GEOS-5 Aerosol Modeling & Data Assimilation:
Update on Recent and Future Development

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AEROCENTER Annual Meeting
GSFC Visitor Center
Greenbelt, MD, 31 May 2013
Talk Overview

GEOS-5

Aerosol Development

Summary

Recent

Last Year

Future

~ 5 years

On-going

~ 1 year
GEOS-5 Earth-System Model

From weather to seasonal to decadal time scales
Integrated Earth System Analysis

Data Assimilation in GEOS-5
Global 5-day chemical forecasts customized for each campaign
- O₃, aerosols, CO, CO₂, SO₂
- Resolution: Nominally 25 km

Driven by real-time biomass emissions from MODIS

Assimilated aerosols interacts with circulation through radiation

http://gmao.gsfc.nasa.gov/forecasts/
Past Year Highlights
## MERRAero Overview

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model</strong></td>
<td>GEOS-5 Earth Modeling System (w/ GOCART) Constrained by MERRA Meteorology</td>
</tr>
<tr>
<td></td>
<td>(Replay) Land sees obs. precipitation (like MERRA_{\text{Land}}) Driven by</td>
</tr>
<tr>
<td></td>
<td>QFED daily Biomass Emissions</td>
</tr>
<tr>
<td><strong>Aerosol Data Assimilation</strong></td>
<td>Local Displacement Ensembles (LDE) MODIS reflectances</td>
</tr>
<tr>
<td></td>
<td>AERONET Calibrated AOD’s (Neural Net) Stringent cloud screening</td>
</tr>
<tr>
<td><strong>Period</strong></td>
<td>mid 2002-present (Aqua + Terra)</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>
AERONET Validation

Aerosol Optical Thickness PDF (2007-2010)

\[ \eta = \log(\tau + 0.01) \]
Maritime Aerosol Network

Smirnov et al. (2011)

- GOCART-SP
- GEOS-Chem-SP
- AeroCom Median-SP
- MODIS-SP
- MISR-SP
- Terra (Standard)-SP
- DA Terra-SP
- Aqua (Standard)-SP
- DA Aqua-SP

frequency of occurrences, %

AOD diff (Model/Sat - SP)

MERRAero O-A (2007-2010)

PDF

Parameter: \( \tau \)
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 (thanks to LANCE)
- Prescribed diurnal cycle

JCSDA: inclusion of geo-stationary information
Modeling Interannual Variability of Biomass Burning Emissions

- BB emission anomalies respond directly to precipitation and surface humidity conditions.
- The normalized Canadian Fire Weather Index captures the *flammability* conditions as a function of surface meteorology.

Parameterization:

\[ E = \mathcal{E} \left( \frac{I}{I_{clm}} \right)^{\alpha_b} E_{clm} \]

Maritime Continent Example
GEOS-5/GOCART Transition to NCEP GFS

Development and operational implementation of the NEMS-GFS Aerosol Component represents a successful three-year “research to operations” project sponsored by NASA Applied Science Program, JCSDA and NWS

Operational September 2013

Mark Iredell (NEMS team lead)
Sarah Lu (aerosol modeling)
Shrinivas Moorthi (physics)
Yu-Tai Hou (radiation-aerosol)
Henry Juang (dynamics)
Jun Wang (I/O and ESMF infrastructure)
Hui-Ya Chuang (unified post)
Weiyu Yang (ESMF infrastructure)
Perry Shafran (verification)

Collaborators
GSFC (Arlindo da Silva, Mian Chin, Peter Colarco) for aerosol modeling
NESDIS (Shobha Kondragunta and Xiaoyang Zhang) for biomass burning emissions
NRL (Jeff Reid, Walter Sessions) for model inter comparison
ECMWF (Angela Benedetti, Jean Jacques Morcrette, Johannes Kaiser, Luke Jones) for volcanic ashes

Courtesy: Sarah Lu
Joint NASA/GMAO, NESDIS/STAR, and NWS/NCEP project to:

- Develop near real time biomass burning emissions product covering the whole globe from polar and geostationary satellites for NEMS-GFS-GOCART
  - Globally, biomass burning is one of the primary sources of aerosols; burning varies seasonally, geographically and is either natural (e.g., forest fires induced by lightning) or human induced (e.g., agricultural burning for land clearing). Satellites can provide this information on a real time basis.
- Develop and deploy a global aerosol prediction system that can in the future assimilate satellite-derived atmospheric composition parameters

Meet Research (NASA) to Operations (NOAA) goals of the JCSDA

- QFED code transitioned from NASA to NOAA in 2013

Courtesy: Shobha Kondragunta
Short Term

- DISCOVER-AQ
  - SEAC4RS
  - HS3
  - ATTREX
- Data Assim.
- Missions
- On-going
  - ~ 1 year
- Reanalysis
- OSSE
- New Nature Run
  - CEOS/GEO-CAPE
- SO2/Ash forecasting
- MISR
  - AVHRR
  - OMPS/LP
- NCA
  - FP for IT
  - MERRA-2

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## GEOS-5 Reanalyzes

<table>
<thead>
<tr>
<th>Name</th>
<th>Nominalk Resolution</th>
<th>Period</th>
<th>Aerosol Data</th>
<th>Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>MERRA-1</td>
<td>50 km</td>
<td>1979-present</td>
<td>NONE</td>
<td>now</td>
</tr>
<tr>
<td>MERRAero</td>
<td>50 km</td>
<td>2002-present</td>
<td>MODIS C5</td>
<td>now</td>
</tr>
<tr>
<td>FP for Inst. Teams</td>
<td>50 km</td>
<td>1997-</td>
<td>MODIS C5</td>
<td>In progress</td>
</tr>
<tr>
<td>NCA</td>
<td>25 km</td>
<td>2010-</td>
<td>MODIS C5, MISR</td>
<td>In progress</td>
</tr>
<tr>
<td>MERRA-2</td>
<td>50 km</td>
<td>1979-present</td>
<td>AVHRR, SeaWIFS, MODIS C5, MISR</td>
<td>Late 2013/2014</td>
</tr>
</tbody>
</table>
A global GEO OSSE activity for GEO-CAPE & CEOS

David Edwards (NCAR) and Arlindo da Silva (NASA GSFC)
with input from the GEO-CAPE SWG
CEOS/MACC-II OSSE Workshop

is sponsored by the National Science Foundation
Geostationary Satellite Constellation for Observing Air-quality

(GEOCAPE, Sentinel-4, POGEQA, GMAP-Asia, GEMS)

(Richter, 2005)
GEOS-5 Global 7 km Nature Run

- **Components**
  - Atmospheric GCM on cubed-sphere, **non-hydrostatic**
  - Prescribed SST, sea-ice
  - Constituents
    - Radiatively coupled aerosols
    - Carbon species
    - GMI Combo Chemistry (*)

- **Emissions**
  - Prescribed daily biomass-burning emissions (QFED)
  - New dust source function from Ginoux
  - Anthropogenic inventories downscaled to 10km

- **GEOS-5 2013 NR**
  - Global, 7 km
  - Aerosol, parameterized Chemistry
    - ~2 years *simulation*
  - Aerosol, full chemistry
    - ~ 1 month (TBD)
  - Availability
    - Free, on-line
    - ~ August 2013

- **GEOS-5 2016+ NR**
  - Global, 3.5 km
  - Improved model
  - Cloud-aerosol microphysics, etc.

(*) GMI combo chemistry used for short experiments only.
MODIS Level 1/2 Simulator

Example: no aerosols

With Gala Wind, Steve Platnick
Mid- to Long-Term
Aerosol-Cloud Interactions

New Cloud Microphysics Requires Aerosol Microphysics

Cloud Microphysical Processes in The Atmosphere

- Ice Crystal Freezing
- Crystal Growth
- Sedimentation
- Aggregation Break-Up
- Evaporation

Mixed Phase Level (Liquid + Ice)

- Droplet Growth Coalescence Collision
- Evaporation
- Precipitation

Global Aerosol Cycles

- SO$_2$ + OH $\rightarrow$ H$_2$SO$_4$
- Gaseous oxidation
- H$_2$SO$_4$ $\rightarrow$ Nucleation
- H$_2$SO$_4$ $\rightarrow$ Condensation
- $\cdot\cdot\cdot\cdot$ Coagulation
- $\cdot\cdot\cdot\cdot$ Water uptake

Cloud processing
- Re-evaporation
- Wet deposition
- below-cloud scavenging

Sedimentation
- Dry deposition
- Transport

Activiation

LAND

OCEAN

Prediction of aerosol mass & number
New Cloud Microphysics

- Explicit ice nucleation (Barahona and Nenes, 2009) and CCN activation (Fountoukis and Nenes, 2005) coupled to GOCART aerosol.
- New cloud fraction scheme.

Great improvement in the representation of liquid and ice water content.
Effective sizes are explicitly calculated accounting for aerosol effects.
More realistic cloud fields (cloud water path, cloud fraction, optical thickness).
7-Mode Modal Aerosol Module (MAM)
ESMF Component Derived from CAM5 Implementation
In Collaboration with Xiaohong Liu, Steve Gahn (PNNL)

- **Aitken**
  - number
  - sulfate
  - ammonium
  - secondary OM
  - sea salt

- **Accumulation**
  - number
  - sulfate
  - ammonium
  - secondary OM
  - hydrophobic OM
  - BC
  - sea salt

- **Fine Soil Dust**
  - number
  - soil dust
  - sulfate
  - ammonium

- **Fine Sea Salt**
  - number
  - sea salt
  - sulfate
  - ammonium

All modes log-normal with prescribed width. Total transported aerosol tracers: 31 Cloud-borne aerosol and aerosol water predicted but not transported.
Number concentration (cm\(^{-3}\)) of aerosol particles in the fine sea-salt mode. Monthly mean values at 850mb (top) and 950mb (bottom) for March, 2010.

Number concentration (cm\(^{-3}\)) of aerosol particles in the fine dust mode. Monthly mean values at 850mb (top) and 950mb (bottom) for March, 2010.
Summary

- Aerosols are an integral part of the GEOS-5 modeling and data assimilation systems
- General framework: *Integrated Earth System Analysis* (IESA)
- Capabilities
  - Prediction from weather to decadal scales
  - Assimilated datasets for synthesizing the information content of models and satellite data
  - OSSEs for supporting future NASA observing mission
- Close collaboration between modelers and data producers is key.