A Narrowband Database for the Rapid Convolution of LBL Transmittances

D.S. Turner
Atmospheric Environment Service (AES)
Downsview, Ontario, Canada

1. INTRODUCTION

In order to operationally process the vast amounts of satellite data received daily, fast and efficient radiative transfer models are required. These models usually employ parameterized monochromatic equivalents of the top of the atmosphere (TOA) transmission function instead of the more accurate, but computationally expensive, line-by-line (LBL) transmittance models.

Typically coefficients of a parameterized model are derived by regressing an appropriate set of independent variables against LBL generated transmittances for a set of representative atmospheric states. This process is repeated for all channels of interest.

Since a parameterization is based on the convolution of an instrument response function with simulated atmospheric spectra, the parameterization coefficients are inherently channel specific. Consequently a new set of coefficients must be assembled each time a new instrument is placed in orbit, which in turn requires new LBL TOA transmittance simulations. This process requires enormous quantities of computational resources.

In order to reduce the computational resources required to obtain simulations, the Atmospheric Environment Service (AES) has created a database that contains moderate resolution transmittance spectra to facilitate the speedy production of mean transmittances. The database consists of the TOA transmittances for AES's set of representative atmospheric states for various absorbers and zenith angles. The database is primarily designed to support our work with the GOES and NOAA infrared channels.

2. THE LINE-BY-LINE MODEL

The transmittance calculations are performed using AES's fast LBL radiative transfer model, FLBL (Turner 1995). Essentially the FLBL is an LBL model that uses absorption coefficient lookup tables to replace the time consuming part of an LBL code that calculates absorption coefficients directly from a spectral database. The FLBL assumes a plane parallel atmosphere, no scattering and no refraction.

The FLBL lookup absorption coefficients were calculated assuming; a Voigt line shape, the water vapour continuum developed by Clough (1980), the modified lineshape of Cousin (1985) for CO_2 in spectral regions greater then 2000(cm^{-1}), the empirical formulations of the collisional induced continua of O_2 (Thibault 1997) and N_2 (Lafferty 1996), and the HITRAN96 spectral database (Rothman 1998). A lookup table exists for each of the main absorbers (H_2O, CO_2, O_3, N_2O, CO, CH_4, O_2 and N_2) in the 600 to 1600(cm^{-1}) and the 2000 to 3000(cm^{-1}) spectral regions at a resolution of .005(cm^{-1}). At each wavenumber, contributions from lines as far away as 200(cm^{-1}) may be considered.

The atmospheric state database consists of 189 profile sets. Each set consists of a temperature profile and mixing ratio profiles for H_2O and O_3, CO_2, N_2O, CO, CH_4, O_2 and N_2. The latter six are fixed to US standard values. The database has been described elsewhere (Turner 1997).

Employing the FLBL, the mean TOA transmittance across a .5(cm^{-1}) narrowband is evaluated for the usual 42 TOVS pressure levels, for eight absorbers at six zenith angles. The six angles ($\sec\theta$=1, 1.25, 1.5, 2., 2.5, 3.) cover a range that is excessive for a polar orbiting sounder, but was extended for GOES research. In addition, an extra transmittance that contains the contributions from all absorbers is generated for a total of nine categories. This was repeated for each narrowband in the range from 600 to 1600(cm^{-1}) and from 2000 to 3000(cm^{-1}). These calculations are repeated for the 189 representative state resulting in a large set of .5(cm^{-1}) resolution transmittance spectra.

3. COMPARISON WITH FLBL

A subset of 32 states was taken from the atmospheric state database and mean transmittances were generated by convolving the NOAA 12 HIRS response functions with the narrowband data base and integrating with respect to wavenumber. Transmittances for this subset were also generated using the FLBL. Integrating the narrowband data is approximately 400 times faster than processing with the FLBL.

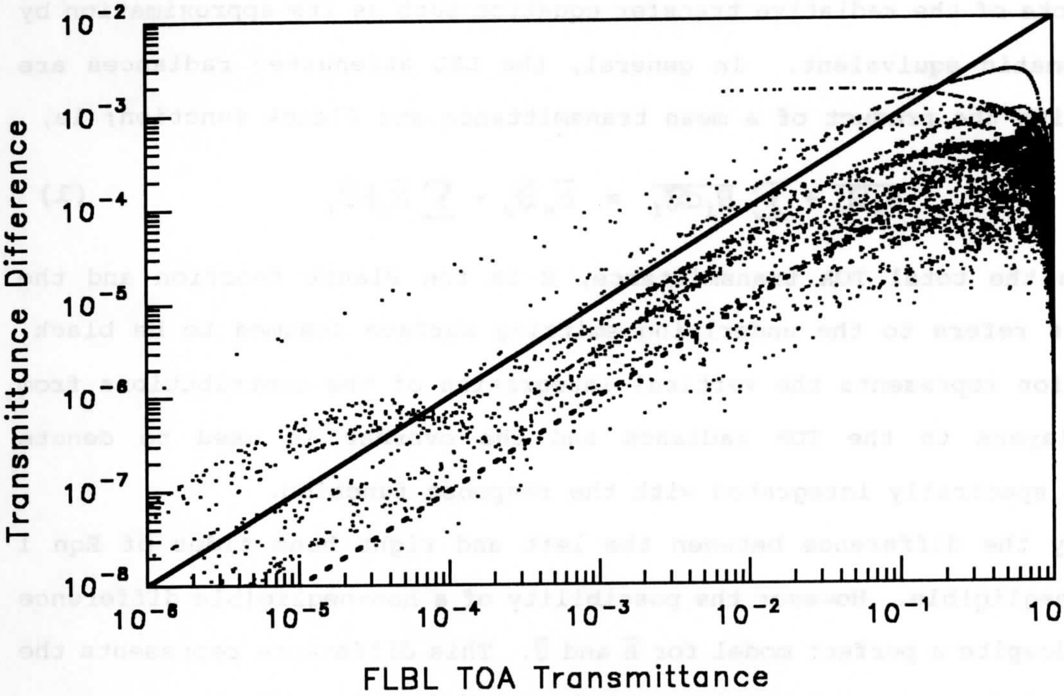

Figure 1: Comparison of FLBL and narrowband generated TOA transmittances. The maximum absolute value of the difference is plotted for all channels, absorbers and levels. The solid and dotted lines are the absolute percentage difference at 1% and .1%, respectively.

Figure 1 compares the maximum absolute differences between the FLBL and narrowband generated TOA transmittances observed in the group of 32 profiles for each of the levels, categories, channels and angles. For the most part the transmittances are in good agreement. They are in generally within .001 of each other. The points on the upper side of the one percent line are due to CO_2 (HIRS 1, 2 and 6) for transmittances greater than .01 and due to CO_2 and H_2O elsewhere. All other absorbers fall below the one percent line.

4. AN APPLICATION

The narrowband database's main purpose is to provide for the rapid generation of mean transmittances. These transmittances are used to generate coefficients for a parameterized forward model or to validate models whose coefficients have been generated by some other means. Thus far, the database has been used to tune the AES forward model (Garand 1997) for the GOES 8 and 10, and the NOAA 12 and 14 sounding channels.

The narrowband database has other uses. For example, it can be used to study aspects of the radiative transfer equation such as its approximation by a monochromatic equivalent. In general, the LBL attenuated radiances are replaced with the product of a mean transmittance and Planck function; ie,

$$\overline{B_s\mathfrak{T}_s} + \sum \overline{B_i d\mathfrak{T}_i} \approx \bar{B}_s\bar{\mathfrak{T}}_s + \sum \bar{B}_i \delta\bar{\mathfrak{T}}_i \tag{1}$$

where $\mathfrak{T}$ is the total TOA transmittance, B is the Planck function and the subscript s refers to the underlying emitting surface assumed to be black. The summation represents the vertical integration of the contributions from emitting layers to the TOA radiance and the overbar is used to denote quantities spectrally integrated with the response function.

Ideally the difference between the left and right hand sides of Eqn 1 should be negligible. However the possibility of a non-negligible difference can exist despite a perfect model for $\bar{B}$ and $\bar{\mathfrak{T}}$. This difference represents the error in assuming a monochromatic-equivalent model to the LBL.

The radiances for each quantity in Eqn 1 were evaluated for the NOAA12 HIRS channels by integrating across the narrowband transmittances. The Planck function where required is evaluated at the midpoint of the .5cm^{-1} narrowband. This was for each of the 189 states at six zenith angles assuming a "black" surface at 1000mb. The left and right hand sides of Eqn 1 were then transformed to brightness temperature space and differenced. The mean difference, or bias, and its standard deviation of the 189 differences for each channel at 6 zenith angles is tabulated in Table 1.

The magnitude of the bias varies from channel to channel. For most channels the difference is not particularly significant. Significant being defined as biases that are greater than .1K. HIRS 12 has the most significant bias at .38K, with HIRS 10, 13 and 15 coming in at roughly half that value. The standard deviations correlate with the biases at values less than .1K, which implies that the approximation primarily would affect the biases in a retrieval scheme.

Noticeable angular dependencies can be seen in HIRS 10, 11, 13, 15 and 16, however unless high angles are being considered (ie, potentially with GOES sounding channels) the dependencies are not significant.

Clearly the approximation of a monochromatic-equivalent type forward model results in a systematic error in some channels.

Table 1: Mean and standard deviation of ΔBT for 6 zenith angles assuming a black surface at 1000mb

	θ= .0° mean std	θ=36.9° mean std	θ=48.2° mean std	θ=60.0° mean std	θ=66.4° mean std	θ=70.5° mean std
1	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00
2	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00
3	.00 .01	.00 .01	.00 .00	.00 .00	.01 .01	.01 .01
4	-.02 .01	-.02 .01	-.02 .01	-.02 .01	-.01 .01	-.01 .01
5	-.01 .00	-.01 .00	-.01 .00	-.01 .00	-.01 .00	-.01 .00
6	-.01 .00	-.01 .00	-.01 .00	-.01 .00	-.01 .00	-.01 .00
7	-.02 .00	-.02 .00	-.02 .00	-.02 .00	-.03 .01	-.03 .01
8	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00	.00 .00
9	.07 .02	.07 .02	.07 .02	.08 .03	.08 .03	.08 .03
10	.12 .04	.14 .04	.15 .04	.17 .05	.19 .05	.20 .05
11	.05 .04	.04 .05	.04 .04	.03 .04	.03 .04	.02 .04
12	.38 .06	.38 .06	.38 .07	.38 .07	.37 .08	.36 .08
13	.13 .02	.14 .03	.15 .03	.17 .03	.19 .04	.20 .04
14	.05 .01	.05 .01	.06 .01	.06 .01	.07 .02	.07 .02
15	.17 .06	.16 .06	.16 .07	.15 .08	.13 .08	.11 .08
16	.10 .09	.08 .08	.06 .08	.03 .07	.00 .06	-.02 .05
17	.05 .01	.05 .01	.05 .01	.05 .01	.05 .01	.05 .01
18	.00 .00	.00 .00	.00 .00	-.01 .00	-.01 .00	-.01 .00
19	-.01 .01	-.01 .01	-.01 .01	-.01 .01	-.02 .02	-.02 .02

5. SUMMARY

A database has been created at AES containing .5(cm^{-1}) resolution TOA transmittance spectra for numerous levels, angles and absorbers for AES's atmospheric state database. These spectra cover the regions relevant to infrared sounding instruments found on both POES and GOES satellites.

The database's primarily use is to provide a more timely means of generating new fast transmittance model coefficients for new instruments by generating mean transmittances quickly.

The database can be used for other studies such as examining the effectiveness of the monochromatic approximation of the radiative transfer equation. For some channels, notably HIRS 12, the approximation leads to a systematic error of .38K which may be significant in some applications. Although this error could be reduced in a bias correction scheme, it would be better if the parameterized model could be modified in order to reduce the differences. Work is currently in progress to try and reduce the magnitude of this error.

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