Update on The NASA GEOS-5 Aerosol Modeling System

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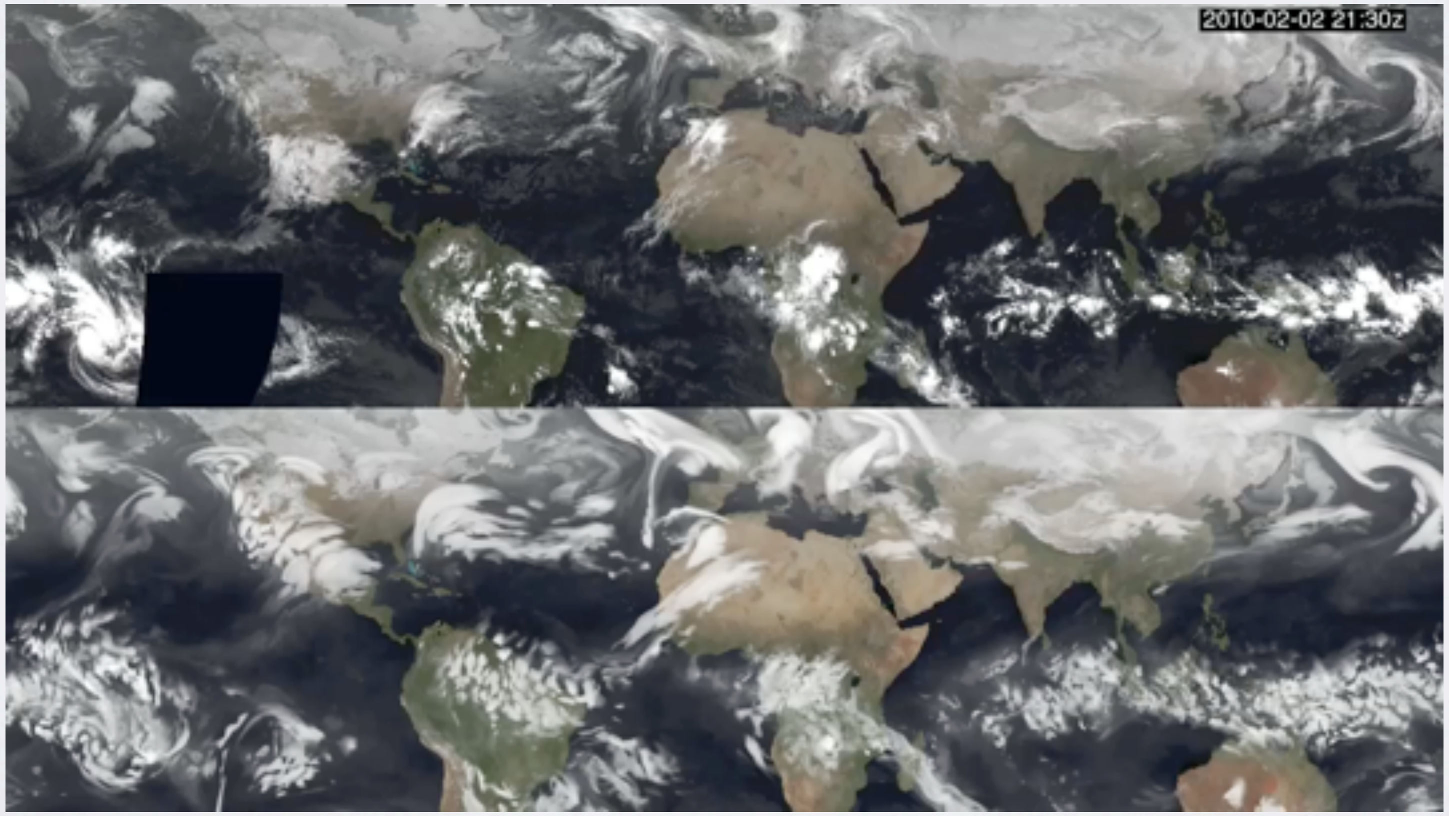
GEOS-5

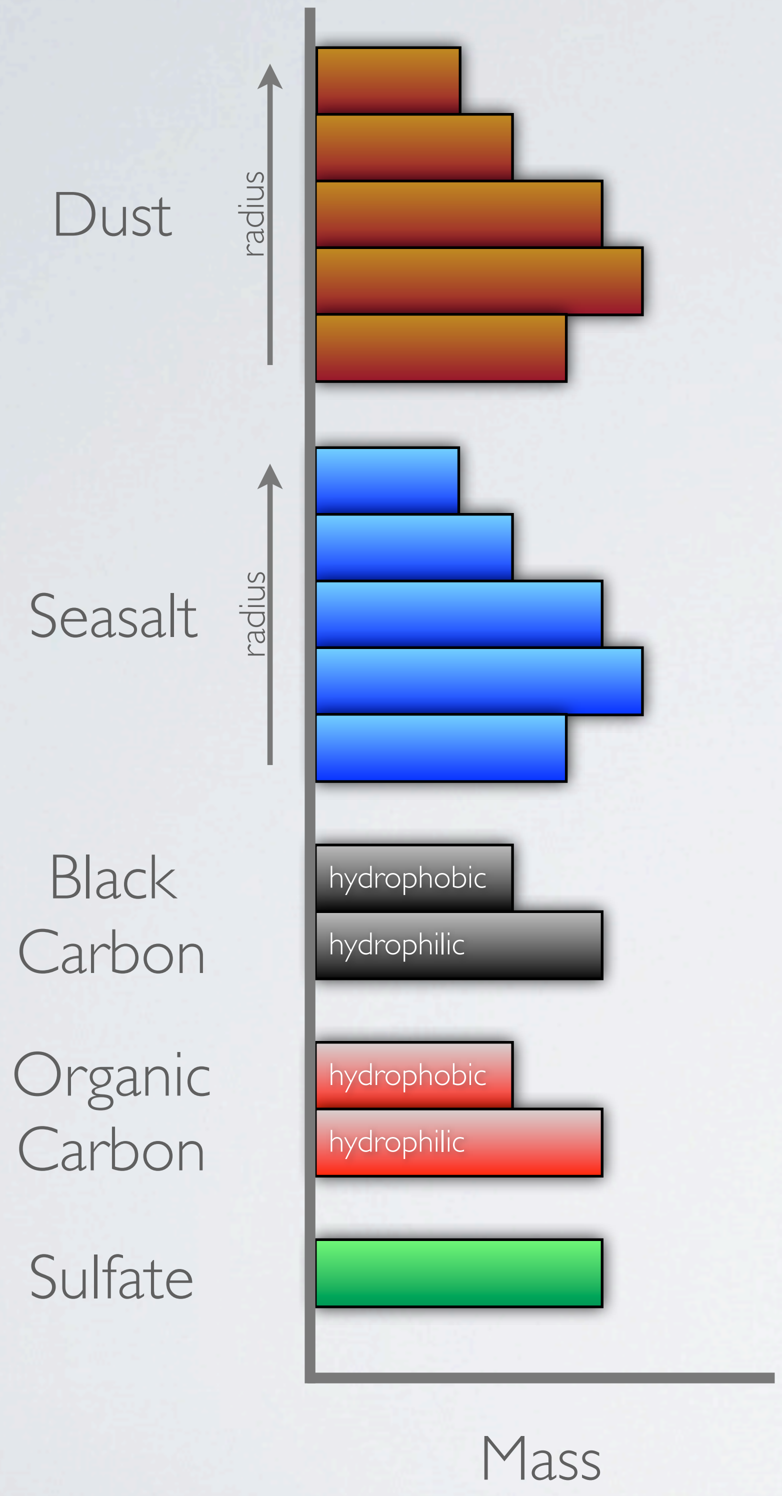
- Goddard Earth Observing System Model, Version 5
- System of models integrated using the Earth System Modeling Framework (ESMF)
- Atmospheric analysis integrates the AGCM with the Gridpoint Statistical Interpolation (GSI) package (NASA/NCEP/EMC)
- Aerosols and chemical tracers carried online (radiatively interactive) within the AGCM
- NASA Global Modeling and Assimilation Office (GMAO) is overall model custodian, runs forecasts
- Collaborative component development (e.g., chemistry, aerosols, data assimilation)

Geostationary IR Imagery

GEOS-5 5 km OLR Cubed-Sphere



GOCART Component



- Goddard Chemistry, Aerosol, Radiation, and Transport Model [Chin et al. 2002]
- Sources and sinks for 5 non-interactive species

dust	wind and topographic source, 5 mass bins
sea salt	wind driven source, 5 mass bins
black carbon	anthropogenic and wildfire source, mass hydrophobic and hydrophilic
organic carbon	anthropogenic, biogenic, and wildfire source, mass hydrophobic and hydrophilic
sulfate	anthropogenic and wildfire source of SO2, oxidation to SO4 mass

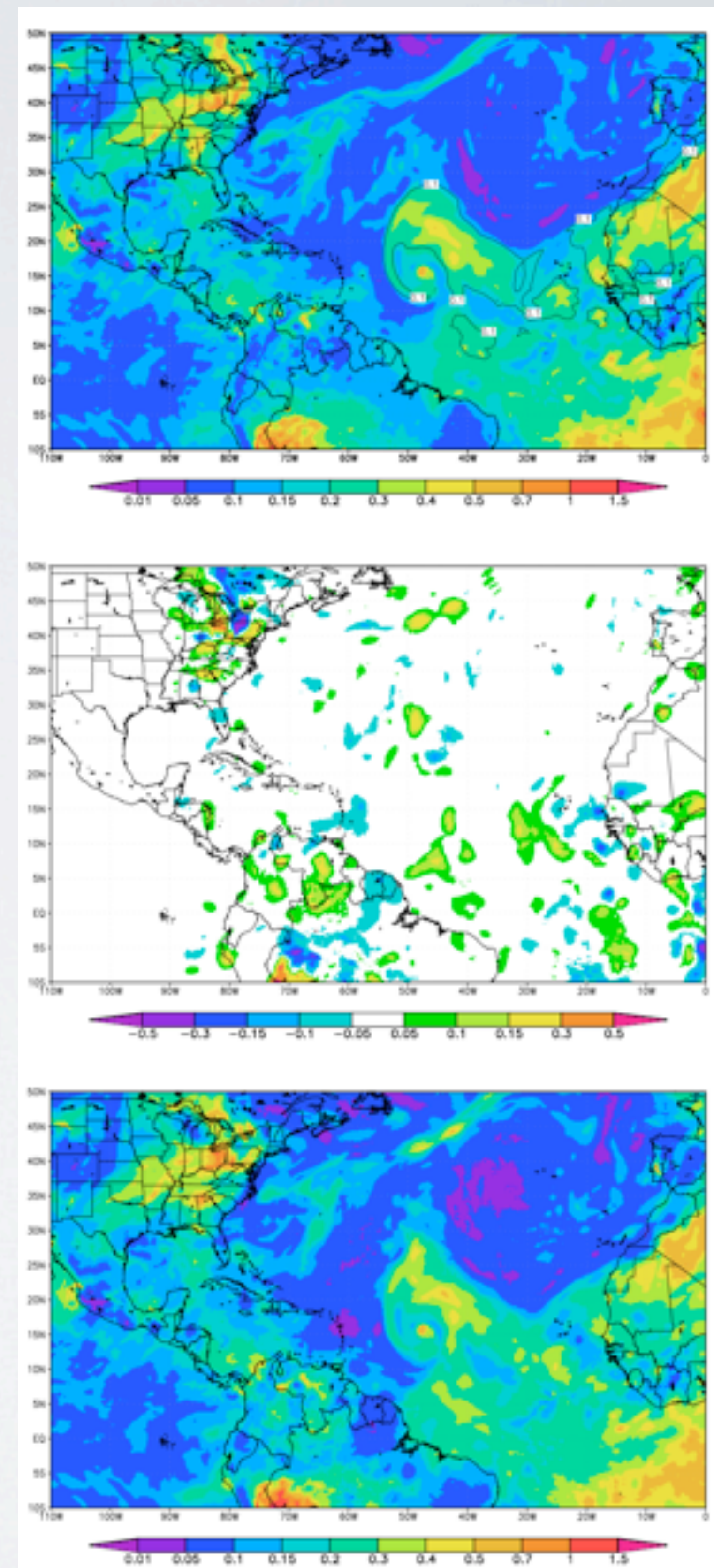
- Wet removal: convective updrafts and large scale precipitation
- Dry removal: turbulent deposition and sedimentation (dust and sea salt only)
- Optics based primarily on OPAC

Aerosol Assimilation

GAAS: GEOS-5 Aerosol Assimilation System

- Assimilates MODIS-based aerosol optical thickness
  - -Land and ocean, Terra and Aqua
  - -other sensors (e.g., MISR) in development
- MODIS observations subject to additional QA
  - -Attempt to correct biases in MODIS AOT
  - -Adaptive statistical quality control (Dee et al., 1999)
    - State dependent, adapts to error of the day
    - Background and buddy check based on log-transformed AOD
  - -Error covariance models (Dee and da Silva, 1999)
    - Innovation based
    - maximum likelihood
- Lagrangian displacement ensemble technique captures, e.g., plume misplacements
- Result is updated aerosol tracer mixing ratios every 3 hours

Example: Sept. 1, 2011

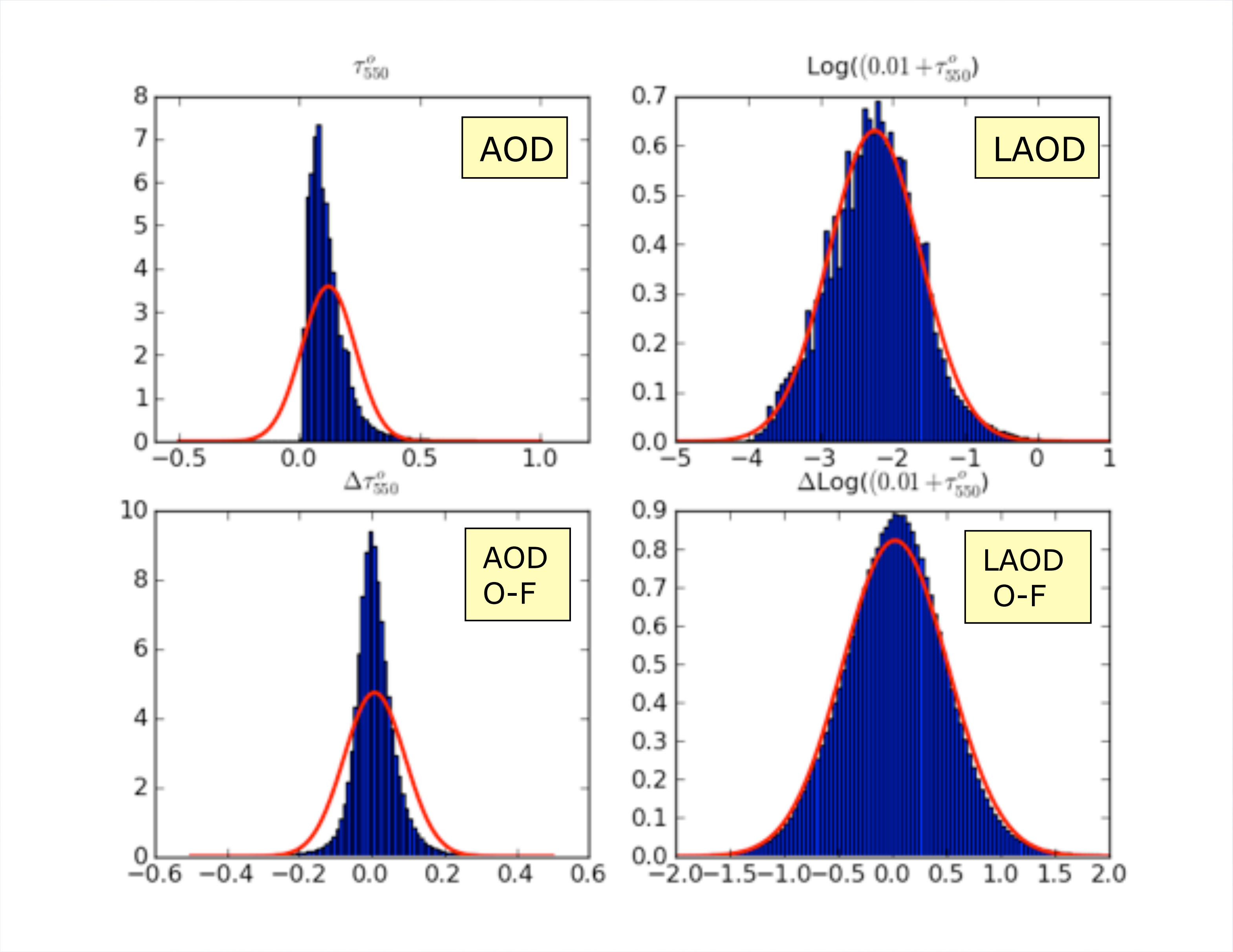


Forecast

Correction

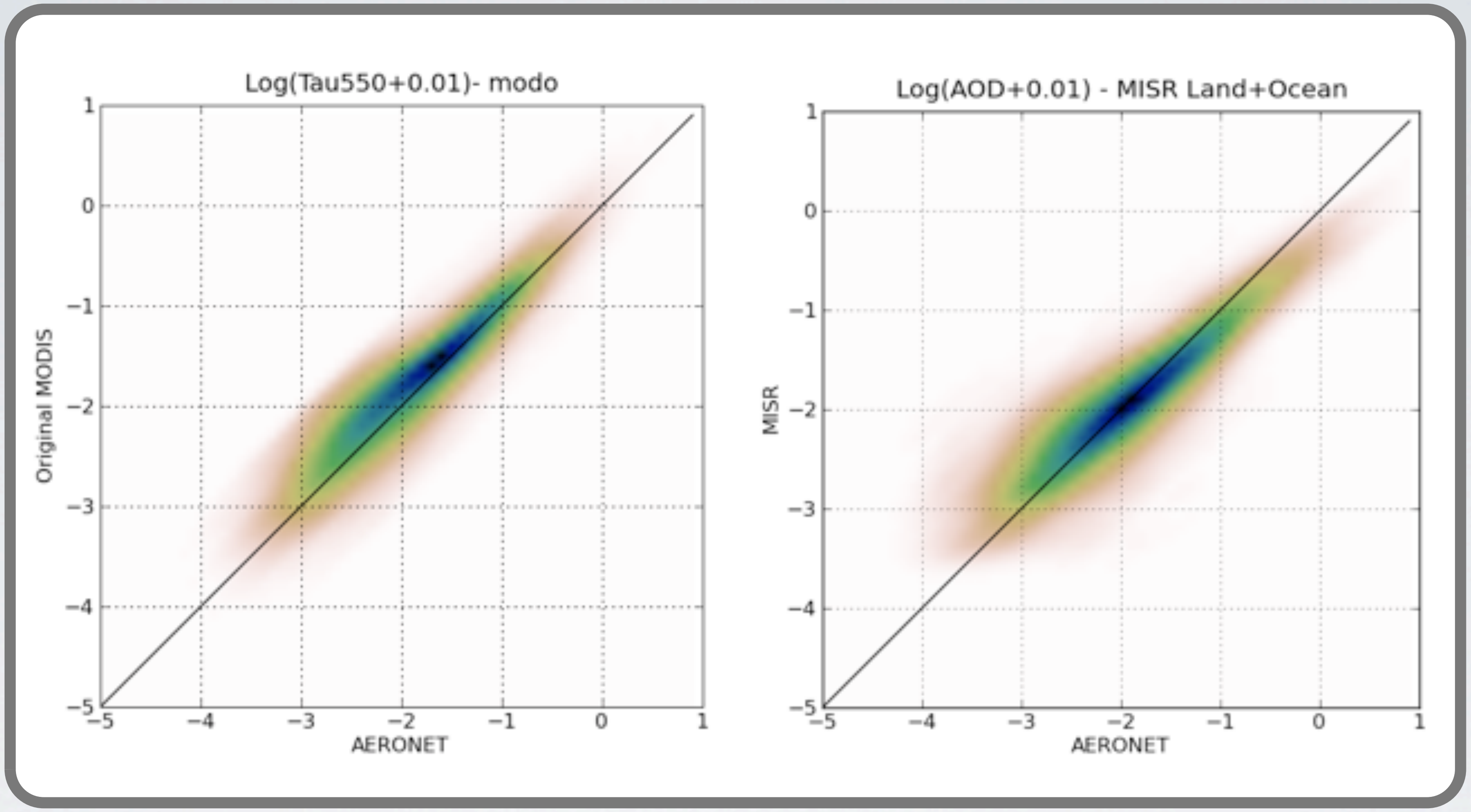
Analysis

Observation Correction



- Analysis variable is $\eta = \log(\tau + 0.01)$
- Observation bias correction is necessary
- Neural network retrieval: derive AOT from relationship of MODIS radiances to AERONET AOT

Observation Correction



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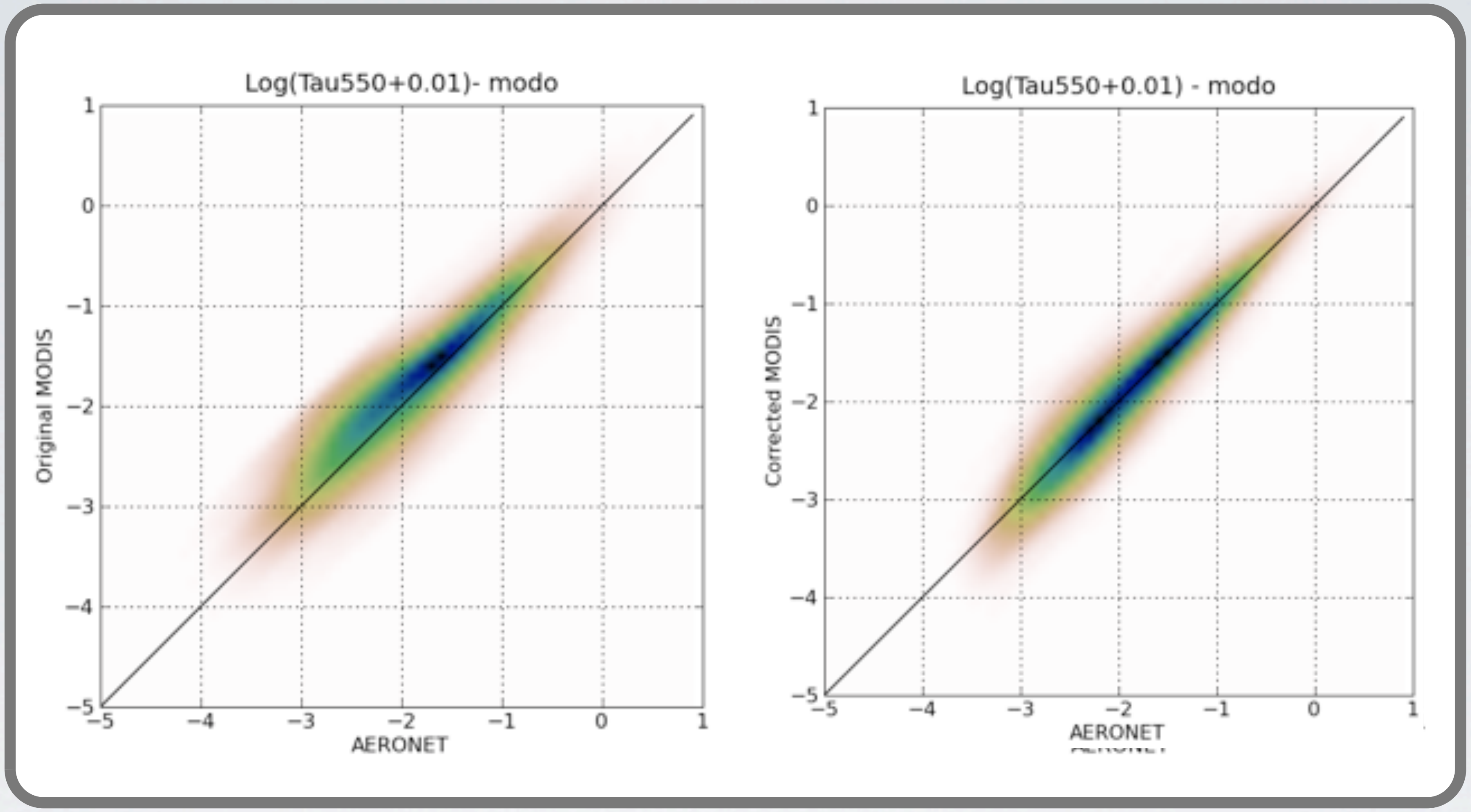

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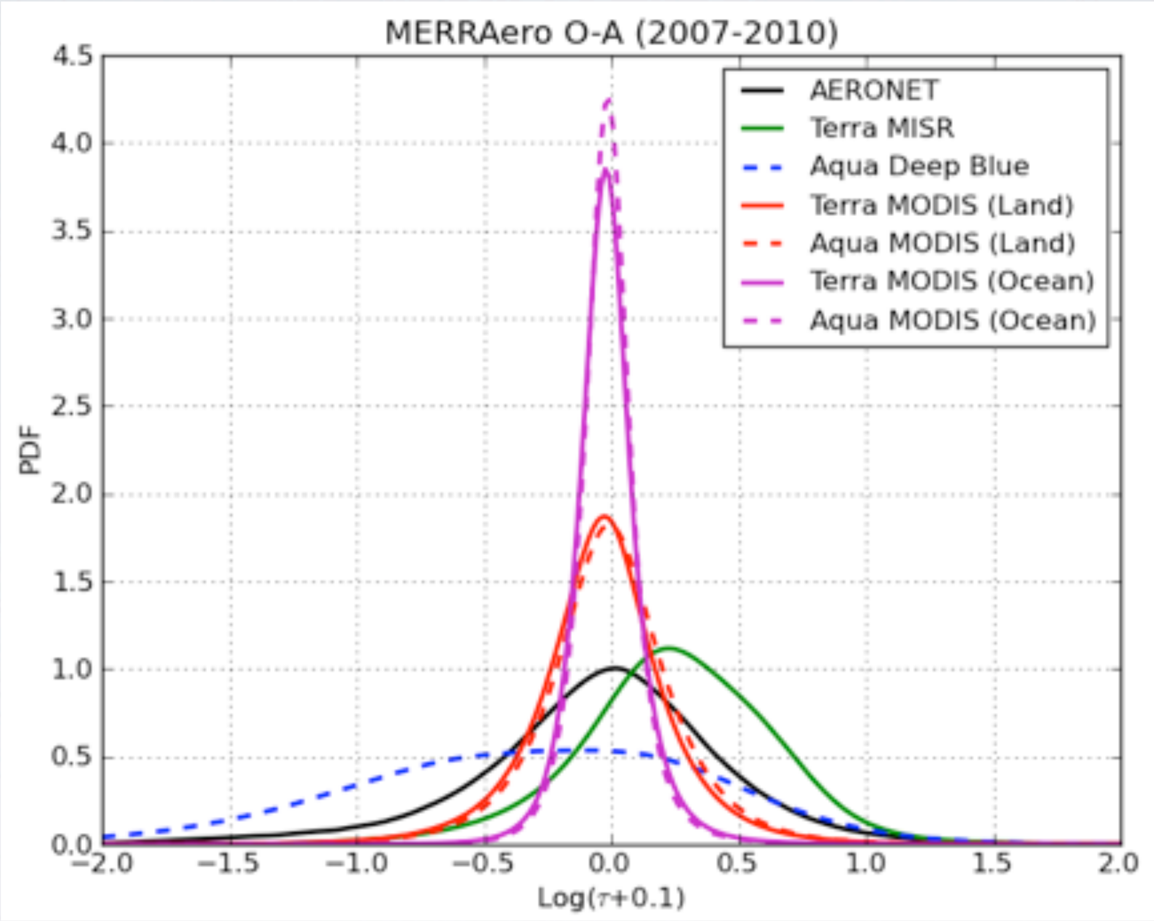

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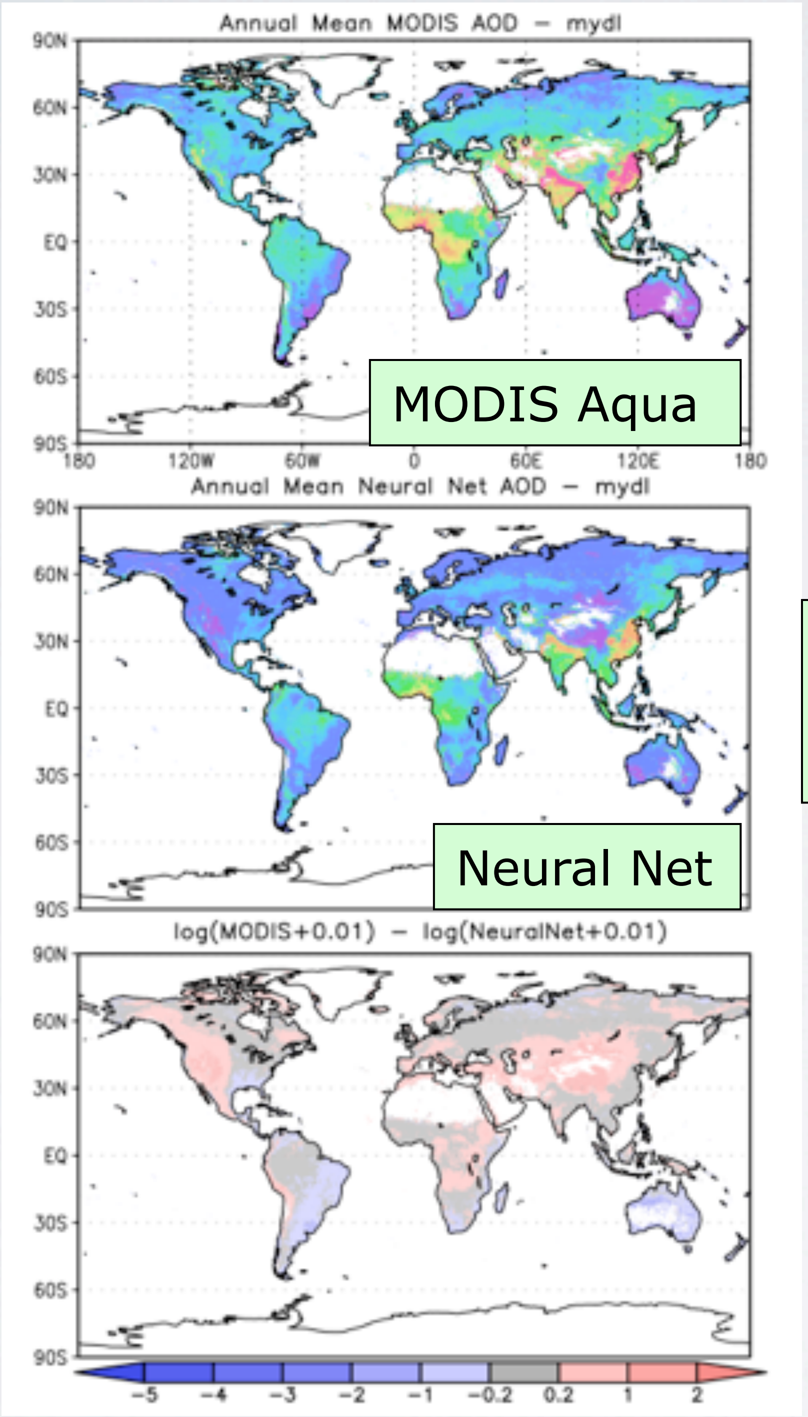
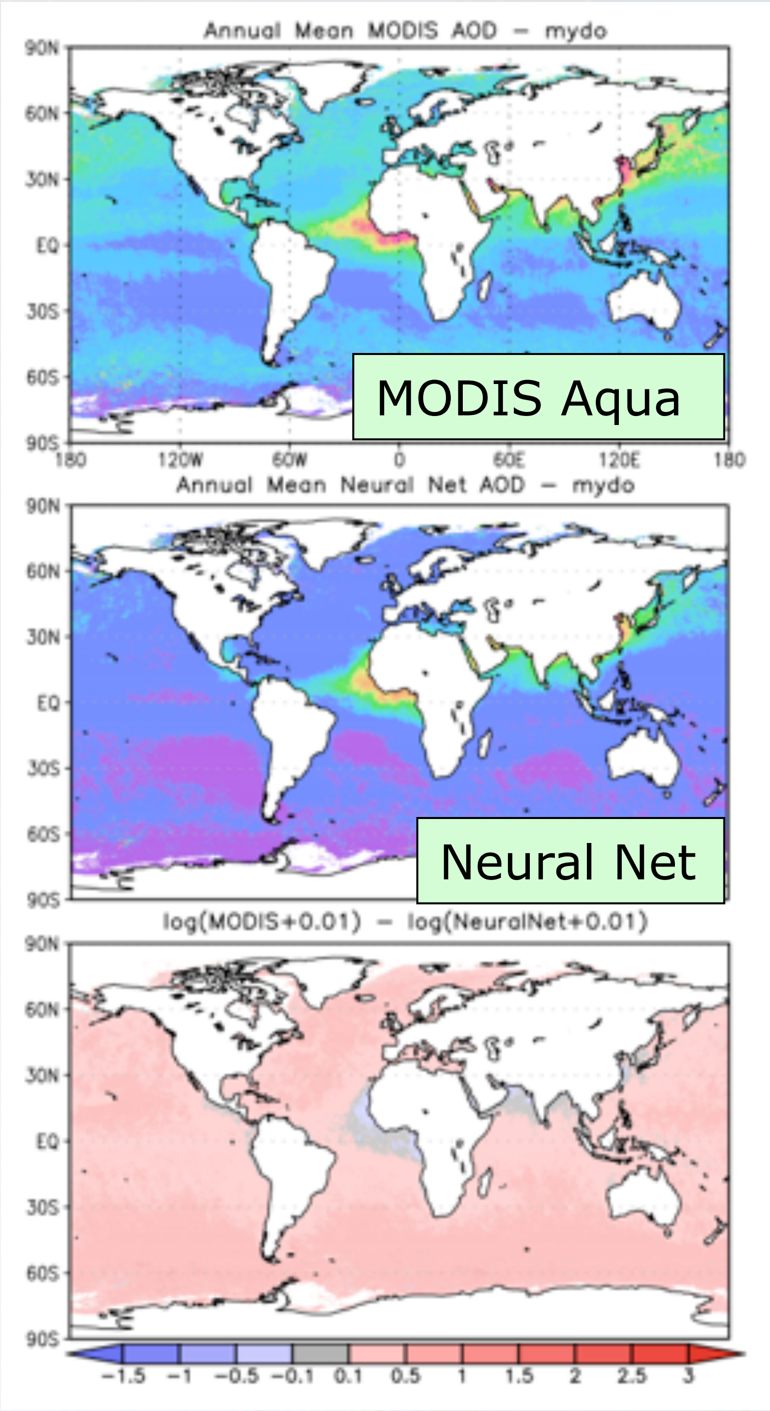
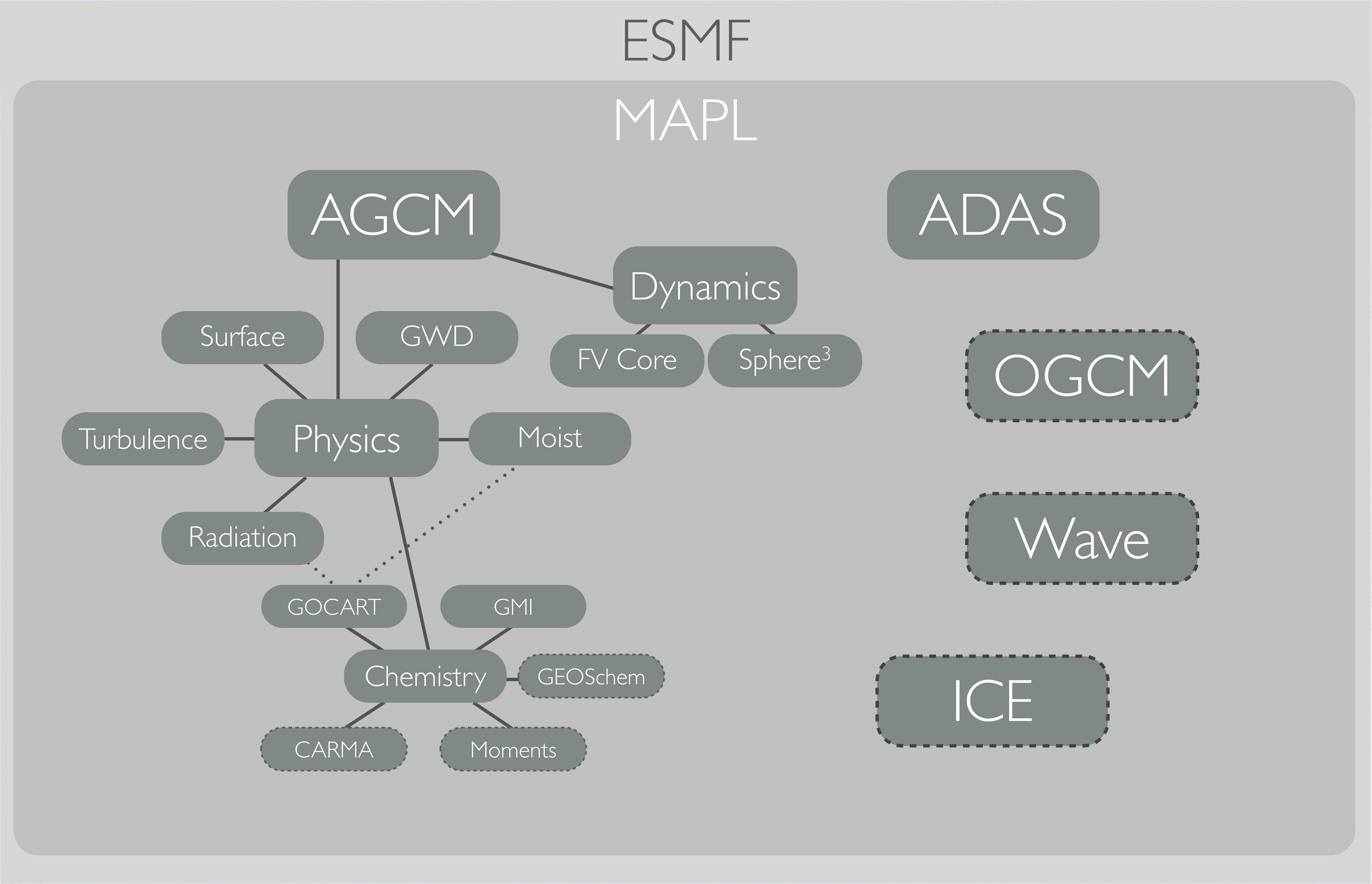
Observation Comparison



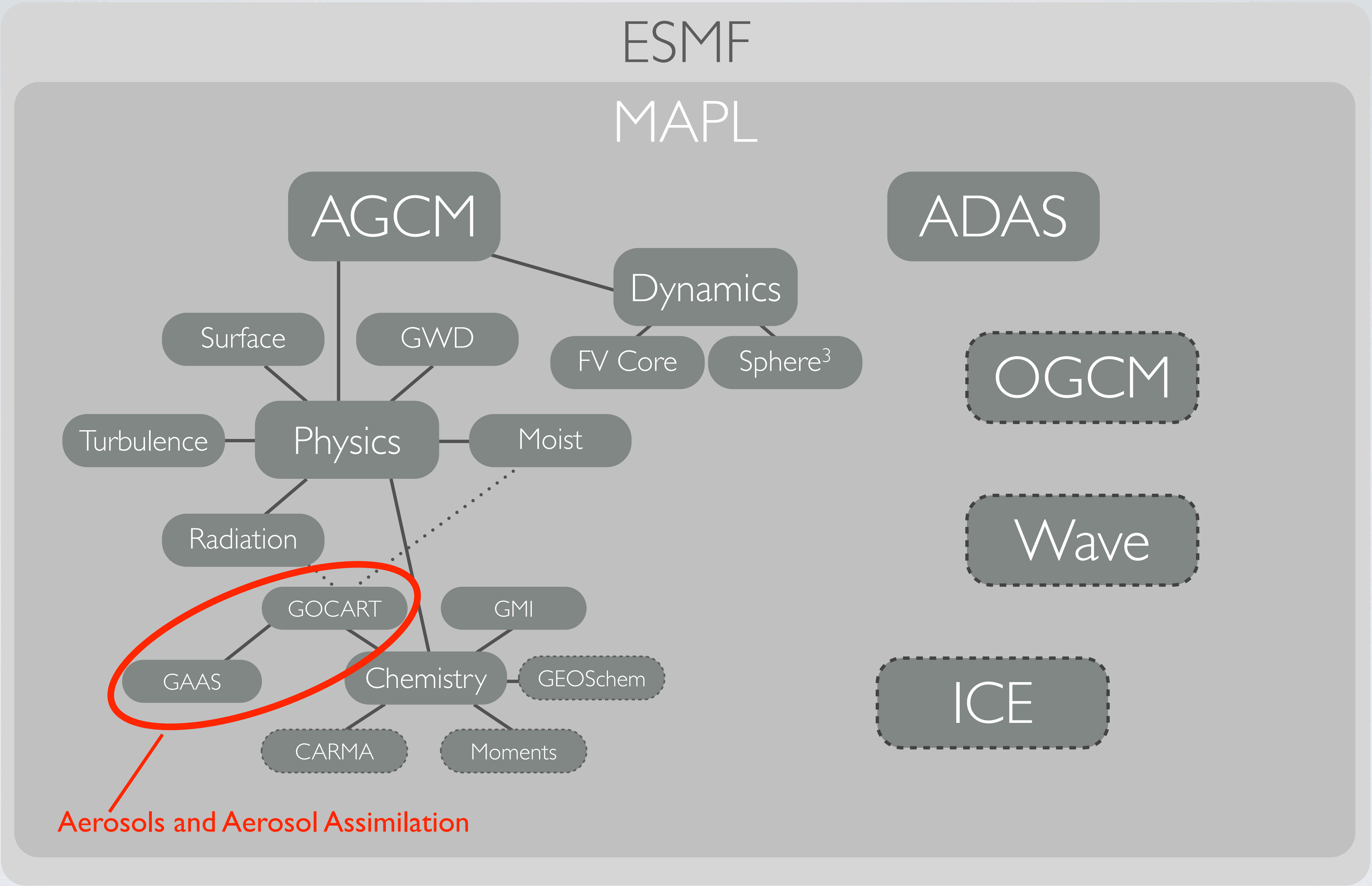
Annual Mean 2008



GEOS-5 Structure



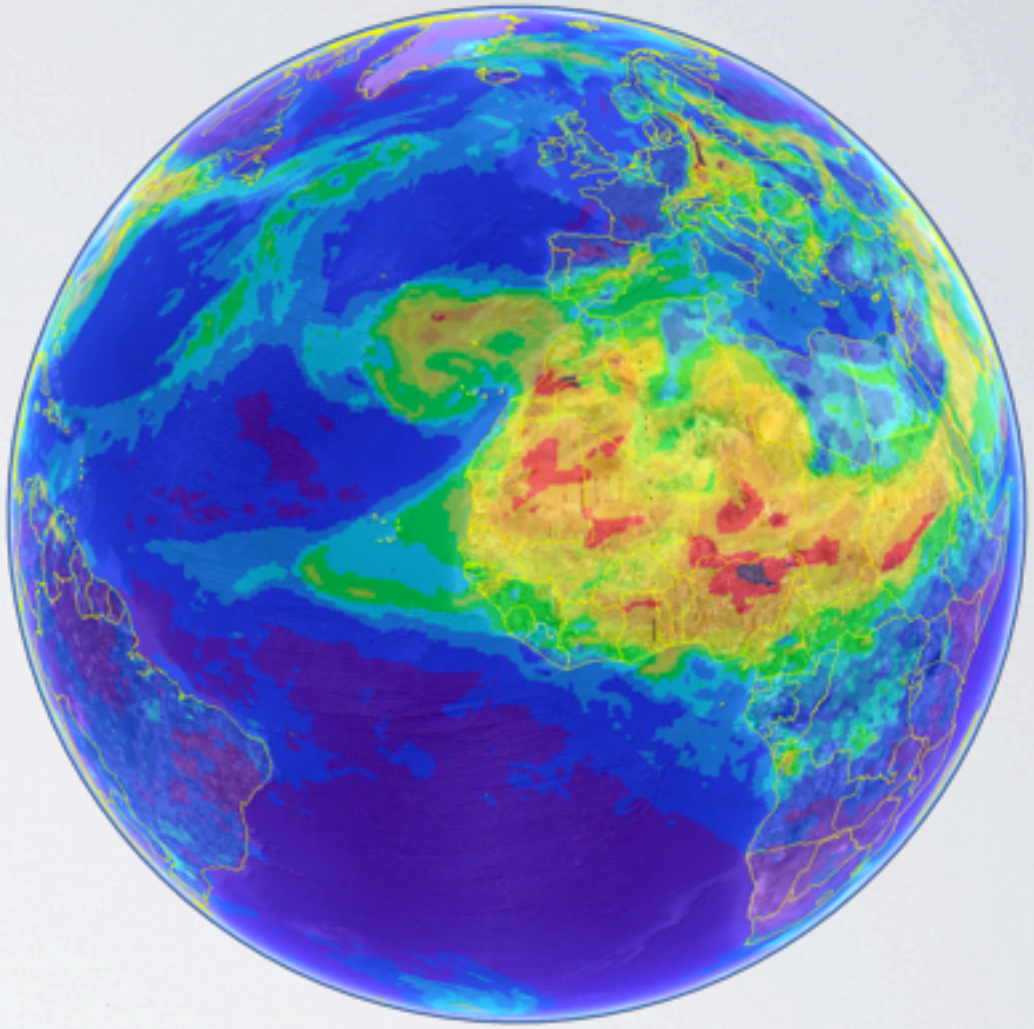
Aerosol Assimilation



GAAS - Goddard Aerosol Assimilation System

Applications

- Principal application of GEOS-5 system is research and data assimilation
  - Analyses provide a model prior to satellite retrieval teams (e.g., CALIOP, MLS, CERES)
  - OSSEs to develop next generation sensors
  - Research applications have focus on dynamics and chemistry-climate interactions
  - Aerosol and meteorological forecasts support NASA field missions (TC4, ARCTAS, GRIP, HS3, SEAC4RS, etc.)
- The same model is used for research, forecasting, and data assimilation activities



Experimental Forecast Suite

Global, 0.25° × 0.3125°, 72 hybrid η levels
2x daily, 5-day forecasts of meteorology, aerosols, CO
http://gmao.gsfc.nasa.gov/forecasts/

Model Developments

- Aerosol Forecasting System
- Tuning of the sea salt emissions
- Observation Simulations
- Aerosol-Climate Coupling
- Aerosol Reanalysis

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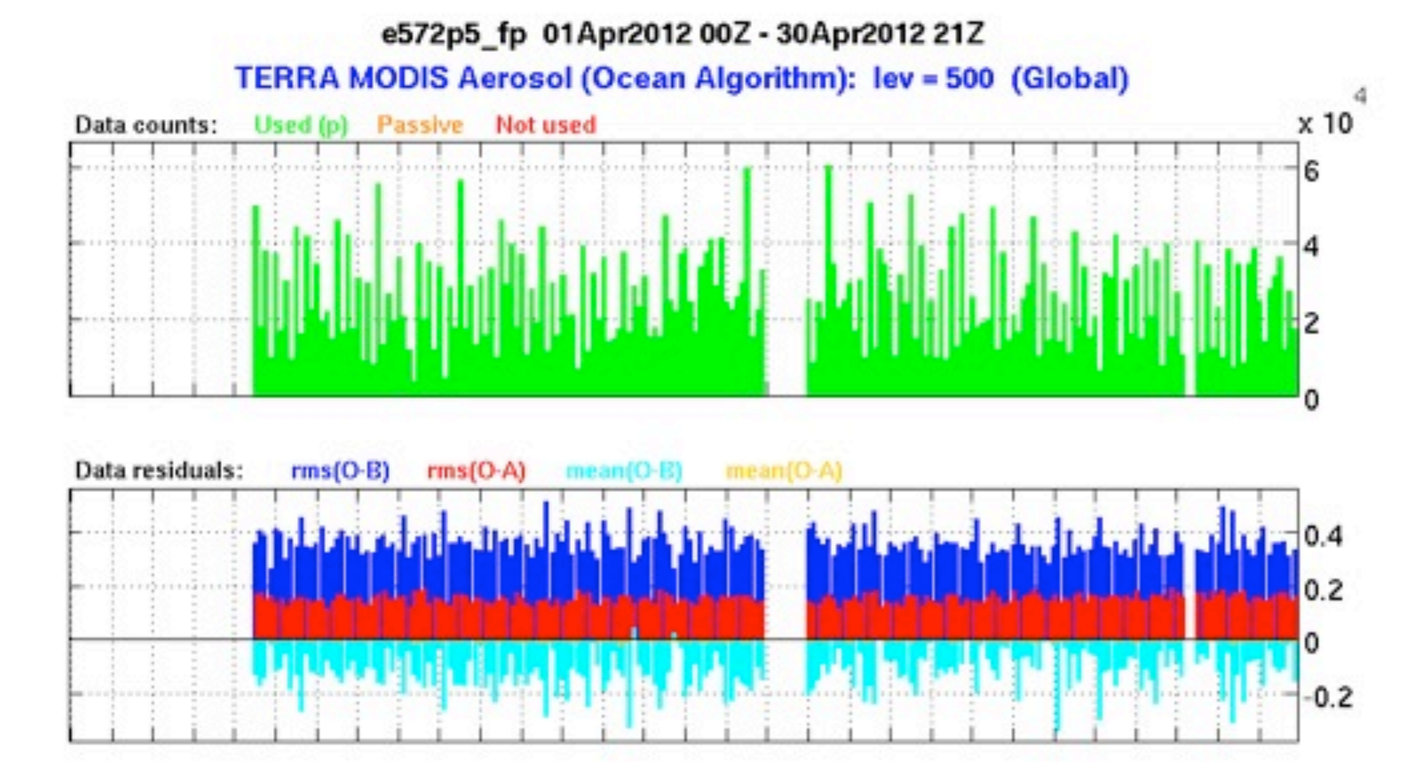
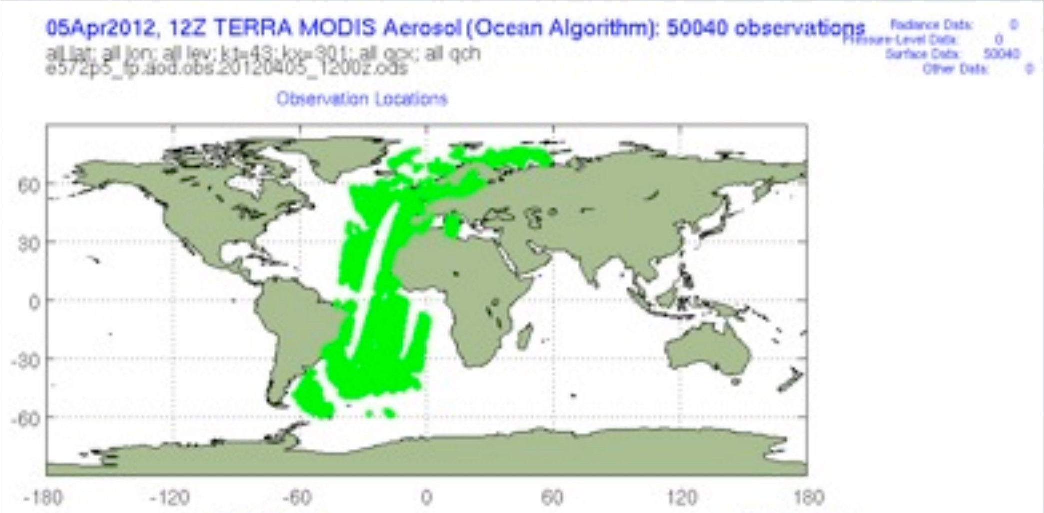
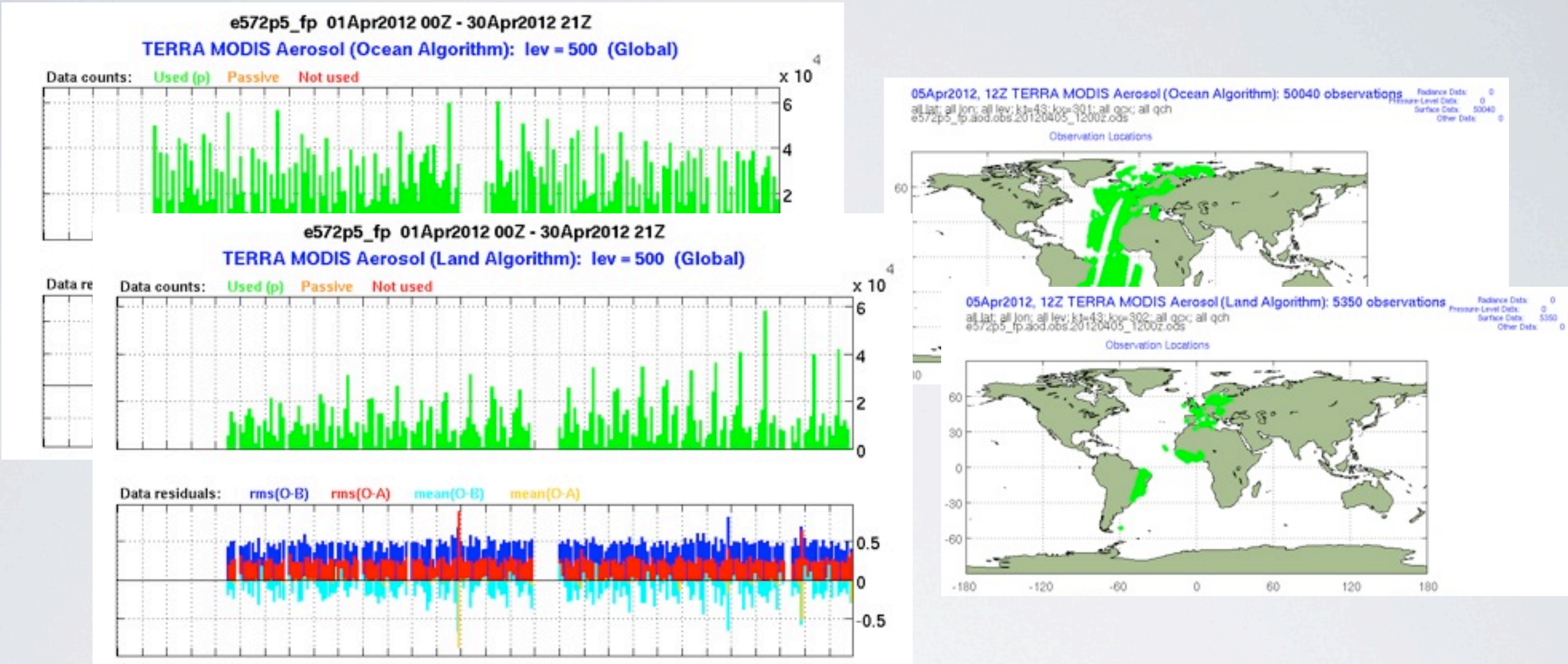
Aerosol Forecasting System





- Forecasting system live with aerosol assimilation since August 2011
- Assimilating MODIS derived AOT (land/ocean, Terra/Aqua) every 3 hours
- Collecting obs statistics

Aerosol Forecasting System



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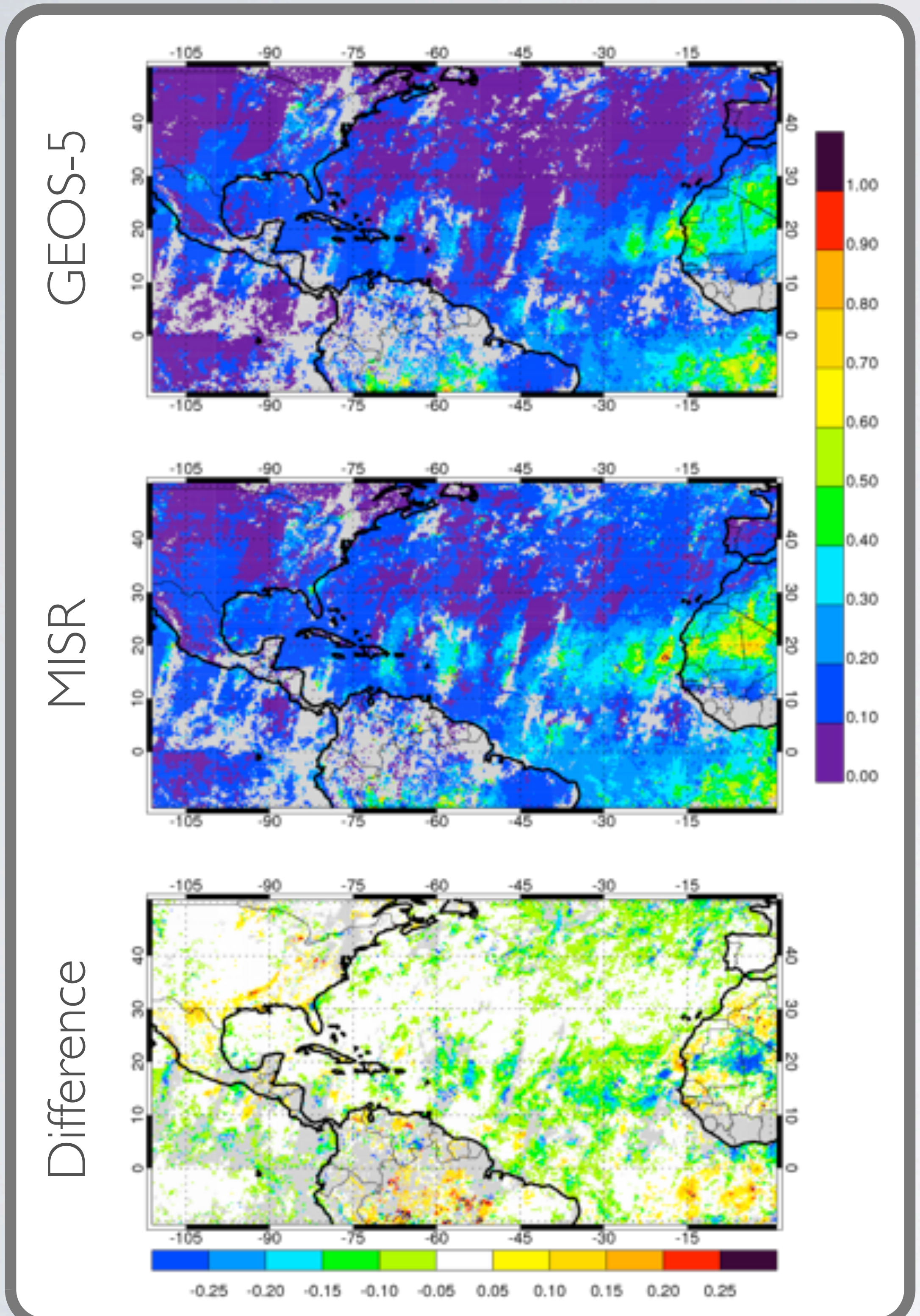
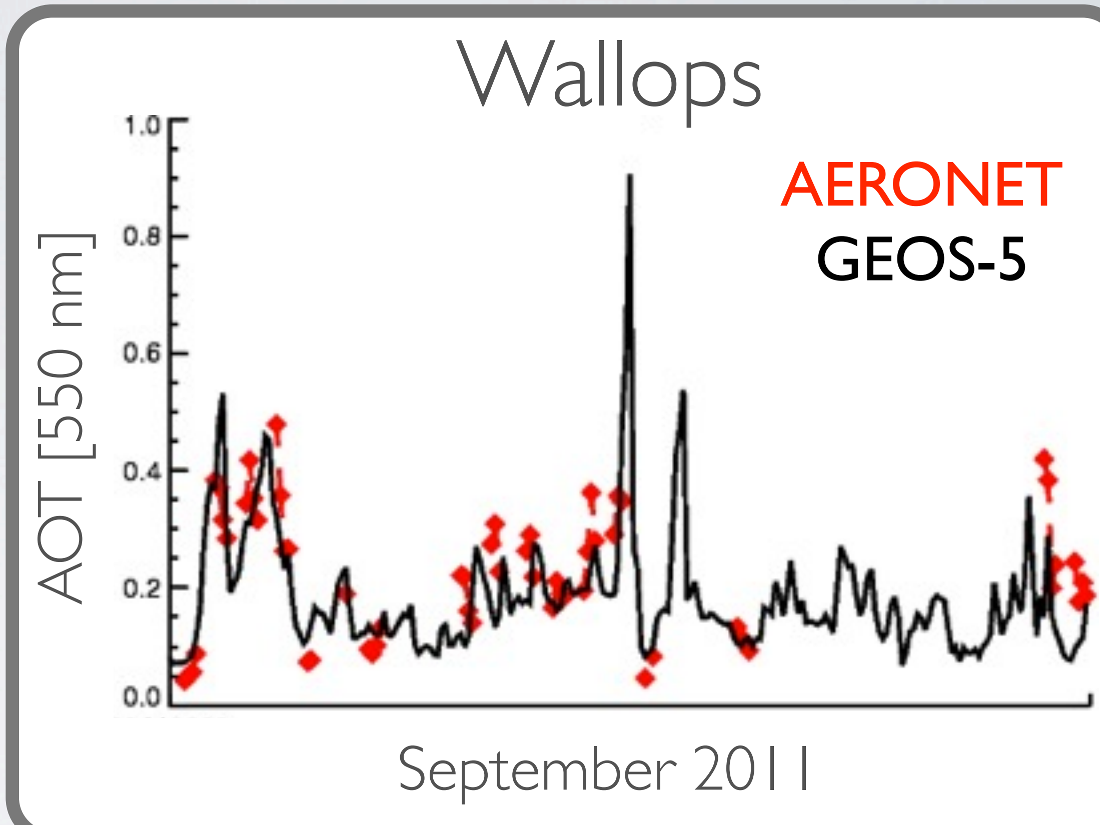
Verification





- GEOS-5 forecasting system live with aerosol assimilation since August 2011
- Forecast system assimilates MODIS derived AOT every 3 hours
- Comparisons shown to independent MISR and AERONET data for September 2011

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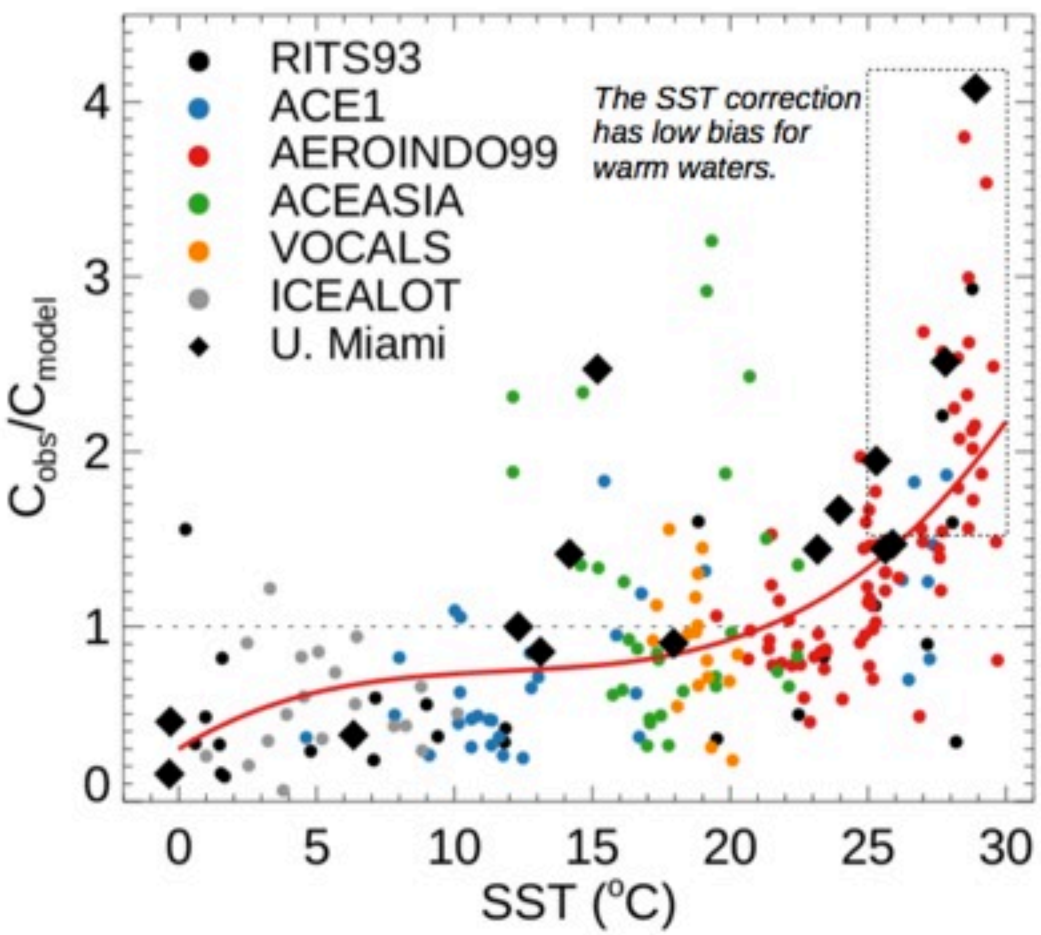
Seasalt Emission Tuning

Ratio of observed to modeled (MODEL-STD) mass concentrations of coarse mode SS as a function of observed sea surface temperature (SST)



•The red line is the result of a least-squares fitting of the points to a 3rd order polynomial: Cobs /Cmodel = 0.3 + 0.1 × SST − 0.0076 × SST^2 + 0.00021 × SST^3

•Each PMEL cruise is indicated by different colored circles

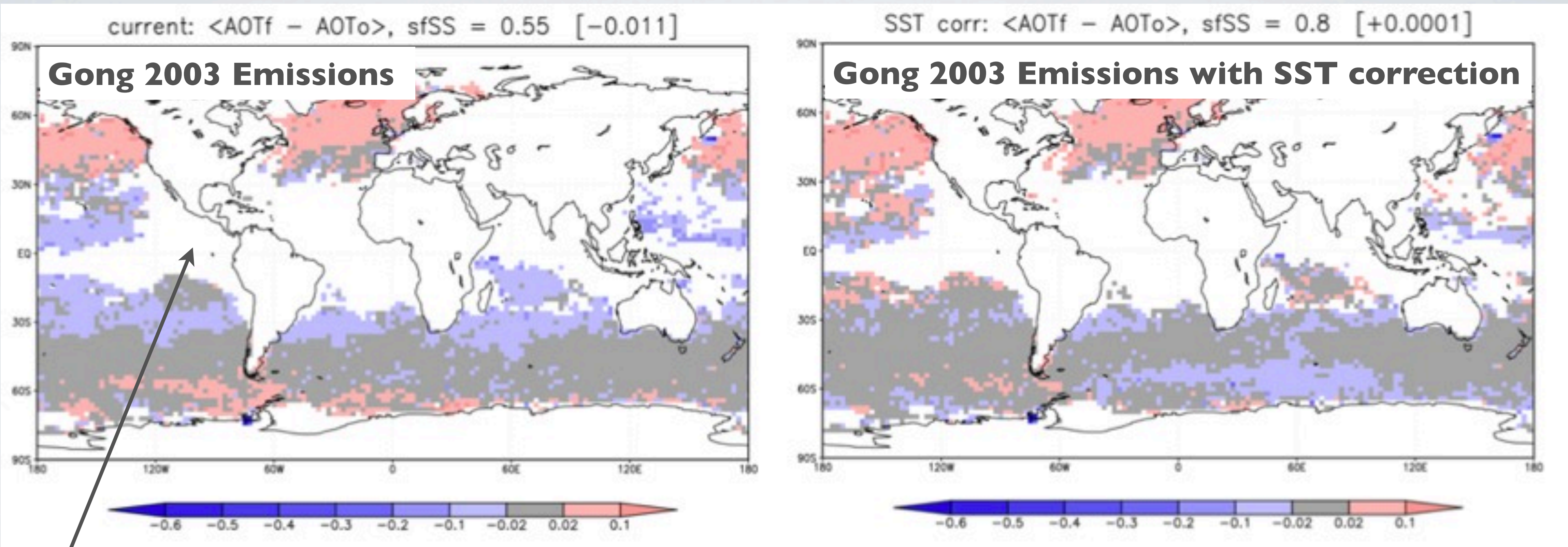
•Show are points where u10 m > 6 m s−1

•Also shown are the observed to modeled ratios for the 15 ground-based stations (black diamonds).

source: L. Jaegl´ et al.: Global distribution of sea salt aerosols, ACP, 2011

- Jaeglé et al. ACP 2011 note apparent SST dependence on seasalt mass loading
- Baseline model version biased low in AOT in tropical oceans
- Adding SST correction improves RMSE and increases AOT

Seasalt Emission Tuning



Seasalt not major contributor to AOT: $AOT_{SS}/AOT < 0.75$

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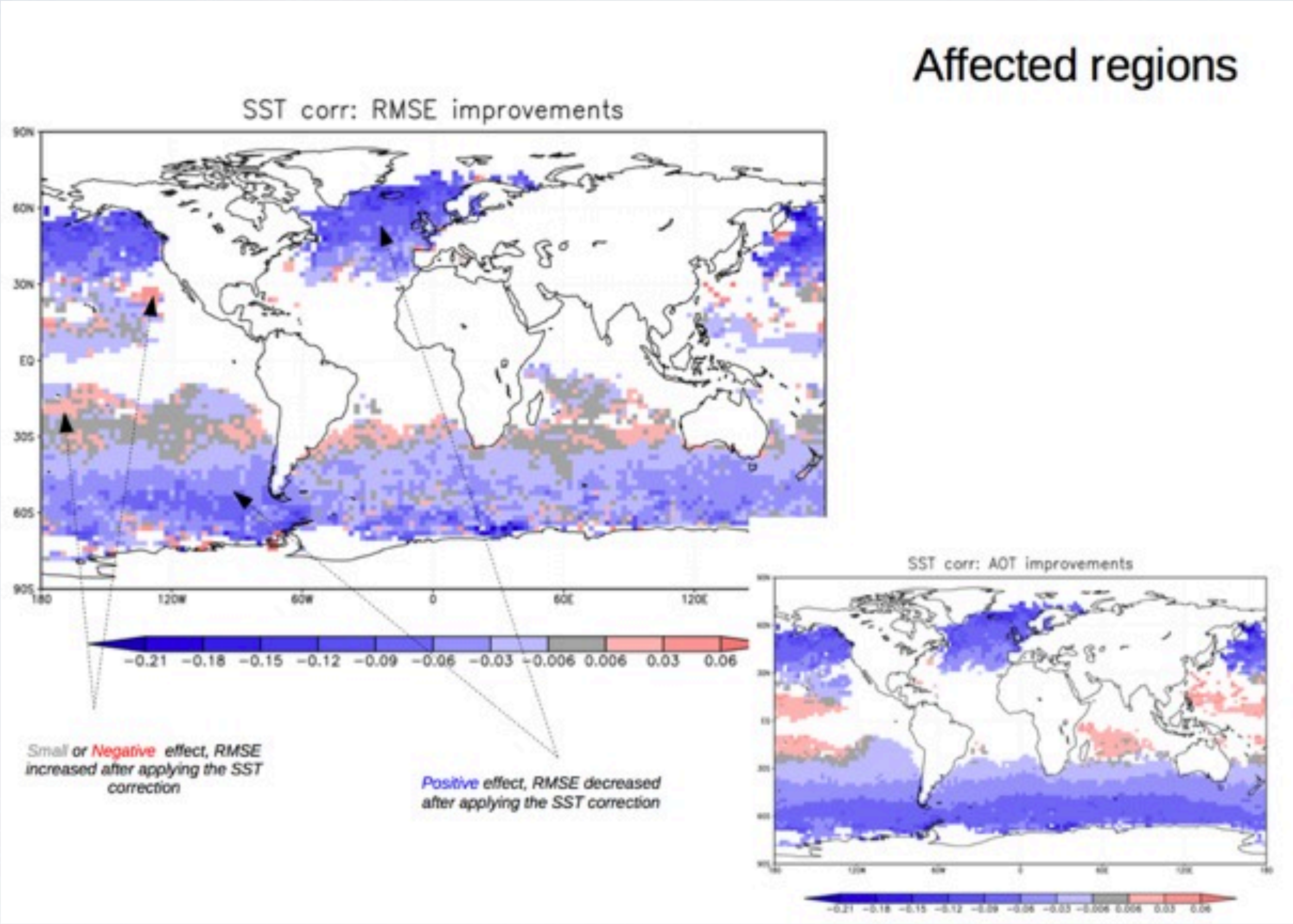
Seasalt Emission Tuning



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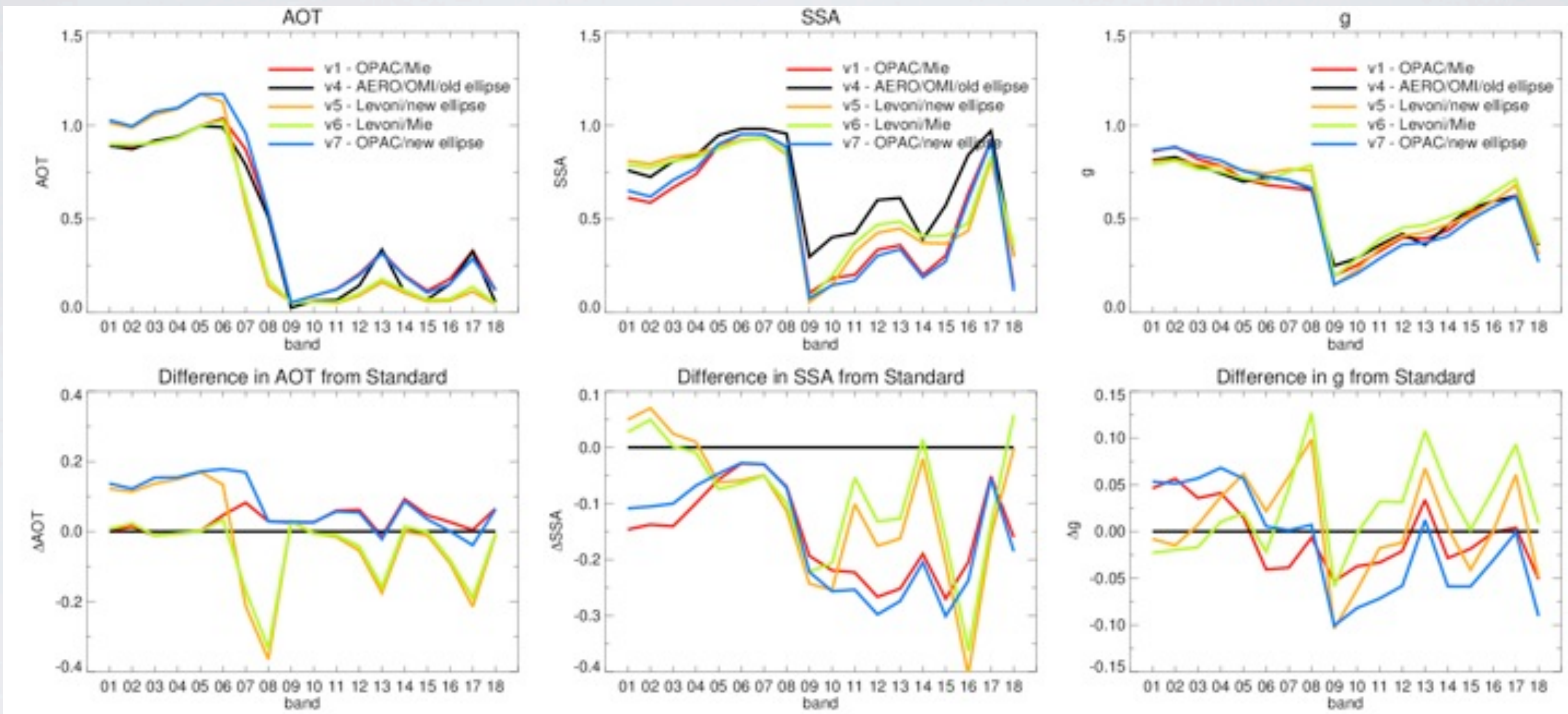
Observation Simulator

Dust particles are not spherical

Special techniques are required to compute the optical properties of non-spherical dust particles. We have implemented a database of non-spherical dust optical properties in GEOS-5.



- Standard (old) optics
- SW absorbing spheres
- SW less absorbing spheres
- SW absorbing ellipsoids
- SW less absorbing ellipsoids

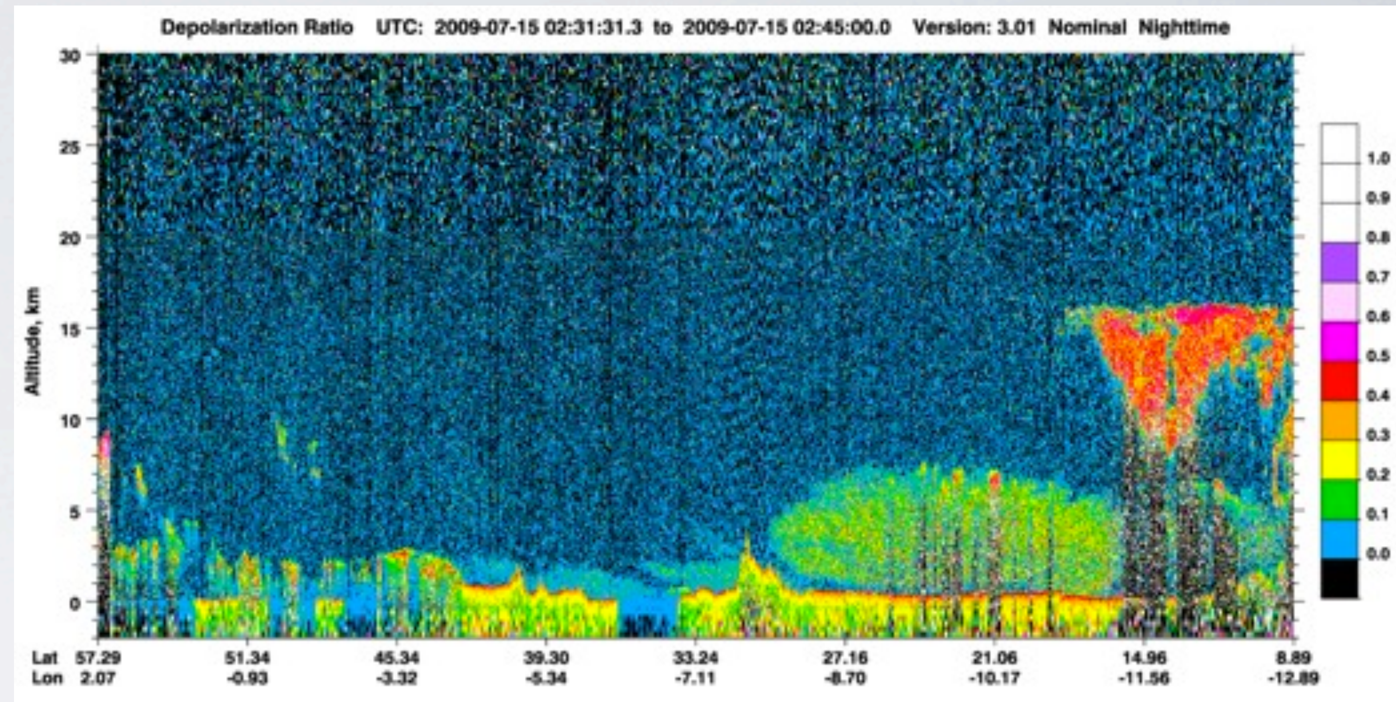
Simulated dust aerosol optical thickness (AOT, left), single scatter albedo (SSA, middle), and asymetry parameter (g, right) as a function of wavelength (band, from SW to IR). Simulation is based on a GEOS-5 simulated particle size distribution normalized to an AOT of 1.0 at 550 nm.

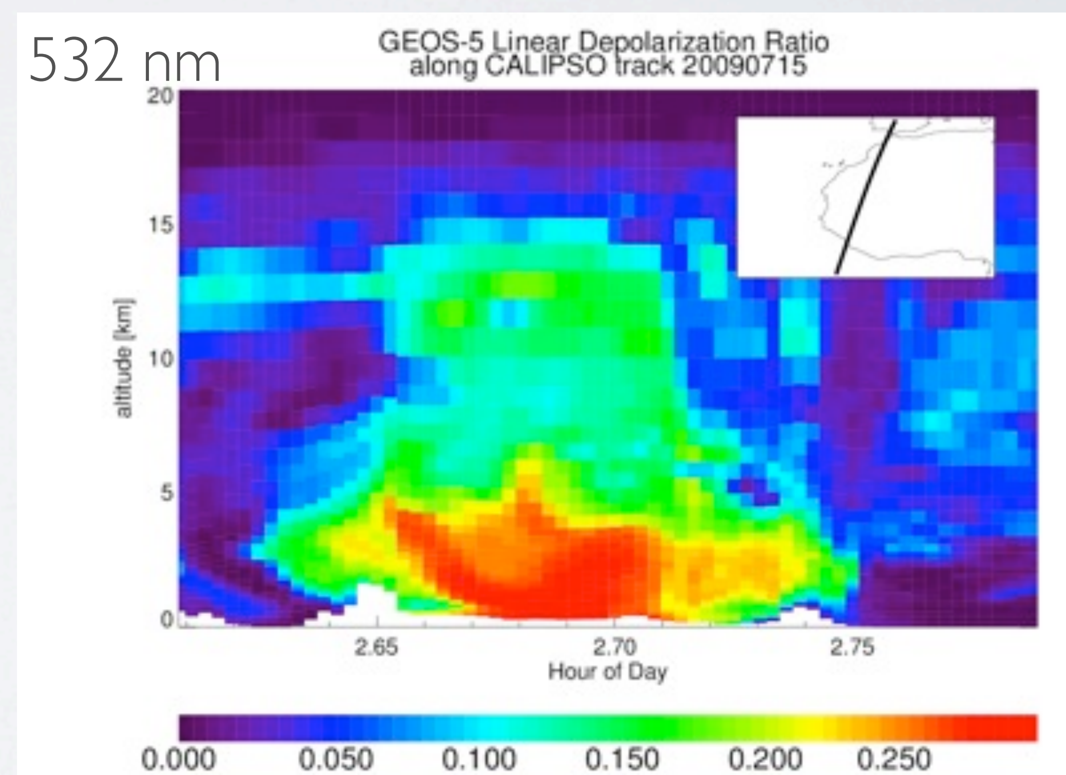
Dust non-spherical optics based on database developed by Ping Yang's group at Texas A&M

Observation Simulator

Inclusion of the dust non-spherical optics permits for the first time simulation of the linear depolarization ratio based on GEOS-5 simulated aerosol fields.

The simulated linear depolarization ratio at 532 nm is shown here for a sample of the GEOS-5 model fields along the CALIPSO track over northern Africa on July 15, 2009.





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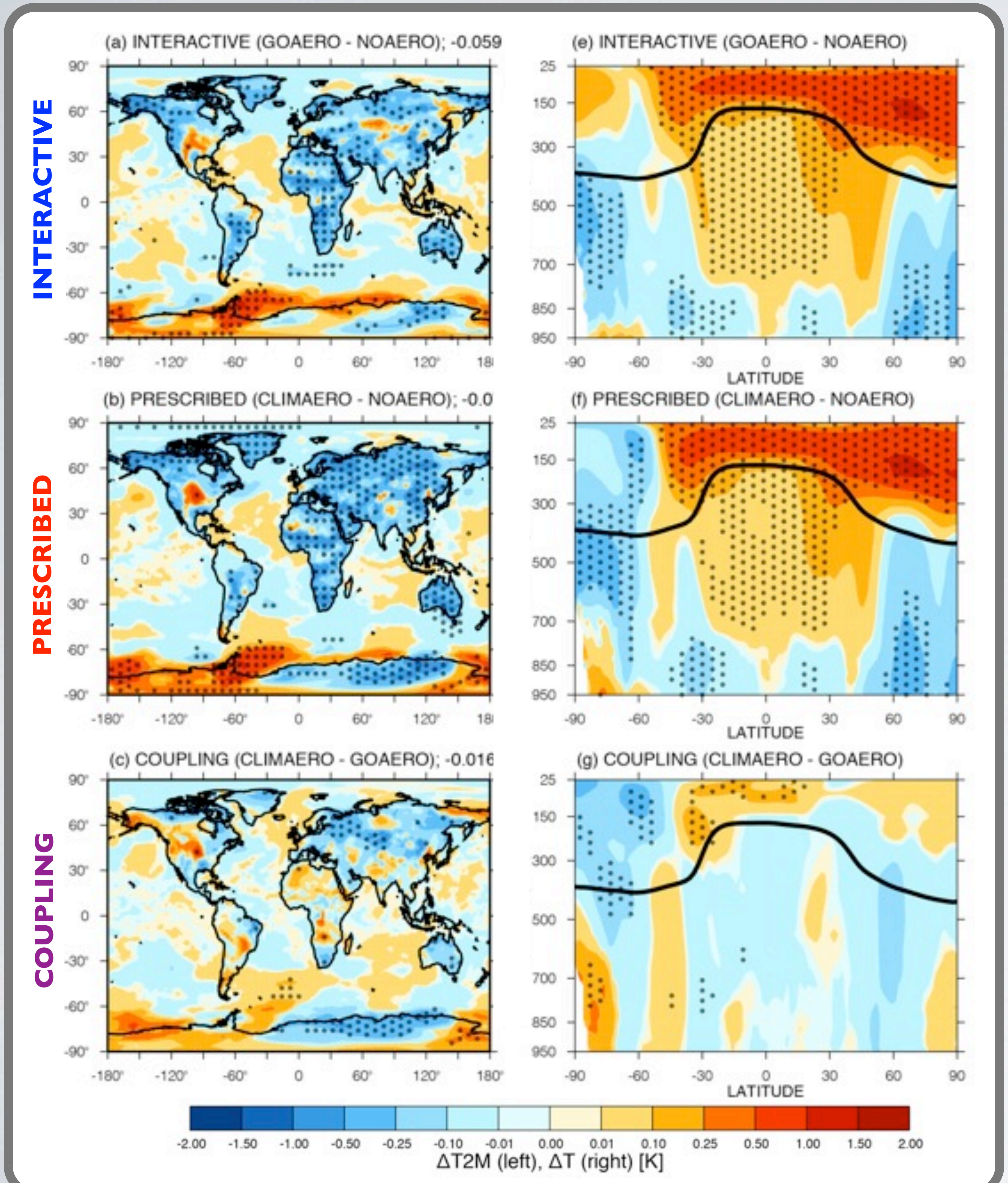
Aerosol-Climate Coupling

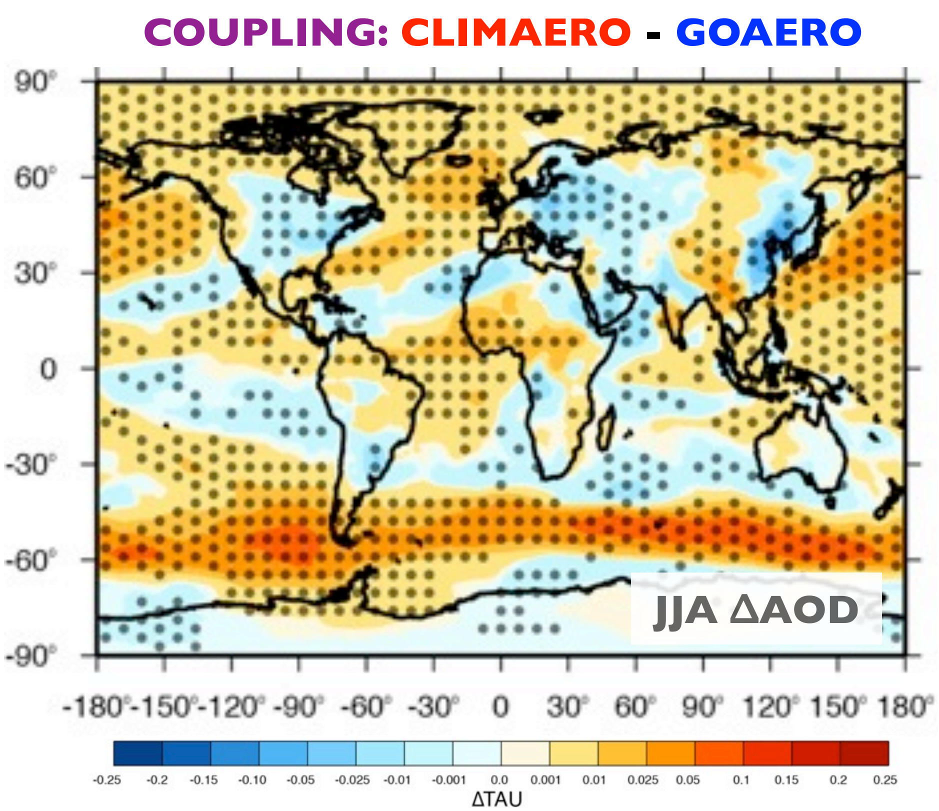


- Globally, relative to the NOAERO control case, the sign of temperature change is the same for the INTERACTIVE and PRESCRIBED signals.
- However, the magnitude of the PRESCRIBED signal is generally stronger.
- There are regional differences in the response, particularly at higher latitudes, higher altitudes.
- Difference in stratospheric temperature in the winter hemisphere due to dynamics since this region is remote from direct aerosol heating.

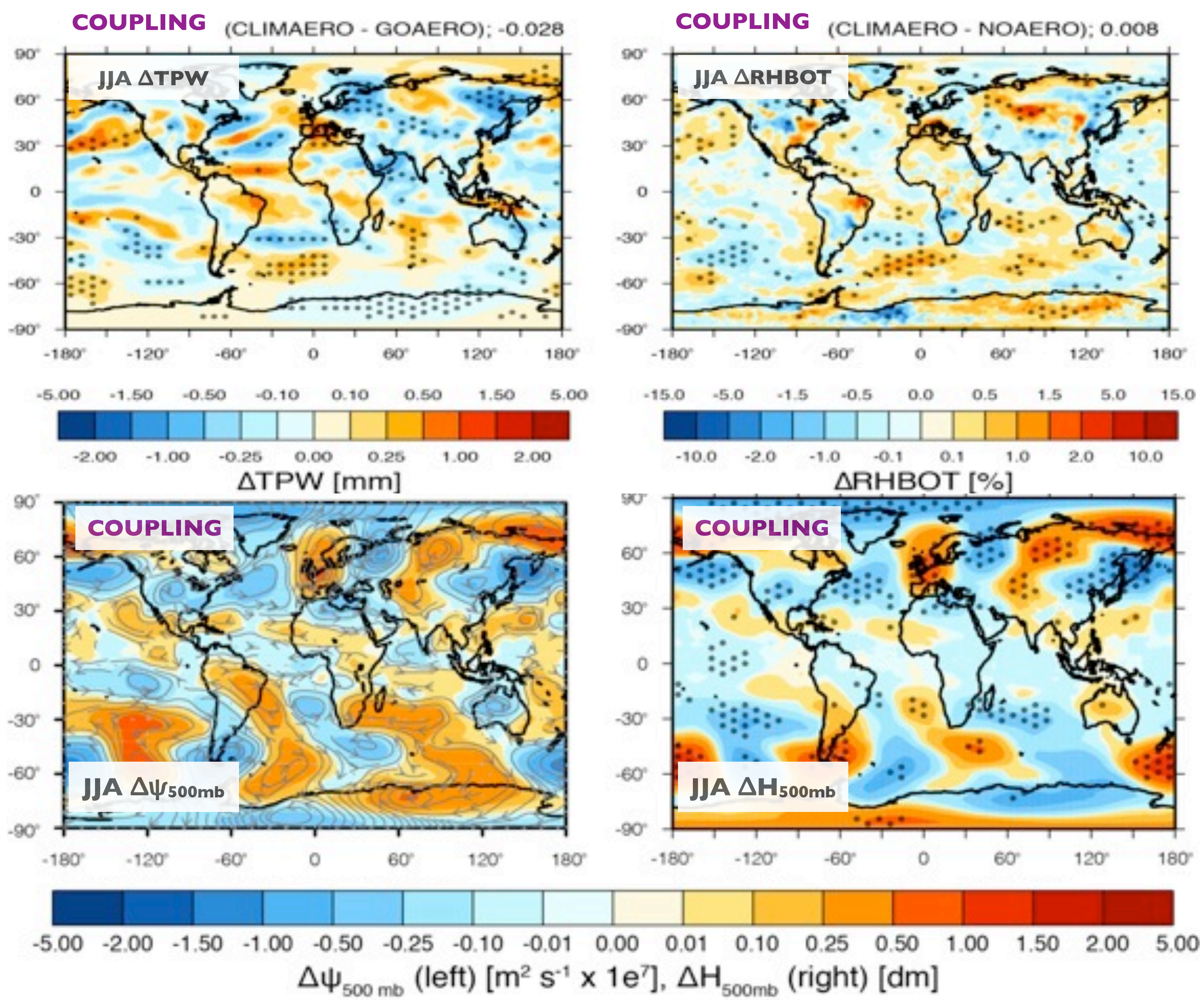
% Change
100 × (PRESCRIBED – INTERACTIVE)/INTERACTIVE

	Land JJA	Ocean JJA
T2M	29.2 ↑	~~50 ↑~~
S850	37.6 ↑	17.1 ↑
S500	8.4 ↑	32.1 ↓

Small differences in global forcing … but larger differences regionally due to water vapor/RH changes (JJA)!



Differences in RH impact AOD!



AOD differences impact forcing, especially over the ocean!

Simulation/Source	Clear-sky TOA DRE Ocean (Land)	Clear-Sky ATM DRE Ocean (Land)	Clear-sky SFC DRE Ocean (Land)
GOAERO Clear-sky DRE	-4.8 (-4.5)	1.7 (3.8)	-6.5 (-8.3)
CLIMERO Clear-sky DRE	-5.1 (-4.6)	1.7 (3.8)	-6.7 (-8.4)

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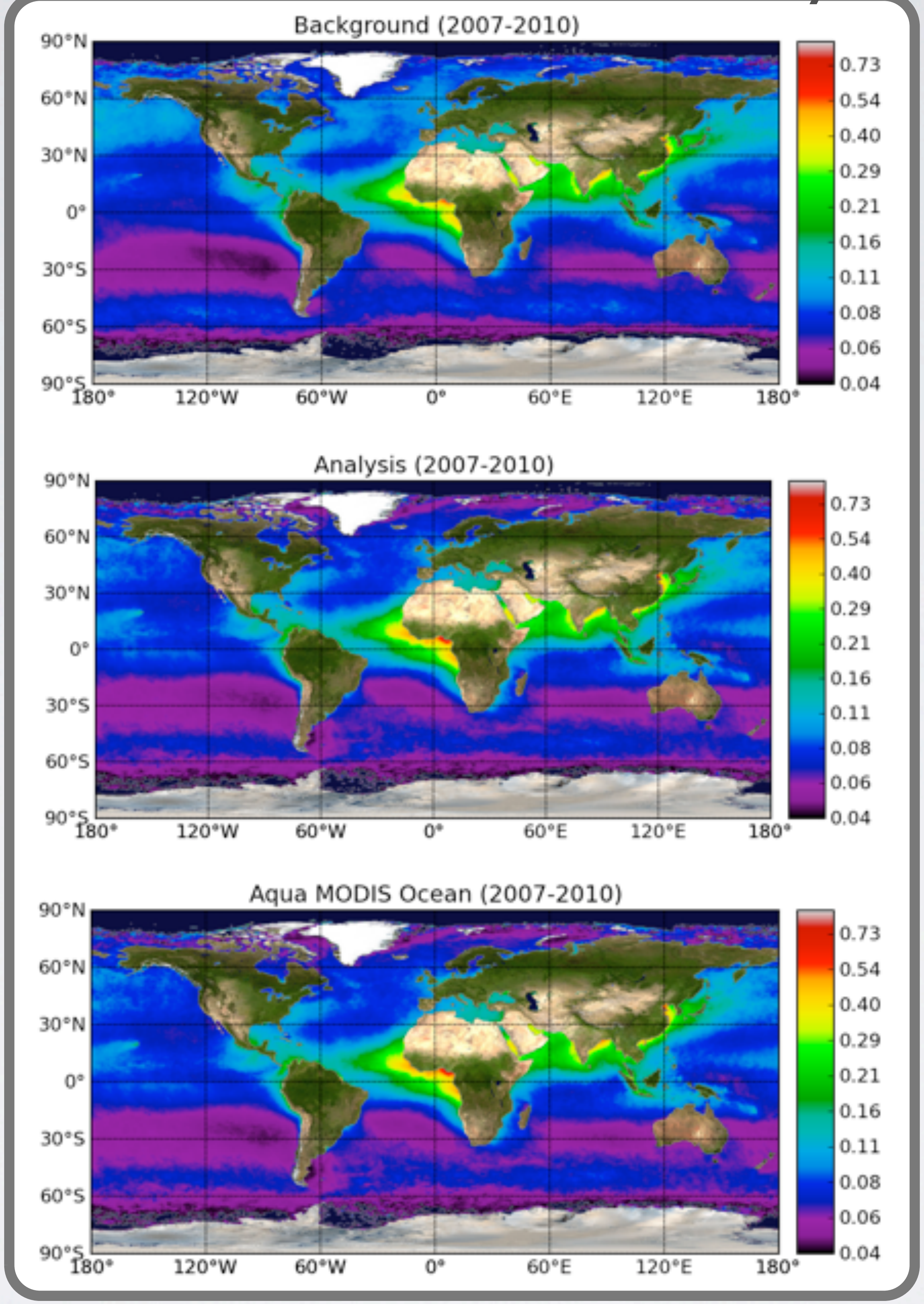
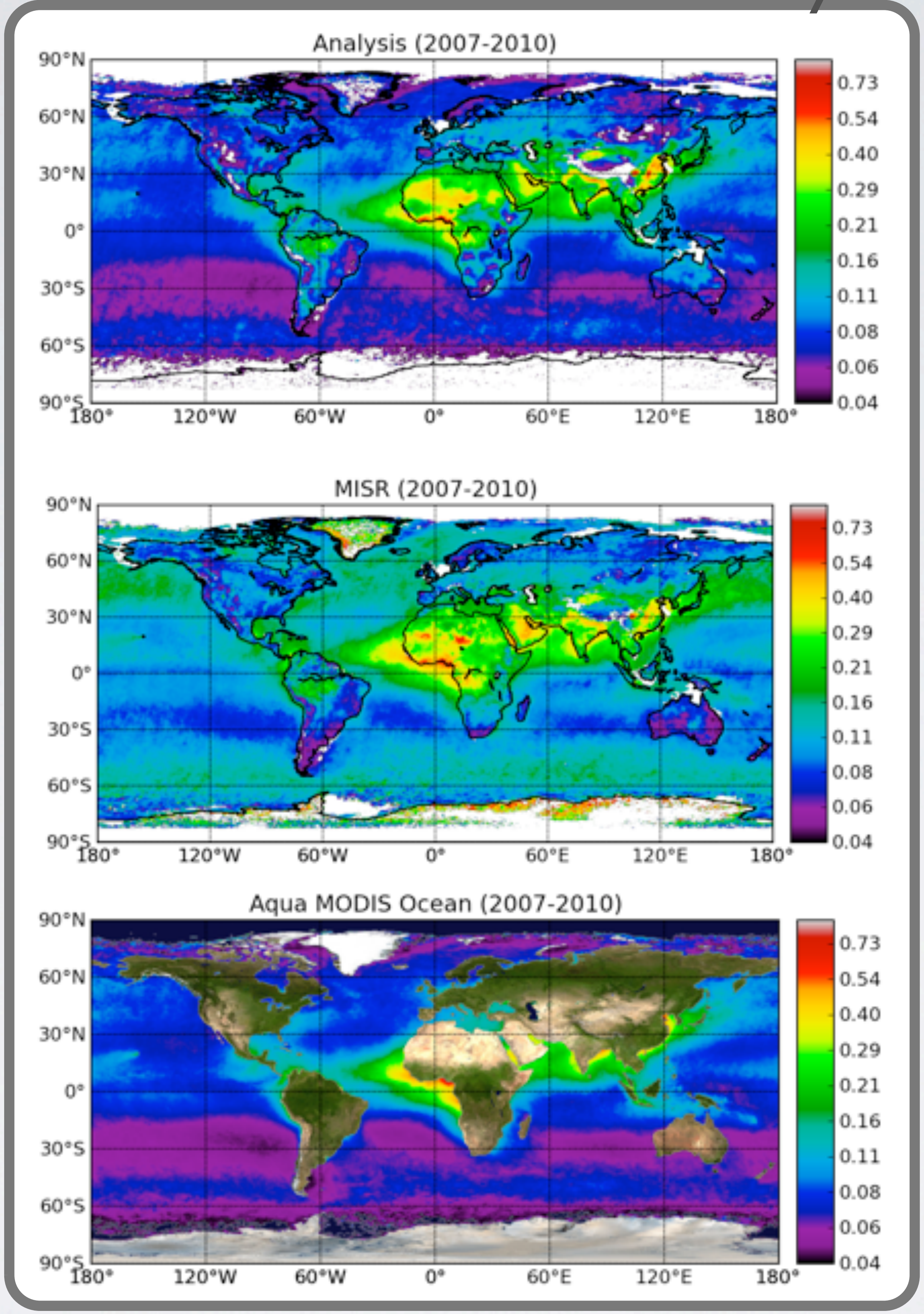
Aerosol Reanalysis

Feature	Description
Model	GEOS-5 Earth Modeling System (w/ GOCART) Constrained by MERRA Meteorology (Replay) Land sees obs. precipitation Driven by QFED daily Biomass Emissions
Aerosol Data Assimilation	Local Displacement Ensembles (LDE) MODIS reflectances AERONET Calibrated AOD's (Neural Net) Stringent cloud screening
Period	mid 2002-present (Aqua + Terra)
	2000-mid 2002 (Terra only)
Resolution	Horizontal: nominally 50 km Vertical: 72 layers, top ~85 km
Aerosol Species	Dust, sea-salt, sulfates, organic & black carbon

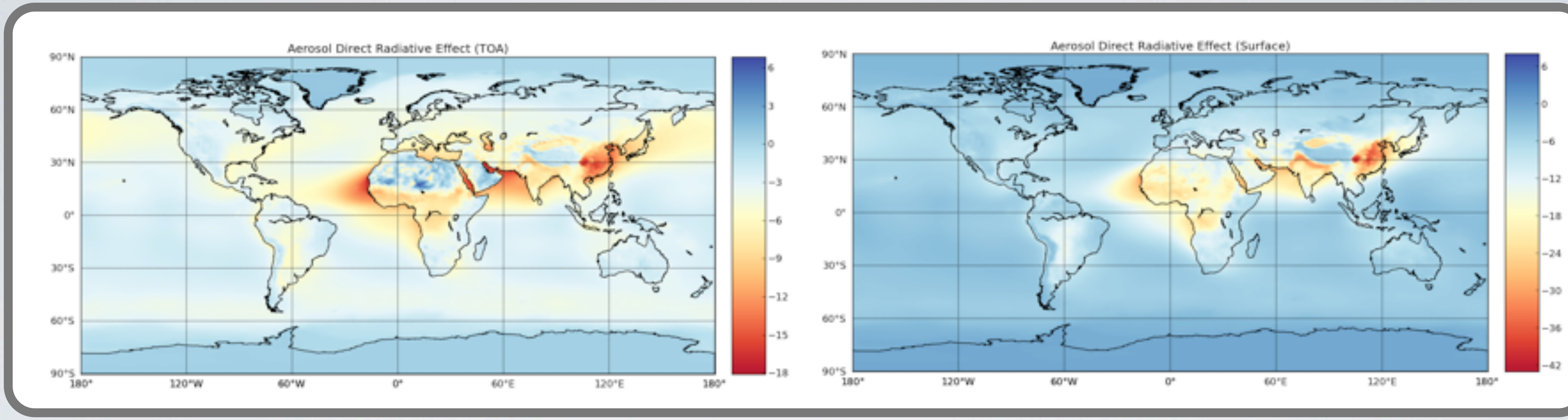
Aerosol Reanalysis



Aerosol Reanalysis



Clear-Sky Aerosol Direct Radiative Effect



Source	TOA SW DRE Ocean (Land)	Atmos. Ocean (Land)	Surface SW DRE Ocean (Land)
MERRAero	-3.8 (-4.3)	2.8 (6.8)	-6.6 (-11.1)
Other Observational Yu *et al.* (2006)	-5.5 ± 0.2 (-4.9 ± 0.7)	3.3 (6.8)	-8.8 ± 0.7 (-11.8±1.9)
Multi-model Ensemble Yu *et al.* (2006)	-3.4 ± 0.6 (-2.8 ± 0.6)	1.4 (4.4)	-4.8 ± 0.8 (-7.2 ± 0.9)
GEOS-5 (Free)	-3.4 (-2.7)	0.5 (2.8)	-3.9 (-5.5)

$$DRE_{SW} = \left(F_{SW}^{\downarrow} - F_{SW}^{\uparrow}\right)_{Aerosols} - \left(F_{SW}^{\downarrow} - F_{SW}^{\uparrow}\right)_{NoAerosols}$$

Future Directions

- Supporting upcoming HS3 and SEAC4RS missions
- Improved aerosol microphysics: MAM and CARMA
- GSI + Ensemble forecasting for model error characterization
- Advanced dynamical cores