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)
GOCART Component

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

<table>
<thead>
<tr>
<th>Species</th>
<th>Source Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>dust</td>
<td>wind and topographic source, 5 mass bins</td>
</tr>
<tr>
<td>sea salt</td>
<td>wind driven source, 5 mass bins</td>
</tr>
<tr>
<td>black carbon</td>
<td>anthropogenic and wildfire source, mass hydrophobic and hydrophilic</td>
</tr>
<tr>
<td>organic carbon</td>
<td>anthropogenic, biogenic, and wildfire source, mass hydrophobic and hydrophilic</td>
</tr>
<tr>
<td>sulfate</td>
<td>anthropogenic and wildfire source of SO2, oxidation to SO4 mass</td>
</tr>
</tbody>
</table>

- 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
• 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
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Observation Correction

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Observation Correction

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Observation Comparison

MODIS Aqua

Neural Net

Annual Mean 2008
Aerosol Assimilation

GAAS - Goddard Aerosol Assimilation System

ESMF

MAPL

AGCM

Surface

Turbulence

Radiation

GWD

GOCART

GAAS

Physics

Dynamics

FV Core

Sphere

Moist

Chemistry

GMI

GEOschem

CARMA

MOMents

Aerosols and Aerosol Assimilation

ADAS

OGCM

Wave

ICE

P. Colarco, ICAP Workshop, May 14 - 17, 2012, Frascati, Italy
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° x 0.3125°, 72 hybrid 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
Model Developments

• **Aerosol Forecasting System**
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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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- Assimilating MODIS derived AOT (land/ocean, Terra/Aqua) every 3 hours
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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
Model Developments

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Seasalt Emission Tuning

- 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

![Graph showing the ratio of observed to modeled mass concentrations of coarse mode SS as a function of observed sea surface temperature (SST). The graph includes data from various cruises and a polynomial fit for warm waters.](image-url)
Seasalt Emission Tuning

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Seasalt not major contributor to AOT: $\text{AOT}_{ss}/\text{AOT} < 0.75$
Seasalt Emission Tuning

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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.

Simulated dust aerosol optical thickness (AOT, left), single scatter albedo (SSA, middle), and asymmetry 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.
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**
• Aerosol Reanalysis
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.

<table>
<thead>
<tr>
<th>% Change</th>
<th>Land JJA</th>
<th>Ocean JJA</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2M</td>
<td>29.2↑</td>
<td>50↑</td>
</tr>
<tr>
<td>S850</td>
<td>37.6↑</td>
<td>17.1↑</td>
</tr>
<tr>
<td>S500</td>
<td>8.4↑</td>
<td>32.1↓</td>
</tr>
</tbody>
</table>
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!

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GOAERO Clear-sky DRE</td>
<td>-4.8 (-4.5)</td>
<td>1.7 (3.8)</td>
<td>-6.5 (-8.3)</td>
</tr>
<tr>
<td>CLIMERO Clear-sky DRE</td>
<td>-5.1 (-4.6)</td>
<td>1.7 (3.8)</td>
<td>-6.7 (-8.4)</td>
</tr>
</tbody>
</table>
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# Aerosol Reanalysis

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td><strong>Model</strong></td>
<td>GEOS-5 Earth Modeling System (w/ GOCART)</td>
</tr>
<tr>
<td></td>
<td>Constrained by MERRA Meteorology (Replay)</td>
</tr>
<tr>
<td></td>
<td>Land sees obs. precipitation</td>
</tr>
<tr>
<td></td>
<td>Driven by QFED daily Biomass Emissions</td>
</tr>
<tr>
<td><strong>Aerosol Data Assimilation</strong></td>
<td>Local Displacement Ensembles (LDE)</td>
</tr>
<tr>
<td></td>
<td>MODIS reflectances</td>
</tr>
<tr>
<td></td>
<td>AERONET Calibrated AOD’s (Neural Net)</td>
</tr>
<tr>
<td></td>
<td>Stringent cloud screening</td>
</tr>
<tr>
<td><strong>Period</strong></td>
<td>mid 2002-present (Aqua + Terra)</td>
</tr>
<tr>
<td></td>
<td>2000-mid 2002 (Terra only)</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>Horizontal: nominally 50 km</td>
</tr>
<tr>
<td></td>
<td>Vertical: 72 layers, top ~85 km</td>
</tr>
<tr>
<td><strong>Aerosol Species</strong></td>
<td>Dust, sea-salt, sulfates, organic &amp; black carbon</td>
</tr>
</tbody>
</table>
Aerosol Reanalysis
Aerosol Reanalysis
## Clear-Sky Aerosol Direct Radiative Effect

<table>
<thead>
<tr>
<th>Source</th>
<th>TOA SW DRE</th>
<th>Atmos.</th>
<th>Surface SW DRE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ocean (Land)</td>
<td>Ocean (Land)</td>
<td>Ocean (Land)</td>
</tr>
<tr>
<td><strong>MERRAero</strong></td>
<td>-3.8</td>
<td>2.8</td>
<td>-6.6</td>
</tr>
<tr>
<td><strong>Other Observational</strong></td>
<td>-5.5 ± 0.2</td>
<td>3.3</td>
<td>-8.8 ± 0.7</td>
</tr>
<tr>
<td>Yu <em>et al.</em> (2006)</td>
<td>(-4.9 ± 0.7)</td>
<td>(6.8)</td>
<td>(11.8 ± 1.9)</td>
</tr>
<tr>
<td><strong>Multi-model Ensemble</strong></td>
<td>-3.4 ± 0.6</td>
<td>1.4</td>
<td>-4.8 ± 0.8</td>
</tr>
<tr>
<td>Yu <em>et al.</em> (2006)</td>
<td>(-2.8 ± 0.6)</td>
<td>(4.4)</td>
<td>(-7.2 ± 0.9)</td>
</tr>
<tr>
<td><strong>GEOS-5 (Free)</strong></td>
<td>-3.4</td>
<td>0.5</td>
<td>-3.9</td>
</tr>
<tr>
<td></td>
<td>(-2.7)</td>
<td>(2.8)</td>
<td>(-5.5)</td>
</tr>
</tbody>
</table>

\[
\text{DRE}_{\text{SW}} = (F^\downarrow_{\text{SW}} - F^\uparrow_{\text{SW}})_{\text{Aerosols}} - (F^\downarrow_{\text{SW}} - F^\uparrow_{\text{SW}})_{\text{NoAerosols}}
\]
Future Directions

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