Comparison of ARM AERI with Trent FTS Spectra for the Measurement of Greenhouse Radiative Fluxes

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Introduction

For the past several years, measurements of the atmospheric thermal infrared spectra have been made at the mid-latitude site of Trent University in Peterborough, Ontario, at a high resolution of 0.25 cm^{-1}. These measurements are similar to those conducted with the Atmospheric Emitted Radiance Interferometer (AERI) instrument at the Atmospheric Radiation Measurement (ARM) Program sites, which has a lower resolution of 1 cm^{-1}. We compare the ARM AERI spectra with those measured at Trent University for clear-sky conditions, and use the same analysis techniques on both spectra to derive greenhouse radiative fluxes for all of the main greenhouse gases, including H_2O, CO_2, CH_4, N_2O, and the chlorofluorocarbons. The comparisons demonstrate that the AERI resolution is adequate for this type of flux measurement under most sky conditions. The extensive analysis of the ARM data would extend the mid-latitude surface radiative flux measurements to locations of different latitude and climate regimes, and help to ascertain the global radiative flux at the surface for all of the important greenhouse gases.

Methodology

The measurements of the downward atmospheric thermal emission spectra made at Trent University were collected using a Bomem DA8 Fourier Transform Infrared Radiometer (FTIR) spectrometer at a resolution of 0.25 cm^{-1}. The instrument incorporated a liquid-nitrogen-cooled, narrowband, MCT detector with a 1-mm^2 element. The downward zenith sky radiation from the clear-sky was collected by positioning a gold-coated mirror at the emission port along the optical axis of the instrument. A stored-phase correction was applied to the measured interferogram before conversion was made to the spectral domain to account for phase changes present at 750 and 2000 cm^{-1}. The thermal emission background of the instrument was characterized by measuring a negligible source of thermal radiation, which consisted of a blackened dewar containing liquid nitrogen. The background measurement was taken immediately prior to and after the measurement of the sky radiation to ensure that the spectrometer was thermally stablized.

The calibration of the atmospheric measurement was performed by placing an ambient blackbody source beneath the gold mirror, filling the field-of-view of the spectrometer. The temperature of the blackbody was monitored by a chromel-alumel thermocouple. The atmospheric emission measurements required 15-30 minutes observing time. This resulted in a root-mean-square noise value of about 5.0 10^{-9} W/(cm^2 sr cm^{-1}) in the mid-infrared region.

The FTIR measurements made at the Cloud and Radiation Testbed (CART) site (Lamont, Oklahoma) were obtained using the AERI instrument at a resolution of 1 cm^{-1}. The instrument was calibrated using two blackbodies near the ambient temperature.

Results and Discussion

Some typical spectra of the downward radiance measured in the 5-16 m region with the Trent and AERI FTS are shown in Figure 1. The emission bands from several greenhouse gases are identified. The top spectrum represents an AERI measurement with many intense water lines taken during a warm day in January. The middle spectrum corresponds to an AERI measurement obtained on a cold January day. The overall radiance intensity is reduced and the emission bands of other greenhouse gases become more apparent. The bottom spectrum corresponds to the emission measured on a cold day with the Trent FTS. Qualitatively, the Trent 0.25 cm^{-1} spectrum is similar to the cold AERI 1 cm^{-1} spectrum.

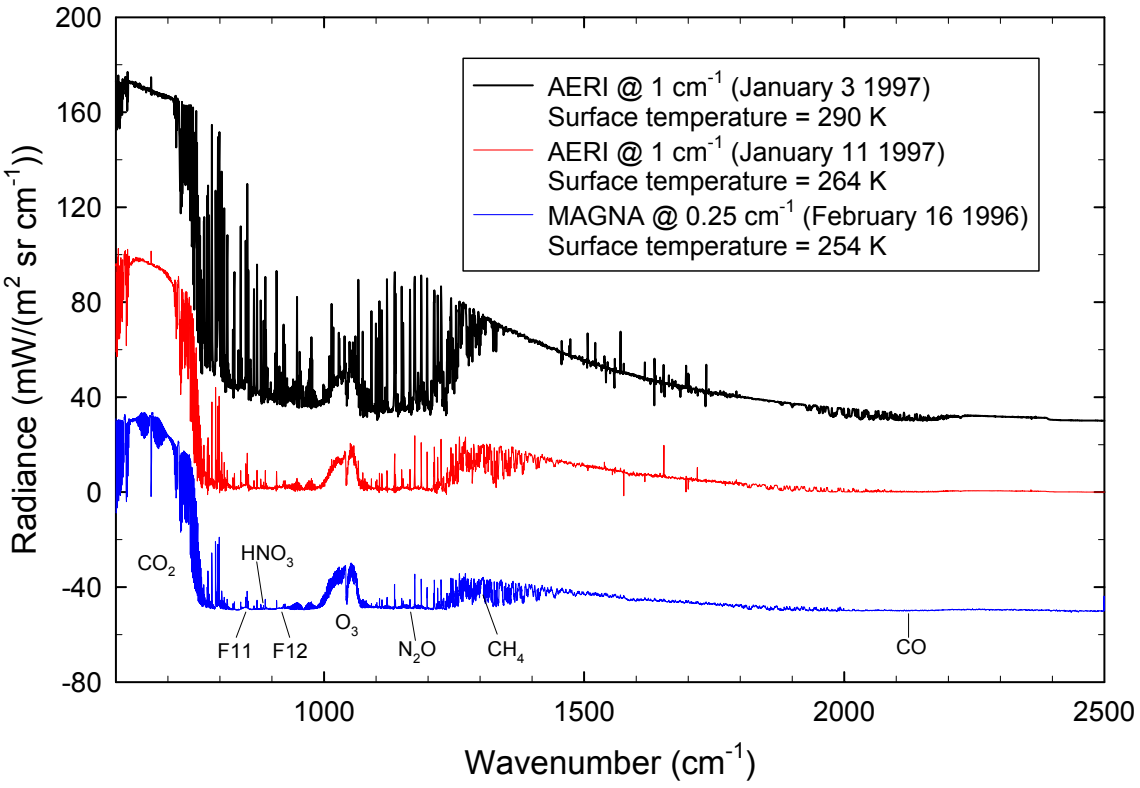

Figure 1. Spectra of the greenhouse radiation at the surface measured for warm and cold days with the Trent and AERI spectrometers, showing the contributions of several greenhouse gases.

To extract the greenhouse flux from individual gases, the background emission of the atmosphere was simulated using the radiative transfer code, FASCOD3 (Clough et al. 1988). The simulations incorporated the temperature, relative humidity, and pressure profiles from radiosonde measurements. The concentrations of background gases were taken from the Air Force Geophysical Laboratory (AFGL) Atmospheric Constituent profiles (Anderson et al. 1986) and scaled to current tropospheric concentrations (IPCC 2001). The line transition parameters for the molecules were provided from the 1996 AFGL high-resolution transmission (HITRAN) database (Rothman et al. 1998). The model utilized an aerosol profile representative of the visibility conditions as monitored by the local weather office. An example extraction using this procedure for the Trent spectrum is illustrated for CFC-12 in Figure 2. Curve A shows the measured downward thermal emission for February 16. Besides the emission from CFC-12 in the 900-940 cm^{-1} region, other gases including nitric acid, water vapour, and carbon dioxide have emission bands that overlap with those of CFC-12, as noted in the figure. The simulated emission of these other gases is represented by curve B in Figure 2. Subtracting the simulated background thermal emission from the measured emission yields the measured downward greenhouse radiation at the surface that is associated with atmospheric CFC-12 (curve C).

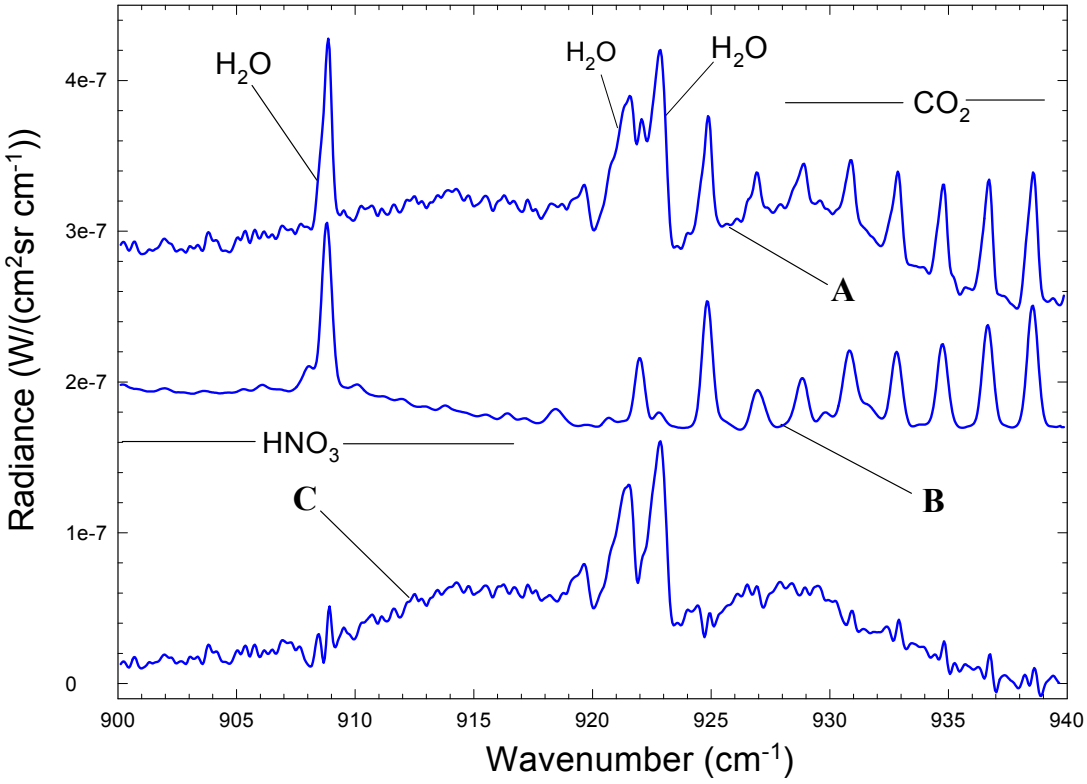

Figure 2. The extraction of the thermal emission band of CFC-12 from the measured atmospheric emission spectrum at 0.25 cm^{-1} (curve A). Curve B represents the simulated background thermal emission in the absence of CFC-12. The subtraction of curve B from curve A represents the greenhouse radiation associated with CFC-12.

Similarly, the emission bands of several greenhouse gases can be extracted from the AERI spectra. The retrieved profiles of pressure, temperature, and water vapour derived from the AERI spectra were used in the FASCOD3 model to represent the background atmospheric thermal emission. An example of one extraction from the AERI spectrum taken on January 11 is shown for O_3 in Figure 3, along with a comparison of the O_3 band extracted from a Trent measurement. A comparison of the greenhouse fluxes measured for several gases with the AERI and Trent FTS is shown in Table 1. In general, the AERI results are higher than the Trent fluxes since the atmosphere was warmer for the AERI measurement.

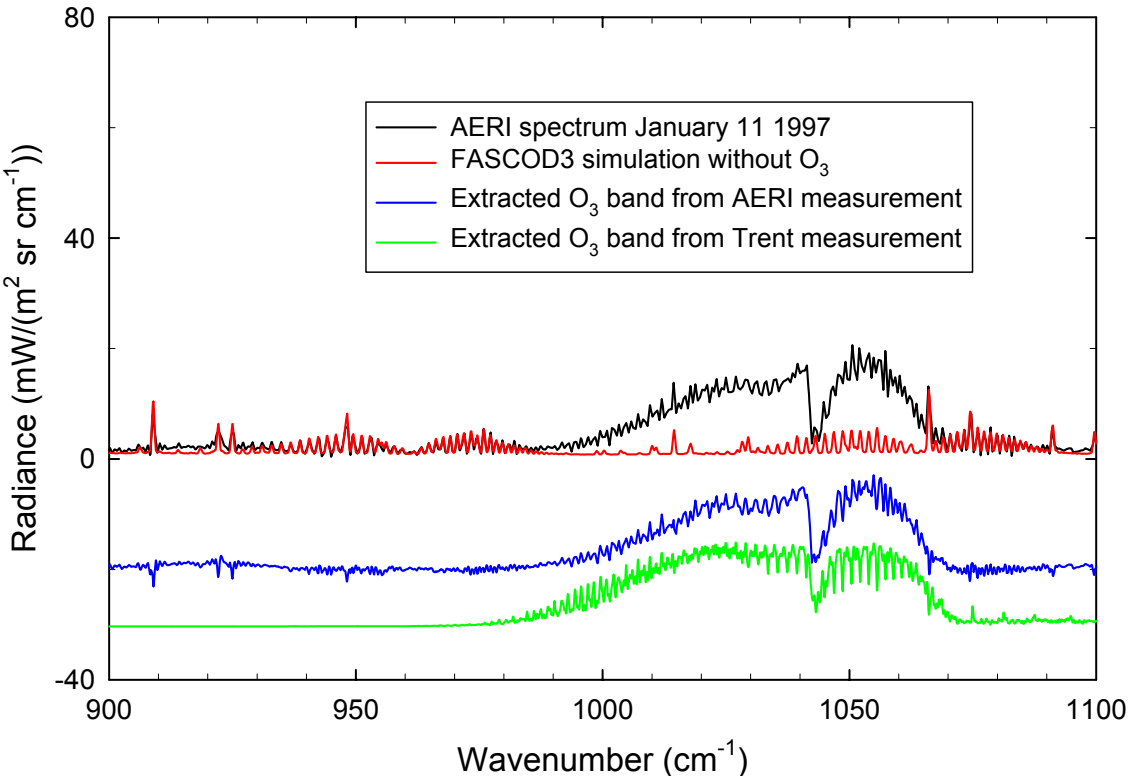

Figure 3. Extraction of the 9.6 m O_3 band from the 1 cm^{-1} AERI measurement, and the comparison to a 0.25 cm^{-1} measurement obtained with the Trent FTS.

Table 1. Comparison of Trent and AERI winter surface greenhouse fluxes.

Greenhouse Gas	Emission Band (cm^{-1})	Trent Flux (W/m^2)	AERI Flux (W/m^2)
CFC-11	830 - 860	0.10	0.12
CFC-12	all bands	0.21	0.26
CFC-11 + 12	all bands	0.31	0.38
CH_4	1200 - 1400	1.02	1.21
N_2O	1200 - 1300	1.19	1.32
O_3	900 - 1100	3.34	3.02
CO_2	all bands	30.9	37.3

Acknowledgments

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