Fast Atmospheric Signature Code for the Environment (FASE)

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Abstract

The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program and the Optical Physics Division of the U.S. Air Force Phillips Laboratory (USAF PL/GPOS) are jointly supporting the development of a state-of-the-art line-by-line (LBL) atmospheric radiative transfer model. The new model, known as FASCODE for the Environment, or "FASE," is an LBL atmospheric radiation code, which is grounded in the original USAF FASCODE (Fast Atmospheric Signature Code) line shape decomposition algorithm and now envelops both agencies' important upgrades. ARM's LBLRTM (LBL Radiative Transfer Model, authored by S. A. Clough and P. D. Brown of Atmospheric and Environmental Research, Inc. [AER]) improved the FASCODE algorithm by specifically addressing scientific and coding issues of particular concern to the climate community including the following: lineshape and radiance algorithms, H_2O and CO_2 continua, code vectorization and array parameterization, and input/output modes. These features have been recombined with the FASCODE non-LTE and laser options, plus shared common elements from MODTRAN (Moderate Resolution Transmittance Model, a 2 cm^{-1} band model) evolution. These latter options include new solar irradiance (for direct transmittance and surface reflectance), upgraded UV cross sections, and improved cloud and aerosol descriptions. This paper gives an overview of recent model validations and the implementation of new features.

Introduction

FASCODE for the Environment (FASE) was developed by combining features from the LBL radiative transfer codes of the U.S. Air Force Phillips Laboratory (FASCODE) (Anderson et al. 1994) and the U.S. Department of Energy (LBLRTM) (Clough et al. 1993). Both of these models were derived from FASCOD3 which was based on FASCOD1B, a four-function LBL code developed by Clough and Kneizys (Clough et al. 1981; Clough and Kneizys 1979). The rationale for the development of FASE is to make available to the atmospheric spectroscopy community the results of on-going work sponsored by the DOE while incorporating the results of continuing research and development at the U.S. Air Force Phillips Laboratory. An initial version of FASE (Snell et al. 1995c) was available for limited release and testing in the summer of 1995; beta-version 2.0 will be available in June 1996. This paper will summarize recent improvements to FASE and describe the on-going effort to fully merge the capabilities of FASCODE and LBLRTM. The reader is referred to the paper by Snell et al. (1995a) for information about initial model validations against measurements.

New/Improved Features

The current version of FASE contains several new or improved features. These include the FASCODE option for LASER calculations, an enhanced method of specifying the

boundary emissivity or reflectivity, new coefficients for absorption cross-sections in the visible and ultraviolet, and the addition of a solar spectrum module for atmospheric transmittance and surface reflectance calculations.

LASER Option

The laser option from FASCODE allows the user to calculate only the narrow region centered at a specific wavenumber and is useful for the simulation of laser-based experiments and as input to LIDAR analyses. Because of the nature of the algorithm employed by FASE, FASCODE, and LBLRTM to merge the optical properties of different atmospheric layers (Snell et al. 1995b), use of the LASER option is recommended for accurate results at a single monochromatic frequency. Calculations show that distortions arising from fixed frequency assumptions can be significant, particularly in spectral regions where the absorption changes rapidly over a narrow spectral interval. For example, at 23.8 GHz (0.794 cm^{-1}) an error of about 5% is introduced if one does not use the LASER option.

Emissivity /Reflectivity Coefficients

Initially FASCODE, LBLRTM, and FASE had the option of specifying the spectral signature of the boundary emissivity and/or reflectivity through the use of quadratic coefficients. Unfortunately, this is not sufficient for simulating surfaces in which the emissivity or reflectivity has a non-uniform spectral distribution, e.g., the sea-surface emissivity (Snell 1995a). To increase the flexibility of FASE, the input file now includes the option of reading the emissivity and reflectivity coefficients from user-supplied data files. This will be particularly useful in simulating measurements that will be made at the new Tropical Western Pacific ARM site, but also for nighttime surface emissivities for known near-IR sources, such as vegetation, snow, or sand.

Calculations in the UV/Visible

Two major changes were made for UV/Visible calculations. First, the coefficients for ozone absorption were updated and a temperature dependence was introduced (Shettle and Anderson [submitted]). The new values, which include both the Chappuis and Wulf absorption, cover the range from 9170 to 24565 cm^{-1} at a resolution of 5 cm^{-1}. The second change in the UV was the inclusion of the O_2 Schumann-Runge absorption cross-sections between 49000 cm^{-1} and 57000 cm^{-1}. The Schumann-Runge system is interesting because it results from a pre-dissociative electronic transition (Yoshino et al. 1983) which leads to natural halfwidths of order 0.5 to 1.0 cm^{-1}, about ten times larger than the assumed NTP halfwidths of the transitions on the HITRAN database. These lines are on the HITRAN96 spectral database but are incompatible with the Voigt lineshape decomposition algorithm employed by FASE, FASCODE, and LBLRTM because of their inherent halfwidth assumption. Thus FASE computes the absorption using polynomial coefficients developed from a fit devised by Minschwaner et al. (1992; in press). The fit was accomplished on a 0.5 cm-1 spectral grid using cross-sections obtained from a LBL radiative transfer model and includes contributions from the temperature-dependent Schumann-Runge continuum.

Figure 1 illustrates the Schumann-Runge absorption in the spectral region from 50500 - 52500 cm^{-1}. The dashed line is the FASE calculation and the solid line is the measured spectrum (Anderson and Hall 1983, 1986). The calculation was made using only the known viewing zenith angle, balloon altitude and corresponding pressure level, and the US Standard temperature and ozone profiles. No specific attempt was made to accurately retrieve molecular amounts to obtain a better fit between model and measurement. However, this comparison shows the good agreement between the structure of the computed spectral features and those of the measurement.

Solar Spectrum

The addition of a solar spectrum module gives FASE the capability of computing solar transmission through the atmosphere. This capability is particularly useful for simulations of experiments employing the technique of solar absorption spectroscopy, but is also necessary when simulating a down-looking measurement over a reflective surface.

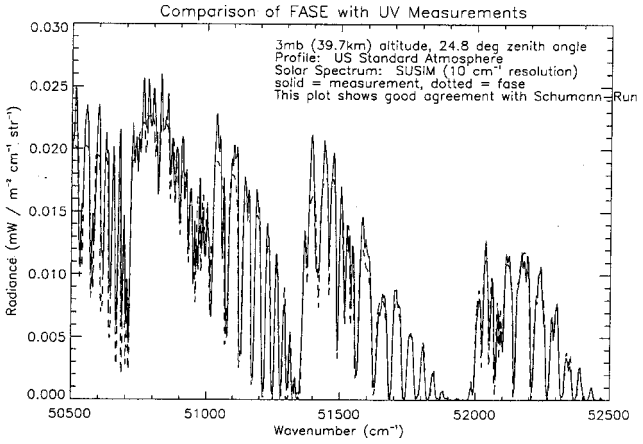

Figure 1. FASE calculation in the UV showing excellent agreement between the modeled Schumann-Runge bands and a measured spectrum.

Currently the module can be used to compute the transmitted solar irradiance either as the direct component (for direct solar observations or limb-viewing cases), or the direct component reflected off a surface (for down-looking applications). Ultimately the solar model will be used with a multiple-scattering routine to include the diffuse radiation component for a better treatment of the atmospheric radiation field. The solar spectrum was calculated by Kurucz (1994) for wavelengths greater than 200 nm; for wavelengths less than 200 nm, SUSIM data collected on the Space Lab 2 flight of the Space Shuttle were used (Hall and Anderson 1991). Figure 2 shows the good agreement between FASE and measurements in the region 49000 - 50000 cm^{-1}. This spectral region contains many solar Fraunhofer lines and this structure is captured in the FASE solar spectrum (as with Figure 1, no attempt was made to retrieve the molecular species and obtain a better fit between the model and the measurement).

On-Going Science Improvements

New Cloud/Rain Descriptors

Changes to the cloud and rain routines are under way based on improvements developed for MODTRAN (Berk 1995). This set of upgrades makes it easier to modify the cloud/rain models (by re-configuring and clarifying the coding structure), as well as provides for a more flexible prescription of realistic cloud and aerosol layers and their associated optical properties

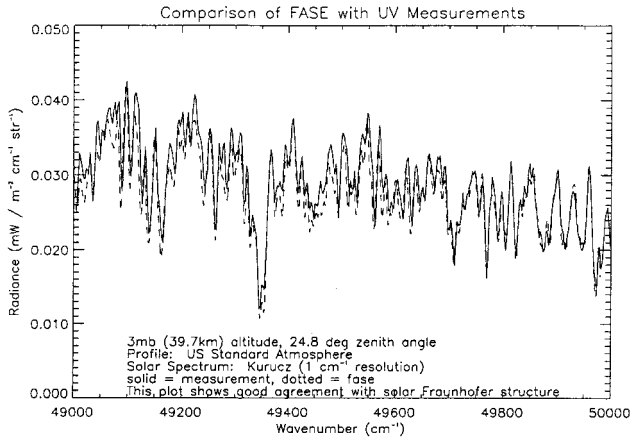

Figure 2. FASE calculation in the UV showing excellent agreement between the model and a measured spectrum. Note that most of the structure in this region is due to solar Fraunhofer lines, which are accurately reproduced with the Kurucz solar spectrum.

The improved layering scheme allows for multiple overlapping and non-overlapping clouds. For cumulus and stratus type clouds, with and without rain, the upgrades include adjustable cloud parameters (thickness, altitude, vertical extinction, etc.); decoupling of the clouds from aerosols (allowing clouds and aerosols to be present at the same altitude); the introduction of ice particles; and a flexible set of user-defined cloud spectral properties, water droplet, ice particle, and rain rate profiles.

Calculations with the new cloud models illustrate (Figure 3) the change in radiance with a change in cloud thickness and base height. The cloud consisted of a cumulus cloud with overlying cirrus (the cloud top and cirrus thickness were held constant). The marked change in radiance for a cloud with a base at 0.4 km and one at 1.88 km shows the need for a versatile cloud simulation capability, even for direct radiance and transmittance (no scattering) calculations.

New Absorption Cross-Sections

Laboratory measurements of the absorption properties of heavy molecules have recently been made by Varanasi and Nemtchinov 1994) (subsequently referred to as "Varanasi's cross sections") and are expected to be included on the release of the HITRAN96 databases (Rothman et al. 1987). Because of the complexity of the transitions of these molecules and the fact that individual spectral lines cannot be resolved at temperatures and pressures typical of the earth's atmosphere, the measurements consist of 0.01 - 0.03 cm^{-1} spectral information in the form of absorption cross-sections (i.e., without information about line strengths, positions, halfwidths, etc.). Many of these molecules have already been

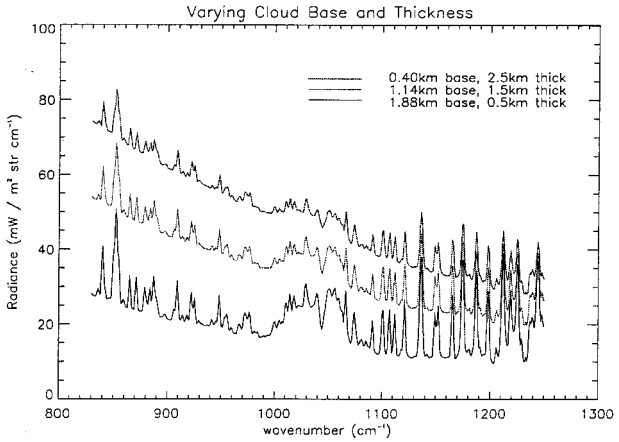

Figure 3. Example of the one of the new FASE cloud options: the user now has the ability to easily change cloud base altitude and cloud thickness.

already been included in that form, as temperature-dependent cross sections, on previous versions of the HITRAN databases. However, the Varanasi measurements are provided as a function of pressure and temperature as opposed to the previous HITRAN format, which extrapolated the temperature-dependent values to zero pressure. (This extrapolation has been done without fully correcting for the change in Voigt line shape at the lower pressures, so that the apparent spectral line features remain those of the primary instrument resolution.) To compute the optical depth for a particular (p,T) combination with the 'old' data, it was necessary to interpolate between temperatures while convolving with the appropriate Lorentz line shape for the pressure, finally combining this derived cross section with the density weighted path amounts. With the Varanasi data, one is required to interpolate and/or extrapolate between the tabulated data in order to arrive at the correct absorption coefficient. Thus, to accommodate this new data directly, it would be necessary to re-configure the FASE algorithms to bypass the convolution and perform the necessary interpolation and/or extrapolation. Further, one must develop an appropriate scheme for extrapolating the tabulated values to pressures and temperatures outside the range of the measurements, which tended to be preselected for pressure/temperature combinations encountered during limb viewing. Limb viewing is only one of many types of viewing geometries supported by FASE; other types of paths must also be supported if users are to be able to take full advantage of these recent measurements.

One approach through which the Varanasi cross-sections may be utilized by the FASE algorithms is to perform a least-squares fit to the data with a series of spectral lines, solving for the line strength, halfwidth, and lower state energy.[(a)] The pseudo-line approach incorporates all the (p,T) combinations of data into the least-squares fit and extends the applicability from a simple interpolation between two (p,T) values. The pseudo-line data are easily merged with the spectral line data taken from HITRAN when creating the spectral line file to be used by FASE, and the radiative transfer calculations are performed as usual, with the model using the spectral line routines, rather than the cross-section routines, when computing the absorption of these species. In Figure 4, Varanasi's data for CFC-12 are compared with the absorption cross-section computed in this manner.

One drawback to the pseudo-line approach is that new sets of pseudo-lines are required as more molecules are added. In the long run, it might be desirable to develop a scheme to use the cross-sections given as a function of pressure and temperature. Since the problem lies in interpolating/extrapolating the absorption coefficient data to specific values of the pressure and temperature, one might use the pseudo-line approach to fill out the full matrix of required pressures and temperatures (that is, use FASE to compute the absorption coefficients for the regions not represented by the measurements). For the time being, the pseudo-line approach has been implemented in FASE and exploration continues on ways in which the actual data can be used, perhaps in conjunction with 'pseudo-data' based on calculations with the pseudo-lines.

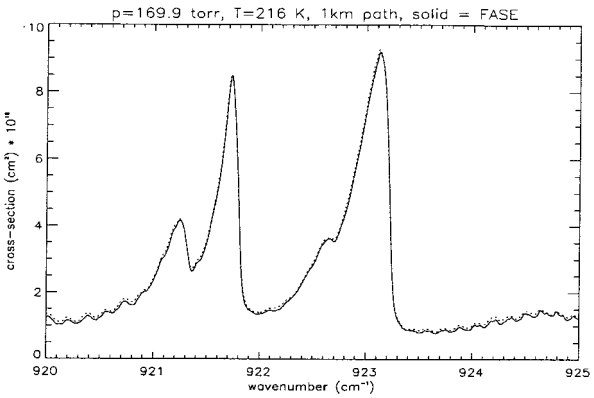

Figure 4. Comparison of the computed CFC-12 cross-section (solid line) with the measured cross-section (dotted line) at 169.9 torr and 216 K.

Conclusions

Significant progress has been made in the merging of FASCODE and LBLRTM to create FASE. The result is a radiative transfer model which contains state-of-the-art atmospheric physics through validations of LBLRTM with ARM data, while also incorporating many of the features from FASCODE not found in LBLRTM but required for flexible use of the code under airborne, ground- and space-based conditions. Current updates planned for FASE include the re-introduction of the FASCODE multiple-scattering routines (Isaacs et al. 1987) and the complete implementation of Varanasi's data as a set of pseudo-line parameters. Further, FASE will undergo continuous validation against measurements from the DOE ARM site as well as a variety of DoD datasets.

Acknowledgments

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(a) Personal communication, Geoff Toon, Jet Propulsion Laboratory, November 1995.

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