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

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1. Introduction

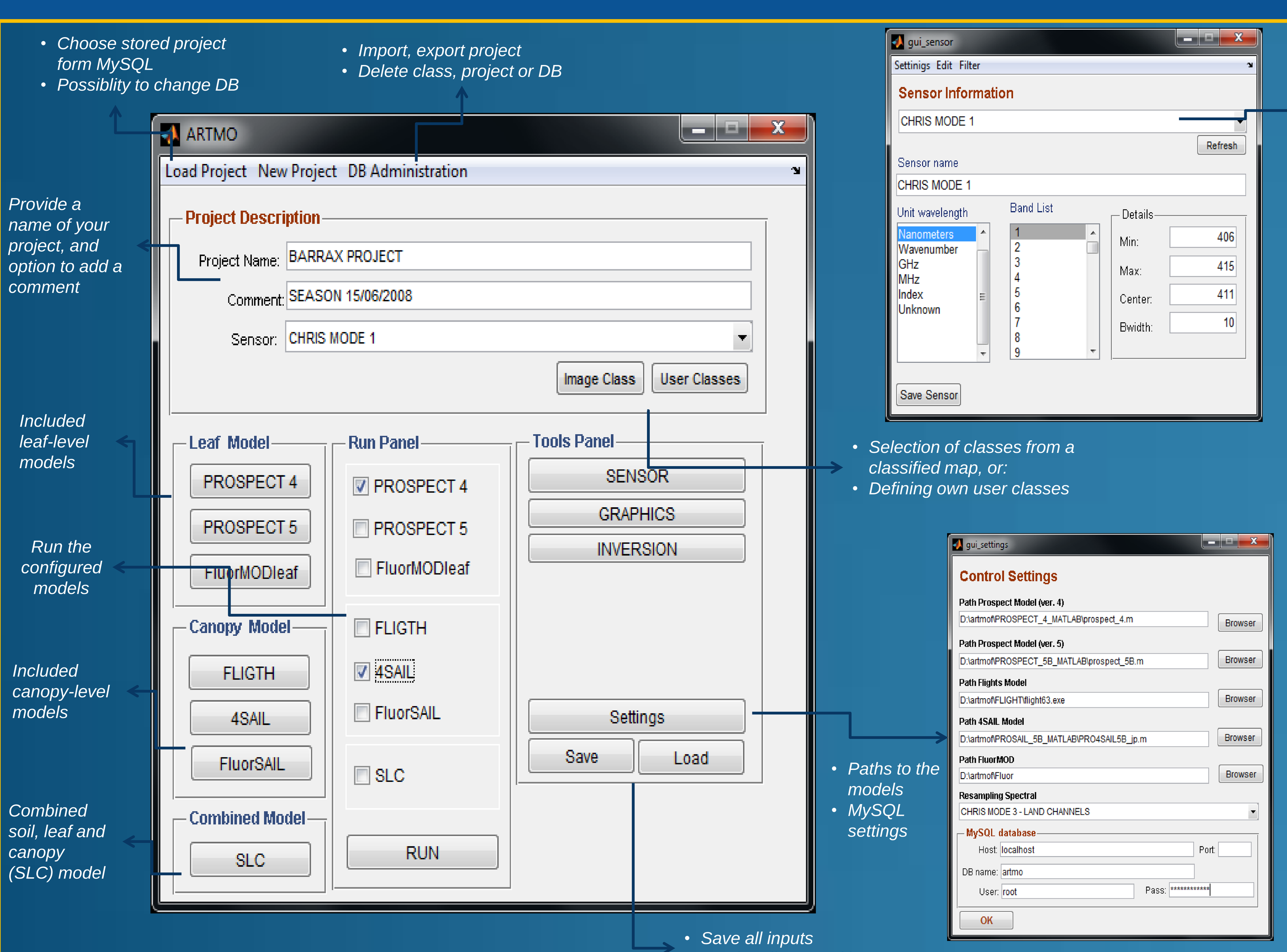
The need for an Automated Radiative Transfer Models Operator (ARTMO) toolbox

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

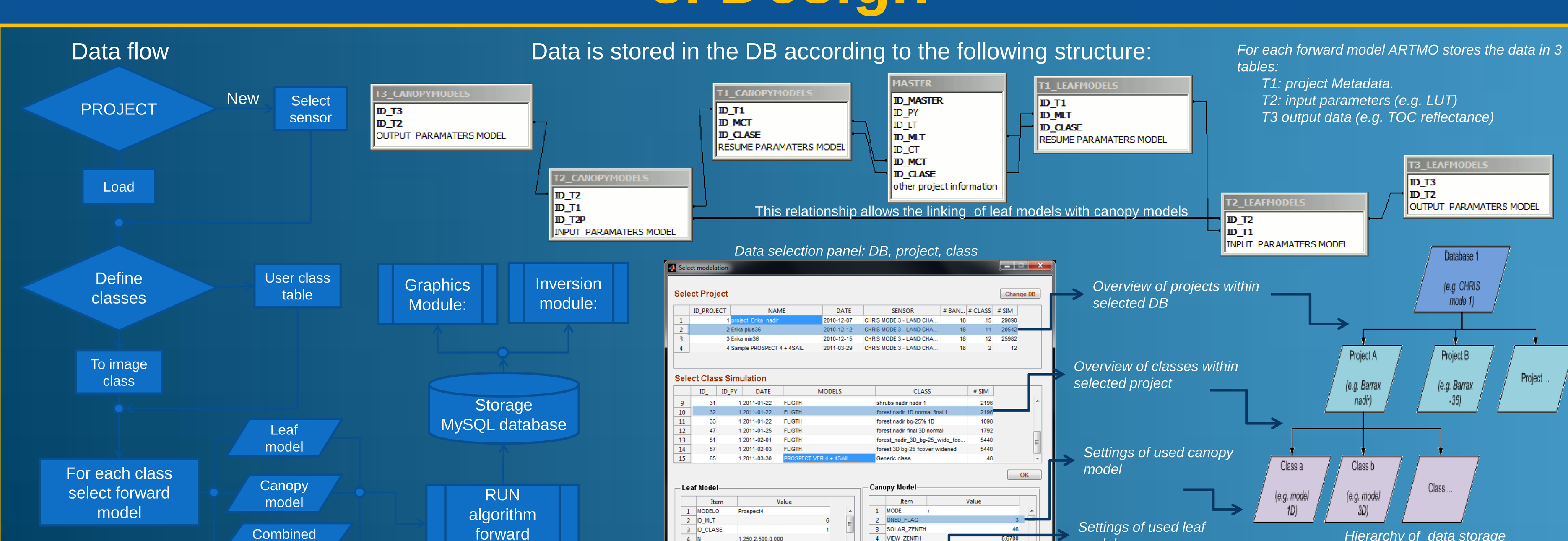


When selecting a sensor, all input data and thus also output data will be automatically resampled to the spectral settings of the selected sensor. This means that any type of spectra (e.g. from field spectrometer or from satellite observations) can be fed into the models (e.g. soil spectra). Moreover,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

3. Design

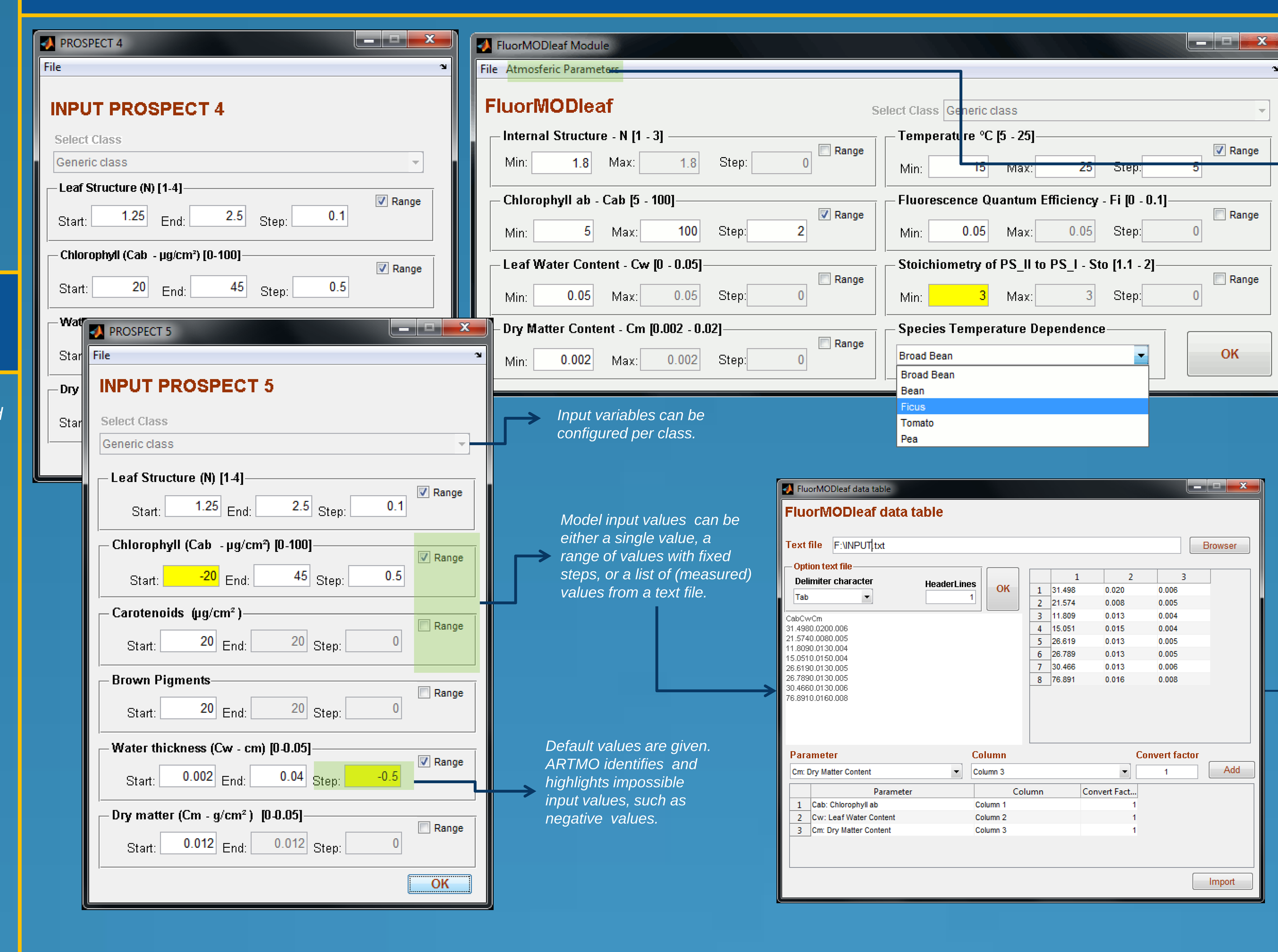


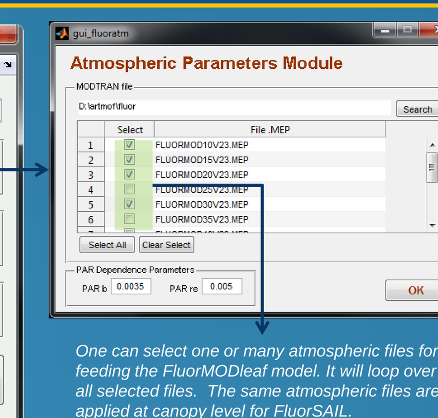
Conclusions

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:

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

4. Leaf-level models

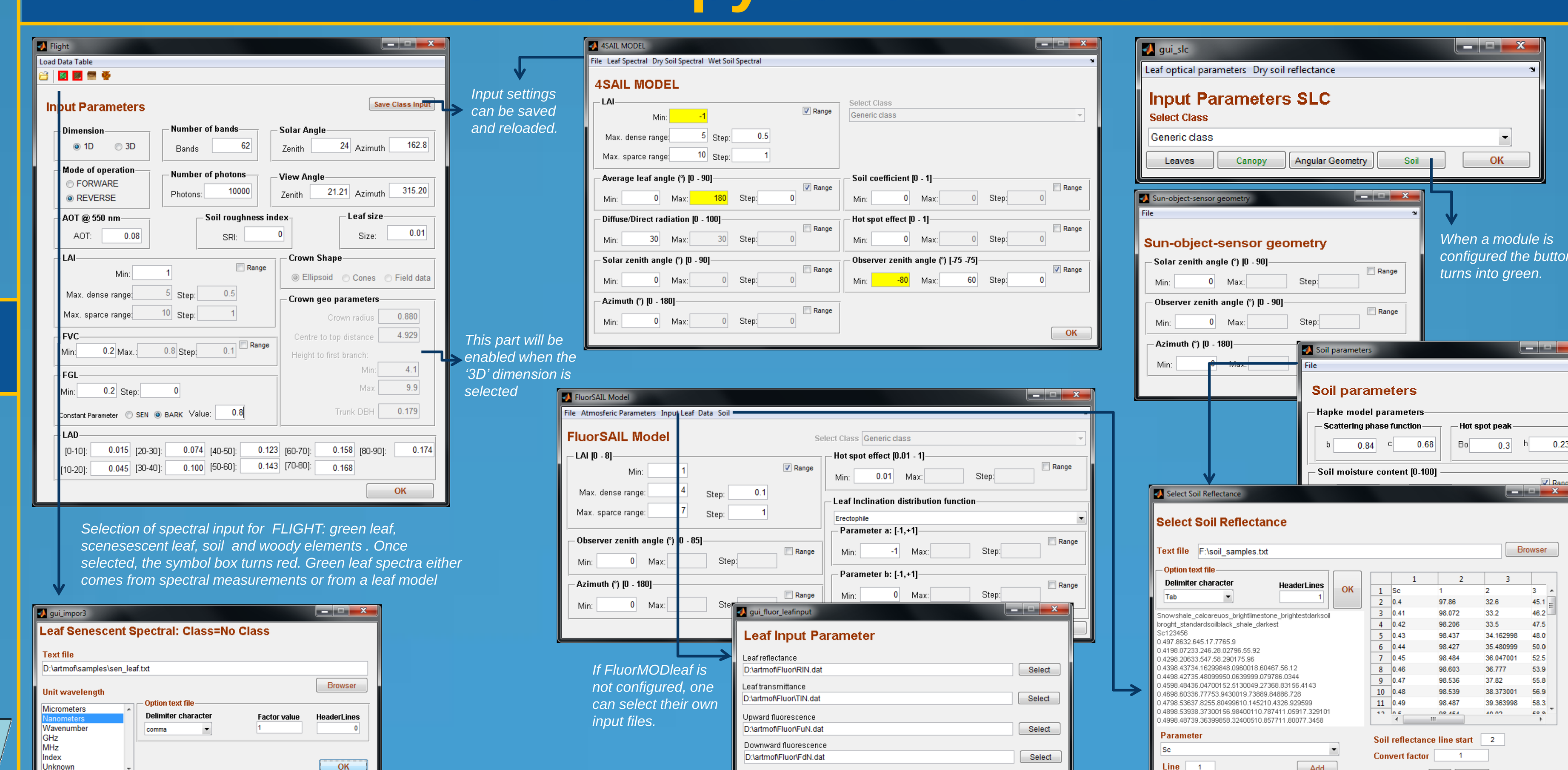




ARTMO can read in text files with model input values, which could come from field measurements. All kinds of text files can be read. Options to select the required column, to convert data, to skip header and to identify the delimiter character are offered. When a model variable is being fed by a text file this variable is disabled in the main input window. This variable can then be combined with user-defined inputs of the remaining variables (single value or range).

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

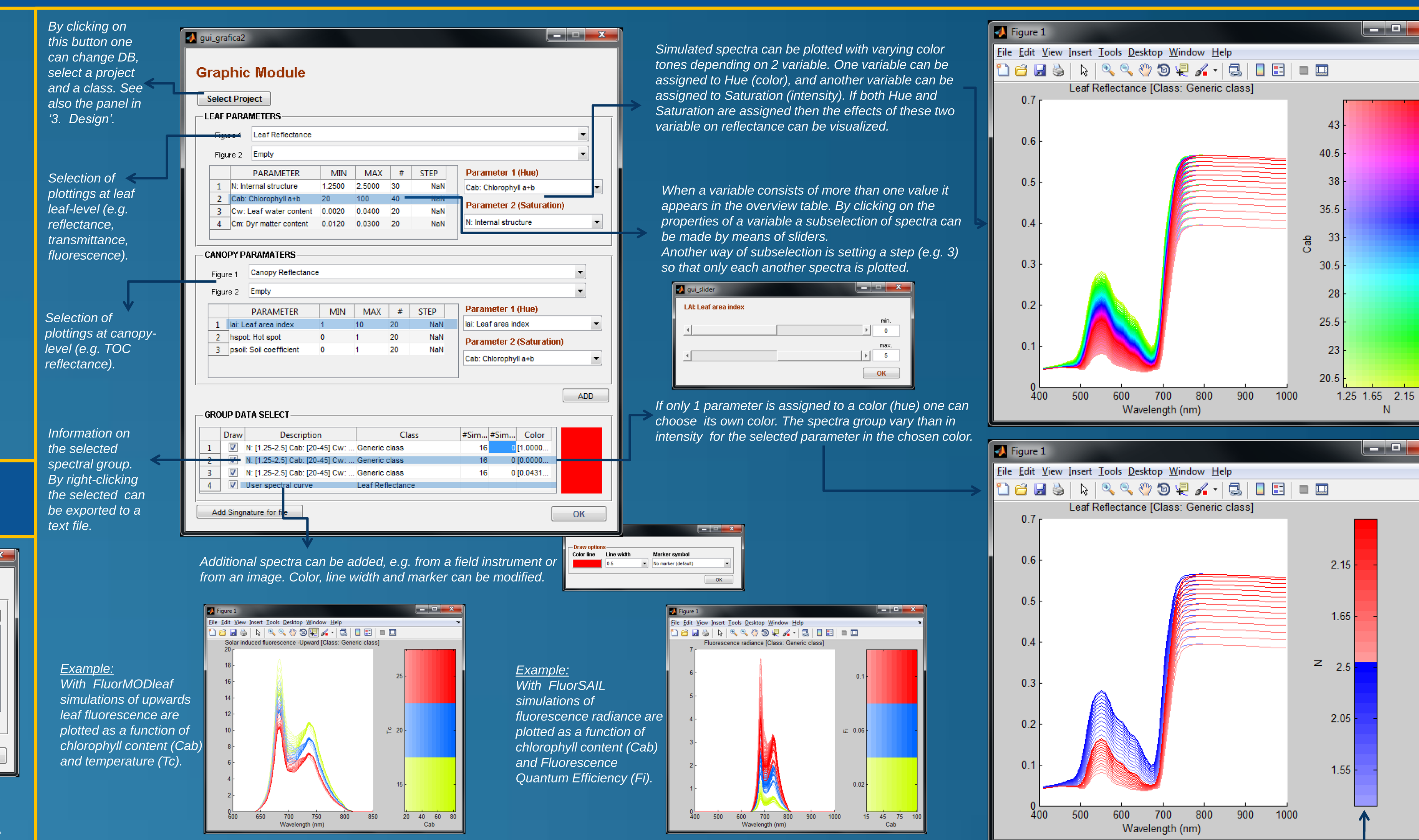
5. Canopy-level models



ARTMO can combine any model variable at the leaf level with any model variable at the canopy level. With this, easily a massive amount of simulations can be generated.

ARTMO offers an assembly of leaf and canopy models, which allows the user to compare the performances of the models. Model selection can be made depending on model complexity (e.g. 1D vs. 3D), performance and processing time.

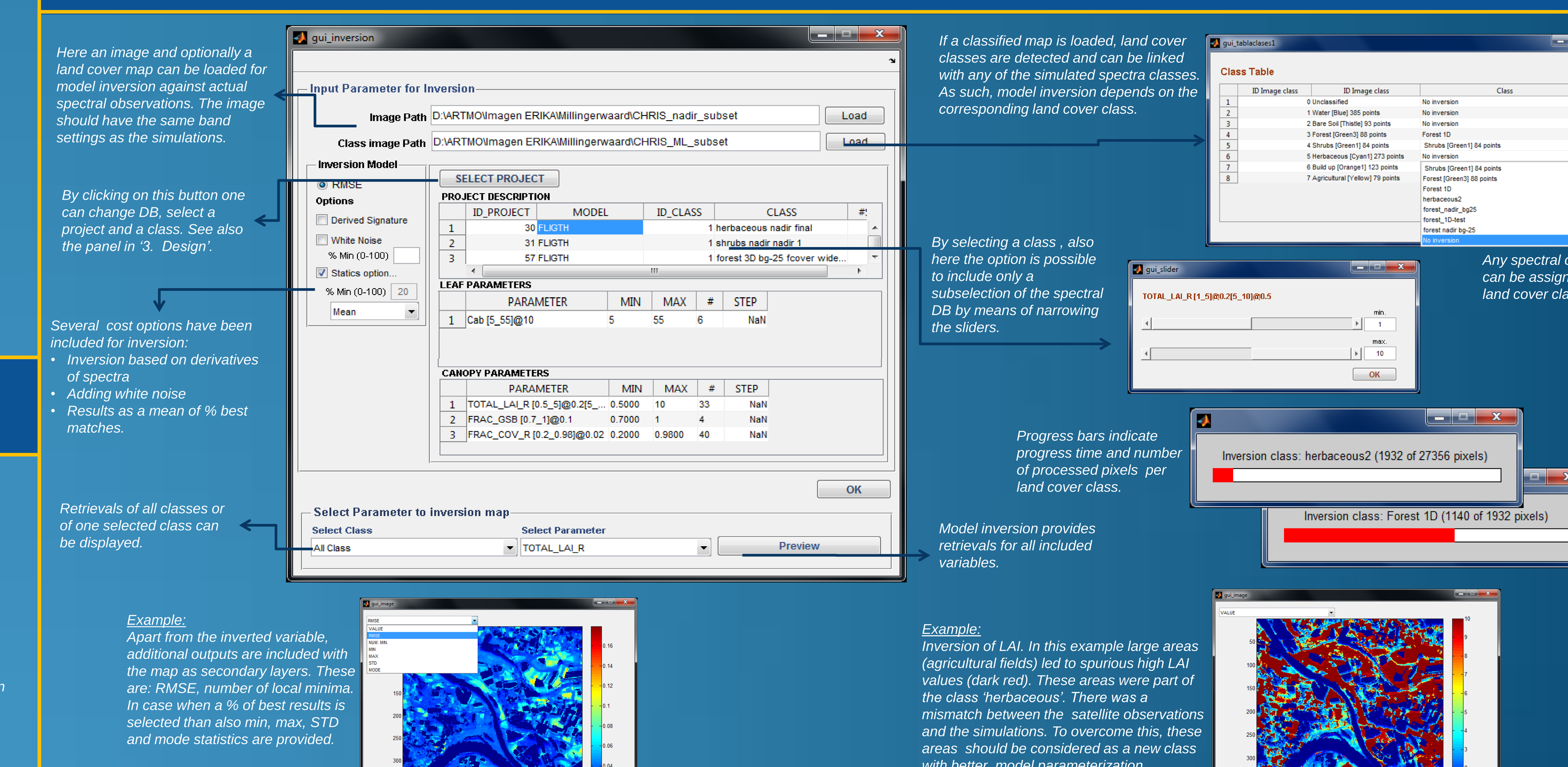
6. Graphics



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.

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.

7. Inversion

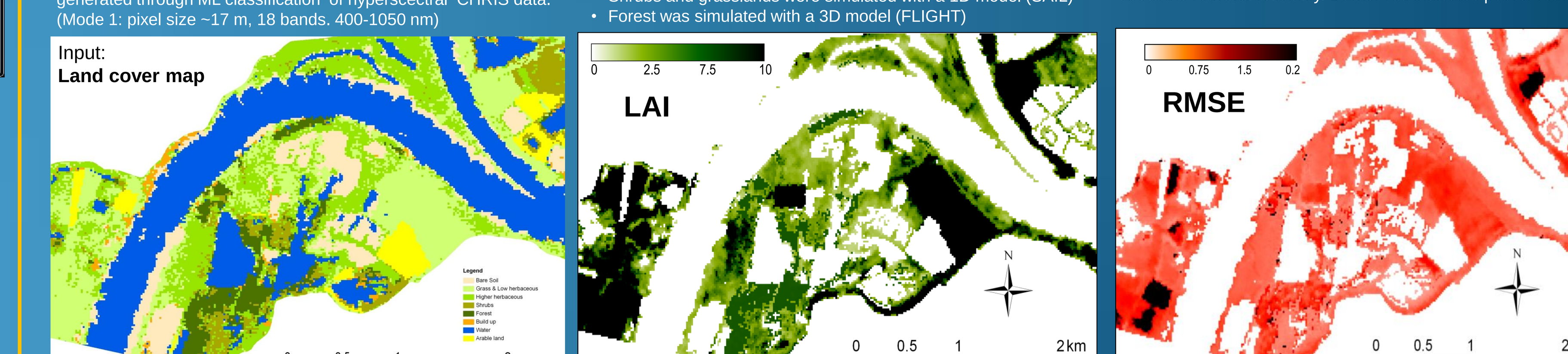


Case study

A floodplain with natural vegetation in the Netherlands. This map is generated through ML classification of hyperscectral 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.



Through model inversion against actual observations maps of biophysical parameters can be derived. The strength of ARTMO lies in that it can execute inversion per land cover class. As such inversion is better adapted to land cover heterogeneity. Classes could be defined based on soil or vegetation type, as well based on sun-target-sensor geometry. Also, the concept of classes allows to make use of multiple RT models within the same project. For instance, homogeneous land cover types (e.g. grasslands, agricultural fields) can be simulated with 1D models, while heterogeneous land cover types (e.g. forest) can be simulated with 3D models.