Status of GEMS

Jhoon Kim¹, U. Jeong², M. Kim², S. Go², X. Liu³, Kelly Chance³
¹P.I., GEMS; ²Yonsei Univ., ³Harvard Smithonian CfA

GEMS Science Team

¹Department of Atmospheric Sciences, Yonsei University, Seoul, Korea
²National Institute of Environmental Research
## GEO-KOMPSAT 2

<table>
<thead>
<tr>
<th></th>
<th>2A</th>
<th>2B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Payload</strong></td>
<td>AMI</td>
<td>GOCI-2</td>
</tr>
<tr>
<td><strong>Lifetime</strong></td>
<td>10 years</td>
<td></td>
</tr>
<tr>
<td><strong>Channels</strong></td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td><strong>Channels</strong></td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td><strong>Wavelength range</strong></td>
<td>0.4 - 13 μm</td>
<td>375 - 860 nm</td>
</tr>
<tr>
<td><strong>Wavelength range</strong></td>
<td>300-500 nm</td>
<td></td>
</tr>
<tr>
<td><strong>Spatial resolution</strong></td>
<td>0.5 / 1 km (Vis) 2 km (IR)</td>
<td>250 m@ eq 1 km (FD)</td>
</tr>
<tr>
<td><strong>Spatial resolution</strong></td>
<td>7 x 8 km² @ Seoul 3.5x8 km² (aerosol)</td>
<td></td>
</tr>
<tr>
<td><strong>Temporal resolution</strong></td>
<td>10 min (FD)</td>
<td>1 hour</td>
</tr>
<tr>
<td><strong>Temporal resolution</strong></td>
<td>1 hour</td>
<td></td>
</tr>
<tr>
<td><strong>Major Products</strong></td>
<td>CTP, CTT, CF, AOD, FMF, OLR, SI, CSR, SST, LST, AMV, … (56)</td>
<td>Ocn. current, chlorophyll, DOM, Phytoplankton, …</td>
</tr>
<tr>
<td><strong>Major Products</strong></td>
<td>AOD, AI, SSA, ACH, CCH, CRF, NO₂, O₃, S O₂, UVI, HCHO, CHOCHO</td>
<td></td>
</tr>
</tbody>
</table>
Objective: Measurements of $O_3$ & aerosol with precursors

- $O_3$, $RO_2$
- $NO$, $NO_2$
- $O$, $h_\nu(<340 \text{ nm})$
- $h_\nu(<420 \text{ nm})$

AOD, type, Height

Oxidation ($OH$, $O_3$, $NO_3$)

$O_3$ (h < 345 nm)

HCHO

CHOCHO

SO$_2$, $NO_2$, $NH_3$, $SO_4^{2-}$, $NO_3^-$, $NH_4^+$

Dry Deposition

Wet Deposition

Emitted Pollutants

Aerolsol particles/aerosols

Power stations (combustion)
Motor vehicles (combustion)
Livestock

Fixed emission source of evaporating volatile organic compounds (VOCs)

Combustion

Vegetation

SPM

Many hazardous substance

Mobile emission source

Fixed emission source of evaporating volatile organic compounds (VOCs)
GEMS Instrument

- Step-and-stare UV-Vis imaging spectrometer scanning at least 8/day in 30 min
- Daily solar and dark calibration
- Images coadded at each position + mirror move back < 30 minutes
- Diffusers for on-orbit solar calibration and onboard LED light source
- 2-axis scan mechanism with gyro feed capability
- Redundant electronics for 10-year lifetime

✓ Hot pixel issues in southern part of the GEMS domain.
✓ Solar calibration time with GOCI-2 within 29-31 deg with the GEMS BTDF characterized at 30 deg.

Courtesy, KARI / BATC
Status of GEMS

• GEMS Development
  – GEMS Telescope shall be assembled, aligned, and tested at KARI in 2015 (JDAK)
  – GEMS System integration and test shall be performed in 2016
  – TRR in Aug. 2016, PSR in 2017 Q1
  – Delivery to KARI from BATC 2017 Q2 for S/C integration

• GEO-KOMPSAT-2 Program
  – SRR in Apr., 2012; SDR in Feb. 2014, PDR in Jul., 2014,

• Launch

• Related activities
  – Air quality forecast in operation since 2013 by NIER/ME
    → GEMS to be an operational sat. (e.g. data assimilation of model with sat. data)
  – ‘KORUS-AQ’ airborne campaign in 2016 (with GEOTASO and MOS)

• Cal/val network
  – MaxDOAS, Pandora Network, AERONET, SONET, SKYNET, LIDARnetwork etc.
Spatial coverage

GEMS East-West Coverage = 10.91°

Orbit Long = 128.2°E, Scan Center at 17.04°N, 114.1°E

Magenta = GEMS Full FOR Requirement (75E-145E)
Blue = GEMS Full FOR Performance Estimate

GEMS Full FOR Analysis Includes All Compensated/Uncompensated Pointing Errors

FOR Requirement (75°E-145°E, 5°S-45°N)
## Baseline products (16)

<table>
<thead>
<tr>
<th>Product</th>
<th>Importance</th>
<th>Min (cm⁻²)</th>
<th>Max (cm⁻²)</th>
<th>Nominal (cm⁻²)</th>
<th>Accuracy</th>
<th>Window (nm)</th>
<th>Spat Resol (km²)@Seoul</th>
<th>SZA (deg)</th>
<th>Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂</td>
<td>O₃ precursor</td>
<td>3x10¹³</td>
<td>1x10¹⁷</td>
<td>1x10¹⁴</td>
<td>1x10¹⁵ cm⁻²</td>
<td>432-450</td>
<td>7 x 8 x 2 pixels</td>
<td>&lt; 70</td>
<td>BOAS DOAS</td>
</tr>
<tr>
<td>SO₂</td>
<td>Aerosol precursor Volcano</td>
<td>6x10⁸</td>
<td>1x10¹⁷</td>
<td>6x10¹⁴</td>
<td>1x10¹⁶ cm⁻²</td>
<td>312-326</td>
<td>7 x 8 x 4 pixels</td>
<td>&lt; 50 (60*)</td>
<td>&lt; 50 (60*)</td>
</tr>
<tr>
<td>HCHO</td>
<td>VOC proxy</td>
<td>1x10¹⁵</td>
<td>3x10¹⁶</td>
<td>3x10¹⁵</td>
<td>1x10¹⁶ cm⁻²</td>
<td>327-356</td>
<td>7 x 8 x 4 pixels</td>
<td>&lt; 50</td>
<td>OE TOMS</td>
</tr>
<tr>
<td>CHOCHO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TropLO₃</td>
<td>Oxidant Pollutant O₃ layer</td>
<td>4x10¹⁷</td>
<td>2x10¹⁸</td>
<td>1x10¹⁸</td>
<td>3% (TOz) 5% (Strat) 20 (Trop)</td>
<td>300-340</td>
<td>7 x 8 x 4 pixels</td>
<td>&lt; 50</td>
<td>OE TOMS</td>
</tr>
<tr>
<td>TropUO₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>StratO₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TotalO₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AOD AI</td>
<td>Air quality Climate</td>
<td>0 (AOD)</td>
<td>5 (AOD)</td>
<td>0.2 (AOD)</td>
<td>20% or 0.1@400nm</td>
<td>300-500</td>
<td>3.5 x 8</td>
<td>&lt; 70</td>
<td>Multi-λ OE O₂O₂</td>
</tr>
<tr>
<td>SSA AEH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[Clouds]</td>
<td>Retrieval Climate</td>
<td>0 (COD)</td>
<td>50 (COD)</td>
<td>17 (COD)</td>
<td>460-490</td>
<td>7 x 8</td>
<td>&lt; 70</td>
<td>O₂O₂ RRS</td>
<td></td>
</tr>
<tr>
<td>ECF CCP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface Property</td>
<td>Environment</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
<td>300-500</td>
<td>3.5 x 8</td>
<td>&lt; 70</td>
<td>Multi-λ</td>
</tr>
<tr>
<td>UVI</td>
<td>Public health</td>
<td>0</td>
<td>12</td>
<td></td>
<td></td>
<td>7 x 8</td>
<td>&lt; 70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Error analysis Using the Optimal Estimation Method

\[
\hat{x} - x = (A - I_n)(x - x_a) + G_y K_b (b - \hat{b}) + G_y f(x,b,b') + G_y e
\]

\(\hat{x}\) : retrieved value  
\(x\) : true value  
\(A\) : averaging kernel  
\(I_n\) : identity matrix  
\(X_a\) : a priori estimates of \(x\)  
\(G\) : contribution function  
\(K\) : Jacobian matrix  
\(b\) : true model parameter

\(\hat{b}\) : best estimate of model parameters  
\(\Delta f\) : forward model error  
\(b'\) : unknown forward model parameters  
\(\varepsilon\) : measurement error

Solution error \(S_{sn}\) : square-root-sum of the diagonal elements of smoothing error and retrieval noise covariance matrices.

\((Rogers, 2000)\)
Results

(U. Jeong)
Effect of aerosol on retrieved gas column density

(U. Jeong)
Examples of retrieved products using OMI

Troposp. O$_3$

O$_3$ profile

NO$_2$

HCHO

Credit:

Mijin Kim (Yonsei U) – Aerosol
Y.S. Choi (EWU) – Cloud
Jae H. Kim (Busan NU) – O$_3$
Hanlim Lee (Pukyung NU) – NO$_2$
Rokjin Park (SNU) – HCHO, CHOCHO
Y.J. Kim (GIST) – SO$_2$
J.M. Yoo(EWU), M.J. Jeong(GWNU) – Sfc prod
M.H. Ahn (EWU) - calibration
Averaging kernel for O$_3$ retrieval

Retrieval sensitivity of tropospheric O$_3$ is high when SZA and VZA is low, or the amount of stratospheric O$_3$ is small.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Degrees of Freedom of O$_3$</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± σ</td>
<td>Median</td>
</tr>
<tr>
<td>Troposphere</td>
<td>0.8 ± 0.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Stratosphere</td>
<td>2.9 ± 0.5</td>
<td>2.8</td>
</tr>
<tr>
<td>Total</td>
<td>3.8 ± 0.4</td>
<td>3.7</td>
</tr>
</tbody>
</table>
Diurnal variations of averaging kernel of O$_3$

(U. Jeong)
## Retrieval of O₃

### Ozone Profile Retrievals

![Ozone Profile Retrievals](image)

<table>
<thead>
<tr>
<th>O₃ (Total)</th>
<th>Goal</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>0.57-0.68</td>
<td>0.99</td>
</tr>
<tr>
<td>A, Slope</td>
<td>0.58-0.68</td>
<td>1.086</td>
</tr>
<tr>
<td>B, Intercept</td>
<td>45.5 DU</td>
<td>21.5 DU</td>
</tr>
<tr>
<td>RMSE</td>
<td>9.1</td>
<td>2.26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>O₃ (Trop)</th>
<th>Goal</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>0.35-0.56</td>
<td>0.74</td>
</tr>
<tr>
<td>A, Slope</td>
<td>0.35-0.64</td>
<td>0.87</td>
</tr>
<tr>
<td>B, Intercept</td>
<td>19.5 DU</td>
<td>8.55 DU</td>
</tr>
<tr>
<td>RMSE</td>
<td>6.5-13DU (13-26%)</td>
<td>8.55 DU (18.41%)</td>
</tr>
</tbody>
</table>

### Total Ozone

![Total Ozone](image)

- N(#): 83234
- CORR: 0.99
- RMSE: 2.26
- Y=1.086X-21.5

### Tropospheric Ozone

![Tropospheric Ozone](image)

- N= 177
- \(y = 0.87x + 7.81\) \(r = 0.738\)
- OMI-SON = -5.28 ± 18.41 DU

(Courtesy, J.S. Park, K.H. Paik, Jae H. Kim)
NO$_2$ Retrieval using OMI L1B data

(Courtesy, H.K. Hong, H. Lee)
Cloud RF retrieval: Validation Results
(ECF, every 1st day of each month, 2007)

(Courtesy, B.R. Lee, Y.S. Choi)
Cloud pressure retrieval: Validation Results

(CP, every 1st day of each month, 2007)

(Courtesy, B.R. Lee, Y.S. Choi)

- More underestimated data in CP especially in summer.

OMI products
\[ y = 0.40x + 0.06 \]
\[ R = 0.88 \]
\[ y = 1.17x + 2.35 \]
\[ R = 0.98 \]

(Courtesy, J.H. Jeong, Y.J. Kim)
HCHO retrieval

HCHO VCDs mean for 11-13 LST
(June 21, 2009)

- Hourly AMF
- w/o consideration of noises

(Courtesy, H.A. Kwon, R. Park)
HCHO retrieval with aerosol (March, 2006)

(Courtesy, H.A. Kwon, R. Park)

 ✓ Systematic underestimation of HCHO VCD is largely due to AMF.
CHOCHO retrieval (437-452.2nm at 13 KST in July 1, 2006)
(Courtesy, H.A. Kwon, R. Park)
Retrieval of AOD, SSA, and HGT

Retrieved AOD [443 nm] from OMI2012m0427t0428
OMI AOD [388 nm]

Retrieved SSA [443 nm] from OMI2012m0427t0428
OMI SSA [388 nm]

Fitted HGT [km] from OMI [km]2012m0427t0428

HGT : Peak level height
CALIOP Lv2 : Top layer height

MODIS RGB : 2012/04/27
Validation of AOD and SSA

AOD validation
AERONET direct measurement(lev2.0)
2005. 01 ~ 12,
Within ±10 min., 0.4° x 0.4°

SSA validation
AERONET inversion data(lev2.0)
2005. 01 ~ 12,
Within ±4 hr, 0.4° x 0.4°
Prelaunch Test and Characterization

• **Spectral Tests (spectrometer+focal plane)**
  – Spectral Bandpass
  – Spectral Range
  – Smile & Keystone

• **Stray Light Tests for Stray Light Model Validation (spectrometer+focal plane)**
  – Diffuser can be placed in the light path
  – Various light source (tunable laser, spectral line source, Xenon arc lamp, Quartz-tungsten-halogen lamp)

• **Spatial Characterization**
  – MTF, Field of View

• **Boresight and Spectral Stability**

• **Diffuser BTDF**
  – On selected wavelengths and spatial positions

• **NIST Traceable Radiometric Calibration**
  – GEMS in ambient or thermal condition
  – Large Spherical Source(LSS) integrating sphere illumination

• **Polarization Sensitivity**
  – Rotatable polarizer
Validation Network

• Ground-based network for gas measurements
  – PANDORA network
  – MaxDOAS
  – AirKOREA and nation-wide network in Asian countries
  – EANET

• Aerosol network
  – AERONET
  – SKYNET (Japanese lead, Asia wide)
  – SONET (China)

• LIDAR network
  – KALION
  – NIES LIDAR network

• Airborne Campaigns
  – KORUS-AQ etc.

• Collaboration under discussion
  – China (Hong Kong), Vietnam,
Campaign (May-Jun 2016) : VAL activities

Airborne
- GEOTASO / B200
- Aerosol LIDAR / DC8
- Gas / King Air
- MOS / B200

GOCI
VIIRS
OMPS
OMI
MOPITT
TROPOMI
GEMS

Ground Network:
- O3 sonde
- O3 LIDAR
- Aerosol LIDAR

Air quality forecast
- O3 sonde
- O3 LIDAR
- Aerosol LIDAR

• Ground Network:
  - PANDORA
  - AERONET
  - SKYNET
  - EANET
  - Air Korea

Shipborne
Synergistic products

AMI

GOCI-2

Cloud center height
AMV
AOD(10 min)
Aerosol type
Sfc. ref.
Cloud mask
Cloud top pressure
...
Ocean current,
AOD, Aerosol type
Green tide, Red tide
SST, AMV, Fog
AOD over desert
Al
SSA
SO$_2$
O$_3$
AOD
Aerosol type
Sfc. ref.
NO$_2$
UV spectrum

✓ 24 hr Asian dust monitoring over dark and bright surface
✓ Cloud morphology (thickness, fraction, type ...)

GEMS
Summary

- GEMS onboard the Geo-KOMPSAT-2B is expected to provide information on aerosol and O$_3$ together with their precursors in high spatial and temporal resolution
  - O$_3$, NO$_2$, HCHO, SO$_2$, AOD/AI/AEH, CHOCHO
  - Clouds (CP, CRF), surface reflectance, UVI

- The predicted performance for the retrieval of trace gas column densities from the current design of GEMS satisfies the product accuracy requirements of NO$_2$, HCHO, stratospheric O$_3$, but partially satisfy for SO$_2$ and tropospheric O$_3$. Meanwhile, the performance is expected to be poor in winter near Korea in particular.

- Careful consideration of aerosol is required to retrieve trace gas concentration from geostationary satellite remote sensing, especially for absorbing aerosols in particular.

- Preflight tests to characterize stray light, polarization, spectral accuracy, diffuser BTDF etc can provide more accurate analysis on the GEMS performance.

- Synergy with AMI and GOCI-2 will provide more reliable products of aerosol and cloud products, which eventually improve the accuracy of trace gas column density.
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GEMS Science Team

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NIER, MoE
KEITI, MoE

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Korea Ocean R&D Institute (KORDI)

Ministry of Science, ICT & future Planning (MSIP)

KARI
GEMS Science Team

Changwoo Ahn
Jay Al-Saadi
P.K. Bhartia
Kevin Bowman
Greg Carmichael
Kelly Chance
Mian Chin
Yunsoo Choi
Ron Cohen
Russ Dickerson
David Edwards
Annmarie Eldering
Ernest Hilsenrath
Daneil Jacob
Scott Janz
Glen Jaross
Siwan Kim
Thomas Kurosu
Qinbin Li
Xiong Liu
Randall Martin
Steve Massie
Jessica Neu
Mike Newchurch
Stan Sander
Omar Torres
Dong Wu
Liang Xu
Ping Yang
Dusanka Zupanski
Miliya Zupanski
Beri Ahlers
Heinrich Bovensmann
John Burrows
Marcel Dobber
Joerg Langen
Pieteren Levelt
Ulrich Platt
Piet Stamnes
Pepijn Veefkind
Ben Veihelmann
Thomas Wagner
Myung Hwan Ahn
Yong Sang Choi
Myeongjae Jeong
Jae Hwan Kim
Young Joon Kim
Hanlim Lee
Kwang Mog Lee
Rokjin Park
Seon Ki Park
Chul Han Song
Jung Hun Woo
Jung-Moon Yoo
Seung Hoon Lee
Sang Soon Yong
D.G. Lee
J.P. Gong
Dai Ho Ko
S.H. Kim
J.H. Yeon
Y.C. Youk
Ji-hyung Hong
Sang-kyoon Kim
Chang Keun Song
Lim Seok Chang
Jae-Hyun Lim
K.J. Moon
M.H. Lee
H.W. Seo
Sukjo Lee
Jin Seok Han
Youdeog Hong
J.S. Kim
Hajime Akimoto
Sachiko
Hayashida
Hitoshi Irie
Yasko Kasai
Kawakami Shuji
Charles Wong

Sangseo Park, Mijin Kim, Ukkyo Jeong, M.J. Choi, J.H. Kim, Š.Ž. Ko; Ju Seon Bak, Kanghyun Baek; Hyeong-Ahn Kwon, H.J. Cho; K.M. Han, Jihyo Chong, Kwanchul Kim; J.H. Park, Y.J. Lee ..., Bo-Ram Kim, M.A. Kang, J.H. Yang, Sujeong Lim, S.W. Jeong;