Development of a Freely-Distributed, Customizable Atmospheric Radiative Transfer Model

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Abstract: We present the University of Lethbridge Transmission and Radiance Atmospheric Model (ULTRAM). A comparison with FASCODE is presented, along with several sample applications of ULTRAM. The source code is freely available and easily customized.
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1. Introduction

Radiative transfer models (RTMs) are required in the design of remote sensing instrumentation in order to predict radiative flux received from a source under varying atmospheric conditions. One of the most commonly used RTMs is the Fast Atmospheric Signature Code [1] (FASCODE), developed by the United States Air Force. FASCODE allows users to simulate nearly any observing geometry through one of six built-in atmospheric profiles or through a user-specified atmosphere. Owing to its development heritage in the 1970's and to its simulation flexibility, FASCODE is a massive FORTRAN program, consisting of 71,000 lines of code in the main program alone. It is difficult to make any changes to the code without causing unanticipated and often far reaching effects in the program. The need for easy customization provided the impetus for the development of a new RTM, the University of Lethbridge Transmission and Radiance Atmospheric Model (ULTRAM), which like its predecessors is a line-by-line, multi-layer atmospheric model.

2. ULTRAM

2.1. Development of the RTM

One of the goals for the development of ULTRAM was to create a RTM that is more easily customized than FASCODE. The first consideration in the development process was the choice of a modern computer language. A fourth-generation computer language, the Interactive Data Language [2] (IDL®), was chosen for its advanced array handling abilities, simple syntax, and data visualisation capabilities.

ULTRAM was not developed to replicate the flexibility of FASCODE observing geometries, but rather with the goal of simulating either an observation through a column of atmosphere on a path from the ground to space, or through a homogenous gas cell (or horizontal path through the atmosphere). The compact nature of IDL® code and the limitation of observing geometries allowed ULTRAM to be written in ~1000 lines, a more manageable size.

Another development goal was to make ULTRAM a user friendly program. A graphical user interface (GUI) has been created to run ULTRAM and provide the user with an intuitive way to interact with the model. The GUI allows users to set up model atmospheres and gas cells according to their specifications. The 6 atmospheric profiles used in FASCODE (tropical, subarctic (winter), subarctic (summer), mid-lattitude (winter), mid-lattitude (summer), and US Standard Atmosphere (1976)) are all available for use in ULTRAM. Users can have ULTRAM automatically set up pressure and temperature profiles by inputting base pressure and temperature, lapse rate, and layer boundary values. Users can also select from 37 molecular species to include in the simulation. ULTRAM uses the 2000 version of the HITRAN [3] spectral line database as the source for line parameters.

2.2. Verification of Results

Simulations by FASCODE were used to validate ULTRAM. At the time of ULTRAM's development, our group was involved in a project that required the modeling of the spectral features of water vapor in the atmosphere above Mauna Kea, Hawaii [4, 5]. Both FASCODE and ULTRAM were used to simulate the transmission of the atmosphere in the 5 – 35 cm^{-1} region, and these spectra are shown in Fig. 1. In the figure, the spectrum produced by

ULTRAM (gray) is displaced vertically for clarity of comparison with the FASCODE spectrum (black). The spectra in Fig. 1 correspond to a column amount of 1 mm precipitable water vapor (PWV) and were produced using identical model atmospheres, pressure and temperature profiles, and atmospheric layer boundaries. The spectra in this region are dominated by strong water vapor lines, such as the one centered at 20.7 cm^{-1}. A manifold of shallow, narrow ozone lines is seen across the top of the spectra.

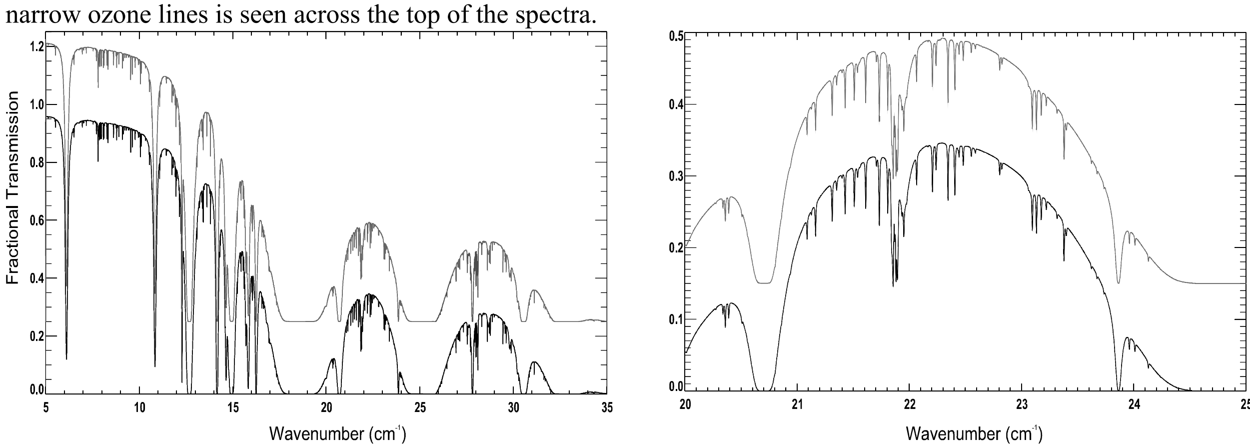

Figure 1: Comparison of FASCODE (black) and ULTRAM (gray, vertically shifted) simulations of the atmosphere above Mauna Kea with water vapor column abundance of 1 mm PWV.

A broad comparison of the two spectra (Fig. 1, left panel) shows that they are very similar. However, a close examination of some of the ozone lines (the 21 – 23 cm^{-1} region, in right panel of Fig. 1) shows that several ULTRAM lines have different strengths than their FASCODE counterparts. This difference was found to be due to an update to the line strengths in the HITRAN spectral line database between FASCODE (which used the 1986 version) and ULTRAM (which used the 2000 version). Further comparisons between ULTRAM and FASCODE spectra repeatedly showed excellent agreement.

3. Applications of ULTRAM

ULTRAM was put to use in several projects [4, 5]. Two sample applications are discussed below.

3.1. Modeling Atmospheric Water Vapor Above Mauna Kea

ULTRAM was used extensively in a research effort to measure the emission of water vapor in the atmosphere above Mauna Kea in the mid-infrared 20 μm (500 cm^{-1}) spectral region with a radiometer [4, 5]. Emission in this region is dominated by numerous water vapor lines, with negligible contribution from other atmospheric species.

A model of the Mauna Kea atmosphere was generated using radiosonde data to create realistic pressure and temperature profiles. ULTRAM used this atmospheric model to simulate emission spectra in the 20 μm region for with varying water vapor column abundances. An emission spectrum corresponding to a water vapor column abundance of 1 mm PWV is shown in Fig. 2. Using the ULTRAM emission models, the atmospheric water vapor column abundance above Mauna Kea can be determined from radiance measurements collected by an infrared radiometer we have built [5].

3.2. Modeling a Methane Leak

ULTRAM has also proven useful to predict the spectral characteristics of methane leaks from natural gas pipelines in the 1250 – 1320 cm^{-1} (8 – 7.6 μm) spectral region. In one scenario, a methane leak results in a plume of cool gas in front of a warm background (such as a hill or building). The warm background emits as a blackbody, while the atmosphere in front of it absorbs at specific wavelengths characteristic of methane.

For the simulation shown in Fig. 3, the background temperature is set at 293 K while the gas in front has a temperature of 283 K. The gas in front of the warm background was simulated as a 100 m cell of atmosphere at sea level with a relative humidity of 20%. The 3 spectra shown in the figure represent an addition of 1 ppm (bottom), 10 ppm (middle), and 100 ppm (top) by volume of methane. The 10 and 100 ppm spectra are vertically displaced for clarity. The strong absorption feature at ~1305 cm^{-1} (~7.66 μm) is due to methane and shows the potential use of this wavelength range as a diagnostic for methane leaks. Many of the lines which do not change strength in the spectra are due to water vapour (for instance, the feature at 1280 cm^{-1}).

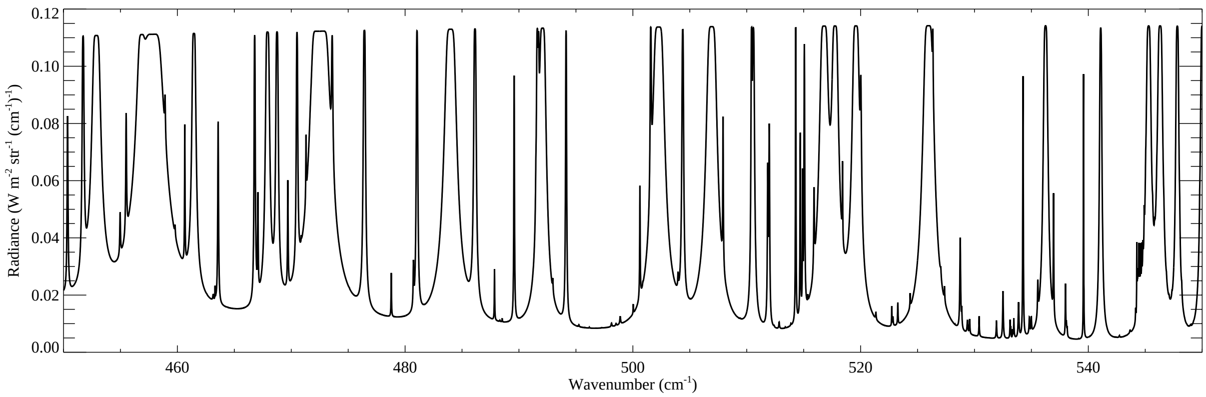

Figure 2: Emission spectrum for the atmosphere above Mauna Kea with a water column abundance of 1 mm PWV.

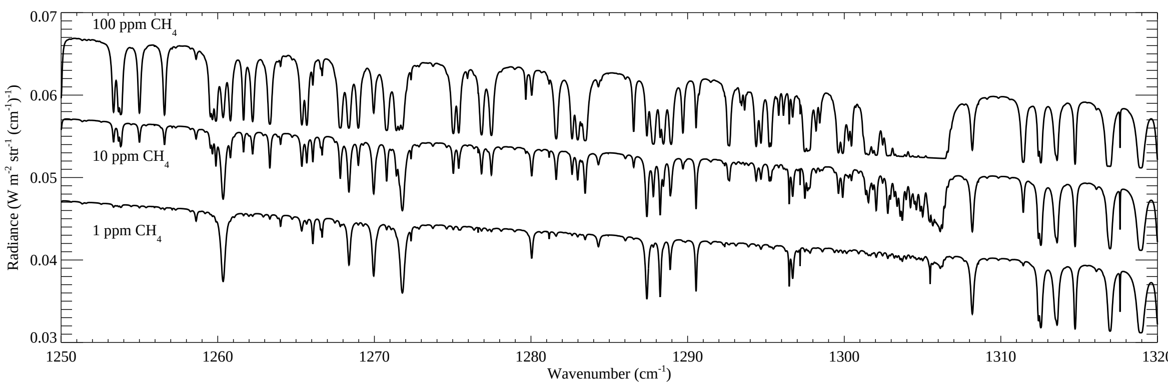

Figure 3: Spectra of 100 m cells of 283 K methane in front of a 293 K blackbody background. From bottom to top, the cell had 1, 10, and 100 ppm by volume of methane in air respectively. While the majority of features in this region are due to methane, emission from other atmospheric constituents is also evident (e.g. 1280 cm^{-1}).

4. Future Work

Currently, ULTRAM has only a rudimentary GUI with limited controls. Work on a new GUI with more options and a more intuitive design is in progress. The new GUI will allow users to save parameters used in their modeling sessions, present them with more options in creating a model atmosphere, and allow for the importation of custom atmospheres using text files.

Currently, ULTRAM only simulates a simple, straight-line path through an atmosphere or gas cell. Further development of ULTRAM will focus on adding to the possible observing geometries as well as adding further modules to simulate scattering and radiative transfer through aerosols.

With the addition of the virtual machine in IDL® 6.0, ULTRAM can now be freely distributed to interested users. An automatic installer is being developed which will allow users to easily install ULTRAM on their own systems. Parties interested in obtaining ULTRAM are invited to contact either of the authors via email for downloading instructions. An automatic distribution system over the web is currently being developed and will be implemented as it is completed.

5. References

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