The GEOS-5 Aerosol Forecasting and Data Assimilation System

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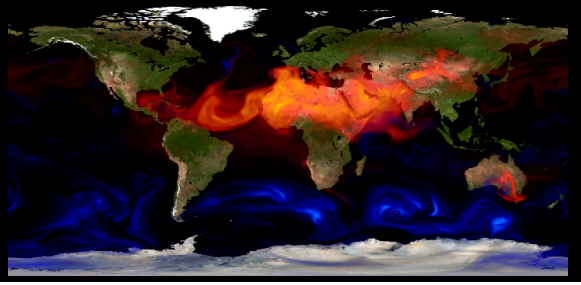
Outline

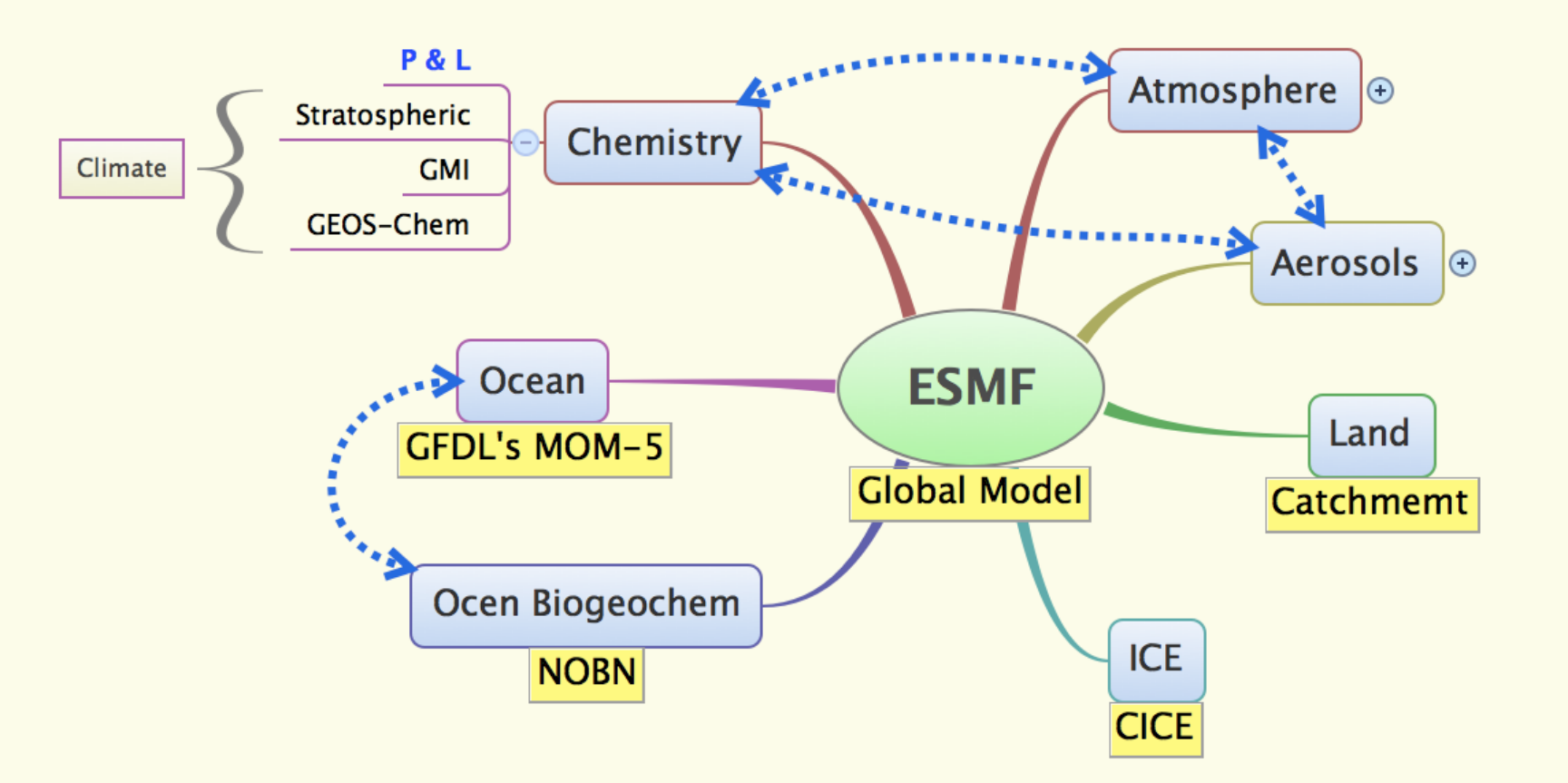
- GEOS-5 Overview
- Current capabilities and future directions
- Highlights:
  - Aerosol forecasting and field campaigns
  - Aerosol Reanalysis
  - ~~OSSEs~~
- Concluding Remarks

Aerosol activities at GMAO



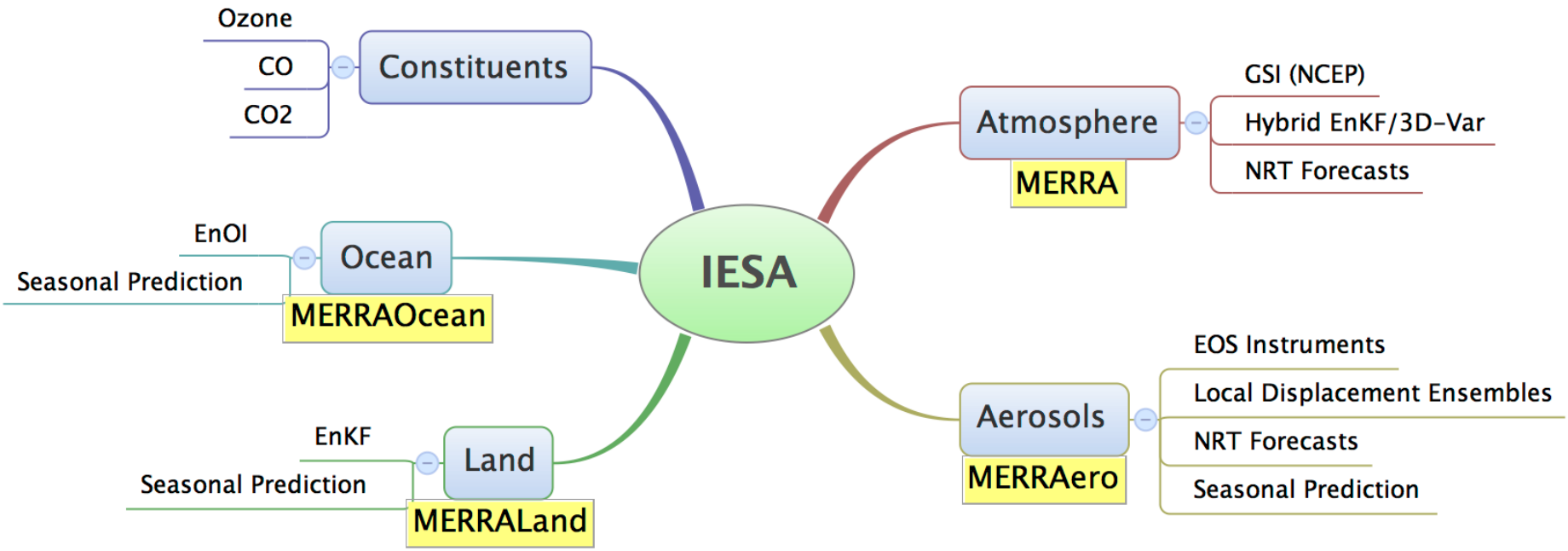
- Developing a **hierarchy of *global* models** capable of skillfully representing
  - the global aerosol distribution as depicted by available in-situ and remotely-sensed measurements
  - the microphysical processes needed for parameterizing cloud/ precipitation-aerosol feedbacks
  - Aerosol interaction 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.

GEOS-5
Earth System Model



From weather to seasonal to decadal time scales

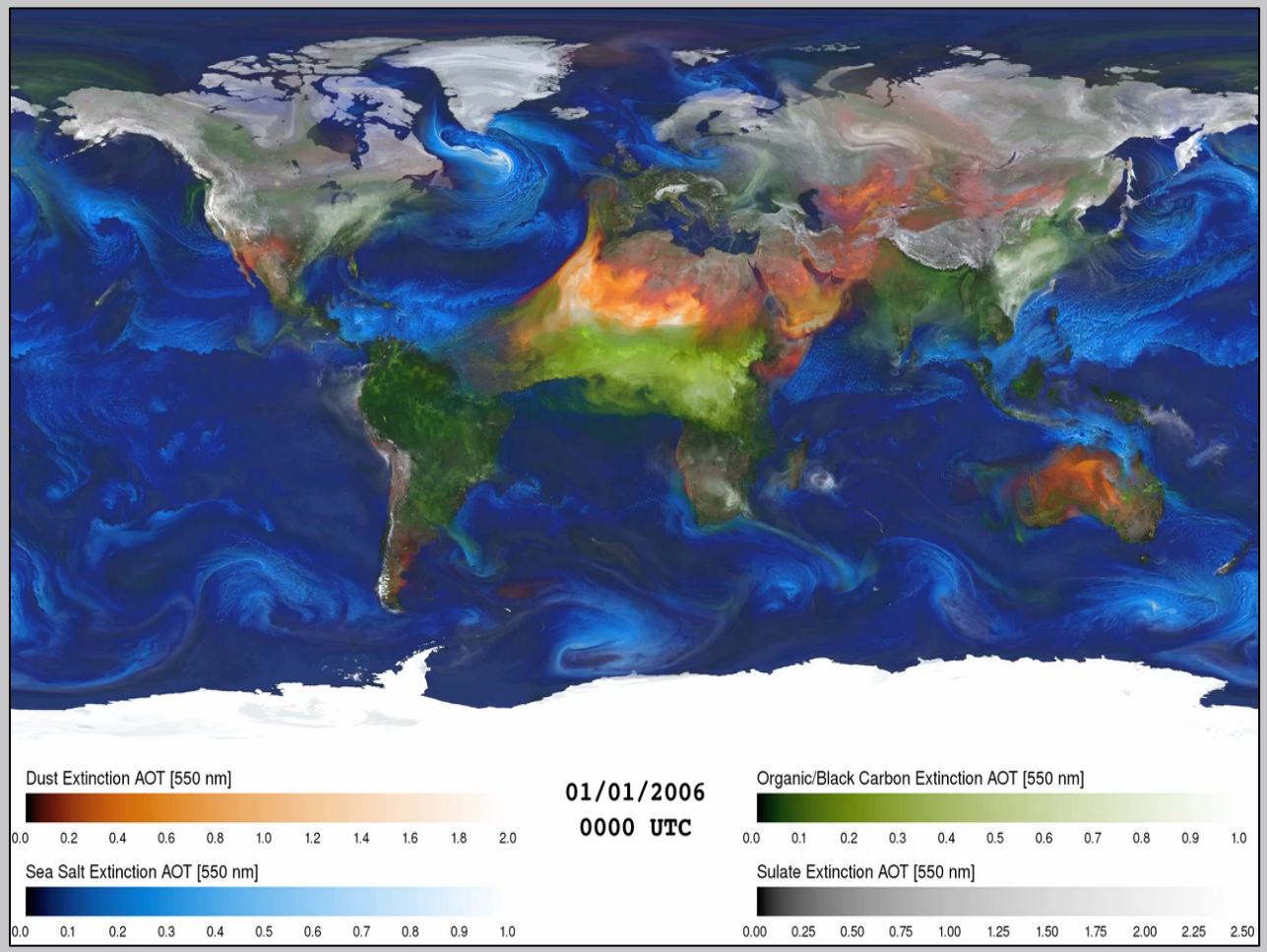
GEOS-5 Data Assimilation



Global Aerosols

7 km GEOS-5 Nature Run
Global Mesoscale Simulation

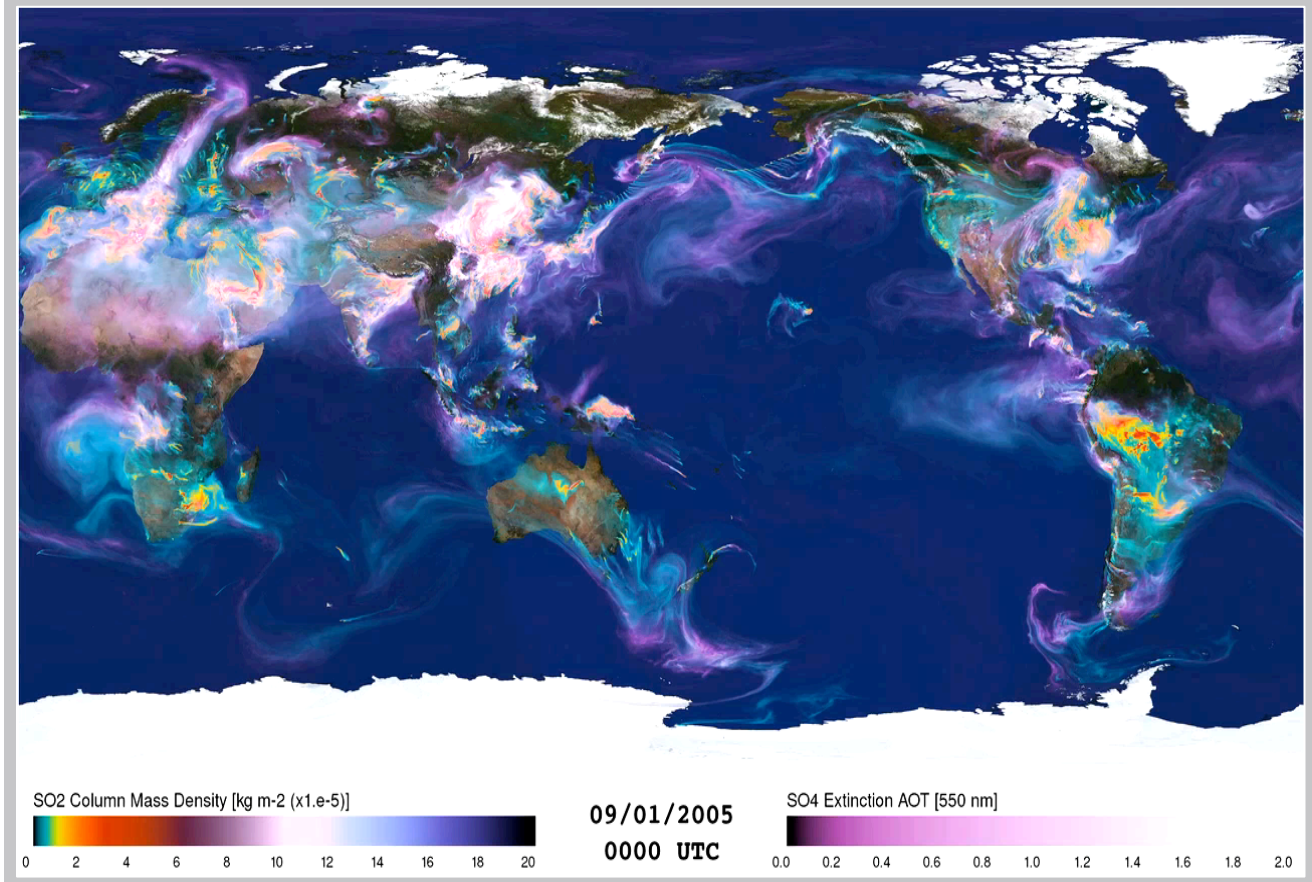
Aerosols play an important role in both weather and climate. They are transported around the globe far from their source regions, interacting with weather systems, scattering and absorbing solar and terrestrial radiation, and modifying cloud micro- and macro-physical properties. They are recognized as one of the most important forcing agents in the climate system.



Sulfur Dioxide
Sulfate Aerosols

7 km GEOS-5 Nature Run
Global Mesoscale Simulation

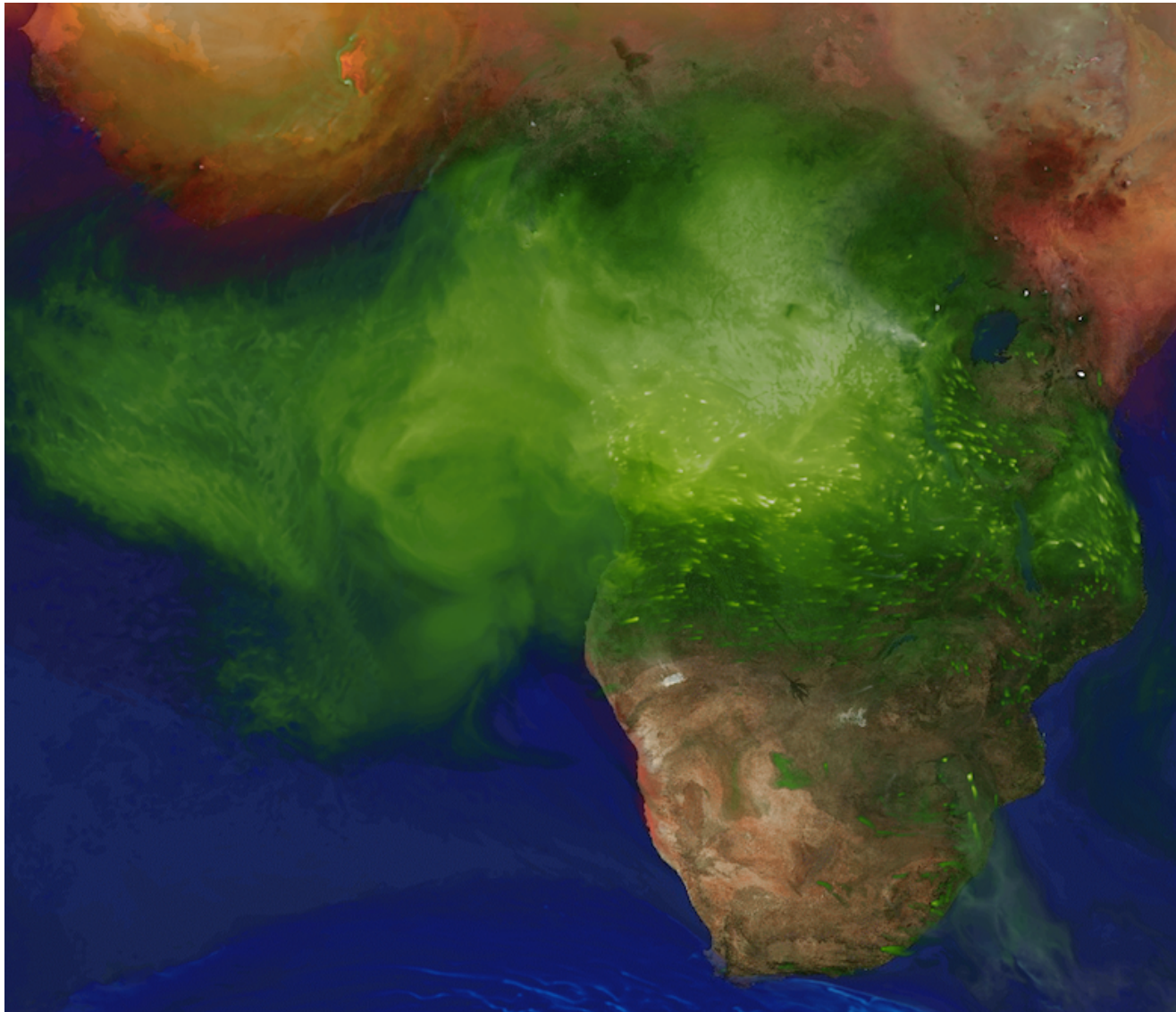
Sulfur dioxide (SO_2), produced during the burning of fossil fuels and from volcanic eruptions, is a short lived gas which can act as pollutant near the surface with detrimental health and acidifying effects. With a mean life time of just a couple of days in the troposphere, emitted SO_2 is quickly converted to sulfate aerosol (SO_4) through oxidation by OH or by reaction with H_2O_2 within clouds. The resulting SO_4 exerts a direct radiative effect on the atmosphere and it can also have an indirect radiative effect by inducing changes in cloud and precipitation microphysics.



Biomass Burning

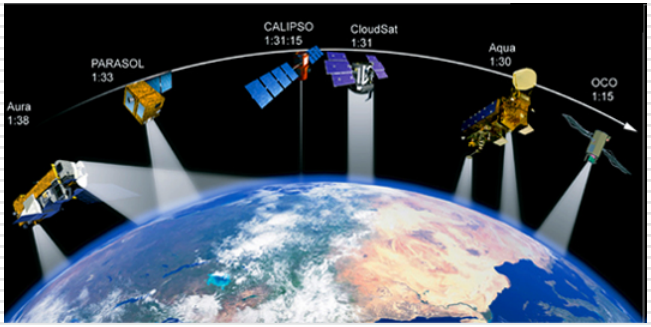
QFED: Quick Fire Emission Dataset

- 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
- In GEOS-5 BB emissios are deposited in the PBL.



Aerosol Data Assimilation
2014 NRT Configuration

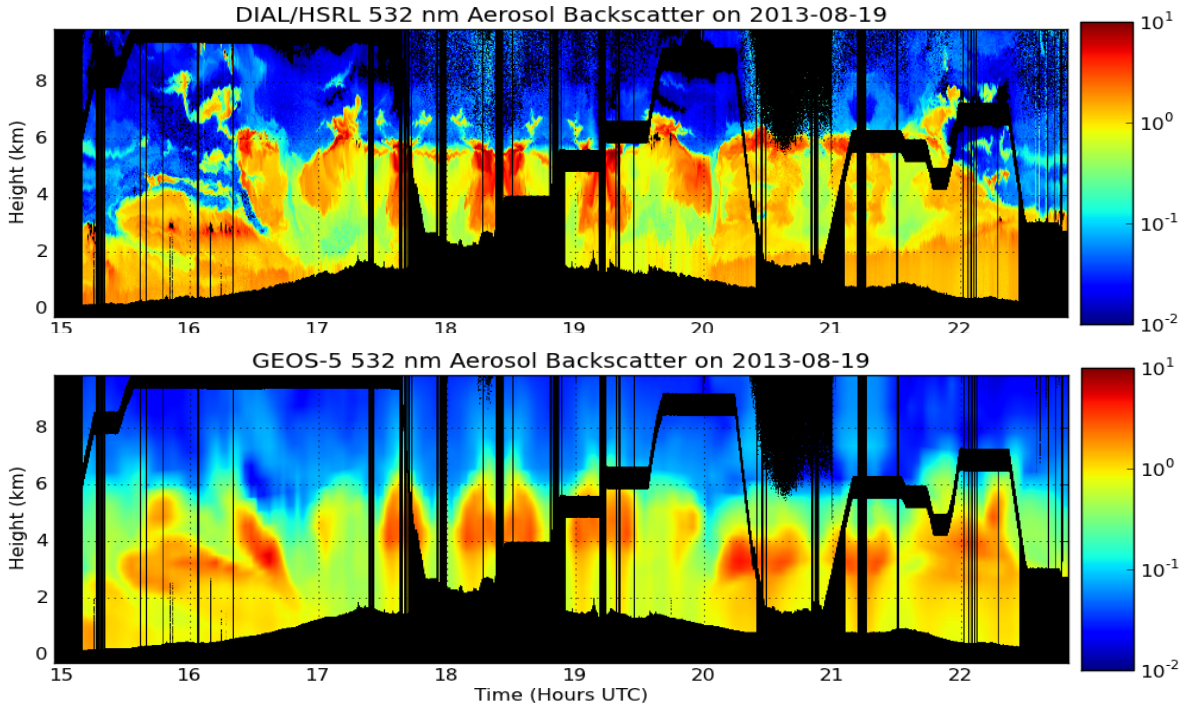
- Focus on NASA EOS instruments, MODIS for now



- Global, high resolution 2D AOD analysis
- 3D increments by means of Local Displacement Ensembles (**LDE**)
- Simultaneous estimates of background bias (*Dee and da Silva 1998*)
- Adaptive Statistical Quality Control (*Dee et al. 1999*):
  - State dependent (adapts to the error of the day)
  - Background and Buddy checks based on log-transformed AOD *innovation*
- Error covariance models (*Dee and da Silva 1999*):
  - Innovation based
  - Maximum likelihood

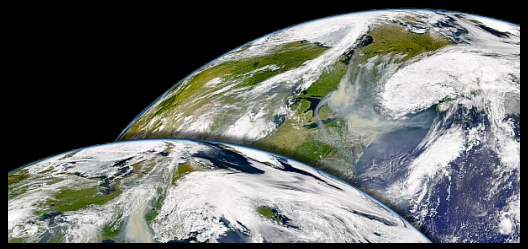
Field Campaign Support

- Global 5-day chemical forecasts
  - O_3, aerosols, CO, CO_2, SO_2
  - Nominally 25 km
- Driven by real-time biomass emissions from MODIS FRP (QFED)
- Constituents transported on-line, interactively
- Since 2007 supported several field missions including TC4, ARCTAS , GloPac, ATTREX, DISCOVER-AQ, HS3 ,SEAC4RS, etc.



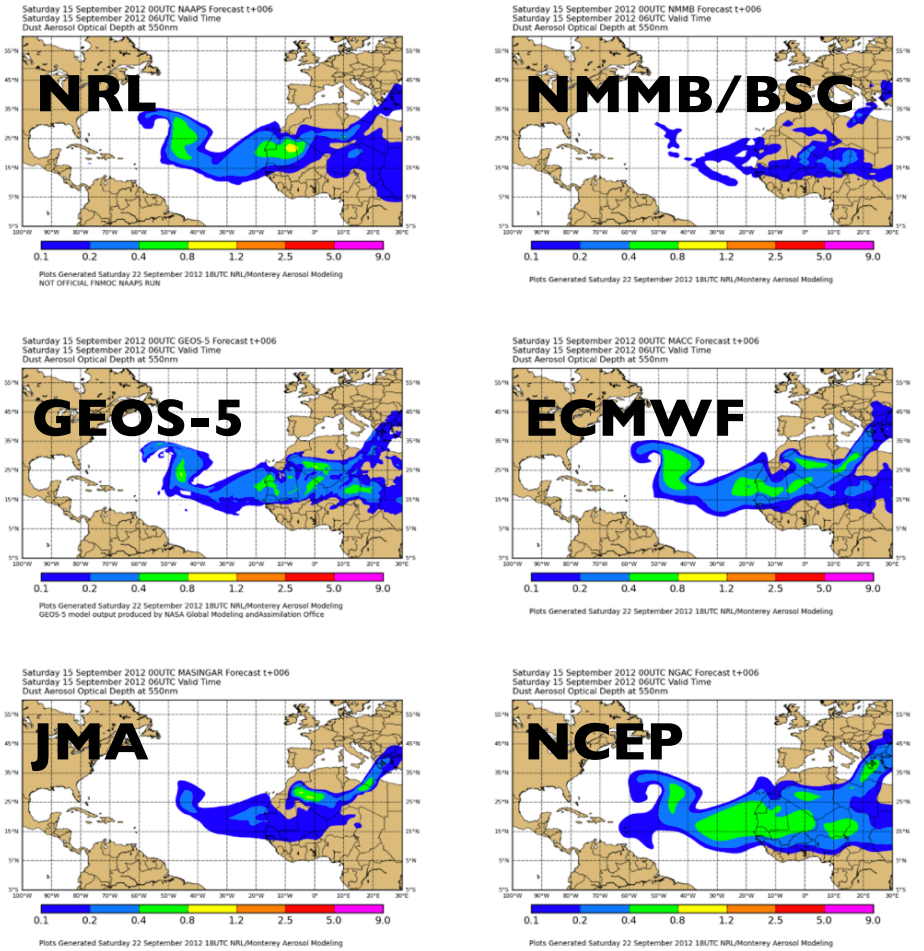
Comparison of observed (top) and simulated (bottom) aerosol backscatter for a slight during the 2013 SEAC4RS campaign.

http://gmao.gsfc.nasa.gov/forecasts/



International Cooperative for Aerosol Prediction (ICAP)

ICAP is an international forum for aerosol forecast centers, remote sensing data providers, and lead systems developers to share best practices and discuss pressing issues facing the operational aerosol community.



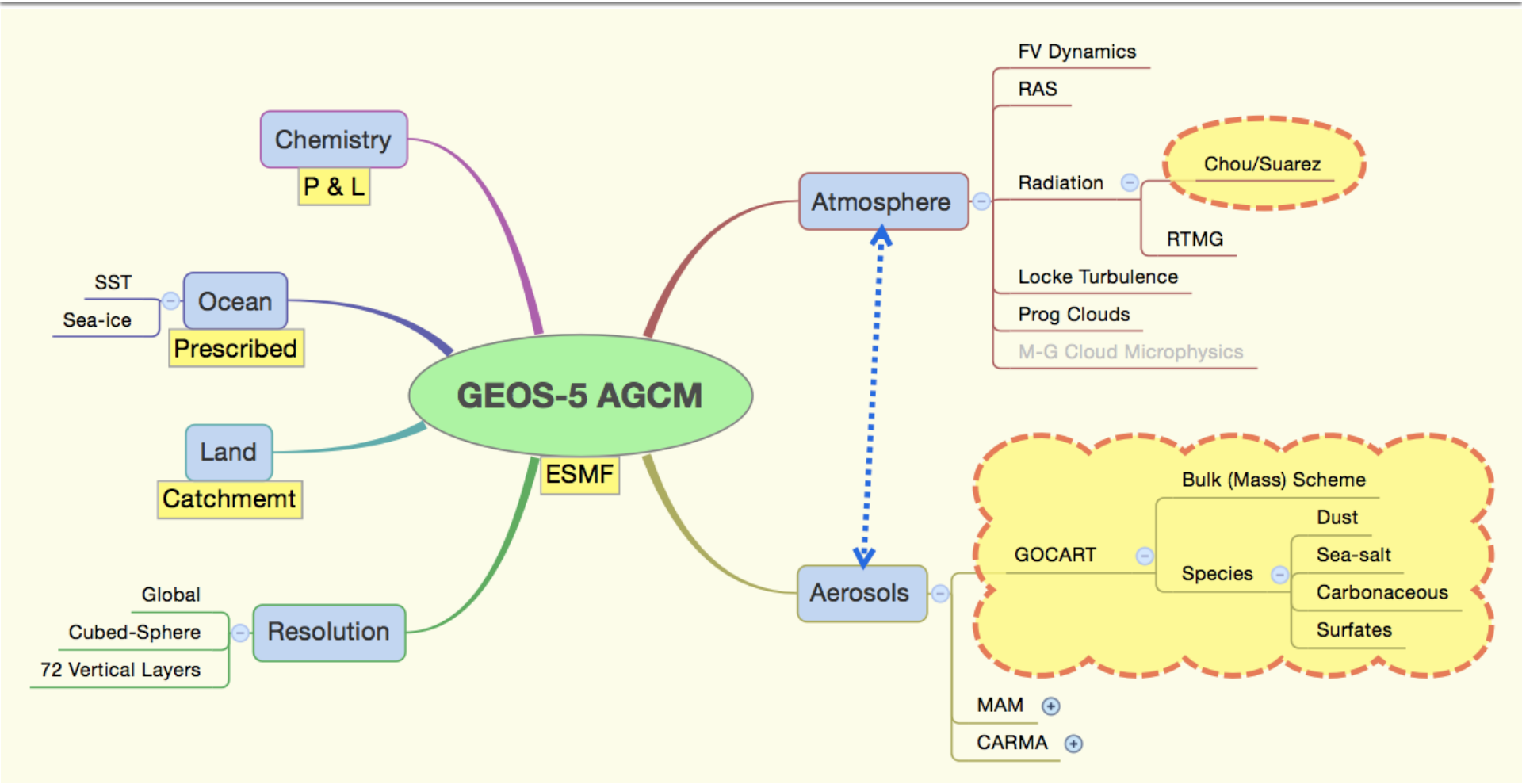
ICAP Multi-Model Ensemble Dust Forecast

Sessions et al., ACPD, 14, 14933–14998, 2014

Summary of GEOS-5 Reanalysis Activities

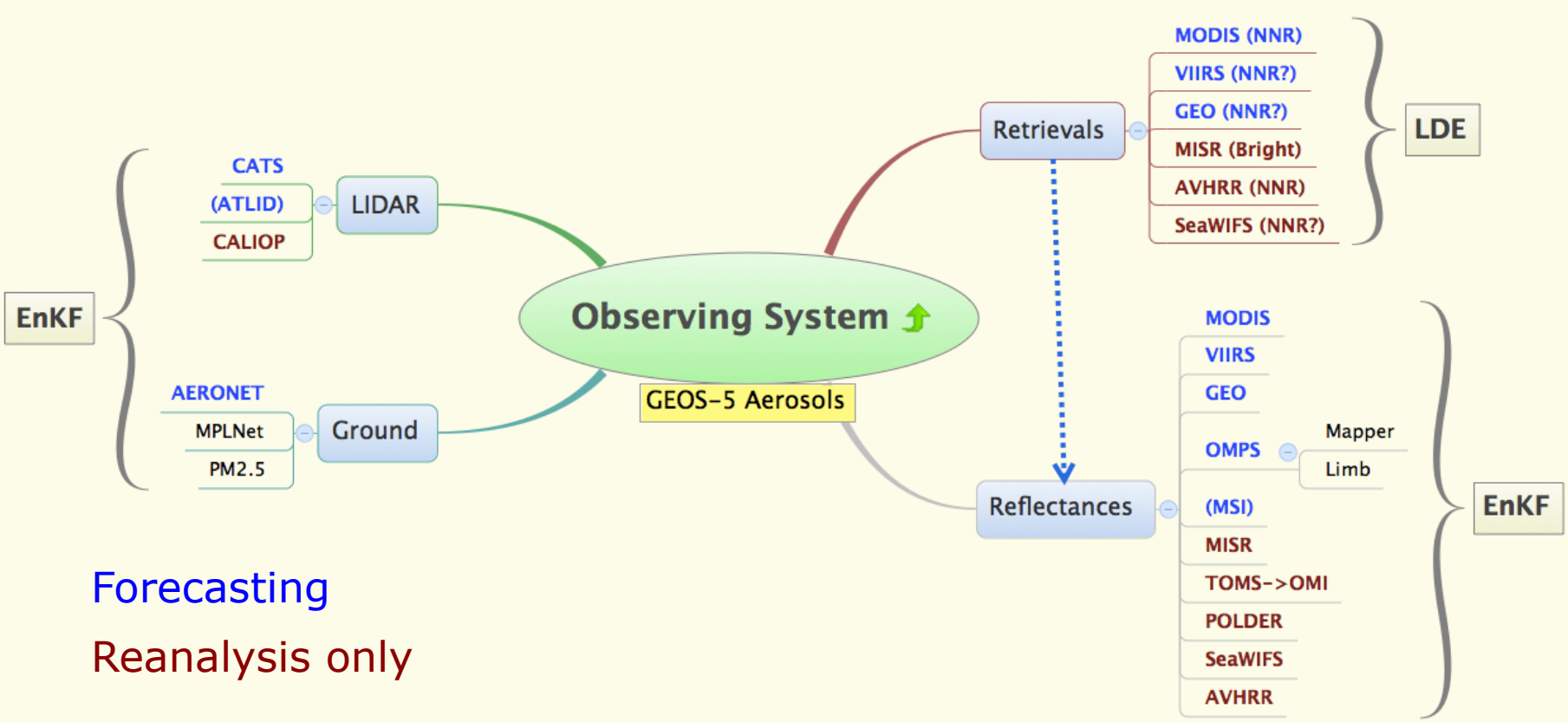
Name	Nominal Resolution	Period	Aerosol Data	Available
MERRA-1	50 km	1979-present	NONE	now
MERRAero	50 km	2002-present	MODIS C5	now
FP for Inst. Teams	50 km	1997-	MODIS C5	In progress
NCA	25 km	2010-11	MODIS C5, MISR	Now
MERRA-2	50 km	1979-present	AVHRR, MODIS C5, MISR,AERONET	Summer 2015
MERRA-2 Dynamical Downscaling	12.5 km	2000-2015	AVHRR, MODIS C5/C6, MISR, AERONET	Q4 2015

GEOS-5 Model Configuration for and MERR*Aero* MERRA-2



Global, 50 km, 72 Levels, top at 0.01 hPa

Aerosol Observing System



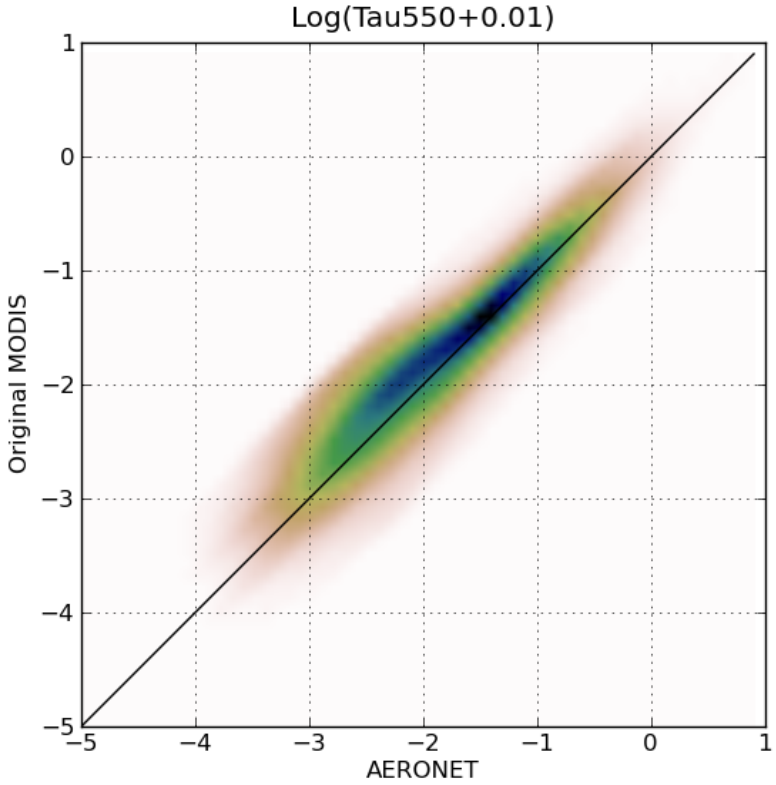
Aerosol Data Assimilation in GEOS-5

MERR*Aero* Overview

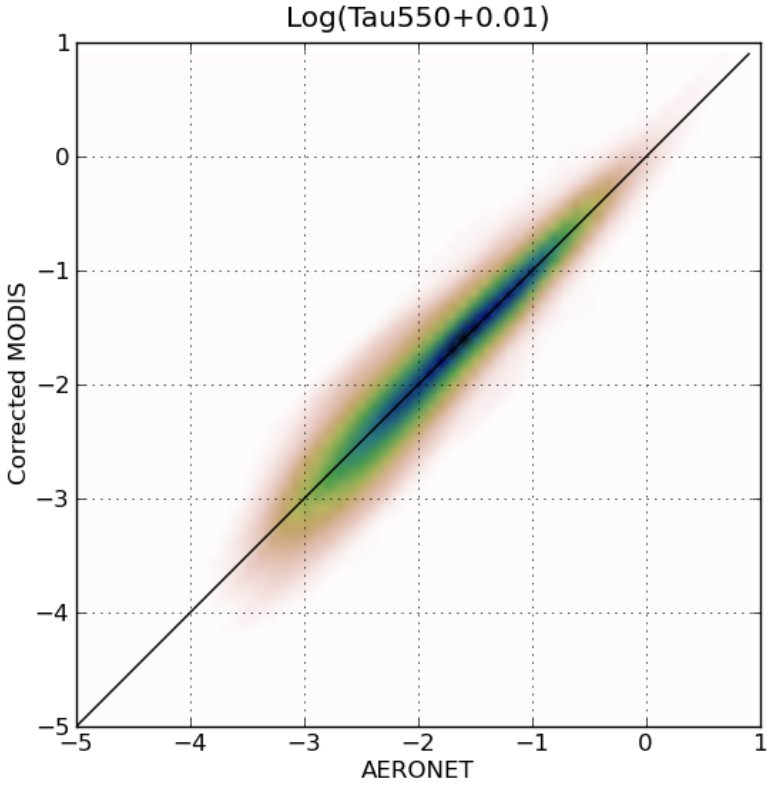
Feature	Description
Model	GEOS-5 Earth Modeling System (w/ GOCART) Constrained by MERRA-1 Meteorology (Replay) Land sees obs. precipitation (like MERRA*Land*) Driven by QFED daily Biomass Emissions Version 2.2
Aerosol Data Assimilation	Local Displacement Ensembles (LDE) Neural Net MODIS Aerosol Optical Depth Retrievals • Trained on AERONET Level 2 AOD's Stringent cloud screening
Period	mid 2002-present (Aqua + Terra)
Resolution	Horizontal: nominally 50 km Vertical: 72 layers, top ~85 km
Aerosol Species	Dust, sea-salt, sulfates, organic & black carbon

Observational Bias

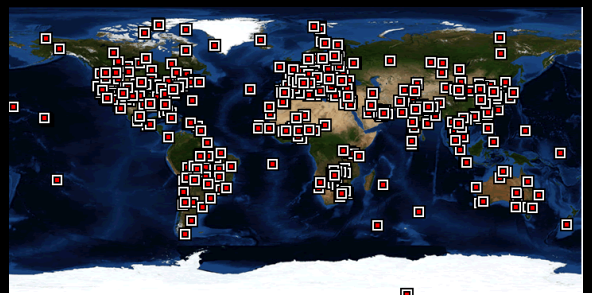
ORIGINAL MODIS AOD

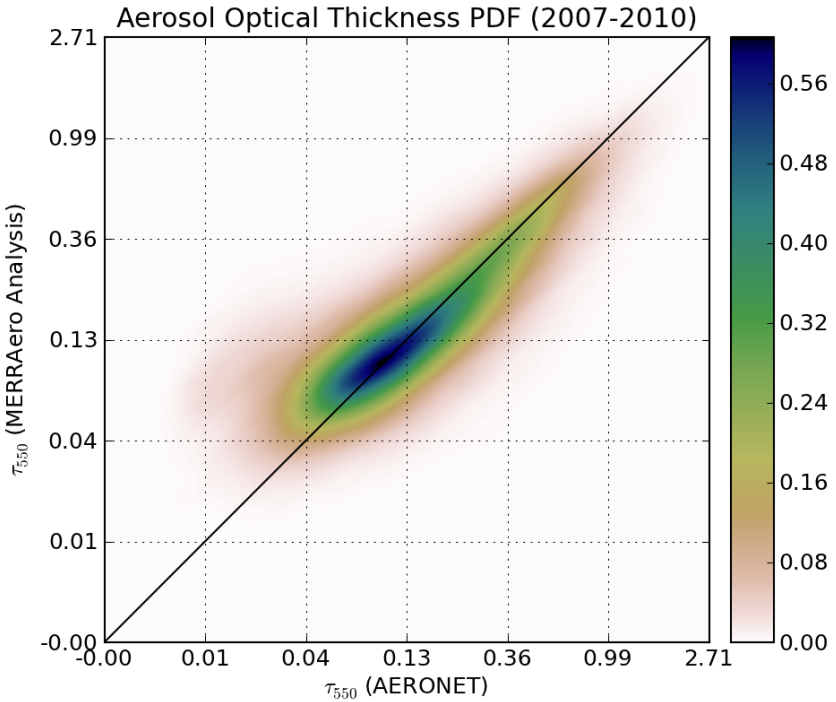


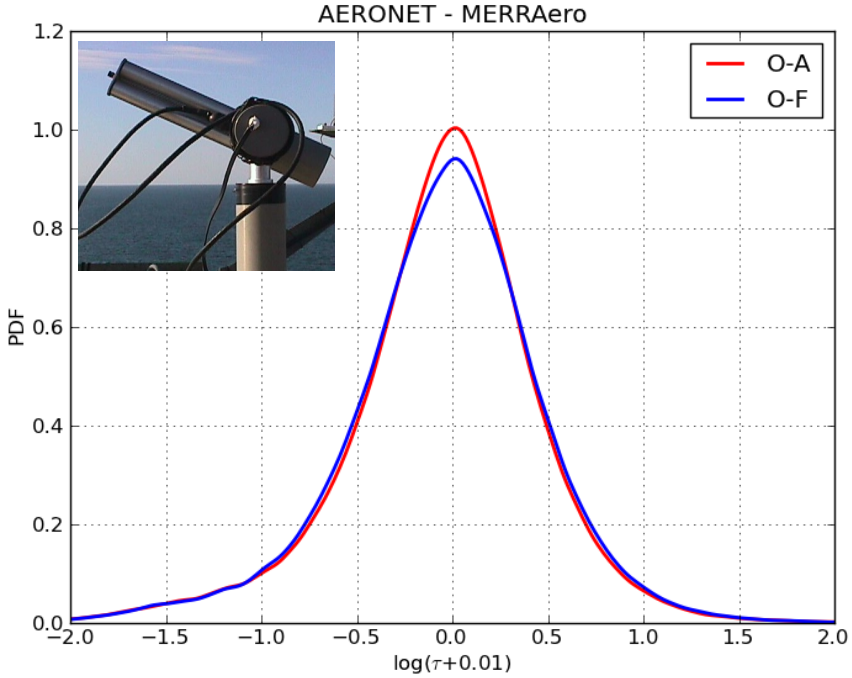
BIAS CORRECTED AOD



AERONET MERRAero Validation

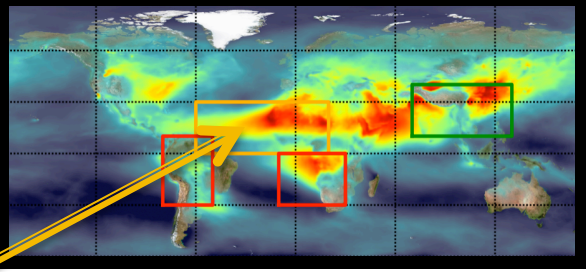




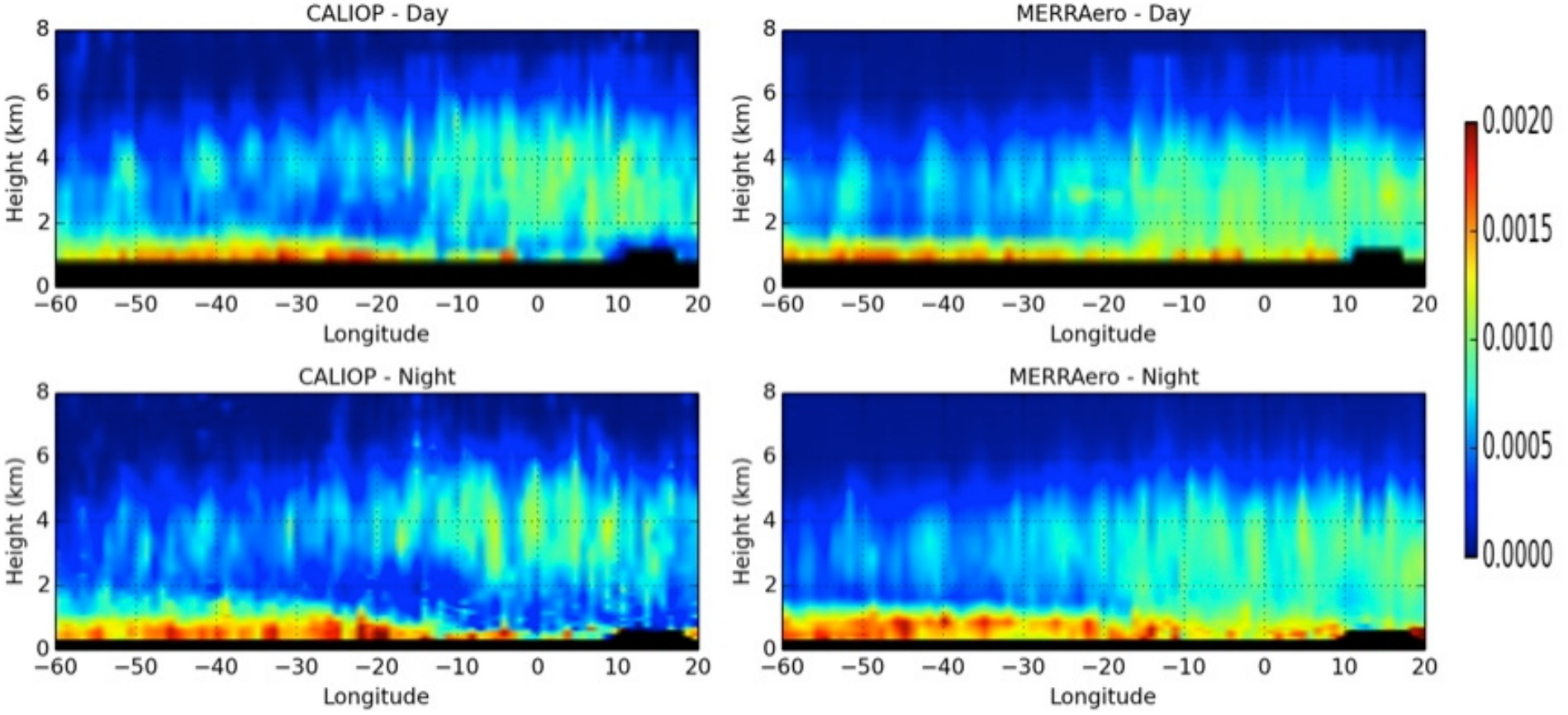


$$\eta = \log(\tau + 0.01)$$

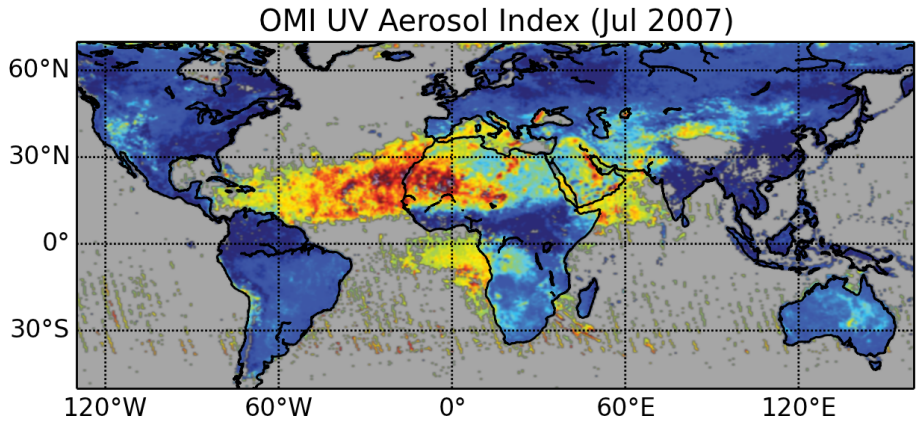
Vertical Structure: Comparison to CALIOP

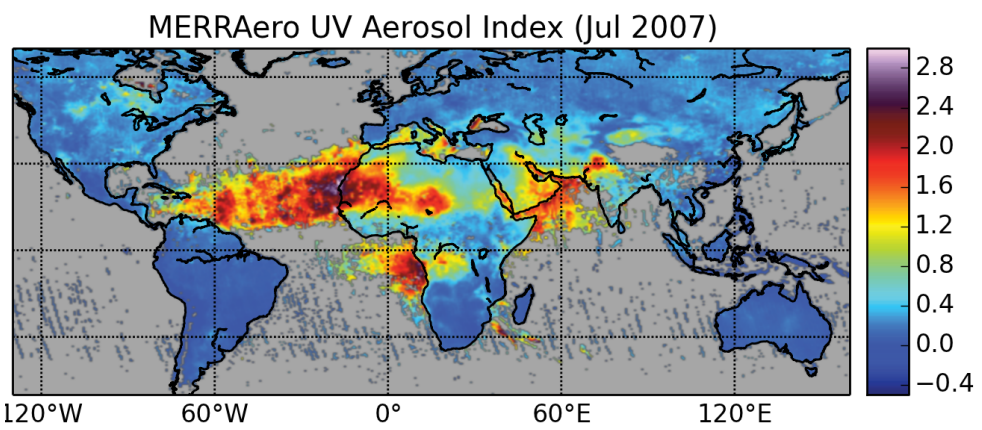


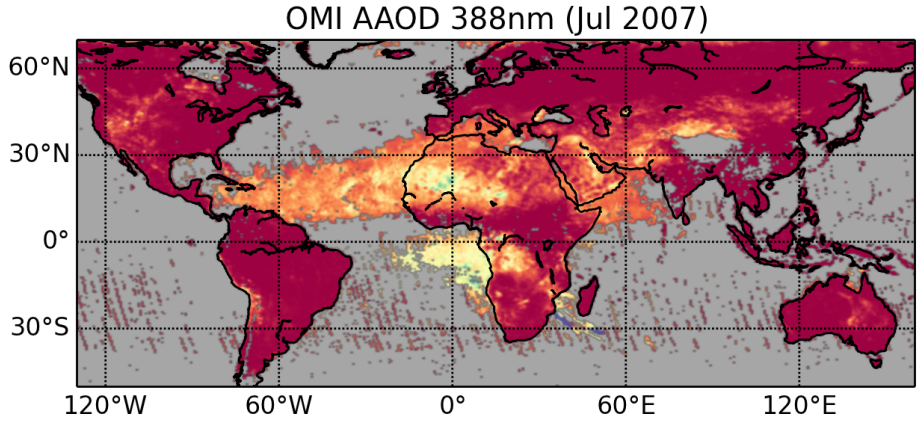
DUST

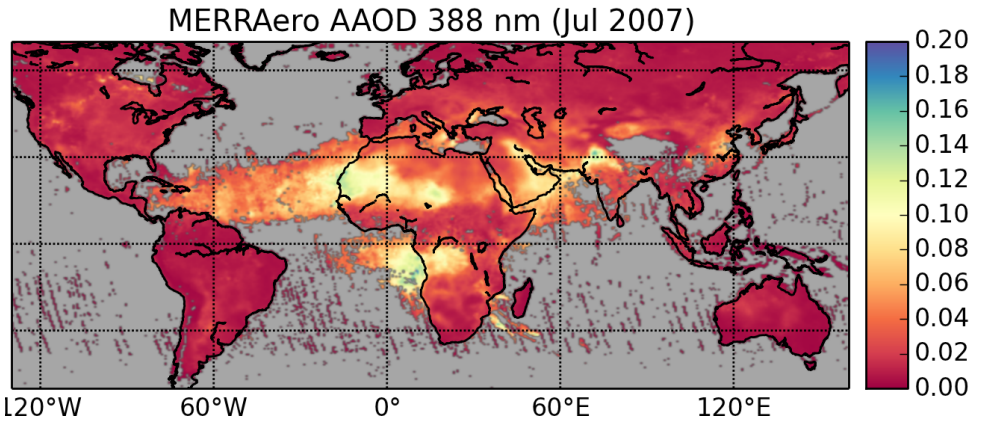


Evaluation of MERRAero Absorption using OMI

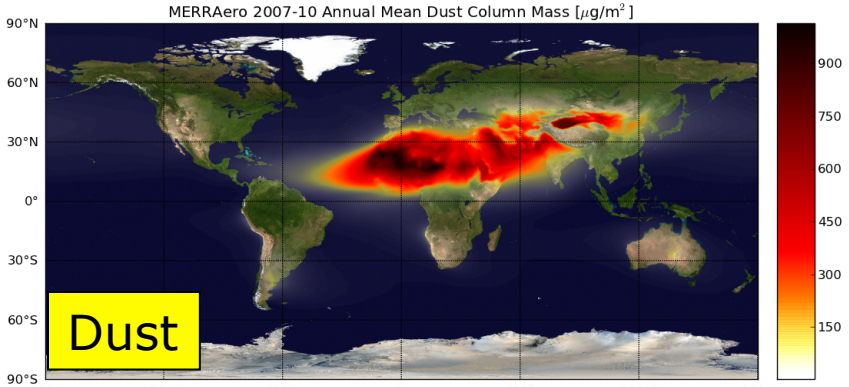


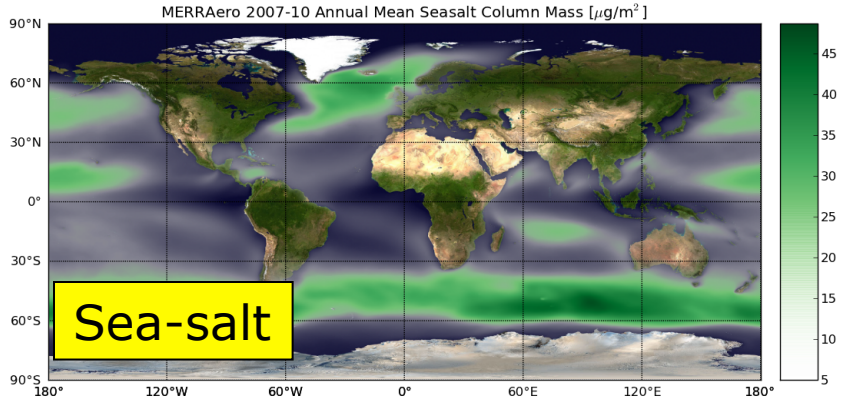


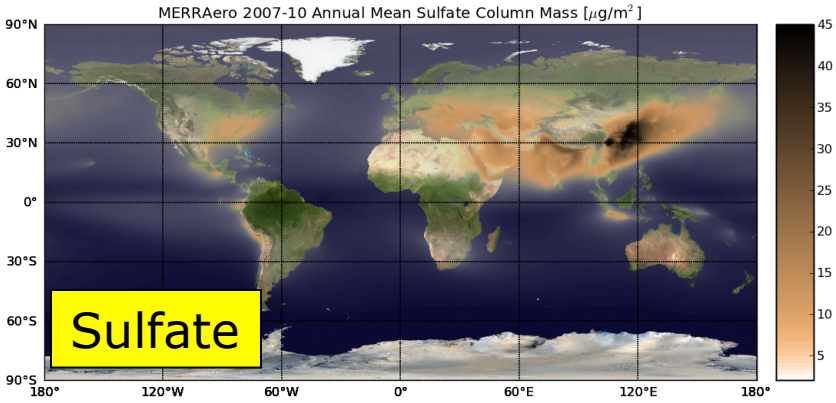


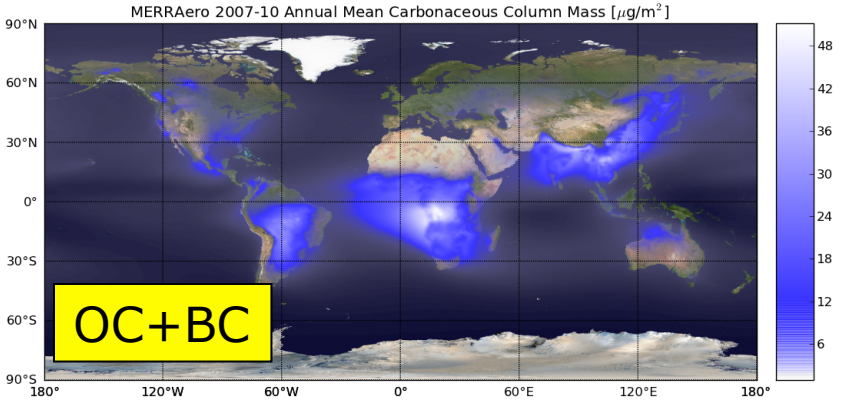


Assimilated Aerosol Annual Mean Mass



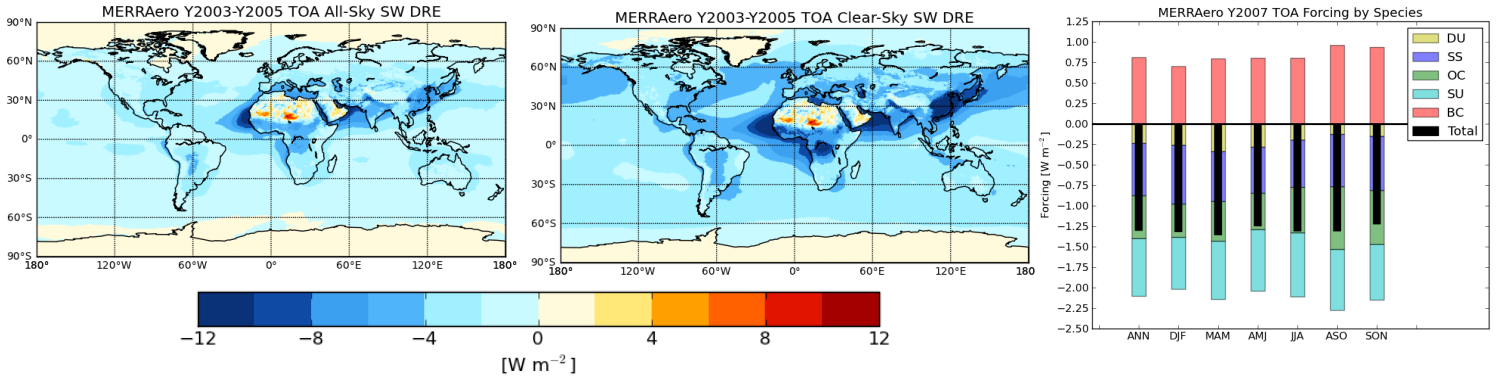






Speciation potentially adjusted by spectral reflectances

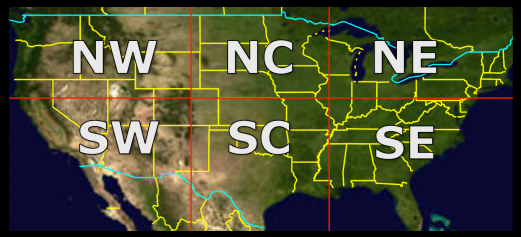
MERRAero Aerosol Reanalysis

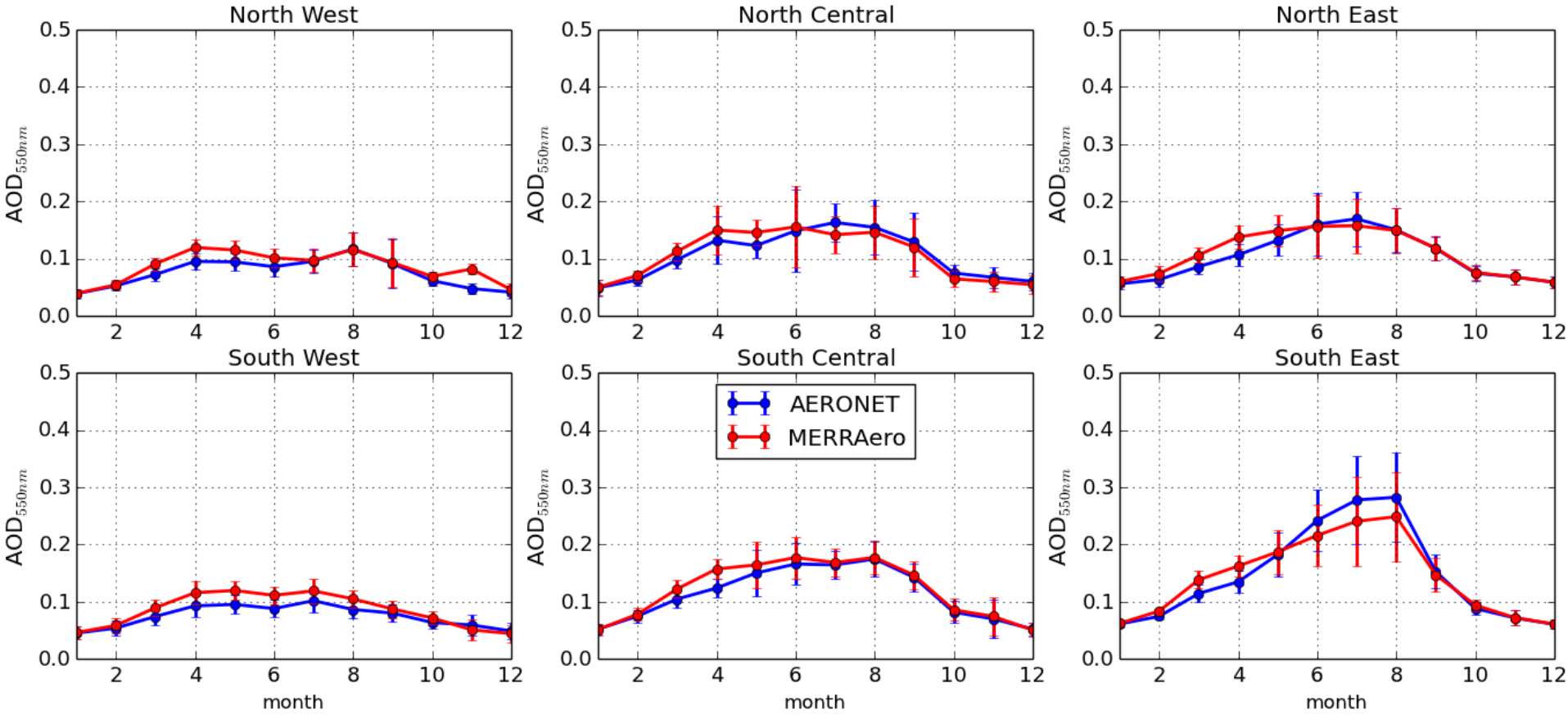


Comparison of globally averaged SW clear-sky aerosol direct radiative effect (DRE)			
Source	TOA SW DRE Ocean (Land)	ATM SW DRE Ocean (Land)	SFC SW DRE Ocean (Land)
MERRAero (Y2003-Y2005)	-3.5 (-3.2)	2.2 (5.4)	-5.7 (-8.6)
Observational (Y2000-Y2003) Yu *et al.* (2006)	-5.5 ± 0.7 (-4.9 ± 0.5)	3.3 (6.8)	-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)

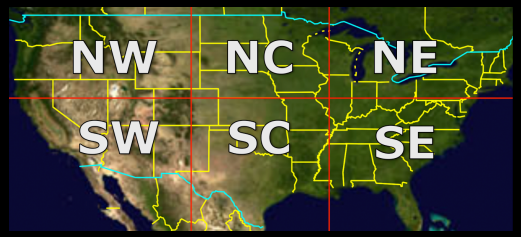
MERRAero provides observation constrained estimate of aerosol radiative forcing, which can be analyzed by component

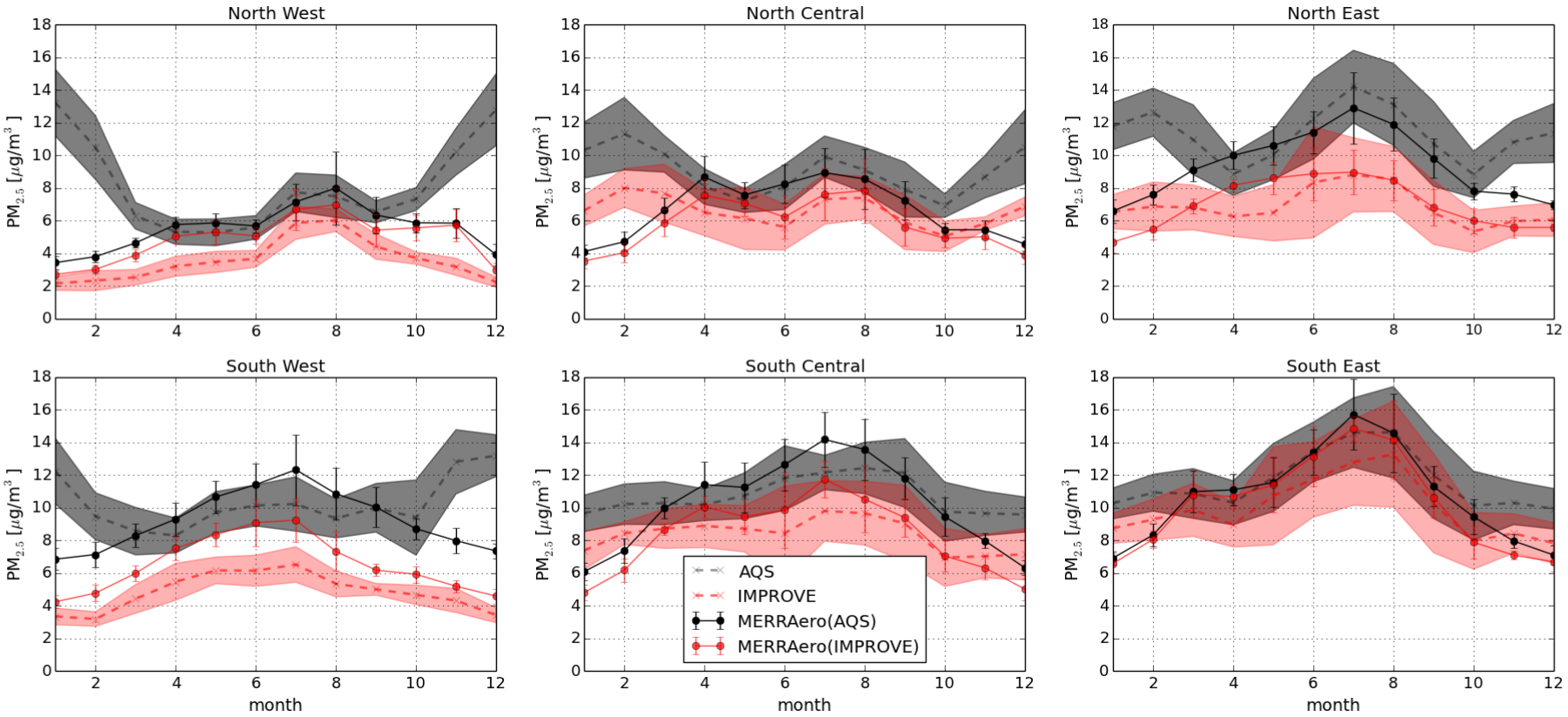
Aerosol Optical Depth Regional Climatology



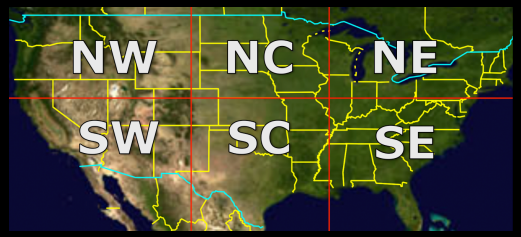


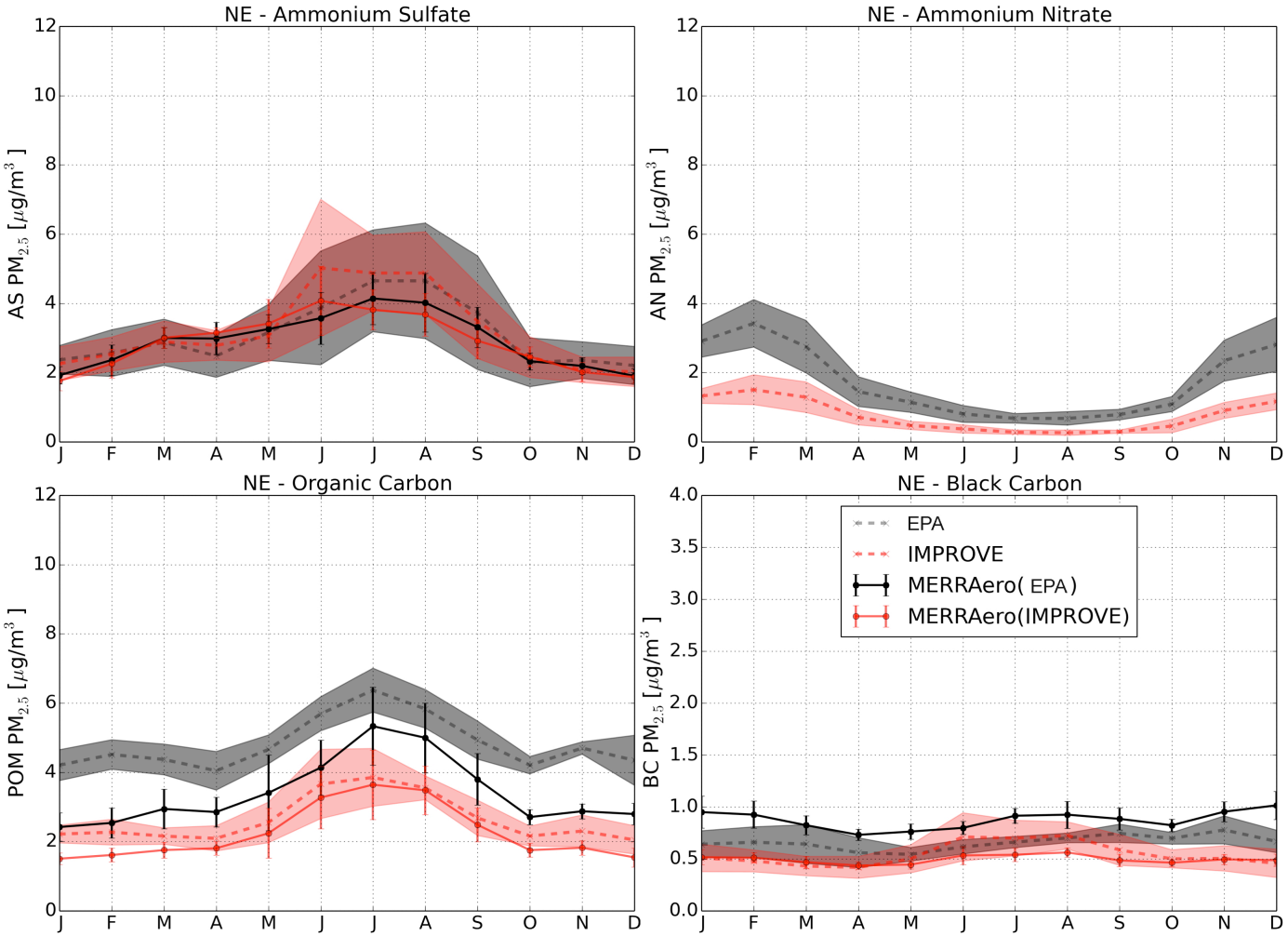
$PM_{2.5}$ (Total) Regional Climatology





$PM_{2.5}$ (Speciated) Northeast Climatology



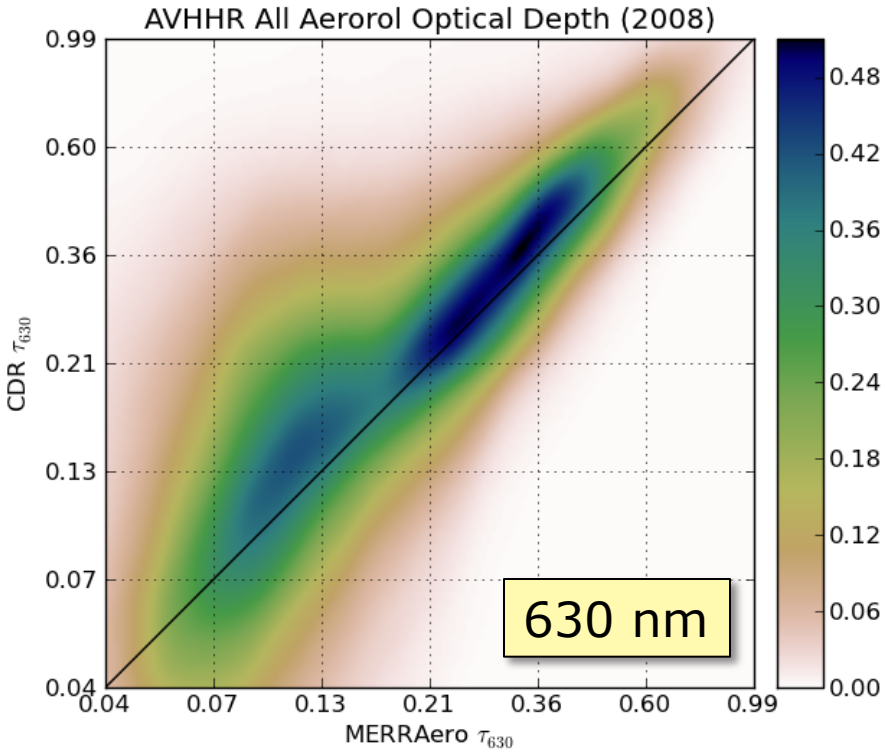


Aerosols in MERRA-2

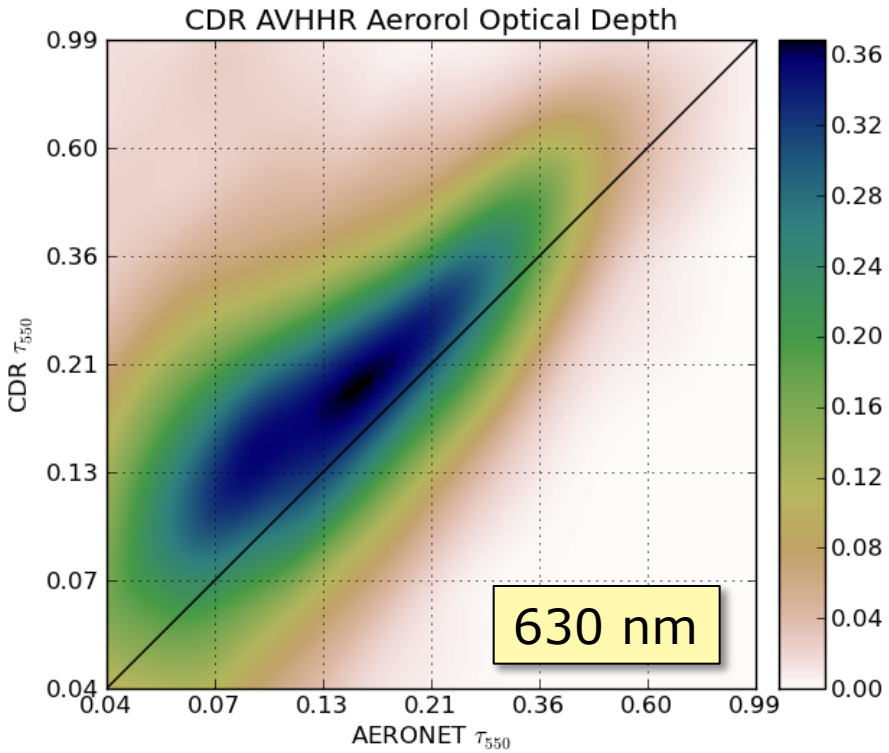
Feature	Description
Model **Emissions**	GEOS-5 Earth Modeling System (w/ GOCART) Interactive aerosols with AOD data assimilation Land sees obs. precipitation (like MERRA*Land*) Daily QFED for 2000-on, monthly calibrated RETRO before
Aerosol Data Assimilation	Local Displacement Ensembles (LDE) Neural Net MODIS Aerosol Optical Depth Retrievals v2 MISR AOD data over bright surfaces AVHRR Neural Net Retrieval Stringent cloud screening
Period	1980-present
Resolution	Horizontal: nominally 50 km Vertical: 72 layers, top ~85 km
Aerosol Species	Dust, sea-salt, sulfates, organic & black carbon

AVHRR NOAA CDR AOD

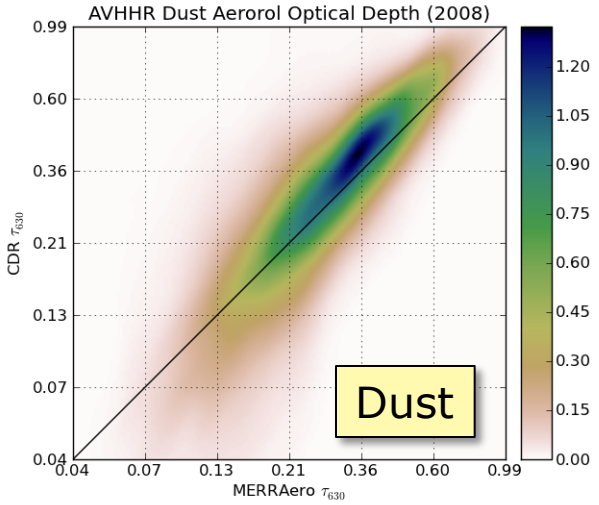
MERRAero, AERONET Comparison



MERRAero

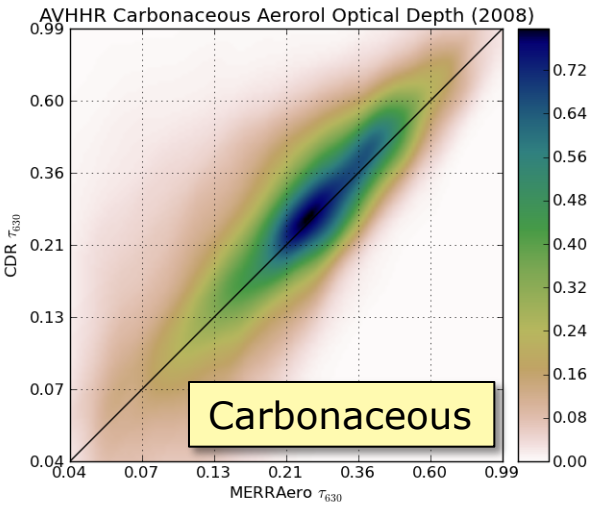


AERONET

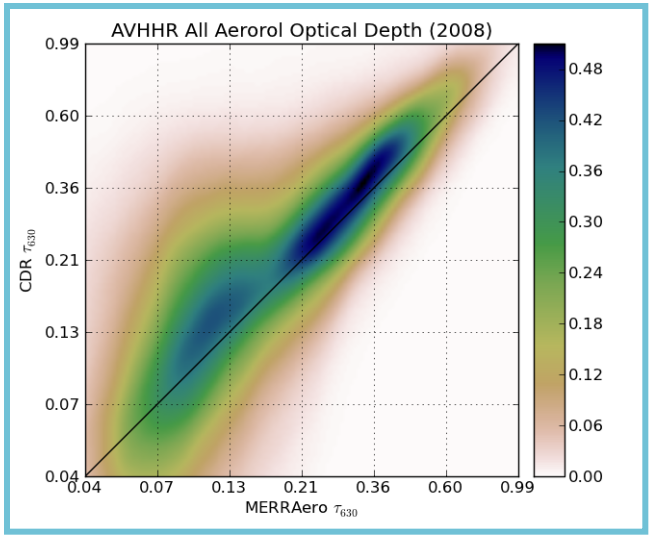


Dust

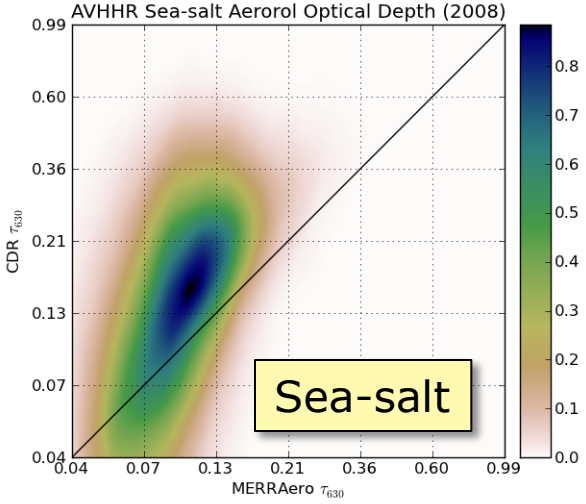
CDR: 2008



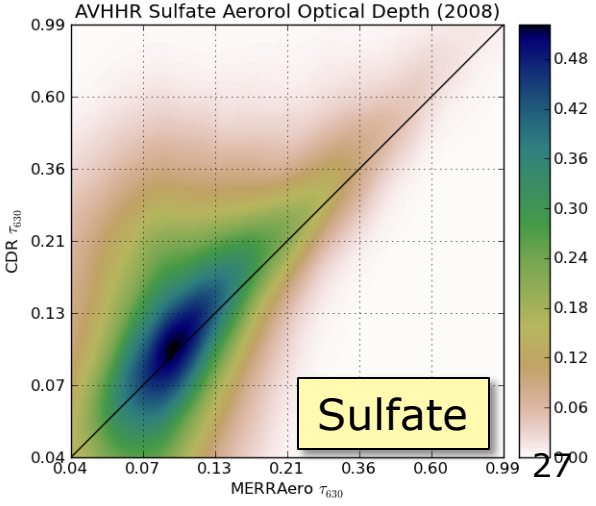
Carbonaceous



Multiple Species



Sea-salt



Sulfate

PATMOS-x

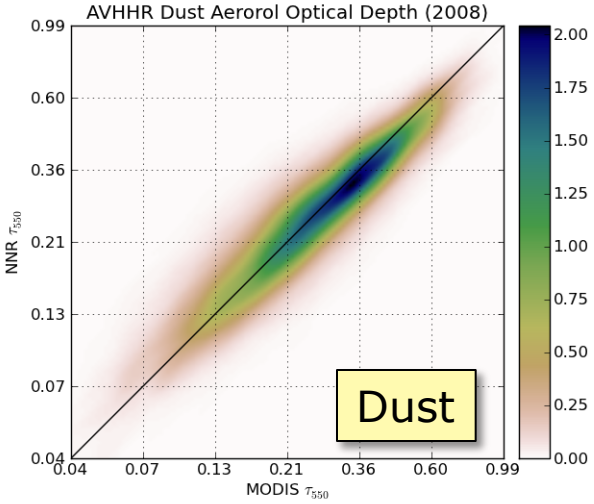
AVHRR Pathfinder Atmospheres - Extended

PATMOS-X DATASET

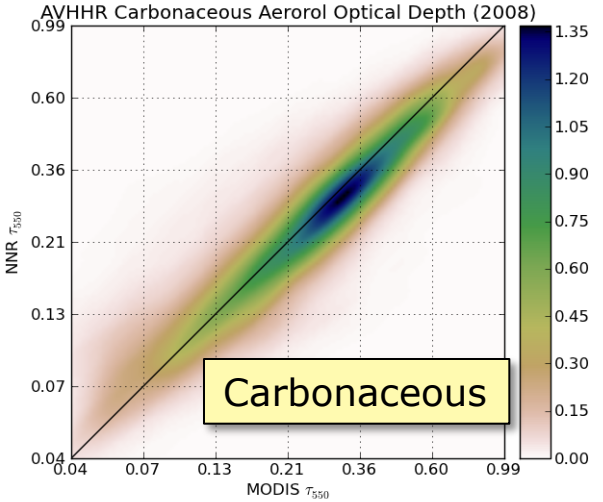
- Version 5 Level 2B
- 0.1 degree sampling (not average)
- Period: 1978-2009
- Inter satellite calibration (MODIS reference)
- Bayesian probabilistic cloud detection (CALIPSO reference)
  - **cpd <0.5%**

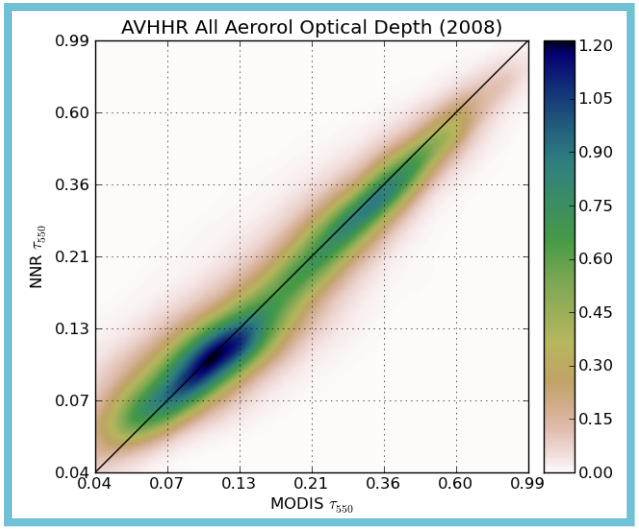
NEURAL NET RETRIVAL

- Ocean Predictors
  - TOA Reflectances
  - 630 and 860 nm
  - TPW
  - Ocean albedo (wind)
  - Solar and sensor angles
  - GEOS-5 fractional AOD speciation
- Target:
  - AOD at 550 nm
  - Balanced MODIS NNR

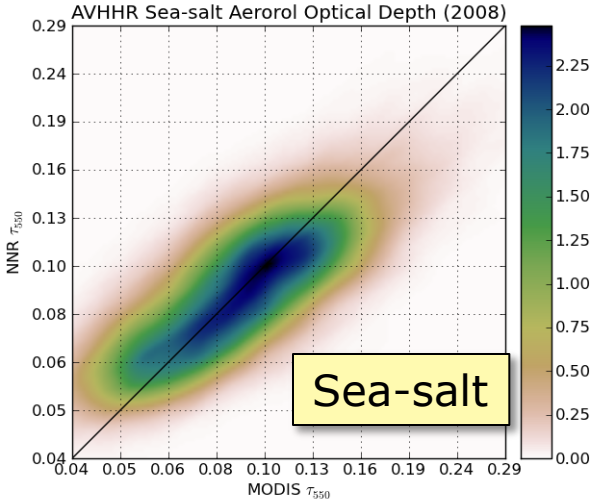


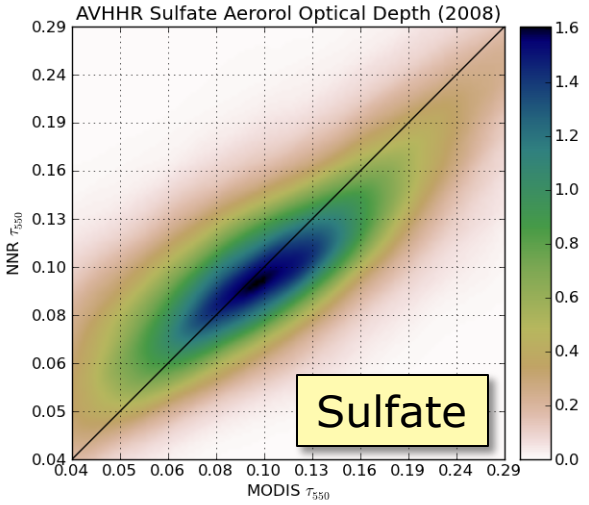
2008



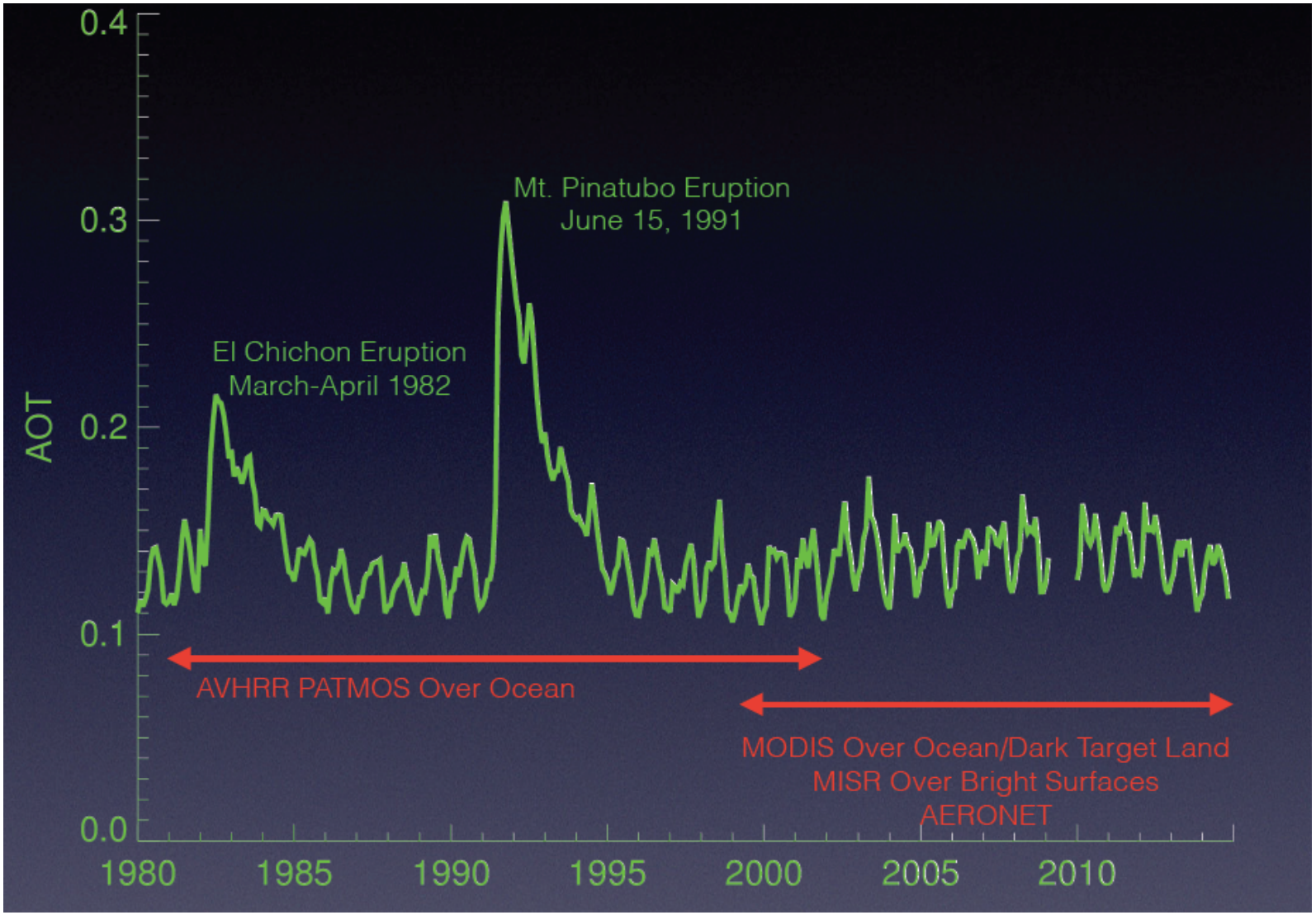


Multiple Species

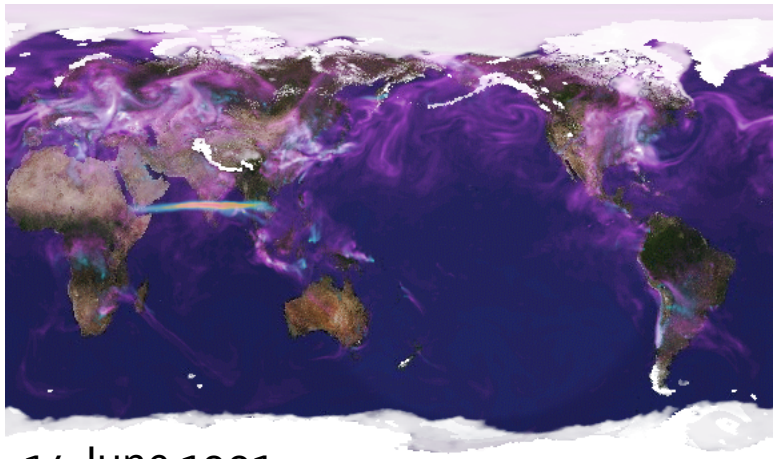




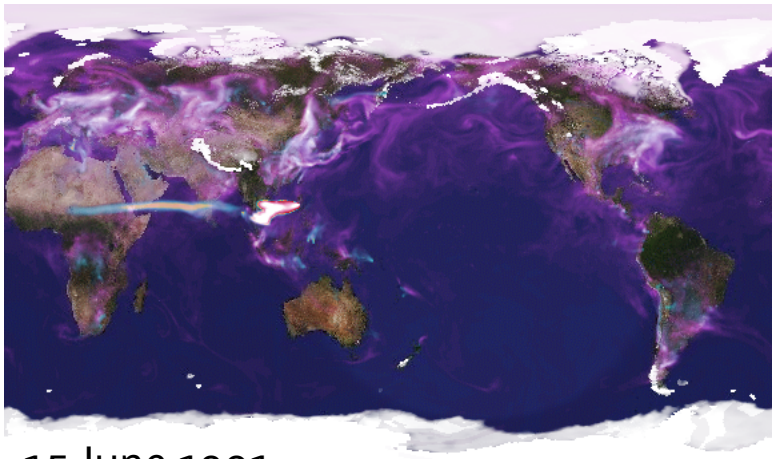
MERRA-2 Global AOD



Pinatubo Eruption: 15 June 1991



14 June 1991



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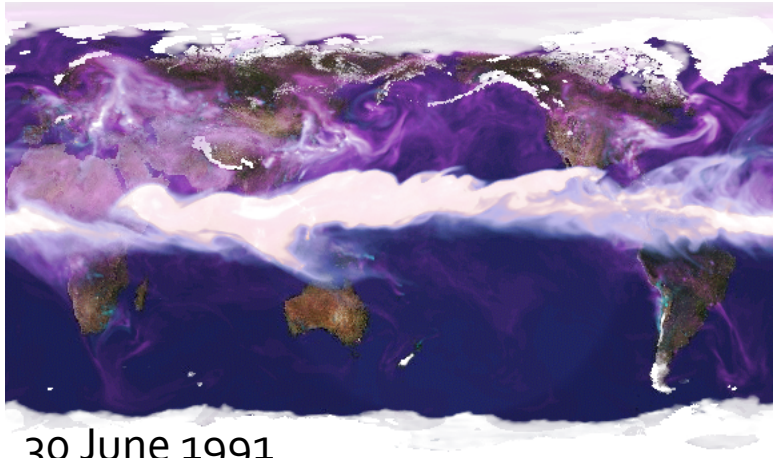

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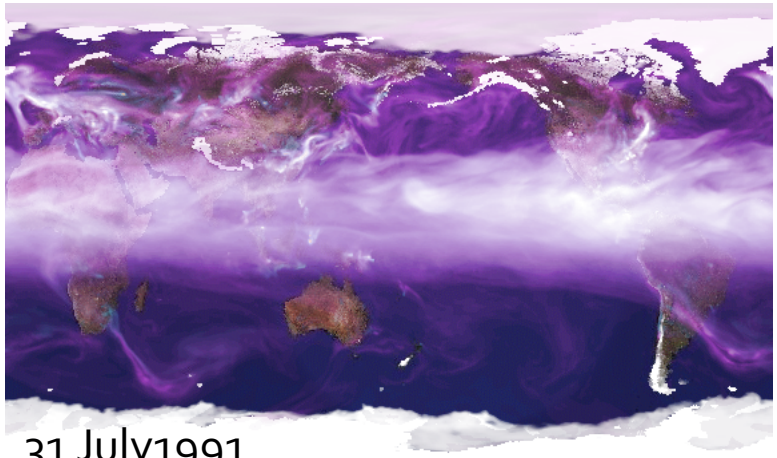
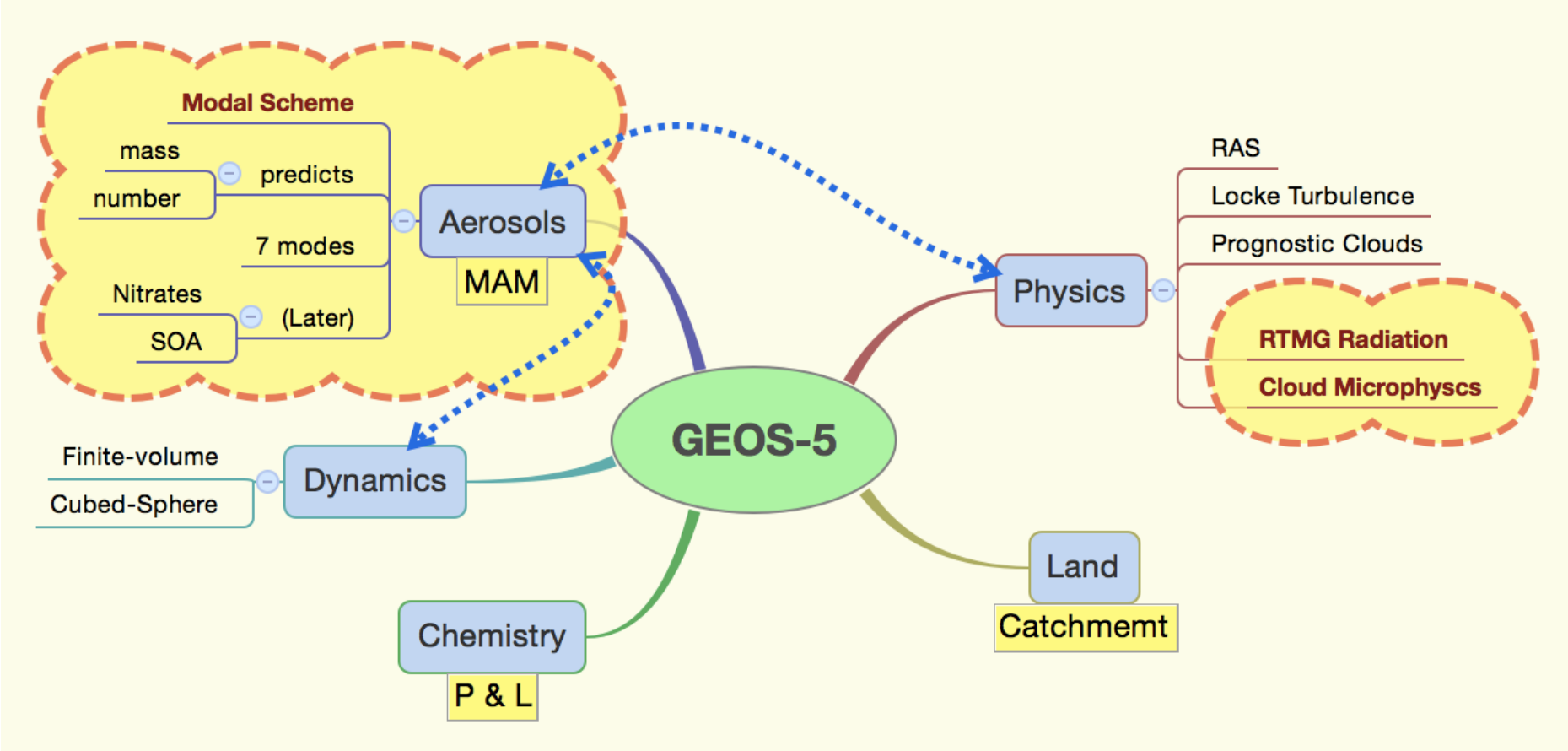


31 July1991

Current GEOS-5 Development: Aerosol & Clouds Microphysics



Global, **12.5 km**, **72** Levels, top at 0.01 hPa

Concluding Remarks

AEROSOLS IN GEOS-5

- The GEOS-5 Earth Modeling System includes data assimilation of its major components
- Aerosols are an integral part of the GEOS-5 NRT and re-analysis systems
- GEOS-5 OSSE activities in support of new NASA observing missions
  - Builds on NWP capabilities, extends it to constituents and other components

GEOS-5 EVOLUTION

- Aerosol/cloud processes evolving from bulk to modal/2-moment schemes
- Aerosol assimilation evolving into a EnKF sub-system within the atmospheric 4D-EnVar