THE EXTRACTION OF THE THERMAL RADIATION ASSOCIATED WITH GREENHOUSE GASES FROM AIRS MEASUREMENTS

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ABSTRACT:

For the purpose of investigating the contributions of various gases to climate change, the thermal radiation associated with greenhouse gases are extracted from AIRS (Atmospheric Infrared Sounder) infrared radiances over the tropical pacific region. AIRS instrument which was launched on the EOS-Aqua satellite in May 2002 covers the spectral range from 650 cm^{-1} to 2700 cm^{-1} with a spectral resolution of between 0.4 cm^{-1} and 1 cm^{-1}. In order to extract the thermal radiation absorbed by individual gases, the interfering background radiances at the top of the atmosphere are simulated using the radiative transfer code MODTRAN (MODerate spectral resolution atmospheric TRANsmittance). The simulations incorporated the temperature and water vapor profiles taken from NCEP (National Centers for Environmental Prediction) reanalyses. The differences between the simulated background radiance and AIRS-measured radiance result in the absorption of upward longwave radiation by atmospheric gases (i.e. greenhouse effect). The extracted absorption bands of individual gases will allow us to quantify the radiative forcing of individual greenhouse gases and thus those data will be useful for climate change studies and for the validation of radiative transfer codes used in general circulation models.

KEY WORDS: Greenhouse effect, Thermal radiation, AIRS, MODTRAN, NCEP

1. INTRODUCTION

The increase in anthropogenic emissions of greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and the halocarbons, induces additional radiative forcing that could lead to climatic global warming. The potential impact that global warming has on society is extensive, such as changes in water and coastal resources, health, agriculture, fisheries, forest and energy. In order to investigate this global threat, the contributions of various greenhouse gases to the Earth's radiation budget need to be identified.

Although there are extensive model calculations of radiative forcing, there are few measurements of the greenhouse radiation. Evans and Puckrin (1995, 2001), as one of rare studies, quantified the radiative flux associated with greenhouse gases at ground level.

The spectrum of outgoing longwave radiation is a measure of the cooling to space of the Earth's surface and atmosphere due to absorption and emission at characteristic wavelengths and carries the imprint of the gases that are responsible for the greenhouse effect. Spaceborne spectrometric observations therefore may allow us to estimate the radiative forcing of greenhouse gases on a global scale and to follow their temporal evolution. Harries et al. (2001) found direct experimental evidence for a significant increase in the greenhouse effect from the outgoing longwave radiation spectra. Chazette et al. (1998) showed the radiative forcing of methane can be determined directly by use of nadir spectral radiances measured from space.

In line with the previous studies, the thermal radiation associated with greenhouse gases are extracted from AIRS (Atmospheric Infrared Sounder) infrared radiances over the tropical pacific region. This will allow an accurate measure of the radiative forcing of the greenhouse gases using spaceborne instrument.

2. DATA AND METHODOLOGY

2.1 The AIRS instrument

The AIRS (Atmospheric Infrared Sounder) was launched on the EOS-Aqua satellite by NASA in May 2002. Aqua orbits on a 705.3 km polar sun-synchronous orbit giving twice daily global coverage.

AIRS is a high spectral resolution spectrometer with 2378 channels in the thermal infrared (3.7 - 15.4 μm) and 4 channels in the visible (0.4 - 1.0 μm), with two samples per channel. The spectral resolution of a grating spectrometer is controlled by the aperture of the detectors on the focal plane array of the instrument. The detectors

in AIRS are all 10 μm x 10 μm with 10 μm gaps between each detector and its nearest neighbour. This gives a resolution of between 0.4 cm^{-1} and 1 cm^{-1}.

Each scan line contains 90 infrared footprints, with a resolution of 13.5 km at nadir and 41km x 21.4 km at the scan extremes. The visible and near infrared spatial resolution is approximately 2.3 km at nadir.

2.2 Quality control and cloud clearing

Before using the AIRS thermal radiation data for analysis quality control was performed. AIRS infrared data are filtered by checking the Quality Assurance parameters according to Olsen et al. (2005).

Cloud clearing was performed using a two-step brightness temperature threshold technique (Strabala et al., 1994). In the first step, the brightness temperature at a wavenumber where the atmosphere is at its most transparent (1128.495 cm^{-1}) is compared to the underlying sea surface temperature taken from the NCEP reanalysis dataset. If the difference exceeded a set threshold then the spectrum was rejected as being cloud-contaminated because a colder spectrum indicates cloud. Threshold (6 K) was chosen by finding the value which the rate of the remaining spectra is similar with the ISCCP (International Satellite Cloud Climatology Project) monthly total cloud amount from July 1983 to December 2004. The remaining spectra were subjected to the second step in an attempt to remove the effects of absorption due to thin cirrus. In the second step, brightness temperatures at 1249.753 cm^{-1} (~8 μm) and 901.001 cm^{-1} (~12 μm) are compared because the absorption characteristics of ice particles cause greater brightness temperature difference between the two wavelengths than in the corresponding clear-sky situation. A spectrum with higher difference than a selected threshold was rejected as being cloudy. The threshold value was chosen as before step.

2.3 Simulation of outgoing longwave radiation

In order to extract the thermal radiation absorbed by individual gases, the interfering background radiances at the top of the atmosphere are simulated using the radiative transfer code MODTRAN4 (MODerate spectral resolution atmospheric TRANsmittance).

MODTRAN was run with user defined profiles constructed using a number of gas concentration datasets. The simulations incorporated the temperature and water vapor profiles taken from NCEP (National Centers for Environmental Prediction) reanalyses dataset. The incorporation of temperature profiles uses 18 individual layers of NCEP and the upper 17 layers (32.5 km ~ 100 km) of AFGL Atmospheric Constituent profiles (Anderson et al., 1986) while the incorporation of water vapor profiles uses 9 layers of NCEP and the upper 24 layers of Anderson et al. (1986).

Gas concentrations were taken from IPCC 2001 values and Climate Monitoring and Diagnostics Laboratory's flask measurements system at the Mauna Loa and the Samoa observatories. These concentrations are used to scale the AFGL Atmospheric Constituent profiles for the correct gases. The gas concentrations used in the MODTRAN simulations are summarized in Table 1.

3. RESULTS AND DISCUSSIONS

A thermal infrared emission spectrum showing the contributions of several greenhouse gases is shown in Figure 1. The spectrum was obtained from AIRS over the Tropical Pacific region (0.24°S, 148.18°W) on July 5, 2005.

An expanded view of the AIRS observed thermal emission spectrum (Figure 1) in the CH_4 band region is shown in Figure 2-(A) as a solid line. Besides the absorption by CH_4 in the region, water vapor and N_2O have absorption bands that overlap with those of CH_4, as indicated in the Figure 1.

Table 1. Gas concentrations used in the MODTRAN simulations

Constituent	Concentration
CO_2	375 ppm
O_3	260 DU
CH_4	1785 ppb
N_2O	320 ppb
CFC-11	255 ppt
CFC-12	535 ppt
CFC-22	132 ppt
CFC-113	79 ppt
CCl_4	95 ppt

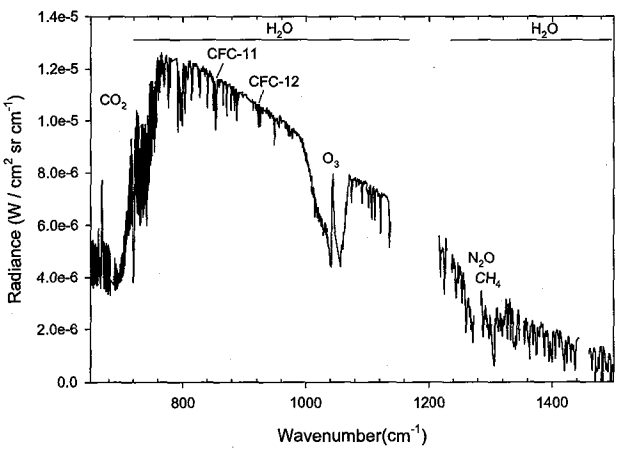

Figure 1. A thermal infrared emission spectrum observed from AIRS over the Tropical Pacific region (0.24°S, 148.18°W) on 5 July 2005. Prominent contributions of several greenhouse gases are identified in the spectrum.

In order to extract the CH_4 absorption band from the AIRS observed emission, the background emission of the atmosphere was simulated using the band model MODTRAN4. In Figure 2-(A), the simulated background thermal emission spectrum in the absence of CH_4 is shown as a dotted line. The subtraction of solid line from dotted line results in the observed absorption of upward longwave radiation by CH_4, that is greenhouse effect of CH_4 (upper line, Figure2-(B)).

For the purpose of comparison, a simulation of the atmospheric radiance was repeated accounting for the presence of methane. The simulated total atmospheric emission was subtracted from the simulated background radiance of Figure 2-(A) to produce the absorption band of CH_4 (lower line, Figure 2-(B)). The observed CH_4 absorption radiance and the simulated CH_4 absorption radiance are consistent with each other. The consistence implies that the simulation result using the radiative transfer code is very reliable and thus extracted absorption radiance is reliable.

The extraction of the other greenhouse gases, CO_2 and N_2O, is also performed by the same process of CH_4. The observed and simulated absorption bands of CO_2 and N_2O are shown in Figure 3 and Figure4. The observed absorption bands of two gasses also show good consistence with simulated absorption bands.

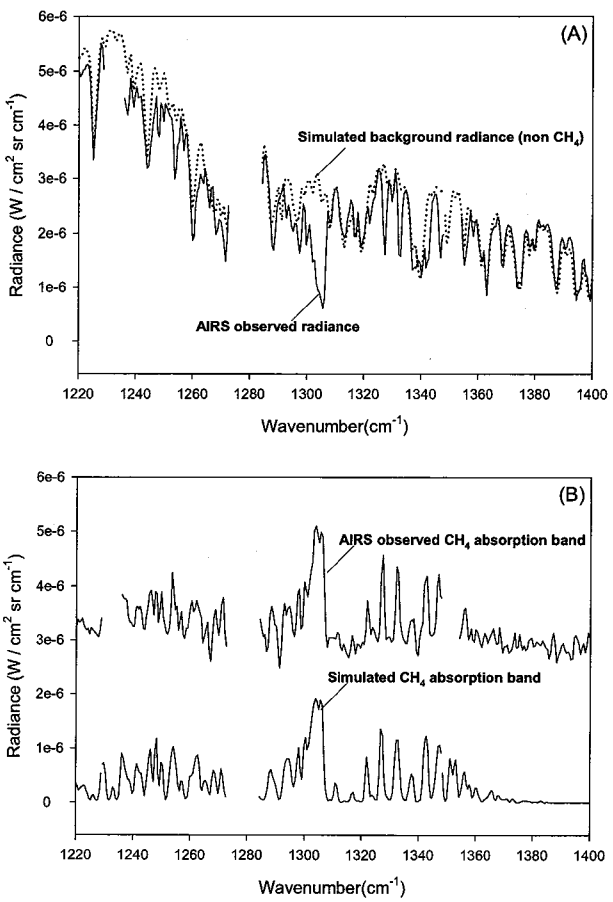

Figure 2. (A) An expanded view of the AIRS observed thermal emission spectrum (Figure 1) in the CH_4 band region and the simulated background thermal emission spectrum in the absence of CH_4 are shown. (B) Upper line represents the subtraction of AIRS observed thermal emission spectrum from the simulated background spectrum showing the AIRS observed CH_4 absorption band. Lower line represents the simulated CH_4 absorption band obtained by simulating the total atmospheric emission and subtracting it from the simulated background radiance. For clear comparison of the two lines, the upper line have been shifted upward by 3×10^{-6} W (cm^2 sr cm^{-1})$^{-1}$.

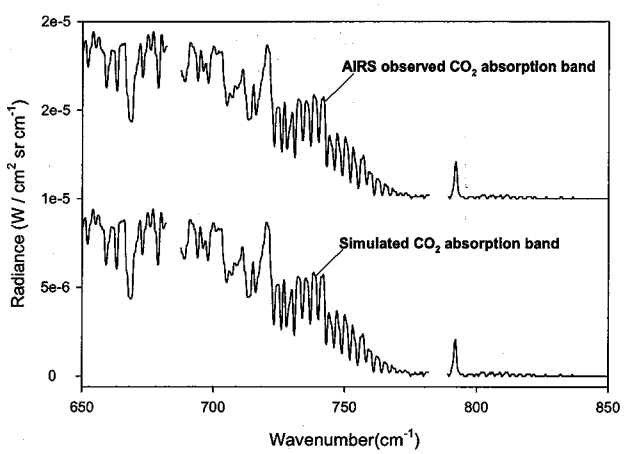

Figure 3. Same as Figure 2-(B), but for CO_2. For clear comparison of the two lines, the upper line have been shifted upward by 1×10^{-5} W (cm^2 sr cm^{-1})$^{-1}$.

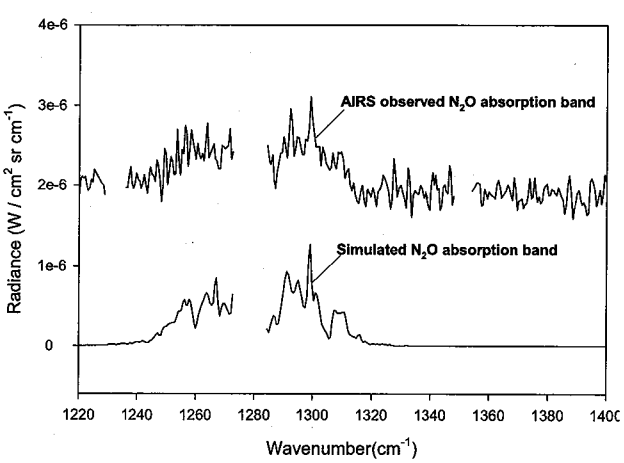

Figure 4. Same as Figure 2-(B), but for N_2O. For clear comparison of the two lines, the upper line have been shifted upward by 2×10^{-6} W (cm^2 sr cm^{-1})$^{-1}$.

In Figure 4, however, simulated N_2O absorption band clearly shows the limits of MODTRAN code due to the lower spectral resolution of 1 cm^{-1} compared with AIRS. MODTRAN cannot simulate water vapour absorption lines and thus the simulated N_2O absorption band is broader than AIRS observed one. This result implies that the extracted absorption radiances of greenhouse gases from AIRS using MODTRAN include the uncertainty due to the spectral resolution.

4. SUMMARY AND CONCLUSIONS

For the purpose of investigating the contributions of various gases to climate change, the thermal radiation associated with greenhouse gases are extracted from AIRS infrared spectrum over the tropical pacific region. The interfering background radiances at the top of the atmosphere are simulated using MODTRAN4 by incorporating temperature and water vapor profiles taken from NCEP and gas concentrations taken from IPCC 2001 and NOAA/CMDL measurements. We extract the greenhouse gas (CH_4, CO_2 and N_2O) absorption bands by subtracting AIRS measured radiance from the simulated background radiance.

The extracted absorption bands were compared with the simulated absorption bands, which are the difference between the simulated total atmospheric emission and the simulated background radiance. In the comparison, the AIRS observed absorptions bands of CH_4, CO_2 and N_2O are in good consistence with the simulated absorption bands implying that the extracted absorption radiances are reliable. Simulated N_2O absorption band, however, clearly showed the limits of MODTRAN code due to the lower spectral resolution resulting in broader absorption band than AIRS observed one. This result suggests that the uncertainty due to the lower spectral resolution of MODTRAN should be considered. When the extraction method is applied for greenhouse gases with narrow absorption band, the uncertainty may induce significant problem.

The extracted absorption bands of greenhouse gases will allow us to quantify the radiative forcing of individual greenhouse gases and thus those data will be useful for climate change studies and also for the validation of radiative transfer codes used in general circulation.

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