Hydro-ecological modelling supported by imaging spectroscopy

Okke Batelaan¹
Boud Verbeiren¹
Le Quoc Hung¹
Nixon Asante¹

Lammert Kooistra²
Uchenna Aduaka²
Arjen Meddens²
Michael Schaepman²

Luc Bertels³
Bart Deronde³

Jan Bogaert⁴

1: Dept. of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel
2: Wageningen University, Centre for Geo-Information
3: VITO, Flemish Institute for Technological Research
4: Laboratoire d'Écologie du Paysage, Université Libre de Bruxelles
Shallow groundwater, lush vegetation

Groundwater recharge areas

Wetlands
Highly valued areas

Huybrechts
Effect of climate and landuse change

- Urbanisation
- Agriculture
- Groundwater extraction

• Challenge for ecohydrology: Coupling required of carbon (photosynthesis) and water balance, including plant water uptake (roots), translocation and evapotranspiration (Newman et al., 2006)
Objectives and contents of presentation

Objective
- To further develop ecohydrology by imaging spectroscopy

Contents – Examples:
1\textsuperscript{st} IS performance in detailed vegetation mapping
2\textsuperscript{nd} IS for ET, moisture-groundwater depth mapping
3\textsuperscript{rd} IS performance for complex dune vegetation mapping
4\textsuperscript{th} IS for aboveground Net Primary Productivity
- Outlook
1st example: Doode Bemde, BE

Overlay of Regions of Interest

- 'Glanshaver' grassland
- 'Dotter' grassland
- 'Moerasspirea' herbage
- 'Grote zegge'
- Reed
- Transition grassland
- Forest & trees
- Cultivated land
- Bare soil
- Water
- Built-up area
- Shadow
1\textsuperscript{st}: Linear Discriminant Analysis

Classified image using Linear Discriminant Analysis; first 14 bands were used.

Majority smoothing
1st: Accuracy assessment

Doode Bemde classification

<table>
<thead>
<tr>
<th>VTYPE_1_GG</th>
<th>VTYPE_2_GG</th>
<th>VTYPE_3_GG</th>
<th>VTYPE_4_GG</th>
<th>VTYPE_6_GG</th>
<th>VTYPE_12_GG</th>
<th>Bos</th>
<th>Akker</th>
<th>Cultuur grasland</th>
<th>Schaduw</th>
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Kappa: total weighted: 0,96
Kappa: total mean: 96
1st: Millingerwaard, NL
1st: Smoothed LDA Classification
Airborne hyperspectral remote sensing with the LDA classifier proves to be suited to classify natural vegetation in detail.

<table>
<thead>
<tr>
<th>Forest &amp; trees</th>
<th>Grassland with herbs</th>
<th>Water</th>
<th>Bare soil (dark)</th>
<th>Bare soil (light)</th>
<th>Built-up area</th>
<th>Cultivated land</th>
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<tbody>
<tr>
<td>97</td>
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</table>

Kappa: Total weighted: 95
Kappa: Total mean: 97

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<th>Broad classes</th>
<th>Fine classes</th>
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<tbody>
<tr>
<td>Kappa: 0.95</td>
<td>Kappa: 0.80</td>
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<tr>
<td>Total weighted: 95</td>
<td>Total weighted: 83</td>
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<tr>
<td>Total mean: 97</td>
<td>Total mean: 80</td>
</tr>
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</table>
2nd Example: Doode Bemde, Phreatophytes

Becker and Huybrechts (2000)

Vegetation type:
- Arrhenatheretum elatioris
- Calthion palustris
- Filipendulion
- Magnocaricion
- Magnocaricion with Phragmites australis
- Phragmitetalia
- Carici elongatae-Alnetum glutinosae
- Mapped species area
- River, brook
**2nd: vegetation-groundwater dependence**

Simulated Discharge  
52% surface  
2.6 mm/day

Groundwater level fluctuation  
< 1m

Groundwater Depth < 0.5 m

Location of phreatophytes
Evapotranspiration = Net radiation – Soil heat – Sensible heat flux

2\textsuperscript{nd}: Surface Energy Balance

- Net radiation
- Sensible heat
- Latent heat
- Evapotranspiration
- Soil heat

SEBAL model
2nd: Energy fluxes fen meadow

Vegetation density
red = low
green = high

Soil heat <
blue = low
red = high

Latent heat >

Net radiation
Sensible Heat <
Daily evapo-transpiration
2nd: Spatial distribution soil moisture

\[ \Lambda = 1.0237 - \frac{0.0264}{\left(\frac{\theta}{\theta_{sat}}\right)} \quad (R^2 = 0.51, \ p < 10^{-4}) \]
Differences:

Red-edge index

Correlates

De Becker et al. (1999)

-3 -2 -1 0 1

max. gw depth (m)

25 percentile
Median
75 percentile
Outliers

Median max. groundwater depth vegetation types (m)

R² = 0.86
Conclusions 2nd Example

• SEBAL evapotranspiration and soil moisture simulation is successful with spatial and spectral high resolution imagery
• Evapotranspiration varies considerably over vegetation types and short distances
• The red-edge index is promising in ecohydrological (groundwater) characterization of phreatophytic vegetation
Objective: Development of RS based monitoring for vegetation mapping in dune valleys under influence of soil subsidence due to gas extraction
- Study area: Wadden-Island Ameland (NL)
- IS data: AHS 2005 (63 bands)
- Identification of six vegetation structure types
- Vegetation relevees: 2004 (n=140), 2005 (n=104)

Comparison of classification methods:
1. Maximum Likelihood Classification
   - Selection of bands: Redundancy analysis
   - Expert selection of training areas
2. Mixture Tuned Match Filtering
   - Expert selection of training areas
   - Averaged spectra 2004
   - Pixel Purity Index (PPI)
Overall classification accuracy (%)
Dataset  |  MLHC  |  MTMF
2004 (n=140) | 66.9   | 69.1
2005 (n=104) | 41.4   | 44.1
nr. classes  | 6      | 4

Results
• Differences in accuracy per class: low for class B due to influence seawater
• Low accuracy for PPI endmembers
• Soil background major source of spectral variation
• Influence of sampling strategy

Future
• Combination of IS with kriging approach
• Up-scaling to whole Wadden-Island

MLHC classification with band selection based on Redundancy Analysis of vegetation relevées

MTMF classification using the averaged 2004 pixel spectra as endmembers
4th: Derivation of ANPP in river floodplains

**Objective:** Regional estimation of aboveground Net Primary Productivity (ANPP) for river floodplain ecosystems using IS

- Study area: Millingerwaard floodplain (NL)
- IS data: HyMap 2004 + ground data
- Light Use Efficiency (LUE) based method:

\[
\text{HyMap ANPP} = (\text{PRI}) \left(f_{\text{APAR}} \right) \left(\text{PAR}_{\text{IC}}\right)
\]

\(\text{PRI} = \text{Photochemical Reflectance Index}\)

\(f_{\text{APAR}} = \text{fraction of absorbed photochemical radiation}\)

\(\text{PAR}_{\text{IC}} = \text{Photosynthetically Active Radiation (meteo data)}\)

- Comparison of HyMap derived ANPP with results Dynamic Vegetation Model (DVM) SMART2-SUMO2

\(\text{(Gammon et al., 1997)}\)

\(\text{(Sellers, 1994)}\)
4th: Mapping ANPP and carbon storage

Application of IS for:
- Regional scale ecosystem modeling
- DVM initialization, calibration and validation
- Scenario development including human impact

Comparison of HyMap and SMART2-SUMO2 derived ANPP

Aduaka, 2006
• IS derived variables (NPP, PFT) can be used for initialization and validation of dynamic vegetation models
• This approach could assist nature manager in making a more reliable and site-specific evaluation of the effect of management measures on vegetation succession
• however, up-scaling required to, e.g., catchments or whole island, use of satellite based IS data (MODIS, MERIS etc.)
Outlook: Spatial Pattern Analysis

LANDSCAPE ECOLOGY → PATTERN-PROCESS PARADIGM → SPATIAL PATTERN ANALYSIS USING LANDSCAPE METRICS

AGGREGATED INFORMATION IS MORE RELIABLE

AGGREGATED INFORMATION CORRESPONDS TO ECOLOGICAL PROCESSES

DEGREE OF AGGREGATION REFLECTS DATA RELEVANCE

IRRELEVANT

RELEVANT
Conflict or opportunity?

Toward a Synthesis of the Newtonian and Darwinian Worldviews

Physicists seek simplicity in universal laws. Ecologists revel in complex interdependencies. A sustainable future for our planet will probably require a look at life from both sides.

<table>
<thead>
<tr>
<th>PHYSICS/HYDROLOGY</th>
<th>ECOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>The more you look the simpler it gets</td>
<td>The more you look, the more complex it gets</td>
</tr>
<tr>
<td>Primacy of initial conditions</td>
<td>Primacy of complex historical factors</td>
</tr>
<tr>
<td>Universal patterns; search for laws</td>
<td>Weak trends; reluctance to seek laws</td>
</tr>
<tr>
<td>Predictive</td>
<td>Mostly descriptive, explanatory</td>
</tr>
<tr>
<td>Central role for ideal systems</td>
<td>Disdain for caricatures of nature</td>
</tr>
</tbody>
</table>
Synthesis ingredients

• Simple falsifiable models: mechanistic, lumped system variables
• Search for patterns and laws: e.g. spatial scaling
• Embrace science of place: try to understand very specific environments, then it is possible to go from pattern to process to generalizations
END!