First comparison of radiances measured by AIRS/AQUA and HIRS/NOAA-16&-17

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Introduction

Cross sensor comparison of the measured radiances has become increasingly important, as it is not only highly significant for the validation of instrument performance, but also is crucial for inter-satellite calibration to achieve consistency and tractability required for long-term climate studies. The High Resolution Infrared Radiation Sounder (HIRS) has flown on National Oceanic and Atmospheric Administration (NOAA)'s polar-orbiting satellites for over two decades. Data from the HIRS instruments are used, in conjunction with other instruments, to calculate the atmosphere's vertical temperature profile, Outgoing Long-wave Radiation (OLR), and upper tropospheric humidity. AIRS (Atmospheric Infrared Radiation Sounder) is a relatively new hyperspectral thermal sensor onboard AQUA with spectral overlaps to most of the HIRS channels (see Table 1). Comparing the radiances measured by these two instruments allows us to check their calibration to ensure consistency. In addition, the hyperspectral nature of AIRS may allow us to evaluate the spectral response functions of HIRS, which has uncertainties due to lack of stringent specification. In this paper, we present the method and results of the comparison between HIRS/NOAA-16&-17 radiances with the convolved AIRS radiance.

Satellite data

The data used in this comparison are level-1b radiance data from HIRS/NOAA-16&17 and that from AIRS/AQUA. AIRS is a high spectral resolution spectrometer with coverage in nearly 2400 bands in the infrared and visible ranges: 3.7 - 15 μm and 0.4 - 1.0 μm. It views the earth through a cross track rotary scan mirror which provides a viewing angle of ±49.5° and with a spatial resolution of 13.5km in the infrared and Vis/NIR spatial resolution of 2.3km, respectively. AIRS has been flowing onboard AQUA - NASA EOS PM (1:30 pm Equatorial Crossing Time) polar orbiting platform since April 2002. HIRS is onboard NOAA polar orbiting satellites. Similar to AIRS, HIRS observes the earth through a scanning mirror with a viewing angle of ±49.5°, and a spatial resolution of around 20 km, slightly larger than AIRS. It consists of 19 broadband IR channels (7 channels in the wavelength rang from 3.7 to 4.6 μm and 12 channels in the wavelength range from 6.5 to 15.0 μm). The spectral overlap between AIRS and HIRS IR channels can be seen in Figure 1, which shows that all the HIRS channels have some spectral overlaps with AIRS. However, only 7 HIRS channels are fully overlapped by AIRS. To minimize the uncertainty associated with the spectral differences, comparisons shown in this study are only for the 7 fully spectrally overlapped channels.

The time period of the collocated AIRS and HIRS data in this study covers from March 11, 2003, the first day when AIRS becomes publicly available, to October 15, 2003. AIRS level-1b data before September 1 are obtained from the NASA DAAC, hereafter the corresponding data are provided operationally by the NESDIS AIRS team. The HIRS level1b data are acquired from the NOAA Satellite Active Archive.

Table 1. Specification of AIRS/Aqua and HIRS/NOAA

	AIRS/Aqua	HIRS/NOAA
Spectral Coverage	3.74~4.61μm 6.20~8.22μm 8.88~15.4μm	7 channels:3.70~4.60μm 12 channels:6.5~15.0μm
Scan angle	±49.5 from nadir	±49.5 from nadir
IFOV	1.1°	SWIR: 1.4 ° LW IR: 1.3 °
Earth view Coverage	13.5 km at Nadir	20.3 km at Nadir SWIR 18.9 km at Nadir LWIR

Collocating, remapping and convolving

Based on predictions using orbital perturbation models (Cao, et al., 2003), it is found that simultaneous nadir overpasses between Aqua and NOAA-16 & -17 occur every 2-3 days. After collecting AIRS granules and HIRS orbits which contains potential intersections, simultaneous nadir observations (SNO) between AIRS and HIRS are selected based on two criteria, i.e., distance between nadir pixels < half the size of the HIRS pixels (~10 km), and time difference between nadir pixels < 30 seconds. As a result, a total number of 50 and 70 intersections are found for Aqua vs. NOAA-16 and Aqua vs. NOAA-17 respectively, during the time period from March 11 to October 15 2003. The locations of these intersections are given in Figure 2. It is seen that nearly all intersections occur in polar regions. The distance between pixels of two satellites (*D*) is defined as:

$$D = R/[\cos(\sin l_1 \sin l_2 + \cos l_1 \cos l_2 \cos(m_2 - m_1)] \qquad (1)$$

here *R* is the mean Earth radius, given as 6378km. l_1 and l_2 is pixel latitude, respectively of the AIRS and HIRS. m_1 and m_2 is the corresponding pixel longitude.

After finding the SNOs, HIRS observations are remapped to AIRS pixels around SNOs by using the same criteria as mentioned above. However, in order to compare with the HIRS radiances in 7 fully spectrally overlapped broadband channels, AIRS hyperspectral measurements must be convolved with the HIRS spectral response function. This is carried out in two steps. First of all, since every measurement at AIRS channel is a convolved result of its neighboring 471 channels (+235), spectral response function of HIRS (SRF_{HIRS}) at AIRS channel λ_1 is first convolved with AIRS spectral response function (SRF_{AIRS}) as shown in equation 3. Secondly, AIRS radiance is further convolved with the consequent spectral response function values ($w(\lambda_1)$), as shown in equation 2, producing the radiance equivalent to HIRS measurements with the same spectral coverage.

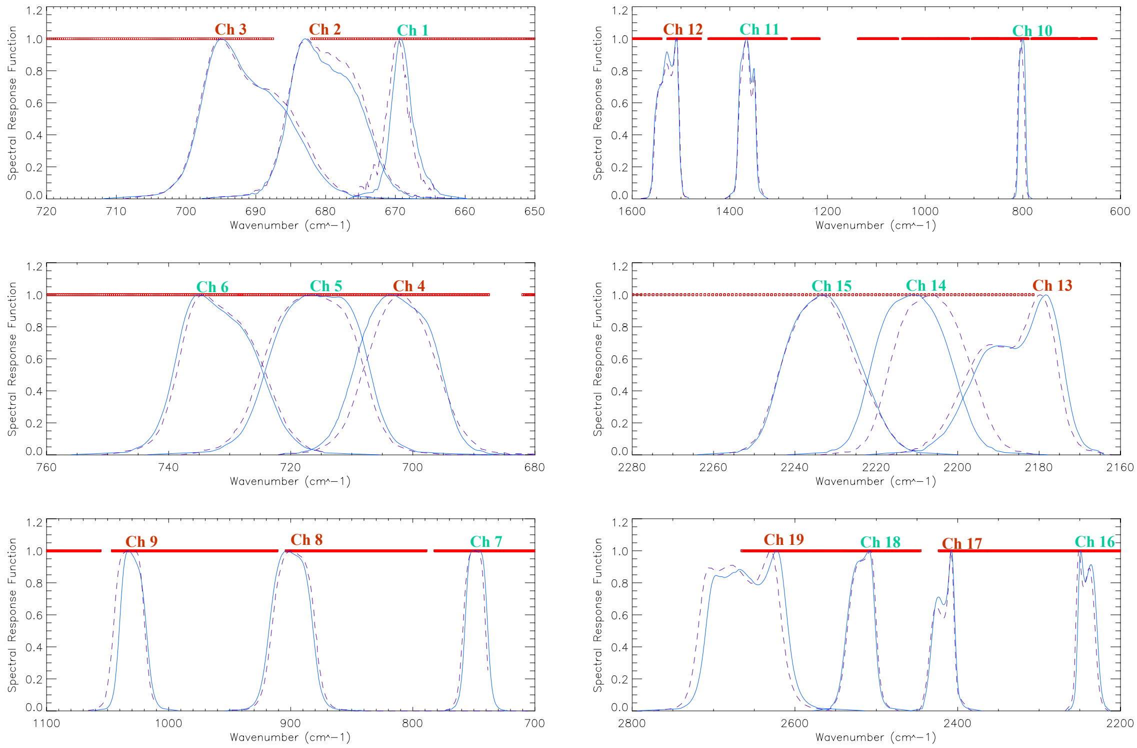


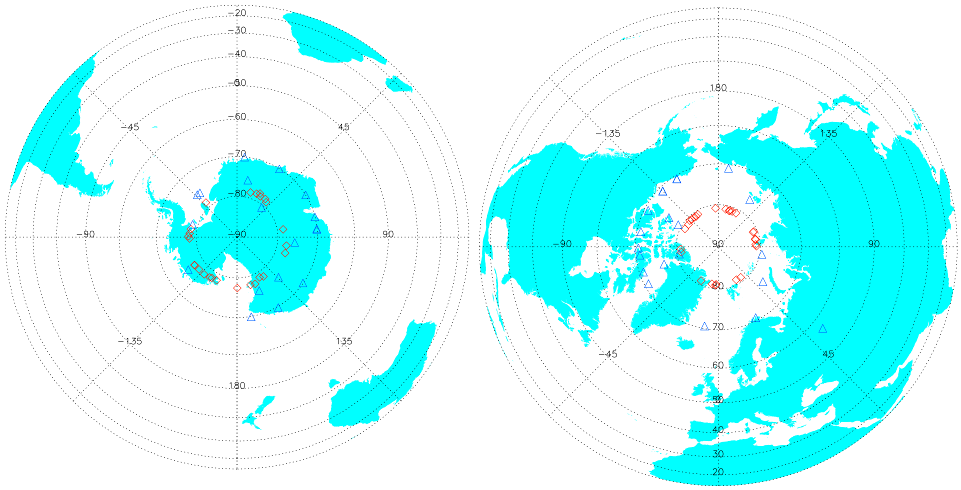
Figure 1. HIRS spectral response functions for the 19 IR channels (solid line for NOAA-16; dashed line for NOAA-17). Red lines show the corresponding AIRS spectral channel coverage. Only 9 HIRS IR channels are fully spectrally overlapped by AIRS, shown as green color.

$$R_{COV} = \frac{\int_{\lambda_1}^{\lambda_2} R_{AIRS}(\lambda) \bullet w(\lambda) \bullet d\lambda}{\int_{\lambda_1}^{\lambda_2} w(\lambda) \bullet d\lambda} \qquad (2)$$

$$w(\lambda_1) = \frac{\int_{\lambda_1 - \Delta\lambda}^{\lambda_1 + \Delta\lambda} SRF_{HIRS}(\lambda_1) \bullet SRF_{AIRS}(\lambda) \bullet d\lambda}{\int_{\lambda_1 - \Delta\lambda}^{\lambda_1 + \Delta\lambda} SRF_{AIRS}(\lambda) \bullet d\lambda} \qquad (3)$$

Results

Difference between the collocated measurements from two different satellites may originate from several sources. The purpose of the comparisons in this study is to evaluate the calibration differences since uncertainties due to differences in observation geometry, spectral coverage, and time have been reduced to a level that is negligible in this study by using simultaneous nadir observations. The contribution from the difference in viewing geometry and small differences in the spatial resolution are further reduced by only using the averaged radiance in a box with 4 by 5 pixels around the SNO pixel in this study.



□ —— Aqua&NOAA-16 Δ —— Aqua&NOAA-17

Figure 2. Collocated intersections between AIRS/AQUA and HIRS/NOAA-16 (or NOAA-17)

An example is given in Figure 3 which shows simultaneous nadir observations between AIRS/Aqua and HIRS/NOAA-16 on July 22, 2003. It is seen that, for all 7 spectrally fully overlapped channels, similar pattern are shown in both the remapped HIRS radiance and the convolved AIRS radiance. However, there is a significant discrepancy (as much as 3~4 K) in the HIRS channel 1, and the spread is relatively large. This may indicate a problematic calibration in this HIRS channel, which has a number of known calibration problems. For other channels, both HIRS observations and the convolved AIRS measurements have much smaller differences. In addition, the difference between the mean HIRS and AIRS radiance inside the nadir window box at the SNO pixel is less than 1 K (see Figure 3), which indicates a good agreement between AIRS and HIRS.

To investigate thoroughly the agreement between HIRS and AIRS observations, the mean and standard deviation of measured radiances in the window described above are calculated for all the intersections and for both NOAA-16 and NOAA-17. In addition, to evaluate a newly developed HIRS calibration algorithm (Cao and Pubu, 2003), i.e. Version 4.0, HIRS radiance is calculated with both the current operational calibration algorithm (i.e., Version 3.0) and the new one. The results are shown in Figure 4a and b, which presents the mean radiance difference between the convolved AIRS radiance and HIRS radiance as a function of Julian day, for NOAA-16 and NOAA-17 respectively. The corresponding statistics of the resulting difference in brightness temperature is given in Table 2. It is seen that, except for channel 1, the agreement between the observed HIRS and AIRS is generally good. The difference in brightness is generally smaller than ±1K. In addition, it appears that the deviations are considerably smaller in

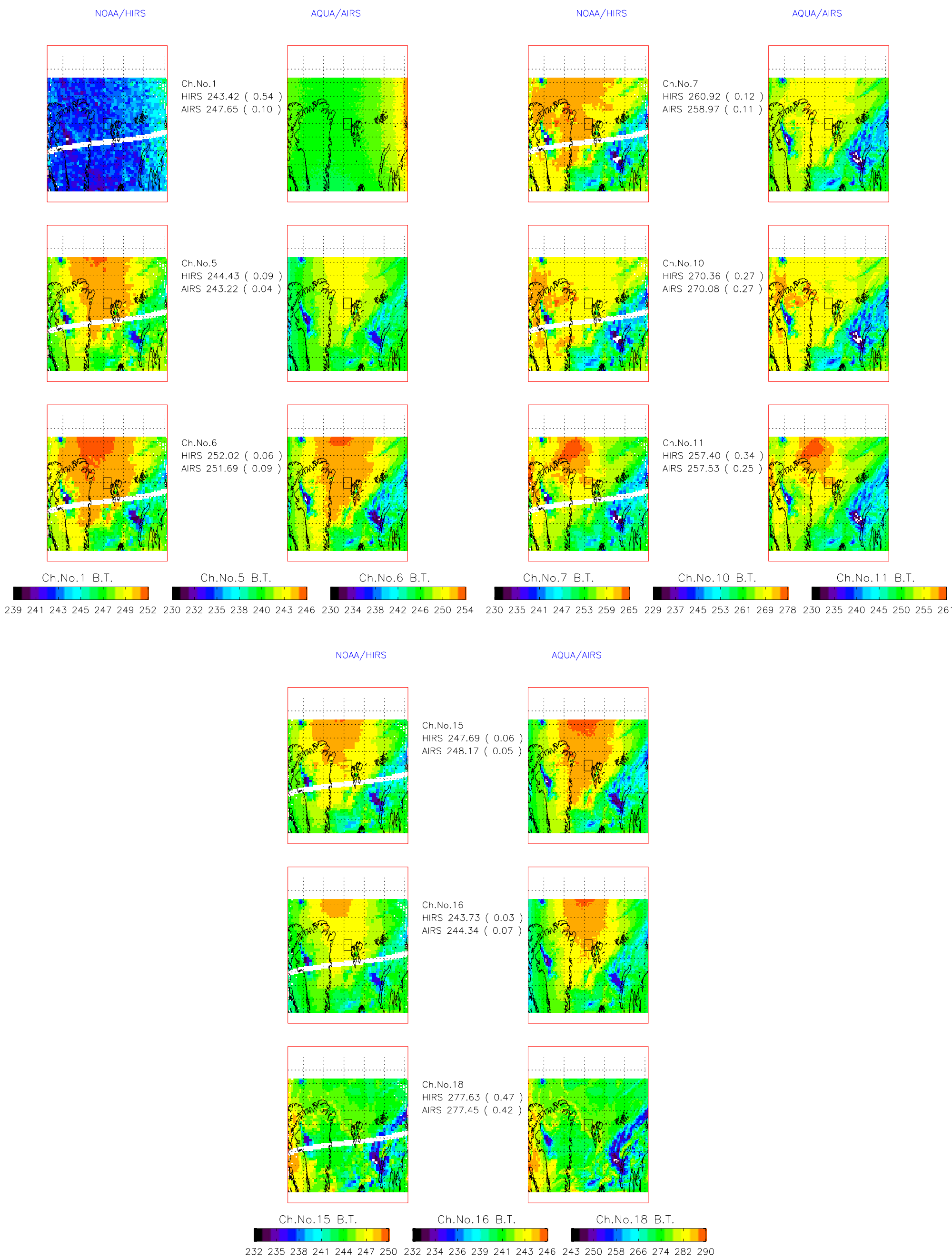


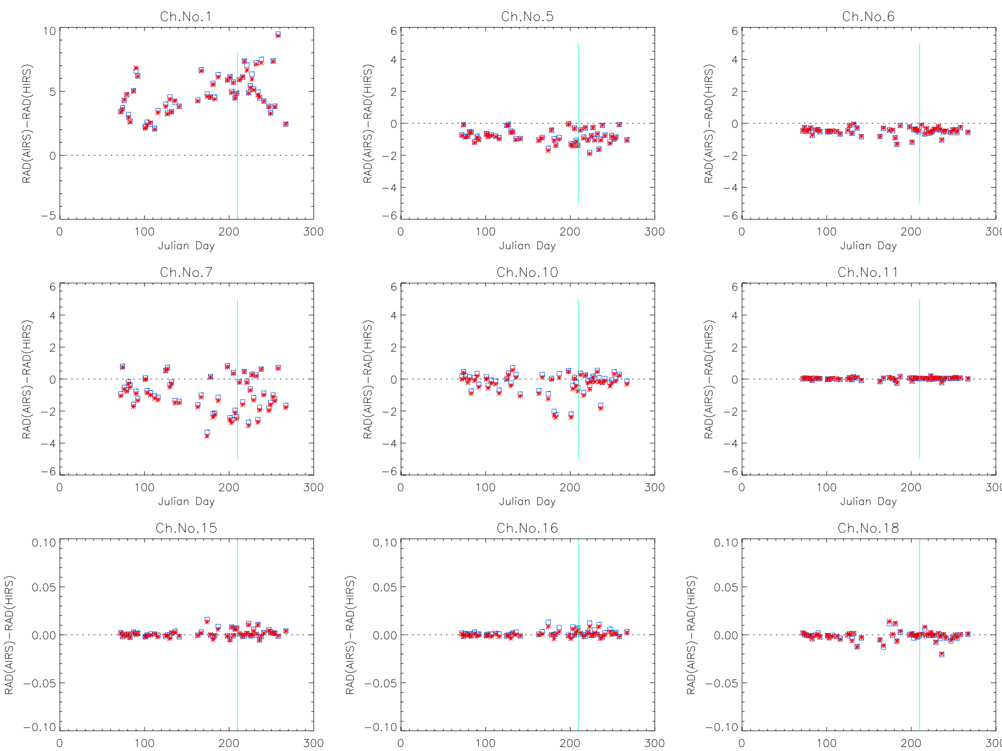
Figure 3. Example data set shows simultaneous nadir observations between AIRS/Aqua and HIRS/NOAA-16 on July 22, 2003. AIRS data are spectrally convolved with HIRS spectral response functions, and HIRS pixels are remapped to AIRS pixels. The black box in the center represents the 4 by 5 pixels window near the nadir intersection of these two satellites, for which the brightness temperature differences (mean and standard deviation) are given in the parenthesis.

the longwave channels than in the shortwave channels. For example, the brightness temperature difference in channel 5 is about -0.8 K, while it decreased to less than 0.1 K for channel 16. There is no significant difference between NOAA-16 and NOAA-17 in terms of the mean bias for most channels, however, the standard deviation of the difference is noticeably smaller in NOAA-16/HIRS than those for NOAA-17/HIRS (see Table 2). On the other hand, it is also found that the application of the newly developed calibration algorithm does not have significant effect on the systematic bias in the comparisons shown in this study. This is probably due to the fact that the HIRS orbits used in this study do not have the problems of rapid filter temperature change, which was the problem that the new algorithm is designed to solves [Cao and Pubu , 2003].

Concluding remarks

Comparisons of HIRS with AIRS radiance is carried out by comparing the simultaneous nadir observations at intersections of these two satellites. The AIRS spectral radiances are convolved with the HIRS spectral response functions to generate HIRS equivalent channels based on AIRS spectral radiance data. The comparisons are carried out for both NOAA-16/HIRS and NOAA-17/HIRS.

a. NOAA-16



b. NOAA-17

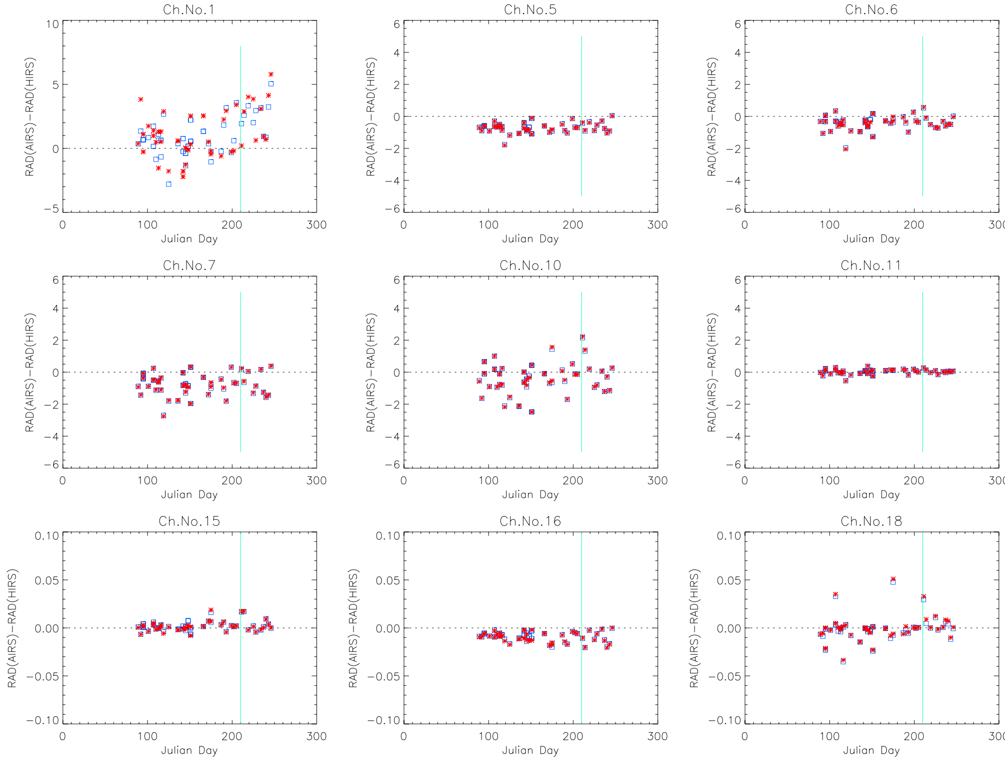


Figure 4. Difference between AIRS (spectrally convolved to match HIRS) and HIRS are given in radiance (a and b), and brightness temperature (c and d). The green line indicates the date when AIRS L1B data changed from version V. 2.7 to V. 3.05. □ — HIRS calibration algorithm 3; * — HIRS calibration algorithm 4

Table 2. Brightness temperature comparison summary. ΔBT1 and ΔBT2 represent the difference (AIRS – HIRS) for HIRS calibration algorithm 3 and 4 respectively.

AIRS-HIRS			Ch. 1	Ch. 5	Ch. 6	Ch. 7	Ch. 10	Ch. 11	Ch. 15	Ch .16	Ch. 18
NOAA-16	ΔBT1	mean	5.1	-0.8	-0.5	-0.7	-0.1	0.04	0.02	0.1	-0.4
		Std	2.1	0.4	0.2	0.9	0.6	0.3	0.4	0.4	0.8
	ΔBT2	mean	5.0	-0.8	-0.5	-0.8	-0.3	0.1	0.02	-0.01	-0.2
		std	2.0	0.4	0.2	0.9	0.6	0.3	0.3	0.3	0.8
NOAA-17	ΔBT1	mean	1.0	-0.7	-0.4	-0.7	-0.3	0.07	0.08	-1.0	-0.3
		std	1.6	0.3	0.4	0.6	0.8	0.5	0.5	0.3	0.9
	ΔBT2	mean	1.0	-0.7	-0.4	-0.7	-0.3	0.07	0.05	-1.0	-0.1
		std	1.9	0.3	0.4	0.6	0.8	0.5	0.5	0.4	0.9

It was found that observations by HIRS and AIRS generally agree well with each other for most channels. The agreement is better than 0.5 K for HIRS Channel 6, 10,11,15,16 and 18. Slightly larger (about 1K) discrepancy is observed for channel 5 and 7. For channe1 1, considerably large difference exists. No significant difference between NOAA-16/HIRS vs. AIRS and NOAA-17/HIRS vs. AIRS comparisons. However, NOAA-17 appears to give a larger standard deviation. Finally, comparisons made in this study are based on 68 (or 57) intersections for NOAA-16 vs. AIRS (or NOAA-17 vs. AIRS) during a 6 months period. More data is needed to better characterize the agreement between HIRS and AIRS to account for any possible seasonal variations.

Acknowledgements

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References

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