Hyperspectral OLR Retrieval Towards OLR Climate Data Record Production

Hai-Tien Lee
Cooperative Institute for Satellite Earth System Studies (CISESS, previously CICS)
Earth System Science Interdisciplinary Center (ESSIC)
University of Maryland College Park
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Outline

• Background
• Theoretical Basis
• Comparison of OLR Products
• Summary
Background

- NOAA/UMD OLR Climate Data Record (CDR)
  - HIRS OLR retrieval (primary), blended with Geo Imager OLR
  - 1979-Present, Global
  - 1° Daily and 2.5° Monthly

- Currently functional HIRS on NOAA-18,19 and Metop-A/M2,B/M1
  - *The last HIRS* is on Metop-B (since 2013)

- OLR CDR to be extended with OLR retrieved from operational hyperspectral sounder observations, supplementing/replacing HIRS
  - (09:30) Metop IASI (Infrared Atmospheric Sounding Interferometer)
  - (13:30) JPSS CrIS (Cross-track Infrared Sounder)
Theoretical Basis
Spectral OLR Model Principles

- **Broadband**: Broadband radiance observations and Angular Distribution Model (ADM)

\[
\text{OLR} = \frac{\int I_\nu(z;\theta,\phi) d\nu}{\text{ADM (angles, scene, cloud, } T, q, \ldots)}
\]

- **Spectral**: Spectral radiance observations and Spectral Angular Model (SAM)

\[
\text{OLR} = \int F_\nu d\nu
\]

\[
F_\nu = \int_0^{2\pi} \int_0^{\pi/2} I_\nu(z;\theta,\phi) \cos \theta \sin \theta d\theta d\phi = \text{SAM} (I_\nu(\theta), \theta)
\]

- **Spectral flux estimation principles**:
  1. **Inter-Frequency Correlations** - Radiances at one frequency strongly correlate with radiances at another frequency with similar absorption features.
  2. **Intra-Frequency/Angle Correlations**
     - Using absorption strengths to surrogate optical path lengths
     - Spectral flux integration can be estimated with radiances at selected angles (Gaussian quadrature)

- **Previous works**: Total LW spectrum reconstruction from IASI observations – Lee, Ellingson & Gruber (2010); Turner, Lee & Tett (2015)
IASI OLR Model is a 3-predictor multiple linear regression model in quadratic forms. Predictors are natural log of IASI radiances aggregated to 10 cm\(^{-1}\) intervals in 650-2500 cm\(^{-1}\). (2500-2760 cm\(^{-1}\) radiance observations not used to avoid solar contamination.)

\[
OLR = \int F_v \, dv
\]

\[
\log(F_v) = a_0(\theta) + a_1(\theta)x_1(\theta) + a_2(\theta)x_2(\theta) + a_3(\theta)x_3(\theta)
+ a_4(\theta)x_1^2(\theta) + a_5(\theta)x_2^2(\theta) + a_6(\theta)x_3^2(\theta)
\]

\[
x_v(\theta) = \log(I_v(\theta))
\]

RMS regression errors for Total OLR estimation range from 0.13 - 0.47 Wm\(^{-2}\), dominated by “FIR” spectral flux estimation errors.
Comparisons of OLR Products

Assessing Retrieval Accuracies at Instantaneous Foot-print Level

- Mean OLR Diff – Relative Bias
- StdDev OLR Diff – Random errors (Precision)
## Data

**Temporal:** Jan, Apr, Jul & Oct, 2018

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Platform</th>
<th>Product</th>
<th>Ver.</th>
<th>Source</th>
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</thead>
<tbody>
<tr>
<td>CERES</td>
<td>Terra Aqua</td>
<td>SSF OLR</td>
<td>XTRK Ed4a</td>
<td>LaRC/NASA</td>
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<td>IASI</td>
<td>MetOp-A/02 MetOp-B/01</td>
<td>Level 1C</td>
<td>OLR</td>
<td>CLASS/NOAA</td>
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<td></td>
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<td>CISESS/UMD</td>
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</table>

### Collocation and Processing

- **Collocation:** closest and within 0.5° to reference target FOV, regardless observing angle, within ±60 minutes
  - LZA-Matched = |dLZA| < 5°
  - Nadir = |LZA| < 10°
- **Daytime:** 6:00-18:00 local time
- **“Homogeneity”** metrics: STD of OLR in 1° circle encompassing target
Mean OLR Diff

- All collocated data
- LZA-matched
- Nadir
Best Estimate of Precision at “Pristine Conditions”

Reducing Sampling Errors
Precision at “Pristine Condition”

- The spread of OLR in 1° circle encompassing target is a metrics for Scene Homogeneity – a crucial factor for sampling errors.

- The STD OLR differences of collocated pairs is subject to the “Threshold” of Homogeneity of the scenes.

- The STD OLR difference extrapolated to Threshold=0 represents the best estimate of the Precision at “Pristine Condition”.

![Chart showing the spread of OLR differences for different sensors and the best estimate for pristine condition](chart.png)
CERES July 2018 Daytime Issues
Terra-Aqua Jul2018 Daytime Issue

- Relatively large Terra-Aqua biases were found in Daytime, July 2018.
- The biases occur over land.
  - Mean OLR diff between Terra and Aqua for all Daytime data [top] and for three 10°-zones [bottom] clearly show the biases in tracking with land masses, except Greenland.

- Pure speculations:
  - Residual degradation correction error
  - Polar ADM model land/sea differences
  - Snow/Ice map input bug
  - ADM lookup bug
Summary

• A new high-precision OLR estimation method for hyperspectral instruments using Spectral Angular Model (SAM) has been developed, with a theoretical accuracy of about 0.2 Wm\(^{-2}\).

• Mean OLR differences for IASI-CERES are on par with those within the two CERES (Terra-Aqua), with relative biases well within \(±1\) Wm\(^{-2}\).

• Best estimate of Precision (random errors) of instantaneous IASI OLR retrieval is within 2 Wm\(^{-2}\), similar to those within CERES.

• Terra-Aqua for July 2018 Daytime (N. Polar) show apparent relative biases over land. (reason?)

• Slight limb dependence in IASI OLR relative CERES is shown for LZA > 50°. IASI OLR retrieval limb property is considered improved over HIRS, more agreeable with CERES.

• Future Works
  – RTM (LBLRTM) and Cloud properties
  – Spectral interval size for SAM
  – Scene discretion (Gaussian mixture model)
  – Investigate Day/Night differences in limb dependence
End
Backup Slides
IASI Instrumentation and Data

- The *Infrared Atmospheric Sounding Interferometer* (IASI) is composed of a Fourier transform spectrometer and an associated Integrated Imaging Subsystem (IIS).

- Three bands between $645 \text{ cm}^{-1}$ and $2760 \text{ cm}^{-1}$ (15.5 and 3.63 µm), with a spectral resolution of 0.5 cm$^{-1}$ (FWHM) after apodization (L1C spectra). (the spectral sampling interval is 0.25 cm$^{-1}$)

<table>
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<tr>
<th>Band</th>
<th>Wavenumbers (cm$^{-1}$)</th>
<th>Wavelength (µm)</th>
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<tbody>
<tr>
<td>1</td>
<td>645 – 1210</td>
<td>8.26 – 15.50</td>
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<tr>
<td>2</td>
<td>1210 – 2000</td>
<td>5.00 – 8.26</td>
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<tr>
<td>3</td>
<td>2000 – 2760</td>
<td>3.62 – 5.00</td>
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</table>

- **Level 1C data**: Calibrated apodized radiance spectra with geolocation and time stamp information at the Effective FOV (EFOV) composed of 2x2 Instantaneous FOV (IFOV) at **12 km at nadir**.


Terra-Aqua

M2 IASI – M1 IASI

M1 IASI - Aqua

M1 IASI – M1 HIRS

Jan

Apr

Jul

Oct

