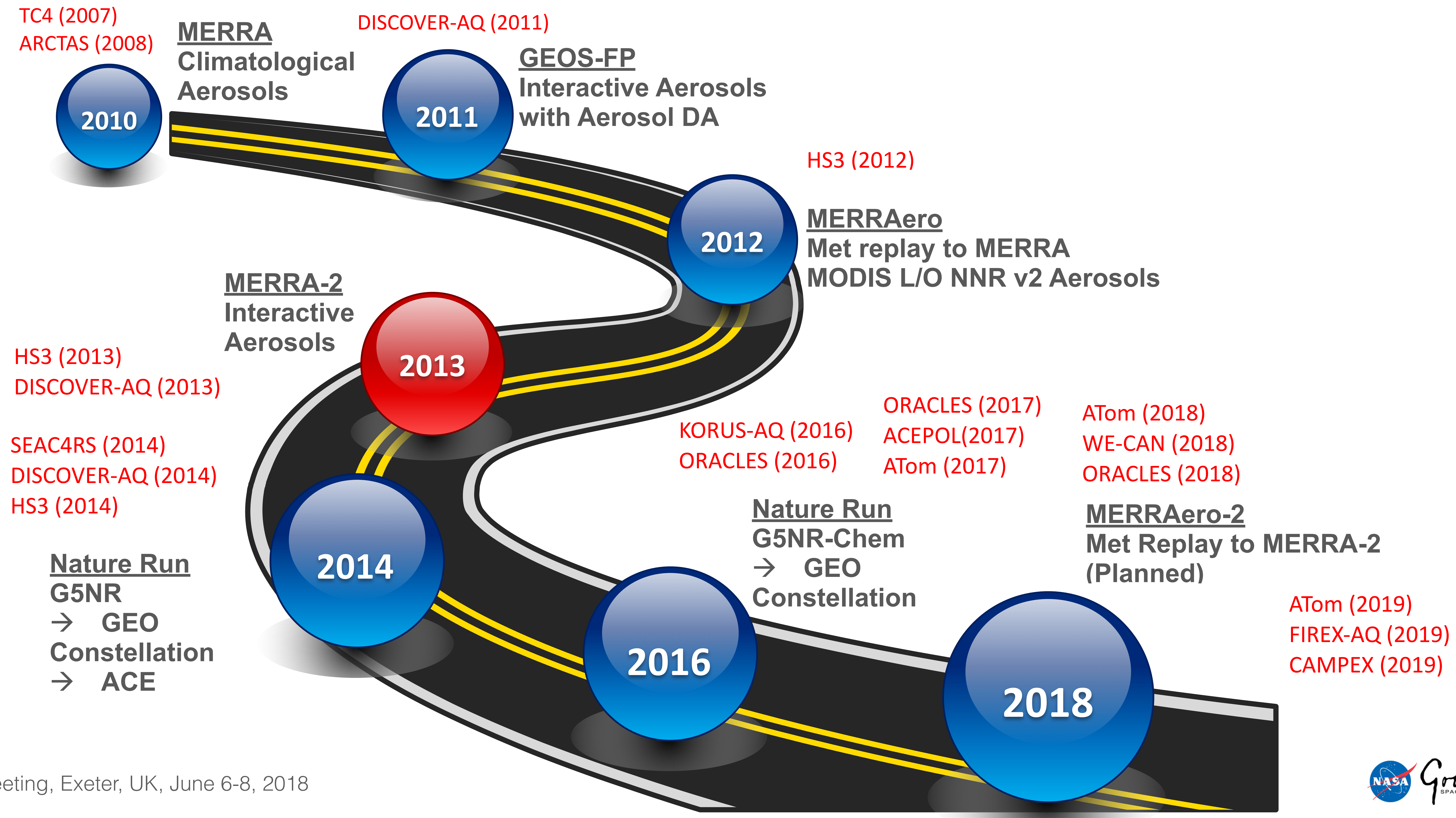
GMAO

Data Assimilation
Composition OSSEs
Modeling
Field Campaigns

Atmospheric Chemistry and Dynamics Lab



Aerosol Milestones in GEOS



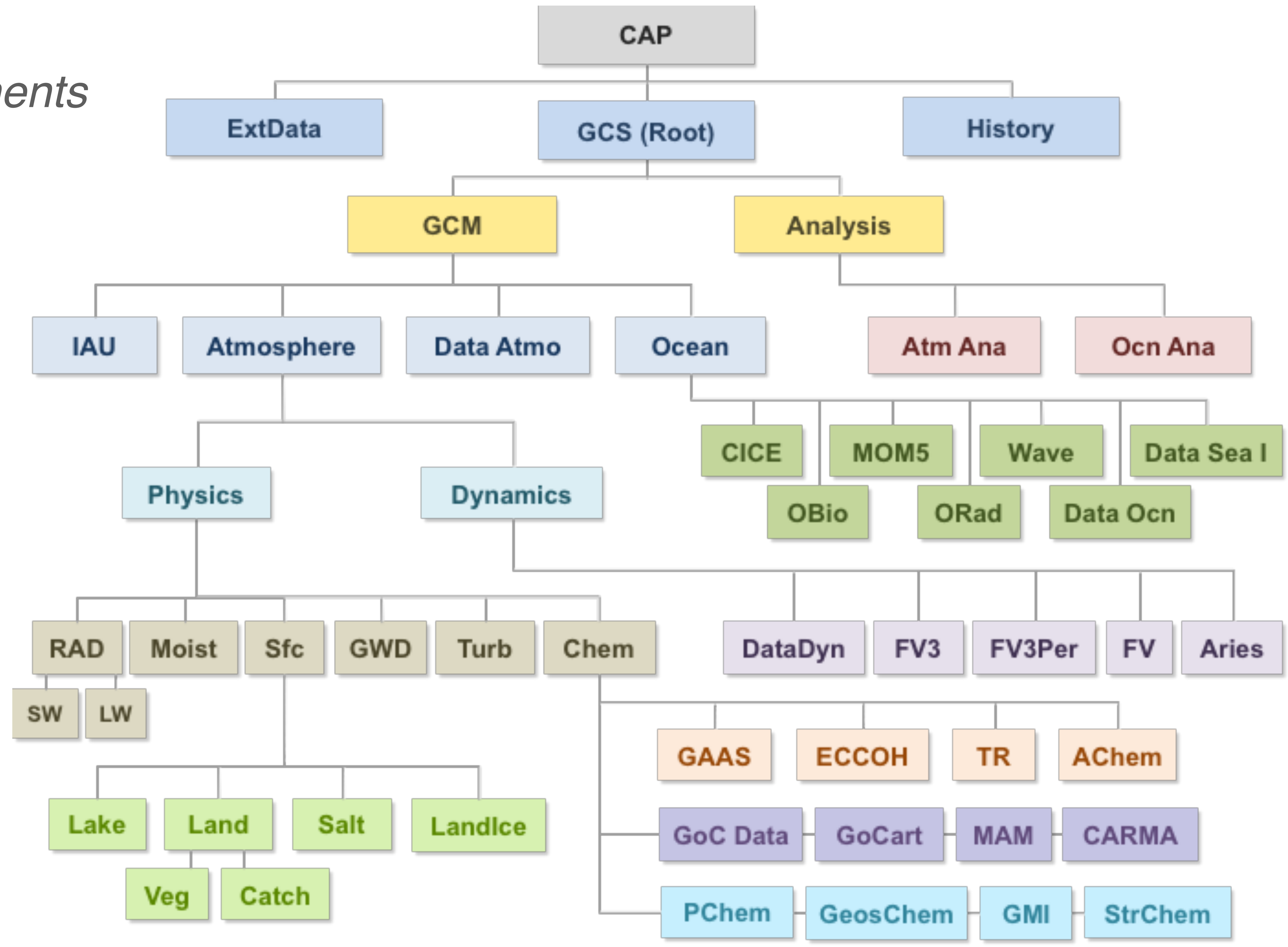
GEOS Model Architecture

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)



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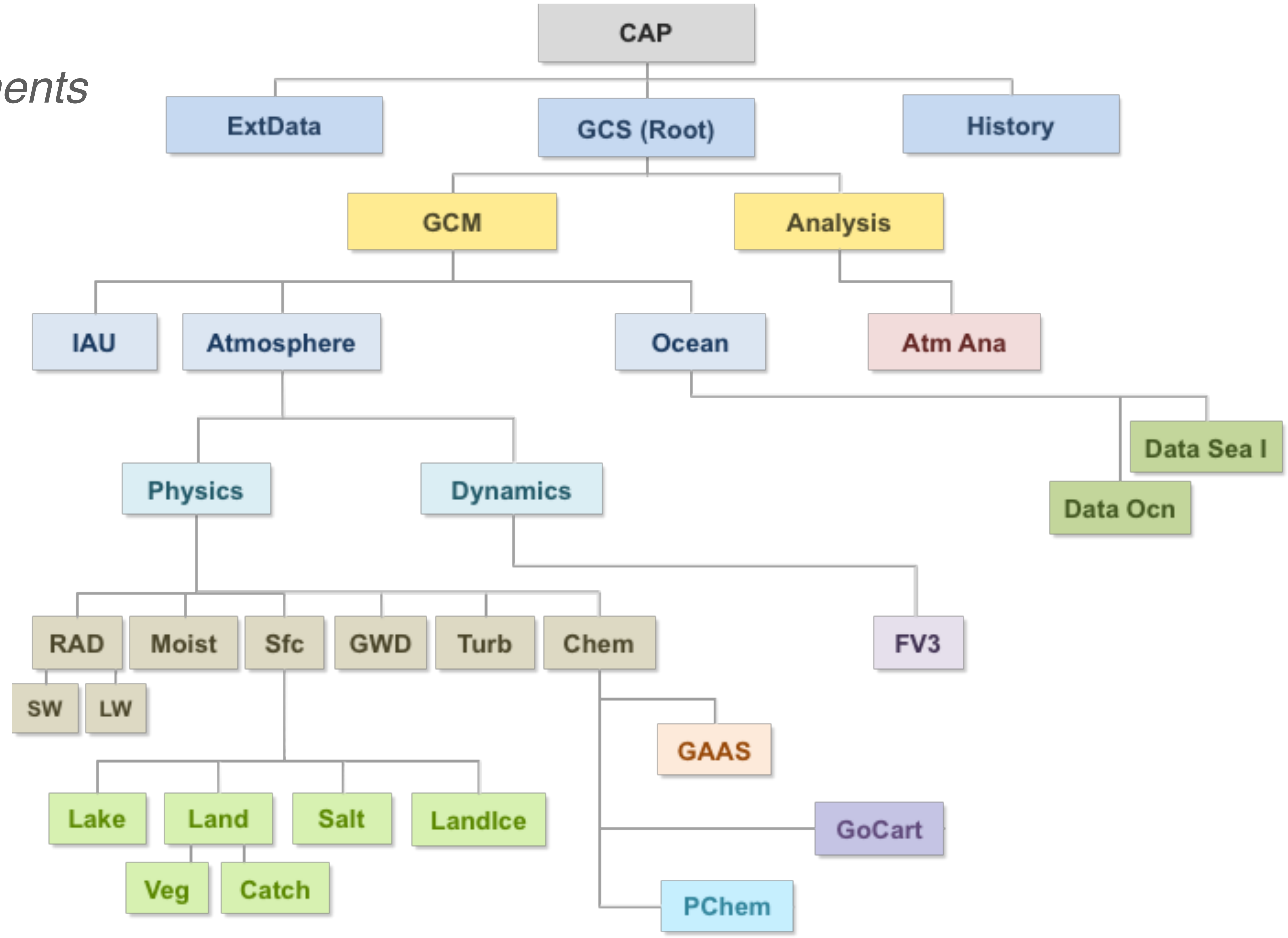
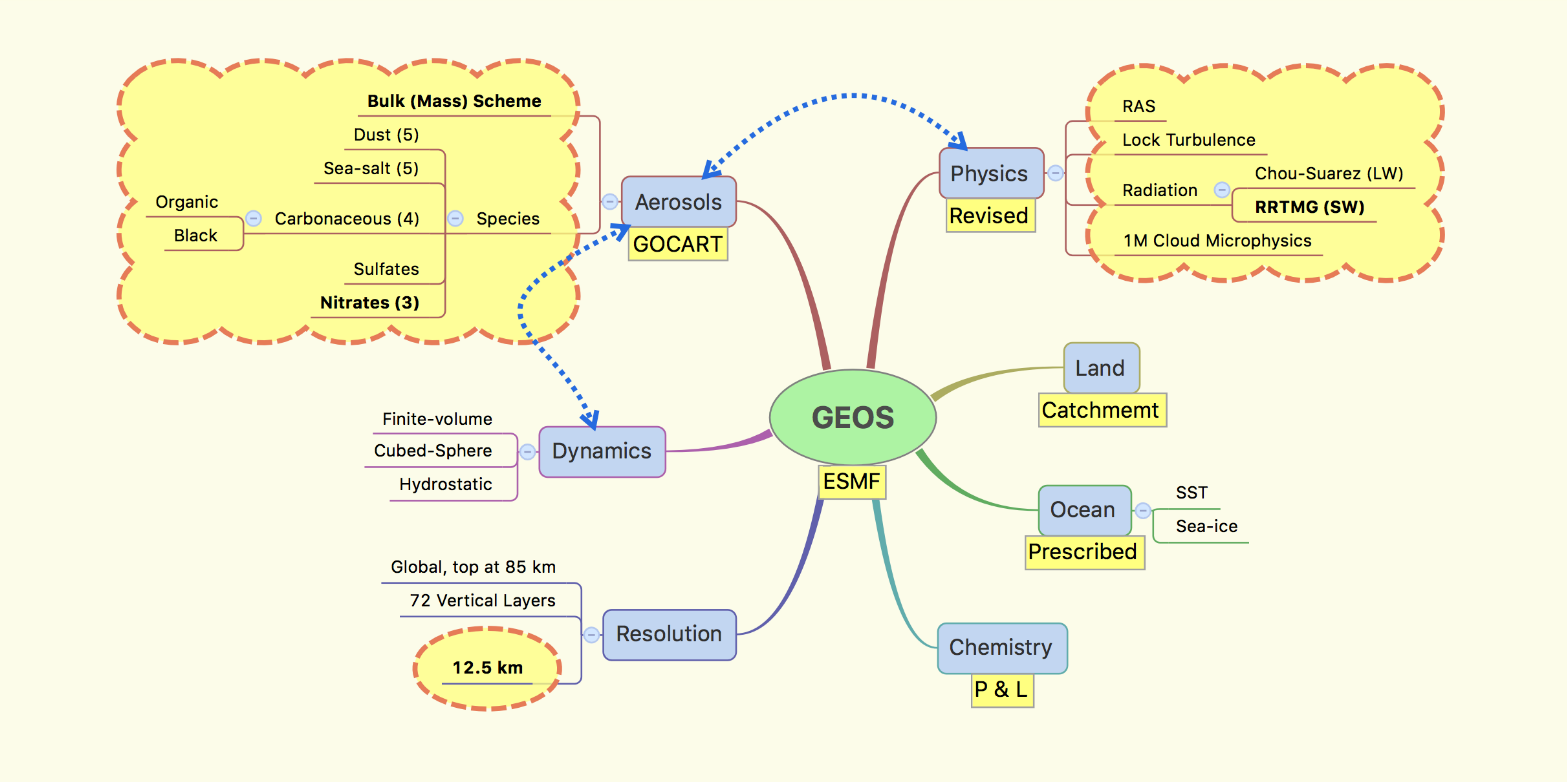
Architecture permits flexibility

- *For example:*
  - NWP configuration
  - S2S configuration (coupled ocean)
  - CCM configuration (advanced chemistry)
  - CTM configuration (offline met fields)

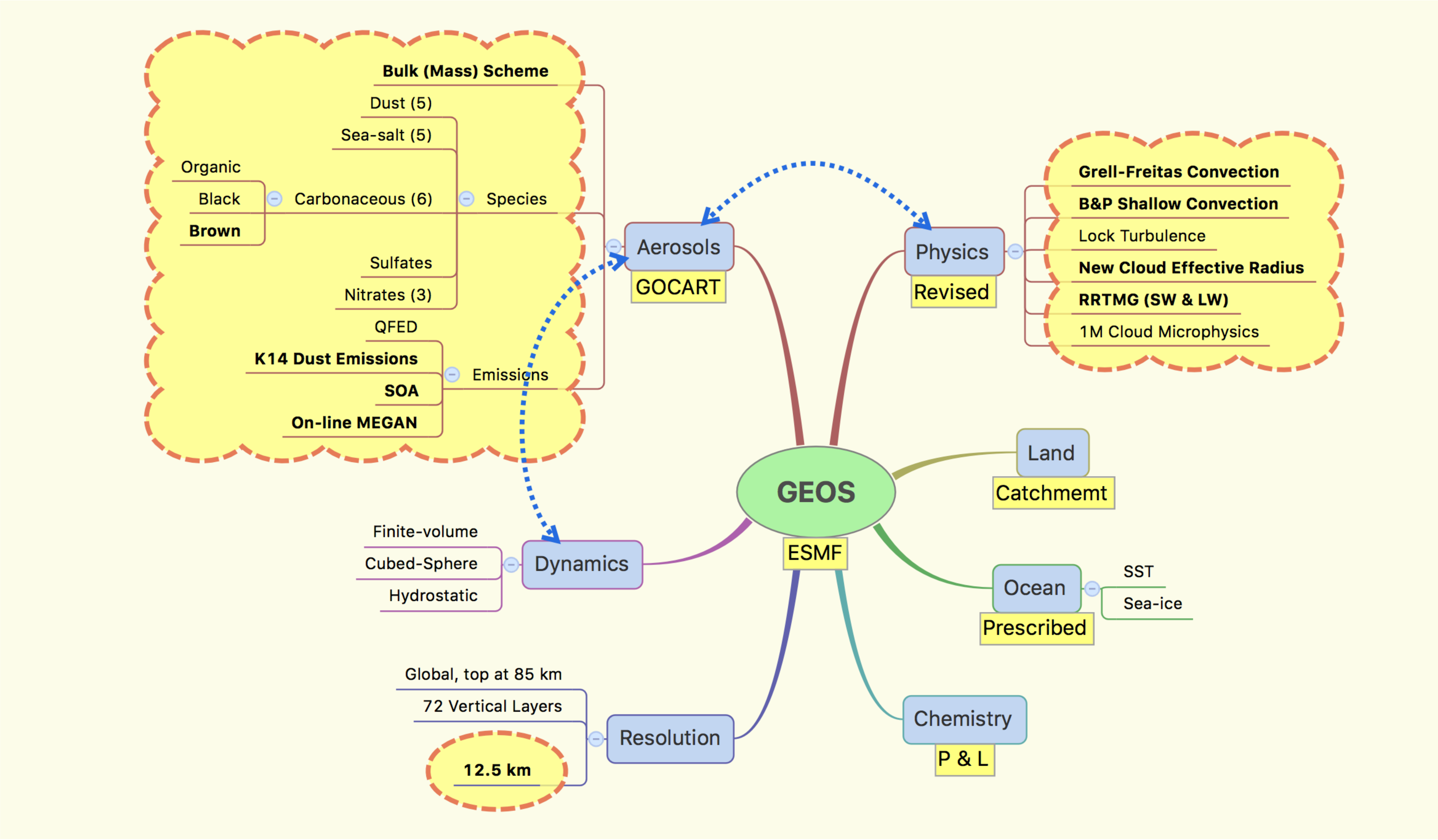


GEOS NWP Configuration

GEOS Current NWP Configuration



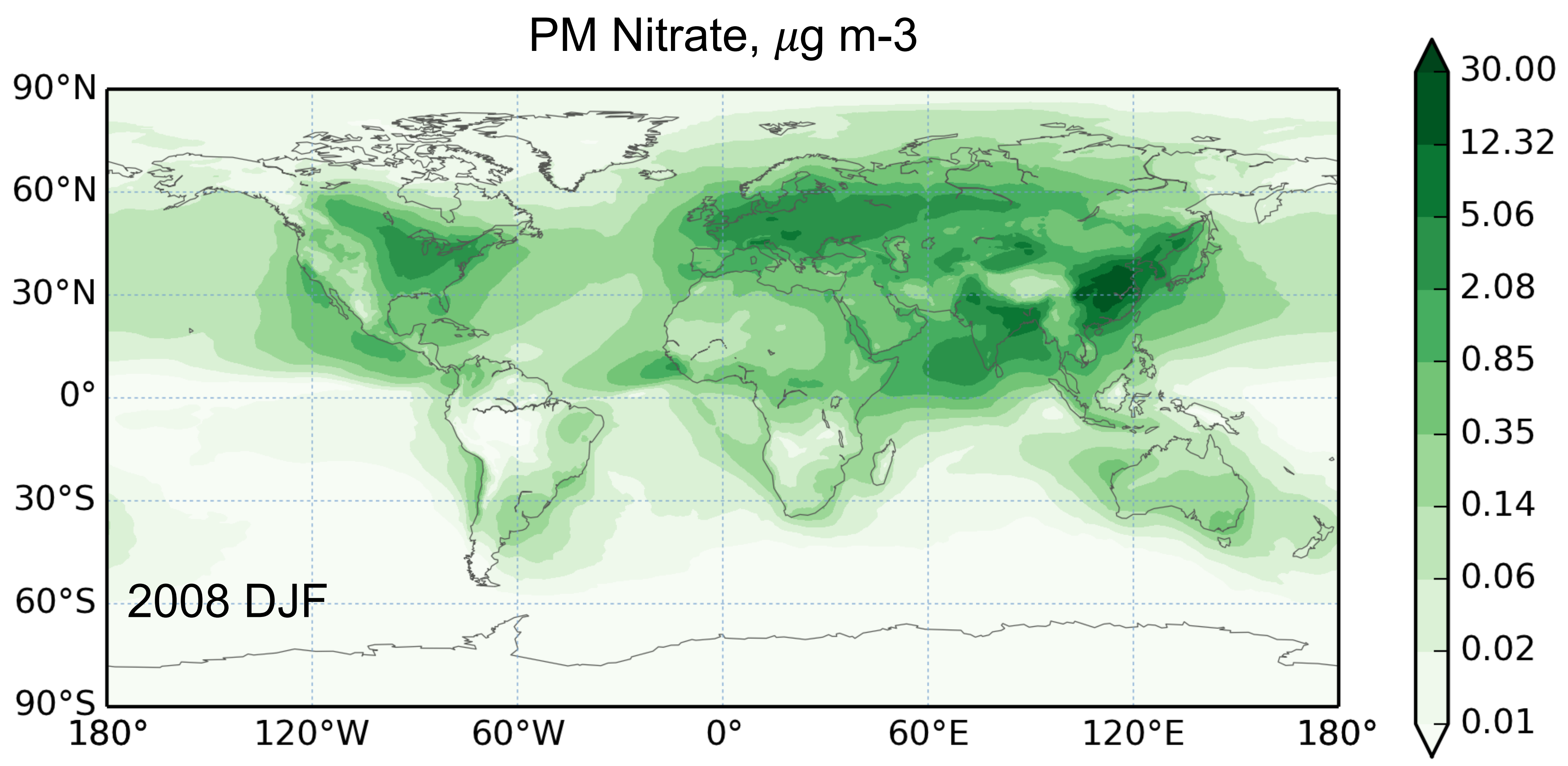
GEOS Next NWP Configuration

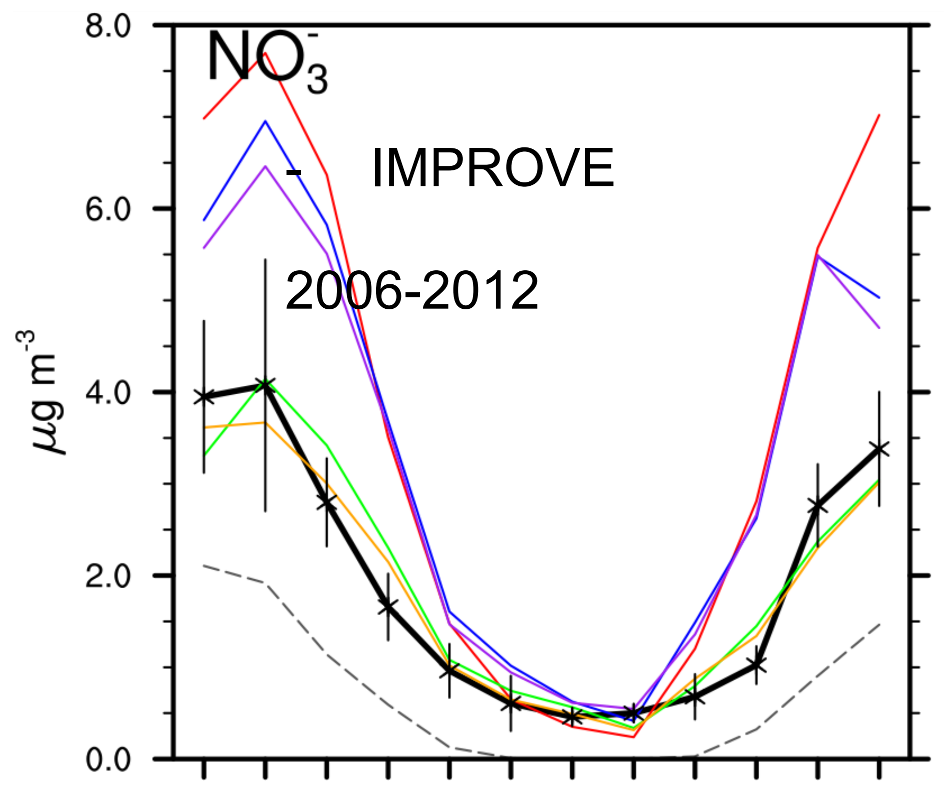


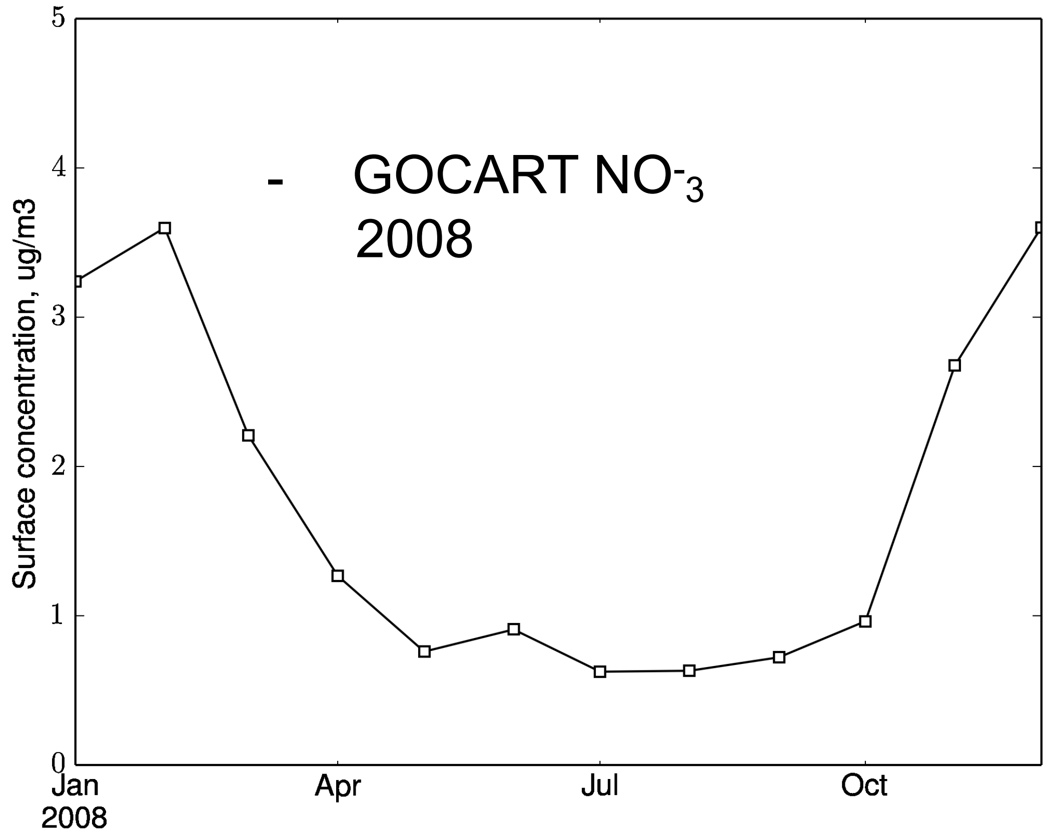
Aerosol Model Development

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.

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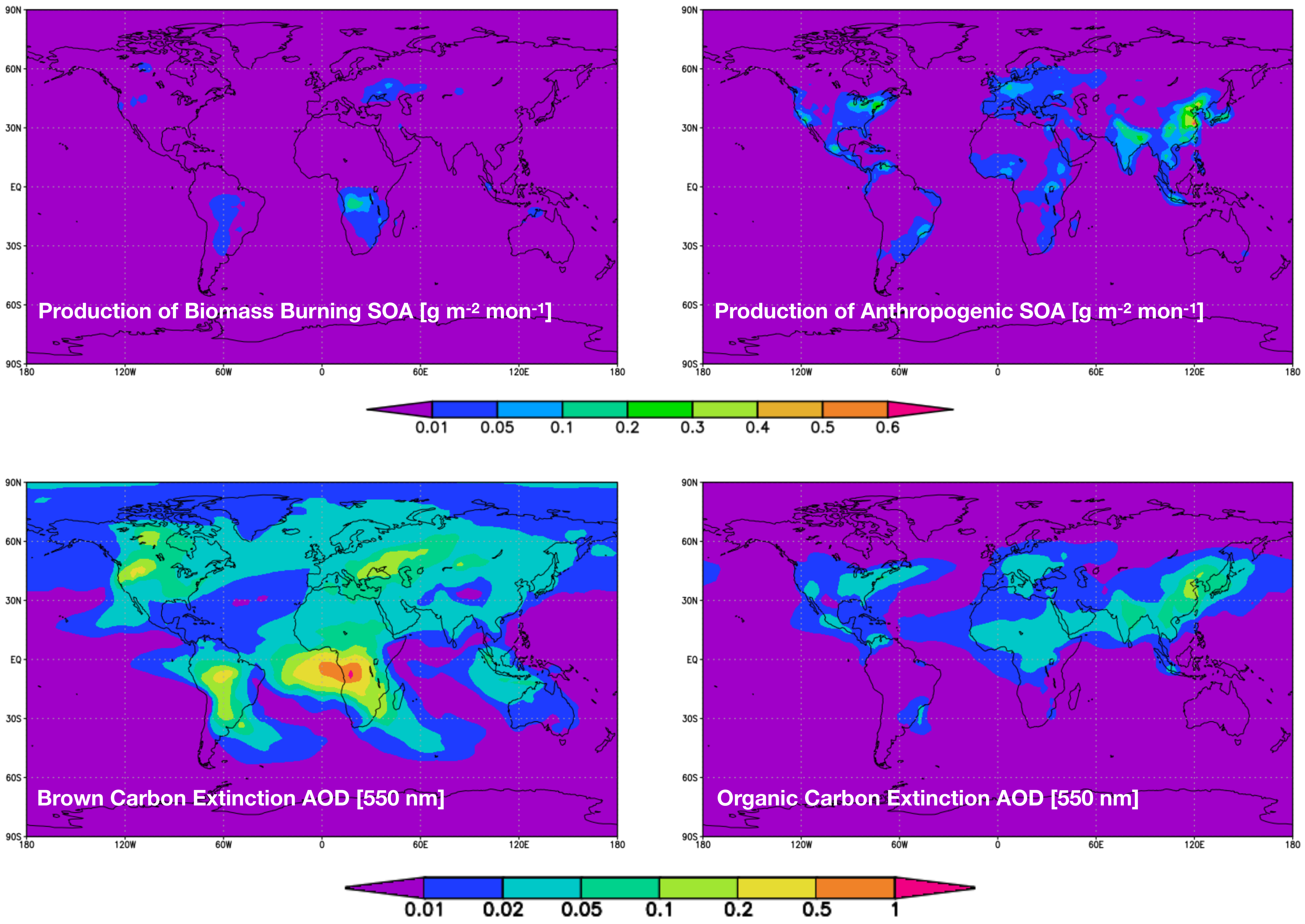
Updates to Carbonaceous Aerosols

- *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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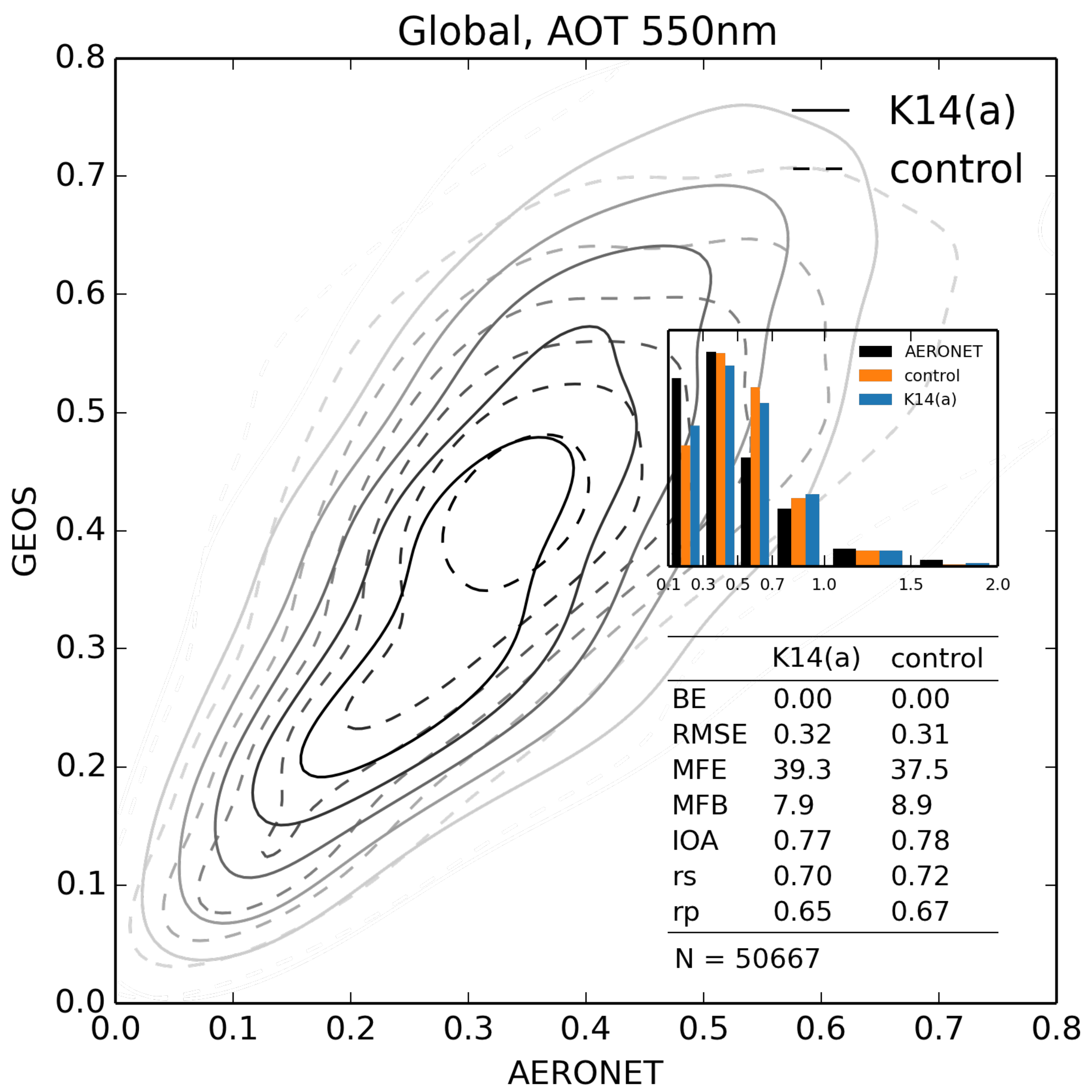
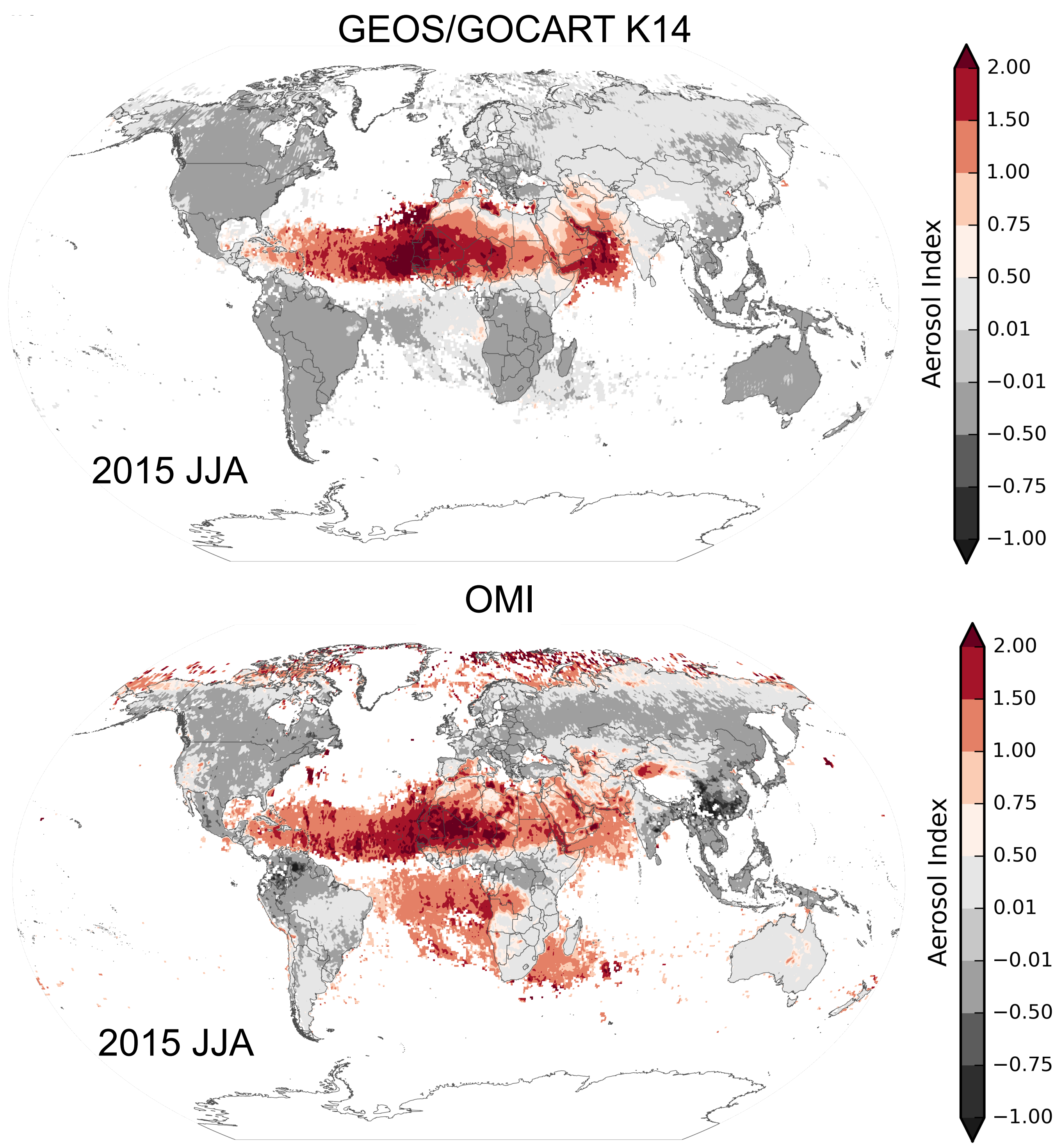
Physically-based Dust Emissions

- *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*





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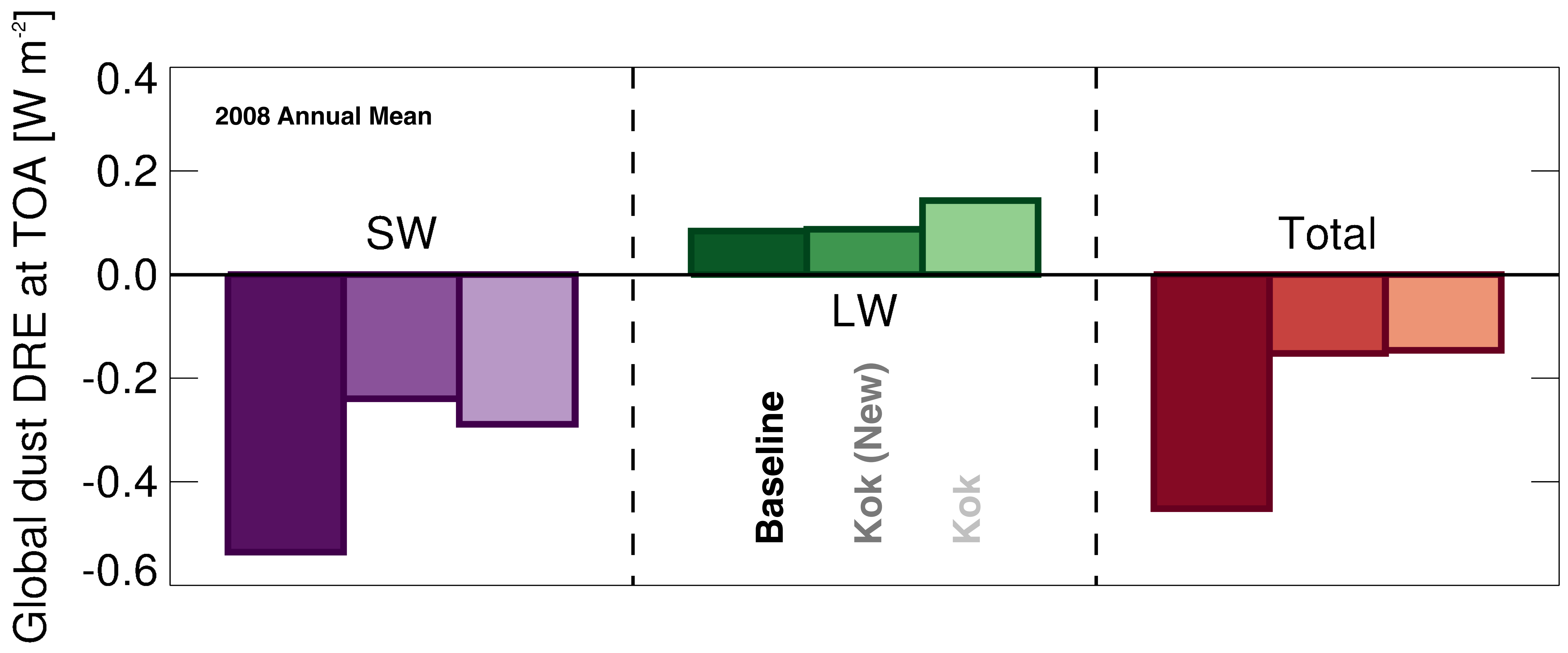
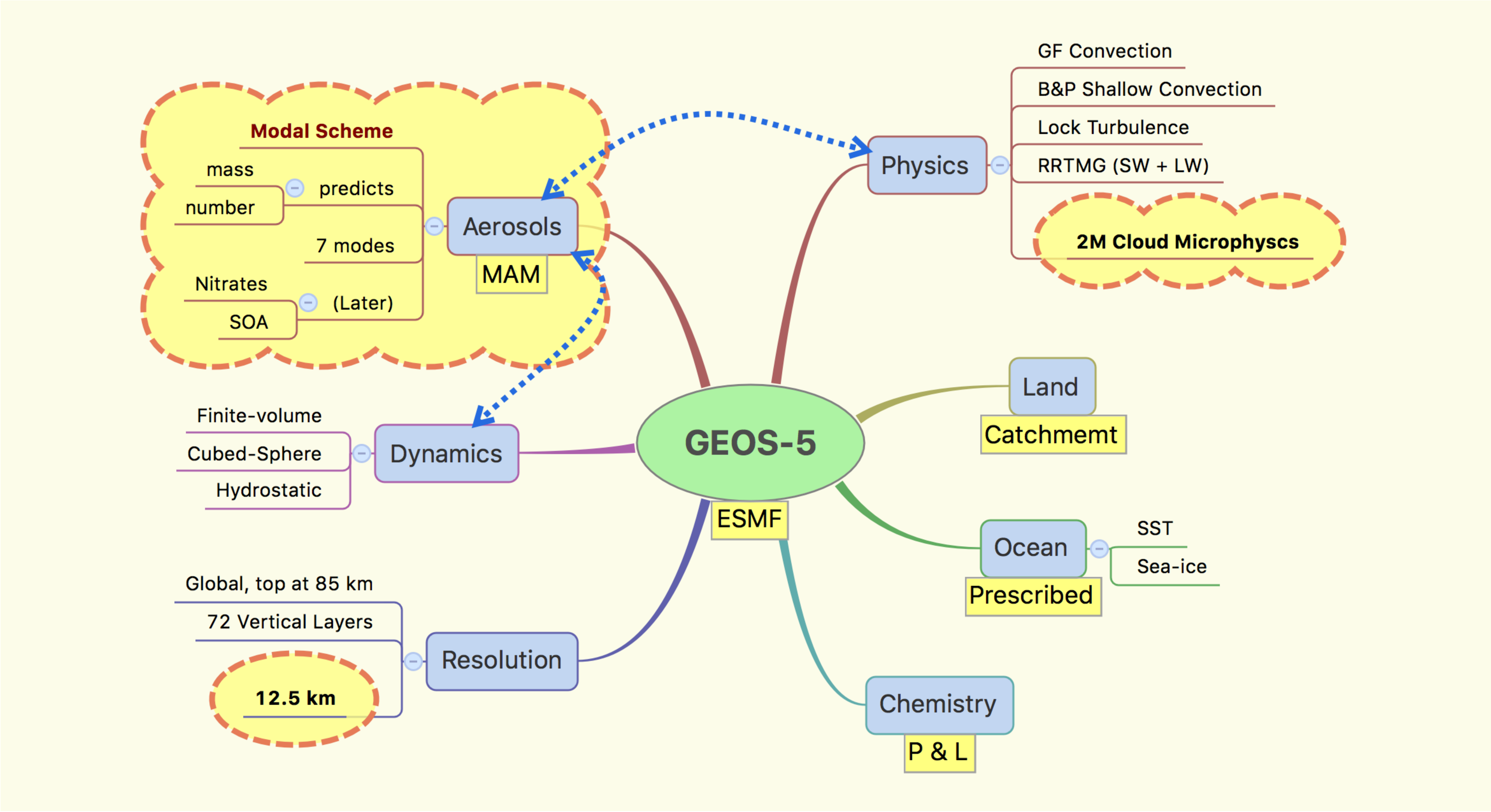
- *Implement Kok (2011) initial particle size distribution*
- *Scheme is found to perform well in GEOS system*
- *Developing new dust optical properties*

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

Modal Aerosol Microphysics in GEOS



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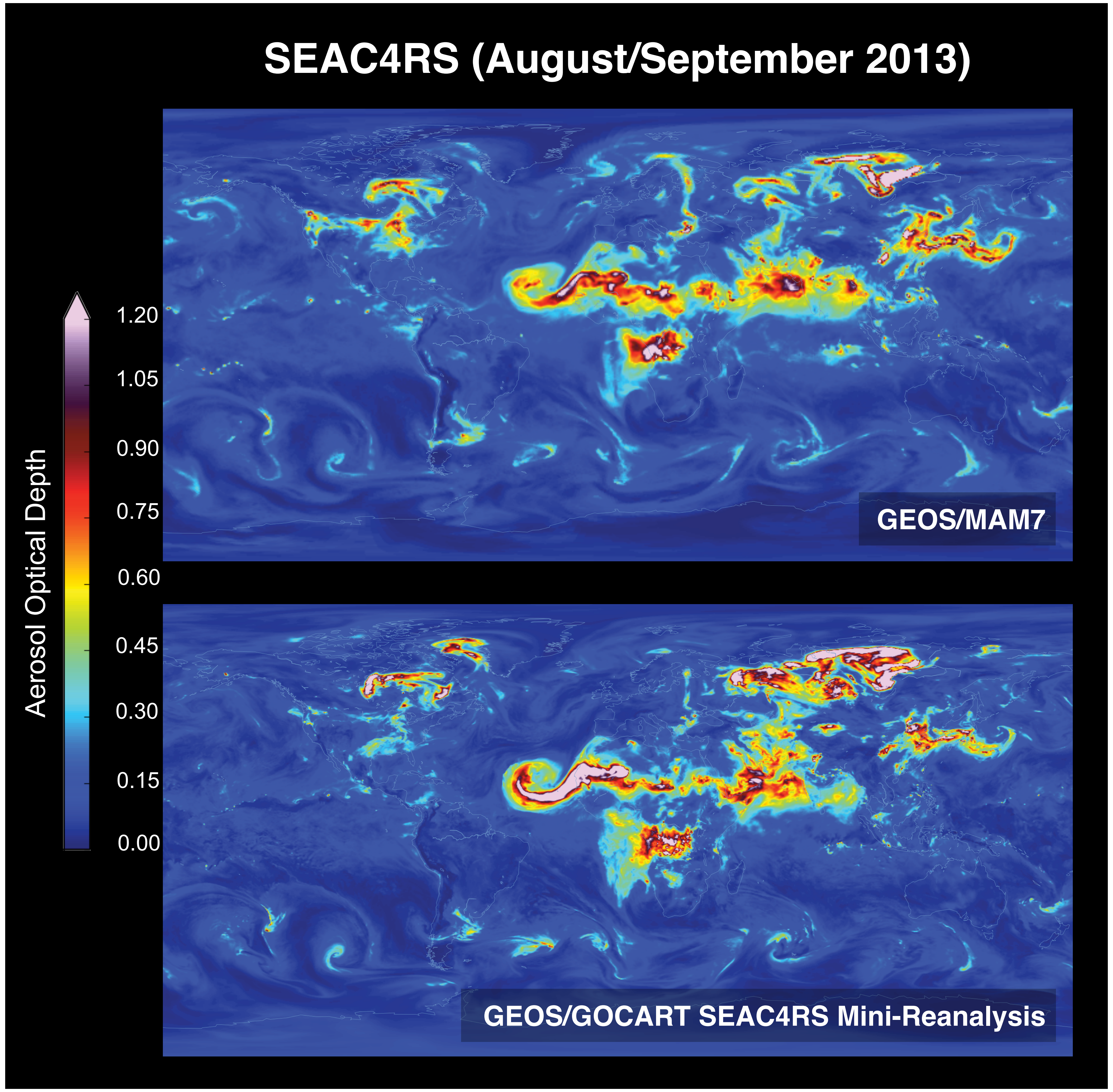
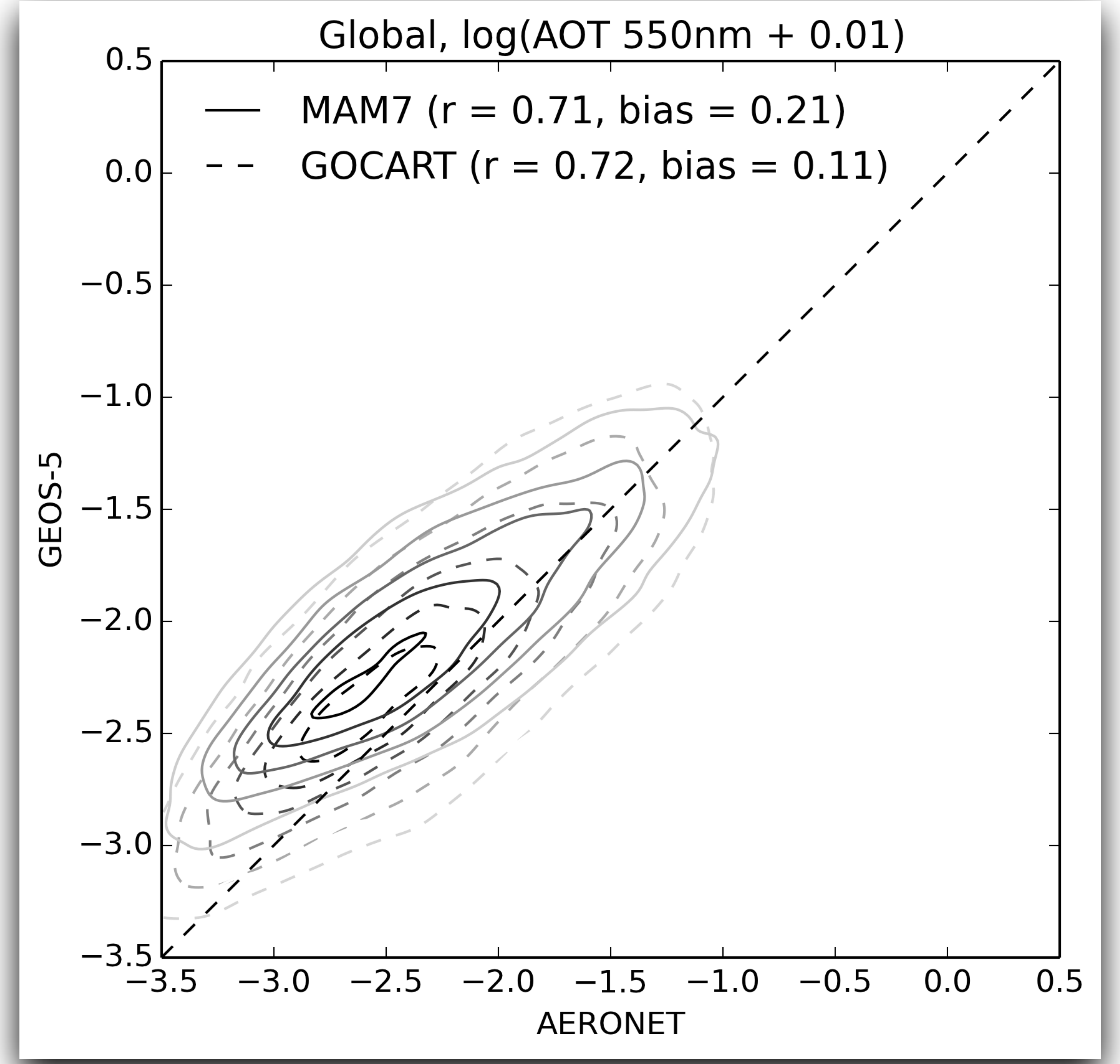
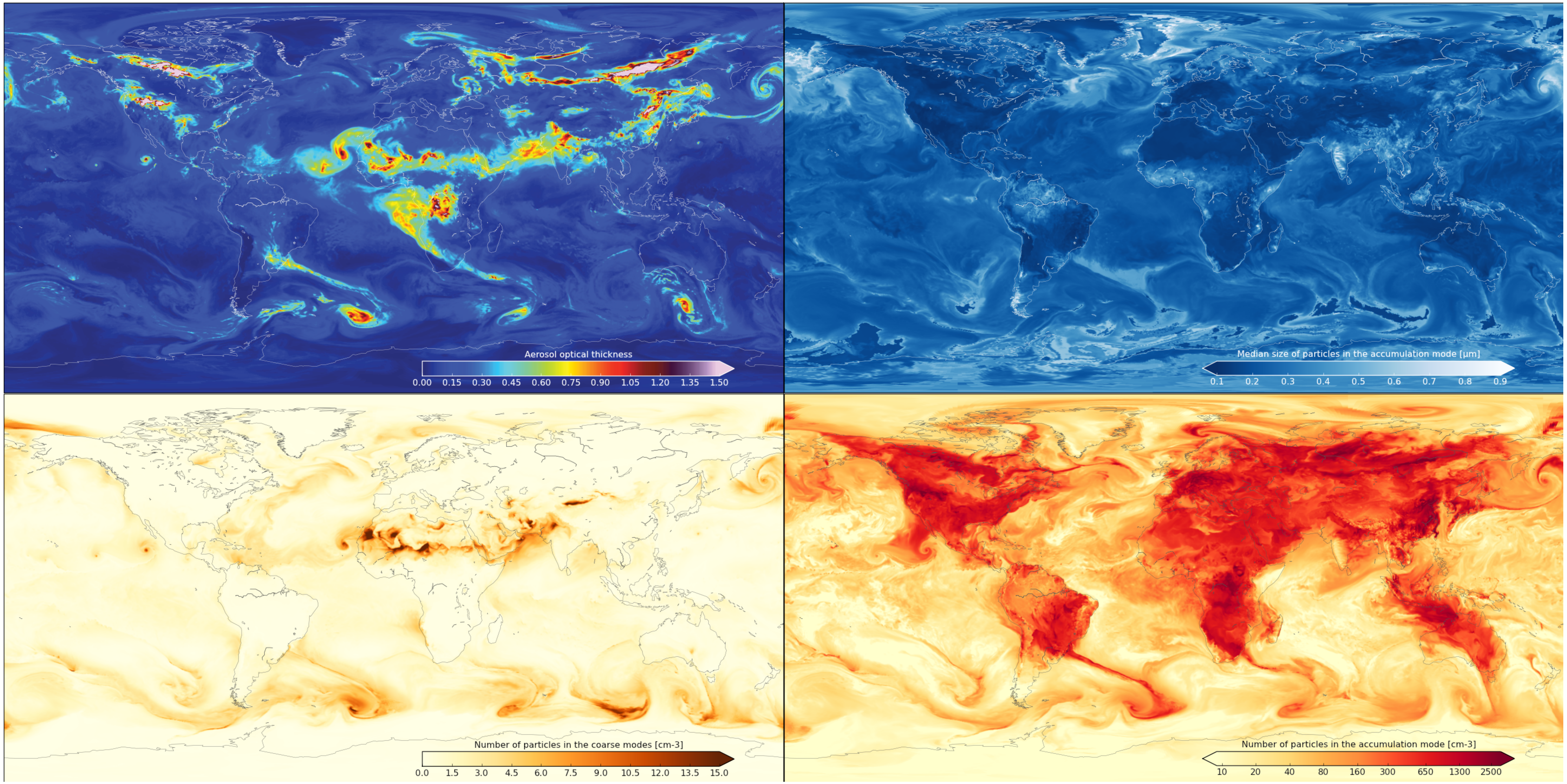




- Aerosol optical depth from GEOS aerosol simulations and reanalysis, including a modeling experiment with aerosol microphysics (MAM7)
- MAM7 results agree well with the reanalysis and the AERONET observations

Modal Aerosol Microphysics in GEOS

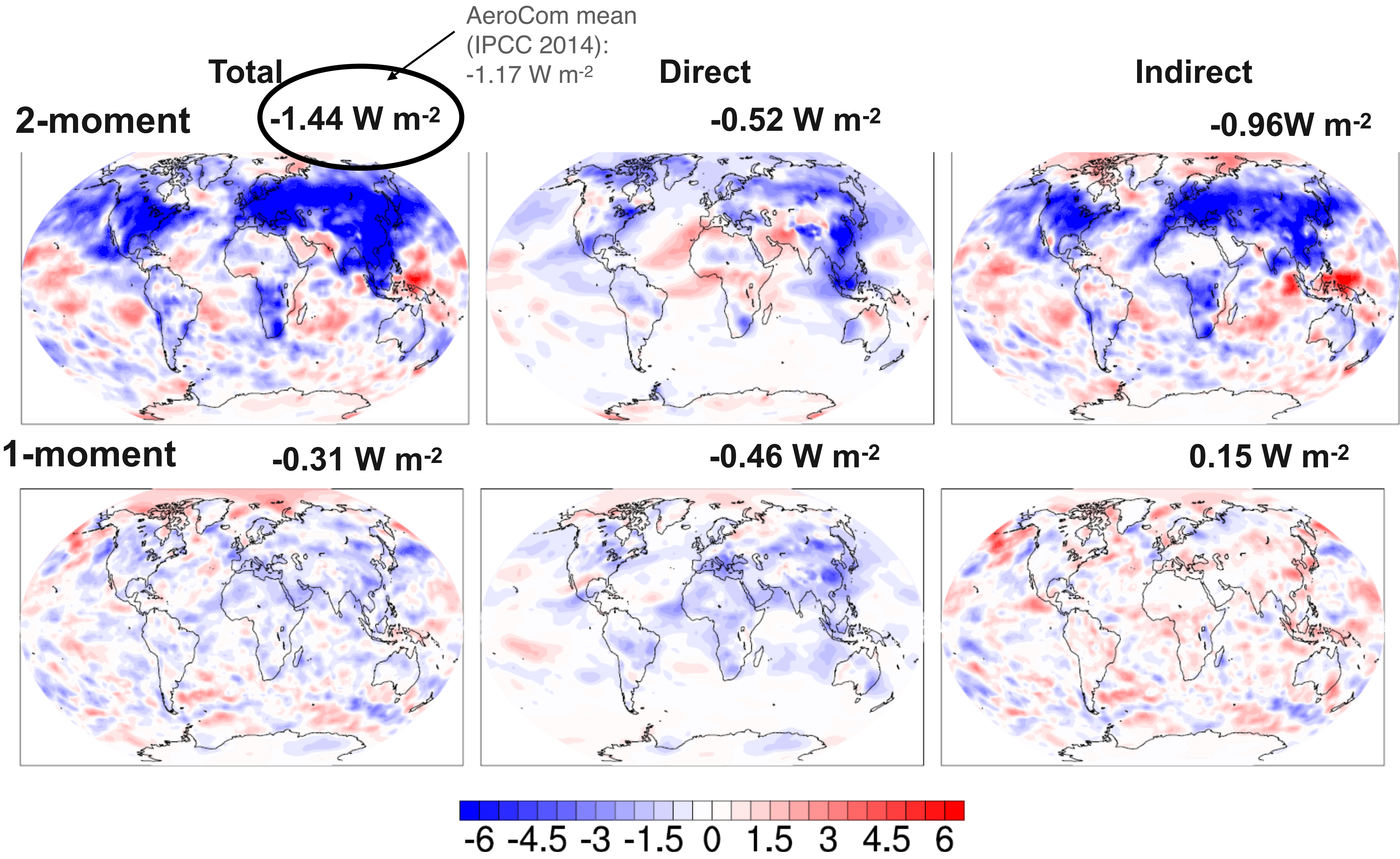


Modal Aerosol Microphysics in GEOS

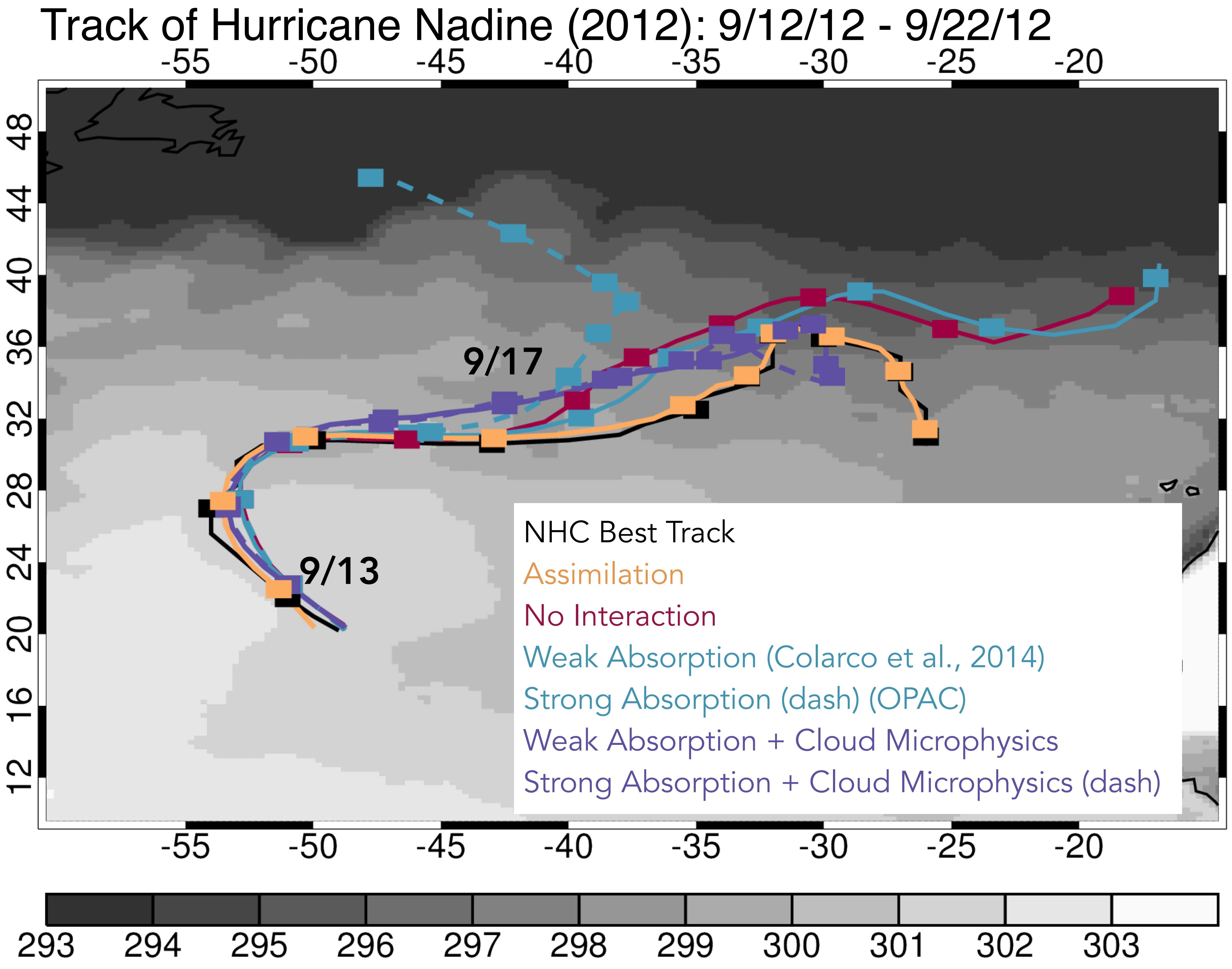
With MAM-enabled aerosol microphysics GEOS is now able to simulate the aerosol effect on clouds and climate

Further development:

- prognostic precipitation
- Fully integrated aerosol scavenging.
- Integration of 2M with the GF convective parameterization and shallow cumulus schemes.
- Prognostic graupel and hail.
- Ice nucleation on organics and biological material.
- Develop metrics to evaluate the indirect effect in production systems.



Impact of 2-Moment Cloud Microphysics on Hurricane Track



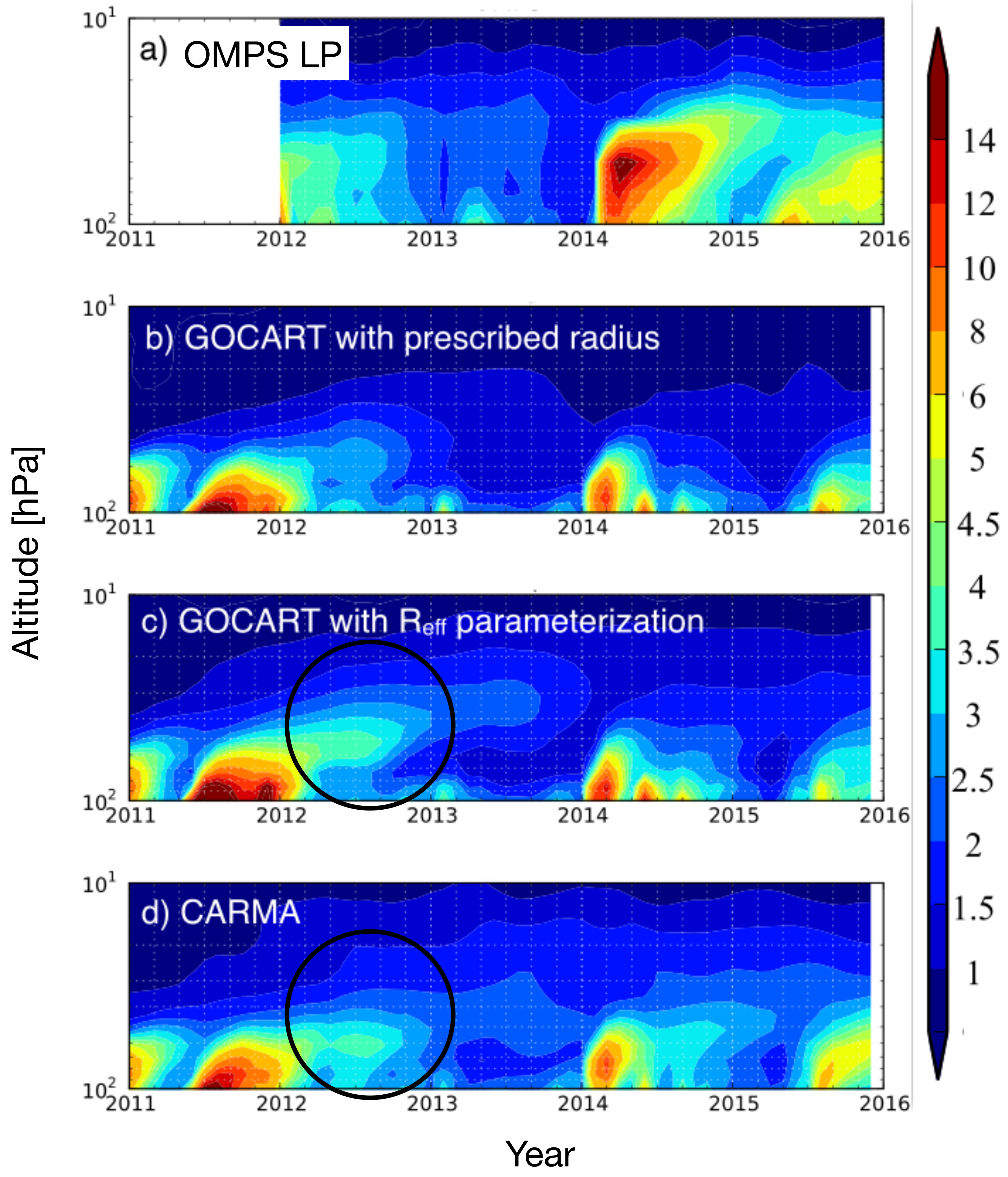
Nowottnick et al. 2018, in press, JAS

Using the NASA GEOS AGCM & assimilation system, the sensitivity of Hurricane Nadine (2012) to varying dust optical properties and the inclusion of a 2-moment cloud microphysics scheme was explored:

- Nadine's track showed strong sensitivity to assumed dust optical properties when only aerosol-radiation impacts are included
  - ➢ The more absorbing dust introduced a shortwave temperature perturbation that impacted Nadine's structure and steering flow
- When aerosol-cloud interactions were added, the track exhibited little sensitivity to dust optical properties
  - ➢ Enhanced longwave atmospheric cooling from clouds counters shortwave atmospheric warming from dust

Sectional Aerosol Microphysics

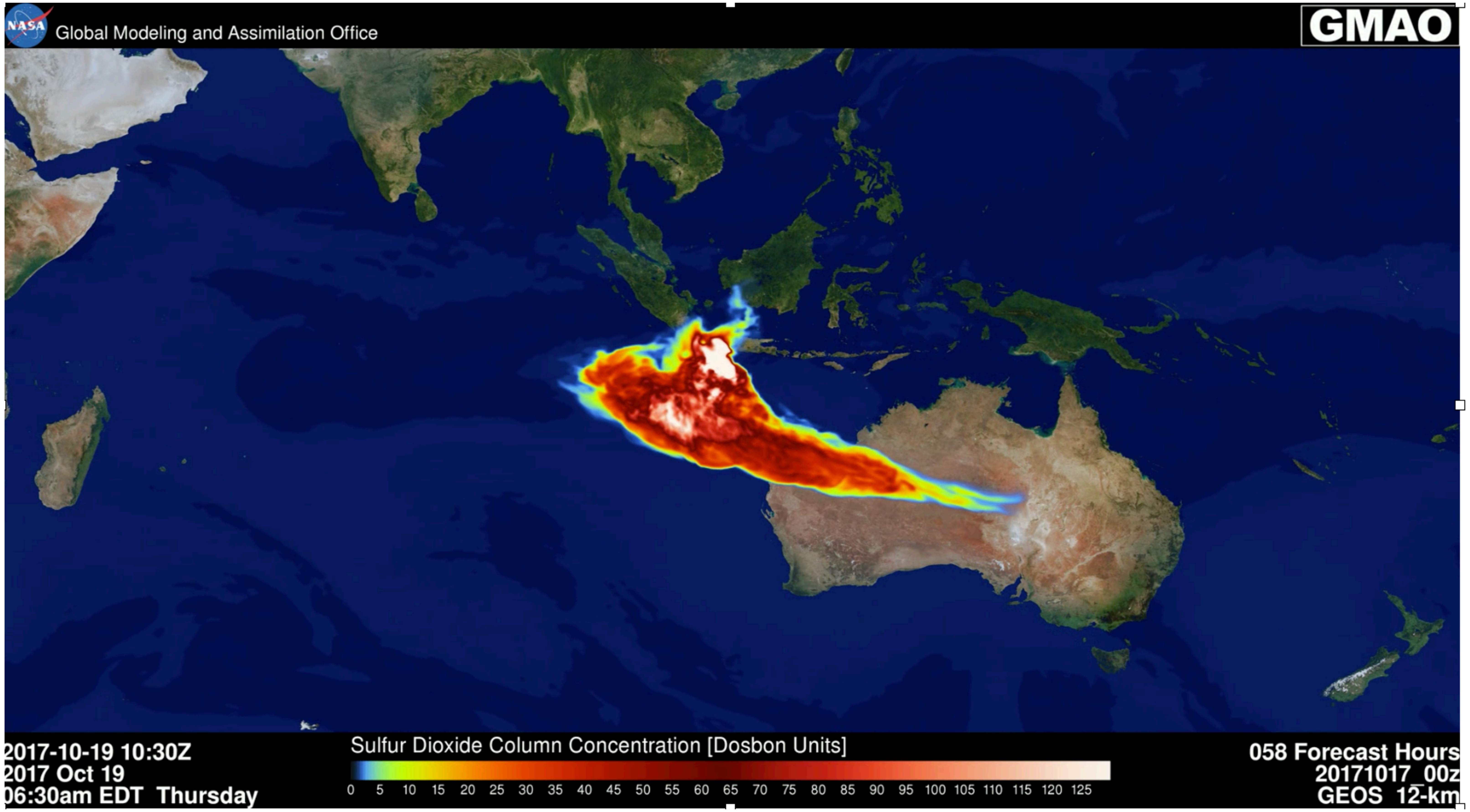
- Stratospheric sulfate aerosol source mechanism via OCS oxidation added in StratChem module and coupled to radiation
  - *Coupling with GMI mechanism is ongoing*
  - Now provides capability to simulate background stratospheric composition and perturbations, which can be compared with OMPS-LP observations
  - Mechanism is coupled to GOCART (bulk) and CARMA (sectional) aerosol modules, which themselves are coupled via surface area to StratChem; *coupling to MAM (modal) module and GMI mechanism ongoing*
  - Use of higher order CARMA mechanism to improve representation of evolving aerosol size in GOCART is being test



NRT Volcanoes

- None of the operational global aerosol modeling centers have a clear mandate to provide forecasts in event of a major volcanic eruption — this is the purview of the VAACS, who have as a mission to forecast ash distributions for (mainly) aviation purposes

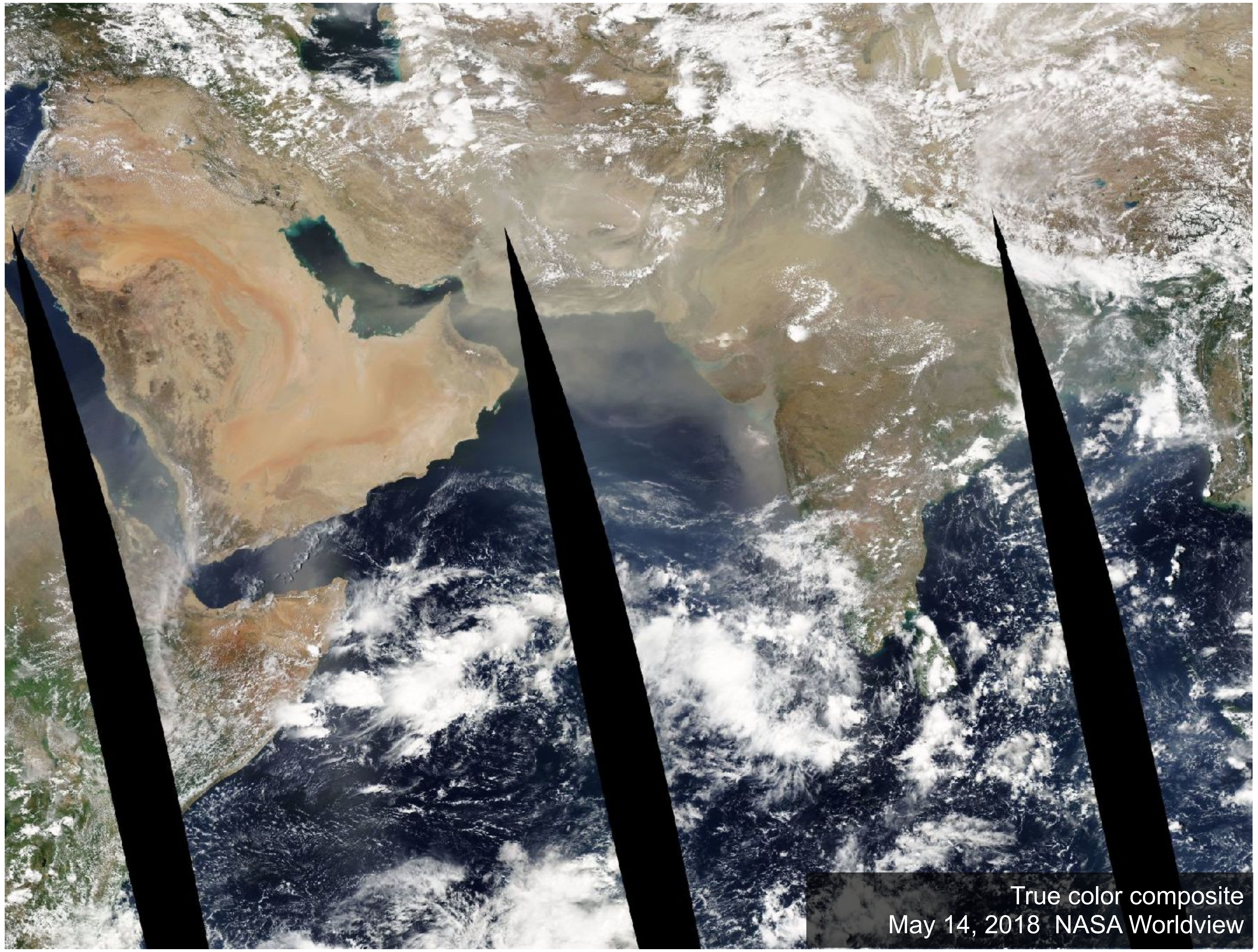
- We are watching the increased seismic activity in Bali at Mt. Agung, which was the third largest volcanic eruption of the 20th century in 1963



Future aerosol development

- Improve in-cloud and below-cloud wet removal in GOCART and MAM coupled with Moist Physics
- Couple aerosol schemes with the more comprehensive GMI and GEOS-Chem chemistry modules
- Extend MAM to include numerically efficient implementation of nitrate aerosols
- Complete integration of speciation in CARMA sectional model
- Use fire weather and flammability indexes to modulate fire emissions
  - *Complementary MAP project to tie biomass burning emissions to dynamic vegetation model*

- Wave model
  - *Implement sea-state based parameterization of primary marine aerosols emissions that predict size and composition (organic and inorganic fractions)*
  - *Strengthen ocean-atmosphere coupling through the implementation of physically based and explicitly resolved air-sea interface*



Aerosol Observing System

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

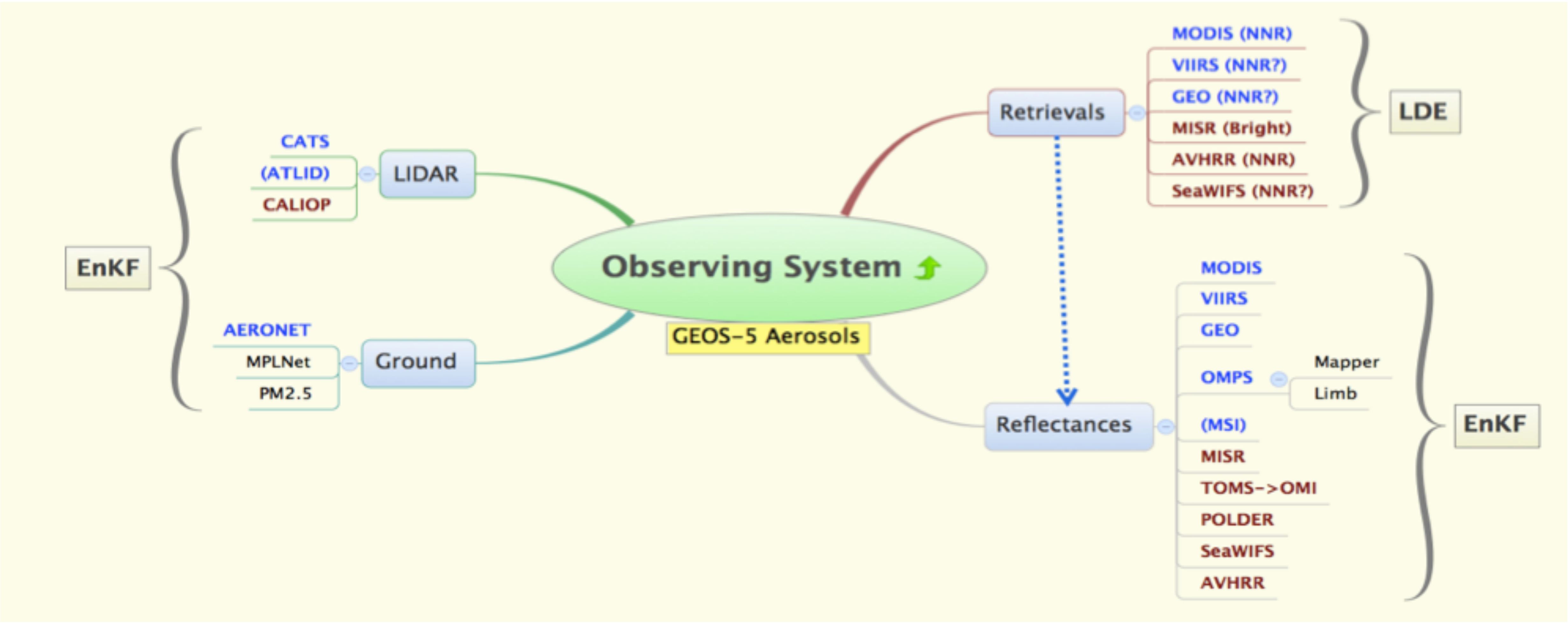
- Vertically integrated mass weighted by extinction coefficient, summed over multiple species: ***low observability***

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

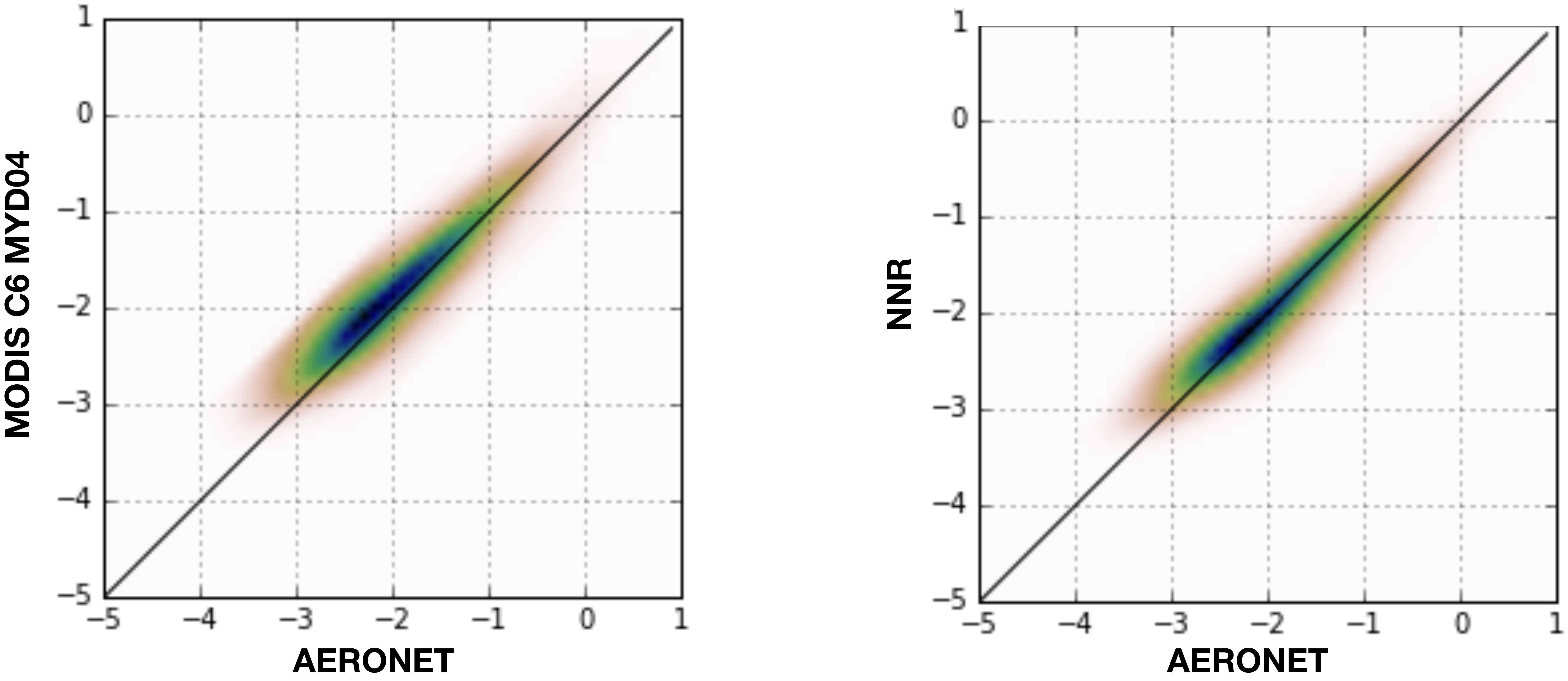
Neural Net for AOD_{550} Empirical Retrievals

- **Ocean Predictors**
  - Multi-channel
    - ~~**Operational AOD retrieval**~~
    - **TOA reflectances**
  - Solar and viewing geometry:
    - Glint
    - Solar
    - Sensor
  - Cloud fraction (<70%)
  - Wind speed
- Target: AERONET
  - **η = log(AOD+0.01)**

- **Land Predictors**
  - Multi-channel
    - ~~**Operational AOD retrieval**~~
    - **TOA reflectances**
  - Solar and viewing geometry:
    - Solar
    - Sensor
  - Cloud fraction (<70%)
  - Surface Albedo or BRDF Kernels
- Target: AERONET
  - **η = log(AOD+0.01)**

Neural Net for AOD_{550} Empirical Retrievals

MODIS Neural Net AOD_{550} Retrievals trained on AERONET



From LEO to GEO: Calibration Transfer

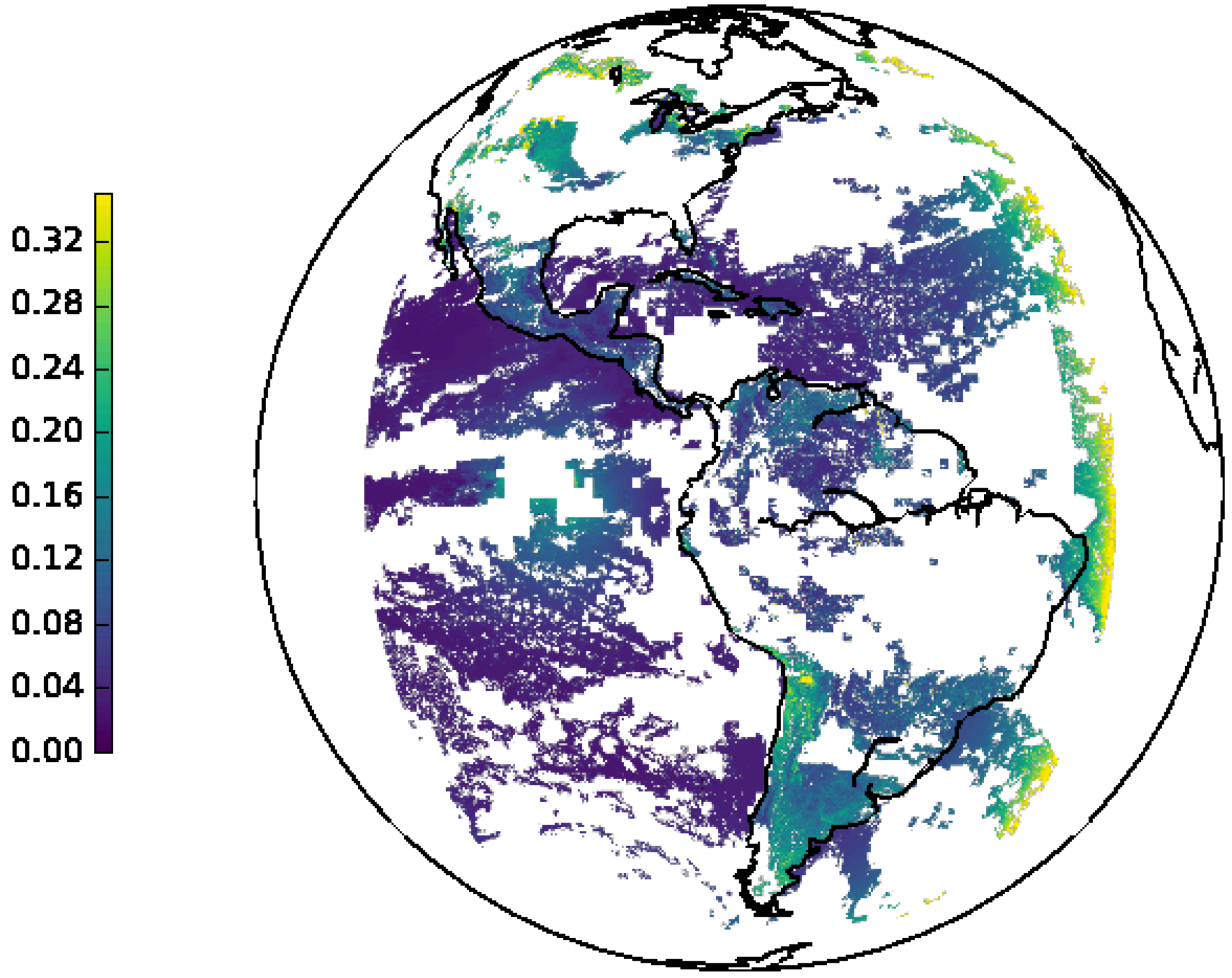
NRT SatCORPS cloud cleared GOES-16 and AHI-8 TOA reflectances

- ➢ Provided by NASA Langley SatCORPS Group (R. Palikonda, W. Smith)
- ➢ 1 full disk scan per hour

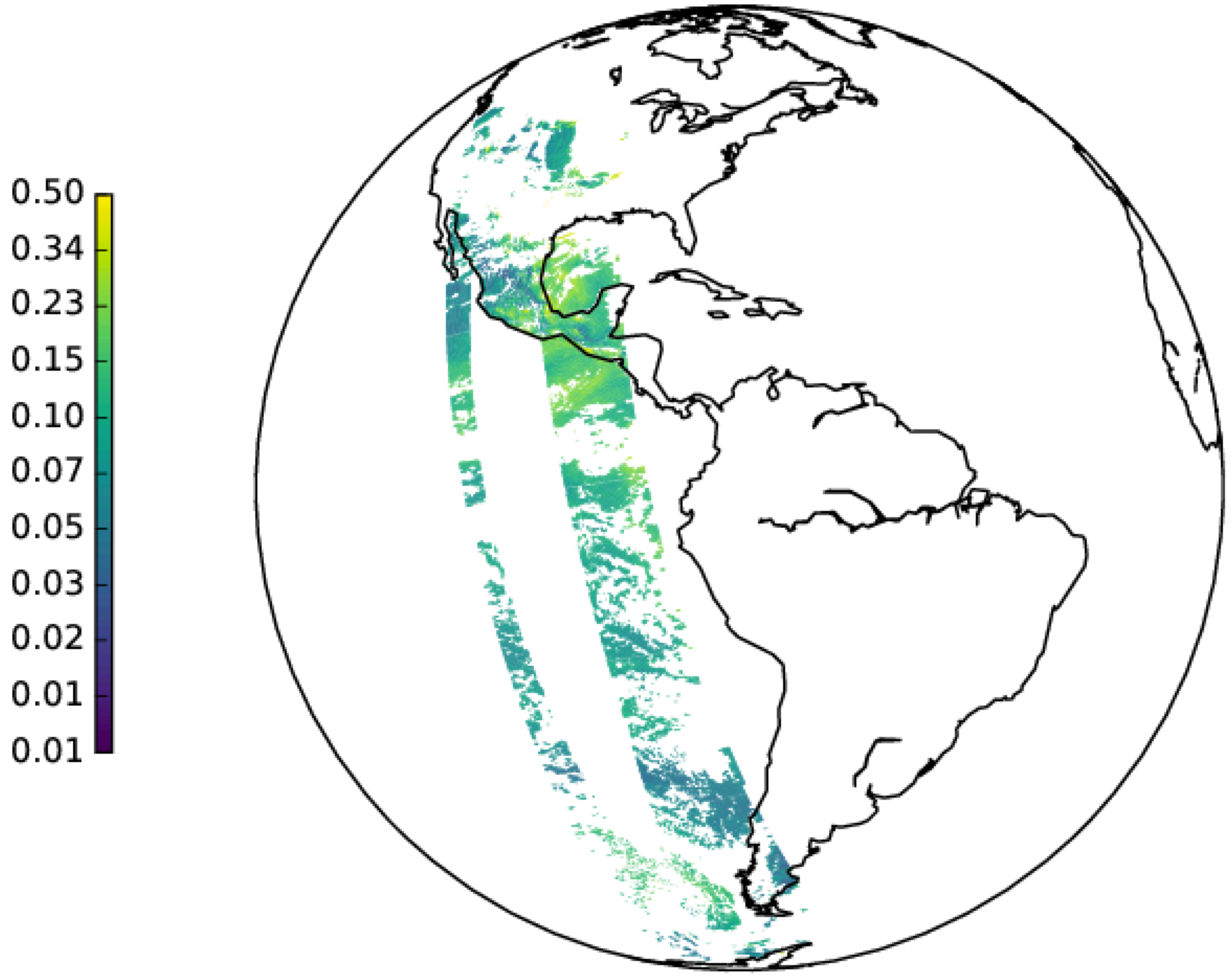
Use MODIS-NNR AOD as targets for training GEO Reflectance observations

INPUTS → TARGETS

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



MODIS Aqua NNR AOD 2018-03-11 20Z



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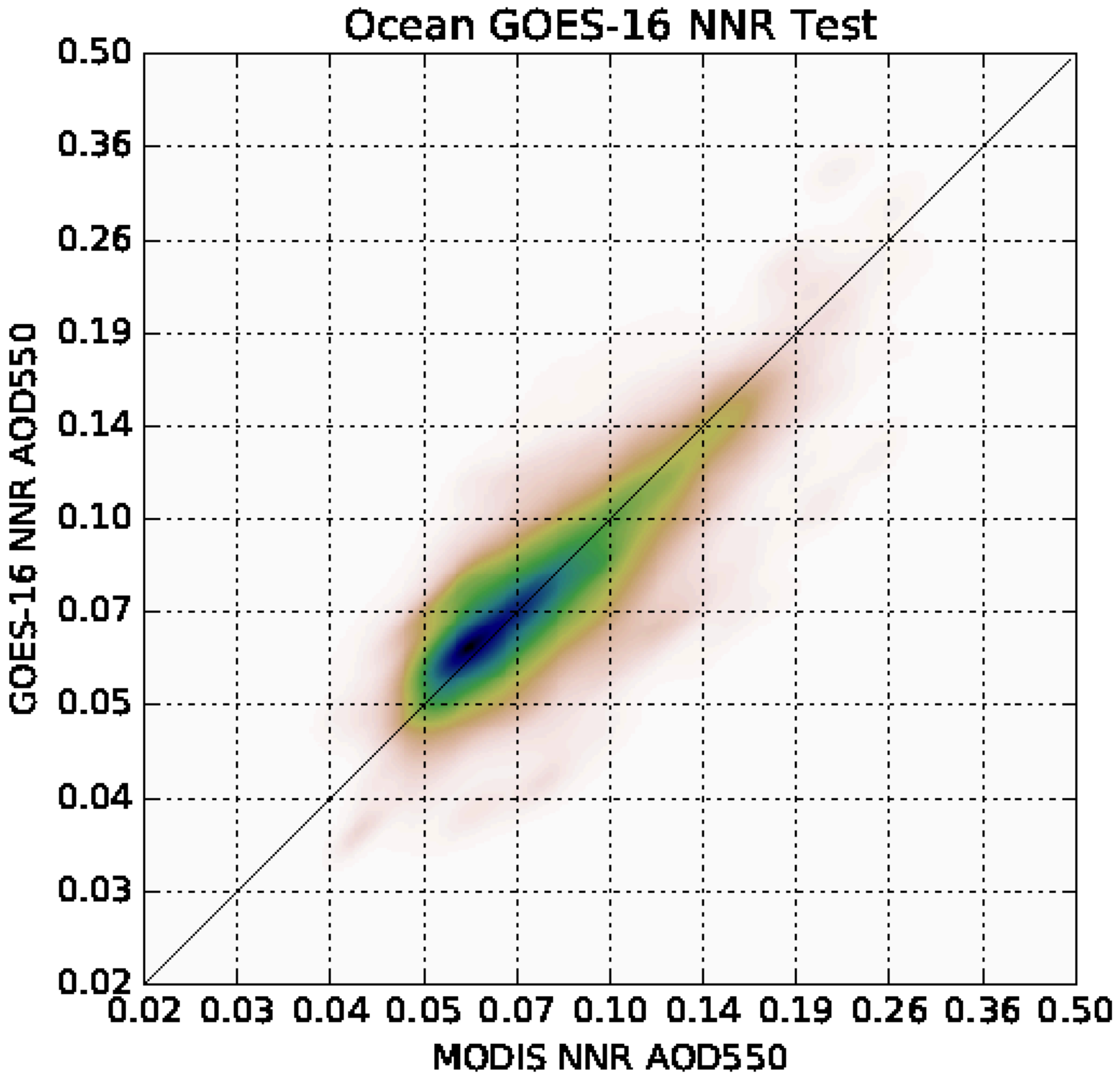


Preliminary Test with Ocean Data

- 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)

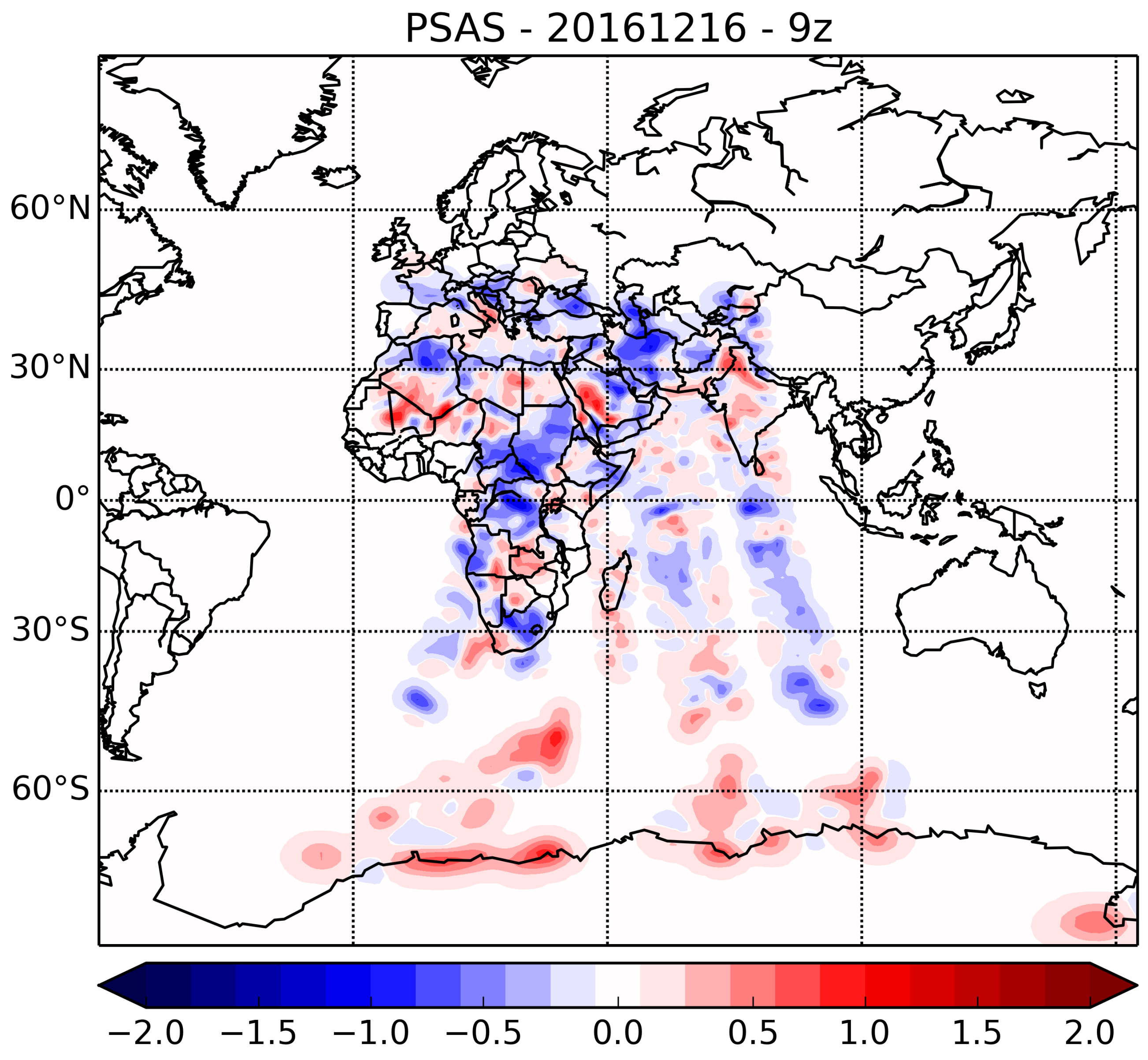
Aerosol EnKF

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

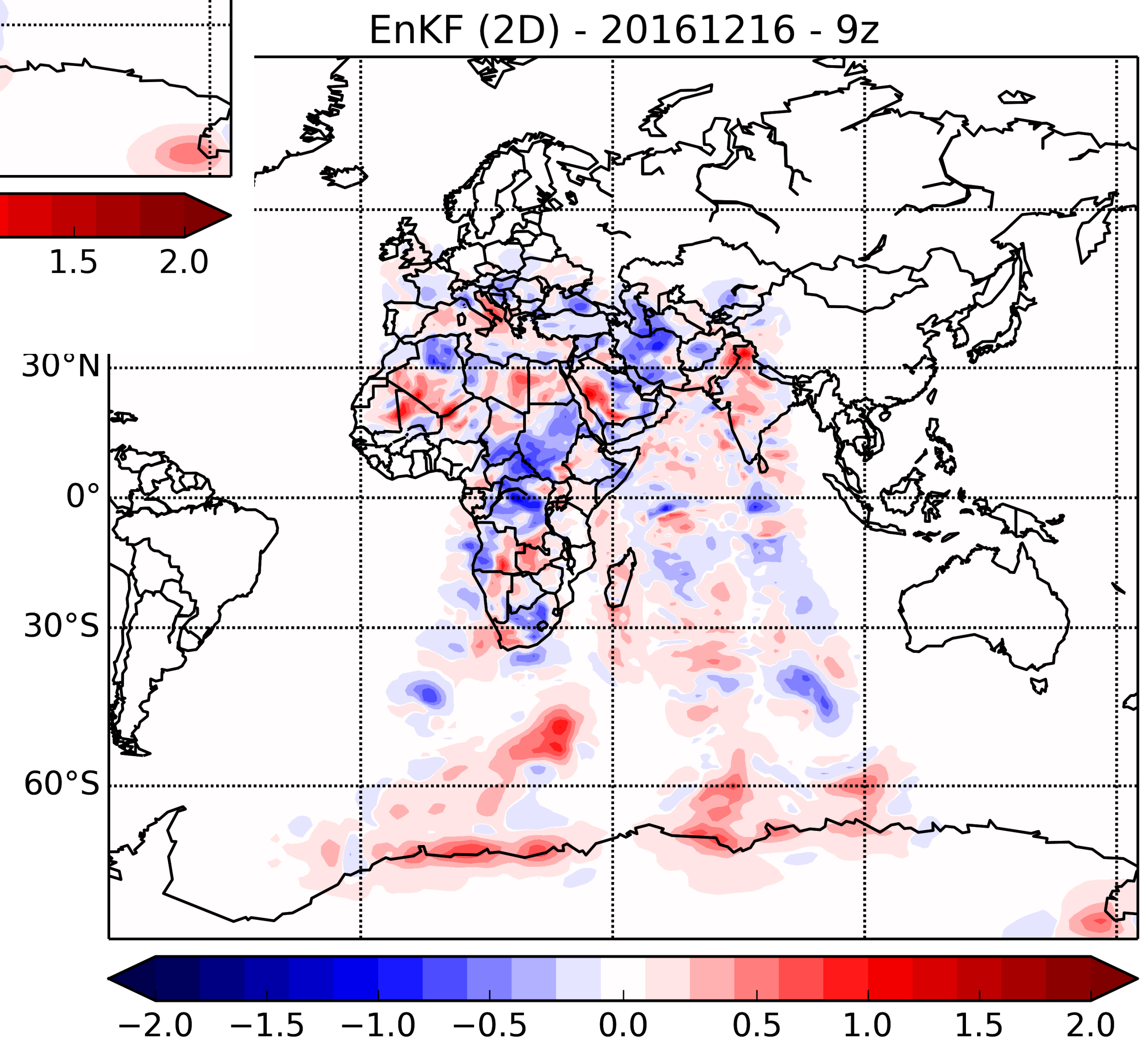
The same Whitaker-Hamill EnKF used for the hybrid Meteorological assimilation has been adapted for aerosols

Target observation systems

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



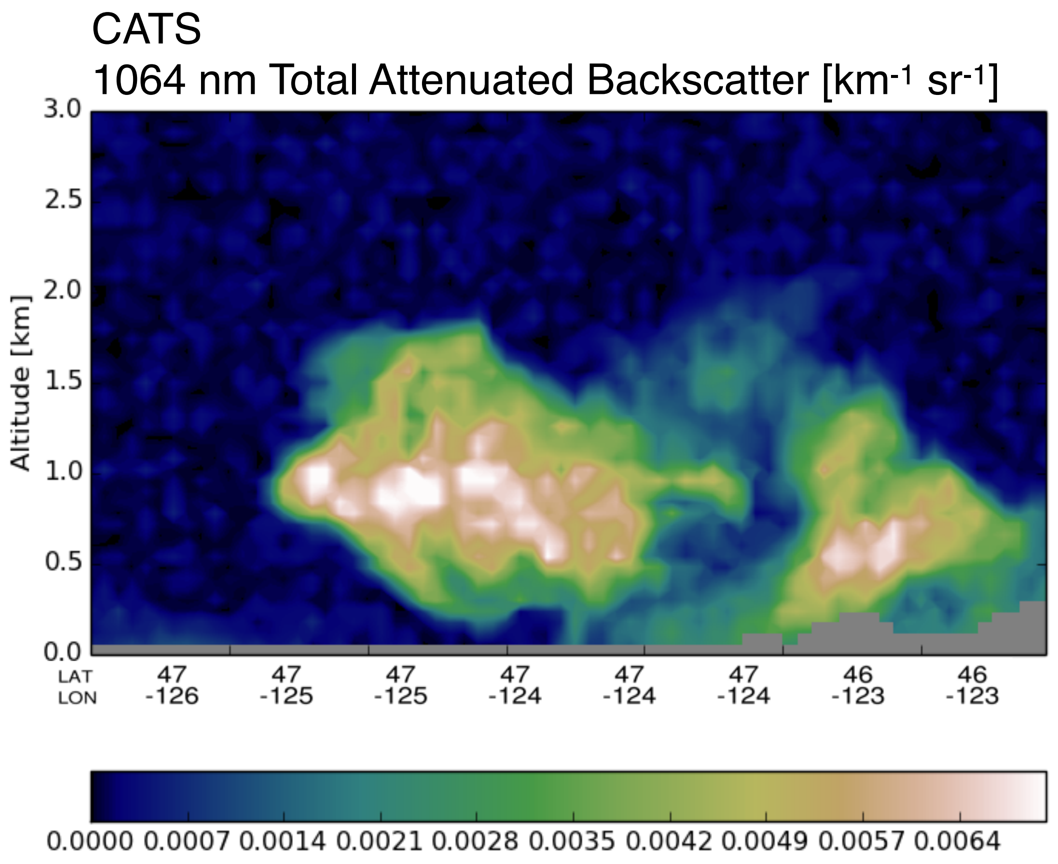
Current PSAS Based Analysis

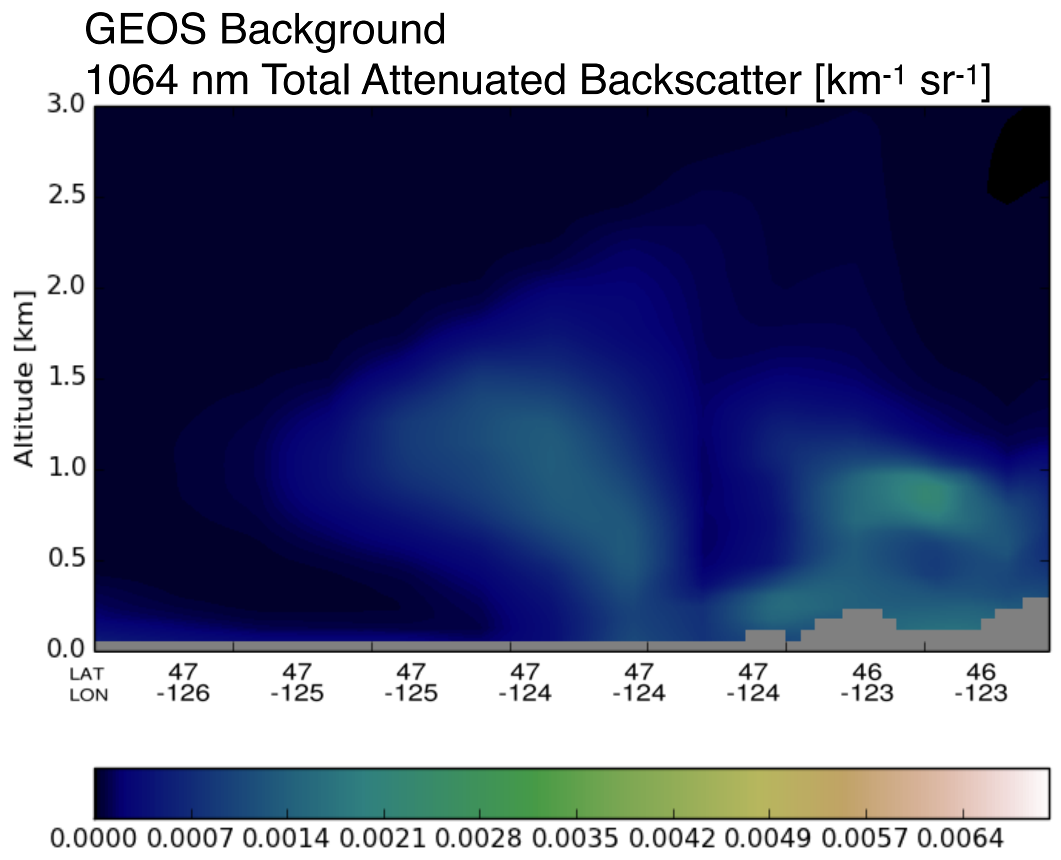


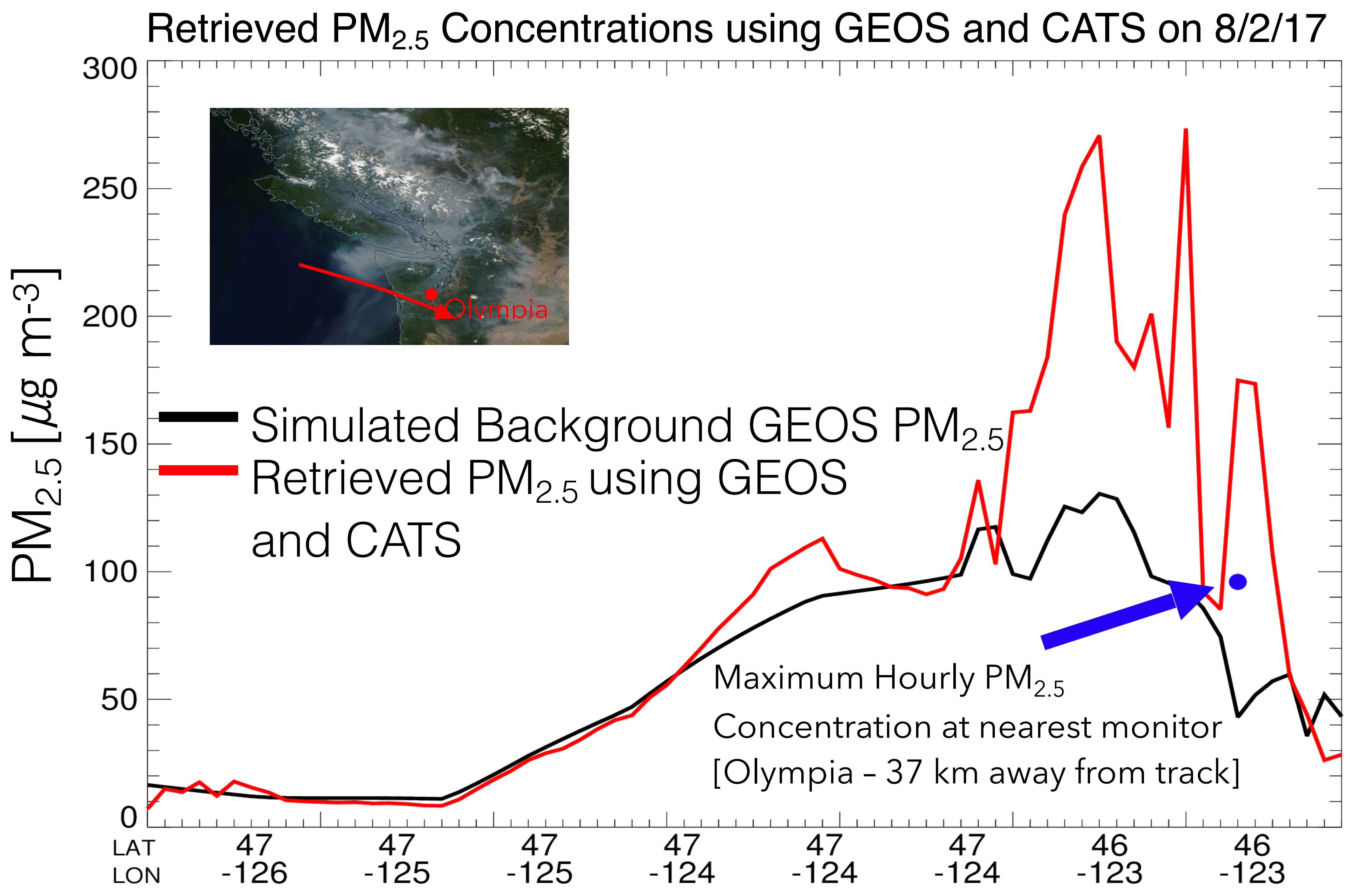
Ensemble Mean EnKF Analysis

Retrievals of Surface Mass Concentration using GEOS and CATS

- Using vertical profiles of total attenuated backscatter from the CATS lidar on the ISS, we have developed a 1-D ensemble based (1-D EnsVar) retrieval technique that produces vertically resolved estimates of aerosol optical quantities and mass concentrations using the GEOS aerosol modeling system
- Recently, we have built on this capability to retrieve speciated aerosol quantities, with a focus on surface air quality
- In this example, the GEOS background simulated the vertical extent of a smoke plume over the Pacific NW US, but failed to match the intensity observed by CATS
- After incorporating CATS observations, retrieved surface $PM_{2.5}$ concentrations increased where the plume was observed at the surface
- This technique demonstrates the utility of having NRT lidar products for air quality forecasting applications



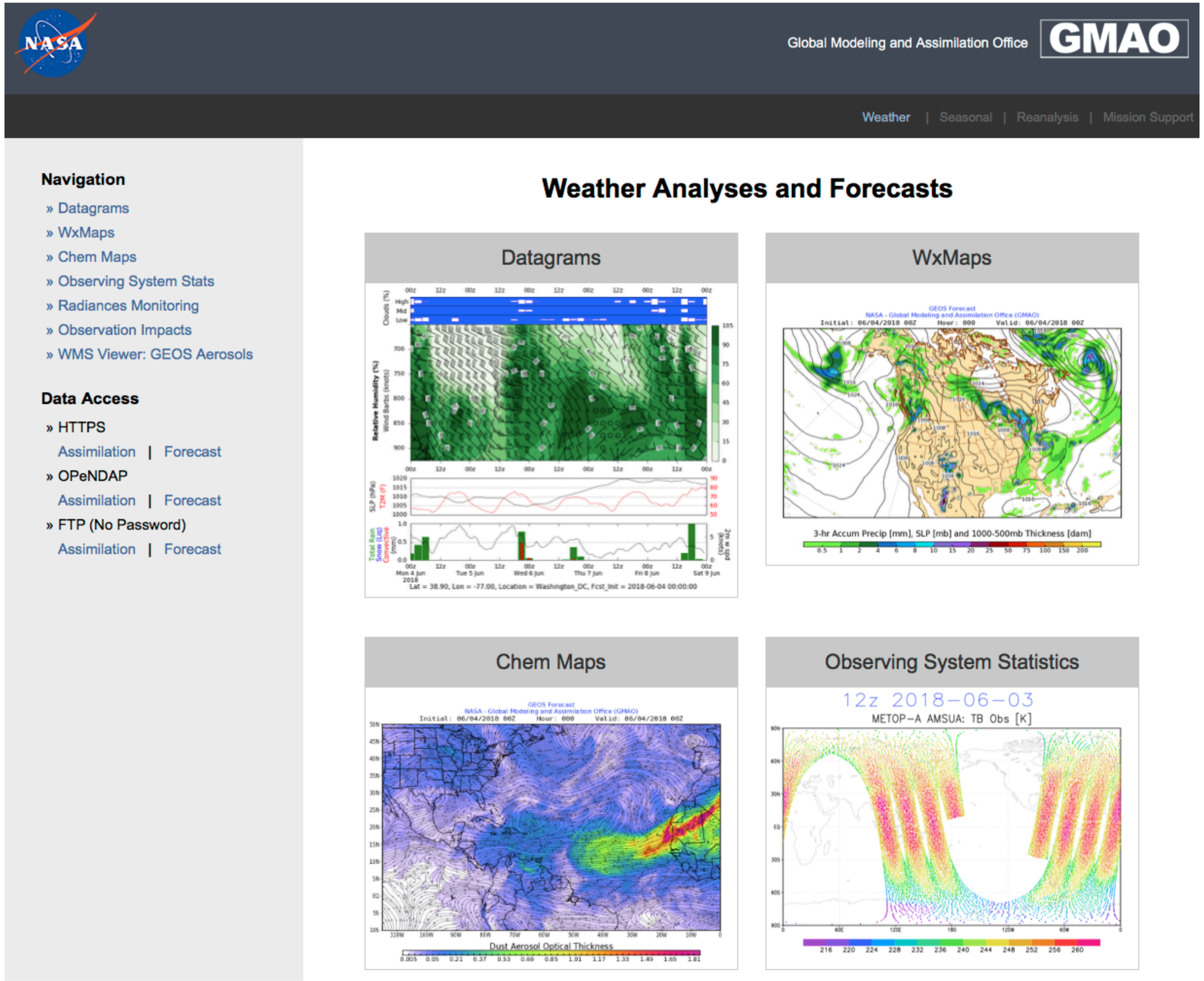




Field Campaign Support

Global 5-day chemical forecasts

- O_3, aerosols, CO, CO_2, SO_2
- Constituents transported on-line, radiatively interactive
- Nominally 12.5 km



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

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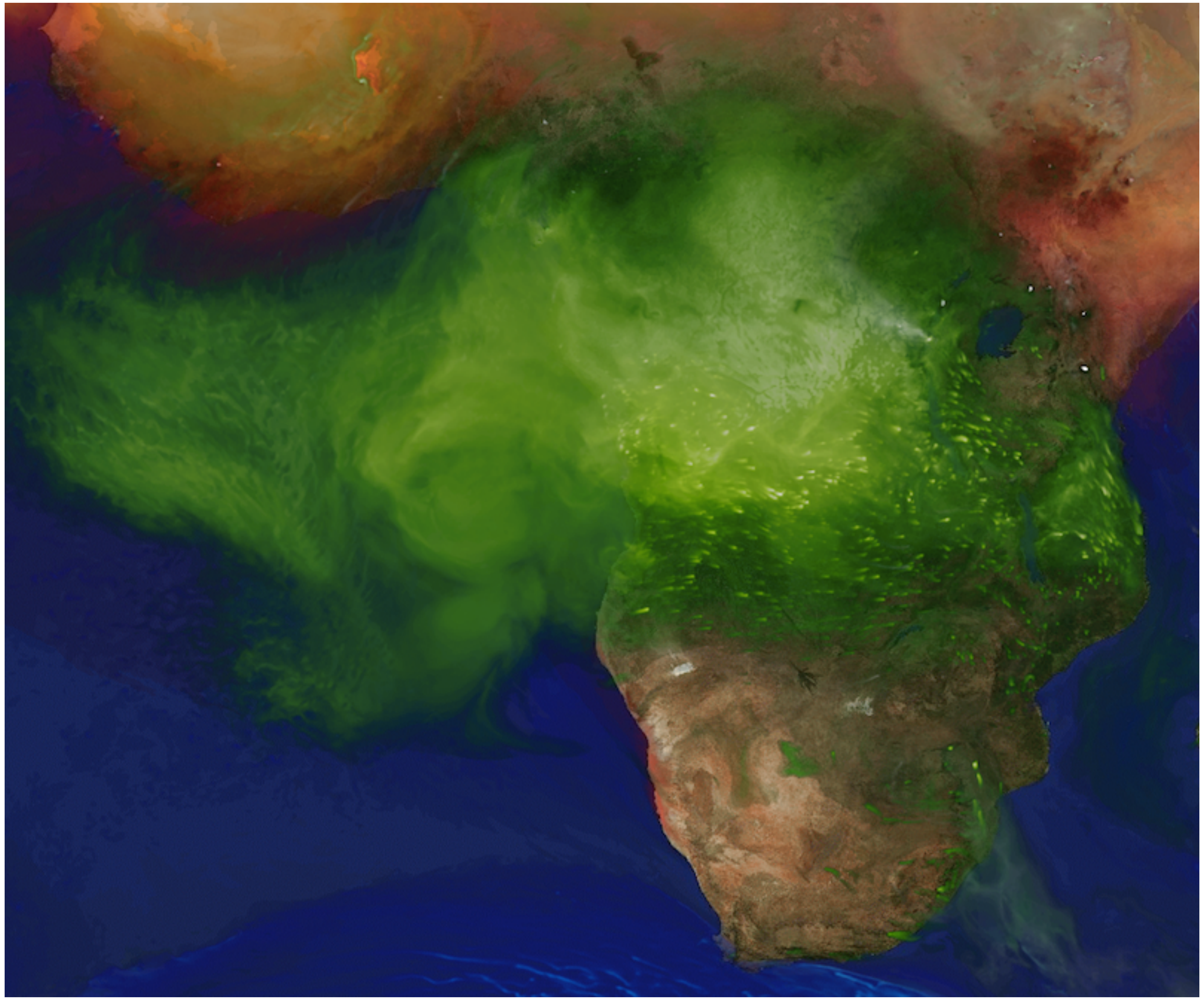
QFED real-time biomass emissions

- Top-down algorithm based on MODIS Fire Radiative Power (Aqua/Terra)
- FRP emission factors tuned by means of inverse calculation based on MODIS AOD data
- Daily mean emissions, NRT
- Prescribed diurnal cycle
- BB emissions are deposited in the PBL



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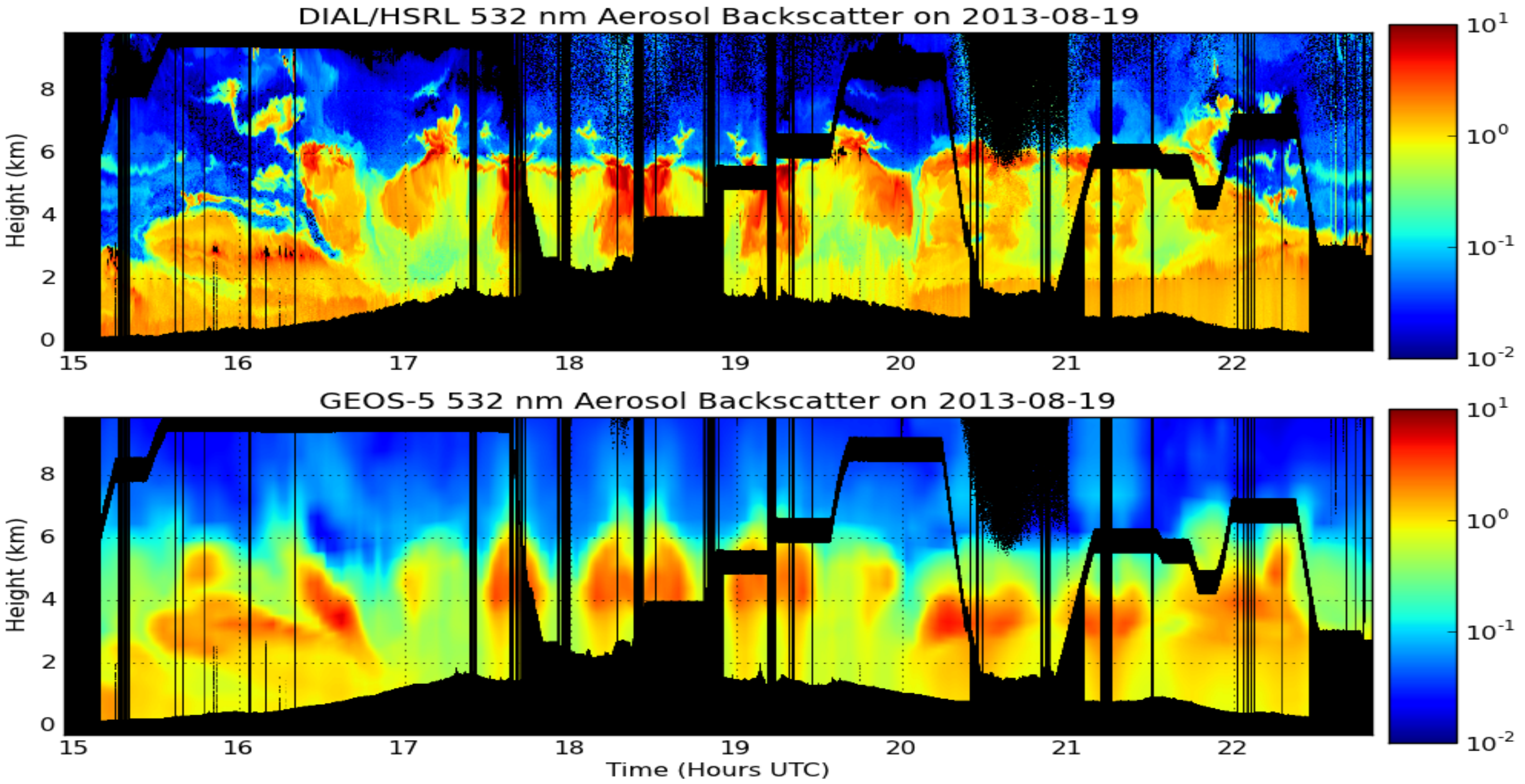
Since 2007 supported field missions include: TC4, ARCTAS, GloPac, ATTREX, DISCOVER-AQ, HS3, SEAC4RS, ATom, ORACLES



Comparison of observed (top) and simulated (bottom) aerosol backscatter for a slight during the 2013 SEAC4RS campaign.

MERRA-2 Global Mean AOD Analysis: 1980 - Onward

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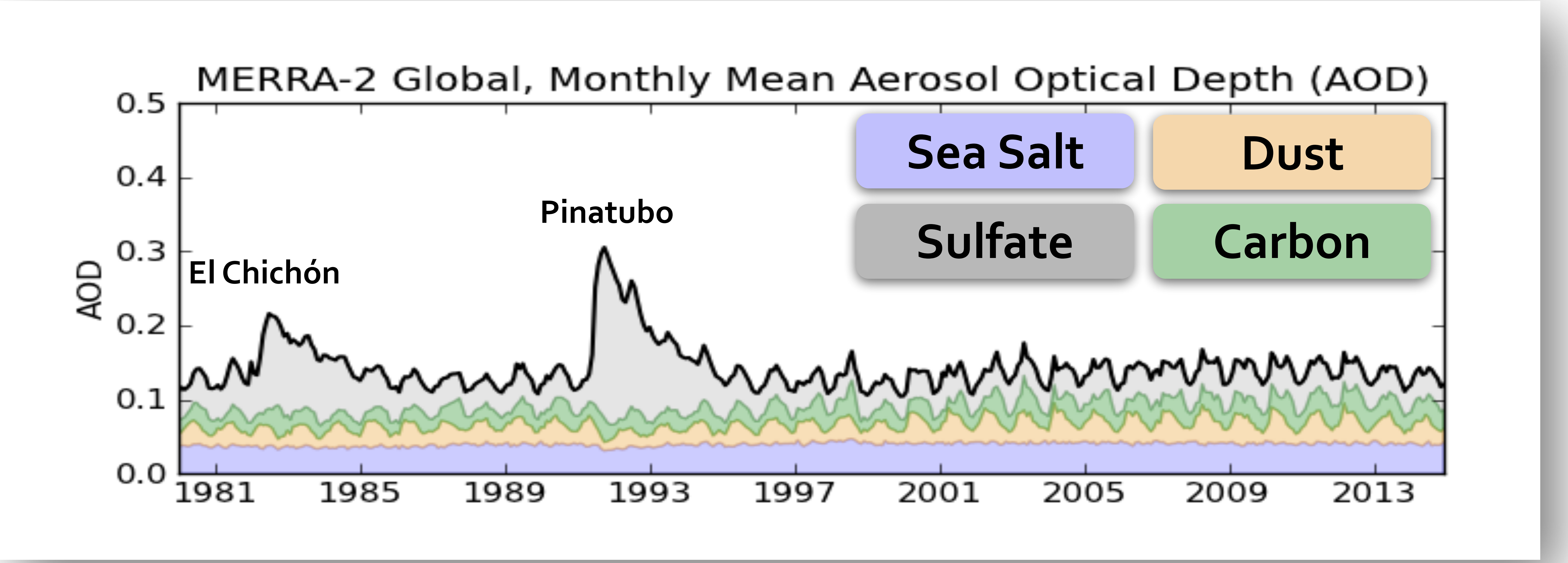
- Aerosols are ***coupled*** to the meteorological reanalysis (both radiatively and through emissions/loss processes).



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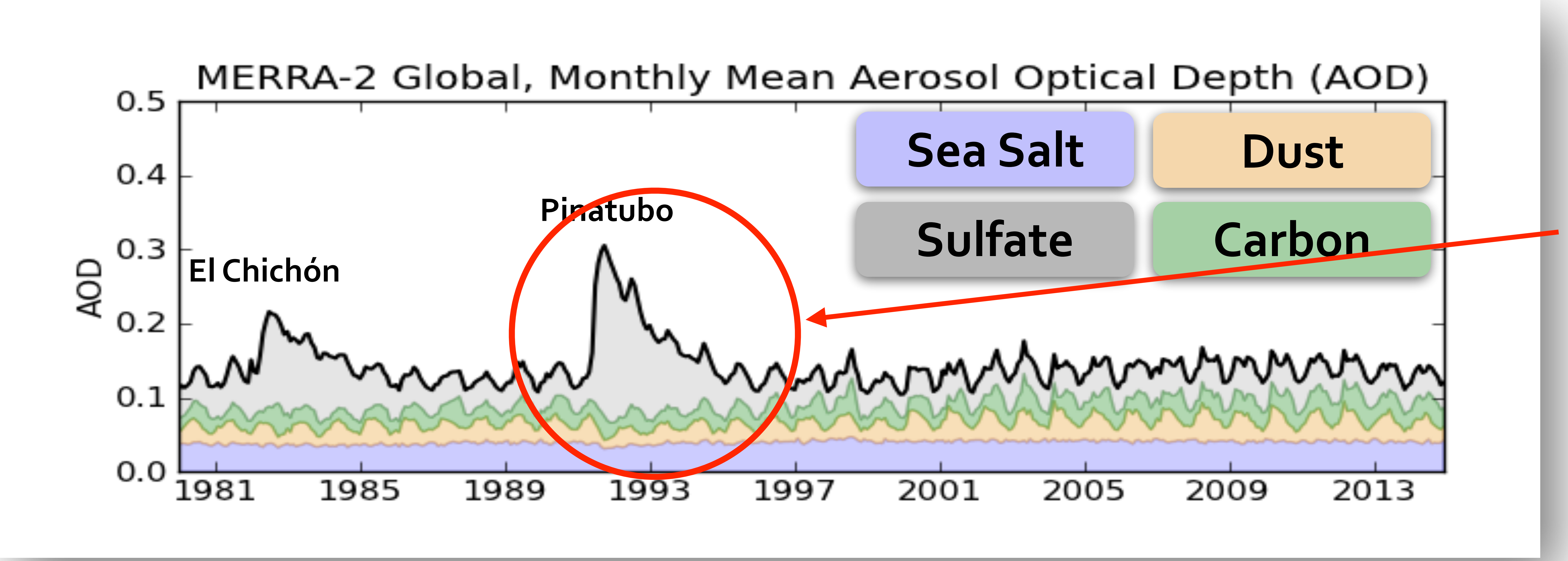
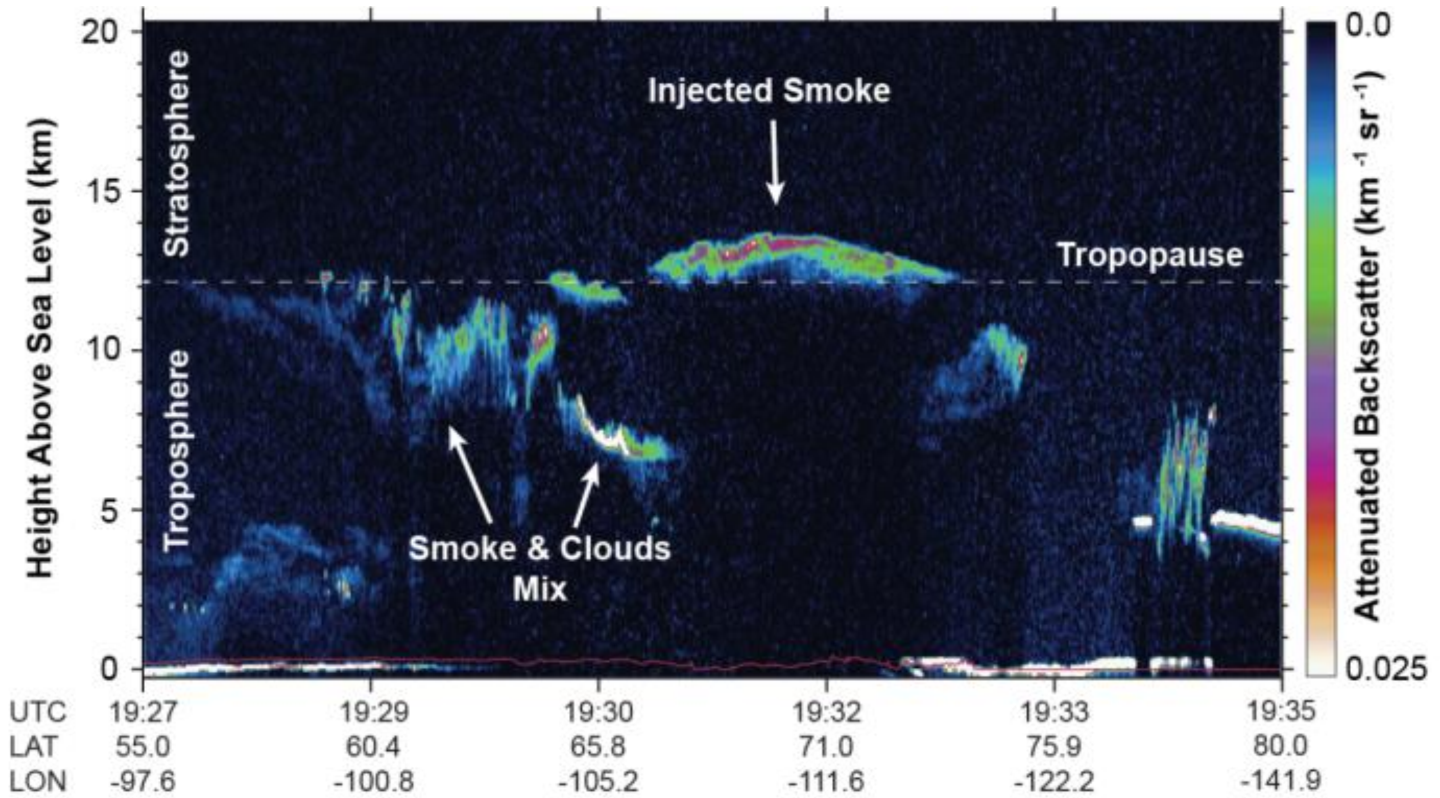
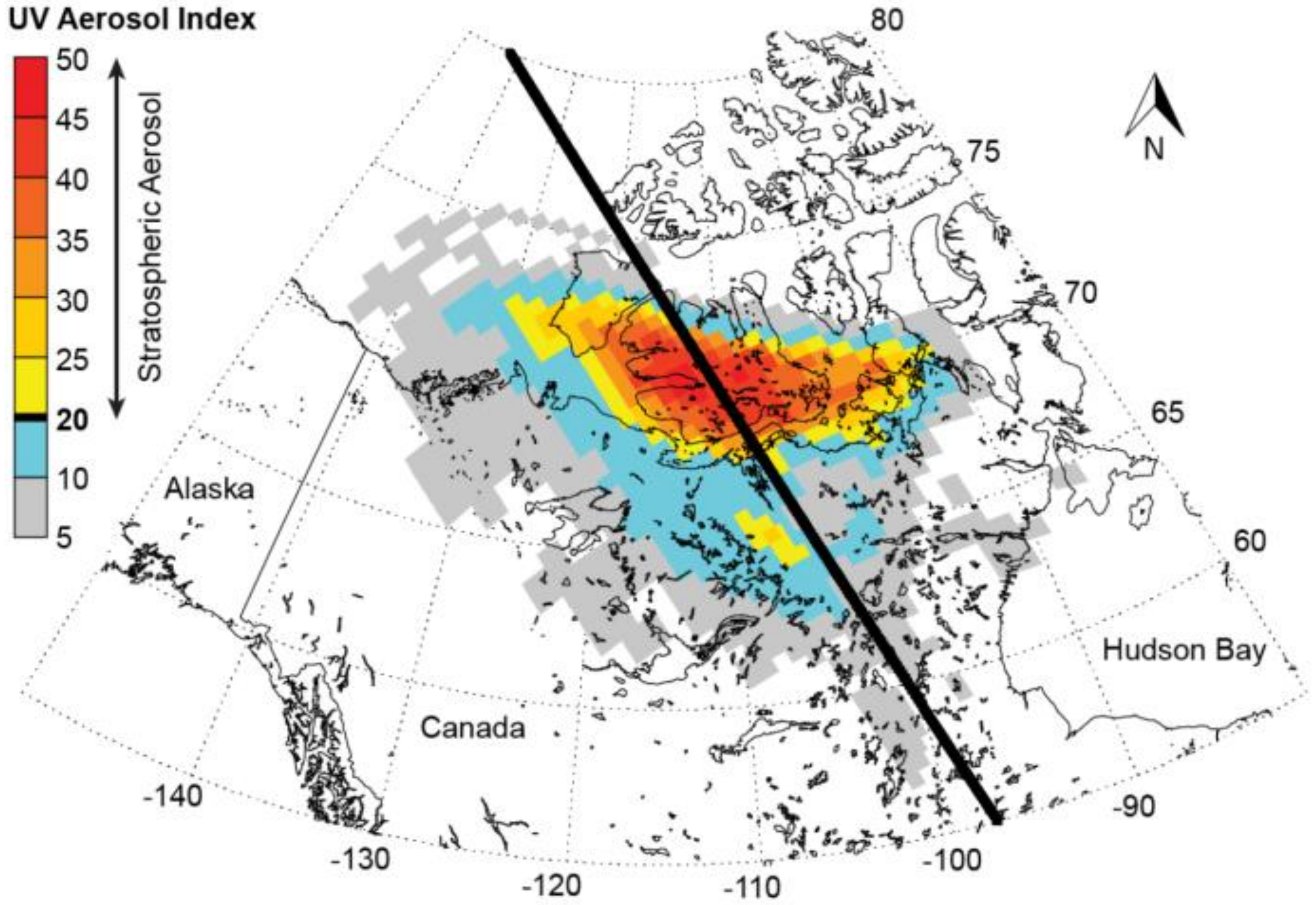


Errors in aerosol properties and vertical distribution propagate to mis-apportionment of aerosol species

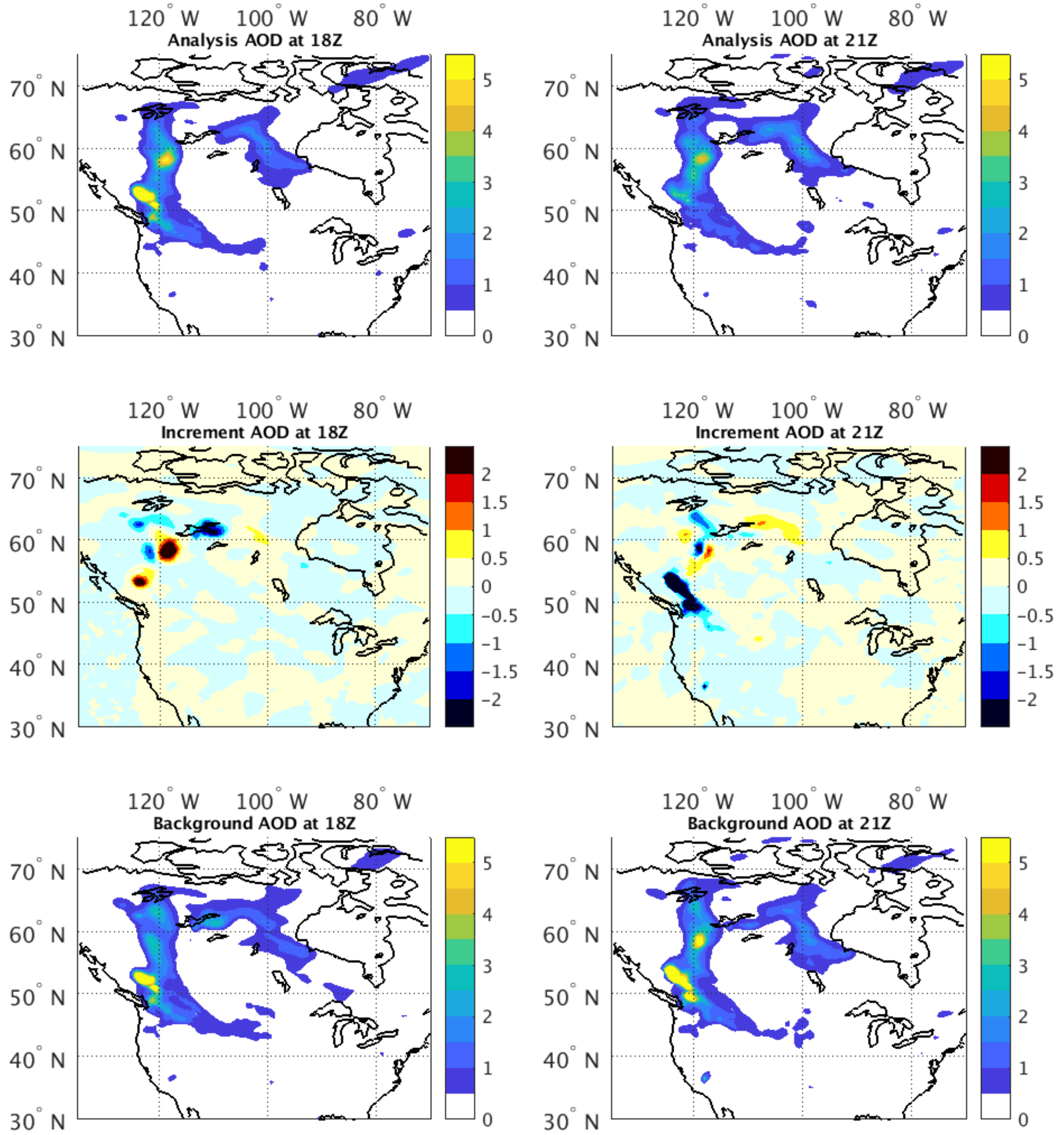
Example: 2017 Canadian Pyro-Cb Event

Observations: 20170814

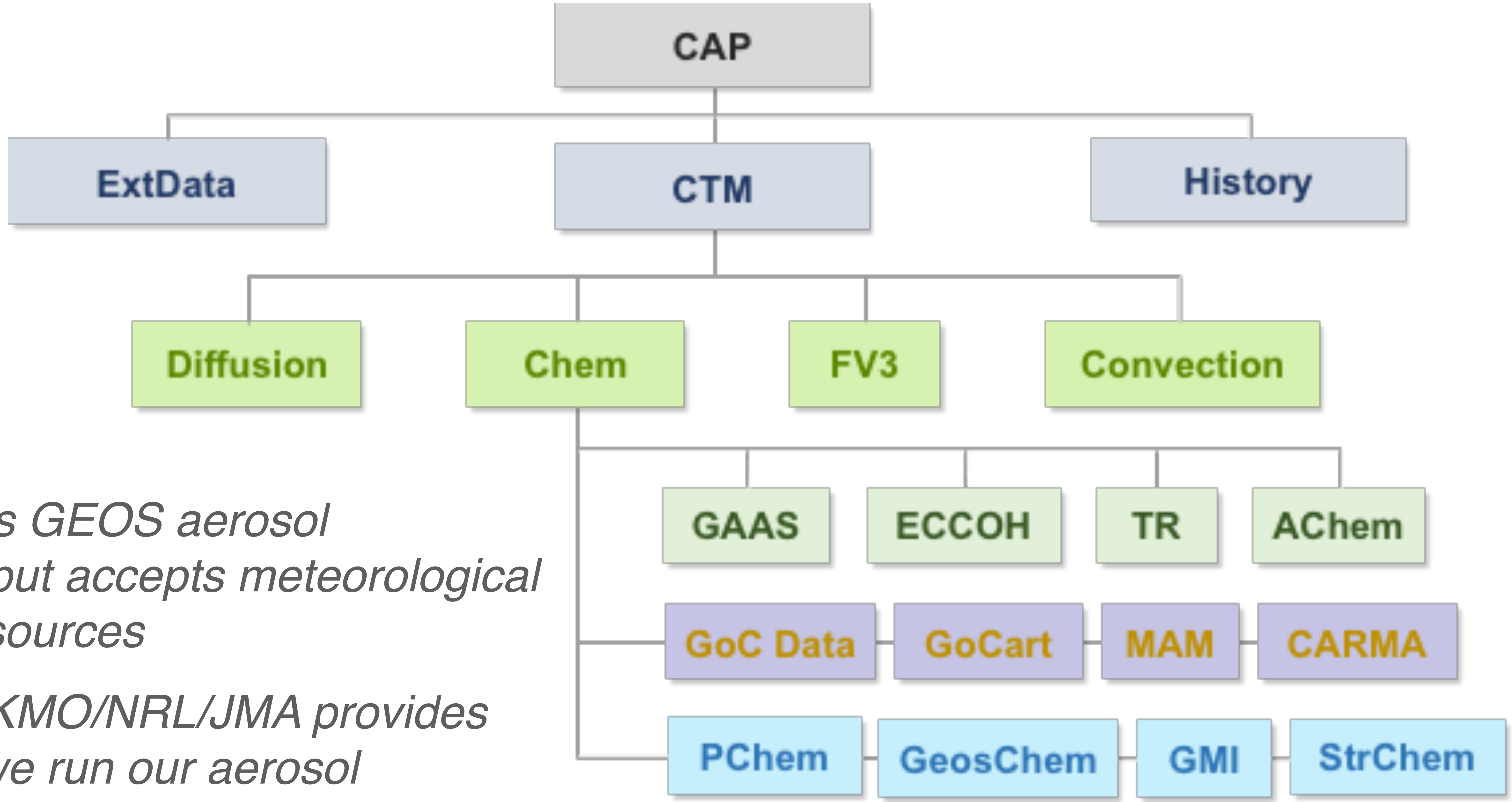




MERRA-2: 20170812



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