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Using the ARTMO toolbox for automated retrieval of biophysical parameters through radiative transfer model inversion: Optimizing LUT-based inversion

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Radiative transfer (RT) modeling plays a key role for earth observation (EO) because it is needed to design EO instruments and to develop and test inversion algorithms. The inversion of a RT model is considered as a successful approach for the retrieval of biophysical parameters because of being physically-based and generally applicable. However, to the broader community this approach is considered as laborious because of its many processing steps and expert knowledge is required to realize precise model parameterization.

We have recently developed a radiative transfer toolbox ARTMO (Automated Radiative Transfer Models Operator) with the purpose of providing in a graphical user interface (GUI) essential models and tools required for terrestrial EO applications such as model inversion. In short, the toolbox allows the user: i) to choose between various plant leaf and canopy RT models (e.g. models from the PROSPECT and SAIL family, FLIGHT), ii) to choose between spectral band settings of various air- and space-borne sensors or defining own sensor settings, iii) to simulate a massive amount of spectra based on a look up table (LUT) approach and storing it in a relational database, iv) to plot spectra of multiple models and compare them with measured spectra, and finally, v) to run model inversion against optical imagery given several cost options and accuracy estimates.

In this work ARTMO was used to tackle some well-known problems related to model inversion. According to Hadamard conditions, mathematical models of physical phenomena are mathematically invertible if the solution of the inverse problem to be solved exists, is unique and depends continuously on data. This assumption is not always met because of the large number of unknowns and different strategies have been proposed to overcome this problem. Several of these strategies have been implemented in ARTMO and were here analyzed to optimize the inversion performance. Data came from the SPARC-2003 dataset, which was acquired on the agricultural test site Barrax, Spain. LUTs were created using the 4SAIL and FLIGHT models and were inverted against CHRIS data in order to retrieve maps of chlorophyll content (chl) and leaf area index (LAI). The following inversion steps have been optimized:

1. Cost function. The performances of about 50 different cost functions (i.e. minimum distance functions) were compared. Remarkably, in none of the studied cases the widely used root mean square error (RMSE) led to most accurate results. Depending on the retrieved parameter, more successful functions were: ‘Sharma and Mittal’, ‘Shannon′s entropy’, ‘Hellinger distance’, ‘Pearson′s chi-square’.
2. Gaussian noise. Earth observation data typically encompass a certain degree of noise due to errors related to radiometric and geometric processing. In all cases, adding 5% Gaussian noise to the simulated spectra led to more accurate retrievals as compared to without noise.
3. Average of multiple best solutions. Because multiple parameter combinations may lead to the same spectra, a way to overcome this problem is not searching for the top best match but for a percentage of best matches. Optimized retrievals were encountered when including an average of 7% (Chl) to 10% (LAI) top best matches.
4. Integration of estimates. The option is provided to integrate estimates of biochemical contents at the canopy level (e.g., total chlorophyll: Chl × LAI, or water: Cw × LAI), which can lead to increased robustness and accuracy.
5. Class-based inversion. This option is probably ARTMO′s most powerful feature as it allows model parameterization depending on the image′s land cover classes (e.g. different soil or vegetation types). Class-based inversion can lead to considerably improved accuracies compared to one generic class.

Results suggest that 4SAIL and FLIGHT performed alike for Chl but not for LAI. While both models rely on the leaf model PROSPECT for Chl retrieval, their different nature (e.g. numerical vs. ray tracing) may cause that retrieval of structural parameters such as LAI differ. Finally, it should be noted that the whole analysis can be intuitively performed by the toolbox. ARTMO is freely available to the EO community for further development. Expressions of interest are welcome and should be directed to the corresponding author.