Hyperspectral Sounder
Performance for Cold Scenes

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Intro – AIRS & CrIS

• AIRS and CrIS are hyperspectral infrared sounders in similar 1:30 PM sun-synchronous orbits.

• AIRS on EOS-Aqua has been flying since 2002.

• CrIS-1 on SNPP has been flying since 2012.

• More CrIS instruments will fly on JPSS-1, 2, 3 (NOAA-20, etc.) for decades to come.

• We need to characterize the instruments very carefully before we can make a merged record.
Intro- Cold scenes are important

• We investigate 200-K non-polar scenes here
  • These are the coldest scenes observed in large numbers.
  • They represent clouds near the tropopause that fill the field-of-view (FOV).

• These scenes are important to track:
  • Changes in the height of the tropopause
  • The frequency of severe storms
  • Polar change

• Cold scenes also impact cloud-clearing retrievals
Intro- Cold scenes are useful

• 200K scenes are a valuable “stress test” for the evaluation of the calibration of AIRS and CrIS.

• For AIRS these regions are extremely cold scenes and the sensitivity to the accuracy and stability of the space view.

• For CrIS the extreme cold and hot scenes stress the linearity correction equally, since the instrument operates near 280K.
  • In addition, the self-emission of the instrument can essentially cancel the scene signal for certain conditions between 270 and 280K.
Intro- Cold scenes are misleading

• AIRS and CrIS are designed to be accurate to 0.1-0.2 K at nominal scene conditions.

• The shape of the Planck function means that small differences in radiance make a relatively large difference in Kelvins for cold temperatures.

• 1 K is a more reasonable target for 200 K scenes, and they generally achieve this.
Intro – Read the paper

• This is very technical and there’s a lot of material to cover.

• Read the paper in the SPIE proceedings

Hyperspectral sounder performance for cold scenes

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Axioms

1. Cold clouds have a basically flat spectrum
   • Except for regions of stratospheric emission

2. AIRS and CrIS should see the same stuff
   • Except the fine print
     • Different frequency coverage
     • Different spectral sampling -- AIRS is higher resolution

3. Left & right should look the same

4. Different years should look the same

5. Different CrIS FOVs should look the same

6. Day and night should look the same
   • Not really! But day minus night should look the same
   • Not shown
Worst case numbers

<table>
<thead>
<tr>
<th>Band Name</th>
<th>Band Frequency range (cm(^{-1}))</th>
<th>Largest suspected artifact AIRS (K)</th>
<th>Largest suspected artifact CrIS (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longwave</td>
<td>650 - 1150</td>
<td>0.7 (right/left, trend)</td>
<td>0.5 (FOV)</td>
</tr>
<tr>
<td>Midwave</td>
<td>1200 - 1700</td>
<td>0.1 (right/left)</td>
<td>0.2 (right/left)</td>
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<tr>
<td>Shortwave</td>
<td>2150 - 2670</td>
<td>5.0 (trend)</td>
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• At 200 K!
What are we looking at?

• For each category, we select only scenes where BT at 939 cm\(^{-1}\) is 200 +/- 1 K
• These are very cold cloudy scenes
  • clouds near the tropopause occupy nearly the full FOV
  • Flat except for stratospheric emission & daytime shortwave reflected solar
• AIRS data is v5 with problem channels removed
• CrIS data is the normal spectral resolution IDPS public product, apodized
• Details in the paper
200 K spectrum

- These spectra are broken up by band
  - With longwave further broken at 785 cm\(^{-1}\)

- Axiom 1: Cold clouds have a basically flat spectrum
  - The spectra are flat at 200 K except for stratospheric emission from CO\(_2\), O\(_3\), CH\(_4\), H\(_2\)O.

- Axiom 2: AIRS and CrIS should see the same stuff
  - Almost all visible differences are from differences in instrument specs: resolution & coverage.
  - But in the shortwave...
Right/Left

- Axiom 3: right & left should look the same.
  - So right minus left should be about zero. And it is.
- AIRS shows significant left-right bias in the 1070-1135 cm\(^{-1}\) region.
- AIRS has discontinuities at boundaries between detector modules, including 852, 905, 975, 1070, 1340, 1450, and 2555 cm\(^{-1}\), and has some curvature within the modules.
- CrIS has some wavy structure 1220-1700 cm\(^{-1}\) with a period of \~125 cm\(^{-1}\) and an amplitude of \~0.15 K.
- Both instruments show temperature dependence in right-left bias.
AIRS Trends 1

- Axiom 4: different years should look the same.
  - Can’t test with CrIS data yet.

- Showing annual averages for even years 2004-2016

- There’s a clear trend in the shortwave region and more subtle changes
AIRS Trends 2

- The same data as the previous image but now shown as difference from a 2004 baseline.
- The stratospheric interannual differences are real.
- A/B detector differences up to +/- 0.6 K are very obvious but are actually decreasing.
- Shortwave trend is up to 5 K.
- There’s also a trend up to 0.3 K ~1100 cm\(^{-1}\).
CrIS FOVs

• Axiom 5: different CrIS FOVs should look the same.
  • All 9 FOVs are plotted as differences from the mean
  • Solid lines for 2016; dotted for 2013.

• FOV 5 (red) is a known outlier in the longwave.
  • It misbehaves at spectral features near 668, 720, and 1043 cm\(^{-1}\)
  • But also at 775 & 990 cm\(^{-1}\)
  and the band end at 1095 cm\(^{-1}\).

• There are biases among the bands.
Those numbers again

• Worst-case artifacts at 200 K

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Conclusions

• We have a new tool to probe hyperspectral IR sounder instrument artifacts.

• We found some. (But: 200 K!)

• Both instrument teams are working on improvements.