Update on the NASA GEOS-5 Aerosol Forecasting and Data Assimilation System

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ICAP Meeting, Lille, France, June 26 - 28, 2017

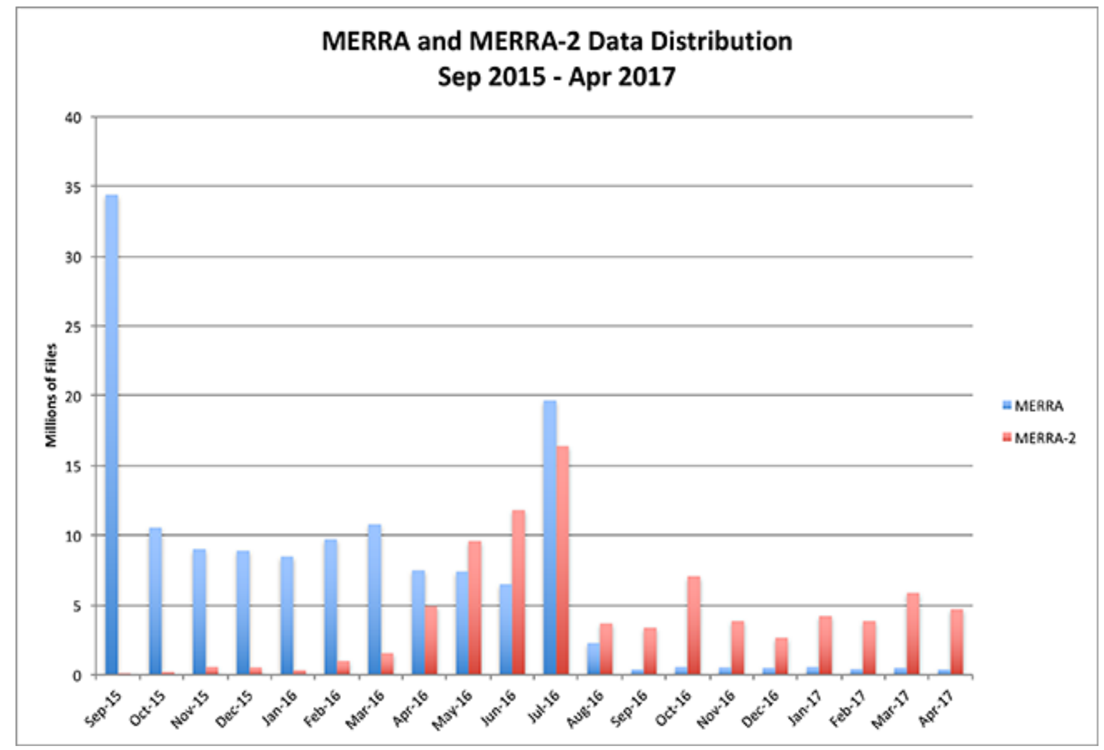
NASA Goddard Space Flight Center

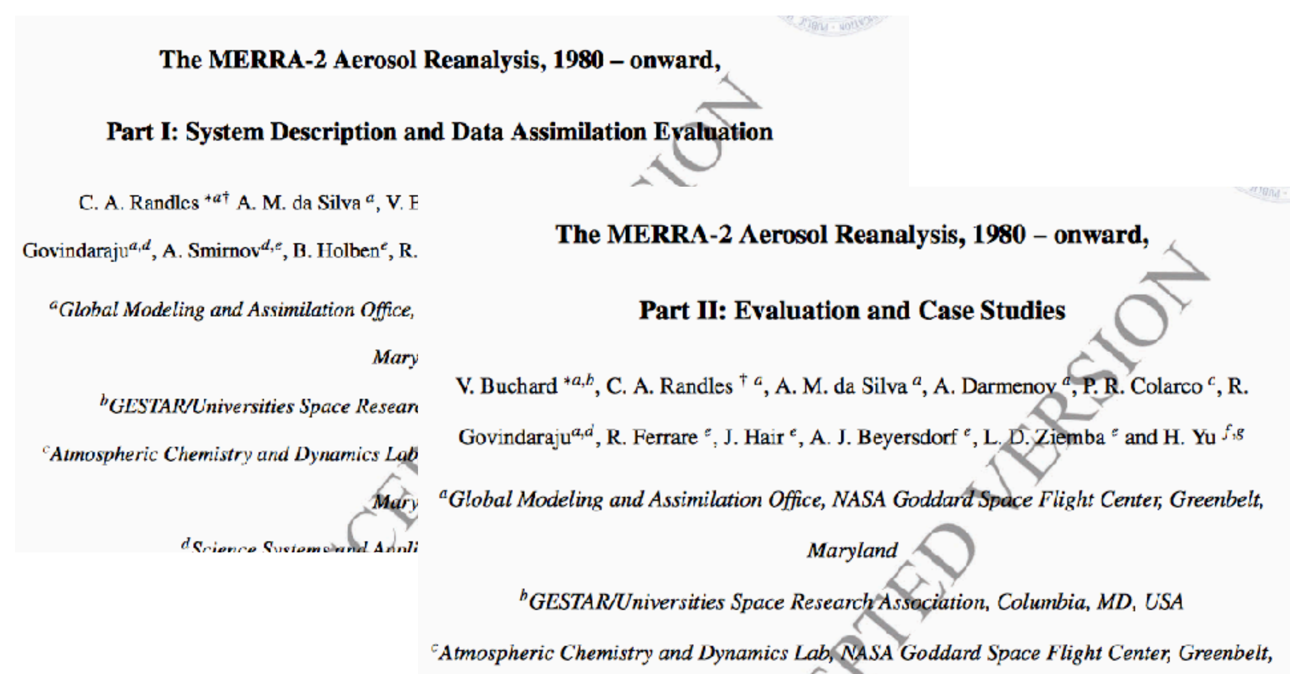
GEOS-5

- GEOS-5 is the Goddard Earth Observing System model
- GEOS-5 is maintained by the NASA Global Modeling and Assimilation Office
- Core development is within GMAO, Goddard Atmospheric Chemistry and Dynamics Laboratory, and with external partners
- Primary GEOS-5 functions:
  - Earth system model for studying climate variability and change
  - provide research quality reanalyses for supporting NASA instrument teams and scientific community
  - provide near-real time forecasts of meteorology, aerosols, and other atmospheric constituents to support NASA airborne campaigns

MERRA-2 Aerosol Reanalysis

- 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
- Special issue of Journal of Climate





The MERRA-2 Aerosol Reanalysis, 1980 – onward,

Part I: System Description and Data Assimilation Evaluation

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Govindaraju a,d, A. Smirnov d,e, B. Holben e, R.

a Global Modeling and Assimilation Office,

Mary

b GESTAR/Universities Space Resear

c Atmospheric Chemistry and Dynamics Lab

Mary

The MERRA-2 Aerosol Reanalysis, 1980 – onward,

Part II: Evaluation and Case Studies

V. Buchard *a,b, C. A. Randles † a, A. M. da Silva a, A. Darmenov a, P. R. Colarco c, R. Govindaraju a,d, R. Ferrare e, J. Hair e, A. J. Beyersdorf e, L. D. Ziemba e and H. Yu f,g

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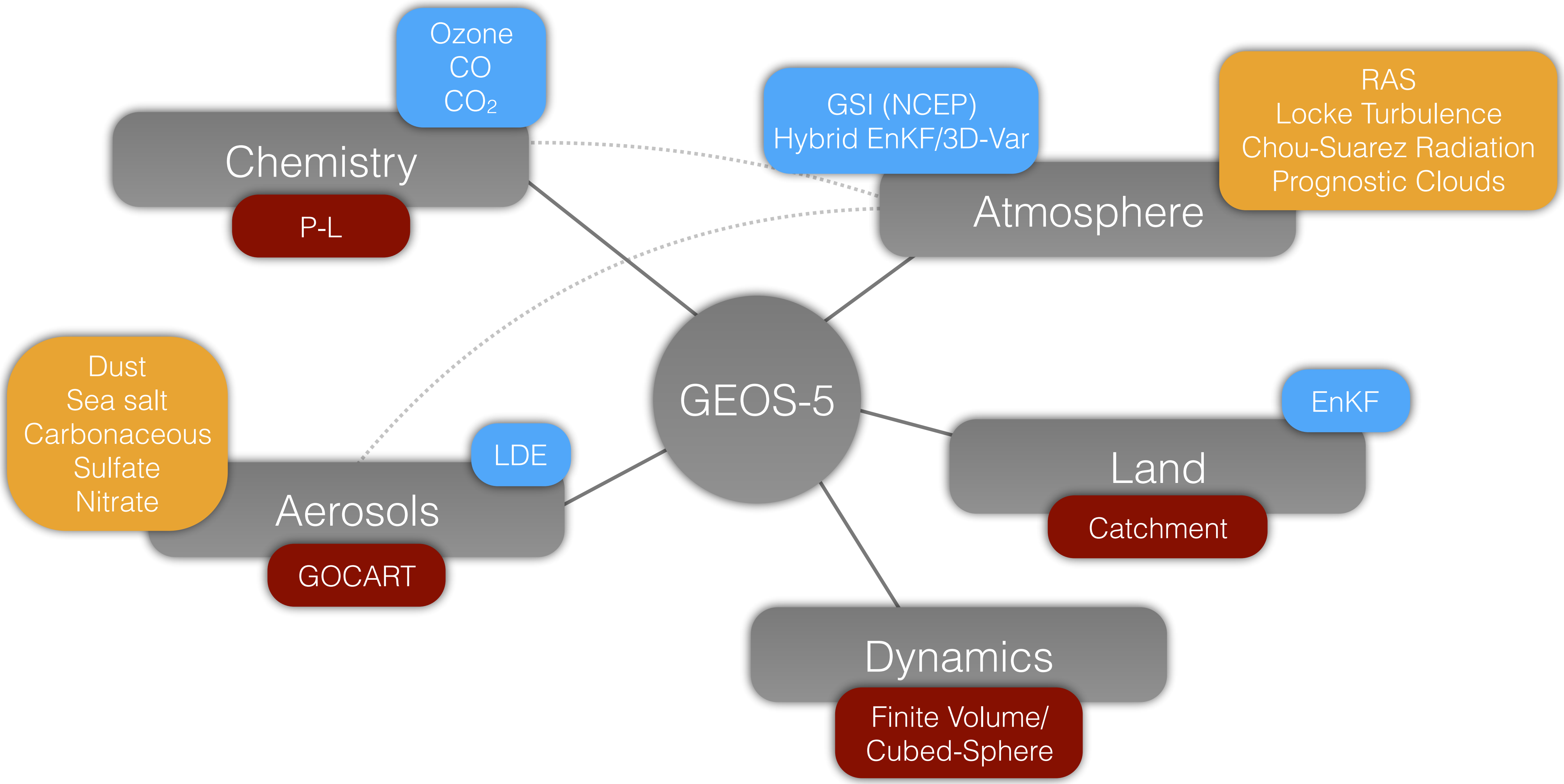
c Atmospheric Chemistry and Dynamics Lab, NASA Goddard Space Flight Center, Greenbelt,

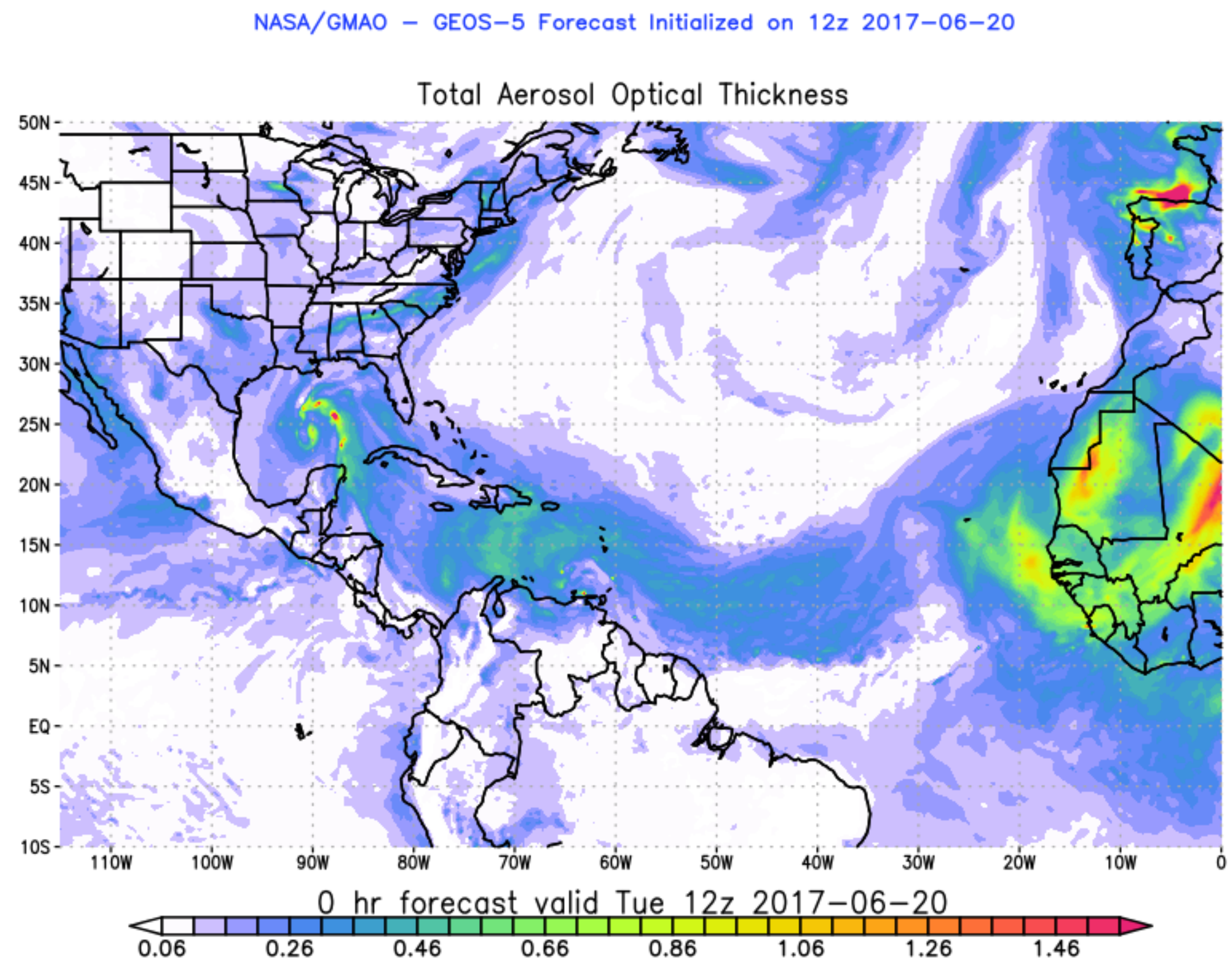
Current NRT Configuration



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

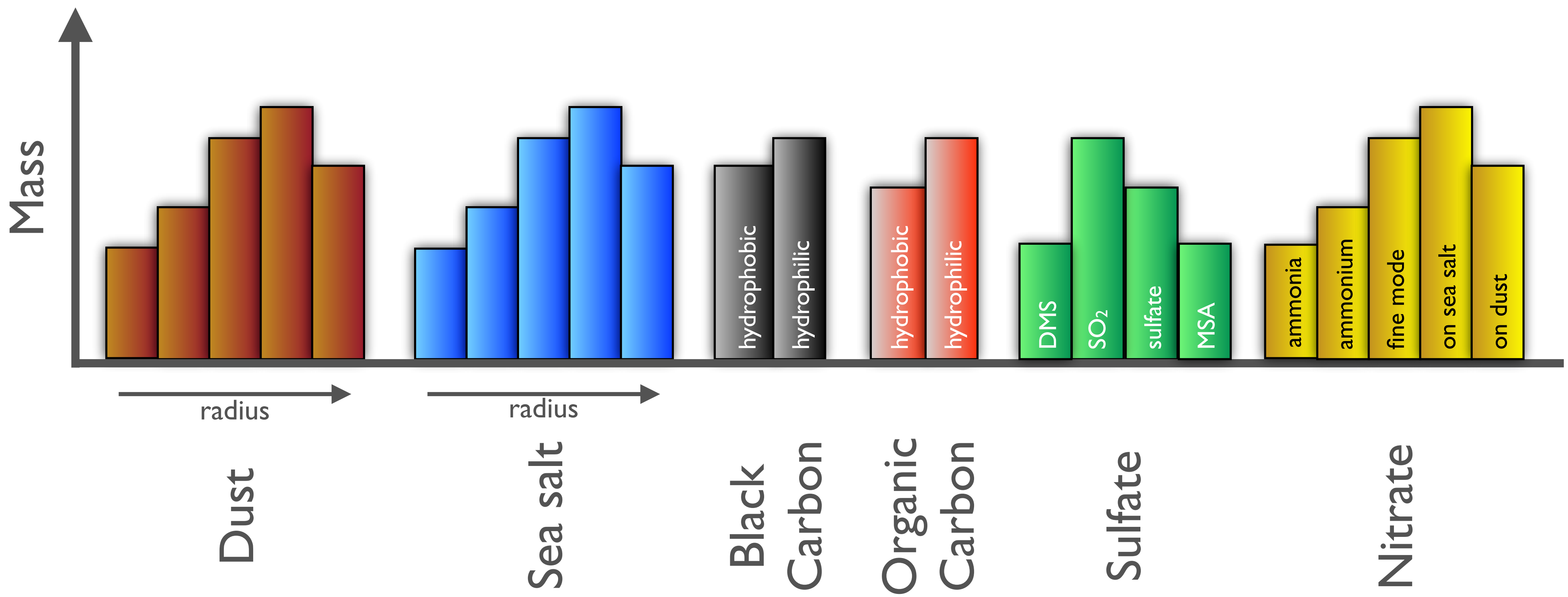
Aerosol Products

- Aerosol module based on GOCART, radiatively coupled and inline with meteorological assimilation
- Assimilation of MODIS-derived total aerosol optical depth (550 nm) using PSAS and local displacement ensembles (LDE)
  - January 2017: updated for Collection 6 Dark Target and Deep Blue aerosol products
- NRT MODIS FRP-based biomass burning emissions (QFED)
- 4 x day forecasts
  - 0z: 10-day forecast
  - 12z: 5-day forecast
  - 6,18z: 30-hour forecast
- GMAO provides customized web portals for missions and campaigns



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

GOCART Configuration



- Nitrate module went active in January 2017
  - climatological nitric acid from GMI chemistry module, biomass burning and anthropogenic sources of ammonia, thermodynamic partitioning of nitrogen between sulfate and nitrate aerosol phase, ammonia, and aerosol ammonium
  - heterogeneous production of aerosol nitrate on dust and sea salt

Update NNRv3 to MODIS Collection 6 Algorithms

INPUT NODES

- MXD04 L2 Reflectance
  9-channel Dark Target: 412-2100 nm
  3-channel Deep Blue: 412,470,660 nm

Geometry

- Scattering Angle
- cos(SZA)
- Glint Angle

Surface Reflectance

- MCD43C1 BRDF
  7-channel Dark Target: 470-2100 nm
  4-channel Deep Blue: 550,650,1600,2100

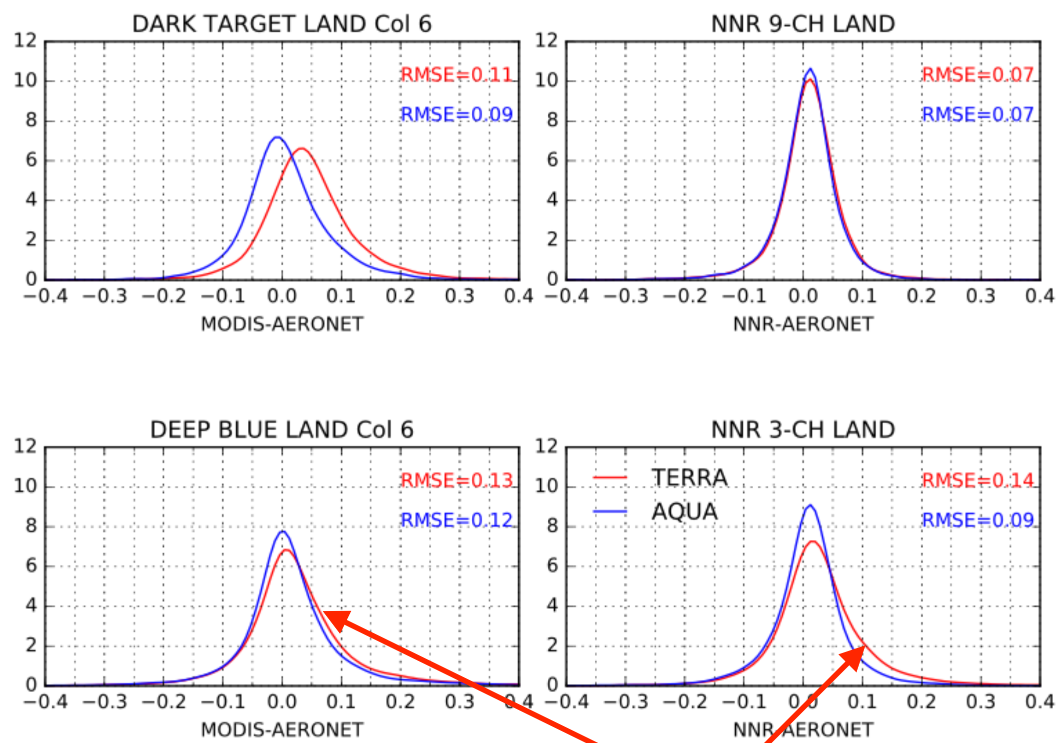
Aerosol Type

- GEOS-5 Aerosol Fractional Composition
  - f_{dust}, f_{BC+OC}, $f_{sulfate}$
  (For training we use MERRA-2)

→ 2xN-Inputs Hidden Nodes →

OUTPUT NODE

- AERONET AOD

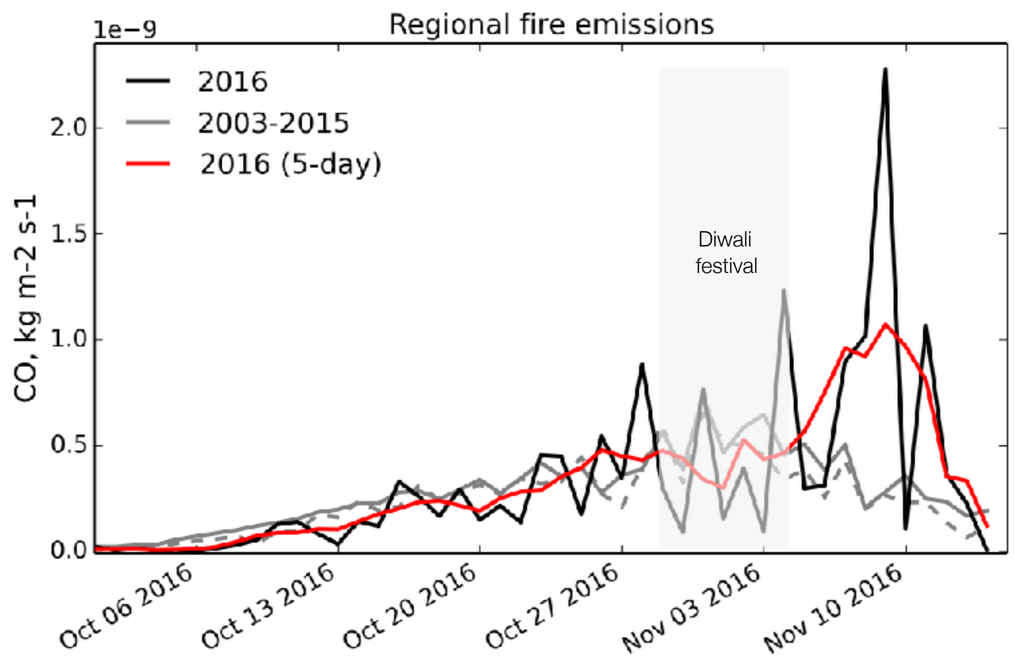


Terra calibration is degrading rapidly...will account for this in NNR update

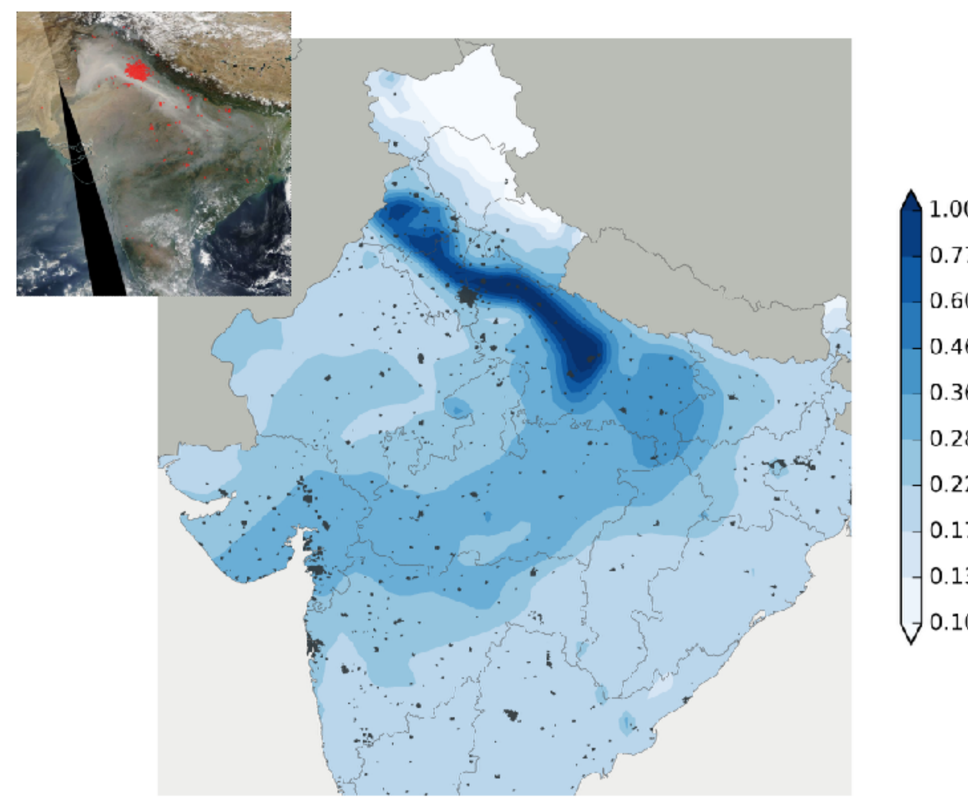
- Discontinuation of MODIS Collection 5 prompts update to C6
- NNR methodology revisited to use additional information from model and incorporate Deep Blue

Indian Regional Air Quality

The 2016 agricultural fire emissions in Punjab peaked later and were above the average in the first half of November.



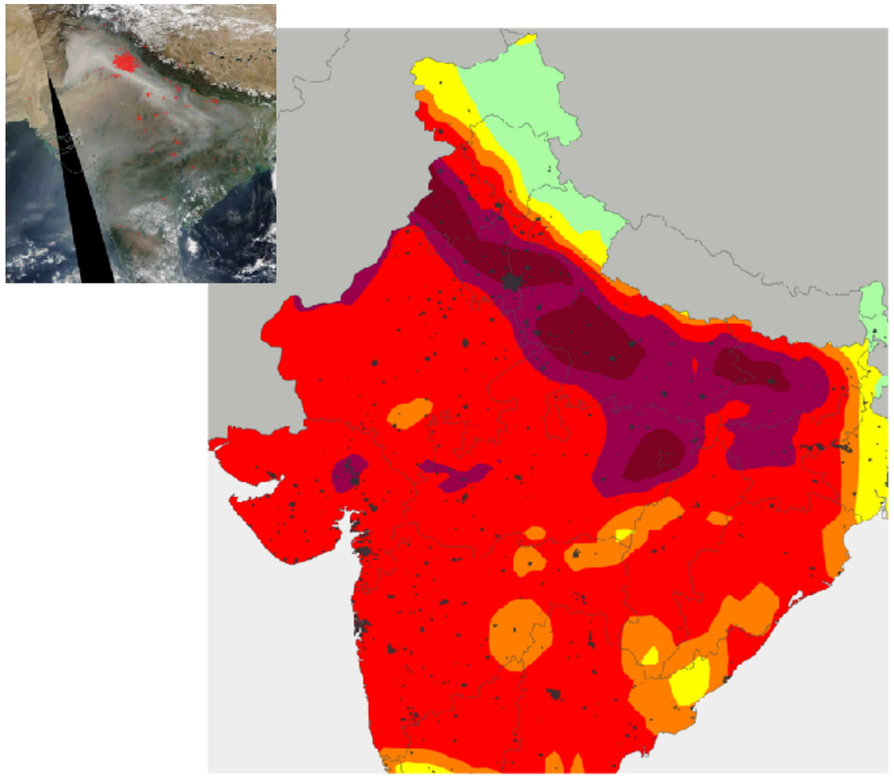
Time series of the regional mean daily fire emissions of CO from the Quick Fire Emissions Dataset (QFED).



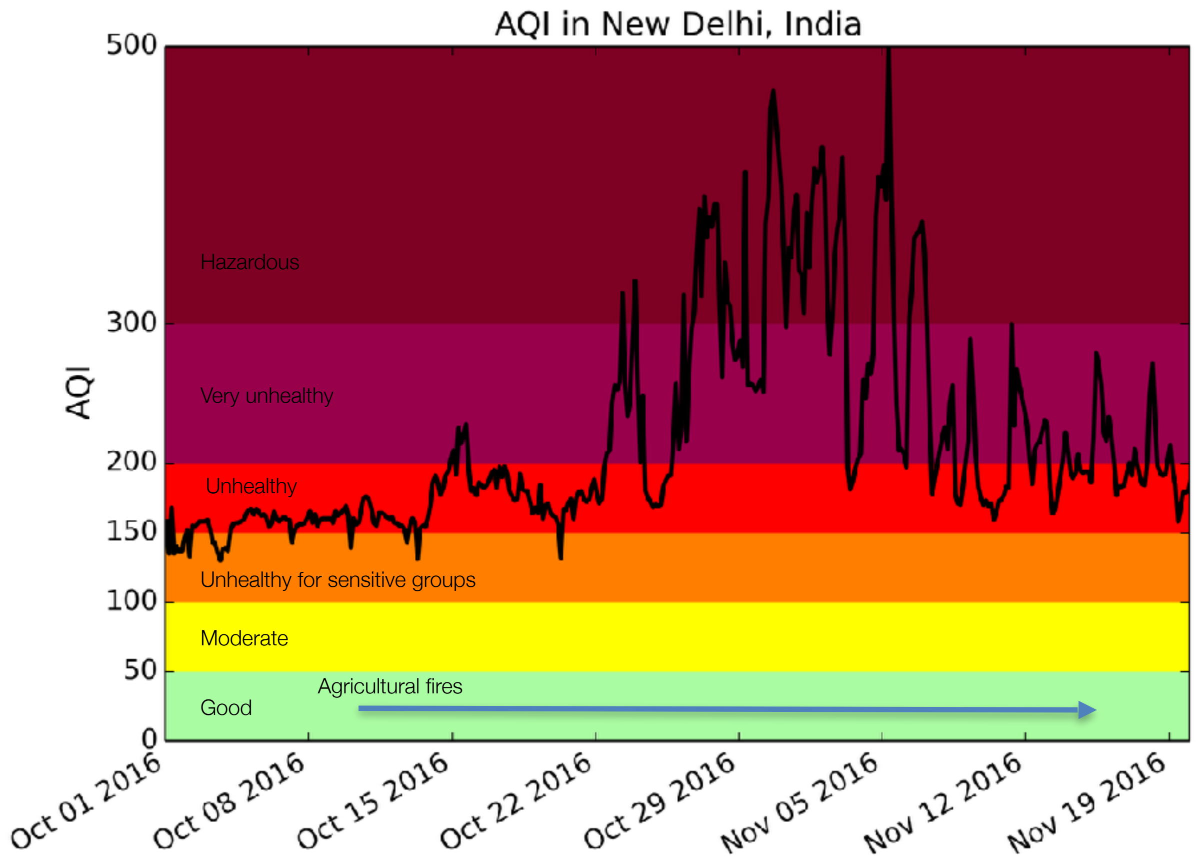
GEOS/FP CO(fires) column load (in 1e18 cm-2) in India at 08Z on November 06, 2016.

Indian Regional Air Quality

The EPA Air Quality Index (AQI) combines several pollutants and is used to communicate air quality to the public in the US.

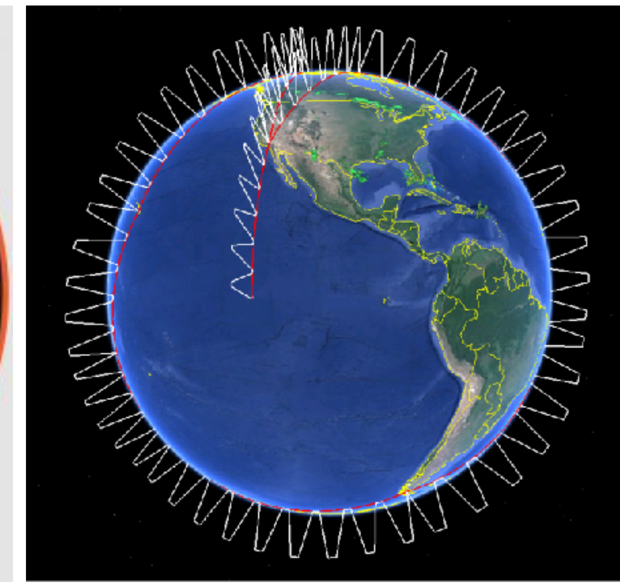


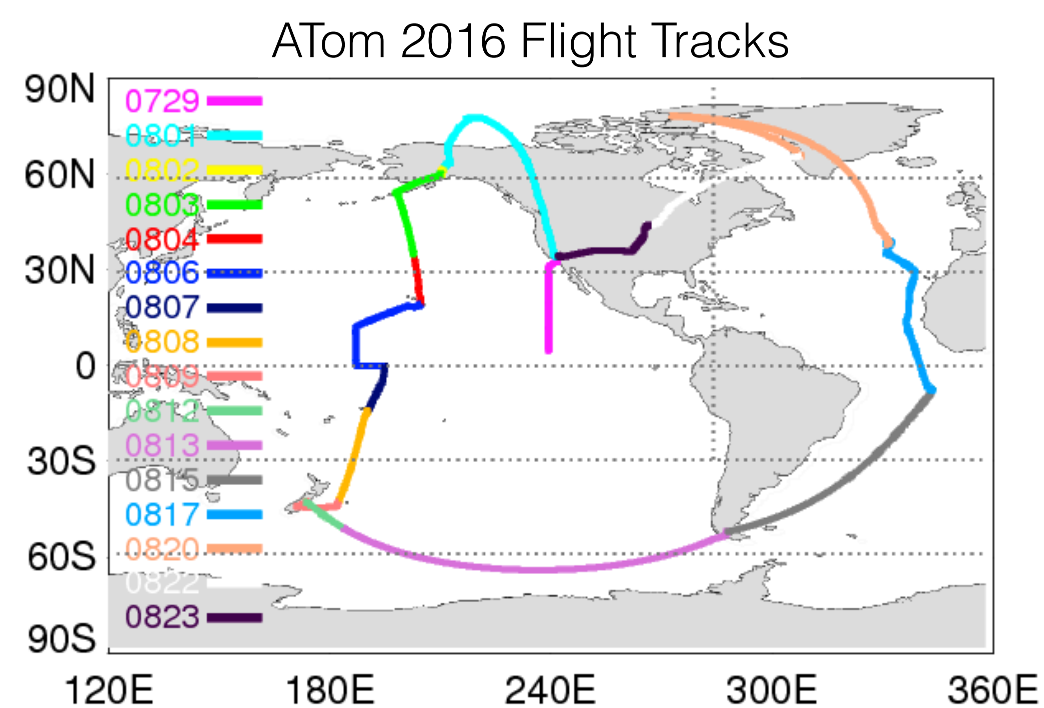
GEOS/FP combined (PM, SO2 and CO) air quality index (AQI) in India at 07:30Z on November 06, 2016.



Campaign Support
ATom

- NASA DC-8 Atmospheric Tomography Mission (PI: Steve Wofsy, Harvard)
- Fly 4 seasons over 2016 - 2018 period, profiling surface - 12 km
- Study impact of air pollution on greenhouse gases and chemically reactive gases in the atmosphere
- Extensive aerosol and trace gas measurements





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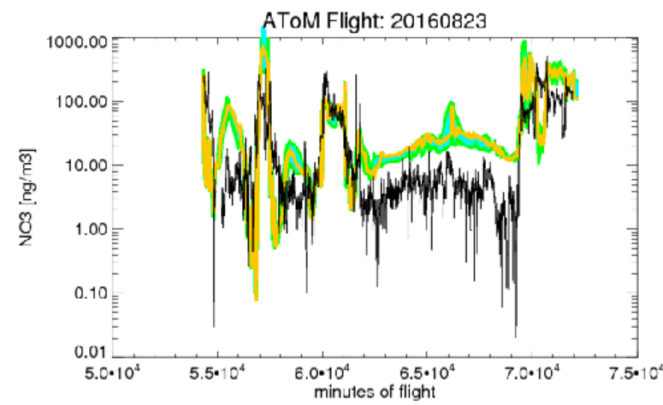
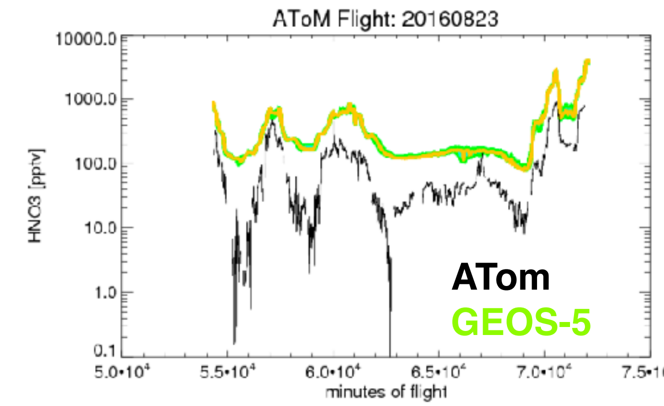
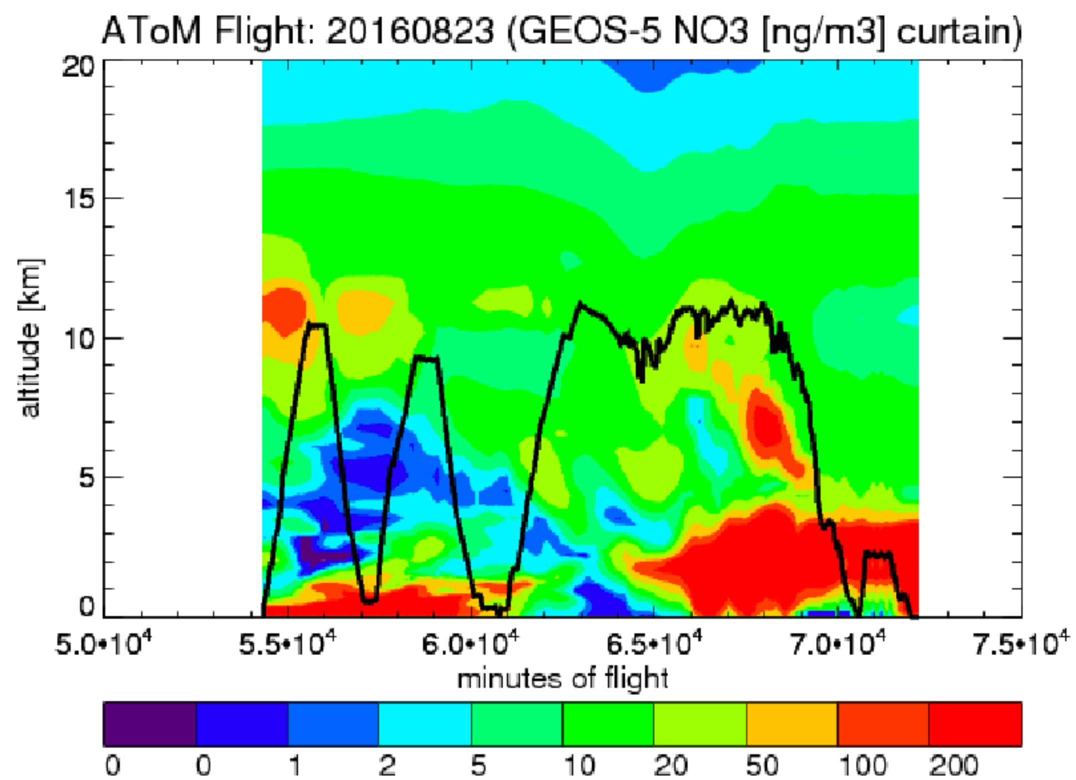
Nitrate

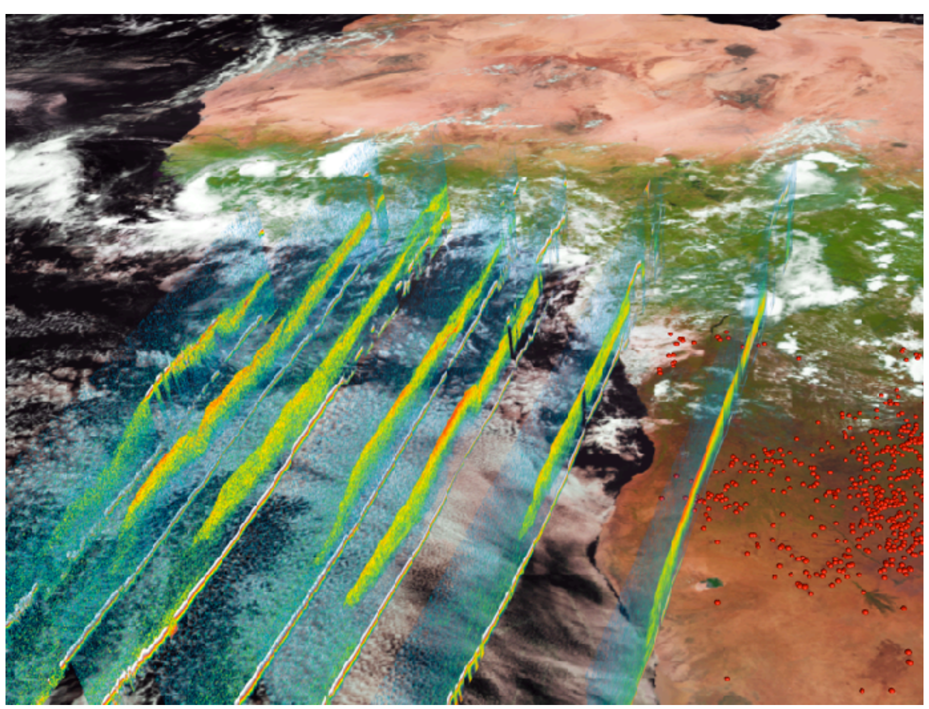


Nitric Acid





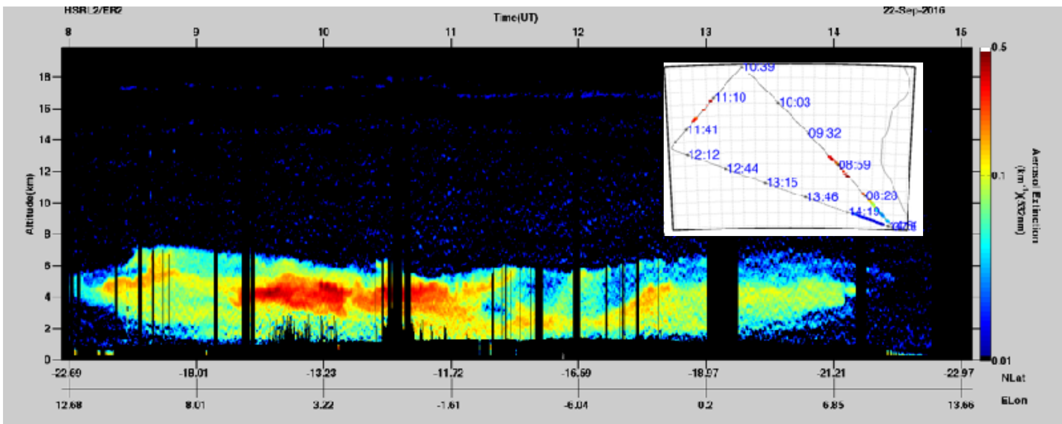
Campaign Support ORACLES



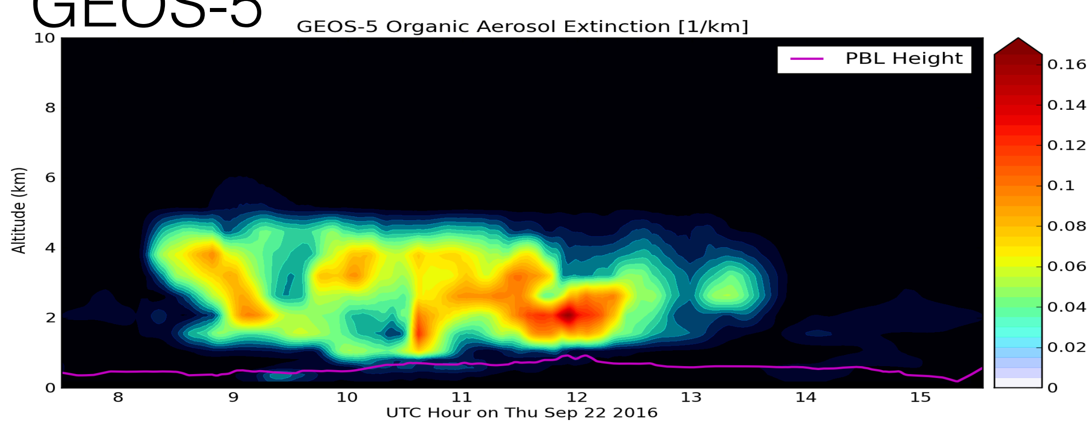
- ORACLES: Observations of Aerosol above Clouds and their Interactions (PI: Jens Redemann, NASA Ames)
- Determine impact of African biomass burning aerosol on cloud properties and the radiation balance over the South Atlantic
- 2016 deployment out of Walvis Bay, Namibia
- 2017 deployment out of São Tomé and Príncipe (Gulf of Guinea)

Campaign Support
ORACLES

HSRL



GEOS-5



During the campaign, GEOS-5 smoke plume was systematically lower than observations

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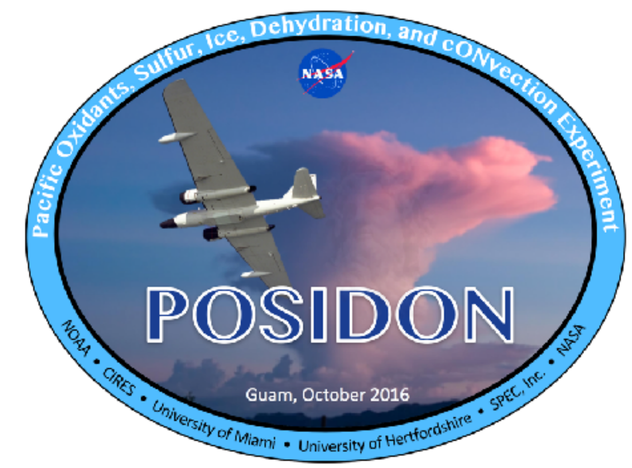
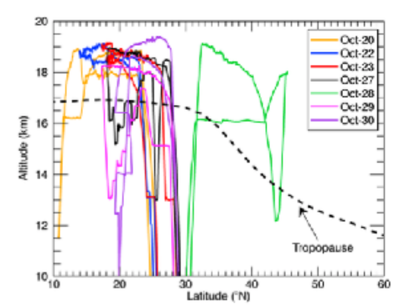
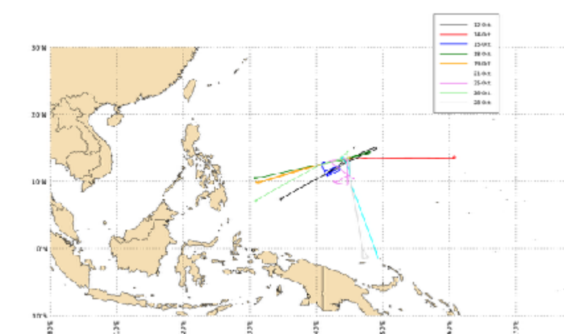
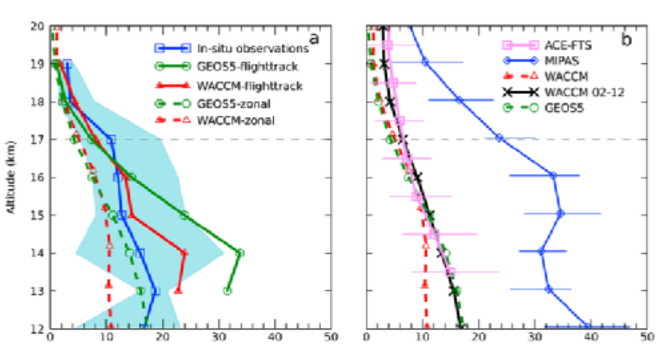
Campaign Support VIRGAS/POSIDON

- VIRGAS: Volcano-plume Investigation Readiness and Gas-phase and Aerosol Sulfur, Oct. 2015
- POSIDON: Pacific Oxidants, Sulfur, Ice, Dehydration, and cONvection, Oct. 2016
- WB-57 aircraft missions targeting (among other things) transport of sulfur species from troposphere into UTLS

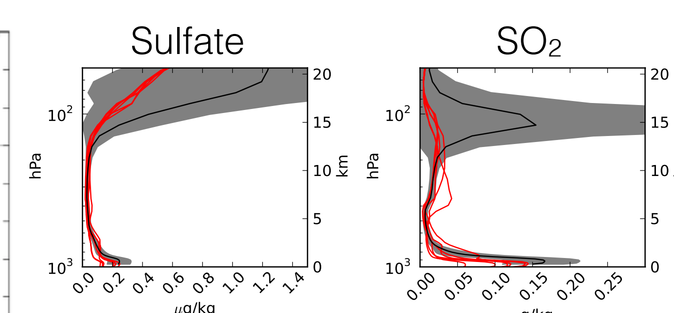








Rollins et al. GRL 2017



GEOS-5 climatology

GEOS-5 POSIDON flights

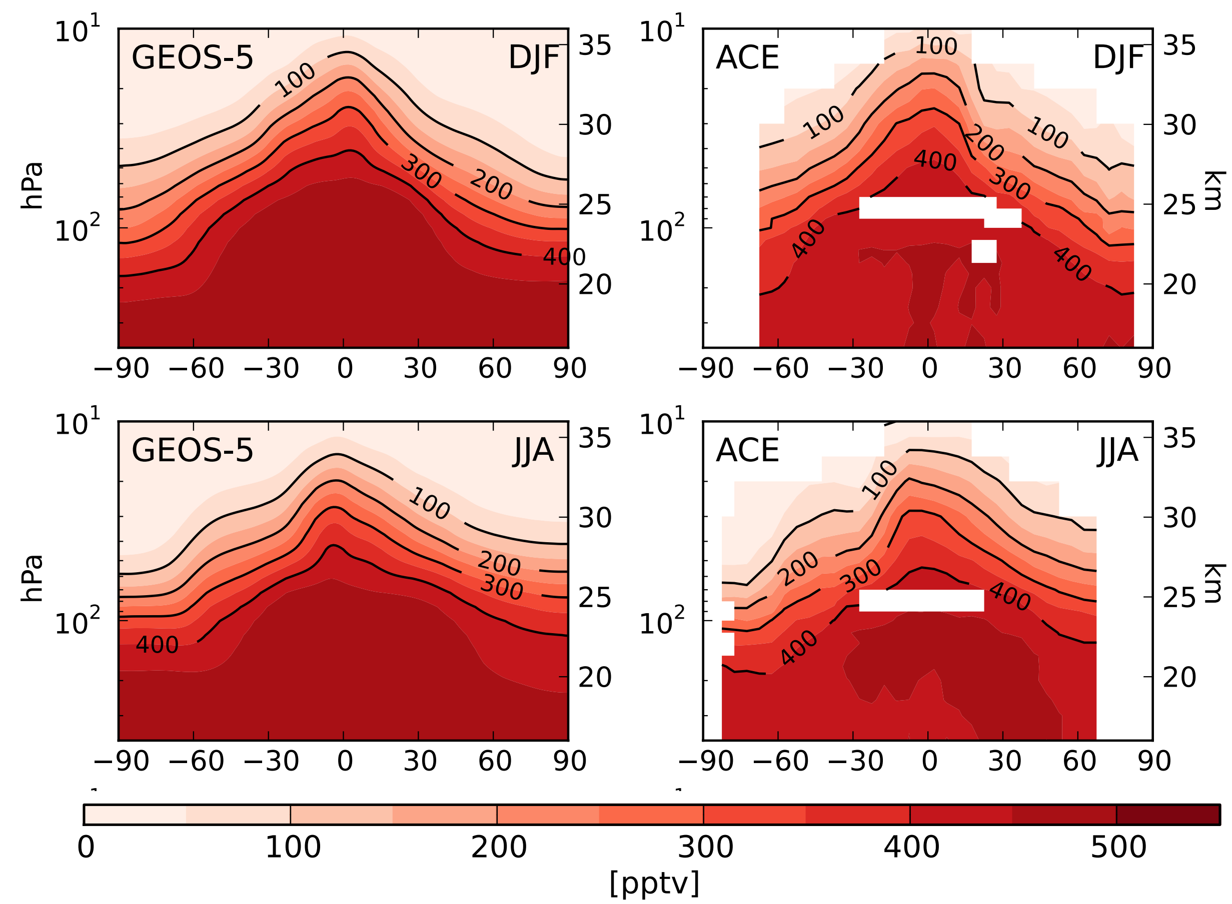
Stratospheric Aerosol

- Developed a source function for production of SO_2 from naturally occurring carbonyl sulfide (OCS)
- This is the source of mid-stratospheric Junge layer sulfate aerosol (detectable by OMPS-LP, SAGE, OSIRIS, …)
- Perturbations to this layer by volcanic and anthropogenic sources impact of energy balance of atmosphere and stratospheric ozone
- To do: simplify - current mechanism requires (expensive) stratospheric chemistry mechanism, implement climatological OCS photolysis

Zonal mean OCS mixing ratio

GEOS-5 2003 - 2016

ACE 2004 - 2013



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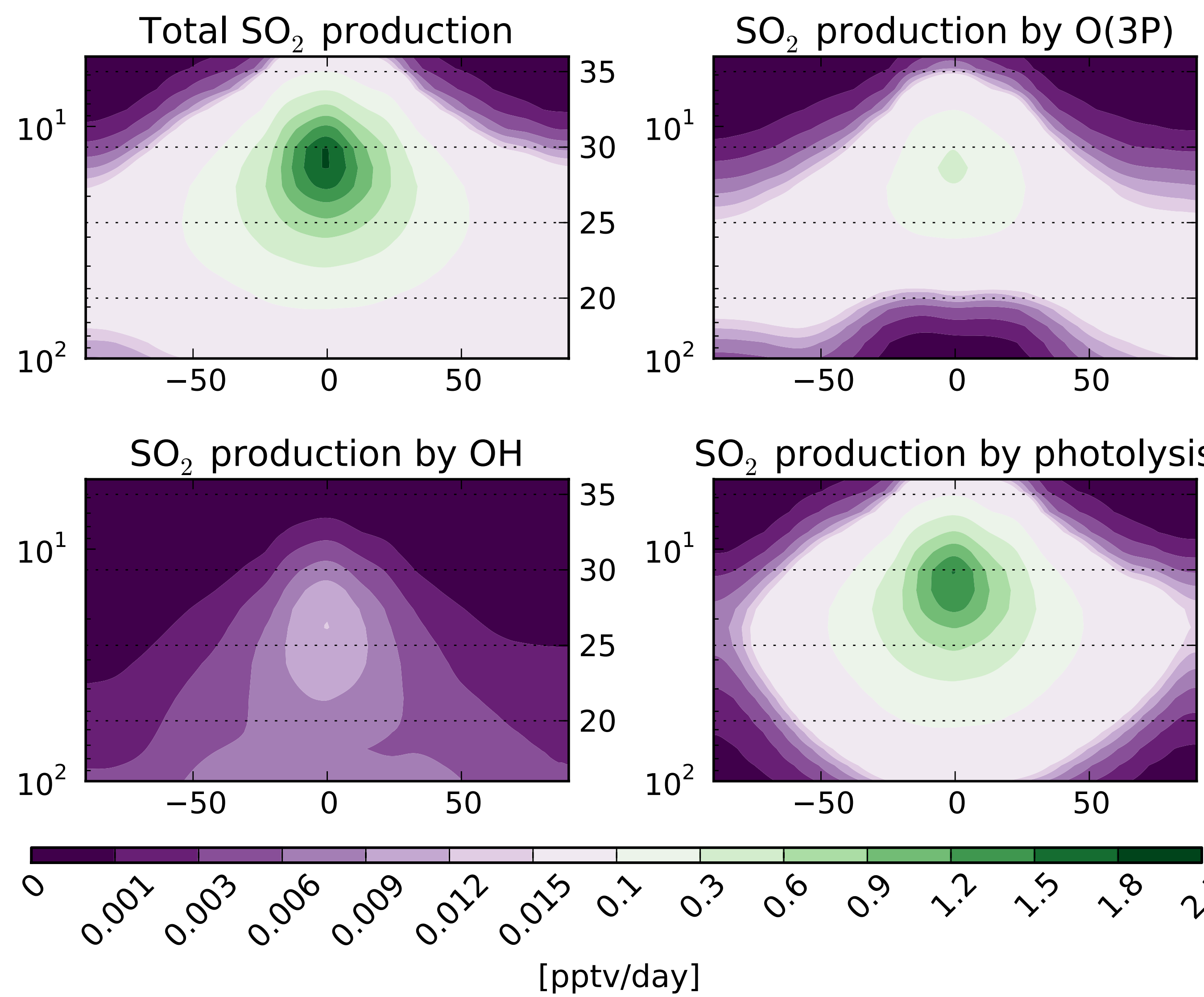
Simulated production of SO_2 by OCS

Total | OCS+O(3P)



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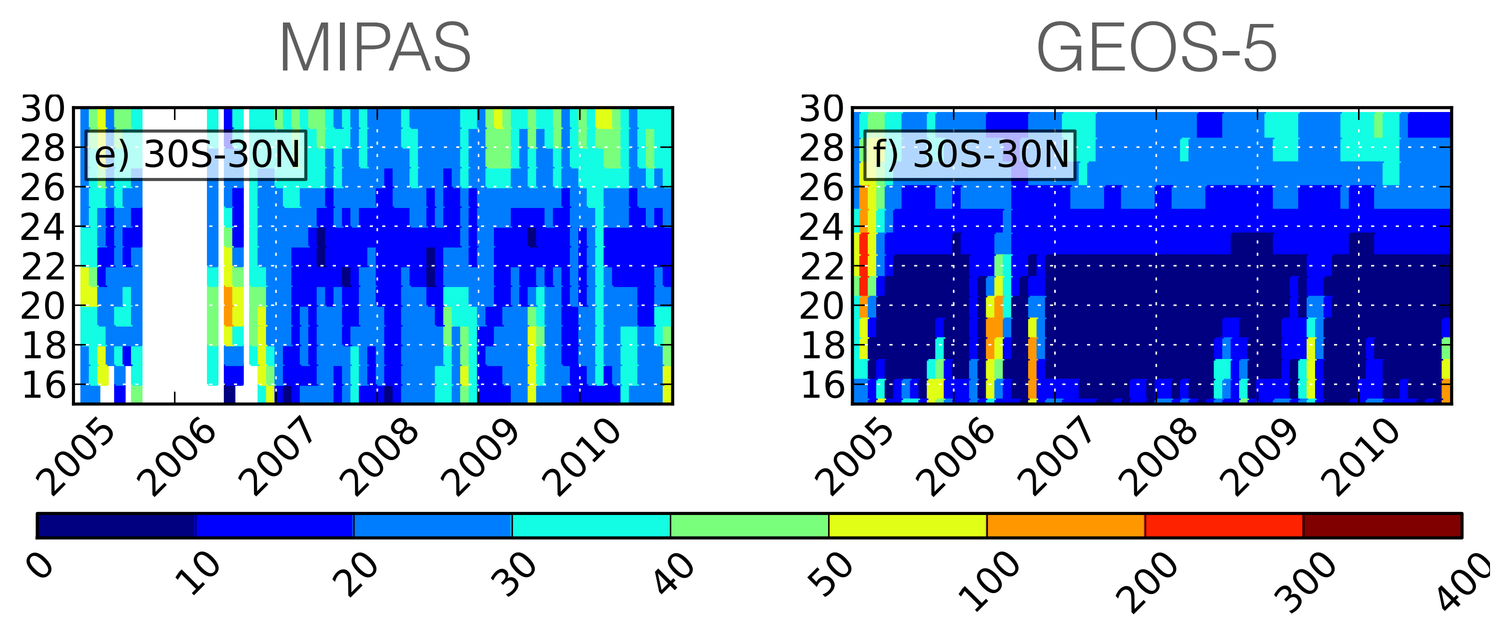
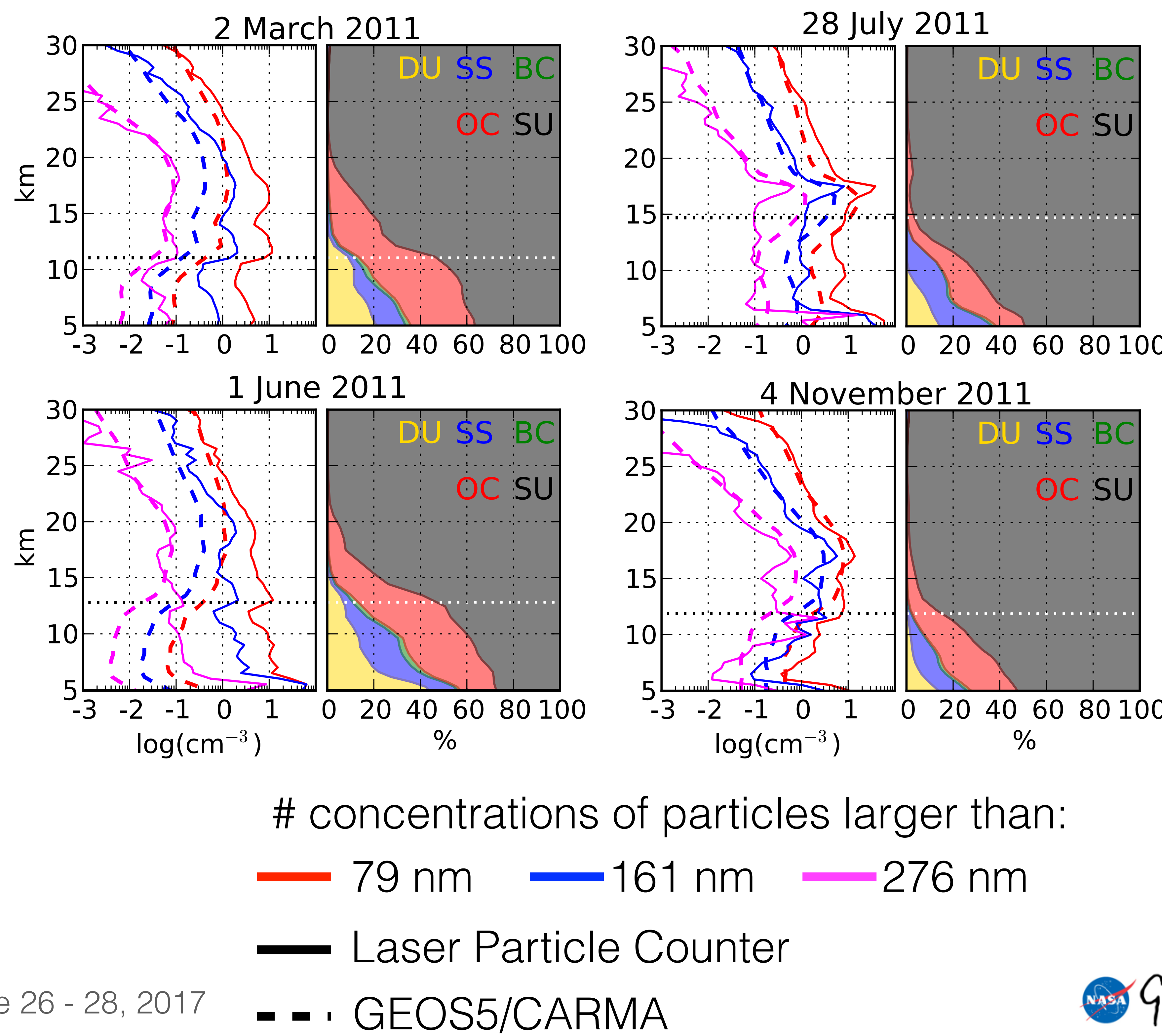
SO_2 tropical mass mixing ratio [ppt]



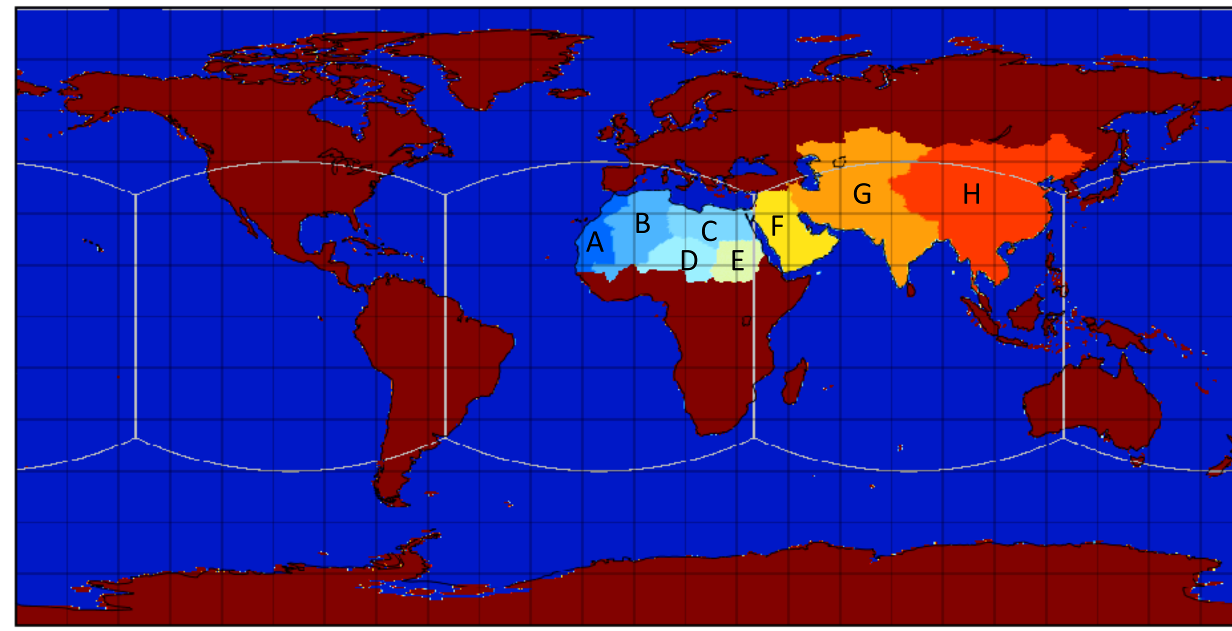
Sectional Aerosol Microphysics

- CARMA sectional aerosol microphysics module incorporated in GEOS-5, setup for stratospheric sulfate
- Comparison of CARMA simulated particle sizes to balloon observations from University of Wyoming (T. Deshler)
- Good agreement (even following Nabro volcano) in parts of stratosphere where sulfate dominates (as determined from parallel GOCART run)

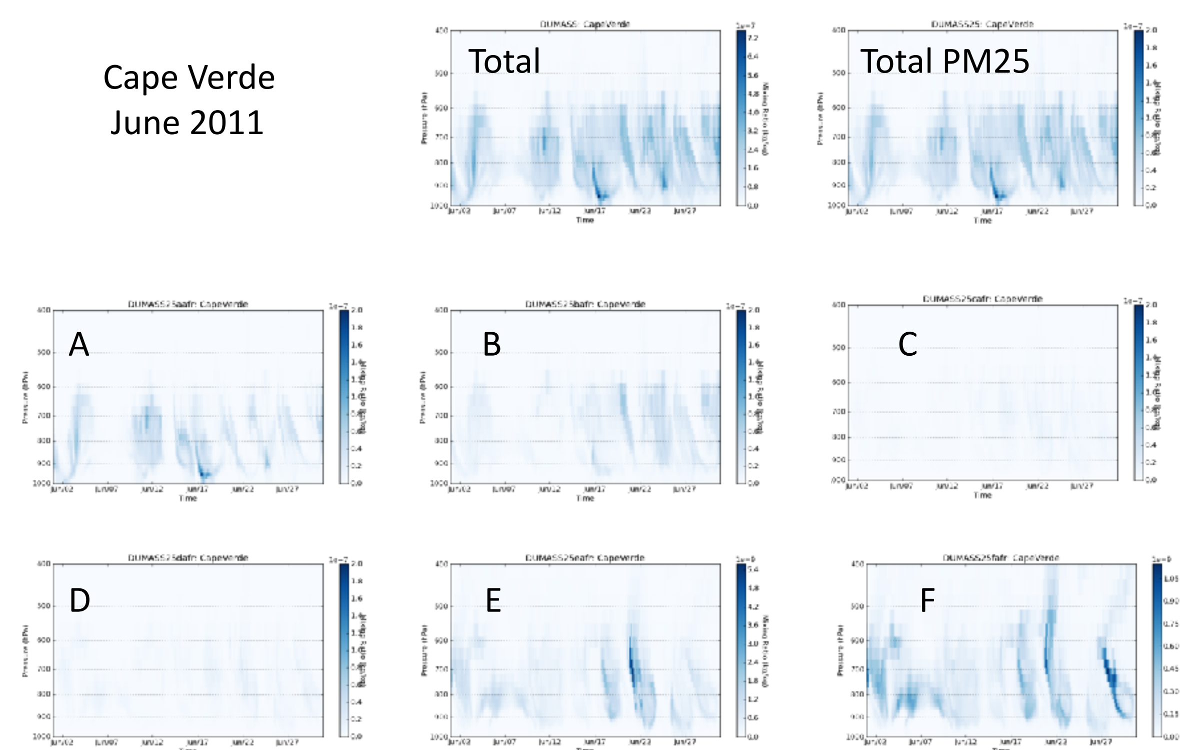


Dust

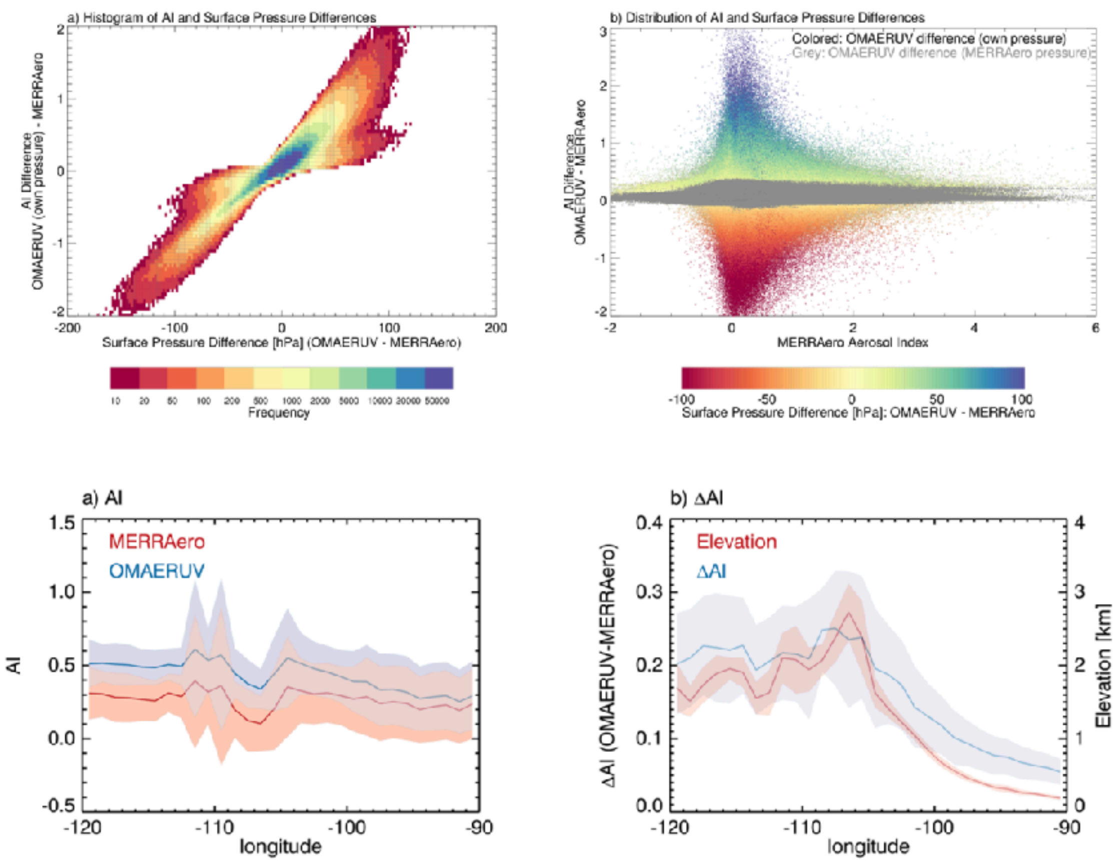
- Developing source specific tuning factors to improve agreement between simulated and Deep Blue/ MISR/AERONET observations
- Region specific tagging of dust eventually leads toward partitioning of mineralogy or composition; impacts on radiance simulation and climate forcing
- Updating mobilization scheme toward Kok et al. 2014; relax dependency on FOO-type source maps



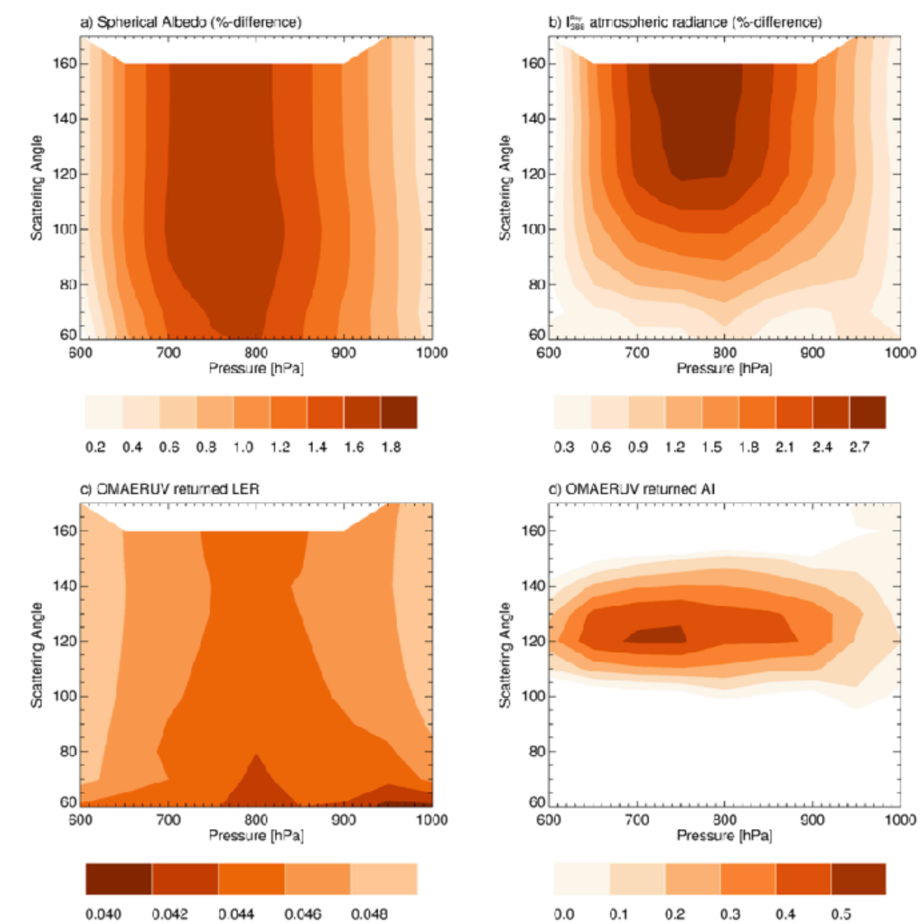
Cape Verde
June 2011



OSSEs



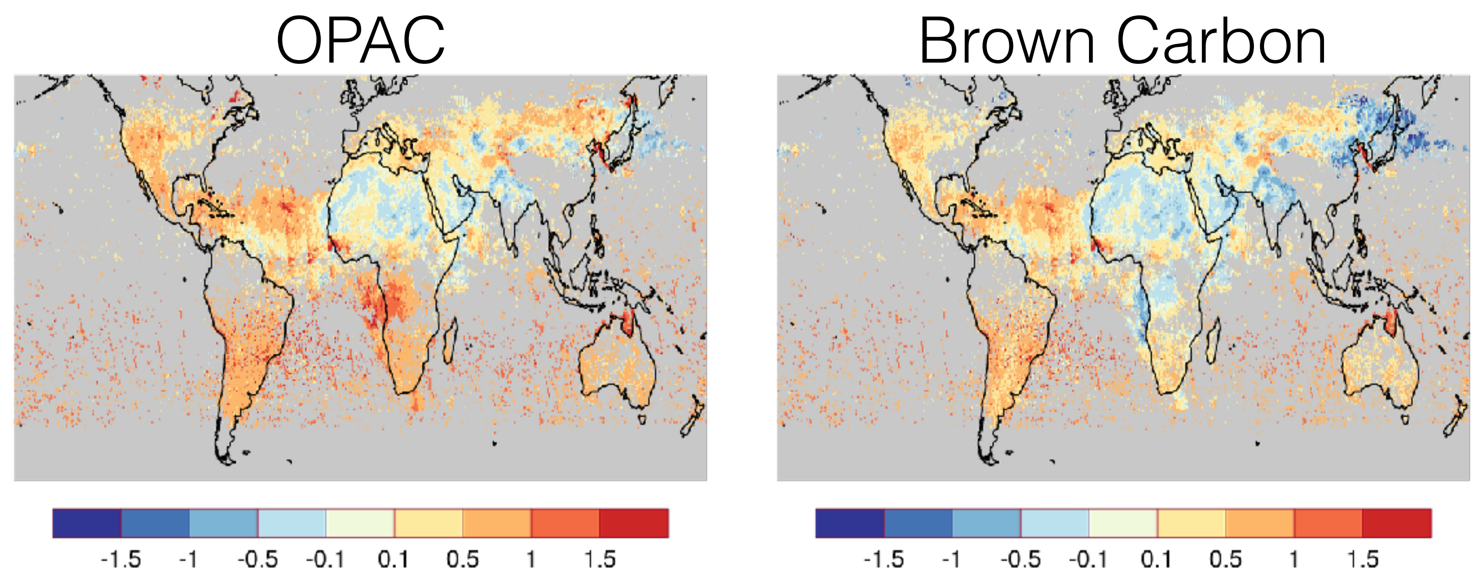
Colarco et al., AMTD, 2017



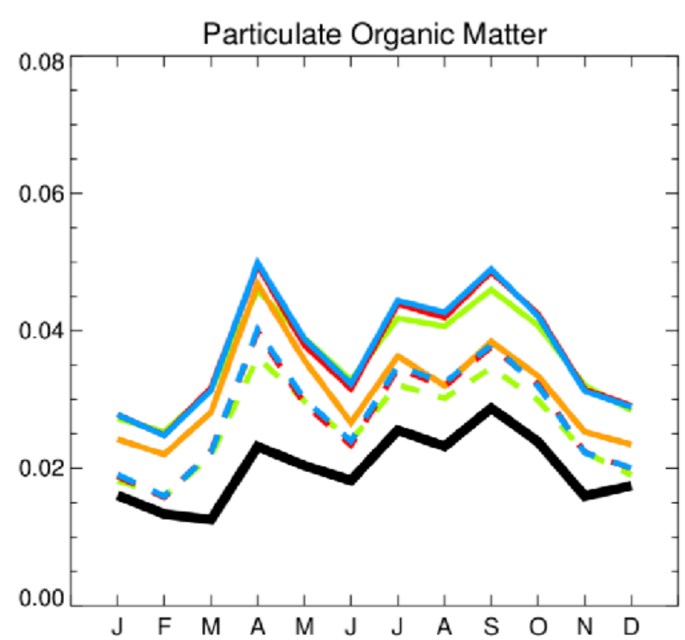
- Simulating radiances of observing systems provides a powerful tool to interrogate retrieval algorithms
- A number of these observing system simulation experiments are underway: MODIS (aerosols and clouds), OMI, TEMPO, OMPS, and TOMS (e.g., revisit Pinatubo eruption impact on aerosol and ozone retrievals)
- Example here shows sensitivity of OMI aerosol index to assumptions of surface pressure and limitations of pre-computed radiative transfer calculations; impact is to tie retrievals more closely to assimilated meteorology products and increase nodal points in RT lookup tables

Brown Carbon/SOA

- OSSEs and comparisons to campaign data cause us to revisit assumptions of aerosol optical properties
- Recently introduced tracer and optics for “brown carbon” species into GOCART
- Testing and tuning is underway to partition POM between nominal OC and new BRC tracers
- Additionally, testing and tuning recently implemented anthropogenic VOC/SOA parameterization based on CO emissions (after Hodzic et al. 2011)



Above: Simulated OMI - MERRAero difference in AI for June 2007 for two different assumptions of spectral dependence in organic carbon optics

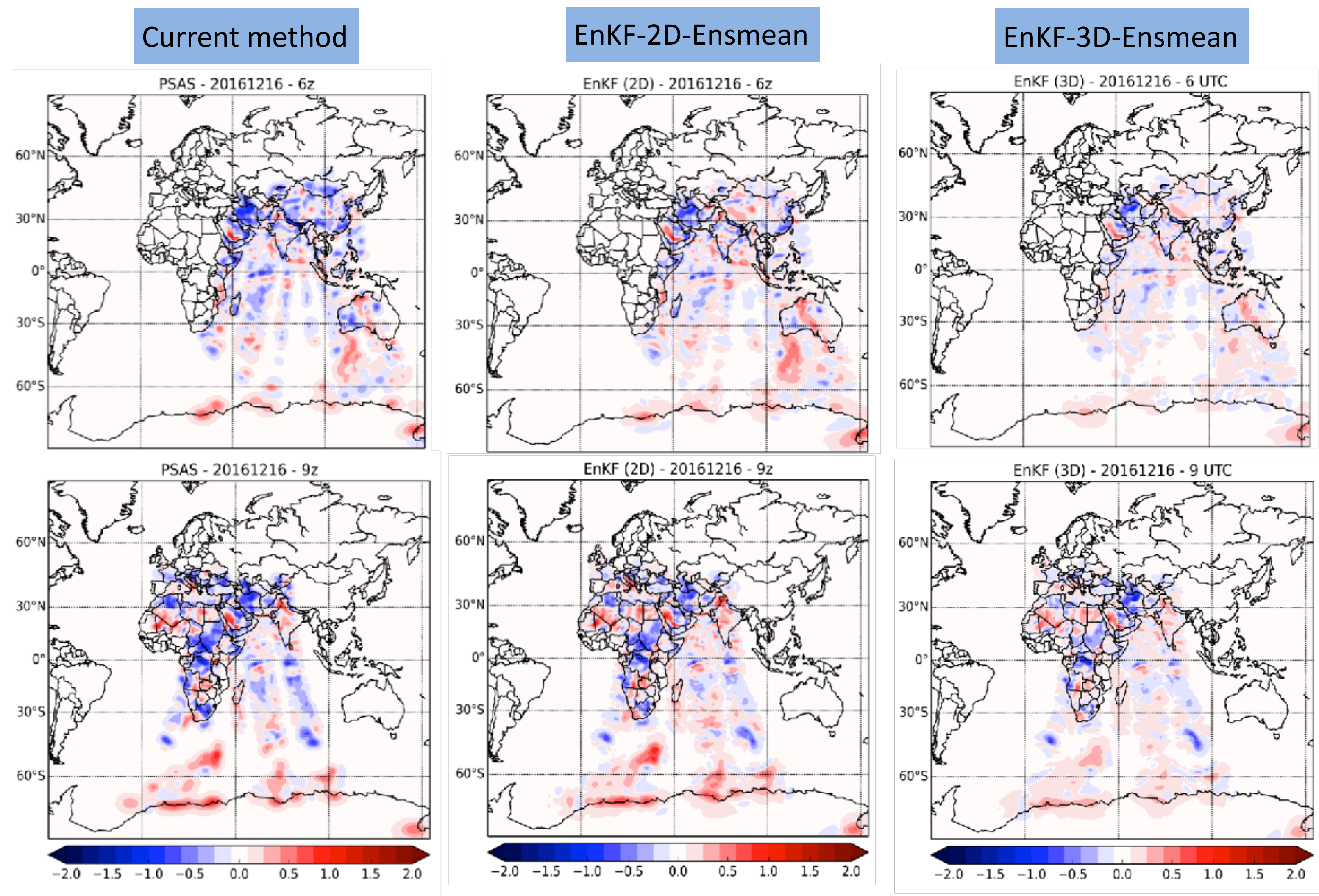


Left: Time series of POM AOD from GEOS-5 simulations compared to **MERRA-2**. Dashed lines are AOD without SOA; solid lines include SOA. Additional reasons for enhanced AOD due to biomass burning emissions and POM/OC ratio.

Aerosol EnKF

- Ensemble Square Root Filter (EnSRF) code (Whitaker and Hamill, 2002) used for the hybrid meteorological assimilation adapted for assimilating aerosols observations
- Framework development for assimilation of 2D aerosol observations (bias-corrected log(AOD + 0.01) at 550 nm) is advanced
- 32 ensemble members produced routinely every 6 hours by the meteorological assimilation at 0.5° horizontal resolution in the current GMAO's hybrid system (preliminary results shown here use ensemble members produced at 1°)
- Quality control (buddy-check of Dee et al. (2001)) of AOD observations is performed on the ensemble mean and allows each member to see exactly the same set of observations.
- Analysis in term of 2D log(AOD) or in term of 3D aerosol mass mixing ratio (this last one becomes computationally expensive as we increase the horizontal resolution of the aerosol background for each member).

Preliminary results: AOD analysis increments – 16 December 2016 at 6UTC (top) and 9UTC (bottom)

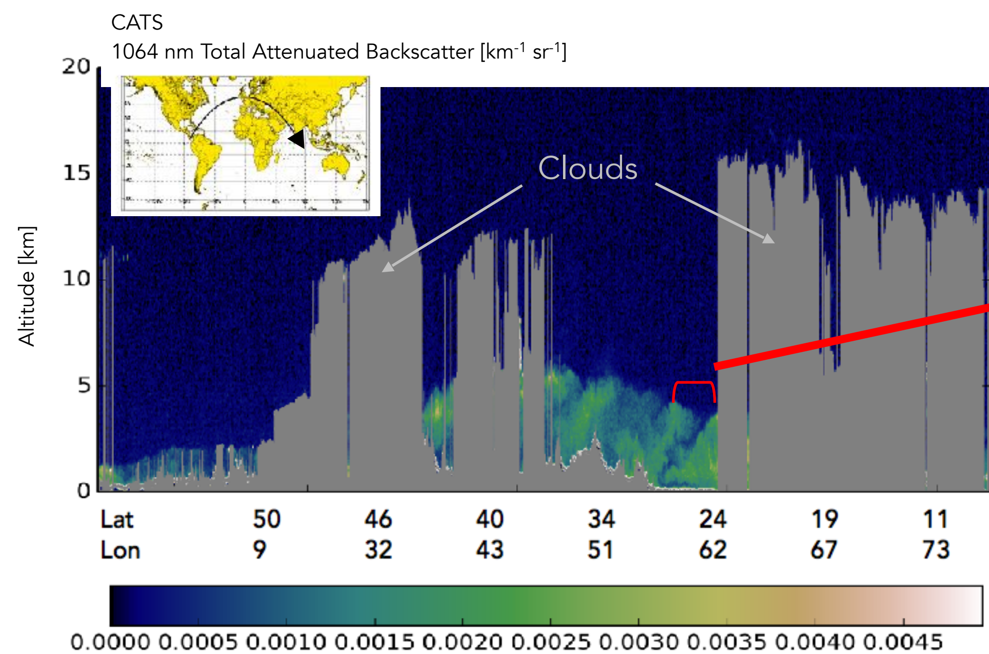


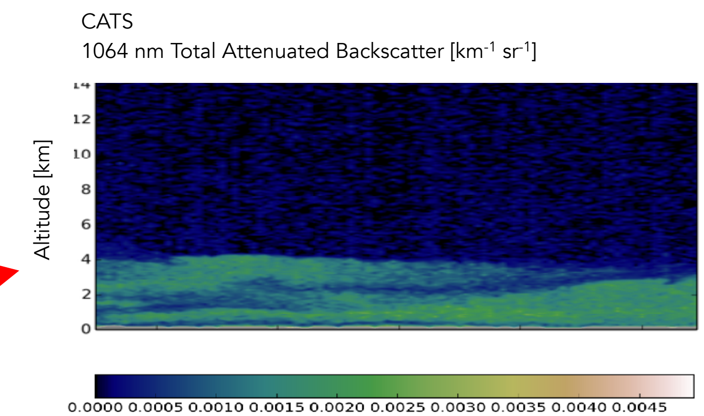
Future work:

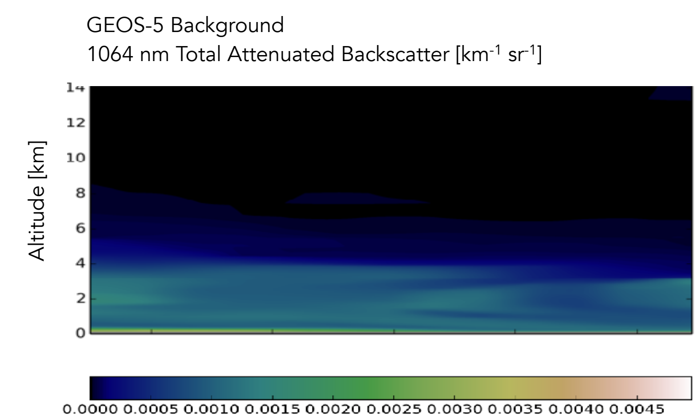
- increase horizontal resolution of members by doing a proper remapping of the background (i.e., take into account the topography),
- tune observations errors,
- add more observation types to better constrain the aerosol speciation and vertical distribution (e.g., multi-wavelength AOD, lidar observations (CALIOP/CATS))

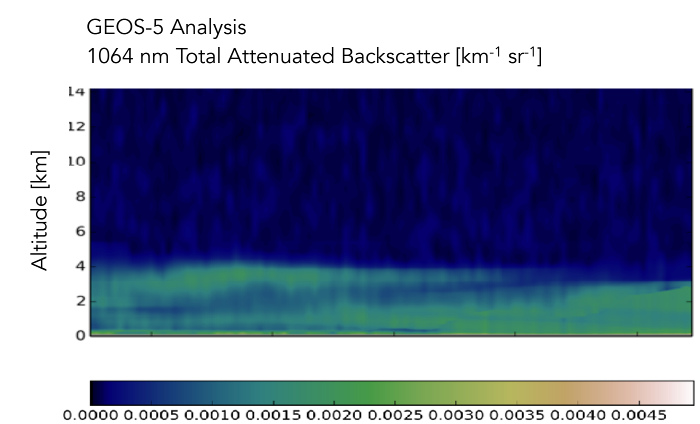
Lidar Assimilation

Example:
Sept. 30, 2015





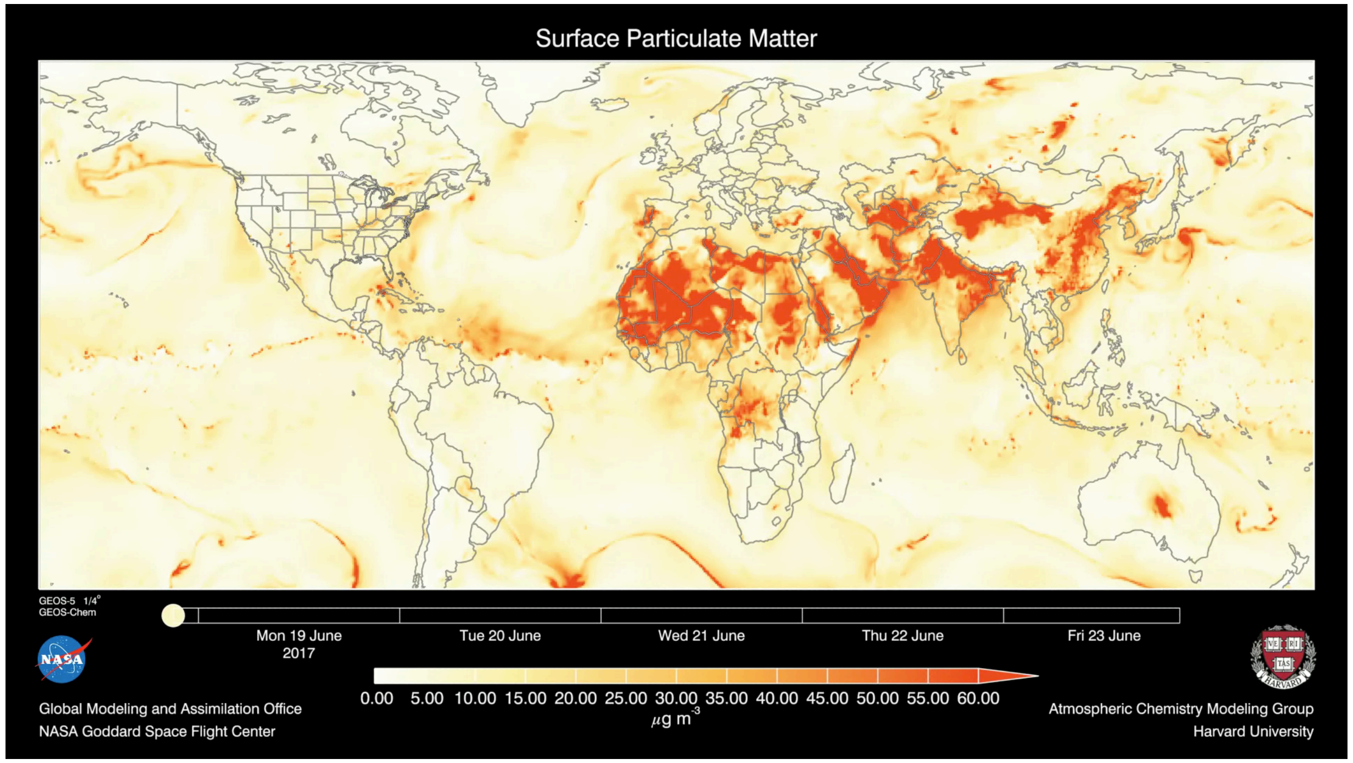


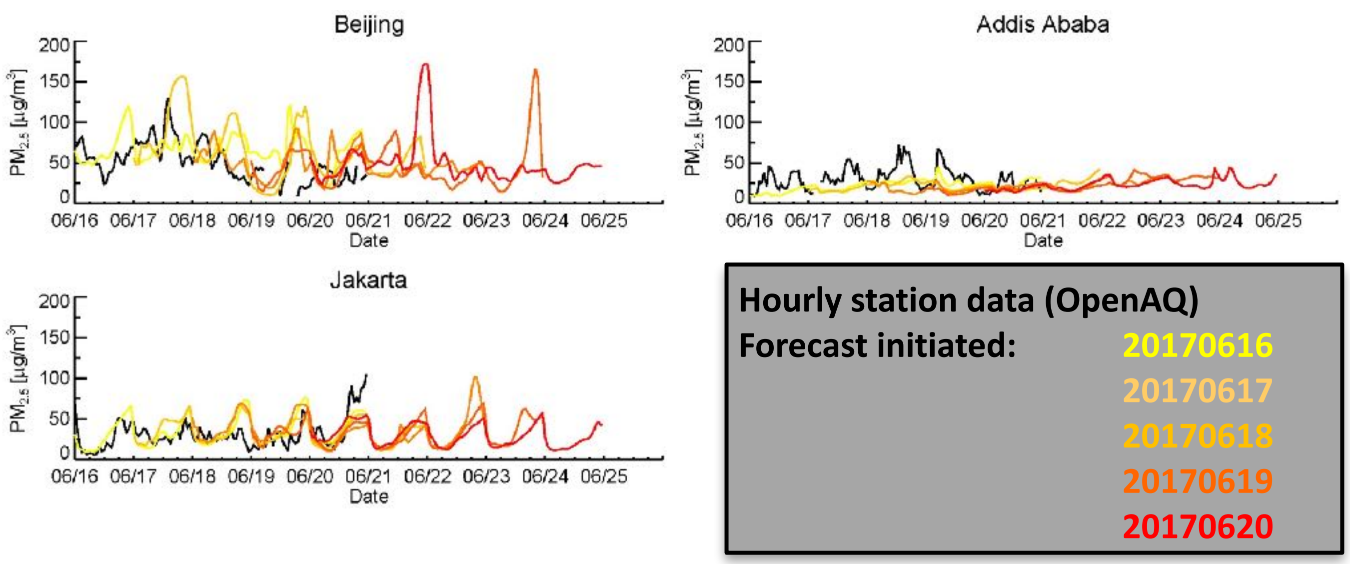


- Column observations of aerosol optical thickness (AOT) are currently assimilated into the GEOS-5 modeling and assimilation system, however, the vertical distribution of aerosols is unconstrained.
- The Cloud Aerosol Transport System (CATS) lidar onboard the ISS provides near-real time (NRT - within 6 hours) observations of attenuated total backscatter and depolarization ratio at 1064 nm, providing a unique opportunity to assimilate vertical aerosol information into GEOS-5 forecasts.
- Currently, techniques are being developed for assimilating cloud screened CATS NRT observations into the GEOS-5 assimilation system using a 1-D ensemble approach.

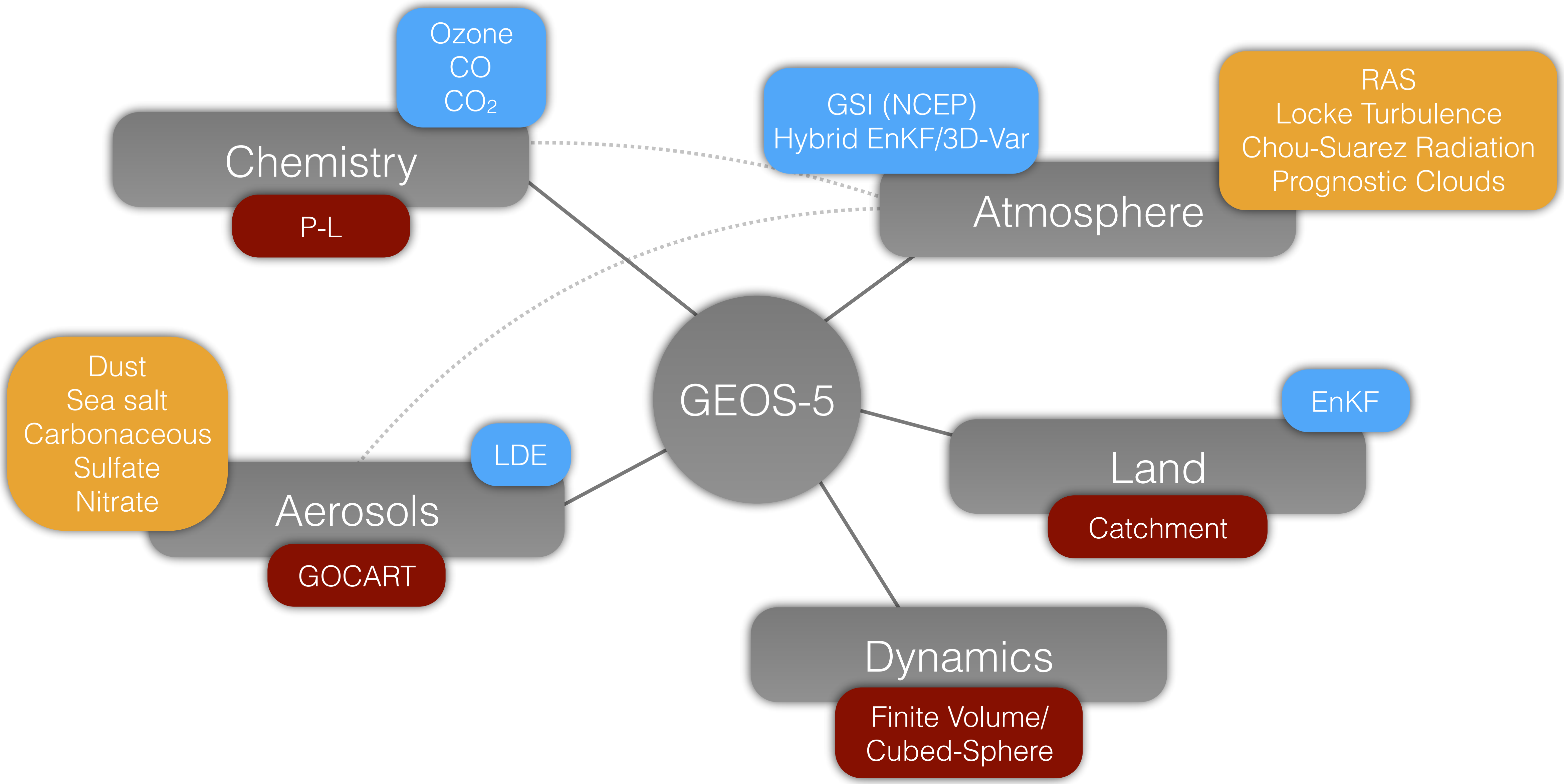
Atmospheric Composition Forecasting

- Semi-operational chemical forecasting system based on GEOS-5 FP with GOCART and GEOS-Chem full chemistry module
- Runs daily 1-day analysis + 5-day forecast at global 0.25°, initialized from prior day analysis (which has seen aerosol assimilation)
- Ongoing work to evaluate and distribute products to AQ-interested stakeholders



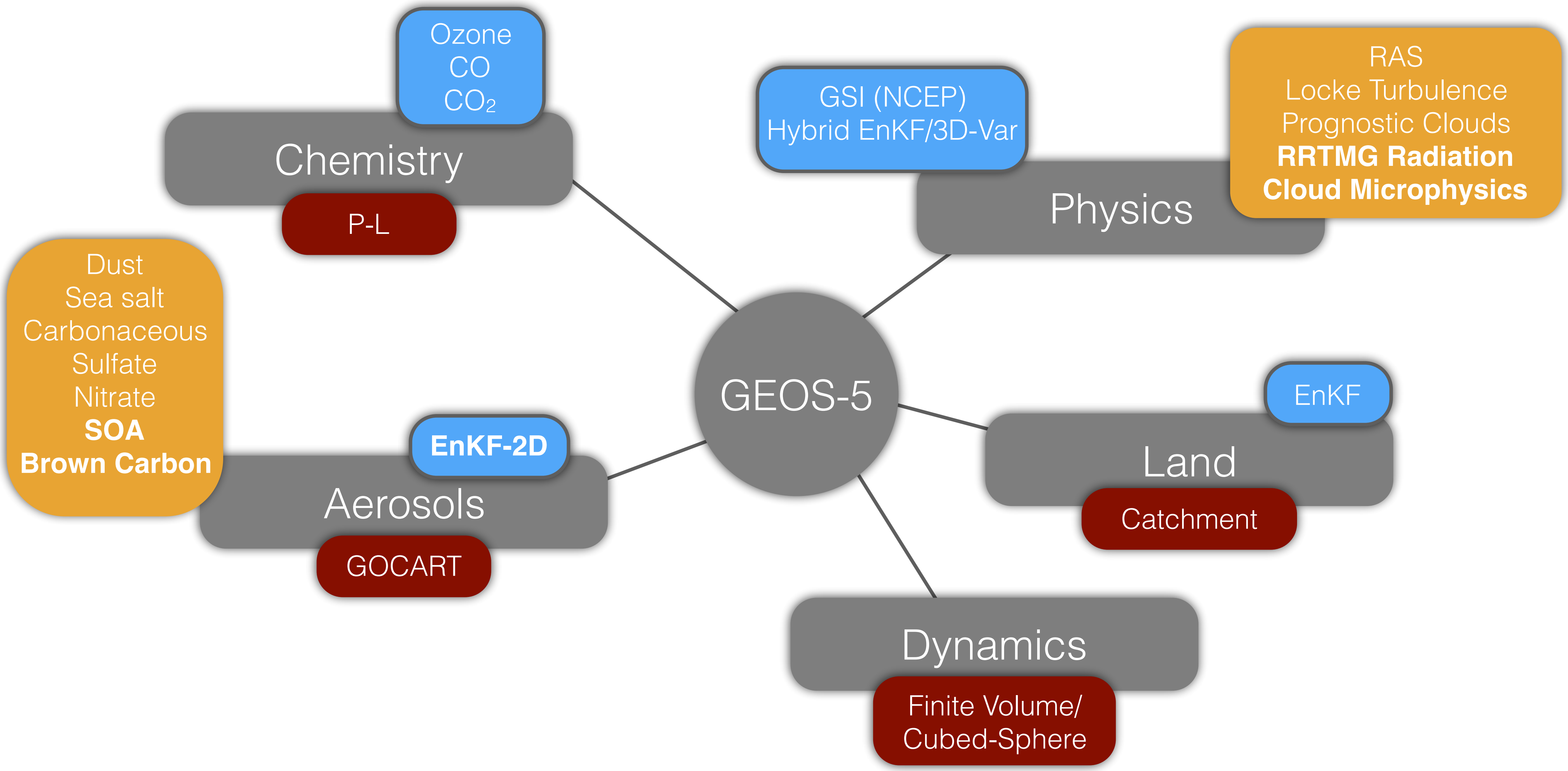


Current NRT Configuration



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

Late 2017 NRT Configuration



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

Ongoing

- Still targeting MAM-7 as replacement for GOCART
  - A lot of work has gone into optimizing code, with throughput improved from GEOS-5/MAM7 @ 2.5x GEOS-5/GOCART to 1.4x GEOS-5/GOCART
  - ongoing work for micro-physically aware aerosol wet removal/scavenging
  - tuning of this system targeted for Q4 2017
- HEMCO as provider of emissions (diurnal cycles, biogenic SOA)
- Stratospheric aerosol as provided by climatological OCS photolysis
- Snow darkening codes