OPERATIONAL SIMULATION OF AT SENSOR RADIANCE SENSITIVITY USING THE MODO / MODTRAN4 ENVIRONMENT

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ABSTRACT

The MODTRAN radiative transfer code is a well established standard for simulating the at sensor radiance for optical instruments and imaging spectrometers from the UV to the thermal infrared. However, its efficient use is a task not easily accomplished. This situation has led to various developments for improving the efficiency as well as for the inversion of the model for atmospheric correction. The MODO user interface to MODTRAN is a tool for the forward modeling task which so far has been in use by various expert users. This paper describes workflows and examples for simulating the at sensor radiance for standard remote sensing situations. An interface design is proposed and implemented as part of MODO which improves the reliability of simulations for hyperspectral instruments. This end-to-end solution starts with inclusion and selection of surface reflectance functions from spectral libraries. Second, the atmospheric parameters most critical to the radiative transfer are to be defined and third, the components of the at sensor radiance shall be produced directly for specific sensor response functions. The selection of relevant parameters describing the situations is done on experience in various application area. The integration of the given principles leads to a comprehensive graphical user interface design which is proposed for setting up MODTRAN runs in an efficient manner.

INTRODUCTION

MODTRAN-4 has been established for many years as de-facto standard for simulating the at sensor radiance for imaging spectrometers (1, 2). It has been used for sensititvity analysis, sensor definition studies (3) but also for the development of hyperspectral applications, and atmospheric correction procedures (4, 5, 6). The MODO user interface to MODTRAN is a tool which has been created to ease the use of the original radiative transfer code (7). Based on the experience of the past years, an update of the tool in view of a more efficient sensitivity analysis has become critical. The capabilities of current and upcoming instruments for selected standard applications and measurement situations shall be simulated in an efficient manner. Specifically, the impact of surface reflectance signatures or of the spectral calibration on the at-sensor signatures is typically analysed. Furthermore, the comparison of simulated spectra to field measurements leads to a better understanding of the performance of an instrument. The most important tasks to be modeled are:

- sensitivity of signal to variations in response functions and spectral bandwidths/positions,
- surface reflectance signatures propagations (including the propagation of HDRF field measurements),
- intercomparison of signatures at various sensor systems for cross-calibration,
- support to vicarious calibration procedures by intercomparison of ground measurements to the respective sensor signal,
- creation of sensitivity series for retrieval of atmospheric gases and aerosols, and
- fast derivation of at-sensor radiance levels for adjustments of sensor gain and performance settings.

The related software design has lead to new workflows and interfaces as described hereafter.

SIMULATION WORKFLOW AND IMPLEMENTATION

The MODTRAN code as provided by the Air Force Geophysics Laboratory (AFGL) through ONTAR Inc. (http://www.ontar.com) is written in the FORTRAN computing language. It is handled by rigidly formatted ASCII input files. The 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. MODO provides the 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 updates now include streamlined workflows for the 'daily work'.

The whole workflow requires a library of sensor response functions which has compiled in collaboration with DLR, Munich. It contains most currently known sensor response functions, both as explicit functions or as gaussian approximation (as often used in high resolution spectrometers). The library lets you easily select a sensor of choice for direct simulation of the response-dependent at-sensor signal.

At-Sensor Signals Simulation

The core interface of the MODO procedure is a 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. However, the various input options to MODTRAN may be misleading if a fast result of at-sensor signals is to be calculated. Thus, a streamlined version of this window has been created. It uses four standard processing options, which allow the trade-off between processing accuracy and speed (the indicated approximative time is given for the radiance simulation of one hyperspectral standard situation on a 1.5 GHz machine).

- Low resolution: (4 seconds)

- High resolution: (1 minutes)

- High resolution with DISORT multiple scattering algorithm (5 minutes)

- High resolution with DISORT and correlated-k approach (3-4 hours - not to be recommended..).

Despite the differences in speed, this four standard options exhibit significant differences of the simulated radiance values, specifically within or at the edges of atmospheric absorption features. A non-respresentative example is given in Figure 1, where the deviations of the first three methods from the most accurate option is shown. Differences, inherent to the MODTRAN radiative transfer code are found which are at up to 5% in standard cases but may even be higher when strong absorption is present.
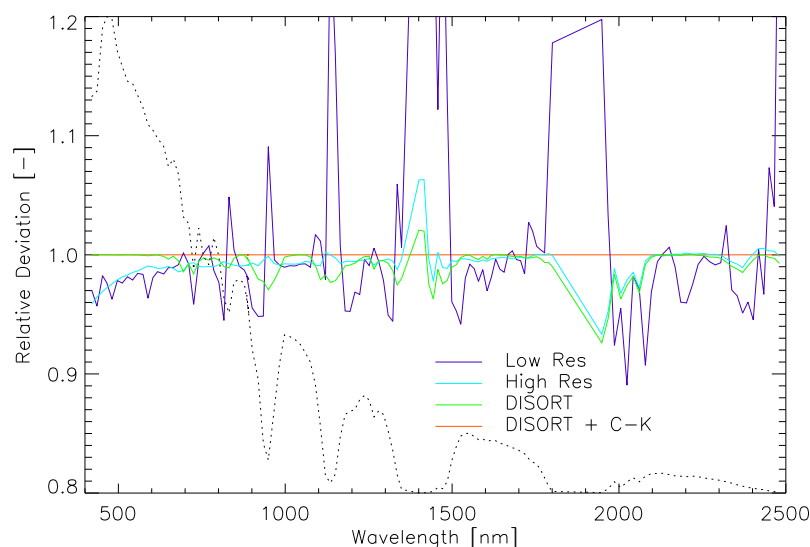

Figure 1   **Relative difference of standard scattering algorithms from correlated-K approach (dotted: at-sensor radiance curve).**

Furthermore, the parameters most often used for simulations have been selected from the standard options. All cloud options have been omitted as they usually are not required – nor desired – for imaging spectrometry applications. The respective workflow from standard situations to at-sensor radiance is depicted in Figure 2. It includes the extraction of the at-sensor radiance/irradiance or transmittance and a convolution to the selected sensor response function.
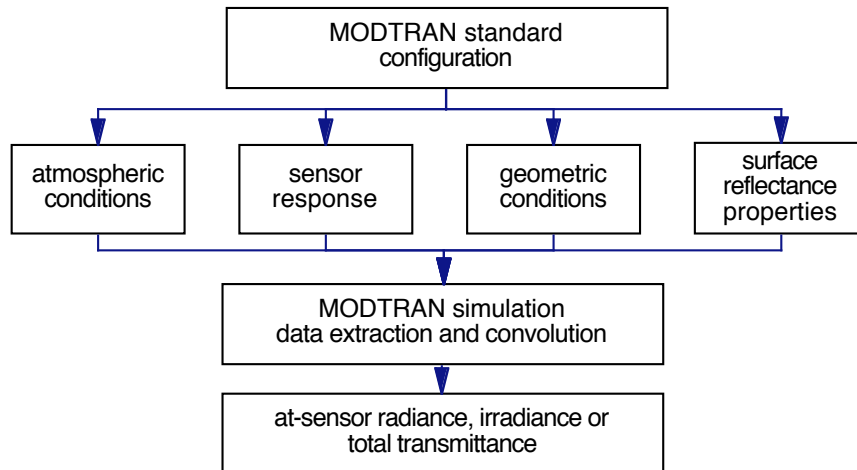

Figure 2   At-sensor radiance simulation workflow with 4 input sections based on standard MODTRAN configurations.

The graphical implementation groups the four main inputs 'atmosphere', 'surface', 'geometry', and 'sensor' together in frames as shown in Figure 3.

Figure 3:   Fast signature simulation for a sensor using four standard MODTRAN calculation options and the most often used parameters.

Series Simulation

Sensitivity analysis usually requires a creation of series of radiative transfer calculations, where one specific parameter under question is varied systematically. A dedicated tool for this task is therefore of common interest, triggering MODTRAN to perform a number of calculations at once. The MODTRAN output is then parsed for the searched radiance (or irradiance/transmittance, respectively) component which leads to a series of outputs compiled in one singular output file. The respective workflow is given in Figure 4. The parameters currently included are:

- Visibility (aerosol optical thickness) and Aerosol model (standard models only)
- Standard atmospheres
- Gases: water vapor, ozone, carbon dioxide
- Geometry: view zenith, sun zenith, relative azimuth
- Sensor height and ground altitude, and
- surface reflectance.

For user friendliness, the inclusion of spectral libraries as parameter-series option has been implemented in a separate GUI, as it requires an additional side input by interfacing to the spectral libraries. The output may be the default total radiance/transmittance, but also components such as path radiance or direct reflected radiance may be chosen for more specific analysis.
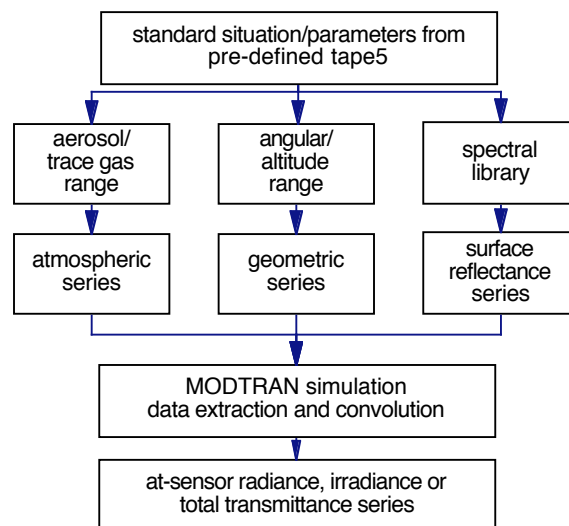

Figure 4   Workflow for sensitivity analysis. A series of calculations is created from a pre-defined standard configuration, where only one parameter is varied at a time.

The appearance of the related GUIs is depicted in Figure 5 and Figure 6, respectively. Within a pre-defined standard situation (tape5), one parameter can be varied by providing a comma separated list of entries. The output is finally directly convolved to the sensor of interest as selected from the internal sensor response library.
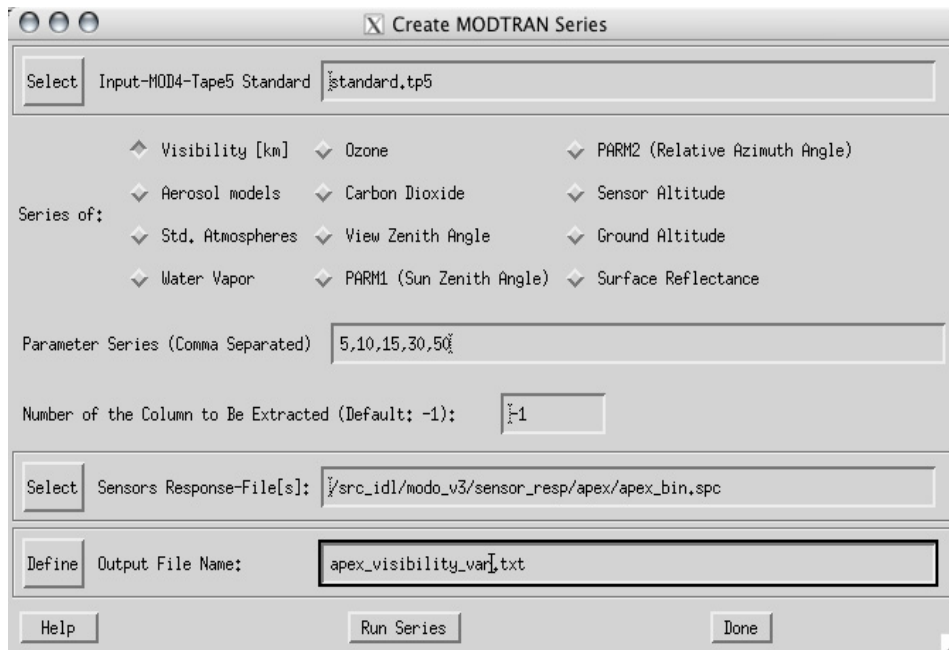
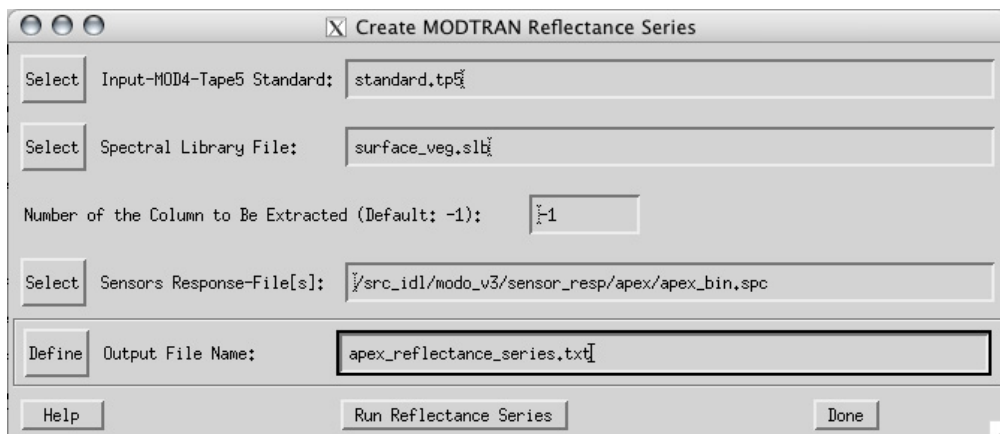**Figure 5   Creation of a series of Modtran runs from standard tape5 configuration.**

Figure 6   Creation of a series using a spectral library reflectance input.

RESULTS

Some example results using the updated system are given below:

Sensor Systems Simulation

The selection of the correct sensor resolution for a specific hyperspectral application is a task to be done cautiously. Figure 7 shows the sampling of calcite and dolomite signatures in the SWIR spectral range with four typical imaging spectrometers (APEX, AVIRIS, HyMap, and Hyperion). The results depict that the increased resolution clearly aids ad resolving these sharp absorption features, specifically when looking into the shape of the feature slopes. The lower spectral resolution of Hymap at about 15 nanometers reduces the information content significantly in comparison to the 10 nm resolution of the other instruments.
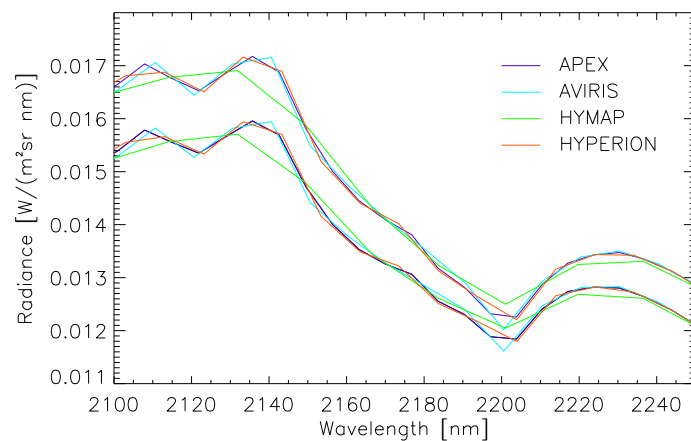
Figure 7   Sampling differences of the Calcite absorption feature at sensor, modeled for four hyperspectral instruments, calculalted for two different laboratory spectra of calcite.

Angular Series for CHRIS Proba

Viewing the same object from various angles may lead to significant variations of the path scattered radiance component, an effect known as atmospheric BRDF. ESA's CHRIS sensor observes an object within a view angle range from -55 to 55 degrees. Over dark objects at 4% reflectance, the relative variation of the total radiance at sensor exceeds an error of 20% easily (see Figure 8). This is an example that appropriate correction for atmospheric effects is a must to derive directional reflectance properties of the ground.
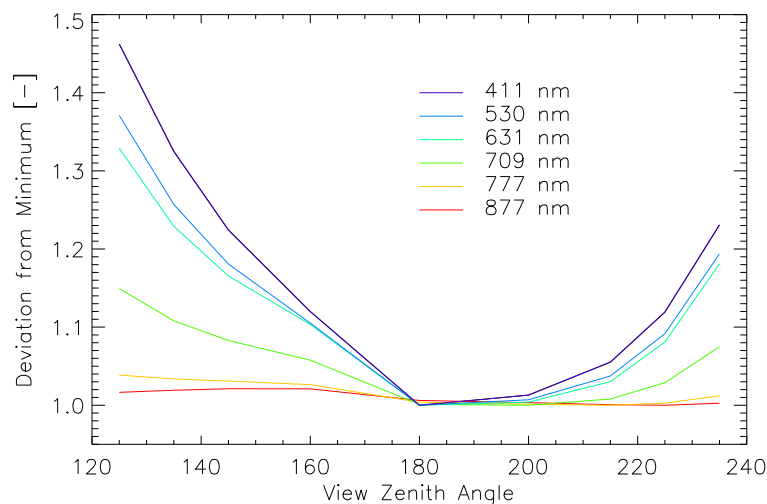

Figure 8   View angle dependency of CHRIS at sensor radiance for a standard forest target at 6 selected spectral bands. 180 degrees is nadir looking, 125 degrees is towards the backward scattering direction.

Spectral Library Series

At sensor radiance variations from spectral libraries may, e.g., be used to derive the radiometric range to be covered by an instrument for monitoring a typical target by an instrument. Figure 9 shows the results if a spectral library of modelled chlorophyll variations is propagated to the APEX sensor (8, 9). Such simulations allow for an estimate of typical and extreme radiance levels which are expected for terrestrial applications.
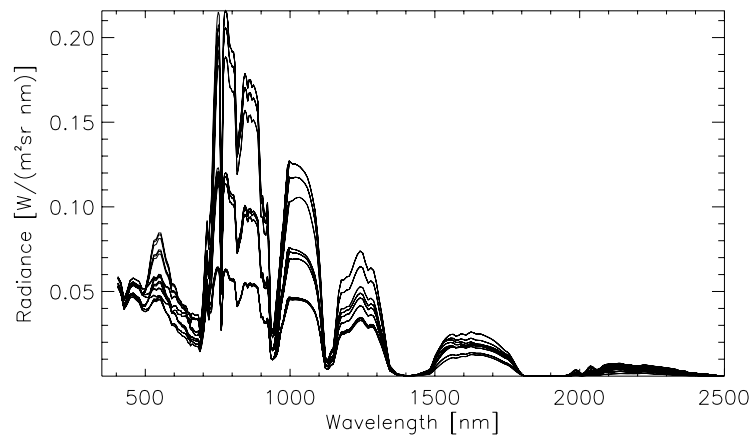
Figure 9   At sensor radiance variation using simulated surface reflectance spectra for vegetation with chlorophyll content (Cab = 25, 45, 70 µg/cm²) on three simulated vegetation density levels (LAI = 0.5, 2 and 6).

Atmospheric Sensitivity

The dependency of at sensor radiance on topograpy is one of the major effects seen when taking data in an alpine environment. It bears the variations of both aerosols and trace gases, which are usually not distributed uniformly in altitude as well as spatially. A typical alpine series is shown in Figure 10. The water vapor variations dominate the spectrum in this range while the oxygen feature at 760 nm is more stable in the depicted lower atmosphere.
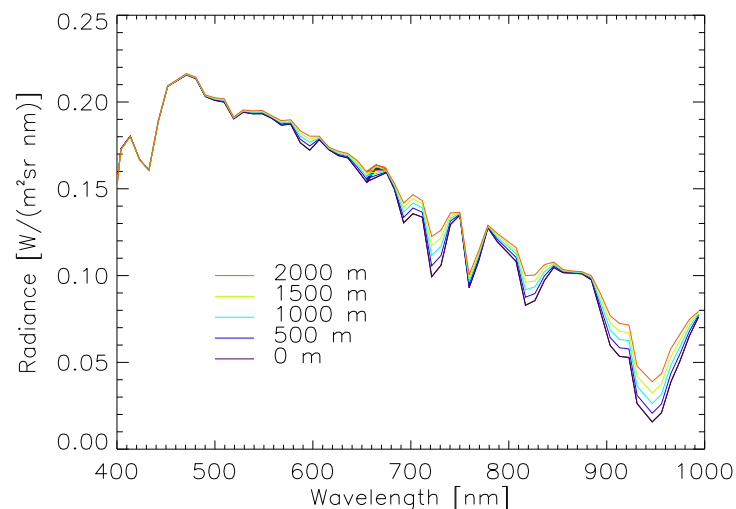

Figure 10   Atmospheric sensitivity of a constant 40% reflectance signal to ground altitude variations as seen from 5 km at nadir, resampled to AVIRIS spectral resolution.

CONCLUSIONS

Updates to the MODO interface to MODTRAN have been presented which eases the use of this radiative transfer code for sensitivity analyses substantially. The tools have been further optimized for research applications in imaging spectroscopy. Exemplary applications show the versatility of the enhanced features.

The current implementation is suited for radiative transfer and remote sensing research, but still requires basic knowledge about the principles of the MODTRAN code. The addition of lower level GUI (e.g., for direct at sensor radiance simulation) will also help in education to increase the consiousness about various elements influencing the at-sensor signal of a remote sensing instrument.

Functionality which might be included in the future is the direct simulation of BRDFs and the dinclusion of sun photometry validation tools. Further features may include the addition of a generic sensor model to derive sensor-specficic digital response from the at-sensor simulations. Such a tool will be useful for further definition of the APEX sensor as well as its configuration with regards to the trade-off between spectral binning patterns and sensor saturation.

ACKNOWLEDGEMENTS

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