NASA Aerosol DA Activities

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GEOS ESM Architecture Overview

GEOS is a hierarchy of ESMF components

An infrastructure for building GEOS applications:

- Standardized component interfaces
- Low level data containers for data sharing
- Grid classes for the physical domain
- Parallel communication
- Others: Regridding, Logging, Calendar

The MAPL layer interface to ESMF

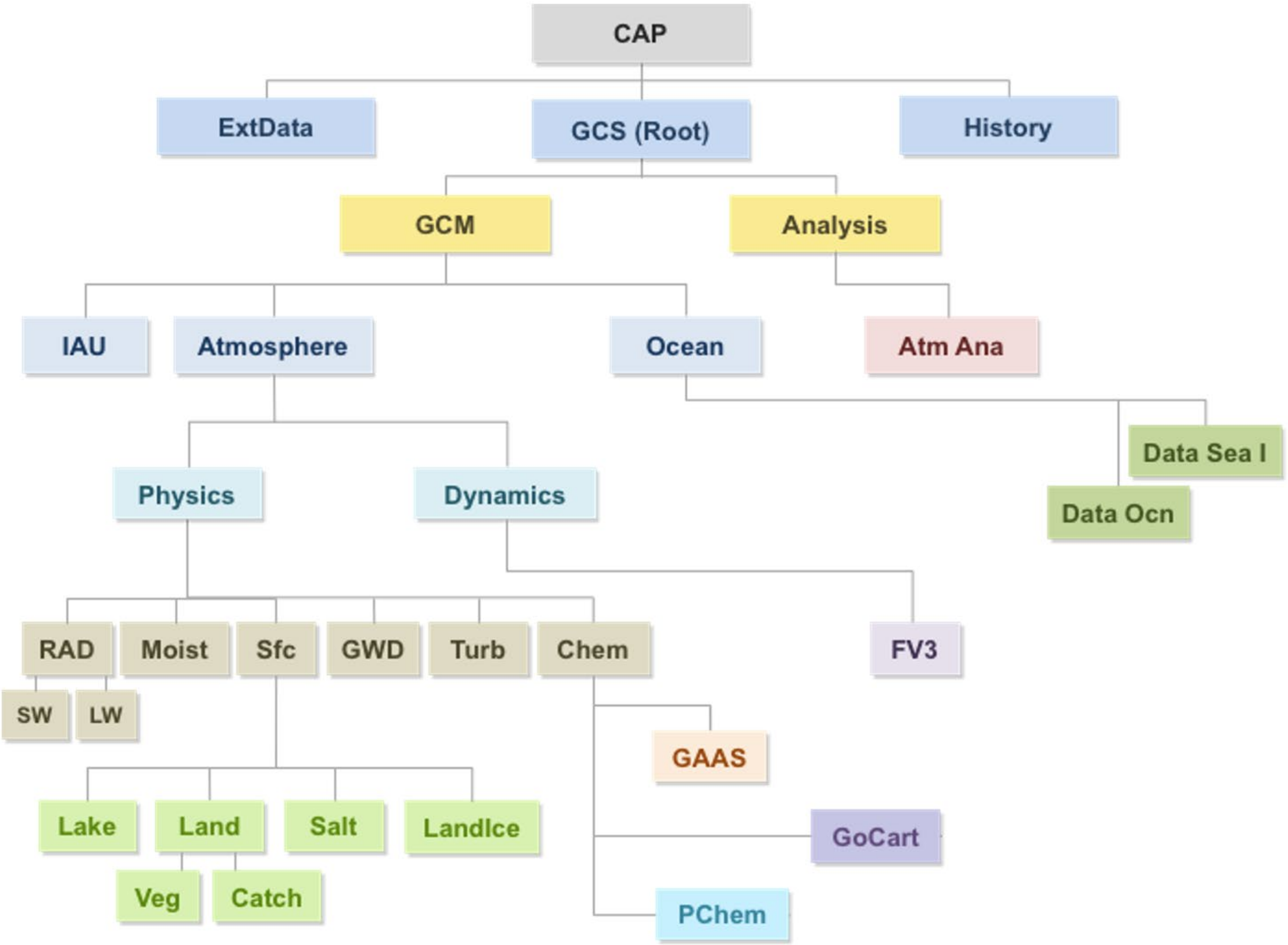
Provides an abstraction of software issues including:

- Generic Initialize/Finalize/Run
- Simplified hierarchy (creation of child components)
- IO Layers (Asynchronous file server output)
- Regridding transforms (grids and tiles)
- Profiling (Performance and Memory)
- Input (ExtData) / Output (History)

Architecture permits flexibility

- NWP configuration
- S2S configuration (seasonal, w/coupled ocean)
- CCM configuration (advanced chemistry)
- CF configuration (full chemistry NRT forecasting)
- NR configuration (high resolution for OSSEs)
- CTM configuration (offline met fields)

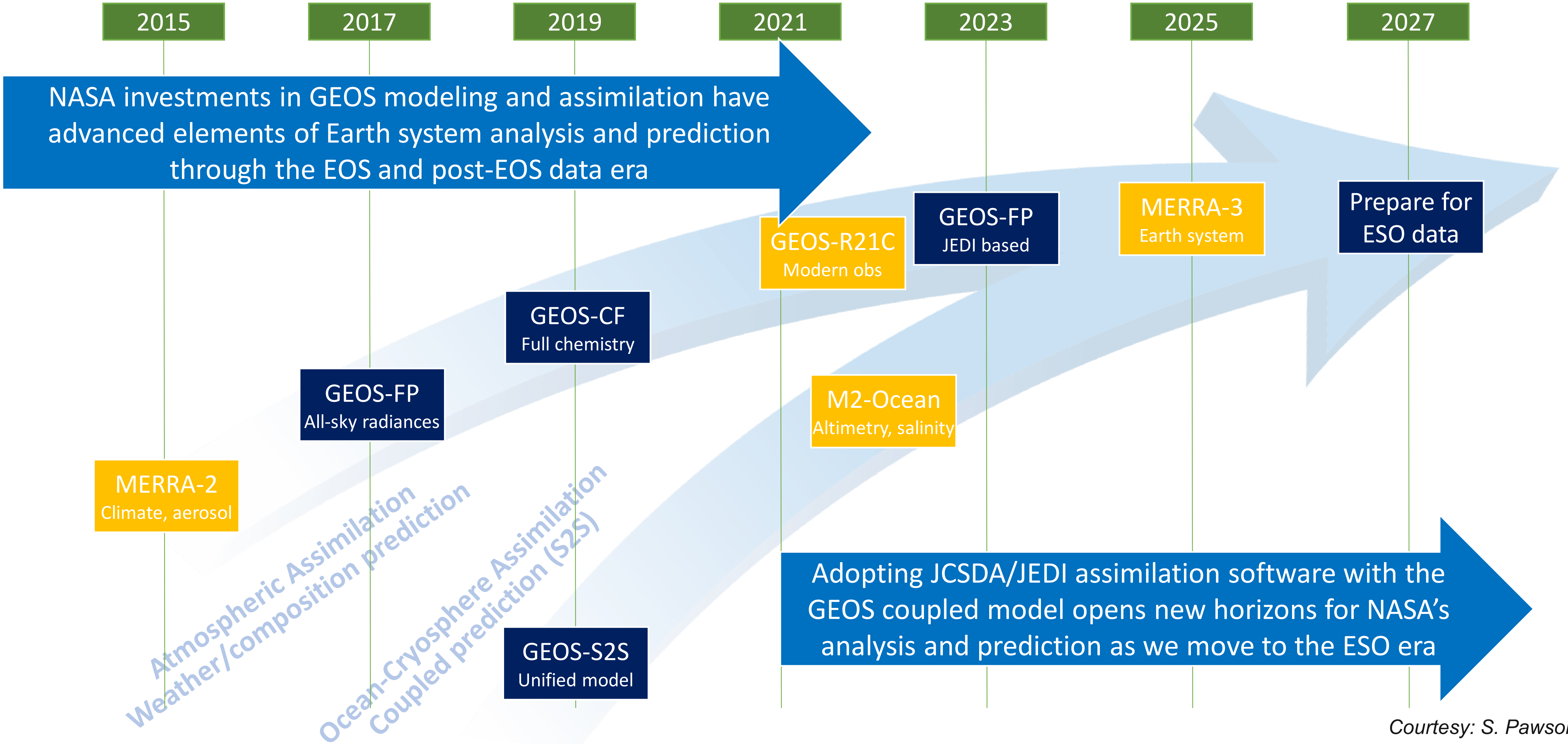
All these use the same core model components



GEOS Main Systems

GEOS Products	Purpose	Nominal Res.	Aerosol DRE	Aerosol DA
GEOS-IT	N.R.T. analysis system for Instrument Teams	50 km	√	√
GEOS-FP	Wx/Aerosols 5-20 Forecasts (in ICAP MME)	12 km	√	√
GEOS-S2S	Coupled system for S2S predictions	50 km	√	(√)
GEOS-CF	Composition Forecast, full reactive gas chemistry (GEOSchem mechanisms) ▻ Being coupled to GOCART	50 km	√	(√)
MERRA-2	Current reanalysis	50 km	√	√

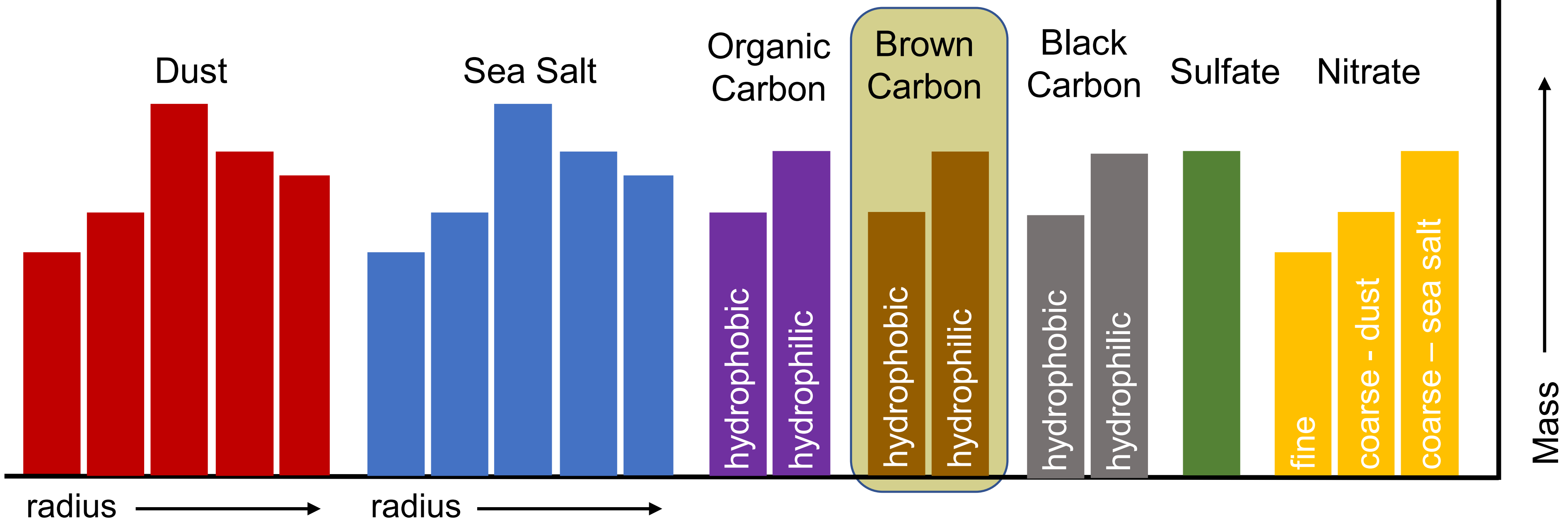
Timeline for GEOS Systems



Courtesy: S. Pawson

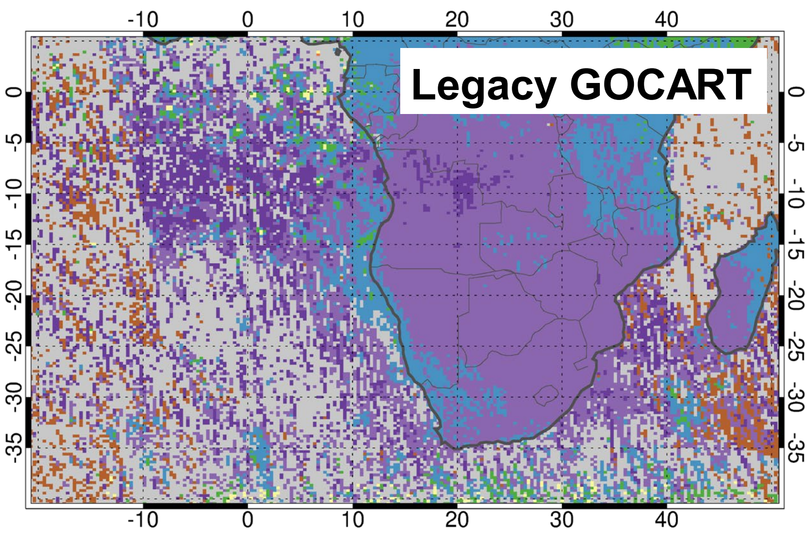
Recent Updates to GEOS Aerosol Scheme: GOCART-2G

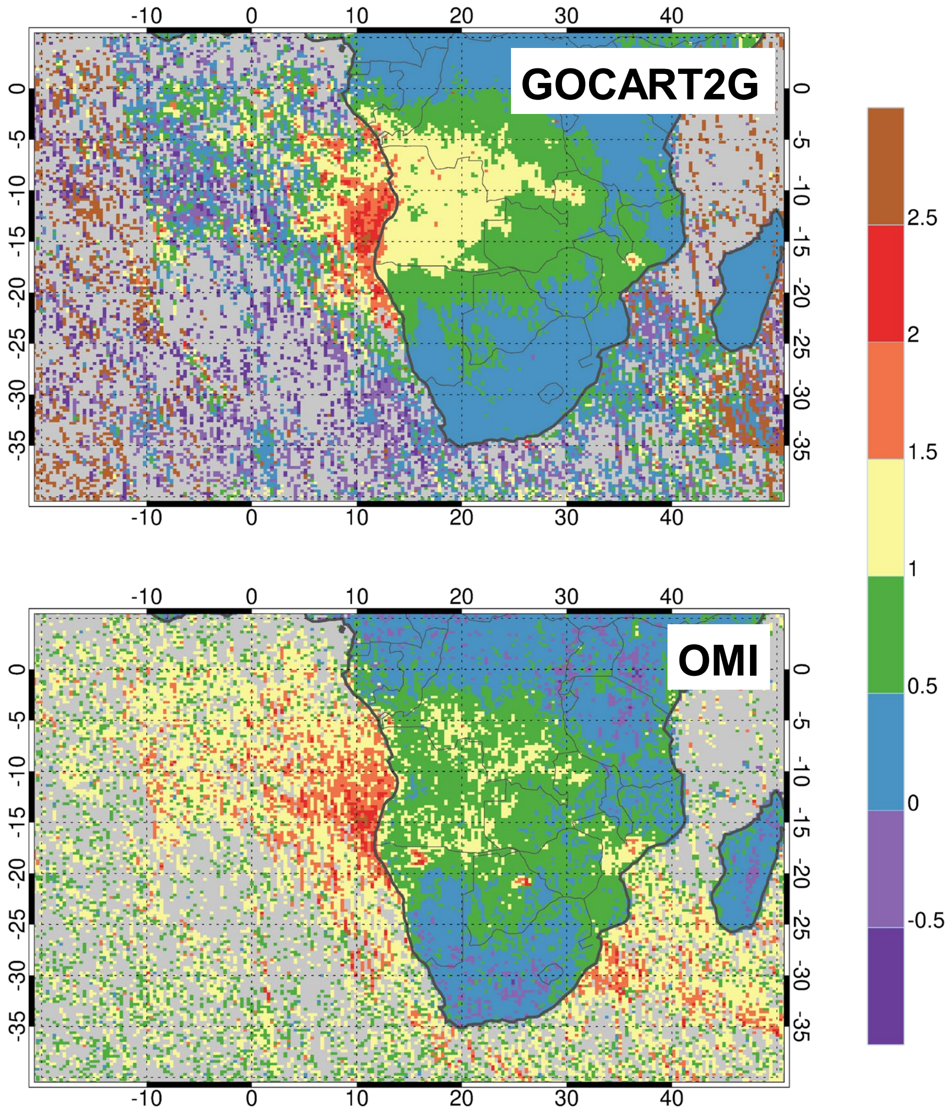
- Separation of organic aerosol into “white” (anthropogenic) and “brown” (biomass burning) components with distinct optical properties
- Increase OA:OC ratio in line with recent airborne measurements
- Inclusion of an ACHEM-driven SOA scheme for anthropogenic and biomass burning sources
- Inclusion of a HEMCO/MEGAN-driven biogenic SOA scheme
- Introduction of “point wise” source emissions for pyroCb inputs
- Update anthropogenic emissions to downscaled-CEDS emission inventory and input oxidant fields to MERRA-2 GMI (valid range of both is 1980 - 2019; padding outside years with endpoints



Pete

Impact of Brown Carbon

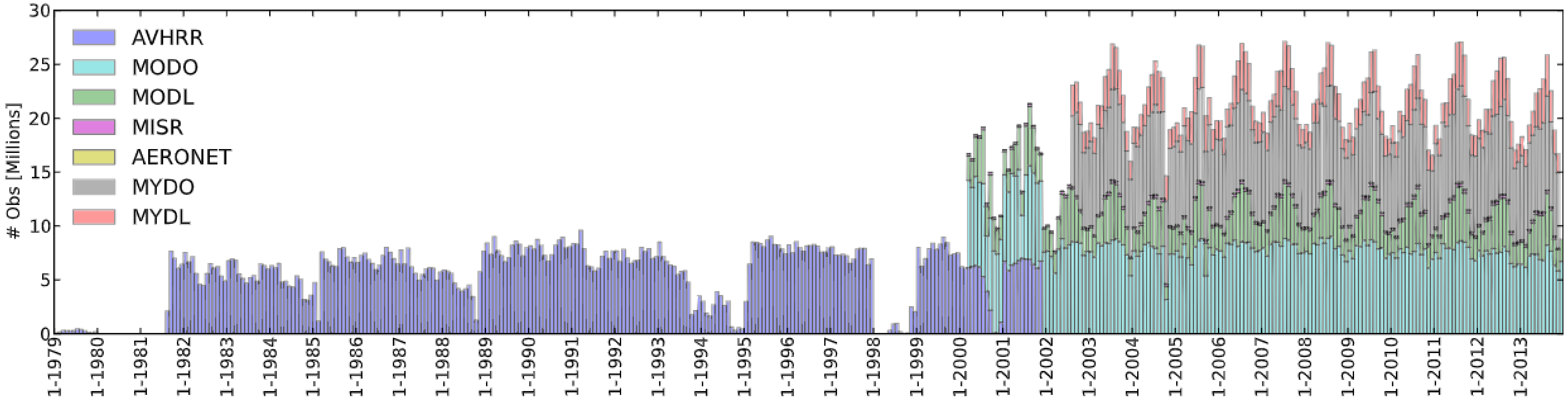




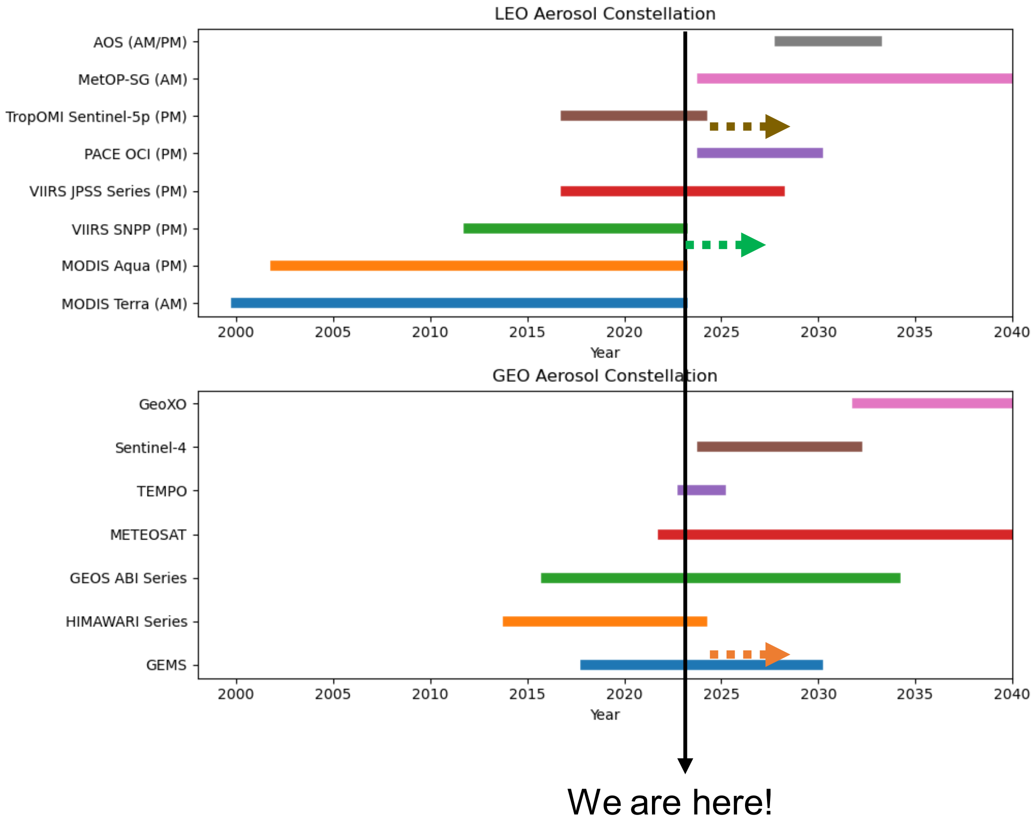
- Brown carbon optical properties are assigned to organic aerosol from biomass burning sources
- Increasing aerosol absorption toward shorter wavelengths results in a more favorable comparison to OMI absorbing aerosol products
- Shown are the simulated (top) and observed (bottom right) UV Aerosol Index for September 2016

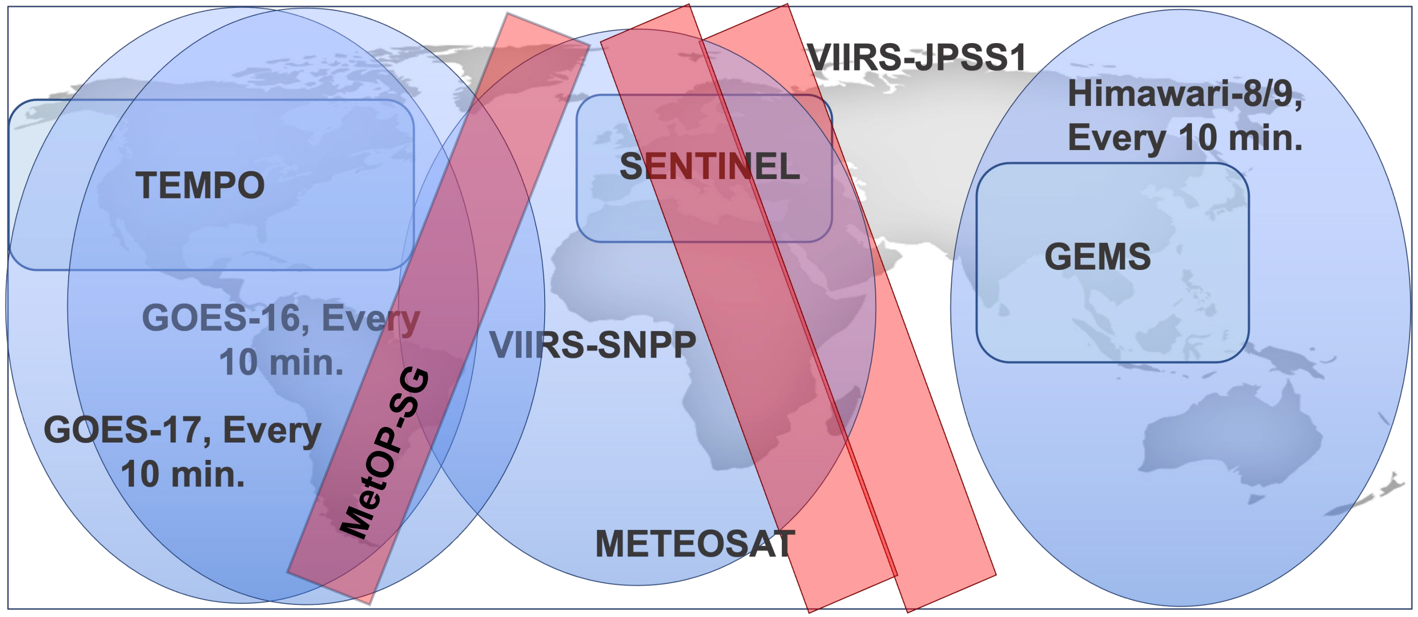
GEOS Aerosol Observing System

MODIS Terra & Aqua observations of 550 nm AOD have been, by far, the main sources of aerosol observations for the GEOS aerosol DA system



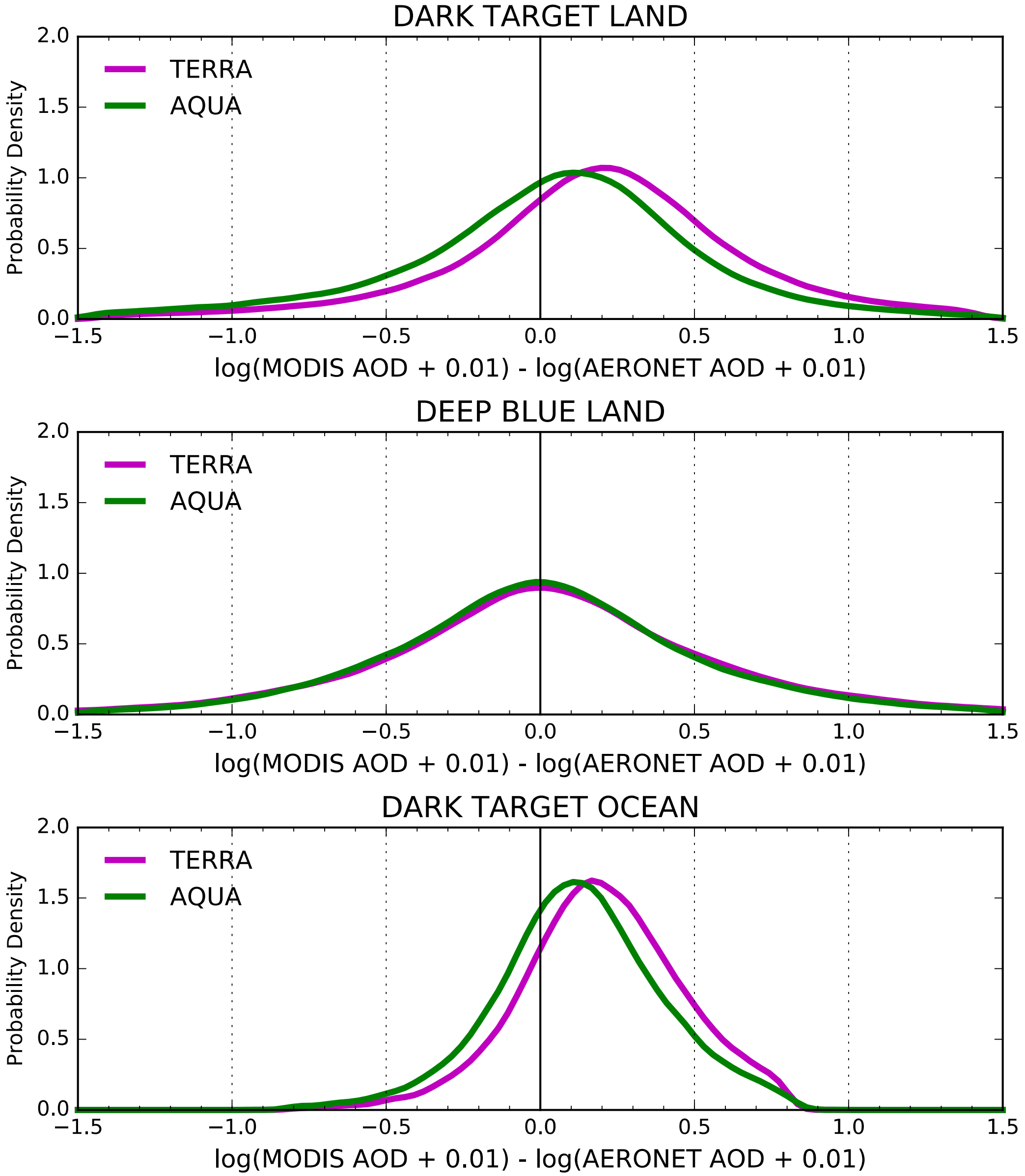
Aerosol Constellation Beyond the EOS Era





Aerosol DA Requires Bias Correction of AOD Observations

- The aerosol DA problem requires a homogenized AOD observing system across many different platforms
- Biases between datasets can propagate in the model forecast and lead to artificial variability



MODIS AOD Retrieval Algorithms

L1 Reflectance

↓

Generate L2 Reflectance
- ❑ Cloud mask
- ❑ Quality control

↓

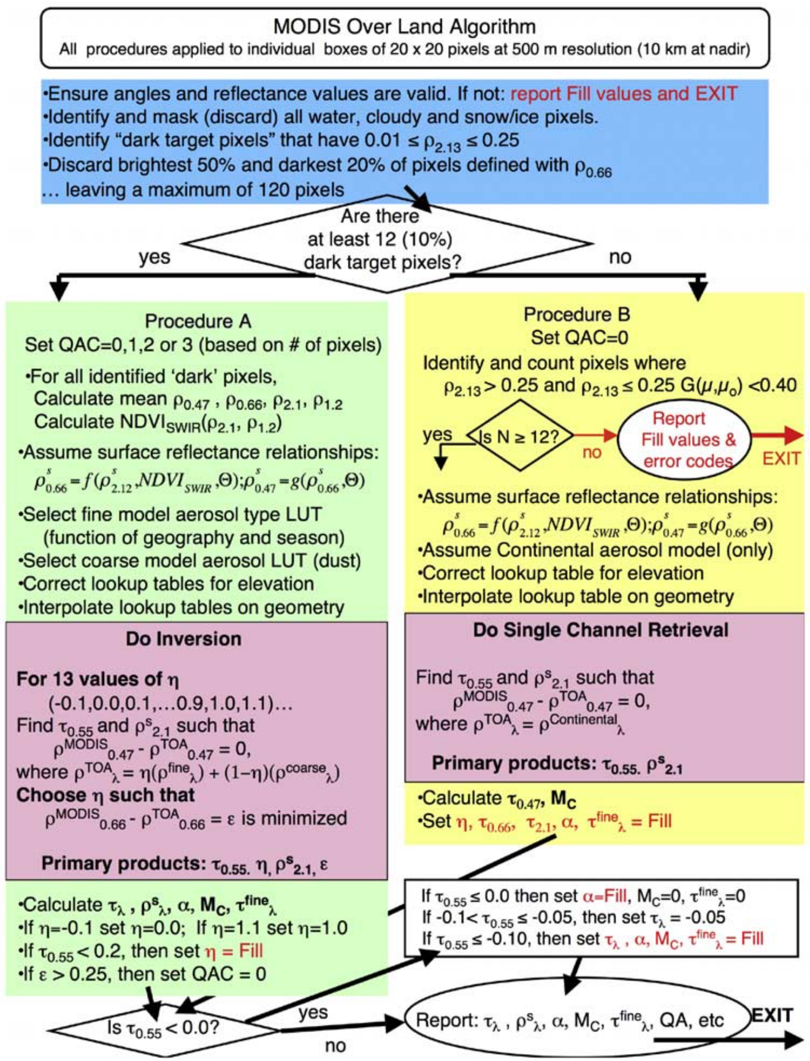
Collect Ancillary Data/Assumptions to Help Solve Underdetermined Problem
- ❑ Surface reflectance
- ❑ Aerosol model
- ❑ Winds, column O_3, etc

↓

Do Inversion via LUT

↓

AOD



Homogenization of AOD Observations with Machine Learning

L1 Reflectance

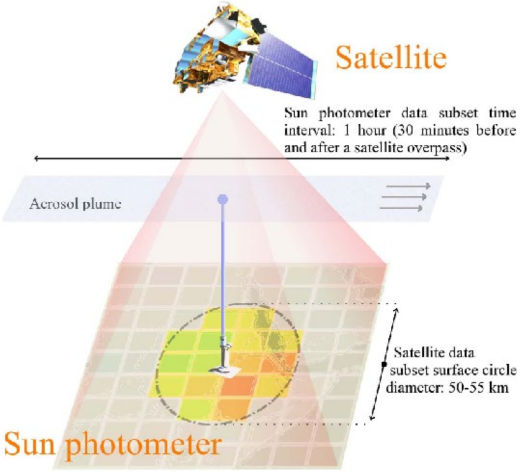
Generate L2 Reflectance
- ❑ Cloud mask
- ❑ Quality control

Collect Ancillary Data/Assumptions to Help Solve Underdetermined Problem
- ❑ Surface reflectance
- ❑ ~~Aerosol model~~ *GEOS Predictions of Aerosol Mixtures*
- ❑ Winds, column O_3, etc

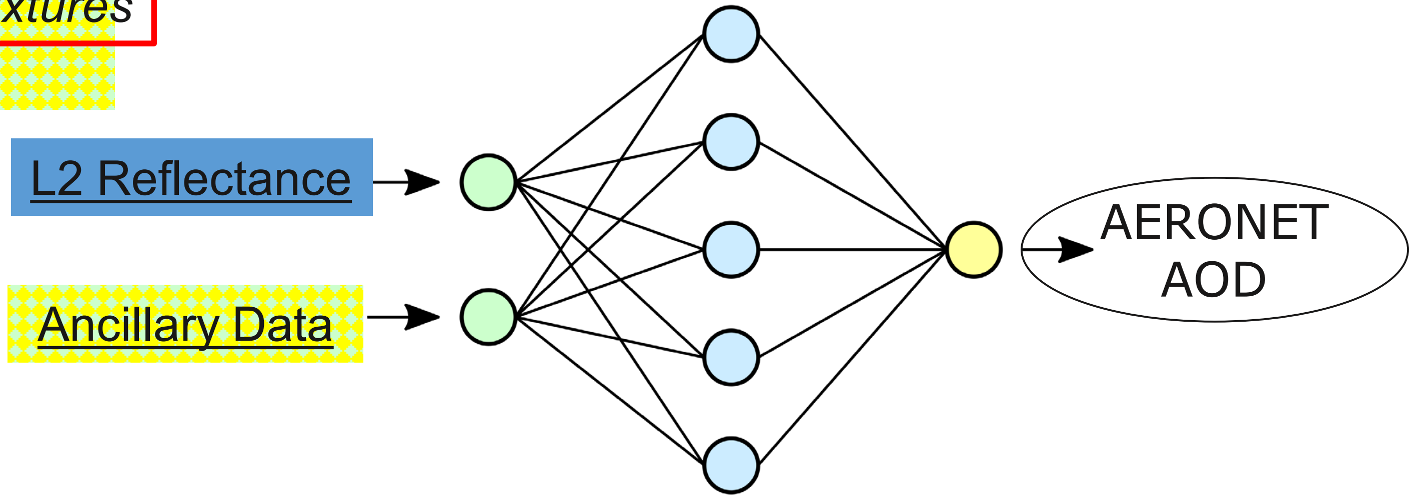
Machine Learning Algorithm trained with AERONET observations

~~nversion via LUT~~

AOD



- AERONET provides a calibration reference
- A database of satellite-AERONET data pairs is used to train a neural network that predicts AOD

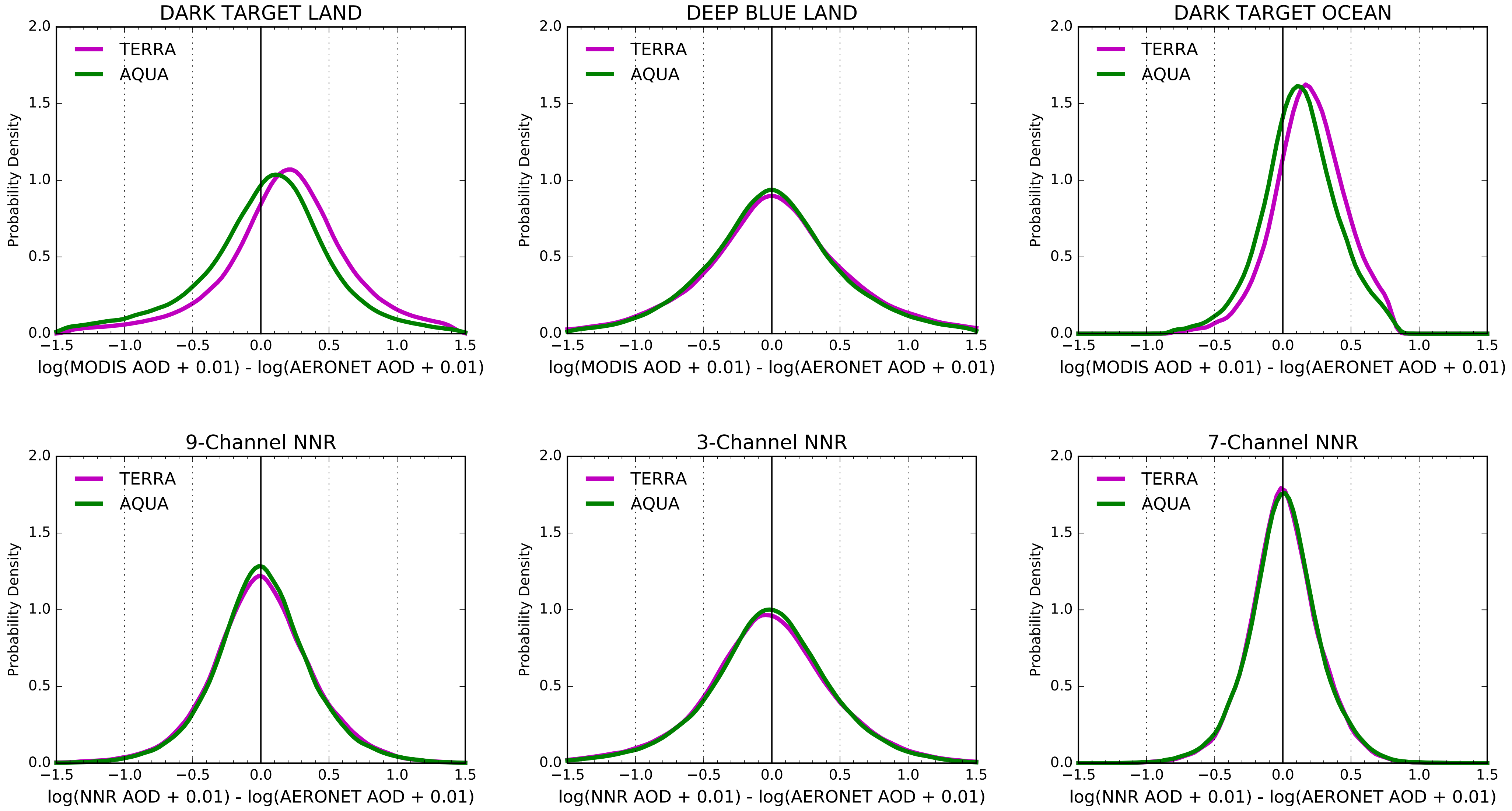


Homogenized MODIS AOD

LAND - Dark Surface | LAND - Bright Surface | OCEAN

MODIS Standard Retrievals

Neural Network Retrievals



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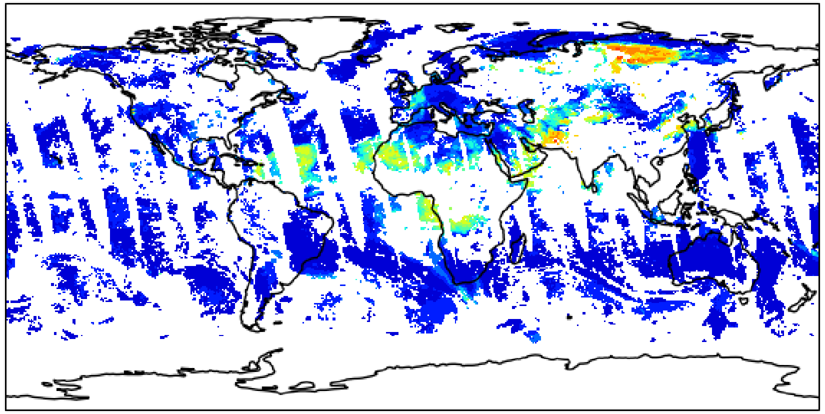
MODIS Algorithms Ported to VIIRS & GEO Imagers

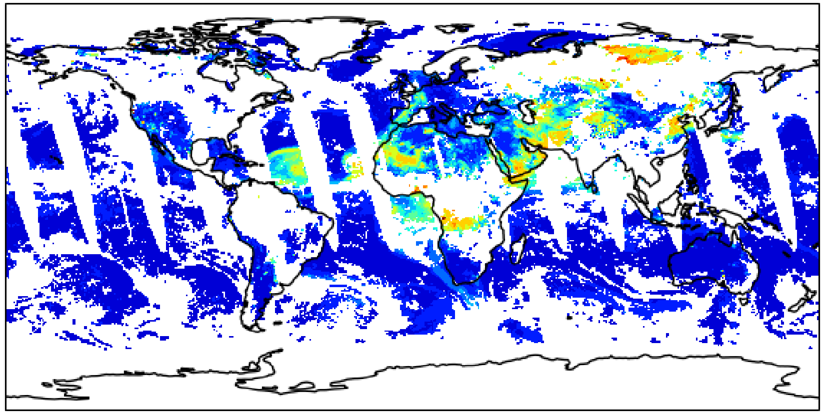
- NASA ROSES has funded the Dark Target and Deep Blue Teams to implement their MODIS algorithms on VIIRS and the constellation of GEO imagers
- For VIIRS-SNPP, which has a long time-series, this allows us to readily replicate the NNR approach

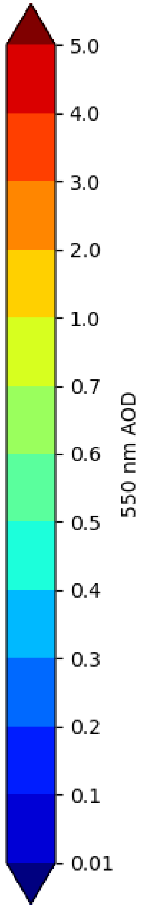
NNR Implemented on VIIRS-SNPP

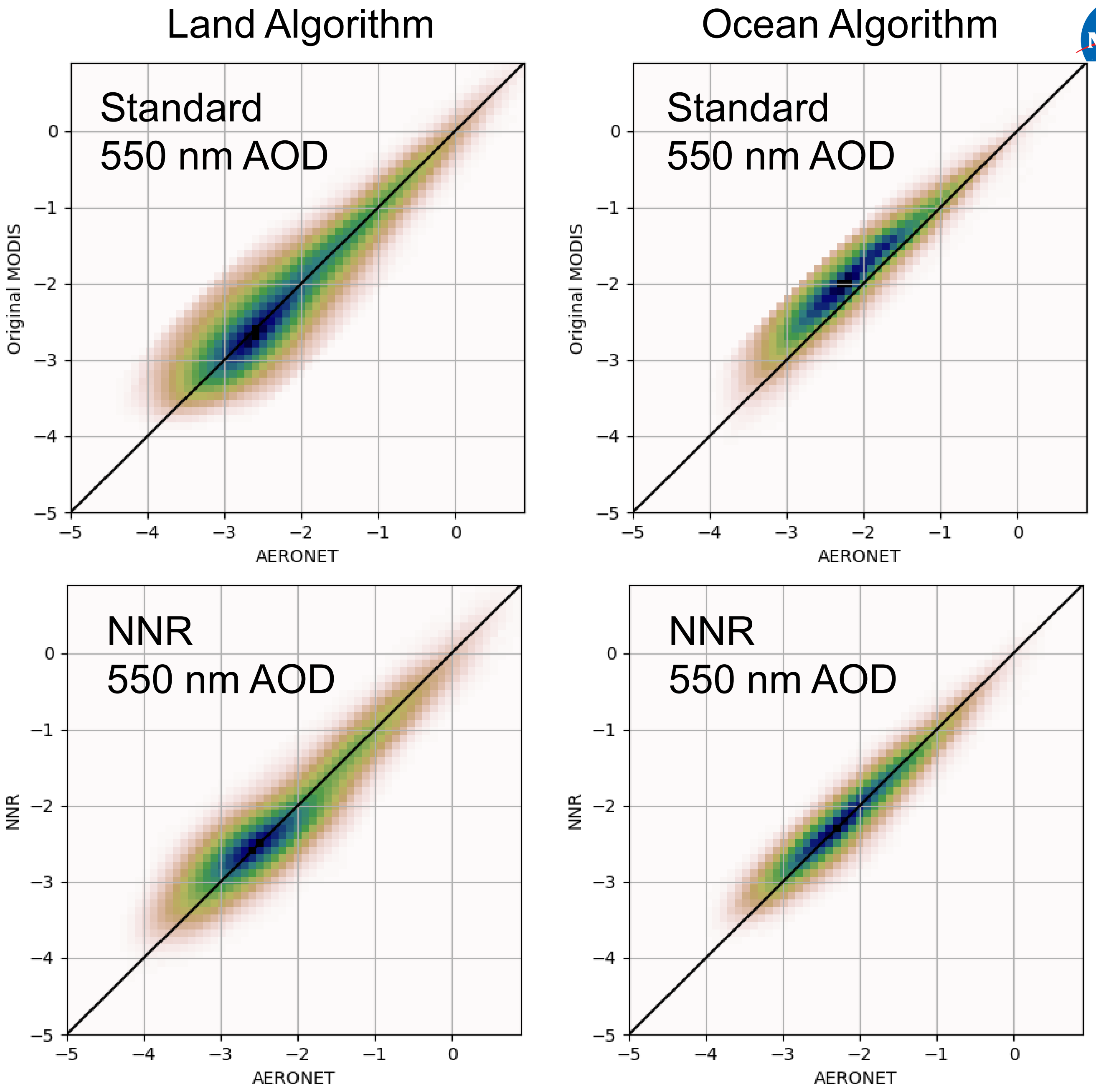
MODIS Aqua NNR 550 nm AOD 20130802



VIIRS SNPP NNR 550 nm AOD 20130802

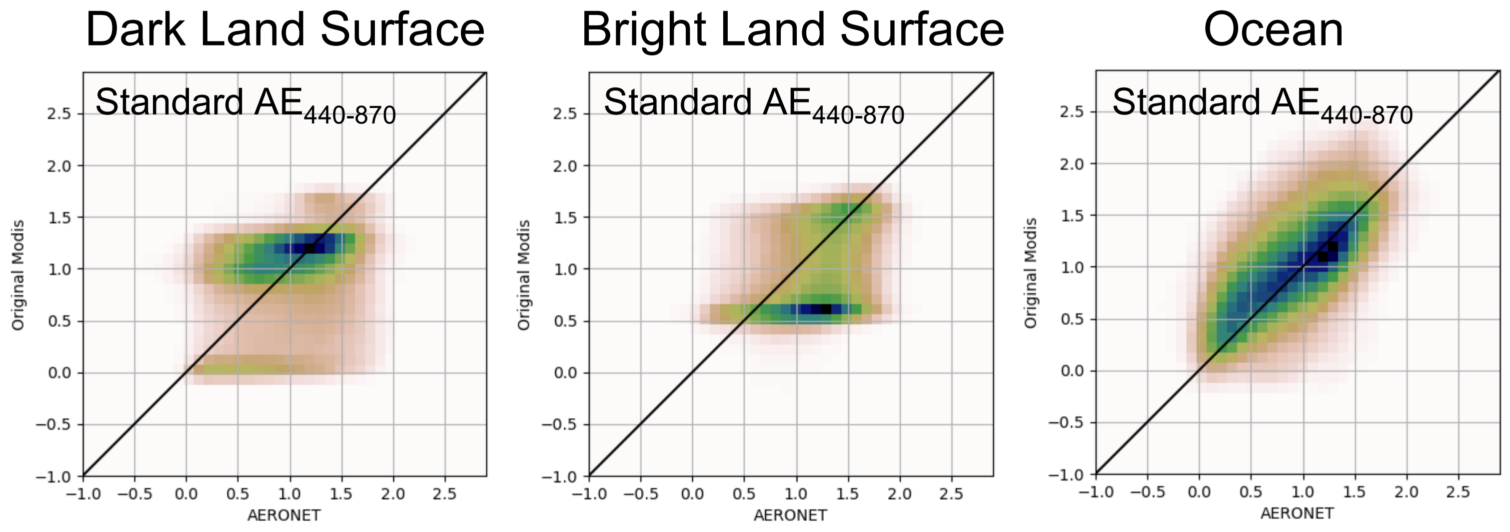


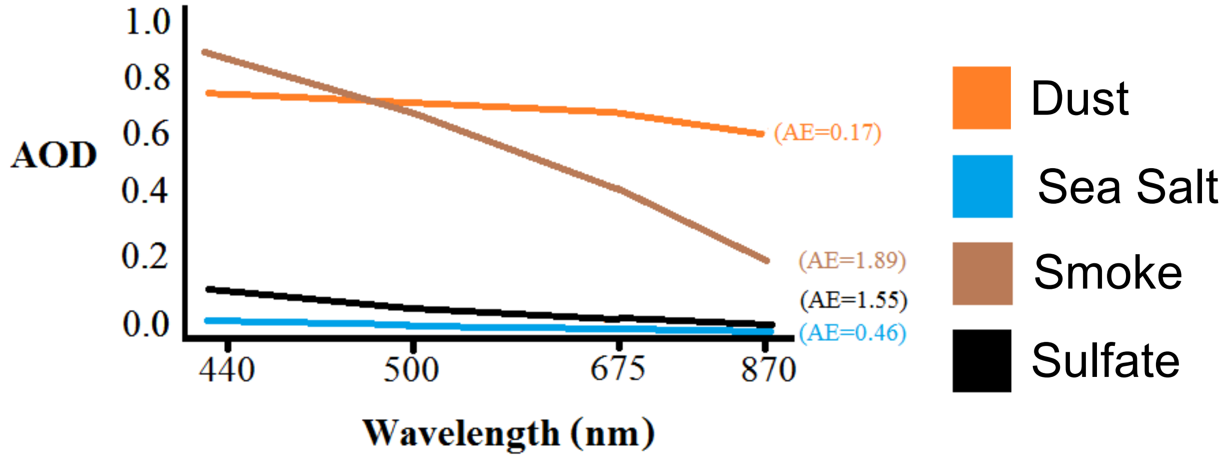




Satellite Visible Angstrom Exponent

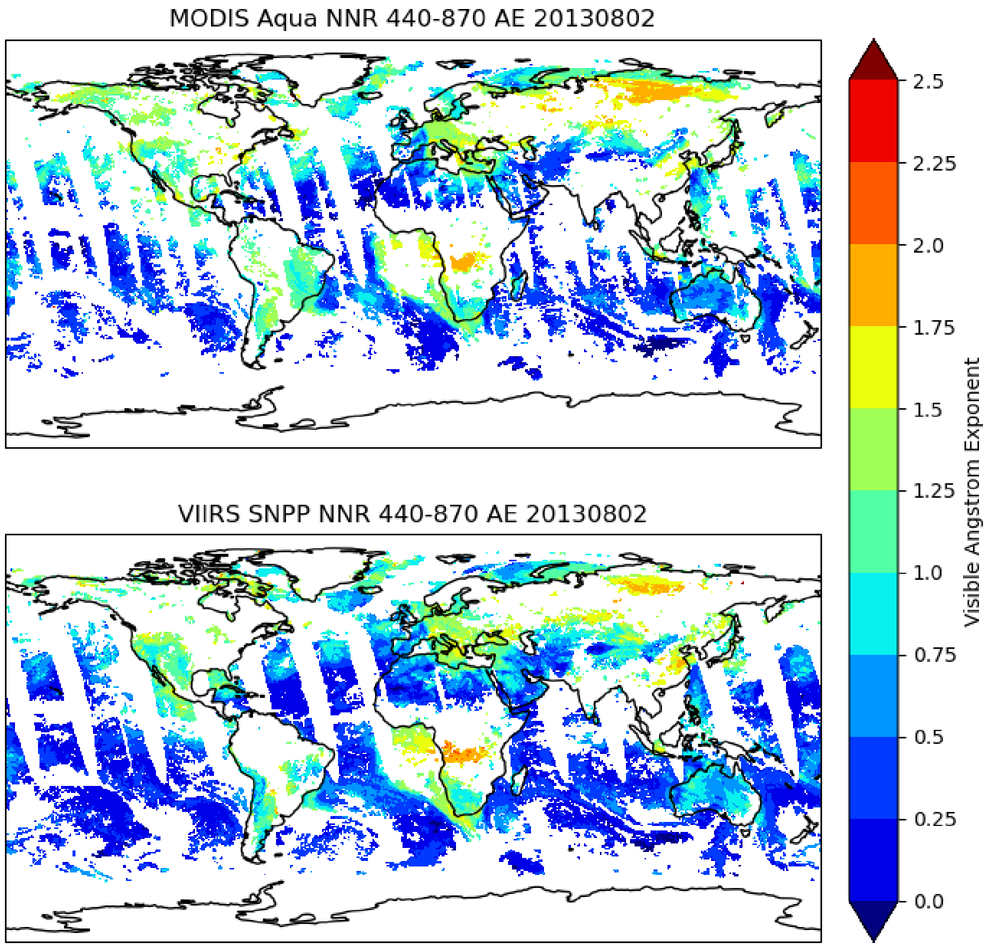
- Spectral AOD can help distinguish different aerosol types
- Large aerosol (dust, sea salt) have low spectral AOD variability (low AE), while fine aerosol (smoke, sulfate) have high variability



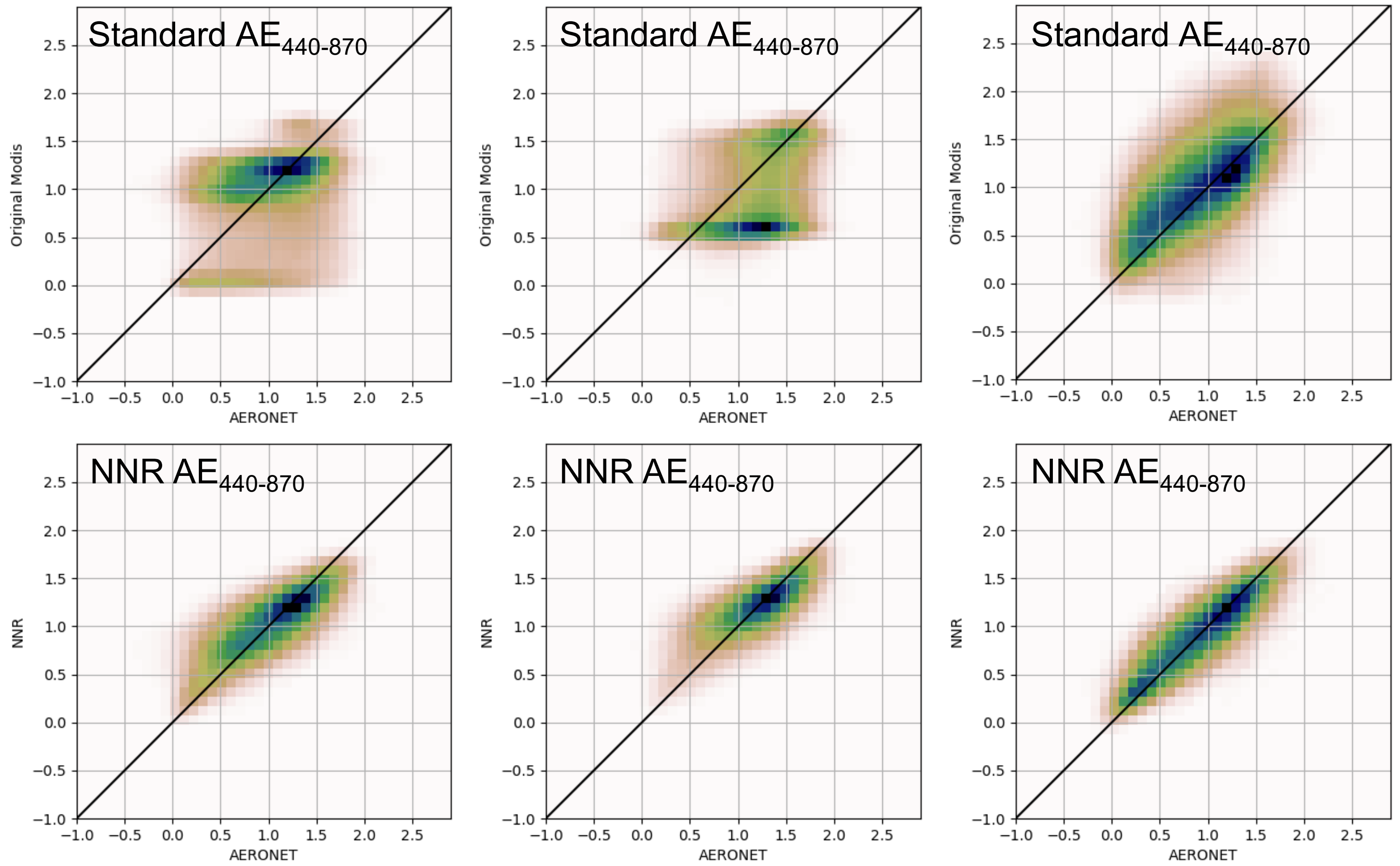


- Standard AOD retrievals depend on a limited number of assumed aerosol optical models
- As the NNR is based on simulated aerosol types, more variability in the aerosol optical model is possible

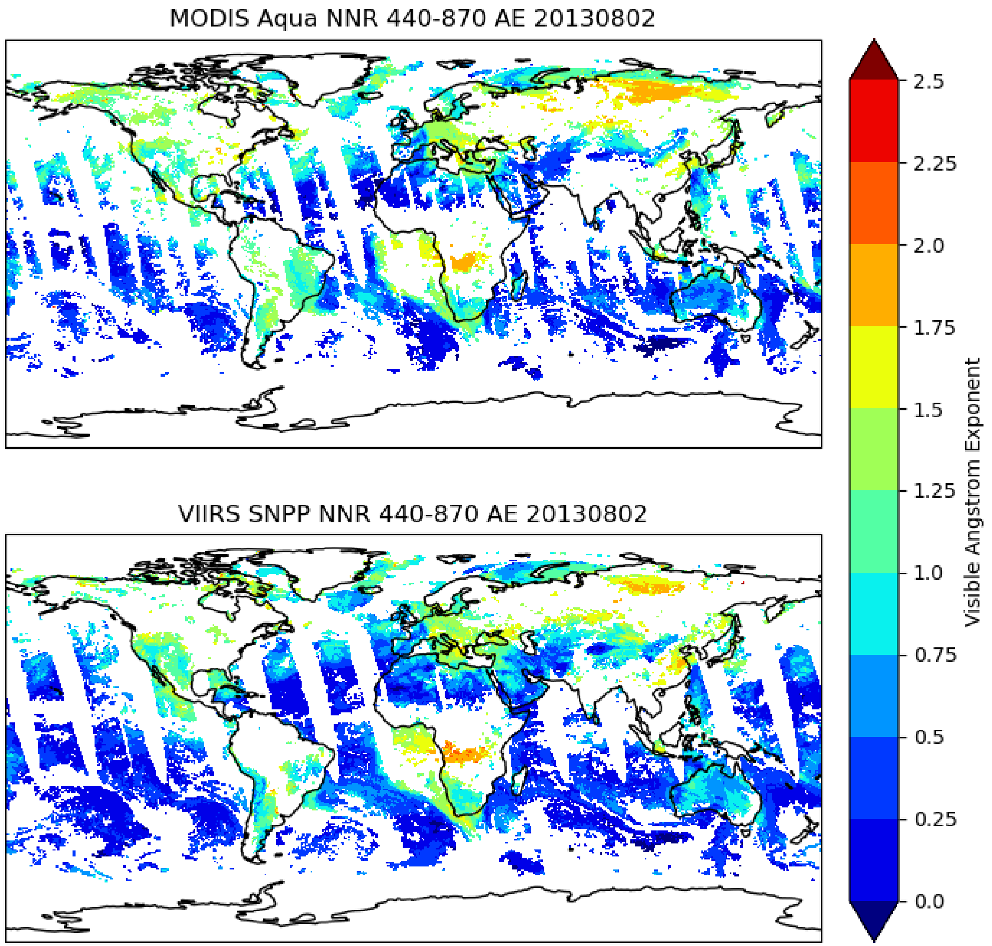
NNR Algorithm Modified to Predict Visible Angstrom Exponent

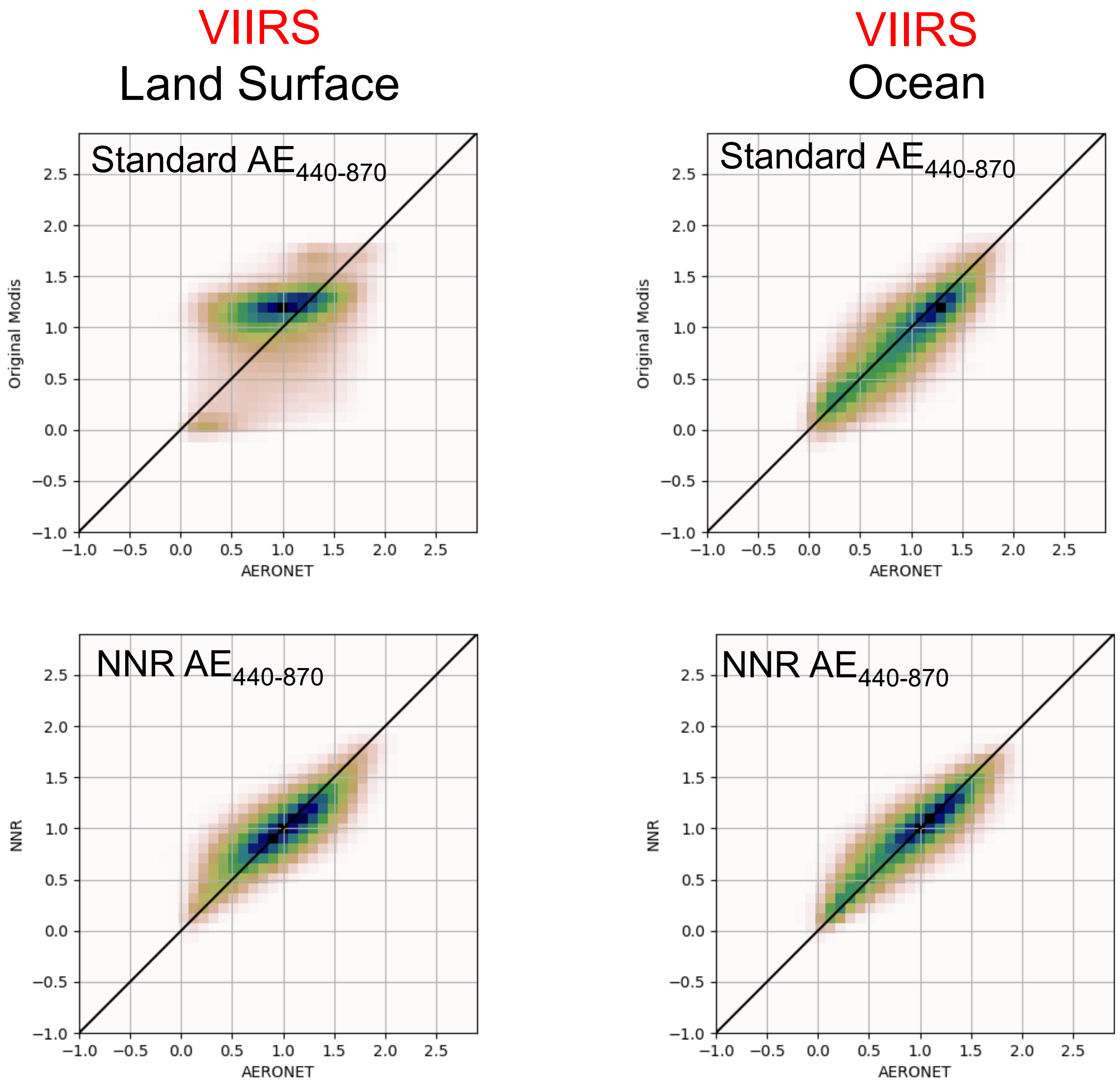


MODIS Dark Land Surface | MODIS Bright Land Surface | MODIS Ocean



NNR Algorithm Modified to Predict Visible Angstrom Exponent

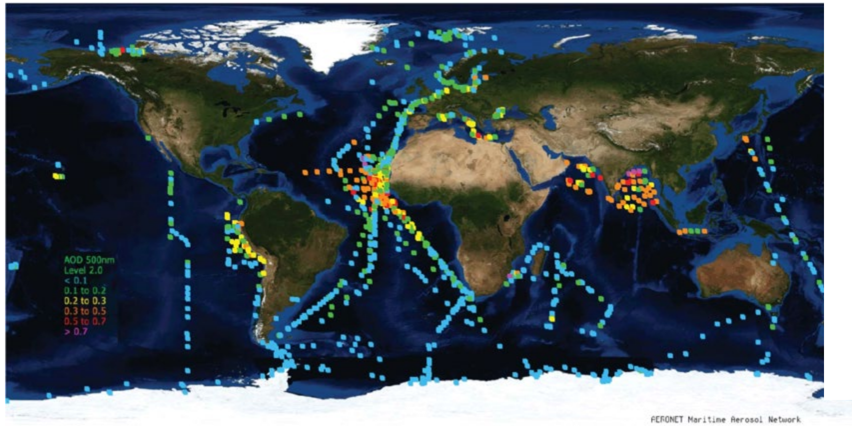


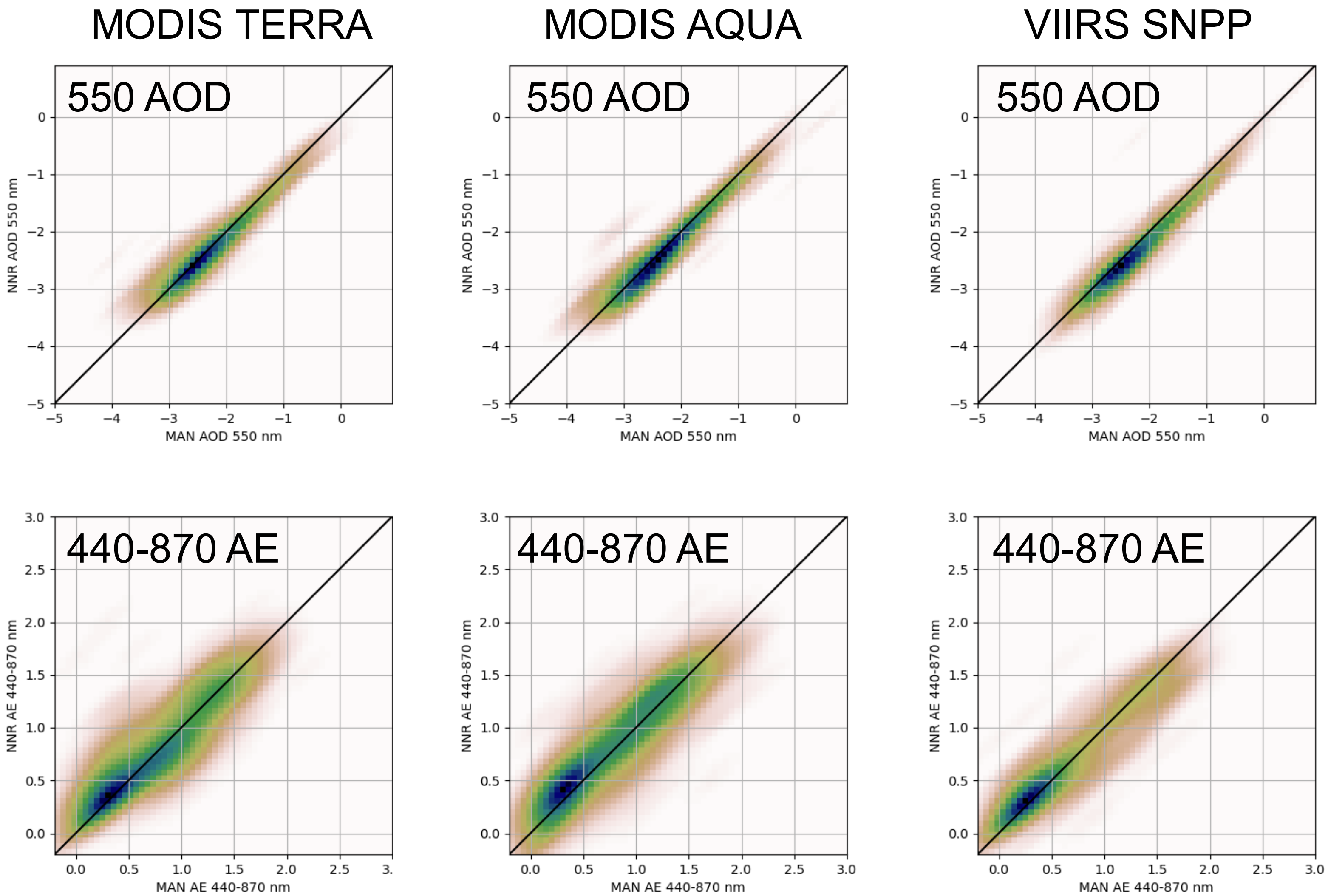


Validation: Comparison to Maritime Aerosol Network

Handheld sun photometers are deployed during research cruises

MAN Cruise Tracks

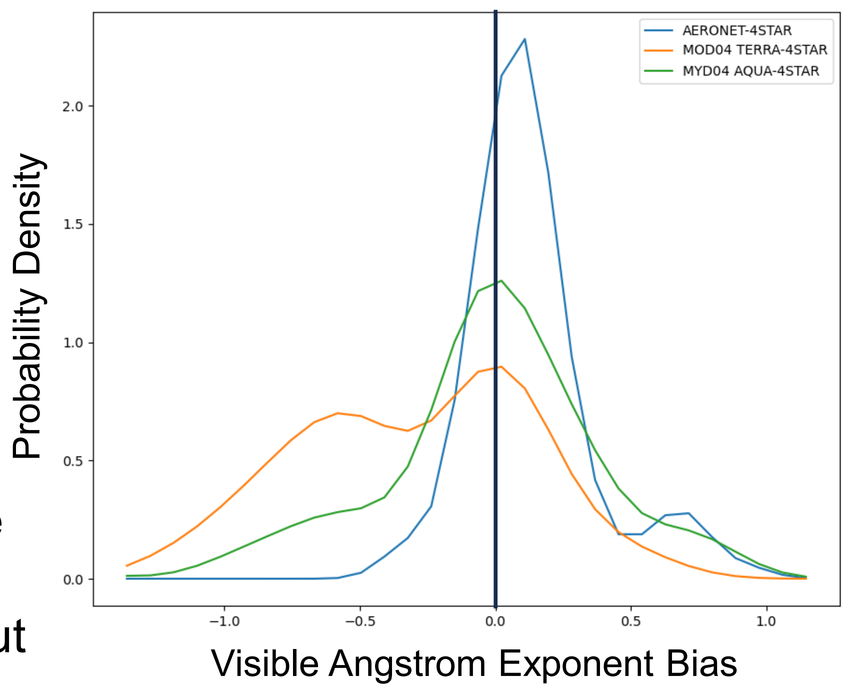


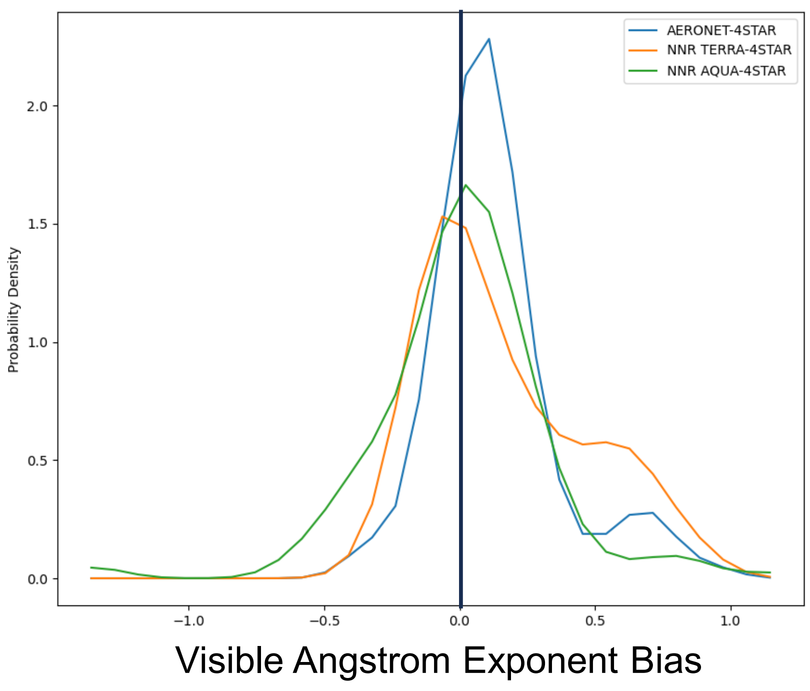


Comparison to 4STAR Airborne Observations of AE

Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR)

- Airborne sun-sky spectrophotometer measuring direct beam transmittance
- Measures column above aircraft
  - Extensive AOD will be biased, but intensive AE is a more robust comparison
- MODIS underpasses where the aircraft was below 1000 m were considered:
  - KORUS-AQ
  - TCAP
  - NAAMES
  - SEAC4RS





- As 4STAR measures the partial column, errors are to be expected in comparisons to total column observations
- Here we look at the contextual bias:
  - The NNR AE predictions has a similar error PDF as AERONET

JEDI Updates to Support Multi-Spectral AOD Assimilation

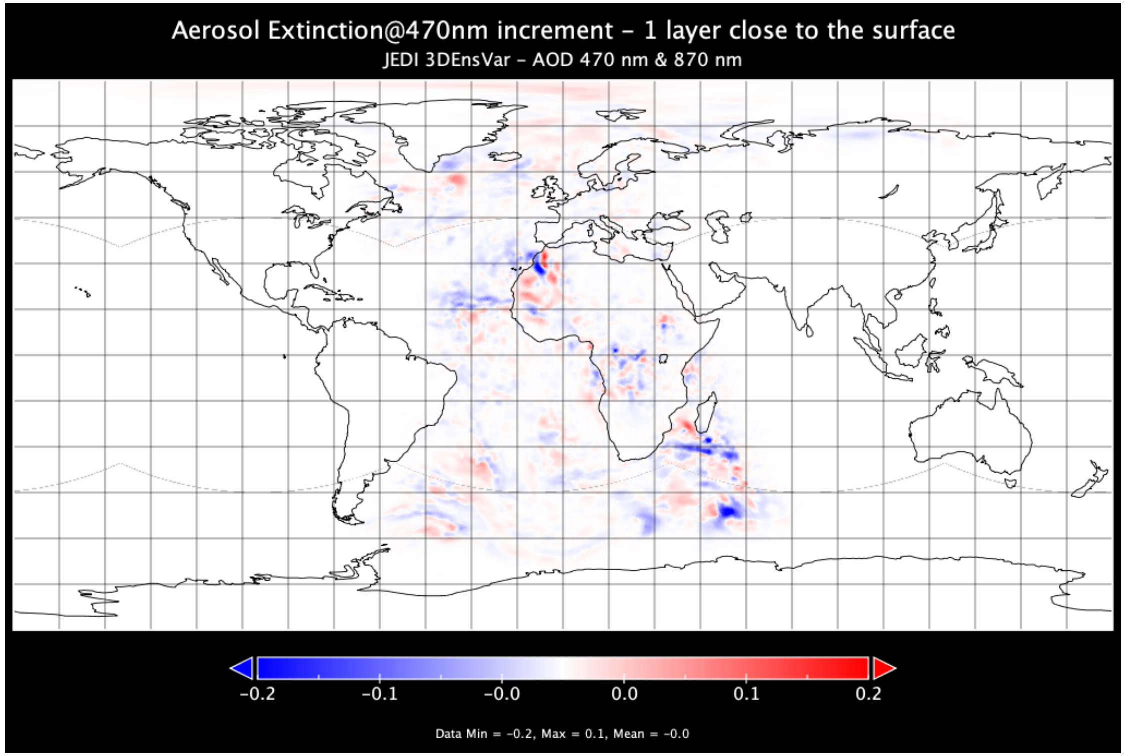
Current System: 2D-PSAS aerosol analysis with local displacement ensembles

- **Control Variable:** single-wavelength 2D – AOD
- **Observable:** AOD observation at 550nm (NNR)
  - Single-wavelength AOD measurements primarily constrain the amount of aerosol in a column, with the vertical structure and speciation primarily determined by the specified emissions and the vertical (and horizontal) transport provided by the model.

New System: JCSDA–JEDI hybrid ensemble-variational scheme

- **Control Variable:** vertically resolved aerosol extinction
- **Observable:** multi-wavelength AOD (NNR)
  - Open doors to future observables: lidar observables, radiances

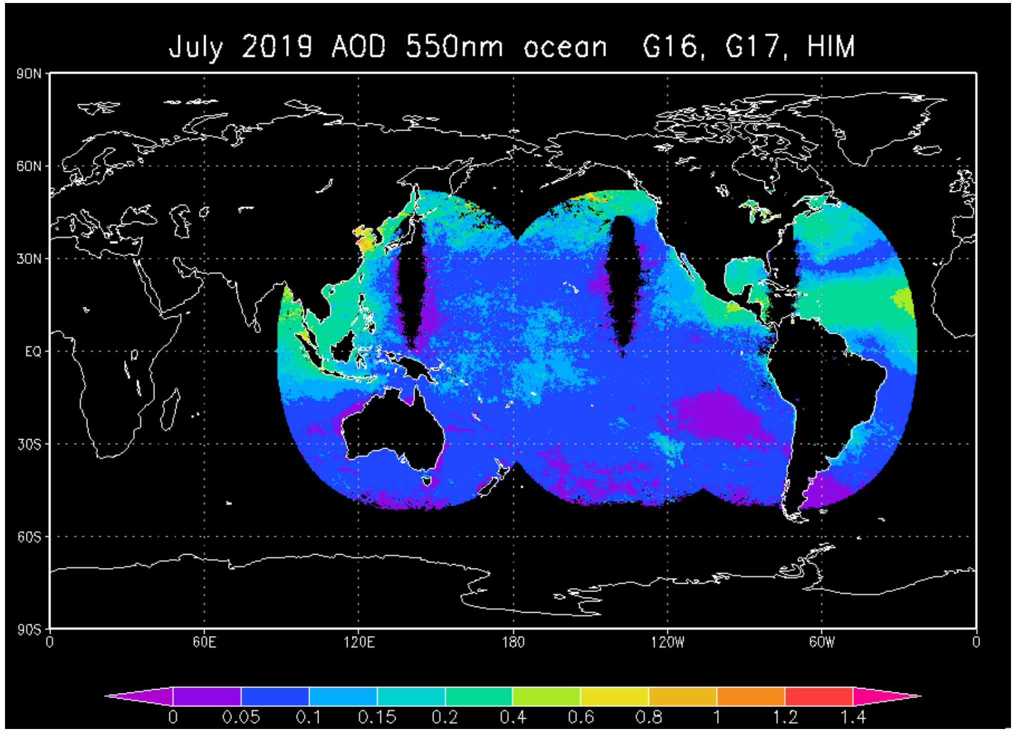
This new scheme brings flow-dependence into the background error specification inherent in ensemble methods but retains some of the flexibility of variational methods, permitting assimilation of multi-spectral passive and active aerosol measurements.

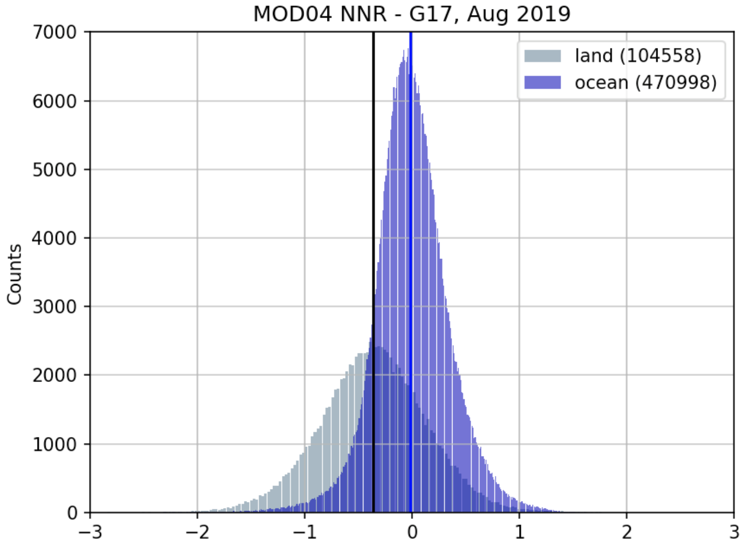


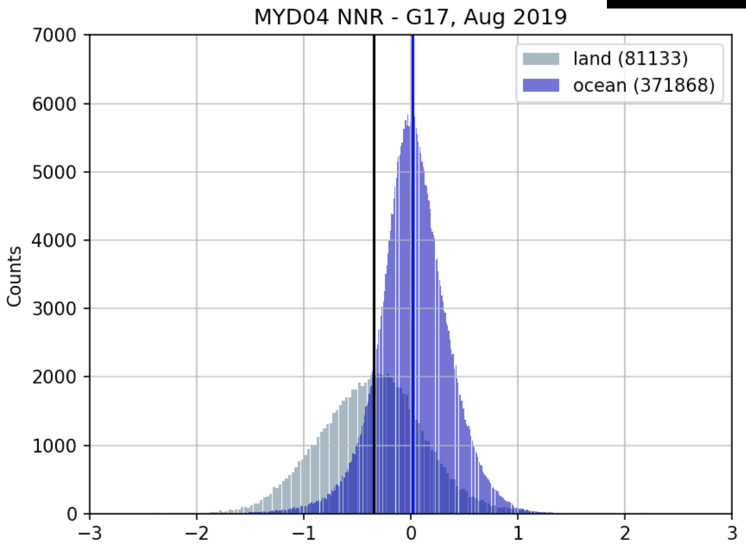
Aerosol extinction increments at 470 nm (for one model layer)
after one analysis cycle at C90:
Observing system: multi-wavelengths NNR AOD at 470 & 870 nm

Future Direction: Geostationary Assimilation

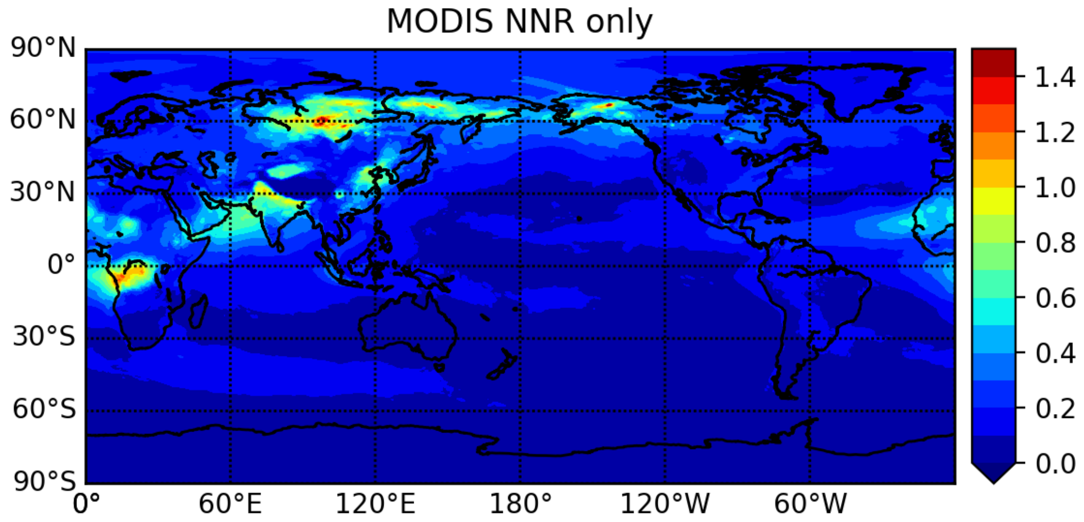
- NASA has funded the Dark Target and Deep Blue teams to implement their algorithms on the GEO constellation
- These data will be the focus of our next developments, and we will use transfer learning techniques to propagate the AOD homogenization to new sensors

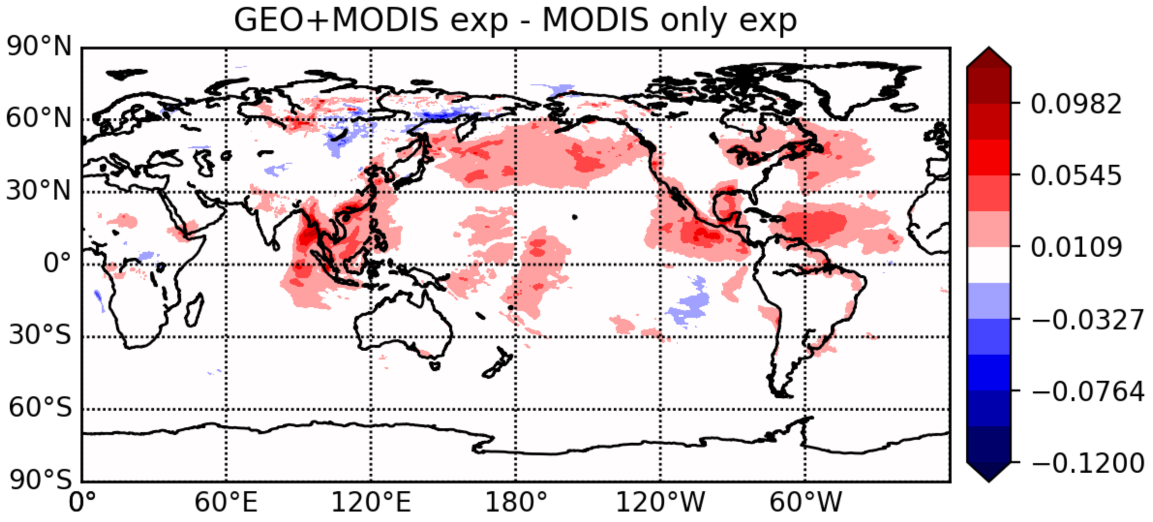


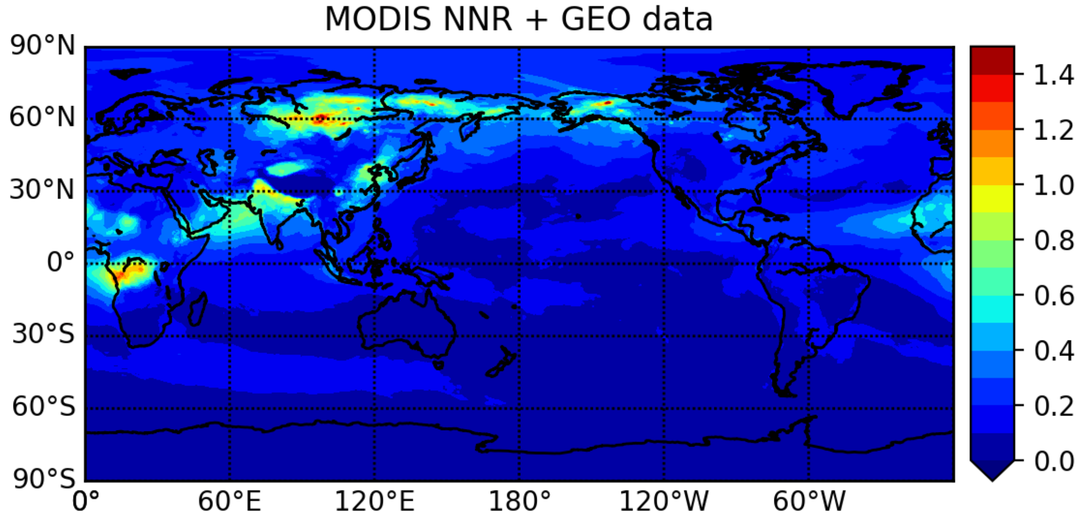


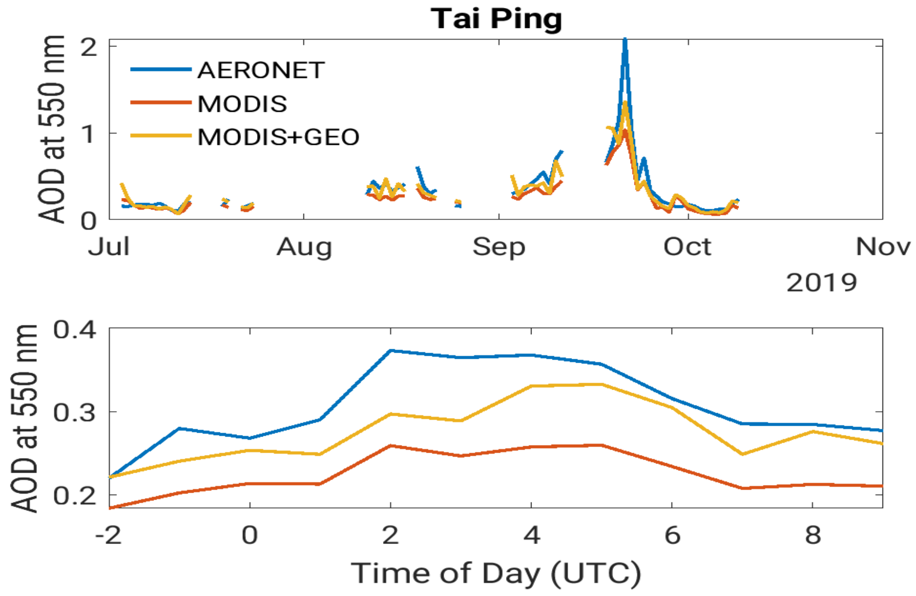


Assimilation of GEO 550 nm AOD Over Ocean



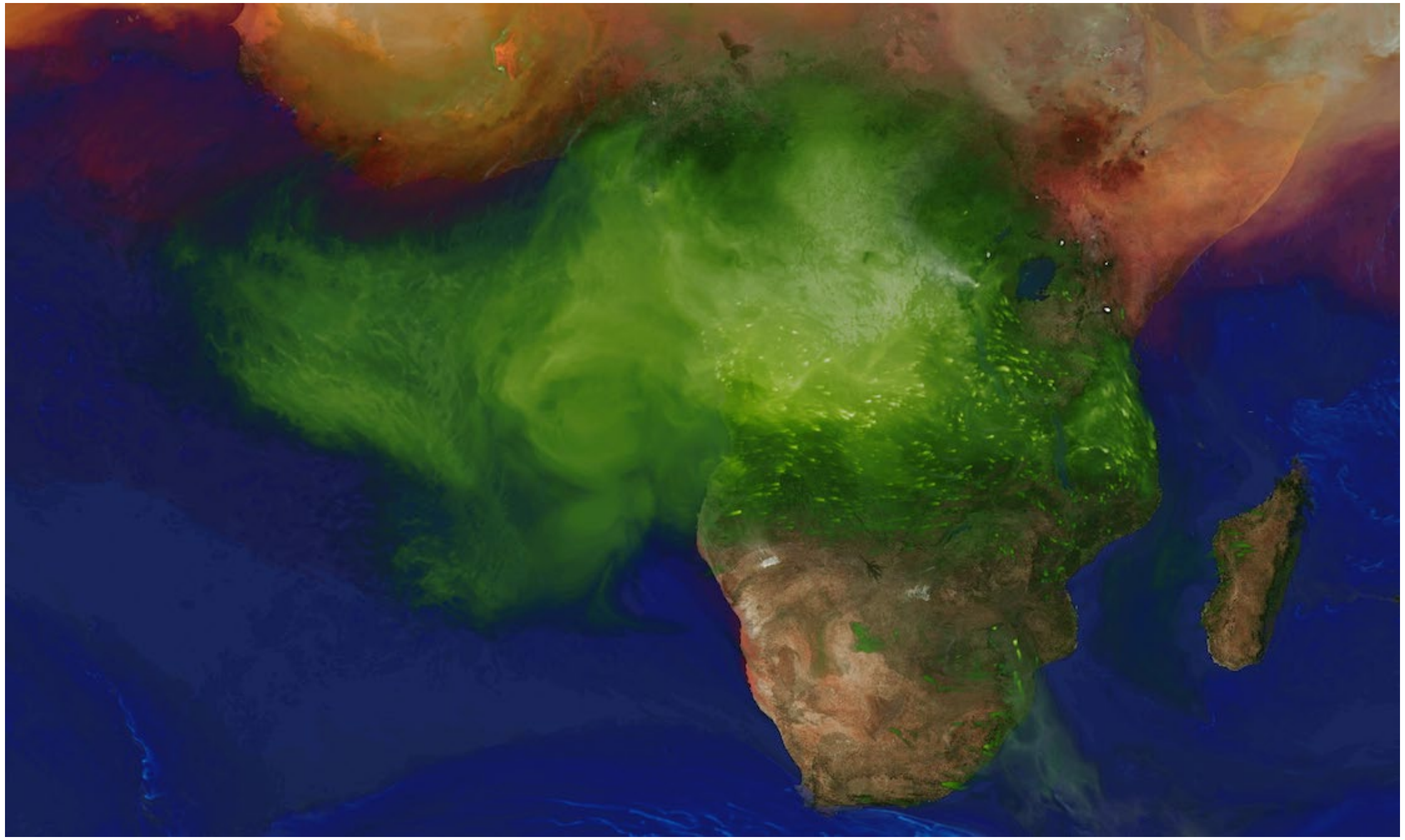






QFED: Quick Fire Emission Dataset

- 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
- VIIRS FRP being evaluated, to eventually include estimates of Modified Combustion Efficiency
- Geostationary FRP for adaptive diurnal cycle estimation



Summary & Outlook

- EOS-era constellation is coming to an end – transitioning to a new observing system
- NASA has funded the Dark Target and Deep Blue teams to implement their MODIS algorithms on VIIRS enabling continuity
  - Without TERRA, there will no longer be a LEO morning orbit
  - MetOP-SG can fill the morning gap, but there is no NASA funding for aerosol algorithm development
- Aerosol DA transition to JEDI is progressing
  - New control variable and flow dependent background errors open the door to assimilating more observables (e.g. multi-spectral AOD, lidar profiles)
- The geostationary constellation provides substantial temporal and spatial coverage
  - 3 years (2019-2022) of DT & DB retrievals on GEOS and HIMAWARI have been recently released
  - These data will be the focus of our next developments, and we will use transfer learning techniques from the LEO sensors to propagate the AERONET calibration to GEO sensors
  - However, other than TEMPO, there is no future NASA support for GEO constellation aerosol retrieval development