Radiometric Comparison of AIRS and CrIS from 3 years of data

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Summary: AIRS and CrIS brightness temperatures in the 900 cm-1 channel agree within 0.1K for tropical day and night ocean data, but only for tropical land night data. For tropical day land data CrIS has a 0.3 K warm bias relative to corresponding AIRS data. This warm bias is small compared to the CrIS absolute calibration accuracy requirement. The warm bias is traced to a cold bias in the CrIS imaginary component of the warmest spectra, most prominently those from day tropical land. This suggest that the observed bias is an artifact of a phase correction deficiency in the current CrIS calibration software, which may be corrected in a future release. For some applications this issue may be resolved by a tighter quality control filter, which improves the calibration of the spectra which pass. However, this filter creates a sampling bias, which complicates the interpretation of the data for climate change applications.

Introduction:

AIRS [1], CrIS [2] and IASI [3] are hyperspectral infrared sounders with similar specification in 1:30 PM, 1:30 PM and 9:30 AM ascending node polar orbits since 2002, 2007 and 2012, respectively. AIRS is a grating array spectrometer, CrIS and IASI are Fourier Transform Spectrometers (FTS). There are numerous papers and presentations comparing AIRS and CrIS and IASI using Simultaneous Nadir Overpasses (SNO) and (obs-calc) under clear conditions that the three instruments are calibrated at the better than 100 mK level [4, 5, 6]. While 100 mK appears to be a small number, it is important from a climate perspective, since it equals the current global warming per decade. None of these papers have dealt with observations under extremely cloudy, cold or hot scene conditions. These conditions are important from a climate perspective, since changes in extremes are expected to be detected first. The radiometric agreement between AIRS and CrIS is easier to evaluate since the two instruments are in almost identical orbits at 705 km and 825 km altitude, but slightly different inclinations. There have been several papers and presentations [7, 8] comparing AIRS and CrIS under cloudy conditions using SNO from the tropical zone (TSNO) , which claim that under conditions typical for day land the CrIS data are increasingly warmer than AIRS by considerable more than 100 mK. In the following we compare AIRS and CrIS data between May 2012 and May 2015 using a time series of observations of the tropical zone. During this time period we had data from 1147 day with AIRS and CrIS data.

For the analysis we use daily random nadir samples. Each day we saved 21000 random nadir samples at all latitudes. From AIRS and CrIS. The sampling strategy down-weights the highly oversampled high latitude regions of the globe. Typically 10500 samples (50% of the area of the globe) come from the tropical zone (latitude 30S to 30N). The data can be further divided into day/night and land/ocean. While for SNO we can analyzed the AIRS and CrIS data pairs, in a time series we compare daily mean values for day/night and land /ocean zones. The advantage of this method is that it contains two orders of magnitude more data than the SNO analysis.

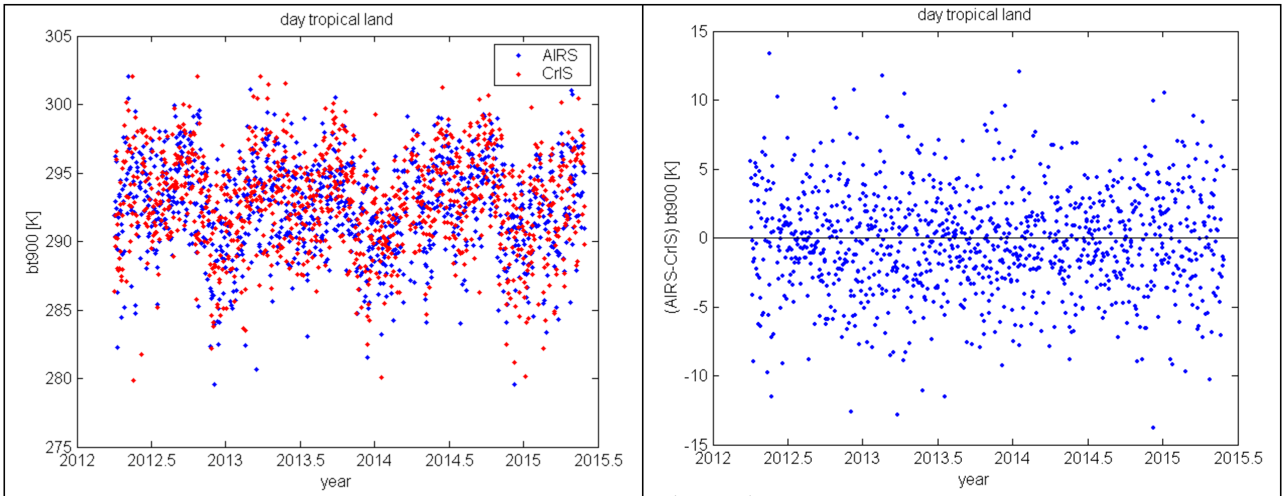

Figure 1a. Figure 1b

CrIS and AIRS have differences in the spectral resolution and sampling grid. These differences are minimized when we limit our analysis to the brightness temperature of the 900 cm-1 atmospheric window channel, bt900. This channel is in the CrIS Longwave (LW) band.

CrIS and AIRS use different quality indicator. For AIRS we use the CalChanSummary, where the quality of each channel is described by a one byte per scan line. Each of the 8 bits flags a different conditions (e.g. moon in the space view or overflow) which may lead to degradation of calibration. CrIS uses a quality indictor for each of its three spectral bands indicators, QF3_CRISSDR [9], which is derived from several calibration related parameter, including the magnitude of the imaginary component of the spectrum. Only CalChanSummary=0 and QF3_CRISSDR=0 data were saved for our analysis. The CrIS data use the NOAA/IDPS calibration. The AIRS data are posted on the GSFC DIS site.

Figure 1a illustrates the method using day land data. Each blue point represents the mean of typically 2500 AIRS bt900 measurements from one day. The corresponding CrIS mean is shown in red. The AIRS and CrIS data are highly correlated, as they should be, since they are in the same orbit, and there is a seasonal cycle. Figure 1b shows the AIRS-CrIS difference for the same data as shown in Figure 1a. The difference is relatively Gaussian distributed with no obvious changes between 2012 and 2015. The mean of the difference is -0.30K with 3.7K standard deviation for 1147 point. The Probable Error (PE) in the mean is 0.113 K. Table 1 summarizes the mean temperatures and their mean difference, "±" and the Probable Errors (PE) in the mean for the four zones.

bt900	AIRS	CrIS	AIRS-CrIS
Night ocean	283.52±0.038	283.52±0.041	0.008±0.046
Day ocean	284.08±0.043	284.20±0.042	-0.111±0.050
Ocean Day-night	0.56±0.057	0.68±0.058	
Night land	278.28±0.087	278.28±0.094	-0.011±0.093
Day land	292.48±0.105	292.78±0.109	-0.30±0.113
Land Day-night	14.20±0.136	14.50±0.144	

Table. 1

Results and Discussion.

The nominal absolute calibration accuracy requirement for the CrIS LW band is defined as 0.45% of the radiance of a blackbody at 287K. Converted to brightness temperature uncertainty this corresponds to 0.5K between 300K and 340K. The AIRS absolute calibration requirement is similar. However, it is clear from Table 1 that the radiometric agreement between AIRS and CrIS for the 900 cm-1 window channel is considerably better than the requirement. Averaged over all tropical zone data CrIS is 0.16±0.1K warmer than AIRS. This is consistent with the previously referenced clear (obs-calc) and SNO analysis. While the disagreement between AIRS and CrIS for tropical night ocean, night land and day ocean are not 2 sigma significant, the 0.3K disagreement for day land is significant. We also note that the mean bt900 for the day land data is 10K warmer than for the night data due to the presence of a large number of bt900>300K cases. This result is consistent with the previous referenced observations of a significant warm bias in CrIS relative to AIRS using TSNO.

A number of reasons have been proposed, but none are convincing: 1. This could be a diurnal cycle effect [8]. In the tropical zone SNO the CrIS data lead the matching AIRS data by 6 minutes, on average, i.e. are closer to local noon. Since at 1:30 PM the surface temperatures are still rising, this argument can be discounted. 2) This could be a footprint size effect. The AIRS footprint at nadir is 13.5 km while that of CrIS is 14.1 km, both (full diameter at ½ peak) . However, the AIRS is cross-track scanning, while CrIS uses a step-and-stare approach with image motion compensation. This may make the CrIS effective footprint smaller than that of AIRS, such as to pick up more extreme hot cases. This argument is weak.3) The warm bias could be an AIRS non-linearity artifact. The AIRS calibration blackbody is at 308K, while the CrIS calibration blackbody is at near 275K. Since the calibration pivots about the temperature of the blackbody, the AIRS residual non-linearity under extreme warm conditions is much less of an issue than for CrIS. 4) The warm bias could be a CrIS calibration artifact. This is discussed in the following paragraphs.

In order to evaluate of the warm bias at warm temperature is a CrIS artifact we look at the imaginary component associate with each CrIS spectrum. Figures 2a and 2b show two CrIS spectra between 650 and 1100 cm-1, both of which pass the QFR_CRISSDR quality filter. For a well phase corrected FTS spectrum the imaginary component varies pseudo randomly about zero, with a spectral average of zero [10, chapter 6]. A phase correction error causes the mean of the imaginary component to deviation from zero. If the deviation of the imaginary component is negative, the corresponding real component of the spectrum is larger (warmer) than the true spectrum, assuming an otherwise perfect calibration blackbody, space view and linearity correction. The CrIS calibration team [9] characterizes the imaginary component by max1i and min1i, the maximum and minimum value between 800 and 980 cm-1 in the CrIS LW band. If q1i=max1i–min1i >1.5 Radiance Units (RU, mW/(m^2 cm^{-1} sterad)), the spectrum is flagged as invalid in the QF3_CRISSDR quality indicator.

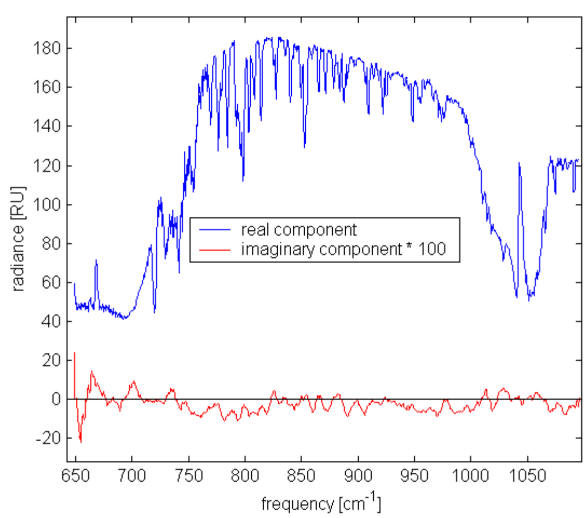

Figure 2a. CrIS spectrum showing the real and imaginary (*100) componts. p1i=-0.03 RU and q1i=0.58.

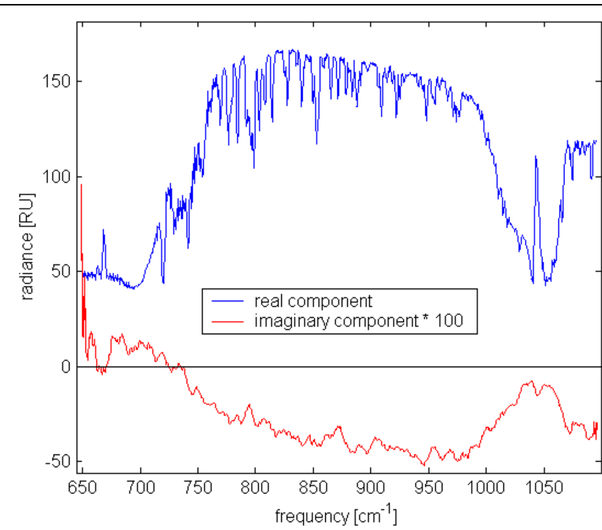

Figure 2b. CrIS spectrum showing the real and imaginary (*100) componts. p1i=-0.82 RU and q1i=1.42.

The q1i parameter does not fully characterize the quality of the spectrum. For this we define p1i=max1i+min1i. For well calibrated data p1i should be zero mean and symmetric about zero with increasing bt900. Figure 3a and 3b show scatter plots of q1i and p1i in RU as function of bt900 . Figure 3a shows no point with q1i>1.5 RU, since they are eliminated by the q1i<1.5 quality control filter.

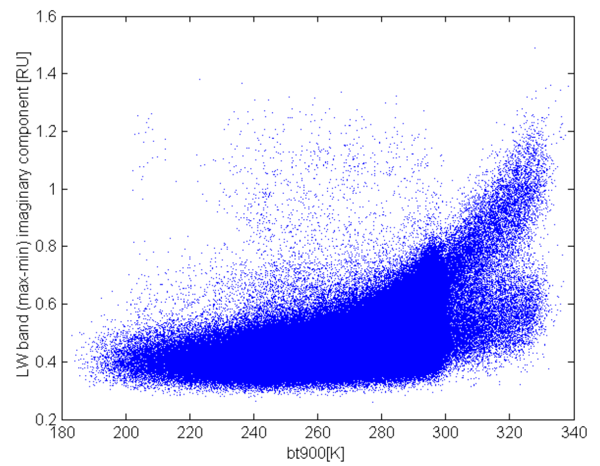

Figure 3a. The q1i indicator as function of bt900 show a steep increase with increasing temperatures until the data are cut off by the quality control at q1i>1.5 RU

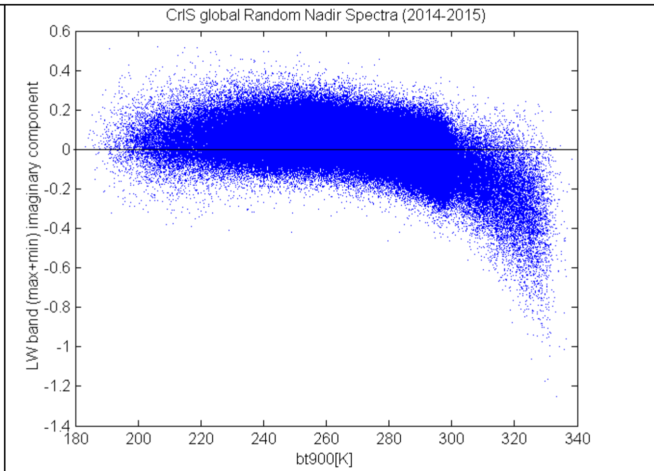

Figure 3b.The p1i indicator as function of bt900 should be zero mean and symmetric as function of signal strength. The CrIS LW band show a steep decrease as bt900 increases above 280K

The p1i indicatoror is reasonably symmetric about zero for 200<bt900<280K. At warmer bt900 tempertaure p1i decreases with increasing bt900 scene temperature to values as low as -1.2 RU. This results in an increasingly warm bias in the CrIS data. A -1.2 RU at 340K corresponds to a 0.5K warm bias.This is consistent with our observations of the AIRS-CrIS difference for tropical day land data.

For some applications adding a p1i threshold to the quality filter would be adequate. A abs(p1i)<0.4 RU filter would have essentially no effect on the day and night ocean data and the night land data, but it would eliminate the worst offending spectra by preferentially excluding warm extremes from day land. For a statistical analysis for climate applications the day land data would then no longer be representative of the true distribution.

Conclusion

AIRS and CrIS brightness temperatures in the 900 cm-1 channel agree within 0.1K for tropical day and night ocean data, but only for tropical land night data. For tropical day land data CrIS has a 0.3 K warm bias relative to corresponding AIRS data. This warm bias is small compared to the CrIS absolute calibration accuracy requirement. The warm bias is traced to a cold bias in the CrIS imaginary component of the warmest spectra, most prominently those from day tropical land. This suggest that the observed bias is an artifact of a phase correction deficiency in the current CrIS calibration software, which may be corrected in a future release. For some applications this issue may be resolved by a tighter quality control filter, which improves the calibration of the spectra which pass. However, this filter creates a sampling bias, which complicates the interpretation of the data for climate change applications.

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