Lessons from 18 years of hyperspectral infrared sounder data

H. H. Aumann[a], E. M. Manning[a] and L. L. Strow[b]

[a] Jet Propulsion Laboratory, California Institute of Technology,
[b] University of Maryland, Baltimore County

Abstract

By the end of 2013 NASA and EUMETSAT will have accumulated more than 11 years of AIRS, 6 years of IASI and one year of CrIS data. All three instruments were nominally specified to support the NWC for short term weather forecasting with a five year lifetime, but continue to exceed the accuracy requirement needed for weather forecasting alone. This allows use of their data for a much broader range of applications, including the calibration of broad-band instruments in space and climate research. We illustrate calibration aspects with examples from AIRS, IASI and CrIS using spatially uniform clear conditions, simultaneous nadir overpasses and random nadir samples. The differences between AIRS, IASI and CrIS for the purpose of weather forecasting are small and we expect that the excellent forecast impact demonstrated by the combination of AIRS and IASI will be continued by the combination of CrIS and IASI. Clear data are useful for calibration, but contain no climate signal. The analysis of random nadir samples from AIRS and CrIS identifies larger biases for observation of extreme conditions, represented by 1% and 99%tile data than for non-extreme observations. This is relevant for climate analysis. Resolution of these differences require further work, since they can complicate the continuation of trends established by AIRS with CrIS data, at least for extrema. The unequaled stability of the AIRS data allows us to evaluate trends using random nadir sampled data. We see an increasing frequency in severe storms over land, a decreasing frequency over ocean. The 11 years of AIRS data are too short to tell if these trends are significant from a climate change viewpoint, or if they are parts of multi-decadal oscillations.

Keywords: Climate change, sampling bias, hyperspectral infrared, deep convection, Quality Control

1. Introduction.

By the end of 2013 NASA and EUMETSAT will have accumulated more 11 years of AIRS [1] , 6 years of IASI [2] and one year of CrIS [3] data. AIRS and CrIS on EOS Aqua and NPP, respectively, are in 1:30 PM ascending node polar orbits, but there is a 0.4 degree difference in inclination of their orbits and AIRS is at 705 km , CrIS at 825 km altitude. IASI is in 840 km altitude 9:30 ascending node orbit. The three instruments have a comparable Field of View (FOV), AIRS 13.5 km, CrIS 15.8 km and IASI 12.0 km at nadir, comparable spectral coverage, spectral resolution and signal-to-noise. While the most obvious difference in the design of the three instruments is that AIRS is a grating array spectrometer, while IASI and CrIS is a Fourier Transform Spectrometer (FTS), there are other differences. AIRS and CRIS make 9 measurements in a 3x3 pattern, IASI makes 4 measurements for the 45 km diameter of the scene. Unlike for AIRS, where the 9 measurements come from the same detector, the 9 CrIS (4 IASI) measurements come from 9 (4) different detectors in each of three broad spectral bands. There is also a difference in the scan pattern. The AIRS cross-track scan is continuous, with 20 msec dwell time per spectrum. The IASI and CrIS crosstrack scans are composed of a sequence of step and settle, then stare for the 200 msec at a point on the ground while creating each interferogram. During these 200 msec the spacecraft moves about 10% of the FOV. IASI and CrIS slowly pivot their scan mirror by about 0.1 degree during the integration time to compensate for the spacecraft motion. In the IASI design scene variability effects can be further mitigated by the use of an 11 micron total power detector in the focal plane. The CrIS and IASI interferometers both operate at spacecraft ambient temperature, about 270K. This design is sensitive to occasional near cancellation of the signal at zero-path-difference for low spectral contrast scenes between 240 and 250K by the 180 degree out-of-phase thermal emission of the interferometer. Both CrIS and IASI take two-sided interferograms, but in the CrIS design the laser fringe count is maintained when the interferometer mirror reverses direction, making CrIS insensitive to uncertainties in the zero-path difference position.

hhaumann@jpl.nasa.gov Proc. SPIE 2013 Conference on Optical Engineering and Applications. Imaging Spectroscopy XVIII. 8870-6

Cross-calibration and Climate applications require a different level of accuracy than weather forecasting. This is related to Quality Control (QC). As part of the conversion of the raw data numbers to calibrated radiances (referred to as L1b product) each instrument creates parameters associated with each spectrum which indicate if the data quality meets the instrument specification. Typically more than 99% of the data pass the QC provided by the instrument. Weather forecasting sometimes uses the QC parameters provided with the data as a first filter, but does not critically depend on them. The data are re-screened by comparing them to the expected signal based on the forecast. Data which disagree with the forecast by more than some threshold are discarded as "cloudy" or otherwise in error. With current data assimilation systems only 1% of the AIRS and IASI data are used in the forecast. For cross-calibration, such as Simultaneous Nadir Overpasses (SNO) [4] of instruments on two satellites, the data are sometimes used only if both pass their respective QC. In the case of the analysis of the difference between the observed brightness temperatures (obs) and those calculated (calc) based on the state of the atmosphere provided by GCM, data where OMC=(obs-calc) exceeds some tight threshold are rejected as "cloudy". While OMC provide information about the mean accuracy of the calibration, a robust climate signal requires analysis of all-sky scenes . Climate applications critically depend on the QC parameters provided by the instrument calibration algorithms.

The AIRS QC parameters are summarized in CalFlag, an array of 2378 integers in the L1b data record. Data from channel "n" are used only of CalFlag(n)==0. This is true 99.6% of the time for the "good" AIRS channels. "Good" AIRS channels are identifies by a Noise equivalent Delta T at 250K of less than 1 K. Of the 2378 AIRS channels, 2250 are "good". The IASI QC parameters are summarized in the "GQisFlagQual" integer attached to each spectrum. Data are used only if GQisFlagQual==0. Since August 2007 typically 99% of the IASI spectra are identified a "good". 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 ($mW/m^2/sr/cm^{-1}$), 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 1 data are identified as "good". CrIS QC flags are not used for the SNO inter-comparisons presented here.

All three instruments were nominally specified to support the NWC for short term weather forecasting with a five year lifetime, but continue to exceed the accuracy requirement needed for weather forecasting alone. This allows use of their data for a much broader range of applications, including the cross-calibration with other instruments in space and climate research. We illustrate this with examples from AIRS, IASI and CrIS. In the following we compare data from the three instruments under clear conditions, for Simultaneous Nadir Overpasses (SNO) and under globally representative random (clear and cloudy) conditions.

The AIRS calibrated radiances (L1B, v5.0) are available from the NASA/GSFC/DIS FTP site. The SDR data from IASI and CrIS (equivalent to the AIRS L1b) were obtained from NOAA/CLASS. Since the CrIS data are distributed without apodization, we applied the three point Hanning apodization. The IASI data are distributed with a truncated Gaussian apodization. The data volume created by these instruments each day is staggering, not in terms of storing the data, but in terms of processing years of data. All results shown in the following are based on daily subset of about 1% of the data. In the case of AIRS they are called AIRS Calibration Data Subsets (ACDS). Similar daily subsets are being created for IASI and CrIS. The daily subsets were further decimated by creating daily summary files for 100 key channels. These daily files are typically 100 MB in size and are used to support the calibration and climate trend analysis. The overall reduction in data volume is a factor 5000.

In order to avoid the need for making radiometric corrections for differences in the spectral response functions of the three instruments, we restrict our analysis to data from a single ~1 cm^{-1} wide channel at 900 cm^{-1} in the 11 micron atmospheric window which is relatively free of water lines. Figure 1 shows the large separation of the location of this channel (red star) from interfering water lines. For AIRS we used channel#759 at 900.3 cm-1, for IASI and CrIS we use the 900.0 cm^{-1} channel.

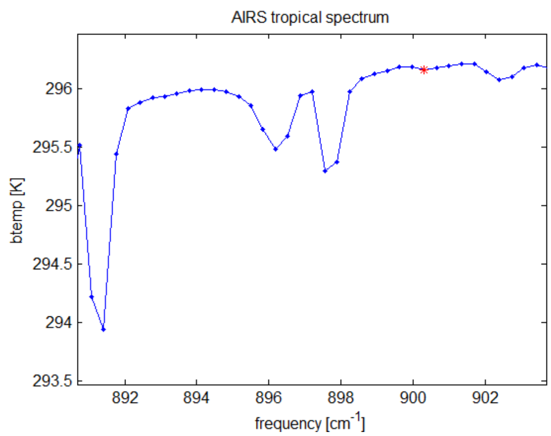


Figure 1. AIRS tropical spectrum of part of the 11 micron atmospheric window. The channel at 900 cm^{-1} is highlighted.

2. Results

We discuss results in two sections. The first is related to calibration, the second is related to climate change.

2.1. Results related to calibration.

2.1.1. (obs-calc) for tropical ocean cloud-filtered conditions
A straightforward test for the evaluation of the radiometric accuracy is the comparison of the observed brightness temperature (obs) and the calculated brightness temperature (calc) under tropical ocean clear conditions. For tropical oceans the SST is accurately known from the floating buoys, the surface emissivity is well known, and the correction for atmospheric absorption due to water vapor, typically only 2K, can be made using a split window technique or can be calculated using the water vapor in the forecast with an accuracy of better than 50 mK. The limitation in (obs-calc) is the clear filter. Due to instrument design difference the AIRS, IASI and CrIS clear filters are not identical. For AIRS and CrIS we use the 3x3 measurements while for IASI we use the 2x2 measurements, all centered on the AMSU 45 km (at nadir) footprint. We define the spatial contrast ce900 at 900 cm-1 as the difference between the maximum and the minimum bt900 in the 3x3 or 2x2 pattern. If ce900 is less than 0.5K, then the spectrum at the center of the pattern is defined as “coherence clear”. The “coherence clear” spectra contain significant number of spectra from uniform low stratus. The ce900<0.5K test is therefore followed by a test of the depth of the water lines. The atmosphere above most clouds is extremely dry. If the depth of the water lines is consistent with the climatology surface temperature, then the spectrum is identified as “clear”. Figure 2 shows the result for AIRS and IASI clear filtered since May 2007 for day and night clear tropical ocean. Each dot represents a daily mean.

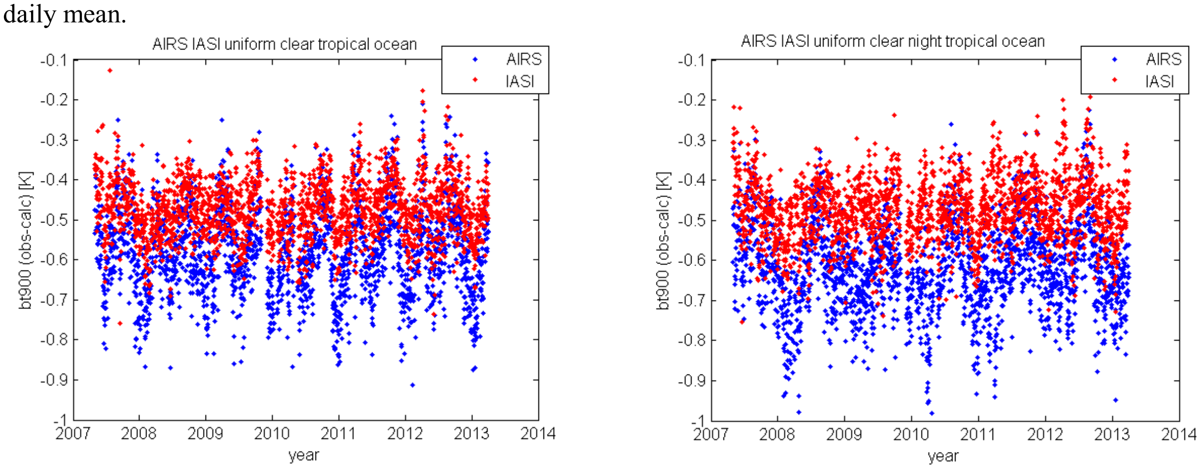


Figure 2. (obs-calc) clear tropical ocean a) day b) night

The AIRS mean clear yield is 7274 per day, 6578 per night. IASI mean clear yield is 10193 per day, 7875 per night. The difference is due to differences in the clear filter and the difference in the overpass time. Table 1 summarizes the 6 year mean bias in (obs-calc) for the 900 cm^{-1} channel. We refer to the 9:30 AM and 1:30 PM overpasses as “day”, 9:30 PM and 1:30 AM as “night”.

Clear tropical ocean	AIRS (6 year)	IASI (6 year)	AIRS (7 months)	CrIS (7 month)
Day	-0.58K	-0.47 K	-0.14K	-0.26K
Night	-0.62 K	-0.47 K	-0.19K	-0.41K

Table 1. The 6 year mean bias for (obs-calc) from AIRS and IASI, 9 month for AIRS and CRIS.

The cold bias in AIRS and IASI is due to a residual cloud leak. The seasonal modulation of the bias is due to the seasonal change in the cloud types which leak into the clear filter. A tighter cloud filter reduces the yield, but it also reduces the cold bias due to clouds leaks. For AIRS data it has been shown [5] that the cold bias asymptotically approaches a value of less than 50 mK as the clear filter is made increasingly tighter. Figure 3 shows (obs-calc) for AIRS and CrIS since August 2012 using a tighter clear filter. The mean bias of (obs-calc) from AIRS and CrIS since August 2012 is summarized in Table 1. The difference in the AIRS bias between the 6 year and the 7 month data period is due to a difference in the clear filter. AIRS, IASI and CrIS use conceptually similar, but not identical cloud filters. This example illustrates why the usefulness of (obs-calc) with spatial coherence clear filtered data in support of absolute calibration verification ends at the 0.3 K level. This also explains part of the reason why the NWC assimilate empirically bias corrected AIRS, CrIS and IASI data.

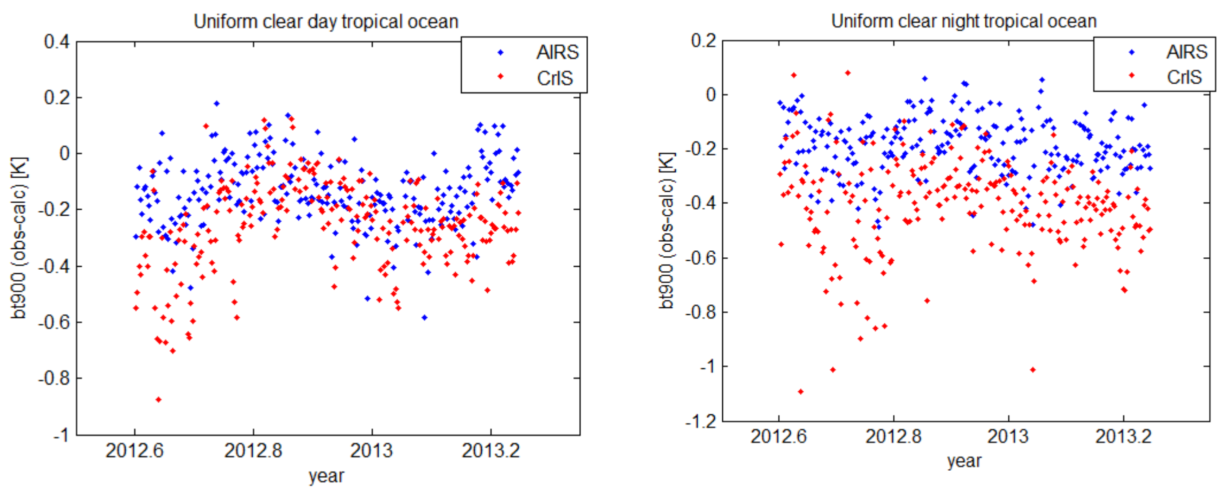


Figure 3. (obs-calc) for clear tropical ocean from AIRS and IASI between April 2012 and April 2013. a) day b) night

The daily mean bt900 (obs-calc) data from AIRS and IASI shown in Figure 2 can be used to evaluate the stability of the measurements relative to the SST. Figure 4 shows the AIRS and IASI (obs-calc) anomaly for clear filtered tropical ocean conditions. For AIRS we find a trend of +0.8±1.1 mK/yr, for IASI the bias trend is +1.2±0.9 mK/yr. This means that trend for both instruments has to be stated as an upper limit of less than 2 mK/yr. At this time the CrIS data record is too short to make a meaningful trend measurement.

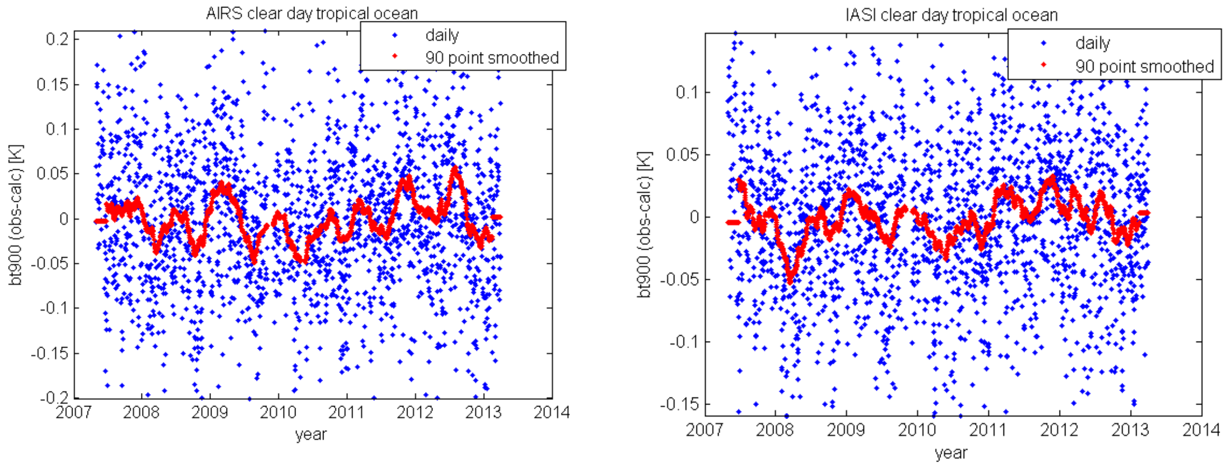


Figure 4 a) AIRS (obs-calc) anomaly b) IASI (obs-calc) anomaly

2.1.2. Simultaneous NADIR Overpasses (SNO)

Data from Simultaneous Nadir Overpasses (SNO) provide a simple and accurate method to inter-compare and evaluate IASI and AIRS and AIRS and CrIS [6, 7]. Unlike cloud filtered clear data, SNO can be clear or cloudy. For each SNO event data are collected from within 8 km and 10 minutes of the nominal geographical location and time where the orbits cross. Typically 6 to 8 spectra are collected per SNO from each instrument. The CrIS SNOs are filtered to provide BTs between 100 and 400K, which resulted in a total of 301915 spectra with bt900 ranging from 185.4 to 301.7K. The AIRS SNO data matched with CrIS were unfiltered, but converted to L1c form, which replaces 100 noisy or dead channels (of 2378 channels) with radiances from a nearby buddy channel with very similar BTs. The IASI and AIRS SNO data are QC filtered. The resulting data sets are used to calculate the mean and standard deviation IASI-AIRS, and CrIS-AIRS. Since AIRS and IASI orbits have different ascending nodes, the AIRS-IASI SNO results are limited to two narrow latitude bands around 73N and 73S. Figure 5 illustrates the steps in the SNO analysis average for the mean of the 73N and 73S latitude bands for IASI and AIRS.

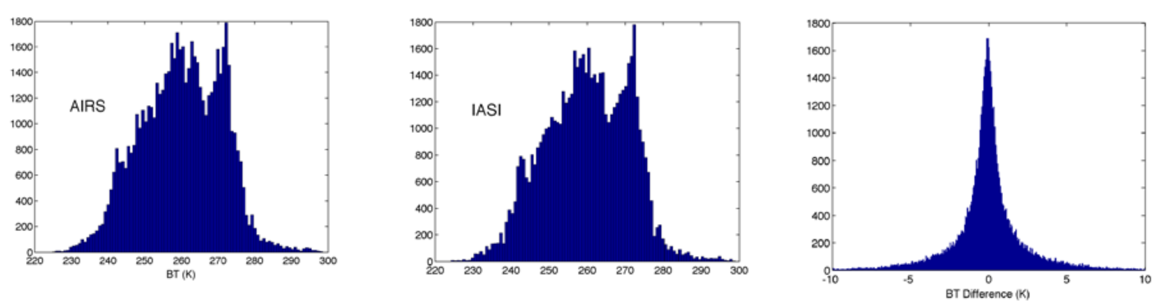


Figure 5. SNO from bt900 b) IASI c) IASI-AIRS
a) AIRS

The AIRS and CrIS orbits have the same ascending node. This means that SNO are available from all latitudes, although most are still from high latitudes. This is apparent from Figures 6 a,b, and c, which illustrates the steps for AIRS and CrIS SNO.

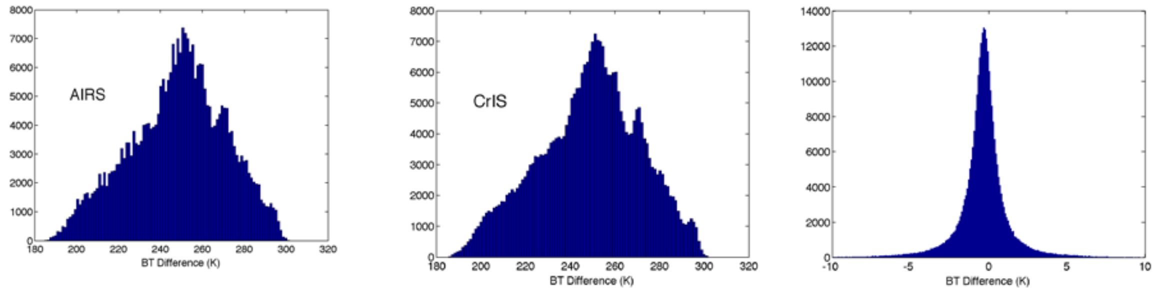


Figure 6. SNO from bt900 a) AIRS b) CrIS c) AIRS-CrIS

The mean AIRS-CrIS and AIRS-IASI SNO differences for bt900 are typically less than 100 mK with a probable error of 25 mK. This performance far exceeds the required measurement accuracy of AIRS, CRIS and IASI in support of weather forecasting. Figure 6d shows the difference between the AIRS and CrIS SNOs (for bt960, which is similar to bt900) as a function of scene temperature. The differences vary by about 0.1K with the scene with a PE of about 0.05K or better. The agreement is excellent for all scene temperatures from about 190K to 300K. However, note that this SNO dataset was limited to high temperatures of 300K, so does not probe AIRS and CRIS differences at higher temperatures.

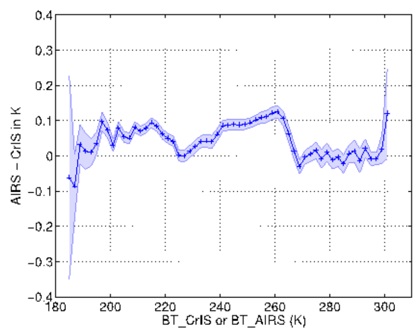


Figure 6d. Difference between AIRS and CrIS SNO B(T) for bt960 versus scene temperature.

Differences between the three instruments at the 100 mK level are difficult to interpret. In the case of AIRS, each of the 2378 and the each of the 9 detector elements in CrIS (4 in IASI) in each of the three bands used in the CrIS and IASI FTS design have their own calibration. In addition, the adjustment of the SRF centroids, with the exception of few window channels, 900 cm^{-1} being one of them, can also introduce error at the 100 mK level. The analysis is limited to the comparison of the mean bt900 of the 3x3 (2x2) elements in the LW part of the IASI and CrIS spectra.

2.1.3. Random sampled data.

An alternative for the comparison of data from two instruments in the same orbit at the same time is the use global random sampling. Each day we randomly collect about 20000 spectra and their associated coordinates and quality flags from a 90 km wide gound swath within 3 degrees of nadir from AIRS, IASI and CrIS. The sampling is thinned at high latitudes sample proportional to cos(latitude), which corrects for the heavy spatial over-coverage of the high latitudes by polar orbiting satellites. Figure 7a shows the coordinates of each CrIS random sample from 28 April 2013 on a mercator projection. On this scale a similar plot of AIRS data would be indististinguishable from the CrIS data. Since there are 14 orbits each day and the nadir track moves with a 16 day repeat cycle, 90 x 14 x 16 =20,000 km, represents the linear coverage of this sampling along the equator for either a daytime or nighttime view. Since the circumference of the earth is 40,000 km, this sampling measures approximately one-half of the surface at the equator during the day and half of the surface of the equator at night, with higher sampling at higher latitudes. We have not determined the precise overlap of the CrIS and AIRS random sampling, although this approach should provide nearly uniform global coverage. Note that NPP and AQUA nadir views nearly overlap every 2.667 days.

The uniformity of the 6 million samples from AIRS and CRIS between August 1, 2012 and June 26, 2013 can be assessed as function of latitude and longitude. For a spherical surface 3.5% of the area is above 68N and below 68S.

In our sample 3.5% of the sampes come from above 71N and below 71S. Figure 7b shows the count of AIRS and CrIS data in one degree wide longitude bins as function of longitude. Each longitude bin has typically 15,000 samples. Differences of less than 1% in the sample count in each longitude bin can be seen due to differences in the downlink and the preferred location for orbit maneuvers.We conclude that the AIRS and CRIS data represent a large reasonably uniform sample of the globe, but, unlike SNO, the AIRS and CrIS samples are not time and space coincident.

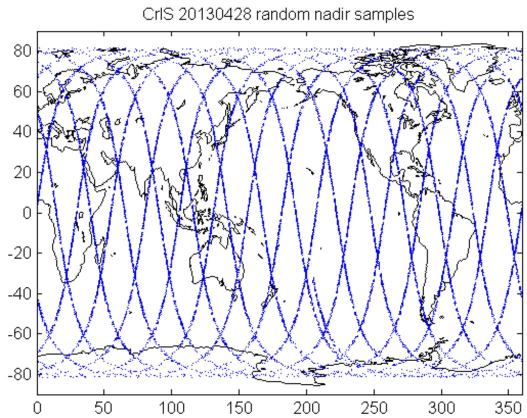
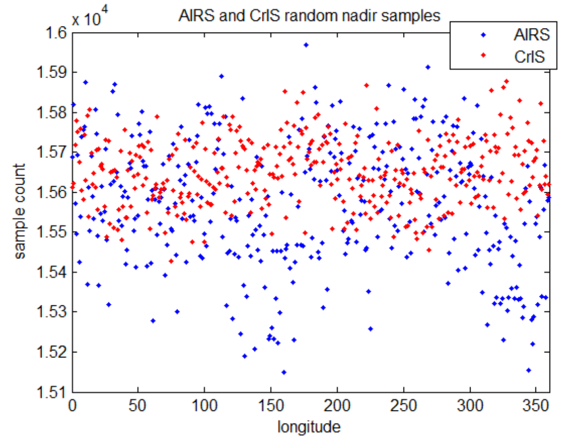
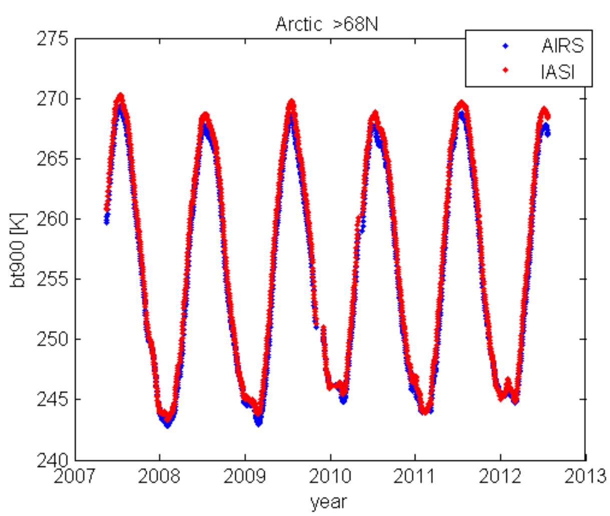


Figure 7 a) geographical distribution of random nadir samples from one day of CrIS data.



b) Sample count from AIRS and CrIS for one degree wide longitude bins as function of longitude.

We illustrate illustrate random sampling in Figure 8 with daily mean bt900 random nadir samples from the overpasses of the Artic and Antarctic of AIRS and IASI. Because of the polar orbit there are typically 400 samples per day from AIRS and IASI measured within 30 minutes of each other. For the Antarctic the AIRS measurement is 0.8K colder than IASI (255.7K, vs. 256.5K), while for the Antarctic AIRS is 1K warmer than IASI (237.6 K vs. 236.6 K). The observed difference between AIRS and IASI, in particular the sign reversal, is at present not understood. The imaginary component associated with each spectrum would provide a helpful diagnostic tool, but is currently not included with the IASI data.



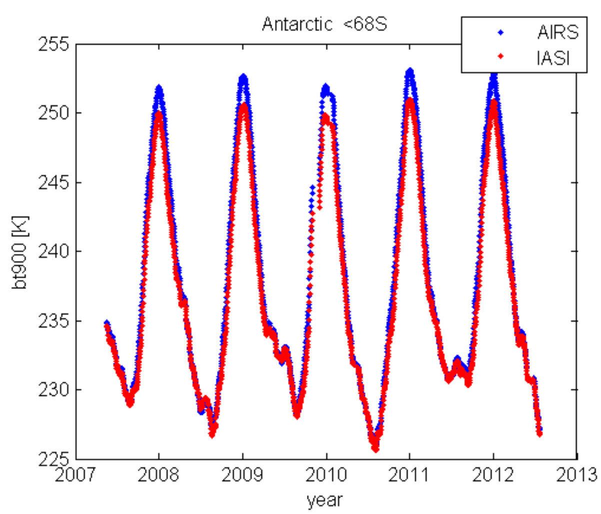
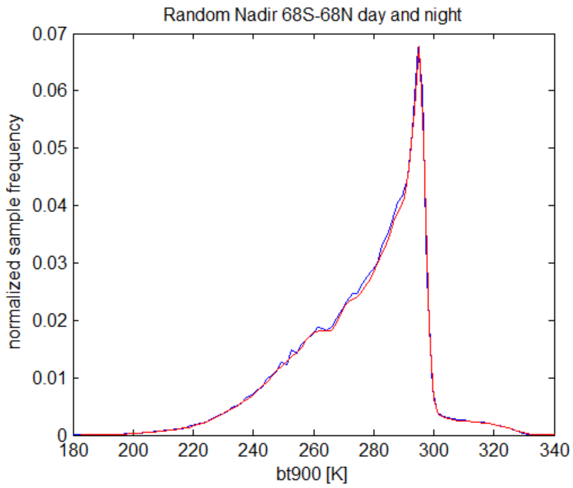


Figure 8. Results from five years of of daily bt900 AIRS and IASI random sampling. a) Arctic

b) Antarctic.

In the case of IASI and AIRS the interpretation of random sampled results is complicated because of the difference in the orbit. Random sampling can be used for the evaluation of the calibration, if two instruments are in the same orbit at the same time. If it is a fair sample and big enough, then the central limit theorem states that the statistical properties of the Probability Density Function (PDF) created from the AIRS and CRIS samples for any area of the globe should be indistinguishable. We illustrate this with the 6 million random nadir samples from AIRS and CRIS between August 1, 2012 and June 26, 2013. In order to retain a big enough sample we restrict this illustration to large zones.

Figures 9a shows the of the PDF from bt900 created from all data collected day and night between 68S and 68N, 5 million AIRS and CrIS samples. The PDF is basically a histogram where the sample count in each bin is divided by the sum of the sample counts in all bins.The difference between the AIRS median and CRIS median for the PDF is very small, -0.033 ± 0.010 K, where the number following the "±" sign is the probable Error (PE) in the difference. Careful inspection of the PDF shows that the AIRS (blue) and CRIS (red) PDFs are slightly different.



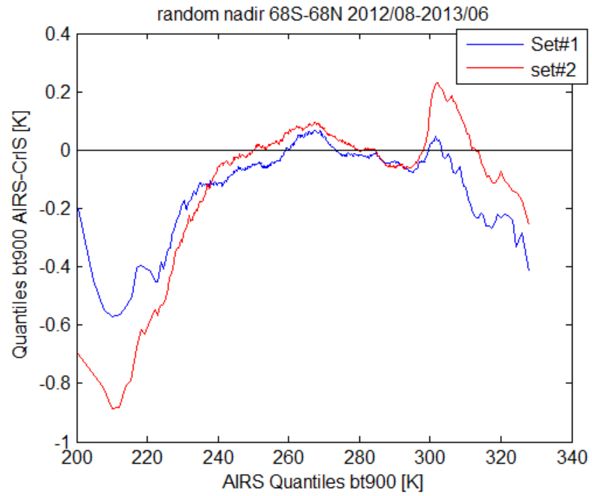


Figure 9 Distribution of bt900 random nadir samples from day/night between 68S and 68N a) PDF b) Quantile Analysis of the PDF.

This difference is more obvious from the Quantile Analysis (QA) [8] of the two PDFs. In QA we calculate the percentiles from each data set on a grid, incremented from 0.1% to 99.9%. Associated with each of the 10,00 percentile values is a bt900 value, called the Quantile, from AIRS, Qbt900a, and from CrIS, Qbt900c. In order to estimate the uncertainty of this procedure, we split the data randomly into two independent sets. Figure 9b shows the Quantile difference, Qbt900a-Qbt900c, vc. Qbt900a results from both sets. The separation between the two traces is a very rough equivalent to the PE. Between 240K and 310K the Quantile difference is less than 0.05K. This basically confirms the global analysis from SNO and OMC, although the SNO results show far better agreement between 200 and 240K. At the 1%tile (215K) and 99%tile (320K) we see a considerably larger warm bias in the CRIS data relative to AIRS. Below the 0.1%tile (roughly 200K) and above the 99.9%tile (roughly 330K) levels the QA becomes noisy. In Table 2 we summarize the results of QA for eight large zones in terms of the 1, 10, 50, 90 and 99% Quantiles. In Table 2a we show the values of the CrIS AIRS averaged Quantiles.

zone	AIRS-CrIS 1%tile	AIRS-CrIS 10%tile	AIRS-CrIS median	AIRS-CrIS 90%tile	AIRS-CrIS 99%tile
Above 68N	226.3	238.1	253.5	269.7	278.7
Below 68S	198.4	215.6	239.1	259.0	269.2
68S to 68N	219.9	247.6	276.5	296.3	317.7
Tropical Ocean day	214.5	256.2	284.1	296.9	299.44
Tropical Ocean night	214.2	259.8	283.4	296.2	298.5
Tropical land day	213.7	258.6	292.3	319.1	328.9
Tropical land night	214.5	256.2	284.1	296.9	299.4

Table 2a. Summary of AIRS CrIS averaged quantiles

In Table 2b we show the Quantile differences and their Probable Error (PE) Here we separated the AIRS and CrIS data randomly into ten independent subsets and repeated the QA for each subset. The mean and PE of the Quantiles for the entire data set are then derived from the average and the standard deviation of the results from the ten subsets. The row for the 68S-68N zone shown in Figure 9 is hightlighted.

zone	AIRS-CrIS 1%tile ± PE	AIRS-CrIS 10%tile ± PE	AIRS-CrIS median±PE	AIRS-CrIS 90%tile ± PE	AIRS-CrIS 99%tile ± PE
Above 68N	0.277 ± 0.088	-0.095 ± 0.047	0.109 ± 0.036	0.192 ± 0.032	0.241 ± 0.109
Below 68S	0.070 ± 0.114	0.044 ± 0.065	0.040 ± 0.051	0.001 ± 0.061	-0.018 ± 0.056
68S to 68N	-0.514 ± 0.057	-0.044 ± 0.032	-0.033 ± 0.010	-0.055 ± 0.006	-0.192 ± 0.047
Tropical Ocean day	-0.789 ± 0.116	0.048 ± 0.148	-0.098 ± 0.026	-0.070 ± 0.005	-0.028 ± 0.012
Tropical Ocean night	-0.804 ± 0.138	0.269 ± 0.108	-0.035 ± 0.025	-0.079 ± 0.006	-0.135 ± 0.013
Tropical land day	-1.640 ± 0.254	-1.009 ± 0.176	-0.377 ± 0.071	-0.341 ± 0.042	-0.464 ± 0.052
Tropical land night	-0.256 ± 0.243	0.463 ± 0.153	0.134 ± 0.038	0.010 ± 0.019	-0.033 ± 0.039

Table 2b. Summary of AIRS CrIS Quantile differences

A consequence of the central limit theorem is that in the limiting case of infinite unbiased sampling of a PDF, the sampled PDF will be identical to the true PDF. The least sampled set in Table 2, tropical land, still has 500,000 samples for day and night each. This means that the 1%tile is calculated from 5000 points. However, unlike SNO, the samples from CrIS and AIRS are not spatially or time coincident. For all cases except for tropical land and the polar caps the difference in the AIRS-CrIS median is less than 100 mK. Table 2 shows differences between the AIRS and the CrIS at the 10%tile in all zones, and larger differences which are statistically significant at the 1%tile level, The CrIS 1%tile is typically 0.5K warmer than AIRS. The reasons for these discrepancies are at present not understood and may be instrument related, or may be due to geographical sampling biases between SNO and random samples. However, as noted in the paragraph on QC, CrIS data with an imaginary component magnitude as large as 1.5 radiance units are accepted as "good". At the 1% tile bt900 is typically 210K, where 1.5 radiance units correspond to a radiometric offset of as much as 2.7K. It should be noted that the AIRS, CRIS and IASI measurement requirements are for spatially uniform conditions and mean values near 280 K (250K for AIRS), with the unstated assumption that the errors are globally and regionally Gaussian distributed. This specification is clearly not adequate for climate observations, where the 1%tile and the 99%tiles contain key information related to climate change. If AIRS and CrIS were not in the same orbit at the same time, the difference in their PDFs could be misinterpreted as climate signal, depending on the details of the analysis.

2.2. Results related to climate studies using AIRS, IASI and CRIS.

2.2.1. Climate change is expected to be detected first as changes in extreme values rather than in mean values. In the context of extremes the 1%tile and 99%tile of PDFs are important. The 1%tile represents the coldest clouds, related to severe storms, while the 99%tile for land corresponds to the hottest clear scenes and can be related to desertification. Trends in severe storms and desertification are of great socital and climate interest. The excellent radiometric stability of the AIRS data provides a unique insight into processes related to climate change. Figure 10 shows the trend in the 1% of bt900 for tropical land and tropical ocean [8] using the random nadir sampled data discussed in the previous section. For the tropical ocean the coldest spectra are getting warmer, while they are getting colder for the tropical land. This is a manifestation of a shift in the frequency of deep convection from ocean to land [9] in the past 11 years of AIRS data. With only 11 years of data it is not clear of this shift is related to a long term climate change or if it is part of a multi-decadal oscillation.

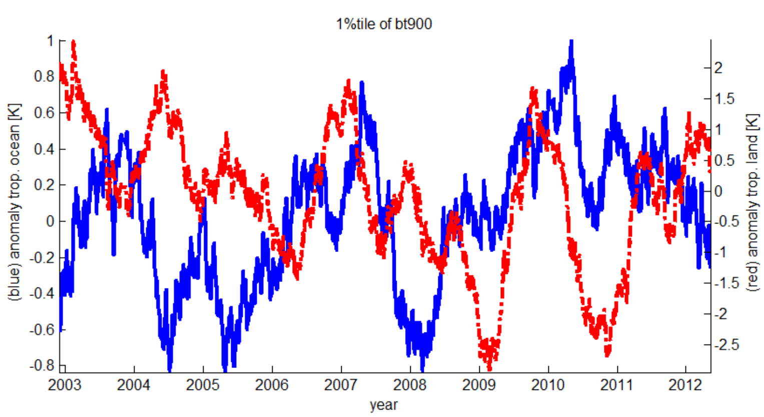


Figure 10. The trend in the 1% of bt900 for tropical land and tropical ocean is anticorrelated.

2.22. .Some lessons from AIRS, IASI and CrIS data for weather forecasting and climate.

The insight into hyperspectral sounders presented in this paper was based on one atmospheric window channel at 900 cm^{-1} under clear clear conditions (less than 1% of the data), using SNOs, and for random nadir sampled conditions (less than 1% of the data) from AIRS, IASI and CrIS.

a) NWC support: It is well known that about 200 Principal Components (PC) equivalent to about 300 channels at most, capture all geophysical information in the 2378 and the more than 8000 IASI channels. We now know which those channels are, the 900 cm^{-1} is one of them, and this is what the NWC ingest for the forecast. The real limiting factor of the AIRS, IASI and CrIS data for NWC use is not random noise or calibration accuracy but clouds in the 15 km footprints. Analysis of AVHRR and MODIS data indicates that 1-2 km footprints are much better with regards to cloud contamination. We know that less than 1% of the data are reasonable clear, and the 5% of the data which are close enough to being reasonably clear and may be usable in the future by NWC can easily be identified by in-board software. For NWC support we should consider downlinking only the 200-300 key channels (a saving of a factor 10-20), and download only the 5% of the data which have a reasonable hope of being assimilated for the full cross-track scan. However, this could impact non-NWP science done with the hyperspectral sounders, such as minor gas retrievals and surface emissivity studies.

b) The climate analysis:

For climate, clouds are not a source of noise, but a key component in climate change. Changes in extreme events, either cold (210K and less) or hot (320K and more) could be the first indicators of climate change. The functional specifications of AIRS, IASI and CRIS were based on NWC requirements, and may not be adequate for critical climate analysis.

A major limitation of using AIRS, CRIS and IASI data for climate is the enormous data volume created every day by the global coverage for NWC support. Even the best data set are of limited usefulness, if they are so big that they can't be effectively processed. We show that the near nadir track, 1% of the data, covers the global every 16 days. It retains the critical spatial resolution for the detection of clear cases and extreme cases and may suffice for climate change analysis.

We see some trends in the AIRS data which are real, since they are much larger than the instrument trend derived from OMC. With only 11 years of data it is not clear if the observed trends are related to a long term climate change or if they are part of multi-decadal oscillations.

3. Summary

1. Under spatially uniform clear tropical ocean and SNO conditions the AIRS, CrIS and IASI mean bt900 agree within 100 mK. Globally random nadir sampled data are an interesting alternative to SNO, but they can also be used for climate analysis. For global random sampled data AIRS and CrIS bt900 agree within 100 mK. Since the weather forecasting centers assimilate AIRS/IASI and CrIS surface channels only under clear conditions and subject to their own much tighter quality control, the positive forecast impact achieved by the combination of AIRS and IASI should continue with the combination of CrIS and IASI.

2. AIRS, CRIS and IASI measurement requirements pertain to spatially uniform conditions and mean values between 250 and 300K, with the unstated assumption that the errors are globally and regionally Gaussian distributed over the full dynamic range. This requirement specification is clearly not adequate for climate observations, where the 1%tile (210K) and the 99%tiles (320K) contain key information related to climate change.

3. The analysis of random nadir samples from AIRS and CrIS identifies some significant differences for observation of extreme conditions represented by 1% and 99%tile data. However, the PE of these differences are large, so more work is needed to determine if they are real. Resolution of these differences requires further work, since they can complicate the continuation of trends established by AIRS with CrIS data, at least for extrema.

4. The upper limit in the trend for AIRS and IASI is 2 mK/yr level (2 sigma upper limit) in the IASI band 1 and equivalent AIRS data. The 11 year AIRS data record is starting to provide the insight into multi-decadal trends. We show the increase in the 1%tile for land, related to the increase in the frequency of deep convection (thunderstorm) over land, and a decrease in deep convection over ocean. One year is not long enough to establish CrIS instrument stability.

5. The best data sets are of limited use for climate analysis, if they are so big that they can't be effectively analyzed. We show that the near nadir track, 1% of the data, retains the critical spatial resolution for the detection of clear cases and extreme cases and may suffice for climate change analysis.

Acknowlegements

The research described in this paper at JPL and UMBC was funded by NASA HQ. The Jet Propulsion Laboratory is operated by California Institute of Technology under NASA contract. Dr. Alex Ruzmaikin (JPL) introduced us to Quantile Analysis.

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