ASTI-SORTI Comparison

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Abstract

The Absolute Solar Transmittance Interferometer (ASTI) determines the absolutely calibrated solar spectral radiance from 1 micron to 5 microns (10000 to 2000 cm^{-1}) with a 1 cm^{-1} spectral resolution. Recently, the Solar Radiance Transmission Interferometer (SORTI) was configured to operate in the near infrared, providing spectra from 750 nm to 2400 nm (13000 to 4000 cm^{-1}) with 0.035 cm^{-1} resolution. Simultaneous ASTI and SORTI observations at the Southern Great Plains (SGP) Atmospheric Radiation Measurement (ARM) program site are compared in the overlap region and ASTI spectra from SGP and other sites are compared to atmospheric model calculations.

Introduction

The need to study the absolute characterization of the solar infrared (IR) radiance at the top of the atmosphere and through atmospheric paths to the earth's surface has lead to the development of two instruments: SORTI and ASTI. The University of Denver has designed and built these instruments for use in measuring the absolutely calibrated solar radiance at the earth's surface and the infrared transmission of the atmosphere. SORTI is a SGP ARM central site instrument and ASTI is frequently involved in measurements during Intensive Observation Periods (IOPs) at the site.

Experiments, in the shortwave infrared (SWIR) band, involving these instruments has three objectives:

1. The capability to provide absolute spectra in the SWIR.
2. The data used to model the total column amounts of constituent molecules.
3. The possibility to calibrate relative data and extend it to shorter wavelengths.

These combined studies focus on direct beam radiance measurements and analyses that will later be extended the determination of the exo-atmospheric radiance.

Instrumental Details

The ASTI instrument has been tested, calibrated and it's performance evaluated at four locations during multiple seasons. All the ASTI measurements presented are for periods of clear-sky. This radiance is measured in the SWIR band covering 1950 to 10,100 cm^{-1} at 1 wavenumber resolution. This instrument uses a calibrated source to produce absolute ground-based solar spectra.

ASTI is based on a Bomem MB120 Fourier Transform Spectrometer (FTS) and includes associated optics all mounted on a dual axes solar tracker. The input mirror directs either the solar or the calibration source radiation into the entrance of the FTS. The Bomem FTS uses a liquid nitrogen cooled InSb detector and records single-sided interferograms. The solar energy is filtered through one of three optical filters, mounted on a filter wheel, which are used to limit the intensity of the light impinging upon the detector, thus avoiding saturation and non-linearity effects. The output optics contains two-field stops, such that the first (circular) aperture limits the field of view of the instrument and the second (rectangular) aperture selects the effective area of the source for observation. This method uses the symmetry of window-pupil design to ensure that the same area in phase space is sampled by the system for both the sun and the calibration sources. One co-added interferogram typically consists of 10 scans recorded over a 100 second time interval at a given solar zenith angle. The instrument operates automatically and spectra are recorded continuously throughout the day, weather conditions permitting. ASTI has been employed to measure the calibrated solar radiance at four different sites:

1. University of Denver, Colorado, 5,400 feet
2. SGP ARM site, Oklahoma, 319 feet
3. Echo Lake, Colorado, 10,600 feet
4. Mount Evans, Colorado, 14,100 feet

Measurements of the solar radiance at different zenith angles will produce spectra of different amplitudes due to the differing atmospheric transmissions associated with the variation in total airmass along the observation path. Langley regressions can be made when operation of the instrument allows for the acquisition of lower zenith angle spectra. When the Langley regressions are complete, comparisons to exo-atmospheric radiance measurements (satellite data) can be made.

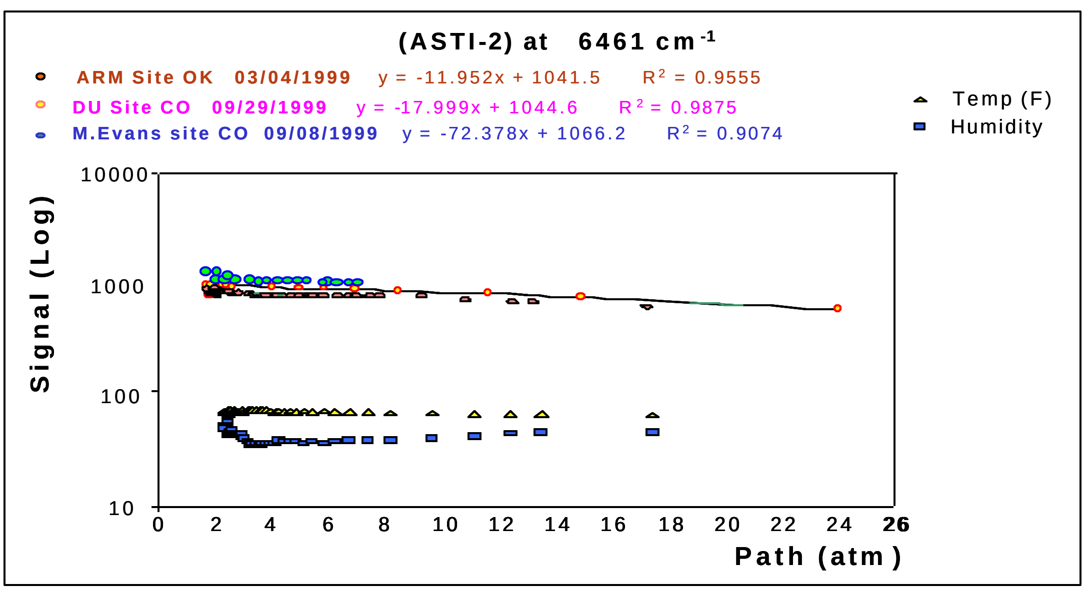

Figure 1. Langley plot for data recorded from three different sites using ASTI-2. The regression of data from the Mount Evans site is of limited quality, because of the scarcity of data points and which were all taken with effective airmasses less than 10.

The SORTI instrument is a ground-based optical radiometer that produces ultra-high resolution infrared spectra (0.0035 cm^{-1}) of solar radiation transmitted through the atmosphere. SORTI was installed at the SGP CART (Cloud and Radiation Testbed) site in November 1993 and is located in the Optical Trailer at an altitude of 315.2 meters. A solar tracker mounted above the level of the top of the trailer receives and directs the solar radiation into the interferometer. During normal observations spectra are collected at in six bandpass filter regions (620 to 1350 cm^{-1}, 1500 to 2050 cm^{-1}, 2020 to 2550 cm^{-1}, 2420 to 3080 cm^{-1}, 3010 to 3830 cm^{-1}, and 4020 to 4300 cm^{-1}) three times per day, on clear-sky days. The first measurement starts when the sun reaches a solar zenith angle of 85 degrees and progresses through 60 degrees solar zenith angle. The second measurement period is at noon (maximum solar angle with respect to the horizon). The final measurement period occurs from solar zenith angles of 60-degrees solar zenith angle to 30 degrees. Each spectra is obtained from a co-add of two interferograms and the instrument takes from 20 minutes to 50 minutes to collect selected spectra in all of the wavelength ranges, depending upon the spectral resolution selected for the series of observations.

The ultra-high solar spectral resolution of this instrument permits verification of theoretical line-by-line calculations of atmospheric transmittance between 1000 and 13,000 cm^{-1}. The calibrated spectra are used to quantify the total integrated column amounts of N_2O, O_3, NH3, and HNO_3 in the atmosphere.

Observed Data

The ASTI and SORTI instruments were operated at the optical trailer at the SGP ARM site during an IOP in March of 1999. The instruments were synchronized to record spectra simultaneously; consequently, the observations are for the same solar path. During these observations, SORTI was configured for observations in the near infrared. The data from March 3, 4, and 5 were selected for this analysis, based on their quality and the atmospheric conditions. These data have been compared in the spectral range from 8000 to 10,100 cm^{-1}, where the spectral regions overlap for the two systems.

A sample ASTI spectrum is shown in Figure 2, where a comparison is made during two days measurements.

The SORTI provides data uncalibrated in terms of radiance units. The ASTI was used as a calibration transfer standard for the SORTI. Because the SORTI has better spectral resolution than the ASTI, comparison of the two sources of data requires that the resolution of the SORTI data be degraded by manipulation of the spectra. A calibration function is then derived from comparison of the ASTI data and the low resolution SORTI data. Interpolation is then used to determine the calibration function for the original, high-resolution SORTI spectra.

Figure 4 shows a comparison between an ASTI spectrum and a calibrated resolution-degraded SORTI spectrum. The agreement is excellent, although the SORTI spectrum is at slightly higher resolution. The calibration function calculated from the comparison of the spectra was transferable to other days during the IOP. Methods of extending the calibration and using site data to maintain a SORTI calibration are being investigated.

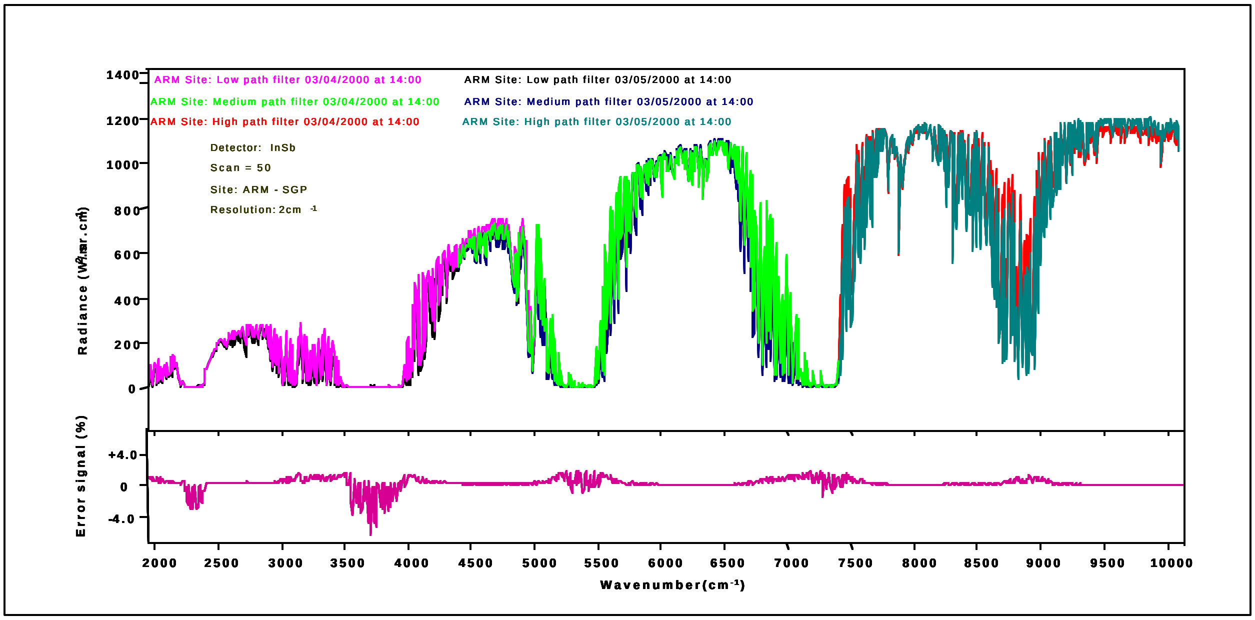

Figure 2. A typical ASTI-2 calibrated solar spectra, for the three bandwidths, recorded on March 4 to 6, 1999 (top), and the differences over the two days (bottom).

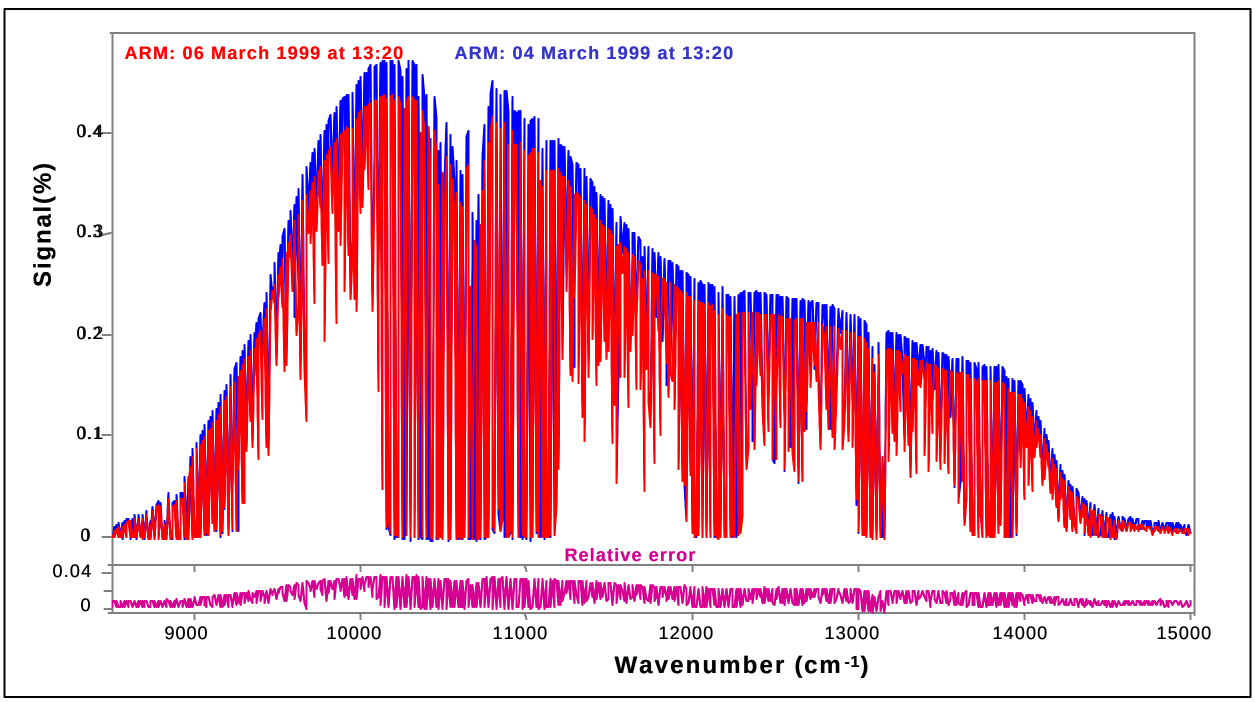

Figure 3. A typical SORTI relative solar spectra, recorded in March 4 to 6, 1999 (top), and the relative differences over the two days (bottom).

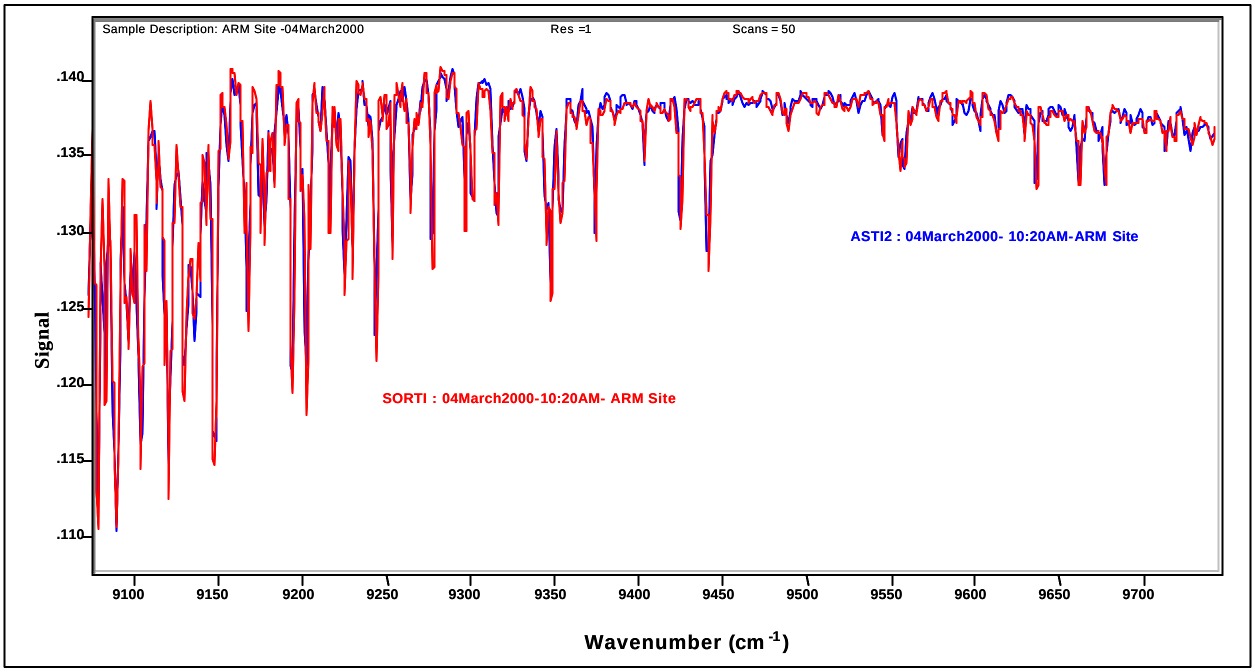

Figure 4. Comparison between measured ASTI-2 spectra and degraded SORTI spectra at 1 cm^{-1} spectral resolution.

Spectral validations of the ASTI measurements are performed with line-by-line calculations using line-by-line radiative transfer model (LBLRTM). Input profiles of atmospheric temperature, water vapor, and other trace gases are obtained by scaling radiosonde profiles from the ARM site. Figure 5 shows the comparison between ASTI observed spectrum and LBLRTM calculated spectrum over the spectral range 4400 to 5000 cm^{-1} taken March 4 to 6, 1999 at 60.5 zenith angle. Residuals between ASTI-observed radiance and the LBLRTM calculation, for these two days are shown in the bottom panel of Figure 5. There is very good agreement between the calculations and measurements for the two days. The large spectral residuals in the regions near 4625 and 4750 cm^{-1} are due to solar lines not accounted for in the modeling of the spectra.

Discussion of calibrated spectra

In this study, the emphasis was on calibrating the high-resolution SORTI spectra, using a blackbody to calibrate the lamp and then the calibrated lamp to calibrate the ASTI instrument. The calibration of ASTI solar spectra is accomplished using the following:

$O_L(\nu)$ measured lamp spectrum
$O_S(\nu)$ measured solar spectrum
$S_L(\nu)$ the calibration lamp's radiometric spectrum calibrated against a blackbody
G ASTI instrumental gain factor.

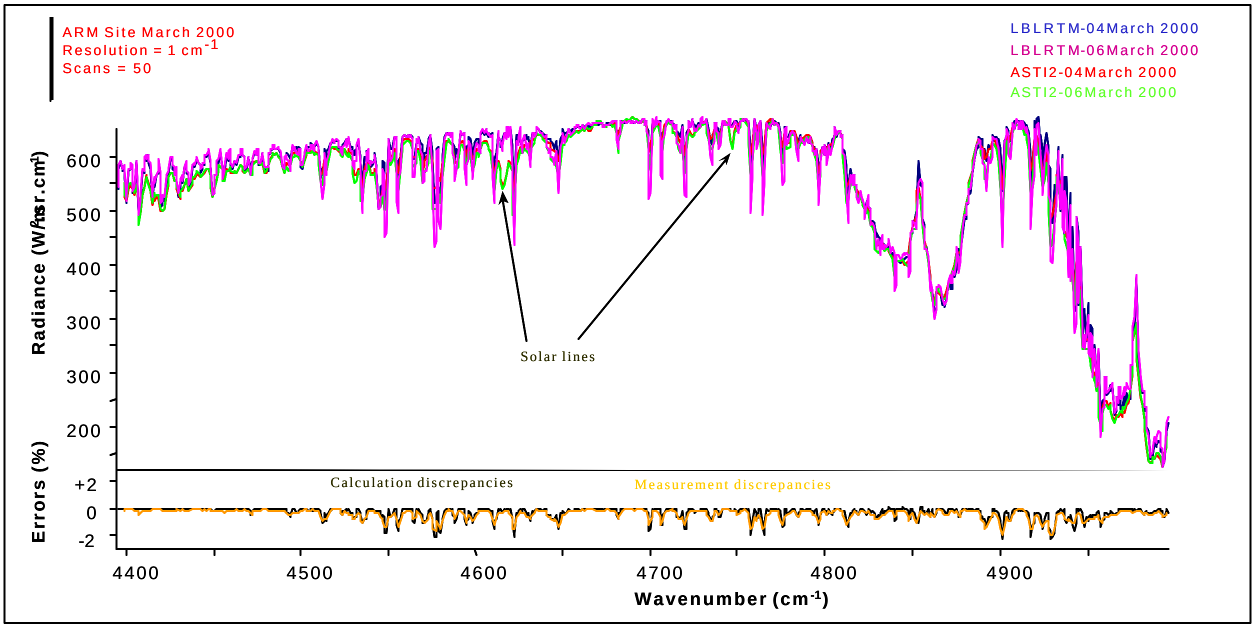

Figure 5. Comparison between measured and calculated spectra during the IOP, ARM-winter 2000 from clear-sky over the spectral range 4300 to 5000 cm^{-1} (zenith angle of 60.5°). ASTI2-04: Solar radiances measured with ASTI2 on March 4, 2000; ASTI2-06: Solar radiances measured with ASTI2 in March 6, 2000; LBLRTM-04: Calculated radiance by LBLRTM using the sounding data from March 4, 2000; LBLRTM-06: Calculated radiance by LBLRTM using the sounding data from March 6, 2000.

The retrieved solar radiance, $S_S^{ASTI}(\nu)$, using ASTI can then be expressed as the combination of the lamp and solar spectra:

$$S_S^{ASTI}(\nu) = \left\{ \frac{O_S^{ASTI}(\nu)}{O_L^{ASTI}(\nu)} \times S_L(\nu) \right\} \times G$$

The calibration transfer function, $T^{SORTI}(\nu)$, is then determined by taking the ratio of the retrieved solar radiance from the ASTI measurement to the resolution reduced, measured solar spectrum from SORTI, $O_S^{SORTI-R}(\nu)$:

$$T^{SORTI}(\nu) = \frac{S_S^{ASTI}(\nu)}{O_S^{SORTI-R}(\nu)}$$

Calibrated high resolution SORTI absolute radiance is then determined by multiplying the full resolution SORTI spectrum by the calibration transfer function, after it has been smoothly interpolated to match the high-resolution spectrum:

$$S_S^{SORTI}(\nu) = O_S^{SORTI}(\nu) \times T_{Full-Res}^{SORTI}(\nu)$$

As seen in Figure 6 the agreement between the calibrated ASTI spectra and the calibrated SORTI high-resolution spectra are quite good.

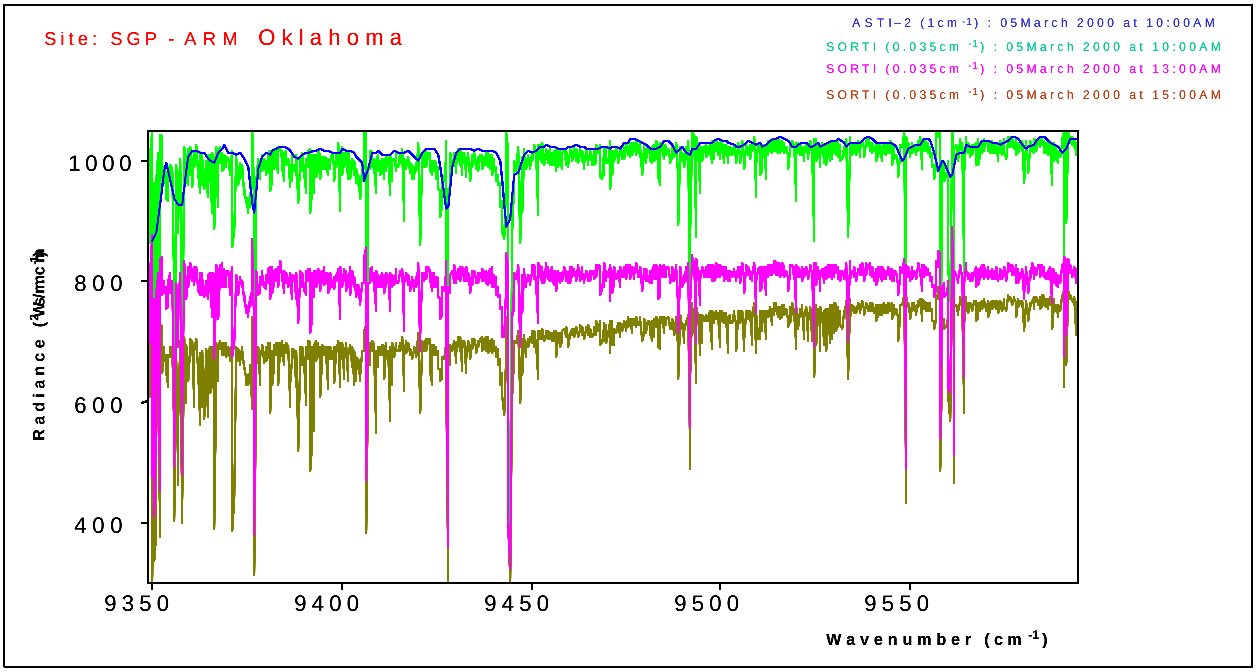

Figure 6. Calibration of the SORTI high-resolution (0.035 cm^{-1}) solar spectra measured during the winter IOP, ARM Site, using the ASTI absolute process. Spectra recoded during a clear-sky period, between 9:00 AM and 17:00 PM.

Conclusion

The validation between ASTI-observed radiance and LBLRTM model results show remarkable agreement for different solar zenith angles and column water vapor amounts. The SORTI spectra could be calibrated using the ASTI absolute spectra demonstrates that the ASTI and SORTI instruments provide comparable measurements of solar radiances. The application of the ASTI instrument to the determination of absolute exo-atmospheric radiances has been demonstrated and this work will continue. The use of ASTI to calibrate the SORTI instrument has been demonstrated. The use of ASTI to provide a base line calibration of SORTI and the subsequent use of ARM site instrumentation to validate this calibration will be investigated. Future work will be to extend this calibration over the spectral coverage of other instruments using visible wavelength, to include other constituents and data sets.

Acknowledgements

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