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MODTRAN3: AN UPDATE AND RECENT VALIDATIONS AGAINST AIRBORNE HIGH RESOLUTION INTERFEROMETER MEASUREMENTS

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1. Introduction

MODTRAN, the Moderate Resolution Atmospheric Radiance and Transmittance Model, encompasses all the capabilities of LOWTRAN 7 (*Kneizys et al.*, 1988), the widely used 20 cm^{-1} resolution radiance code, but incorporates a much more sensitive molecular band model with 2 cm^{-1} resolution. The band model is based directly on the HITRAN spectral line compilation, including both temperature and pressure (Voigt line shape) dependencies. The 2 cm^{-1} spectral resolution of the MODTRAN band model is based on the original development of Berk, Bernstein, and Robertson (*Berk et al.*, 1989). With the expected release of HITRAN94 data base at the end of 1994, MODTRAN will be immediately updated to accommodate new spectroscopy. MODTRAN contains many important elements that other band model based radiative transfer codes do not incorporate. It shares with FASCODE: spherical geometry, single and multiple scattering (Rayleigh, Mie), default atmospheric profile descriptors (gases, aerosols, clouds, fogs, and rain), and molecular continua (H_2O, CO_2, O_3, O_2, N_2). In addition, it can calculate the solar/lunar direct and scattered radiation. MODTRAN3 was released to the general public in November 1994. It has several important features that the previous version, MODTRAN2, does not have. Chloro-fluorocarbon (CFC) and related heavy molecules (whose spectroscopic properties first appear on the HITRAN92 data base as temperature-dependent cross sections) have been incorporated into pseudo-band models, with provision for using both default and user supplied profiles. The addition of SO_2 and NO_2 in the UV, along with upgraded ozone Chappuis bands in the visible is also part of MODTRAN3. An improved multiple scattering algorithm, the DIScrete Ordinate Radiative Transfer (DISORT) (*Stamnes et al.*, 1988), has also been incorporated into MODTRAN3 (*Stamnes*, 1994). MODTRAN is very fast; simple timing runs of MODTRAN3 .vs. FASCOD3 show an improvement of more than a factor of 100 for a typical 500 cm^{-1} spectral interval and comparable vertical layering. Speed is an important consideration in heating/cooling rates calculations, where a large number of radiative transfer calculations are needed. The MODTRAN3 used in this study is based on HITRAN92, but as mentioned above, it will be upgraded to HITRAN94 upon its release at the end of 1994.

MODTRAN has been adopted by some researchers in the AVIRIS program as one radiative transfer code to derive surface reflectance from AVIRIS measurements. The accuracy of the code is very important because any errors in the radiative transfer calculation will directly translate into errors in the derived surface reflectance. In this paper, the new solar irradiance calculated by Kurucz (*Kurucz*, 1994), which is adopted in MODTRAN3, will be presented. Recent validations of MODTRAN3 with airborne high resolution interferometer measurements over ocean will be discussed. Good agreement between model calculations and measurements was achieved.

2. New High Resolution Solar Irradiance in MODTRAN3

An error in the solar irradiance data of MODTRAN2 was discovered by Green and Gao in 1993 (*Green and Gao*, 1993). They also proposed an update based on the Neckels and Labs continuum spectrum (*Neckels et al.*, 1984). In MODTRAN3, we adopted a new solar irradiance calculated by Kurucz. The resolution of solar irradiance is an input parameter in the MODTRAN3 control file 'tape5', and can be changed based on user requirements. Fig. 1. shows the solar irradiance at the top of the atmosphere and the transmitted solar irradiance calculated by MODTRAN3 and degraded to the average resolution of AVIRIS from 0.4 - 2.4 μm (25,000 - 4167 cm^{-1}) of about 100.0 cm^{-1}. It seems that the problems with the old solar irradiance in MODTRAN2 discussed by Green and Gao are fixed in this new solar irradiance.

3. Comparisons of MODTRAN3 Calculations with Airborne Michelson Interferometer Measurements During Daytime

The data used for the validation of MODTRAN3 during daytime is the down-looking spectra taken by the High-resolution Interferometer Sounder (HIS) of CIMSS/University of Wisconsin (*Revercomb et al.*, 1988) and NWS balloon sonde data over the Eastern Pacific off the California coast on 14 April 1986. The reason for choosing the interferometer measurement over ocean is that the surface reflectance and emissivity are more uniform and easier to define compared with that of land surface. Since our primary objective is to validate MODTRAN3, it is not prudent to introduce the land surface reflectance/emissivity complication by using measurement over land. HIS is a Michelson interferometer, the spectral region from about 600 cm^{-1} to 2700 cm^{-1} is divided into 3 bands (*Revercomb et al.*, 1993). The spectral resolutions and maximum optical path differences of each band for the Eastern Pacific experiment are listed in Table 1.

In the MODTRAN3 calculations, the radiosonde profiles of temperature, H_2O, and O_3 were used. The profiles of the remaining radiatively important species (CO_2, CO, CH_4, N_2O, O_2) were defaulted to the 1976 U.S. Standard Atmosphere (model 6 in MODTRAN3). Heavy molecules, such as CCl_4, CFC11, CFC12, were not included in this calculation. The high resolution HIS spectra was degraded to 2.0 cm^{-1} using the FASCOD3 triangular scan function with a FWHM of 2.0 cm^{-1}. Figure 2 shows the HIS spectrum, MODTRAN3 calculated spectrum, and residual for the third band in the short IR (2000 cm^{-1} to 2700 cm^{-1}) with and without solar contribution. In the MODTRAN3 calculation with solar contribution, a sea surface albedo of 0.05, solar zenith angle of 38°, and day number of 104 corresponding to the day and time (14 April 1986, 1800 UTC, off the California coast at -120.5 longitude and +34.7 latitude) when the HIS spectra was taken, were used. Clearly much better agreement between model calculation and interferometer measurements was achieved by including the solar contribution. The remaining differences around 2400 cm^{-1} arise from difficulties in the band model parameterization at the sharp CO_2 band edge (*Anderson et al.*, 1994). The large residual close to the edge of HIS band III from 2640 cm^{-1} to 2700 cm^{-1} is likely due to instrument or calibration (*Knuteson and Revercomb, private communication*, 1994).

4. Summary and Conclusions

The new solar irradiance in MODTRAN3 was presented and discussed. Problems with the old solar irradiance in MODTRAN2 were solved. Good agreement between model calculation and airborne high resolution interferometer measurement was achieved. Validation of MODTRAN3 in the solar region and the spectral region of AVIRIS (0.4 - 2.4 μm) is in progress with measurements by the ground-based Solar Radiance Transmission Interferometer (SORTI) developed at the University of Denver (*Murcray, private communication* , Nov. 1994). We expect to show some preliminary results on the validation of MODTRAN3 against SORTI measurements in the solar region at the AVIRIS workshop.

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6. References

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Table 1. Spectral resolution and maximum optical path difference of HIS for the Eastern Pacific flight on 14 April 1986 [*Revercomb et al.*, 1993b].

HIS band	Spectral resolution (cm^{-1})	Maximum optical path (cm)
I	0.3640322	1.3735050
II	0.6370564	0.7848598
III	0.6370564	0.7848598

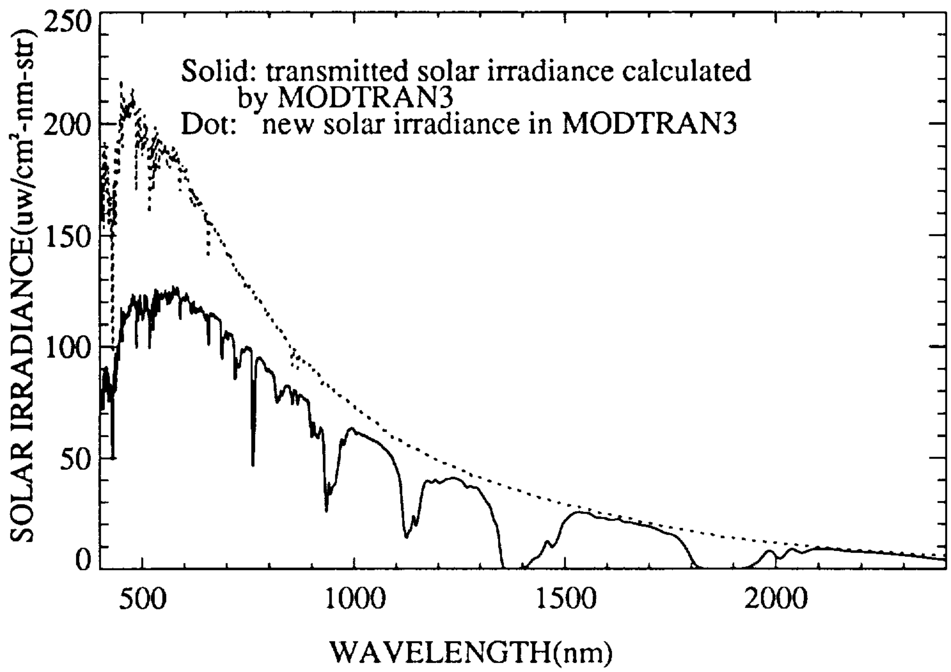

Fig. 1. New solar irradiance in MODTRAN3 based on the calculation by Kurucz.

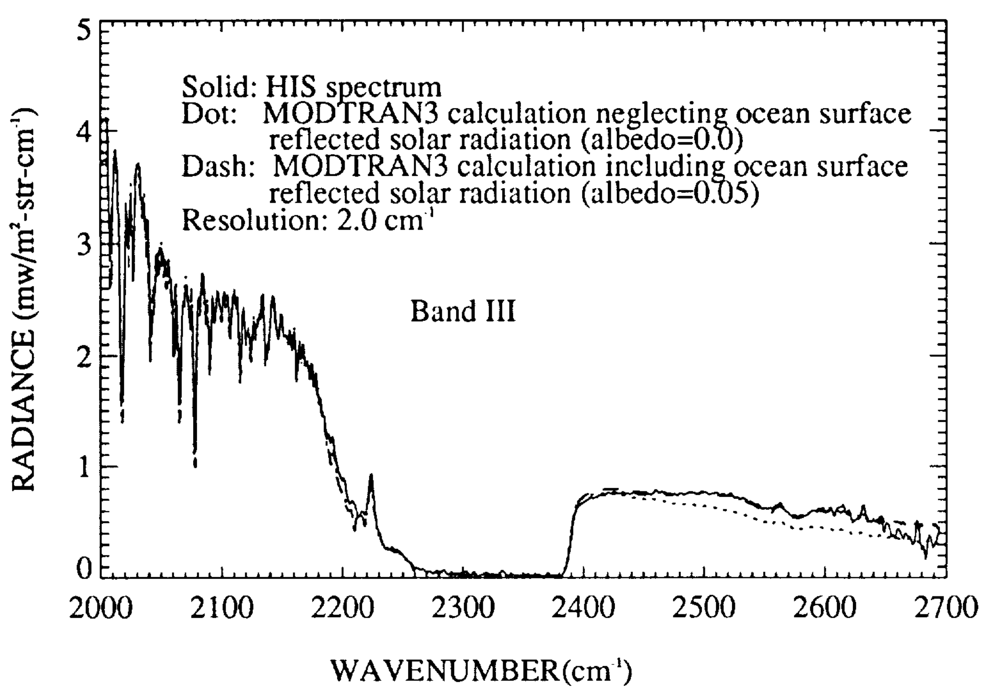

Fig. 2. Comparison between HIS measurement and MODTRAN3 calculations with and without solar contribution.