I. TES Level 1B Calibration Algorithm

Sources of Error in Baseline 1B Calibration Algorithm
- Improper sampling phase alignment
- Model for time variability in response and offset
- Interference in sampling array (phase modulation error)

Prototype for improved TES calibration
- Use of sampling phase information across detector arrays
- Introduces inter-pixel dependency (code re-design)
- Improves limb and cold space alignment
- Improves temporal variability
- Model estimate for time dependent response and offset
- Interferogram sampling array (phase modulation error)

Complex Calibration:
C_{BB} = \text{cold space complex spectrum}
C_{CS} = \text{cold space blackbody complex spectrum}
\varepsilon = \text{blackbody emissivity}
C_{BB}(\nu) = \text{Planck function for blackbody}

Estimation of instrument response and offset

NADIR spectrum example for Australia, taken 5/22/2005. The detector average radiances with min/max (blue/red) are shown in the top right panel and average brightness temperature is shown in the bottom left panel. Right side panels show geolocation of the spectrum (top) and the variation of brightness temperatures across the detector array (bottom).

Table 1. TES Instrument Specifications

<table>
<thead>
<tr>
<th>Spectrometer Type</th>
<th>Conn estype 4-port Fourier Transform Spectrometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Optical Path</td>
<td>\pm 0.85 cm (nadir &amp; calibration) \pm 3.36 cm ( limb)</td>
</tr>
<tr>
<td>Time (Scan)</td>
<td>4 sec (nadir) + calibration 16 sec (limb)</td>
</tr>
<tr>
<td>Sampling Metrology</td>
<td>Nd: YAG laser</td>
</tr>
<tr>
<td>Spectral Resolution</td>
<td>0.06 (nadir) \pm 0.05 (limb)</td>
</tr>
</tbody>
</table>
| Coverage          | 650 to 3050 cm^{-1} (3.2 to 15.5 
|                     | \mu m) |
| Detector Arrays   | 4 (1 x 16) arrays, optically-coupled, at 1 MCT PV, 65 K |
| Field of Regard   | 208 sec (nadir) scans |
| Spat. Resolution  | 0.5 x 5 km (nadir) 2.3 x 23 km (limb) |
| Calibraton        | Cavity blackbody (340K) + cold space view |
| Calibraton        | Internal thin slit source |

Radiance (W/cm^2 sr/um)

LIMS spectrum for 63.7 N, 34.5 W, taken 9/20/2004: Spectra clearly show features due to Nitric Acid and CFC-11, 12, with distinct altitude dependence. O_3, CO_2 and H_2O spectral lines are also visible. The surface is obscured by clouds (detectors viewing the surface are not shown). L1B calibration results corresponding to the baseline calibration (RT) are shown in red. Results from the latest L1B prototype algorithm are shown in black, with data processed at the spectral resolution normally used for the nadir view. Note improvements in the higher detectors where we expect a zero radiance level on the left part of the spectra.
II. AIRS-TES Radiance Comparisons

Applying AIRS SRF to TES spectra:
Test with simulated data

Top panel (A) shows a simulated, unconvolved (monochromatic) spectrum in black compared to spectra convolved with the TES instrument response function (SRF) in red. Panel (B) shows the monochromatic spectrum convolved directly with AIRS SRF (red) overlaid with the same spectrum convolved first with TES ILS followed by AIRS SRF. Difference in brightness temperature is well below the TES noise equivalent delta-temperature (NEDT) and confirms the radiance comparison method.

Brightness Temperature Comparison

Top panel (A) shows a direct brightness temperature comparison for a selected, homogenous nadir target. TES pixel #8. Panel (B) shows that same comparison after the AIRS SRF is applied to the TES data. Panel (C) shows AIRS-TES differences compared to the TES NEDT; black dots show our baseline calibration results and green line shows the difference after using the L1B prototype with improved algorithms.

Ensemble comparisons vs. radiance and frequency:
Test of TES L1B algorithm improvement

After identifying 100 TES nadir targets from a 16-orbit Global Survey with 0.5 K homogeneity across a detector array, 50 of these were confirmed as homogenous for AIRS also. These homogenous nadir targets are the test cases for TES L1B algorithm improvements. Both plots show the radiance ratio (TES/AIRS) vs. radiance and color coded for frequency ranges. Panel (A) shows the spread in values over the homogenous cases for the baseline calibration; panel (B) shows this for the prototype improved calibration (Test Case).

Top panel (A) shows a simulated, unconvolved (monochromatic) spectrum in black compared to spectra convolved with the TES instrument response function (SRF) in red. Panel (B) shows the monochromatic spectrum convolved directly with AIRS SRF (red) overlaid with the same spectrum convolved first with TES ILS followed by AIRS SRF. Difference in brightness temperature is well below the TES noise equivalent delta-temperature (NEDT) and confirms the radiance comparison method.

Frequency and time dependence of AIRS-TES comparisons for TES 2B1, 1B2 and 2A1 filters. For each filter, the top panel shows the average over 50 nadir targets of the AIRS-TES brightness temperature difference as a function of frequency on the AIRS frequency grid. (TES data are for a single pixel and have been convolved with the AIRS SRF). The bottom panels show averages over frequency as a function of target index or time - spanning about 26 hours. These plots demonstrate how the different prototype improvements affect our frequency ranges. In the 2B1 filter, the most significant improvement is from modeling the time dependence, while in 1B2 and 2A1, the time dependence is nearly flat in both the baseline and prototype runs, as expected from the spectral dependence of ice absorption. For 1B2, and especially 2A1, we see large improvements due primarily to the improved sampling phase alignment algorithm.

Comparisons of AIRS, SHIS and TES (with different spectral convolutions) to LBLRTM (Line-By-Line Radiative Transfer Model) using GMAO profiles as input. The four horizontal panels are for TES filters 2B1, 1B2, 2A1 and 1A1, respectively, with frequency ranges as noted.

Table 2. AIRS-TES Comparison Summary

<table>
<thead>
<tr>
<th>TES Filter</th>
<th>Freq. Range (cm⁻¹)</th>
<th>Mean AIRS-TES Δ BT (K)</th>
<th>RMS AIRS-TES Δ BT (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2B1</td>
<td>650 - 920</td>
<td>0.18 (0.29)</td>
<td>0.13 (0.31)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.46 (0.86)</td>
<td>0.42 (0.54)</td>
</tr>
<tr>
<td>1B2</td>
<td>920 - 1160</td>
<td>-0.01 (0.05)</td>
<td>0.12 (0.19)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.48 (0.52)</td>
<td>0.38 (0.38)</td>
</tr>
<tr>
<td>2A1</td>
<td>1090 - 1340</td>
<td>-0.34 (-1.05)</td>
<td>-0.35 (-1.37)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.36 (0.37)</td>
<td>0.32 (0.70)</td>
</tr>
</tbody>
</table>

Comparison results are shown for TES runs taken on two different days. The numbers are the mean and rms of brightness temperature differences (Δ BT in K) averaged over frequency, 16 TES detectors and nadir target scenes (50 targets for run 2147 and 20 for run 2931). Brightness temperature differences are given for the L1B prototype results with baseline L1B comparisons in parenthesis.

Bias and RMS for AIRS-TES differences are < 0.5 K for improved TES L1B calibration

III. SHIS-TES Radiance Comparisons

Comparisons of AIRS, SHIS and TES (with different spectral convolutions) to LBLRTM (Line-By-Line Radiative Transfer Model) using GMAO profiles as input. The four horizontal panels are for TES filters 2B1, 1B2, 2A1 and 1A1, respectively, with frequency ranges as noted.

Frequency and time dependence of AIRS-TES comparisons for TES 2B1, 1B2 and 2A1 filters. For each filter, the top panel shows the average over 50 nadir targets of the AIRS-TES brightness temperature difference as a function of frequency on the AIRS frequency grid. (TES data are for a single pixel and have been convolved with the AIRS SRF). The bottom panels show averages over frequency as a function of target index or time - spanning about 26 hours. These plots demonstrate how the different prototype improvements affect our frequency ranges. In the 2B1 filter, the most significant improvement is from modeling the time dependence, while in 1B2 and 2A1, the time dependence is nearly flat in both the baseline and prototype runs, as expected from the spectral dependence of ice absorption. For 1B2, and especially 2A1, we see large improvements due primarily to the improved sampling phase alignment algorithm.

III. SHIS-TES Radiance Comparisons

Comparisons of AIRS, SHIS and TES (with different spectral convolutions) to LBLRTM (Line-By-Line Radiative Transfer Model) using GMAO profiles as input. The four horizontal panels are for TES filters 2B1, 1B2, 2A1 and 1A1, respectively, with frequency ranges as noted.

Direct TES-SHIS comparisons over TES frequency ranges. Data from both instruments were reconvolved with the ILS of the other instrument. Difference in brightness temperature is well below the TES noise equivalent delta-temperature (NEDT) and confirms the radiance comparison method.

Next steps: Use of retrieved profiles in LBLRTM for both TES and SHIS

IV. Summary and Outlook

CONCLUSIONS:

The improvements to the TES L1B algorithm will produce TES spectra with an accuracy sufficient for quantitative analyses using TES L2 retrievals.

Remaining errors in TES radiance spectra, such as those due to interferogram sampling jitter (phase modulation) are under investigation for detection and possible correction methods. They are currently mitigated by selection of frequency ranges in the L2 retrieval that do no include filter band edges.

Model produced by H. Revercomb and D. Tobin, et al. (U. Wise) to simulate TES spectral errors due to interferogram sampling jitter.

http://tes.jpl.nasa.gov