Detection of Extremes with AIRS and CrIS

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Abstract

Climate change is expected to be detected first as changes in extreme values rather than in mean values. The availability of data of from two instruments in the same orbit, AIRS data for the past eleven years and AIRS and CrIS data from the past year, provides an opportunity to evaluate this using examples of climate relevance: Desertification, seen as changes in hot extremes, severe storm, seen as a change in extremely cold clouds and the warming of the polar zone. We use AIRS to establish trends for the 1%tile, the mean and 99%tile brightness temperatures measured with the 900 cm^{-1} channel from AIRS for the past 11 years. This channel is in the clearest part of the 11 micron atmospheric window. Substantial trends are seen for land and ocean, which in the case of the 1%tile (cold) extremes are related to the current shift of deep convection from ocean to land. Changes are also seen in the 99%tile for day tropical land, but their interpretation is at present unclear. We also see dramatic changes for the mean and 99%tile of the North Polar area. The trends are an order of magnitude larger than the instrument trend of about 3 mK/year. We use the statistical distribution from the past year derived from AIRS to evaluate the accuracy of continuing the trends established with AIRS with CrIS data. We minimize the concern about differences in the spectral response functions by limiting the analysis to the channel at 900 cm^{-1}.While the two instruments agree within 100 mK for the global day/night land/ocean mean values, there are significant differences when evaluating the1% and 99%tiles. We see a consistent warm bias in the CrIS data relative to AIRS for the 1%tile (extremely cold, cloudy) data in the tropical zone, particularly for tropical land, but the bias is not day/night land/ocean consistent. At this point the difference appears to be due to differences in the radiometric response of AIRS and CrIS to differences in the day/night land/ocean cloud types. Unless the effect can be mitigated by a future reprocessing the CrIS data, it will significantly complicate the concatenation of the AIRS and CrIS data records for the continuation of trends in extreme values.

Keywords: Climate change, extremes, sampling bias, hyperspectral infrared, deep convection

1. Introduction.

Climate change is expected to be detected first as changes in extreme values rather than in mean values. The unambiguous detection of climate change requires decades of satellite data. Since no single instrument can span decades of time, observations from many instruments on different satellites have to be concatenated. The instruments used for this concatenation have to produce climate quality data. The process by which this climate quality is established has still to fully evolve. Ohring et al. [1] define infrared instruments with absolute accuracy of better than 100 mK and stability of better than 10 mK/year as producing climate quality data. This definition is generally interpreted as a bias in the observed brightness temperature (Obs) minus the brightness temperature calculated (Calc) relative to a trusted standard, e.g. the SST in the tropical oceans, derived from floating buoys, under cloud free ("clear") conditions (OMC) and the analysis of differences in Simultaneous Nadir Overpasses (SNO). However, climate observations are carried out under a wide range of scene conditions and climate change is expected to be detected first as changes in extreme values rather than in mean values and under the restricted conditions of OMC and SNO.

We use AIRS [2] data to illustrate the magnitude of trend seen in the past ten years. For the purpose of this paper we define extremes as the 1% and 99% of a population. The hottest extremes (99%tile) of infrared brightness temperatures is related to desertification, and the coldest extremes, the 1%tile infrared brightness temperatures, related to severe storms. We then illustrate with data from the past years that the concatenation of the AIRS data record with CrIS [3] identifies unexpected issues, in spite of the fact that AIRS and CrIS show agreement of mean values at the better than 100 mK level based on OMC and SNO [4, 5, 6].

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2. Data

AIRS and CrIS on EOS Aqua and NPP, respectively, are both in 1:30 PM ascending node polar orbits. Since AIRS is at 705 km , CrIS at 825 km altitude. The two instruments have a comparable Field of View (FOV), 13.5 km and 14 km at nadir, respectively, comparable spectral coverage, spectral resolution and signal-to-noise. The data from AIRS (V5.0 Level 1B) are available from the GSFC/DAAC/DIS FTP site. The data from CrIS (SDR, equivalent to the AIRS L1B record) were obtained from NOAA/CLASS/. Although the CrIS SDR product achieved Beta maturity status on April 19, 2012, we use only data since August 2012, when a software update (mx6.2) was enabled in the CrIS onboard computer. In order to minimize concern about possible differences in the spectral response functions, we focus on the11 micron atmospheric window using the spectral channel nearest to 900 cm^{-1}, and refer to its brightness temperature as bt900. We use AIRS channel#759 at 900.31 cm^{-1}. For CrIS we use the 900.0 cm^{-1} channel from band 1 with Hanning apodization.

Careful Quality Control (QC) of any data set is always important, but for the data used in the analysis of extremes it is critical. For AIRS data we use the 8 bit CalFlag for quality control. CalFlag indicates for each scan line for each of the 2378 AIRS spectral channels if something happened, such as missing blackbody or space view data, moon in view during the space view or noise abnormality, which is technically corrected in the calibration software, but may have impacted the calibration accuracy. The flag mCalFlag is created for each of the 90 footprints in a scan line by replicated CalFlag for that scan line. We use data only if mCalFlag==0. For CrIS the QC parameters are still being refined. For CrIS the QF3 flag is associated with each spectrum. Since December 2012 the QF3 flag includes a limit on the magnitude of the imaginary component between 800 and 980 cm-1 in band 1. If it is less than 1.5 (RU=$mW/m^2/sr/cm^{-1}$), the data quality is “good”. For earlier data the magnitude of the imaginary component has to be calculated directly. This is what we have done to be consistent with the updated QF3. Since August 2012 typically 99.9% of the CrIS band 1data are identified as “good”.

3. Results

For each day for which we have AIRS or CrIS data we collected 20,000 samples from AIRS and from CrIS randomly from within 3 degrees of nadir, such that the sample is approximately area representative. This thinning of high latitude sample proportional to cos(latitude) corrects for the heavy spatial over-coverage of the high latitudes by polar orbiting satellites. This sample includes data irrespective of the QC. This allows us to estimate the fraction of the data which is rejected by QC. For the 6.5 million AIRS samples collected between August 1, 2012 and June 26, 2013 99.4% of the data were identified as good for the approximately 2200 of the 2378 channels which have an NEDT of less than 0.5 K, including channel #759. The bt900 ranged from 182.30K to 341.85K. For the 6.8 million CrIS samples from the same time period 99.99% of the CrIS spectra were identified as “good”. The CrIS bt900 ranged from 183.32K to 341.06K. For the statistical analysis the AIRS and CrIS data are QC filtered.

We first present some trend in 11 years of AIRS data to illustrate climate trends using bt900. We then evaluate how well the mean values of AIRS and CrIS agree for the past year.

3.1. Trend.

In order to discuss trends in extremes from the AIRS data, we first have to estimate the magnitude of the instrument trend. The baseline for trends from AIRS is the trend in OMC for bt900 using clear filtered tropical ocean data. Since the atmospheric absorption (due to water vapor) in the best atmospheric window channel, such as bt900, is typically only 2K, OMC is closely tied to the Sea Surface Temperature (SST), which is derived from the floating buoys. Figure 1a shows the daily mean value of bt900 since 2002 for the tropical oceans. We define the tropical zone as latitudes 30S to 30N. Only about 1% of the data from the tropical oceans pass the clear test. There is a small cold bias due to a residual clouds leaking into the clear filter. This can be seen in the semi-annual modulation, which is related to changes in cloud pattern. During some parts of the years, there is consistently less cold bias (cloud leak) than in other parts of the year. We fit the data to a low order harmonic function with annual and semi-annual periodicity and subtract this function from the daily observation. The result is referred to as the anomaly. The result is shown in Figure 1b. The linear trend in the anomaly for bt900 OMC under tropical ocean clear conditions is +3±2 mK/yr. The value following the "±" symbol is the one sigma trend uncertainty. Inspection of Figure 1b shows the anomaly includes components which do not fit a linear trend. These may be due to multi-annual changes in the cloud types, which leak into the "clear" filter.

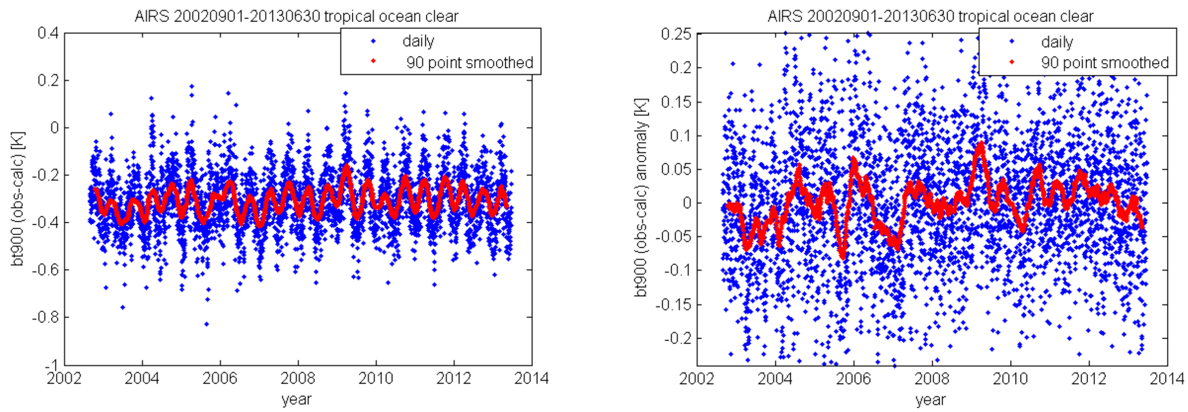

Figure 1. a) The OBC for bt900 under tropical ocean clear filtered conditions shows a bi-annual variability. b) The anomaly of the data shown in a) reveals a complicated pattern of inter-annual variability.

The very good accuracy and and the very low trend of OMC from bt900 under clear filtered conditions establishes a baseline for the crediblity of trends derived for climate change analysis. Figure 2a shows the daily mean value of bt900 since 2002 using the nadir sampled data for day tropical land. There is a clear semi-annual modulation related to the cloud pattern. The bt900 anomaly is shown in Figure 2b. The mean bt900 from random observations is dominated by clouds. For the daily 99%tile, i.e. the warmest of the daily bt900 observation, the effect of clouds is eliminated. The temperature of the daily 1%tile, typically near 210K, is a metric for the presence of strong convection. Cloud tops colder than 210K are associated with Deep Convective Clouds (DCC). DCC are associated with severe storms.

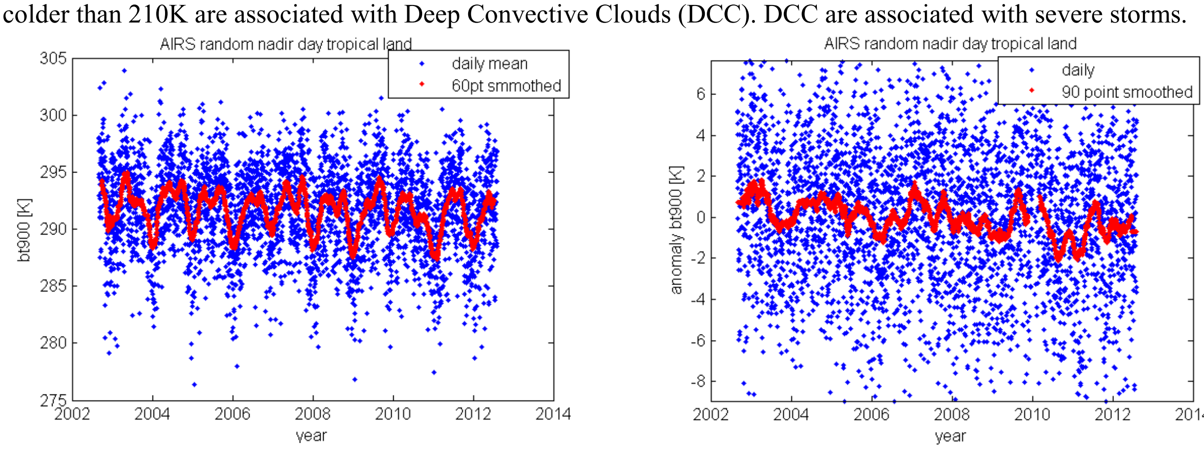

Figure 2. bt900 a) daily mean of tropical day land observations. b) daily mean anomaly shows a clear decrease in bt900

Figures 3 and 4 show the anomalies of the mean and the 99%tile from the regions north of 68N and south of 68S latitude. The red trace is the result of a 90 day running mean. Figure 5 shows the anomaly of the 1% of bt900 from tropical ocean (blue) and and tropical land (red). The 1%tile for ocean is decreasing, meaning fewer extreme high clouds, while the 1% for land is increasing, i.e. more extreme high clouds. Table 1 summarizes the trends in the mean, the 99%tile and the 1%tile of bt900 for a number of latitude zones. The first two rows in Table 1 show the trend in (obs-calc) at 900 cm^{-1} under clear conditions. Ideally this trend should be zero, since it is referenced on the daily SST from NCEP. Trends of less than 3 mK/yr and trends smaller than the PE have to be ignored. For reference, the trend in the RTGSST from NCEP for the non-frozen oceans is -11 ± 1 mK/yr. The 99%tile trends may be related to desertification.

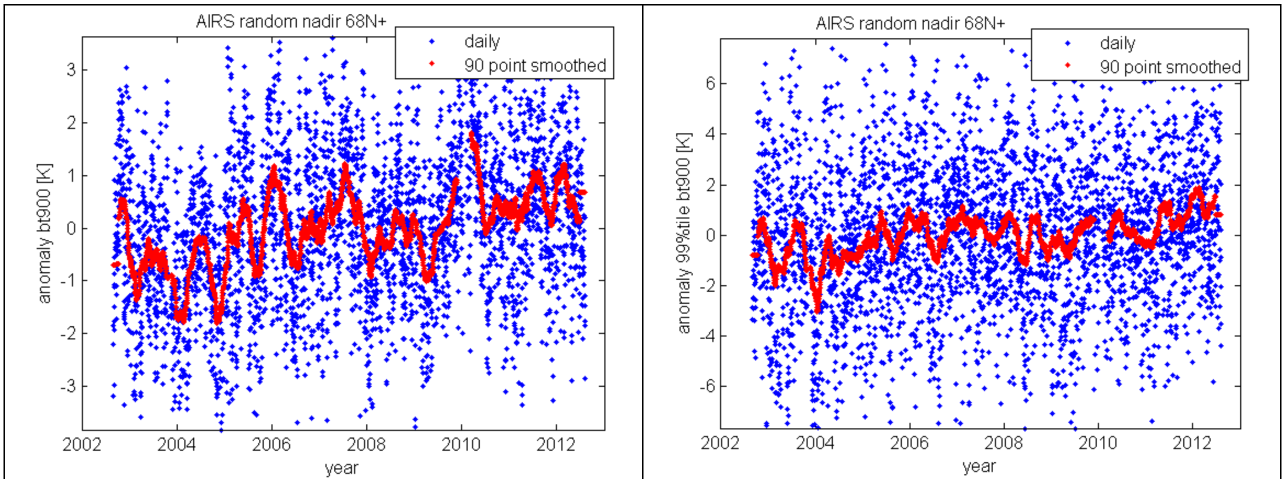

Figure 3. a) mean bt900 anomaly from data north of 68N | b) 99%tile bt900 anomaly

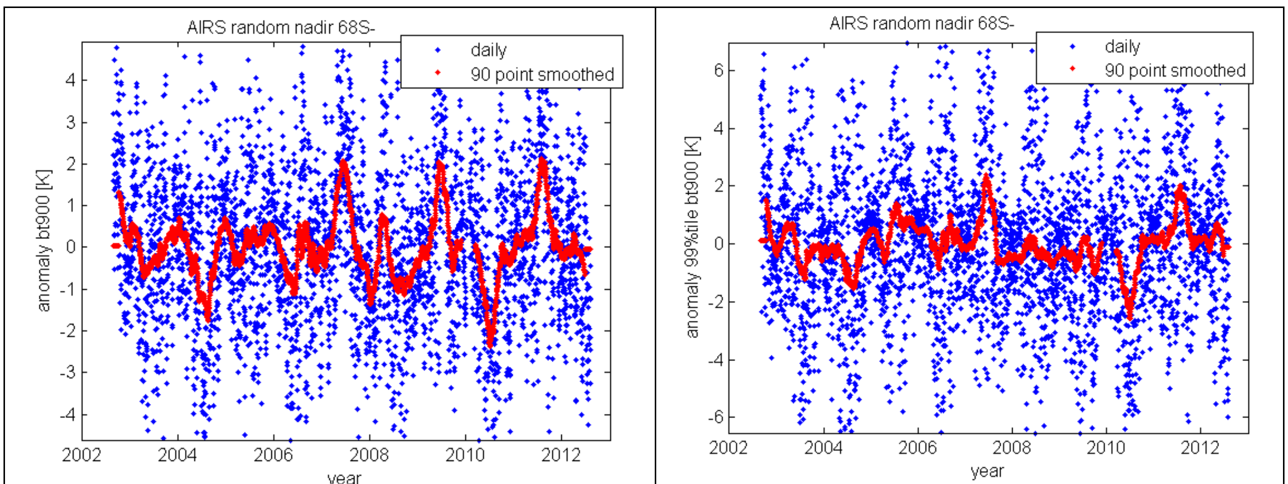

Figure 4. a) mean bt900 anomaly for data below 68S | b) 99%tile bt900 anomaly

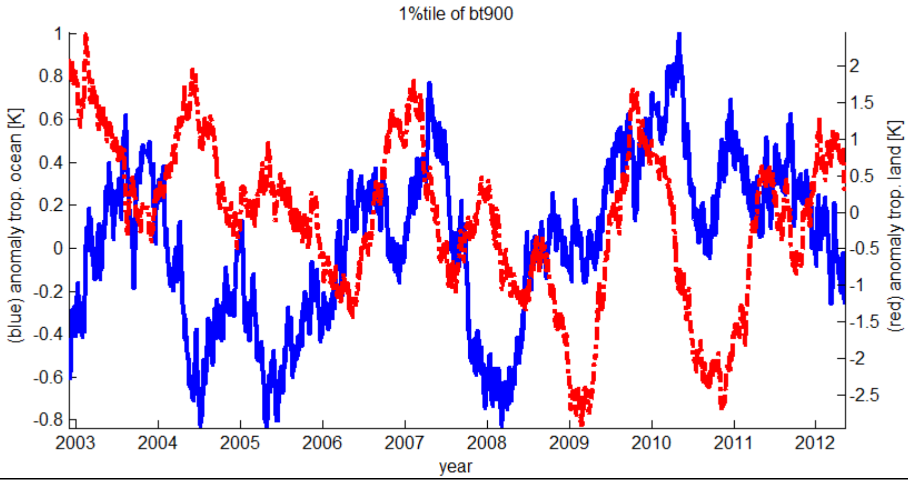

Figure 5. The trend in the 1% of bt900 for tropical land and tropical ocean is anticorrelated.

bt900	AIRS 10 year mean trend±PE	Mean [K]
Mean trends		
Clear day tropical ocean	+2.4±2 mK/yr	
Clear night tropical ocean	+3.3±2 mK/yr	
Random above 68N	+140.0±9 mK/yr	254.6
Random below 68S	-8±12 mK/yr	238.1
Random Non-frozen Ocean day	+3.8±6 mK/yr	278.8
night	+1±6 mK/yr	277.9
Random Tropical Ocean day	-28±9 mK/yr	
night	+1±8 mK/yr	
Random Tropical Land day	-139±21mK/yr	291.7
night	-50±18mK/yr	277.4
99 percentile trends		
Random above 68N	+163 ±17 mK/yr	276.6
Random below 68S	-25 ±15 mK/yr	264.5
Random Tropical Ocean day	-16 ± 4 mK/yr	299.4
night	-11 ± 3 mK/yr	298.4
Random Tropical Land day	-129 ±18mK/yr	327.2
night	-11 ±7 mK/yr	298.0
1 percentile trends		
Tropical ocean day	+52 ± 24 mK/yr	211.5
Night	+95± 34 mK/yr	210.3
Tropical Land day	-172± 52 mK/yr	211.3
night	-88± 66 mK/yr	210.1

Table 1. Trend in bt900 from AIRS data.

3.2. AIRS/CrIS comparison.

For the AIRS CrIS comparison we use the random sampled data. Each day we collect typically 20,000 random samples from within 3 degree of nadir. The samples are actually pseudo random, in that we collected 20,000 each day with a prescribed number of N samples per data granule. In order to compensate for the heavy spatial overcoverage of the high latitudes, the sampling is thinned by collecting N* cos(mean granule latitude) samples from each data granule (2 minutes of AIRS, 6 minutes of CrIS data). Figure 6.a. shows the location of the random nadir samples from one day of data overlaid on a map.Figure 6.b. shows this for the 600,000 random nadir samples colleced in June 2003. Most of what appear to be patters are printer pixelation artifacts.

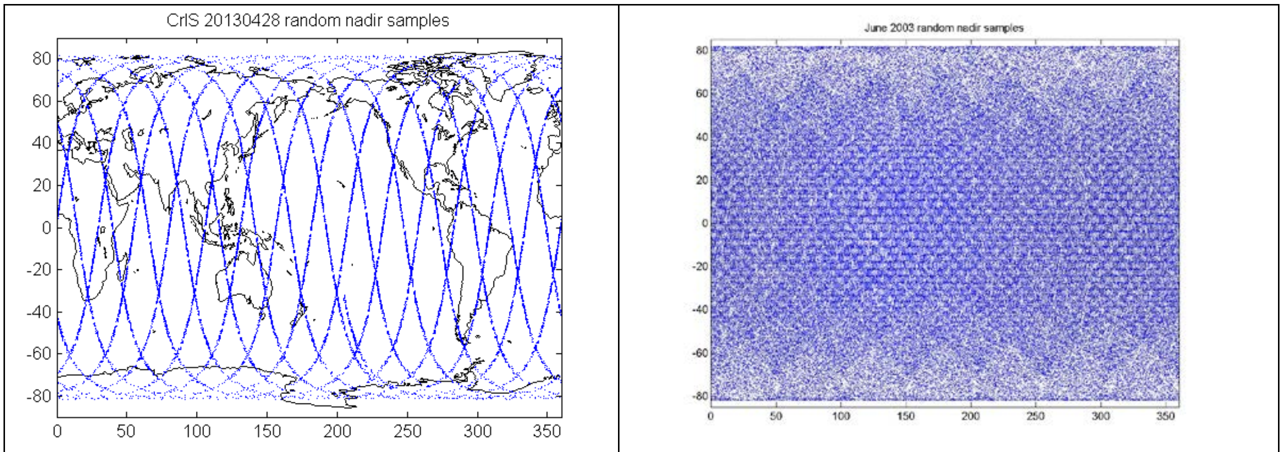

Figure 6 a) location of the random nadir samples from one day of data.	b) The geographical distribution of the 600,000 random nadir samples colleced in Juune 2003 on a mercator projection.

Since we have CrIS data only since April 2012, and the QF3 for data from before August 2012 was not working properly, we combined all daily samples collected from AIRS and CrIS between August 2012 and June 2013 where we have AIRS and CrIS data. Due to small differences between the way the random samples are collected, this data set contains 6.8 million CrIS and 6.5 million AIRS samples. Although the number of samples differ by 5%, both constitute unbiased samples of the globe for the same time period. Table 2 lists the mean, standard deviation, and various percentiles to show that our sample is a statistically fair, area representative sample of the globe for the August 2012 – June 2013 time period from the same orbit. We now paraphrase the central limit theorem: The statistical properties of the Probability Density Function (PDF) created from the AIRS and CRIS samples for any area of the globe should be statistically indistinguishable.

	AIRS	CRIS
Latitude mean	-0.0346	0.0300
3.6%tile	-71.2575	-72.1526
25%tile	-31.4157	-31.5198
75%tile	31.3637	31.5783
96.4%tile	71.2227	72.2740
Solar zenith angle mean	89.9414	90.0668
1%tile	20.3606	17.6653
99%	159.6403	162.3780
Ocean fraction	0.7031	0.7025

Table 2. The latitude, day, night and land/ocean sampling of CRIS and AIRS are nearly identical.

For an exact area representative sampling 3.5% of the data should be above 68N and below 68S. A mean solar zenith angle of 90 degree means that that are split evenly into day and night. The land pixels are identified by positive elevations.

Figure 7a shows the PDF of bt900 for all data between 68S and 68N from AIRS and CrIS. This area covers 94% of the globe. The PDF is a histogram of the of the count in each of the many bins (we used 100) bt900 bins, divided by the sum ot the count in all bin. The histograms show an almost perfect overlay of the AIRS and CRIS PDFs. The two distributions agree within 33 mK in the mean (276.512 K, 276.545 K), the standard deviations agree within 26 mK (20.326 K, 20.300 K). In order to explore more quantitatively how identical the two distributions are, we use Quantile Analysis [7]. In QA we calculate the percentiles from two data set on a very fine grid. In our case the grid was uniformly incremented between 0.005% to 99.995%. Associated with each of the 20,000 percentile values is in our example a bt900 values, called the quantile from AIRS, abt900q, and from CrIS, cbt900q. We used the function qqplot from the Matlab statistics library. Figure 7b is a plot of the CrIS cbt900q vs. the AIRS abt900q. Since the plot of perfectly matching PDFs would be a straight line, the AIRS and CrIS PDFs appear to be almost identical. Figure 7c shows a plot of the quantile difference, abt900q-cbt900q, vs. abt900q. Between 230K and 310K the quantiles agree within 100 mK, but CrIS is biased about 0.5K warm relative to AIRS at the hot and cold extremes.

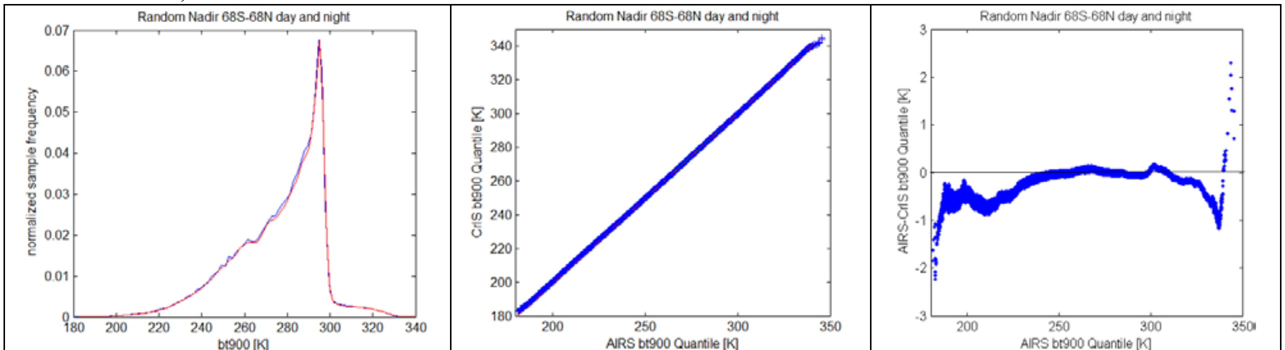

Figure 7a. The two distributions agree within 33 mK in the mean (276.512K, 276.545K) and std agree within 26 mK (20.326K, 20.300K)	b) Quantile analysis of the same data. The two distributions are virtually identical, except at the extremes.	c) The quantile difference reveals that CrIS is biased about 0.5K warm relative to AIRS at the hot and cold extremes.

This difference between AIRS and CRIS is day/night land/ocean and latitude dependent.   Figure 8 shows the PDF of bt900 for day tropical land data. Figures 8b and 8c shows the result of the quantile processing. A much larger systematic difference between AIRS and CrIS can be seen for the cold and hot extremes of the PDF than for global data.

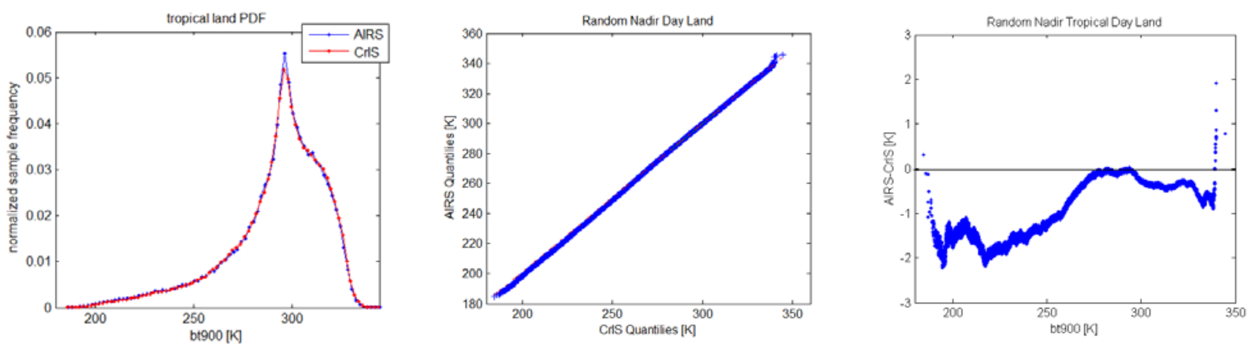

Figure 8 Distribution of bt900 day tropical land a) full PDF. AIRS-CrIS -0.38K.

b) Quantile analysis of the same data. The two distributions are virtually identical, except at the extremes.

c) At the 1%tile of the distribution AIRS-CRIS=-1.72K, at the 99%tile it is -0.46K.

For a quantitative analysis of the PDF we randomly divided the AIRS and CrIS data sets each into 10 subsets. For each subset we calculated the mean, the 1%tile and the 99%tile bt900 brightness temperature. The mean and the standard deviation of the results from the 10 subsets then give an estimate of the mean and theProbable Error (PE) of the mean. Table 3 summarize the mean, 1%tile and 99%tiles of the AIRS and CRIS PDF for seven cases. The day/night ocean land mean difference between AIRS and CrIS is less than 100 mK (-33±28 mK), but there are much larger differences at the 1% and 99%tile levels. For the 1%tile the AIRS-CrIS difference is -522±99 mK , while for the 99%tile it is -

188±76 mK, i.e. CRIS is considerably warmer than AIRS, particularly at night. This difference is dominated by the tropical day land. The cases where the difference is within 2*PE of zero in Table 1 are highlight yellow. Between 68S and 68N the mean values of CRIS and AIRS agree within 100 mK. Our mean values for the tropical oceans results are consistent with OMC, the mean values for 68S-68N are consistent with the global analysis of SNO [3, 4, 5].

zone	AIRS-CrIS mean±PE	AIRS-CrIS 1%tile ± PE	AIRS-CrIS 99%tile ± PE
global	0.176± 0.028	-0.110± 0.092	-0.113± 0.070
Above 68N	0.109± 0.079	0.280± 0.185	0.276± 0.200
Below 68S	0.040± 0.134	0.056± 0.241	-0.020± 0.127
68S to 68N	-0.033± 0.028	-0.522± 0.099	-0.188± 0.076
Tropical Ocean day	-0.098± 0.070	-0.779± 0.262	-0.029± 0.025
Tropical Ocean night	-0.035± 0.073	-0.771± 0.328	-0.133± 0.025
Tropical land day	-0.377± 0.200	-1.717± 0.701	-0.463± 0.118
Tropical land night	0.134± 0.082	-0.274± 0.635	-0.041± 0.040

Table 3. The mean, 1%tile and 99%tiles from AIRS and CRIS distribution between August 2012 and June 2013 based on the PDF analysis (airs.cris.stack.analysis.20130713pc).

4. Discussion

Based on clear day and night tropical ocean OMC, the instrument trend in the bt900 channel is less than3 mK/year. The OMC trend contains no climate information, but establishes a floor for the evaluation climate trends. The thermal infrared is extremely sensitive to clouds. The interpretation of the mean and changes in the mean are therefore ambiguous, since they can be due to changes in the surface temperature, the cloud amount or both. We therefore focus on the trends in the extremes, i.e. in the 1% and the 99%tile of the data. Some of the observed trends are more than one order of magnitude larger than the 3 mK/year instrument trend. The large warming trend seen above 68N, compared to no significant change seen below 68S confirms what is already known. Particularly intriguing is the trend in the 1%tile seen in the tropical zone, shown in Figure 5. The 1%tile for ocean is getting warmer (fewer extreme high clouds), while the 1% for land is getting colder (more extreme high clouds). Aumann et al. [8] attribute this to a shift in deep convection from the ocean to land as part of a multi-decadal oscillation, but parts of it could be a previously unnoticed steady climate shift. The 99%tile of bt900 is decreasing for day and night tropical oceans, at essentially the same rate as the current change in the NCEP RTGSST. A similar decrease is also seen in the 99%tile bt900 trend for night tropical land. For day tropical land the much faster decrease at the rate of -129±18 mK/yr is not understood. The interpretation is complicated due to the interaction between a decrease in surface emissivity (due to the exposure of bare soil), causing a decrease in bt900, while a decrease in moisture content of the top of the soil would cause an increase in the daytime temperature. Continuing the trends of the extreme values with future instruments is therefore of great interest.

The accuracy to which the trends in the extreme values can be continued by concatenating data from several instruments is a function of how well the observations match up during the period when two instruments are both functioning. AIRS and CrIS provide an opportunity to evaluate this. AIRS has been in orbit for 12 years, CRIS has been in orbit for the past one and half years. Extensive tests of AIRS and CrIS using OMC and SNO [3, 4, 5] show agreement, averaged over broad groups of channel, at the 100 mK level. The mean of our globally averaged random sampled result agrees with OMC and SNO results. However, while there is satisfactory agreement between AIRS and CrIS for the mean, there are significant differences for the 1%tile and the 99%tile. The 1%tile temperature of CrIS in the tropical zone is more than 0.5 K warmer than AIRS. For tropical day land the difference is 1.7K. For tropical ocean night and tropical land day the 99%tile of CrIS is also significantly warmer than the corresponding AIRS value. If AIRS and CrIS were not in the same orbits, with no time overlap, and the spatial sampling of the data were done with great care to insure no sampling bias, one would interpret the observed differences as climate change signals. The differences seen between AIRS and CrIS in our case are not climate, but due an artifact.

It may be argued that the observed regional and day/night bias is a data sampling bias. This could be a bias in the geographical sampling or bias due to overly tight quality screening. We have argued previously that the 5 million random nadir samples from AIRS and CrIS are geographically, day/night and land/ocean unbiased. During the past year we only used data from all days where AIRS and CrIS data were available. Of the received CrIS data since August 2012 99.9% are identified as "good" quality. Of the received AIRS data 99.6% are identified as "good" quality. Based on fact that the geographical distribution of the AIRS and CrIS samples match extremely well and that more than 99.9 percent are good quality, the argument that missing data are the cause of observed land/ocean bias under extreme conditions is not convincing.

The CrIS absolute radiometric accuracy requirement for the LW (band1) is stated as 0.45% when viewing a 287K blackbody. This corresponds to 0.43 RU (corresponding to 0.3K at 287K) at 900 cm^{-1}.The 1%tile brightness temperature is about 210K. A calibration error has to be day/night land/ocean consistent. If we interpret the 0.43 RU as an additive error, it corresponds to a brightness temperature error of 0.8K at 210 K. This is consistent with the observed warm bias for the tropical ocean day and night, but not for tropical land.

A more likely explanation for the observed differences between AIRS and CrIS is a difference in their sensitivity to scene content. For a given bt900 the only difference between tropical land and ocean day/night is the nature of the clouds. Particularly for land day there are many spatially isolated thunderstorms. How this explains the consistently warm bias of CrIS relative to AIRS under extreme conditions, but is also consistent with the excellent agreement between AIRS and CrIS for the mean conditions, is currently a matter of conjecture. Appendix 1 discusses this in more detail. Since this effect has just been noticed, potential reasons are just starting to be explored. At this point the cause for the disagreement between AIRS and CrIS for measuring extreme values does not matter. In spite of the carefully matched sampling, there is a difference, which in this case is recognized as an artifact. Unless the effect can be mitigated by a future reprocessing the data, it will significantly complicate the concatenation of the AIRS and CrIS data records for the purpose of trending extreme events for climate change evaluations.

Reliable identification of extremes for climate trend analysis requires observation under global conditions. The functional requirements of AIRS, IASI and CrIS state the absolute radiometric accuracy for a uniformly illuminated scene, with the assumption that any error due to scene non-uniformity cancels for the large averages. If it is confirmed that sensitivity of the CrIS absolute radiometric accuracy to scene non-uniformity causes the observed bias for measurements of extremes, then the specifications of future instruments should make insensitivity to scene content an explicit requirement.

Summary

Climate change is expected to be detected first as changes in extreme values rather than in mean values. We measured trends in the 1%tile and 99%tile brightness temperatures measured with the 900 cm^{-1} channel from AIRS for the past 11 years. This channel is in the clearest part of the 11 micron atmospheric window. We show that the instrument trend in this channel is about 3 mK/year. More than one order of magnitude larger changes are seen for land and ocean, which in the case of the 1%tile (cold) extremes are related to the current shift of deep convection from ocean to land. Changes are also seen in the 99%tile for day tropical land, but their interpretation is at present unclear. We use the statistical distribution from the past year derived from AIRS to evaluate the accuracy of continuing with CrIS data the trends established with the AIRS data. In order to minimize differences in the spectral response functions we limit the analysis to the channel at 900 cm^{-1}. While the two instruments agree within 100 mK for the global day/night land/ocean mean values, there are significant differences when evaluating the1% and 99%tiles extremes. We see a consistent warm bias in the CrIS data relative to AIRS for 1%tile (extremely cold, cloudy) data in the tropical zone, particularly for tropical land, but the difference is not day/night land/ocean consistent. The difference is likely due to the differences in the radiometric response of AIRS and CrIS to differences in the day/night land/ocean cloud types. Unless the effect can be mitigated by a future reprocessing the data, it will significantly complicate the concatenation of the AIRS and CrIS data records for the purpose of trending extremes.

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Appendix: The scene dependent CrIS warm bias relative to AIRS for extreme values.

We find a warm bias of CrIS relative to AIRS under extreme conditions, but, except for tropical day land, excellent agreement between AIRS and CrIS for the mean conditions, including the very cold conditions in the north and south polar caps. One possible clue for the difference between AIRS and CrIS can be found in the CrIS real and imaginary component of the spectrum. The imaginary component is a measure of the noise and the radiometric fidelity of the spectrum (related to the accuracy of the phase correction). Saved with each spectrum are the maximum value of the absolute value of the imaginary component in a representative region in each of the three CrIS bands, 800 -980 cm^{-1} in the case of band 1,which we refer to as max1i, max2i and max3i. Since December 2012 the CrIS QC limits max1i< 1.5 (in RU= radiance units) for "good" quality spectra Since we are using data since August 2012, we include only data which passes the max1i<1.5 RU test. This is the case for 99.9% of the data. Figures A.1 and A.2 show the results of a scatter diagrams of max1i as function of bt900 (a channel in the LW band) for the day/night land/ocean tropical zone. The land data continue to brightness temperatures as high as 340K, but for this illustration we limited the graph to bt900<300K. Rather than plotting max1i vs. bt900 for millions of points we divided the bt900 range into 2 K wide bins and calculated the mean and the PE of the mean for each bin. We then plotted the mean + PE and mean - PE. The PE becomes significant only at the lowest values of bt900. There is a difference between day and night for ocean (Figure A.1), and a much more pronounced difference between day and night for land (Figure A.2) in the relative magnitude of max1i as function of bt900. Only spectra with max1i less than 1.5 were used in this analysis..

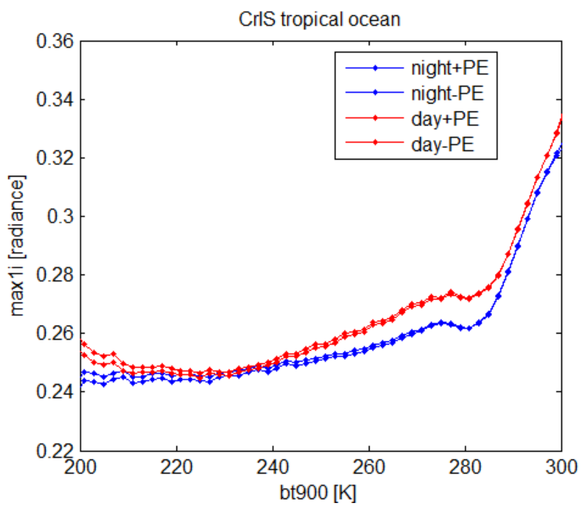

Figure A.1. max1i as function of bt900 for day and night tropical ocean. Max1i is typically larger during the day than at night.

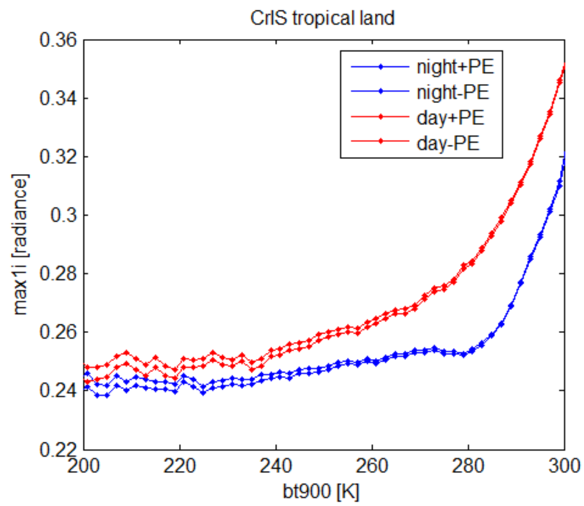

Figure A.2. Max1i as function of bt900 for day and night tropical land. Max1i is always considerably larger during the day than at night.

This indicates that the CrIS instrument, or the onboard digital processing, or the radiometric calibration software on the ground , or a combination of the above, respond different to scenes which have the same bt900. The bt900 measurement is the sum of the contribution of clear and cloudy pixels in the 14 km diameter footprint. The larger max1i , the more of the radiance is in the imaginary component. As bt900 increases, it is not unreasonable to see max1i increase, but it was not expected that this increase would be day/night land/ocean dependent. For a given bt900 the only difference between tropical land and ocean day/night is the nature of the clouds in the 14 km diamter footprint. The start of intense convection at noon creates many spatially isolated thunderstorms, which create very high spatial contrast scenes. Since these conditions are found in the 1%tile of the data, their effect on the mean is minimal.