ARM SGP and BN AERI Instrument Diagnostic Comparison and Preliminary Assessment

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Abstract

A continuous collection for diagnostic instrumental comparison was conducted at the Southern Great Plains (SGP) Lamont site from June 11 to the 13, 2003 using the Atmospheric Emitted Radiance Interferometer (AERI) at the site and the AERI owned by the U.S. Department of Energy (DOE), National Nuclear Security Administration and operated by Bechtel-Nevada (BN). Analysis produced the following preliminary results: (1) sky radiance data collected by both instruments are compatible and consistent and both preserve key atmospheric features such as water vapor, ozone and carbon dioxide, (2) the relative difference of both datasets is in the range of 5%, except for the water vapor bands (wavenumber 750-1250, 2000-2200, and beyond 2380), and (3) over the entire spectral range from wavenumber 666 to 3000, the estimate of sky radiance by the SGP AERI instrument is 2 to 3% less than the estimate by the BN AERI instrument. Statistical tests suggest that the difference between SGP and BN data are small and systematic. Empirical relationships between the two instruments were established using a regression method.

Introduction

During summer 2003, the DOE BN test and evaluation team conducted an instrument test at ARM SGP site. Simultaneous data collection was performed using both the SGP AERI and the BN FTIR AERI spectrometer. The collected data were compared and analyzed to determine the similarities and differences between the two instruments and to develop a general method to compare datasets taken with the two different AERI-configuration FTIR instruments. This paper reports the preliminary results of the comparison work.

Both the BN FTIR spectrometer and the SGP AERI instrument were built using the same concept (Knuteson el al. 1999) with one main exception; the BN FTIR has a higher scan speed, and subsequently a higher signal to noise ratio (SNR) than SGP AERI (Griffiths 1975). For simplicity, BN AERI-configuration FTIR will be called the BN AERI in the context of this paper.

The nominal temporal resolution of the SGP AERI data taken for this experiment was roughly 8 minutes. To match the SGP AERI data collection resolution, the BN AERI was programmed to collect the sky radiance data at a rate of roughly 8-minutes per collection as well. The BN crew also attempted to synchronize the sampling time with SGP AERI. However, due to the differences in computer control, scanning speed, and other factors, precise synchronization between the two instruments has been proven impossible.

Measurements for this experiment were collected from June 11 through 13, 2003. During this period, the SGP AERI made 411 sky radiance measurements and BN AERI made 333 measurements. The BN AERI instrument made fewer measurements because it was frequently interrupted by manual operations due to weather and other conditions.

Resampling and Sample Data

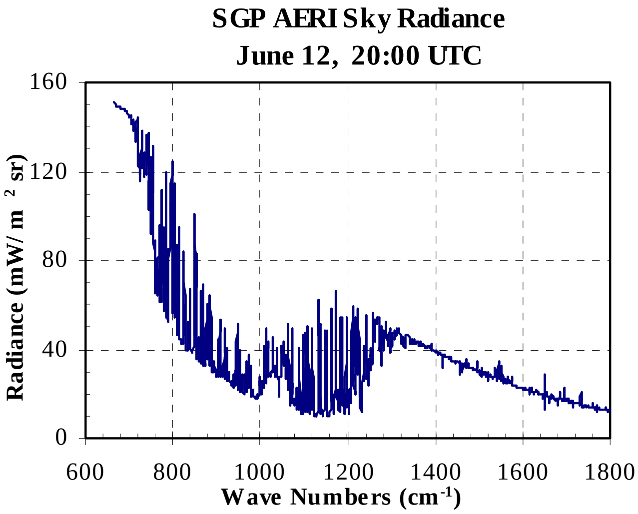
To facilitate comparison between the two datasets, both SGP and BN sky radiance data were resampled to a common temporal-spectral grid with nominal sampling window size of 10-min. This resampling work was done using a temporal-spectral sampling algorithm designed to mimic the temporal sampling behavior of both instruments (Yuan and Williams 2004).

Sample sky radiance spectra obtained by SGP and BN AERI data timed at June 12 20:00 Universal Time Coordinates (UTC) are plotted in Figure 1. This measurement occurred during a period in which the atmosphere contained significant amounts of water, a very wet atmosphere. The spectra obtained by two instruments show, by comparison, that the data from both instruments are compatible, roughly in the same range, and clearly identify significant atmospheric features, such as the cloud base pressure and atmospheric chemical composition including, ozone, water vapor, carbon dioxide and nitrous oxide (Smith et al. 1999).

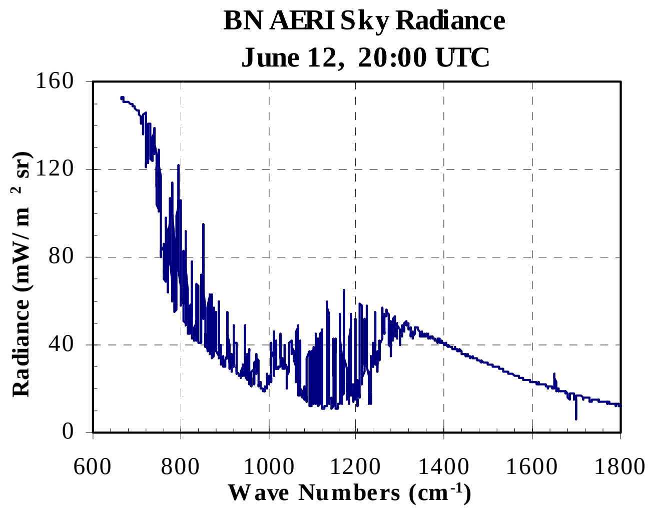
Statistical Comparison

In order to analyze the relative stability of both AERI instruments, the sky radiance coefficient of variances were computed. The coefficient of variance is the ratio of the standard deviation over the mean for the data. It can be viewed as a measure for the relative error in the data. The results from data collected on June 12 are shown in Figure 2. The data from both instruments show similar pattern. The SGP data demonstrated a substantially higher noise component in the wavenumber range from 1250 to 1800, which is consistent with the fact that its SNR is lower than that of BN AERI.

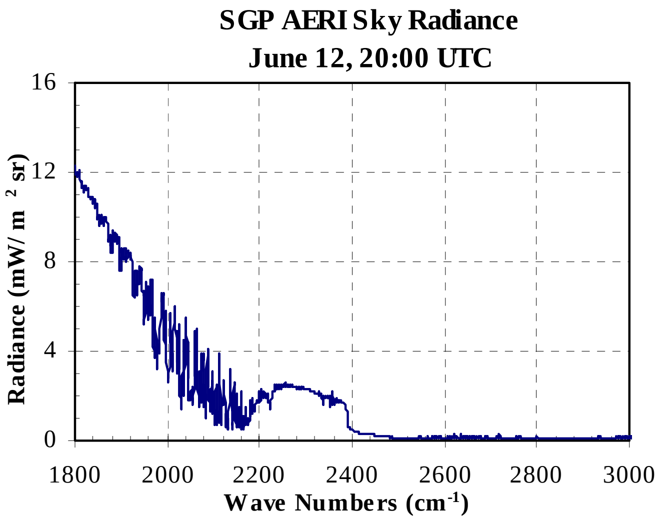
Figure 2 shows that the coefficient of variances for both instruments are smaller than 0.1 in the non-absorption regions (wavenumber 600-750, 1250-1950, 2200-2400), though towards the end of spectrum, namely from wavenumber 2400 and beyond, the coefficient of variance does exceed 0.1. Due to smaller amount of energy received by the instruments in this range, even small changes in radiance data cause large fluctuations in the coefficient of variances and therefore, the consideration of relative errors is meaningless beyond wavenumber 2400.



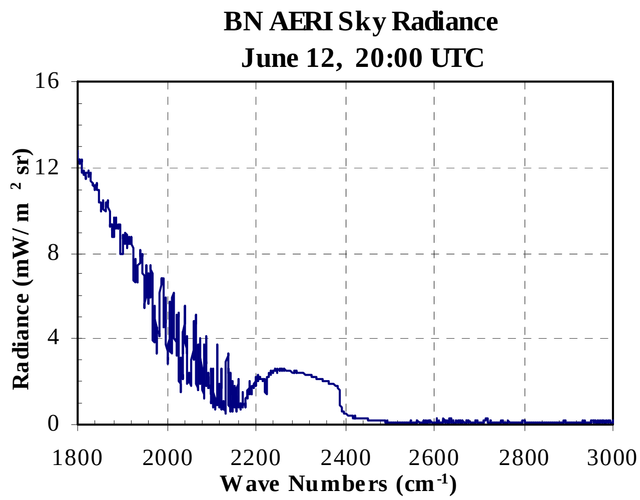
(a) SGP AERI detector A sky radiance



(b) BN AERI detector A sky radiance



(c) SGP AERI detector B sky radiance

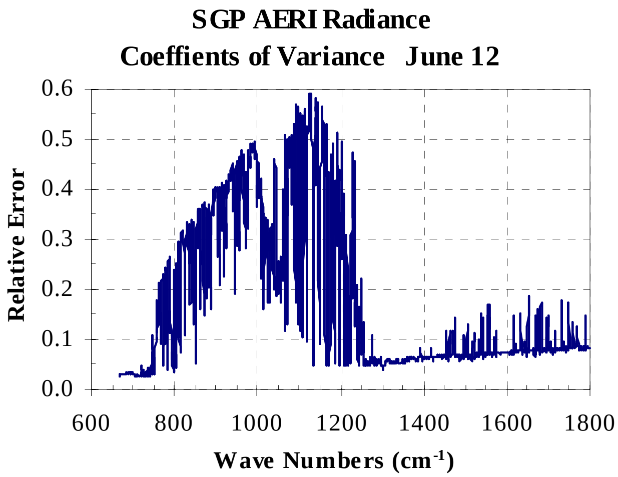


(d) BN AERI detector B sky radiance

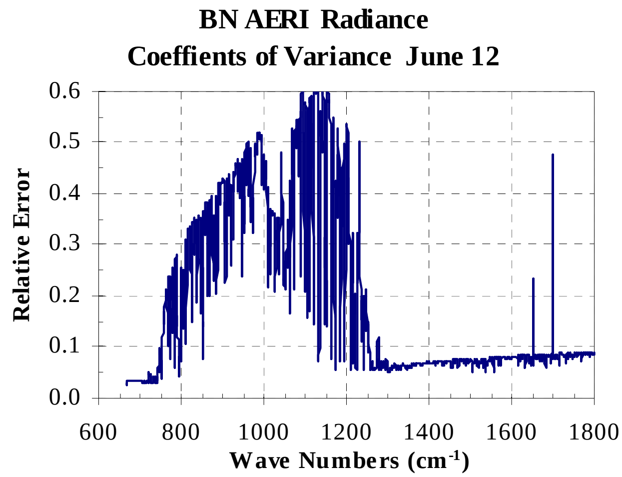
Figure 1. Sky radiance measured by SGP and BN AERI at 20:00 UTC, June 12.

Difference Analysis

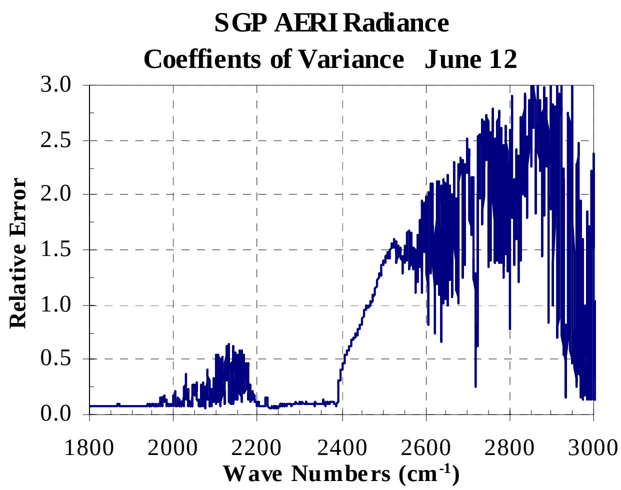
Band by band differences were computed and analyzed for the available datasets. This analysis reveals the characteristics of the difference between the two AERI instruments. The mean ARM-BN sky radiance difference and relative difference spectra of June 12 are presented in Figure 3. The difference spectra show that the SGP AERI sky radiance are generally smaller than the corresponding BN AERI sky radiance, and that this difference approaches zero as the wavenumber increases. The relative difference spectra in Figure 3 were computed using BN AERI data as reference. These spectra show that the relative differences between the two instruments are usually in the range of 0.03 for detector A and 0.05 for detector B, except in the water absorption channels.



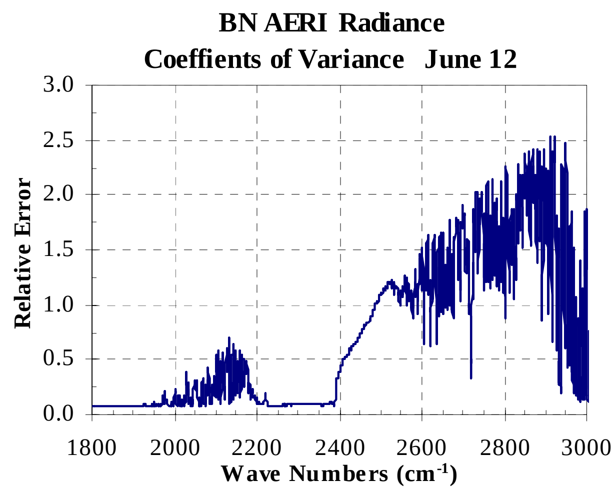
(a) SGP coefficient of variance (Detector A)



(b) BN coefficient of variance (Detector A)



(c) SGP coefficient of variance (Detector B)



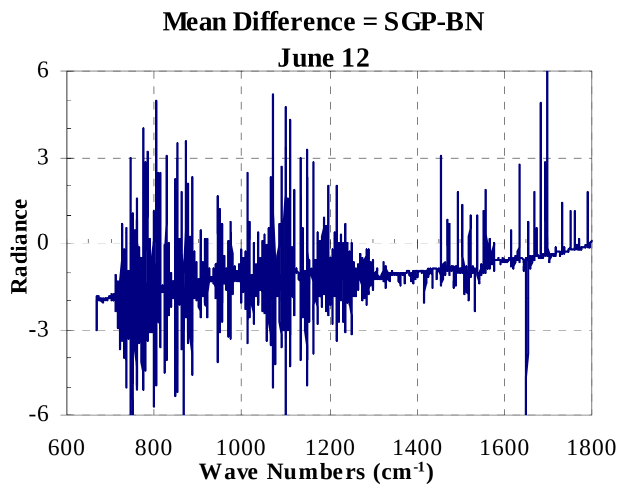
(d) BN coefficient of variance (Detector B)

Figure 2. SGP and BN AERI sky radiance data coefficients of variance spectra.

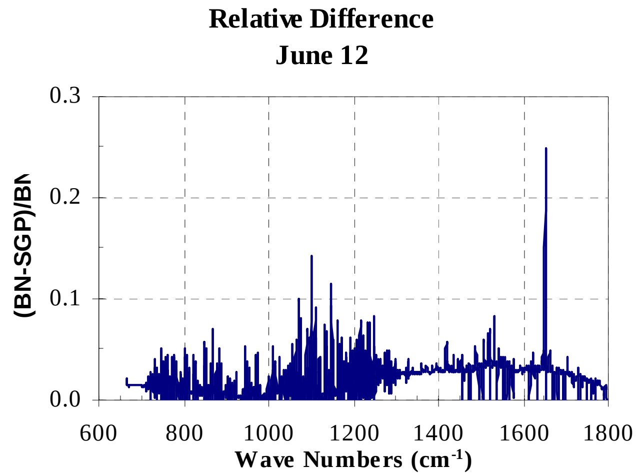
Empirical Relationships

Regression analysis was performed for determining channel-by-channel empirical relationships between the two AERI instruments. The analysis was conducted using the data collected on June 12. By observation of the regression results the spectrum measured by these instruments can be divided into four regions. Within each of these regions, the empirical relationships demonstrate similar patterns.

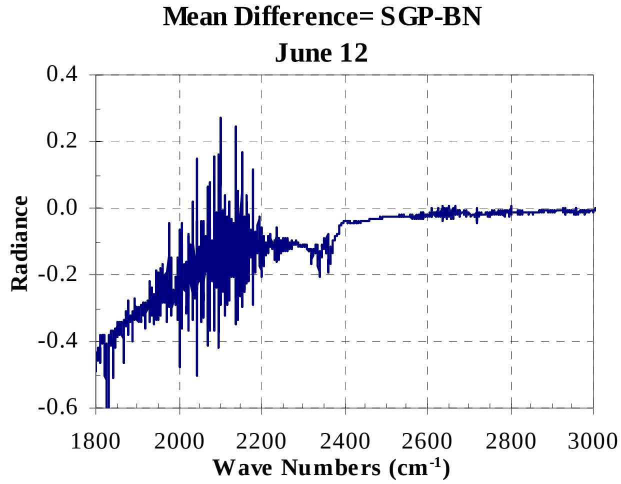
Range 1 (wavenumber 666 ~1380) roughly corresponds to the long wavelength range of these spectra. The regression analysis shows a trend between the two datasets. The majority of the gains estimated by the regression analysis are in the range of 1.0 to 1.1. The corresponding offset estimates do vary across the range of the analysis and appear random. Based on this analysis, calibration is needed and is possible in this range (see Eq. 1).



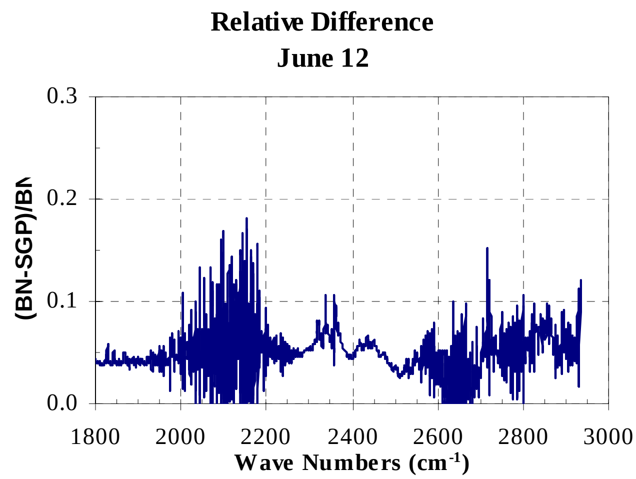
(a) Mean difference spectrum (Detector A)



(b) Relative mean difference (Detector A)



(c) Mean difference spectrum (Detector B)



(d) Relative mean difference (Detector B)

Figure 3. June 12 SGP-BN sky radiance difference and related difference spectra.

Range 2 (wavenumber 1381-1799) corresponds to a relatively smooth portion of the sky radiance spectra. In this range, the differences between the two instruments are small, usually within 2 mW/m^2 sr and the relative differences are within 3%. Both the regression gain and the offset estimates are extremely unstable. However this can be attributed to the small differences and that these differences are random and not indicative of systematic differences between the two instruments. Because of the small difference between the BN AERI and the SGP AERI radiance in this range, no calibration is needed.

Range 3 (wavenumber 1800-2300) shows similar behavior to range 1, but with a much smaller magnitude. The differences and relative difference between the two instruments are significant compared with the other regions of data collected by detector B, regression analysis shows that this difference is quantifiable. Calibration in Range 3 is appropriate and possible (see Eq. 1).

Range 4 (wavenumber 2301-3000) shows a similar pattern to range 2. In this spectral range, radiance data collected by both SGP and BN AERI instruments are relatively smooth and have very little difference between them., Regression results in this range are variable and appear random. No linear calibration is suggested in this range.

For Ranges 1 and 3 identified above, linear equations were fitted to the smoothed regression gain and offset spectra. This resulted in the following channel-by-channel empirical relationships:

$$R_{wn}^{RSL} = \begin{cases} (0.00005wn + 1.044)R_{wn}^{SGP} + 0.0078wn - 11.74, & \text{wavenumber } 666\text{-}1380 \\ (0.0001wn + 0.8266)R_{wn}^{SGP} - 0.0009wn + 2.0698, & \text{wavenumber } 1800\text{-}2300 \\ R_{wn}^{SGP}, & \text{otherwise} \end{cases} \tag{1}$$

Result Summary

Based on the comparison and analysis performed on the data collected during this experiment, the following preliminary conclusions can be drawn about the sky radiance data collected by the SGP and BN AERI instruments:

Consistencies

The sky radiance data collected by the SGP and BN AERI instruments are compatible and consistent. Data collected by both instruments have similar ranges and trends across the wavenumber spectra measured for this experiment. The fluctuations or uncertainties (measured by coefficient of variances) in both datasets are in a similar range, roughly 0.05 for non-absorption channels. The BN AERI tends to produce cleaner radiance data (less apparent random fluctuations) because it has a substantial higher sigh-to-noise ratio than the SGP AERI.

Differences

SGP AERI instrument tends to generate smaller sky radiance than the BN AERI instrument. This difference ranges from less than 5 mW/(m^2 sr cm^{-1}) at the 666 wavenumber to close to zero at the 3000 wavenumber. The relative difference (coefficient of variance) between the two datasets are generally in the range of 0.05 with the exceptions of the water vapor bands (wavenumber 750-1250, 2000-2200, and beyond 2380). The difference between the data in the range of wavenumber 2400 to 3000 is small and can be ignored. T-tests show that the differences between the SGP and BN AERI sky radiance data are systematic and can be corrected.

Relationships

Channel-by-channel empirical relationships between SGP and BN AERI sky radiance data were established using linear regression models. These relationships may be used to transform data from one instrument to match data from the other. This may allow data from the different instruments to be used together for analysis. This use has not been operationally confirmed.

This comparison project resulted in two general products that can be used by the research community. These are: (1) Temporal-Spectral Resampling Algorithm and (2) Temporal and Spectral Kit (TASK) Software Package. The temporal-spectral resampling algorithm for AERI-like dataset has been submitted for publication (Yuan and Williams 2004). The TASK software package as well as the comparison datasets used for this paper can be obtained by sending request to yuand@nv.doe.gov.

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