Aerosol Data Assimilation at GMAO

Arlindo da Silva and Virginie Buchard

Global Modeling and Assimilation Office

NASA Goddard Space Flight Center

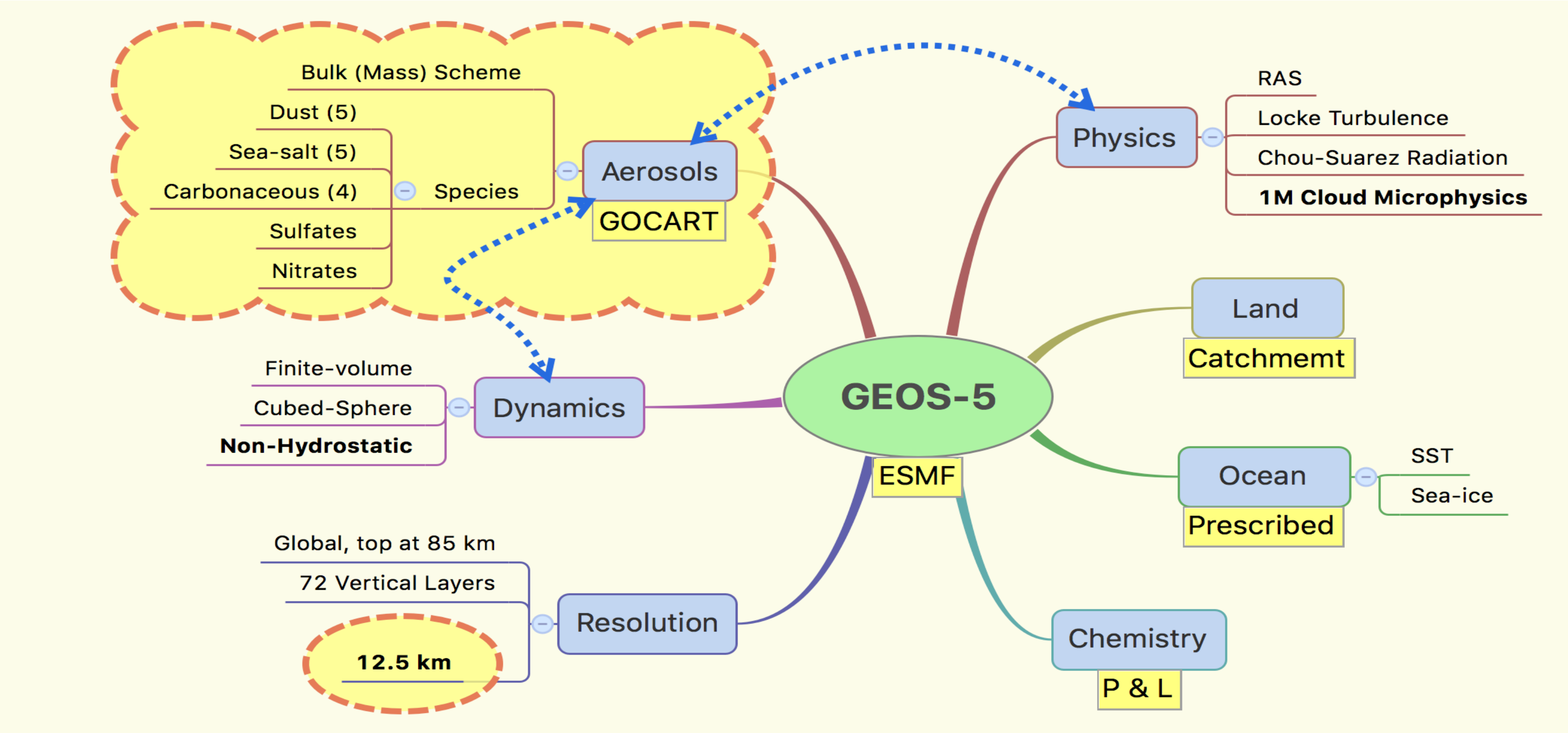
15th JCSDA Workshop

College Park, May 17-19, 2017

Outline

- **The GMAO Forward Processing System**
  - Model overview
  - Emissions
- **AOD Assimilation with Local Displacement Ensembles**
- **Some Applications**
  - MERRA-2
  - Field Campaigns
  - Aerosol Impact on simulation of IR radiances
- **Going forward: Aerosol EnKF**
- **Concluding Remarks**

GEOS-5 Model Configuration for current NRT System



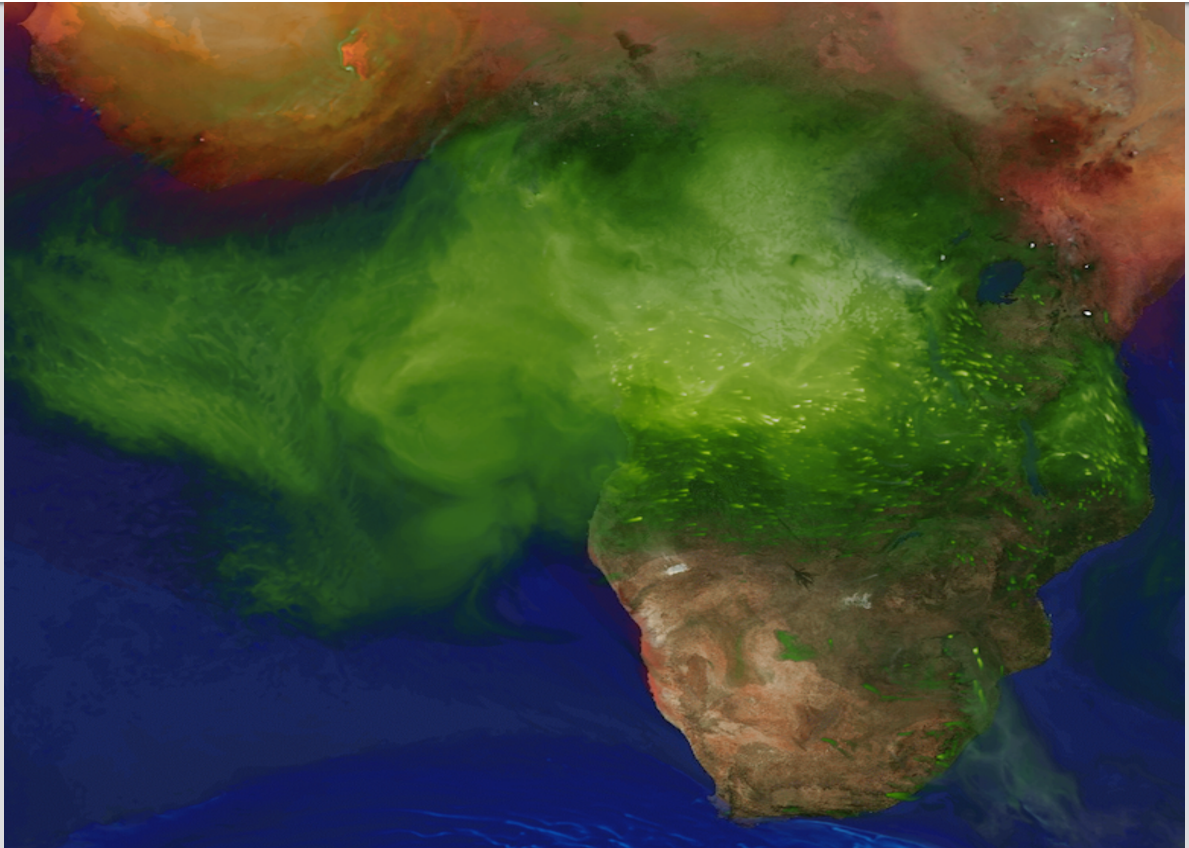
Global, 12.5 km, 72 Levels, top at 0.01 hPa

Biomass Burning

QFED: Quick Fire Emission Dataset

SPACE FLIGHT CENTER

- 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 emissions are deposited in the PBL.



Aerosol Data Assimilation

State representation

- Multiple 3D concentrations
  - Mass
  - Number (modal schemes)
  - Bin sizes (sectional schemes)
- Number of tracers: tens to hundreds

Emissions:

- Dynamic: dust, marine, biogenic aerosols
- Remotely sensed: biomass burning
- Inventories: anthropogenic

Observation operators

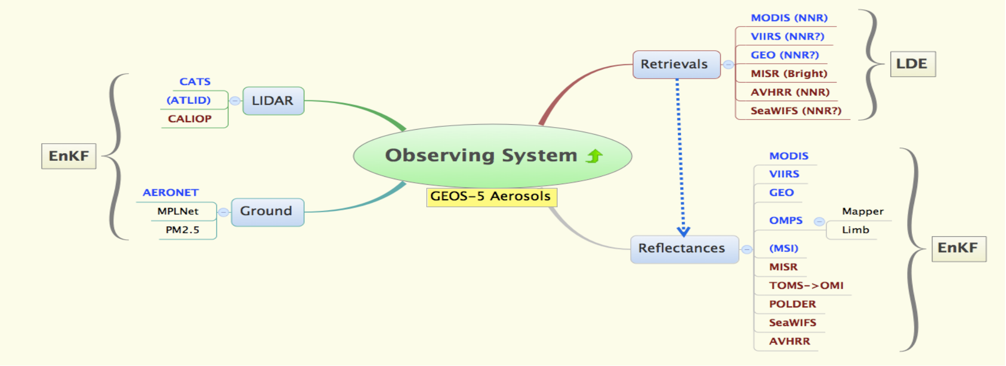
- Intrinsic aerosol optical properties needed for remotely sensed data:
  - Mass extinction coefficient, single scattering albedo, phase matrix
  - These are often poorly known but assumed to be known due to identifiability issues:

$$\tau = \beta \bullet M$$

- Given diversity of aerosol representation in models, *DA software should not hardwire optical properties.*

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*
  - Available multi-spectral AOD measurements are not really measured
- **Radiance assimilation:**
  - Vector scattering calculations needed for UV-VIS measurements are not cheap
  - Surface BRDF characterization is a challenge
- **Surface PM 2.5**
  - Single level
  - Often plagued by representativeness



- **Lidar measurements provide vertical info**
  - Spatially coverage is poor (pencil thin)
  - Attenuated backscatter again requires optical assumptions which are not directly measured
    - New HSRL concept is promising

Aerosol Analysis: Splitting

2D AOD ANALYSIS

- Observable 550 nm AOD is 2D
  - Constrains column averaged optics
  - Cannot constrain speciation or 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 TO 3D CONCENTRATIONS

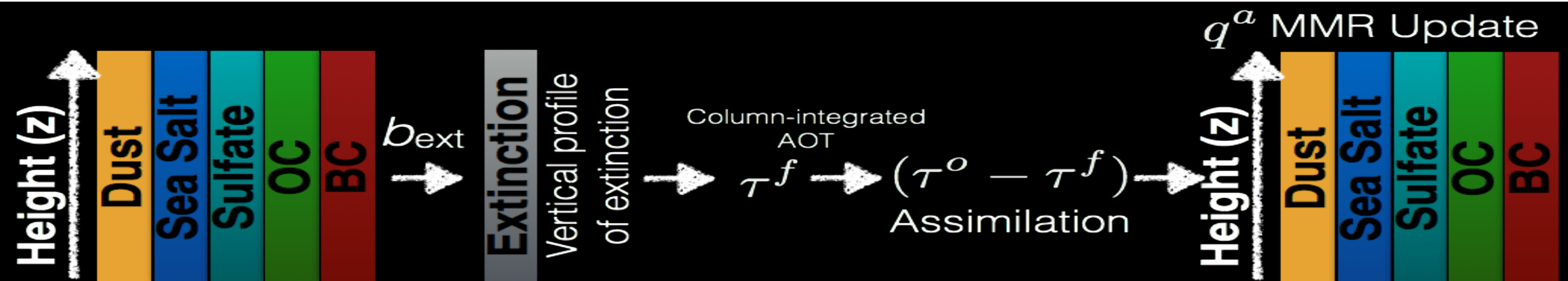
- Based on error covariances:

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

- Using ensemble perturbations,

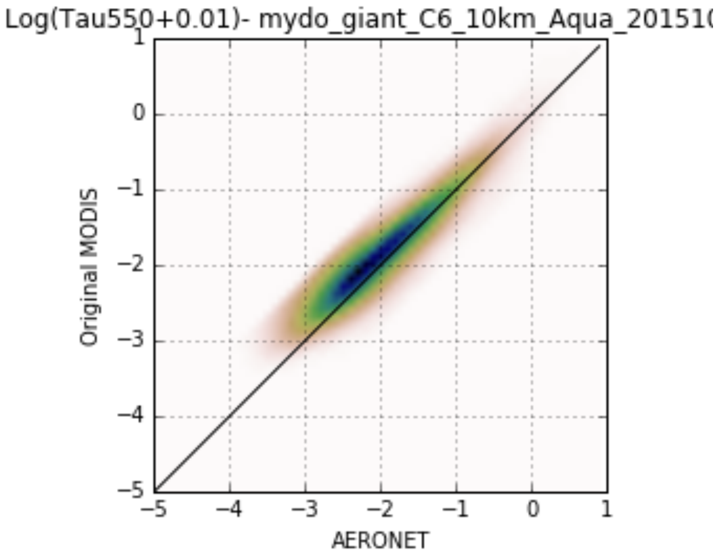
$$\delta q^a = XY^T\left(YY^T\right)^{-1}\delta\tau^a$$

- NRT GEOS-5 uses Local Displacement Ensembles (LDE), in 1D

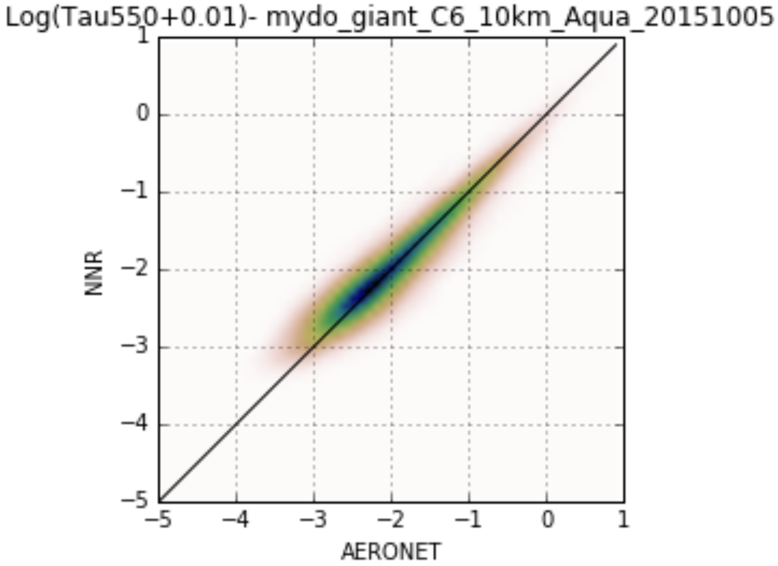


Observational Bias

ORIGINAL MODIS C6 AOD

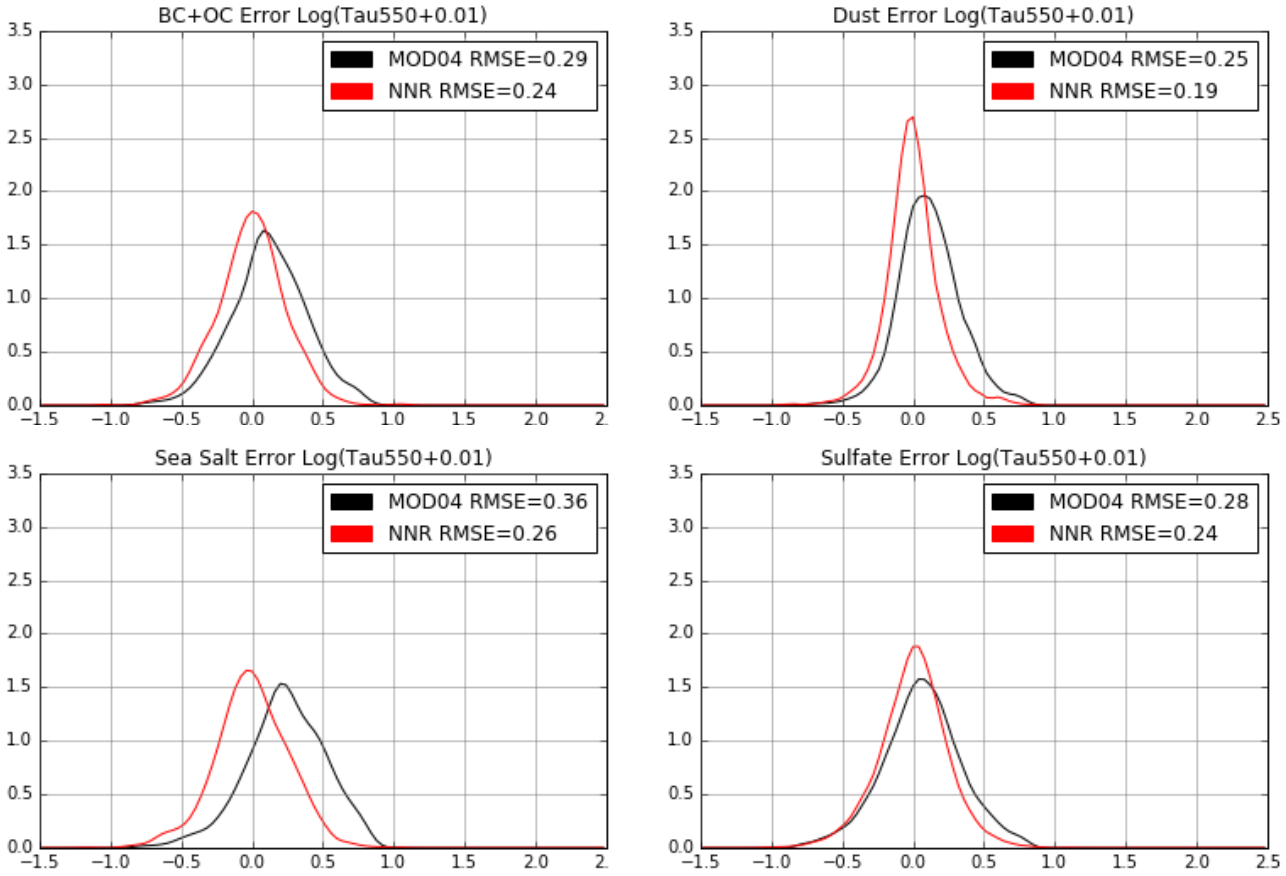


BIAS CORRECTED AOD



MODIS Neural Net AOD Retrievals trained on AERONET

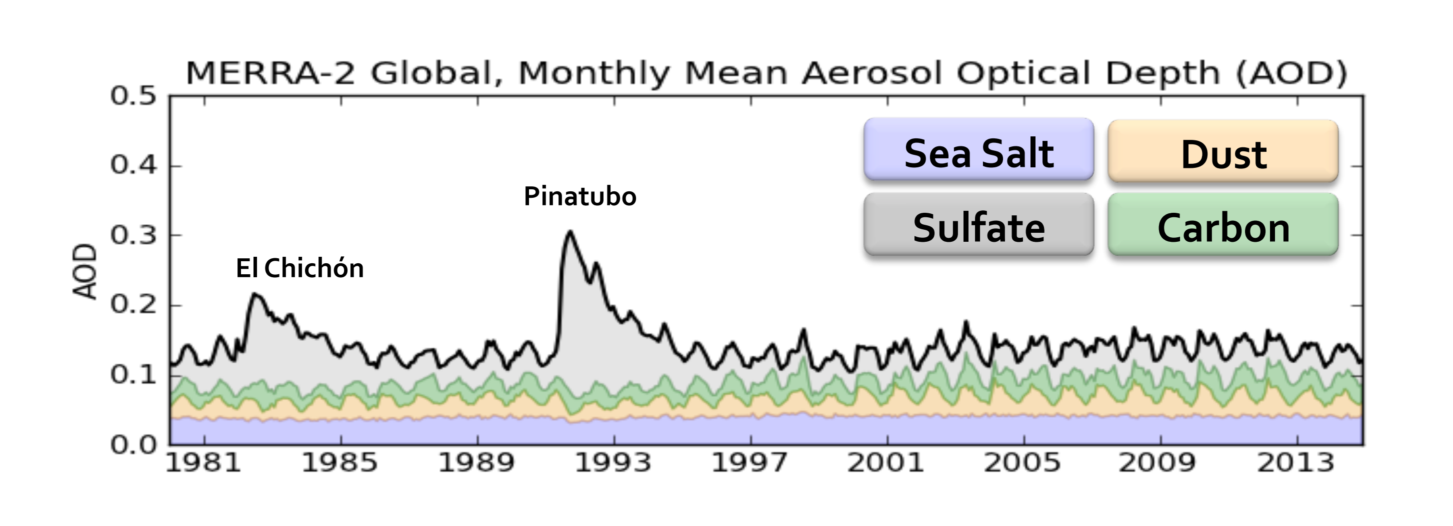
MODIS Collection 6: Aqua



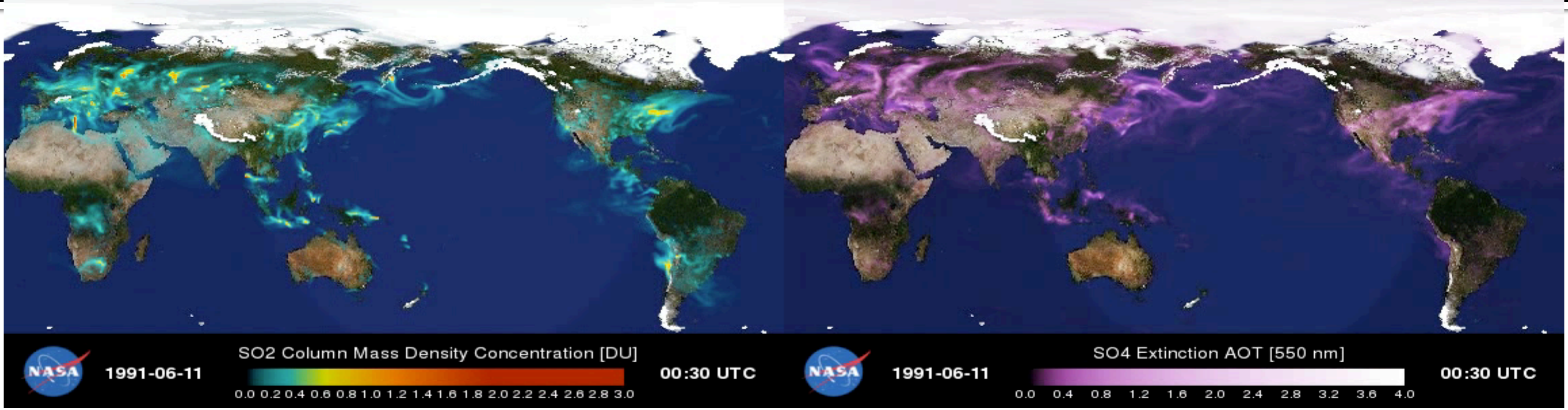
APPLICATIONS

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).



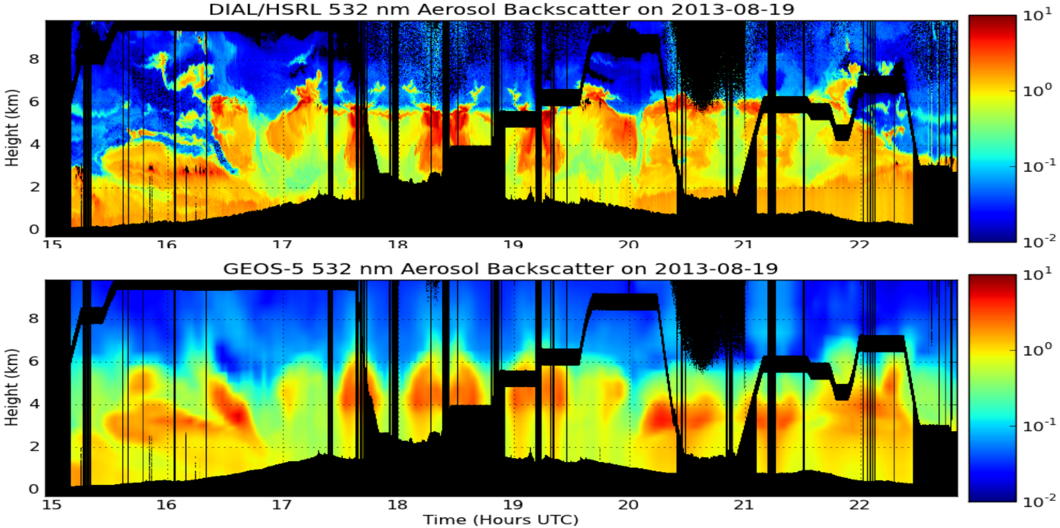
MERRA-2: Pinatubo Eruption



- First aerosol assimilation to include major historic volcanic events like El Chichón (1982) and Pinatubo (June, 1991).
- Movie shows the co-evolution of gaseous SO2 emissions from Pinatubo (left) and formation of the the sulfate aerosol plume (right) as SO2 is converted into particles.
- SO2 (g) is from emissions inventories and unconstrained by assimilation. Sulfate aerosol AOD (right), however, is impacted by the assimilation of total aerosol AOD.

Field Campaign Support

- Global 5-day chemical forecasts
  - O3, aerosols, CO, CO2, SO2
  - 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, KORUS-AQ, ORACLES, etc.

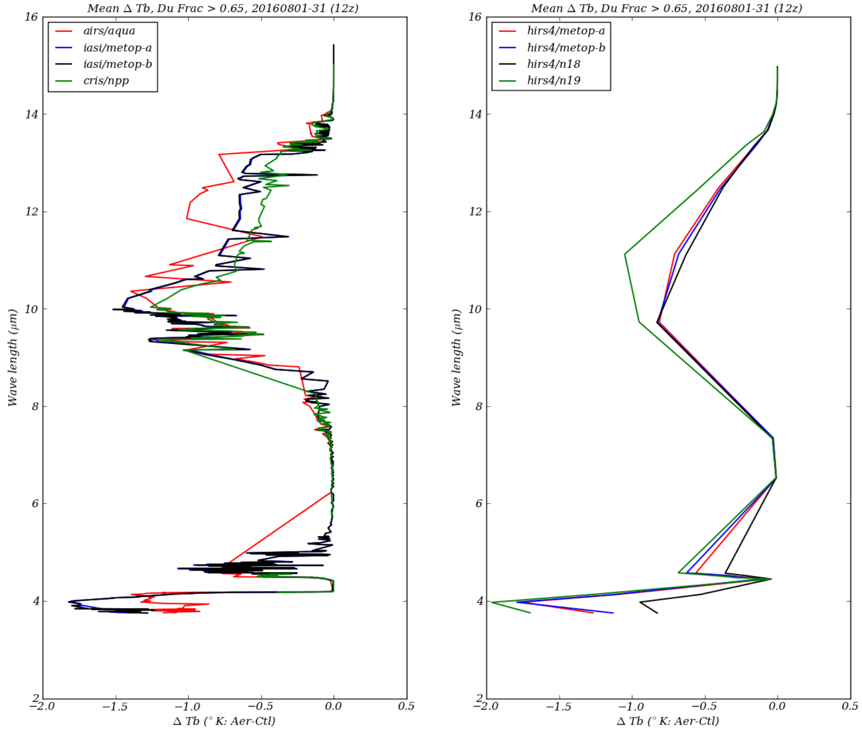


Comparison of observed (top) and simulated (bottom) aerosol backscatter for a flight during the 2013 SEAC4RS campaign.

Aerosol Impact on Meteorological Assimilation

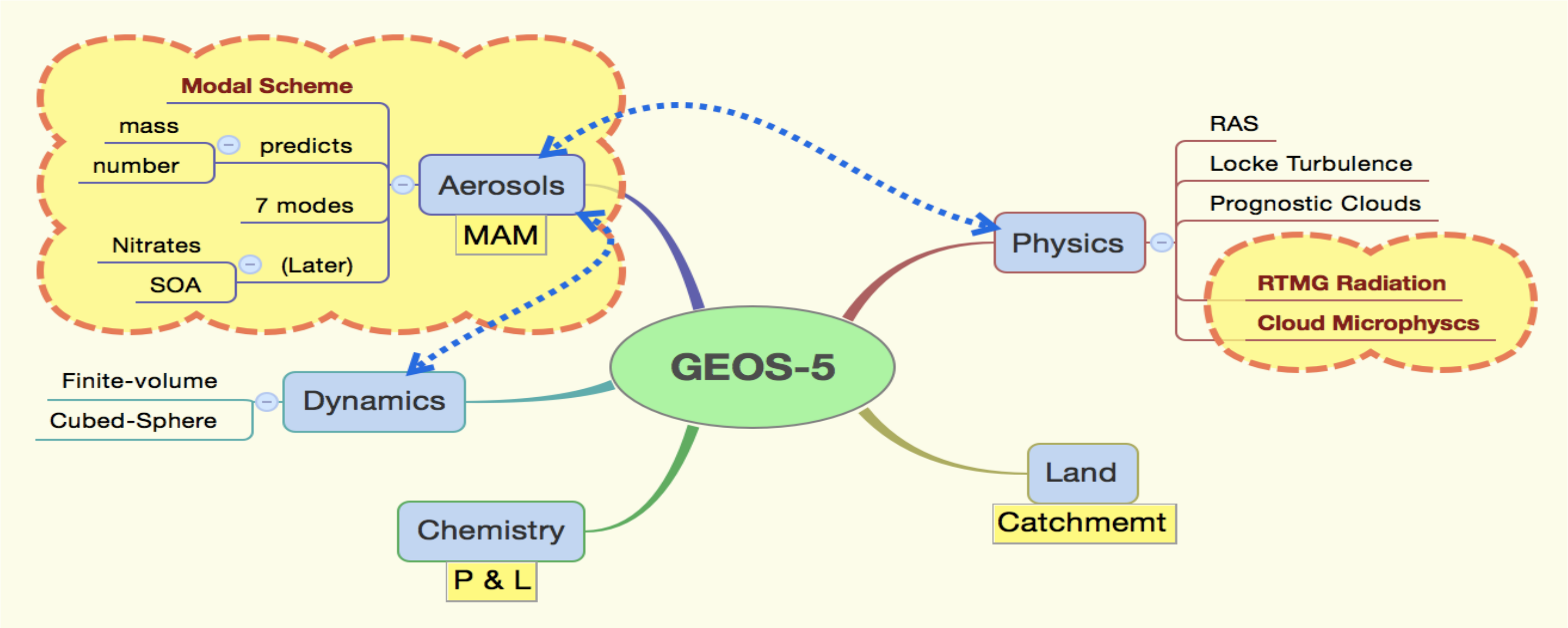
- While hybrid aerosol-meteorology data assimilation may not be computationally attractive in the near future, separately analyzed aerosol fields may be used as parameters in the observation operator of IR channels (AIRS, IASI, etc.)
- Figure on the right shows monthly mean brightness temperature difference (aerosol minus no-aerosol) for several GSI IR sensors with fractional dust AOD > 0.65.

See Jong Kim poster for more details.



GOING FORWARD

Current GEOS-5 Development: Aerosol & Clouds Microphysics

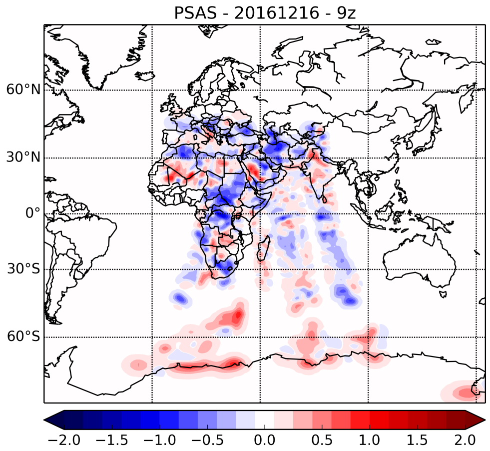


Global, **12.5 km**, **72** Levels, top at 0.01 hPa

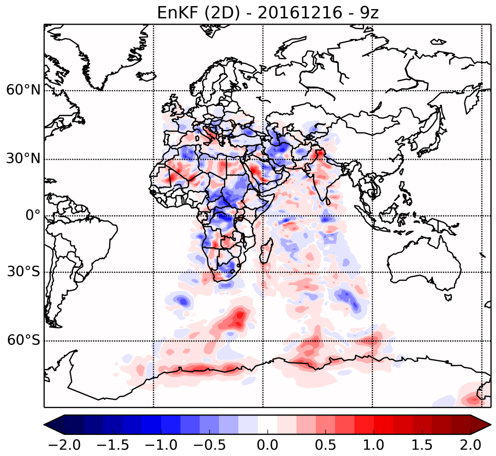
Aerosol EnKF

- 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

PSAS AOD inc (current method)



EnKF AOD inc Ensmean



Concluding Remarks

- **Aerosols are an integral part of the GEOS-5 N.R.T. and re-analysis systems**
  - Aerosols are run at the same resolution as the main meteorological model
- **MERRA-2 provides the first integrated aerosol-meteorology reanalysis for the satellite era**
- **Current GEOS-5 developments incorporate cloud and aerosol microphysics**
  - Aerosol-cloud interactions, better representation of aerosol mixing state
  - There is great need for in-situ and remotely sensed data to evaluate/validate new parameterizations
- **QFED biomass burning emissions to include diurnal cycle from GEO satellites**
- **Aerosol analysis migrating to an EnKF based system**
  - New observables: multi-spectral AOD, attenuated backscatter
  - New active/passive sensors: VIIRS, GEO, CATS/CALIOP, TropOMI