Current and Future Applications of the GEOS-5 Aerosol Modeling System

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- Forecasting Support and Event Simulation
- Observation Simulation
- Aerosols-Chemistry-Climate
- Future Applications

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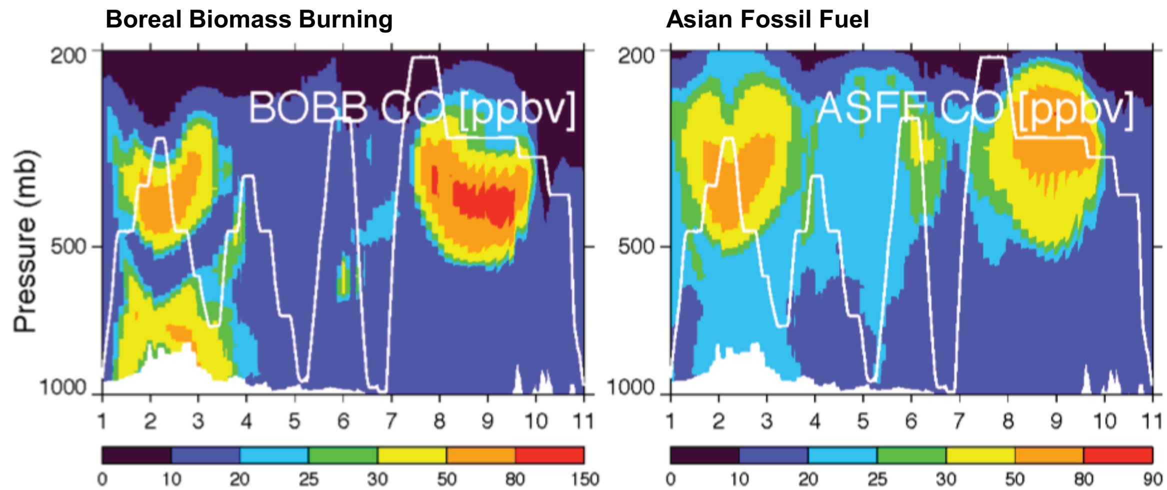
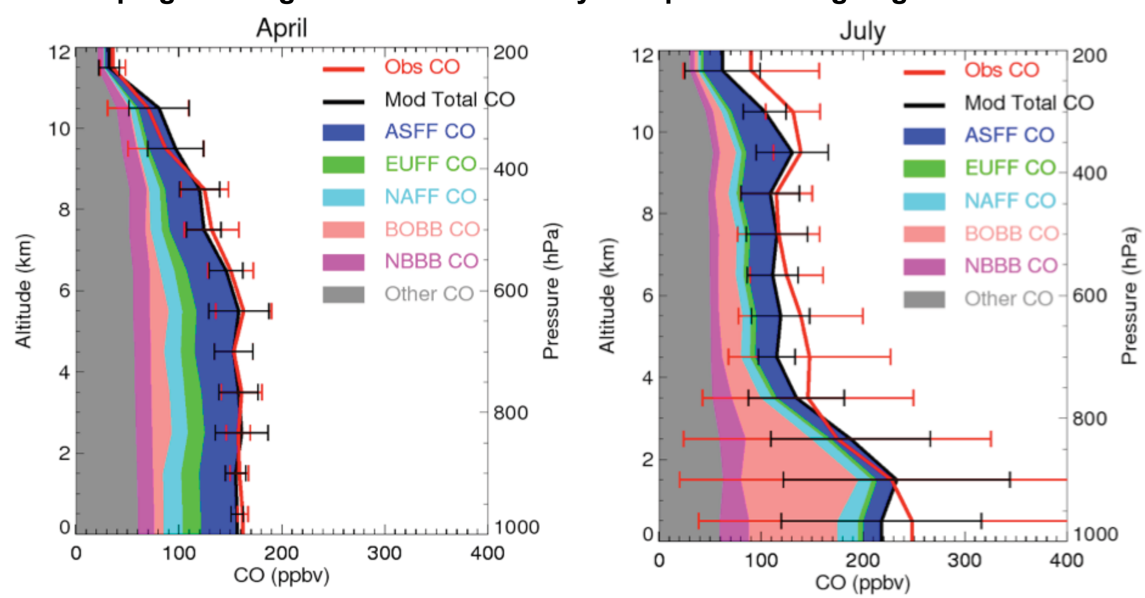
Forecasting for NASA Airborne Field Missions

- For ARCTAS GEOS-5 forecasting system deployed with online aerosol and CO tracers
- CO tracers tagged by region of origin or emission source to show air mass history
- Interpretation of observations
- Important: People deploy with the model to assist in interpretation, forecasting, and flight planning
- Contributions to numerous campaigns: TC4, ARCTAS, GloPac, SEAC4RS, HS3, DISCOVER-AQ, ...

Simulated CO profiles along July 21, 2008, flight from Cold Lake, Alberta, to Thule, Greenland



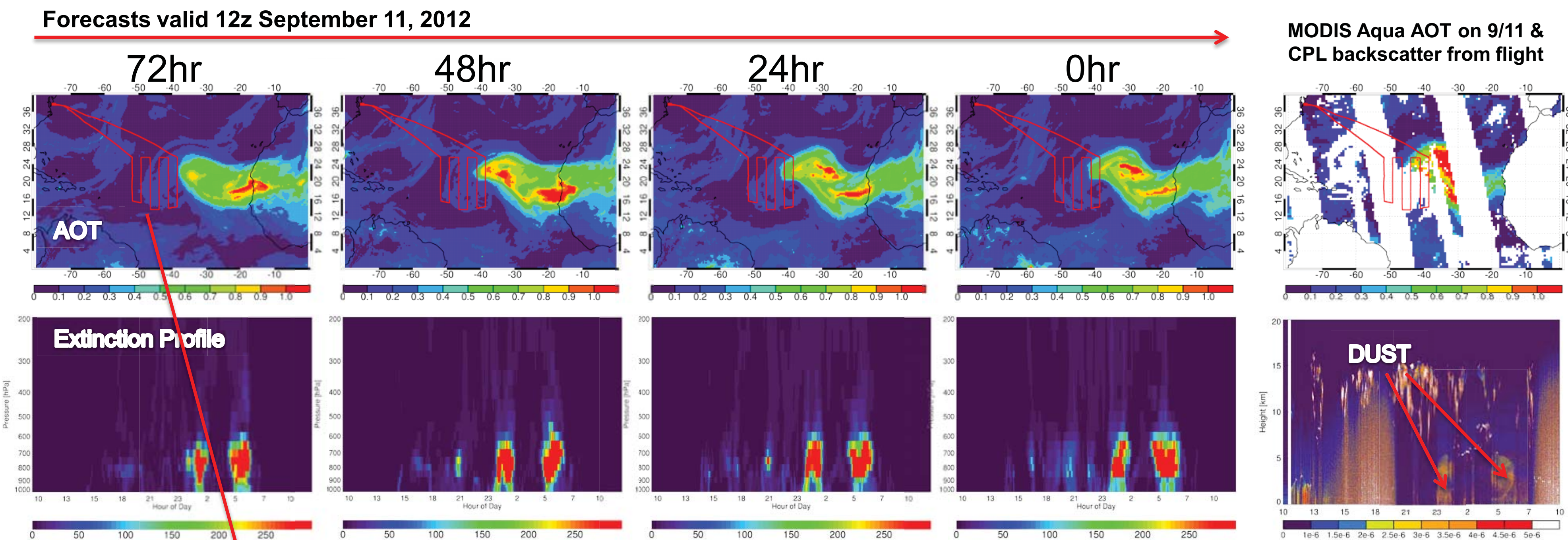
Campaign Averaged CO Distribution by Component Along Flight Tracks

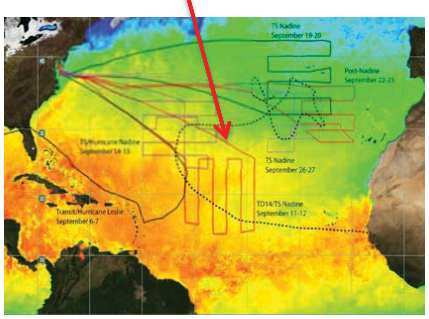


Bian et al., Source Attributions of Pollution to the Western Arctic During the NASA ARCTAS Field Campaign , *Atmos. Chem. Phys.*, 13, 4707-4721 (2013)

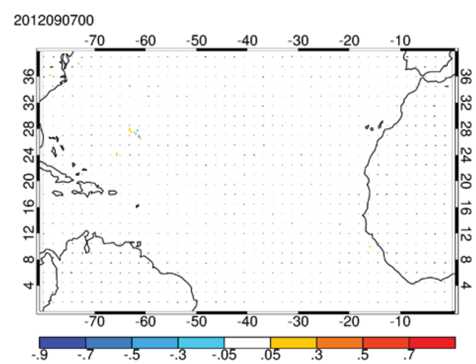
Aerosol Impacts on Cyclogenesis During HS3

- For NASA HS3 aircraft campaign GEOS-5 aerosol forecasts used to guide and interpret Global Hawk flights over hurricane Nadine (September 2012)
- One objective is to evaluate the skill of forecast as a function of lead time
- Another objective is to understand aerosol impact on storm development



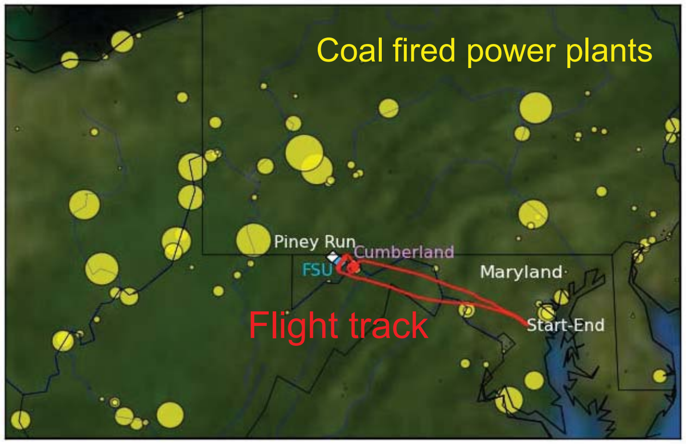


2012 HS3 Flight Tracks

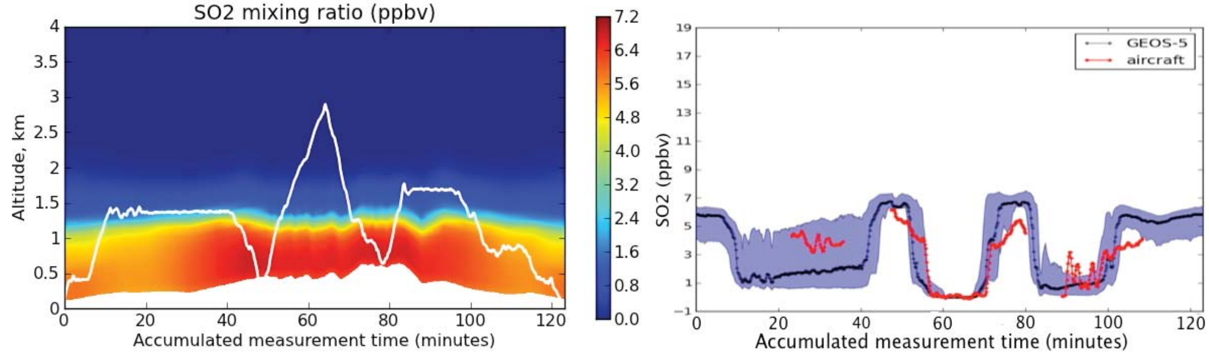


Forecast development of Hurricane Nadine shown as the difference in mid-troposphere winds (arrows) and aerosol optical thickness between simulations with and without aerosol radiative forcing

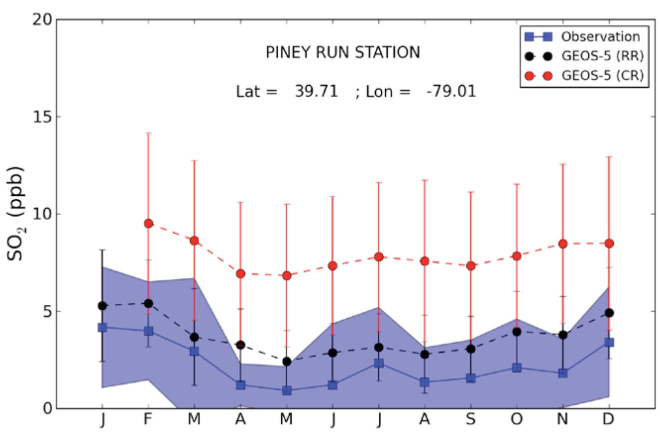
SO_2 simulations : Frostburg, MD Field Campaign



GEOS-5/GOCART SO_2 simulations (revised run) along flight track.



Monthly averaged concentrations of SO_2 at the surface in 2010 at the Piney Run station in Maryland.



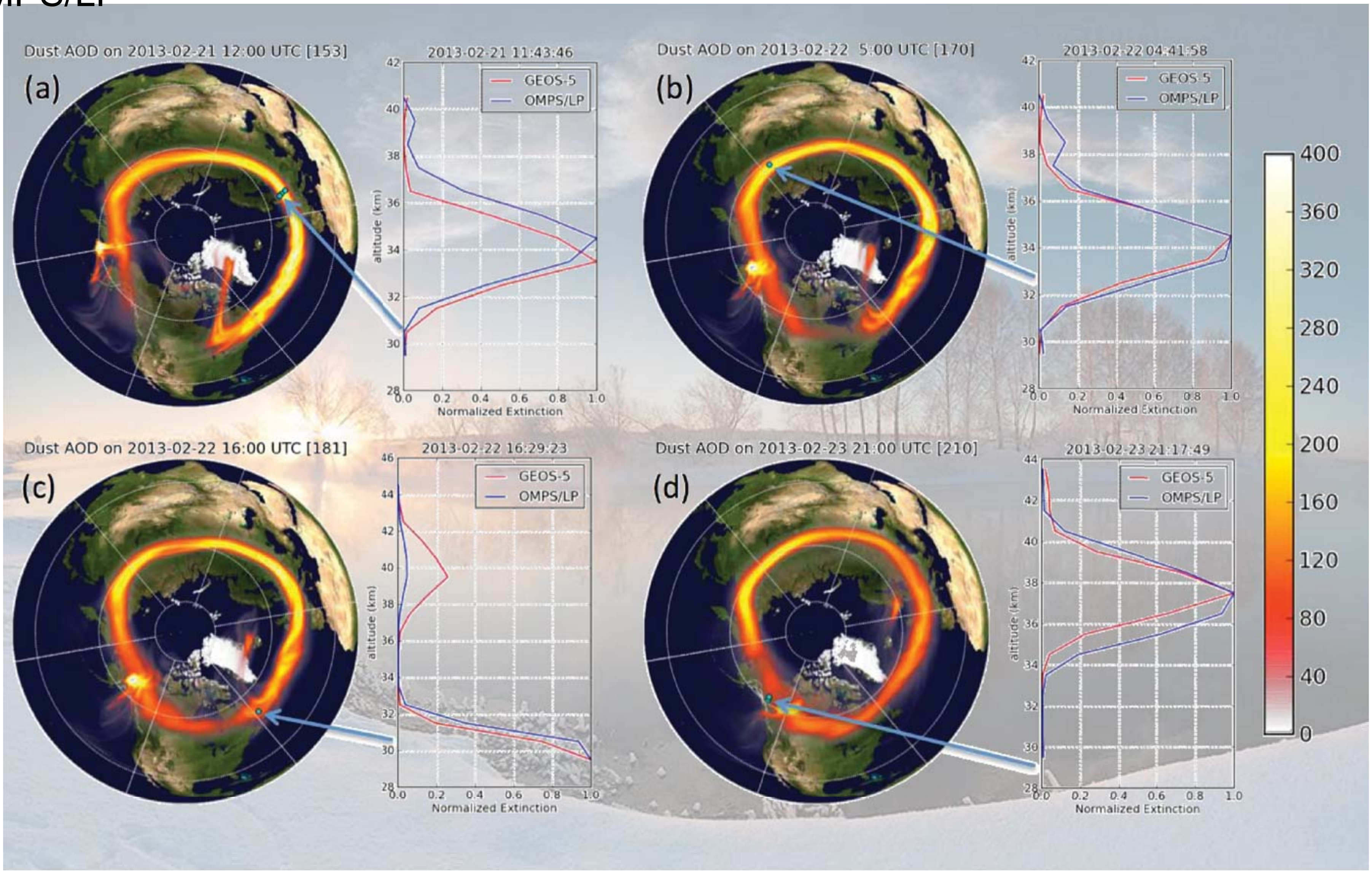
Opportunity to evaluate the GEOS-5 model simulations of SO2 against in-situ and aircraft measurements and guide model improvements :

- Evaluation of the GEOS-5 vertical distribution of SO2 : GEOS-5 captures most of the major features of the aircraft observations
- Evaluation of the GEOS-5 SO_2 surface concentrations :
  - New SO_2 anthropogenic emission dataset (EDGAR v4.1)
  - Adjustment of the vertical placement of the emissions in the model

Buchard et al., Manuscript to be submitted

Event Simulations: February 2013 Russian Meteorite

Debris from meteorite explosion over Chelyabinsk observed for weeks in Suomi NPP OMPS/LP



da Silva et al., Manuscript in preparation

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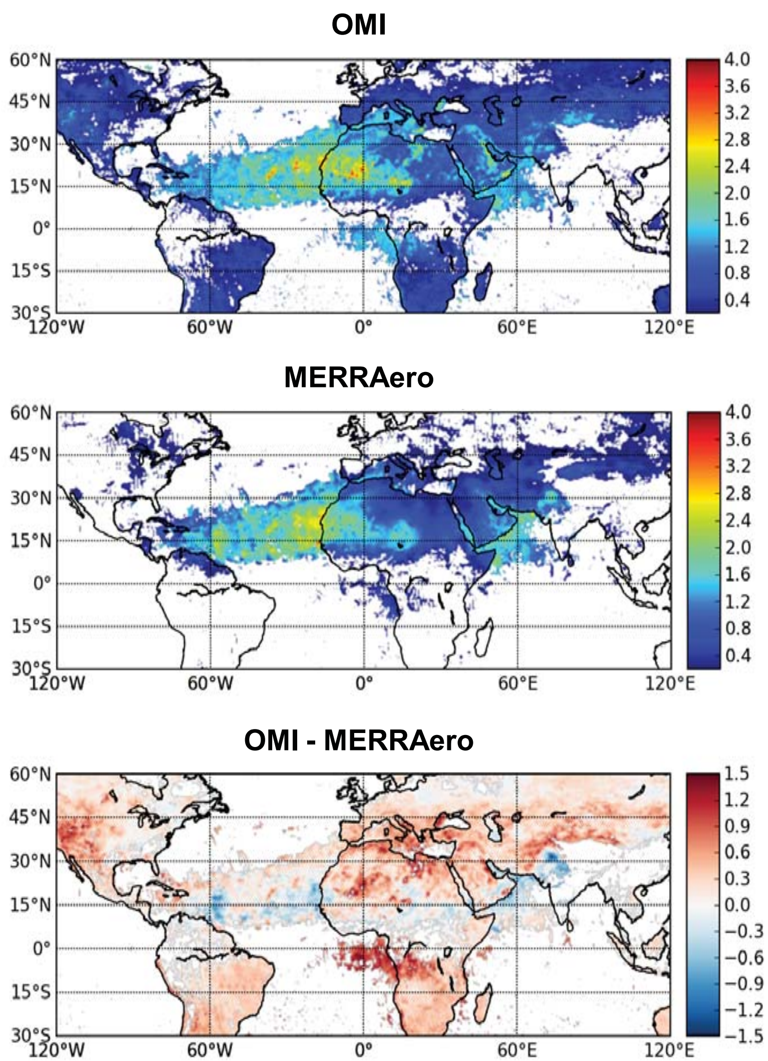
Observation Simulation from MERRAero

Comparison of Simulated GEOS-5 Aerosol Index to OMI observations (July 2007)



MERRAero uses MODIS aerosol observations to constrain total aerosol loading (AOT), but vertical distribution and composition remain unconstrained

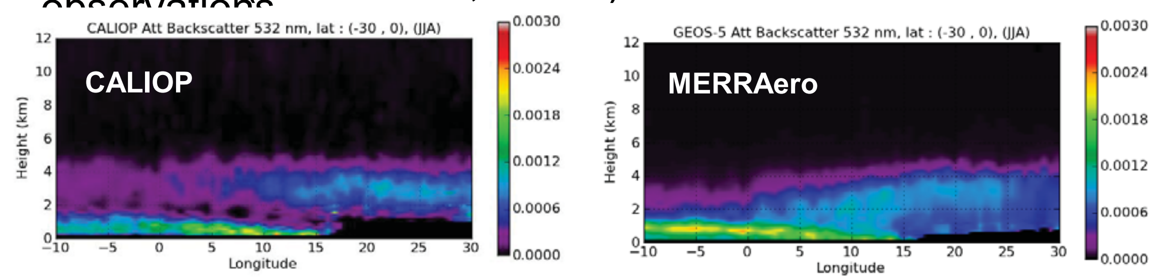
Simulation of the UV Aerosol Index at OMI locations:

- Developed interface between GEOS-5 and VLIDORT radiation code
- Simulated aerosol index sensitive to both absorption and aerosol plume height. Dust is well captured, but not African biomass burning

Simulation of aerosol backscatter at CALIOP locations

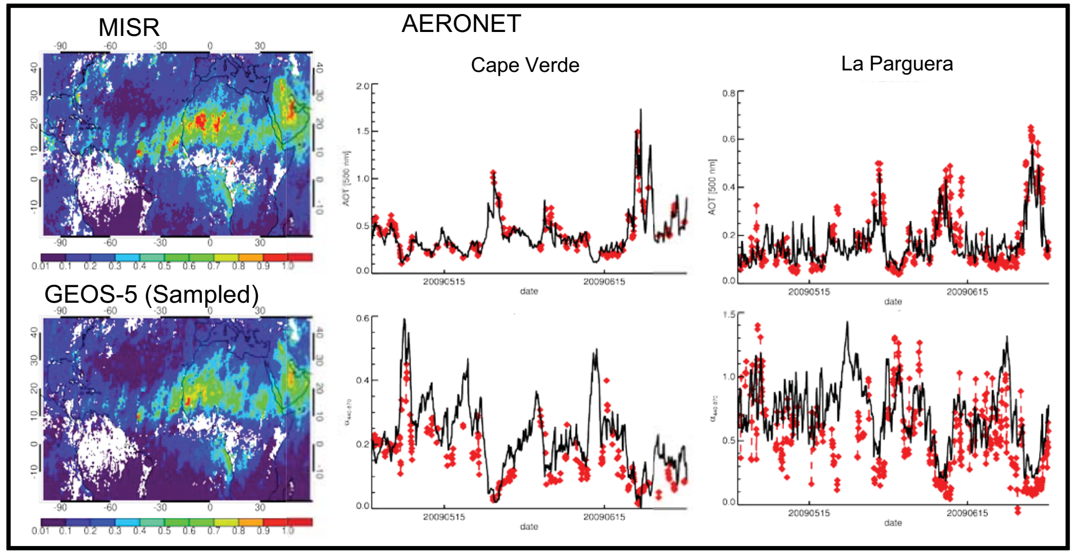
- CALIOP measurements : ascertain the misplacement of plume height by the model: the GEOS-5 biomass burning plume does not remain elevated in the simulation as it does in the observations

Comparison of GEOS-5 derived Attenuated Backscatter Coefficient to CALIOP measurements (Southern Africa, JJA 2011)

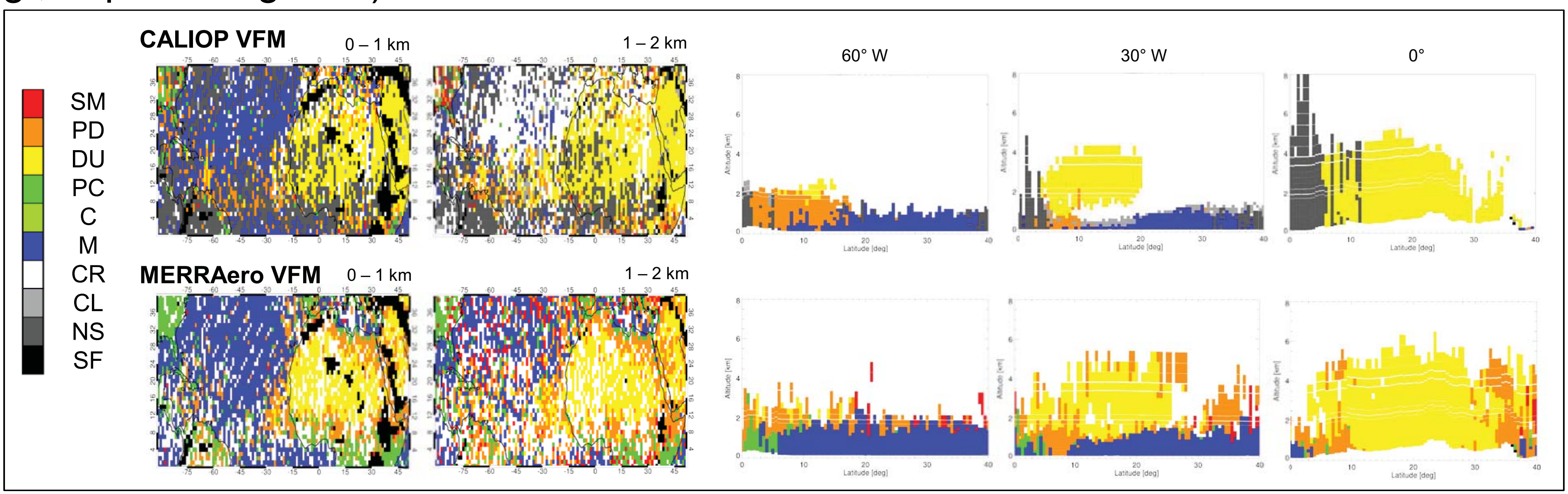


Buchard et al., Manuscript in preparation

Using the CALIOP Vertical Feature Mask to Evaluate Aerosol Composition



A complementary approach to investigate aerosol vertical distribution is to simulate the CALIOP lidar signal from MERRAero fields and then run CALIOP vertical feature mask algorithm (vertical composition mapping). This is possible because of detailed optical models (e.g., depolarizing dust)



Nowottnick et al., Manuscript in preparation

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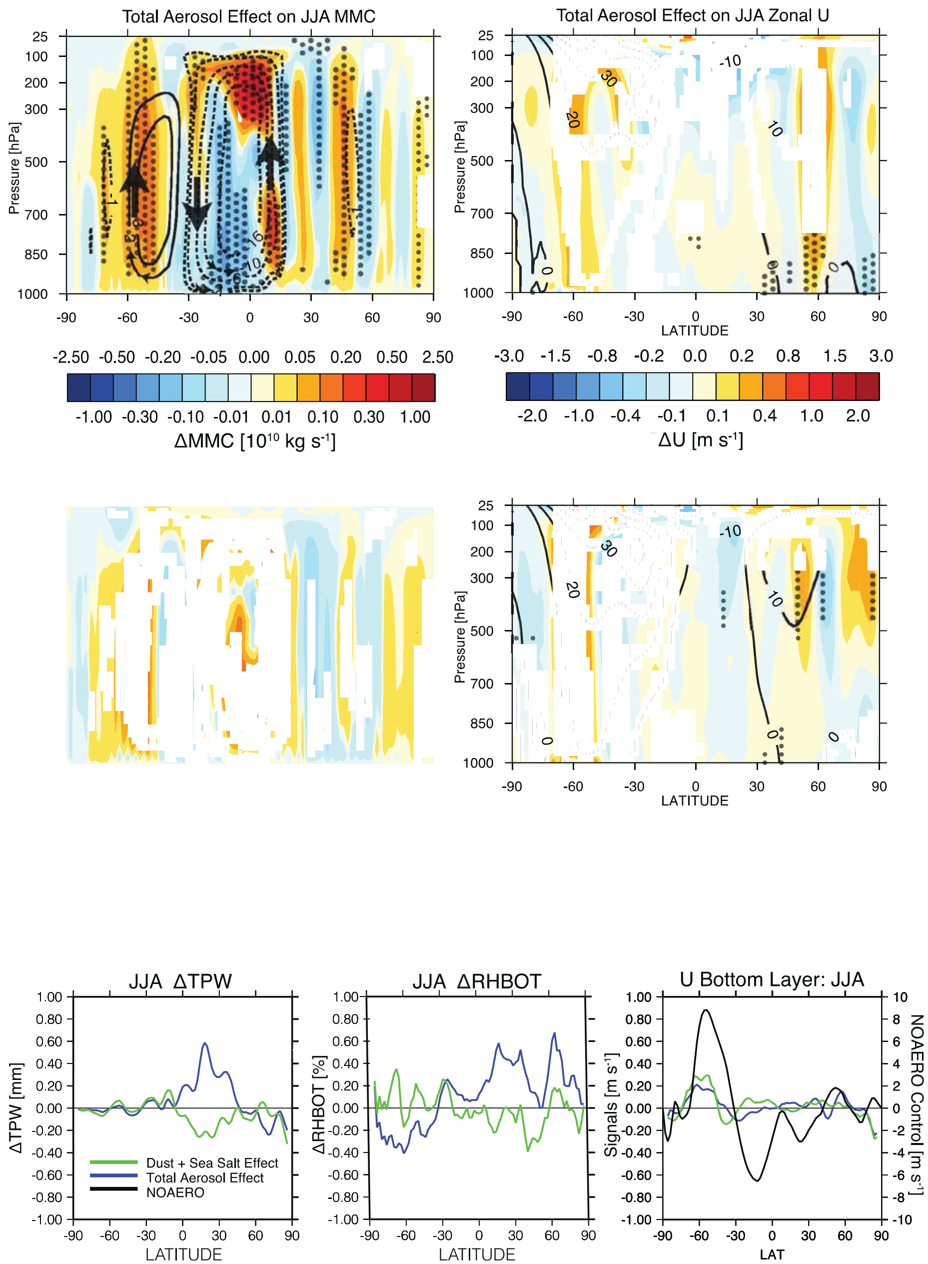
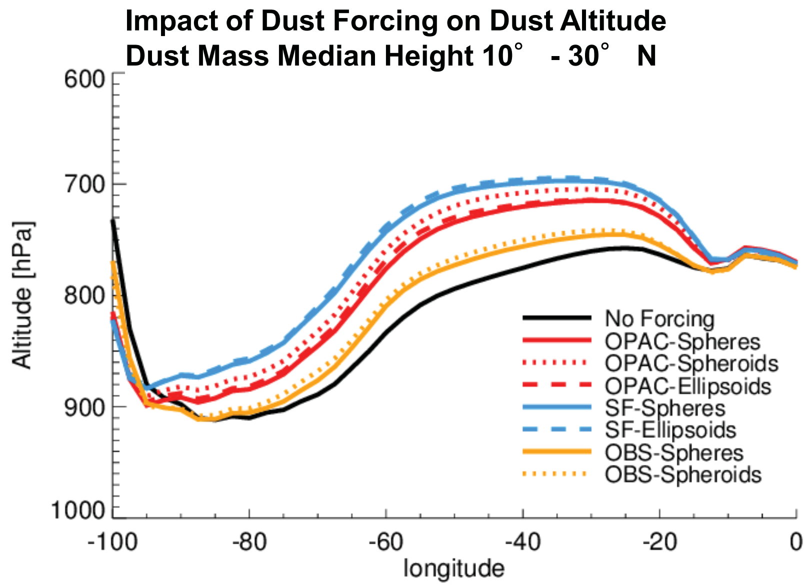
Response to Aerosol Direct and Semi-Direct Effects



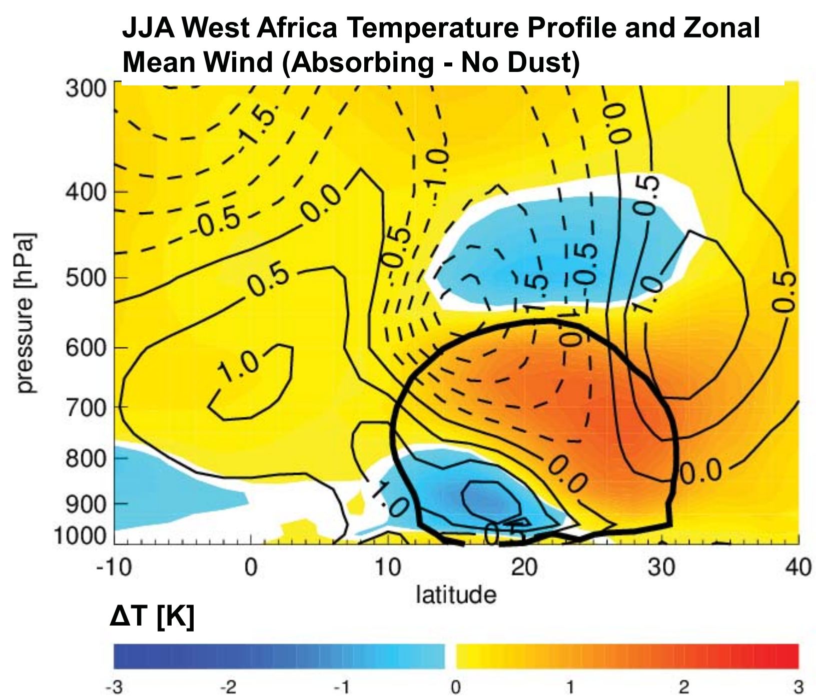
- Climate simulations forced with either *all* or *natural* (dust + sea salt) aerosols
- Aerosols radiatively coupled: direct and semi-direct effects included
- Total aerosol effect
  - Cooler land surface and warmer troposphere in tropics and midlatitudes reduces cloud amount (positive semi-direct effect)
  - Strengthened Hadley circulation, strengthening and poleward migration of midlatitude jets and storm tracks (expansion of the tropics)
  - Increased water vapor
- Natural aerosol effect
  - Generally opposite of total aerosol effect (weakened Hadley circulation, decreased atmospheric water vapor)
  - Response in SH strongly influenced by

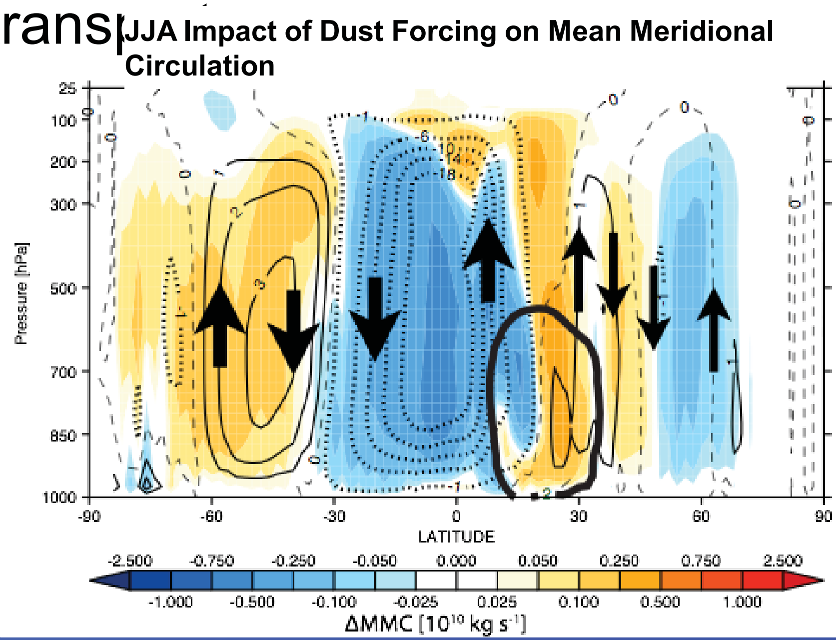
Randles et al., Direct and semi-direct aerosol effects in the NASA GEOS-5 AGCM: aerosol-climate interactions due to prognostic versus prescribed aerosols, *J. Geophys. Res.*, doi:10.1029/201

Dust Radiative Impact on Transport and Lifecycle



- Multi-decadal climate simulations with interactive dust aerosols
- Sensitivity to dust optical properties, including refractive index and particle shape
- Strengthening of African Easterly jet and elevation of Saharan dust plume associated with enhanced dust absorption leads to longer range transport

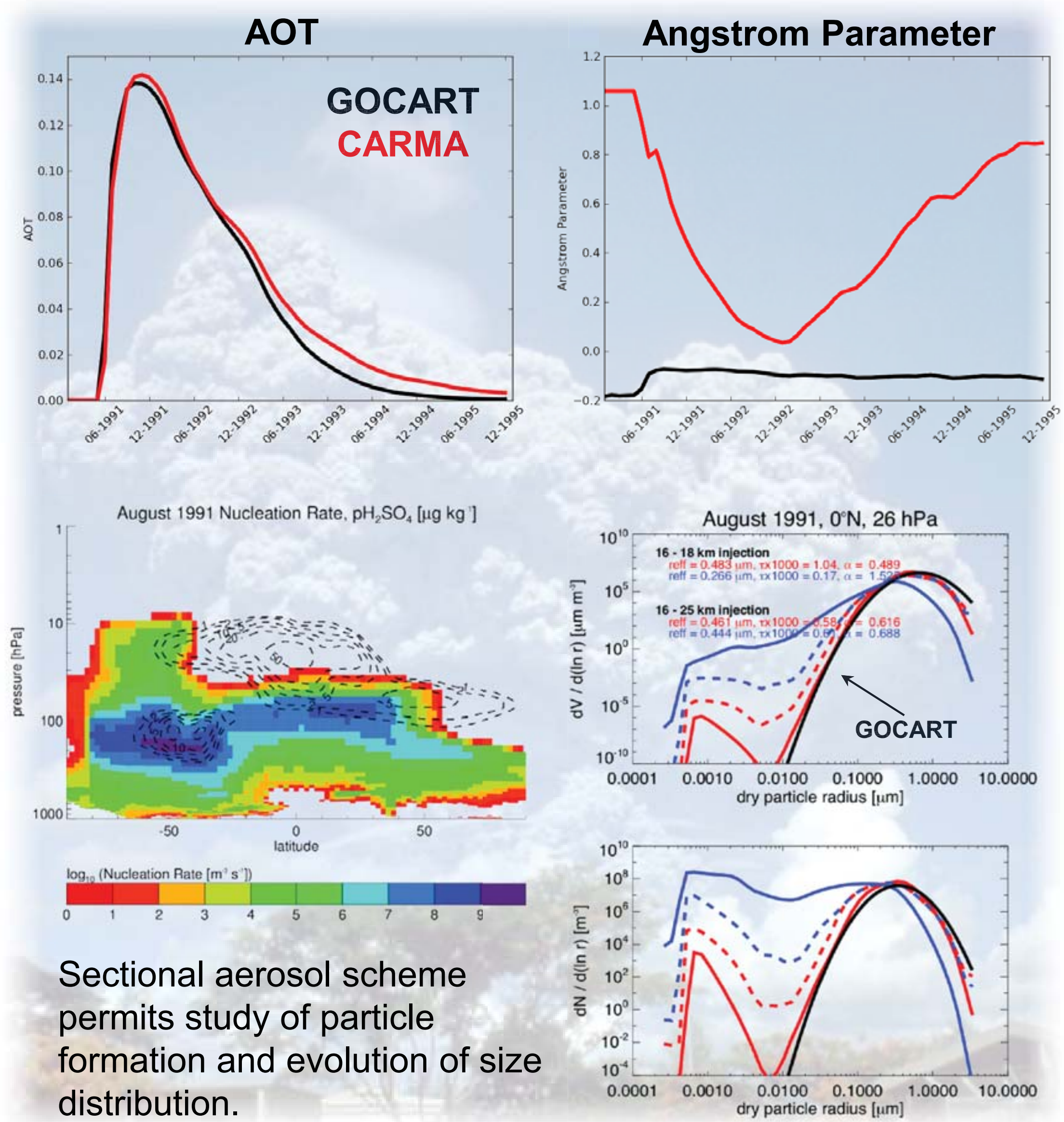




Colarco et al., Impact of Radiatively Interactive Dust Aerosols in the NASA GEOS-5 Climate Model: Sensitivity to Dust Particle Shape and Refractive Index, submitted *J. Geophys. Res.* (2013)

Simulation of Stratospheric Aerosols

- Modification of GOCART mechanism to treat a separate stratospheric sulfate with its own optical properties
- Coupling of stratospheric sulfate tracer with stratospheric chemistry module to investigate ozone impacts
- Additionally, development of a new sectional aerosol microphysical module (CARMA) that explicitly resolves evolution of aerosol particle size distribution
- Application to studies of 1991 Mt. Pinatubo eruption



Sectional aerosol scheme permits study of particle formation and evolution of size distribution.

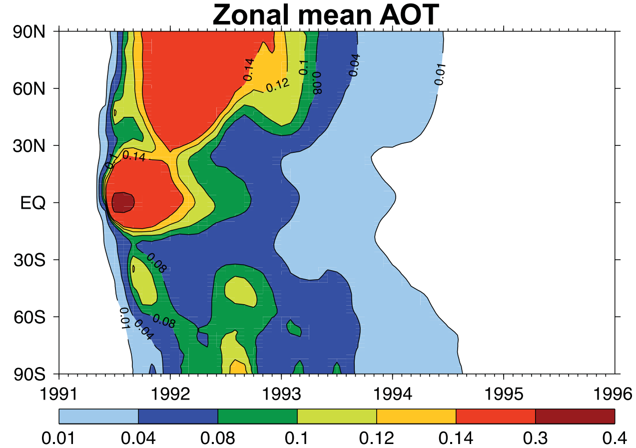
Aquila et al., Dispersion of the Volcanic Sulfate Cloud from a Mount Pinatubo-like Eruption, *J. Geophys. Res.*, 117, D06216, doi: 10.1029/2011JD016968 (2012)

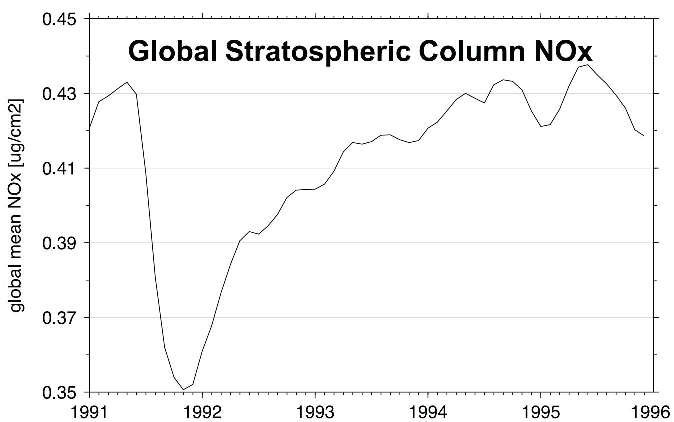
Aquila et al., The Response of Ozone and Nitrogen Dioxide to the Eruption of Mt. Pinatubo at Southern and Northern Midlatitudes, *J. Atm. Sci.*, 70 DOI: 10.1175/JAS-D-12-0143.1 (2013)

Aerosol-Chemistry-Climate Interaction

- GEOSCCM with coupled aerosol (GOCART) and stratospheric chemistry.

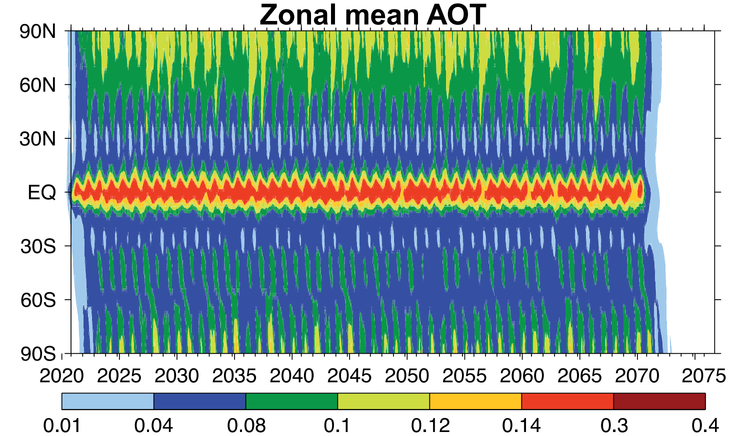
- Pinatubo: 20 Tg SO_2 injection between 15 km and 18 km on 15 June 1991

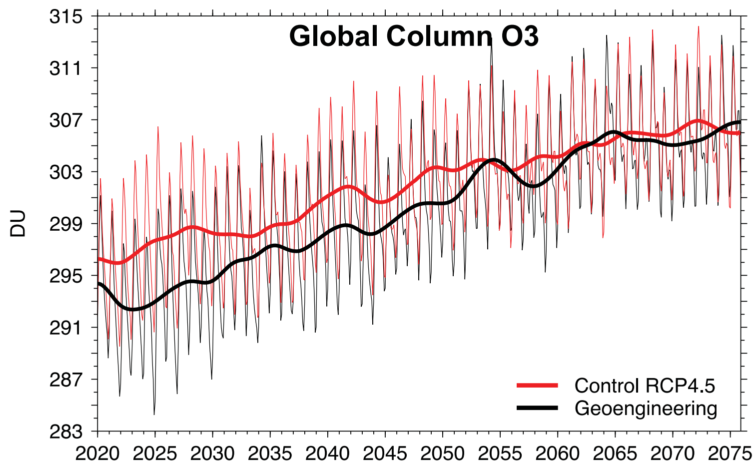




Aquila et al., The Response of Ozone and Nitrogen Dioxide to the Eruption of Mt. Pinatubo at Southern and Northern Midlatitudes, *J. Atm. Sci.*, 70 DOI: 10.1175/JAS-D-12-0143.1 (2013)

- Geoengineering: 5 Tg/year SO_2 between 16 km and 25 km for 50 years





Pitari et al., Stratospheric Ozone Response in Experiments G3 and G4 of the Geoengineering Model Intercomparison Project (GeoMIP), in preparation for J. Geophys. Res. (2013)

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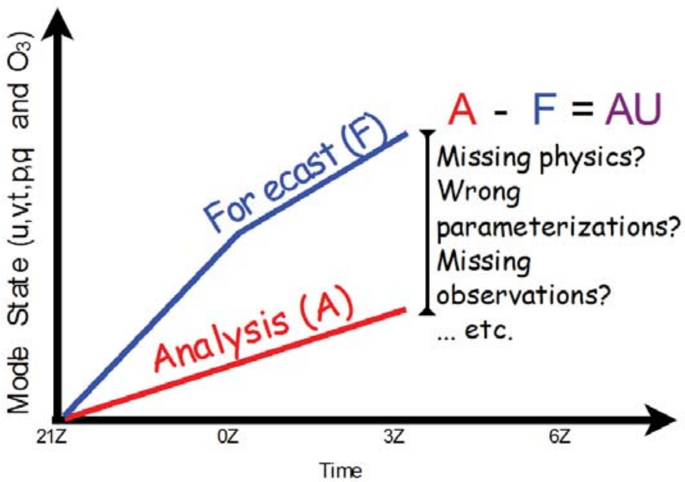
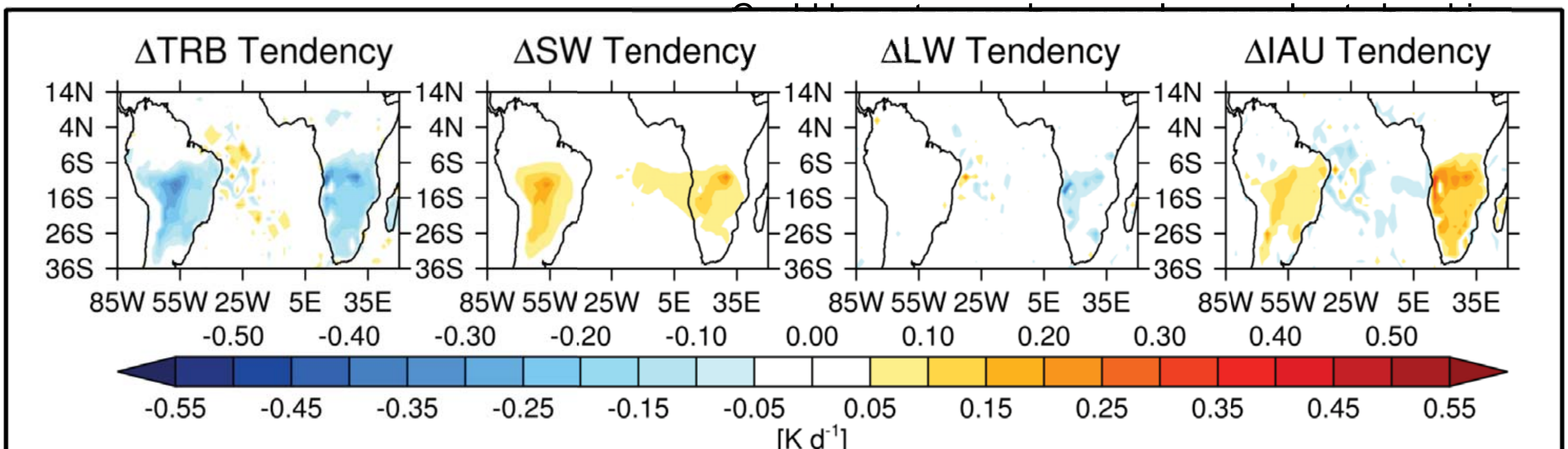
Biomass Burning Aerosol Direct and Semi-Direct Effects



- Replaying from MERRA, the GEOS-5 Analysis Update (AU) constrains the model state (*u, v, t, p, q*) every 6-hours, preventing aerosol heating from inducing regional-scale circulation changes that could impact clouds → <u>isolates thermodynamic semi-direct effect only.</u>
- AU can also be used, along with observations of aerosol properties, as an additional tuning parameter in a series of sensitivity studies:
  - Biomass burning aerosols heat atmosphere (positive SW temperature tendency, below).
  - BUT, AU shows that additional heating is needed!

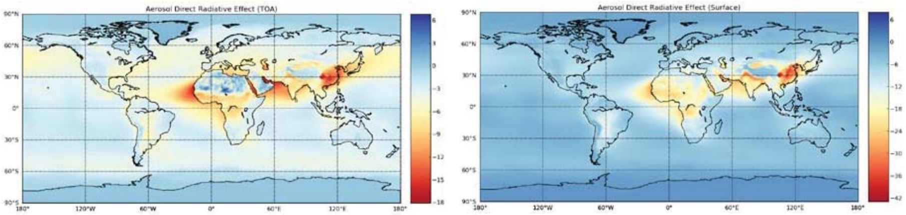


850-mb Temperature tendencies due to biomass burning aerosol

Randles et al., Improving estimates of biomass burning aerosol direct and semi-direct effects using the GEOS-5 Incremental Analysis Update (IAU), (NNH10ZDA001N-ACMAP)

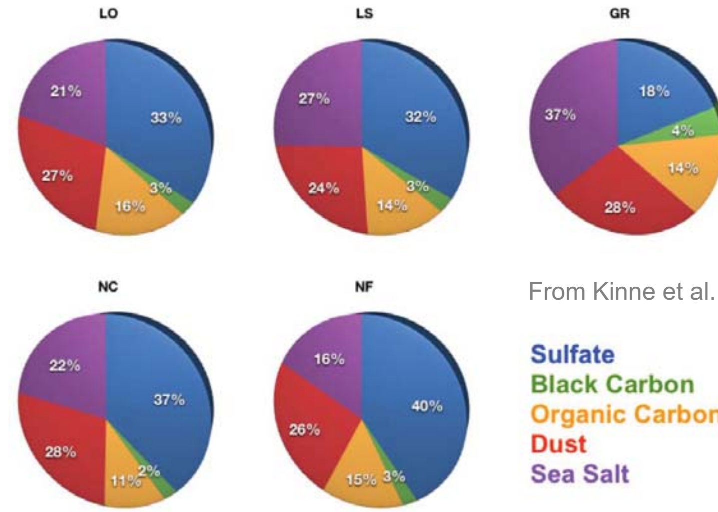
Diagnosing Model Dependent Uncertainty in Estimates of Aerosol Direct Effect

MERRAero Estimated Clear-Sky Aerosol Radiative Effect



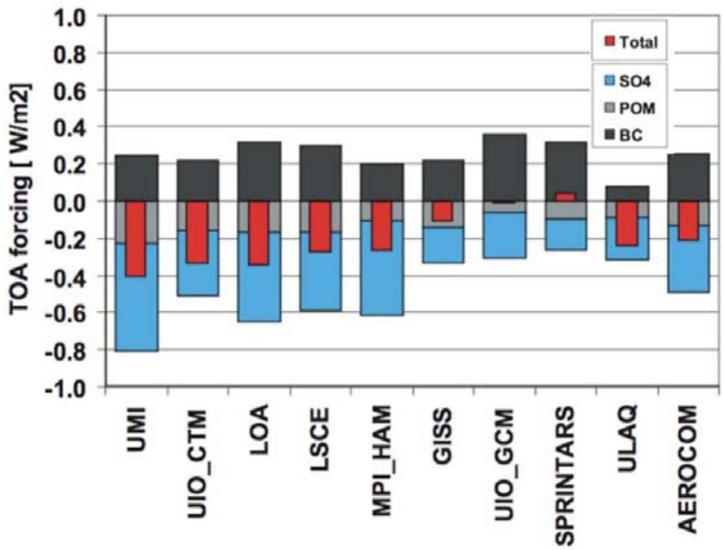
Source	TOA SW DRE Ocean (Land)	Atmos. Ocean (Land)	Surface SW DRE Ocean (Land)
MERRAero	-3.8 (-4.3)	2.8 (6.8)	-6.6 (-11.1)
Other Observational Yu *et al.* (2006)	-5.5 ± 0.2 (-4.9 ± 0.7)	3.3 (6.8)	-8.8 ± 0.7 (-11.8±1.9)
Multi-model Ensemble Yu *et al.* (2006)	-3.4 ± 0.6 (-2.8 ± 0.6)	1.4 (4.4)	-4.8 ± 0.8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

Sampling of Aerosol Composition Diversity in AeroCom



From Kinne et al. 2006

Diversity in AeroCom Anthropogenic Direct Forcing

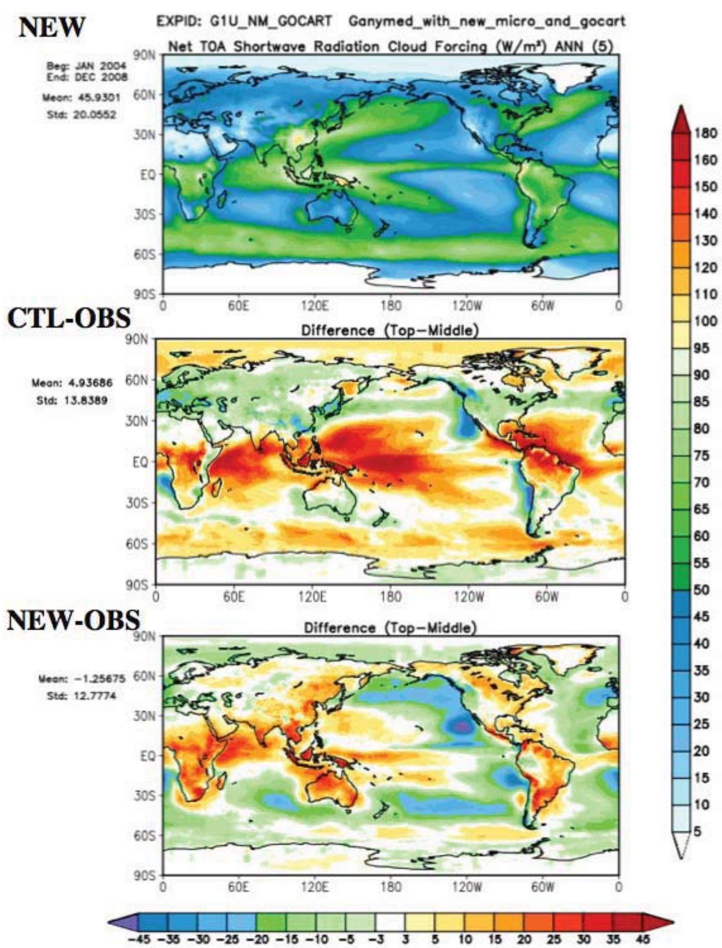


From Schulz et al. 2006

- MERRAero constrains the total AOT (550 nm)
- Aerosol composition, vertical distribution, etc., remain very model dependent → corresponding uncertainties in forcing
- Indeed, AeroCom and other studies make clear that there are large model dependencies in estimates of aerosol direct effect
- Biomass burning aerosols heat atmosphere (positive SW temperature tendency, below).
- BUT, AU shows that additional heating is needed!
- Could be not enough aerosol, aerosol not absorbing enough, etc.

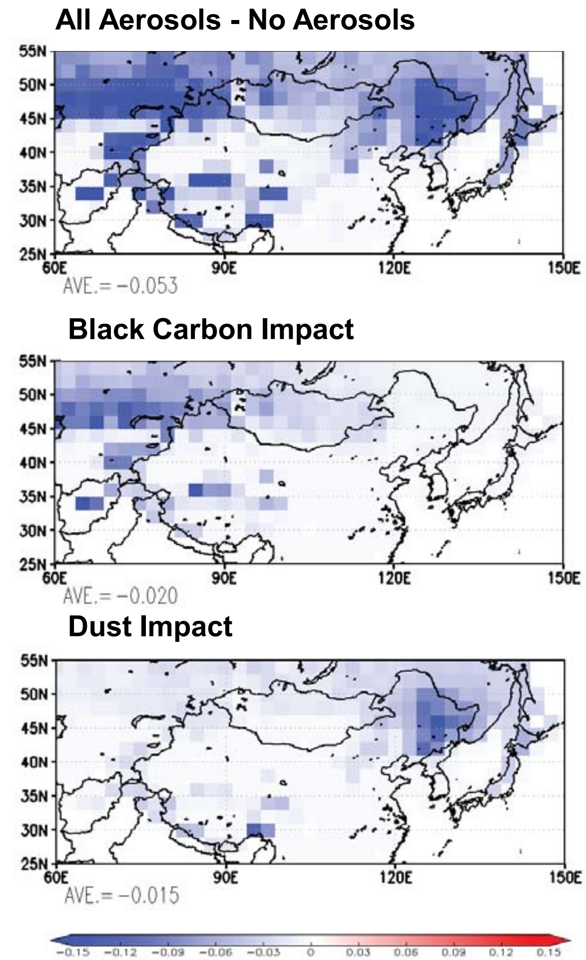
Future Applications

Enhanced Composition and Size Modeling for Aerosol Direct and Indirect Effects



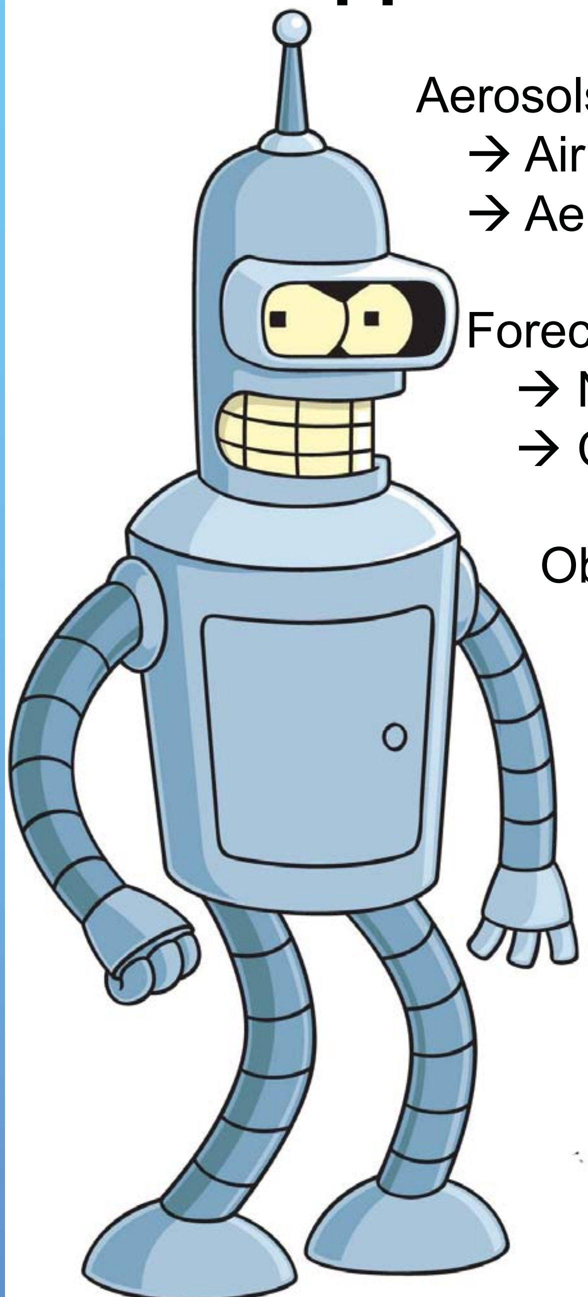
Courtesy Donifan Barahona

Change in Surface Reflectance Due to Aerosol Deposition over Snow



Courtesy Teppei Yasunari

Future Applications



Aerosols Composition and Chemistry
- → Air quality (TEMPO, Geo-CAPE, GEMS, Sentinel-4)
- → Aerosol-Clouds (CATS, PACE/ACE, EarthCare)

Forecasting and Event Simulation
- → NRT volcanic emission forecasting
- → Continued involvement with field missions

Observation Simulation
- → Observation interpretation (PODEX)
- → OSSEs for mission design (ACE, CATS)
- → Data assimilation activities (…)

Aerosols-Chemistry-Climate
- → Stratospheric aerosols, ozone recovery
- → CCMI
- → Coupled ocean → climate impacts