Satellite Aerosol Air Mass Type Mapping, And its Role in the Global Picture

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JPL and GSFC

http://www-misr.jpl.nasa.gov

• 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
Eight Years of Seasonally Averaged Mid-visible Aerosol Optical Depth from MISR

...includes bright desert dust source regions

MISR Team, JPL and GSFC
MISR-AERONET AOT Comparison for 3,995 Coincidences
Stratified by expected aerosol air mass type

0.05 or 20% AOT
0.03 or 10% AOT
Solid = Version 22
Dashed = Version 12

Biomass Burning
Continental
Dust
Maritime
Urban
Hybrid

Kahn, Gaitley et al., JGR in preparation
MISR-MODIS *Aerosol Optical Depth* Comparison
[MISR V22 vs. MODIS/Terra Collection 5; January 2006 Coincident Data]

Over-ocean regression coefficient **0.90**
Regression line slope 0.75
MODIS QC ≥ 1

Over-land regression coefficient **0.71**
Regression line slope 0.60
MODIS QC = 3

*Kahn, Nelson, Garay et al., TGRS 2009 in press*
**MISR-MODIS** Coincident AOT *Outlier Clusters*

- **Dark Blue** [MISR > MODIS] — N. Africa *Mixed Dust & Smoke*
- **Cyan** [MODIS > MISR, AOD large] — Indo-Gangetic Plain *Dark Pollution Aerosol*
- **Green** [MODIS >> MISR] — Patagonia and N. Australia *MODIS Unscreened Bright Surface*

*Kahn et al., TGARS 2009, in press*
Overall, about 15% of Earth’s surface produces successful MISR automatic aerosol retrievals.

Dark blue = Ocean retrieval  
Light blue = Land retrieval

From experience with MISR & MODIS:

For global, \(\sim 1^\circ \times 1^\circ\) AOD, in general, MISR data need to be aggregated to \(~ 3\text{-month sampling}\) to converge with MODIS.
Overall, 6% to 7% of overlapping observations produce coincident, MISR & MODIS aerosol retrievals.

Some coincident coverage over much of the planet.

Point density varies:
- Desert
- Snow & Ice
- Cloud
- Polar night
- Glint

Kahn, Nelson, Garay et al., TGRS, 2009 in press
MISR-MODIS-AERONET *Sampling* Differences

[Ascension Island 18 February 2005]

Kahn et al., JGR 2007

Sampling: MISR; MODIS; AERONET

AOT Snapshot: AERONET > MISR > MODIS

AERONET Time Series - Changing AOT

Clean, maritime aerosol air mass, but AOT changes 60% across RH boundary

*Using any one of these to represent the entire region AOT --> large errors*

*Taken together, they give a better picture…*

*Sampling Effects is a continuing story…*
Smoke from Mexico -- 02 May 2002

Aerosol:
- Amount
- Size
- Shape

Smoke Particles

Medium Spherical Smoke Particles

Dust blowing off the Sahara Desert -- 6 February 2004

Dust Particles

Large Non-Spherical Dust Particles
MISR-retrieved Aerosol Types

[Lowest Residual Mixtures; AOT>0.15]

**Biomass Burning**

N. Summer & Autumn Events

- Spherical
- Non-Abs + Absorbing

**Dusty**

N. Spring & Summer Events

- Spherical Non-Abs + Non-Sph
  [but few cases w/AOT>0.15]

**Continental**

N. Spring & Summer

**Maritime**

N. Spring & Summer

Kahn, Gaitley, et al JGR, in preparation
MISR **Angstrom Exponent** Validation vs. AERONET

588 Events at **Biomass Burning** Locations

560 Events at **Dust** Locations

1060 Events at **Continental** Locations

Kahn, Gaitley, et al JGR, in preparation
MISR **SSA** Validation vs. AERONET

- **Bio-Burning Sites**
  - Small Events
  - Medium-Small Events

- **Urban Sites**
  - Small Events
  - Medium-Small Events

### AOT Intervals
- **0.1 < AOT < 0.2**
- **0.2 < AOT < 0.4**
- **0.4 < AOT < 0.6**
- **0.6 < AOT < 1.0**

*Kahn, Gaitley, et al JGR, in preparation*
SAMUM Campaign Morocco – June 04, 2006

Ouarzazate
(30.93, -6.91)
AOT(558) ~0.30-0.45

Tinfou
(30.23, -5.61)
AOT(558) ~0.45-0.55

Falcon HSRL
Distance (km)

AOT

Ouarzazate AERONET
A. Ansmann

Spectral Optical Depth

MISR AOT(558)
~ 0.45-0.55

Tinfou Sun Photometer
W. von Hoyningen-Huene & T. Dinter

MISR AOT(558)
~ 0.45-0.55

Spectral Optical Depth
• A dust-laden density flow in the SE corner of the MISR swath
• High SSA, ANG & Fraction Spherical region SE of Ouarzazate, includes Zagora

Kahn et al., Tellus 2009
With *current* technology, we are aiming for Regional-to-Global Aerosol Type Discrimination something like this...

5 Groupings Based on Aerosol Properties

13 Groupings Based on Aerosol Properties

Global, Monthly Aerosol Maps Based on Expected MISR Sensitivity

The examples shown here are simulated from aerosol transport model calculations...

- With MISR – *About a dozen* Aerosol Air Mass type distinctions, based on 3-5 size bins, 2-4 bins based on SSA, and spherical vs. non
- Sensitivity depends on conditions; $AOD >~0.15$ needed, etc.
  - Adding *NIR & UV* wavelengths, *Polarization* should increase this capability

*Kahn et al., JGR 2001*
### Pre-Launch, Model-Derived Aerosol Air Mass Types

<table>
<thead>
<tr>
<th>CLASSIFICATION</th>
<th>Component 1</th>
<th>Component 2</th>
<th>Component 3</th>
<th>Component 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a.</td>
<td>0.67</td>
<td>0.13</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>1b.</td>
<td>0.41</td>
<td>0.13</td>
<td>0.27</td>
<td>0.19</td>
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<tr>
<td>1c.</td>
<td>0.40</td>
<td>0.32</td>
<td>0.17</td>
<td>0.11</td>
</tr>
<tr>
<td>2. Dusty Maritime + Coarse Dust</td>
<td>Sulfate</td>
<td>Sea Salt</td>
<td>Accum. Dust</td>
<td>Coarse Dust</td>
</tr>
<tr>
<td>2a.</td>
<td>0.52</td>
<td>0.17</td>
<td>0.21</td>
<td>0.10</td>
</tr>
<tr>
<td>2b.</td>
<td>0.29</td>
<td>0.13</td>
<td>0.39</td>
<td>0.19</td>
</tr>
<tr>
<td>3. Carbonaceous + Black Carbon Maritime</td>
<td>Sulfate</td>
<td>Sea Salt</td>
<td>Carbonaceous</td>
<td>Black Carbon</td>
</tr>
<tr>
<td>3a.</td>
<td>0.51</td>
<td>0.18</td>
<td>0.26</td>
<td>0.05</td>
</tr>
<tr>
<td>3b.</td>
<td>0.35</td>
<td>0.10</td>
<td>0.47</td>
<td>0.08</td>
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<tr>
<td>4a.</td>
<td>0.61</td>
<td>0.21</td>
<td>0.05</td>
<td>0.10</td>
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<tr>
<td>4b.</td>
<td>0.40</td>
<td>0.35</td>
<td>0.09</td>
<td>0.16</td>
</tr>
<tr>
<td>4c.</td>
<td>0.22</td>
<td>0.51</td>
<td>0.16</td>
<td>0.11</td>
</tr>
<tr>
<td>5. Carbonaceous + BC Continental</td>
<td>Sulfate</td>
<td>Accum. Dust</td>
<td>Carbonaceous</td>
<td>Black Carbon</td>
</tr>
<tr>
<td>5a.</td>
<td>0.59</td>
<td>0.12</td>
<td>0.23</td>
<td>0.06</td>
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<tr>
<td>5b.</td>
<td>0.25</td>
<td>0.12</td>
<td>0.54</td>
<td>0.09</td>
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<tr>
<td>5c.</td>
<td>0.44</td>
<td>0.23</td>
<td>0.26</td>
<td>0.07</td>
</tr>
</tbody>
</table>

*Kahn et al., JGR*
Overall, such agreements suggest that global data sets of aerosols and cloud parameters released by recent satellite experiments (MISR, MODIS and CERES) meet the required accuracy to use them as input to simulate the radiative fluxes within instrumental errors.” -- Kim & Ramanathan JGR 2008
Over-Land Aerosol Short-wave Radiative Forcing w/Consistent Data

The slope of:

TOA albedo vs. AOD

For data stratified by:

Surface BHR

Produces:

Spectral aerosol radiative efficiency

Bright surface + dark aerosol = decreasing albedo w/AOD

Y. Chen et al. JGR 2009
Air Quality: MISR Column AOD + GEOS-Chem AOD Fraction in the BL

MISR AOD
Jan 2001 - Oct 2002

Derived PM$_{2.5}$

Van Donkelaar et al. JGR 2006
Assimilating MODIS Over-Ocean AOD into the NAAPS Operational Aerosol Forecast Model

Filtering & Empirical Corrections to MODIS Collection 4 AOD - assimilating the best data produces forecast improvements

- **Quality Tests** – Use only QC=2, 3; AOD < 3.0; Cloud Fr. < 80%; Removes ~30% of data
- **De-spike** – Remove ~10% of data, where 3x3 pixel Standard Error exceeds threshold

- ~25,000 AERONET coincidences used to assess MODIS
- Linear relationship for mid-visible AOD < 0.6, slope >~ 0.92

- **Wind speed** [6 m/s assumed] – glint & whitecap lower BC
  -- AOD correction based on NOGAPS wind speed (~±0.02)
  -- Use correlation coeffs. as functions of glint angle

- **Cloud contamination** – increases with cloud fraction
  -- Use MODIS cloud fraction to empirically correct AOD

- **Aerosol microphysical properties** – correlate w/fine-mode fraction for AOD > 0.2
  -- AOD underestimated for low SSA particles (smoke & pollution)
  -- AOD overestimated for non-spherical dust

Significant forecast improvement for at least 48 hrs – Zhang et al. JGR 2008

*Zhang & Reid JGR 2006*
Constraining Aerosol Sources, Transports, & Sinks
Complementary MISR & MODIS AOD; Saharan Dust Plume over Atlantic June 19-23, 2000

Contours: AOT=0.15 (yellow); AOT=0.5 (purple)

Kalashnikova and Kahn, JGR 2008
NAAPS dust plume extent predictions:

- In qualitative agreement with MISR & MODIS
- Magnitudes differ... constrains dust Source Strength & Removal Rate

*Kalashnikova et al., 2008*
Atlantic Transported Dust Plume Climatology

[MISR + MODIS AOD Map]

AOD Contoured at 0.15 & 0.5 to map Extent & Properties
Dust is injected near-surface…

Kahn et al., JGR 2007
Transported dust finds elevated layer of relative stability…

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

→ Broad swath + high spatial resolution needed to characterize sources
MISR and MODIS data are changing the way smoke is represented in Chemical Transport Models (CTMs), used to predict air quality and climate impacts.

- MISR stereo-derived smoke plume heights are showing that between 10% and 30% of wildfires inject smoke above the near-surface atmospheric boundary layer (ABL) in many regional studies.
- Previously, most CTMs represented smoke sources as injecting smoke only into the ABL.
- Smoke injected above the ABL travels farther and remains airborne longer, increasing environmental impacts.
- New relationships between smoke injection height, atmospheric stability profile, fuel type, and MODIS fire radiant energy, being developed, will help extrapolate injection heights to the much larger MODIS coverage.

Percent of plumes >0.5 km above BL, stratified by year and vegetation type [North America]

http://www-misr2.jpl.nasa.gov/EPA-Plumes/

Val Martin, et al., ACPD 2009
Wildfire Smoke Plume Database
[In Development]

http://www-misr2.jpl.nasa.gov/EPA-Plumes/

N. America

Africa
2005, 2006

David Nelson, et al., 2009
MISR Aerosol Product Applicability

• On a Monthly, Global basis, the MISR Aerosol Data Set provides **Limited Statistical Representation** of AOT & Type
  -- **Cloud-Free Bias**
  -- **High-AOT Bias** for Aerosol Type
  -- Overall **Sampling** – gradients, plumes, diurnal variations

• For some applications, this is **NOT critical**
  -- **Plume Heights**
  -- AOT contours to constrain **Aerosol Transports**
  -- Aerosol **Air Mass Type Mapping**
Aerosol-Climate Prediction

Satellites
- Remote-sensing Analysis
  - Retrieval Validation
  - Assumption Refinement
- Model Validation
  - Parameterizations
  - Climate Sensitivity
  - Underlying mechanisms
- Current State
  - Initial Conditions
  - Assimilation
- Regional Context
- Sub-orbital
  - Targeted chemical & microphysical detail
  - Point-location time series

Models
- Space-time interpolation,

R. Kahn