Evaluation of Ozone Profile and tropospheric ozone retrievals from GEMS and OMI spectra

J. H. Kim\textsuperscript{a}, J. Bak\textsuperscript{b}(sunnypark@pusan.ac.kr), X. Liu\textsuperscript{b}, K. Chance\textsuperscript{b}, and J. Kim\textsuperscript{c}

\textsuperscript{a}Pusan National University, Pusan, South Korea
\textsuperscript{b}Harvard-Smithsonian Center for Astrophysics, MA, USA
\textsuperscript{c}Yonsei University, Seoul, South Korea
GEMS will be launched in 2019 on board Korea’s GEO satellite with AMI (Advanced Baseline Imager) and GOCI-2 (Geostationary Ocean Color Imager-2) to provide high spatial (7km NS x 8 km EW at Seoul) and temporal (hourly) measurements of O3, NO2, HCHO, So2, and aerosol over the Asian-Pacific region.
GEMS ozone information

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Spectral Coverage</th>
<th>Spectral Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMI (2004–now)</td>
<td>270–500 nm</td>
<td>0.42–0.63 nm</td>
</tr>
<tr>
<td>GEMS</td>
<td>300–500 nm</td>
<td>0.6 nm</td>
</tr>
</tbody>
</table>

- Four orders of magnitude decrease in the O3 absorption cross section from 270 to 330 nm.

Objects
- What is obtained useful stratospheric ozone information contents from the reduced GEMS spectral coverage?
- Is it possible for GEMS to obtain tropospheric ozone information comparable to OMI?
Ozone Profile Algorithm

- **Main developer:** Xiong Liu @ Harvard-Smithsonian Astrophysical Observatory
- **Principal theory:** Optimal Estimation Tech. (Rodgers, 2000)
- **Heritage:** GOME (Liu et al. 2005), OMI(Liu et al. 2010), GOME-2 (Cai et al. 2012)

Satellite Data

\[ Y, S_a \]

Optimal Estimation

\[
\chi^2 = \frac{1}{S_y^2} \{ K_i (X_{i+1} - X_i) - [Y - R(X_i)] \}^2 + \frac{1}{S_a^2} (X_{i+1} - X_a)^2
\]

\[
X_{i+1} = X_i + (K_i^T S_y^{-1} K_i + S_a^{-1})^{-1} \{ K_i^T S_y^{-1} [Y - R(X_i)] - S_a^{-1} (X_i - X_a) \}
\]

Averaging kernels

\[
A = \frac{\partial x_{\text{ret}}}{\partial x_{\text{true}}} = (K^T S_y^{-1} K + S_a^{-1})^{-1} K^T S_y^{-1} K
\]

- Degrees of Freedoms for Signal (DFS)
  # of independent pieces of information available from measurements
- **Solution Error**
  Root-sum-square of random noise error, \( G S_y G^T \) and smoothing error, \( (A - I) S_a (A - I)^T \)
DFS and Retrieval errors

- Retrieval characteristics from OMI L1b Data at 4 spectral ranges

**Tropospheric retrievals**
- DFS (Retrieval error) tend to be larger (smaller) at smaller SZA
- GEMS DFS and Retrieval error are comparable to OMI (270-330 nm)
- Significant changes of 305-330 nm relative to OMI

**Stratospheric retrievals**
- DFS is reduced by a factor of 2.5 due to the reduced GEMS spectra.
- GEMS retrieval error is comparable to OMI

- The proposed GEMS spectral coverage is nearly optimal for maximizing the tropospheric ozone information available from UV and for simplifying instrument design.
- The exclusion of spectral information below 300 nm substantially reduces stratospheric DFS.
Comparison of Averaging kernels

- both instruments show similar vertical distribution below ~ 20 km.
- Above 30 km, GEMS AKs show very broad features, with rapid reduction in their DFS values. GEMS retrieval errors become larger than OMI.
- Above 40 km, there is no peak of AKs, the magnitude of GEMS retrieval errors becomes close to a priori error.
Can we obtain any useful information over the stratosphere?

Evaluate GEMS stratospheric ozone profile retrievals against the MLS V3.3 standard ozone products for April 2006.

- MLS (Microwave Limb Sounder) is on board the Aura platform with OMI, the effect of the spatiotemporal variability on comparison with OMI is relatively small [Liu et al., 2010b].
- MLS is limb-viewing and thus has higher vertical resolution (~ 3km), but much sparser horizontal coverage than OMI.
- The precision of ozone profile is ~ 5 % for much of stratosphere, ~ 10 % at the lowest stratospheric altitude, and stratospheric column ozone down to 215 hPa is about 2 %.
Evaluation for stratospheric ozone profiles

**Mean Biases**
- OMI and GEMS show similar agreements around tropopause
- The largest impact of not using measurements below 300 nm is mainly found for pressures less than ~3 hPa (~40 km).
- More vertical oscillation in the biases between 1-50 hPa especially in tropics.

**Standard deviations**

Fig. Relative differences (%) versus 10 latitude bins at each MLS layers from 0.22-215 hPa for April 2006.
Evaluation of GEMS retrievals against Sonde

- Period: 2004 to 2008

- 38 stations at latitude > 30°S
  where collocated samplings between OMI and sonde is enough
  comparison between OMI/GEMS and sonde shows the smooth variations from
  station to station.
OMI and GEMS have similar agreements with sonde below 35 km.
Mean Biases is within 10 % for most layers except fro tropopause
Standard deviation range 5-20% in the troposphere and 5 % (tropics) and 10 % (mid/high) In stratosphere
Scatter between OMI/GEMS and SONDE

- **Tropospheric Column Ozone** [surface to tropopause]
  
  ![Graph showing scatter plot for tropospheric column ozone]
  
  - \( N = 3655 \)
  - \( Y = 0.86X + 3.74, R = 0.80 \)
  - \( \text{RMSE} = 6.01 \text{DU} \)
  - \( \text{OMI-SON} = 3.48 \pm 5.76(\text{DU}) = 5.50 \pm 17.79(\%) \)

- **Stratospheric Column Ozone** [tropopause to ~ 35 km]
  
  ![Graph showing scatter plot for stratospheric column ozone]
  
  - \( N = 3677 \)
  - \( Y = 0.89X + 1.91, R = 0.79 \)
  - \( \text{RMSE} = 6.48 \text{DU} \)
  - \( \text{OMI-SON} = 2.00 \pm 5.86(\text{DU}) = 7.29 \pm 17.70(\%) \)

  ![Graph showing scatter plot for stratospheric column ozone]
  
  - \( N = 3668 \)
  - \( Y = 1.02X - 4.83, R = 0.98 \)
  - \( \text{RMSE} = 14.97 \text{DU} \)
  - \( \text{OMI-SON} = 0.61 \pm 14.33(\text{DU}) = 0.31 \pm 6.79(\%) \)

  ![Graph showing scatter plot for stratospheric column ozone]
  
  - \( N = 3658 \)
  - \( Y = 1.02X - 2.83, R = 0.98 \)
  - \( \text{RMSE} = 14.87 \text{DU} \)
  - \( \text{OMI-SON} = 1.26 \pm 14.25(\text{DU}) = -0.22 \pm 8.74(\%) \)
GEMS tropospheric (stratospheric) column ozone retrievals are negatively (positively) biased relative to OMI.

The little changes of the retrieval characters need to be carefully considered in developing the GEMS algorithm for the tropospheric ozone.
• Retrieval sensitivity
  - Proposed GEMS spectral coverage is nearly optimal for maximizing the tropospheric ozone information available from UV measurements
  - Exclusion of spectral information below 300 nm leads to loss of stratospheric ozone information mostly above 20 km and no information above ~ 40 km.

• Evaluation with MLS
  - Similar ability to retrieve the stratospheric ozone retrievals below ~ 40 km relative to OMI, but the significant dependence on a priori information above them.

• Evaluation with SONDE
  - Similar ability to retrieve the ozone retrievals below 35 km relative to OMI.
  - Tropospheric ozone retrievals show more impact due changed retrieval characteristic compared to stratospheric ozone retrievals

Acknowledgements: This research was supported by the Eco Innovation Program of KEITI (ARQ201204015), Korea. Research at the Smithsonian Astrophysical Observatory was funded by NASA and the Smithsonian Institution. We acknowledge OMI and MLS science teams for providing the satellite data used in this study.