Aerosol Characterization
Using Integrated Satellite and Surface Measurement

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A&WMA International Specialty Conference, May 10-14, 2010, Xi’an, Shaanxi Province, China
Leapfrogging Opportunities for Air Quality Improvement
Satellite Aerosol Detection Principle

[Diagram showing aerosol scattering and reflectance processes.]

Orbits

Geostationary Orbit

Polar Orbit

Twilight Zone

[Graph showing measured phase functions for different conditions.]
First Aerosol Challenge: Characterization of Aerosols

- Aerosol complexity is due 7-dim. data space
- The ‘aerosol dimensions’ $D, C, S$ determine the effects on health and climate

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Abbr.</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial dimensions</td>
<td>X, Y</td>
<td>Satellites, dense networks</td>
</tr>
<tr>
<td>Height</td>
<td>Z</td>
<td>Lidar, soundings</td>
</tr>
<tr>
<td>Time</td>
<td>T</td>
<td>Continuous monitoring</td>
</tr>
<tr>
<td>Particle size</td>
<td>D</td>
<td>Size-segregated sampling</td>
</tr>
<tr>
<td>Particle Composition</td>
<td>C</td>
<td>Speciated analysis</td>
</tr>
<tr>
<td>Particle Shape/Mixing</td>
<td>S</td>
<td>Microscopy, Source Type</td>
</tr>
</tbody>
</table>

![Images of aerosol particles and mass distribution]

Mass Distribution

- Fine
- Coarse

Efficiency, $m^2/g$

Scattering, Absorption

Satellite Range
Technical Challenge: Characterization

- PM characterization requires many different instruments and analysis tools.

- *Each sensor/network covers only a fraction of the 7-Dim PM data space.*

![Diagram showing satellite-integrals over various environmental factors]

Satellites, integrate over height, size, composition, shape...dimensions

These data need de-convolution of the integral measures

\[ I = \int_{\text{Height}} \int_{\text{Comp}} \int_{\text{Size}} \int_{\text{Source}} \int_{\text{Mix}} H \cdot C \cdot D \cdot Q \cdot M dH dC dD dP dS \]
Satellite Remote Sensing Since 1972

- First satellite aerosol paper, Francis Parmenter, 1972
- Qualitative surface-satellite aerosol relationship shown, 1976
- Focus on regional ‘hazy blobs’, sulfate pollution

Regional Haze


SMS GOES June 30 1975
AVHRR satellite optical depth climatology over the oceans, 1988-90

Husar, Prospero, Stove, 1997

**Surprise: Small Sulfate Plume, Spring, Summer Only**
Co-Retrieval of Surface and Aerosol Properties
Apparent Surface Reflectance, $R$

- The surface reflectance $R_0$ objects viewed from space is modified by aerosol scattering and absorption.

- The **apparent reflectance**, $R$, is: $R = (R_0 + R_a) T_a$

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<table>
<thead>
<tr>
<th>Apparent Reflectance</th>
<th>Surface Reflectance</th>
<th>Aerosol Reflectance</th>
<th>Aer. Transmittance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R$ may be smaller or larger than $R_0$, depending on aerosol reflectance and filtering.</td>
<td>The surface reflectance $R_0$ is an inherent characteristic of the surface.</td>
<td>Aerosol scattering acts as reflectance, $R_a$ adding ‘airlight’ to the surf. refl.</td>
<td>Both $R_0$ and $R_a$ are attenuated by aerosol extinction $T_a$ which act as a filter.</td>
</tr>
</tbody>
</table>

Aerosol as Reflector: 

$$R_a = (e^{-\tau} - 1) P$$

Aerosol as Filter: 

$$T_a = e^{-\tau}$$

$$R = (R_0 + (e^{-\tau} - 1) P) e^{-\tau}$$
Co-Retrieval:
Seasonal Surface Reflectance, Eastern US

April 29, 2000, Day 120
July 18, 2000, Day 200
October 16, 2000, Day 290
Summer AOT 60 Percentile

2000-2004 SeaWiFS AOT, 1 km Resolution

Mountain – Low AOT
Valley – High AOT

Atlanta
Birmingham
Cloud Contamination?
Satellite Aerosol Optical Thickness Climatology
SeaWiFS Satellite, Summer 2000 - 2003

20 Percentile
60 Percentile
90 Percentile
98 Percentile

Smoke Sources 98 Percentile
Kansas Smoke

April 10, 2003

April 12, 2003
Kansas Smoke Emission Estimation

April 11: 87 T/day
April 10: 1240 T/d

Assuming Mass Extinction Efficiency: 5 m²/g

April 10: 1240 T/d
April 11: 87 T/day
Kansas Agricultural Smoke, April 12, 2003

- Fire Pixels
- PM25 Mass, FRM: 65 ug/m³ max
- Organics: 35 ug/m³ max
- Ag Fires
- SeaWiFS, Refl
- SeaWiFS, AOT Col
- AOT Blue
On April 27, the dust cloud arrived in North America. Regional average PM10 concentrations increased to 65 $\mu$g/m$^3$. In Washington State, PM10 concentrations exceeded 100 $\mu$g/m$^3$. On April 29, hourly PM10 concentrations peaked.
Challenge: Aerosol Retrieval Quality

MODIS vs. MISR: Poor AOT Correlation over Land

MODIS vs. MISR: Poor AOT Correlation over Land
Challenge: Aerosol Size, Composition

Aerosol size and chemical composition poorly characterized
Challenge: Vertical Distribution of Aerosols

Vertical Distribution:
- Layering
- Size Distr.
- Composition

**Vertical Distribution of Aerosol Types**

<table>
<thead>
<tr>
<th>Stratospheric</th>
<th>Volcanic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropospheric</td>
<td></td>
</tr>
<tr>
<td>TropDust</td>
<td>TropSmoke</td>
</tr>
</tbody>
</table>

**Boundary Layer**

<table>
<thead>
<tr>
<th>BioOrg</th>
<th>BioSulfate</th>
<th>Sea Salt</th>
</tr>
</thead>
<tbody>
<tr>
<td>SmokeOrg</td>
<td>SmokeSoot</td>
<td></td>
</tr>
<tr>
<td>AntSulfate</td>
<td>AntOrg</td>
<td></td>
</tr>
<tr>
<td>AntSocot</td>
<td>AntNitrate</td>
<td>BL Dust</td>
</tr>
</tbody>
</table>

**Sahara Dust and Biomass Smoke over the Atlantic**

- Sahara Dust
- Biomass Smoke
- Low Clouds
- High Clouds
- Marine BL
- Dust Layers
- ITCZ
- 5 km
Summary

The main scientific challenge in the study of particulate matter (natural or man made) is to understand the immense structural and dynamic complexity of the 6-dimensional aerosol system \((X, Y, Z, T, \text{Diameter}, \text{Composition})\).

Each sensor/network covers only a limited fraction of the 8-D data space; some measure only a small subset of the PM pollution data and need extrapolating. Others provide broad integral measures of the aerosol system. Satellites, for example, integrate over atmospheric height, particle size, composition, shape, and mixture dimensions. The interpretation of these integral data requires considerable de-convolution of the integral measures.

Given its many dimensional properties, the aerosol system is largely self-describing. The analyst's challenge is to derive the pattern by filtering, aggregating and fusing the multidimensional data.

Initial aerosol characterization is possible with SeaWiFS satellite sensor data along with companion PM surface concentration and PM chemical composition.

There are still enormous challenges in integrating multi-sensory data for characterizing aerosols.

Solutions will require collaboration along several dimensions:

- inter-disciplinary (aerosol science, remote sensing, surface science)
- inter-agency (regulatory, science, management agencies)
- inter-national (regional and global)
Air Pollution Pattern and Trends Over China:

An exploration of the Satellite and Surface Visibility Observations

R. B. Husar, L. Du and E.M. Robinson
Washington University, St. Louis, MO, USA

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Leapfrogging Opportunities for Air Quality Improvement
Satellites show the synoptic aerosol pattern and provide rich spatial context ... e.g. pollution in valleys.
The Perfect Dust Storm...

Apr. 7, 2001 SaeWiFS
Population density

Emissions - NO$_x$
Satellite Column Concentration: NO2, 2009

OMI Spectrometer Sensor
OMI NO2 – Seasonal NO2

Dec, Jan, Feb

Mar, Apr, May

Jun, Jul, Aug

Sep, Oct, Nov
OMI NO$_2$ Day of Week: Thursday
OMI NO$_2$ Day of Week: Sunday
Emissions – SO₂

OMI SO₂: Dec, Jan, Feb

OMI SO₂: Jun, Jul, Aug
OMI SO$_2$: Thursday
OMI SO$_2$: Sunday
Aerosol AOT – MODIS

January

April

July

October
MODIS4 AOT: Thursday
MODIS4 AOT: Sunday
MODIS4 AOT: Thursday
MODIS4 AOT: Sunday
MODIS Fire Pixels

MODIS Fire Pixels Jan

MODIS Fire Pixels Apr

MODIS Fire Pixels Jul

MODIS Fire Pixels Oct
OMI CHCO Formaldehyde

January

April

July

October
Visibility is recorded at 7000+ stations hourly
Surface Extinction Coefficient

Jun, Jul, Aug

Dec, Jan, Feb

October
Binhai, Tanjin

Jun, Jul, Aug

Dec, Jan, Feb

Binhai

Tianjin
Sichuan Basin

- **Jun, Jul, Aug**
  - Chengdu

- **Dec, Jan, Feb**
  - Chengdu
  - Chongqing
New International Program (China is key formal participant):
Global Observing System of Systems (GEOSS)

GEOSS: A Global, Coordinated, Comprehensive
and Sustained System of Observing Systems

A cordial invitation for collaboration … in the framework of GEOSS