

An Automated Radiative Transfer Models Operator (ARTMO) toolbox for automated retrieval of biophysical parameters through model inversion



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1. Introduction

The need for an Automated Radiative Transfer Models Operator (ARTMO) toolbox

Radiative transfer (RT) modeling plays a key role for earth observation (EO) because it is needed to design and develop EO instruments, and to test and apply inversion algorithms. In the scientific community a number of often highly specialized leaf and canopy RT models has been developed, each of which emanates from a different set of original requirements. During the development of RT models a tradeoff has to be made between the invertibility and accuracy of the model, leading to large diversity of models with varying degrees in complexity. Currently there exists no user-friendly toolbox that brings these models together.

Objective

The aim of this study was to develop a plug-n-play canopy radiative transfer toolbox that couples state-of-the-art leaf-level and canopy-level RT models for pursuing a better understanding of the interactions between terrestrial vegetation and solar radiation in the visible and near-infrared (VNIR) spectral range. Specifically, the objective was to design a toolbox that easily generates and visualizes leaf and canopy spectra through forward modeling, and permits retrieval of biophysical parameters (e.g. LAI, fractional vegetation cover, chlorophyll content) through model inversion of the simulated datasets against actual spectral observations.

2. ARTMO main module

• Choose stored project from MySQL
• Import, export project
• Delete class, project or DB
• Possibility to change DB

• Selection of sensor or creation of own band settings
• A number of sensors are already included:
• CHRIS mode 1, 2, 3, 4, 5
• Sentinel-2

When selecting a sensor, all input data and thus also output data will be automatically resampled to the spectral settings of the selected sensor. This means that any type of spectra (e.g. from field spectrometer or from satellite observations) can be fed into the models (e.g. soil spectra). Moreover, a warning message appears when ARTMO detects that spectral resampling is required.

Any spectral settings can be defined by the user. This is helpful for simulations studies of new or upcoming sensors such as EnMAP, APEX, FLEX.

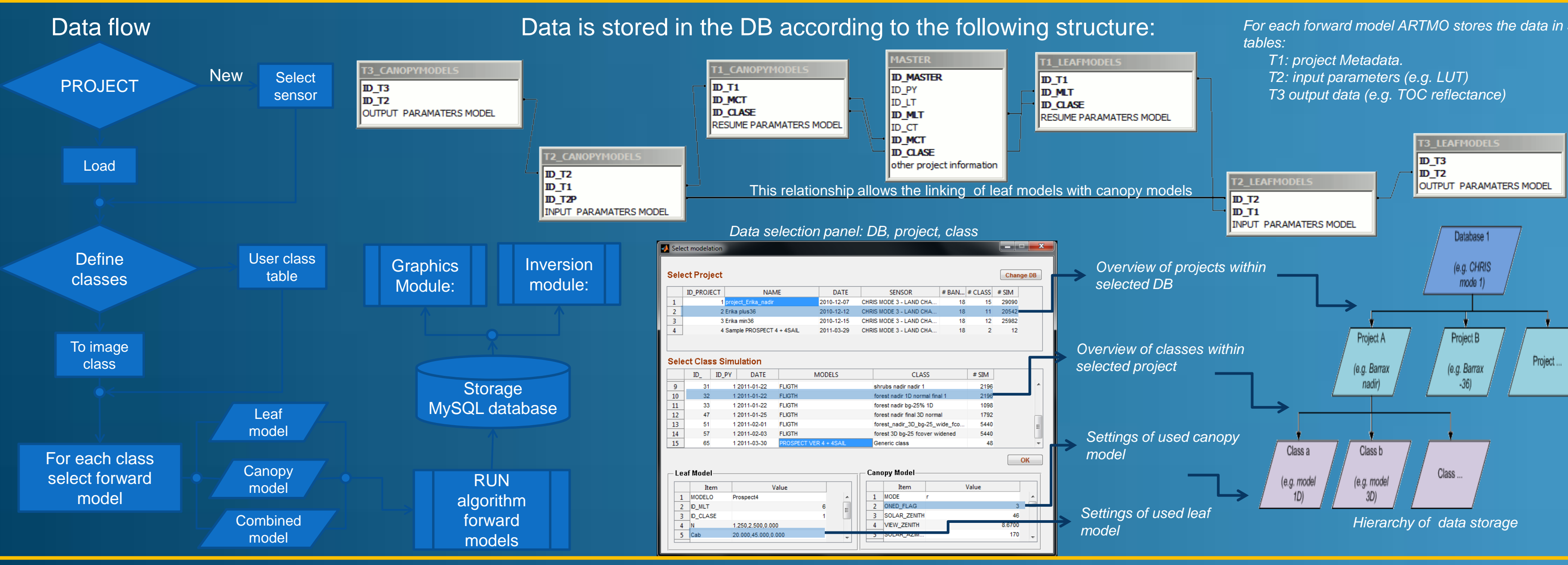
On time-consuming tasks such as forward simulation and inversion ARTMO keeps track of processing time and executed simulations or inverted pixels by providing progress bars.

• Selection of classes from a classified map, or
• Defining own user classes

• Paths to the models,
• MySQL settings

• Save all inputs
• Load earlier saved inputs

3. Design



Conclusions

The here presented ARTMO toolbox aims to implement all the necessary models and features required for terrestrial EO applications in a graphical user interface (GUI). The toolbox, developed in Matlab, allows the user:

- To choose between various leaf-level and canopy-level RT models
- To choose between spectral band settings of various sensors, or to define own band settings
- To simulate a massive amount of spectra based on a look up table (LUT) approach and storing it in a spectral database
- To plot simulated spectra of multiple models and compare it with measured spectra
- To run model inversion against airborne or spaceborne images given land cover classes, several cost options and accuracy estimates.

4. Leaf-level models

• One can select one or many atmospheric files for feeding the FluorMODleaf model. It will loop over all selected files. The same atmospheric files are applied at canopy level for FluorSAIL.

• Input variables can be configured per class.

• Model input values can be either a single value, a range of values with fixed steps, or a list of (measured) values from a text file.

• Default values are given. ARTMO identifies and highlights impossible input values, such as negative values.

• As ARTMO essentially handles inputs and outputs around RTM models but does not modify the models itself, new model versions can be directly implemented into the toolbox.

5. Canopy-level models

• Input settings can be saved and reloaded.

• When a module is configured the button turns into green.

• This part will be enabled when the 3D dimension is selected.

• Selection of spectral input for FLIGHT: green leaf, senescent leaf, soil and woody elements. Once selected, the symbol box turns red. Green leaf spectra either comes from spectral measurements or from a leaf model.

• If FluorMODleaf is not configured, one can select their own input files.

• One or various soil spectra can be selected.

6. Graphics

• By clicking on this button one can change DB, select a project and a class. See also the panel in '3. Design'.

• Selection of plottings at leaf level (e.g. reflectance, transmittance, fluorescence).

• Selection of plottings at canopy-level (e.g. TOC reflectance).

• Information on the selected spectral group. By right-clicking, the selected can be exported to a text file.

• Simulated spectra can be plotted with varying color tones depending on 2 variable. One variable can be assigned to Hue (color), and another variable can be assigned to Saturation (intensity). If both Hue and Saturation are assigned then the effects of these two variable on reflectance can be visualized.

• When a variable consists of more than one value it appears in the overview table. By clicking on the properties of a variable a subsection of spectra can be made by means of sliders. Another way of subsection is setting a step (e.g. 3) so that only each another spectra is plotted.

• If only 1 parameter is assigned to a color (hue) one can choose its own color. The spectra group vary then in intensity for the selected parameter in the chosen color.

• Additional spectra can be added, e.g. from a field instrument or from an image. Color, line width and marker can be modified.

• Example: With FluorMODleaf simulations of upwards leaf fluorescence radiance are plotted as a function of chlorophyll content (Cab) and fluorescence quantum efficiency (Fv).

• Example: With FluorSAIL simulations of leaf fluorescence radiance are plotted as a function of chlorophyll content (Cab) and fluorescence quantum efficiency (Fv).

• Multiple spectral groups can be added within the same graph. Each spectral group can be assigned to a user-defined color. Here 2 spectral groups are plotted with different chlorophyll contents (20 µg/cm², blue, 45 µg/cm², red) and a range of N. Likewise, spectral groups could also consist of different variables or the same variable from different models.

• The graphics module is handy for quick visualization of the employed simulations. It allows plotting multiple spectral groups both at the leaf level and canopy level at once. External spectra can be added (e.g. from field spectrometer or from air- or space-borne observations). Finally, spectral groups can be exported to a text file for further use.

7. Inversion

• Here an image and optionally a land cover map can be loaded for model inversion against actual spectral observations. The image should have the same band settings as the simulations.

• If a classified map is loaded, land cover classes are detected and can be linked with any of the simulated spectra classes. As such, model inversion depends on the corresponding land cover class.

• By selecting a class, also have the option to include only a subsection of the spectral DB by means of narrowing the sliders.

• Any spectral class can be assigned to a land cover class.

• Progress bars indicate progress time and number of processed pixels per land cover class.

• Model inversion provides retrievals for all included variables.

• Retrievals of all classes or of one selected class can be displayed.

• Example: Apart from the inverted variable, additional outputs are included with the map as secondary layers. These are: RMSE, number of local minima. In case when a % of best results is selected then also min, max, STD and mode statistics are provided.

• Maps can be stored in Envi format.

• Example: Inversion of LAI. In this example large areas (agricultural fields) led to spurious high LAI values (dark red). These areas were part of the class herbaceous. There was a mismatch between the satellite observations and the simulations. To overcome this, these areas should be considered as a new class with better model parameterization.

• Case study: A floodplain with natural vegetation in the Netherlands. This map is generated through ML classification of hyperspectral CHRIS data. (Mode 1: pixel size ~17 m, 18 bands, 400-1050 nm)

• Model inversion against hyperspectral CHRIS data by ARTMO.

- Shrubs and grasslands were simulated with a 1D model (SAIL)
- Forest was simulated with a 3D model (FLIGHT)

• ARTMO additionally delivers a RMSE map. This map gives an idea about the retrieval reliability. Darker red indicates poorer retrievals.