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Comparison of the AIRS, IASI, and CrIS 900 cm^{-1} channel for Dome Concordia.

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We compare AIRS, IASI-A and CrIS under the cold conditions encountered in the daily overpasses of Dome Concordia, which is located on a high plateau in Antarctica, between May 2012 and March 2016. The brightness temperatures at DomeC for the 900 cm^{-1} atmospheric window channel is 218K on average, but varies seasonally from 185K to 255K. Averaged over all simultaneous overpass data AIRS is 26±13 mK warmer than IASI-A, AIRS is 116±7 mK colder than CrIS. However, we find that differences for both AIRS/IASI-A and AIRS/CrIS are temperature dependent, with AIRS being 250mK colder than IASI-A at 200K. These effects have been independently verified by other investigators. AIRS and CrIS bt900 results for simultaneous overpasses and daily mean values agree within 100 mK. AIRS and IASI simultaneous overpasses agree within 100 mK, but AIRS is 2K warmer than IASI for daily mean values. We attribute this effect to an overactive IASI QC which is sensitive to scene temperature above about 240K. The DomeC data do not reveal if this QC effect is present at temperatures warmer than 255K. These effects need to be taken into account when comparing results from AIRS, IASI and CrIS, and even more so when analyzing data from vintage instruments with respect to climate change.

1. Introduction.

Temperature changes in a global warming environment, currently at the rate of 100 mK/decade, are of great interest to the polar zones due to the melting of the ice, particularly the Antarctic. There are currently three well calibrated infrared radiometers in polar orbit, AIRS [1], IASI-A [2] and CrIS [3], which can make observations at high latitudes. However, measurements at extreme cold conditions are difficult. A number of studies have been published which compare AIRS and IASI-A, and AIRS and CrIS, in the 900 cm-1 atmospheric window channel. Tobin et al. [4] used Simultaneous Nadir Overpasses (SNO) from AIRS and IASI-A. Hewison [5] used the double difference between IASI-B and IASI-A and Meteosat. Wang et al. [6] compared Southern SNO, Tropical SNO and Northern SNO from AIRS and CrIS. The observed differences of the order of 100 mK and less between what appear to be measurements of equivalent quantities, measured at essentially the same time by three well calibrated instruments, are small. However, the differences point to a scene temperature dependent bias. These differences are not inconsequential from the perspective of global warming, since they are the equivalent of 10 years of global warming. The temperature dependence of the differences further complicates the interpretation of global data. We [7, 8] have previously used use AIRS, IASI-A and CrIS overpasses of Dome Concordia to gain insight into their relative calibration. Dome Concordia, in the following referred to as DomeC, is located on a 3200 meter high plateau in Antarctica at latitude 75 degree South, 123 degree East. Being on a high plateau in Antarctica, DomeC is one of the coldest and dries places on Earth. Temperatures range from 250K during the summer to 190K during the winter months. The following comparison of AIRS, IASI-A and CrIS expands this comparison.

2. Data

We have AIRS data since September 2002, IASI-A (referred to in the following as IASI) data since May 2007 and CrIS data since May 2012. AIRS, IASI and CrIS typically each have 20 overpasses of DomeC every day. All three instruments scan approximately ±50 degrees cross-track with comparable 13 km footprint diameters at nadir. AIRS and CrIS have 9 samples in a 50 km diameter, IASI has 4 samples in a 50 km diameter. Attached to each spectrum is a calibration software provided quality indicator, referred to as QC. We collected all calibrated radiance spectra at all scan angles of the three instruments from theses overpasses within a 55 km radius of the nominal position of DomeC. Only those data which passed their respective QC, more than 99% of all data, were used in the analysis. Figure 1a shows the number of spectra saved each day. On average there are 245 DomeC overpass spectra saved from AIRS, 102 from IASI and 232 from CrIS. There are about 6.5% fewer IASI samples (corrected for the 4/9 coverage difference) and 5.5% fewer CrIS samples than expected.

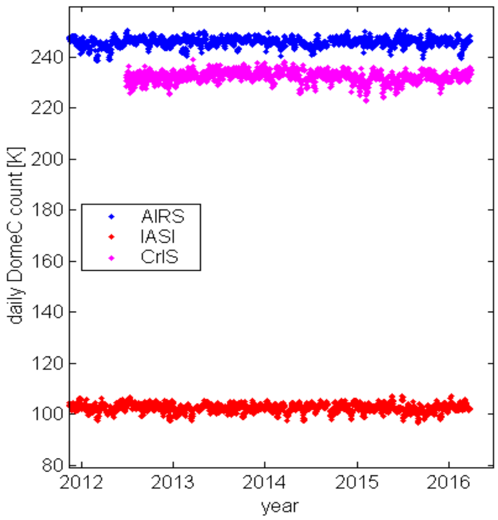

Figure 1a. Daily count of AIRS, IASI and CrIS spectra collect during the DomeC overpasses

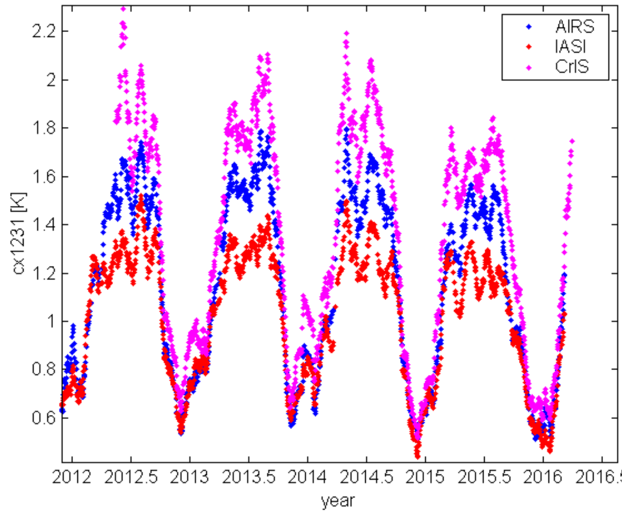

Figure 1b. Daily mean scene contrast

A significant advantage of DomeC is the homogeneity of the scene relative to tropical or mid-latitude regions. We characterize the scene contrast using the standard deviation of the brightness temperature in the 1231 cm-1 window channel, cx1231, in units of degree K, of the spectra in a 50 km diameter footprint group, i.e 4 from IASI, 9 from AIRS and CrIS. Under perfectly homogeneous scene conditions cx1231 approaches the Noise equivalent Delta Temperature (NeDT). The result from AIRS, IASI and CrIS is shown in Figure 1b. To first order AIRS, IASI and CrIS show the same seasonal patterns. During the Antarctic summer (November to January) the scene contrast is the smallest, i.e. the scenes are the most homogeneous, for all three instruments.

We focus on the brightness temperature of the 900 cm-1 atmospheric window channel, bt900, which is sufficiently wide that spectral resolution and sampling differences between AIRS, IASI and CrIS are insignificant. There are two ways to analyze the data: 1) We can create subsets of AIRS/IASI and AIRS/CrIS data pairs which were taken "simultaneously" to be defined later. 2) We can expand the definition of simultaneous to mean data taken from the DomeC overpasses on the same day. In a previous publication [8] we took the second approach. We analyzed the daily mean bt900 difference between 7 years of AIRS/IASI data, and two years of AIRS/CrIS data. In this analysis AIRS and CrIS agreed within 100 mK, but AIRS agreed with IASI only during the coldest seasons. IASI was a 2K colder than AIRS and CrIS when averaging over all seasons. No convincing explanation was offered to explain the difference. We now have AIRS, IASI and CrIS data between 2012 and 2016. In the following we first repeat the daily mean analysis using only days between May 2012 and March 2016 where we have AIRS, CrIS and IASI data. We then repeat the analysis for the same time period for pairs of AIRS /IASI and AIRS/CrIS where the DomeC overpasses are "simultaneous". We define simultaneous as data from AIRS/IASI and AIRS/CrIS pairs which are collected within 10 minutes of each other, without placing a restriction on the satellite zenith angle.

3. Results.

3.1. DomeC daily mean analysis

We limited the AIRS/IASI/CrIS comparison to the 1213 days between June 2012-March2016 where AIRS, IASI and CrIS data were available. This produced 297,000 AIRS, 285,000 CrIS and 126,000 IASI points, each of which passed QC. The temperatures ranges from 188K to 253K for AIRS and CrIS, 185K to 247K for IASI. For each day we then calculated the mean and standard deviation. Figure 2a shows the overlay of the daily mean bt900 for AIRS and IASI for the entire time when AIRS and IASI data were available. As can be seen from Figure 2b, AIRS and

IASI agree during the cold winter months, but IASI is significantly colder during the summer months. This disagreement is consistent throughout the time of AIRS/IASI data availability.

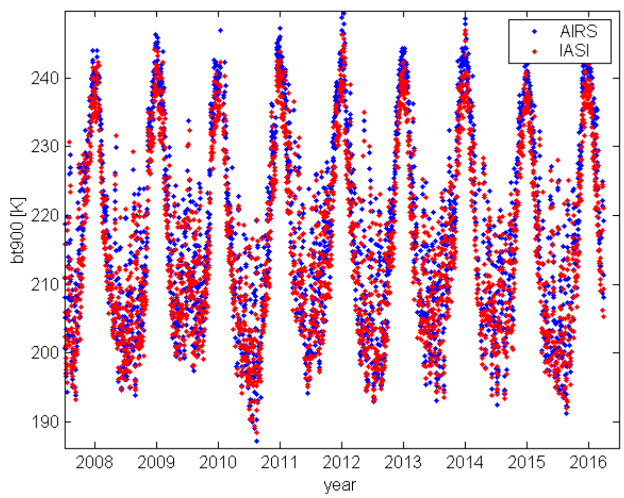

Figure 2a AIRS and IASI daily mean bt900

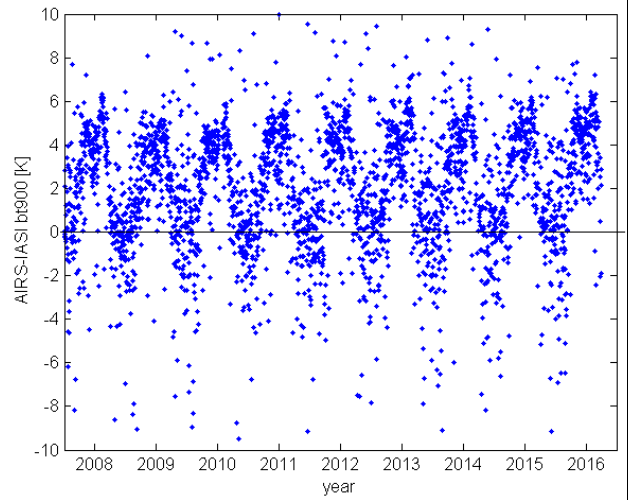

Figure 2b. AIRS minus IASI daily mean.

Figure 3a shows the daily mean for bt900 AIRS and CrIS. The mean bt900 averaged for the 1227 days when AIRS, IASI and CrIS was available were AIRS=218.49K, CrIS=218.42K, IASI = 216.19K. The probable error in the mean of 0.4K is dominated by the large inter-seasonal variability. Figure 3b shows the difference between the AIRS-CrIS daily mean. There is no seasonal dependence of the difference between AIRS and CrIS.

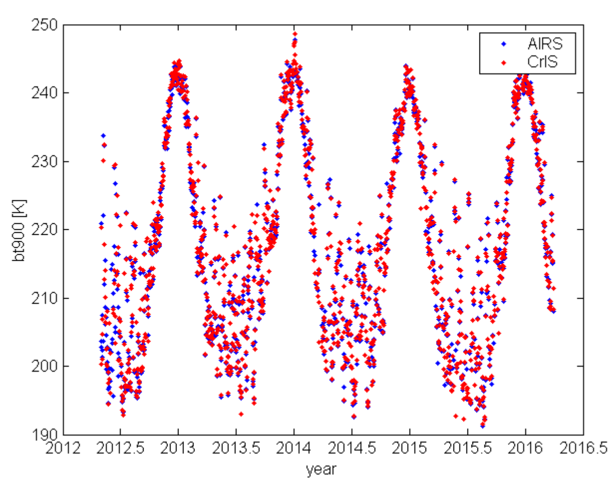

Figure 3a. Overlay of AIRS and CrIS

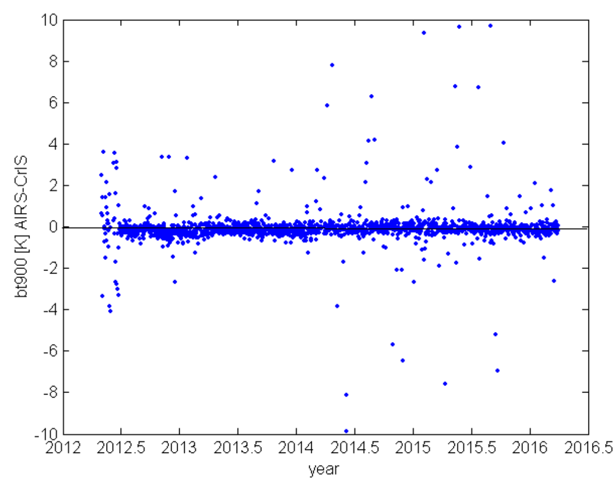

Figure 3b. AIRS-CrIS

The large inter-seasonal variability is removed if we calculate daily mean differences. With this analysis AIRS is 68mK colder than CrIS with a probable error in the mean of 34mK and AIRS is 2.2K warmer than IASI with a probable error in the mean of 0.034K.

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3.2. DomeC simultaneous overpasses.

For the 1227 days between May 2012 and March 2016 we have AIRS, IASI and CrIS data we found 9239 AIRS and IASI and 56,217 AIRS and CrIS data pairs taken within a 10 minute time window. Figure 4 shows the scatter diagram of AIRS-IASI and AIRS-CrIS as function of the mean bt900. The scatter in AIRS-CrIS looks larger than the scatter in AIRS-IASI. This is a plotting illusion since the AIRS-CrIS data set is more than five times as large as the AIRS-IASI data set. Note that there are very few IASI spectra matched up with AIRS with bt900 warmer than 240K compared to AIRS matchups with CrIS, although we picked exactly the same days within the same time period. Averaged over all matchups AIRS-IASI mean=+0.026K, stdev=1.28K, Probable Error in the mean, PE,= 0.013K. The corresponding AIRS-CrIS for this time period mean=−0.116K, standard deviation=1.10K, with PE=0.007 K. Figure 5 shows the same data, but analyzed as the mean of 14 bins, each 5K wide, between bt900 of 190K and 260K. Bins with less than 100 points are not shown. Most of the points fall between 204 and 232K.

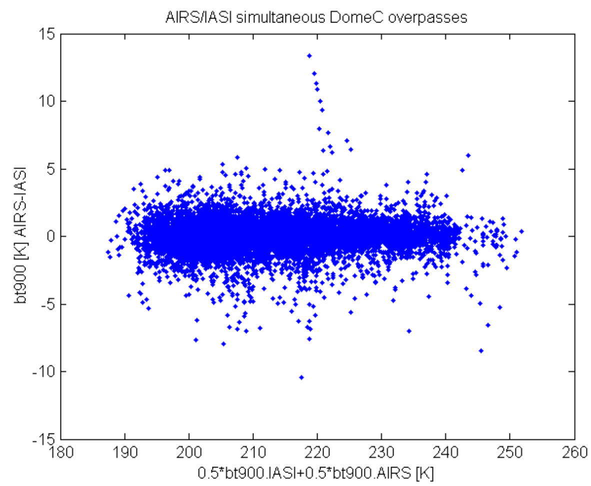

Figure 4a AIRS-IASI

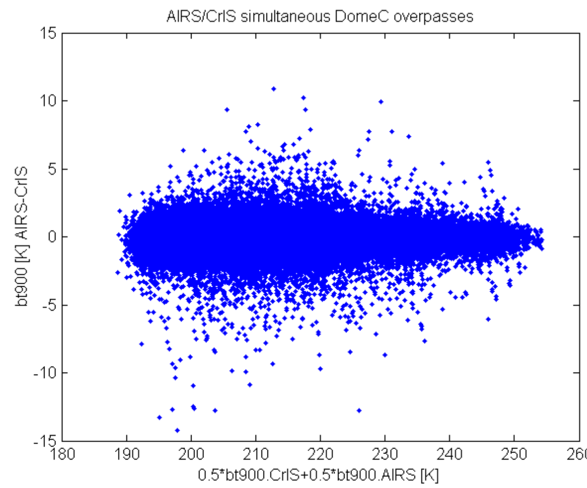

Figure 4b. AIRS-CrIS

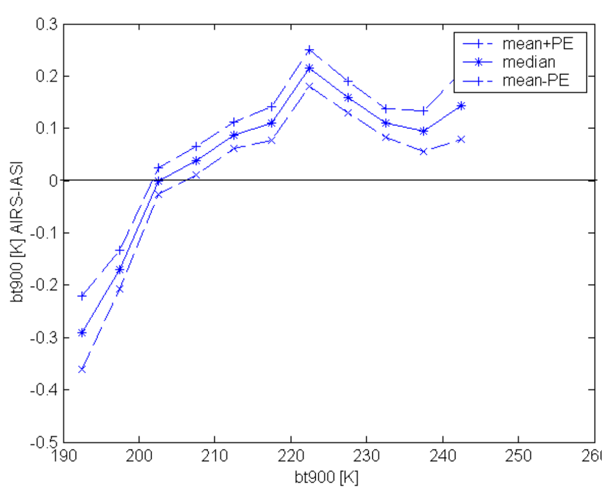

Figure 5a. AIRS-IASI

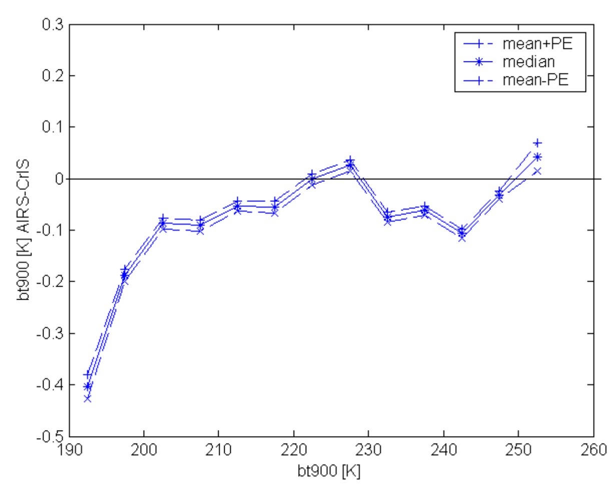

Figure 5b. AIRS-CrIS

4. Discussion

There are two ways to analyze the AIRS/IASI/CrIS DomeC data: 1) The analysis "simultaneous" data pairs and 2) The analysis of the daily mean differences. A factor of five to 10 more data is available to the daily mean analysis compared to the simultaneous analysis. A potentially big difference between the two methods is that each of the AIRS, CrIS and IASI points satisfied their own QC, while for the simultaneous data pairs both spectra in a pair have to satisfy the QC. Figure 6 shows the difference in terms of the PDF of bt900 for AIRS and IASI. The CrIS PDF is an almost dead overlay on the AIRS PDF and is not shown. The PDFs created by the two analysis methods look very different. The PDF for the simultaneous overpasses from AIRS and IASI agree very well, but the PDF of the daily mean values shows an area between 240 and 250 where IASI has fewer spectra, but this appears to be balanced by the area between 230 and 240K where IASI has more spectra.

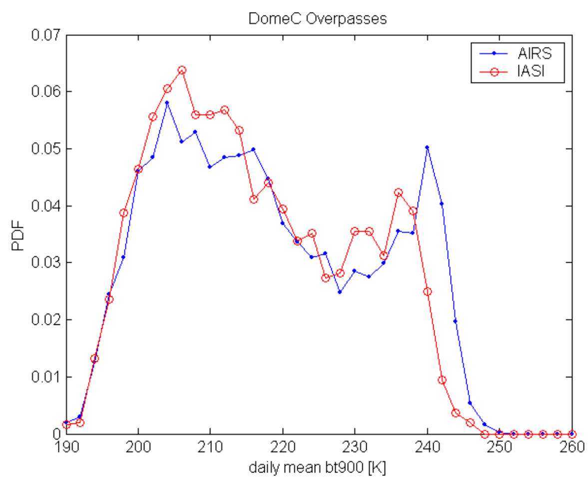

Figure 6a. PDF of daily mean values

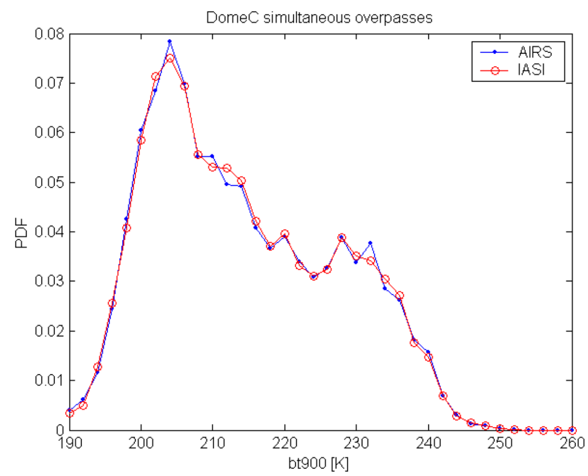

Figure 6b. PDF of bt900 from simultaneous overpasses

At first glance what may expect the results from the analysis of daily means and the analysis of simultaneous overpasses to be close to identical, but they are not. The larger discrepancy between AIRS and IASI for the daily mean values are consistent with the results published earlier with the more limited data set [8]. The differences between AIRS/IASI and AIRS/CrIS simultaneous overpass filtered data are much smaller. These results are discussed first.

4.1. Simultaneous overpass results

The differences between AIRS/ CrIS and AIRS/IASI are led than 100 mK. Figure 5 reveals a significant temperature dependence of this difference. A temperature dependence of the bias been AIRS and IASI was first reported by Tobin et al. [4]. They used Simultaneous Nadir Overpasses (SNO) and found that AIRS is about 120mK colder than IASI-A for the Southern SNO (typically at 73S, 230K), while for the warmer Northern SNO (typically 73N, 260K) they found AIRS to be 50mK colder then IASI. Hewison [5] used the double difference between IASI-B and IASI-A and Meteosat to show that there is a significant temperature dependence: Metop−B is 350mK colder than Metop−A at 200K, while the two instruments agree nearly perfectly at 290K. Based on our comparison of AIRS−IASI-A the observed temperature dependence appears to be an IASI−A artifact, not IASI−B. We also see a temperature dependence in the AIRS-CrIS below 200K. Wang et al. [5] found that for the Southern SNO (at about 250 K) AIRS is 21mK colder than CrIS, while AIRS was only 10 mK colder than CrIS for the Northern SNO (about 270K). This is consistent with our results. For temperatures at 200K AIRS is 200 mK colder than CrIS.

4.2. AIRS/IASI and AIRS/CrIS daily mean values

The mean bt900 of all AIRS and CrIS pairs from overpasses of DomeC agrees within 100 mK, while AIRS is 2K warmer than IASI for the same time period is 214K. This 2K difference is an order of magnitude larger than the differences observed in the various analysis of SNO in the literature. The differences between AIRS and IASI are very small during the Antarctic winter months, when the temperatures never exceed 230K, and are the largest during the “warm” Antarctic summer months, when the temperatures at DomeC reach above 240K. Why is there this large discrepancy between with daily mean values and the simultaneous overpass values? We consider scene contrast bad QC and overactive QC as potential reasons.

4.2.1. Scene Contrast: The comparison of Figure 2b and 3b shows that the difference between daily mean values of AIRS and CrIS is season (and temperature) independent, while there is a strong seasonal dependence in the AIRS-IASI result. Figure 1b showed that during the Antarctic summer (November to January) the scene contrast is the smallest, i.e. the scenes are the most homogeneous, for all three instruments. This is the time where we see the largest differences in the mean bt900 between AIRS and IASI, while AIRS and CrIS agree within 100 mK. We conclude that the observed effect is not related to scene inhomogeneity.

4.2.2 Bad QC. We define "bad QC" as a QC which fails to flag bad data. This is sometimes referred to "missed alarm". In the discussion of Figure 6 we noted that the PDF of the daily mean values shows an area between 240 and 250K where IASI has fewer spectra than AIRS, but this appears to be balanced by the area between 230 and 240K where IASI has more spectra than AIRS. This raises the possibility for data in the 240-250K region the IASI calibration shifts entire spectra to significantly colder temperatures, but the effect is not recognized and flagged in the QC. If this assumption is true, then it would have been already reported in the analysis of AIRS/IASI SNO. Since it has not been reported in the SNO analysis, we reject the "Bad QC" hypothesis.

4.2.3Overactive QC Filter. We define "overactive QC" as QC which flags good data as bad. This is often referred to as "false alarm". .For the simultaneous overpass analysis AIRS/IASI or AIRS/CrIS matchup pairs are created only from data which pass strict Quality Control (QC), i.e. AIRS and IASI spectra have to be time and position coincident and satisfy the AIRS and IASI QC. Points which did not passed the IASI QC were not saved.. The missing points at the warmest temperature for the simultaneous analysis give a clue. Assume that the instrument radiometric performance is in some way scene temperature sensitive and the IASI QC labels many points warmer than 242K as bad. As consequence few IASI and AIRS points warmer than 242K are present in the simultaneous analysis. We can estimate the magnitude of this effect using AIRS data. When we filter out all bt900 points warmer than 240K, we lose 6% of the data and the 242K filtered mean is 2 K colder than that of the unfiltered result. This 6% effect matches the previously mentioned 6% fewer IASI samples than expected from geometrical considerations. This speculation is confirmed in Figure 7, which shows the daily count for the entire AIRS/IASI and AIRS/CrIS data periods. Unlike Figure 1a, we scaled the count from AIRS and CrIS by 4/9 to match the IASI count. This highlights variability as a fraction of the daily yield. The variability from IASI is much higher than that of AIRS and CrIS. We conclude that the observed difference between the daily mean bt900 and the simultaneous analysis is due to a QC effect related to scene temperatures warmer than 240K. Since the DomeC data never exceeded 255K, we can't tell if this effect is present at warmer temperatures. If it is, it would not be seen in a SNO analysis of AIRS/IASI data pairs.

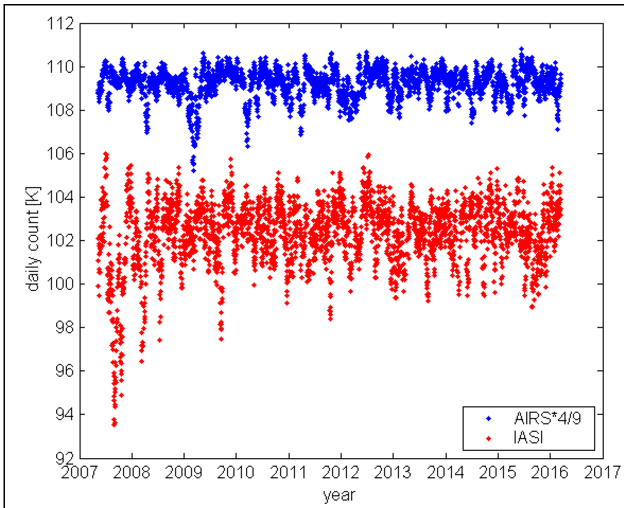

Figure 7a. Daily count of AIRS and IASI spectra (AIRS count is normalized to the IASI 2x2 pattern)

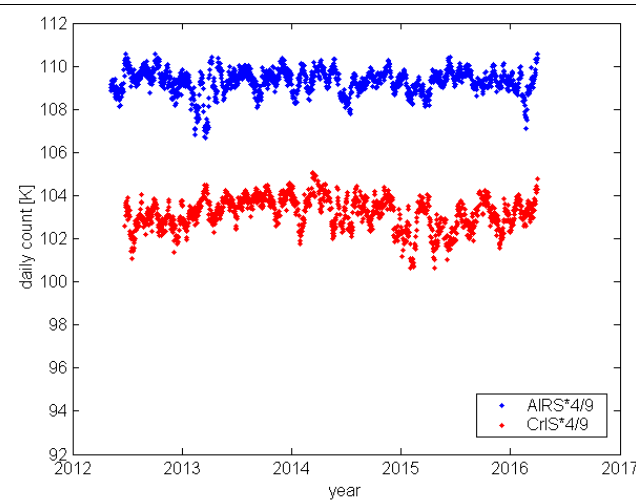

Figure 7b. Daily count of AIRS and CrIS spectra AIRS and CrIS are both multiplied by 4/9 to match the scale of Figure 1a.

DomeC is an insignificantly small part of the globe. However, the reported temperature dependent bias seen in this and other referenced studies indicate that agreement between instruments under SNO conditions is interesting only as a lower limit of a bias, useful from an instrument calibration viewpoint. For climate applications, i.e. the comparison of results from vintage instruments of nominally equivalent performance, the comparison has to be based on the means calculated from regional or global data. A scene temperature dependent bias or an overactive scene sensitive QC will create artifacts, sometime referred to as sampling errors, which could be an order of magnitude larger than 100 mK differences seen in the SNO analysis. Concern about this effect has also been expressed by other investigators [4, 5 and 6]

5. Summary

Averaged over all simultaneous overpass data AIRS is 26±13 mK warmer than IASI-A, AIRS is 116±7 mK colder than CrIS. This is excellent agreement and consistent with SNO analysis in the literature. We find that differences for both AIRS/IASI-A and AIRS/CrIS are temperature dependent, with AIRS being 250mK colder than IASI-A at 200K. These effects have also been independently verified by other investigators. AIRS and CrIS bt900 results for simultaneous overpasses and daily mean values agree within 100 mK. AIRS and IASI simultaneous overpasses agree within 100 mK, but AIRS is 2K warmer than IASI for daily mean values. We attribute this effect to an overactive IASI QC which is sensitive to scene temperature above about 240K. The DomeC data reach only 255K. If this QC effect is present at warmer temperatures than 255K, it would not be seen in any SNO analysis of AIRS/IASI data pairs. These effects need to be taken into account when comparing data from current instruments , and even more so when analyzing data from vintage instruments with respect to climate change.

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