Improved O$_3$ and CO Profile Retrievals Using Multispectral Measurements from NASA “A Train”, Suomi NPP, and S5P Satellites

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The rapid change in global emissions and their impact of air quality and climate requires a new observing system of GEO and LEO sounders to quantify global sources of local pollution.

- LEO A-Train AIRS/OMI and SNPP CrIS/OMPS can support this constellation by distinguishing lower and upper tropospheric O₃ signals
- LEO sounders will be a crucial link between GEO sounders over America, Europe and Asia as well as the sole satellite observations in the SH.
This presentation will mainly report:

- Joint AIRS/OMI ozone profile retrievals
- Joint CrIS/TROPOMI carbon monoxide profile retrievals
Multi-Spectra, Multi-Species, Multi-Sensors (MUSES)

- Builds off of heritage from the Tropospheric Emission Spectrometer (TES) optimal estimation (OE) algorithm to combine *a priori* and satellite data; including rigorous error analysis diagnostics and observation operators needed for trend analysis, climate model evaluation, and data assimilation.

- Has generic design to incorporate forward model radiances from hyperspectral measurements from multiple sensors into the joint retrieval algorithm.

- We will demonstrate through prototype studies the following missions:
  - **ozone profiles**
    - AIRS/OMI/MLS -> provide decade long global record of O$_3$ profiles with the highest vertical resolution and accuracy compared to any single platform on A-Train satellites.
    - CrIS/OMPS -> extend EOS O$_3$ data records with the highest vertical resolution and accuracy compared to any single nadir sensor on SNPP satellite.
  - **carbon monoxide profiles**
    - CrIS/TROPOMI -> extend EOS MOPITT CO data records – submitted to AMTD 2015.
JPL MUSES provides rigorous error analysis diagnostics and observation operators needed for trend analysis, climate model evaluation, and data assimilation.

Joint AIRS/OMI vs. each instrument alone:
- Use single footprint L1B radiances into the retrievals
- Show improved vertical sensitivity and resolution
- Show smaller total error
The TexAQS-II aircraft flight campaign is a joint regional air quality and climate change study.

- Joint AIRS/OMI shows capability of distinguishing the amount of O₃ between LT and UT.
- AIRS operational L2 CO data products showed enhanced CO plume from North Dakota into Washington States due to the fires. Joint AIRS/OMI detected enhanced O₃ collocated in those plumes, where the averaging kernels indicate high sensitivity in the plume.
Comparisons to Aura-TES Operational L2 O₃ Data Products

Joint AIRS/OMI ozone retrievals
- Differ from the *a priori* profiles
- Present similar vertical and horizontal distribution to TES
- Show best agreement to TES, in comparisons to each instrument alone

Collocated Transect Measurements over Western USA

Mean differences to TES
The JPL MUSES has been implemented and applied to joint AIRS/OMI ozone retrievals over global scale for August 2006.

Characteristics:
- Both TES and Joint AIRS/OMI show similar spatial patterns, e.g., capturing the enhanced ozone over the continental outflow and biomass burning active regions.
- Differ from a priori.
Joint AIRS/OMI ozone data has been assimilated into the CHASER-DA, which has a proven capability to assimilate the atmospheric composition observations from multiple A-Train instruments.

CHASER-DA leads to chemically/dynamically consistent integrated atmospheric state.

Dr. Kazuyuki Miyazaki, implemented the CHASER data assimilation system.
All NASA space missions capable of measuring atmospheric CO concentration from space, have passed their nominal lifetime longer than 5 years.

MOPITT is the only satellite borne sensor now or in planning that has both TIR and NIR channels.

Joint TROPOMI/CrIS measurements are the only space sensors in the coming decade that could extend the MOPITT multi-spectral data record.

<table>
<thead>
<tr>
<th>Mission</th>
<th>Nominal Life Time</th>
<th>Years after Its Design Life Time</th>
<th>Spectral Resolution</th>
<th>Footprint Size</th>
<th>Swath Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>CrIS/TROPOMI</td>
<td>2016 – 2023</td>
<td>0</td>
<td>TIR(^a) cm(^{-1})</td>
<td>14 × 14</td>
<td>2200</td>
</tr>
<tr>
<td>MOPITT</td>
<td>2000 – 2006</td>
<td>9</td>
<td>NIR(^b) cm(^{-1})</td>
<td>22 × 22</td>
<td>640</td>
</tr>
<tr>
<td>CrIS</td>
<td>2011 – 2026</td>
<td>0</td>
<td>0.625</td>
<td>NA</td>
<td>π × (14/2)(^2)</td>
</tr>
<tr>
<td>TES</td>
<td>2004 – 2010</td>
<td>5</td>
<td>0.060</td>
<td>8 × 5</td>
<td>5</td>
</tr>
<tr>
<td>AIRS</td>
<td>2002 – 2008</td>
<td>7</td>
<td>~ 1.800</td>
<td>NA</td>
<td>π × (14/2)(^2)</td>
</tr>
<tr>
<td>TROPOMI</td>
<td>2016 – 2023</td>
<td>0</td>
<td>NA</td>
<td>~ 0.458</td>
<td>7 × 7</td>
</tr>
<tr>
<td>SCIAMACHY</td>
<td>2002 – 2007</td>
<td>Terminated</td>
<td>NA</td>
<td>~ 0.485</td>
<td>30 × 60</td>
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</tbody>
</table>

\(^a\) First fundamental band of carbon monoxide, centered around 4.6 µm in the thermal infrared.

\(^b\) First overtone band of carbon monoxide, centered around 2.3 µm in the near infrared.
Data Products in Comparisons

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<thead>
<tr>
<th></th>
<th>Mean</th>
<th>1 σ Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CrIS - MOPITT TIR</td>
<td>-6.93</td>
<td>22.77</td>
</tr>
<tr>
<td>CrIS - MOPITT Joint TIR/NIR</td>
<td>-22.91</td>
<td>38.80</td>
</tr>
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</table>
### Joint CrIS/TROPOMI CO Retrievals – Improving Vertical Sensitivity and Reducing Uncertainty

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Sensor</th>
<th>TIR</th>
<th>NIR</th>
<th>Joint TIR/NIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface to TOA</td>
<td>MOPITT</td>
<td>1.44</td>
<td>0.51</td>
<td>1.88</td>
</tr>
<tr>
<td></td>
<td>CrIS</td>
<td>1.57</td>
<td>-</td>
<td>2.22</td>
</tr>
<tr>
<td></td>
<td>TROPOMI</td>
<td>-</td>
<td>1.32</td>
<td></td>
</tr>
</tbody>
</table>

### Diagrams

- **Joint MOPITT TIR/NIR** (A)
- **CrIS** (B)
- **TROPOMI** (C)
- **Joint CrIS/TROPOMI** (D)

- **Joint MOPITT TIR/NIR** (A)
- **Joint TROPOMI/CrIS; CrIS; TROPOMI** (C)
The JPL MUSES retrieval algorithm has the capability of combining AIRS and OMI measurements to provide improved ozone data products, in compared to each instrument alone.

- are able to distinguish the ozone abundances in the upper troposphere from the lower troposphere
- show better agreement to the well-validated TES data products

The JPL MUSES retrieval algorithm is able to process joint AIRS/OMI observations over global scale – leading to provide the decade long global ozone data records that fully satisfy the NASA EOS data product standards.

The joint AIRS/OMI data products have been assimilated in global CTM “CHASER”, demonstrating the potentials of this data products.

The flexibility of JPL MUSSE has demonstrated through the prototype retrievals for multi-satellite missions [TES/OMI, AIRS/OMI, CrIS/OMPS].

We are preparing manuscripts that summarize the JPL MUSES retrieval algorithm, sample retrievals and their characteristics.

Thank you for attention. Questions?
Backup
Joint CrIS/OMPS Retrievals – towards extending Earth Observing System O₃ data records

Monthly mean TES O₃ @ 681 hPa

Joint CrIS/OMPS Retrievals over Africa on October 21, 2013

Averaging kernels of joint CrIS/OMPS vs. CrIS

[A] Uncertainty of joint CrIS/OMPS retrievals
[B] Error reduction of joint CrIS/OMPS retrievals
By incorporating the assimilated Aura MLS ozone profiles into the joint retrievals, the vertical resolution and error characteristics of these joint OMI/AIRS tropospheric ozone estimates can be substantially improved, compared to joint OMI/AIRS measurements.

This increased sensitivity is critical for evaluating the radiative response of ozone to surface emissions and the role of stratospheric / tropospheric exchange, long range transport, and tropical fires (or pyro-convection) on the tropospheric ozone distribution.