A Hyperspectral Closure Study Using AIRS Radiances, ARM SGP Observations, and MERRA2 & ERA-interim Reanalyses: how good is good enough?

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Outline

• Motivations
• Approach
• Results
• Extrapolation
• Conclusions and discussions
Motivations

• Any observation or measurement has its own uncertainty
• When evaluate reanalysis/model against observations, how good is good enough?
  – For SARB project, how much can the T/q profiles be tweaked?
• Premise: if two simultaneous high-quality observations exist and they differ by $\Delta$, then
  – If mod-obs/reanalysis-obs smaller than $\Delta$, then mod is indistinguishable from obs
  – Otherwise, model/reanalysis has a bias.

In this study: $T(z)$ and $q(z)$
Table 1. AIRS Standard Products in Version 5.0

<table>
<thead>
<tr>
<th>Product</th>
<th>RMS Requirement</th>
<th>Uncertainty Estimate</th>
<th>Vertical Coverage</th>
<th>Val Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiancees (Level 1B)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AIRS IR Radiance</td>
<td>3%</td>
<td>&lt;0.2%; 0.1 K at Antarctica</td>
<td>N/A</td>
<td>Val5</td>
</tr>
<tr>
<td>AIRS VIS/NIR Radiance</td>
<td>20%</td>
<td>15-20%</td>
<td>N/A</td>
<td>Prov</td>
</tr>
<tr>
<td>AMSU Radiance</td>
<td>0.25-1.2 K</td>
<td>1-3 K</td>
<td>N/A</td>
<td>Val3</td>
</tr>
<tr>
<td>Standard Geophysical Products</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud Cleared IR Radiance</td>
<td>1.0 K</td>
<td>Accuracy ~1 K, precision 0.3-8 K</td>
<td>N/A</td>
<td>Val3</td>
</tr>
<tr>
<td>Sea Surface Temperature</td>
<td>0.5 K</td>
<td>1.0 K</td>
<td>N/A</td>
<td>Val1</td>
</tr>
<tr>
<td>Land Surface Temperature</td>
<td>1.0 K</td>
<td>2-3 K</td>
<td>N/A</td>
<td>Prov</td>
</tr>
<tr>
<td>Temperature Profile</td>
<td>1 K / km</td>
<td>1-2 K / km in troposphere, 2-3 K / km above</td>
<td>Surface to 1 hPa</td>
<td>Val4</td>
</tr>
<tr>
<td>Water Vapor Profile</td>
<td>15% / 2 km</td>
<td>20 % / 2 km lower trop; 20-60% / 2 km upper trop</td>
<td>Surface to 200 hPa or tropopause</td>
<td>Val4</td>
</tr>
<tr>
<td>Total Precipitable Water</td>
<td>5%</td>
<td>5-20%; 0.1 mm wet bias in Antarctica</td>
<td>N/A</td>
<td>Val5</td>
</tr>
<tr>
<td>Fractional Cloud Cover</td>
<td>5%</td>
<td>5-30%, cloud type dependent</td>
<td>900 to 100 hPa</td>
<td>Val2</td>
</tr>
<tr>
<td>Cloud Top Height</td>
<td>0.5 km</td>
<td>0.5-2 km, cloud type dependent</td>
<td>900 to 100 hPa</td>
<td>Val3</td>
</tr>
<tr>
<td>Cloud Top Temperature</td>
<td>1.0 K</td>
<td>1-2 K</td>
<td>900 to 100 hPa</td>
<td>Val1</td>
</tr>
<tr>
<td>Total Ozone Column</td>
<td>-</td>
<td>5% tropics; 5-40% poles</td>
<td>N/A</td>
<td>Val3</td>
</tr>
<tr>
<td>Ozone Profile</td>
<td>-</td>
<td>20%</td>
<td>200 hPa to 70 HPa</td>
<td>Val4</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>-</td>
<td>10-50% at 500mb</td>
<td>800-200 hPa layer</td>
<td>Val3</td>
</tr>
<tr>
<td>Methane</td>
<td>-</td>
<td>1.5% monthly in mid-trop.</td>
<td>700-200 hPa layer</td>
<td>Prov</td>
</tr>
<tr>
<td>Carbon Dioxide (Research)</td>
<td>&lt; 2 ppm</td>
<td>&lt; 1.45 ppm</td>
<td>500-300 hPa</td>
<td>Beta</td>
</tr>
<tr>
<td>Outgoing Longwave Radiation</td>
<td>-</td>
<td>&lt; 5 W/m²</td>
<td>N/A</td>
<td>Prov</td>
</tr>
</tbody>
</table>
Observations

- AIRS L1 spectral radiances and L2 retrievals

<table>
<thead>
<tr>
<th></th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>Highly accurate (NeBT &lt; 0.3K) and stable (drift &lt;0.03K). Forward modeling is accurate</td>
<td>Clouds, trace gases also contribute</td>
</tr>
<tr>
<td>L2</td>
<td>Directly comparable with model/reanalysis</td>
<td>Retrieval uncertainties</td>
</tr>
</tbody>
</table>

- ARM observations
  - MMCR (30km-by-30km scan)
  - Raman lidar for T (<0.3K) and q (~0.4%)
  - Surface temperature and surface radiation
Downward LW flux at surface calculated using MODTRAN5

Forward modeling is straightforward.

Regression slope: 0.9934
Corr. Coef. = 0.993
Approach

• Using ARM MMCR to identify clear-sky scene when Aqua passed over (Dolinar et al., 2016, JGR)
  – 51 scenes selected for 2004 to 2013 (19 day; 32 night)
• Fed ARM in-situ obs to PCRTM to generate synthetic AIRS L1 spectrum
• Do the same with the ERA-interim/MERRA-2/AIRS-L2 profiles
• Single out channels that are affected by only T, q, and CO₂ (done with LBLRTM/HITRAN/AIRS SRF)
• Make comparisons
Grouping channels based on the peaks of their W.F.

<table>
<thead>
<tr>
<th>Group</th>
<th>CO$_2$ band Peak of the W.F. (hPa)</th>
<th>Number of channels</th>
<th>H$_2$O band &amp; WN band Peak of the W.F. (hPa)</th>
<th>Number of channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1000-800</td>
<td>155</td>
<td>1000-800</td>
<td>442</td>
</tr>
<tr>
<td>2</td>
<td>800-600</td>
<td>45</td>
<td>800-600</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>600-400</td>
<td>46</td>
<td>600-400</td>
<td>124</td>
</tr>
<tr>
<td>4</td>
<td>400-200</td>
<td>33</td>
<td>400-200</td>
<td>136</td>
</tr>
<tr>
<td>5</td>
<td>200-70</td>
<td>77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>70-30</td>
<td>67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>30-1</td>
<td>28</td>
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</tbody>
</table>
The **devil** is in the **detail**: surface skin temperature

Old: Calculation using ARM SGP profiles, surface temperature and woody savannas emissivity

New: Calculation using ARM SGP profiles and *surface skin temperature* derived from ARM upward/downward LW fluxes at surface

\[ F_{sfc}^{\uparrow} = \int_{0}^{\infty} \varepsilon_{v} \pi B(T_s) dv + (1 - \bar{\varepsilon}) F_{sfc}^{\downarrow} \]

Still using woody savannas emissivity

51 clear-sky cases at ARM SGP site (36.61°N, 97.49°W)
Old: surface temperature directly from ARM
New: surface skin temperature from LW measurements @ARM SGP
AIRS L1 – Synthetic using ARM SGP data: Channels grouped w.r.t. peaks of weighting functions

Sensitive to T

Sensitive to T & q
Direct T & q comparisons
Results
Synthetic mean spectrum – AIRS mean spectrum

- ARM SGP - AIRS L1
- MERRA2 - AIRS L1
- ECMWF - AIRS L1
- AIRS L2 - AIRS L1

Mean BT difference (K)

Wavenumber (cm\(^{-1}\))

600  800  1000  1200  1400  1600
1. Reanalyses wet bias in mid-upper troposphere
2. AIRS L2 agrees with ARM SGP and AIRS L1 in all groups except 800-600hPa H₂O
3. Similar results when compositing the difference w.r.t. season or w.r.t. TCWV
4. Difference in the 1000-800 hPa groups: additional factor for ARM – AIRS L1
Extending the comparison

MERRA2 – AIRS L1 at ARM-SGP site

Clear-sky; 51 cases in total

MERRA2 – AIRS L1 in 30°-40°N

Clear-sky, 187,053 cases in total

MERRA2 – AIRS L1 at ARM-SGP site

MERRA2 – AIRS L1 in 30°-40°N
Conclusion and discussion

• AIRS and ARM-SGP clear-sky radiances agree well with 0.5K in BT.
• Both ERA-interim and MERRA show wet bias in 600-200 hPa, for ARM-SGP site and beyond.
• Additional constrain on how much tweaks can be done to UTH in SARB algorithm.
• Using two observations to bracket observational uncertainties:
  – Other ARM sites (TWP and NSA)
  – Overcast and broken clouds
Thank You!
Atmospheric input profiles and radiative transfer forward model

- ARM SGP sounding profiles (T, q; o3 is from MERRA-2)
  - 1-minute time resolution, 266 levels from surface to ~20 km
- AIRS version 6 level2 standard products (AIRS + AMSU; T, q, o3)
  - Horizontal resolution: ~45 km at nadir; Water vapor mixing ratio: 15 levels from surface to 50 hPa, and temperature and traces gases: 28 levels from surface to 0.1 hPa
- MERRA-2 (T, q, o3)
  - 3-hourly MERRA-2 data on a horizontal grid of 0.5° latitude by 0.625° longitude with 42 vertical levels up to 0.1 hPa
- ECMWF ERA-Interim (T, q, o3)
  - 6-hourly ECMWF ERA-Interim data on the 0.75° by 0.75° horizontal resolutions and 37 vertical levels from surface to 1 hPa
- PCRTM-based satellite simulator (Chen et al., 2013)
  - Profiles are linearly interpolated onto AIRS trajectories; Surface emissivity is from IGBP woody savannas
  - (This is not the forward model used in AIRS L2 retrievals)
CO$_2$ band: 650-810 cm$^{-1}$
Wave vapor and window bands excluding CO$_2$, O$_3$, CH$_4$ and N$_2$O: 810-990, 1093-1205 and 1400-1612 cm$^{-1}$.

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<th>Peak of the W.F. (hPa)</th>
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Why blackbody surface has the smallest difference of Obs.-ARM? Surface thermal inhomogeneity?
Downward LW flux at surface calculated using MODTRAN5
WRT to season
WRT to total column water vapor
Retrieval might be easy. But clear-sky forward modeling is.

Downward LW flux at surface (obs vs. calculation)
AIRS L1 – Synthetic using ARM SGP data

51 profiles

Mean difference

Standard deviation

Old: surface temperature directly from ARM
New: surface skin temperature from LW measurements @ARM SGP