The GEOS-5 Aerosol Modeling and Data Assimilation System

Updates and Future Development

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ICAP 6th Working Group Meeting, Boulder, CO, October 21 - 24, 2014

Aerosol Modeling Objectives

- Developing a **hierarchy of global models** capable of skillfully representing
  - the global aerosol distribution as constrained by available in situ and remotely sensed measurements
  - the microphysical processes needed for parameterizing aerosol-cloud-precipitation interactions
  - aerosol interactions with Earth-system components

- Developing a **comprehensive aerosol data assimilation capability** for constraining and calibrating aerosol transport models, including the estimation of emissions needed for driving such models

- Developing an **aerosol forecasting capability** in support of NASA field campaigns.

- Developing an **aerosol observing system simulation capability** for aiding planning of future NASA observing missions.

Outline

- GEOS-5 Configuration
- Forecasting and Mission Support
- Reanalysis Activities
- GEOS-5 Nature Run
- Observation Simulation
- Future Directions

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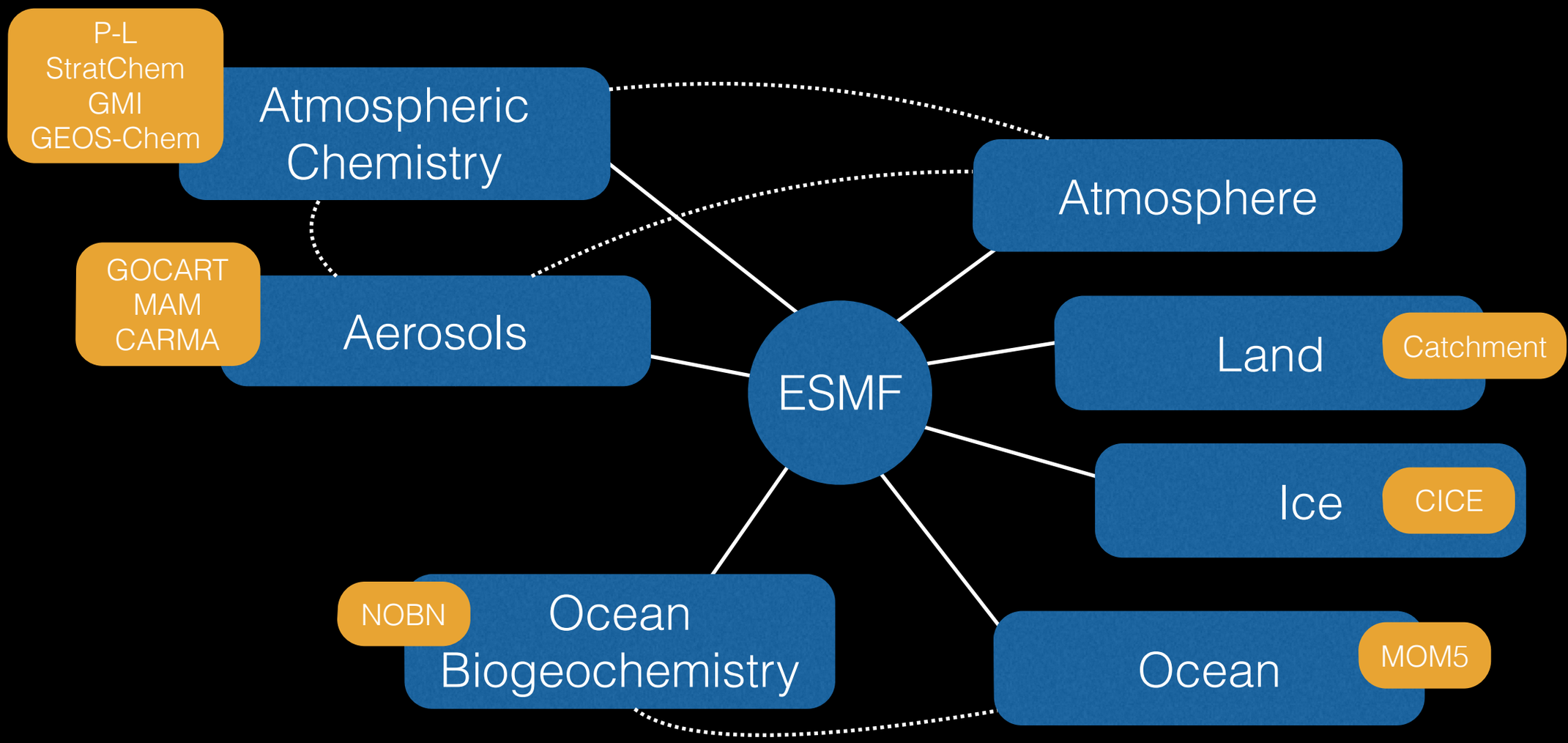
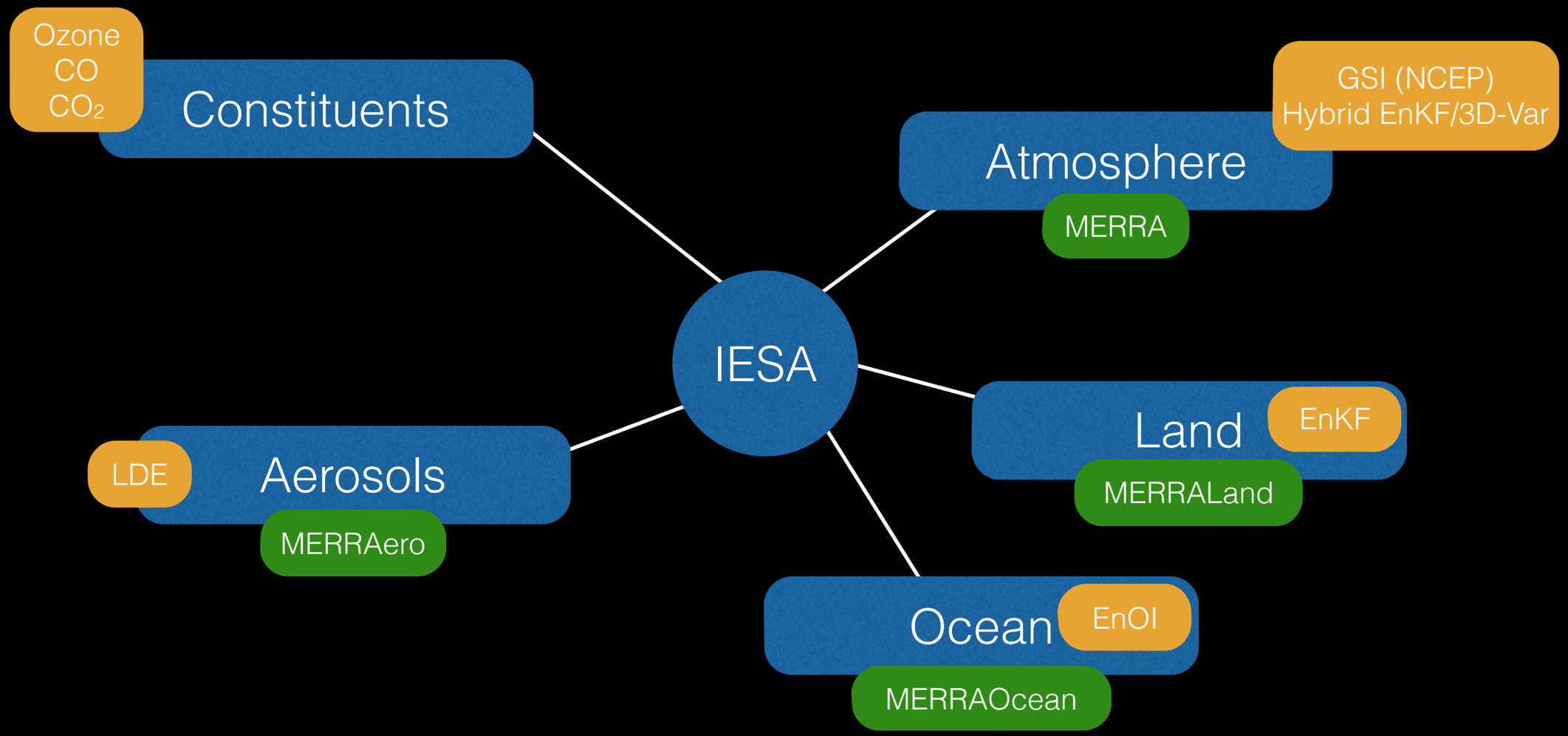
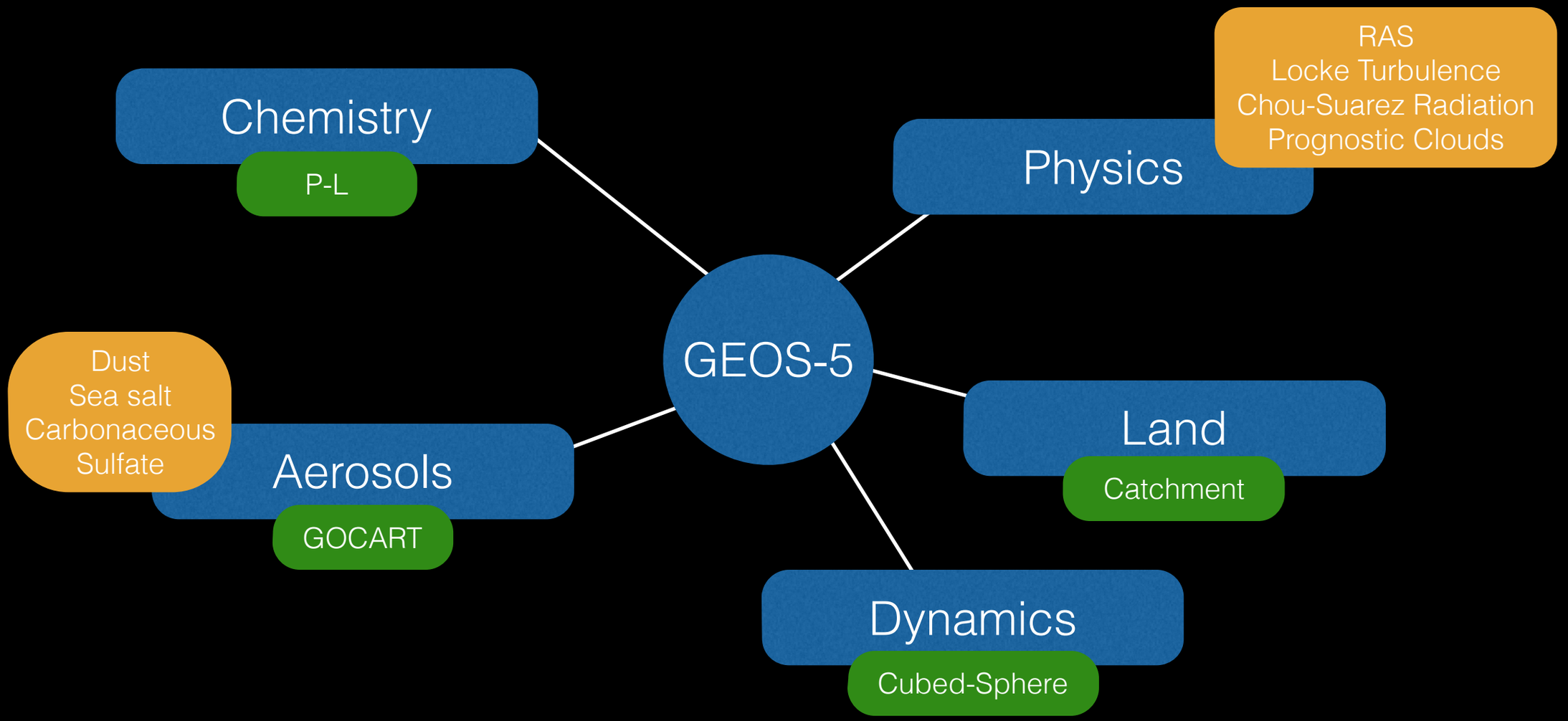
GEOS-5 Earth System Model



Integrated Earth System Analysis



2014 NRT Configuration



Global, 25 km, 72 levels, top at 0.01 hPa

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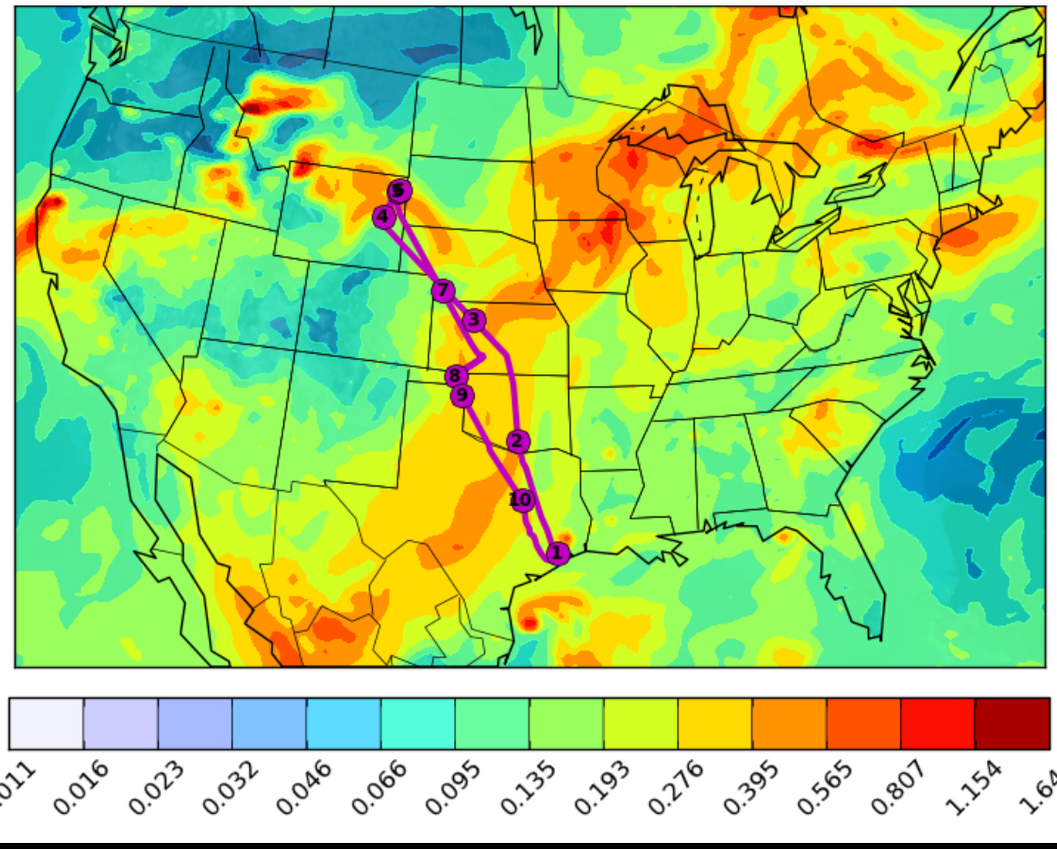
GEOS-5 Forecasting Support

SEAC⁴RS

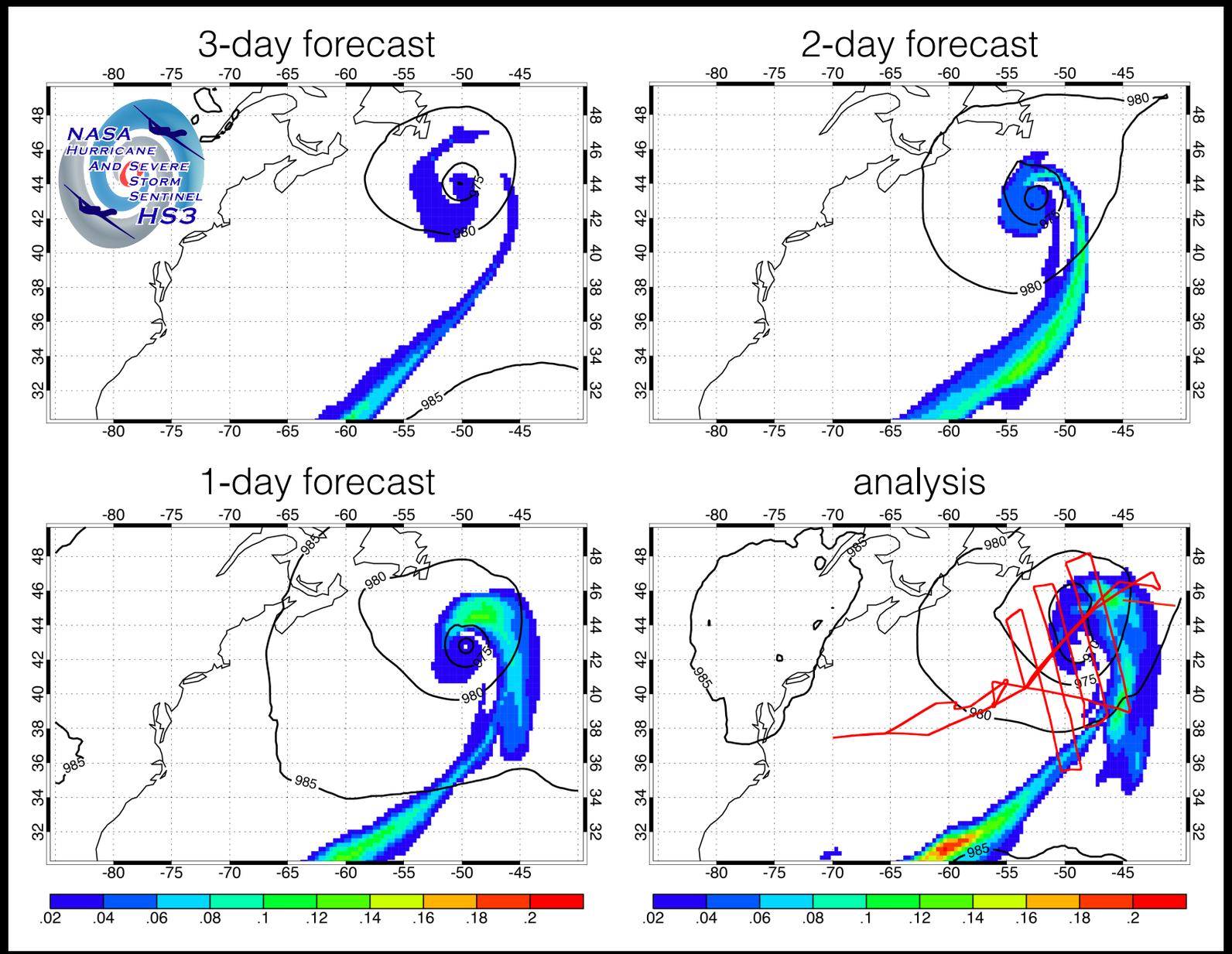
- US regional atmospheric composition, clouds, and climate aircraft mission based out of Houston, TX (August-September 2013)
- GEOS-5 provided forecasting of aerosols and meteorology for flight planning support and science analysis

GEOS-5 Forecast AOT 8/19/13, 18z



August 19, 2013, NASA DC-8 sampled multiple smoke plumes over central US.

GEOS-5 Forecasting Support



Hurricane Cristobal was a Category 1 hurricane undergoing extratropical transition when overflown by the NASA Global Hawk on August 29, 2014. Shown are the forecast GEOS-5 dust AOT distributions and surface pressures.

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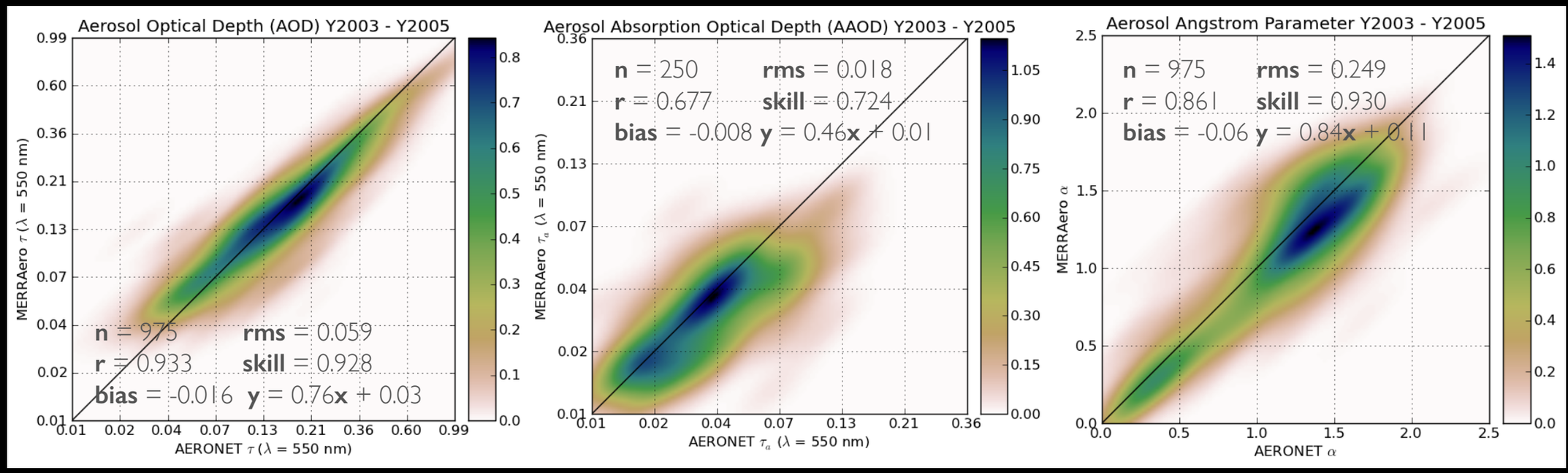
GEOS-5 Reanalysis Activities

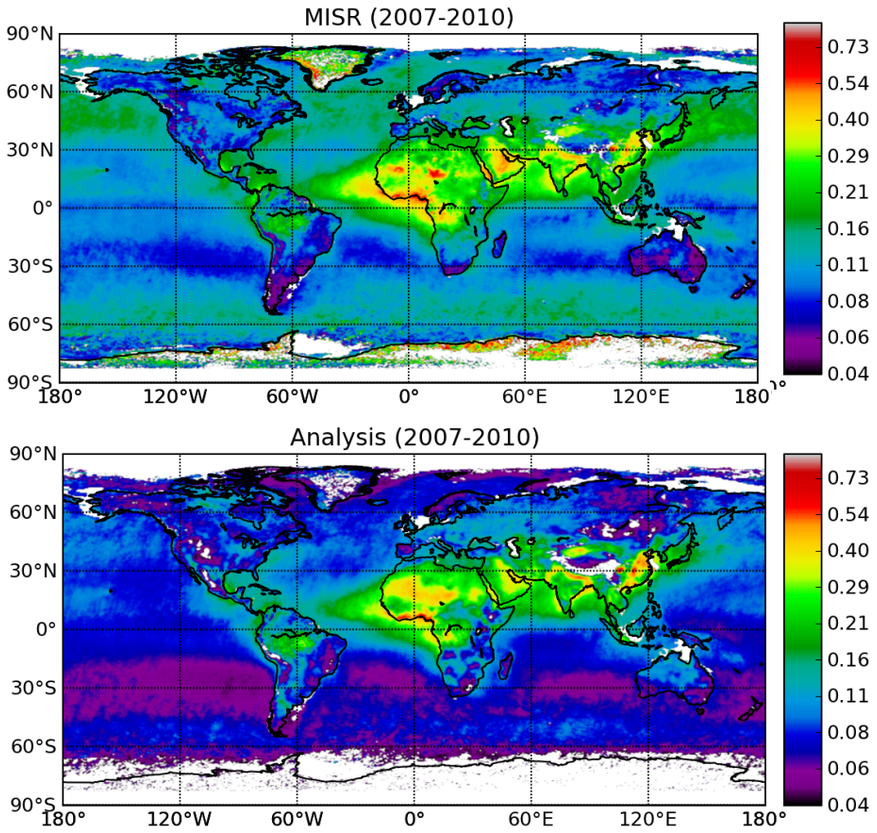
MERRAero

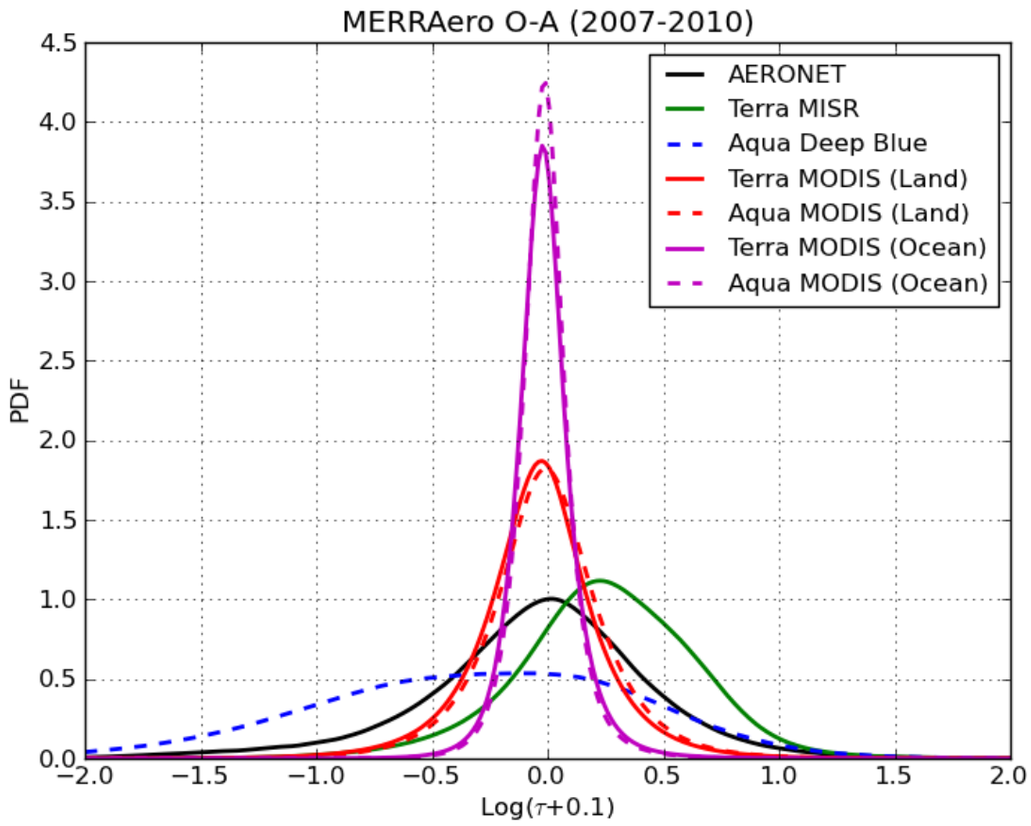
- Aerosol reanalysis based on MERRA meteorological analysis
- Time period: 2002 - present
- AOT assimilation from QC-ed MODIS over ocean and dark target land observations
- Precipitation imposed from prior data-constrained land surface reanalysis
- Global, high temporal frequency atmosphere and aerosol output:
  0.5° x 0.625°, 72 vertical levels



Comparison of AOD, AAOD, and Angstrom parameter from MERRAero with AERONET

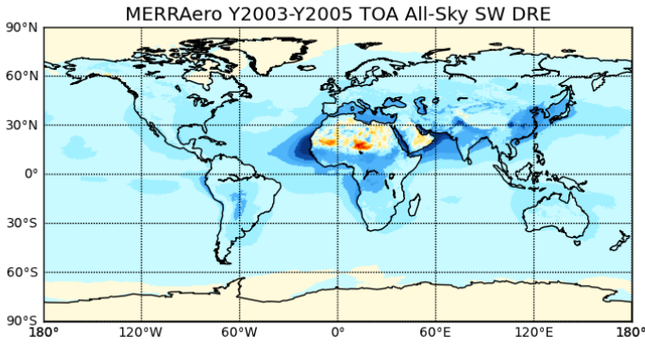
GEOS-5 Reanalysis Activities

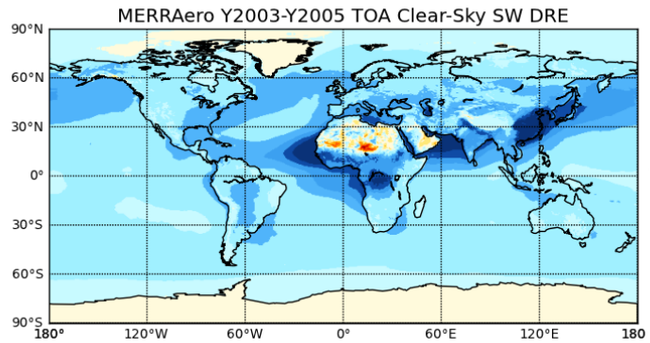


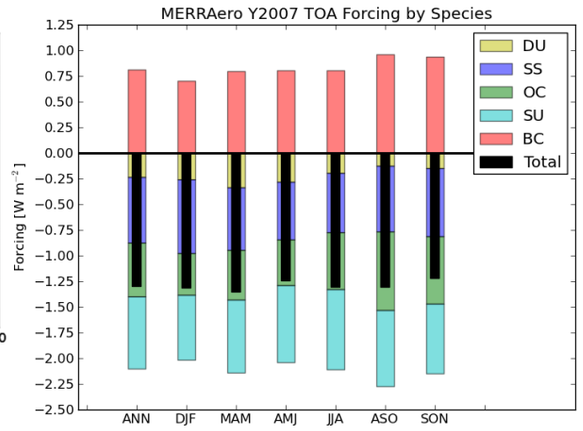


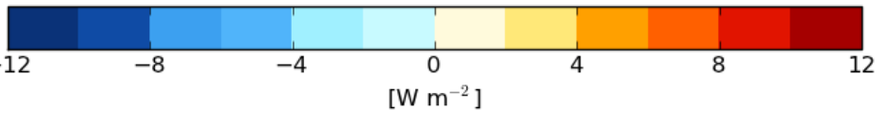
Comparison to multi-year satellite data sets

MERRAero: Radiative Forcing









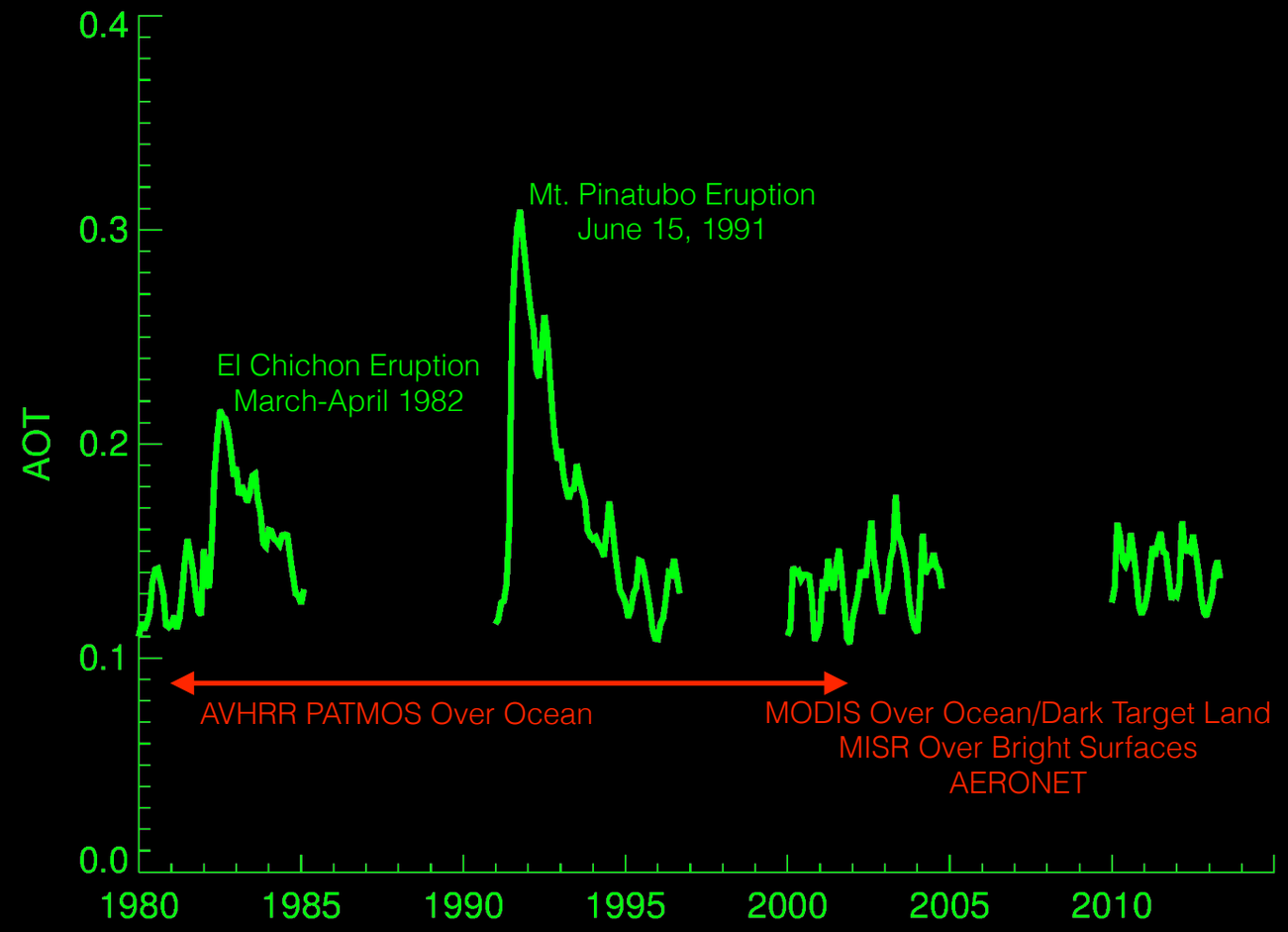
Comparison of globally averaged SW clear-sky aerosol direct radiative effect (DRE)			
Source	TOA SW DRE Ocean (Land)	ATM SW DRE Ocean (Land)	SFC SW DRE Ocean (Land)
MERRAero (Y2003-Y2005)	-3.5 (-3.2)	2.2 (5.4)	-5.7 (-8.6)
Observational (Y2000-Y2003) Yu *et al.* (2006)	-5.5 ± 0.7 (-4.9 ± 0.5)	3.3 (6.8)	-8.8 ± 1.7 (-11.7 ± 1.2)
Multi-Model (Y2000-Y2003) Yu *et al.* (2006)	-3.5 ± 1.3 (-2.8 ± 1.2)	1.3 (4.4)	-4.8 ± 1.6 (-7.2 ± 1.9)

MERRAero provides observation constrained estimate of aerosol radiative forcing, which can be analyzed by component.

GEOS-5 Reanalysis Activities

MERRA2

- Joint atmospheric and aerosol reanalysis
- Updated model and data assimilation system since MERRA
- Updated aerosol emissions
- Time period: 1979 - present
- Global, high temporal frequency atmosphere and aerosol output: 0.5° x 0.625°, 72 vertical levels



Progression of 4 parallel MERRA-2 production streams with projected availability by Q2 2015

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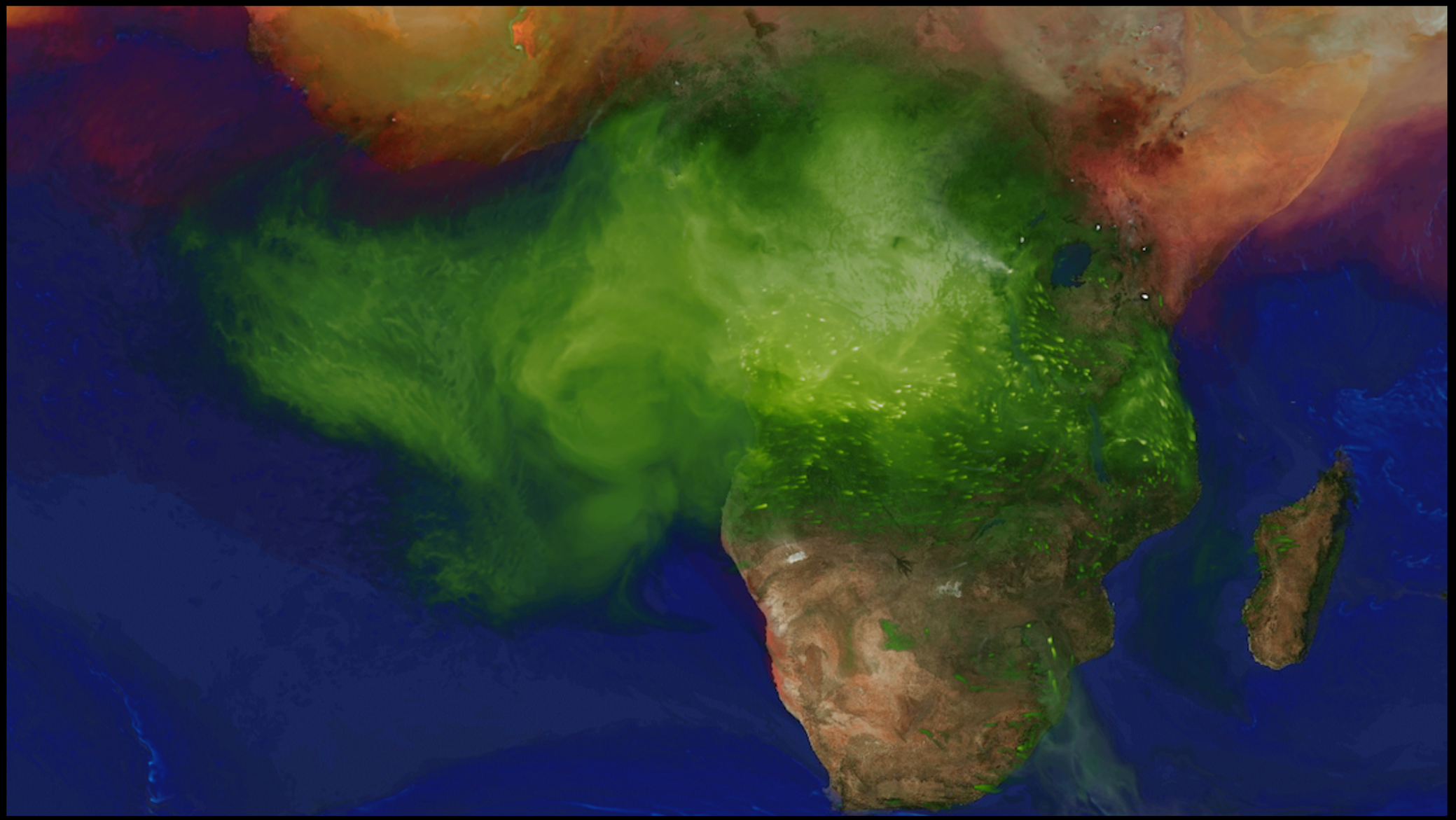
Global 7-km Nature Run

- Objective is to produce a global atmospheric known state (i.e., “nature” state) for OSSEs and studies of weather and climate

- Must be free running simulation (i.e., unconstrained by observations) that produces realistic weather and variability, with a climatology representative of nature

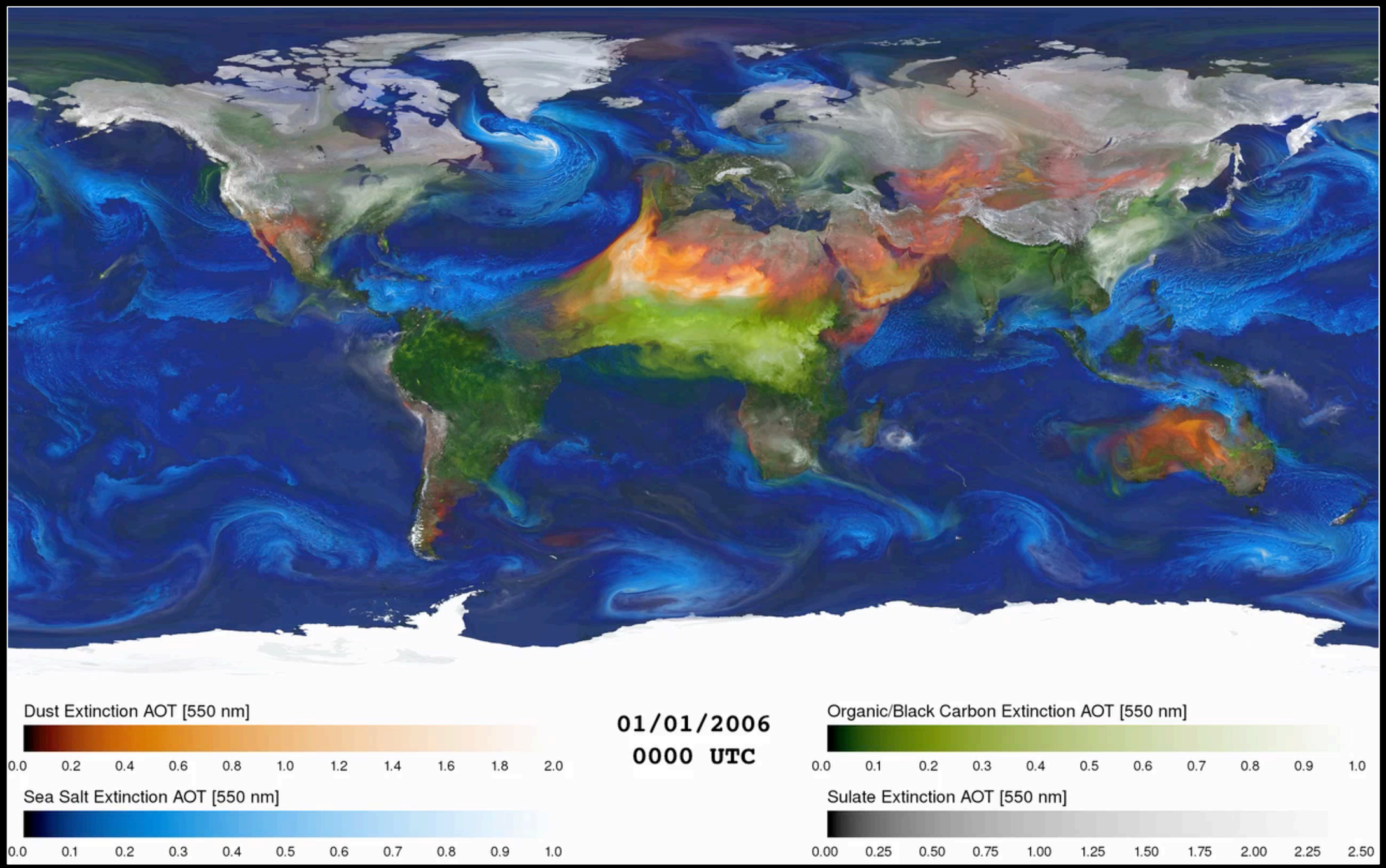
- Details
  - 2-years: June 2005 - June 2007
  - 7-km global resolution
  - 72 vertical levels, 0.01 hPa top
  - Non-hydrostatic dynamics
  - Limited deep convection parameterization
  - Includes GOCART aerosol

Emissions in Nature Run



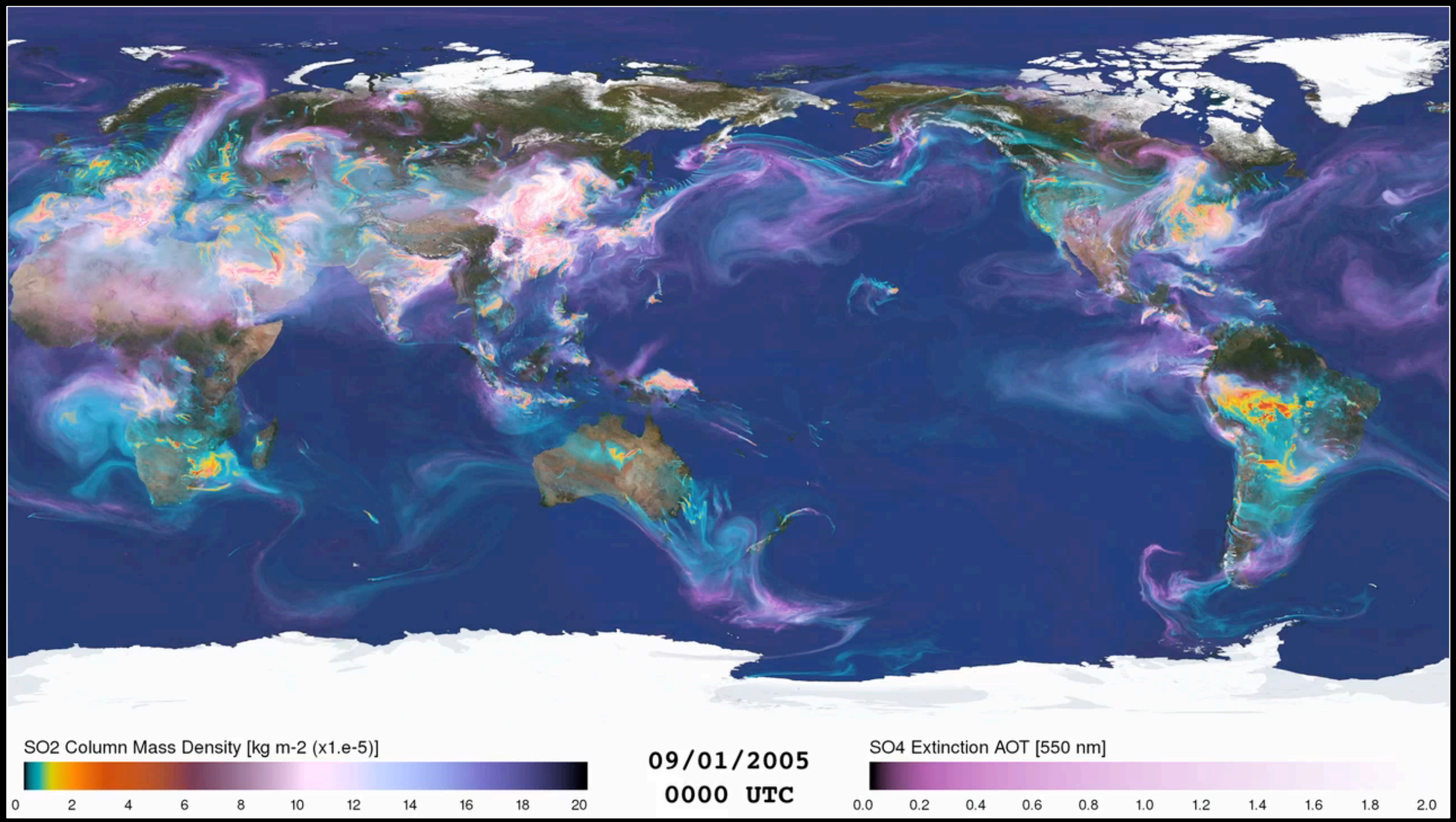
- *Down-scaled anthropogenic inventory emissions (e.g., EDGAR 0.1° SO_2)*
- *Dust and sea salt resolved winds at 7-km*
- *QFED biomass burning*

Aerosol Distributions



Global distributions of aerosol loading and composition in 7-km Nature Run

SO_2 and Sulfate Distributions



Global distributions of SO_2 and Sulfate aerosol in 7-km Nature Run

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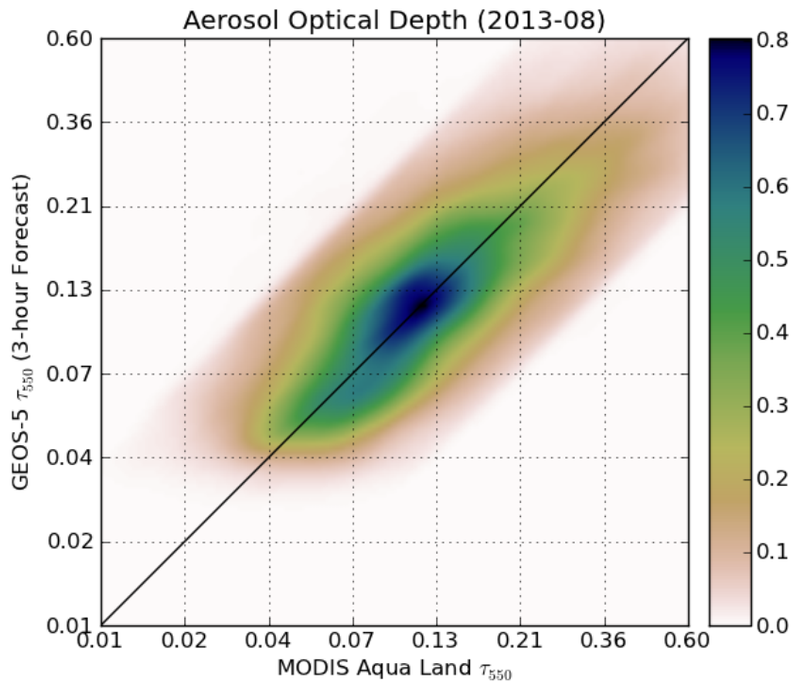
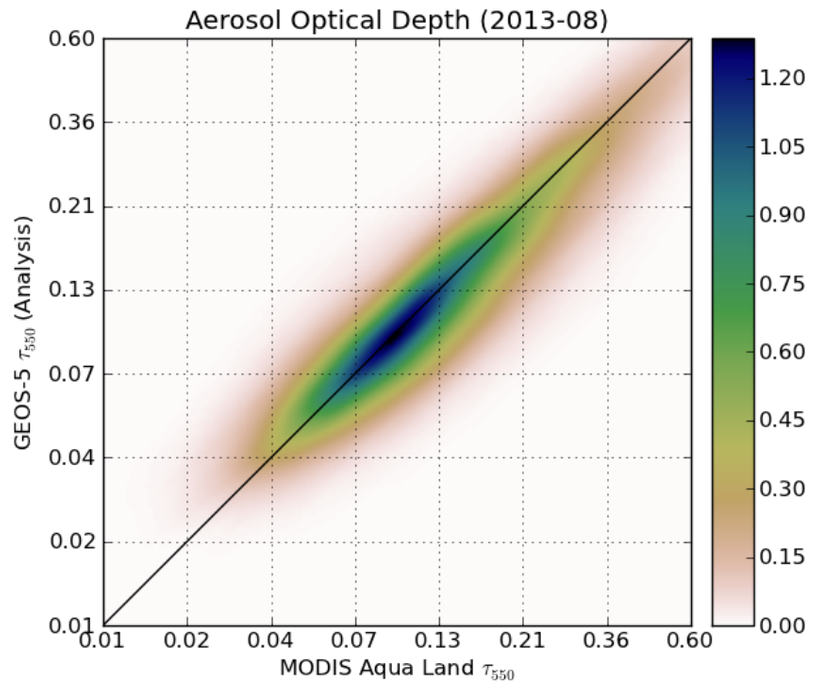
SEAC⁴RS Mini-Reanalysis

MODIS Aqua NNR Impact Over Land

Background



Analysis



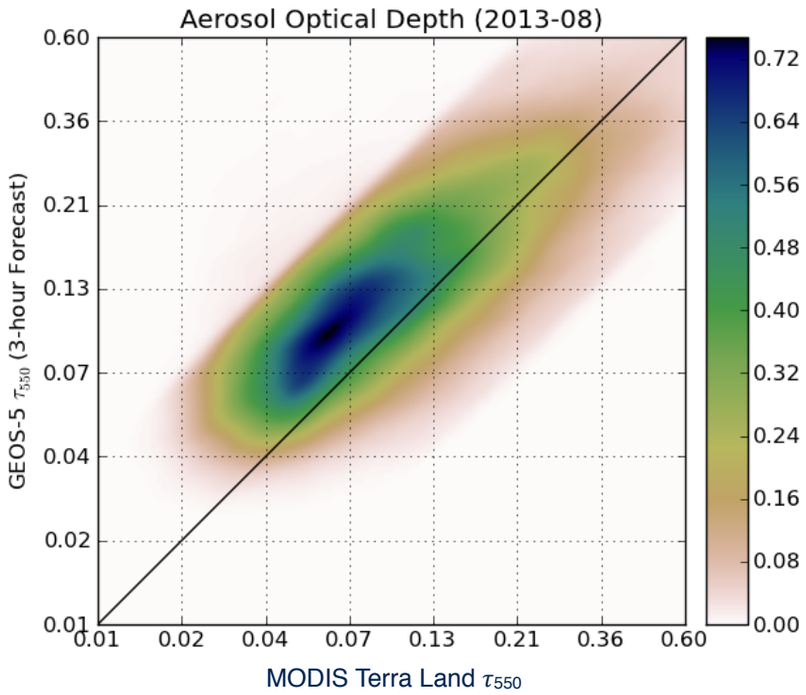
Model sampled as observations

GEOS-5 replay with assimilation of MODIS NNR, MISR "Bright Target," and AERONET

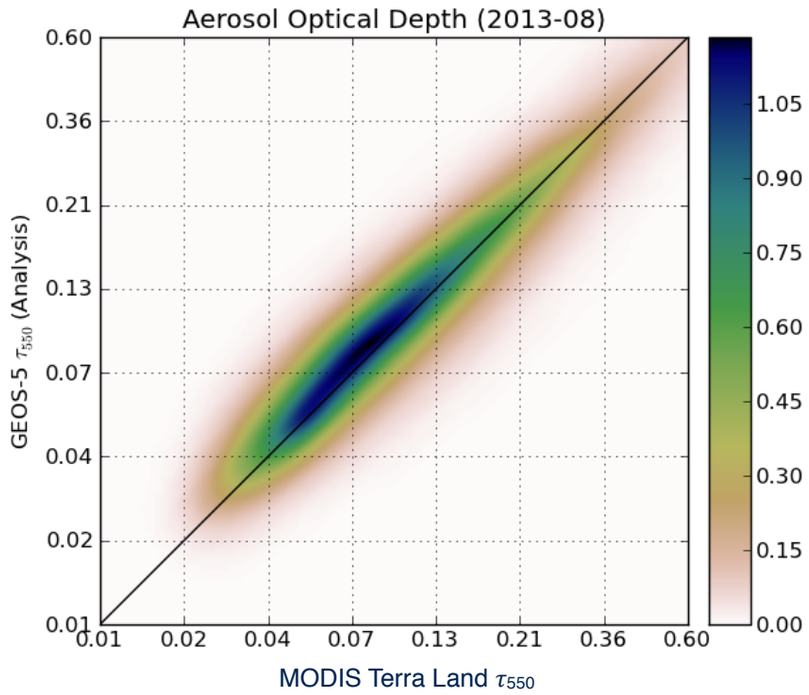
SEAC⁴RS Mini-Reanalysis

MODIS Terra NNR Impact Over Land

Background



Analysis



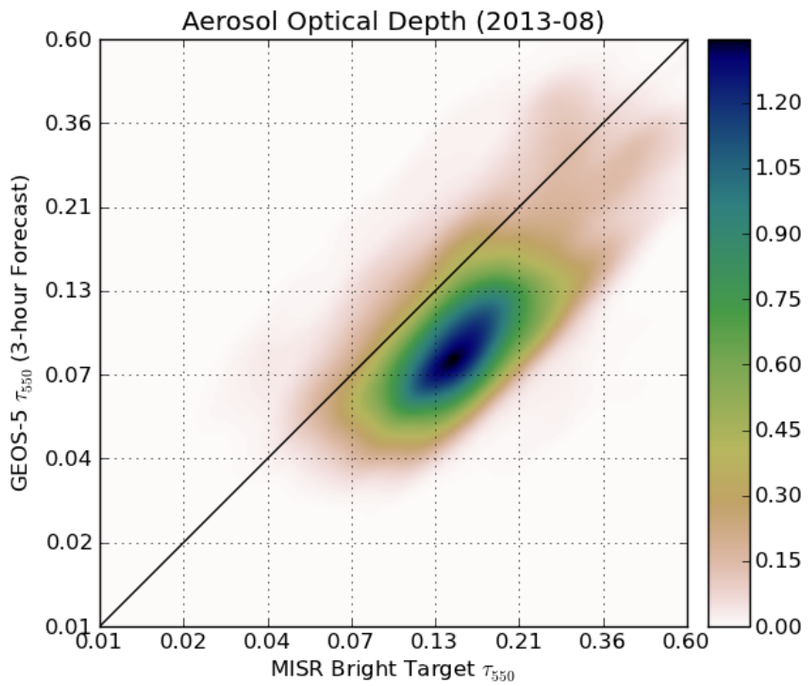
Model sampled as observations

GEOS-5 replay with assimilation of MODIS NNR, MISR "Bright Target," and AERONET

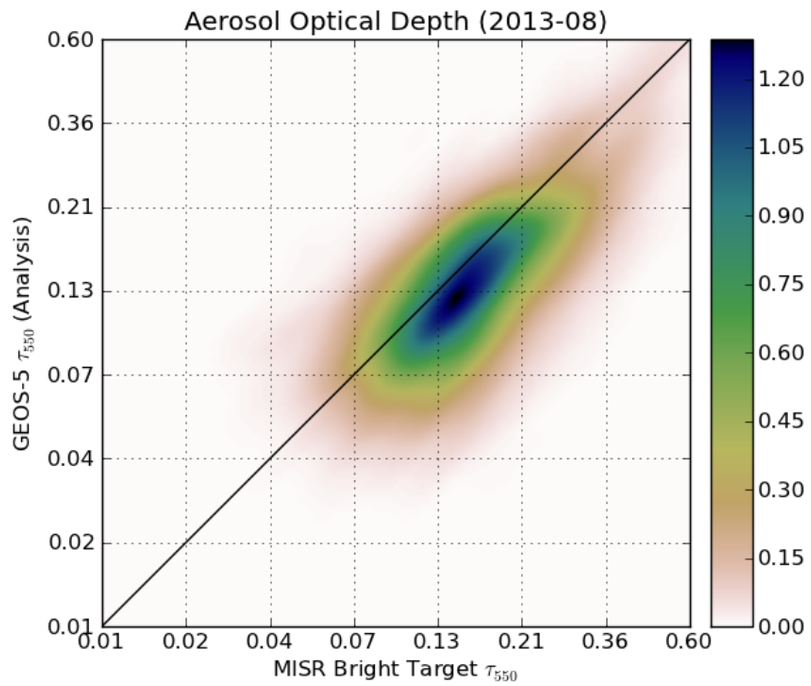
SEAC^{4}RS Mini-Reanalysis

MISR "Bright Target" Impact Over Land

Background



Analysis



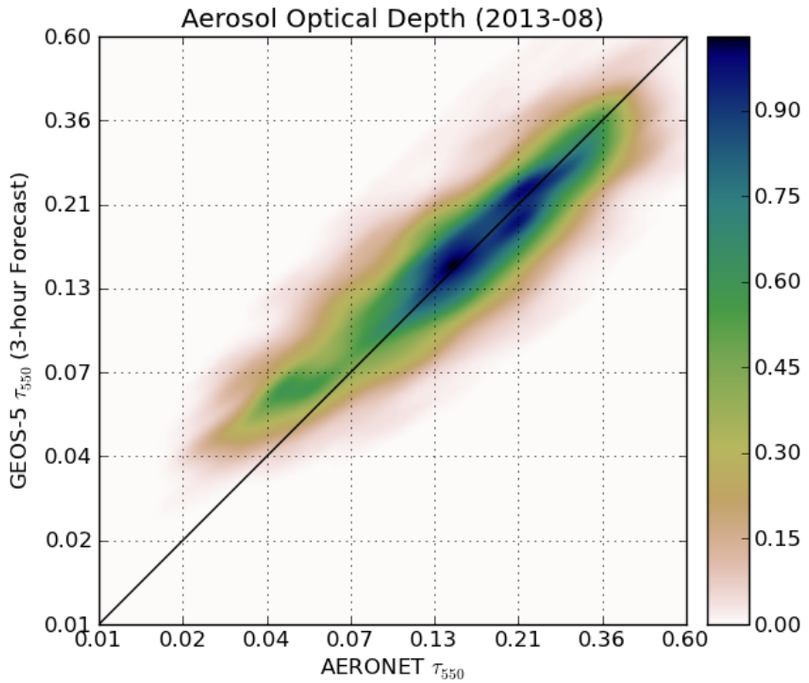
Model sampled as observations

GEOS-5 replay with assimilation of MODIS NNR, MISR "Bright Target," and AERONET

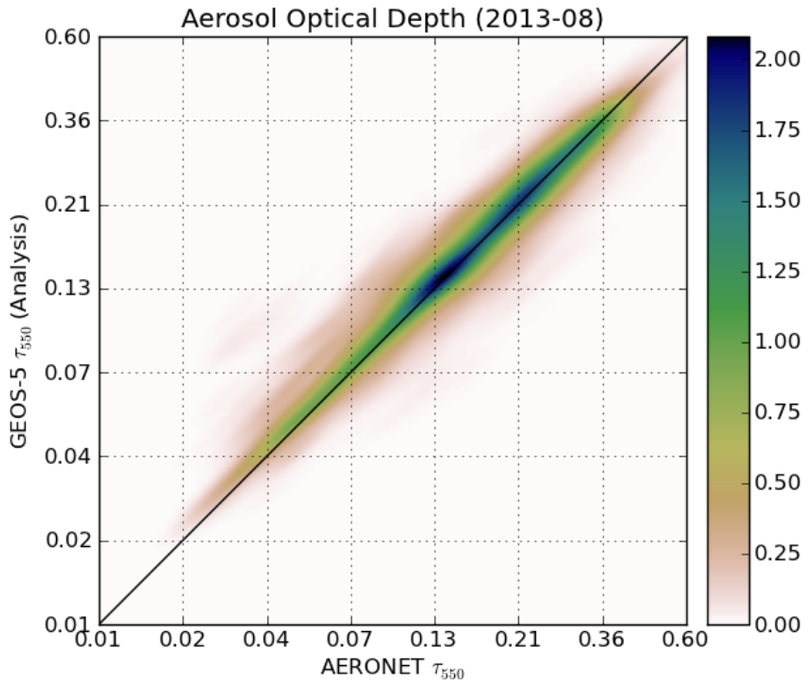
SEAC⁴RS Mini-Reanalysis

AERONET Impact

Background



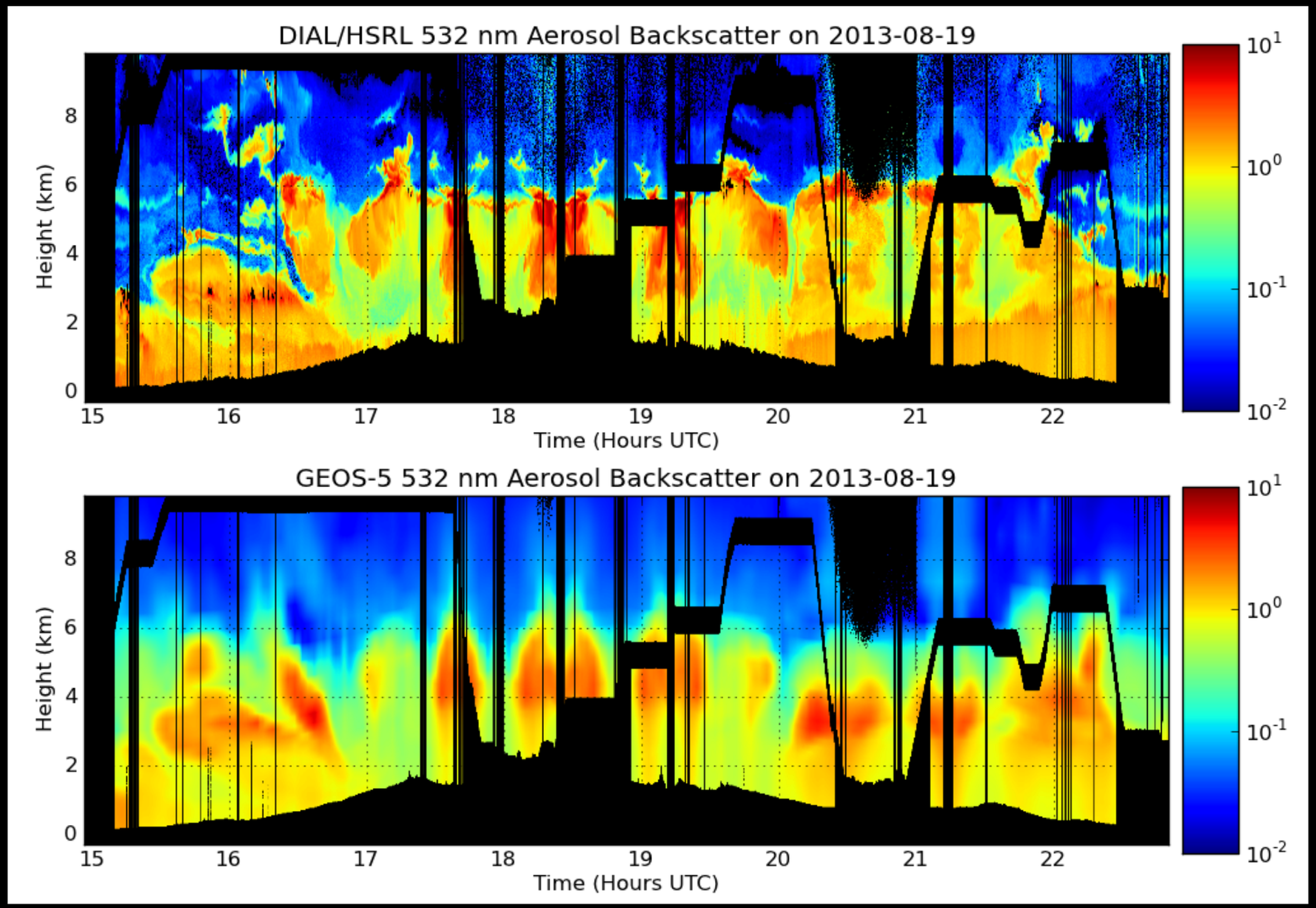
Analysis



Model sampled as observations

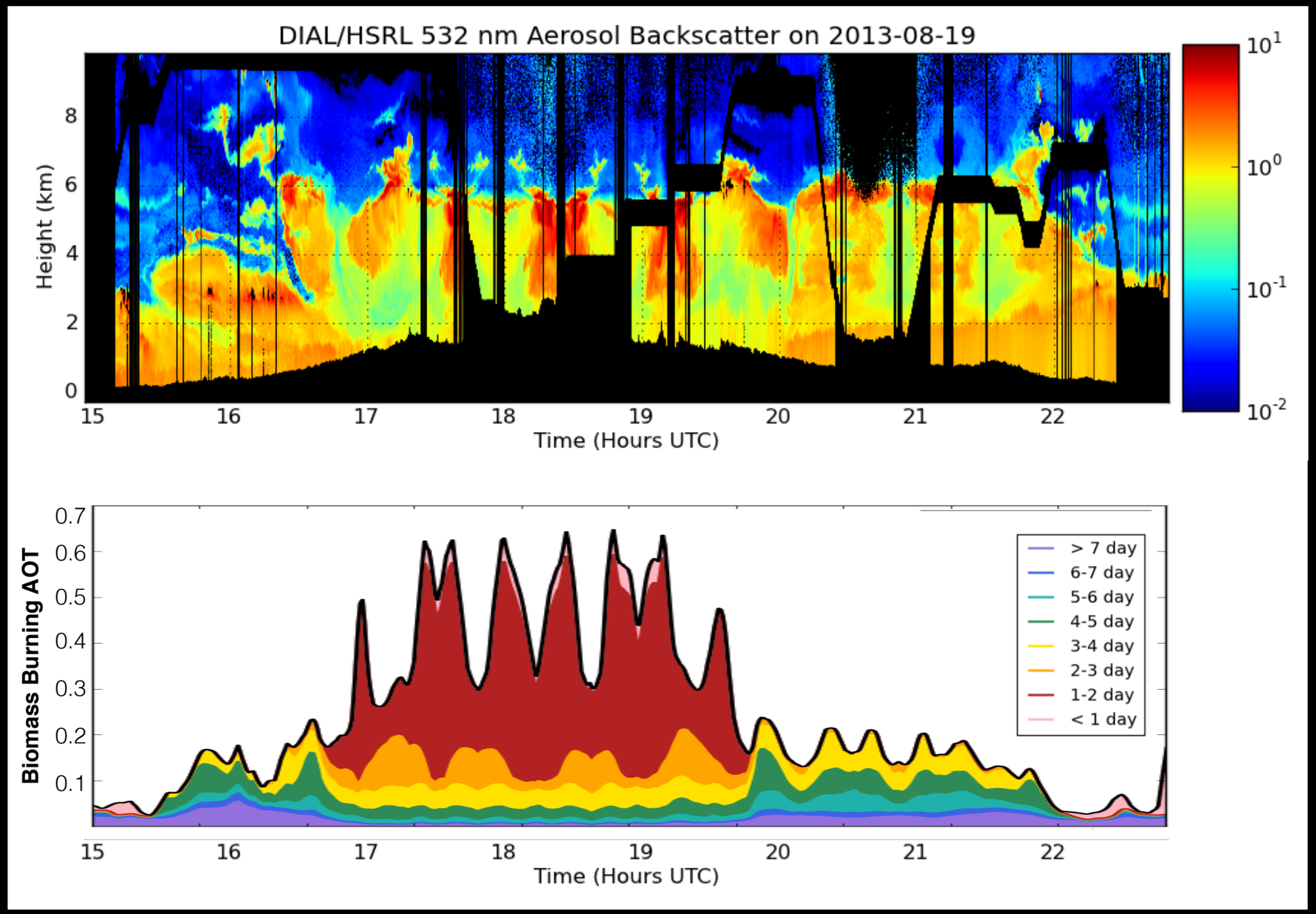
GEOS-5 replay with assimilation of MODIS NNR, MISR "Bright Target," and AERONET

SEAC⁴RS Mini-Reanalysis



Replay GEOS-5 simulation, including assimilation of MODIS, MISR, and AERONET. Comparison of observed and simulated aerosol backscatter along flight track.

SEAC⁴RS Mini-Reanalysis

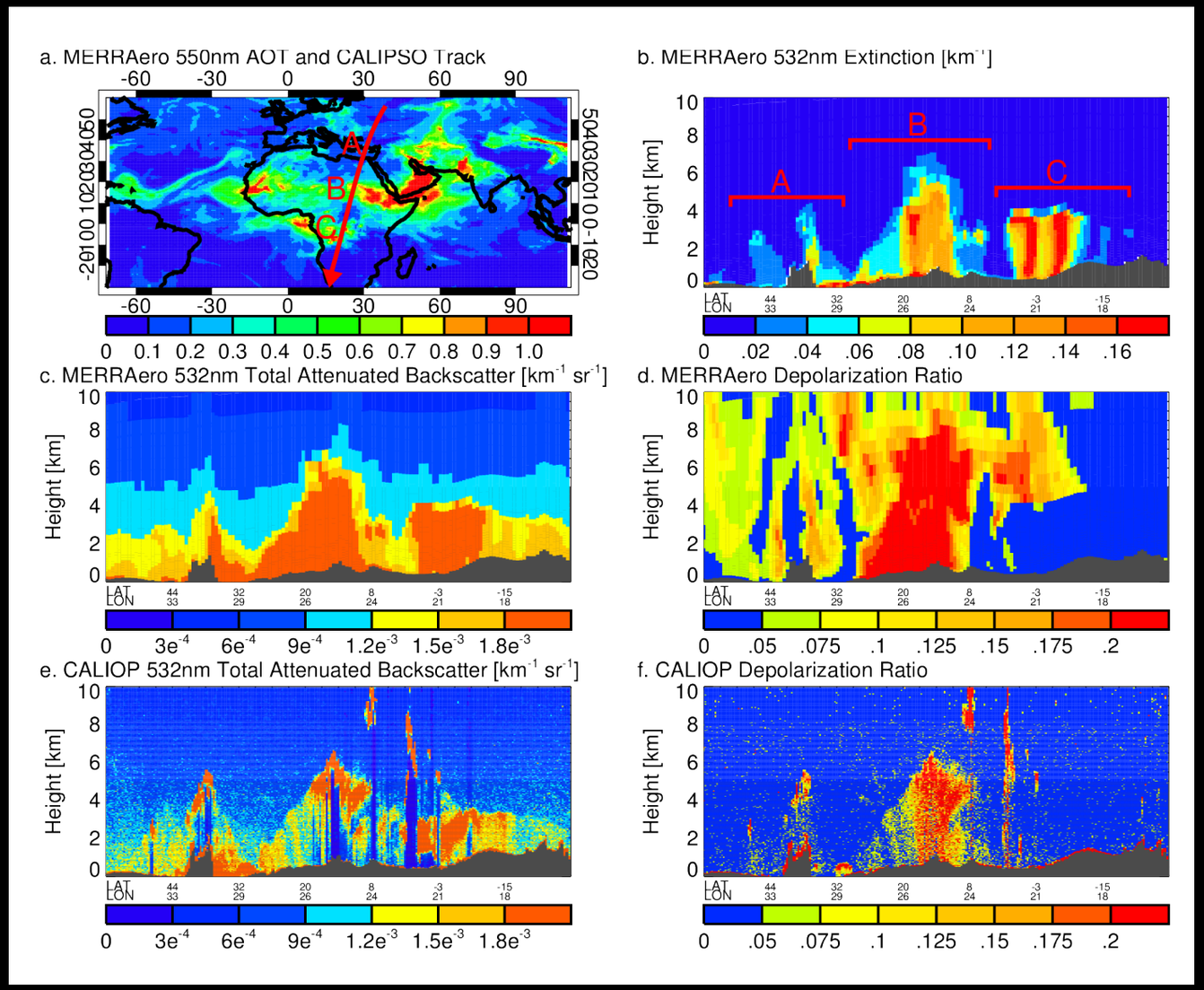


Flight encountered multiple smoke plumes. In reanalysis we introduced smoke tracers tagged by day of emission, making it possible to infer age of smoke encountered along the aircraft flight track.

MERRAero: Lidar Simulation

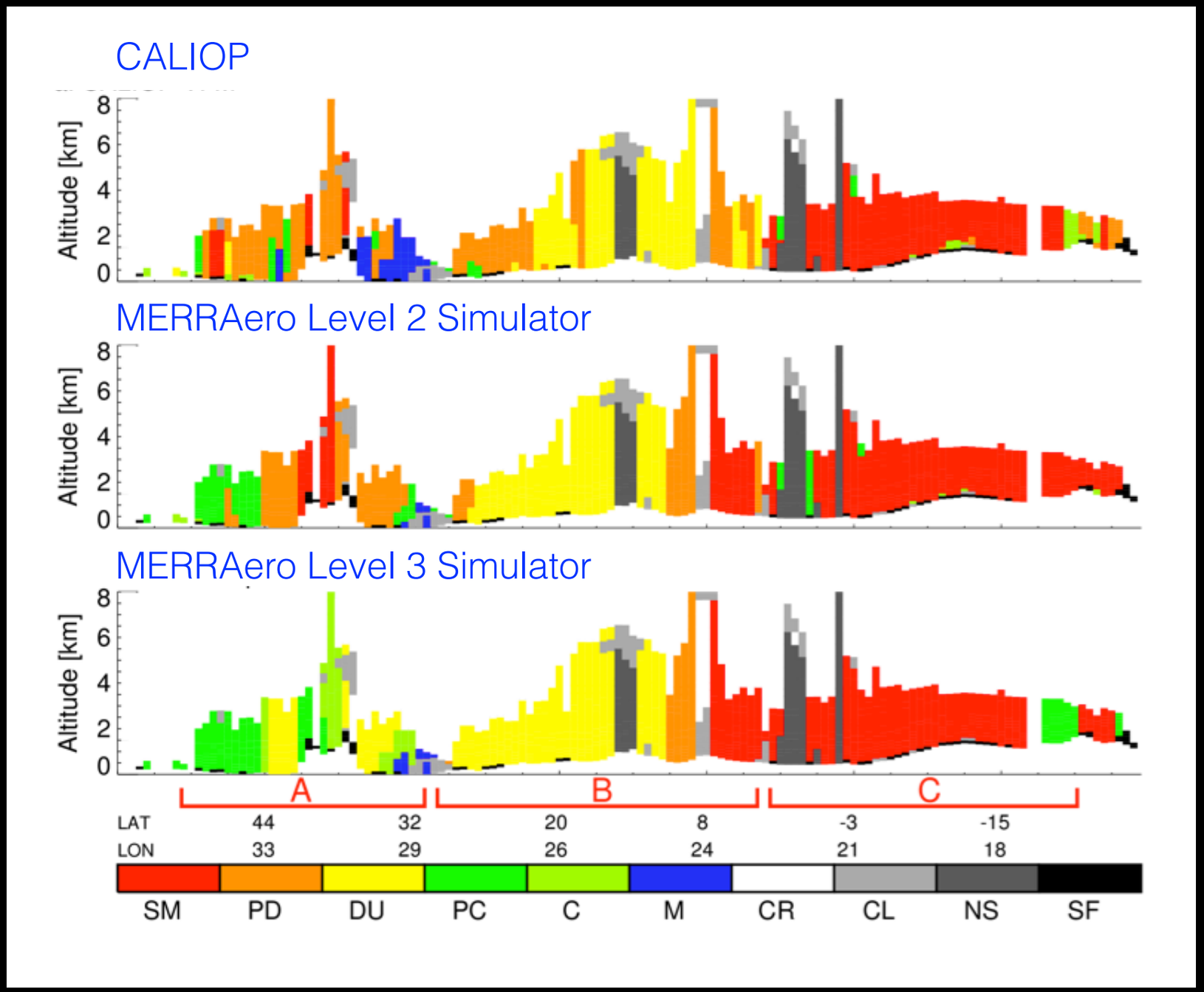
CALIOP Simulator

- From MERRAero aerosol fields we simulate the CALIOP 532 nm attenuated backscatter and depolarization ratio
- Simulation of depolarization ratio is possible through inclusion of non-spherical dust optical properties (other species in development)
- Level 2 CALIOP simulator: by simulating the observables we can feed these as inputs to CALIOP VFM algorithm and evaluate aerosol typing
- Level 3 CALIOP simulator: a complementary typing analysis can be performed by using aerosol speciation from MERRAero



Case study evaluation of MERRAero vertical profile with respect to CALIOP observations, July 9, 2009

MERRAero: Lidar Simulation

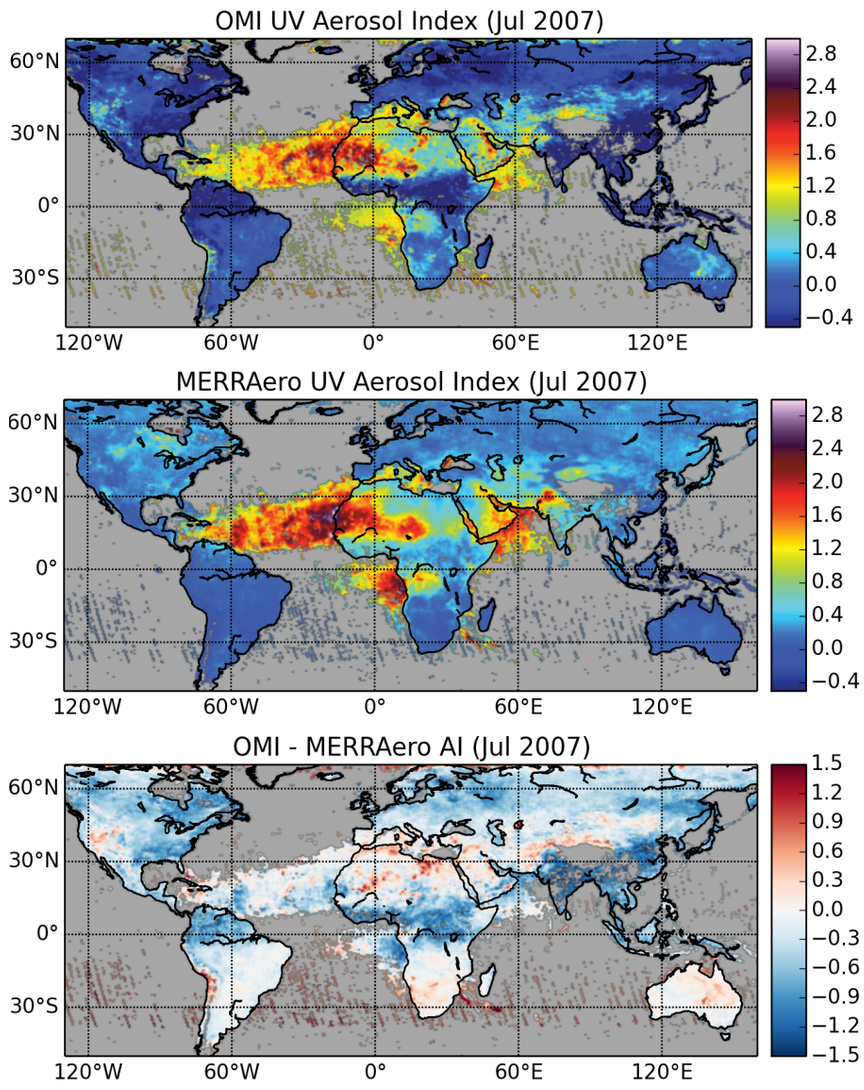


Evaluation of MERRAero aerosol typing with the CALIOP Vertical Feature Mask

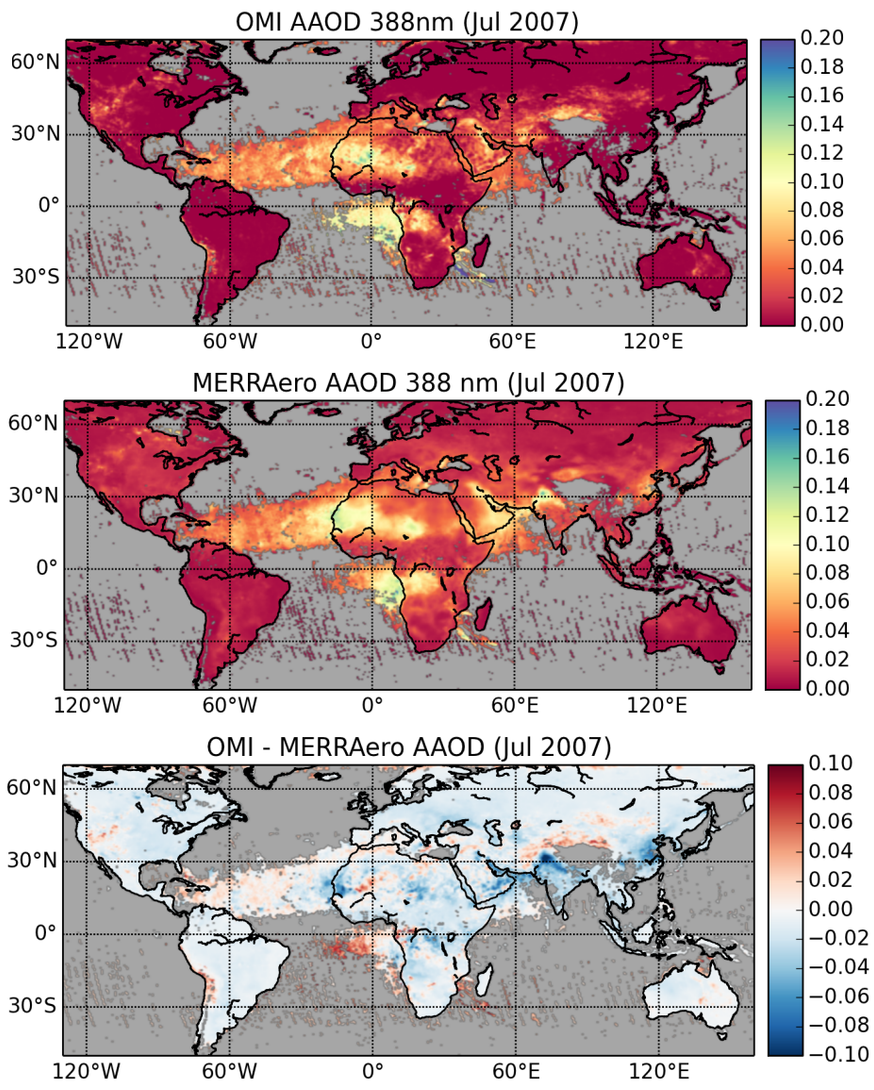
ICAP 6th Working Group Meeting, Boulder, CO, October 21 - 24, 2014

MERRAero: Aerosol Absorption

Aerosol Index (AI)

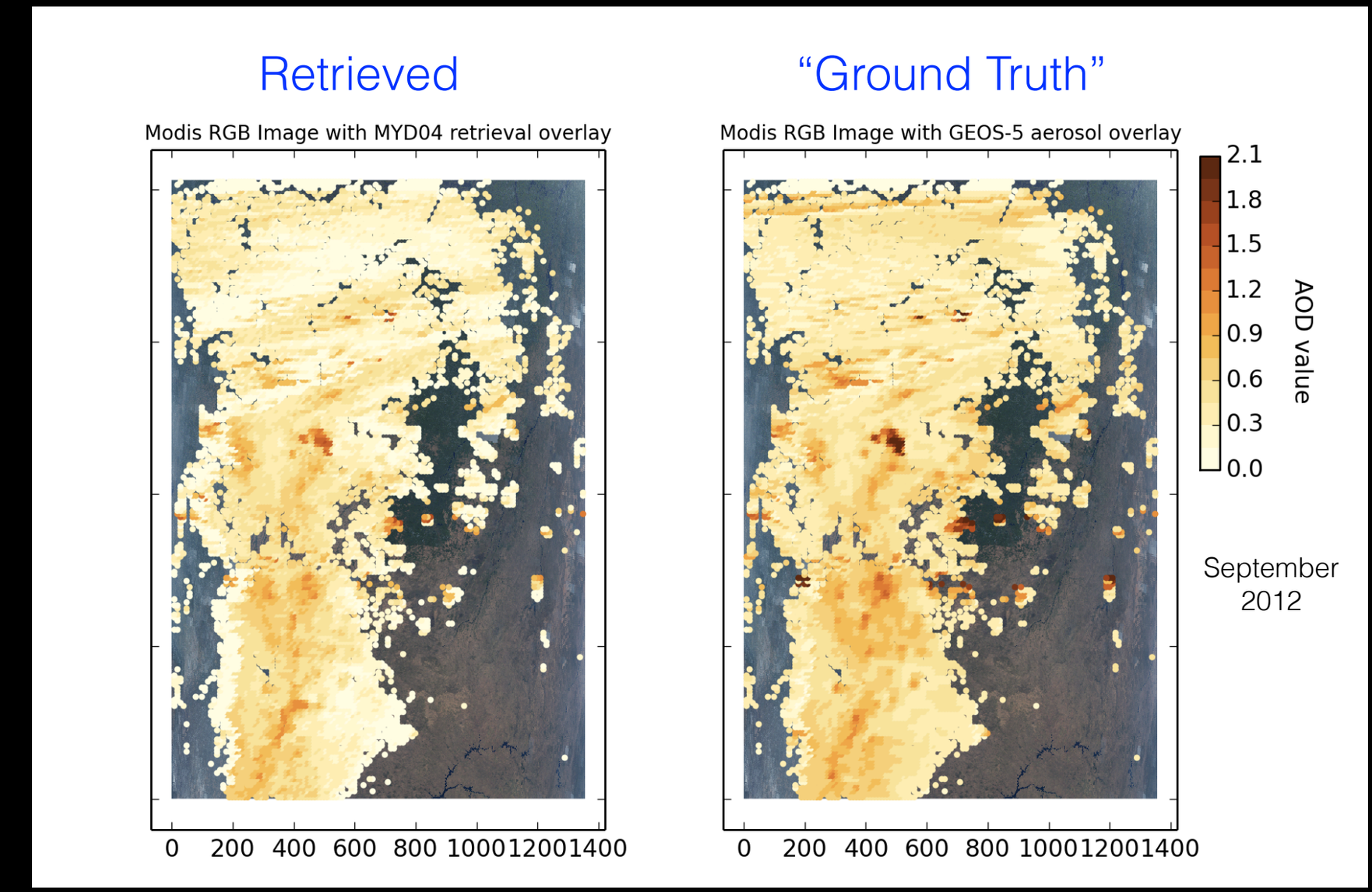


AAOD (AI)



Comparisons of MERRAero and OMI aerosol index (left) and AAOD (right) for July 2007.

Radiance Simulator for OSSEs



GEOS-5 provides input aerosols and atmosphere to simulate the MODIS reflectances. Here we show comparison of GEOS-5 AOT (right, "ground truth") to retrieved AOT using MODIS algorithms (left).

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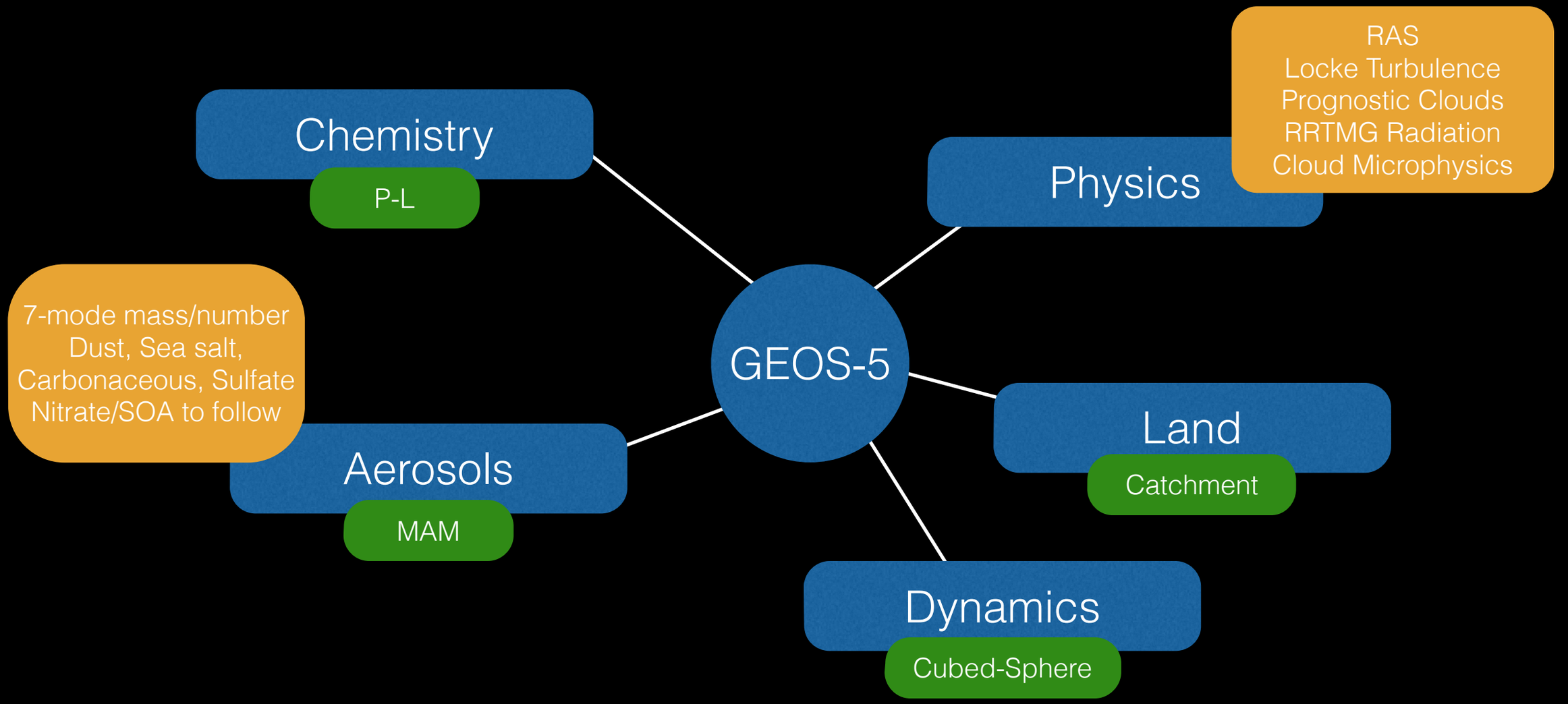
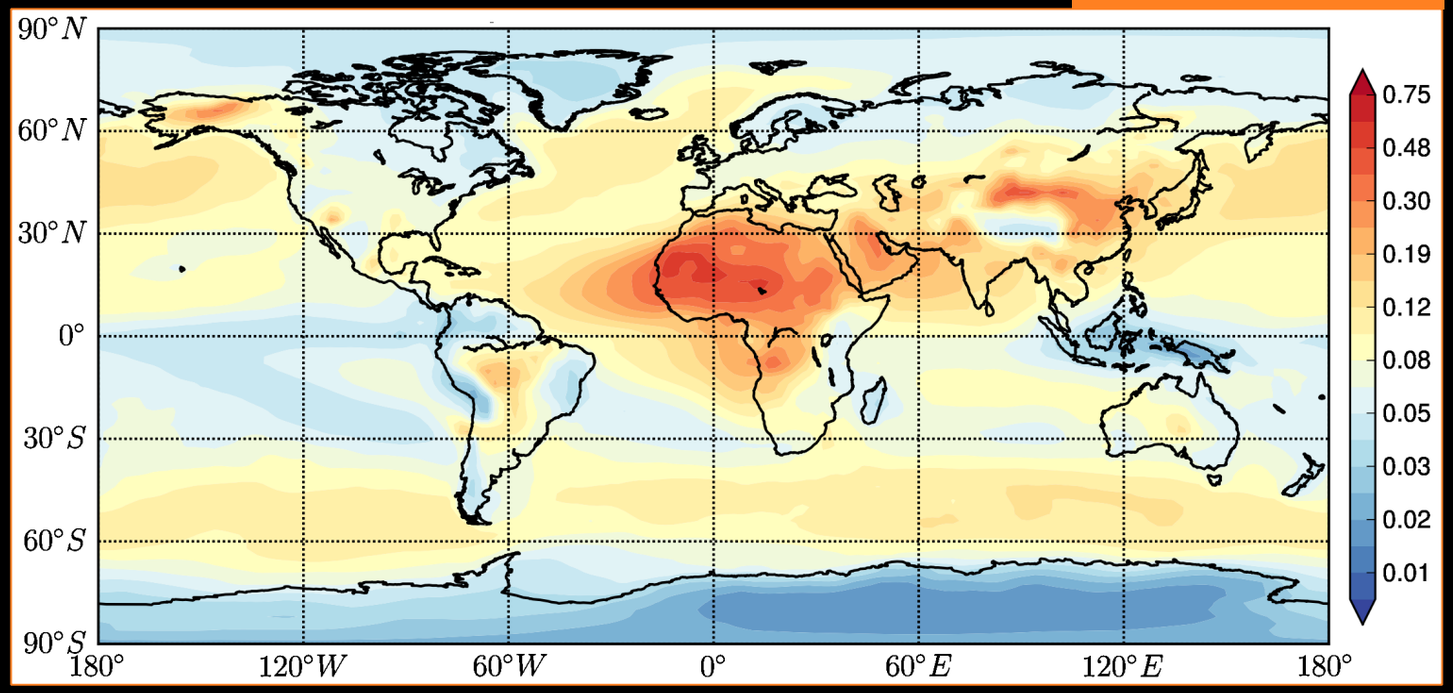
2015 NRT Configuration



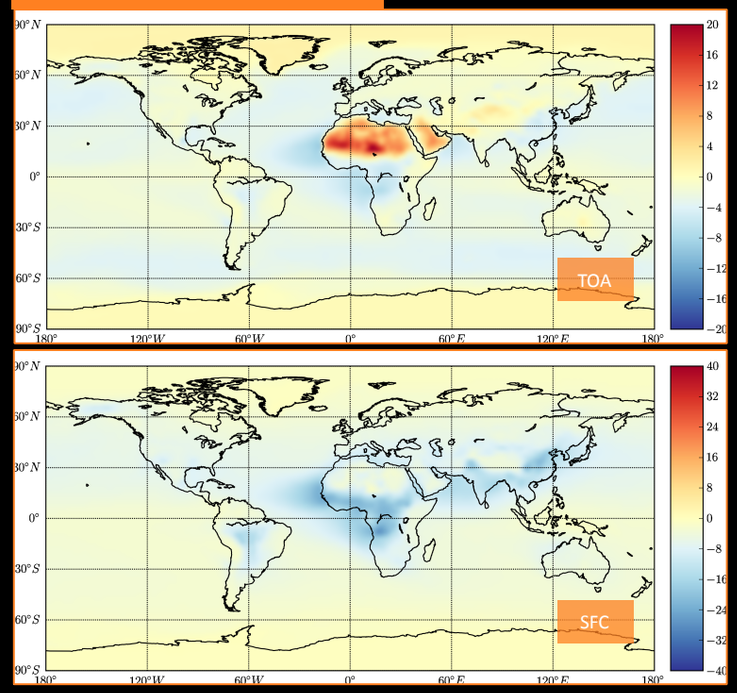
Global, 14 km, 137 levels, top at 0.01 hPa

Modal Aerosol Module

Aerosol Optical Thickness



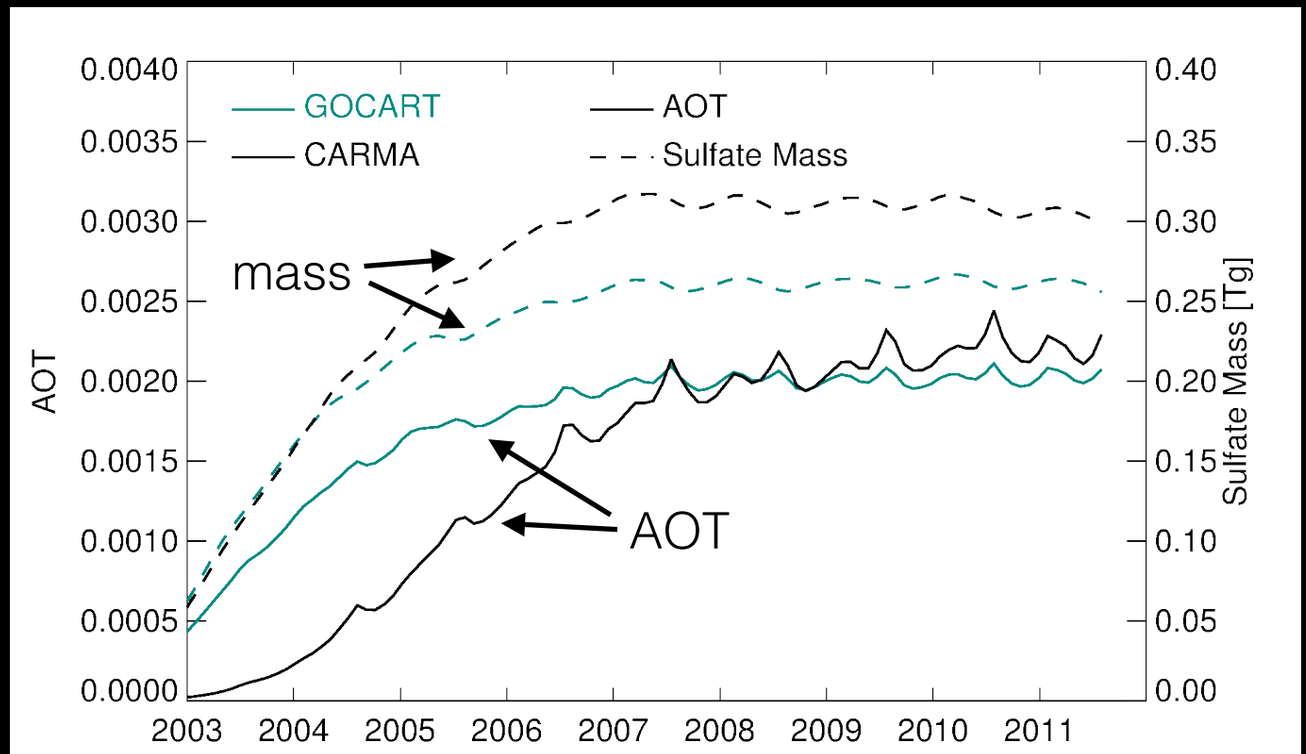
Aerosol Direct Radiative Effect



To improve the modeling capabilities in GEOS-5 a sophisticated model that can predict aerosol size distribution and mixing state of sulfate, ammonium, primary and secondary organic matter, sea salt and dust aerosols is currently being implemented. Shown are annual mean aerosol optical thickness and clear-sky aerosol direct radiative effect (W m-2) from a GEOS-5/MAM7 replay run with radiatively active aerosols.

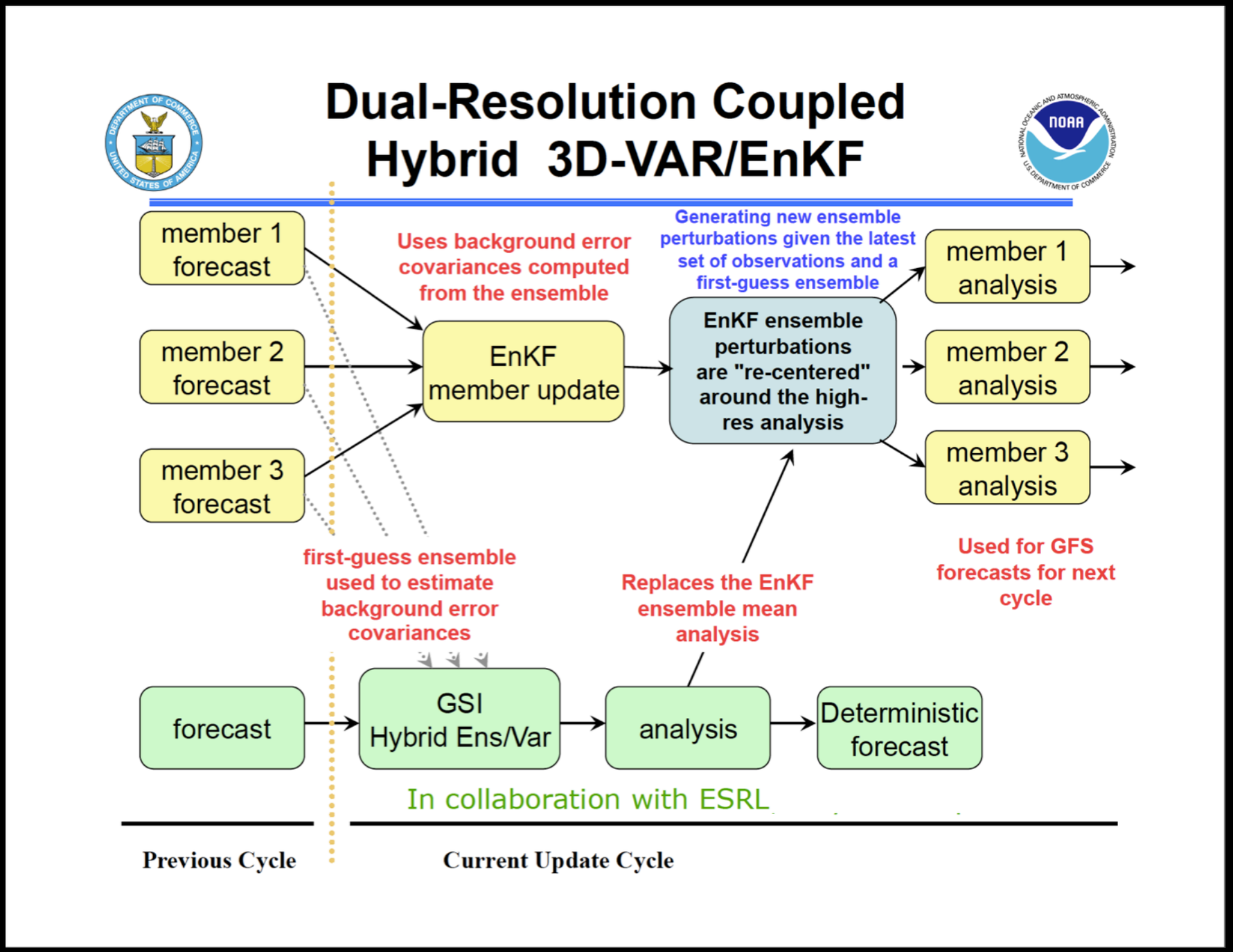
Stratospheric Aerosols

- Recently introduced mechanisms for stratospheric sulfate production:
  - OCS surface concentration specified
  - OCS transported
  - OCS photolysis rates computed in StratChem module
  - SO_2 production from OCS+OH, OCS+O, and OCS+hν
  - SO_4 production from SO_2+OH, SO_2+NO_3, SO_2+aqueous
  - GOCART: SO_4 is aerosol
  - CARMA: nucleation, condensation
- Permits simulation of background and perturbations to stratospheric aerosol (e.g., volcanic eruption)



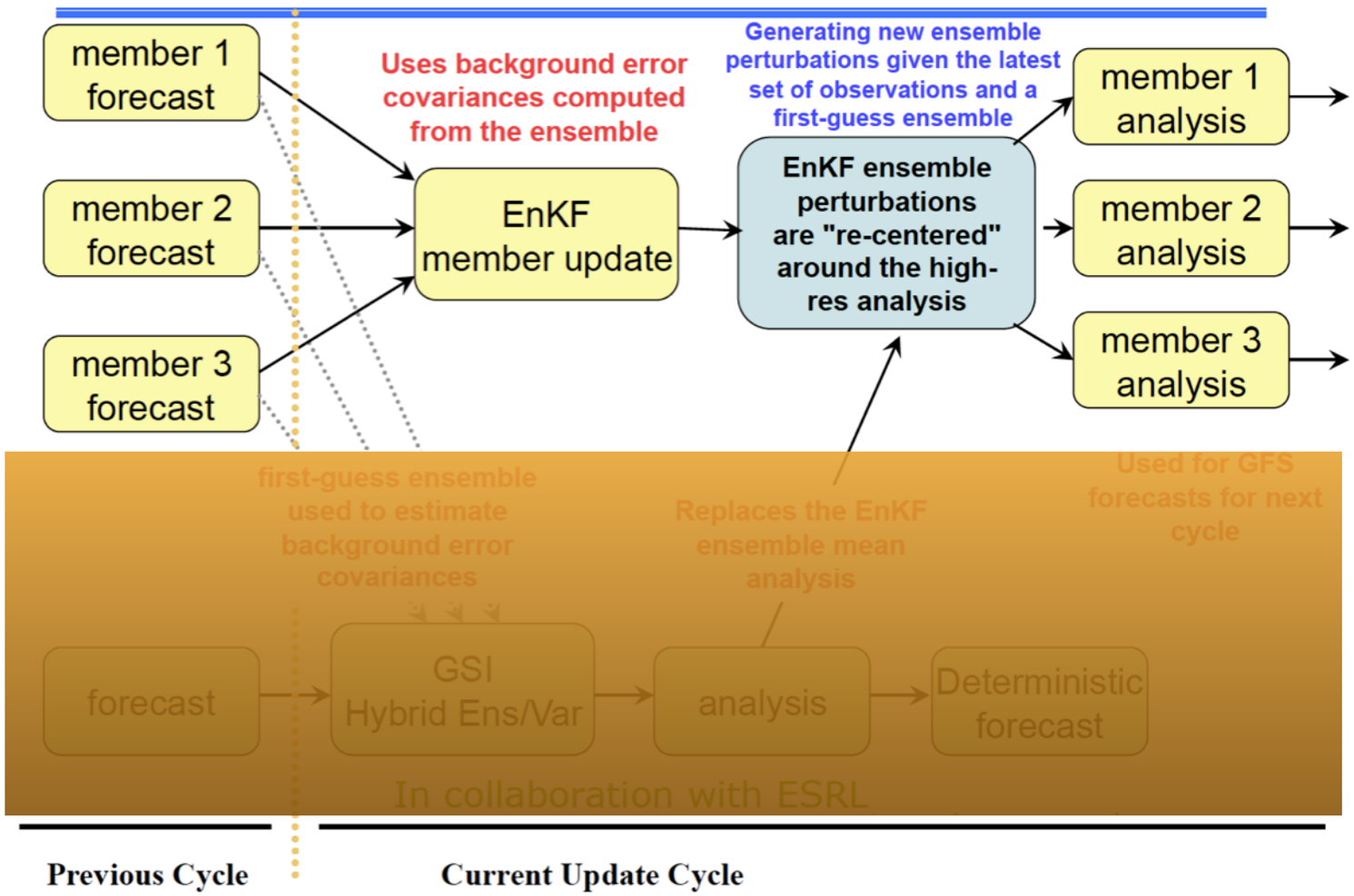
Spin-up of stratospheric sulfate from simultaneous run of GOCART and CARMA

EnKF


Dual-Resolution Coupled
Hybrid 3D-VAR/EnKF
member 1 forecast
member 2 forecast
member 3 forecast
Uses background error covariances computed from the ensemble
EnKF member update
Generating new ensemble perturbations given the latest set of observations and a first-guess ensemble
EnKF ensemble perturbations are "re-centered" around the high-res analysis
member 1 analysis
member 2 analysis
member 3 analysis
Used for GFS forecasts for next cycle
first-guess ensemble used to estimate background error covariances
Replaces the EnKF ensemble mean analysis
forecast
GSI Hybrid Ens/Var
analysis
Deterministic forecast
In collaboration with ESRL
Previous Cycle
Current Update Cycle

EnKF

GEOS-5 Aerosol Assimilation
Phase 1: EnKF Only



Other Developments

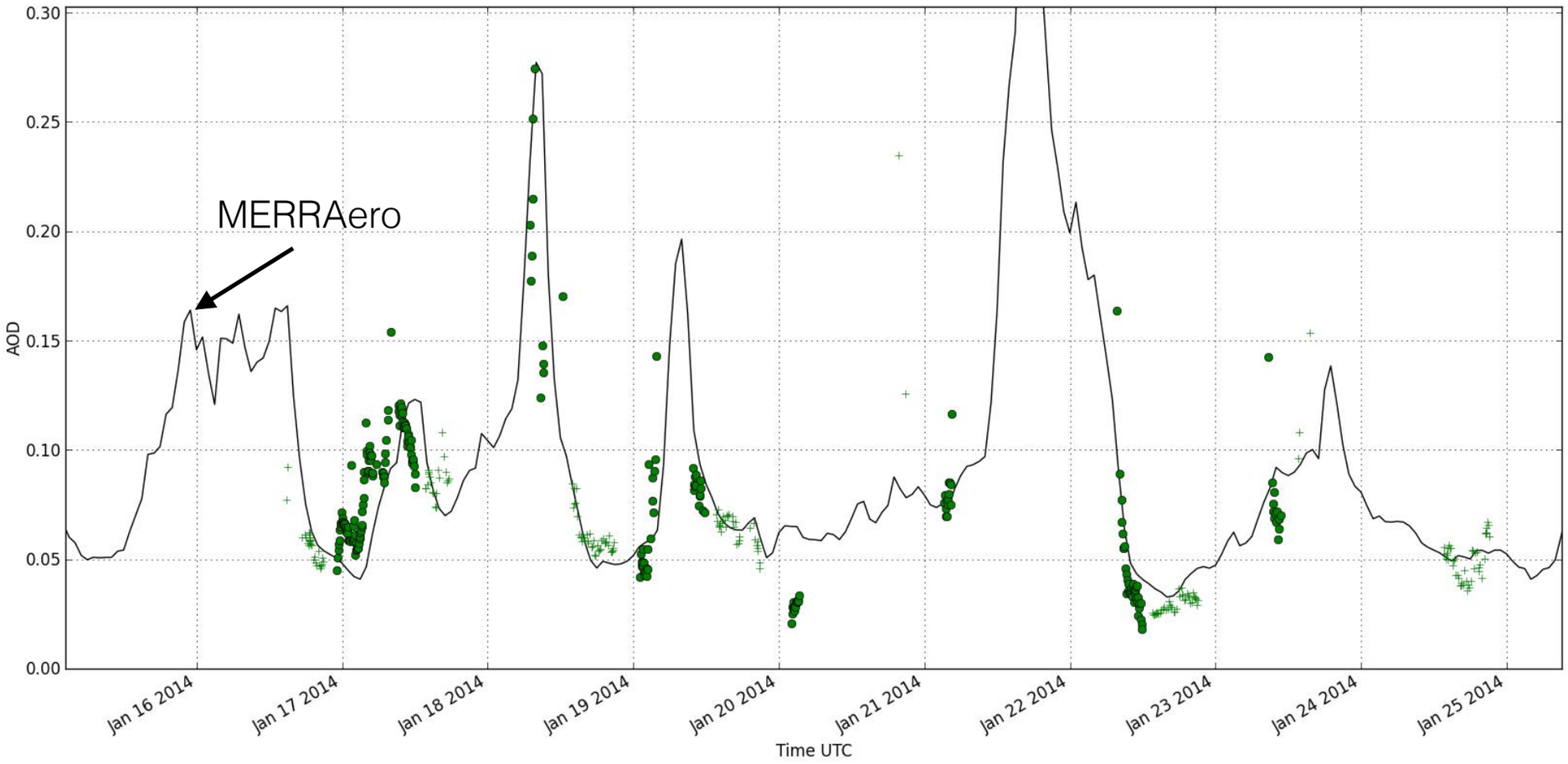
- Aerosol impact on meteorological assimilation
  - Use CRTM to simulate aerosol radiances to inform GSI observation operator
  - Preliminary work shows mild but noticeable improvement in temperature fields in, e.g., dusty regions, and increased number of acceptable observations to assimilation

- Updates to emissions
  - Add MEGAN module component for emissions of trace gas and aerosol precursor species (e.g., for SOA)
  - Perform emissions in “tile” space rather than at atmospheric grid

Additional Slides

Nighttime AOD

GSFC



MERRAero comparison to sun photometer ("+") and nighttime "moon" photometer observations ("●")

SEAC^{4}RS Mini-Reanalysis

Summary of Statistics

Observing System	GEOS-5 AOD	Statistics			
AERONET	Background	0.78	0.75	-0.42	2.10
	Analysis	0.90	0.89	-0.19	1.53
MISR	Background	0.50	0.76	-0.80	9.21
	Analysis	0.54	0.75	-0.62	8.45
MODIS, Terra Land	Background	0.61	0.66	-0.53	0.77
	Analysis	0.86	0.89	-0.22	0.52
MODIS, Aqua Land	Background	0.72	0.76	-0.41	1.11
	Analysis	0.95	0.96	-0.08	0.53
MODIS, Terra Ocean	Background	0.60	0.68	-0.62	0.93
	Analysis	0.83	0.86	-0.32	0.65
MODIS, Aqua Ocean	Background	0.71	0.76	-0.42	0.97
	Analysis	0.93	0.94	-0.13	0.50

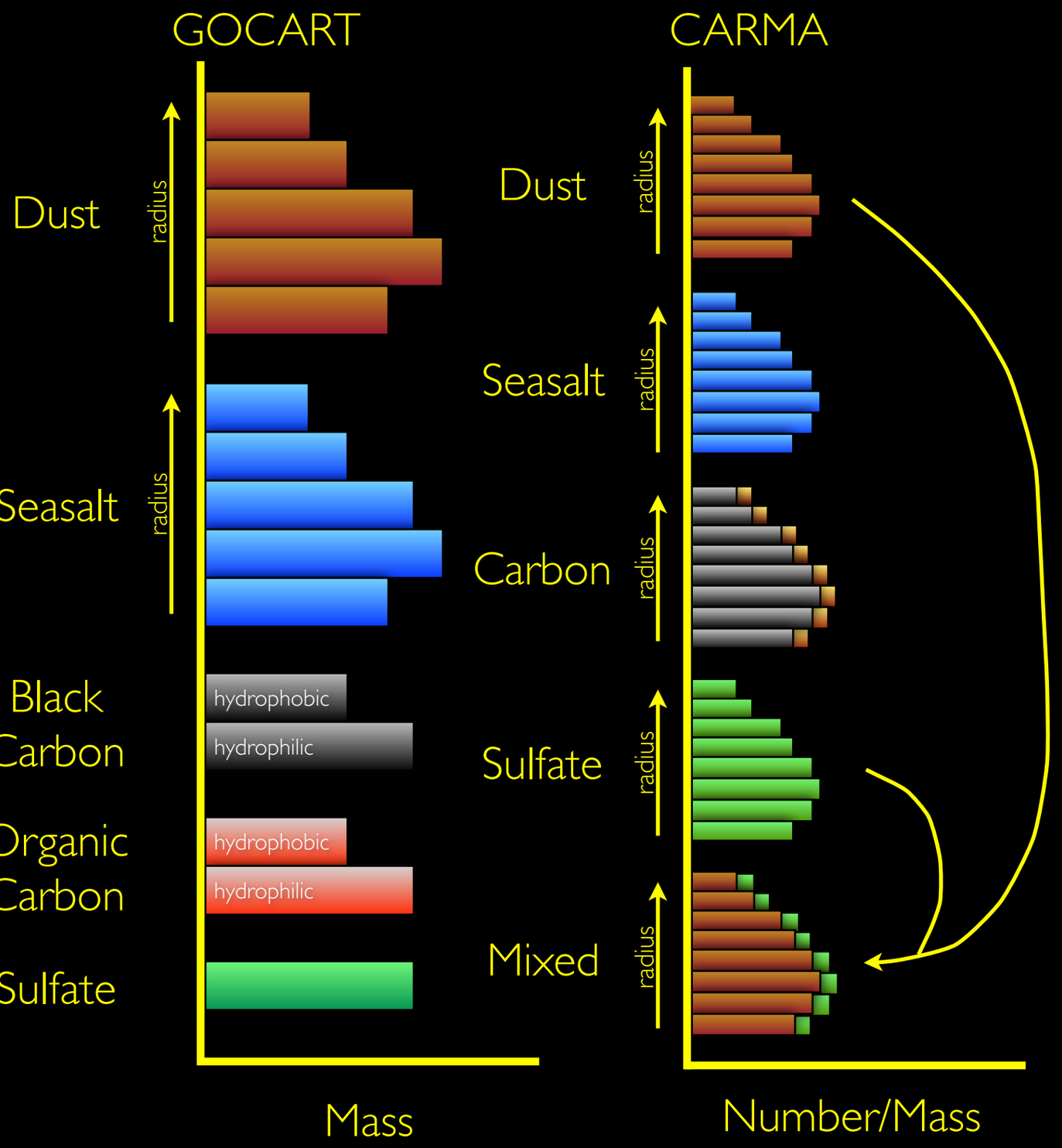
**standard error multiplied by 1000*

A series of GEOS-5 replays to investigate impact of individual data sources on assimilation.

CARMA: Sectional Aerosol Microphysics

CARMA

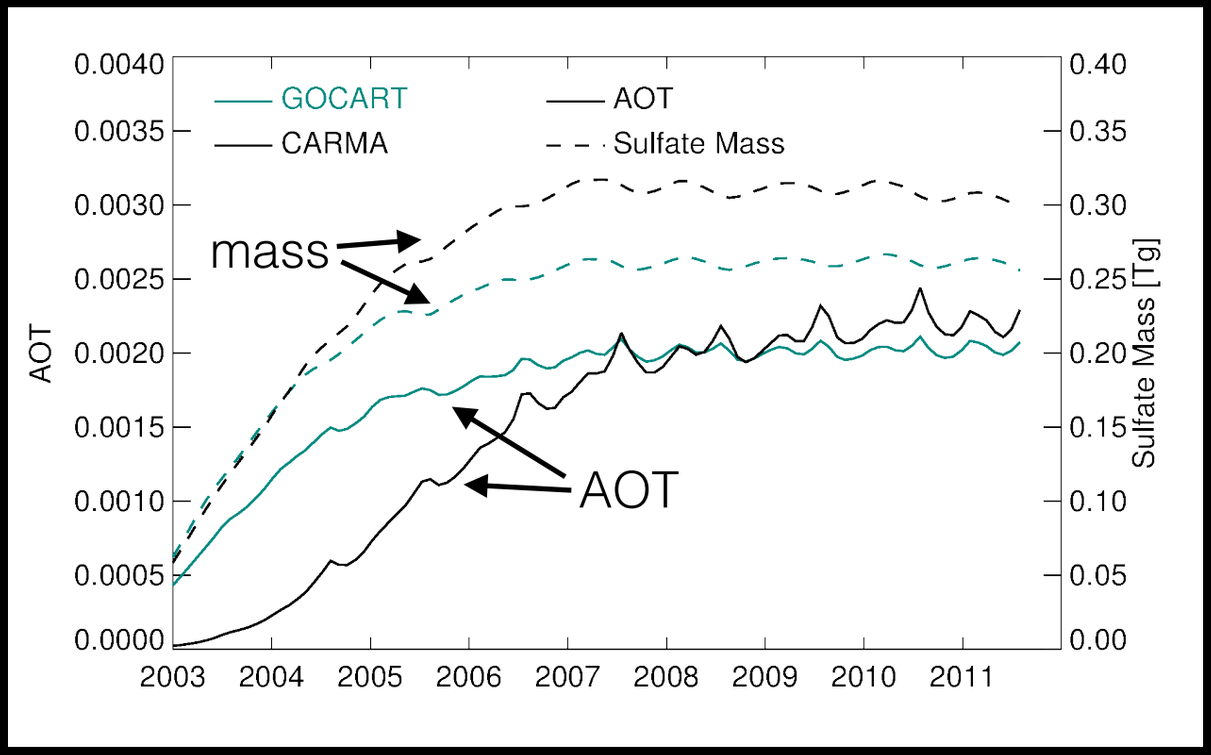
- Community Aerosol and Radiation Model for Atmospheres
- Size resolving (sectional) aerosol, cloud, and radiation model
- Share core code-base with NCAR/University of Colorado
- Implemented online in GEOS-5 with radiation and chemistry coupling
- Objective is to improve simulation of particle size and composition (*clouds, chemistry, radiation, …*)



CARMA: Stratospheric Aerosols

Stratospheric Aerosols

- Recently introduced mechanisms for stratospheric sulfate production:
  - OCS surface concentration specified
  - OCS transported
  - OCS photolysis rates computed in StratChem module
  - SO_2 production from OCS+OH, OCS+O, and OCS+hν
  - SO_4 production from SO_2+OH, SO_2+NO_3, SO_2+aqueous
  - GOCART: SO_4 is aerosol
  - CARMA: nucleation, condensation
- Permits simulation of background and perturbations to stratospheric aerosol (e.g., volcanic eruption)



Spin-up of stratospheric sulfate from simultaneous run of GOCART and CARMA

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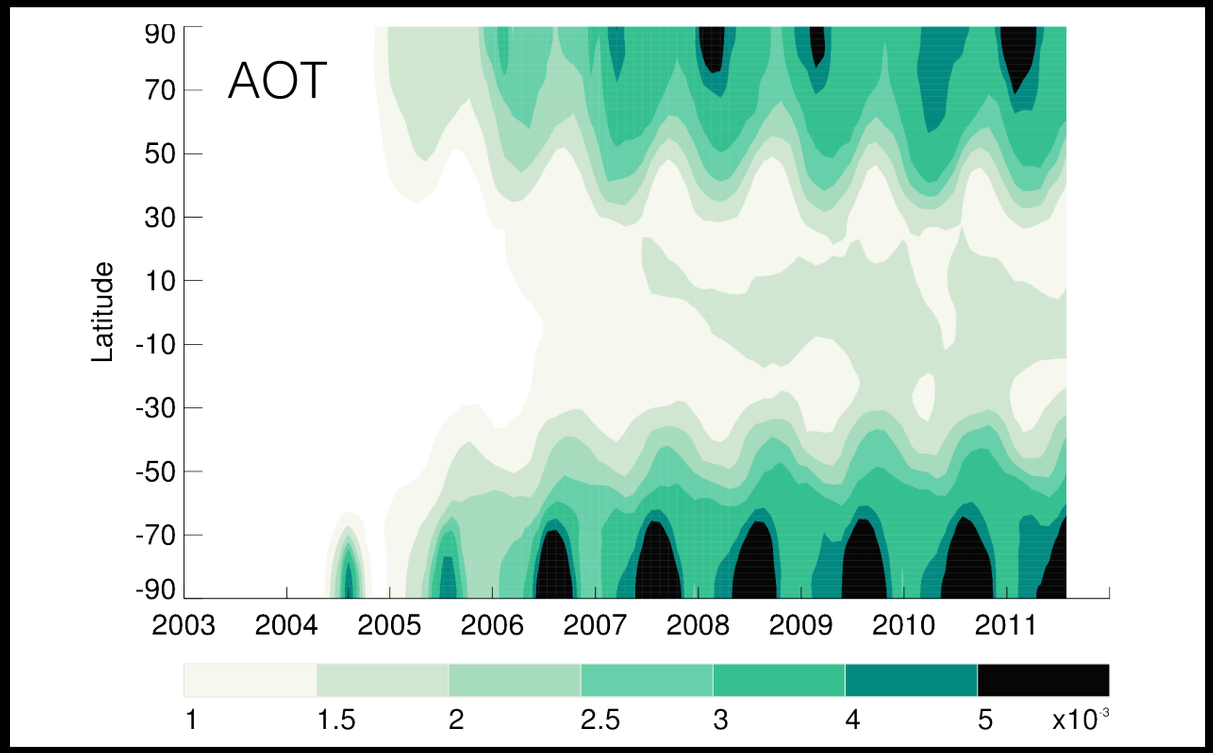

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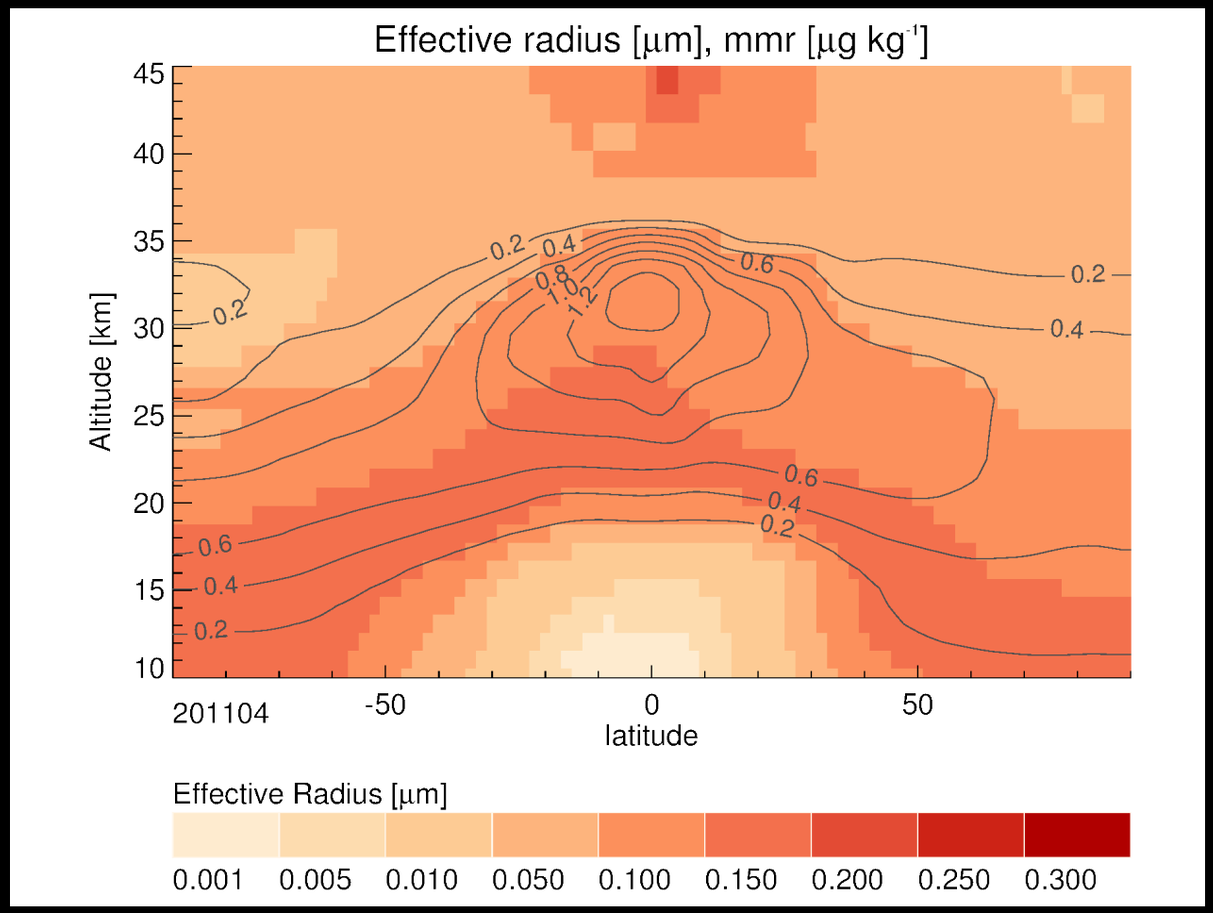

For comparison, in GOCART we assume a fixed particle size distribution (r_{eff} = 0.07 μm)