An Update on Radiative Transfer Model Development at Atmospheric and Environmental Research, Inc.

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Introduction

Over the last decade, a suite of radiative transfer models has been developed at Atmospheric and Environmental Research, Inc. (AER) with support from the Atmospheric and Radiation Measurement (ARM) Program. These models span the full spectral regime from the microwave to the ultraviolet, and range from monochromatic to band calculations. Each model combines the latest spectroscopic advancements with radiative transfer algorithms to efficiently compute radiances, fluxes, and cooling rates. These models have been extensively validated against high-resolution spectral measurements and broadband irradiance measurements. Several of these models are part of the broadband heating rate profile value-added product (BBHRP VAP), currently being established at the ARM Southern Great Plains (SGP) site.

A Web site has been established to host the AER radiative transfer models (http://rtweb.aer.com). The Web site facilitates access to the models and is a convenient platform on which to provide model updates.

LBLRTM and Continuum Update

The foundation of the suite of AER models is the Line-by-Line Radiative Transfer Model (LBLRTM) (Clough et al. 1992). LBLRTM calculates optical depths and radiances at high resolution from the far infrared to the ultraviolet, utilizing the most recent spectroscopic information and CKD continuum model (Clough et al. 1989). An example of an LBLRTM calculation and validation is shown in Figure 1.

LBLRTM has recently been updated (version 6.01), and includes:

- The capability to input an atmospheric profile on either an altitude or pressure grid, and to output the optical depths and radiances on either an altitude or pressure grid.
- The capability to compute quantities for atmospheric layers, which are not in local thermodynamic equilibrium (Non-LTE option).
- The exponential function and the exact "linear in tau" function are now tabulated at 5000 values, and a table lookup is used in the radiative transfer calculation.

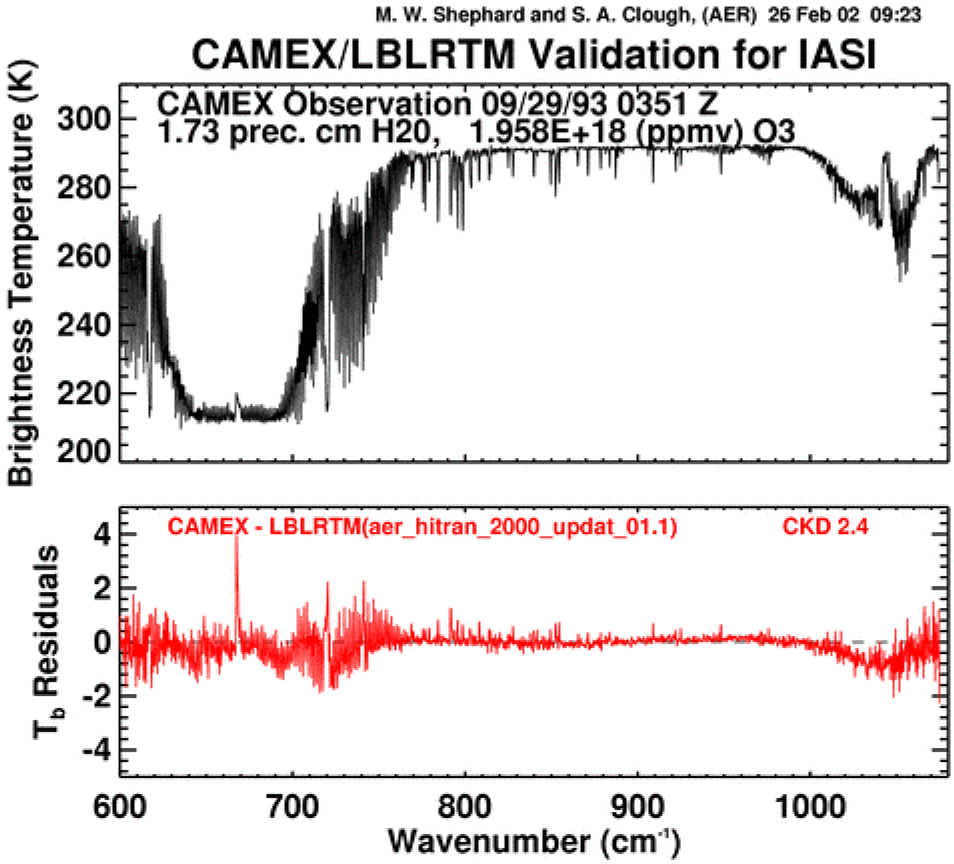

Figure 1. Plot of (top) observed U. Wisconsin HIS brightness spectrum in equivalent brightness temperature, and (bottom) observed – LBRLTM calculated spectral residuals.

- An update of the universal constants.

- The continuum model CKD 2.4 contains collision induced O_2 (15,000 to 29,870 cm^{-1}) continuum (Greenblatt et al. 1990).

- A "bug" correction in the fourth function contribution to the optical depth for lines with line coupling.

- Corrections for a number of errors associated with "scanmrg" options.

A new formulation of the water vapor continuum is being developed assuming contributions from two physical processes: (1) deviations from the line shape given by the impact approximation (the Lorentz lineshape) due to duration of collision effects; and (2) contributions to the absorption due to collision induced effects. The main effect of (1) is to reduce the absorption in the far wings from the Lorentz function. The main effect of (2) is to provide increased absorption in the central region of the water vapor bands, the magnitude and spectral width of which is a function of the collision physics. The new model is expected to be released in the summer of 2002.

LNFL and Line Parameter Database Update

LBLRTM calculations require detailed information about each spectral line within the spectral region of interest. These properties are obtained from large line parameter databases.

A line parameter database is currently available on the AER Web site. The currently available version, aer_hitran_2000_updat_01.1, is comprised of high-resolution transmission HITRAN_2000 (see http://www.hitran.com) with the following updates (http://www.hitran.com/hitran/updates.html):

- oxygen update 01/2001,
- methane update 02/2001,
- water update 04/2001,
- oxygen-A band line parameters from Camy-Peyret (2000) for isotopes other than the main isotope.

A FORTRAN Program (LNFL.f) is available to transform the database information into a format that can be input into LBLRTM. This program extracts a subset of the larger full line parameter database (i.e., selected species, wavenumber range, etc.) and adds line-coupling (mixing) parameters to the line parameter database. LNFL has been updated (v1.0) to include the following changes:

- Line coupling parameters for the CO_2 Q branches in the nu2 region (600-800 cm^{-1}) have been updated to be consistent with the HITRAN_96 line parameters (Includes first and second order coupling parameters).
- Line coupling parameters for CO_2 have been included (following Strow et al. 1994) at 1932, 2076, 2093, 2193 cm^{-1} (First order coupling only).
- Capability to have molecule numbers large than 36 in the linefile.

First Release of MonoRTM

MonoRTM is a radiative transfer model designed to process one or a number of monochromatic wavenumber values (Boukabara et al. 2001). It is particularly useful in the microwave spectral region, and is applicable to atmospheric laser propagation studies. Features of MonoRTM include:

- Utilizes the same physics and continuum model as the LBLRTM.
- Suitable for the calculation of radiances associated with absorption by molecules and cloud liquid water in the atmosphere.
- Applicable to uplooking/downlooking configurations.

- Spectral validity depends only on the spectral region covered by the spectral lines provided in the line parameter database file.

- The Monochromatic Optical Depth Model (MODM) module, dedicated to the calculation of the molecular optical depths, is the core component of MonoRTM.

- Uses the CKD continuum to include contributions from the far wings of the lines (Clough et al. 1989; CKD).

- Includes line coupling effects, which are important for oxygen lines in the microwave region (Hoke et al. 1989).

- Uses the Humlicek Voigt Line Shape (J. Humlicek 1982).

- Cloud liquid water absorption is calculated using a model developed by the Liebe, Hufford, and Manabe (1991).

RRTM_SW and RRTM Updates

RRTM_SW (Mlawer et al. 1998) and RRTM (Mlawer et al. 1997) are shortwave and longwave rapid radiative transfer models, which utilize the correlated-k approach to calculate fluxes and heating rates efficiently and accurately.

RRTM_SW

RRTM_SW (v2.4) has just been publicly released, and is available on the AER Web site. Key features of RRTM_SW are:

- k-distributions are obtained directly from LBLRTM, which has been extensively validated against observations, principally at the ARM SGP site.

- Fluxes and cooling rates can be calculated over fourteen contiguous bands in the shortwave (820-50000 cm^{-1}).

- Modeled sources of extinction are water vapor, carbon dioxide, ozone, methane, oxygen, aerosols, and Rayleigh scattering.

- Liquid cloud optical properties are parameterized using the Hu and Stamnes parameterization (1993).

- Ice cloud optical properties are parameterized using the Fu parameterization (1996).

- DISORT (Stamnes et al. 1988) is used to perform scattering calculations.

- Agreement with line-by-line calculations: 1 W/m^2 for direct irradiance, 2 W/m^2 for diffuse irradiance.

RRTM

RRTM (v2.3) is available on the AER Web site, and a new version is expected to release in June 2002. Key features of RRTM are:

- k-distributions are obtained directly from a LBLRTM, which has been extensively validated against observations, principally at the ARM SGP site.

- Fluxes and cooling rates can be calculated over sixteen bands contiguous bands in the longwave (10-3000 cm^{-1}).

- Modeled molecular absorbers are: water vapor, carbon dioxide, ozone, nitrous oxide, methane, oxygen, nitrogen and halocarbons.

- The flux accuracy, when compared against LBLRTM, is better than 0.6 W/m^2 in any band, and 1.0 W/m^2 over all bands. The cooling rate accuracies are .07 K/day in the troposphere and lower stratosphere, and .75 K/day in the upper stratosphere.

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