Overview and Status of MODIS Aerosol and Cloud Data Assimilation in GEOS-5

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MODIS Science Team Meeting
Atmosphere Team Breakout Session
Silver Spring, MD, 16 April 2013
Talk Overview

- GEOS-5 overview
  - Model and data assimilation
- QFED Biomass Emissions
- Aerosol Data Assimilation
- Cloud Data Assimilation
- Concluding Remarks
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: Normally 25 km

Driven by real-time biomass emissions from MODIS
Assimilated aerosols interacts with circulation through radiation

http://gmao.gsfc.nasa.gov/forecasts/
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
QFED v2 – Fire Radiative Power

- Assumes simple linear relationship for each biome

\[ E(x,y,t) = C_{\text{biome}} * \text{FRP}(x,y,t) \]

- Only 4 global constants to estimate (boreal, tropical fires, savannah, grasslands)

- Spatial structure determined by satellite data

- Accounts for pixels obscured by clouds

- Emission factor parameters determined using inverse modeling techniques.
Gridding
Biomass Burning Emissions

- “Observed” Emissions
  \[ E^o = \frac{\alpha_s}{A^o} \sum_b C_b R_b \]

- “Obscured” Emissions: \( E^* \)
  - A priori information
  - Damped-persistency model

- Grid-box estimate:
  \[ E = E^* + \frac{A^o}{A^o + A^*}(E^o - E^*) \]

- It is important to have information about obscured and not-burning pixels

- \( \bullet \) burning
  \( \bullet \) not burning
  \( \bullet \bullet \) obscured
  \( \bullet \bullet \bullet \) water
QFED Calibrated by MODIS AOD

GEOS-5 Aerosol Optical Depth
- QFED (GFED Calibrated)
- QFED (MODIS Calibrated)
- MODIS Retrievals
More QFED intercomparison

- Poster:

Ellison, Luke, and Charles Ichoku:

_The FEER coefficient of emission (Ce) product and a comparison to other common emission inventories._
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:

\[ E = \mathcal{E} \left( \frac{I}{I_{clm}} \right)^{\alpha_b} E_{clm} \]
GEOS-5 Nature Run for OSSEs

GEOS-5 10km Global Mesoscale Simulation: SST, aerosol emissions
Aerosol Data Assimilation

- Focus on NASA EOS instruments, MODIS for now
- Global, high resolution 2D AOD analysis
- 3D increments by means of Local Displacement Ensembles (LDE)
- Simultaneous estimates of background bias (Dee and da Silva 1998)
- Adaptive Statistical Quality Control (Dee et al. 1999):
  - State dependent (adapts to the error of the day)
  - Background and Buddy checks based on log-transformed AOD innovation
- Error covariance models (Dee and da Silva 1999):
  - Innovation based
  - Maximum likelihood
NRL Empirical AOD Corrections

Critical evaluation of the MODIS Deep Blue aerosol optical depth product for data assimilation over North Africa

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An over-land aerosol optical depth data set for data assimilation by filtering, and aggregation of MODIS optical depth retrievals

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Publications on behalf of the European Geosciences Union.
Neural Net for AOD Empirical Retrievals

Ocean Predictors
- Multi-channel
- TOA Reflectances
- Retrieved AOD
- Angles
- Glint
- Solar
- Sensor
- Cloud fraction (<85%)
- Wind speed

Target: AERONET
- Log(AOD+0.01)

Land Predictors
- Multi-channel
- TOA Reflectances
- Retrieved AOD
- Angles
- Solar
- Sensor
- Cloud fraction (<85%)
- Climatological albedo
- < 0.25

Target: AERONET
- Log(AOD+0.01)
MODIS AOD over Ocean

Collection 5 (Aqua)  NNR Retrieval

Log(Tau550+0.01) - mydo

Log(Tau550+0.01) - mydo
MODIS AOD over Land

Dark Target Coll. 5  NNR Retrieval

Log(Tau550+0.01) - mydl

Original MODIS

Corrected MODIS

AERONET

AERONET
MODIS AOD over Land

Deep Blue Coll. 5  NNR Retrieval

Bright Surfaces (albedo > 0.15)
Challenge: AOD Spatial Coherence

July 2008
## MERRAero Overview

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Model**                | GEOS-5 Earth Modeling System (w/ GOCART)  
Constrained by MERRA Meteorology (Replay)  
Land sees obs. precipitation (like MERRA*Land*)  
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 |
AERONET Validation

\[ \eta = \log(\tau + 0.01) \]
Clear-Sky Aerosol Direct Radiative Effect

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

<table>
<thead>
<tr>
<th>Source</th>
<th>TOA SW DRE</th>
<th>Atmos. Ocean (Land)</th>
<th>Surface SW DRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MERRAero</td>
<td>-3.8 (-4.3)</td>
<td>2.8 (6.8)</td>
<td>-6.6 (-11.1)</td>
</tr>
<tr>
<td>Other Observational Yu et al. (2006)</td>
<td>-5.5 ± 0.2 (-4.9 ± 0.7)</td>
<td>3.3 (6.8)</td>
<td>-8.8 ± 0.7 (-11.8 ± 1.9)</td>
</tr>
<tr>
<td>Multi-model Ensemble Yu et al. (2006)</td>
<td>-3.4 ± 0.6 (-2.8 ± 0.6)</td>
<td>1.4 (4.4)</td>
<td>-4.8 ± 0.8 (-7.2 ± 0.9)</td>
</tr>
<tr>
<td>GEOS-5 (Free)</td>
<td>-3.4 (-2.7)</td>
<td>0.5 (2.8)</td>
<td>-3.9 (-5.5)</td>
</tr>
</tbody>
</table>
Karman Vortex Streets

28 km

14 km

7 km

3.5 km
Cloud Data Assimilation

- We cannot simply insert clouds in the model
  - We need to convince the model to make clouds
- Recent GCM cloud parameterizations are based on a PDF of total water (vapor+condensate)
  - much higher resolution satellite data can be used to constrain total water PDF
  - “Cloud relocator”
- Improved cloud distribution essential for effective assimilation of cloudy radiances in 3D/4D Var:
  - Microwave data used to constrain cloud liquid water
- Data retention requires high degree of consistency across GCM and assimilation algorithms.
- Validation: CloudSat, CERES, SRB
Clouds & Sub-grid Variability

- PDF-based cloud parameterizations provide very useful information about sub-grid variability.
- Given a PDF of total water one can generate sub-columns consistent with that PDF.
- Observation simulators can account for representativeness error by operating on these sub-columns.

\[ S = \frac{q_v + q_L + q_i}{q_s(T)} \]
Bayesian Parameter Estimation

- Within a grid column, consider a set of measurements
  \[ y = (y_1, \ldots, y_P) \]
  say MODIS cloud top pressure, cloud optical depth

- Goal:
  - estimate PDF parameters \( \alpha_k \)
  - Given the observations \( y \)

- Bayes theorem:
  \[ p(\alpha|y) \sim p(y|\alpha) \ p(\alpha) \]

- Maximum-likelihood estimation
  - Find \( \alpha \) that maximizes \( p(\alpha|y) \)

- In short: find PDF parameters that “matches” MODIS hi-res data

Markov Chain Monte Carlo Method
Stratocumulus

bkg

obs

ana

Tb [K]

COT

NASA
Cloudy OSSEs

- MODIS Cloud Retrieval Simulator
  - PDF based sub-grid sampling of GEOS-5 fields (ICA)
  - Spatial “clumping”
  - Radiances for 27 MODIS channels
  - Operational MOD06 cloud retrieval algorithm
- Extension for aerosols
  - Add aerosol optical properties
  - Produce MOD04

With Gala Wind, Steve Platnick
Concluding Remarks

- MODIS data have provided the foundation for GEOS-5 aerosol and cloud modeling and data assimilation.

- Going further...
  - Modeling of cloud-aerosol microphysical processes in GEOS-5 will present new challenges and opportunities
  - GEOS-5 data assimilation evolving into an hybrid Ensemble-variational system
  - As we move to more direct measurements (radiances) close collaboration with instrument team is crucial.
GEOS-5 Aerosols

2006-08-17 12:00

GEOS-5 10km Global Mesoscale Simulation: SST, aerosol emissions