Monitoring particulate pollution using GOCI COMS

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Collaborators

- **National Institute of Environmental Research (NIER)**
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- **Sites in Korea**
  Baeksa Elementary School, Gangneung Wonju National University, GIST, Hanguk University of Foreign Studies, Iksan Fire Station, KMA (Anmyeon, Gosan Station), KNJ Engineering, Kyungpook National University, Pusan National University, Seoul National University, Songchon Elementary School, UNIST

- **Satellite Remote Sensing**
  Korea Meteorological Administration (MI), Korea Ocean Satellite Center (KOSC), JMA, NICT

- **NASA Goddard Space Flight Center**
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- **NASA Langley Research Center**
  James Crawford, Jay Al-Saadi (GeoTASO, MOS), John Hair (DIAL/HSRL)

- **NASA Ames Research Center**
  Jens Redemann (4STAR)

- **Yonsei University**
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Development of Satellite RS Capability for AQ

Spatial Resolution (km)

Temporal Resolution

- week
- day
- hr
- min

GOCI-2
GOCI
TEMPO
H-8
AMI
MODIS
TROP
OMI
OMI
GOSAT
CAI
GOME-2
GOME
SCIAMACHY
SCIAMACHY
GOSAT
CAI
OMPS
S-4
GEMS
GOCI-2

Aerosol
Trace Gases
KORUS-AQ combined assets from the Korean and U.S. atmospheric science communities and their supporting organizations (NIER, NASA, Universities, etc.) to implement an integrated observing system for improving our understanding of Air Quality.

- Model evaluation and improvement, chemical process understanding, Satellite Cal/Val and observing strategies
- GOCI, MI, Himawari-8, MODIS, OMI, MOPITT.
- Broad spatial coverage for key atmospheric components (aerosols, ozone, precursors)

Operational Air Quality Forecasts, Regional and Global models of atmospheric composition

Air Quality Network, Research Sites, Research Vessels including in situ and remote sensing observations (Aeronet, Pandora, Lidar)

[Courtesy of James Crawford]
<table>
<thead>
<tr>
<th>Reference</th>
<th>Products</th>
<th>Channels</th>
<th>Temporal Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOCI/COMS (KOSC/KIOST, Korea)</td>
<td>AOD, FMF, AE (6 km)</td>
<td>8 bands in VIS-NIR (0.5 km)</td>
<td>1-hour interval for East Asia (total 8 times in daytime)</td>
</tr>
<tr>
<td>MI/COMS (NMSC/KMA, Korea)</td>
<td>AOD (4 km)</td>
<td>4 bands in VIS (1 km)</td>
<td>15-min interval for Asia</td>
</tr>
<tr>
<td>MI/COMS (NMSC/KMA, Korea)</td>
<td>4 bands in IR (4 km)</td>
<td>3-hour interval for FD</td>
<td></td>
</tr>
<tr>
<td>AHI/Himawari-8 (JMA, Japan)</td>
<td>AOD, FMF, AE (6 km)</td>
<td>12 bands in VIS-NIR (0.5/1.0 km)</td>
<td>10-min interval for Full Disk</td>
</tr>
<tr>
<td>Products</td>
<td>4 bands in VIS (1 km)</td>
<td>12 bands in IR (2 km)</td>
<td></td>
</tr>
</tbody>
</table>

Reference:
- M. Choi et al. (AMT 2016)
- M. Kim et al. (RSE 2014; ACP 2016)
- H. Lim et al. (KJRS 2016)

* Datasets readily available for past years for GOCI and MI. AHI dataset is under processing.
Case of 25 May 2016

1~2 km (Median of aerosol extinction profile)

Aerosol Extinction 532 nm

Altitude (km)

0.0 0.2 0.4 0.6 0.8 1.0

Extinction (/km)

All campaign data avg.
Mean of case date
Range of 16/50/84 percentile

HSRL Aerosol type

Dusty Mix
Smoke

Anmyon (36.54N,126.33E)
NOAA HYSPLIT Backward trajectory modeling

KORUS_Idxan [lon=127.01°E, lat=35.96°N]

20160524-20160525

AERONET AOD
GOCI AOD
PM$_2.5$
PM$_{10}$

AOD at 500 nm
0.0 0.5 1.0 1.5 2.0

PM$_2.5$, PM$_{10}$ (µg/m$^3$)
0 50 100 150

May-24
May-25
May-26

Data (KST)

00 12 00 12 00

NOAA-HYSPLIT model
Backward trajectories ending at 00:00 UTC 25 May 16
GFSG Meteorological Data

NOAA HYSPLIT Backward trajectory modeling
Case of 05 June 2016

1~3 km (Median of aerosol extinction profile)

Aerosol Extinction 532 nm

Aerosol type: Fresh Smoke and Smoke
### Land surface reflectance climatology using a minimum reflectivity technique with multi-year samples

<table>
<thead>
<tr>
<th>Version 1 (Choi et al., AMT, 2016)</th>
<th>Version 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite <strong>each year/month/hour samples</strong> within 6 km × 6 km → darkest 1-3% at 412 nm</td>
<td>Composite <strong>5-year/month/hour samples</strong> within 500 m × 500 m as higher resolution (pros) → darkest 1-3% at each channel → <strong>possibility finding clear pixels increases</strong> (pros)</td>
</tr>
<tr>
<td>Less influence of degradation/calibration issue (pros)</td>
<td>Much 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, 04:30 utc, Ch3) |

![Surface reflectance (15 May, 04:30 utc, Ch3)](image1)

### V2 Surface reflectance database (15 May, 04:30 utc, Ch3) |

![Surface reflectance database (15 May, 04:30 utc, Ch3)](image2)
Land/Ocean AOD (Total 27/17 AERONET sites, 5yr)

<table>
<thead>
<tr>
<th>GOCI YAER V1 (all QA)</th>
<th>GOCI YAER V1 (QA3)</th>
<th>GOCI YAER V2</th>
<th>MODIS DT</th>
<th>MODIS DB</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Land AOD" /></td>
<td><img src="image" alt="Ocean AOD" /></td>
<td><img src="image" alt="Land AOD" /></td>
<td><img src="image" alt="Ocean AOD" /></td>
<td><img src="image" alt="Land AOD" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land AOD</th>
<th>N</th>
<th>R</th>
<th>Median Bias</th>
<th>Ratio within $EE_{DT}$</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1 AllQA</td>
<td>47850</td>
<td>0.86</td>
<td>-0.01509</td>
<td>0.49</td>
<td>0.24</td>
</tr>
<tr>
<td>V1 QA3</td>
<td>38183</td>
<td>0.92</td>
<td>-0.06581</td>
<td>0.49</td>
<td>0.18</td>
</tr>
<tr>
<td>V2</td>
<td>45818</td>
<td>0.91</td>
<td>0.01947</td>
<td>0.60</td>
<td>0.16</td>
</tr>
<tr>
<td>DT</td>
<td>3228</td>
<td>0.92</td>
<td>0.042744</td>
<td>0.62</td>
<td>0.18</td>
</tr>
<tr>
<td>DB</td>
<td>3463</td>
<td>0.93</td>
<td>0.007057</td>
<td>0.73</td>
<td>0.16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ocean AOD</th>
<th>N</th>
<th>R</th>
<th>Median Bias</th>
<th>Ratio within $EE_{DT}$</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1 AllQA</td>
<td>19945</td>
<td>0.83</td>
<td>0.056303</td>
<td>0.55</td>
<td>0.17</td>
</tr>
<tr>
<td>V1 QA3</td>
<td>18308</td>
<td>0.88</td>
<td>0.042779</td>
<td>0.62</td>
<td>0.13</td>
</tr>
<tr>
<td>V2</td>
<td>18588</td>
<td>0.89</td>
<td>0.008028</td>
<td>0.71</td>
<td>0.11</td>
</tr>
<tr>
<td>DT</td>
<td>680</td>
<td>0.92</td>
<td>0.033227</td>
<td>0.73</td>
<td>0.09</td>
</tr>
</tbody>
</table>

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

- $EE_{DT} = \pm(0.05 + 0.15 AOD_A)$
AOD error analysis from long-term validation

No. of each bin samples = 1000, Symbols: 50 percentile, Lines: 16-84 percentile

Reduced bias, increased error in high AOD
shorter atmospheric path length, and higher signal of surface in high scattering angle

Positive bias and wider error range in low AE (large particle), (could be aerosol model error)

Positive bias in NDVI of 0.1-0.3 (urban over China, Osaka, especially)

positive AOD bias in higher NDVI (open ocean) due to not considering water-leaving radiance
AOD error analysis from long-term validation

Positive bias in high cloud fraction

Positive bias in inhomogeneous AOD
Spatial distribution: GOCI monthly AOD

- North China Plane (including Beijing, Tianjin, and Hebei)
  - Expanded to Korea and Japan in March to May, highest in June-July-August
  - Minimum mean AOD is above 0.4
- Korean Peninsula: increased in March and April, highest in June
  - Spatial distribution is well matched with MODIS results (Kim et al. 2007; Levy et al. 2013; Hsu et al. 2013) and VIIRS results (Liu et al. 2014)
- High AOD over turbid water (a few samples)
AHI Aerosol Products

AHI RGB image

AHI YAER AOD

AHI JAXA AOD

AHI YAER aerosol type

MODIS AOD (Terra,Aqua)

VIIRS AOD (suomi NPP)

MODIS FMF (Terra,Aqua)

AHI YAER FMF
Monthly validation results – AHI YAER vs AERONET

- Analysis period: 2016.03.01 – 2016.7.31
- Spatial colocation: average of AHI pixels within 25km at AERONET sites
  - (Mar: 29 sites, Apr: 42 sites, May: 44 sites, Jun: 40 sites, Jul: 26 sites)
- Temporal colocation: average of AERONET data within 5min at satellite measurement time
- Expected Error (EE) = 0.05 + 0.15*AERONET AOD (Levy et al., 2007)
AHI IR cloud masking in AHI YAER algorithm

- AHI IR cloud masking works successfully on GOCI AOD to filter out cirrus or shallow cloud contamination as retaining high AOD well.
- AHI IR cloud masking results in increased correlation coefficient b/w GOCI and MODIS/VIIRS over ocean ($R: 0.90 \rightarrow 0.95$ with MODIS, $0.88 \rightarrow 0.92$ with VIIRS)

Kim et al. (2017)
Application of GOCI YAER AOD to Air quality modeling studies

Data assimilation of GOCI AOD with CMAQ
Application to the PM$_{10}$ (GIST)
[Park et al., 2014, ACP]

Data assimilation of GOCI & MODIS AOD with WRF-chem
Application to the PM$_{10}$ (Univ. of Iowa and NCAR)
[Saide et al., 2014, GRL]
(also carried out during 2016 KORUS-AQ as NRT)

GIST: spatial-temporal kriging to fill the empty data for model time and cloud-masked area

Estimation ground-level PM$_{2.5}$ from GOCI AOD and GEOS-chem
[Xu et al., 2015, ACP] (Dalhousie Univ.)
Retrieving $X_{CO2}$ from GOSAT FTS over East Asia Using Simultaneous Aerosol Information from CAI

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Keywords: CO$_2$; aerosols; GOSAT; East Asia; optimal estimation
GOCI-2

- Spectral bands

<table>
<thead>
<tr>
<th>GOCI Band</th>
<th>GOCI-II Band</th>
<th>Band center</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>1</td>
<td>380 nm</td>
<td>20 nm</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>412 nm</td>
<td>20 nm</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>443 nm</td>
<td>20 nm</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>490 nm</td>
<td>20 nm</td>
</tr>
<tr>
<td>-</td>
<td>5</td>
<td>510 nm</td>
<td>20 nm</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>555 nm</td>
<td>20 nm</td>
</tr>
<tr>
<td>-</td>
<td>7</td>
<td>620 nm</td>
<td>20 nm</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>660 nm</td>
<td>20 nm</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>680 nm</td>
<td>10 nm</td>
</tr>
<tr>
<td>-</td>
<td>10</td>
<td>709 nm</td>
<td>10 nm</td>
</tr>
<tr>
<td>7</td>
<td>11</td>
<td>745 nm</td>
<td>20 nm</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
<td>865 nm</td>
<td>40 nm</td>
</tr>
<tr>
<td>-</td>
<td>13</td>
<td>643.5 nm</td>
<td>483 nm</td>
</tr>
</tbody>
</table>

- Reference Local Area (RLA), 10 images a day

- Full Disk (FD), once a day

- 250 m for RLA / 1 km for FD

- Concept of GOCI-2 Aerosol algorithm

GOCI-2 L1B radiance (reflectance) in 250 m resolution

Land/Sea Separation
Inland water Masking
Cloud Masking

Surface reflectance retrieval
Land: Minimum reflectivity technique
Ocean: Ocean BRDF (wind speed)

Turbid water detection
Absorbing aerosol detection (using short wavelength channels including 360 nm)

Aerosol Models
AERONET Inversion database
AOD/FMF/SSA classification + UV/Visible AI sensitivity

Pre-calculated Lookup-Table for each aerosol model and simulated status using RTM

Inversion from radiance to aerosol optical properties
Comparison b/w observed radiance and LUT

Final retrieved
Spectral AODs, Particle size parameter (FMF/AE)
Absorbing parameter (AI, SSA)

Courtesy of Dr. Youngje Park (KOSC/KIOST)
Geostationary Constellation of UV-Vis spectrometer & Meteorological Payload

TEMPO + GOES-R (America)

GMES S4 UVN + FCI + IRS (Europe)

TROPOMI, OMPS, VIIRS, APOLLO ...

Himawari 8, FY-2, 3, COMS, INSAT ...

GEMS + AMI + GOCI2 GEO KOMPSAT (Asia)

UV-Vis 290-690 nm

UV-Vis-NIR 300-500 nm

Constellation synergy
- Improving spatial and temporal coverage to monitor globalized pollutants & SLCF
- Sharing basic requirements on data products and instrument to maintain data quality
- Consolidating socio-economic benefit analysis
- Supporting QA and CAL/VAL

UV-Vis 305-500, 750-775 nm
Conclusion

• GOCI has provided long term dataset on aerosol properties in high spatial and temporal resolution, which has been validated with ground-based AERONET and SONET. Meteorological imager such as MI and AHI.

• Satellite aerosol retrieval algorithm has been under continuous improvement through the evaluation and diagnosis of the AOPs, especially according to aerosol vertical distribution and types. It could provide the key of AOPs-PM relations over wider region.

• Data assimilation with GOCI aerosol dataset improve the accuracy of air quality forecasting. Further application with GOCI AOD was demonstrated to estimate surface PM10 and PM2.5 with correlation coefficients up to 0.8, which then can be used for public health studies.

• GOCI-2 to be launched in 2019 is expected to provide much more information with its UV channels at 380 nm together with aerosol precursor measurements by GEMS and high temporal resolution observation by AMI.

• GOCI data is available in near real time (NRT) and the past, 6-yr dataset is readily available upon request. GOCI data are distributed through KIOST website.