Version 7 Level 1B Radiometric Calibration Updates

Thomas S. Pagano
George Aumann, Steven E. Broberg, Evan M. Manning, Ken Overoye*
Chris Wilson

Jet Propulsion Laboratory, California Institute of Technology,
4800 Oak Grove Dr., Pasadena, CA 91109
tpagano@jpl.nasa.gov, (818) 393-3917, http://airs.jpl.nasa.gov

*AIE Systems, Nashua New Hampshire (Retired)

AIRS Science Team Meeting

October 6, 2020
Overview

• AIRS radiances are of high value to the scientific community
  • AIRS measures the upwelling Earth’s hyperspectral infrared radiances with high precision and accuracy and global daily coverage
  • AIRS data have been nearly continuous in time, beginning in September 2002 and continuing to the present
  • AIRS data are used for climate benchmarking and radiance trending
  • AIRS is a cross-calibration reference sensor in GSICS
  • AIRS data are assimilated into reanalysis models

• Radiometric Calibration Coefficients Updated
  • The current operational version uses coefficients derived pre-flight
  • Updates provided to polarization, emissivity, nonlinearity (V7.1)

• V7.1 differences from V5:
  • Reduced L/R Assymetry in Cold Scenes
  • Lower radiometric uncertainty
**AIRS Radiometric Calibration Equations**

**Scene Radiance**

\[ L_{ev} = L_o(\theta) + \frac{c_1'(dn_{ev} - dn_{sv}) + c_2(dn_{ev} - dn_{sv})^2}{[1 + p_r p_t \cos 2(\theta - \delta)]} \]

**Mirror Polarization Contribution**

\[ L_o(\theta) = \frac{L_{sm} p_r p_t [\cos 2(\theta - \delta) - \cos 2(\theta_{sv,i} - \delta)]}{[1 + p_r p_t \cos 2(\theta - \delta)]} \]

**Gain Term**

\[ c_1' = \frac{[\epsilon_{obc} P_{obc} - L_o(\theta_{obc})][1 + p_r p_t \cos 2\delta] - c_2(dn_{obc} - dn_{sv})^2}{(dn_{obc} - dn_{sv})} \]

**Symbols and Definitions**

- **\( L_{ev} \)**: Spectral Radiance in the Earth Viewport (W/m²-sr-μm)
- **\( L_{sm} \)**: Spectral Radiance of the Scan Mirror for Unity Emissivity at \( T_{sm} \) (W/m²-sr-μm)
- **\( L_o \)**: Spectral Radiance Correction for Scan Mirror (W/m²-sr-μm)
- **\( c_1 \)**: Instrument gain (W/m²-sr-μm-counts)
- **\( c_2 \)**: Instrument nonlinearity (W/m²-sr-μm-counts²)
- **\( dn_{ev} \)**: Digital counts while viewing Earth for each footprint and scan (counts)
- **\( dn_{sv} \)**: Digital counts while viewing Space for each scan (counts)
- **\( p_r p_t \)**: Product of scan mirror and spectrometer polarization diattenuation (unitless)
- **\( \theta \)**: Scan Angle measured from nadir (radians)
- **\( \delta \)**: Phase of spectrometer polarization (radians)
- **\( P_{obc} \)**: Plank Blackbody function of the OBC blackbody at temperature \( T_{obc} \) (W/m²-sr-μm)
- **\( T_{obc} \)**: Telemetered temperature of the OBC blackbody (K) with correction of +0.3K.
- **\( \epsilon_{obc} \)**: Effective Emissivity of the blackbody
- **\( dn_{obc} \)**: Digital number signal from the AIRS while viewing the OBC Blackbody

---

- T. Pagano et al., “Pre-Launch and In-flight Radiometric Calibration of the Atmospheric Infrared Sounder (AIRS),” IEEE TGRS, Volume 41, No. 2, February 2003, p. 265
- T. Pagano, H. Aumann, K. Overoye, "Level 1B Products from the Atmospheric Infrared Sounder (AIRS) on the EOS Aqua Spacecraft", Proc. ITOVS, October 2003
V7.1 Uses Space Views to Compute Polarization Terms

SV Angle (Deg)
SV1: 91.6943
SV2: 101.0621
SV3: 75.0212
SV4: 82.9796

- Regression of polarization response to every space view in the mission between 2003-2017 (171 mo)
- Plots and Data from Evan Manning

Earth

\[(dn_{sv,i} - dn_{sv,1})c_1' = -L_{sm}p_{rp_t}[\cos^2\theta_{sv,i}\cos2\delta + \sin2\theta_{sv,i}\sin2\delta + \cos2\delta]\]
V7.1 Polarization Coefficients improve L/R Asymmetry

- Polarization Amplitude Similar to V5
- V7.1 AB Side Dependent
- V7.1 Polarization Amplitude Time Dependent (Mostly only affects M5)
- V5 Phase binary due to use of sign on $p_r p_t$ rather than true phase
- V7.1 Phase channel and time Dependent

- AIRS Cal Subset: AIRXBCAL for V5
- 50S to 50N, Tsc < 210K
- 1/3 of Scan Right – 1/3 of Scan Left
- V7.1 Curve produced using ez_rad_conv (V5 to V7)
- Data from E. Manning
Space View Roll Test Confirms $a_0=0$

Residual Radiance (with $a_0$)

Residual Error to Space View Roll at: $T=260$ K
Includes $a_0$

Residual Radiance ($a_0 = 0$)

Residual Error to Space View Roll at: $T=260$ K
• In addition to the coefficient changes, v7.1 L1B will modify the logic which combines observations from the four space view ports to estimate the zero-signal level (offset)
  • The spaceviews will be adjusted to a common level to compensate for small polarization-related biases
  • The spaceviews closest to Earth will not be used for a region near the south pole where an extraneous signal has been observed.
V7.1 Coefficients use more pre-flight test data than V5

- V5 based on Test Number 1 and 2
- V7.1 based on Tests 1-14
- V7.1 Radiometric Coefficients derived using V7.1 Polarization Coefficients

<table>
<thead>
<tr>
<th>Number</th>
<th>Side</th>
<th>AOI</th>
<th>200 K</th>
<th>205 K</th>
<th>220 K</th>
<th>230 K</th>
<th>240 K</th>
<th>250 K</th>
<th>265 K</th>
<th>280 K</th>
<th>295 K</th>
<th>310 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>N</td>
<td>1687</td>
<td>1692</td>
<td>1693</td>
<td>1698</td>
<td>1704</td>
<td>1710</td>
<td>1718</td>
<td>1719</td>
<td>1727</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>B</td>
<td>1688</td>
<td>1689</td>
<td>1696</td>
<td>1697</td>
<td>1705</td>
<td>1706</td>
<td>1715</td>
<td>1720</td>
<td>1726</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>40</td>
<td>1827*</td>
<td>1830</td>
<td>1841</td>
<td>1844</td>
<td>1849</td>
<td>1852</td>
<td>1857</td>
<td>1860</td>
<td>1865*</td>
<td>1872</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>40</td>
<td>1828*</td>
<td>1829</td>
<td>1842</td>
<td>1843</td>
<td>1850</td>
<td>1851*</td>
<td>1858</td>
<td>1865</td>
<td>1866</td>
<td>1871</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number</th>
<th>Side</th>
<th>AOI</th>
<th>197 K</th>
<th>207 K</th>
<th>221 K</th>
<th>235 K</th>
<th>250 K</th>
<th>265 K</th>
<th>280 K</th>
<th>295 K</th>
<th>310 K</th>
<th>325 K</th>
<th>340 K</th>
<th>357 K</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>A</td>
<td>N</td>
<td>528</td>
<td>534</td>
<td>540</td>
<td>548</td>
<td>554</td>
<td>560</td>
<td>569</td>
<td>575</td>
<td>581</td>
<td>587</td>
<td>593</td>
<td>599</td>
</tr>
<tr>
<td>10</td>
<td>A</td>
<td>N</td>
<td>530</td>
<td>537</td>
<td>542</td>
<td>551</td>
<td>556</td>
<td>563</td>
<td>571</td>
<td>577</td>
<td>582</td>
<td>588</td>
<td>594</td>
<td>601</td>
</tr>
<tr>
<td>11</td>
<td>A</td>
<td>N</td>
<td>533</td>
<td>539</td>
<td>545</td>
<td>551</td>
<td>559</td>
<td>565</td>
<td>572</td>
<td>578</td>
<td>584</td>
<td>590</td>
<td>596</td>
<td>602</td>
</tr>
<tr>
<td>12</td>
<td>B</td>
<td>N</td>
<td>529</td>
<td>535</td>
<td>541</td>
<td>549</td>
<td>555</td>
<td>561</td>
<td>568</td>
<td>574</td>
<td>580</td>
<td>586</td>
<td>592</td>
<td>598</td>
</tr>
<tr>
<td>13</td>
<td>B</td>
<td>N</td>
<td>531</td>
<td>536</td>
<td>543</td>
<td>550</td>
<td>557</td>
<td>562</td>
<td>570</td>
<td>576</td>
<td>583</td>
<td>589</td>
<td>595</td>
<td>600</td>
</tr>
<tr>
<td>14</td>
<td>B</td>
<td>N</td>
<td>532</td>
<td>538</td>
<td>544</td>
<td>550</td>
<td>558</td>
<td>564</td>
<td>573</td>
<td>579</td>
<td>585</td>
<td>591</td>
<td>597</td>
<td>603</td>
</tr>
</tbody>
</table>

Effective Emissivity, $\varepsilon$

Nonlinearity $a_2/a_1^2$
V7.1 Coefficients very close to V5

- Effective Emissivity Smoothed over Modules
- No A/B Dependence
- Nonlinearity Smoothed Within Each Module
- Nonlinearity AB Side Dependent
- Deviation from fit taken as ‘uncertainty’ on per ch. basis

T. Pagano, Candidate Coefficients for V7 L1B: V7p, JPL Internal Memorandum, AIRS Project Office, ADF 1006, May 11, 2020
V7.1 has lower residuals than V5 to pre-flight test data

V7.1 Residual Errors for All Test

V7.1 RMS Error over all Tests

V7.1 Residuals for Individual Tests
V7.1-V5 Greatest at cold scenes. V7.1 has slight time dependence.
AIRS V7.1-V5 Compared to CHIRP L1C Biases

E. Manning, ‘ADFM: v7 changes to v5 compared to CHIRP CrIS SNPP vs v5 biases’, ADF TBD, 10/5/20
AIRS Radiometric Accuracy Improved in V7.1

Errors at 260K by Contributor

- All Errors are 1-sigma and RSS of contributors
- Height of contributors within each bar is percentage of total
- V5 errors dominated by polarization uncertainty
- V7.1 errors dominated by Nonlinearity and OBC Emissivity
- V7.1 Results are Preliminary

Modest improvements to the AIRS Level 1B calibration coefficients have been made based on a better understanding of pre-flight and in-flight measurements. No impact to trends except M5

- Polarization changes verified to L/R Asymmetry
- Space views corrected two ways
  - Remove stray signals at poles
  - Offset by median relative to SV1 to remove polarization bias amongst SV’s
- Radiometric coefficients updated. Use more pre-flight data than V5
- Improved knowledge of nonlinearity and role of a0
- V7.1 Differences with V5 mostly at cold scenes and less than 200 mK
- V7.1-V5 differences compare favorably in some modules with biases seen in AIRS L1C-CHIRP
- Radiometric Uncertainty in V7 expected to be better in M5 and M9, M10 due to better knowledge of polarization