

MODO: AN INTERFACE TO MODTRAN FOR THE SIMULATION OF IMAGING SPECTROMETRY AT-SENSOR SIGNALS

Daniel Schlöpfer

*1) Remote Sensing Laboratories (RSL),
Department of Geography, University of Zurich, CH-8057 Zurich, Switzerland
Phone: +41 1 635 52 50, Fax: +41 1 635 68 46, E-mail: dschlapf@geo.unizh.ch*

*2) ReSe Applications Schlöpfer,
Langeeggweg 3, CH-9500 Wil, Switzerland, <http://www.rese.ch>*

1. INTRODUCTION

The radiative transfer code MODTRAN, version 4 (Berk et al., 1998; 2000) has been established as de-facto standard for the simulation of imaging spectrometry data and for quantitative modelling of the signal at the sensor level. The original interface of MODTRAN consisting of ASCII-file based inputs leads often to misunderstandings and mistakes in such analyses. Almost every frequent user of MODTRAN has therefore some tools available to ease the setup of the inputs.

The MODTRAN interface described in this paper includes an extensive translation of the logical structure and the parameters of the input `tape5` as well as utilities for the extraction and convolution of radiation component spectra. It also supports surface reflectance spectra from external data sources. Its functionality including the workflow is described first. Some examples for the simulation of imaging spectrometry radiance levels follows.

2. INTEGRATION WITH MODTRAN

The MODTRAN code as provided by the Air Force Geophysics Laboratory (AFGL) is written in the FORTRAN computing language. It is handled by rigidly formatted ASCII input files: The “`tape5`” is used for the definition of the atmosphere and the geometry while the file `spec_alb.dat` (e.g.) defines the background reflectance characteristics. Other optional input files concern the solar irradiance or the spectral band model. The direct handling of these files is very sensitive and requires experience with the code. This also bears the danger of introducing errors in at-sensor data simulations. The goals of the efforts described herewith was to ease the use of MODTRAN by providing a graphical user interface for the creation of the input files as well as for the treatment of the outputs with respect to hyperspectral remote sensing. The efforts resulted in the MODO (‘MODTRAN Organizer’) concept. The interface is based on the IDL (IDL, 2001) programming language which has been established as de-facto standard for hyperspectral image processing. The design has been optimized for research applications and thus does not support high degrees of automatism, avoiding ‘black box’ mechanisms. The MODO concept as shown in Figure 1 is based on the standard distribution of MODTRAN by interfacing with the inputs `‘tape5’` and `‘spec_alb.dat’` and evaluating the outputs `‘tape7’` and `‘flux’`.

The core interface of the procedure is the `tape5` editor window. It allows to set most of the input parameters using pull-down menus instead of manually editing the rigidly formatted ASCII file. Logics within the `tape5` are considered, such that if, e.g., the transmittance mode has been selected it is not possible to set the irradiance source options. Sub-interfaces will pop up for supported special functions such as the import of user defined atmospheres, the selection of the surface reflectance, or the definition of the four standard aerosol layers. The interface is grouped in the same way

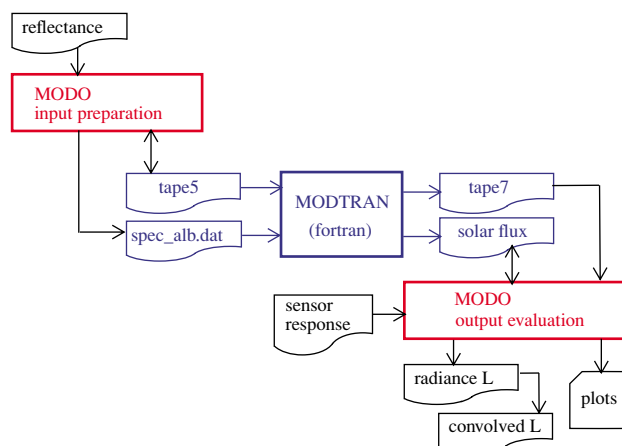


Figure 1: Integration of the MODTRAN standard code with the MODO interface.

as in the original tape5 to be consistent with the documentation as provided with MODTRAN. If one or more parameters shall be varied, the setup of ‘multiple run’ tape5s has proven to be very useful. Each run within such tape5s can be accessed, edited, or deleted individually by browsing through the tape5. Some dedicated save options help to keep various tape5s organized. A sample of the MODO tape5 editor window is shown in Figure 2.

Figure 2: Example of the MODTRAN interface ‘MODO’; translator and organizer for the ASCII input file ‘tape5’.

The inclusion of surface reflectance spectra has become of high importance for modelling at-sensor radiance values for known targets. An interface has therefore been included for importing reflectance data into MODTRAN from ENVI (ENVI, 2001) spectral libraries or ASCII reflectance files. The spectra can afterwards be selected for the target as well as for the background if adjacency effects shall be studied (see Figure 3).

The startup of the original MODTRAN executable is managed by a UNIX child process from within MODO. A UNIX shell script is invoked which automatically links the original MODTRAN DATA directory and its contents to the startup location if no DATA reference is available there. This allows to use MODTRAN from whatever directory the tape5 has been saved to. On non-Unix operating systems, MODTRAN still may be invoked externally after saving the tape5 from the MODO interface.

Additional interfaces are included for the following tasks:

- plotting of the spectral output (tape7 or solar flux),
- calculation of solar angles for time and date,
- save/restore of settings,
- extraction of single spectra from the whole output,
- convolution to hyperspectral (Gaussian) channel characteristics, and
- export of radiance spectra to ENVI spectral libraries.

All these utilities have been developed in support of a flexible handling of the MODTRAN inputs and outputs for a fast simulation of at-sensor radiance values.

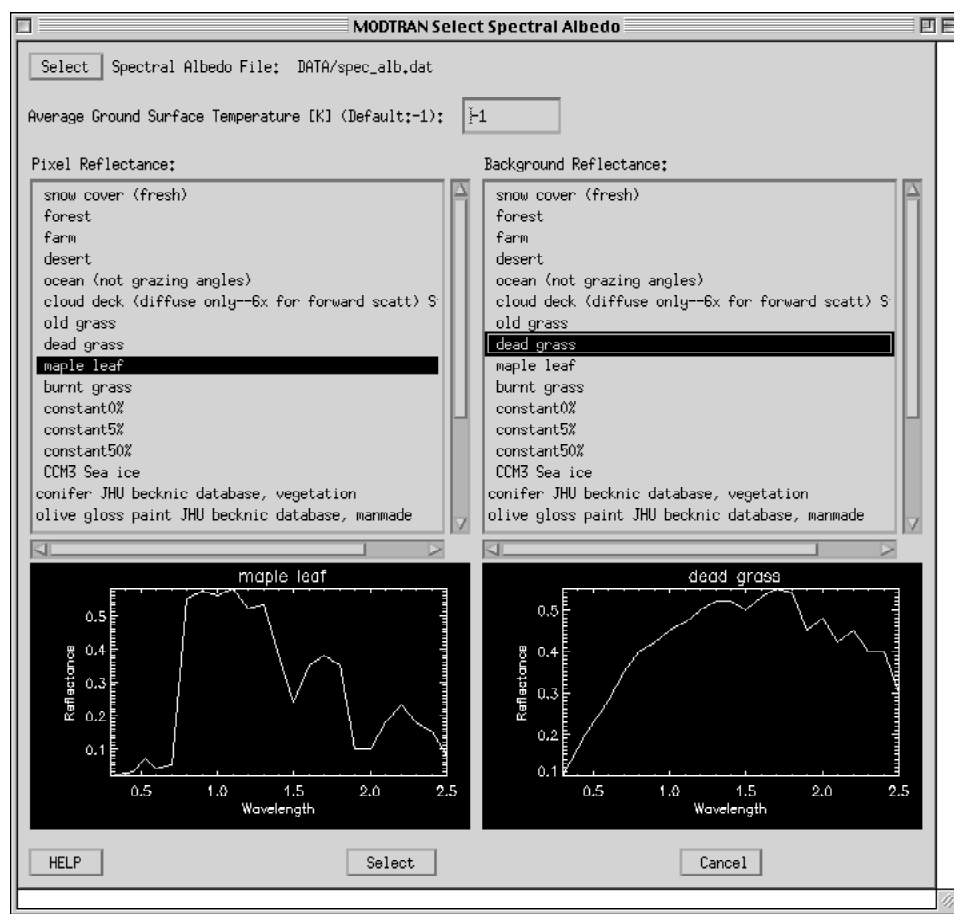


Figure 3: Interface for the selection of spectra from the spectral albedo file for the MODTRAN background reflectance option.

3. PROCEDURES

The typical workflow using the MODO utility depends on the task to be performed. In imaging spectroscopy, the normal case starts with known surface reflectance spectra which need to be transposed to at-sensor radiance values. For the creation of spectral databases or Look-Up-Tables for later inversion, standard setting for reflectance and discrete values for parameter variation are taken as basic input. An overview of a typical data simulation workflow is given in Figure 4.

3.1 MODTRAN Setup

After the surface reflectance has been defined, the various parameters need to be set in the tape5 window. One may choose to vary certain parameters and create a multiple run tape5. At this point, additional knowledge of the geometric and meteorologic situation to be simulated is required. Furthermore, some basic comprehension of the MODTRAN functionality helps to create inputs to MODTRAN making physical sense.

MODTRAN can be run afterwards in one of its four major modes, as radiance, transmittance, solar irradiance, or thermal radiance. Depending on the settings for the DISORT option and the wavelength resolution, such runs may be very time consuming for the radiance options. The first run in the standard output tape7 or in the optionally created “.flx” file may be plotted directly afterwards for quick visualization of the outputs.

3.2 Data Extraction

In normal cases, the total radiance at the sensor is the main output component to be read afterwards from the MODTRAN outputs. Other components such as the path scattered radiance, specific transmittance values, or the solar irradiation are of specific interest for atmospheric applications and corrections routines as well as for validation of the cross sensitivity of the simulated spectra to atmospheric influences. The components are then read from the outputs and converted to SI standard units [$\text{W}/(\text{m}^2 \text{ sr nm})$] from the original units being [$\text{W}/(\text{cm}^2 \text{ sr cm}^{-1})$]. This conversion is based on the well-known relationship between wavelength λ and wavenumber ν :

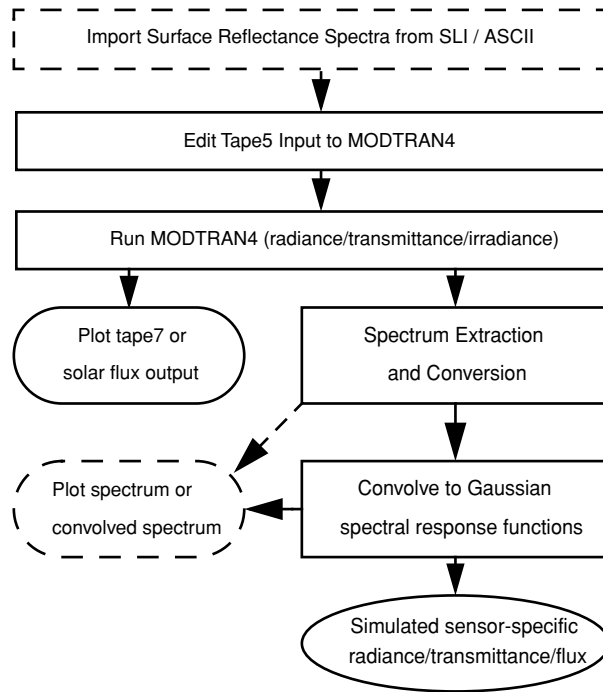


Figure 4: MODO typical workflow structure as used for the simulation of imaging spectrometer data.

$$\lambda = \frac{1}{\nu}, \quad (1)$$

The wavenumber is converted to its equivalent wavelength through the following relationship:

$$|\lambda| [nm] = \frac{1}{|\nu| [cm^{-1}]} = \frac{10^7}{|\nu|} [nm]. \quad (2)$$

The relation between the wavelength interval and the wavenumber interval is given by:

$$d\lambda = -\frac{1}{\nu^2} d\nu \text{ and } d\nu = -\nu^2 d\lambda. \quad (3)$$

The generic relation between the radiance per wavelength and the radiance per wavenumber is derived from the respective definitions:

$$L_{s,\nu} = \frac{d\phi}{dA d\Omega d\nu}, \text{ and with (1): } L_{s,\lambda} = \frac{d\phi}{dA d\Omega d\lambda} = \frac{d\phi \nu^2}{dA d\Omega d\nu}. \quad (4)$$

The unit conversion is derived as follows, where $|L_{s,\lambda}|$, and $|L_{s,\nu}|$ denote data values for the same radiance equivalents and $|\nu|$ the wavenumber value in inverse centimeters:

$$|L_{s,\lambda}| \left[\frac{W}{m^2 sr nm} \right] = |\nu|^2 |L_{s,\nu}| \left[\frac{W (cm^{-1})^2}{cm^2 sr (cm^{-1})} \right] = |\nu|^2 |L_{s,\nu}| 10^4 \left[\frac{W (cm^{-1})}{m^2 sr} \right] = |\nu|^2 |L_{s,\nu}| 10^{-3} \left[\frac{W}{m^2 sr nm} \right]. \quad (5)$$

The standard unit in cm^{-1} is given as the original MODTRAN wavenumber reference which may be related closely to the energy levels of the simulated photons. In imaging spectrometry and spectroscopy of the visible/near infrared part of the spectrum, the usually used wavelength reference are microns or nanometers. As the resolution of current imaging spectrometers is in the range of 5 to 20 nanometers, it has been decided to select the wavelength in nanometers as generic reference for data simulation within MODO.

3.3 Convolution

The MODTRAN data usually is derived in wavelength units using a triangular slit for convolution to the original band data. Since version 3.7 of MODTRAN, an option is included which allows the direct convolution of the MODTRAN outputs to sensor specific response functions. This option is not fully supported within MODO. A separate convolution function convolves extracted and possibly joined spectra to sensor characteristics using a Gaussian approximation of the sensor function. This option leaves higher flexibility for research purposes if, e.g., the response function needs to be varied. The convolved radiance values L_i in a band i are calculated as:

$$L_i = \frac{\int L_s(\lambda) r_i(\lambda) d\lambda}{\int r_i(\lambda) d\lambda} \approx \frac{\sum_j L_s(\lambda_j) r_i(\lambda_j) \Delta\lambda_j}{\sum_j r_i(\lambda_j) \Delta\lambda_j}, \quad (6)$$

where $r_j(\lambda)$ is the spectral response function of the sensor's band. A stepwise assumption is taken for the convolution if the number of raw data values j is sufficient within the width of the spectral band. If the original resolution is not sufficient, a polynomial is calculated through the original data points $L_s(\lambda_j)$ for better approximation of the spectrum and summarized through a number of $k = 100$ interpolated data points, i.e:

$$L_i \approx \frac{\sum_k Poly(L_s(\lambda_j))_k r_i(\lambda_k) \Delta\lambda_k}{\sum_k r_i(\lambda_k) \Delta\lambda_k}. \quad (7)$$

A minimal number of 2 data points within the range of the target bands is required for a sufficient calculation of the convolved data values in any case.

4. EXAMPLE APPLICATIONS

4.1 Simulation of Atmospheric Signatures

The most straight-forward simulation of atmospheric signatures using MODTRAN is the calculation of the transmittance of a specific optical path (see example of such an output in Figure 5). Transmittance curves are derived for the characterization of atmospheric scatterers and gases such as water vapor (cf. Schl pfer et al., 1998). Anyhow, the transmittance runs do not include all effects of multiple scattering on the path. It is thus preferred to use radiance simulations under well known atmospheric parameter variations for realistic results. At-sensor radiance values are then evaluated with respect to the variation of atmospheric parameters available within MODTRAN such as the visibility, cirrus or cloud coverage, humidity, and ozone content or with respect to geometric constraints such as sensor altitude, ground altitude, sun zenith angle, or sensor zenith angle.

Such variations may be combined for building Look-Up-Tables for atmospheric correction as it has been done within the ATCOR programs (Richter, 1997; 2000). The MODO interface does not support directly the construction of such lookup tables but its internal functionality can be used to ease their creation.

4.2 Simulation of At-Sensor Radiance

The at-sensor radiance is the critical parameter for the physical investigation of imaging spectrometry data. It is derived by calibration of a sensor system and needs to be compared to the expected radiance levels. An example of simulated at sensor radiance components is shown in Figure 6. The components of the signal are to be considered for validation of the relative sensitivity of the radiance to atmospheric and surface parameters. Usually, a series of simulations needs to be set up in order to obtain the variation of the signal. This approach may be chosen to simulate the expected radiance levels at sensors to be constructed.

4.3 Evaluation of Sensor Specifications

For the design of new instruments, the specifications need to be fixed based on simulated at-sensor radiance values. The simulations may be done by comparison to measured values of existing instruments (Schl pfer et al., 1999) or by

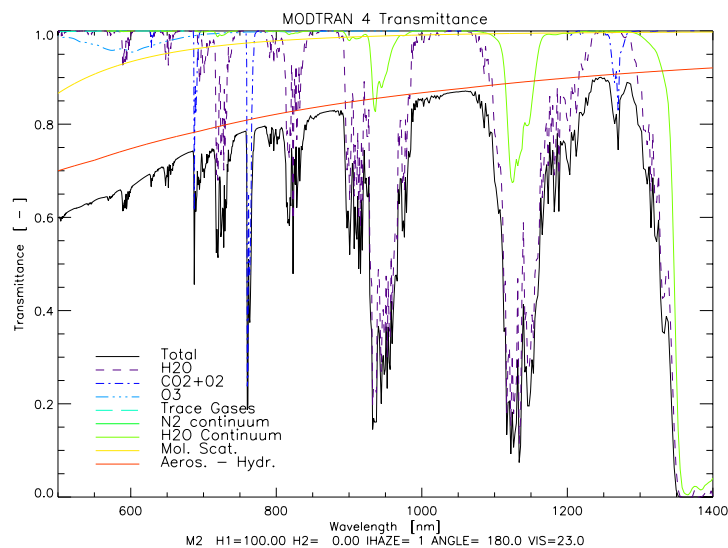


Figure 5: Simulation of atmospheric transmittance using the direct transmittance calculation - Standard MODO output.

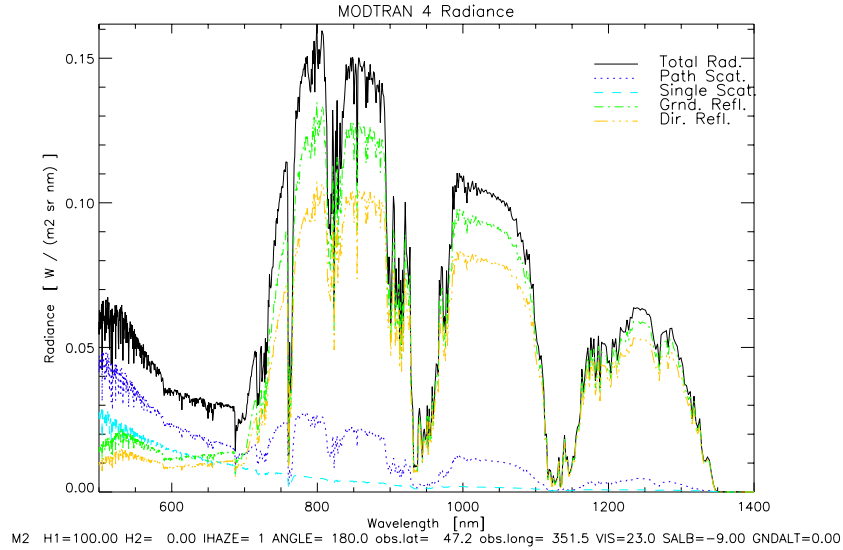


Figure 6: At-sensor radiance simulation raw data over vegetation after MODTRAN simulation - MODO Standard tape7 plot.

fully physical based simulation. MODTRAN has been established as a standard tool for such simulations for imaging spectrometry data. The MODO utility can be used in a supportive manner to derive the following critical parameters:

- Typical and extreme at-sensor radiance levels,
- Application-specific reflectance based signal (delta radiance) simulations,
- Noise equivalent delta radiance specification,
- Spectral resolution (FWHM), and
- Spectral sampling interval requirement.

FWHM spectral resolution and spectral sampling interval are derived by series of convolutions to potential spectral response functions. The sensitivity, e.g., within absorption features may then be characterized to derive recommenda-

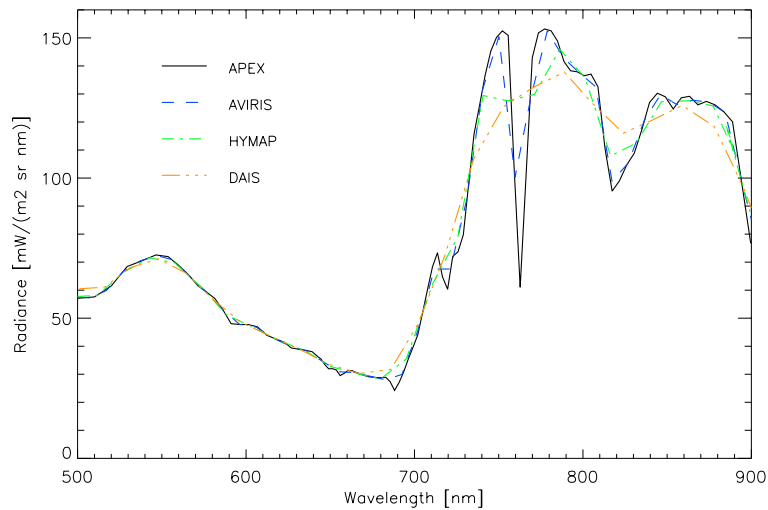


Figure 7: Total at-sensor radiance over vegetation convolved to specifications of the APEX instrument and to reference instruments (AVIRIS, HYMAP, and DAIS 7915).

tions for spectral resolution. An example is given in Figure 7 where the spectral characteristics of existing imaging spectrometers are compared to potential resolution specifications of the upcoming APEX instrument (Itten et al., 1997).

However, the presented approach does not compare to measured data values. If the real signals after optics and electronics are to be simulated, more sophisticated tools such as SENSOR (Börner et al., 1999) are required.

5. CONCLUSIONS

An interface to MODTRAN has been presented which eases the use of this radiative transfer code substantially. It has been optimized for research applications in imaging spectroscopy. The MODO interface has been designed on the actual version of the IDL (RSI, Inc., 2000) programming language. It is available ‘as is’ from the internet as shareware code¹ while MODTRAN itself still needs to be ordered through the Air Force Research Laboratories.

Functionality which might be included in the future is the convolution to multispectral response functions, the support for creating Look-Up-Tables for atmospheric correction, or the inclusion of BRDF modelling approaches. MODO is currently used operationally for the simulation of at-sensor radiance values of the European APEX airborne imaging spectrometry system and will be further developed in support of such simulations.

6. ACKNOWLEDGEMENTS

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¹. URL: <http://www.rese.ch>