Aerosol optical properties retrieval from GOCI and AHI

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Yasko Kasai
NICT, Tokyo, Japan
Outline

• Introduction
• GOCI Aerosol Property Retrieval
• AHI Aerosol Property Retrieval
• GOCI + AHI
• PM estimation from AOD
• Summary
Geostationary observation of aerosol over East Asia

<table>
<thead>
<tr>
<th>MI/COMS (NMSC/KMA, Korea)</th>
<th>GOCI/COMS (KOSC/KIOST, Korea)</th>
<th>AHI/Himawari-8 (JMA, Japan)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>15-min</strong> interval for East Asia</td>
<td><strong>1-hour</strong> interval for East Asia (total 8 times in daytime)</td>
<td><strong>10-min</strong> interval for Full Disk (day and night)</td>
</tr>
<tr>
<td>3-hour interval for Full Disk (day and night)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 bands in VIS (1 km)</td>
<td>8 bands in VIS-NIR (0.5 km)</td>
<td>4 bands in VIS-NIR (0.5/1.0 km)</td>
</tr>
<tr>
<td>4 bands in IR (4 km)</td>
<td></td>
<td>12 bands in IR (2 km)</td>
</tr>
<tr>
<td>Aerosol products (Yonsei) AOD (4km)</td>
<td>Aerosol products (Yonsei) AOD, FMF, AE (6 km)</td>
<td>Aerosol products (Yonsei) AOD, FMF, AE (6 km)</td>
</tr>
<tr>
<td><em>Mijin Kim et al. (2014, 2016)</em></td>
<td><em>Myungje Choi et al. (2016; 2017)</em></td>
<td><em>Hyunkwang Lim et al. (2016)</em></td>
</tr>
<tr>
<td><em>AMI to be launched in 2018</em></td>
<td><em>GOCI-2 to be launched in 2019</em></td>
<td></td>
</tr>
</tbody>
</table>
Flow-chart of the GOCI YAER V2 algorithm. The colored panels are enhanced parts from the V1 algorithm.
Land surface reflectance climatology using a minimum reflectivity with multi-year samples

<table>
<thead>
<tr>
<th><strong>Version 1</strong> (Choi et al., AMT, 2016)</th>
<th><strong>Version 2</strong> (Choi et al., AMTd, 2017)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite each year/month/hour samples within 6 km × 6 km → darkest 1-3% at 412 nm</td>
<td>Composite 5-year/month/hour samples within 500 m × 500 m as higher resolution (pros) → darkest 1-3% at each channel → Chance to find clean pixels increases (pros)</td>
</tr>
<tr>
<td>Less influence of degradation/calibration issue (pros)</td>
<td>Influence of degradation/calibration issue Hard to reflect surface changes (cons)</td>
</tr>
<tr>
<td>Near-real-time retrieval impossible (cons)</td>
<td>Near-real-time retrieval possible (pros)</td>
</tr>
</tbody>
</table>

V1 Surface reflectance (15 May, 04:30utc, Ch3)

V2 Surface reflectance database (15 May, 04:30utc, Ch3)
Results of improved cloud masking: case of 5 May 2015

- Low AOD pixels retains well (over Korea peninsula) (not masked out as cloud due to the inhomogeneous surface reflectance) > results in the increased number of retrieved pixels
- Cloud edge masking is improved compared to V1 all QA products > better similarity with VIIRS EDR products.
- Still, cirrus or shallow cloud is not masked well without IR information.
**Land/Ocean AOD** (Total 27/17 AERONET sites, 2011.03-2016.02)

<table>
<thead>
<tr>
<th>GOCIAER V1 (all QA)</th>
<th>GOCIAER V1 (QA3)</th>
<th>GOCIAER V2</th>
<th>MODIS/Aqua DT C6 (QA3)</th>
<th>MODIS/Aqua DB C6 (QA3)</th>
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</thead>
<tbody>
<tr>
<td><img src="image1" alt="Plot" /></td>
<td><img src="image2" alt="Plot" /></td>
<td><img src="image3" alt="Plot" /></td>
<td><img src="image4" alt="Plot" /></td>
<td><img src="image5" alt="Plot" /></td>
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<td><img src="image6" alt="Plot" /></td>
<td><img src="image7" alt="Plot" /></td>
<td><img src="image8" alt="Plot" /></td>
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<td><img src="image11" alt="Plot" /></td>
<td><img src="image12" alt="Plot" /></td>
<td><img src="image13" alt="Plot" /></td>
<td><img src="image14" alt="Plot" /></td>
<td><img src="image15" alt="Plot" /></td>
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</tbody>
</table>

Most statistics show land/ocean algorithm improvement from V1 to V2

<table>
<thead>
<tr>
<th>Land AOD</th>
<th>V1 AllQA</th>
<th>V1 QA3</th>
<th>V2</th>
<th>DT</th>
<th>DB</th>
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<tbody>
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<td>N</td>
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<td>38183</td>
<td>45818</td>
<td>3228</td>
<td>3463</td>
</tr>
<tr>
<td>R</td>
<td>0.86</td>
<td>0.92</td>
<td>0.91</td>
<td>0.92</td>
<td>0.93</td>
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<tr>
<td>Median Bias</td>
<td>-0.0151</td>
<td>-0.0658</td>
<td>0.01947</td>
<td>0.04274</td>
<td>0.00706</td>
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<tr>
<td>Ratio within EE&lt;sub&gt;DT&lt;/sub&gt;</td>
<td>0.49</td>
<td>0.49</td>
<td>0.6</td>
<td>0.62</td>
<td>0.73</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.24</td>
<td>0.18</td>
<td>0.16</td>
<td>0.18</td>
<td>0.16</td>
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<table>
<thead>
<tr>
<th>Ocean AOD</th>
<th>V1 AllQA</th>
<th>V1 QA3</th>
<th>V2</th>
<th>DT</th>
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<td>N</td>
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<td>680</td>
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<td>R</td>
<td>0.83</td>
<td>0.88</td>
<td>0.89</td>
<td>0.92</td>
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<td>Median Bias</td>
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<td>0.04278</td>
<td>0.00803</td>
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<td>Ratio within EE&lt;sub&gt;DT&lt;/sub&gt;</td>
<td>0.55</td>
<td>0.62</td>
<td>0.71</td>
<td>0.73</td>
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<tr>
<td>RMSE</td>
<td>0.17</td>
<td>0.13</td>
<td>0.11</td>
<td>0.09</td>
</tr>
</tbody>
</table>

**EE<sub>DT</sub> = ±(0.05 + 0.15 AOD)**
Pixel-level error estimation of GOCI YAER V2

- Not only AOD, but its pixel-level AOD error is important for data assimilation in air-quality models to provide observation error information.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Diagnostic (based on AERONET AOD)</th>
<th>Prognostic (based on satellite AOD)</th>
<th>Reference</th>
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<tbody>
<tr>
<td>MODIS DT (ocean)</td>
<td>± (0.05 × AOD_A + 0.03)</td>
<td></td>
<td>Remer et al. (2005)</td>
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<tr>
<td>VIIRS EDR (ocean)</td>
<td>lower: −0.238 × AOD_A + 0.01 upper: 0.194 × AOD_A + 0.048 (considering asymmetry)</td>
<td>± (0.25 × AOD_EDR + 0.009)</td>
<td>Huang et al. (2016)</td>
</tr>
<tr>
<td>GOCI YAER V2 (ocean)</td>
<td>± (0.18 × AOD_A + 0.04)</td>
<td>± (0.21 × AOD_GOCI + 0.03)</td>
<td>This study</td>
</tr>
<tr>
<td>MODIS DT (land)</td>
<td>± (0.15 × AOD_A + 0.05)</td>
<td></td>
<td>Levy et al. (2007)</td>
</tr>
<tr>
<td>MODIS DB (land)</td>
<td>± (0.20 × AOD_A + 0.05)</td>
<td>± (0.56 × AOD_DB + 0.086) / AMF (considering geometrical AMF)</td>
<td>Sayer et al. (2013)</td>
</tr>
<tr>
<td>VIIRS EDR (land)</td>
<td>lower: −0.470 × AOD_A − 0.01 upper: −0.0058 × AOD_A + 0.09</td>
<td>± (0.34 × AOD_EDR + 0.023)</td>
<td>Huang et al. (2016)</td>
</tr>
<tr>
<td>GOCI YAER V2 (land)</td>
<td>± (0.14 × AOD_A + 0.08)</td>
<td>± (0.19 × AOD_GOCI + 0.06)</td>
<td>This study</td>
</tr>
</tbody>
</table>

**Higher offset in estimated error of GOCI: higher error of surface reflectance**
Monthly AOD (1 degree lon-lat) over land

higher accuracy of the monthly mean GOCI AOD as compared to MODIS .. ?

→ Daily mean AERONET AOD is calculated from the all-points (~minutes) measurement, and daily mean GOCI AOD is from eight measurements, but only one or two in MODIS

→ Highly variable AOD pixels are masked out in the daily-mean merging steps
Advanced Himawari Imager (onboard Himawari 8 satellite)

Launched on 7. Oct 2014 at 140.7° East,
Entered operational service on 7. Jul 2015

Temporal resolution: Every 10 minute,
0240 utc and 1440 utc data is missing due to
satellite attitude control from JMA

Targeting area: Full disk

Table 1. Imager specifications.

<table>
<thead>
<tr>
<th>Wave length [μm]</th>
<th>Band number</th>
<th>Spatial resolution at SSP [km]</th>
<th>Central wave length [μm]</th>
<th>Channel name</th>
<th>Spatial resolution at SSP [km]</th>
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<td>0.64</td>
<td>3</td>
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<td>4</td>
<td>1</td>
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<td>-</td>
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<td>-</td>
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<td>10.4</td>
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<td>-</td>
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<td>12.4</td>
<td>15</td>
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<td>12.3806</td>
<td>IR2</td>
<td>4</td>
</tr>
<tr>
<td>13.3</td>
<td>16</td>
<td>2</td>
<td>13.2807</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Central wavelengths of the AHIs are "Moment center wavelength" (provided by Exelis).
SSP: sub satellite point

http://www.data.jma.go.jp/mscweb/en/himawari89/
Overview of AHI-YAER algorithm

- AHI L1B data TOA spectral reflectance and brightness temperature in VIS(0.5km×0.5km, 1km×1km) and IR(2km×2km)

Cloud masking

- Land ocean mask

Surface Reflectance assumption
- Land: Minimum reflectivity technique
- Estimates the surface reflectance at VIS based on SWIR
- Ocean: Minimum reflectivity technique
- Fresnel reflectance according to wind speed, geometry and chlorophyll concentration (base on Cox and Munk)

LUT – (calculate from VLIDORT)
- Aerosol models from AERONET level 2.0 (4 type)

Inversion
- Spectral matching of AOD at 550nm

Final Products
- AOD (550nm)
- FMF (550nm)
- Angstrom Exponent(470-640nm)
- Aerosol type(6km ×6km)

Conversion calibration table
- Provided by JMA

Cloud masking details
- BTD test (B9,11,14,15,16)
- Spatial variability test
- Reflectance threshold test

Radiative Transfer Model (VLIDORT)
- Aerosol Optical Properties
  - Refractive index
  - Number size distribution
- Aerosol Optical Depth
- Terrain height
- Surface Reflectance
- Sun-Satellite Geometry

Lim et al., 2016 KJRS
Choi et al., 2016 AMT
Samples of AHI YAER products

AHI RGB image

AHI YAER AOD
MRMver

AHI YAER AOD
ESRver

AHI YAER aerosol type

MODIS AOD
(Terra,Aqua)

VIIRS AOD
(suomi NPP)

MODIS FMF
(Terra,Aqua)

AHI YAER FMF
Validation of AHI YAER AOD with AERONET Lv2

AHI YEAR AOD MRMver

- Feb.: N=2826, y=0.031+0.748x, R=0.779, RMSE=0.090, MAE=0.057, MBE=-0.012, % within EE =75.9
- May.: N=9064, y=0.024+0.894x, R=0.893, RMSE=0.117, MAE=0.089, MBE=-0.056, % within EE =56.4
- Aug.: N=4419, y=0.034+0.716x, R=0.834, RMSE=0.138, MAE=0.098, MBE=-0.048, % within EE =57.2
- Nov.: N=2466, y=0.072+0.726x, R=0.796, RMSE=0.087, MAE=0.061, MBE=0.016, % within EE =75.5

AHI YEAR AOD ESRver

- Feb.: N=2691, y=0.029+0.693x, R=0.655, RMSE=0.121, MAE=0.073, MBE=-0.024, % within EE =63.0
- May.: N=9080, y=0.023+0.855x, R=0.892, RMSE=0.076, MAE=0.020, % within EE =68.3
- Aug.: N=4463, y=0.093+0.722x, R=0.815, RMSE=0.137, MAE=0.095, MBE=0.013, % within EE =63.1
- Nov.: N=2419, y=0.052+0.451x, R=0.628, RMSE=0.126, MAE=0.099, MBE=-0.062, % within EE =47.3

LAND
Validation of AHI YAER AOD with AERONET Lv2

- Composite method

- Cox and Munk method (Input: wind speed, sun-satellite geometry, CHL)
### L2 Merged AOD products between MRM and ESR

<table>
<thead>
<tr>
<th>MRMver</th>
<th>N</th>
<th>R</th>
<th>RMSE</th>
<th>MBE</th>
<th>%EE</th>
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<td>0.09</td>
<td>-0.012</td>
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<td>5</td>
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<td>0.138</td>
<td>-0.048</td>
<td>57.2</td>
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<tr>
<td>11</td>
<td>2466</td>
<td>0.796</td>
<td>0.087</td>
<td>0.016</td>
<td>75.5</td>
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</table>

<table>
<thead>
<tr>
<th>ESRver</th>
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<th>RMSE</th>
<th>MBE</th>
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<tr>
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<td>2691</td>
<td>0.655</td>
<td>0.121</td>
<td>-0.024</td>
<td>63.0</td>
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<td>5</td>
<td>9080</td>
<td>0.892</td>
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<td>-0.02</td>
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<td>8</td>
<td>4463</td>
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<td>63.1</td>
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<td>11</td>
<td>2419</td>
<td>0.628</td>
<td>0.126</td>
<td>-0.062</td>
<td>47.3</td>
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<table>
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<tr>
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<td>2466</td>
<td>0.78</td>
<td>0.089</td>
<td>-0.016</td>
<td>71.2</td>
</tr>
</tbody>
</table>

- The simple merge method takes an average if both ESRver AOD and MRMver AOD are present, and uses the retrieved value if it is retrieved only in one version.
- Overall, RMSE decreased and percent within EE increased. In other words, we could obtain better quality AOD by composing.
- However, the results of the ESR version were not good in November, and the merge AOD results were not improved.
- For future research, AHI YAER assumes that all aerosol models are spherical, but dust aerosol is non-spherical thus should be treated accordingly.
- It is necessary to improve the surface reflectivity using the ESR method in autumn~winter, and it is also possible to merge at L1b (merged surface reflectance) to establish accurate surface reflectance.
AOD diurnal change in Hokkaido (18 May, 2016)

AHI_merged_Lv2 = Simple average of MRMverAOD and ESRverAOD

AHI_merged_Lv1b = Simple average of $\rho_s$(MRM) and $\rho_s$(ESR) are made before the inversion process.
AHI IR cloud masking works successfully on GOCI AOD to filter out cirrus or shallow cloud contamination as retaining high AOD well.
Inter-comparison: MODIS/VIIRS vs GOCI (0.5 deg grid) during the KORUS-AQ campaign

AHI IR cloud masking results in increased correlation coefficient b/w GOCI and MODIS/VIIRS over ocean (R: 0.90→0.95 with MODIS, 0.88→0.92 with VIIRS)
Estimating PM from GOCI AOD using MLR models

As selecting pixels which FMF above 0.4, 0.6 and 0.8, the number of compared is reduced to 34%, 19%, and 6% respectively. (M07→M10/M12/M13) the R of PM2.5 increase from 0.66 to 0.72, 0.78, and 0.84, respectively.

<table>
<thead>
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<th>No</th>
<th>Variable</th>
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<th>M02</th>
<th>M03</th>
<th>M04</th>
<th>M05</th>
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All reanalysis data + AOD, FMF
All reanalysis data + AOD, FMF + NDVI, DAI, AMF
All reanalysis data + AOD, FMF + NDVI, DAI, AMF + GOCI FMF filtering
Only GOCI data + GOCI FMF filtering

• As selecting pixels which FMF above 0.4, 0.6 and 0.8, the number of compared is reduced to 34%, 19%, and 6% respectively. (M07→M10/M12/M13) the R of PM2.5 increase from 0.66 to 0.72, 0.78, and 0.84, respectively.
PM estimation using M13: case of 21 Oct 2015, 0330UTC

- High AOD at northwestern South Korea (SK)
- Low wind speed in southern SK
- High humidity in northwestern SK
- Measured PM is higher in Western SK (higher in Gwangju than Seoul)

Predicted PM2.5 shows similar pattern with measured PM2.5
Broader coverage in predicted PM2.5 using GOCI
Summary

• GOCI Yonsei aerosol retrieval algorithm were developed and have been improved continuously through 2012 DRAGON-NE Asia, 2016 KORUS-AQ campaigns, and long-term validation. Qualities of retrieved V2 AOPs show reliable qualities against ground-based AERONET and other satellite products. *(Choi et al., AMT, in review, 2017)*

→ expansion of YAER algorithm to AHI and GOCI-II *(including 380 nm, 250m spatial resolution, hourly obs for EA and daily for FD)*

• Hourly and 10 minutes AOPs from GOCI and AHI YAER algorithm can provide information on aerosol diurnal variation. Therefore, it becomes an important part at data assimilation with several air-quality forecasting model over East Asia.

• Currently, the GOCI data have been available based on individual request. However, it will be publicly open in September, 2017 through KOSC/KIOST homepage!

• Data merging between two satellite products or two different algorithm can provide better aerosol products in terms of data coverage and accuracy. Further studies are required for merging methodology including optimal interpolation, weighting etc. based on uncertainty analysis.

*Thank you for your attention!*