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

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Outline:

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

Background

Physically based RTM approaches

RTMs

Development/Evaluation

Retrieval

Mapping biophysical params.

Design

Spectra/VI's

Background

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.

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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, \( S_i, S_{ij}, \ldots, S_{12 \ldots k} \) 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, \( S_{ij}, \ldots, S_{12 \ldots k} \) 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 \( X_i \), i.e. the first order effect as well as its coupling terms with the other input variables:

\[ S_{T1} = S_1 + S_{12} + S_{13} + S_{123} \]

GSA method of Saltelli et al., 2010:

- **First order sensitivity:**
  \[
  S_i = \frac{1}{n} \sum_{j=1}^{n} f(B)_j \left( f(A^i_B)_j - f(A)_j \right) \frac{1}{\text{Var}(L)}
  \]

- **Total sensitivity:**
  \[
  S_{II} = \frac{1}{2n} \sum_{j=1}^{n} \left( f(A)_j - f(A^i_B)_j \right)^2 \frac{1}{\text{Var}(L)}
  \]

**Sample distribution:**

- Random
- Sobol quasi-random sampling sequence (LPTAU)

Total # of samples = \((N_{\text{variables}} + 2)\)\#sample distribution

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

Need for a dedicated toolbox!

ARTMO seems perfectly suited to develop a GSA toolbox.
ARTMO’s RTMs:

**Leaf RTMs**

S. Jacquemoud & JP Féret

**Canopy RTMs**

W. Vehoef

**Outputs:** *reflectance & transmittance*

**ARTMO’s GSA toolbox**

J. Stuckens
T. Dawson

**Outputs:** *directional reflectance*

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

- 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

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#)

**PROSPECT-4**
- Reflectance
- Transmittance

**PROSPECT-5**
- Reflectance
- Transmittance

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

< 3 min
Canopy: PROSAIL (1000#)

**PROSPECT-4 + 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
- 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**

6 variables: 94.8%

**Net radiation of the soil**

5 variables: 93.5%

**Net radiation of the canopy**

5 variables: 95.9%

**ARTMO’s GSA toolbox**
$S_{Ti}$ SCOPE: 25 vars.; #1000; Fluxes (2/2)

**Fraction of absorbed PAR**

- 2 variables: 98.2%

**Total absorbed PAR by leaves**

- 3 variables: 99.3%

**Average canopy temperature**

- 7 variables: 99.3%

**Average soil temperature**

- 5 variables: 95.3%

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.

• 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., Sentinel-2/3, SPOT, EnMAP,...

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/](http://ipl.uv.es/artmo/)

ARTMO’s GSA toolbox

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

Thanks
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
LIBERTY

ARTMO’s GSA toolbox

SCOPE Fluorescence & photosynthesis analysis

Total fluorescence emitted at the top
4 variables: 94.0%

Net photosynthesis of the canopy
10 variables: 99.2%