Assessing the Potential of the Future EnMAP Mission for the Multiseasonal Retrieval of Biophysical Land Surface Parameters

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Outline

Objective in the EnMAP-Context

Multiseasonal Campaign 2012

| In Situ Measurements |
| Airborne Spectroscopy |

Biophysical Parameter Estimation

| Physically-based Modelling |
| Model Inversion |
| Selection Criteria |
| Validation |
| Application of LUT to Airborne Data |
| Crop Analysis |

Transfer to EnMAP Scale

| Spatial Adaption |
| Spectral Adaption |
| Application of LUT to EnMAP Data |

Is it possible to gain multiseasonal data about biophysical land surface parameters from hyperspectral image data without the need of in situ data?
Test Site – Neusling, Lower Bavaria (Size: 3x4 km)

- 6 data acquisitions
  - Apr 28\(^{th}\) (AVIS-3)
  - May 8\(^{th}\) (HySpex)
  - May 25\(^{th}\) (AVIS-3)
  - Jun 16\(^{th}\) (AVIS-3)
  - Aug 12\(^{th}\) (HySpex)
  - Sep 8\(^{th}\) (AVIS-3)

- > 500 in-situ measurements
  - Leaf Area Index (LAI)
  - Leaf Chlorophyll Content (LCC)
  - Soil moisture
  - Plant height
  - phenology
Multiseasonal Campaign 2012
Airborne Spectroscopy

AVIS-3 | Apr 28th

HySpex | May 8th

AVIS-3 | May 25th

AVIS-3 | Jun 16th

HySpex | Aug 12th

AVIS-3 | Sep 8th

Resolution: 4m
Biophysical Parameter Estimation
Physically-based Modelling

- Chlorophyll Content
- Carotenoid Content
- Equivalent Water Thickness
- Dry Matter Content
- Leaf Structure Parameter

PROSPECT5 ➔ PROSAIL ➔ 4SAIL

Reflectance

Leaf Area Index [m m⁻²]

Wavelength [nm]

Average Leaf Angle
Leaf Area Index
Hot Spot
Solar Zenith Angle
Observer Zenith Angle
Observer Azimuth Angle
Soil Coefficient
Diffuse / Direct Radiation
Biophysical Parameter Estimation

Model Inversion

1. Step: Construction of a Look-Up Table Library

- PROSAIL Forward simulation

- 100,000 parameter settings + appropriate spectra

- 209 Zenith & Azimuth settings
  - Zenith 5°-steps
  - Azimuth 10°-steps

- 4 Solar Zenith settings
  - 4 different SZA in 6 flights

Total Amount of Spectra in LUT: 83,600,000

2. Step: Inversion Sequence

- Control of solar zenith setting

- Start at first pixel and control of zenith & azimuth angle

- Selection of corresponding LUT

- Multiplication of measured spectrum 100,000 times

- Application of curve fitting and identification of best match(es)

Criteria?
Biophysical Parameter Estimation
Selection Criteria

How to find the best fit?

A) Band selection
B) Selection of a cost function

- Multispectral: selective choice of bands
- Hyperspectral: continuous spectrum

Root Mean Square Error

\[ RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (V_{est}^i - V_{obs}^i)^2} \]

Nash-Sutcliffe Efficiency

\[ NSE = 1 - \frac{\sum_{i=1}^{n} (V_{obs}^i - V_{est}^i)^2}{\sum_{i=1}^{n} (V_{obs}^i - \bar{V}_{obs})^2} \]

Laplace Distribution

\[ LP = \sum_{i=1}^{n} |V_{obs}^i - V_{est}^i| \]

Geman & McClure Function

\[ GM = \sum_{i=1}^{n} \frac{(V_{obs}^i - V_{est}^i)^2}{1 + (V_{obs}^i - V_{est}^i)^2} \]
Bioophysical Parameter Estimation
Selection Criteria

**How to find the best fit?**

- A) Band selection
- B) Selection of a cost function
- C) Averaging a defined number of best fits
- D) Averaging method

**Ill-posed problem – multiple solutions possible?**

**PROSAIL Input Parameters**

<table>
<thead>
<tr>
<th>SETTING</th>
<th>A</th>
<th>B</th>
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<tbody>
<tr>
<td>Chlorophyll</td>
<td>21.1</td>
<td>29.9</td>
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<td>Carotenoid</td>
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<td>Brown Pigment</td>
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<td>EWT</td>
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<td>Leaf Mass</td>
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<td>Structure</td>
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<td>Leaf Angle</td>
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<td>LAI</td>
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<td>Hot Spot</td>
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<td>Solar Zenith Angle</td>
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<tr>
<td>Obs. Zenith Angle</td>
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<td>Obs. Azimuth Angle</td>
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<tr>
<td>Soil</td>
<td>0.687</td>
<td>0.345</td>
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Biophysical Parameter Estimation
Selection Criteria

**How to find the best fit?**

A) Band selection  
B) Selection of a cost function  
C) Averaging a defined number of best fits  
D) Averaging method  
E) Adding noise to the LUT data

- Randomly generated  
- Gaussian distributed  
- Variance ($\sigma^2$) of that Gaussian distribution corresponds to a defined percentage of reflectance  
- Different modes are possible:  
  - Additive noise  
  - Multiplicative noise  
  - Negative multiplicative noise  
  - Combined noise  
  - Negative combined noise

Model vs. reality – how realistic are the simulated spectra?

**Negative multiplicative Noise**
How to find the best combination of inversion criteria?

Answer: Calculate All!

- 4 cost functions
- 2 averaging methods
- 5 types of noise
- 21 noise percentages (depending on noise type):
  Min = 0%, Max = 20%, Step Range = 1%
- 21 numbers of considered best fits:
  Min = 1, Max = 1000, Step Range = 50

Cost function: Laplace
Averaging method: median
Noise Type: negative multiplicative

17640 combinations
Biophysical Parameter Estimation

Validation

\[ V_{est}^i = mV_{obs}^i + b \]

Problem: NSE (as well as RMSE, RRMSE, \( R^2 \)) are potentially high, even if slope (\( m \)) and intercept (\( b \)) are worse

\( \Rightarrow \) Definition of a threshold for slope (\( 0.75 > m < 1.25 \)) and normalized intercept (\( b < 1.0 \))
Biophysical Parameter Estimation

Validation

Cost Function: \( \text{RMSE} \mid \text{NSE} \mid \text{LaPlace} \mid \text{Geman & McClure} \)
Averaging Method: \( \text{mean} \mid \text{median} \)
Number of fits: \( 550 \mid 100,000 \)
Noise: \( \text{additive} \mid \text{multiplicative} \mid \text{neg. multiplicative} \mid \text{combined} \mid \text{neg. combined} \)
Noise (\( \sigma^2 \)): \( 0.06 \)

\[ R^2 = 0.66 \]
\[ \text{RMSE} = 0.61 \]
\[ \text{RRMSE} = 0.17 \]
\[ \text{NSE} = 0.65 \]
\[ 0.75x + 0.95 \]
Biophysical Parameter Estimation
Application to Airborne Data

LAI (m² m⁻²)

0.0 5.5
Biophysical Parameter Estimation
Crop Analysis

[Diagram showing the growth cycle of various crops with data points for LAI and CCC from April 28th to September 8th]
Transfer to EnMAP Scale
Spatial Adaption

AVIS-3 | Apr 28th

HySpex | May 8th

AVIS-3 | May 25th

AVIS-3 | Jun 16th

HySpex | Aug 12th

AVIS-3 | Sep 8th

Resolution: 4m

-> EeteS ->

Resolution: 30m
Transfer to EnMAP Scale
Spectral Adaptation

AVIS-3 (CIR) – 4m

EnMAP – 30m
Transfer to EnMAP Scale
Application to EnMAP Data

LAI Estimation | AVIS-3 (spectral) | 30m

LAI Estimation | EnMAP (spectral) | 30m
Transfer to EnMAP Scale
Application to EnMAP Data

R² = 0.95
NSE = 0.95
RMSE 0.33
RRMSE 0.19
m | b = 1.00 | 0.11
Thank You For Your Attention.

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