Interpretation and improvement of air quality data from Geostationary Environment Monitoring Spectrometer (GEMS)

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Satellite remote sensing for aerosols & gases

Spatial Resolution (km)

Time Resolution

Purple : UV-Vis
Yellow : Vis/NIR
Red : IR
White : UV-IR

(T): target area observations
(L): Lagrangian point (L1)
Italic & dashed line: to be launched

[Kim et al. (BAMS 2020)]
### Geostationary air quality constellation

<table>
<thead>
<tr>
<th></th>
<th>Sentinel-4</th>
<th>TEMPO</th>
<th>GEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Domain</strong></td>
<td>Europe</td>
<td>North America</td>
<td>Asia-Pacific</td>
</tr>
<tr>
<td><strong>Revisit</strong></td>
<td>1 hour</td>
<td>1 hour</td>
<td>1 hour</td>
</tr>
<tr>
<td><strong>(Planned) Launch</strong></td>
<td>~2023</td>
<td>2022</td>
<td>2020</td>
</tr>
<tr>
<td><strong>Payload</strong></td>
<td>UV–Vis–NIR</td>
<td>UV–Vis</td>
<td>UV–Vis</td>
</tr>
<tr>
<td></td>
<td>305–500 nm</td>
<td>290–490 nm</td>
<td>30–500 nm</td>
</tr>
<tr>
<td></td>
<td>750–775 nm</td>
<td>540–740 nm</td>
<td></td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td>O₃, trop. O₃, NO₂, SO₂, HCHO, CHOCHO, AAI, AOD, ALH</td>
<td>O₃, trop. O₃, 0-2km O₂, NO₂, SO₂, HCHO, CHOCHO, BrO, H₂O, AOD</td>
<td>O₃, trop O₃, NO₂, SO₂, HCHO, CHOCHO, AOD, AAI, AEH, (BrO, IO, H₂O ...)</td>
</tr>
<tr>
<td><strong>Spatial sampling</strong></td>
<td>8 km x 8 km at 45°N</td>
<td>≤ 2.2 km N/S x 5.2 km E/W @36.5°N</td>
<td>3.5 km N/S x 8 km E/W @38°N</td>
</tr>
<tr>
<td><strong>Nominal product resolution</strong></td>
<td>8.9 km N/S x 11.7 km E/W @40°N</td>
<td>≤ 8.88 km N/S x 5.15 km E/W @35°N</td>
<td>7 km N/S x 8 km E/W @38°N (gas), 3.5 km N/S x 8 km E/W @38°N (aerosol)</td>
</tr>
<tr>
<td><strong>Accompanied instruments</strong></td>
<td>MTG-S, MTG-I</td>
<td>GOES-R/S ABI</td>
<td>AMI, GOCI-2</td>
</tr>
</tbody>
</table>
Merits of geostationary satellite applications

Aerosol optical depth (AOD)

LEO* (10 km resolution)

LEO* (3 km resolution)

GEO** (6 km resolution)

[LEO: Low-Earth Orbit]

[GEO: Geostationary Earth Orbit]

Spatiotemporal kriging

April 7, 2012

10:30 (a) 11:30 (b) 12:30 (c) 13:30 (d)

Aerosol optical depth (AOD)

12:00 (e)

[Lee et al. (GMD 2016)]
Considerations for satellite applications

- **Column amount vs. Surface mixing ratio**

- **Species-dependent sensitivity**

- **Clouds**

- **Spatial resolution**

The uncertainties are quantified by validation with independent datasets or estimated during retrievals.
GEMS E-W scan scenario

2048 N-S x 695 E-W x 8 times/day
= 11,386,880 spectra/day

[Kim et al. (BAMS 2020)]

[Courtesy of NIER]
GEMS baseline products

- AOD at 443 nm
  2020.05.12.
  00:45 UTC

- Total O₃
  2020.08.06.
  00:45 UTC

- Tropospheric O₃
  2020.08.06.
  00:45 UTC

- UV Index
  2020.08.06.
  00:45 UTC

- NO₂ (total VCD)
  2020.06.16.
  00:45 UTC

- SO₂ (total VCD)
  2020.08.03.
  00:45 UTC

- HCHO (total VCD)
  2020.08.03.
  00:45 UTC

- CHOCHO (total VCD)
  2020.08.03.
  00:45 UTC

- Total O₃
  2020.08.06.
  00:45 UTC

- UV Index
  2020.08.06.
  00:45 UTC

- Tropospheric O₃
  2020.06.16.
  00:45 UTC

- Cloud centroid pressure
  2020.09.06.
  00:45 UTC

- Effective cloud fraction
  2020.09.06.
  00:45 UTC

- Surface albedo at 477 nm
  2020.08.02.
  00:45 UTC
GEMS validation results

Period: August–October 2020

- **AOD**
  - Versus AERONET
    - GEMS domain: R = 0.75
    - East Asia domain: R = 0.80

- **Trop. O₃**
  - Versus OMI: R = 0.69

- **Total O₃**
  - Versus TROPOMI: R = 0.97

- **NO₂**
  - Versus TROPOMI: R = 0.81

- **SO₂**
  - Versus TROPOMI: R = 0.88

- **HCHO**
  - Versus TROPOMI: R = 0.87

- **Surface albedo**
  - Versus MODIS: R = 0.99

- **Cloud**
  - Versus TROPOMI
    - ECF: R = 0.90
    - CCP: R = 0.84
### GEMS validation results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Goal correlation (R)</th>
<th>Achieved correlation (R)</th>
<th>Slope (a)</th>
<th>Intercept (b)</th>
<th>RMSE</th>
<th>Reference</th>
<th>Region</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₃ (Trop.)</td>
<td>0.5–0.8</td>
<td>0.69</td>
<td>0.86</td>
<td>14.78 DU</td>
<td>13.46 DU</td>
<td>OMI</td>
<td>East Asia</td>
<td>2020.08–2020.10</td>
</tr>
<tr>
<td>O₃ (Total)</td>
<td>0.82–0.97</td>
<td>0.89</td>
<td>0.94</td>
<td>24 DU</td>
<td>1.83 DU</td>
<td>Pandora</td>
<td>Busan &amp; Ulsan</td>
<td>2020.08–2020.10</td>
</tr>
<tr>
<td>NO₂</td>
<td>0.80</td>
<td>0.81</td>
<td>1.69</td>
<td>-2.49×10¹⁵ molec. cm⁻²</td>
<td>1.87×10¹⁵ molec.cm⁻²</td>
<td>TROPOMI</td>
<td>GEMS domain</td>
<td>2020.08–2020.10</td>
</tr>
<tr>
<td>SO₂</td>
<td>0.70</td>
<td>0.88</td>
<td>1.05</td>
<td>-0.03 DU</td>
<td>1.14 DU</td>
<td>TROPOMI</td>
<td>GEMS domain</td>
<td>2020.08–2020.10</td>
</tr>
<tr>
<td>HCHO</td>
<td>0.81</td>
<td>0.87</td>
<td>0.90</td>
<td>-2.0×10¹⁵ molec. cm⁻²</td>
<td>3.08×10¹⁵ molec. cm⁻²</td>
<td>TROPOMI</td>
<td>East Asia</td>
<td>2020.08–2020.10</td>
</tr>
<tr>
<td>AOD</td>
<td>0.70</td>
<td>0.75</td>
<td>0.63</td>
<td>0.10</td>
<td>0.18</td>
<td>AERONET</td>
<td>GEMS domain</td>
<td>2020.08–2020.10</td>
</tr>
<tr>
<td>UVI</td>
<td>0.86–0.96</td>
<td>0.87</td>
<td>1.03</td>
<td>-0.30</td>
<td>0.25</td>
<td>TROPOMI</td>
<td>GEMS domain</td>
<td>2020.08–2020.10</td>
</tr>
<tr>
<td>ECF</td>
<td>0.90</td>
<td>0.90</td>
<td>0.86</td>
<td>0.03</td>
<td>0.15</td>
<td>TROPOMI</td>
<td>GEMS domain</td>
<td>2020.08–2020.10</td>
</tr>
<tr>
<td>CCP</td>
<td>0.80</td>
<td>0.84</td>
<td>0.68</td>
<td>282.24 hPa</td>
<td>152 hPa</td>
<td>TROPOMI</td>
<td>GEMS domain</td>
<td>2020.08–2020.10</td>
</tr>
<tr>
<td>SFC</td>
<td>0.70–0.91</td>
<td>0.99</td>
<td>0.97</td>
<td>0.0001</td>
<td>0.0036</td>
<td>MODIS</td>
<td>GEMS domain</td>
<td>2020.08–2020.10</td>
</tr>
</tbody>
</table>
Results: $O_3$

**GEMS**

Total $O_3$ VCD
2021/10/19 08:45 KST

**TROPOMI**

Total Ozone
2021/10/19 02-09 UTC

[Courtesy of Jae H. Kim (PNU)]
Results: Aerosols – Dust case

- Consistent features
- Retrieval over bright surface

[Lim et al. (RS 2018, AMT 2021)]
The fires have burned ~62,000 square miles across Russia since the start of the year (ABC NEWS, 13 August 2021)

Smoke coming from the Siberian wildfires

GEMS AOD at 443 nm

AHI AOD at 550 nm

Lim et al. (RS 2018, AMT 2021)
Results: NO2

GEMS SCD

NO2 total SCD
2020/08/20 00:45 UTC

GEMS VCD

TROPOMI VCD
Results: Average NO$_2$  

Period: April–June 2021

- NO$_2$ diurnal cycle observed from space
- GEMS NO$_2$ > TROPOMI NO$_2$ (total column)

[Courtesy of Hanlim Lee (PKNU)]
Results: Average NO$_2$ – Ship emissions

- Ship tracks from/to Singapore and Malaysia (Port Klang) are clearly detected.

- Ship-emitted NO$_2$ columns are typically large in the morning.

[Courtesy of Hanlim Lee (PKNU)]
Results: Volcanic SO$_2$ & Aerosols

GEMS SO$_2$

GEMS UV aerosol index

TROPOMI SO$_2$

[Courtesy of Hanlim Lee (PKNU)]

Volcanic eruption at Nishinoshima Island, Japan
Results: Average SO$_2$  Period: April–June 2021

- Both volcanic and anthropogenic SO$_2$ sources are detected.
- GEMS retrievals demonstrate diurnal variations of simultaneous NO$_2$ & SO$_2$ emissions

[Courtesy of Hanlim Lee (PKNU)]
Results: HCHO

GEMS HCHO

HCHO VCD (cloud fraction < 0.4)
2020/07/31 00:45 UTC

TROPOMI HCHO

HCHO VCD (cloud fraction < 0.4)
2020/07/31

[Courtesy of Rokjin Park (SNU)]
Results: UV index

GEMS UV index

UV index
2020/08/06 00:45 UTC

TROPOMI UV index

UV index
2020/08/06
GEMS validation network

[Kim et al. (BAMS 2020)]
GEMS images open to the public

NIER website: https://nesc.nier.go.kr/product/view
Summary and implications

- Several considerations are required for satellite air quality applications, including clouds, spatial resolution, and sensitivity.

- As a part of the geostationary air quality constellation, GEMS has been successfully operating since its launch in Feb 2020, capturing diurnal variations of aerosols and trace gases (O\textsubscript{3}, NO\textsubscript{2}, SO\textsubscript{2}, HCHO, and CHOCHO).

- Continuous validation of GEMS observations is essential to improve the data quality.

- High spatiotemporal coverages of GEMS will provide advantages in applications.

[NIER website (https://nesc.nier.go.kr/product/view)]
Acknowledgements

Thank you!