TOC2TOA: An ARTMO Toolbox to Simulate Top-Of-Atmosphere Radiance Data for Imaging Spectroscopy Applications

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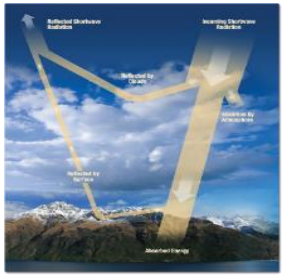
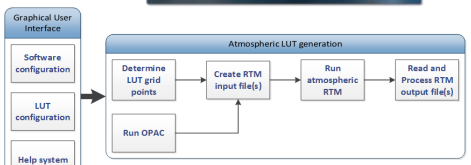
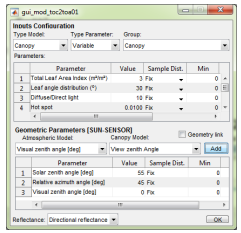
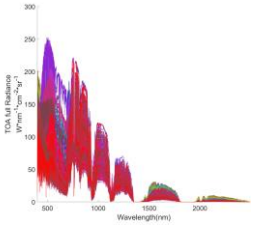
Background

- **Rationale**
- **Theory**
- **ALG**: **atmosphere RTM LUT generator**
- **TOC2TOA** toolbox
- **Applications**
  1. TOA LUT generation
  2. Scene generation
  3. Emulation
  4. GSA
  5. Retrieval
- **Conclusions**





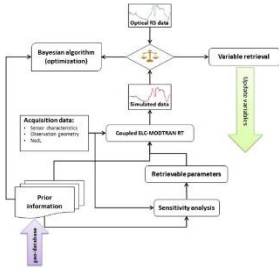




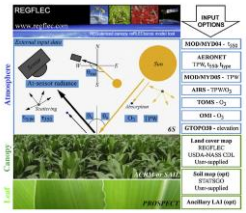
RATIONALE

- The large majority of IS **vegetation properties mapping studies is based on TOC reflectance**, i.e. after atmospheric correction (see review Verrelst et al., 2018)

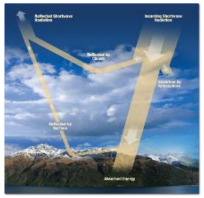
- Only a few studies attempted **to retrieve vegetation properties from TOA radiance**, by coupling with an atmospheric model (e.g., Laurent et al,2011, 2013, 2014, Mousivand et al., 2015)



- Until now these are only experimental studies, i.e. **no software packages have been developed for automated retrievals from TOA data** (however, see REGFLEC, Houborg et al., 2015, 2016)



What is lacking in vegetation properties retrieval, is easy upscaling from TOC to TOA data: **this would avoid the need for an atmospheric correction**

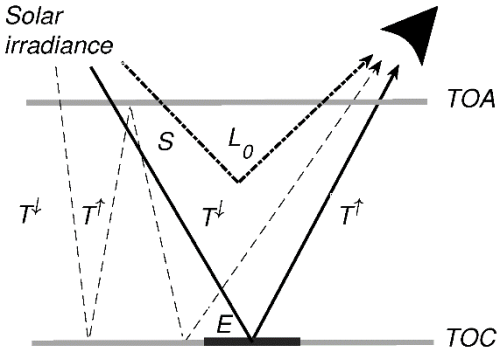


+ ARTMO

- Verrelst, J., Malenovský, Z., Van der Tol, C., Camps-Valls, G., Gastellu-Etchegory, J.P., Lewis, P., Moreno, J. (2018). Quantifying Vegetation Biophysical Variables from Imaging Spectroscopy Data: A Review on Retrieval Methods. *Surveys in Geophysics*,
- Laurent, V. C., Verhoef, W., Clevers, J. G., & Schaepman, M. E. (2011). Estimating forest variables from top-of-atmosphere radiance satellite measurements using coupled radiative transfer models. *Remote Sensing of Environment*, *115*(4), 1043-1052.
- Laurent, V. C., Verhoef, W., Clevers, J. G., & Schaepman, M. E. (2011). Inversion of a coupled canopy–atmosphere model using multi-angular top-of-atmosphere radiance data: A forest case study. *Remote Sensing of Environment*, *115*(10), 2603-2612.
- Laurent, V. C., Verhoef, W., Damm, A., Schaepman, M. E., & Clevers, J. G. (2013). A Bayesian object-based approach for estimating vegetation biophysical and biochemical variables from APEX at-sensor radiance data. *Remote sensing of environment*, *139*, 6-17.
- Laurent, V. C., Schaepman, M. E., Verhoef, W., Weyermann, J., & Chávez, R. O. (2014). Bayesian object-based estimation of LAI and chlorophyll from a simulated Sentinel-2 top-of-atmosphere radiance image. *Remote Sensing of Environment*, *140*, 318-329.
- Mousivand, A., Menenti, M., Gorte, B., & Verhoef, W. (2015). Multi-temporal, multi-sensor retrieval of terrestrial vegetation properties from spectral–directional radiometric data. *Remote sensing of environment*, *158*, 311-330.
- Houborg, R., McCabe, M., Cescatti, A., Gao, F., Schull, M., & Gitelson, A. (2015). Joint leaf chlorophyll content and leaf area index retrieval from Landsat data using a regularized model inversion system (REGFLEC). *Remote Sensing of Environment*, *159*, 203-221.
- Houborg, R., & McCabe, M. F. (2016). Adapting a regularized canopy reflectance model (REGFLEC) for the retrieval challenges of dryland agricultural systems. *Remote Sensing of Environment*, *186*, 105-120.

Theory TOA radiance (Lambertian surface)

$$L_{toa} = L_0 + \frac{(E_{dir}\cos(SZA) + E_{dif})(T_{dir} + T_{dif})\rho}{\pi(1 - S\rho)}$$



Thanks Neus Sabater ☺

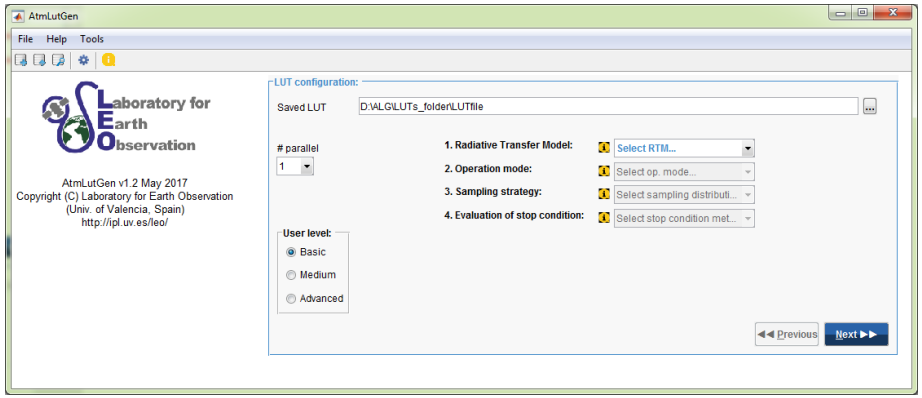
***L0**: Atmospheric path radiance in [$mW \cdot m^{-2} \cdot sr^{-1} \cdot nm^{-1}$].*
***E_{dir}**: At-surface direct solar irradiance in [$mW \cdot m^{-2} \cdot nm^{-1}$]*
***E_{dif}**: At-surface diffuse solar irradiance in [$mW \cdot m^{-2} \cdot nm^{-1}$]*
***T_{dir}**: Target-to-sensor direct transmittance (unit-less).*
***T_{dif}**: Target-to-sensor diffuse transmittance (unit-less).*
***S**: Spherical albedo (unit-less).*
***SZA**: solar zenith angle*
***ρ**: Lambertian Surface reflectance*

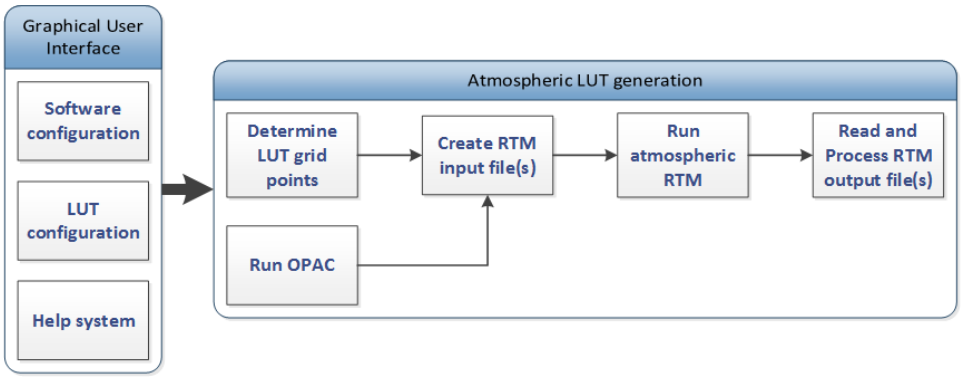
More advanced variations can be developed, e.g. considering non-Lambertian, adjacency effects, etc.

ALG: Atmospheric LUT Generator

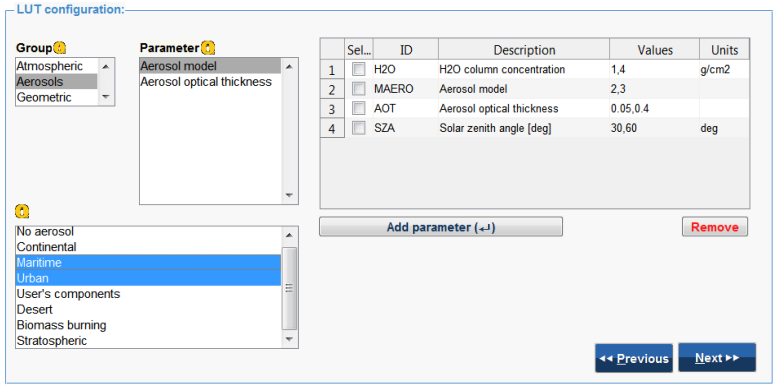
Thanks Jorge Vicent ☺

- **ALG** is a standalone Matlab toolbox (exe: no Matlab required). It can be added to ARTMO
- **ALG** is developed for automated running of **atmospheric RTMs: 6S, MODTRAN5, MODTRAN6, (libRadtran)**
- **LUT generation of atmospheric transfer functions:** $L0\ E_{dir}\ E_{dir}\ T_{dir}\ T_{dif}\ S$

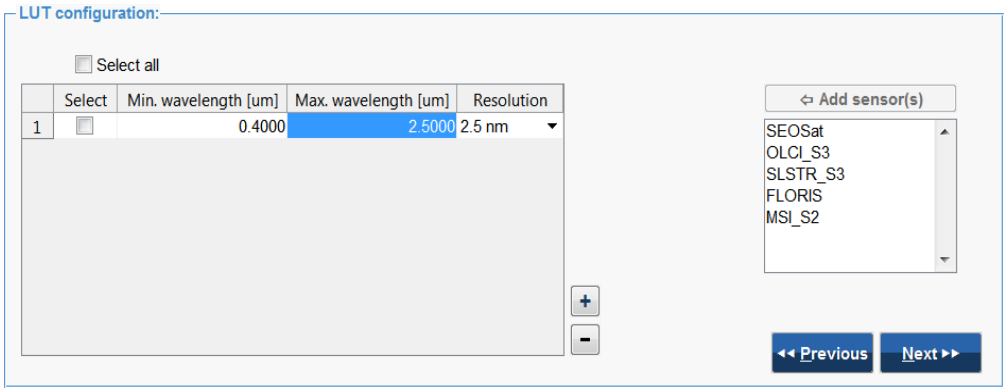




LUT configuration: (1) defining the LUT



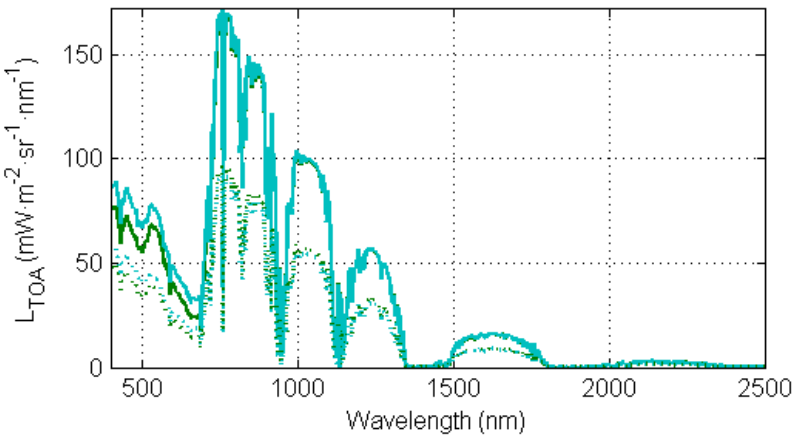
(2) Selecting spectral output



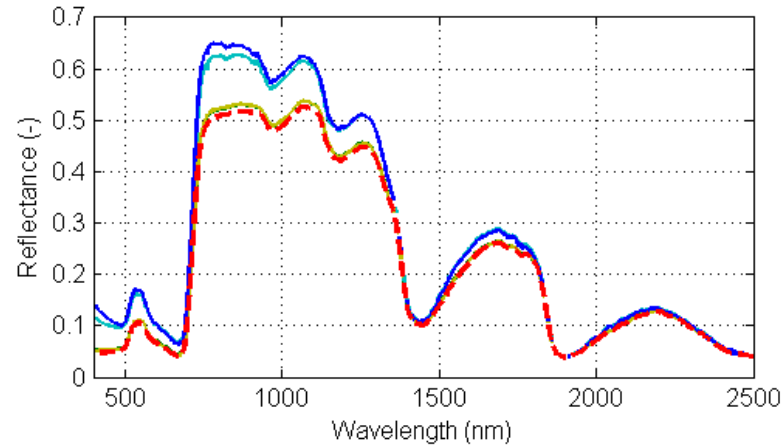
downloadable at: http://ipl.uv.es/artmo/

ALG outputs & applications

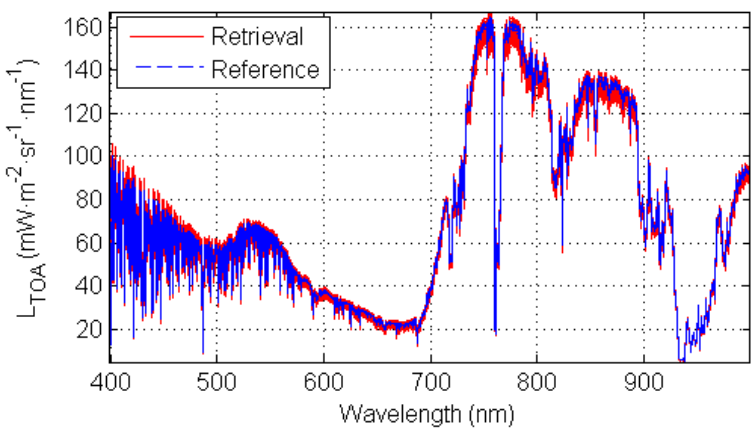
1) TOA radiance



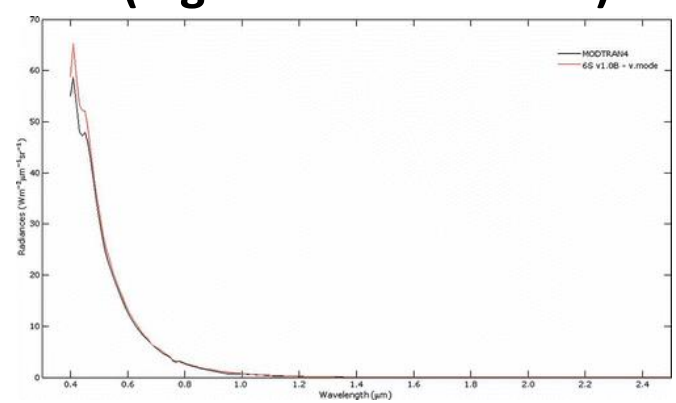
2) atm. Correction



3) Sensitivity



4) Comparison of atm. RTMs (e.g. 6S vs MODTRAN)



Callieco, F., & Dell'Acqua, F. (2011). A comparison between two radiative transfer models for atmospheric correction over a wide range of wavelengths. *International journal of remote sensing*, *32*(5), 1357-1370.

Need for a TOC2TOA toolbox

ARTMO

Leaf

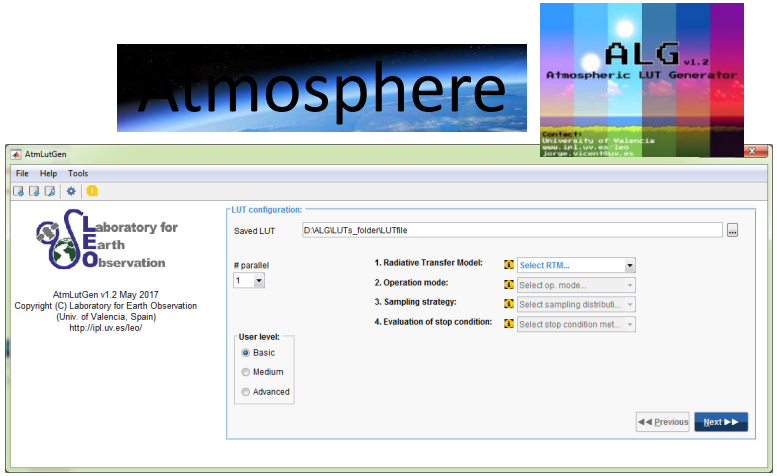
- PROSPECT 4
- PROSPECT 5
- PROSPECT-D
- DLM
- LIBERTY
- Fluspect-B

Canopy

- 4SAIL
- FLIGHT
- INFORM

- SCOPE

Atmosphere



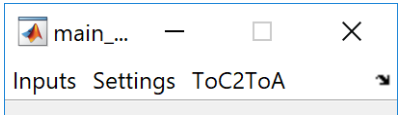
TOC2TOA

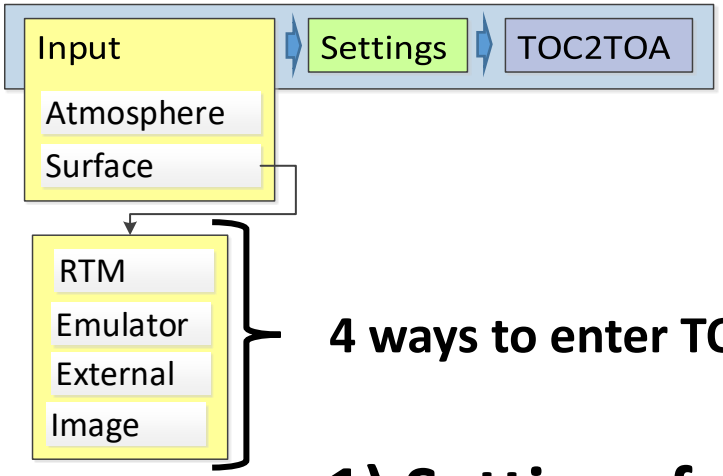
TOC2TOA:

- ✓ **Enables coupling between ARTMO's RTMs and ALG LUTs**
- ✓ Allows any combination of leaf-canopy-atmosphere RTMs
- ✓ Produces TOA radiance LUT for Lambertian surface
- ✓ Resamples to sensor band settings
- ✓ Output TOA LUT is stored in ARTMO's MySQL DB
- ✓ LUT data can then be called by all ARTMO toolboxes, e.g. **retrieval**

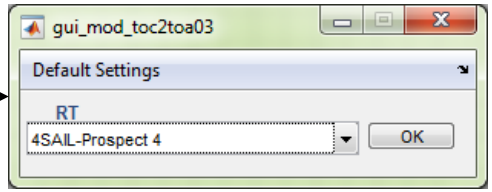
TOC2TOA toolbox enables to upscale image processing applications from TOC to TOA scale

TOC2TOA toolbox:





4 ways to enter TOC data



RTM

ARTMO RTM couplings:

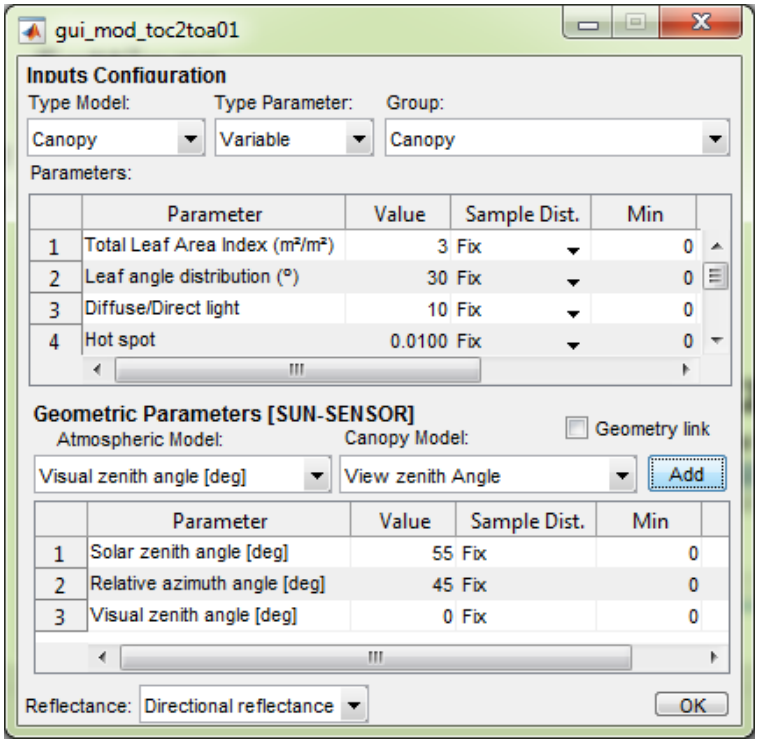
- SAIL – PROSPECT 4
- SAIL – PROSPECT 5
- SAIL – PROSPECT D
- SAIL – LIBERTY
- INFORM – PROSPECT 4
- INFORM – PROSPECT 5
- INFORM – PROSPECT D
- INFORM – LIBERTY
- SCOPE

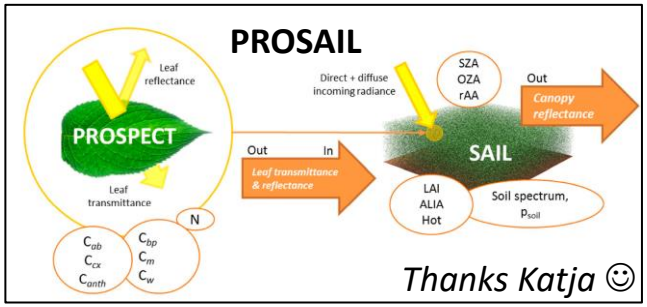
1) Settings for RTM

RTM

Variables settings

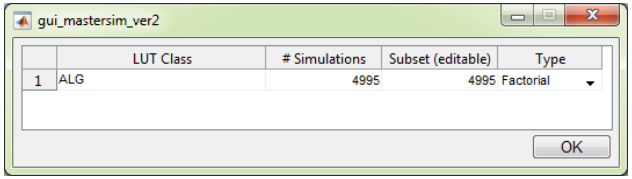
Linking geometry of atmospheric RTM with canopy RTM





TOC2TOA:

Options for generating subsets, LHS



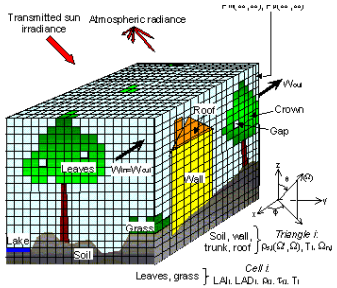
Other TOC options to enter TOC2TOA

RTM
Emulator
External
Image

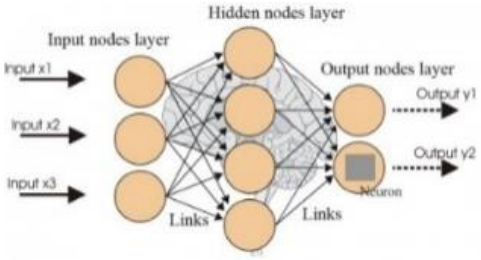
(emulation in Emulator toolbox)

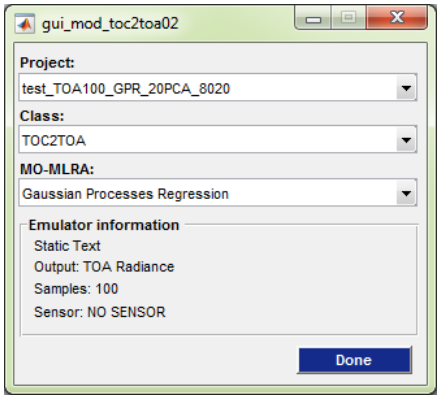
2) Emulator

Canopy RTM

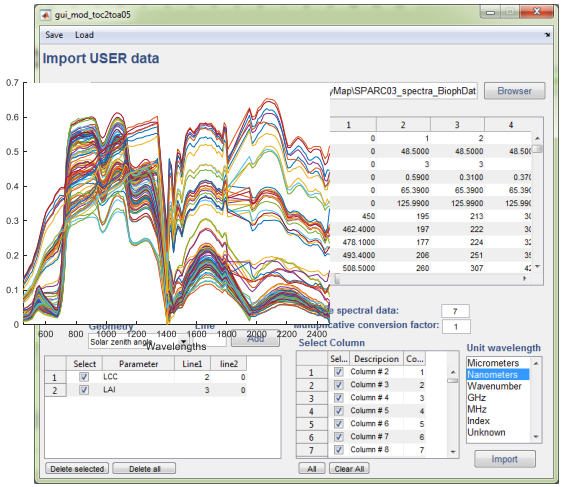


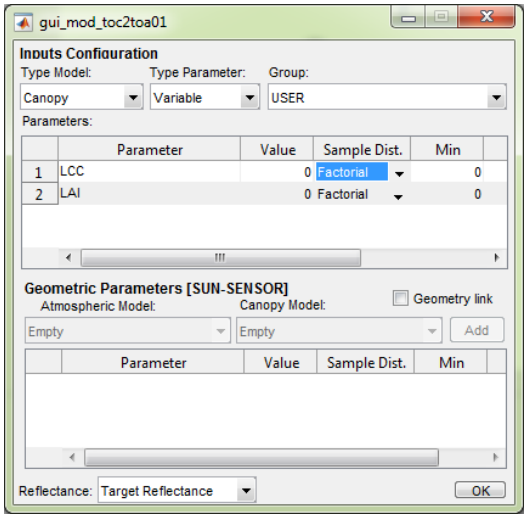
Machine learning

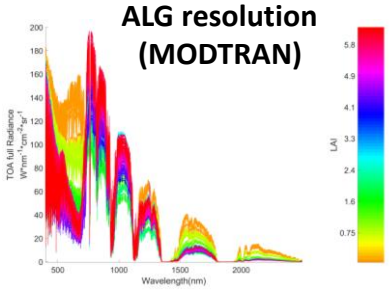


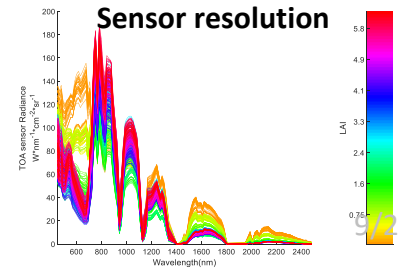


3) External (e.g. measured spectroscopy data)



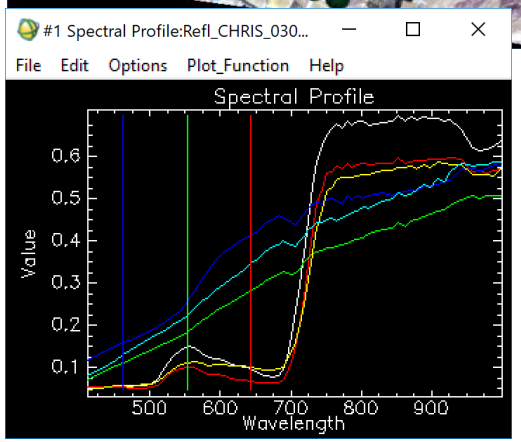




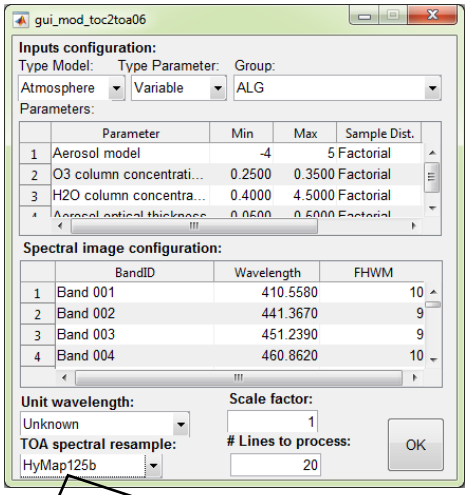


4) Putting an atmosphere upon a TOC image (and resample to other sensor)

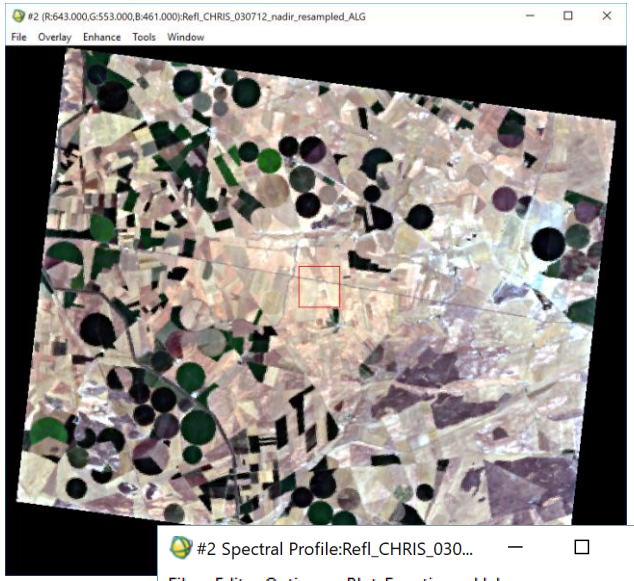
RTM
Emulator
External
Image

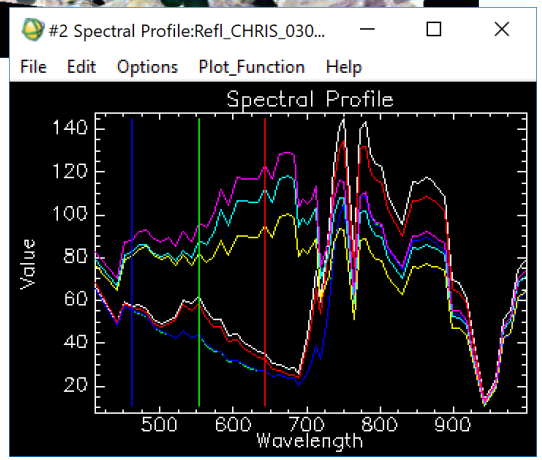


Selecting an atmospheric profile from the ALG LUT



Option to provide TOA according to band settings of other sensor



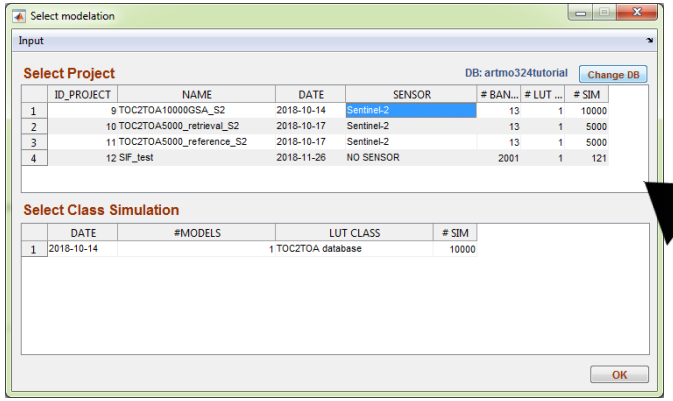


So far only 1 atmosphere. In a next version we will introduce option to vary atm. properties within scene.

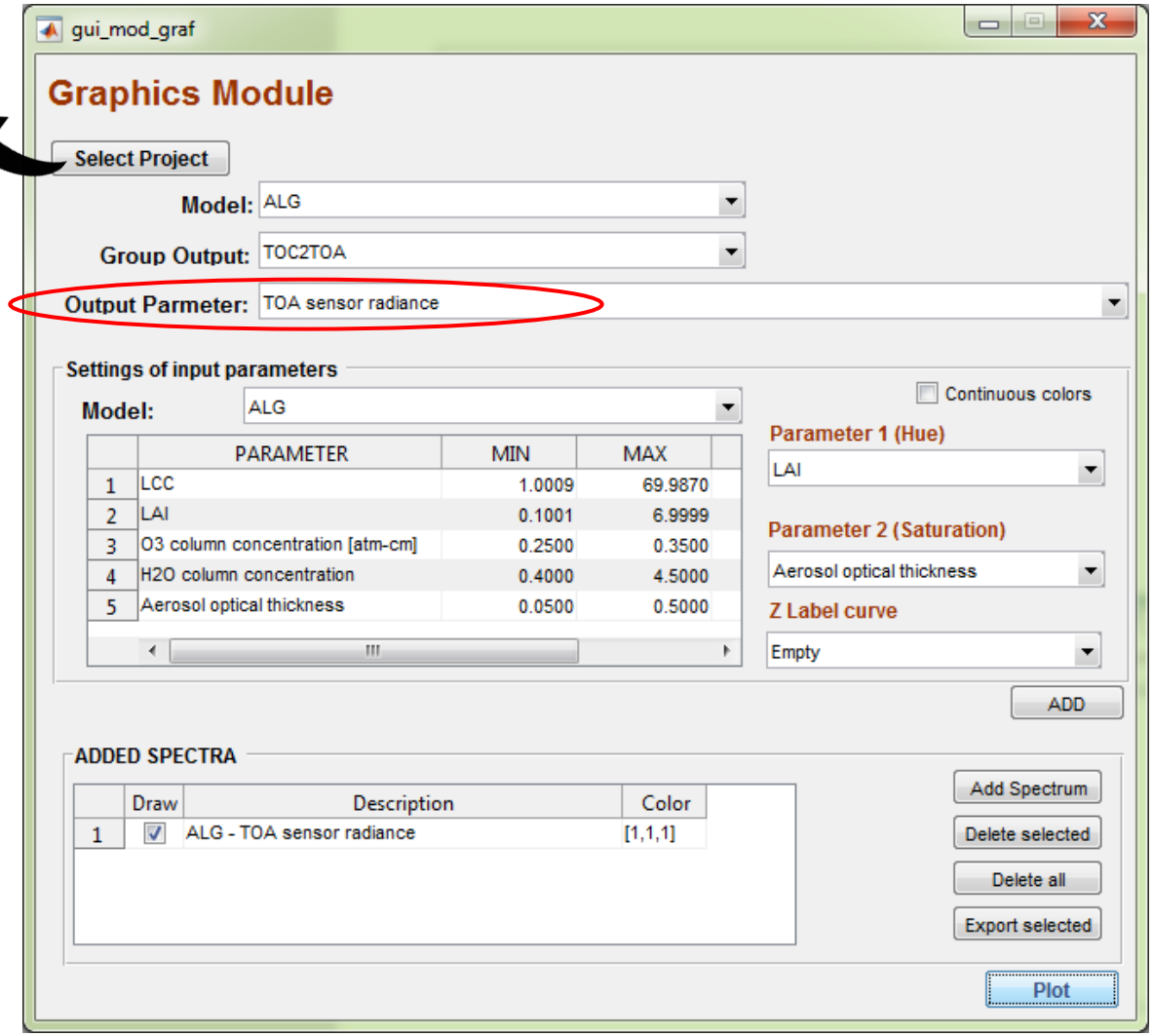
TOC2TOA stores data in ARTMO's MySQL DB

Same as all other ARTMO simulations

ARTMO



Graphics Tool



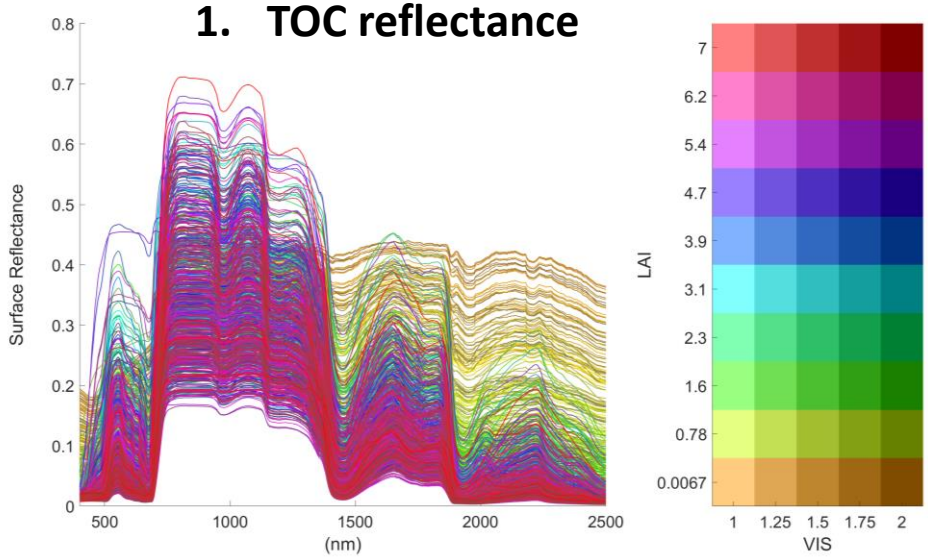
The following outputs can be plotted:

1. **TOC reflectance**
2. **TOA full radiance (ALG RTM)**
3. **TOA sensor radiance**

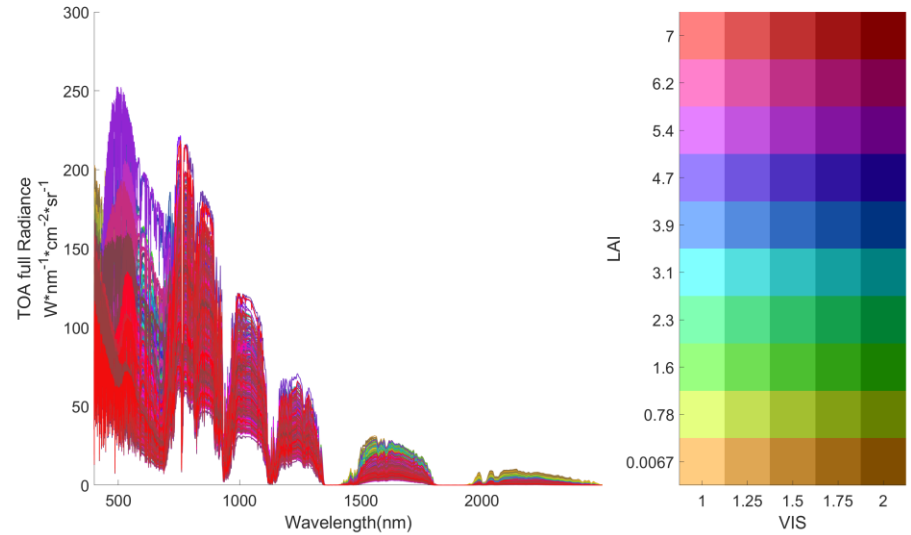
TOA Applications:

1) Plotting/exporting TOA radiance

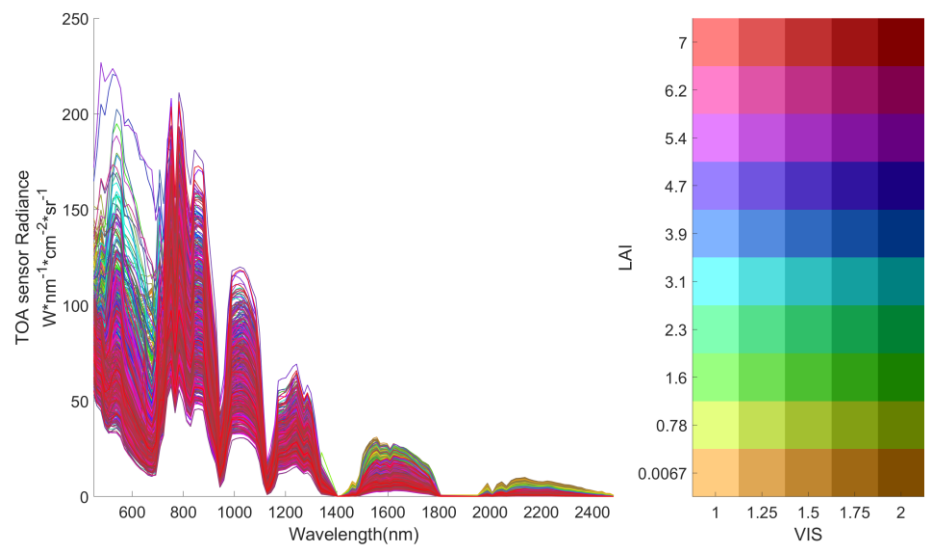
1. TOC reflectance



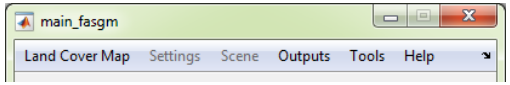
2. TOA full radiance (ALG resolution: MODTRAN)



3. TOA sensor radiance (e.g. HyMap)

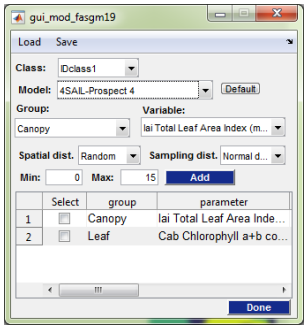


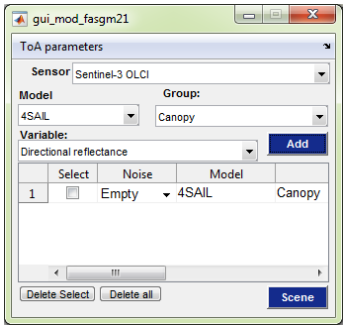
2) Synthetic scene generation toolbox

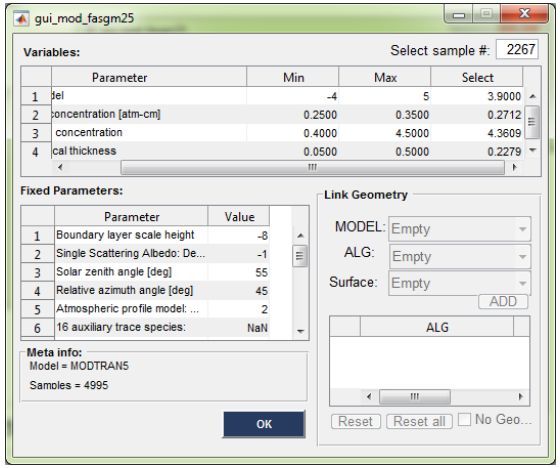


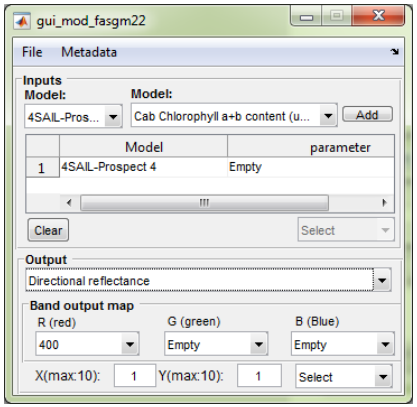
Synthetic scenes can be either generated by: (1) RTMs, (2) emulators or based on (3) real images

TOA



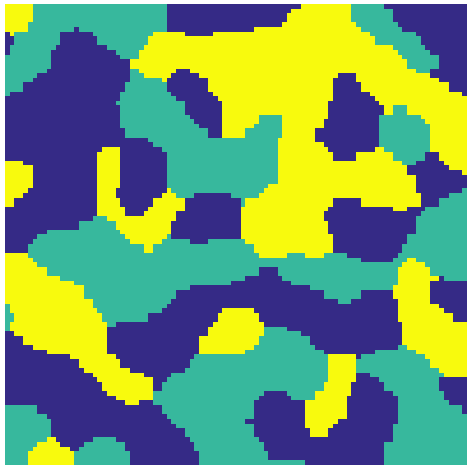






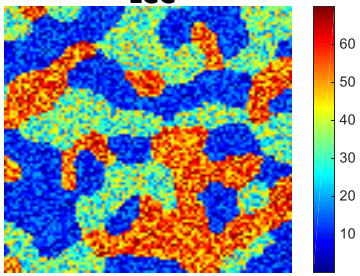
Automated scene generation: 3 classes

Automatically generated land cover map (3 classes)

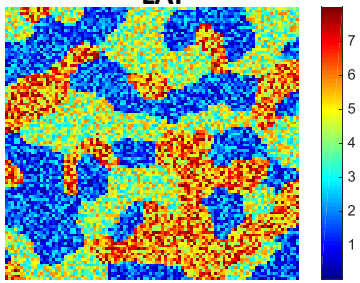


Input maps

LCC



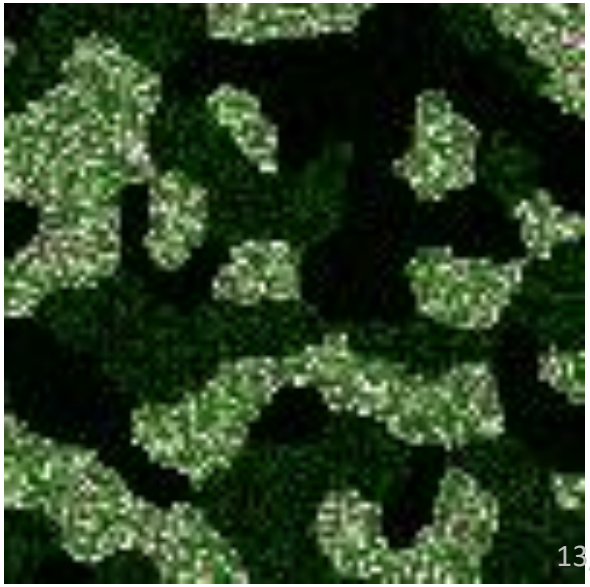
LAI



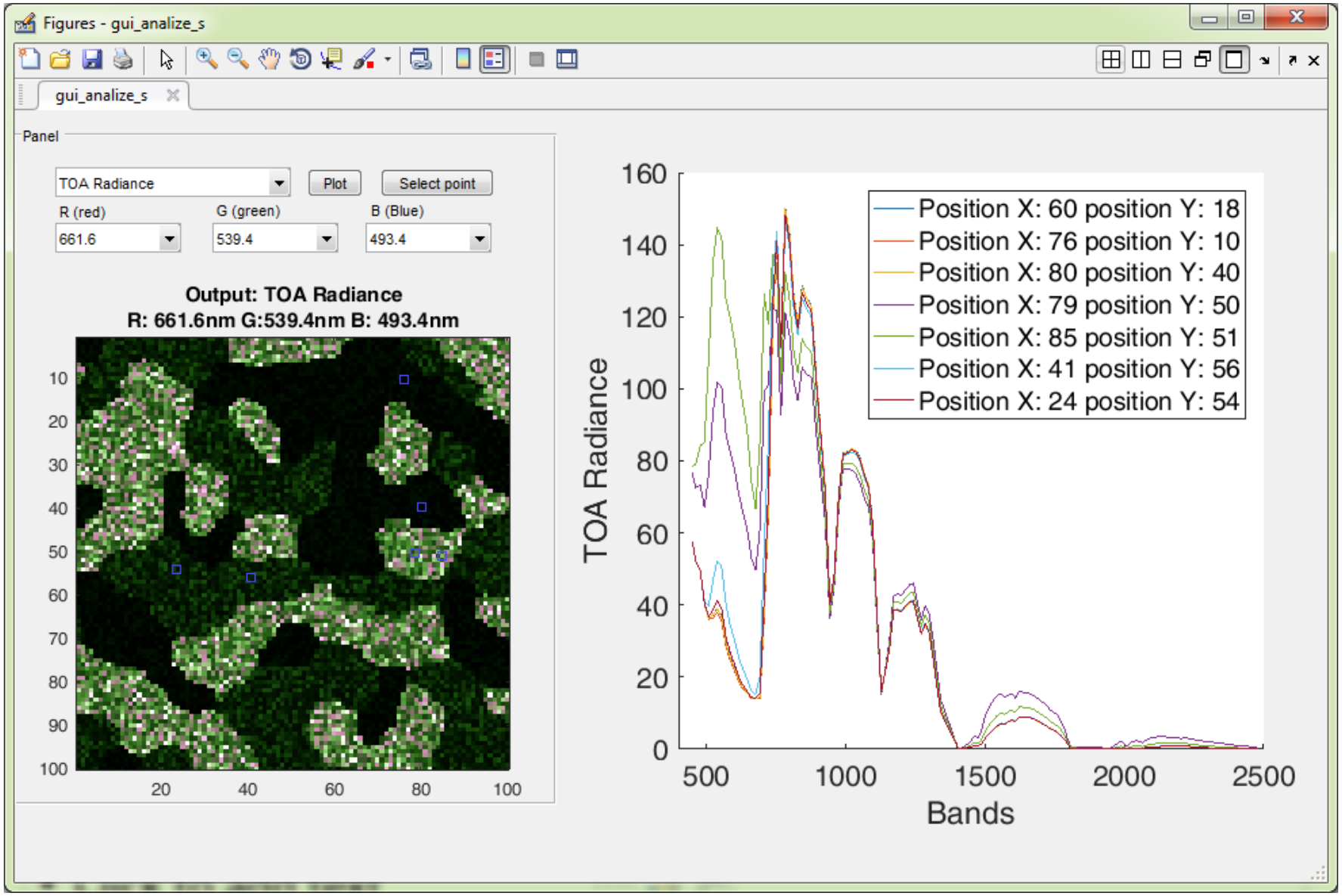
HyMap (TOC & TOA)

Output: TOA Radiance

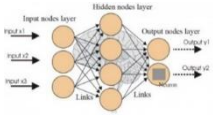
R: 661.6nm G:539.4nm B: 493.4nm



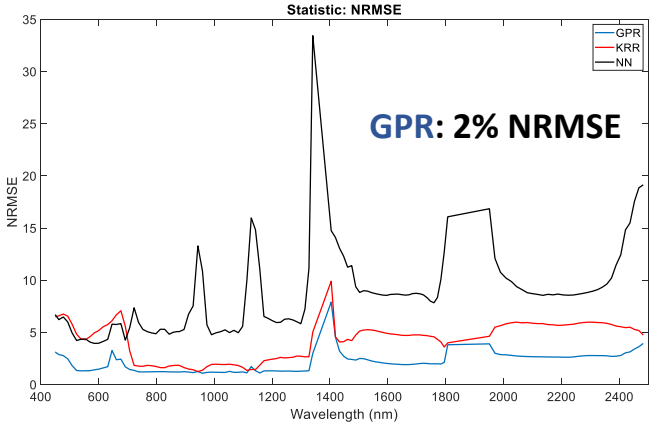
Inspecting TOA radiance scene profiles



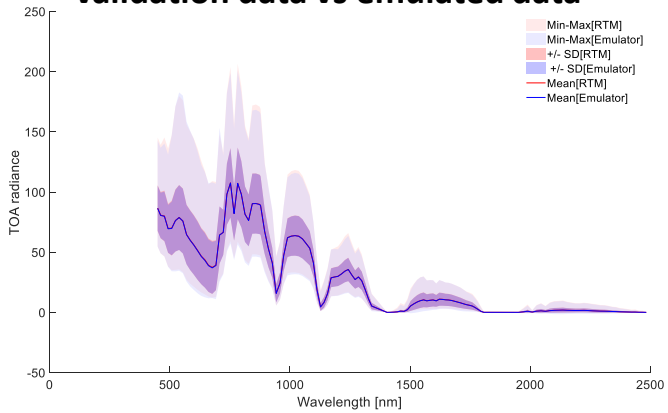
3) Emulation: TOA radiance data (MODTRAN, HyMap-like)



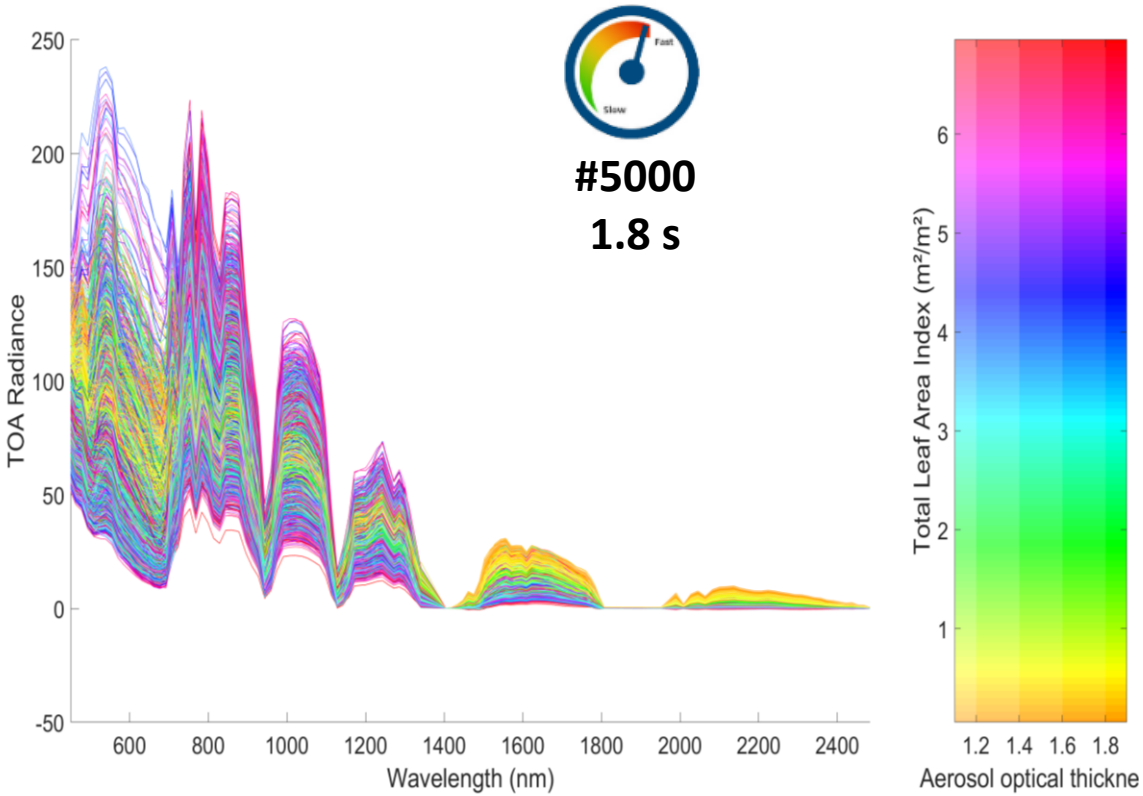
Validation of 3 emulators: GPR, KRR, NN



GPR : comparison stats RTM validation data vs emulated data

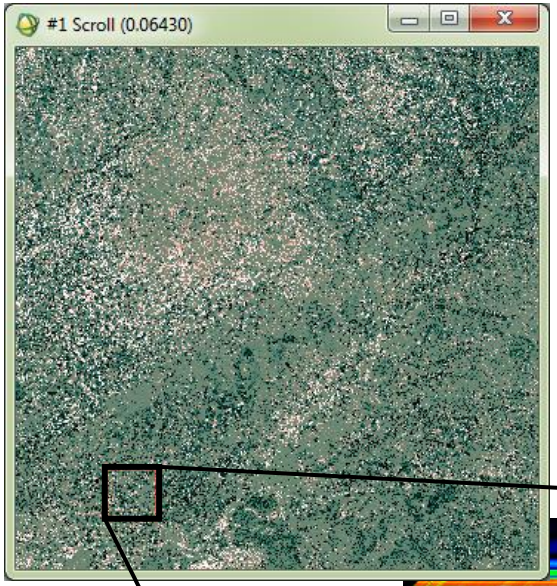


HyMap (125 bands)



Emulation allows super fast generation of LTOA data (varying 9 variables)

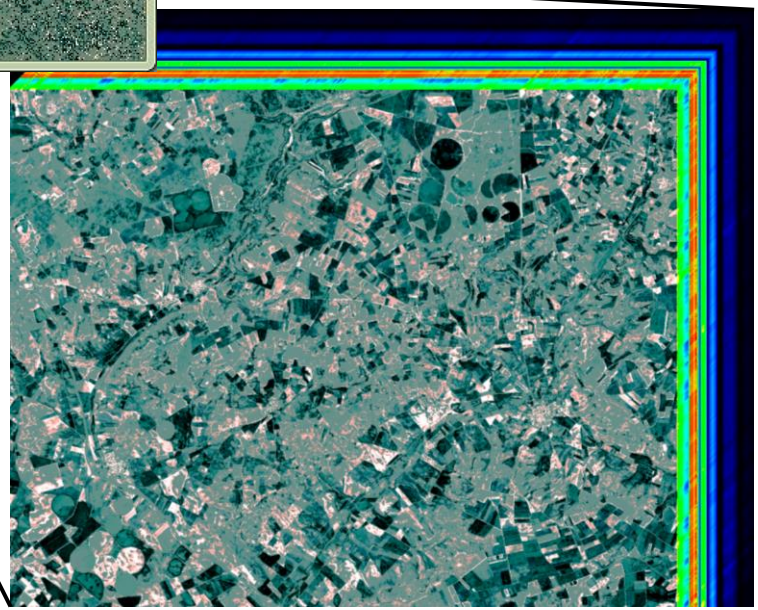
Emulation of LTOA scene

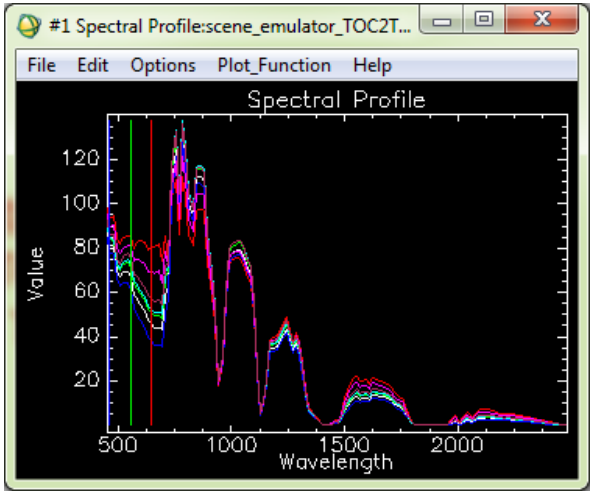


- **Spatial texture of S2**
- **HyMap emulator LTOA: 125 bands**

> 30 million pixels, 125 bands

6 min

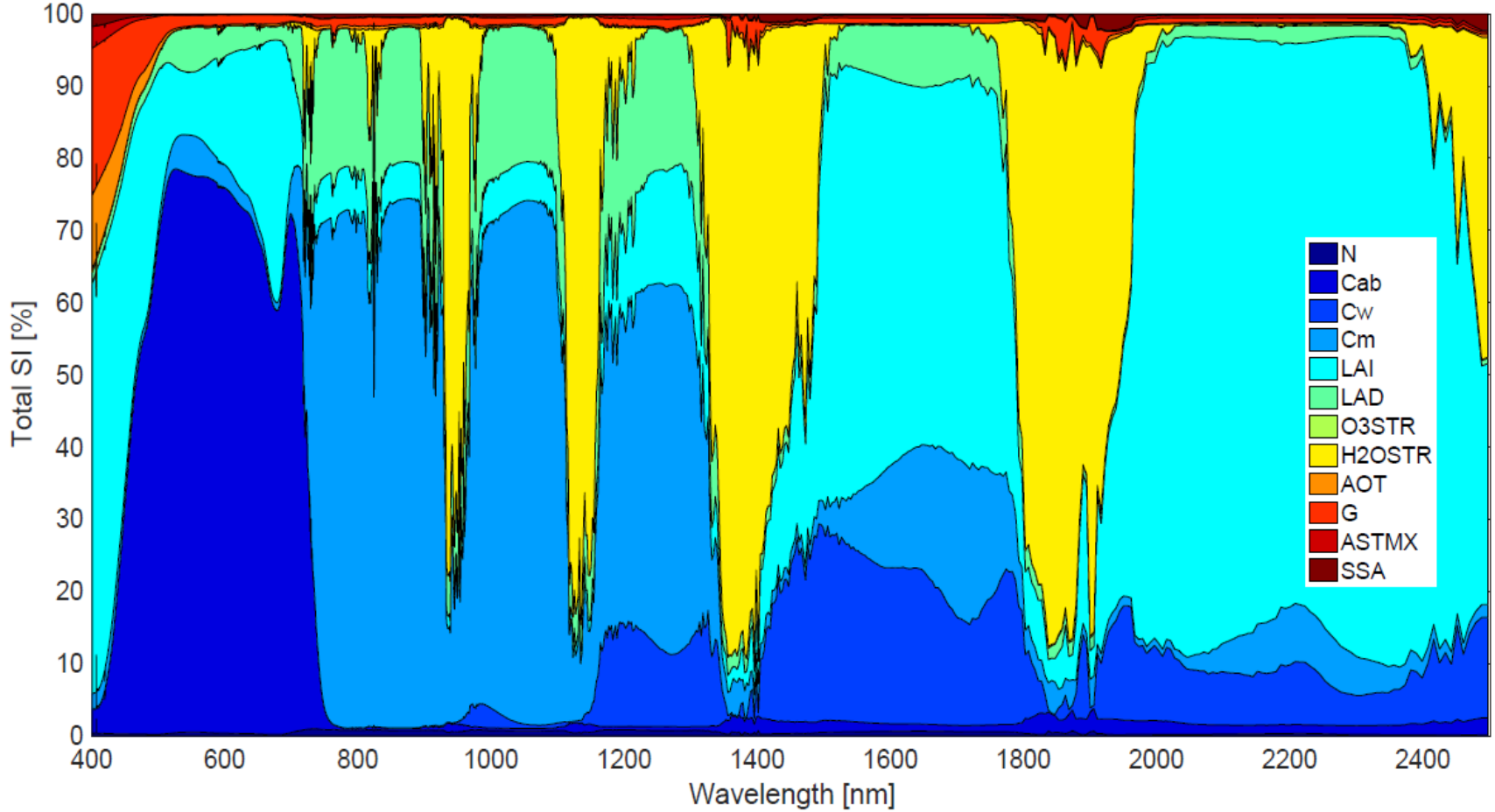




Verrelst, J., Rivera Caicedo, J.P., Vicent, J., Morcillo Pallarés, P., G., Moreno, J. (2019). Approximating Empirical Reflectance Data through Emulation: Opportunities for Synethetic Scene Generation. Remote Sensing. 11(2): 157.

Global sensitivity analysis: emulation of PROSAIL + MODTRAN variables

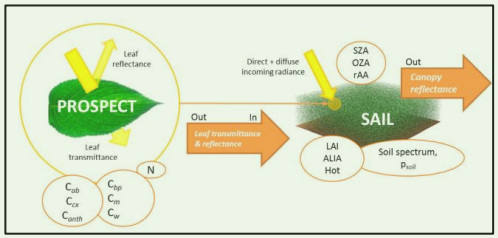
<40 s



- The influence of atmosphere is mainly in H2O absorption regions and in the blue
- In GSA toolbox we can do these kind of analyses for coupling of any leaf + canopy + atmosphere model

4) Biophysical variables retrieval: hybrid

ARTMO PROSAIL

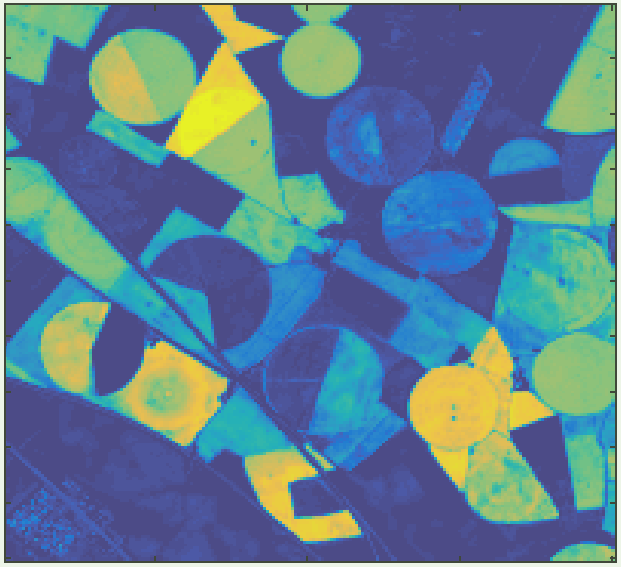


#1000

MLRA: GPR

TOC

LAI

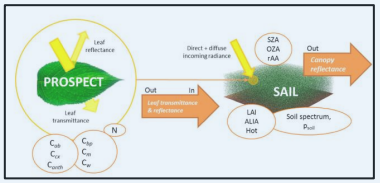


L2A

Sentinel-2
(Barrax, Spain)

L1C

ARTMO PROSAIL, ALG (6S), TOC2TOA



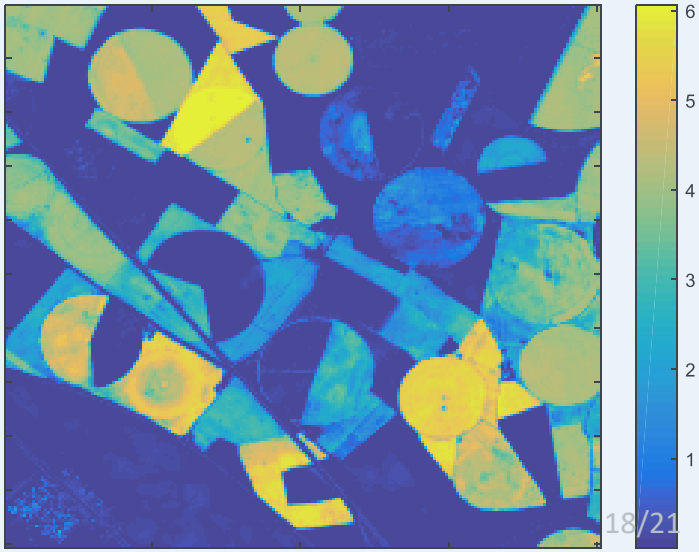
+

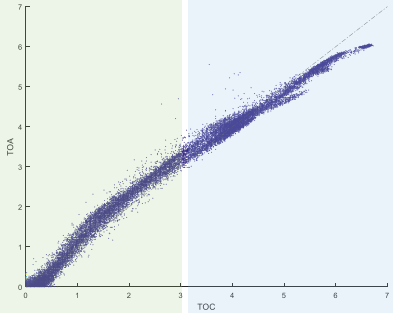
#1000

MLRA: GPR

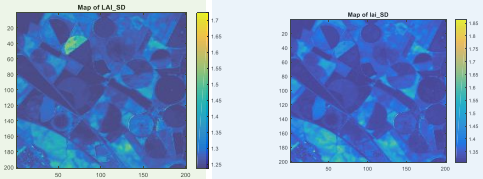
TOA

LAI





Uncertainties



Wrap up: TOC2TOA as part of ARTMO

FORWARD

Leaf
- PROSPECT 4
- PROSPECT 5
- PROSPECT-D
- DLM
- LIBERTY
- Fluspect-B

coupling

Canopy
- 4SAIL
- FLIGHT
- INFORM
- SCOPE

TOC2TOA

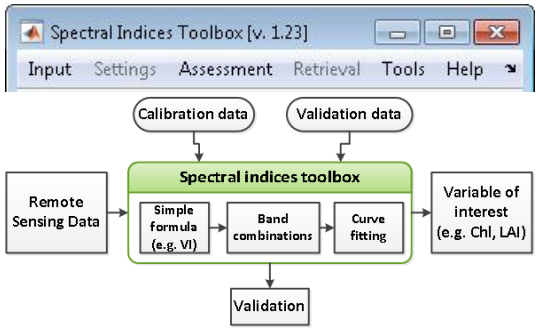
Atmosphere

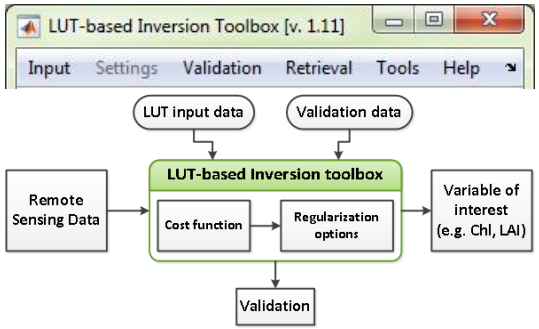
ALG
- 6SV
- MODTRAN5*
- MODTRAN6*

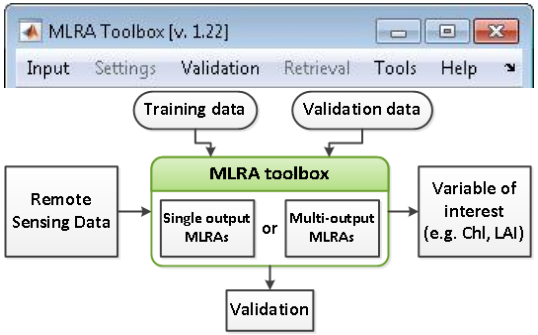
TOC reflectance

TOA radiance

RETRIEVAL





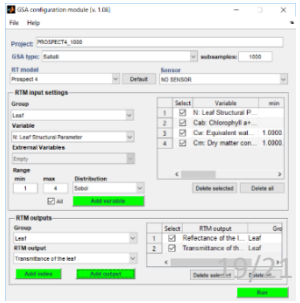


TOOLS

Emulation toolbox

Scene generation toolbox

Global sensitivity analysis



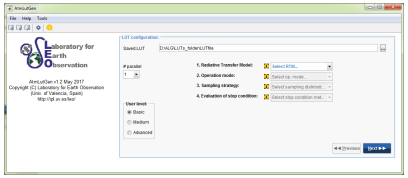
Conclusions

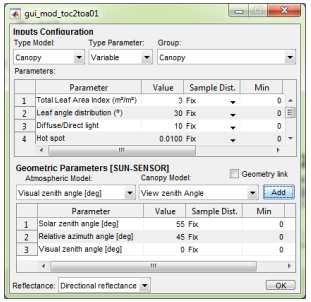
- **ALG** toolbox to automate LUT generation of atmospheric RTMs: **6S, MODTRAN**

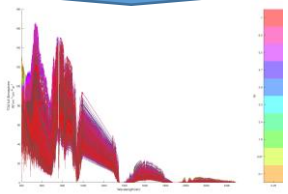
- **TOC2TOA** toolbox to couple ALG-generated LUTs with ARTMO LUTs **to produce TOA radiance data**

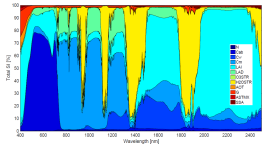
- With **TOC2TOA,** ARTMO´s toolboxes upscaled to TOA radiance:
  1. Scene generation
  2. Emulation
  3. Global sensitivity analysis
  4. Retrieval: indices, machine learning, inversion

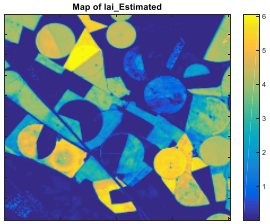
- **TOC2TOA** toolbox soon to be released: altogether, it aims to facilitate TOA radiance data processing to the broader community.











Thanks

Questions?