Aerosol algorithm for GEMS, and observation capabilities from geostationary satellites in GEOKOMPSAT-2

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Outline:

• GEMS Stand alone aerosol algorithm
• Recent research on dust non-spherical particles
• [Research version] OE-based Online Retrieval Algorithm
• AOD fusion technique for GEOKOMPSAT-2
GEMS Standard Aerosol Retrieval Algorithm

Aerosol Algorithm Flowchart

1. Retrieve A priori AOD&SSA @354/388
2. GEMS L1B Radiance Spectrum
   - Read LUT
   - Calculate UV-Al, Visible-Al
   - Aerosol Type Selection
   - Cloud Mask Radiance Thres., STD Test
   - Retrieve a priori AOD and SSA with ALH assumption
   - Optimal Estimation Method
   - AOD, SSA, ALH

A priori ALH (CALIOP Climatology)

A priori spectrums with respect to ALH

GEMS Aerosol Algorithm are being tested with OMI L1B measurement data
Standard GEMS Aerosol Products

GEMS AOD 443nm

OMI AOD 388nm

OMI SSA 388nm

MODIS RGB

GEMS SSA 443nm

GEMS ALH

GEMS RGB
Validation of GEMS Aerosol Products

AOD, SSA validation with AERONET over East Asia

Height Error w.r.t AOD, SSA (validation with CALIOP)

Dust detected pixels, retrieved with Mie LUT, cause error on AOD, SSA, and ALH
GEMS dust detected AOD retrieved with non-spherical particles

✓ Validation Only for Dust detected type

Phase Function simulated with VLIDORT

Aspect ratio = 1.5

<table>
<thead>
<tr>
<th>Dust type AOD w/Mie</th>
<th>Dust type AOD w/T-matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q=45.38%</td>
<td>Q=51.44%</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Dust type SSA w/Mie</td>
<td>Dust type SSA w/T-matrix</td>
</tr>
<tr>
<td>35.09% (within 0.03 diff)</td>
<td>47.22% (within 0.03 diff)</td>
</tr>
<tr>
<td>54.09% (within 0.05 diff)</td>
<td>73.77% (within 0.05 diff)</td>
</tr>
</tbody>
</table>
Flowchart of the OE-based OMAERUV algorithm

1. Normalized radiance @ 354 and 388 nm from OMI TOMS surface reflectances
2. Calculation of the UVAI
3. Cloud masking & algorithm flag (AF)
   - AF > 1: No retrieval
   - AF = 0
4. Aerosol type classification (AIRS CO data & UVAI thresholds)
5. Aerosol peak height estimation (Caliop climatology)
6. Optimal Estimation retrievals of AOD and SSA
   - Coincident estimation of errors in each retrievals
   - Apply logarithmic transformation for AOD
7. Online retrieval methods can reduce errors from the interpolation and are numerically efficient particularly for the smaller number of target retrievals

- 10-year OMAERUV AOT and SSA in spring (May to March) from 2005 to 2014
- But the a priori constraints has been loosen
  → To increase the degrees of freedom
  → To avoid the a priori biases in OMAERUV algorithm

[Jeong et al., ACP 2016]
\[ \varepsilon_{sn} = \sqrt{\varepsilon_{sm}^2 + \varepsilon_{n}^2} \]

- **Estimated Solution Error from OE-based algorithm**
- **Solution error of Retrieved AOT (388nm)**
- **Solution error of Retrieved SSA (388nm)**
GK-2A/2B Satellite instruments FOV

AMI FOV (FD)
GOCI-2 FOV
GEMS FOV
Normal operation

Target center: 120E, 17N
S/L: 128.2E

Projected FOV
Region of interest

(Courtesy, KARI)
## GK-2A/2B Satellite instruments specification

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Payload</td>
<td>AMI (~ABI)</td>
<td>GEMS (~TEMPO)</td>
<td></td>
</tr>
<tr>
<td>Channels (㎛)</td>
<td>16 channels (0.47~13.31)</td>
<td>1000 channels (0.3~0.5)</td>
<td>12 channels + 1 wideband (0.380~0.865)</td>
</tr>
<tr>
<td>Temporal resolution</td>
<td>within 10 min (FD)</td>
<td>(8 times/day)</td>
<td>VIS, NIR</td>
</tr>
<tr>
<td></td>
<td>1km (&lt;0.856㎛, VIS)</td>
<td>(30min imaging + 30min rest)</td>
<td>1 hour</td>
</tr>
<tr>
<td></td>
<td>0.5km (=0.64㎛, VIS)</td>
<td></td>
<td>1 hour</td>
</tr>
<tr>
<td></td>
<td>2km (&gt;1.38㎛, IR)</td>
<td></td>
<td>(10 times/day (Local) + 1 times (FD))</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>-</td>
<td>Gas : 7(NS)x8(EW) km</td>
<td>250m (@130°E)</td>
</tr>
<tr>
<td></td>
<td>- Aerosol : 3.5(NS)x8(EW) km</td>
<td>Aerosol : 3.5(NS)x8(EW) km</td>
<td>1km (FD)</td>
</tr>
<tr>
<td></td>
<td>- Spectral resolution</td>
<td>&lt;0.6nm (3 samples)</td>
<td>12 narrow bands</td>
</tr>
<tr>
<td></td>
<td>- Full Disk</td>
<td>(spectral sampling &lt; 0.2nm)</td>
<td>(10 ~ 40 nm)</td>
</tr>
<tr>
<td>Field of regard (FOR)</td>
<td>- Scene &amp; Surface Analysis</td>
<td>5,000km(N/S) × 5,000km(E/W)</td>
<td>2,500km(N/S) × 2,500km(E/W)</td>
</tr>
<tr>
<td></td>
<td>- Cloud &amp; Precipitation</td>
<td>N/S: 45°N ~ 5°S,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Aerosol &amp; Radiation</td>
<td>E/W: 75°E ~ 145°E</td>
<td></td>
</tr>
<tr>
<td></td>
<td>: (AOD, Asian Dust detection, Particle Size)</td>
<td>(E/W, Selectable)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Atmospheric condition &amp; Aviation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline products</td>
<td>O₃ (Column, Profile), NO₂, SO₂, HCHO, Aerosols (AOD, SSA, ALH), UVI, CHOCHO</td>
<td></td>
<td>- Water quality variable</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>- Marine Environmental products</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>- Atmospheric Properties</td>
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<td></td>
<td>: AOD, dust detection, aerosol type..</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Land variable</td>
</tr>
</tbody>
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5 min Diff

30 min Diff
Performance prediction of GEMS AOD

Courtesy of Ukkyo Jeong

GEMS 500 nm AOT

Estimated Solution Error of 500nm AOT

Required precision: 20% or 0.1
Satisfactory = 97.95%

Retrieved 388 nm AOT

- $Q_{mol} = 65.9\%$
- $N = 246$
- Mean $\varepsilon_{mol} = 0.20$
- Mean bias = 0.08
- $r_{err} = 0.96$

GEMS 500 nm AOT

Estimated Solution Error of 500nm AOT

SZA [°]

GEMS 500 nm AOT

Estimated Solution Error of 500nm AOT

VZA [°]
Previous Research about AOD fusion technique

When valid AOD exist at least one or more.

• Cressman [Cressman, 1959]
• Optimum Interpolation [Xue et al., 2012, 2014; Yu et al., 2003, Singh et al., 2017]
• The Empirical Orthogonal Functions [Liu et al., 2005]
• The linear or second-order polynomial functions [Mélin et al., 2007]
• The arithmetic and weighted average [Gupta et al., 2008]
• The least squares estimation [Guo et al., 2013]
• The maximum likelihood estimate [Nirala, 2008; Xu et al., 2015]

Geostatistical methods : Data assimilation

<spatial only>
• The universal kriging method [Chatterjee et al., 2010; Li et al., 2014]
• The geostatistical inverse modeling [Wang et al., 2013]
• The spatial statistical data fusion (SSDF) method [Nguyen et al., 2012; Puttaswamy et al., 2013]  
  (SSDF : variant of kriging method, multi-sensor AOD fusion)

<spatio-temporal>
• Bayesian Maximum Entropy (BME) [Tang et al., 2016]  
  (temporal autocorrelation + uncertainty of the observation)
• Spatio-Temporal Kriging
GEMS-AMI (~OMI-MODIS) synergies: cloud masking

**Cirrus case**

Better cloud edge masking

**Aerosol case**

Retain high AOD plume

3 yr validation

(a) GEMS AOD @ MODIS CF < 80%
- $R = 0.70$
- $\text{RMSE} = 0.51$
- $Q = 38.69$

(b) GEMS AOD @ MODIS CF < 60%
- $R = 0.77$
- $\text{RMSE} = 0.41$
- $Q = 42.59$

(c) GEMS AOD @ MODIS CF < 40%
- $R = 0.81$
- $\text{RMSE} = 0.35$
- $Q = 47.31$

(d) GEMS AOD @ MODIS CF < 20%
- $R = 0.83$
- $\text{RMSE} = 0.31$
- $Q = 52.15$
Consistent AOD dataset of OMI & MODIS (~GEMS & AMI)

**Maximum Likelihood Estimation (MLE)**

\[
R_{i,k} = \sqrt{\frac{\sum_{i=1}^{M} (s_{i,k} - g_i)^2}{M}}
\]

\[
\tau_{i}^{\text{MLE}} = \sum_{k=1}^{N} \frac{R_{i,k}^{-2}}{\sum_{k=1}^{N} R_{i,k}^{-2}} \tau_{i,k}
\]

*Surface albedo is an important source of the uncertainties in AOD retrieval. AOD amount is also a key parameter related to the error in the retrieved satellite AOD [Xu et al., 2015]*

*Weight matrices for original satellite AOD products for four albedo (MCD43) ranges (0-5%, 5-8%, 8-11%, 11-25%) and four AOD ranges (0.0-0.25, 0.25-0.5, 0.5-0.8, 0.8-5.0) are calculated and used for AOD merging.*

(a) GEMS AOD 550nm

(b) MODIS DT AOD 550nm

(c) GEMS + MODIS Merged AOD 550nm

Maintain Accuracy Spatial Coverage ↑

3yr validation

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>R</th>
<th>Q</th>
</tr>
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<tbody>
<tr>
<td>(a)</td>
<td>972</td>
<td>0.859</td>
<td>57.0</td>
</tr>
<tr>
<td>(b)</td>
<td>1452</td>
<td>0.886</td>
<td>67.36</td>
</tr>
<tr>
<td>(c)</td>
<td>1880</td>
<td>0.889</td>
<td>67.23</td>
</tr>
</tbody>
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Thank you for your attention 😊