Potential of Sentinel-2 for retrieval of biophysical and biochemical vegetation parameters

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Increasing importance of quantifying biophysical and biochemical vegetation parameters from remote sensing data

Sentinel-2 especially suitable for monitoring vegetation dynamics

Central questions of this study:

- Capability of Sentinel-2 to estimate leaf chlorophyll content and leaf area index (LAI)?
  - Comparison to EnMAP and Landsat-8
- Possible synergies between EnMAP and Sentinel-2?
Effect of varying Leaf Chlorophyll Content

Increasing Chlorophyll Content causes:
- Blue / Red absorption maximum
- Red-shift of red edge point
Effect of varying Leaf Area Index

Increasing LAI causes:
- increasing NIR reflectance
- decreasing VIS and SWIR reflectance
Principle of derivation of Leaf Chlorophyll Content and LAI from Sentinel-2, EnMAP and Landsat-8

Data acquisition and processing workflow

Overview

- Canopy reflectance simulation
  - Simulation of sensor specific reflectance
    - EnMAP
    - Sentinel-2
    - Landsat-8
  - Vegetation indices and multi-band metrics
  - Derivation of LAI and Leaf Chlorophyll Content by using polynomial regression models
  - Calculation of sensor specific estimation errors

- Ground truth
  - Sampling
  - Parameter retrieval
  - Sensor performance
PROSPECT + SAIL = PROSAIL

- Combination of *leaf optical properties model* and *canopy bidirectional reflectance model*
- Allows calculation of canopy reflectance in solar domain (400 nm – 2500 nm, 1 nm steps)
- Allows a **variation of**:
  - Leaf biochemical contents (e.g. Chlorophyll content)
  - Canopy structural parameters (e.g. LAI)
  - Soil properties
  - Illumination and acquisition geometry
  - Atmospheric parameters

Canopy reflectance simulation using PROSAIL

Database of simulated canopy reflectance spectra (about 5300 entries)

- Varying leaf chlorophyll content:
  - 1 µg/cm² - 105 µg/cm² (resolution: 1 µg/cm²)

- Varying leaf area index (LAI):
  - values between 0 and 5 (resolution: 0.1 LAI units)

PROSAIL output data:
Simulation of sensor specific reflectance

PROSAIL canopy reflectance database (5355 samples)

End-to-end sensor simulation (Segl et al. 2012) includes:

- **Reflectance to radiance** conversion using MODTRAN4
- Spectral resampling using sensor specific spectral response functions (SRF)
- Incorporation of sensor specific noise characteristics (signal to noise ratio - SNR)
- Atmospheric correction

17 different vegetation indices tested

- Narrow band indices, broad band indices
- Ratios (e.g. RVI)
  Differences (e.g. DVI)
  Normalised differences (e.g. NDVI)
  Modified normalised differences (e.g. OSAVI)
  Other indices (e.g. REIP)

→ Emphasis put on indices relying on canopy reflectance between 700 nm and 850 nm
Calculation of sensor specific vegetation indices

- ChINDI
- Clirededge
- MCARI, TCARI, TCI
- REIP
- NPCI
- RDVI, OSAVI
- Clgreen
- EVI
- MCARI1, MCARI2
- NDVI, DVI, WDRVI, RVI

<table>
<thead>
<tr>
<th>EnMAP</th>
<th>Sentinel-2</th>
<th>Landsat-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30</td>
<td>0.25</td>
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wavelength [nm]
Estimation of leaf chlorophyll content and LAI using regression models (exemplary for Clgreen)

**Leaf chlorophyll content estimation**

- **PROSAIL leaf chlorophyll content [µg/cm²]**
- **Index value of Clgreen**
- **EnMAP**
- **Sentinel-2**
- **Landsat-8**
- **Fitted polynomial**

**Leaf area index estimation**

- **PROSAIL LAI value**
- **Index value of Clgreen**
- **Chlorophyll content = 70 µg/cm²**
- **Rameter retrieval**

**LAI = 3.0**

**Chlorophyll content = 70 µg/cm²**

**RMSE = #**

**Parameter retrieval**
**Averaged sensor specific estimation errors of all evaluated vegetation indices**

<table>
<thead>
<tr>
<th>Leaf Area Index estimation - Median of RMSEs (units of LAI)</th>
<th>Leaf Chlorophyll Content estimation - Median of RMSEs (µg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0</td>
<td>0 2 4 6 8 10 12 14 16 18 20 22 24 26</td>
</tr>
</tbody>
</table>

### Leaf Area Index estimation:

- **ChINDI**: 0.34, 0.48, 0.34, 0.19
- **MCARI**: 0.41, 0.36, 0.32, 0.09
- **MCARI1**: 0.41, 0.36, 0.32, 0.09
- **MCARI2**: 0.41, 0.36, 0.32, 0.09
- **TCARI**: 1.52, 0.64, 0.49, 0.27
- **TCI**: 0.80, 0.61, 0.49, 0.27

### Leaf Chlorophyll Content estimation:

- **Chlgreen**: 0.94, 2.21, 1.89, 3.02
- **Clrededge**: 1.31, 2.08, 1.69, 1.17
- **EVI**: 0.40, 0.23, 0.19, 0.15
- **RDVI**: 0.40, 0.23, 0.19, 0.15
- **OSAVI**: 0.40, 0.23, 0.19, 0.15
- **DVI**: 0.40, 0.23, 0.19, 0.15
- **RVI**: 0.40, 0.23, 0.19, 0.15
- **WDRVI**: 0.40, 0.23, 0.19, 0.15
- **NPCI**: 5.56, 13.31, 18.85, 23.70
- **NDVI**: 7.40, 16.23, 18.36, 23.62
- **EVI**: 3.63, 16.03, 16.14, 16.14
- **RDVI**: 5.56, 13.31, 18.85, 23.70
- **OSAVI**: 7.40, 16.23, 17.77, 23.70
- **DVI**: 6.20, 15.10, 17.88, 23.70
- **RVI**: 7.58, 16.23, 17.22, 23.70
- **WDRVI**: 6.93, 16.21, 17.22, 23.70
- **Clgreen**: 1.75, 1.04, 2.50, 3.60
- **Clrededge**: 0.73, 2.02, 1.24, 0.80

**Legend**:
- EnMAP
- Sentinel-2
- Landsat-8
- Standard deviation of RMSE
Comparison of estimation performance

❖ Best estimations:

**EnMAP**
- **Clrededge:** 0.73 µg/cm² (0.70 %)

**Sentinel-2**
- **REIP:** 0.80 µg/cm² (0.76 %)

**Landsat-8**
- **Clgreen:** 1.04 µg/cm² (1.0 %)

Leaf Chlorophyll Content

Leaf Area Index

DVI:
- **0.08 LAI values** (1.60 %)
- **0.04 LAI values**

DVI:
- **0.05 LAI values** (1.00 %)
- **0.07 LAI values**

DVI:
- **0.02 LAI values** (0.40 %)

after spectral resampling
Conclusions

Leaf Chlorophyll Content estimation:
- Landsat-8 reaches highest estimation accuracies with commonly used broad band indices
- *Red edge bands* of Sentinel-2 enable calculation of highly correlated vegetation indices
- Sentinel-2 is able to reach *higher accuracies than Landsat-8 when red edge bands are used*
- Sentinel-2 based results *almost as precise as* results derived from *hyperspectral data*

→ *EnMAP as possible validation sensor for Sentinel-2*

Leaf Area Index estimation:
- *Lowest estimation errors reached with broad band sensor (Landsat-8)*
- *Higher spectral resolution (of Sentinel-2 or EnMAP) can not increase estimation accuracy*
- *Spectral resampling of EnMAP to Landsat-8 results in enhanced estimation accuracy*

Constraints:
- Study fully relies on simulated spectra
Outlook and future developments

To be evaluated:

- Algorithms to derive optimal band positions for retrieval of vegetation parameters
- Spectral resampling of EnMAP and Sentinel-2 to Landsat-8 in order to increase LAI estimation accuracies
- Updated vegetation spectra database based on 4D plant models (HySimCaR)
- Estimation performance under different acquisition geometries (BRDF effects)

Attempts to be made:

- Investigation of generally valid regression functions for retrieval of vegetation parameters
  - Problem: Interdependency of leaf chlorophyll content and leaf area index
EnMAP and the associated research works are funded on behalf of the German Space Administration with resources of the German Federal Ministry of Economic Affairs and Technology.

Thank you very much for your attention!

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