Scaling AOD to Surface PM$_{2.5}$: USA vs. Taiwan

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• When using satellite AOD to estimate surface PM$_{2.5}$, need to understand regional differences in PM$_{2.5}$ morphology, AOD accuracies, and the relationship between AOD and PM$_{2.5}$

• In this study, we explored the AOD-PM$_{2.5}$ relationships over Continental United States (CONUS) and Taiwan using GOES-16 ABI AOD and Himawari-8 AHI AOD
• Diurnal bias evident in GOES-16 ABI AOD, especially over **urban areas**
  • Maximum around noon local time
  • Attributed to surface spectral reflectance ratios
• A bias correction has been developed and is recommended until surface spectral reflectance ratios (*valid for the time of the day*) are included in the ABI AOD algorithm
GOES-16 ABI AOD Bias Correction Technique over CONUS

• Analysis used ~5 months of ABI AOD data
  • August 6 – December 31, 2018
  • 15-min composite interval

• For each composite of time steps, found lowest ABI AOD in 30-day period

• Assumed the lowest AOD minus background AOD is the bias for each time step
  • Background AOD is obtained from multi-year AERONET AOD analysis (next slide)

• Bias fit to a 2\textsuperscript{nd} degree polynomial as a function of UTC time
  • Separate equations for before noon and after noon

• Example (New York City, NY metro area):
  • Before 17 UTC: -0.28+0.007862t+0.001288t^2
  • After 17 UTC: 5.24-0.4815t+0.01101t^2

  Where \( t \) is time in UTC, e.g. \( t= 13.5 \) for 1330 UTC

• Calculate the bias and subtract it from the original ABI AOD at each time step
• From multi-year AERONET AOD, obtain the lowest 5\textsuperscript{th} percentile AOD as the estimate of the background AOD at each site \(i\) (\(\tau_i\))

• Then interpolate the background AOD to all the places over the globe, i.e. the background AOD at a location is estimated as \(\tau_b = \frac{\sum_i w_i \tau_i}{\sum_i w_i}\), where \(\tau_b\) is the interpolated background AOD, \(w_i\) is the weight defined as a function of the distance (d) between the site i and the interpolation point:
\[
w_i = e^{-d/d_0} \quad (d_0 = 500 \text{ km})
\]

Example: average background AOD over CONUS = 0.025
• GOES-16 ABI AOD was post-processed to correct diurnal bias

• GOES-16 ABI AOD come in three quality flags: High, Medium, Low
  • Top 2 = High + Medium quality

• Correlation, bias, and root mean square error improved for both Top 2 and high quality AOD datasets
  • Greater improvement for Top 2 qualities
  • High quality AOD already filters out some of the biased pixels
Bias Corrected GOES-16 ABI AOD, October 10, 2018
(CONUS, 17:32 UTC)

Original Top 2 Qualities

Bias Corrected Top 2 Qualities
Bias Corrected GOES-16 ABI AOD, October 10, 2018
(CONUS, daytime animation)
Bias Corrected GOES-16 ABI AOD, October 10, 2018
(Northeast US, 17:32 UTC)

Original Top 2 Qualities

Bias Corrected Top 2 Qualities
Bias Corrected GOES-16 ABI AOD, October 10, 2018
(Northeast US, daytime animation)
**ABI AOD Bias Correction Comparison**

AOD histogram for pixels within 27.5 km circle

**Toronto, ON, Canada (urban site)**

AERONET AOD = 1.12

**Grand Forks, ND, USA (rural site)**

AERONET AOD = 1.23

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**Before correction**

(mean AOD=1.18)

**After correction**

(mean AOD=1.01)

**Before correction**

(mean AOD=1.43)

**After correction**

(mean AOD=1.43)
Bias Correction for Himawari-8 AHI AOD over Taiwan

• Analysis used 2 months of AHI AOD data
  • March 1 – April 30, 2017
  • 30-min composite interval

• Background AOD = 0.069

• Problem arose when developing the bias correction algorithm:
  • Taiwan region is often cloudy, so limited AOD retrievals
  • Measured AOD is relatively high
  • Thus, difficult to quantify lowest AOD
  • lowest AOD – background AOD = bias

60-day composite lowest AOD with requirement that at least 5 days have retrieval
• Himawari-8 AHI AOD post-processed using same technique as for ABI AOD
• Himawari-8 AHI AOD come in three quality flags: High, Medium, Low
  • Top 2 = High + Medium
• Little change in correlation, bias, or root mean square error for Top 2 and high quality AOD datasets
  • The large difference in surface reflectance between urban and rural areas seen in CONUS is not present in Taiwan

20170301-20170430
Bias Corrected Himawari-8 AHI AOD, April 2, 2017
(Taiwan, 7:30 UTC)
## PM$_{2.5}$-AOD Correlation Statistics for CONUS and Taiwan

### CONUS PM$_{2.5}$ – AOD Matchups

<table>
<thead>
<tr>
<th>Code Green (Good) 0-12.0 µg/m$^3$</th>
<th>Code Yellow (Moderate) 12.1-35.4 µg/m$^3$</th>
<th>Code Orange (USG) 35.5-55.4 µg/m$^3$</th>
<th>Code Red (Unhealthy) 55.5-150.4 µg/m$^3$</th>
</tr>
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<tbody>
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</tr>
<tr>
<td>High Quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1, 4.2, 87314</td>
<td>-2.5, 7.2, 19589</td>
<td>-15.3, 23.6, 322</td>
<td>-35.7, 49.5, 45</td>
</tr>
<tr>
<td>Top 2 Qualities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2, 4.3, 142322</td>
<td>-2.5, 7.4, 30529</td>
<td>-16.7, 23.5, 520</td>
<td>-35.0, 48.7, 76</td>
</tr>
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### Taiwan PM$_{2.5}$ – AOD Matchups

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<tr>
<td>5.9, 8.3, 456</td>
<td>1.4, 7.9, 1513</td>
<td>-4.0, 10.1, 464</td>
<td>-11.0, 14.7, 112</td>
</tr>
<tr>
<td>Top 2 Qualities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.0, 9.1, 1697</td>
<td>1.3, 7.8, 7767</td>
<td>-4.9, 9.6, 1927</td>
<td>-12.2, 16.3, 300</td>
</tr>
</tbody>
</table>
PM$_{2.5}$-AOD Correlations for CONUS and Taiwan

**CONUS, August 6 – December 31, 2018**

- Equation: $Y=1.00X+0.51$
- $R=0.61$
- Mean Bias = 0.48
- STD of error = 5.30
- RMSE = 5.33

**Taiwan, March 1 – April 30, 2017**

- Equation: $Y=0.89X+3.61$
- $R=0.75$
- Mean Bias = 0.75
- STD of error = 8.61
- RMSE = 8.64

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ABI AOD: Estimated 24-hr PM$_{2.5}$ ($\mu$g/m$^3$)

AHI AOD: Estimated 24-hr PM$_{2.5}$ ($\mu$g/m$^3$)
Summary

• ABI and AHI provide multi-channel AOD at high temporal resolution
  • Potentially revolutionary for use in deriving surface PM_{2.5} in areas without ground-based pollutant monitors

• Diurnal bias discovered in ABI AOD
  • Due to fixed surface reflectance ratios in current AOD algorithm
  • Worse in urban vs. rural areas (in CONUS)

• Simple bias correction technique developed
  • Reduces observed diurnal bias, with largest improvement in urban areas in CONUS
  • Not needed over Taiwan due to more clouds, higher AOD on average
  • Recommended for use with ABI AOD data until algorithm is updated with surface reflectance ratios that vary by time of day

• Resulting AOD-PM_{2.5} correlation relationships can be used to estimate surface PM_{2.5} in CONUS and Taiwan
  • US relationship most accurate at lower PM_{2.5} (Code Green and Yellow)
  • Taiwan relationship accurate from low to high PM_{2.5} (up to Code Red)