Learning about Earth from Space-based, Multi-angle Imaging

*Ralph Kahn, Jim Limbacher, Verity Flower, Maria Val Martin*

NASA Goddard Space Flight Center

- 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
Current GSFC MISR Team Activities

**Climate**

- IPCC
  - AeroCom model constraints, assessment

**Air Quality**

- Air Quality
  - Friberg/Kahn
  - deSouza/Kahn/MIT

**MISR Aerosol Type**

- Research algorithm & calibration
  - Limbacher/Kahn
- Production Code
  - Limbacher/Kahn
- SAM-CAAM
  - Kahn/S-C Team

**Plume/Layer Height**

- Plume/Layer Height
  - MISR Stereo - MINX, CALIPSO
  - Val Martin/Kahn
  - Active Dust/Smoke/Volcanoes
  - Kahn/Canty -- AAP/UMD
  - Junghenn/Kahn/Li/UMD

**Volcano Studies**

- Flower/Kahn

**Aerosol Amount**

- Aerosol Amount
  - Plume source strength
  - Petrenko/Kahn/Chin/JPL

**Aerosol-cloud Interactions**

- Zamora/Kahn

*Additional activities*

- ACPC – iLEAPS/GEWEX
- ACTRIS-2/EC
- ACE/NASA
- COSPAR
- AeroSat/AeroCom
- PUMAS
- NPP/NASA post-docs

June 2018
Black smoke emanates from oil-well fires and white smoke from a burning sulfate plant, during the recapture of Mosul in northern Iraq in October 2016. The sulfate plume remained within the near-surface boundary layer, whereas some of the oil-fire plumes might have escaped into the free troposphere, and traveled much further downwind.
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

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

Val Martin et al. ACP 2010
Petrenko et al., JGR 2012
• About **23,000 smoke plumes** digitized 2008-2010 (~13,000 for 2008)
• Each plume is Operator-Processed using **MINXv4.0**, and Quality Controlled
• For N America, ≥ 4% - 12% of plumes are injected above the PBL; Boreal Forest 18%
• Raw, graphics and summary files, and documentation are **available on-line:**
  https://misr.jpl.nasa.gov/getData/accessData/MisrMinxPlumes2/

Val Martin et al.,
Remt. Sens.2018
Biomass Burning Experiment PHASE 2: Fire Emission \textit{Injection Heights}

- Heights at \textit{1.1 km Horizontal} res., \textit{\sim250-500 m Vertical} res.
- Keyed to the \textit{Elevation of Maximum Spatial Contrast}
- Parallax is corrected for proper motion (\textit{Wind Correction})
- Missing AOD filled w/ \textit{max}; missing height w/ \textit{statistical dist.}
- Both \textit{Pixel-weighted} and \textit{AOD-weighted} profiles derived
- Height histogram gives some \textit{Indication of Vertical Extent}

\textbf{Val Martin et al., Remt. Sens. 2018}
• Fire emissions are **Stratified by Altitude, Region, Ecosystem, & Season**

• The cases in each stratum are **Averaged** to produce a statistical summary

• Inter-annual and/or sub-seasonal **temporal resolution** might be needed in some cases; requires detailed, regional study (e.g., Amazon)
Global Distribution of Percent Injected Within/Above the PBL
Based on MERRA-2 Hourly PBL 10:00-13:00 LT

Accounting for uncertainty
FT = PBL + 500 m

[PBL from MERRA-2]

2 km threshold avoids dependence on PBL height estimate

Val Martin et al., Remt. Sens. 2018
Seasonal Cycle of 5 parameters, stratified by Vegetation Type

MISR Plume Height, MODIS FRP, Model BL Height & Atm. Stability
MISR AOD

Interannual patterns of 4 parameters, stratified by Drought Index

MISR Plume Height, MODIS FRP, MISR AOD, % in Free Troposphere

• FRP and Height tend to increase as the fire season progresses, for all major Amazon biomes
• AOD tends to increase, Height tends to decrease for forest & savannah in drought years

Gonzalez-Alonso et al., ACPD 2018
When the injection height is above the PBL in regions with significant wind shear, MINX-initiated simulations better represent satellite observations.
MISR Research Algorithm With Self-consistent Ocean Surface Retrieval

Limbacher and Kahn AMT 2017
MISR Research Retrievals Over Shallow, Turbid, & Eutrophic Water Bay of Bengal 01/29/2015 (Turbid)

Limbacher & Kahn, AMT 2018
Global Active Volcanism (1960-2017)

VEI 0
VEI 1
VEI 2
VEI 3
VEI 4

*VEI – Volcanic Explosivity Index

Well-monitored
Partially-monitored

GVP Volcano Base Map - https://volcano.si.edu/E3/

Key Information from Global Volcano Monitoring

Aviation and downwind environmental hazard response
Constraints on air quality and climate modeling
Surface and subsurface geology implications

Flower & Kahn 2017-2019
Volcanic eruption plume from *Kilauea Volcano, Hawaii*

**MISR** Active Aerosol Plume-Height (AAP) Project *22 May 2018*

The **core** and **diffuse** plumes concentrate at \(~1 \pm 0.5\) km above the ocean, dispersing to the west. A **small summit plume** is elevated \(~1\) km above the terrain.

The particles are spherical, smaller and brighter than background – sulfate, not ash dominated.

*V. Flower, R. Kahn, J. Limbacher/ NASA GSFC*
Five *Kamchatka Volcano Plumes* 06 January 2013

**CKD: Central Kamchatka Depression**  
(Higher volatiles: subducting Emperor Sea Mount)

**EVF: Eastern Volcanic Front**  
(Lower volatiles: subducting Pacific Plate)

*Flower & Kahn J. Volc., 2017a*
Particle-property maps reflect **plume-to-plume (magma) differences & downwind particle evolution**

Grey=ash-proxy; Purple, Brown=light-absorbing; Green=spherical non-absorbing; Yellow=sulfate-proxy

Flower & Kahn ACP, 2018
**System is capped preventing lava flow development.**

- Minimizing the number and size of plumes.
- System put under strain by upwelling magma from depth.

**Pressure of upwelling magma overcomes cap causing explosive decompression of the system.**

- Fragmentation of the shallow, volatile poor magma generates ash rich plumes with large particles.
- Concurrent outflow of lava correspond to thermal anomaly detection.

**Decompression of the system draws volatile rich magma from depth.**

- Generation of plumes with small ash particles and a higher fraction of sulfate and water.
- Lava flow extension corresponds to an increase in thermal anomalies.

**Decreasing influx of the volatile rich magma from depth corresponds to a shift back to ash rich plumes with minimal volatile components.**

- No thermal anomaly detection indicates cessation of lava flow extension.

**Reduction in upwelling magma increases magma viscosity leading to the development of a cap.**

- Small sulfate/water plumes tend to occur that are less conducive with MISR observations.
- Lava flow development ceases.
Must *stratify* the global satellite data to treat appropriately situations where *different* physical mechanisms apply.
Primary Goals:

• Interpret and enhance ~19 years of satellite aerosol retrieval products

• Characterize statistically particle properties for major aerosol types globally, to provide detail unobtainable from space, adding value to all satellite aerosol data:
  -- Improved aerosol property assumptions-initialization in satellite retrieval algorithms
  -- More robust translation between satellite-retrieved aerosol optical properties and species-specific aerosol mass and size tracked in aerosol transport & climate models

[This is currently a concept-development effort, not yet a project]
Obtain *aerosol intensive property PDFs* required for key aerosol science objectives, but cannot be retrieved with adequate precision, or are *entirely unobtainable, from remote sensing*.

- **Hygroscopicity*** – Particle ambient hydration, aerosol-cloud interactions
- **Mass Extinction Efficiency*** – Translate between retrieved optical properties from remote sensing & aerosol mass book-kept in models
- **Spectral Light-Absorption** – Aerosol direct & semi-direct forcing, atmospheric stability structure & circulation
- **CCN Properties*** – At least part of the CCN size spectrum is too small to be retrieved by remote-sensing

SAM-CAAM is feasible because: Unlike aerosol amount, *aerosol microphysical properties tend to be repeatable* from year to year, for a given source in a given season.
### Table 3.3: Mass Extinction Efficiencies

<table>
<thead>
<tr>
<th>Model</th>
<th>Mass load (mg m⁻²)</th>
<th>MEE (m² g⁻¹)</th>
<th>AOD at 550 nm</th>
<th>TOA Forcing (W m⁻²)</th>
<th>Forcing/AOD (W m⁻²)</th>
<th>Forcing/mass (W g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AeroCom: Identical emissions used for year 2000 and 1750</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M UMI</td>
<td>2.64</td>
<td>7.6</td>
<td>0.02</td>
<td>-0.58</td>
<td>-29</td>
<td>-220</td>
</tr>
<tr>
<td>N UIO-CTM</td>
<td>1.70</td>
<td>11.2</td>
<td>0.019</td>
<td>-0.36</td>
<td>-19</td>
<td>-212</td>
</tr>
<tr>
<td>O LOA</td>
<td>3.64</td>
<td>9.6</td>
<td>0.035</td>
<td>-0.49</td>
<td>-14</td>
<td>-135</td>
</tr>
<tr>
<td>P LSCE</td>
<td>3.01</td>
<td>7.6</td>
<td>0.023</td>
<td>-0.42</td>
<td>-18</td>
<td>-140</td>
</tr>
<tr>
<td>Q ECHAM5-HAM</td>
<td>2.47</td>
<td>6.5</td>
<td>0.016</td>
<td>-0.46</td>
<td>-29</td>
<td>-186</td>
</tr>
<tr>
<td>R GISS**</td>
<td>1.34</td>
<td>4.5</td>
<td>0.006</td>
<td>-0.19</td>
<td>-32</td>
<td>-142</td>
</tr>
<tr>
<td>S UIO-GCM</td>
<td>1.72</td>
<td>7.0</td>
<td>0.012</td>
<td>-0.25</td>
<td>-32</td>
<td>-145</td>
</tr>
<tr>
<td>T SPRINTARS</td>
<td>1.19</td>
<td>10.9</td>
<td>0.013</td>
<td>-0.16</td>
<td>-12</td>
<td>-134</td>
</tr>
<tr>
<td>U ULAQ</td>
<td>1.62</td>
<td>12.3</td>
<td>0.02</td>
<td>-0.22</td>
<td>-11</td>
<td>-136</td>
</tr>
</tbody>
</table>

MEE values for aerosol species are uncertain by factors of 3 or more.

### Table 3.4

<table>
<thead>
<tr>
<th>Model</th>
<th>Mass load (mg m⁻²)</th>
<th>MEE (m² g⁻¹)</th>
<th>AOD at 550 nm</th>
<th>TOA Forcing (W m⁻²)</th>
<th>Forcing/AOD (W m⁻²)</th>
<th>Forcing/mass (W g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AeroCom: Identical emissions for year 2000 &amp; 1750</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L UMI</td>
<td>1.16</td>
<td>5.2</td>
<td>0.0060</td>
<td>-0.23</td>
<td>-38</td>
<td>-198</td>
</tr>
<tr>
<td>M UIO-CTM</td>
<td>1.12</td>
<td>5.2</td>
<td>0.0058</td>
<td>-0.16</td>
<td>-28</td>
<td>-143</td>
</tr>
<tr>
<td>N LOA</td>
<td>1.41</td>
<td>6.0</td>
<td>0.0085</td>
<td>-0.16</td>
<td>-19</td>
<td>-113</td>
</tr>
<tr>
<td>O LSCE</td>
<td>1.50</td>
<td>5.3</td>
<td>0.0079</td>
<td>-0.17</td>
<td>-22</td>
<td>-113</td>
</tr>
<tr>
<td>P ECHAM5-HAM</td>
<td>1.00</td>
<td>7.7</td>
<td>0.0077</td>
<td>-0.10</td>
<td>-13</td>
<td>-100</td>
</tr>
<tr>
<td>Q GISS**</td>
<td>1.22</td>
<td>4.9</td>
<td>0.0060</td>
<td>-0.14</td>
<td>-23</td>
<td>-115</td>
</tr>
<tr>
<td>R UIO-GCM</td>
<td>0.88</td>
<td>5.2</td>
<td>0.0046</td>
<td>-0.06</td>
<td>-13</td>
<td>-68</td>
</tr>
<tr>
<td>S SPRINTARS</td>
<td>1.84</td>
<td>10.9</td>
<td>0.0200</td>
<td>-0.10</td>
<td>-5</td>
<td>-54</td>
</tr>
<tr>
<td>T ULAQ</td>
<td>1.71</td>
<td>4.4</td>
<td>0.0075</td>
<td>-0.09</td>
<td>-12</td>
<td>-53</td>
</tr>
</tbody>
</table>

Similar situation for particle:
- **Hygroscopicity**
- **Light Absorption**

CCSP 2009
**SAM-CAAM Implementation**
[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

- **Dedicated Operational Aircraft** – routine flights, 2-3 x/week, on a continuing basis

- **Sample Aerosol Air Masses** accessible from a given base-of-operations, then move; project science team to determine schedule, possible field campaign participation

- **Process Data Routinely** at central site; instrument PIs develop & deliver algorithms, upgrade as needed; data distributed via central web site, *as with EOS data*

- Parallels the relationship between **AERONET and MODIS / MISR** during EOS era

- Fills gaps in satellite remote-sensing as **IceBridge** did for cryosphere

- Peer-reviewed paper with notional payload *demonstrating feasibility*; subsequent selections based on agency buy-in and available resources

SAM-CAAM is feasible because: Unlike aerosol amount, aerosol microphysical properties tend to be repeatable from year to year, for a given source in a given season

*Kahn et al., BAMS 2017*
Backup Slides


* This work is supported in part by the NASA ACMAP and Climate & Radiation Programs
Implementation of MISR BB Injection Height in \textit{GEOS-Chem} Model

MINX-derived global plume height database in 2008
Val Martin et al. (2018)

Statistically derived profiles (%) based on altitude, land cover unit, region, and season

Map native MISR injection altitude distribution (0–8 km, 250 m) to GMAO 47-layer reduced vertical grid (hPa)

Assign a smoke injection height altitude distribution to GEOS-Chem grid box (2° latitude x 2.5° longitude)

Modify setemis.F in GEOS-Chem (v9.01.01) to distribute biomass burning emissions according to 3-D matrix

Better PAN and CO agreement with ARCTAS aircraft observations using MISR injection heights

\textit{Zhu et al., Geosci. Mdl. Dev. 2018}
1. **AEROSOL PROPERTIES FROM IN SITU MEASUREMENTS & INTEGRATED ANALYSIS**

<table>
<thead>
<tr>
<th>Abbrev.</th>
<th>Required Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EXT</td>
</tr>
<tr>
<td>2</td>
<td>ABS</td>
</tr>
<tr>
<td>3</td>
<td>GRO</td>
</tr>
<tr>
<td>4</td>
<td>SIZ</td>
</tr>
<tr>
<td>5</td>
<td>CMP</td>
</tr>
<tr>
<td>6</td>
<td>PHA</td>
</tr>
<tr>
<td>7</td>
<td>MEE</td>
</tr>
<tr>
<td>8</td>
<td>RRI</td>
</tr>
</tbody>
</table>
### 2. METEOROLOGICAL CONTEXT

<table>
<thead>
<tr>
<th>Abbrev.</th>
<th>Required Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>CO</td>
</tr>
<tr>
<td></td>
<td>Ambient Gases (CO + O₃ + NO₂)</td>
</tr>
<tr>
<td>10</td>
<td>T; P; RH</td>
</tr>
<tr>
<td></td>
<td>Standard Ambient Meteorological Variables</td>
</tr>
<tr>
<td>11</td>
<td>LOC</td>
</tr>
<tr>
<td></td>
<td>Geographic Location</td>
</tr>
</tbody>
</table>

### 3. AMBIENT REMOTE-SENSING CONTEXT

<table>
<thead>
<tr>
<th>Abbrev.</th>
<th>Required Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 A-EXT &amp; A-ABS</td>
<td>Ambient Spectral Extinction &amp; Absorption</td>
</tr>
<tr>
<td>13 A-PHA</td>
<td>Ambient Particle Phase Function</td>
</tr>
<tr>
<td>14 A-CLD</td>
<td>Ambient Cloud &amp; Large-Particle Size/Type</td>
</tr>
<tr>
<td>15 HTS</td>
<td>Aerosol Layer Heights</td>
</tr>
</tbody>
</table>
SAM-CAAM
A Concept for Acquiring Systematic Aircraft Measurements to Characterize Aerosol Air Masses

Ralph A. Kahn, Tim A. Berkoff, Charles Brock, Gao Chen, Richard A. Ferrare, Steven Ghan, Thomas F. Hansico, Dean A. Hegg, J. Vanderlei Martins, Cameron S. McNaughton, Daniel M. Murphy, John A. Ogren, Joyce E. Penner, Peter Pilewskie, John H. Seinfeld, and Douglas R. Worsnop

SAM-CAAM aims to characterize particle properties statistically with systematic, aircraft in situ measurements of major aerosol air masses, to refine satellite data products and to improve climate and air quality modeling.