Flexible, Longwave Radiative Transfer (FLRT) in Clear and Cloudy Atmospheres

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Introduction

This paper introduces a flexible, longwave radiative transfer tool (FLRT), which can be used to create a correlated-k, multiple-scattering model for inhomogeneous atmospheres. The spectral bandwidths can be chosen by the user within the 10 to 3000 wavenumber range. FLRT provides a mechanism from which rapid radiative transfer models (RRTMs) can be generated. Rapid radiative transfer models permit accelerated calculations of radiances, fluxes and cooling rates without comprising accuracy. Such models have a variety of atmospheric radiative transfer applications. One application includes modeling radiance measurements in spectral channels of satellite or ground-based sensors.

Features of the Flexible, Longwave Radiative Transfer Tool (FLRT)

Radiative transfer computations in the infrared spectral region are notoriously demanding due to the complex line structures of the many radiatively active gases. Consequently, the absorption coefficients can vary rapidly across a small spectral interval and many monochromatic computations are required to produce spectrally-integrated quantities such as fluxes and cooling rates. Results from line-by-line models, which capture this variation in absorption coefficients, are extremely accurate but computationally prohibitive. The correlated-k method is an efficient, numerical procedure that substantially reduces the number of calculations in a spectral interval from a line-by-line model without compromising accuracy. This is accomplished by grouping, in ascending order by strength, the absorption coefficients within the wavenumber interval, which creates a smooth "k distribution." A much smaller set of characteristic absorption coefficients κ_j , where j represents a subinterval of the k distribution, can now be used in radiative transfer calculations for each homogeneous layer. The correlated-k method has been reviewed in detail in a number of papers (Arking and Grossman 1972; Goody et al. 1989; Lacis and Oinas 1991; Fu and Liou 1992; Mlawer et al. 1997).

FLRT employs the techniques of the Mlawer et al. (1997) RRTM to create k distributions from absorption coefficients provided by the line-by-line radiative transfer model (LBLRTM) (Clough et al. 1992; Clough and Iacono 1995). Absorption due to water vapor, carbon dioxide, ozone, nitrous oxide, methane and their accompanying continua is included in FLRT. Realizing that κ_j is dependent upon the atmospheric parameters in a given layer, κ_j's are calculated and stored on a grid for a host of pressures and temperatures. For a general atmosphere, κ_j for each layer can then be obtained by linear interpolation. The calculation of optical depths in a spectral band, including a band with overlapping absorbing species, is consistent with the RRTM method. Currently, FLRT uses the correlated-k radiative transfer algorithm employed by RRTM to calculate fluxes and cooling rates. However, its modular structure provides easy portability of optical depths for an atmospheric profile into multiple-scattering algorithms such as DISORT (Stamnes et al. 1988).

Validations of FLRT in the Atmospheric Window

The radiative transfer package, FLRT, automatically validates the correlated-k radiative transfer calculations against LBLRTM calculations using three different atmospheres with 51 layers (Figure 1).

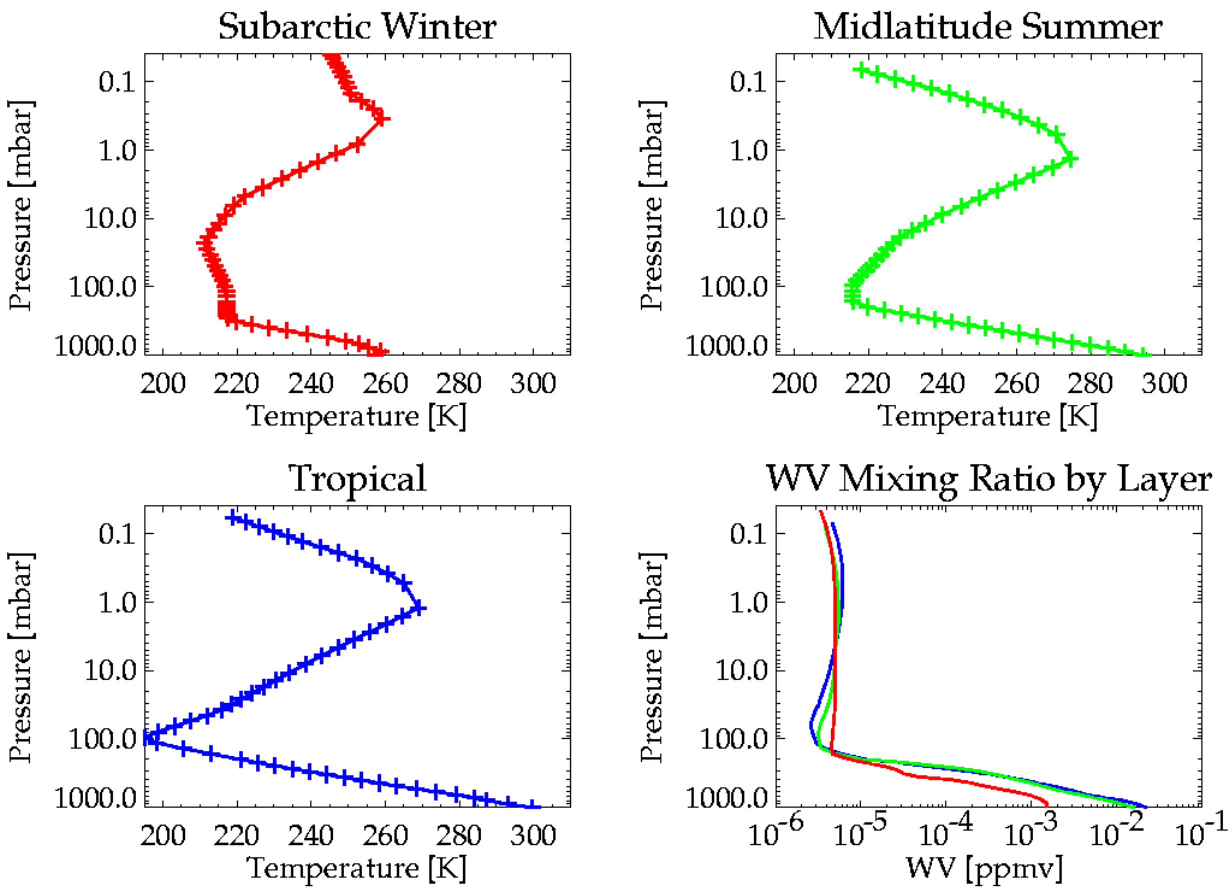

Figure 1. Standard validation atmospheres. FLRT automatically validates the correlated-k radiative transfer calculations against the LBLRTM calculations using three standard atmospheres: mid-latitude summer, tropical, sub-arctic winter. The levels are represented by (+) and all levels are at equivalent altitudes. The temperature and water vapor mixing ratio are plotted as a logarithmic function of pressure.

We now provide a sample calculation of fluxes (Figure 2) and cooling rates (Figure 3) in a spectral region, 910 cm^{-1} to 940 cm^{-1}, contained within the primary atmospheric window. The major absorbing constituent is water vapor with secondary absorption by carbon dioxide.

In a second example, the concentration of carbon dioxide was doubled from 355 ppm to 710 ppm for the mid-latitude summer atmosphere. Table 1 presents the comparison of FLRT calculations to LBLRTM calculations for upwelling and downwelling fluxes at the surface and the top of the atmosphere. The FLRT calculations for doubling carbon dioxide are nearly identical to the LBLRTM calculations.

Continuing Developments with FLRT

Our goal is to develop a user-friendly, flexible tool to generate RRTMs, which provide efficient and accurate calculations of fluxes and cooling rates. Several additional features are currently being integrated into the radiative transfer package. First, we are including the multiple-scattering algorithm DISORT as an option for the radiative transfer algorithm. In parallel with this feature, we are including

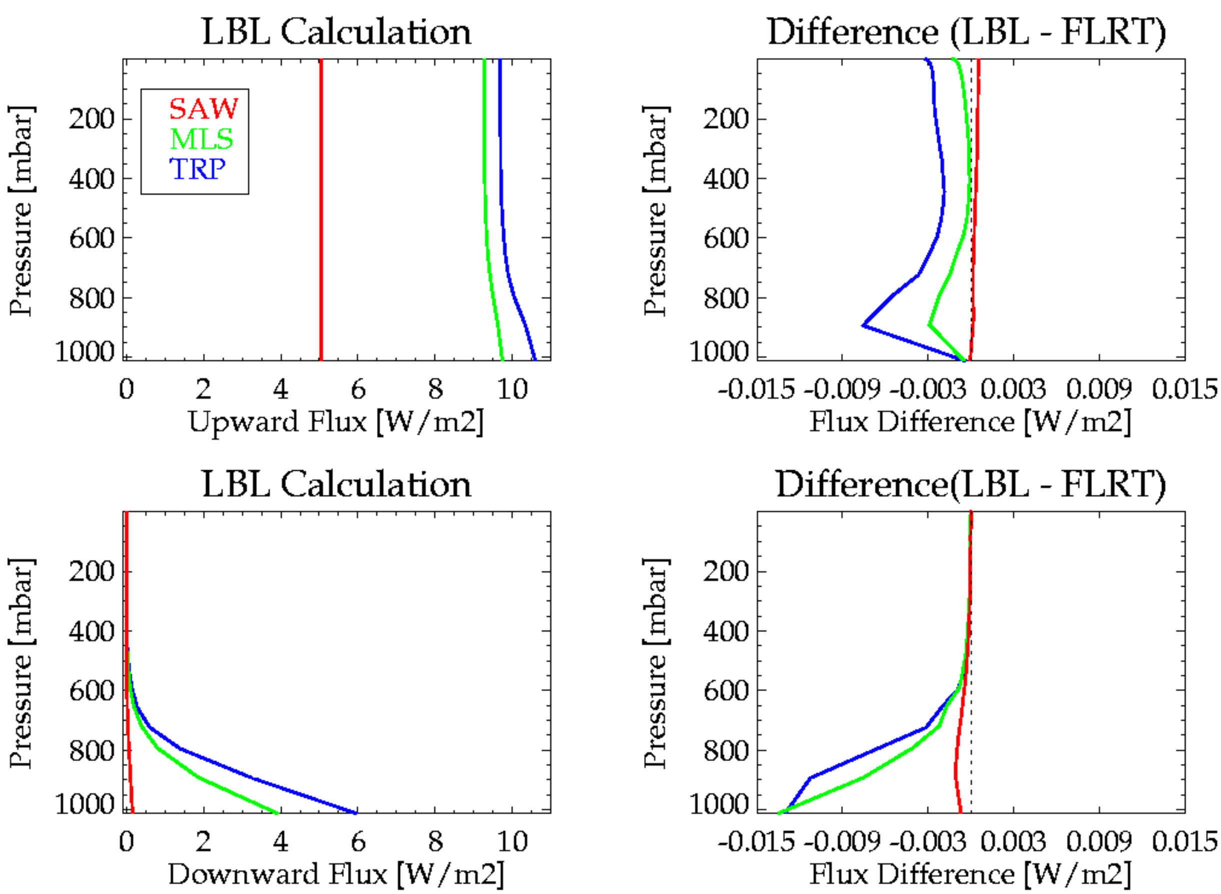

Figure 2. Flux comparison, 910 cm^{-1} to 940 cm^{-1}. Upwelling and downwelling fluxes are shown for three different atmospheres. The second column shows the absolute difference in [W/m^2] between LBLRTM and FLRT calculations.

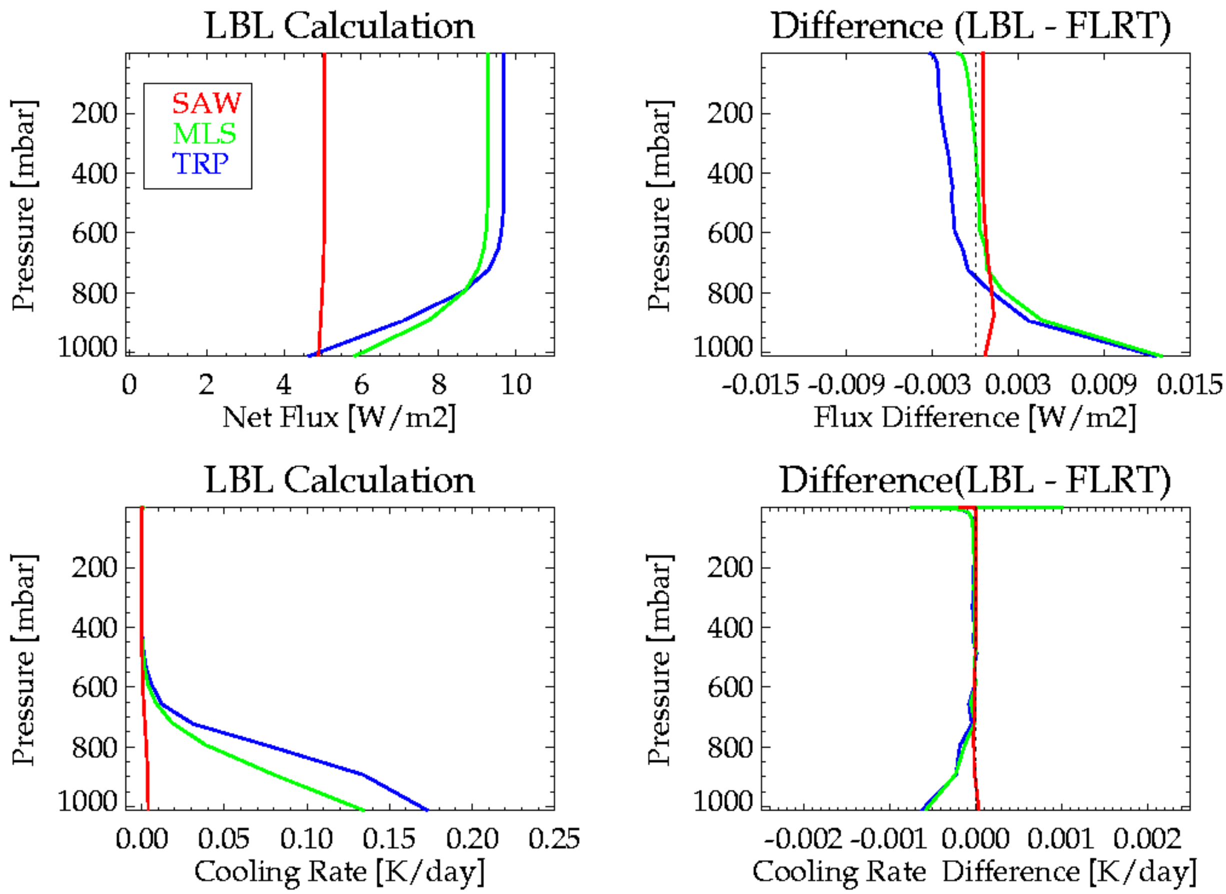

Figure 3. Net flux/cooling rate comparison, 910 cm^{-1} to 940 cm^{-1}. Net fluxes and cooling rates are shown for three different atmospheres. The second column shows the absolute difference in [W/m^2] between LBLRTM and FLRT calculations.

Table 1. Effect of doubling CO_2 in the atmospheric column.

	$F^{\uparrow}_{TOA}$			$F^{\uparrow}_{SFC}$			$F^{\downarrow}_{SFC}$		
CO_2	355	710	$\Delta_{710-355}$	355	710	$\Delta_{710-355}$	355	710	$\Delta_{710-355}$
LBL-RTM	9.268	9.233	-0.035	9.744	9.744	--	3.926	3.992	0.066
FLRT	9.269	9.236	-0.033	9.744	9.744	--	3.939	4.000	0.061

the option to have clouds present in the atmospheric profile. This option calculates the extinction coefficient, single-scattering albedo, and asymmetry parameter for liquid and/or ice particles. Additionally, we will add gaseous absorption by the halocarbons, which have been shown to modulate the lower-tropospheric cooling rates (Clough and Iacono 1995).

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