



GEOS Aerosol Reanalysis Overview

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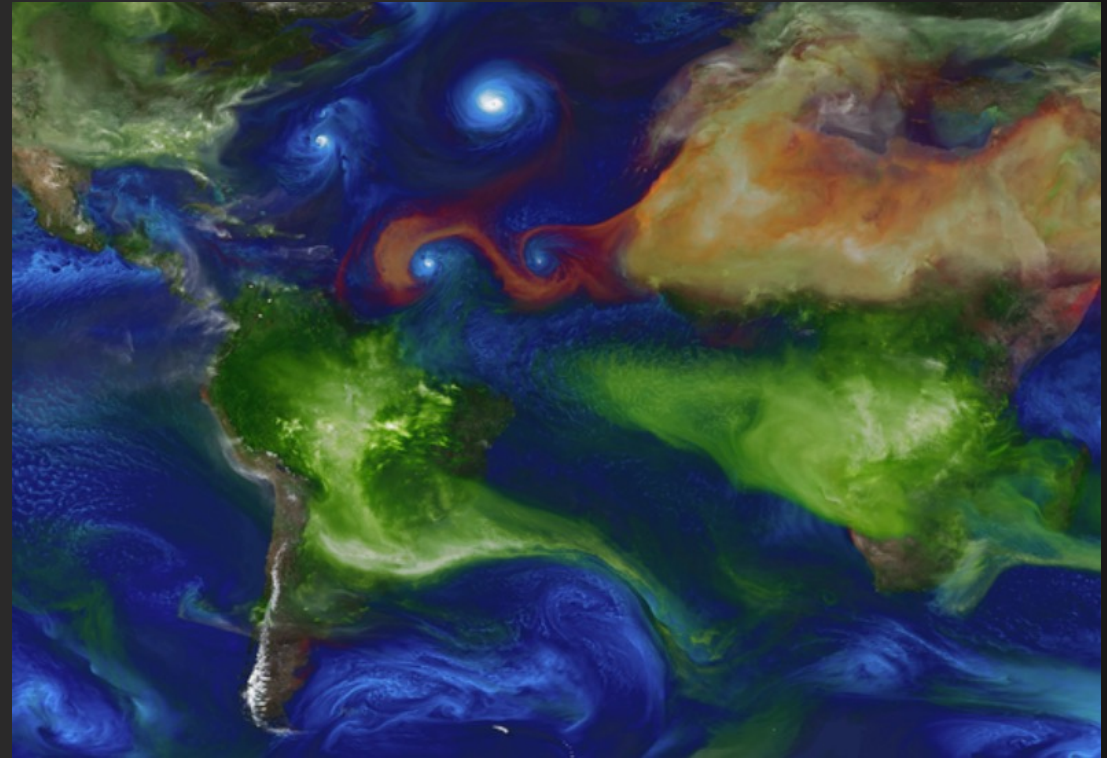
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** With contributions from P. Colarco, A. Darmenov, V. Buchar, P. Castellanos, A. Collow, S. Das, H. Bian et al.*

Outline

- GEOS Reanalyzes
- MERRA-2 Highlights
- GOCART models science
Updates since MERRA-2
- GEOS Aerosol DA updates
 - Observing System updates
 - JEDI-based Aerosol analysis
- Summary





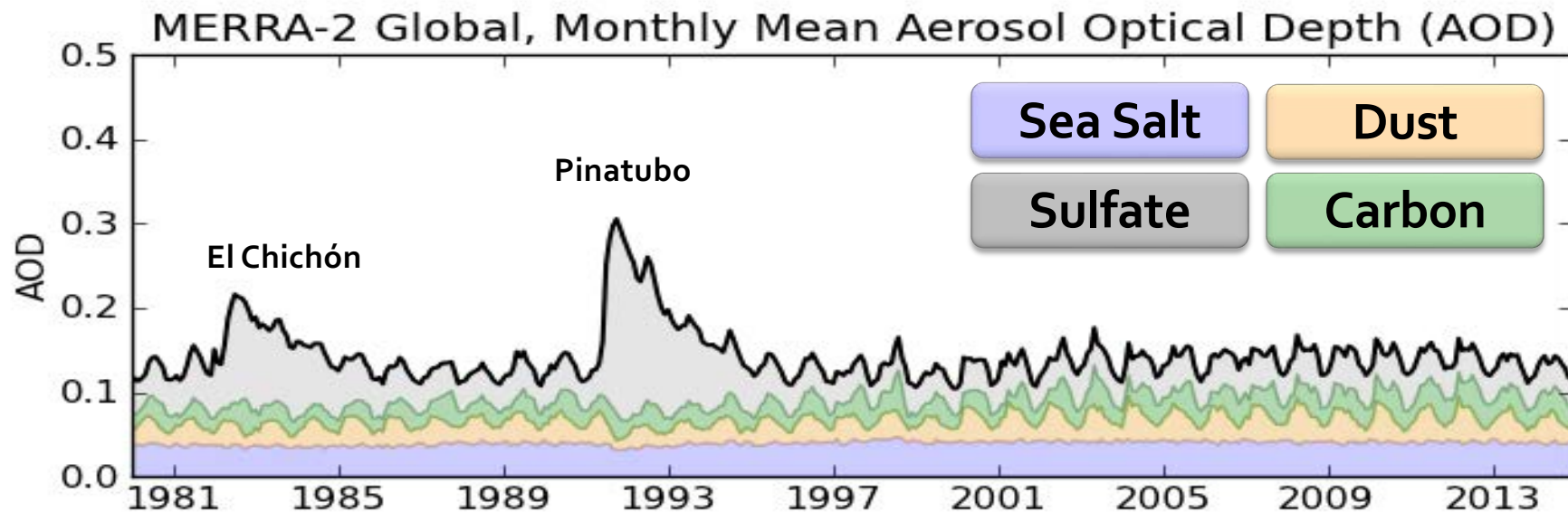
GEOS Reanalysis with Aerosols

GEOS Products	Purpose	Resolution	Production Start
MERRA-2	Current reanalysis: 1980-on	50 km	2012
GEOS-IT	N.R.T. analysis system for Instrument Teams Newer than MERRA-2 but uses Legacy GOCART	50 km	2022
R21C	Interim Reanalysis of the 21 st Century 2000-on	25 km	2023
MERRA-3	Coupled Ocean-Atmosphere reanalysis with aerosols	12 km	202?

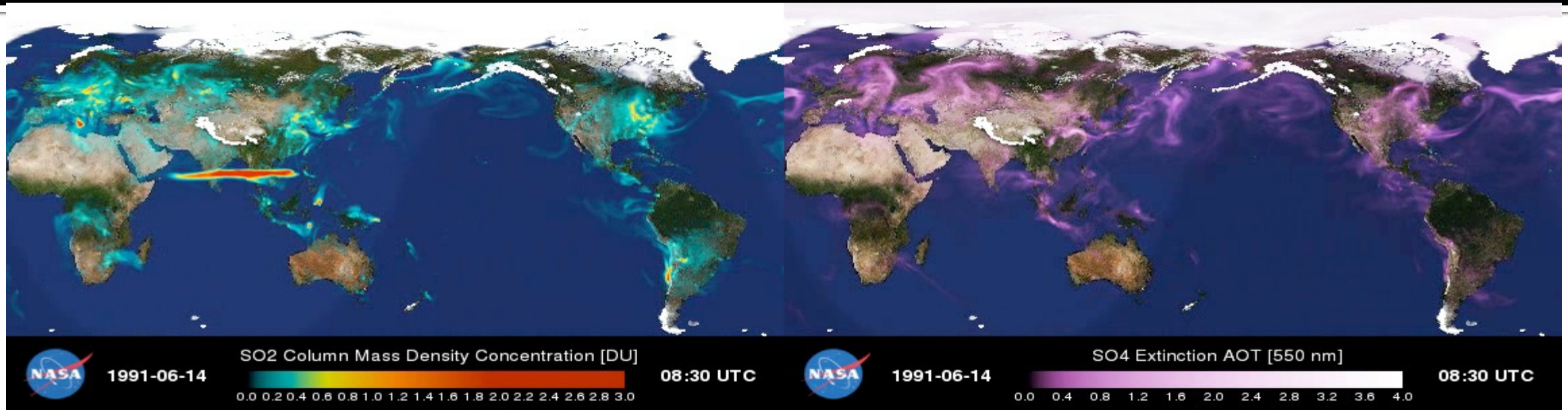
MERRA-2 Global Mean AOD Analysis: 1980 - Onward



- Unique amongst its peers then, the MERRA-2 reanalysis 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).



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 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.

MERRA-2 Emissions



Table 1: Aerosol emissions databases (native temporal and spatial resolutions).

Aerosol Type	Source	Temporal Resolution	Spatial Resolution ^{a,b}
Dust ^c	Wind-driven emissions w/? source	Annual-mean climatology	0.3125° × 0.25°
Sea Salt	Wind-driven emissions	Model	Model
Volcanic (SO ₂)	AeroCom Phase II (HCA0 v2)	Daily	Point-sources
Biogenic terpene	GEIA	Monthly-mean climatology	2° × 2.5°
DMS	Lana <i>et al.</i> 2011	Monthly-mean climatology	1° × 1°
Biomass Burning (SO ₂ , OC and BC) ^d	HFED	Monthly-varying	0.5
Biomass Burning (SO ₂ , OC and BC) ^e	QFED-2.4r6	Daily	0.3125° × 0.25°
Anthropogenic SO ₂ and SO ₄	EDGARv4.2 (Energy + Non-Energy)	Annually-varying	1° × 1°
Anthropogenic OC and BC	AeroCom Phase II (HCA0 v1)	Annually-varying	1° × 1°
Ship (SO ₂ , SO ₄ , OC, BC)	EDGARv4.1 and ?	Annually-varying	1° × 1°
Aircraft (SO ₂)	AeroCom Phase II (HCA0 v1)	Monthly-varying	1° × 1.25° × 72-levels

^a Model = MERRA-2 time-step of 30 minutes with spatial resolution of 0.5° latitude × 0.625° longitude.

^b latitude × longitude

^c Resolution is for source map (Ginoux *et al.* 2001); wind-driven emissions at model time-step.

^d Streams 1-3; Y1979-Y2010

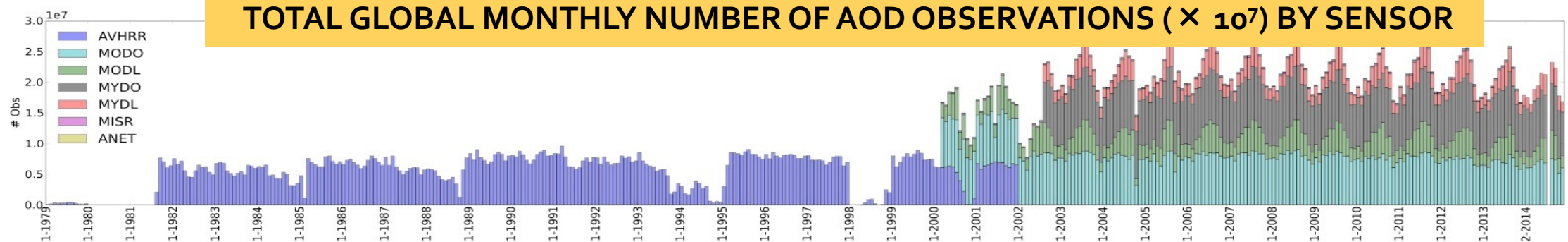
^e Stream 4; Y2010-onward

Ginoux dust emission scheme

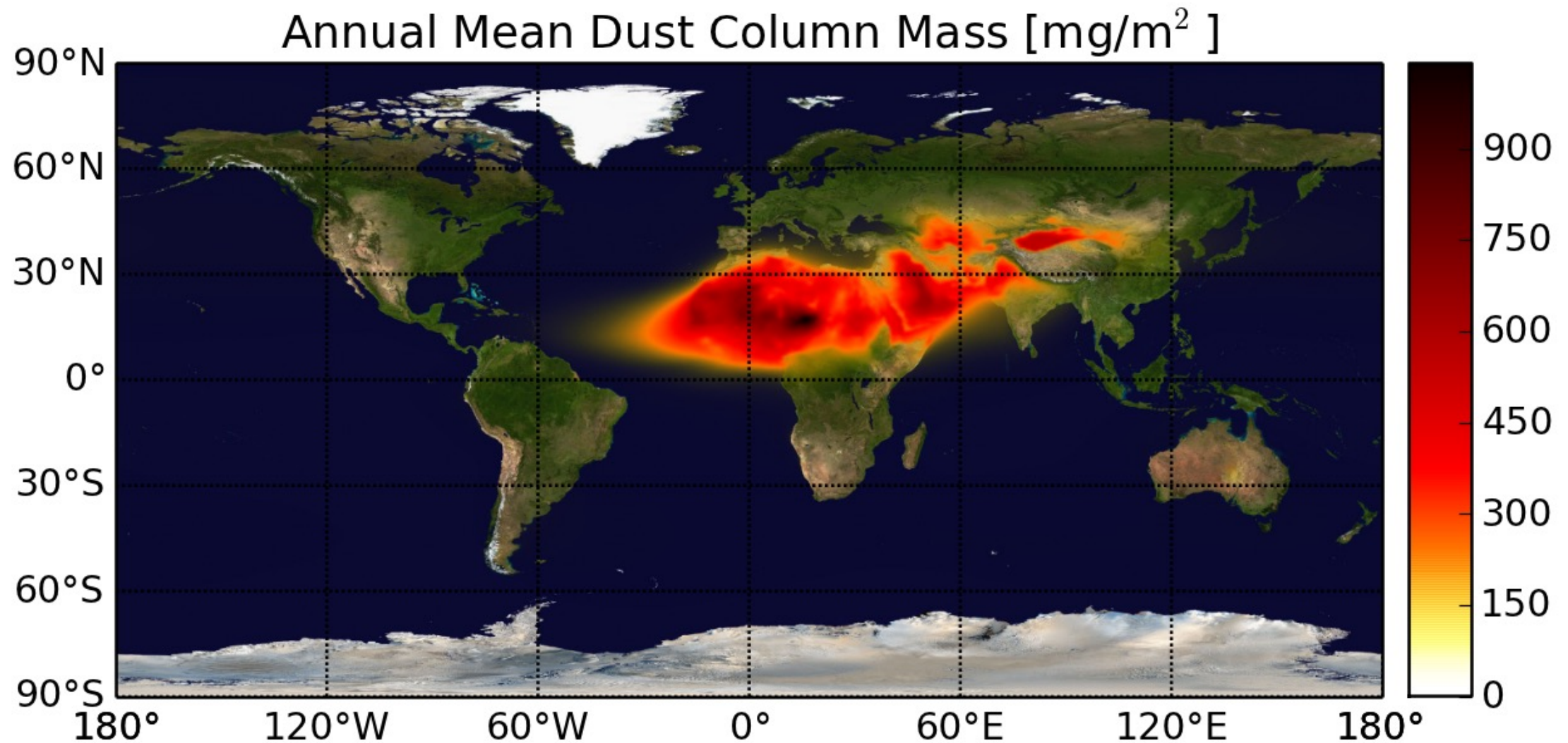
Aerosol Observing System



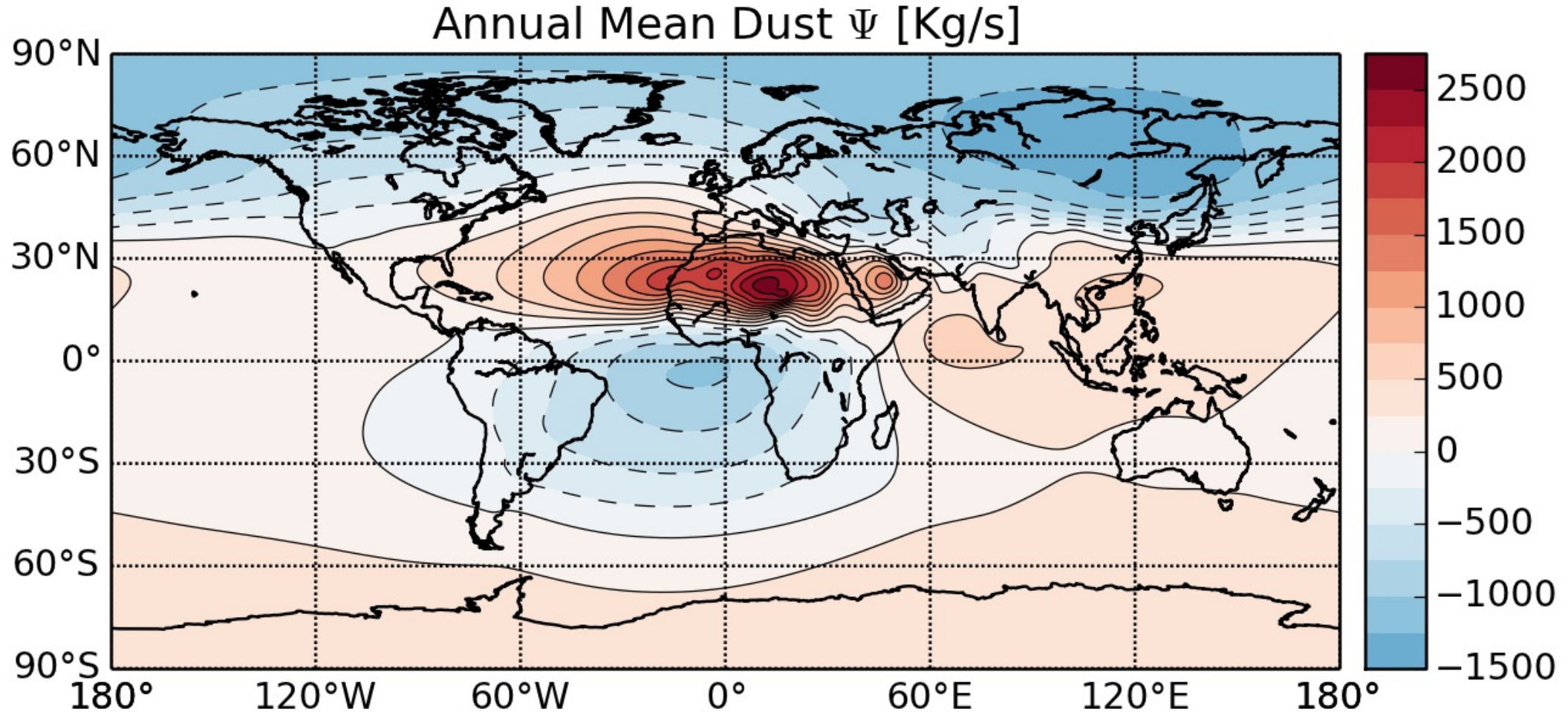
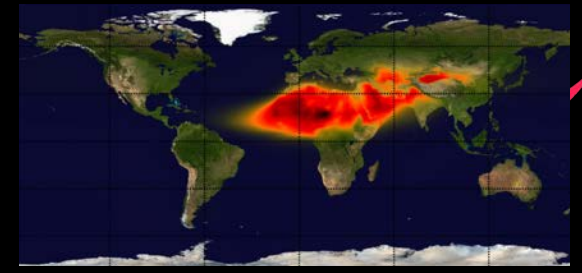
Sensor	Period	Remarks
AVHRR*	1979 – 2002	PATMOS-x; NNR; Ocean Only
AERONET	1999 – 2015	Ground-based stations
MODIS Terra*	2000 – Onward	C5; NNR; Separate land & ocean
MODIS Aqua*	2002 – Onward	C5; NNR; Separate land & ocean
MISR	2000 – 2014	Bright surfaces (albedo > 0.15)



Dust Column Mass

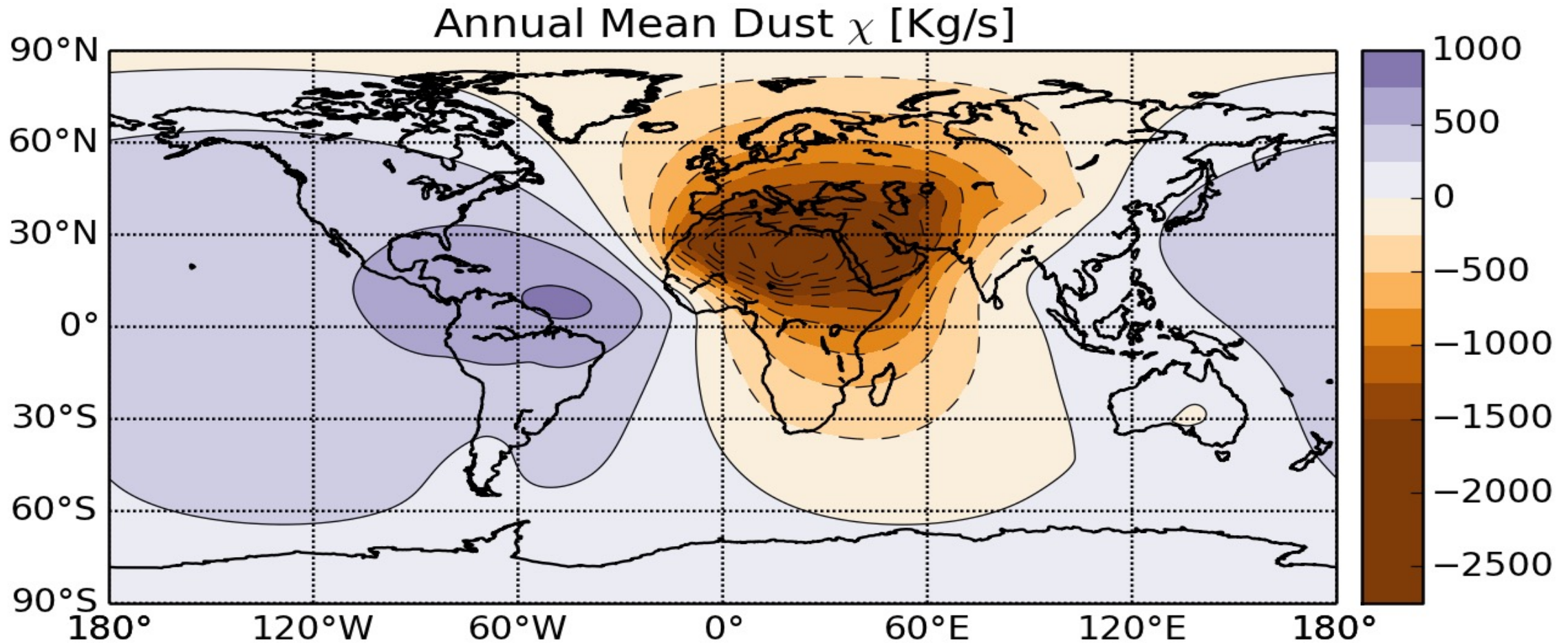
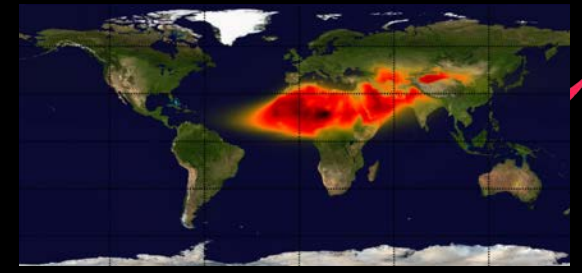


Dust Mass Streamfunction Ψ



Dust Mass Flux Potential:

χ





GEOS Model Update Since MERRA-2

Status

Main Model Changes since MERRA-2



GEOS Atmosphere (2022)

- Grell-Freitas deep convection
- Bretherton-Park shallow convection
- RRTMG (SW & LW) radiation
- Aerosol-aware single moment cloud microphysics for dynamic cloud and ice effective radii, freezing temperatures
- Other features not yet in production:
 - GWD: convective + Ridge orography
 - EDMF and SHOC Turbulence
 - Grell-Freitas 2020
 - GFDL 1M cloud microphysics
 - MG v2/3 2M cloud microphysics

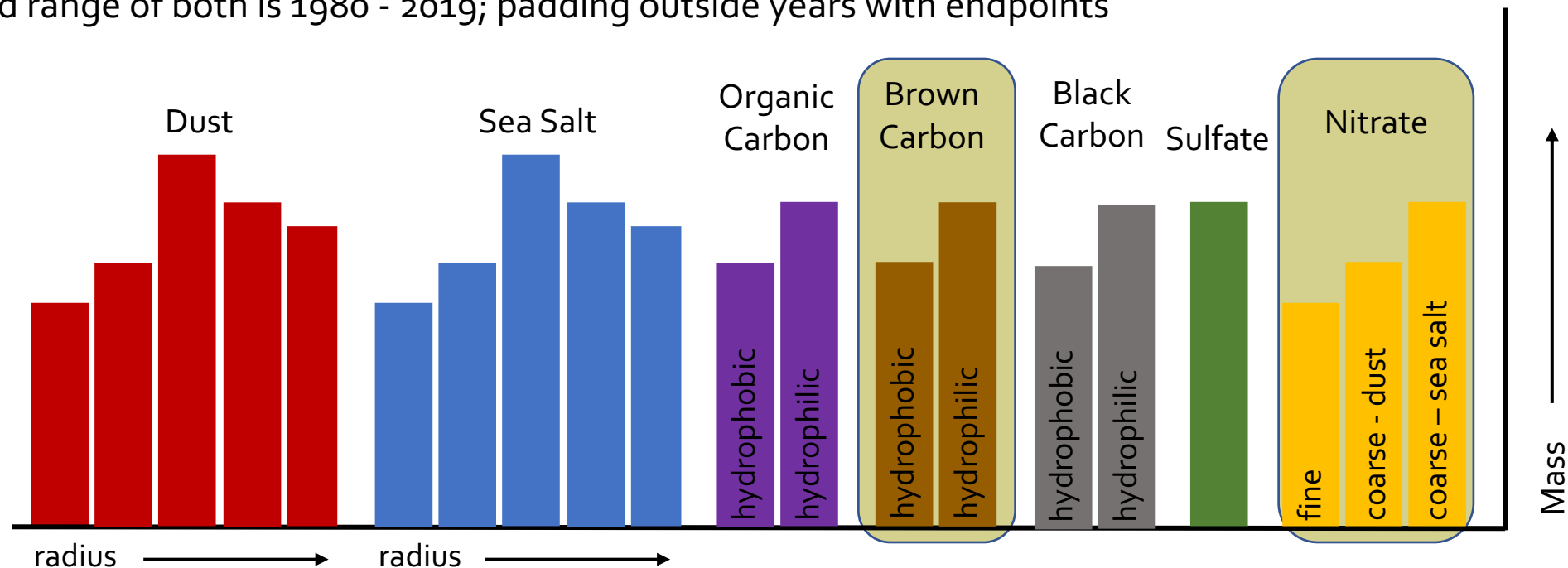
MERRA-2 GEOS Atmosphere

- FV₃ dynamical core on cubed-sphere grid
- ~12.5 km horizontal resolution with 72 vertical levels
- RAS convection
- Lock turbulence
- Catchment land model
- P-L Chemistry (ozone)
- Chou-Suarez radiation

Main Aerosol Changes since MERRA-2



- 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 AICHEM-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)



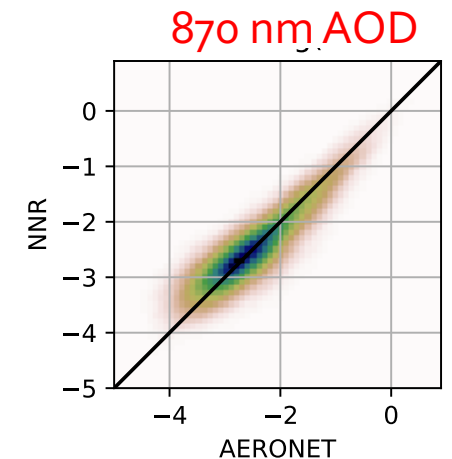
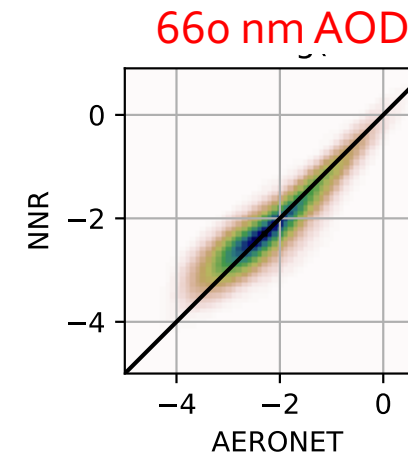
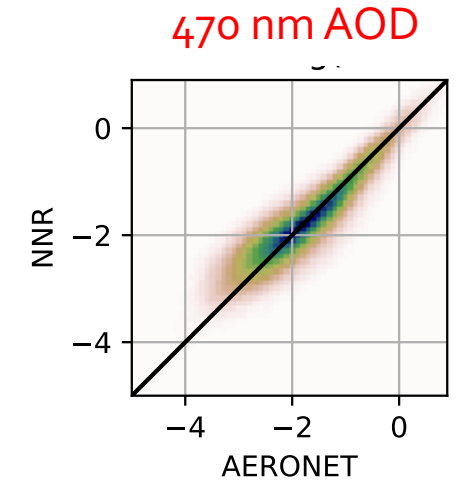
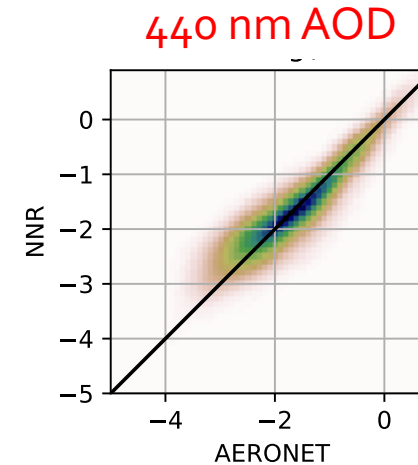


GEOS Data Assimilation Update

Observing System Homogenization

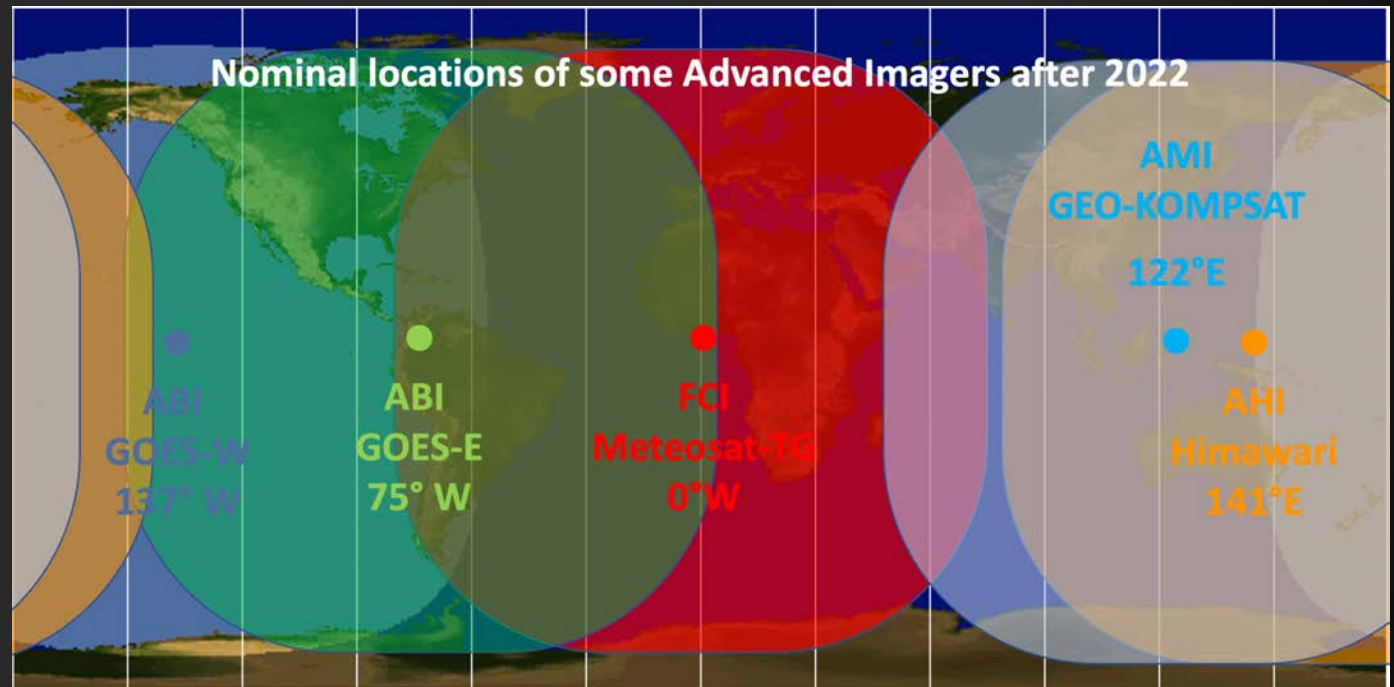
MODIS

- At GMAO AERONET provides the *calibration reference*
- Originally developed Neural Net retrieval algorithm for bias correction of physical retrievals
- Currently, using multi-channel Neural Net Retrieval (NNR) trained on AERONET
- Multi-channel AOD derived from multi-channel *Level 2 Reflectances*:
 - Generally, can reduce latency for NRT applications
 - No dependency on assumed *aerosol models*
 - Model forecast provides speciation prior



Aerosol Observing System in GEOS

- Current sensors used in GEOS-FP:
 - MODIS
 - AERONET
- Sensors in active development
 - VIIRS
 - Geostationary
 - GOES
 - AHI



GEOS Aerosol Data Assimilation



- *Current system for Aerosol Analysis: 2D Analysis Splitting*

- 2D-PSAS aerosol analysis with Local Displacement Ensembles**

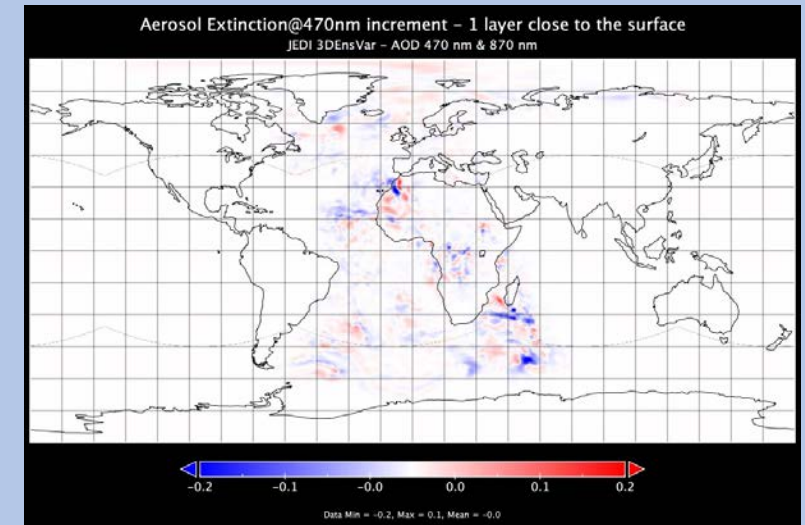
- **control variable:** single-wavelength 2D – AOD (Aerosol optical Depth)
 - **observable:** AOD observation at 550nm (NNR)
 - single-wavelength AOD measurements primarily constrain the amount of aerosol in a column, with the vertical structure and speciation primarily determined by the specified emissions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

- *Aerosol Analysis system under development*

- JCSDA –JEDI hybrid ensemble-variational scheme**

This new scheme brings the flow-dependence in 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.

- **control variable:** vertically resolved aerosol extinction
 - **observable:** multi-wavelength AOD (NNR)
 - Open doors to future observables: lidar observables, radiances



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



Summary

- The GEOS model has evolved since MERRA-2 with the addition of scale aware Grell-Freitas deep convection, shallow convection and RRTMG radiation
- The GOCART component has been entirely rewritten for improved efficiency and flexibility and now includes handling of SOA, explicit Brown Carbon Component and updated emissions
- The GEOS aerosol assimilation scheme is evolving toward a JEDI-based hybrid ensemble-variational scheme.
- Additional aerosol observing system under active development includes VIIRS and geostationary reflectance by means of a neural net retrieval.
- Development of the Modal Aerosol Scheme has been dormant since 2019 but it is expected to be revived with increased focus on aerosol-cloud-precipitation processes in support of the AOS mission.