P6.16 CALIBRATION AND VALIDATION FOR NOAA18 HIRS/4 MEASUREMENTS

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1. INTRODUCTION

A new polar-orbiting environmental satellite - NOAA18, was successfully launched in May 2005. Among the instruments carried aboard NOAA18, the new model of the High Resolution Infrared Sounder (HIRS/4) provides multi-spectral data for direct radiance assimilation, and retrievals of the atmosphere's vertical temperature profile, water vapor, ozone, and clouds. Compared with HIRS/3 flown on NOAA-15, 16 and 17, several modifications have been made: 1) the field of view has decreased to 10 km from 19 km; 2) another PRT has been added to the blackbody, which is directly in the center and will give a better characterization of the temperature gradient as well as providing a better estimate of the blackbody temperature within the smaller angular field of view; and 3) there is a new temperature sensor near the field stop. In addition, although the effects have been made to generate the same filter with the identical spectral response function (SRF), there is still small difference in some channels between HIRS/3 and HIRS/4. The concerns of whether these changes introduce the intersatellite radiance bias are raised by the HIRS data users.

The accurate satellite radiance measurements are important not only for data assimilation of numerical models, but also for the quality of satellite retrieval products. More importantly, long-term climate monitoring also needs much higher calibration accuracy than before. Therefore, major postlaunch calibration and validation efforts for HIRS/4 radiance measurements are made in the National Oceanic and Atmospheric Administration (NOAA) National Environmental, Satellite, Data, and Information Service (NESDIS) satellite sensor calibration team to verify the instrument performance by analyzing instrument noise, calibration bias, and intersatellite consistency (Ciren et al. 2005). This paper presents the results of this study, including: 1) objectively quantify the intersatellite radiance bias between the HIRS/3 on NOAA17 and HIRS/4 on NOAA18, and 2) investigate the root cause of the bias in the context of sensor physics.

2. METHOD

2.1 *Intersatellite Radiance Bias*

Intersatellite radiance bias between the HIRS/3 on NOAA17 and HIRS/4 on NOAA18 is identified by intercomparing the HIRS radiance measurements from the simultaneous nadir overpass (SNO) at the orbital intersections of two satellites, occurring in the Polar Regions every eight days. Since the SNO observations are taken at the same time at the same location at nadir, this eliminates the effects of satellite observation time and view angle difference. The SNO method can objectively and accurately quantify intersatellite radiance bias with little ambiguity, and thus has been extensively applied in postlaunch calibration (e.g., Cao et al. 2005).

The detailed information on the SNO method can be found in the study by Cao et al. (2004, 2005). Here we only summarize the main steps. First, the pixels at the SNO are identified if the nadir distance is less than 30.0km and the time difference is less than 30.0s. And then, a spatial subset of all channels of HIRS radiance data (15 scan lines before and after the SNO pixel with 56 cross-tracks) is extracted near the SNO pixels. Secondly, a pixel-by-pixel collocation between two matching subset is performed based on the ground distance. Finally, a nadir window consisting of 10 cross-track pixels by 11 scan lines is extracted and statistical comparison is performed by calculating the mean and standard deviation of the radiance difference for each channel. The time series of these two values are generated to identify the radiance bias for each channel. A persistent bias in this time series over a long

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period of time represents instrument calibration bias.

2.2 ***Root Cause of Bias***

Once intersatellite radiance bias is found, we need to investigate the root causes of the bias. The radiance bias by intersatellite comparison of earth targets is affected by many factors, including observation time difference, blackbody spectral emissivity, nonlinearity, spectral uncertainty, calibration algorithms, geolocation, scene uniformity and sensor modulation transfer functions, calibration anomaly, and others. For radiance intercomparision with SNO observations, factors other than blackbody spectral emissivity and spectral uncertainty can be reduced to a negligible level as discussed in detail by Cao et al. (2005). In this study, we will focus on the bias caused from onboard blackbody and spectral calibration.

2.1.1 BLACKBODY CHECK

The radiance bias can be caused by the onboard blackbody calibration system. The blackbody emissivity is not unity, and the spectral emissivity may not be constant over the spectral range. Also, there may be discrepancy between blackbody skin and bulk temperature due to solar contamination near terminator regions.

In order to examining the uncertainty of onboard blackbody, we performed comparisons between the HIRS earth view measurements with those of the corresponding channels observed by the Advanced Very High Resolution Radiometer (AVHRR), carried on the same satellite. While the HIRS has nineteen thermal channels (twelve longwave channels and seven shortwave channels), the AVHRR has three thermal infrared channels (channel 3B switch with channel 3A), all of which share the same onborad calibration blackbody. In particular, channel 8 and 19 of the HIRS match channel 4 and 3B of the AVHRR, respectively. The SRFs of these matching channels overlapped and are located in the atmospheric window regions. The brightness temperature from these channels, therefore, should not be too different if their own onboard calibration blackbodies work well. To eliminate the possible effects from satellite view angle and different pixel resolution, we average the AVHRR pixels at nadir views to compare the HIRS nadir view's pixels. We perform independent comparisons for HIRS/3 on NOAA17 and HIRS/4 on NOAA18 to check the HIRS blackbody using the AVHRR blackbody, assuming that the AVHRR calibration blackbody is accurate.

2.2.2 SPECTRAL CALIBRATION

Uncertainties in the SRFs of the HIRS are another source affecting the accuracy of radiance measurements. Since the HIRS does not have onboard spectral calibration system, prelaunch system SRFs are determined and used for processing all HIRS radiance data. The prelaunch spectral calibration involves measuring the filter transmittance, and the spectral response of all other optical piece parts including detectors, beam splitters, mirrors, and lenses. The system level SRFs are generated by multiplying the filter transmittance with the optical piece part response. The possibilities resulting in spectral uncertainty include: 1) the inaccuracy of prelaunch spectral calibration; and 2) postlaunch spectral shift. Thus, the inflight spectral calibration needs to be performed for the HIRS/3 and HIRS/4 individually.

The hyperspectral radiometer - Atmospheric Infrared Sounder (AIRS), carried onboard NASA Aqua satellite, provides 2378 spectral channels in the range of 3.7-15.4 um with onboard spectral and radiometric calibration performed every 2.67 s scan cycle, and is suitable to be used as the reference for spectral calibration. Intercalibration of the HIRS radiance measurements using the AIRS observations has been successfully applied by Ciren and Cao (2003) and Cao and Ciren (2004). In this study, in addition to the comparison of SNO observations at the orbital intersection of the NOAA17 and NOAA18 occurring at the polar region, we also compare the simultaneous alongtrack observations (SAO) occurring in the tropical areas of each pair of satellite. The SAO occurs when the two satellite follow each other along the same track within twenty minutes. The method that we convolve the AIRS radiance measurements into the simulated HIRS radiance is the same as the previous study (Cao and Ciren 2004).

2.2.3 SRF DIFFERENCE

Once we rule out the uncertainties from spectral calibration and onboard blackbody of the HIRS/3 and HIRS/4, the SNO intersatellite radiance bias can be caused by the change of field of view (FOV) (20 to 10 km) or the difference of their SRFs. However, we believe that the spatial resolution difference can not introduce the persistent instrument bias over a long period of time. In other words, owing to the complexity of earth view scenes, the radiance within the narrow FOV (HIRS/4) can not always be larger or smaller than those within the wide FOV (HIRS/4). Instead, their difference should fluctuate along the zero line.

Thus, the most likely cause resulting in the lasting instrument bias is from HIRS SRF difference. For the HIRS/3 and HIRS4 SRFs, they meet the same specification but are not exactly identical, though every effort has been made to generate identical ones. For example, the instrument specification has a tolerance of a few wavenumbers for the center frequency. Also, the shapes of the SRFs are a little different for some channels of HIRS/3 and HIRS/4. The HIRS radiance measurement is extremely sensitive to the SRFs at some channels (e.g., Channel 5, 15, and 16) because that they are located on the slopes of the atmospheric spectral radiance response. The small difference of the SRFs could result in the large systematic bias.

There is two ways to account for the difference of the SRFs. First, the effects of spectral response on radiance can be modeled with forward calculations. We performed forward calculations using line-by-line radiative transfer model (LBLRTM) (Clough et al. 1981) by inputting their own SRFs, with the typical atmospheric profiles near the SNOs. The calculations are examined to see if they are consistent with the intersatellite comparisons of the SNO observations. The second method is to directly convolve the real atmospheric spectral measurements observed by the AIRS, into the HIRS instrument radiance to check their difference. If the results match well with the SNO ones, it will also verify our hypothesis.

3. PRELIMINARY RESULTS

Using the above methods, major postlaunch calibration and validation of the NOAA18 HIRS/4 measurements are done to verify the instrument performance. In this section, we present some preliminary results.

The time series of the radiance difference for each channel at the SNO pixels between HIRS/3 on NOAA17 and HIRS/4 on NOAA18 has been generated since NOAA18 was launched on 20 May 2005, which is used to identify the instrument calibration bias. Till now, the total of 22 SNO events occurred with a sampling interval of approximately eight day interval – composed of 9 at the Arctic and 13 at the Antarctic. The results revealed the persistent biases along the time series for channels 5, 15, and 16, which are out of the range of the instrument specification. Figure 1 gives an example of NOAA-18 and NOAA-17 /HIRS intercalibration time series for channel 5 at the SNOs, which has the average radiance bias are -1.85 (mW/m^2 sr cm^{-1}). It should be noted that the dot in Figure 1 represents the standard deviation of the radiance bias for pixels inside the nadir window, which are caused by noises from instruments and scenes. In the following, we use it as example to show how we identify the root causes of the intersatellite bias.

In order to make sure if this large bias is not caused by the onborad blackbody system, we independently perform inter-channel calibration between AVHRR and HIRS for NOAA17 and NOAA18 and do not find the large difference that can account for the above bias value for the window channels.

Our focus is on the spectral calibration. Here is an example of we perform inflight spectral calibration from the AIRS hyperspectral radiance measurements. The case we choose occurred on 29 August 2005, when NOAA18 and NASA Aqua satellite followed each other and simultaneously pass over the tropical regions in the Atlantic Ocean within 20 minutes. We convolve the AIRS hyperspectral measurements into the HIRS/4 radiance by its SRF at channel 5, shown in Figure 2. And then we collocate the simulated HIRS image with the real HIRS image by pixel-by-pixel match. And the difference of these two images and the statistics of the nadir pixels also is presented in Figure 3, which shows the average bias of 0.18 (mW/m^2 sr cm^{-1}). Considering the diurnal cycle of earth targets and movement of clouds, this small difference indicates that the SRF of HIRS/4 at channel 5 is consistent with that before launch. Using the same method, Ciren and Cao (2004) compared the radiances measured by Aqua AIRS and NOAA17 HIRS/3 at the SNO pixels and did not find the large bias at channel 5. Therefore, we believe that the HIRS/3 and HIRS/4 SRFs at channel 5 meet their specification after launch.

Based on the above analysis, this large bias is most likely caused by the SRF difference of HIRS/3 and HIRS/4. And we did the forward calculations with the Arctic atmospheric profile using the LBLRTM. Figure 4 give the results for the possible radiance difference due to HIRS SRF difference at each channels for NOAA16, NOAA17, and NOAA18 as well as their SRFs. We can see that the bias for channel 5 is consistent with the SNO results.

4. CONLUSION

In this paper, we presented the preliminary results of the calibration study of NOAA18 HIRS/4 radiance measurements. Specially, we focused on the HIRS intersatellite biases between NOAA17 and NOAA18, and their root causes. Several methods are used to find the root causes for instrument calibration bias, including intersatellite calibration of radiances using the SNO and SAO methods, on-orbit spectral calibration using hyperspectral data, inter-channel calibration between instruments on the same satellite, and forward calculation of radiances using radiative transfer models for resolving spectral response related biases. The case study proved the potentials of these methods, which are expected to be used in operational postlaunch calibration for the future satellite sensors, such as those onboard MetOP and NPOESS. It should be noted that a separate problem with NOAA18/HIRS is that the longwave channels do not meet the noise specification. Our study is still on going and the results will be updated in the future.

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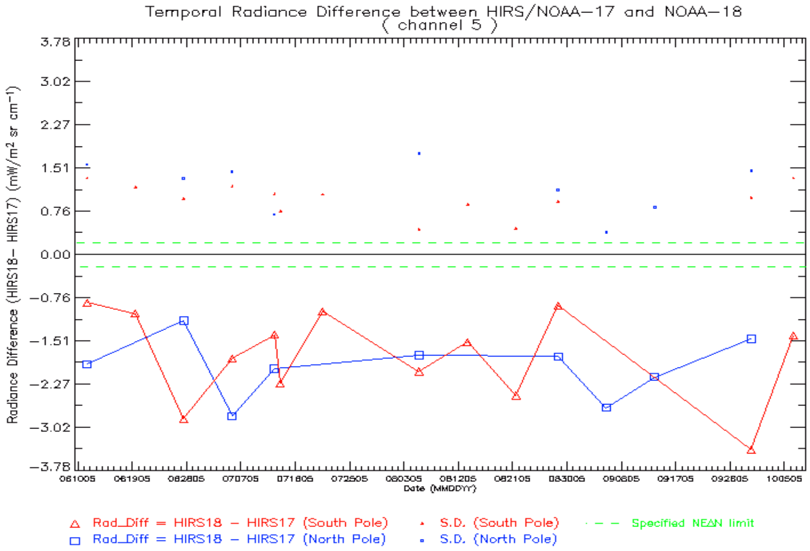

Figure 1 Temporal radiance difference of the HIRS at channel 5 between NOAA17 and NOAA18.

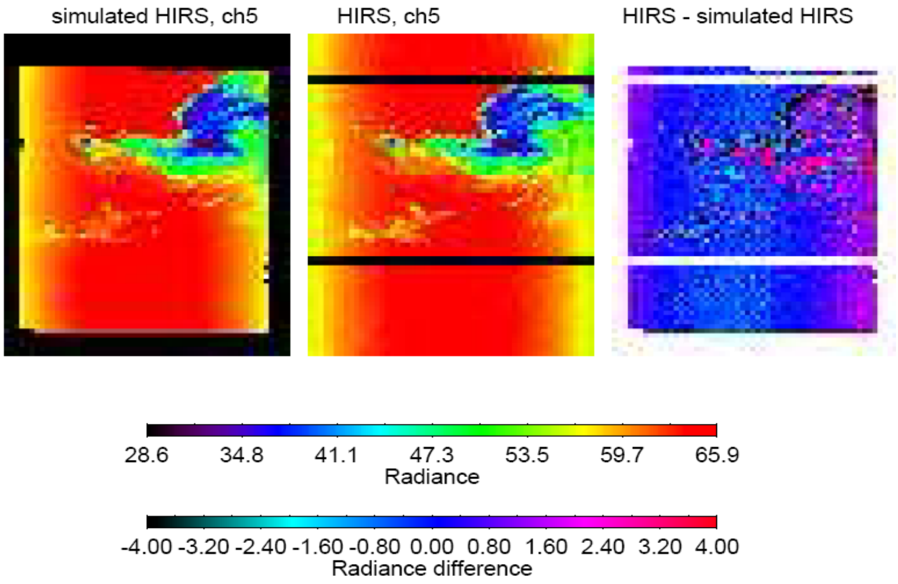

Figure 2 Simulated HIRS radiance from the AIRS observations (left) compared with HIRS radiance measurements (middle) as well as their difference (right).

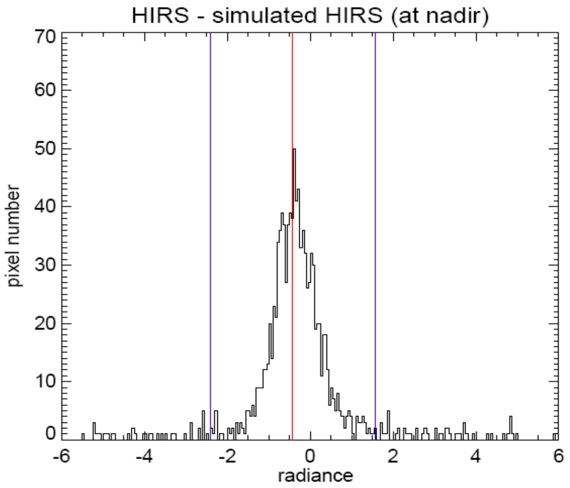

Figure 3 Histogram of the difference (Figure 2) of simulated HIRS radiance and HIRS radiance for channel 5 at nadir view.

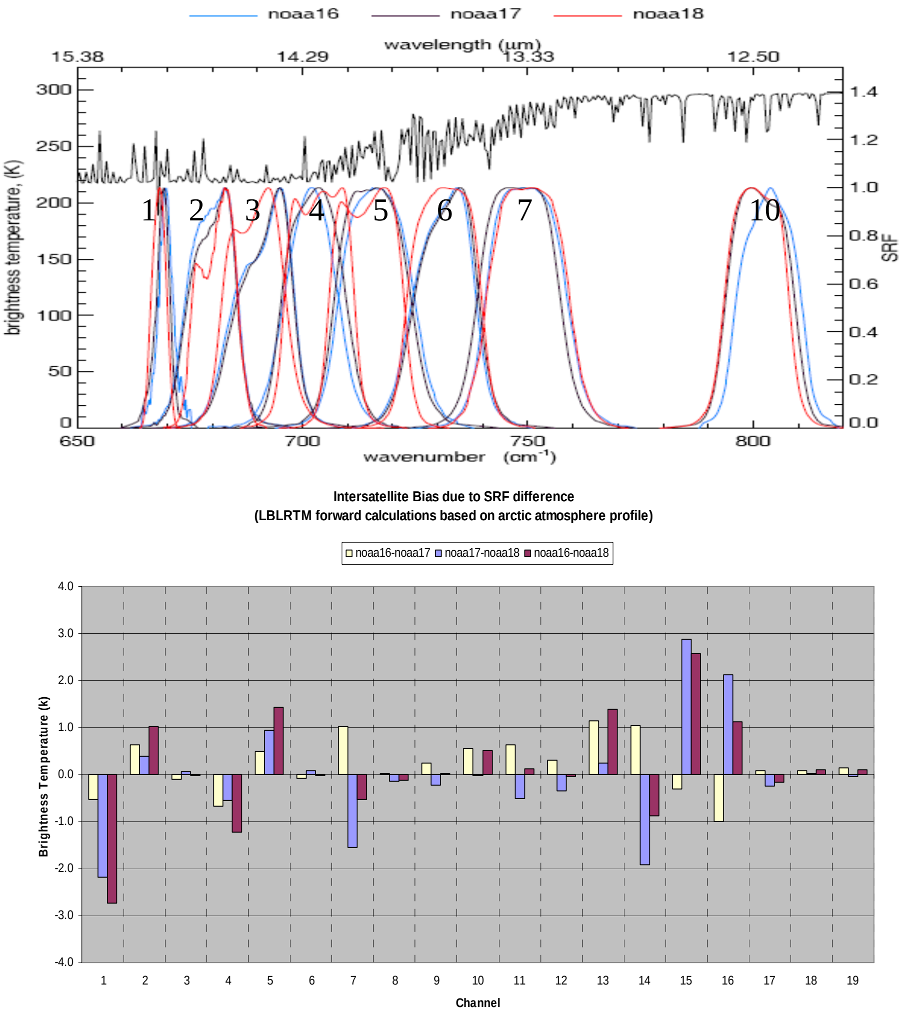

Figure 4 LBLRTM results to account for the difference of HIRS SRFs (bottom). The HIRS SRFs of NOAA16, 17 and 18 are given at the top for channel 1-7 and 10.