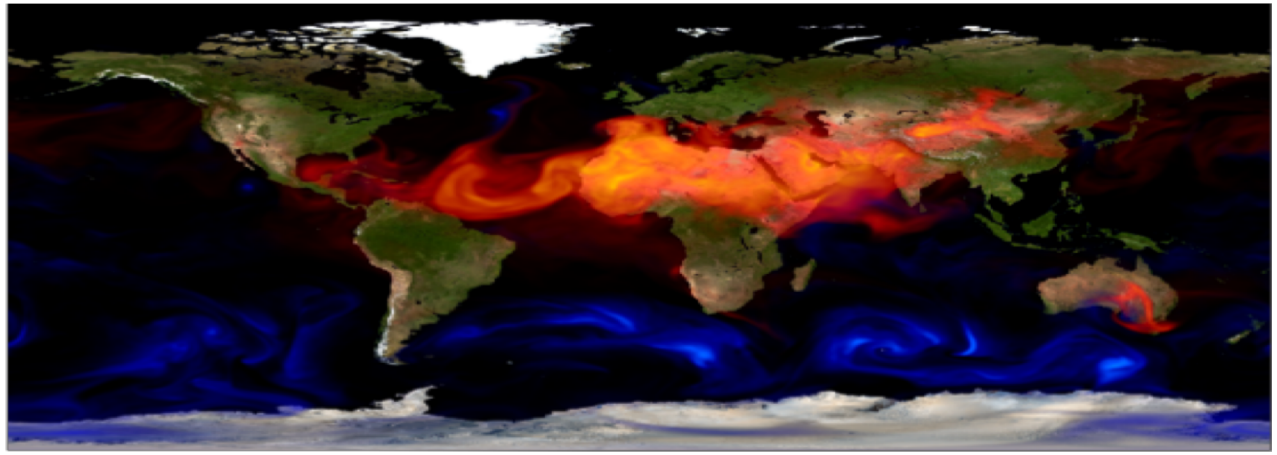
Assimilation of Aerosol Observations in the NASA GEOS Model

Virginie Buchard,
Virginie.buchard@nasa.gov

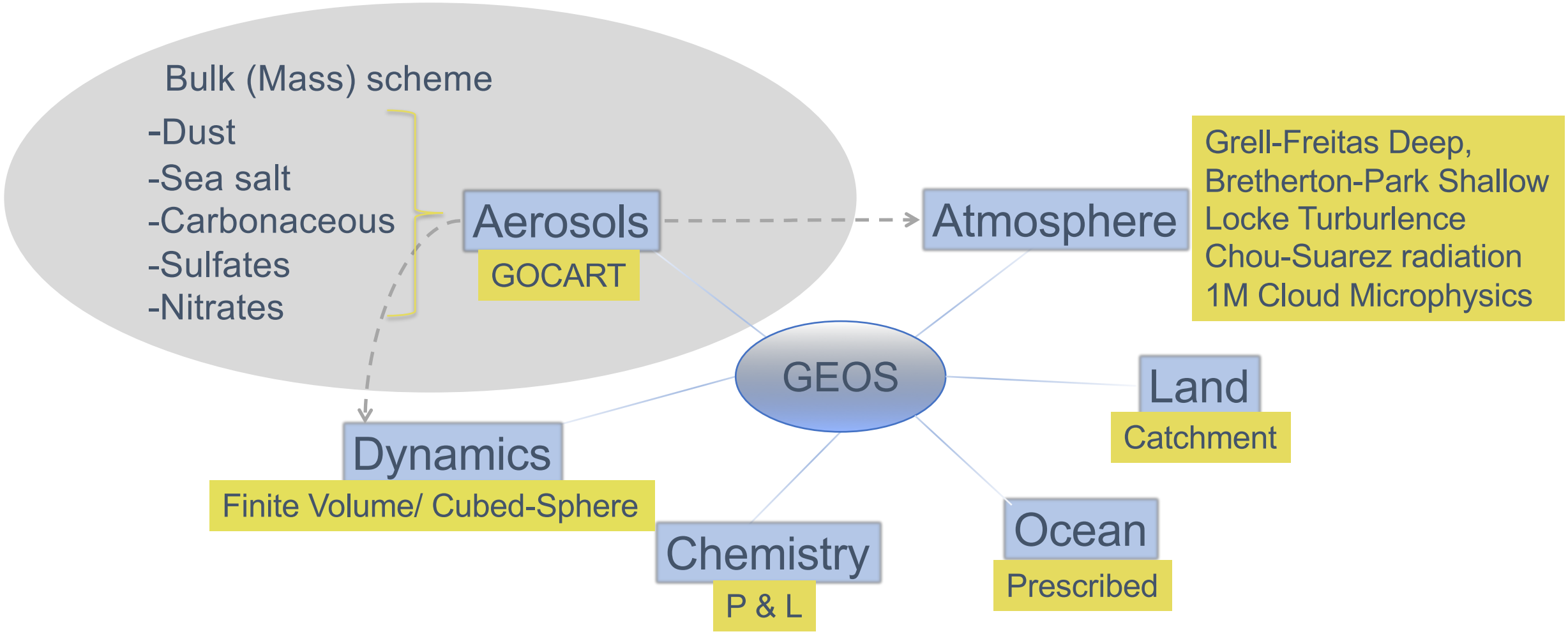
Arlindo da Silva, Dan Holdaway, Ricardo Todling

Outline

- Current GEOS system in Near Real Time
- Aerosol Data Assimilation
  - Introduction
  - Current methodology in GEOS
  - Ongoing work
- Conclusions

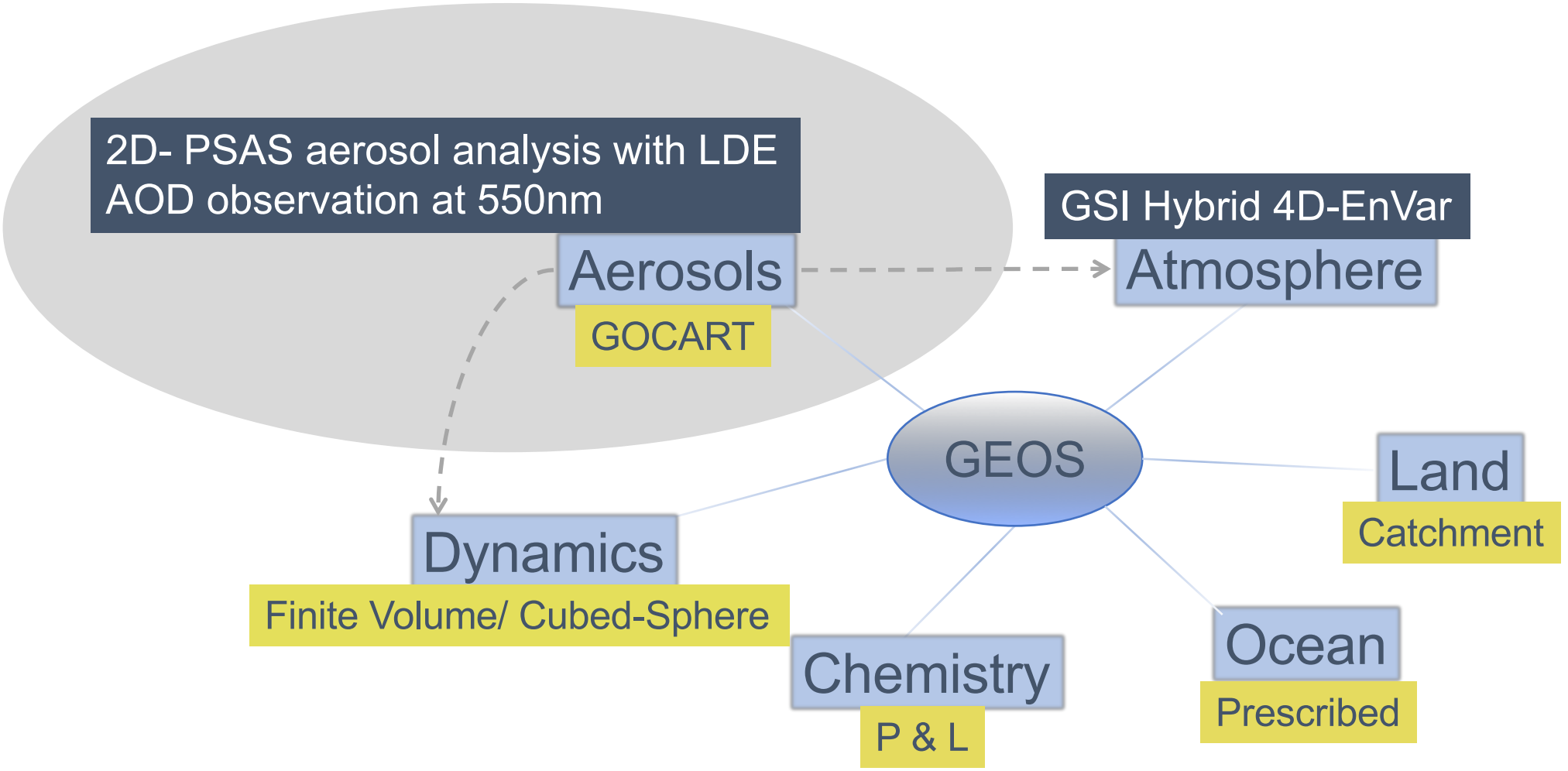


Current GEOS forecasting and Data Assimilation System



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

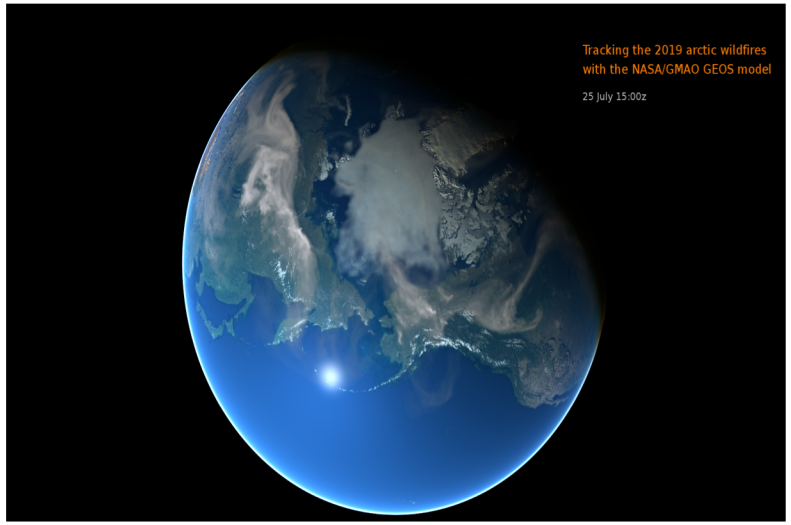
Current GEOS forecasting and Data Assimilation System



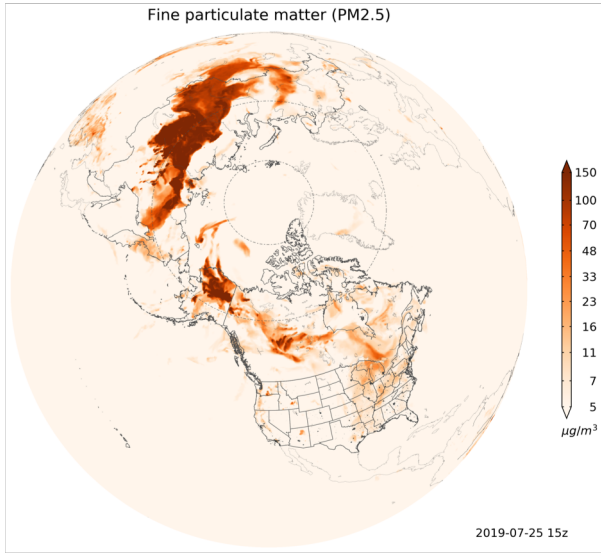
Global, 12.5 km , 72 Levels, top at 0.01 hPa

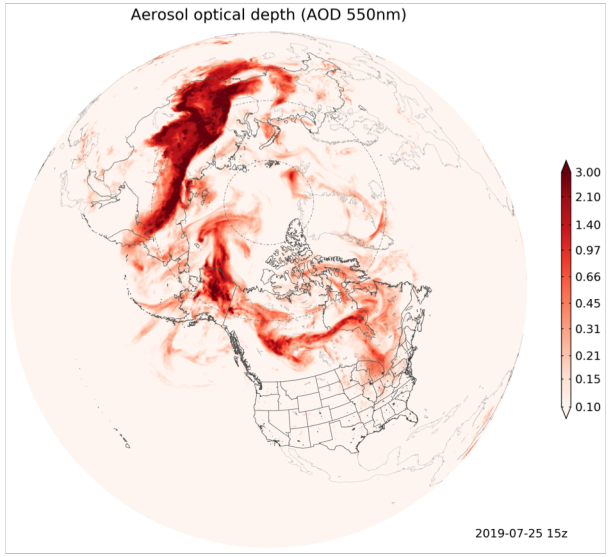
GEOS aerosols in the Near Real Time system

2019 Boreal Forest Fires



- Example for July 25, 2019, using analyses from the NASA/GMAO near real-time atmospheric assimilation system GEOS-FP
- Fine particulate matter at the surface (PM2.5, top) and aerosol optical depth (AOD at 550nm, bottom) from fires in North America and Eurasia.





https://gmao.gsfc.nasa.gov/research/science_snapshots/2019/Arctic_fires_2019.php

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

Current Aerosol Analysis: analysis splitting

- 2D AOD analysis
  - Constrains column averaged optics
  - Cannot constrain speciation or vertical distribution
  - Analysis in observation space

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

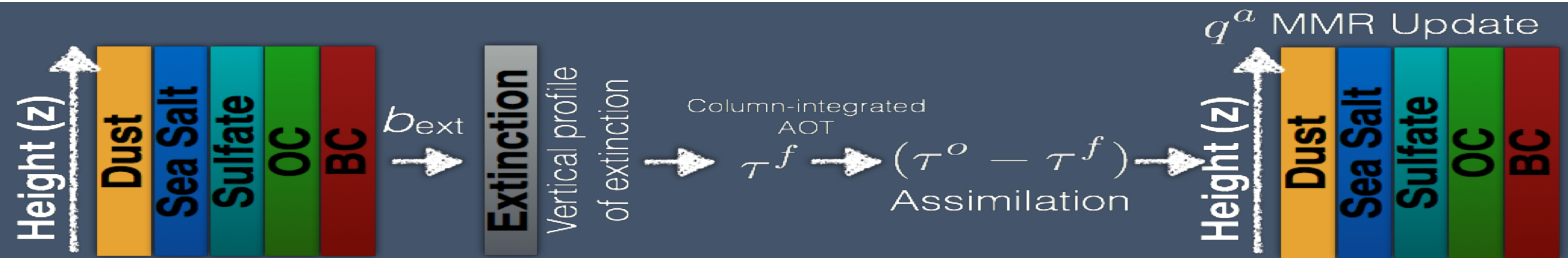
- Going to 3D concentrations
  - Based on error covariances:

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

  - Using ensemble perturbations,

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

  - For computational efficiency, this last step can be performed in 1D.



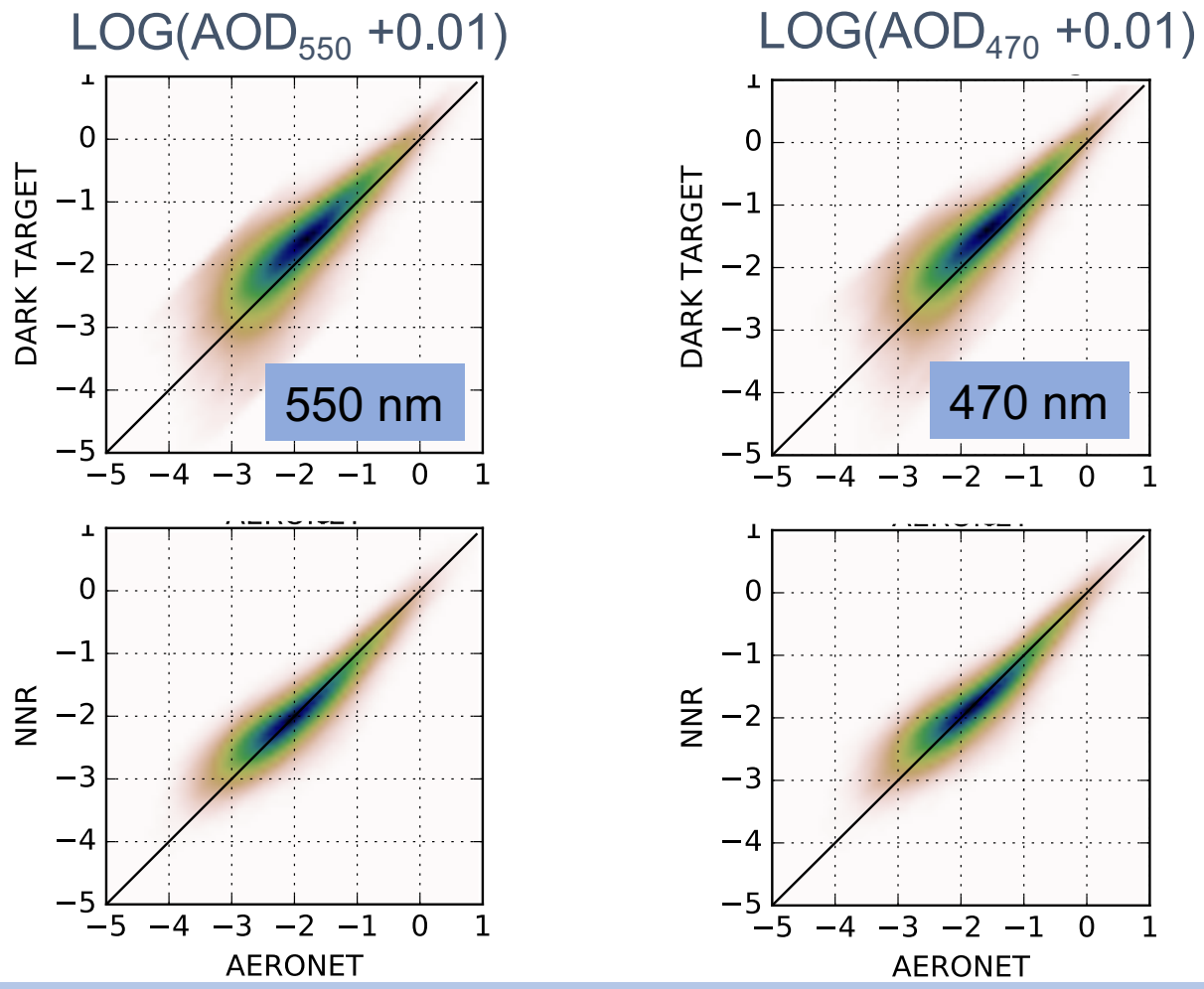
Joint Effort for Data assimilation Integration (JEDI)

The Joint Effort for Data assimilation Integration (JEDI) is a collaborative development led by the Joint Center for Satellite Data Assimilation (JCSDA) in conjunction with NASA, NOAA and the Department of Defense (NAVY and Air Force).

The core goals are to develop a software infrastructure for data assimilation that:

- Is generic and portable, from toy models running on laptops to operational Earth system coupled models running in the cloud.
- Enables native model grid data assimilation.
- Provides a framework for rapid uptake of new observations into operations with generic observation handling and modeling.
- Is enveloped in modern working practices that enable rapid community development.
- Is adaptable to exa-scale computing.
- Shares as much as possible without imposing one approach.

Observing System



ORIGINAL MODIS AOD

BIAS CORRECTED AOD

(NNR AOD retrievals)

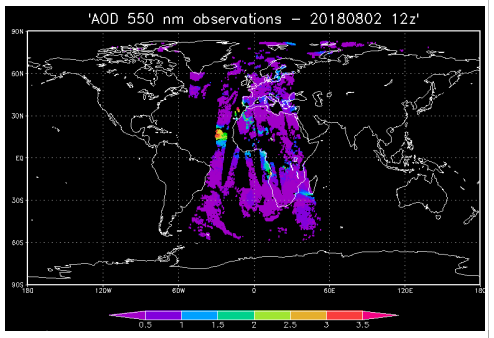
MODIS Neural Net AOD Retrievals trained on AERONET

Aerosol Analysis using JEDI framework – Preliminary results (1)

- An observation operator has been added to the JEDI Unified Forward Operator (UFO) to support the assimilation of AOD observations at one or multiple wavelengths.

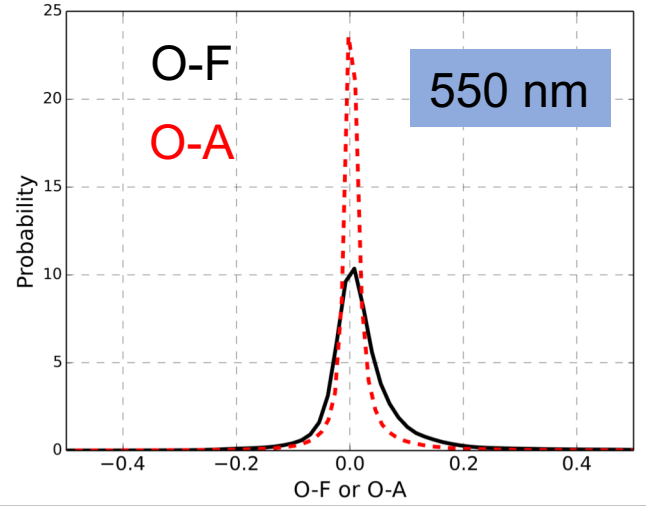
- JEDI 3D-EnsVar static analysis:
  - Aerosol variational analysis with a background error derived from an ensemble of aerosol concentrations produced by the GEOS model
  - Observing system:
    - NNR AOD at 550 nm
    - multi-wavelengths NNR AOD at 470 and 870 nm
  - Horizontal resolution of background and ensemble: 100 km
  - Control variable: 3D aerosol concentrations

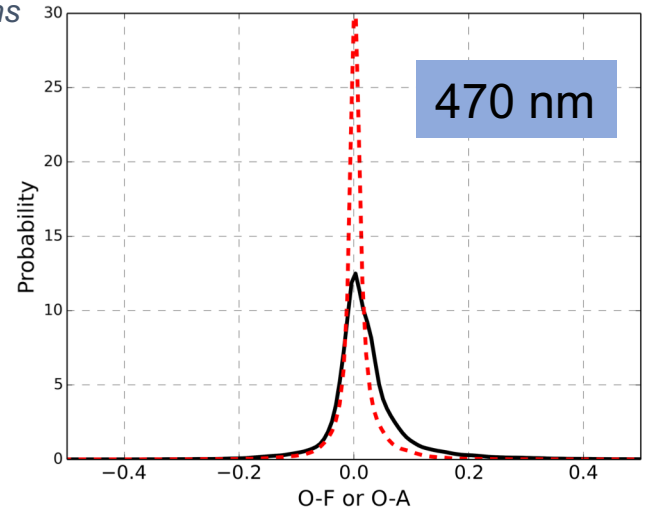
12z August 02 2018



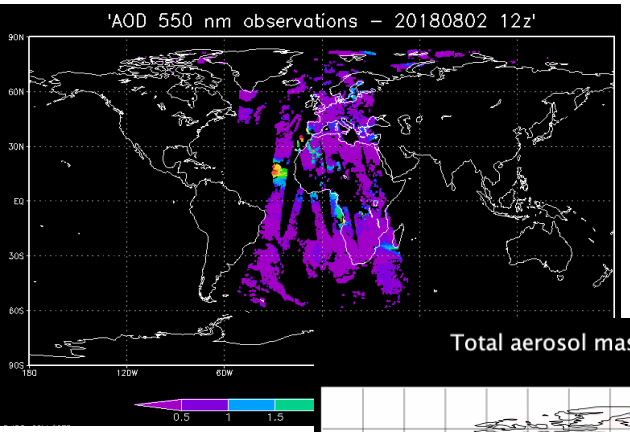
MODIS AQUA/TERRA observations

Innovation Statistics



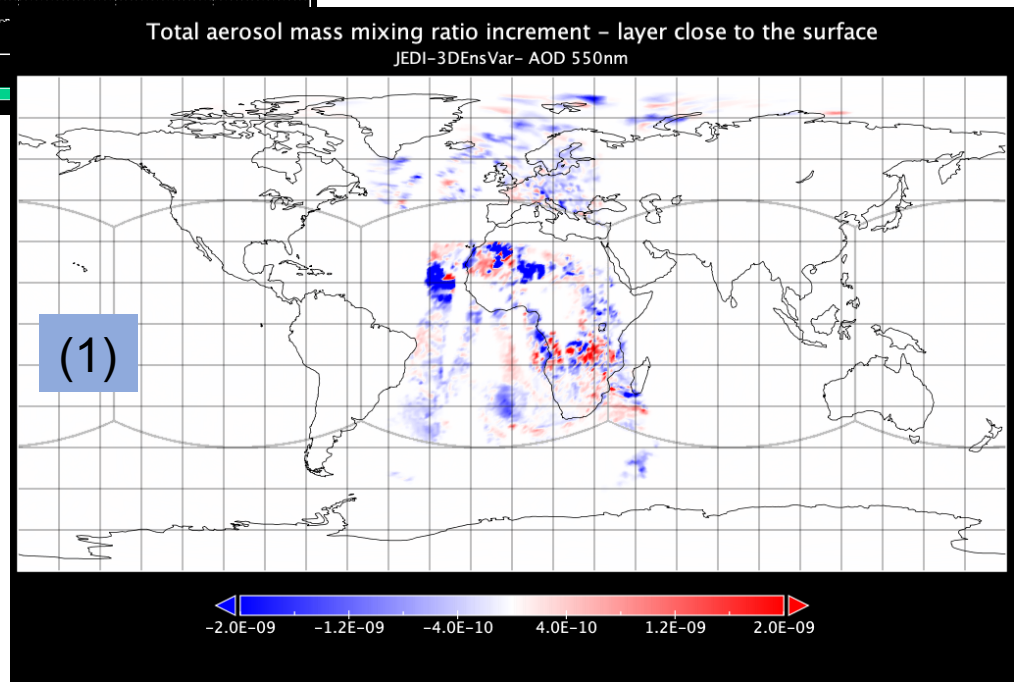


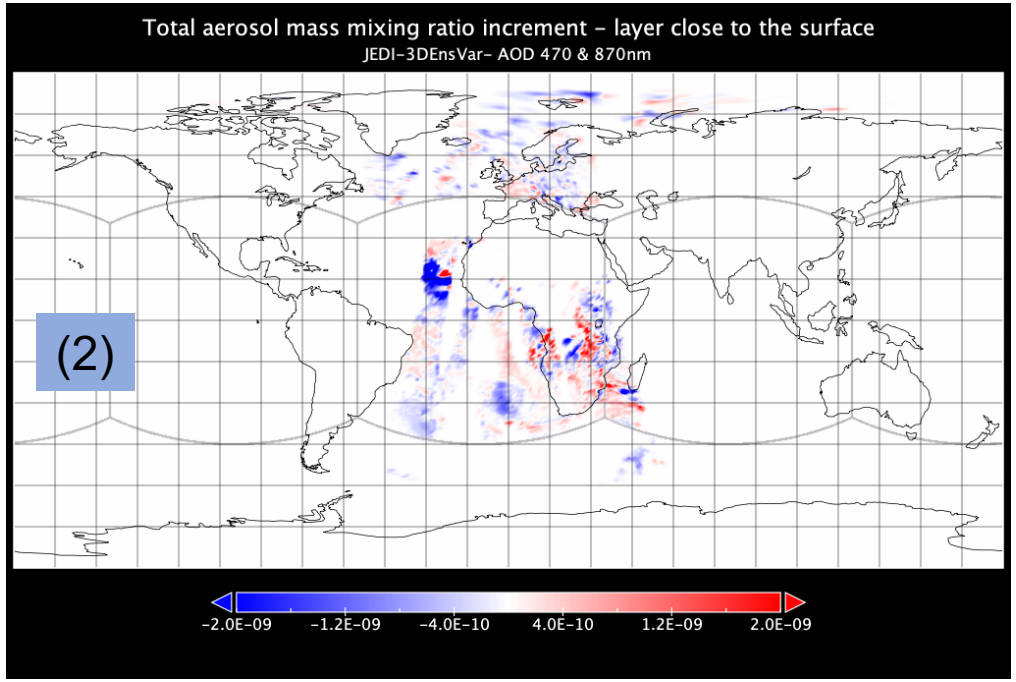
Aerosol Analysis using JEDI framework – Preliminary results (2)



Examples of total aerosol mass increments on the model native grid for one model layer (close to the surface)
after one analysis cycle:

- by analyzing NNR AOD at 550 nm (1)
- by analyzing multi wavelengths NNR AOD at 470 & 870 nm (2)





12z August 02 2018

Conclusions

- Aerosols are an integral part of the GEOS forecasting system
  - Aerosols runs interactively at the model highest resolution
- Current aerosol assimilation system:
  - Aerosol analysis performed by means of analysis splitting: PSAS + LDE
  - Single wavelength AOD observations at 550 nm
- Prototype using JEDI framework under development:
  - Ensemble variational method (3D-EnsVar) with aerosol ensemble members produced by the GEOS atmospheric data assimilation system
  - Static analysis at one time step shows promising results using one or multiple wavelengths AOD observations
    - However, it has been tested on a low resolution model grid: scalability tests need to be perform for higher resolution model simulations
  - Opens door to new observables: multi-wavelength AOD, lidar backscatter, etc.