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

Theory TOA radiance (Lambertian surface)

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

**\(L_0\):** Atmospheric path radiance in [\(mW \cdot m^{-2} \cdot sr^{-1} \cdot nm^{-1}\)].

**\(E_{\text{dir}}\):** At-surface direct solar irradiance in [\(mW \cdot m^{-2} \cdot nm^{-1}\)].

**\(E_{\text{dif}}\):** At-surface diffuse solar irradiance in [\(mW \cdot m^{-2} \cdot nm^{-1}\)].

**\(T_{\text{dir}}\):** Target-to-sensor direct transmittance (unit-less).

**\(T_{\text{dif}}\):** Target-to-sensor diffuse transmittance (unit-less).

**\(S\):** Spherical albedo (unit-less).

**\(SZA\):** solar zenith angle

**\(\rho\):** 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: $L_0 \ E_{dir} \ E_{dir} \ T_{dir} \ T_{dif} \ S$

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)

Need for a TOC2TOA toolbox

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:

1) Settings for RTM

- Options for generating subsets, LHS
- 4 ways to enter TOC data

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

Thanks Katja ☺
Other TOC options to enter TOC2TOA

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)

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

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.
Inspecting TOA radiance scene profiles

Output: TOA Radiance
R: 661.6nm G:539.4nm B: 493.4nm

- Position X: 60 position Y: 18
- Position X: 76 position Y: 10
- Position X: 80 position Y: 40
- Position X: 79 position Y: 50
- Position X: 85 position Y: 51
- Position X: 41 position Y: 56
- Position X: 24 position Y: 54

Bands

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

Validation of 3 emulators: GPR, KRR, NN

- **GPR: 2% NRMSE**
  - GPR: comparison stats RTM validation data vs emulated data

HyMap (125 bands)

#5000
1.8 s

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

Global sensitivity analysis: emulation of PROSAIL + MODTRAN variables

- 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

PROSAIL, ALG (6S), TOC2TOA

Sentinel-2 (Barrax, Spain)

MLRA: GPR

#1000

TOC

L2A

L1C

TOA

LAI

Uncertainties

#1000

PROSAIL

Uncertainties

#1000
Wrap up: TOC2TOA as part of FORWARD

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

Canopy: 4SAIL, FLIGHT, INFORM, SCOPE

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.