ARTMO's Global Sensitivity Analysis (GSA) toolbox to quantify driving variables of leaf and canopy radiative transfer models

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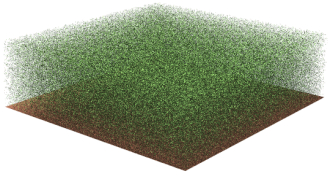
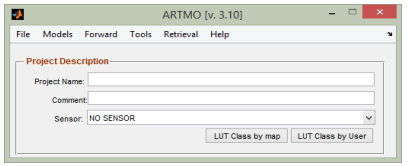
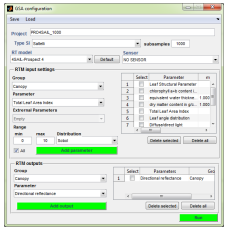
15/04/2015 – 9th EARSeL SIG IS

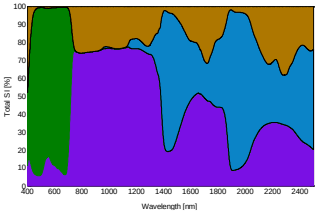
Outline:

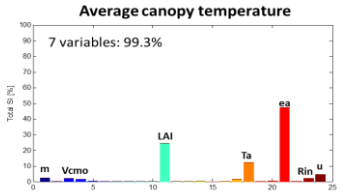
- Background RTM
- GSA theory
- ARTMO's RTMs
- ARTMO's GSA toolbox
- GSA toolbox results
  - Leaf
  - Leaf + canopy
  - SVAT model SCOPE
- Conclusions



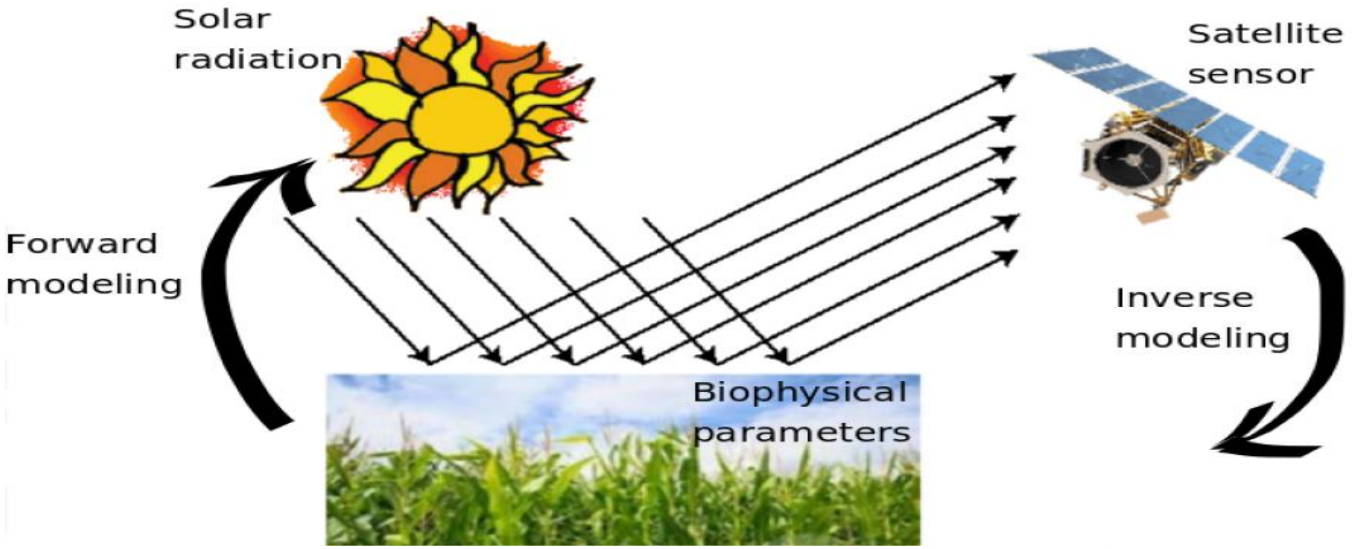








Background



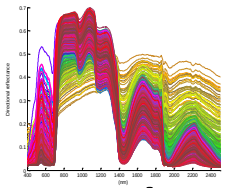
RTMs

Physically based RTM approaches

Development/ Evaluation

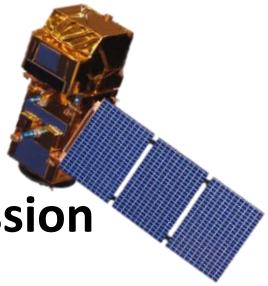
Retrieval

Design



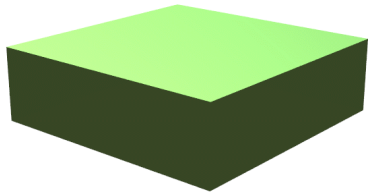
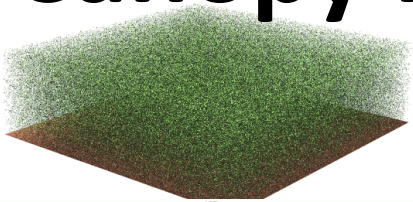
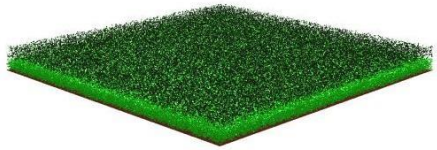
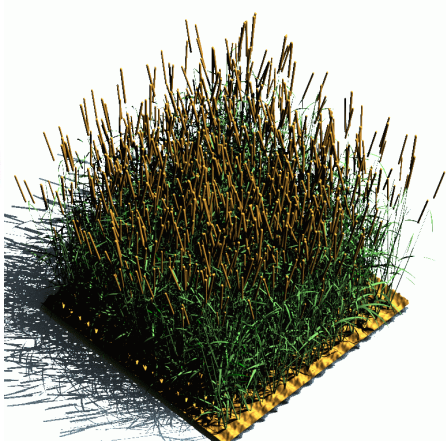
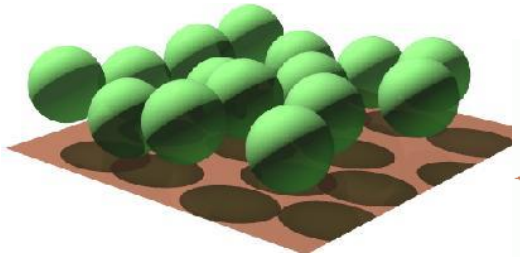
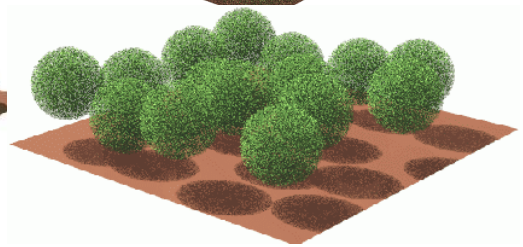
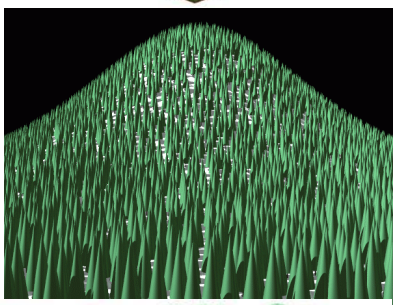
Spectra/ VIs

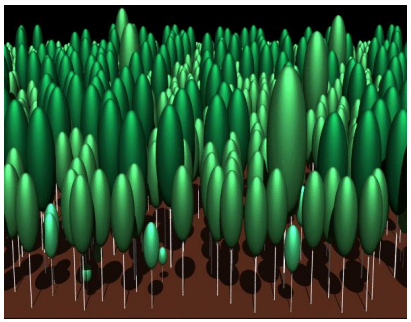
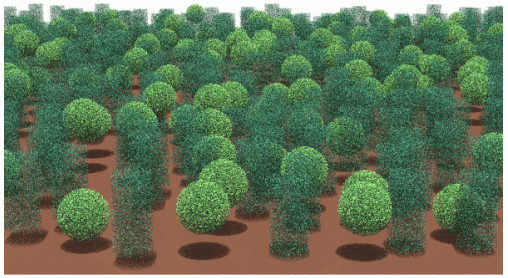
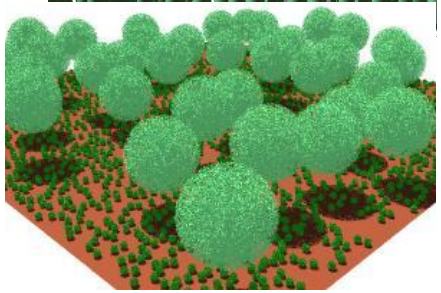
Mapping biophysical param.



mission

Canopy RTMs

- RTMs vary in **design**, **complexity**, number of **input variables**, **processing speed**.
- **Not all RTM input variables play an equally important role**; they are also spectrally dependent.
- For the larger majority of RS applications **there is no need to vary all variables!**

How to identify key RTM input variables, and variables that can be safely set to default values?

Global sensitivity analysis (GSA)

Sensitivity analysis evaluates **the relative importance of each input parameter** and can be used to identify **the most influential parameters in determining the variability of model outputs**.

1. **Local sensitivity analysis**: "**One-factor-at-a-time**" (OAT): changing one input parameter at a time whilst holding all other at their central values . **AOT methods do not cover the whole input parameter space. → Inadequate for analyzing complex models which may have many parameters and may be high-dimensional and/or non-linear.**

2. **Global sensitivity analysis**: **explores the full input parameter space**. The contribution of each input parameter to the variation in outputs is averaged over the variation of all input parameters, **i.e. all input parameters are changed together**.

GSA techniques, which quantify the relative importance of each input parameter to model outputs, **can help set safe default values for those less influential input parameters**.

GSA can greatly simplify model calibration through enabling the most influential parameters to be targeted for data acquisition and refinement.

Variance-based methods - Global sensitivity indices

Variance-based method: the output variance is decomposed to the sum of **contributions of each individual input parameter and the interactions** (coupling terms) between different parameters.

Based on the work of Sobol', **variance-based sensitivity measures** are represented as follows:

$$1 = \sum_i S_i + \sum_i \sum_{j>i} S_{ij} +, \cdots, +S_{12,\ldots,k},$$

in this equation, S_i, S_{ij},…,$S_{12,\ldots,k}$ are ***Sobol's global sensitivity indices***.:

- The ***first order sensitivity index*** S_i measures and quantifies the sensitivity of model **output *Y* to the input parameter X_i (without interaction terms),** whereas, S_{ij},…,$S_{12,\ldots,k}$ are the sensitivity measures for the higher order terms (interaction terms).

- The ***total effect* sensitivity index** S_{Ti} measures **the whole effect of the variable *Xi***, i.e. the first order effect as well **as its coupling terms with the other input variables**:

$$S_{T1} = S_1 + S_{12} + S_{13} + S_{123}$$

Sobol',. I.M., (2001). Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates, Mathematics and Computers in Simulation, 55(1-3), 271- 280

GSA method of Saltelli et al., 2010:

- ***First order sensitivity***:

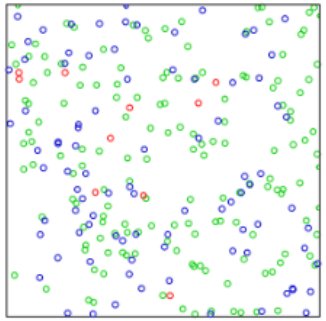
$$S_i = \frac{\frac{1}{n}\sum_{j=1}^{n} f(B)_j \left(f\left(A^i_B\right)_j - f(A)_j \right)}{\mathrm{Var}(L)}$$

- ***Total sensitivity***:

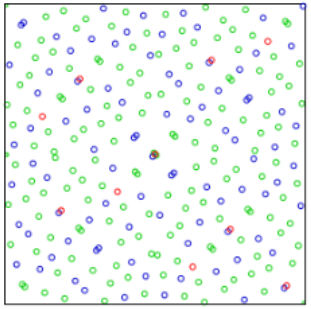
$$S_{Ti} = \frac{\frac{1}{2n}\sum_{j=1}^{n} \left(f(A)_j - f\left(A^i_B\right)_j \right)^2}{\mathrm{Var}(L)}$$

Sample distribution:

Random



Sobol quasi-random sampling sequence (LPTAU)



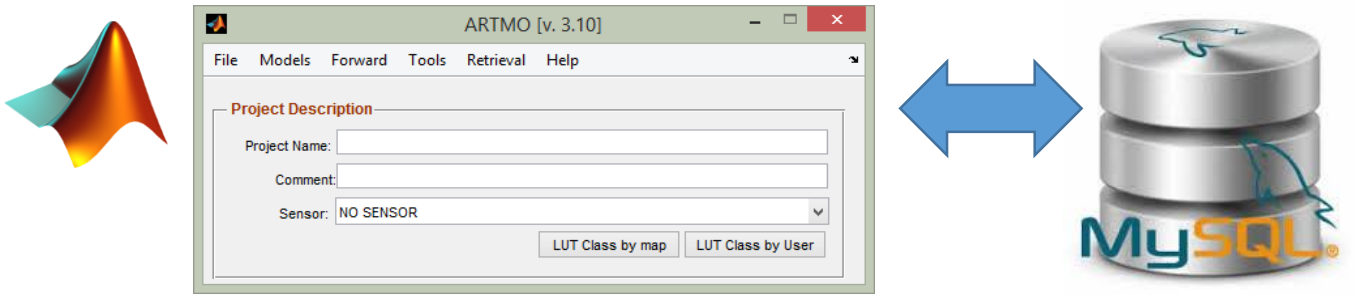
Total # of samples= ($N_{variabls}$ +2)*#sample distribution

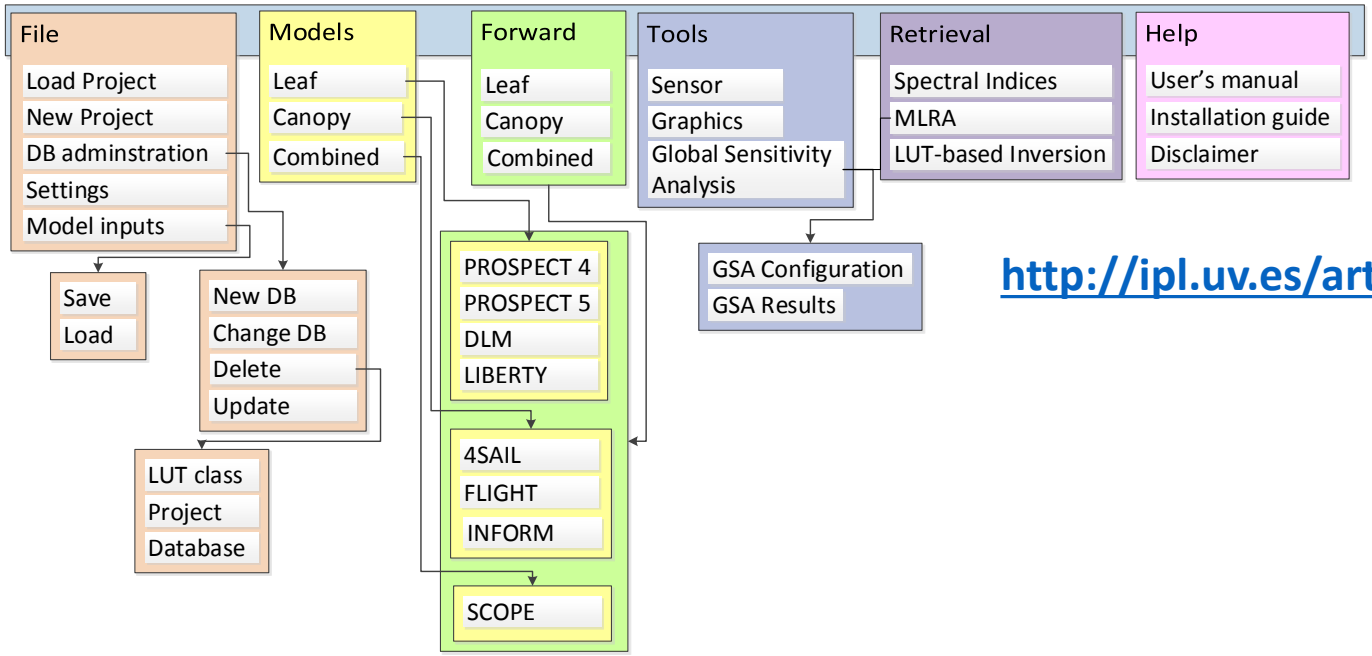
These methods are hard to use – no GSA code publicly available to RTM analysis

Need for a dedicated toolbox!

Saltelli, A., Annoni, P., 2010, How to avoid a perfunctory sensitivity analysis, *Environmental Modeling and Software,* **25**, 1508-1517.

Availability of RTMs:





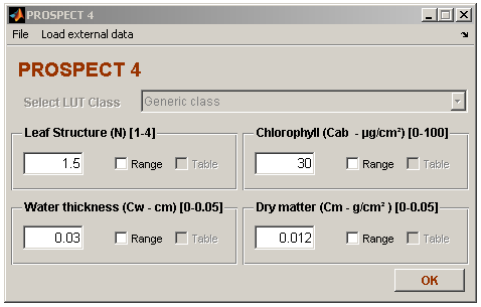
http://ipl.uv.es/artmo/

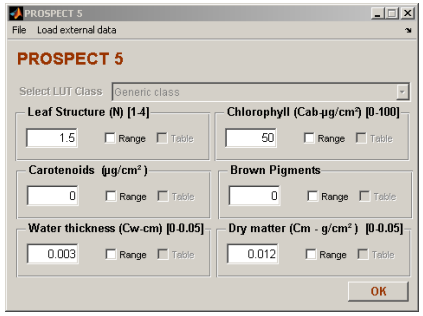
ARTMO seems perfectly suited to develop a GSA toolbox.

ARTMO's RTMs:

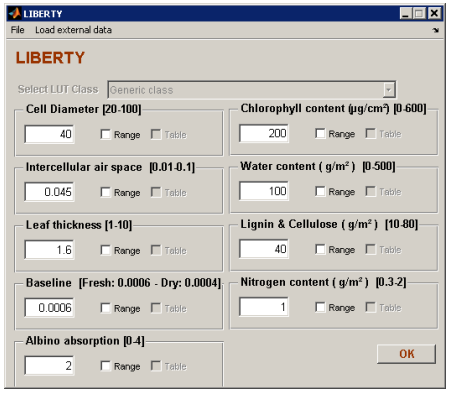
Leaf RTMs

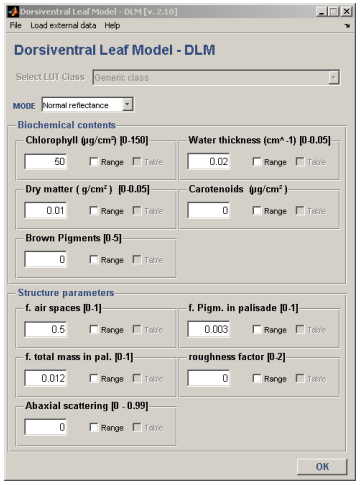
S. Jacquemoud & JP Féret





T. Dawson

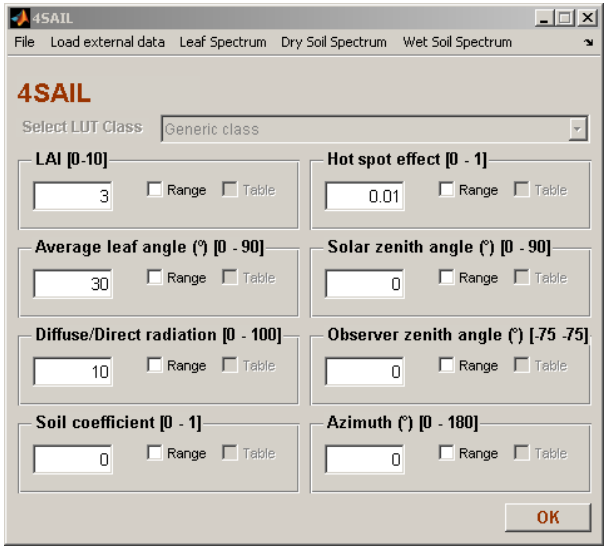




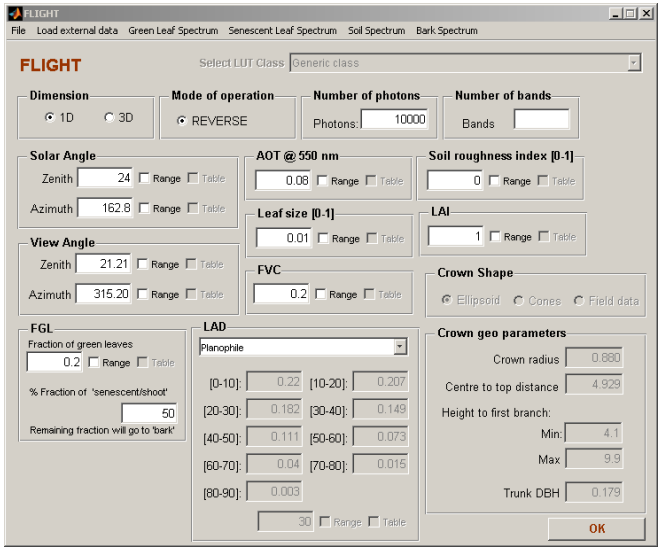
Outputs: *reflectance & transmittance*

Canopy RTMs

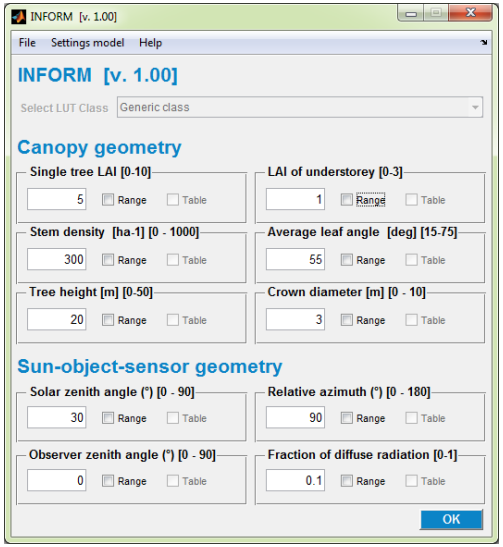
W. Vehoef



P. North



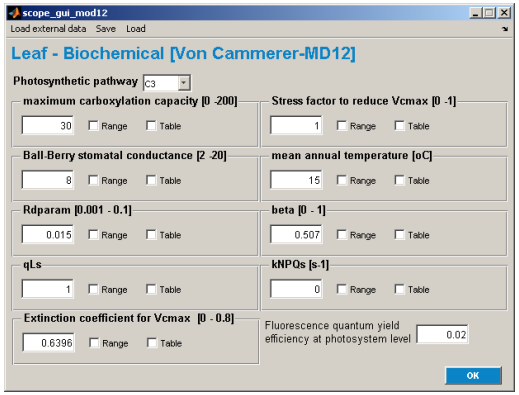
C. Atzberger & M. Schlerf

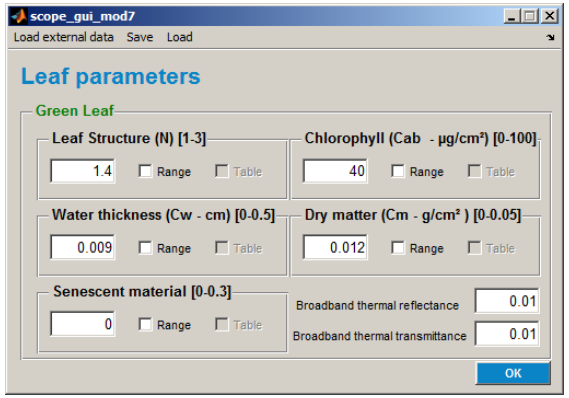


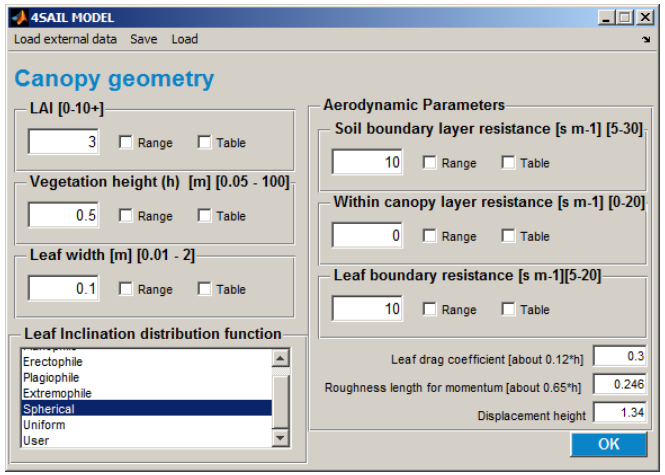
Outputs: *directional reflectance*

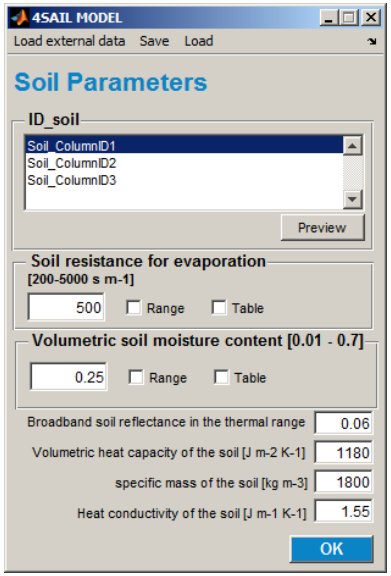
Combined: SCOPE

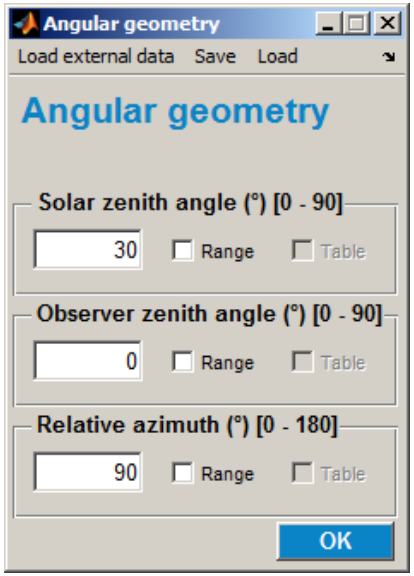
(W. Verhoef, C. vd Tol, F. Magnani)

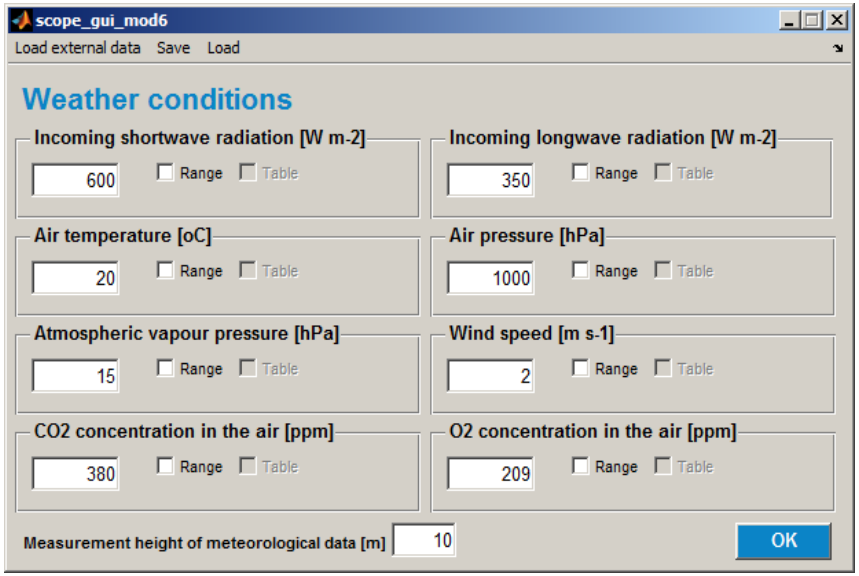












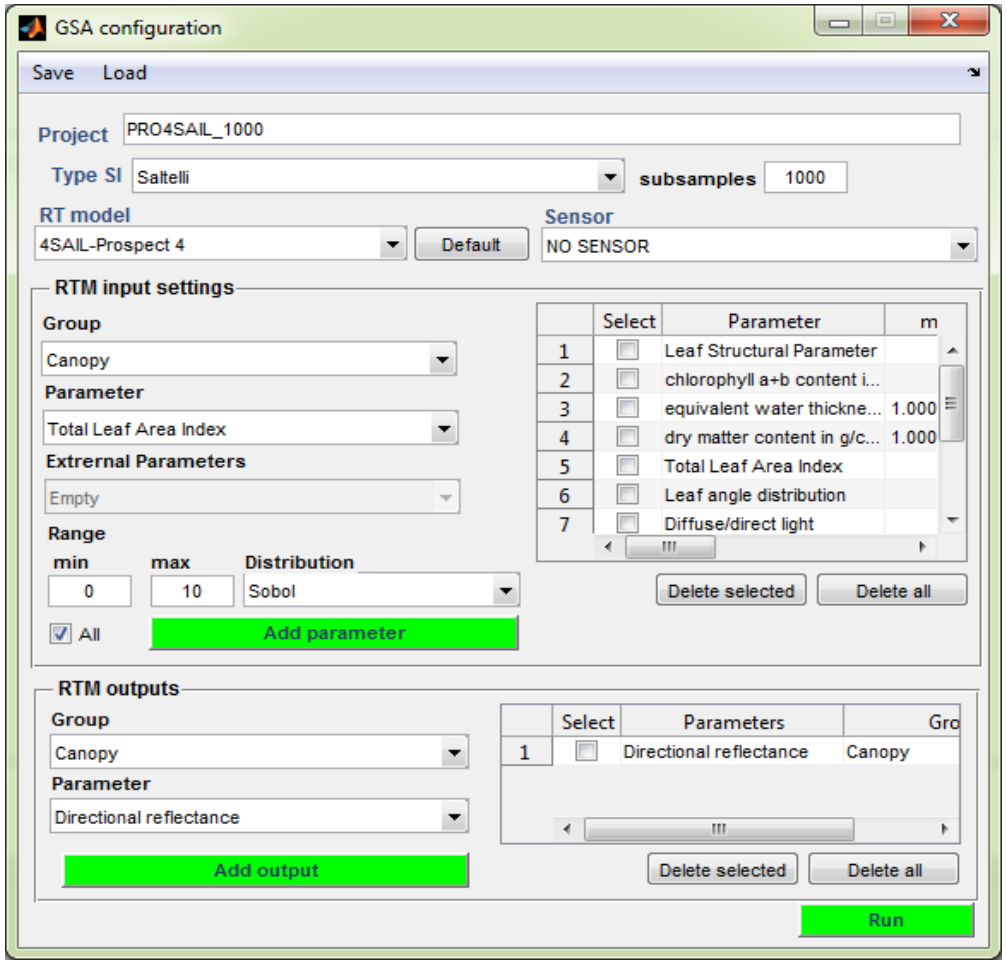
SCOPE is an energy balance model and provides over 50 outputs, grouped according to: aerodynamic, **fluxes (e.g. PAR)**, **radiation**, **reflectance**, spectrum, surface temperature, **fluorescence**.

More about SCOPE see Fluorescence session

GSA Configuration

ARTMO→Tools → Global Sensitivity Analysis

- GSA Configuration
- GSA Results



- Give a **Project** name
- Select GSA (**Saltelli (2010)**, EFAST, Sobol)
- **# Subsamples**
- Select **RTM**. Option to select a **Sensor**.
- Select RTM **input variables**, boundaries and sampling distribution.
- Select RTM **output**: *multiple variables at once can be analyzed.*

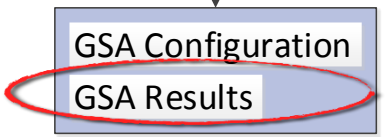
The following RTM combinations have been implemented:

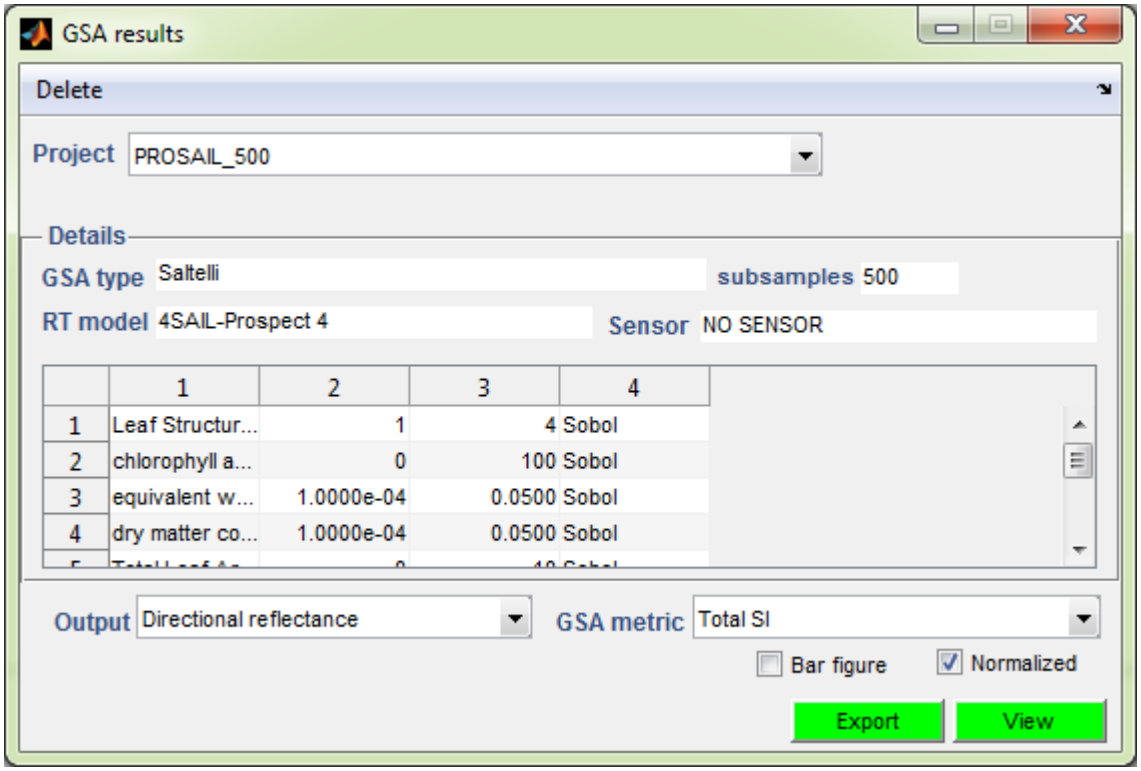
Leaf: PROSPECT4, PROSPECT5, DLM, LIBERTY,

Leaf + canopy: PROSPECT4-SAIL, PROSPECT5-SAIL, LIBERTY-SAIL, PROSPECT4-INFORM, PROSPECT5-INFORM, LIBERTY-INFORM, SCOPE

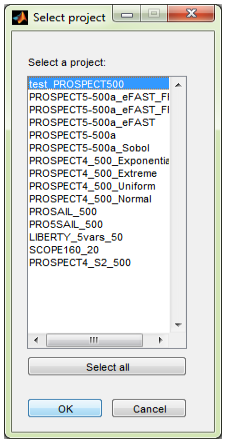
GSA results

ARTMO→Tools → Global Sensitivity Analysis





- **Project** name
- **GSA & RTM** info
- Overview of **input variables**, boundaries and sampling distribution
- Select **output variables** to visualize or export.
- Select ***first*** or ***total*** order **sensitivity indices**.



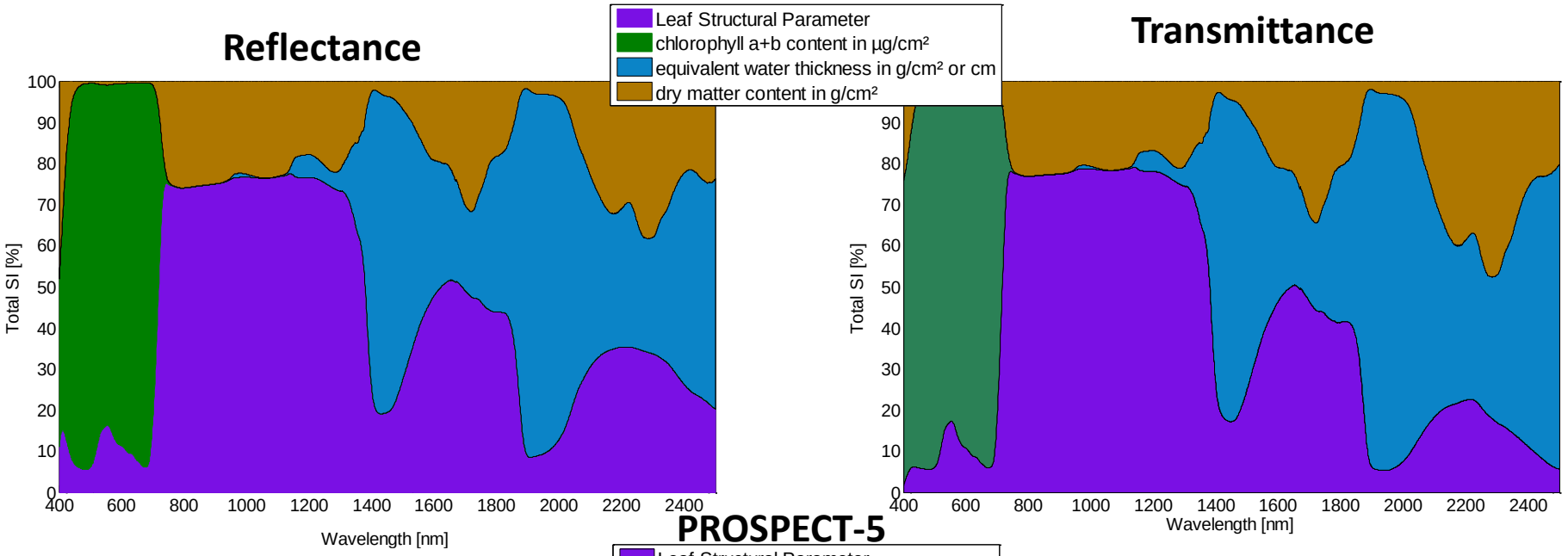
Sensitivity indices results are stored in MySQL database. That allows fast visualizing or deleting of earlier results.

Speed bottleneck is the RTM (e.g. SCOPE) – GSA results fastly generated.

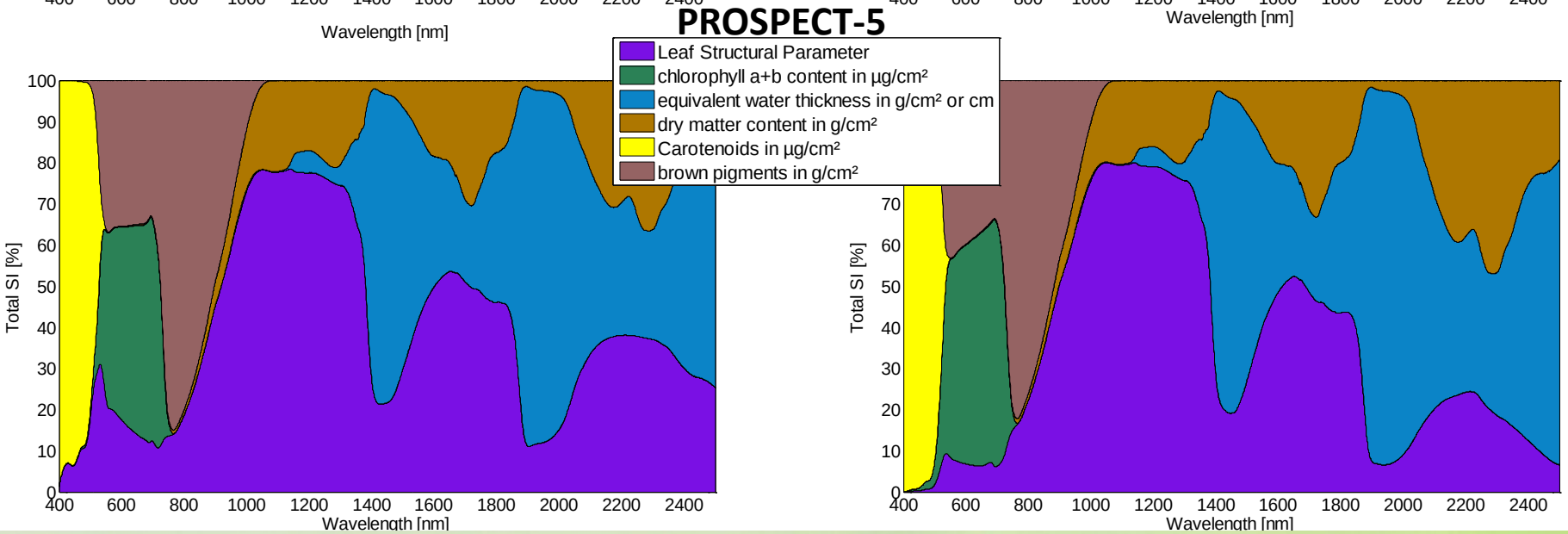
S_{Ti} Leaf: PROSPECT-4/5 (1000#)

< 3 min

PROSPECT-4



PROSPECT-5

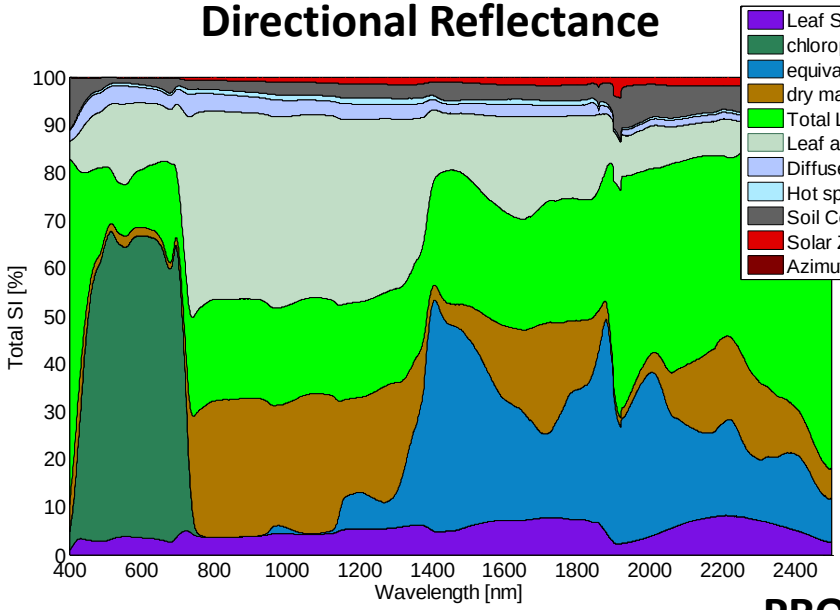


S_{Ti} Canopy: PROSAIL (1000#)

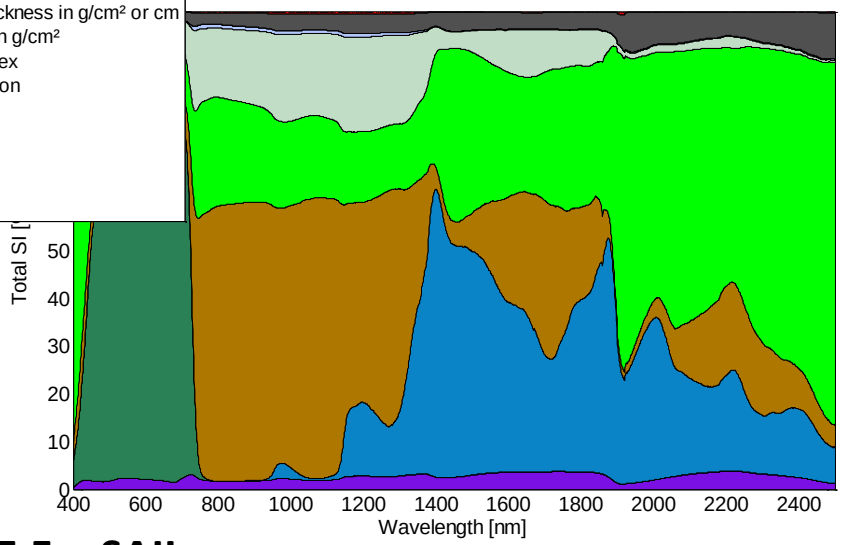
< 5 min

PROSPECT-4 +SAIL

Directional Reflectance

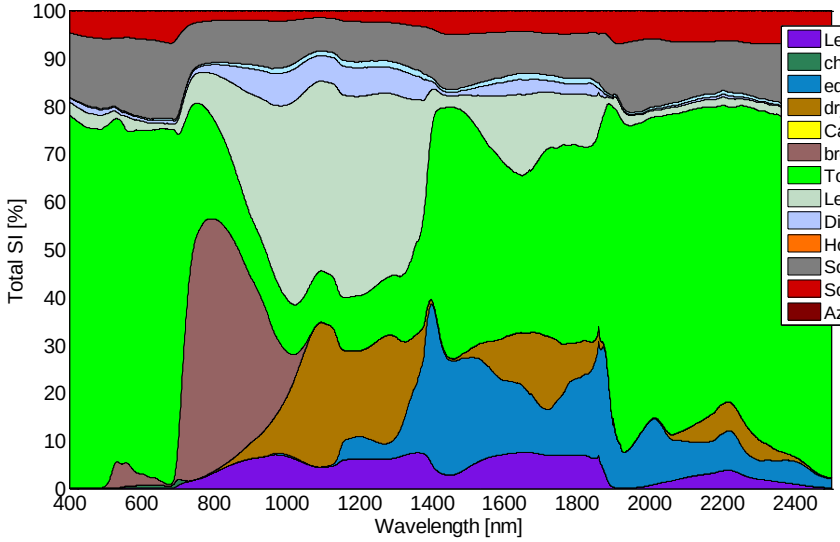


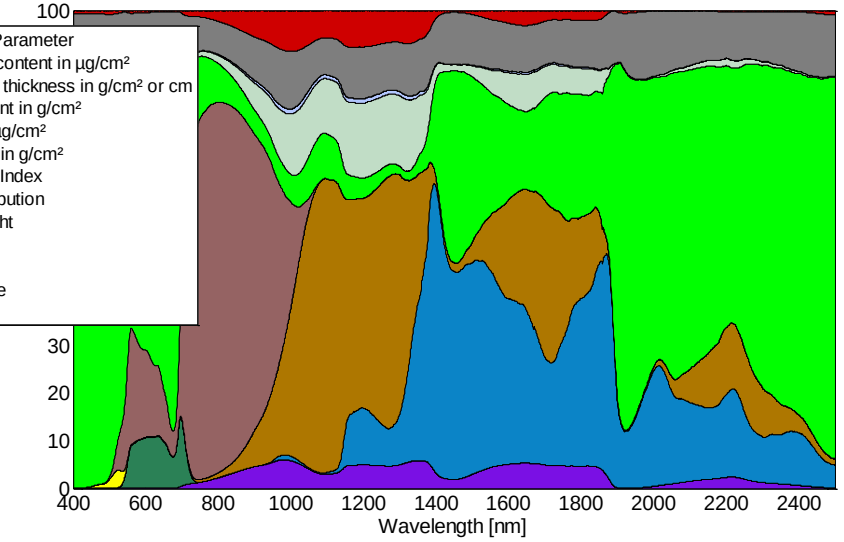
Hemispherical Reflectance



Leaf Structural Parameter
chlorophyll a+b content in µg/cm²
equivalent water thickness in g/cm² or cm
dry matter content in g/cm²
Total Leaf Area Index
Leaf angle distribution
Diffuse/direct light
Hot spot
Soil Coefficient
Solar Zenit Angle
Azimut Angle

PROSPECT-5 + SAIL

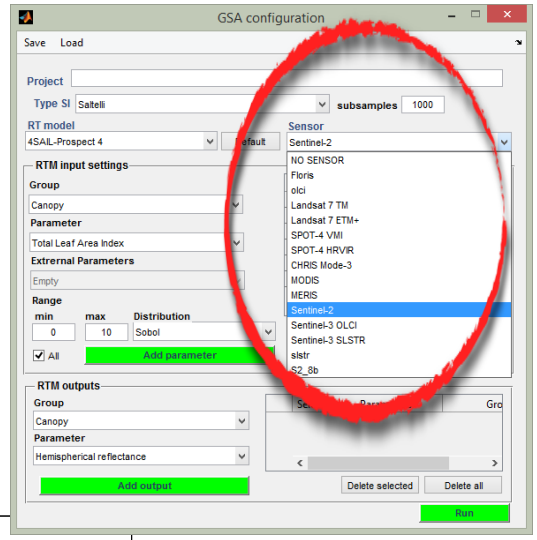


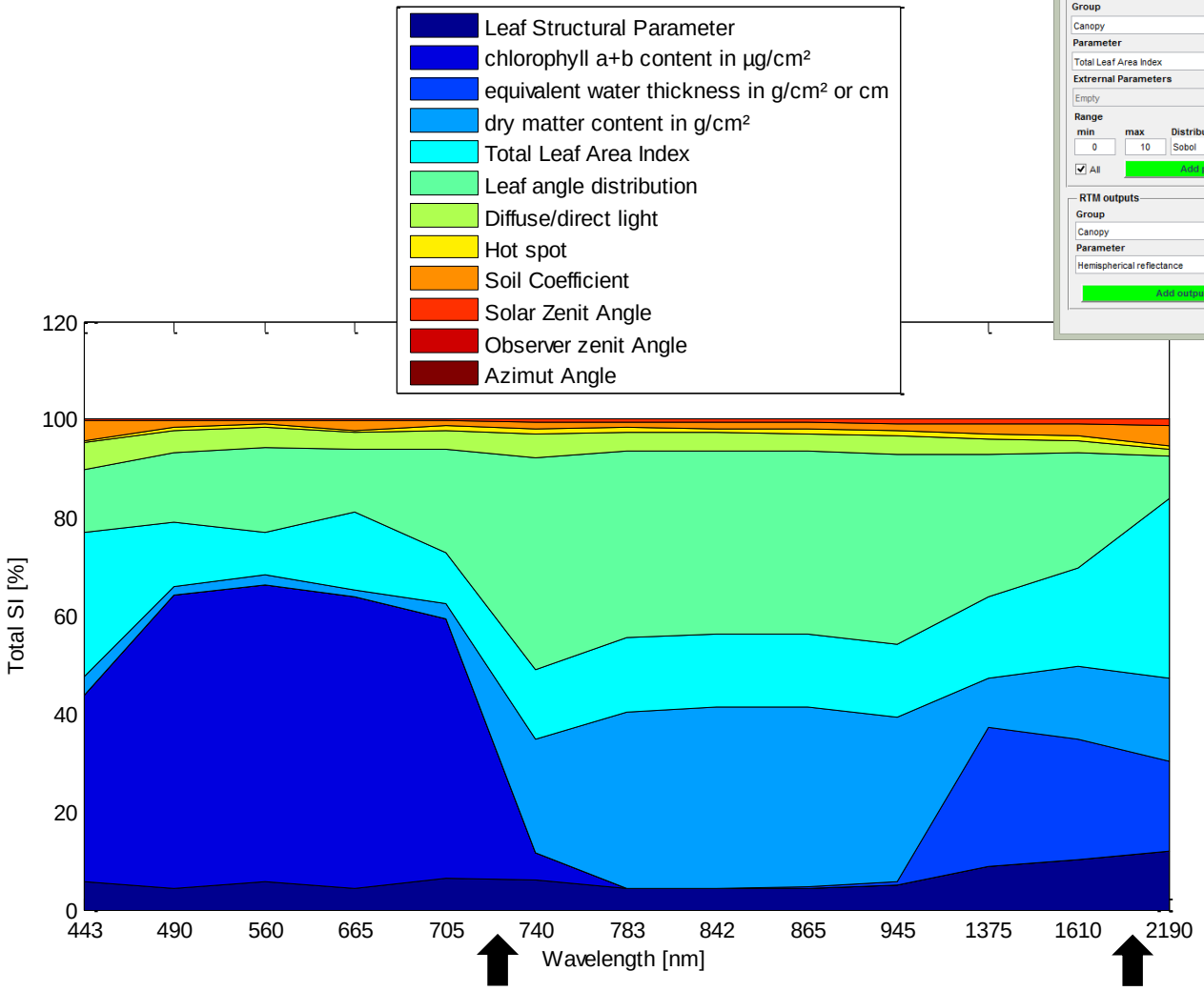


Leaf Structural Parameter
chlorophyll a+b content in µg/cm²
equivalent water thickness in g/cm² or cm
dry matter content in g/cm²
Carotenoids in µg/cm²
brown pigments in g/cm²
Total Leaf Area Index
Leaf angle distribution
Diffuse/direct light
Hot spot
Soil Coefficient
Solar Zenit Angle
Azimut Angle

S_{Ti} PROSAIL with Sensor option

e.g., Sentinel-2:

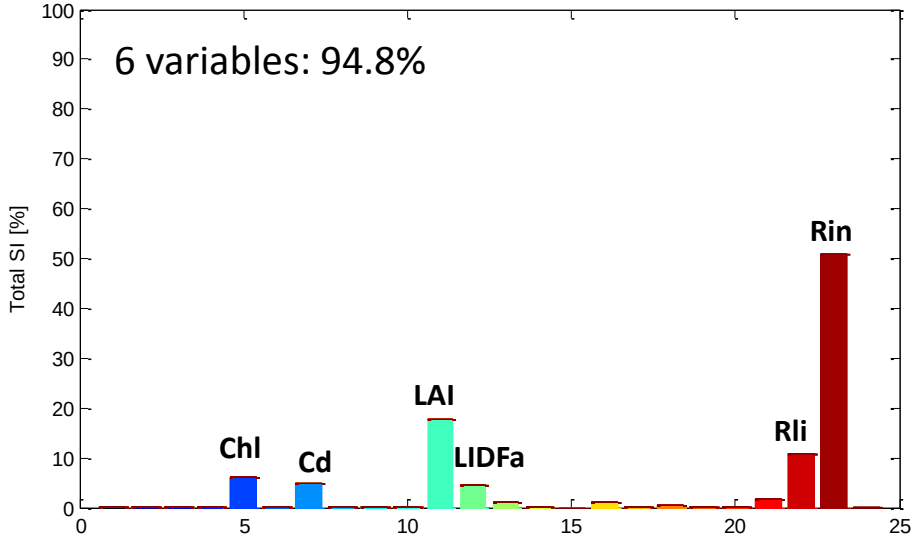


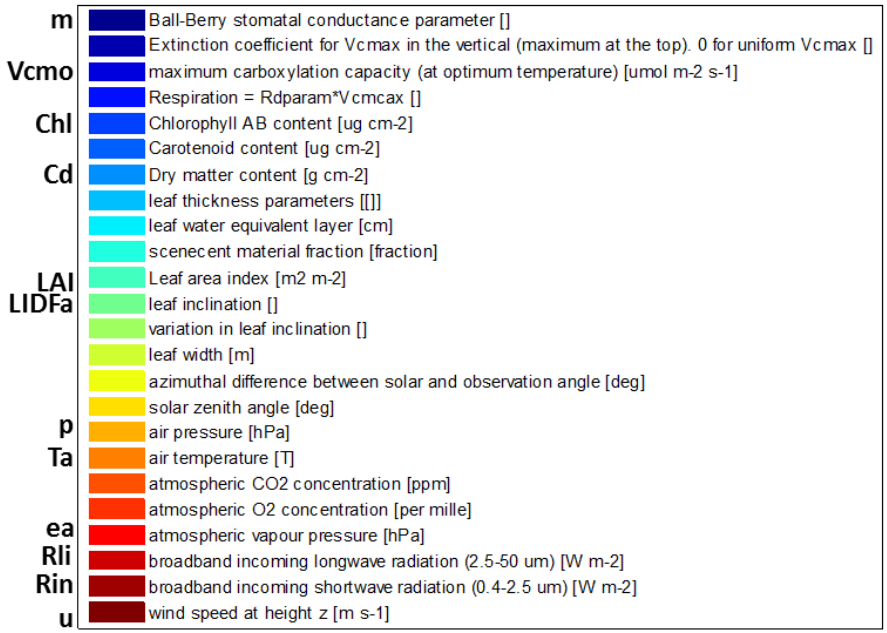


With ARTMO's Sensor module, GSA can be applied to RTMs for any kind of optical sensor (within 400-2400 nm range).

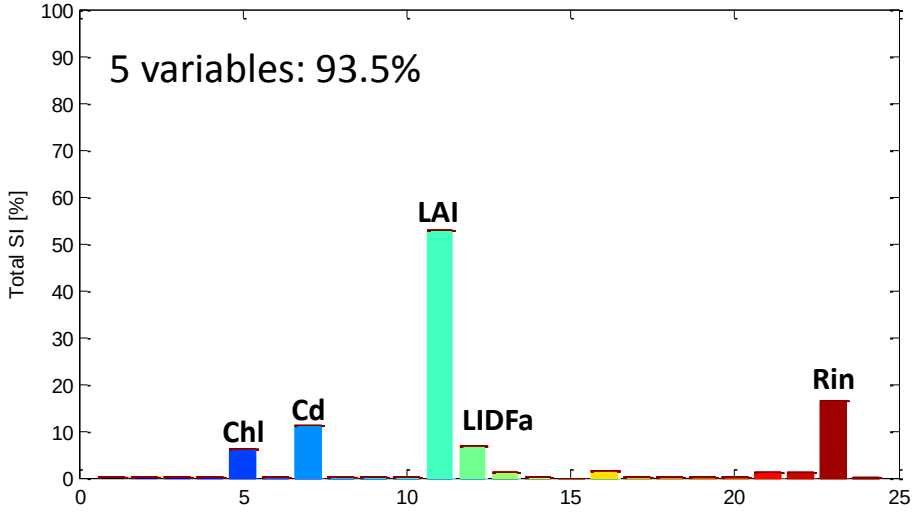
S_{Ti} SCOPE: 25 vars; #1000; Fluxes (1/2)

Total net radiation

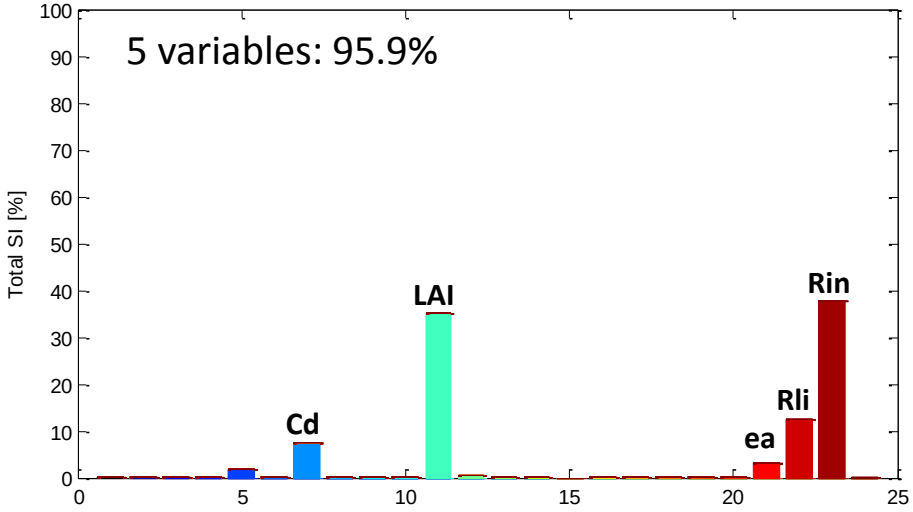




Net radiation of the soil

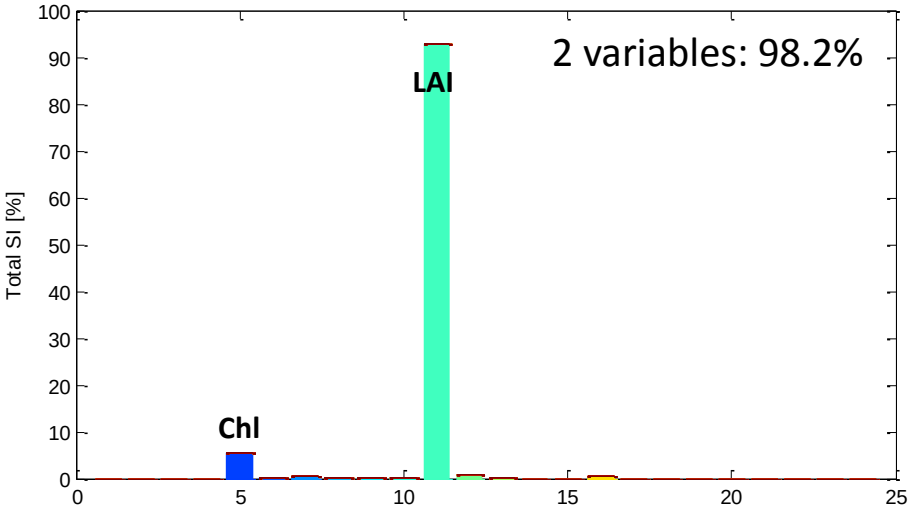


Net radiation of the canopy

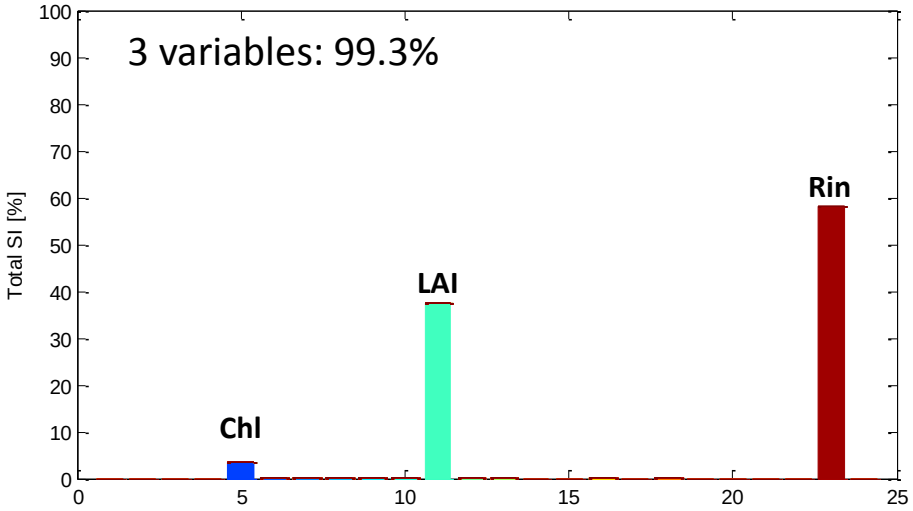


S_{Ti} SCOPE: 25 vars.; #1000; Fluxes (2/2)

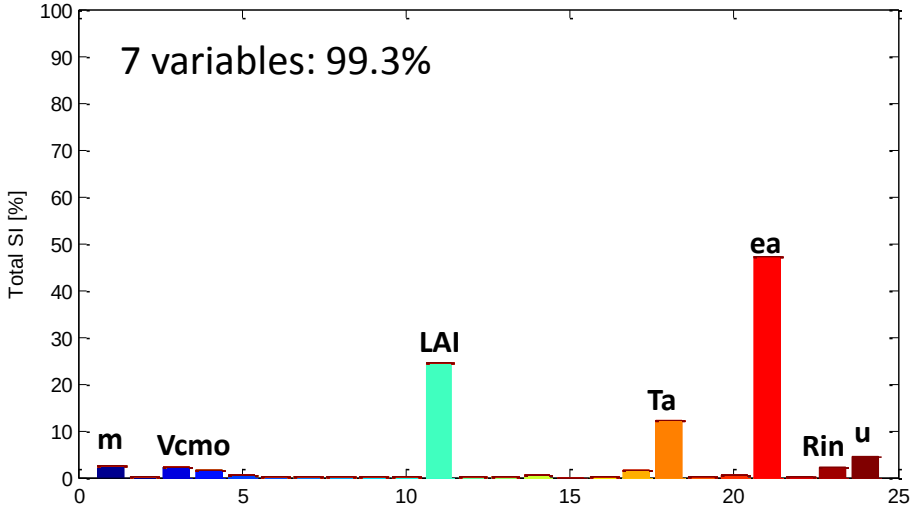
Fraction of absorbed PAR



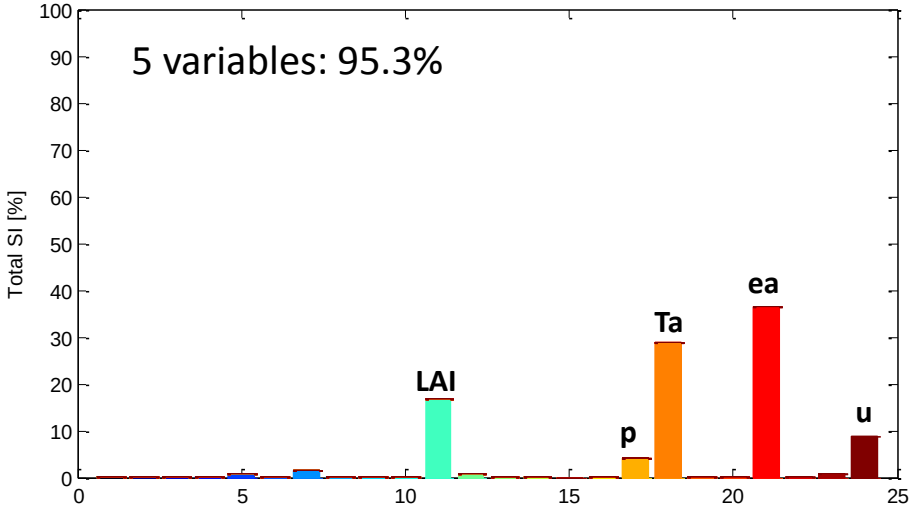
Total absorbed PAR by leaves



Average canopy temperature



Average soil temperature



More about GSA SCOPE see Fluorescence session (O10A)

Applications & further development

- **GSA useful tool to gain insight into radiative transfer fluxes and model performances**, e.g. for a **specific sensor setting**.

e.g., Sentinel-2/3, SPOT, EnMAP,…

- **GSA enables to configure simplified models for retrieval of specific outputs** (e.g. SIF)

- Further development: GSA of imported data (to analyze models outside the ARTMO framework)

e.g., 6S, MODTRAN, DART,…

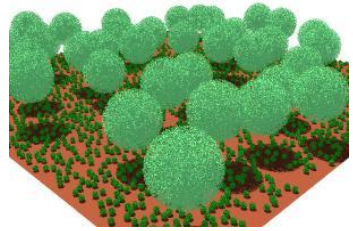
Conclusions

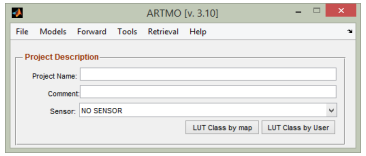
- GSA a useful tool to identify **RTM key and non-influential variables**.

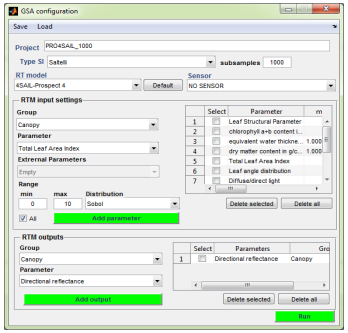
- A new **GSA toolbox** implemented into ARTMO. It calculates Sobol's ***first*** and ***total order*** **sensitivity indices** for a variety of RTMs.

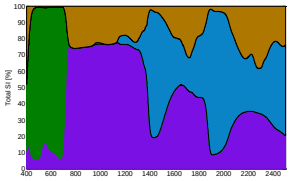
- Depending on the RTM, **not only insight in driving variables along spectral domain, but also of fluxes**.

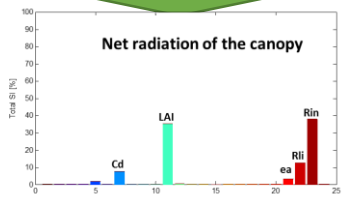
- GSA toolbox soon publicly available: **http://ipl.uv.es/artmo/**

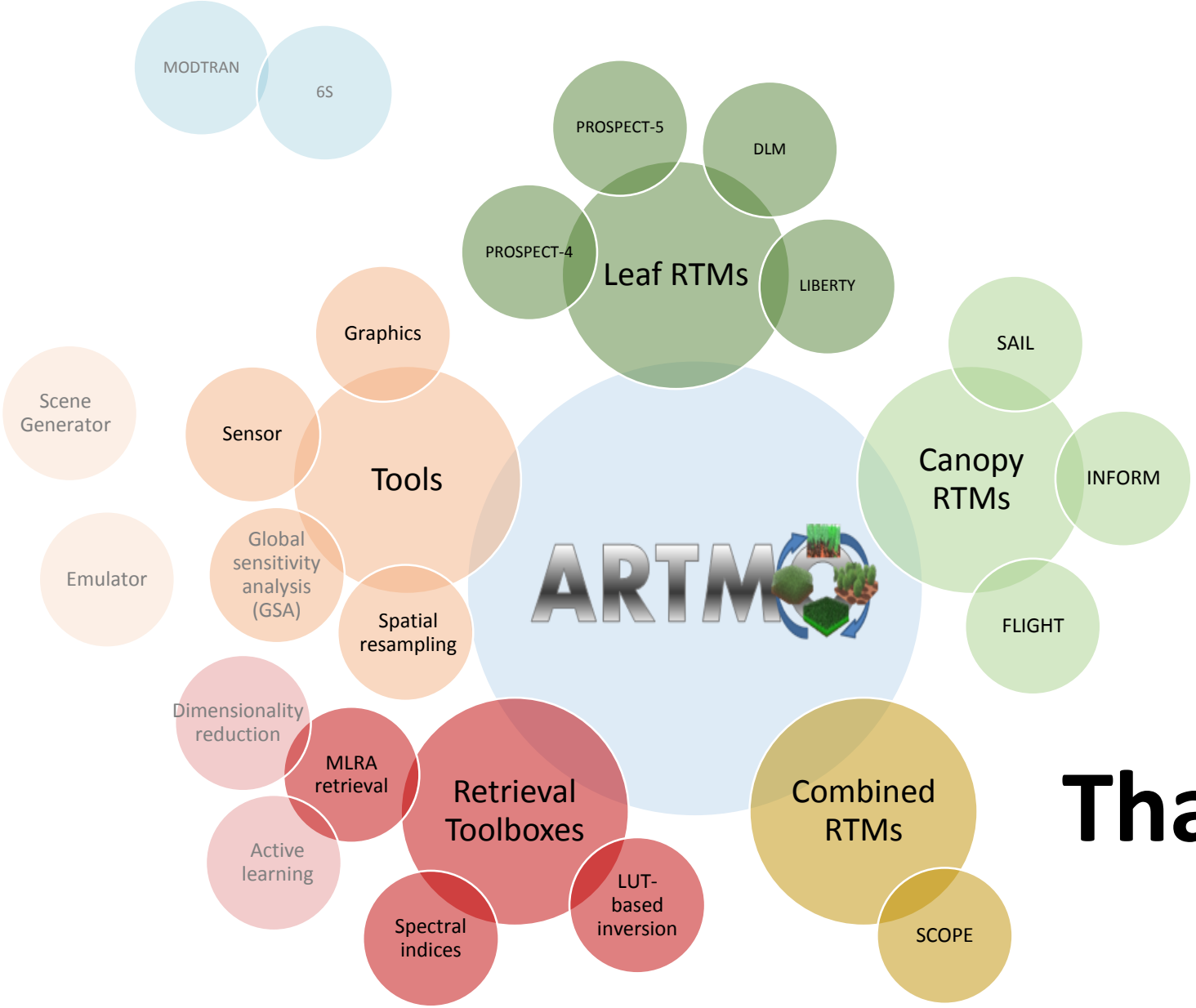








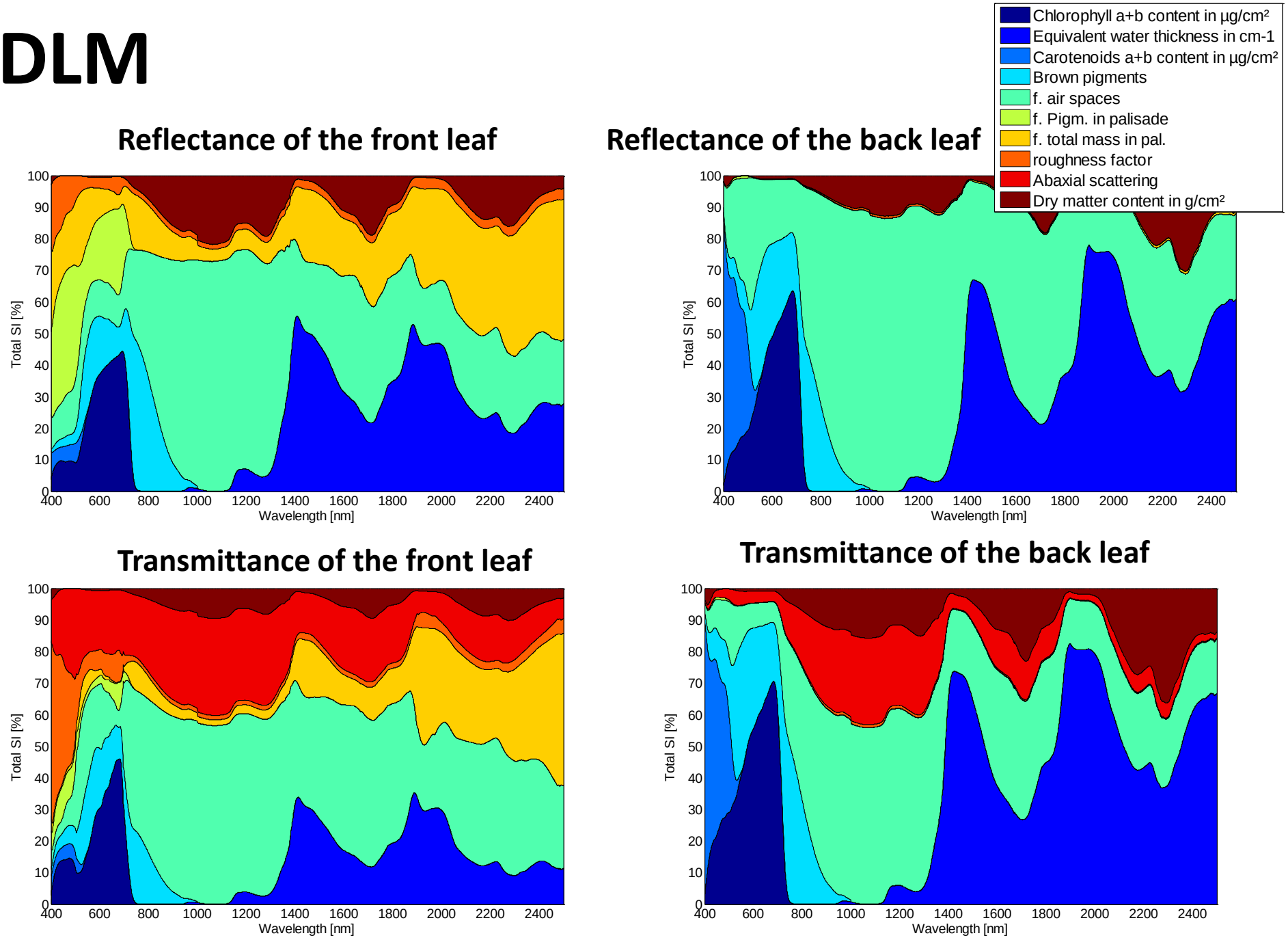




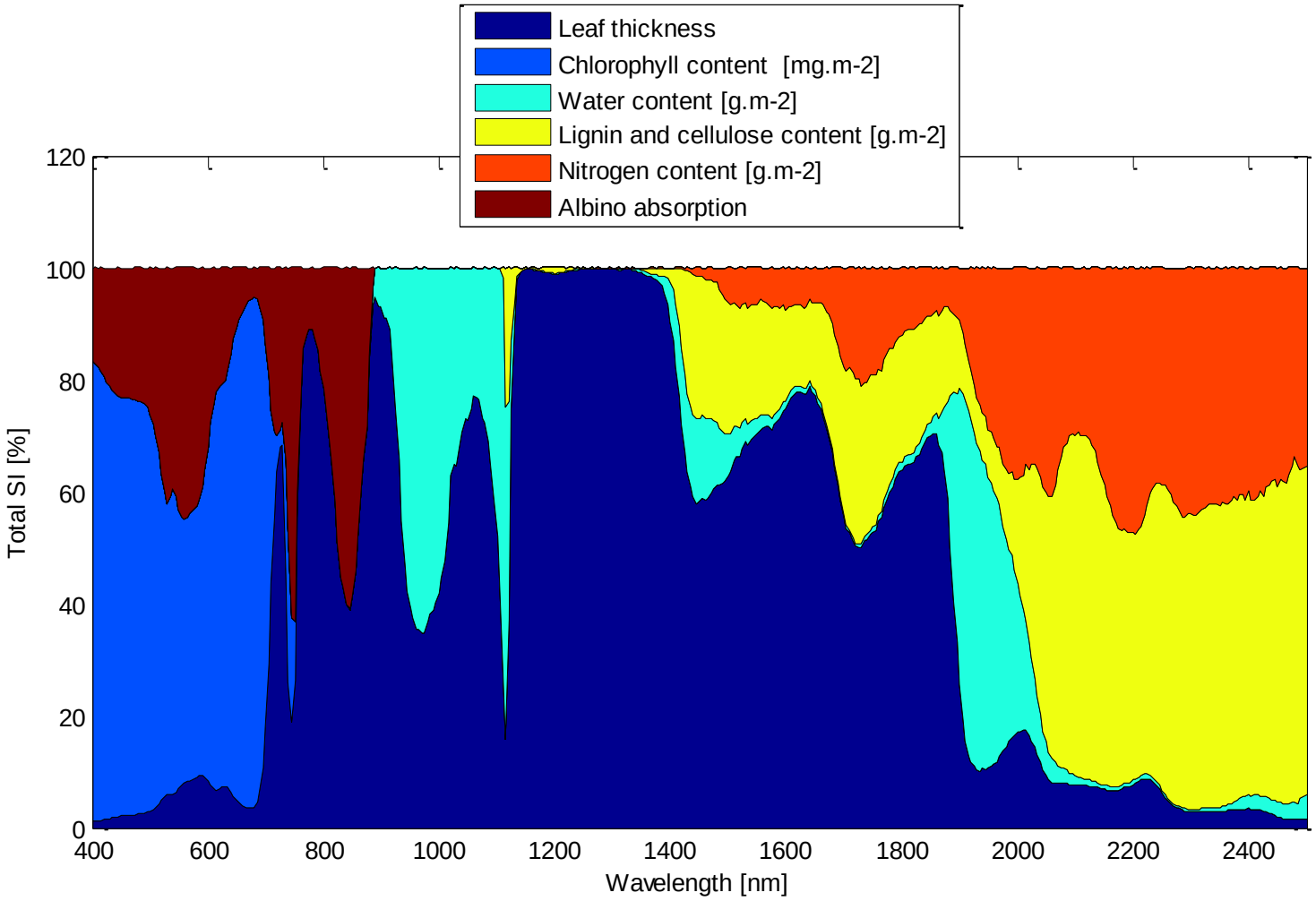
Thanks

http://ipl.uv.es/artmo/

DLM

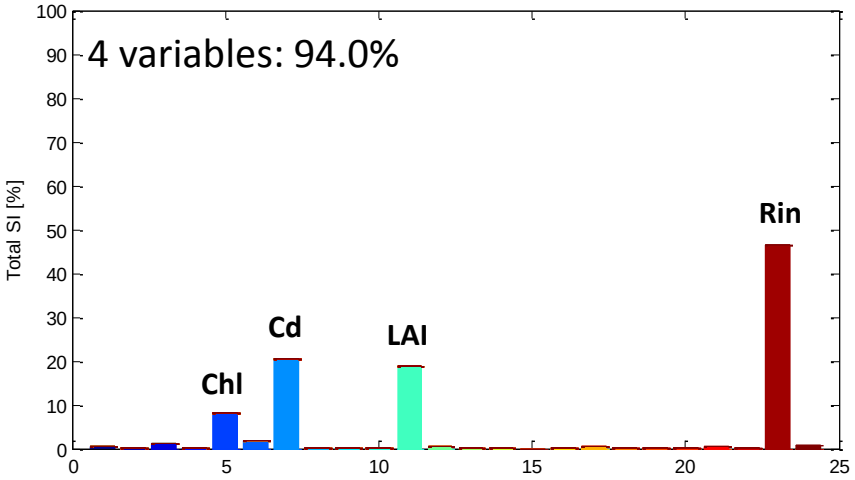

Chlorophyll a+b content in µg/cm²
Equivalent water thickness in cm-1
Carotenoids a+b content in µg/cm²
Brown pigments
f. air spaces
f. Pigm. in palisade
f. total mass in pal.
roughness factor
Abaxial scattering
Dry matter content in g/cm²
Reflectance of the front leaf
Reflectance of the back leaf
Transmittance of the front leaf
Transmittance of the back leaf
Total SI [%]
Wavelength [nm]
0
10
20
30
40
50
60
70
80
90
100
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400

LIBERTY


Leaf thickness
Chlorophyll content [mg.m-2]
Water content [g.m-2]
Lignin and cellulose content [g.m-2]
Nitrogen content [g.m-2]
Albino absorption
Total SI [%]
Wavelength [nm]
0
20
40
60
80
100
120
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400

SCOPE Fluorescence & photosynthesis analysis

Total fluorescence emitted at the top



Net photosynthesis of the canopy