

# Intersatellite Calibration of HIRS from 1980 to 2003 Using the Simultaneous Nadir Overpass (SNO) Method for Improved Consistency and Quality of Climate Data

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**Abstract** – The Simultaneous Nadir Overpass (SNO) method developed at NOAA/NESDIS has been used for the intersatellite calibration in the last few years with excellent results. The objective of this project is to establish and apply an accurate intersatellite calibration procedure to develop inter-satellite calibration data sets and characterize inter-satellite calibration bias, which will be useful for data users in developing time series from NOAA satellite data from 1980 to 2003. It uses the novel approach that takes advantage of inter-satellite calibration using simultaneous nadir overpass (SNO) observations at the orbital intersections between each succeeding pair of satellites. This will ensure the calibration consistency and quality for long-term climate studies, reduce the uncertainties about critical climate trends, and therefore facilitate the construction of long-term climate data records.

## Introduction

The objective of this project is to establish and apply an accurate intersatellite calibration procedure to develop inter-satellite calibration data sets and characterize inter-satellite calibration bias, which will be useful for data users in developing time series from NOAA satellite data from 1980 to 2003. It uses a novel approach that takes advantage of inter-satellite calibration using simultaneous nadir overpass (SNO) observations at the orbital intersections between each succeeding pair of satellites (Figure 1). This will ensure the calibration consistency and quality for long-term climate studies, reduce the uncertainties about critical climate trends, and therefore facilitate the construction of long-term climate data records.

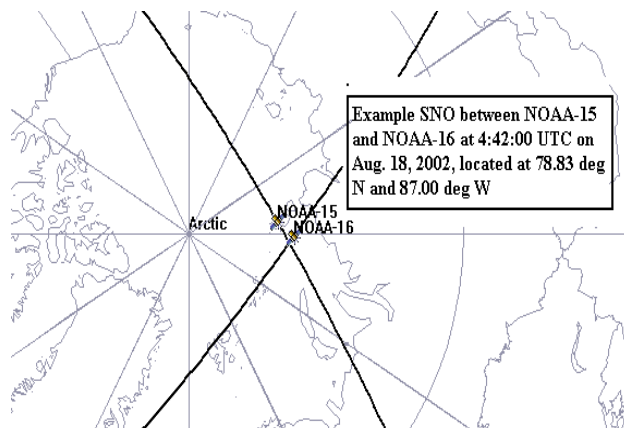


Figure 1. Example Simultaneous Nadir Overpass (SNO) between NOAA-15 and -16

## Methodology

The Simultaneous Nadir Overpass (SNO) methodology is relatively straight forward and the results are highly repeatable. Detailed procedures are as follows:

1. Predict Simultaneous Nadir Overpasses (SNOs) between each succeeding pairs of NOAA satellites using the orbital perturbation model SGP4 and historical two-line-elements (TLEs) (Cao, et al., 2004, 2005b)
2. Level 1B data that contain SNO observations from NOAA-6 to NOAA-17. Criteria for the SNOs: 1). At the SNO, the distance between nadir pixels of two orbits < 20 km. 2). time difference between nadir pixels of the two orbits is less than 30 seconds.
3. A subset data (56 columns by 31 rows) is extracted initially, and the data converted to both radiance and brightness temperature.
4. A pixel by pixel match is performed for the matchup subset data between the two satellites based on the latitude and longitude of each pixel.
5. Statistics of the biases in radiance and brightness temperature between two succeeding NOAA satellites are calculated based on a 4 by 5 box at nadir, or within +/- 5 degrees from nadir.
6. The time series of the biases are plotted.

The results are then analyzed. Further analysis maybe needed to find the root cause of the biases between satellite before the bias can be used for intersatellite bias adjustments.

## Data Processing

All historical SNOs for NOAA-6 to NOAA-17 satellites have been calculated, cross-checked with multiple runs of the software, and validated against HIRS level 1b match-up data sets. The algorithm for predicting the SNOs has been published in Cao, et al., 2004. All predicted SNOs for NOAA-6 to NOAA-17 have been documented in the report by Cao et al., 2005b. Intersatellite calibration of HIRS with the SNO method for NOAA-6 to -17 have been generated. Intersatellite radiance biases have been calculated for each channel of HIRS. The biases have been characterized in correlation plots between pairs of satellites, tables, and time series plots. Forward calculations with the line-by-line radiative transfer code LBLRTM have been performed for all satellites, with sample Arctic, Antarctic, and tropical atmospheric profiles.

Further detailed studies on the radiance biases and possible causes have been conducted with NOAA-15 to -17 data and the results documented in the paper by Cao, et al., 2005a. Efforts have been made to find the source of radiance biases by working with the National Institute of Standards and Technology and the HIRS instrument manufacturer with regard to the measurement uncertainties of the HIRS spectral response function (Kaplan, 2002). The following bias model has been developed:

$$\beta = f(\tau, \varepsilon, l, v, e, g, s, \alpha, o) \quad (1)$$

Where:

$\beta$  = radiance bias

$\tau$  = observation time differences (this is reduced to a negligible level with the SNO method).

$\varepsilon$  = blackbody spectral emissivity and discrepancies between skin and bulk temperatures

*l* =nonlinearity  
*v* =spectral uncertainty  
*e*=calibration algorithm  
*g*=geolocation, including location differences and navigation errors.  
*s*=scene uniformity and sensor modulation transfer functions (MTF)  
*a*=calibration anomaly  
*o*=other factors

## Preliminary Results

Time series plots of radiance bias for each channel show the consistency of the biases during the study period. Arctic and Antarctic data are shown with distinct symbols, while colors represent different satellite combinations. Note that there is a gap for data involving NOAA-8 (around 1984 to 1986) due to the lack of SNO data and the relative short operating period of this satellite

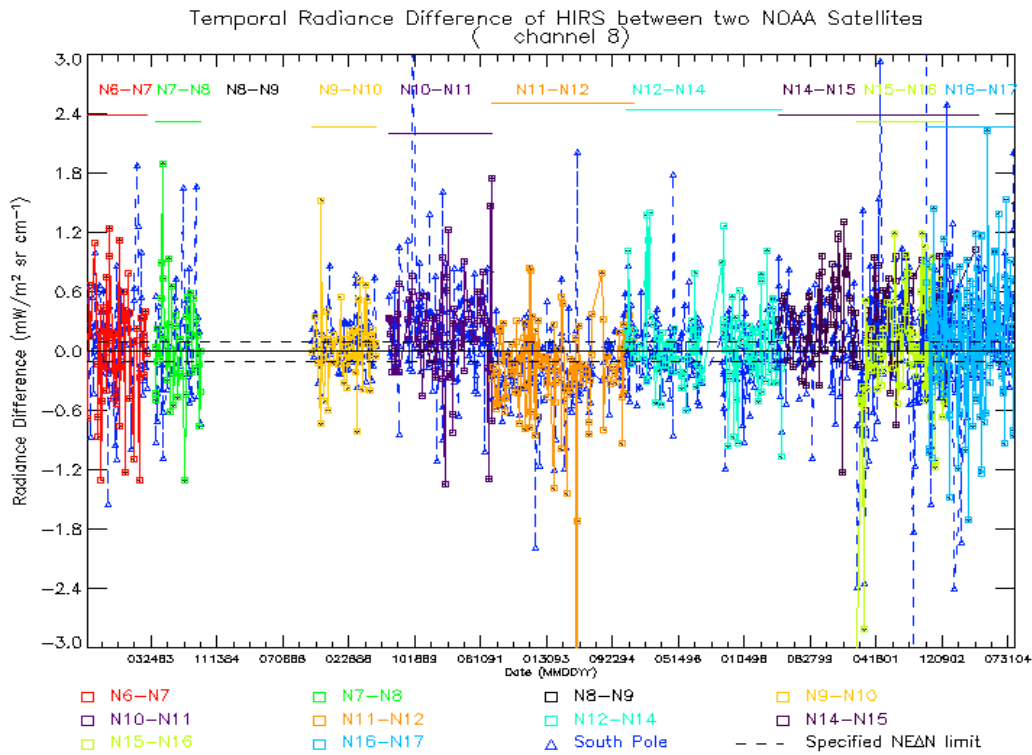


Figure 2. Time Series of Radiance Biases for HIRS Channel 8 (1980 to 2004) that shows small median biases

Preliminary analysis of these biases suggests the following: a). For the window channels such as ch8 and ch19 (Figure 2), the intersatellite biases (median values) are small ( $< 0.3K$ ) for all the satellite pairs. This is important because in the longwave, channels 1-12 share the same HgCdTe detector, and in the shortwave, channels 13-19 share the same InSb detector. Good agreement for the window channels may suggest that the blackbody calibration is relatively reliable for all channels, assuming the blackbody spectral emissivity is relatively flat over the entire spectral region of HIRS.

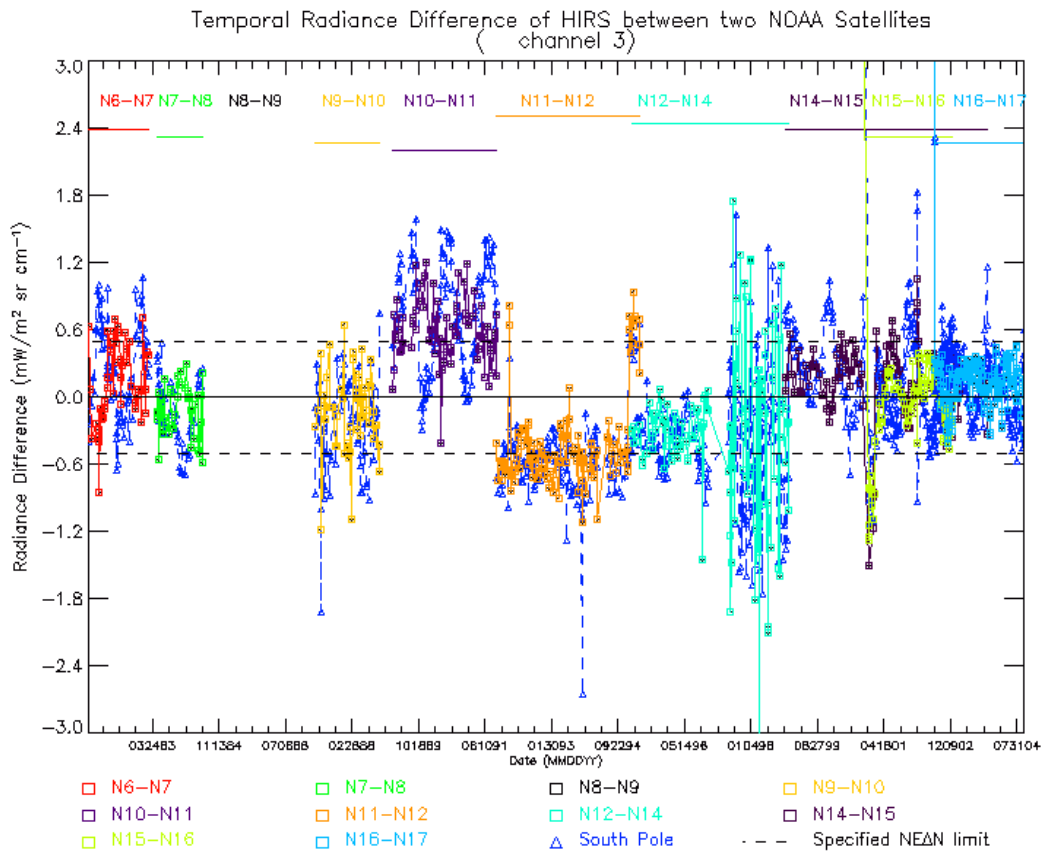


Figure 3. Time Series of Radiance Biases for HIRS Channel 3 that shows seasonal radiance biases between satellites.

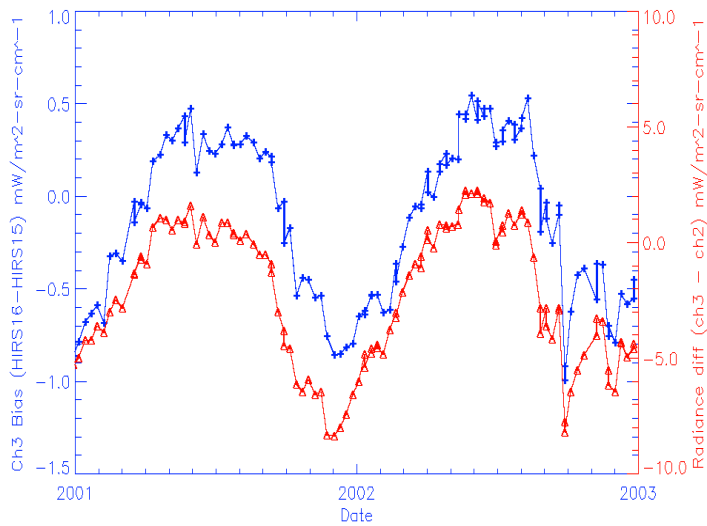


Figure 4. Seasonal biases are highly correlated with the lapse rate

b). The seasonal biases for the stratosphere channels are probably caused by the differences in the spectral response functions and the fact that the atmosphere changes with season. Further analysis shows that the seasonal biases are highly correlated with the lapse rate, suggesting that the small difference in the spectral response functions plays an important role for the biases (Figure 4).

c). The large biases in Channel 1 can not be fully explained by the forward calculations. Based on past studies, the large biases for this channel are probably caused by the measurement inaccuracy and true differences of the HIRS spectral response functions for this channel (Figure 5).

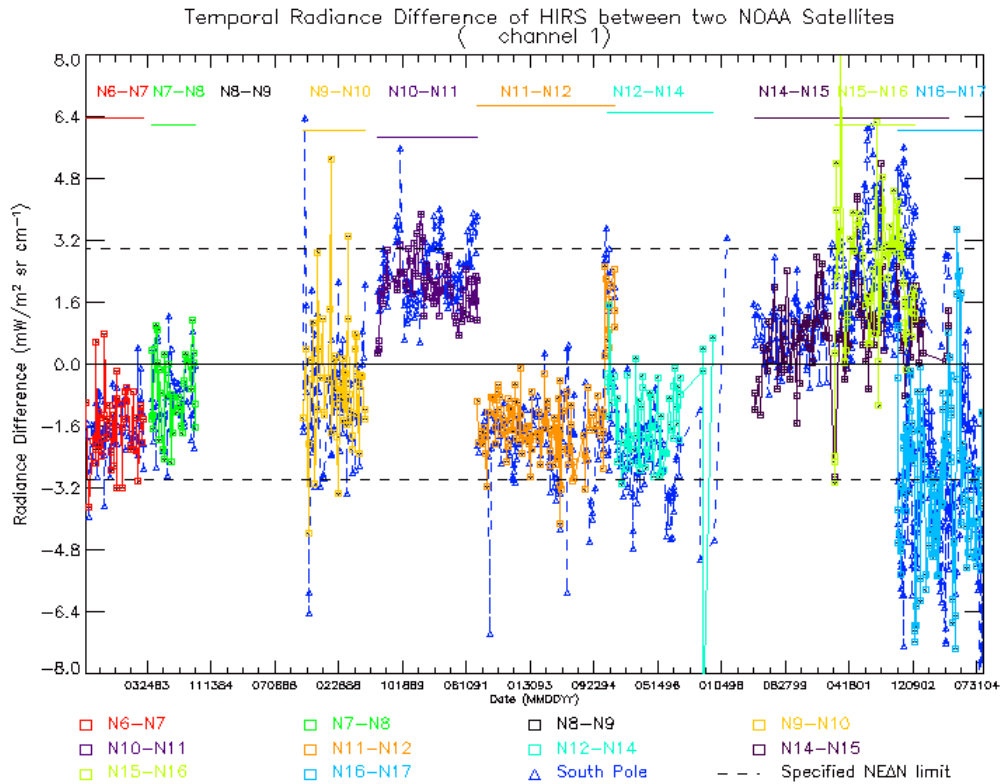


Figure 5. Radiance biases for channel 1 on HIRS NOAA-6 to NOAA-17

d). Radiance biases for channel 10 are not very meaningful for several satellites because the channel was changed to a different spectral region for some succeeding satellites.

e). Results for the short-wave channels are less reliable due to the low signal to noise ratio at typical polar temperatures, and reflected solar radiance in these channels.

## Conclusions

The Simultaneous Nadir Overpass (SNO) method is used in this study to characterize the intersatellite calibration biases for HIRS onboard NOAA-6 to NOAA-17 from 1980 to 2003. The SNO method takes advantage of intersatellite calibration with nadir observations that are taken

within seconds at the orbital intersections between each succeeding pair of satellites. The low uncertainty using this approach allows us to study subtle radiometric and spectral calibration differences for HIRS on different satellites. This provides us an independent check of the instrument performance, and helps users better understand the nature of the intersatellite biases in constructing long-term time series of satellite data.

Analysis of such datasets from 1980 to 2003 reveals unambiguous intersatellite radiance differences, as well as calibration anomalies. The results show that in general, the intersatellite relative biases are relatively small for most HIRS channels. The large biases in some channels differ in both magnitude and sign, and are likely caused by the differences and measurement uncertainties in the HIRS spectral response functions. The seasonal bias variations are found to be highly correlated with the lapse rate factor, approximated by adjacent channel radiance differences. The method presented in this study works particularly well for channels sensing the stratosphere because of the relative spatial uniformity and stability of the stratosphere, for which the intercalibration accuracy and precision are mostly limited by the instrument noise. The SNO method is simple, robust, and the results are highly repeatable and unambiguous. Intersatellite radiance calibration with this method is very useful for the on-orbit verification and monitoring of instrument performance, and is potentially useful for constructing long-term time series for climate studies.

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