Using satellite aerosol data for air quality studies

Mian Chin, Hongbin Yu, Thomas Diehl, Ralph Kahn, Lorraine Remer, Huisheng Bian, Allen Chu, Greg Leptoukh, Ana Prado

NASA Goddard Space Flight Center, U.S.A.
Long-range transport of aerosols:

- Long-range transport of aerosols from their source locations to other regions has been studied for more than 30 years.
- Scope ranging from air quality to climate change.
- As a pollutant, aerosols (aka PM) can:
  - Pose serious health risks.
  - Degrade visibility.
- As a climate forcing agent, aerosol can:
  - Mask some greenhouse warming effects.
  - Affect the hydrological cycle.
  - Modify weather patterns at locations thousands of km away (teleconnection).
Satellite observations of long-range transport of aerosols

Dust and fire: OMI absorbing aerosol index
July 2005

Figure from Mark Schoeberl
Transport of dust and pollution from MODIS

MODIS AOD APR 13 2001

Red: fine mode   Green: coarse mode

Figure from Yoram Kaufman and Reto Stockli
How can we use satellite data to quantify aerosol mass transport flux and to monitor surface air quality?

Today’s talk:
1. Estimate the trans-Pacific transport of pollution and smoke aerosols based on MODIS AOD data
2. Understand how satellite AOD data can be used for predicting surface PM concentrations
Can we quantitatively estimate the transport amount from satellite observations?
  – examples of using MODIS AOD

Kaufman et al., GRL 2005:
  – Estimate trans-Atlantic transport of dust and deposition

Yu et al., JGR 2008:
  – Estimate trans-Pacific transport of pollution and smoke aerosols
Satellite-based estimate on trans-Pacific transport of pollution and smoke aerosols

• Step 1: Estimate anthropogenic (pollution + smoke) AOD based on Kaufman formula:

\[
\tau_a = \frac{(f_\tau - f_d) \tau - (f_m - f_d) \tau_m}{(f_a - f_d)}
\]

- Where \( \tau \), \( \tau_a \) and \( \tau_m \) are total, anthropogenic, and maritime aerosol optical thickness
- \( f_\tau \), \( f_d \), \( f_m \), \( f_a \) are fractions of fine mode, dust, maritime, and anthropogenic aerosol optical thicknesses
- \( \tau_a \) is derived using a modified/improved Kaufman method

Yu et al., JGR 2008
Satellite-based estimate on trans-Pacific transport of pollution and smoke aerosols

• Step 2: Convert anthropogenic AOD to mass loading:
  – Mass extinction efficiency as a function of RH based on field measurements over North Pacific
  – RH profile from AIRS satellite measurements
  – Typical aerosol plume height from GLAS (lidar in space) and ground-based lidar data

Yu et al., JGR 2008
Satellite-based estimate on trans-Pacific transport of pollution and smoke aerosols

• Step 3: Convert anthropogenic aerosol mass loading to transport fluxes:
  – Using wind speeds from GEOS-4 (or other analyzed wind data)
Seasonal variability

East Asia outflow maximum in spring, minimum in summer

Yu et al., JGR 2008
Interannual variability of pollution fluxes

Record intense Eurasia boreal forest fires

Yu et al., JGR 2008
### Interannual variability of pollution fluxes

<table>
<thead>
<tr>
<th></th>
<th>Eurasia Outflow (Tg/yr)</th>
<th>North America Inflow (Tg/yr)</th>
<th>Inflow / Outflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>15.8</td>
<td>3.7</td>
<td>0.23</td>
</tr>
<tr>
<td>2003</td>
<td>20.3</td>
<td>5.7</td>
<td>0.28</td>
</tr>
<tr>
<td>2004</td>
<td>16.0</td>
<td>4.2</td>
<td>0.26</td>
</tr>
<tr>
<td>2005</td>
<td>18.6</td>
<td>4.1</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>17.7</strong></td>
<td><strong>4.4</strong></td>
<td><strong>0.25</strong></td>
</tr>
</tbody>
</table>

About 25% of Asian pollution outflow enters North America, which is nearly 15% of pollution emission in North America

Yu et al., JGR 2008
Comparison with model estimates

- The satellite-based estimate of the trans-Pacific transport of column mass fluxes are consistent with GOCART and GMI model calculations.
- However, the impact on downwind region air quality critically depends on vertical mixing.
- The same model (GOCART) has shown that the imported pollution has rather small contribution to the surface PM2.5 over the U.S., but would have larger implications for climate and weather because of the aloft plume (Chin et al., ACP 2007).
Intercontinental transport of pollution – (NH$_4$)$_2$SO$_4$ as a surrogate

(GOCART model results, Chin et al., 2007)

Asian pollution:
- Eastward transport, efficient removal during transport
- 0.1-0.2 µg m$^{-3}$ to W. US and N. Africa, more to E. Africa and E. Europe
- < 10% contribution to other continents except Arctic

European pollution:
- Pollution widely spread
- Largest impact on N. Africa!
- 0.2-0.5 µg m$^{-3}$ to E. Asia!

North American pollution:
- Relatively regionalized
- Amount to N. Africa & Saudi = Amount from Asia to W.US
Using satellite AOD for monitoring surface PM air quality – possibilities and challenges

Use satellite data to estimate the PM concentration over land where people live. Over many places in the world there are no surface monitoring networks and the satellite data may be used as a proxy for surface PM.
Approach #1: Using satellite AOD to estimate PM2.5

- Using an simple relationship between column AOD and surface PM, e.g.
  \[ PM_{2.5} = a \times AOD + b \]
  \[ PM_{2.5} = a \times AOD^b \]

- This is because AOD tracks PM2.5 at places over the U.S.

- Advantage:
  - Very simple relationship, easy to apply

- Difficulty:
  - Relationship changes with space and time, some times no relationship between AOD and PM

MODIS AOD and EPA PM2.5 at two Illinois sites, Aug-Sep 2003 (Al-Saadi et al., BAMS 2005)

MODIS AOD and EPA PM2.5 over SE U.S., May 2007 (Figure from Ana Prado and Greg Leptoukh)
High AOD-PM2.5 correlation in the E. US but not the W. US

Corr. Coef. of MODIS AOD and EPA PM2.5, Aug-Sep 2003

Western US: not correlated
Eastern US: highly correlated

Figure from Al-Saadi et al., 2005


Western US: not correlated
Eastern US: highly correlated

Figure from Ana Prado and Greg Leptoukh
Can we explain the AOD-PM2.5 correlations?

- We use a global model (GOCART) calculated AOD and PM2.5 to see what relationships we would expect in an “idealized” situation.
- We found the same spatial pattern of correlation between AOD and PM2.5 as shown in the data.
Aerosol vertical distribution is the key…

• Over the eastern US:
  – aerosols are mainly from local pollution sources
  – located within the boundary layer
  – high AOD-PM2.5 correlation is expected
  – Using AOD for PM2.5 prediction is feasible

• Over the western US:
  – Significant fraction of aerosols from outside (e.g. boreal fires and dust)
  – aerosol vertical profile varies a lot
  – Weak or no AOD-PM2.5 correlation is expected
  – Using AOD for PM2.5 prediction is difficult
When aerosol is aloft...

Polar ELF

2006-04-20 14:32:00 - 2006-04-21 00:06:00

Lidar data in Baltimore (From Ray Hoff)
**Approach #2: Using satellite and model together**

- **Using AOD from satellite, vertical profiles and composition fractions from from a chemical transport model:**
  
  $PM_{2.5} = \frac{AOD_{\text{satellite}}}{AOD_{\text{model}}} \times PM_{2.5_{\text{model}}}$

  - **Advantage:**
    - Considering dynamic variation of vertical profiles and chemical composition
  
  - **Difficulty:**
    - Assuming modeled vertical profiles and component fractions are correct
    - Modeled vertical profile and component AOD can be very different among models

- **Example (Liu et al., 2007):**
  - Using MISR AOD
  - Using MISR non-spherical particle fraction to separate dust aerosol from other aerosols
  - Using GEOS-Chem model to “retrieve” PM$_{2.5}$ and speciation from MISR AOD

---

*Figure from Ralph Kahn*
Conclusions

• Satellite data provide global opportunities in studying aerosol sources and long-range transport

• There have been innovative methods to estimate the transport mass fluxes of dust and anthropogenic aerosols across the oceans based on satellite AOD data

• Direct link between column AOD to surface PM2.5 requires stable vertical distributions and composition, such as over the eastern U.S.

• An integrated use of satellite data and model is a good (or the best) idea
Giovanni – interactive tool for data-model comparison and analysis

Giovanni example:
AOD/PM$_{2.5}$ Correlations over the Southeastern US July 31, 2007

- In the southeast (Tennessee, Mississippi, Alabama and Arkansas) MODIS and PM$_{2.5}$ are correlated
- Low OMI UV Aerosol Index and CALIPSO Aerosol flag also indicate aerosols are primarily confined to the boundary layer in these states

Contact: Gregory.g.leptoukh@nasa.gov