ARTMO’s new Spectral Indices (SI) module for mapping biophysical parameters

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Outlook

• Background
  – Biophysical parameter retrieval
  – Revisiting spectral indices
  – ARTMO

• SI toolbox
  – SI settings
  – Results tests
  – Retrievals
  – Coupling with RTMs

• Conclusions
Retrieval of biophysical parameters from optical EO data always occurs through a model; e.g. through statistical models, through inversion of physically-based radiative transfer models (RTM), or through hybrid forms.
Revisiting SIs

- **Parametric regression**: Some constraints introduced
- **Nonparametric regression**: No constraints in developing models (see next presentation)
- **Physically-based approaches**: Inversion of RTMs using parametric or non-parametric inversion techniques.

Use of **Spectral Indices (SIs)**: example of **parametric** approach

Established SIs (e.g. NDVI) are constrained in 3 ways:
1. **The used bands**: why red and NIR would be best?
2. **The formulation**: why the given formulation would be best?
3. **The regression**: why a linear regression would be best?

Given at three levels **imposing limitations** it can be reasonably assumed that this approach is not optimally exploiting the available information. Especially in view of hyperspectral data.

Alternatively, we can also **systematically evaluate and optimize** these 3 types of constraints. For this we developed **ARTMO’s Spectral Indices Module**.

Evaluate performance SI’s based on synthetic data vs. field data.
• Simulations can be done for any sensor in 400-2400 nm range.
• Input, output and metadata stored in MySQL running underneath.
• Modular design – enables implementation of new modules & Apps
V3: Modular design

All models and modules can be accessed from the Menu bar.

LUTs can be configured per land cover class or defined by user.

Simulations according to a predefined sensor setting.

File
- Load Project
- New Project
- DB administration
- Settings
- Model inputs

Models
- Leaf
- Canopy
- Combined

Forward
- Leaf
- Canopy
- Combined

Modules
- Sensor
- Graphics

Retrieval
- Spectral Indices
- Machine Learning
- LUT-based Inversion

Leaf RTMs

Canopy RTMs

Load
- Save
- New DB
- Change DB
- Delete
- Import DB
- Export DB
- Analyze DB

LUT class
- Project
- Database

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Intuitive GUIs

All models synchronized. Input: single value, range (step/distribution) or user-defined values.

Sensor module

Band settings of any optical sensor can be selected or created.

When a sensor is selected then all output data is directly resampled to that band settings. This facilities sensitivity studies and retrievals.

Graphics module

A sub-selection of a LUT-class can be made. Output can be plotted as a function of 1 or 2 parameters. Output can be exported.

Class-based concept

All retrieval approaches can be set class-based. When a classified map is provided, then per land cover class a different retrieval strategy can be developed.
When loading a land cover map then retrieval strategies can be optimized per class.

Input data can come either from RTMs, from field observations or from both.

In ‘SI setting’ multiple SIs, curve fittings and regularization options can be selected.

In Test SIs, run tests with the predefined strategies or load an existing test.

In Retrieval manually set up a SI retrieval strategy or select an earlier evaluated strategy.

In tools new indices and curve fittings can be inserted or loaded.
Spectra Index settings

If active, configure per land cover class.

Select an Index group
- Broadband greenness
- Narrowband greenness
- Leaf pigment (carotenoids, anthocyanins,...)
- Water
- ....

Select one or multiple indices

Select one or multiple curve fittings
*In tools, new curve fittings can be added.*

Options to add noise

Option to mix RTM with field observations

In tools, new index group or SI can be added or imported.

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Results test

Data:
- SPARC campaign, Barrax, Spain

Field data:
- LCC measured with CCM-200
- LAI measured with LiCor LAI-2000

Spectral data:
- CHRIS mode 1 (62 bands; 34m) nadir spectra
- HyMap (5 m resolution; 125 bands; 450-2500 nm)

Case studies

Overview of results. Here, best results per SI and curve fitting

Options to plot all kinds of output and export results

Selected strategies appear here and can be transported to the Retrieval module.

Outputs:
- Curve fitting
- 1:1

Matrices:
- Correlation
- Calibration
- Validation

Results can be organized according to land cover class, parameter, cal/val, and statistical output
SPARC- CHRIS: Impact of Co/Ca, bands & formulation

100% calibration – linear regression

• SR & NDVI results alike
• Most sensitive bands in red edge, but also in PRI region
• Correlation/calibration results can differ

GMES 10% threshold
3-band NDI= \( \frac{(b_3-b_1)}{(b_3+b_2)} \)

### 3-band NDI = (b3-b1)/(b3+b2)

#### LCC – 441 nm fixed

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Band combination</th>
<th>(R^2)</th>
<th>2-band</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCC</td>
<td>441 – 706 - 731</td>
<td>0.91</td>
<td>0.90 (NDVI)</td>
</tr>
<tr>
<td>LAI</td>
<td>410 – 688 - 700</td>
<td>0.91</td>
<td>0.90 (NDVI)</td>
</tr>
</tbody>
</table>

#### LAI – 410 nm fixed

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Band combination</th>
<th>NRMSE [%]</th>
<th>2-band</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCC</td>
<td>718– 725 - 738</td>
<td>8.25</td>
<td>8.13 (SR)</td>
</tr>
<tr>
<td>LAI</td>
<td>522– 553- 674</td>
<td>6.73</td>
<td>7.45 (SR)</td>
</tr>
</tbody>
</table>

**Notes:**
- 3-band SIs can indices further improve accuracies
- Best band combinations depend also on chosen output statistic
- Other formulations probably further improve accuracies. Up to 4 different bands can be analyzed.
• SR and NDVI alike. Curve fitting can play an important role.
• Best band combinations depend also on chosen output statistic.
• Note that PROSAIL results differ from results based on field data.
LAI - Calibrated by PROSAIL, validated by SPARC dataset

100% calibration – 10000 random simulations

Results rather good. Be careful when relying only on RTM data. NIR region most successful.
The full range matters. Best results using bands in visible and SWIR (1340, 2453 nm).

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Retrieval

**Manual options**

- Options to select land cover class and parameter.
- Options to select a spectral index and a curve fitting.
- Options to add noise, select Cal/val distribution and remove outliers

**Selected strategies.**

**Plotting options**

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Best evaluated strategies (3-band SI) applied to CHRIS

Portability is questionable:
- Striping effects, inconsistencies took place.
- Uncertainties are missing
Maps

**HyMap**
- 125 spectral channels (450-2500 nm)
- 5 m resolution

**570-2453 nm**
- $R^2$: 0.87
- NRMSE: 11.0%

**692-1340 nm**
- $R^2$: 0.92
- NRMSE: 9.0%
Conclusions

• **Spectral indices by default a sub-optimal approach.** Not only because of only few bands used, but also because of formulation and parametric regressors.
  – NDVI bands not necessarily best
  – NDVI formulation not necessarily best
  – Linear regression not necessarily best

• **ARTMO’s SI Module** facilitates systematic analysis of SIs.

• **Alternative formulations** (e.g. with more bands) and alternative curve fitting can lead to improved results.

• RTM-evaluated SIs not best for applying to images.
Thanks
Availability

ARTMO is work in progress - beta version

• Accessible at Valencia University under our supervision.
  – Atmospheric models
  – BRDF apps
  – Temporal domain
  – classifiers

• Matlab programmers are encouraged to write their own apps. In turn, a copy can be given.

• Public available after publication (will take some time – so far unsuccessful)

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