Constraints on smoke injection height, source strength, and transports from MISR and MODIS

Ralph Kahn
NASA Goddard Space Flight Center
Mariya Petrenko, Maria Val Martin, Mian Chin

Nelson et al., Remt. Sens. 2013
The NASA Earth Observing System’s Terra Satellite

First Light: February 24, 2000

Source: Terra Project Office / NASA Goddard Space Flight Center
MISR

Multi-angle Imaging SpectroRadiometer

- Nine CCD push-broom cameras
- Nine view angles at Earth surface: 70.5° forward to 70.5° aft
- Four spectral bands at each angle: 446, 558, 672, 866 nm
- Studies Aerosols, Clouds, & Surface

http://www-misr.jpl.nasa.gov
http://eosweb.larc.nasa.gov
Ten Years of Seasonally Averaged Mid-visible Aerosol Optical Depth from MISR

...includes bright desert dust source regions

MISR Team, JPL and GSFC
**Wildfire Smoke** Injection Heights & Source Strengths

[These are the two key parameters representing aerosol sources in climate models]

*MISR*
Stereo Heights:
~3400 Smoke Plumes
Over N. America

% of Plumes injected above boundary layer
stratified by vegetation type & year

Val Martin et al. ACP 2010

**MODIS** Smoke Plume Image & Aerosol Amount Snapshots

**GoCART** Model-Simulated Aerosol Amount Snapshots
for Different Assumed Source Strengths

Different Techniques for Assuming Model Source Strength

Overestimate or Underestimate Observation
Systematically in Different Regions

Petrenko et al., JGR 2012
Changes in geometric perspective with angle

Forward-viewing camera

MISR flight direction

apparent position

plume height

Diner et al.
MISR *Smoke Plume Height* Mapping
July 2, 2004, Canada near Alaska border

Oregon Fire Sept 04 2003
Orbit 19753 Blks 53-55 MISR Aerosols V17, Heights V13 (no winds)

Kahn, et al., JGR 2007
Detail of Wildfire Source Region
Oregon Fire  Sept 04 2003

MISR Nadir 275 m Image

MODIS Image + Fire Power

MISR Plume Heights for Sub-patches

Very Simple Plume Parcel Model

→ Broad swath + high spatial resolution needed to characterize sources
N. America Plume *Injection Height* Climatology


MODIS IGBP land cover map (1x1 Km res)

Percent of plumes >0.5 km *above BL*, stratified by year and vegetation type

Val Martin et al. ACP 2010
Evaluation of a 1D plume-rise model: Towards a parameterization of smoke injection heights

1-D Plume-rise model heights vs. MISR-observed max. plume heights

--- Plume-rise calculations have lower dynamic range than observed, but very variable

To Constrain models:
Need to assess the Parameterizations actually used
Evaluation of a 1D plume-rise model: Towards a parameterization of smoke injection heights

The key factors:
- **Fire Energy**
  (fire area; heat flux, FRP)
- **Atmospheric Stability**
- **Entrainment**

Plume height increases systematically as **FRP** increases and **Atmospheric Stability** decreases

Val Martin et al., JGR 2012
Satellite AOD snapshots to constrain Biomass Burning Emissions

124 Globally Distributed Cases

13 Smoke Emission Estimates

Petrenko, Kahn, Chin, et al., JGR 2012
MODIS-GoCART Total Column AOD Comparisons
Sample Case: Siberia July 20 2006

Goddard Chemistry Aerosol Radiation and Transport (GOCART) model runs

- 3-hourly output
- Resolution: 1°(lat) x 1.25°(lon) x 30 vert. layers
- Meteorological fields GEOS DAS Version 4
- Emissions include: dust, sea salt, anthropogenic, sulfate & precursors, BB
- 13 BB emission options in separate model runs
- Study period: June 2006-June 2007

Petrenko et al., JGR, 2012
Ratio of GOCART to MODIS average AOD
For each case, for 12 emission estimates

Systematic regional patterns; some emissions work better in certain regions
Quantitative Relationship Between Smoke Emission and AOD

**Depends On**
- Wind Speed at source
- Background AOD

Steeper slope ~ Lower wind speed

High background AOD ~ Smoke plume insignificant

-Petrenko et al., JGR 2012-
SEAC4RS Field Campaign

**DC-8** and **ER-2** Flights Monday, 19 August 2013

**Extreme Upwind**
- ER-2: Rosette
- DC-8: 5-Wall

**Downwind**
- ER-2: Bow Tie
- DC-8: 3-Wall

**Cart Site AERONET**

**MODIS Terra**
- Aerosol Optical Depth
  - 17:40 UTC
  - MODIS Terra: 0.27 to 0.70
MISR (Multi-angle Imaging SpectroRadiometer) Overpass
Monday, 19 August 2013 17:40 UTC

17:40 UTC
Path 031
Orbit 72716

South Dakota
Nebraska
Kansas
**MISR Aerosol Optical Depth** (Research Algorithm)

19 August 2013

**Site 2**

**Smoke Plume 1**

**Smoke Plume 2**

**Continental Background**

**Smoke Plume 1**

AOD 0.35 – 0.9

**Smoke Plume 2**

AOD 0.3 – 0.6

**Continental Background**

AOD 0.15 – 0.2

**Nadir View**
Passive-remote-sensing *Aerosol Type* is a *Total-Column-Effective, Categorical* variable!!
Site 2 Smoke Transports
19 August 2013

Smoke Plume 1
AOD 0.35-0.9
ANG 1.5-1.9 (small)
SSA 0.94-0.98 (absorbing)
FrNon-Sph 0-0.2 (mostly sph.)

Continental Background
AOD 0.15-0.2
ANG 1.0-1.5 (medium)
SSA 0.99-1.0 (non-abs.)
FrNon-Sph 0.0 (spherical)

Smoke Plume 2
AOD 0.35-0.6
ANG 1.6-2.0 (smaller)
SSA 0.96-0.98 (less abs.)
FrNon-Sph 0-0.1 (more sph.)
Smoke Plume 1
Younger; Higher AOD
Absorbing
Very Little Dust or Sulfate

Continental Background
Low AOD
Mostly Medium Sulfate

Smoke Plume 2
Older
Lower AOD
Less Absorbing
Even Less Dust and Sulfate
GEOS-5 MODEL Aerosol Type
19 August 2013 18 UTC

Smoke Plume 1
Younger
Higher AOD

Smoke Plume 2
Older
Lower AOD

Smoke Plume 1
Younger
Absorbing

Smoke Plume 2
Older
Less Absorbing

Smoke Plume 1
Younger
Very little Dust

Smoke Plume 2
Older
Even less Dust

Smoke Plume 1
Younger

Continental Background
Larger Fraction
Medium, Non-absorbing
“Sulfate”
We have a substantial set of satellite wildfire plume AOD snapshots and injection heights to help calibrate model/inventory performance.

We are: (1) adding more fire source-strength cases, (2) using MISR to improve the AOD constraints and (3) adding 2008 global injection heights.

We selected GFED3-daily due to good overall source strength performance, but any inventory can be tested.

Joint effort, to test multiple, global models to draw robust BB injection height & emission strength conclusions.

We provide: Satellite-based injection height and smoke plume AOD climatologies.
## Experiment Design

<table>
<thead>
<tr>
<th>Exp.</th>
<th>BB Daily emission</th>
<th>Injection height</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB0</td>
<td><em>No BB emission</em></td>
<td></td>
</tr>
<tr>
<td>BB1</td>
<td>GFED v3</td>
<td>Boundary layer</td>
</tr>
<tr>
<td>BB2</td>
<td>GFED v3 x 0.5</td>
<td>Boundary layer</td>
</tr>
<tr>
<td>BB3</td>
<td>GFED v3 x 2</td>
<td>Boundary layer</td>
</tr>
<tr>
<td>BB4</td>
<td>GFED v3 x 5</td>
<td>Boundary layer</td>
</tr>
<tr>
<td>BB5</td>
<td>GFED v3</td>
<td>From MISR plume ht.</td>
</tr>
<tr>
<td>BB6</td>
<td>GFED v3 x 5</td>
<td>From MISR plume ht.</td>
</tr>
</tbody>
</table>

**Requested output:**

**2-D, 3-hourly, instantaneous**

- Total column **550 nm AOD**
- *Biomass burning AOD*, if available (or AOD’s of individual aerosol species)
- *Wind speeds* in the middle of emission injection height
  
    [e.g., if all smoke is distributed within PBL, output mid-PBL winds]
- PBL height

**3-D [3-hourly]**

- Aerosol *species concentrations*
- Aerosol 550 nm *extinction*
With Source Strength Perturbation Factors: 0.7, 1, 3 & 5

Petrenko et al., 2014, in preparation
Satellites

Model Validation
- Parameterizations
- Climate Sensitivity
- Underlying mechanisms

Remote-sensing Analysis
- Retrieval Validation
- Assumption Refinement

Current State
- Initial Conditions
- Assimilation

Suborbital
- Targeted chemical & microphysical detail
- Point-location time series

Aerosol-type Predictions
- Frequent, global snapshots;
- Aerosol amount & aerosol type maps,
- Plume & layer heights

Regional Context
- Space-time interpolation,
- DARF & Anthropogenic Component
- Calculation and prediction

Kahn, Survey Geophys. 2012