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# Hydro-ecological modelling supported by imaging spectroscopy

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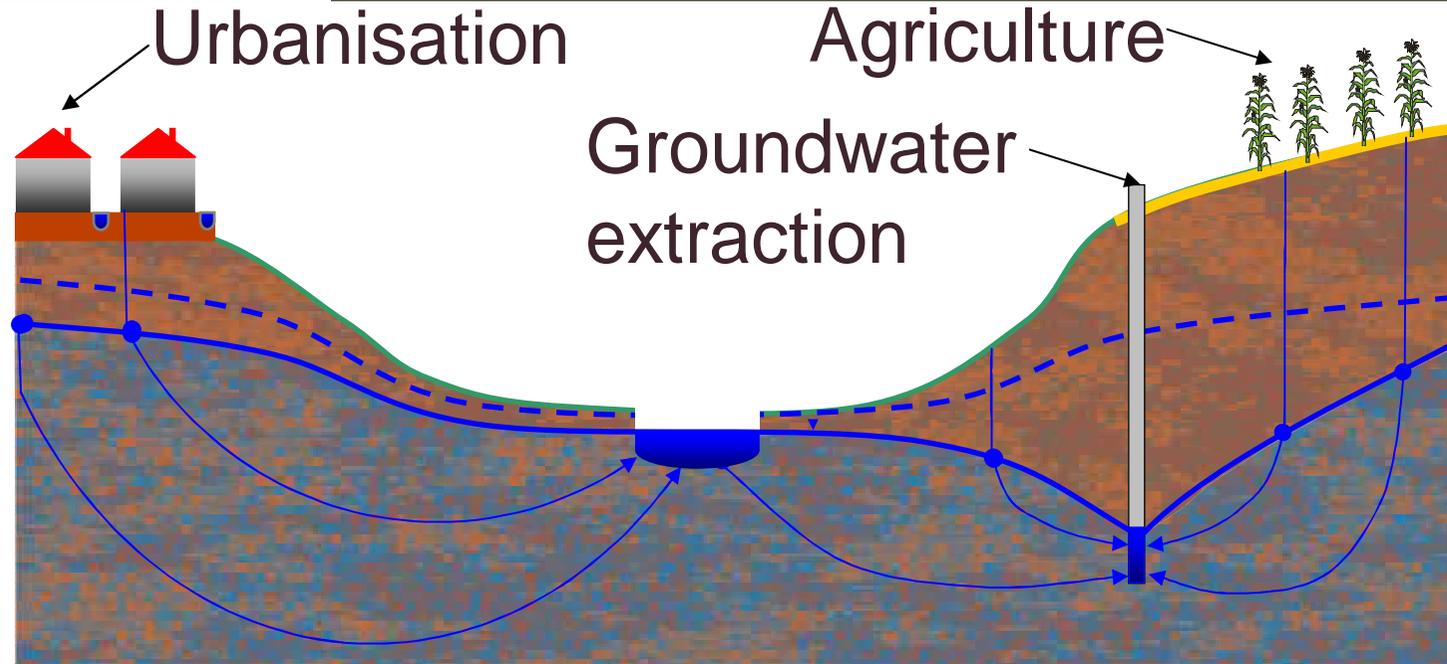4: Laboratoire d'Écologie du Paysage, Université Libre de Bruxelles

# Shallow groundwater, lush vegetation

**Groundwater recharge areas**

**Wetlands**
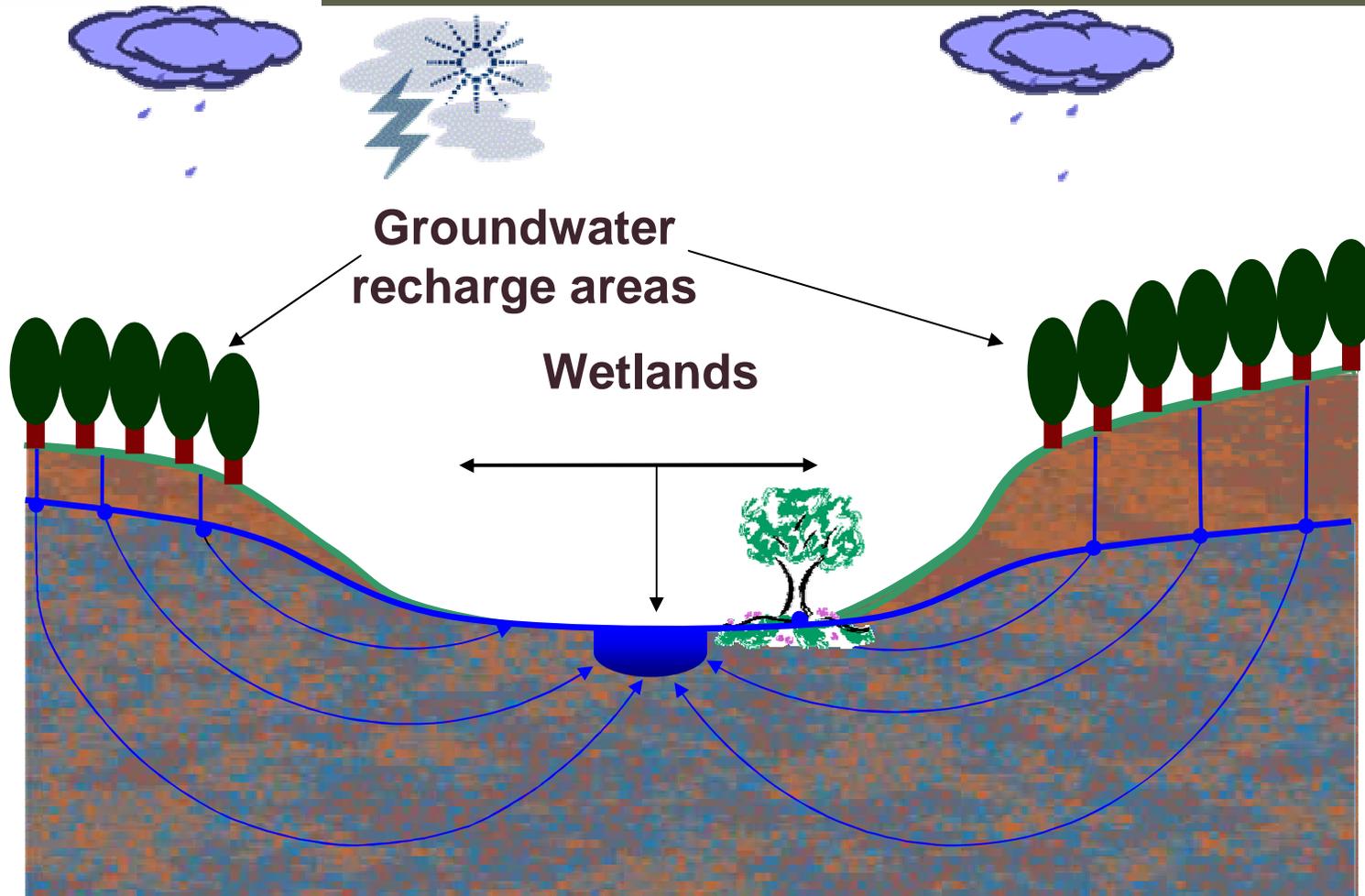
# Highly valued areas



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:

1st IS performance in detailed vegetation mapping

2nd IS for ET, moisture-groundwater depth mapping

3rd IS performance for complex dune vegetation mapping
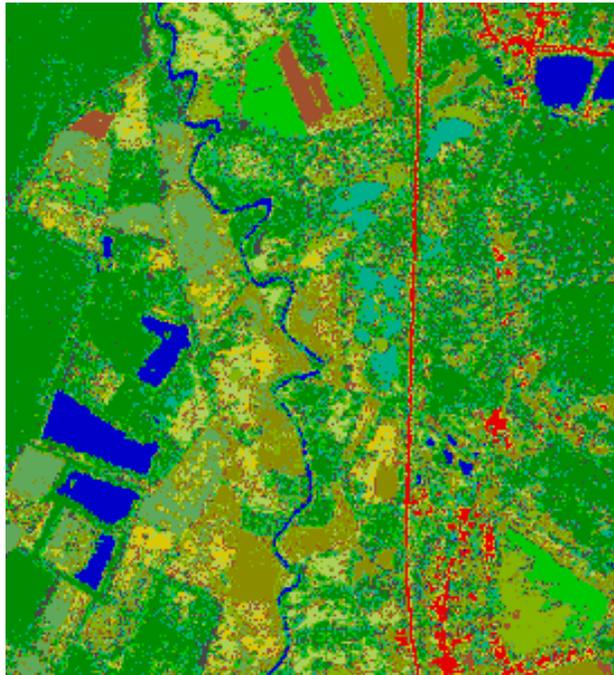
4th IS for aboveground Net Primary Productivity

- Outlook

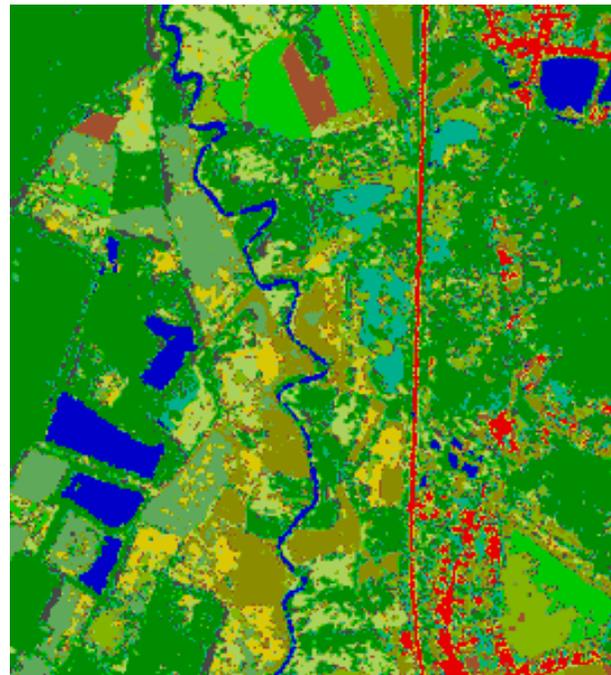# 1st example: Doode Bemde, BE

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

# 1st: Linear Discriminant Analysis



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



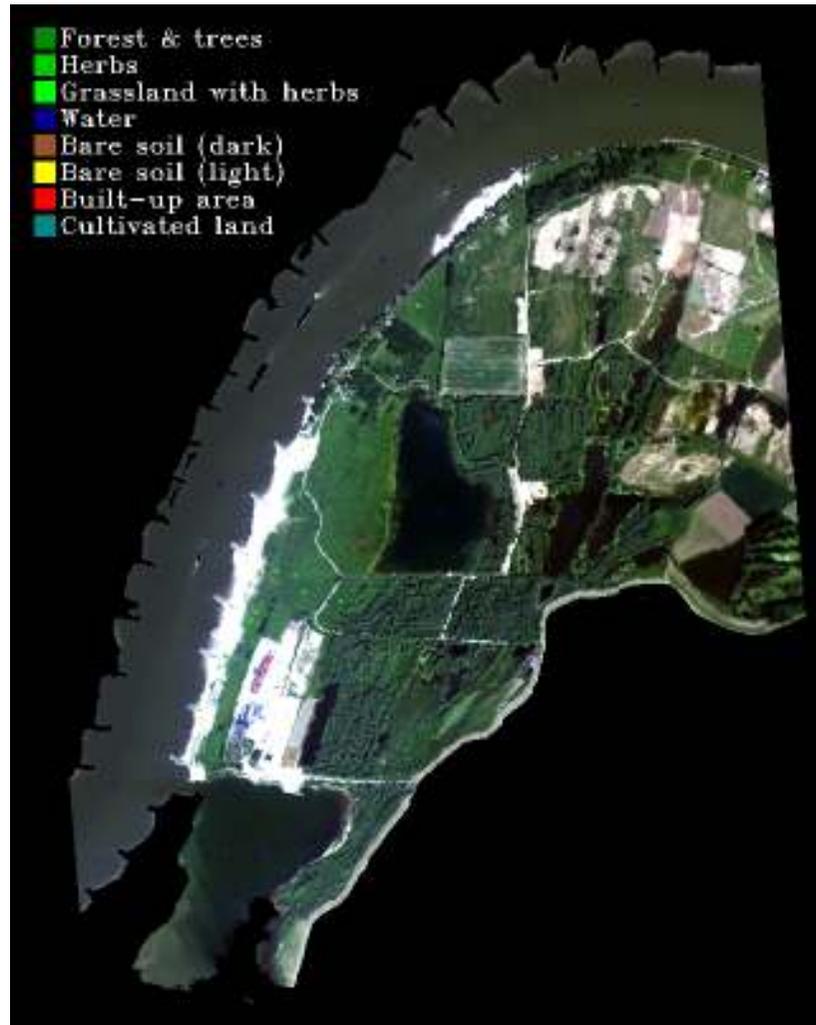Majority smooting

**Legend:**
- 'Glanshaver' grassland
- 'Dotter' grassland
- 'Moerasspirea' herbage
- 'Grote zegge'
- Reed
- Transition grassland
- Forest & trees
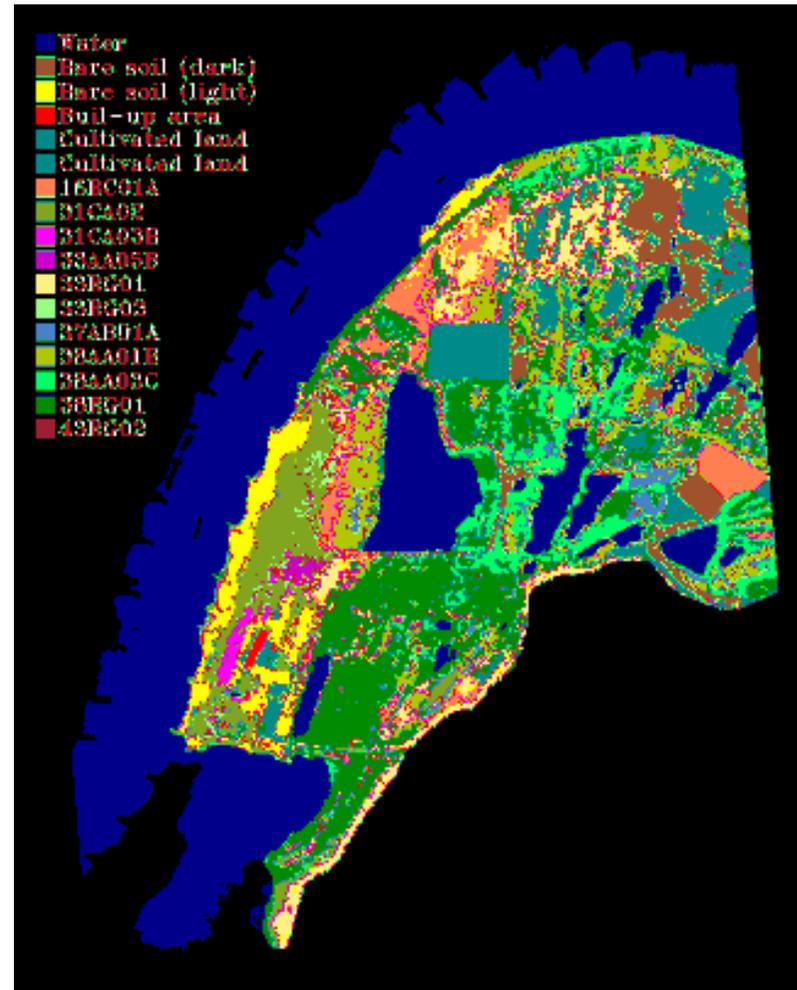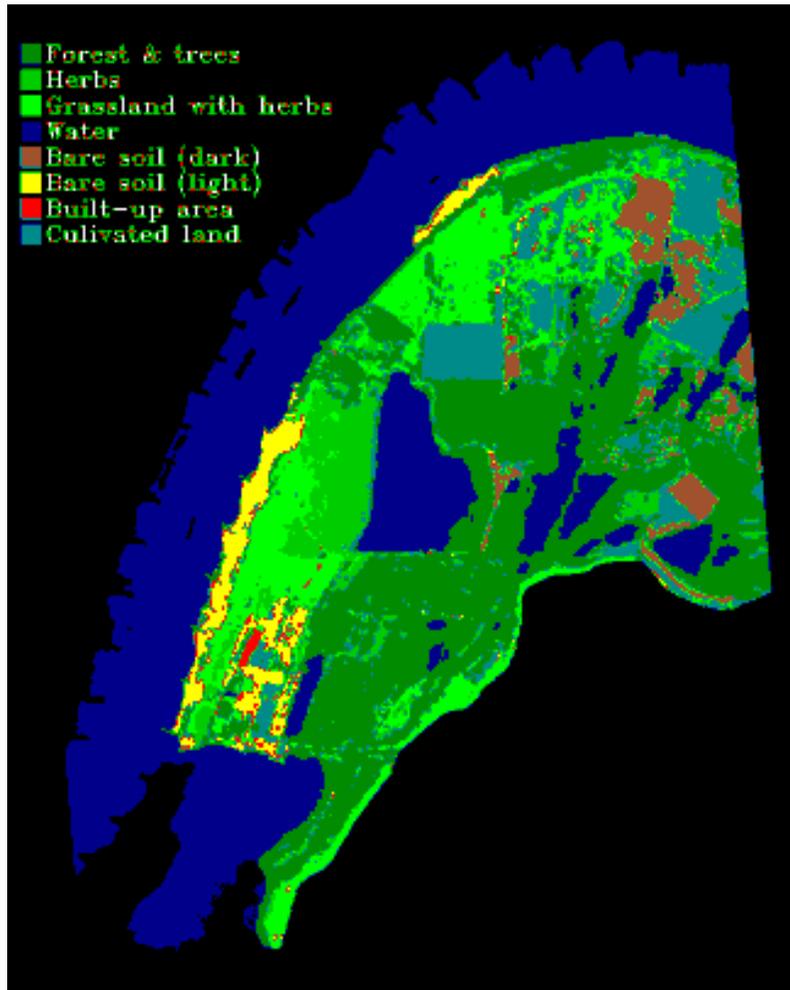- Bare soil
- Cultivated land
- Shadow
- Built-up area
- Water

# 1ˢᵗ: Accuracy assesment Doode Bemde classification

| | VTYPE_1_GG | VTYPE_2_GG | VTYPE_3_GG | VTYPE_4_GG | VTYPE_6_GG | VTYPE_12_GG | Bos | Akker | Cultuur grasland | Schaduw | Verhard | Water |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VTYPE_1_GG | 92 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| VTYPE_2_GG | 2 | 87 | 2 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| VTYPE_3_GG | 0 | 9 | 89 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| VTYPE_4_GG | 2 | 4 | 2 | 89 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| VTYPE_6_GG | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| VTYPE_12_GG | 0 | 0 | 3 | 0 | 0 | 97 | 0 | 0 | 0 | 0 | 0 | 0 |
| Bos | 0 | 0 | 0 | 1 | 1 | 0 | 98 | 0 | 0 | 0 | 0 | 0 |
| Akker | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 |
| Cultuur grasland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 |
| Schaduw | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 |
| Verhard | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 95 | 0 |
| Water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 99 |

Kappa:          0,96
total wighted:  96
total mean:     96

# 1ˢᵗ: Millingerwaard, NL



Forest & trees
Herbs
Grassland with herbs
Water
Bare soil (dark)
Bare soil (light)
Built-up area
Cultivated land

# 1st: Smoothed LDA Classification

# 1ˢᵗ: Accuracy assesment Millingerwaard classification

**Airborne hyperspectral remote sensing with the LDA classifier proves to be suited to classify natural vegetation in detail.**

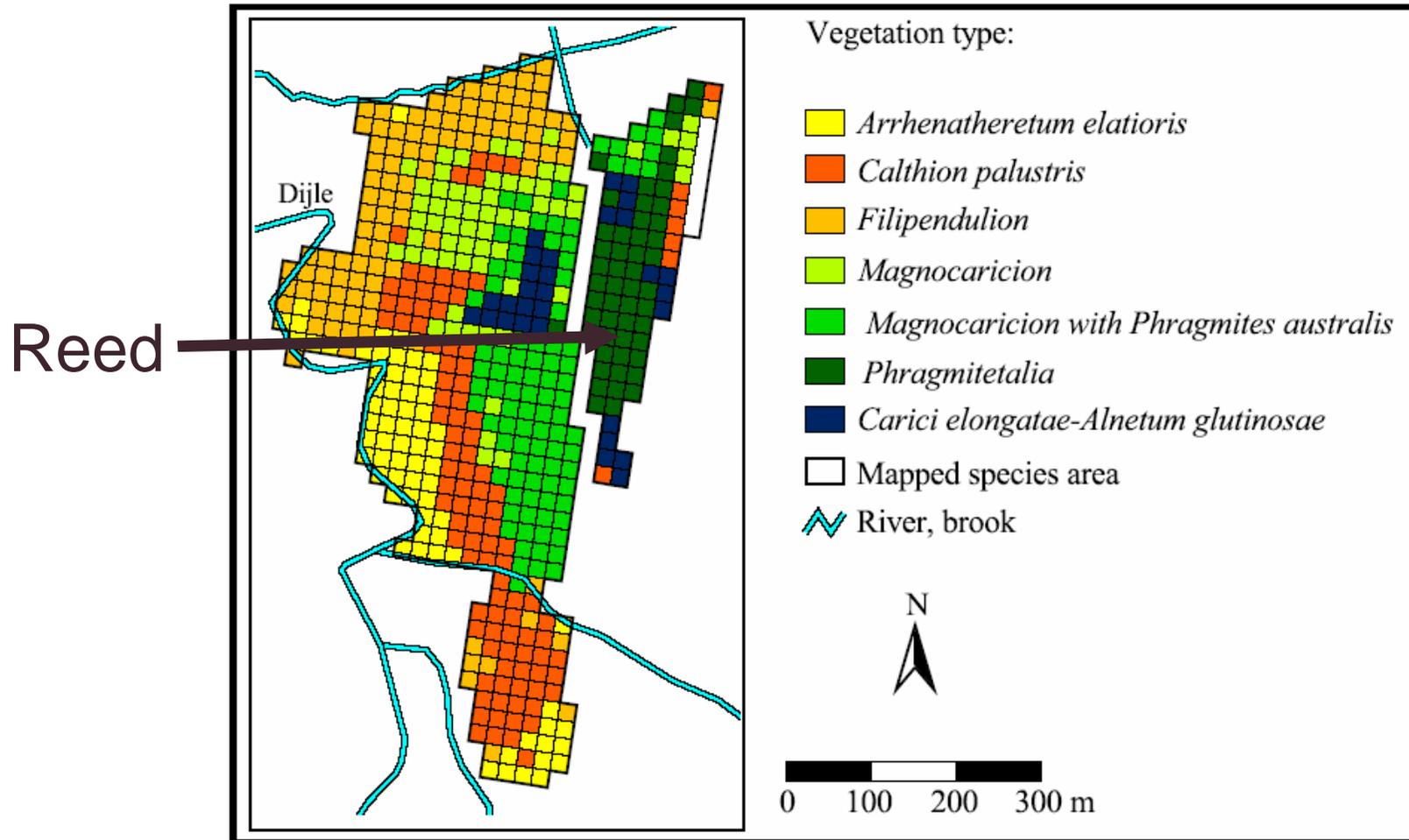| | 16BC01A | 31CA02 | 31CA03B | 33AA05B | 33RG01 | 33RG03 | 37AB01A | 38AA01B | 38AA03C | 38RG01 | 43RG02 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16BC01A | 89 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 |
| 31CA02 | 0 | 98 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |

Cultivated land ... 0 0 0 0 0 0 0 100

43RG02 ... 11 11 0 0 0 33 0 0 0 0 44

| Broad classes | | Fine classes | |
|---|---|---|---|
| Kappa: | 0,95 | Kappa: | 0.80 |
| Total weighted: | 95 | Total weighted: | 83 |
| Total mean: | 97 | Total mean: | 80 |

# Broad classes    Fine classes

Reed

Vegetation type:

- Arrhenatheretum elatioris
- Calthion palustris
- Filipendulion
- Magnocaricion
- Magnocaricion with Phragmites australis
- Phragmitetalia
- Carici elongatae-Alnetum glutinosae
- ☐ Mapped species area
- ∿ River, brook

N

0  100  200  300 m

Dijle

Becker and Huybrechts (2000)

# 2nd: vegetation-groundwater dependence
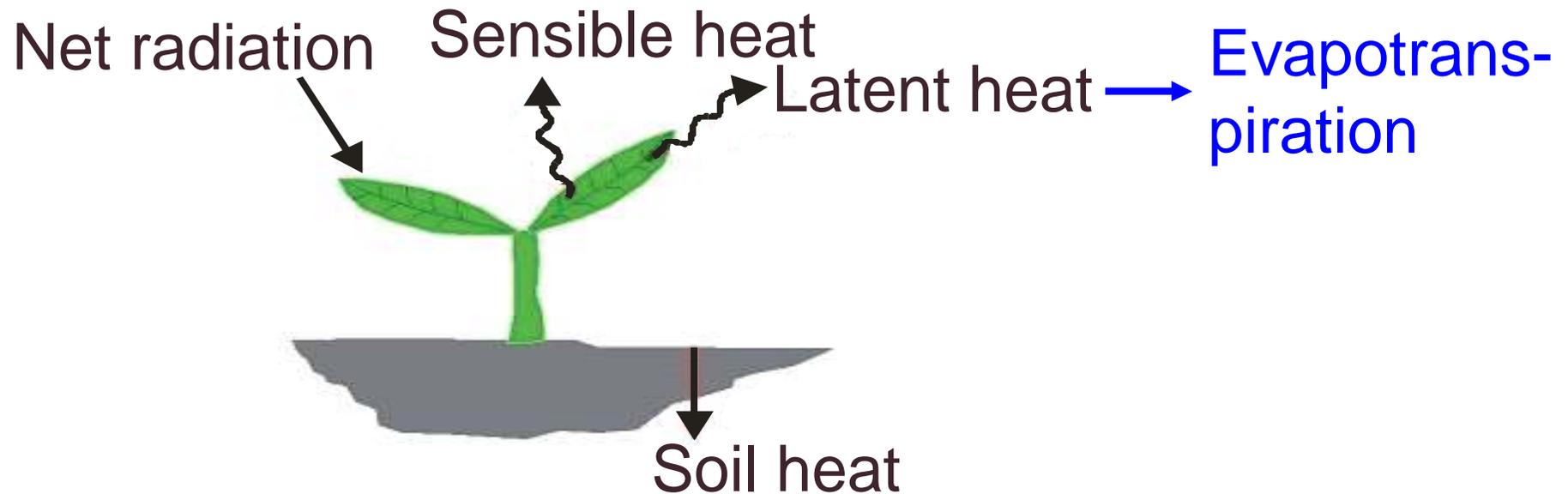
**Simulated Discharge 52% surface 2.6 mm/day**

**Groundwater level fluctuation < 1m**

**Groundwater Depth < 0.5 m**

**Location of phreatophytes**
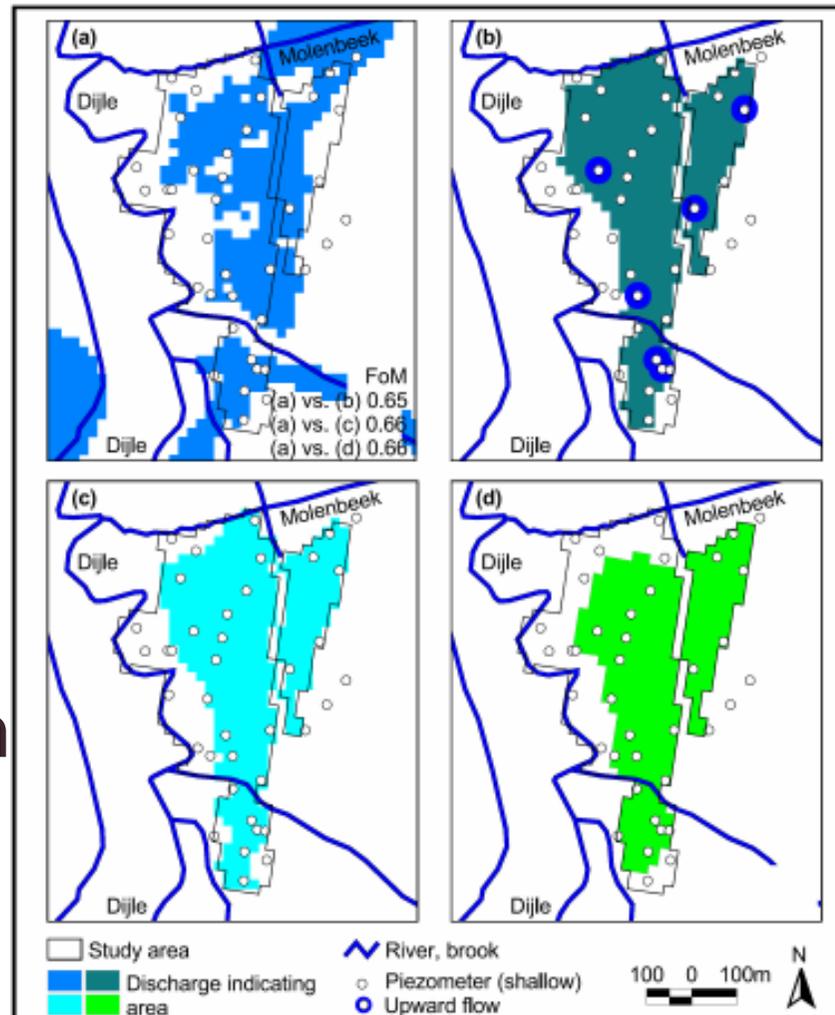
# 2nd: Surface Energy Balance

Net radiation    Sensible heat

Latent heat → Evapotrans-piration

Soil heat

Evapotranspiration = Net radiation – Soil heat – Sensible heat flux
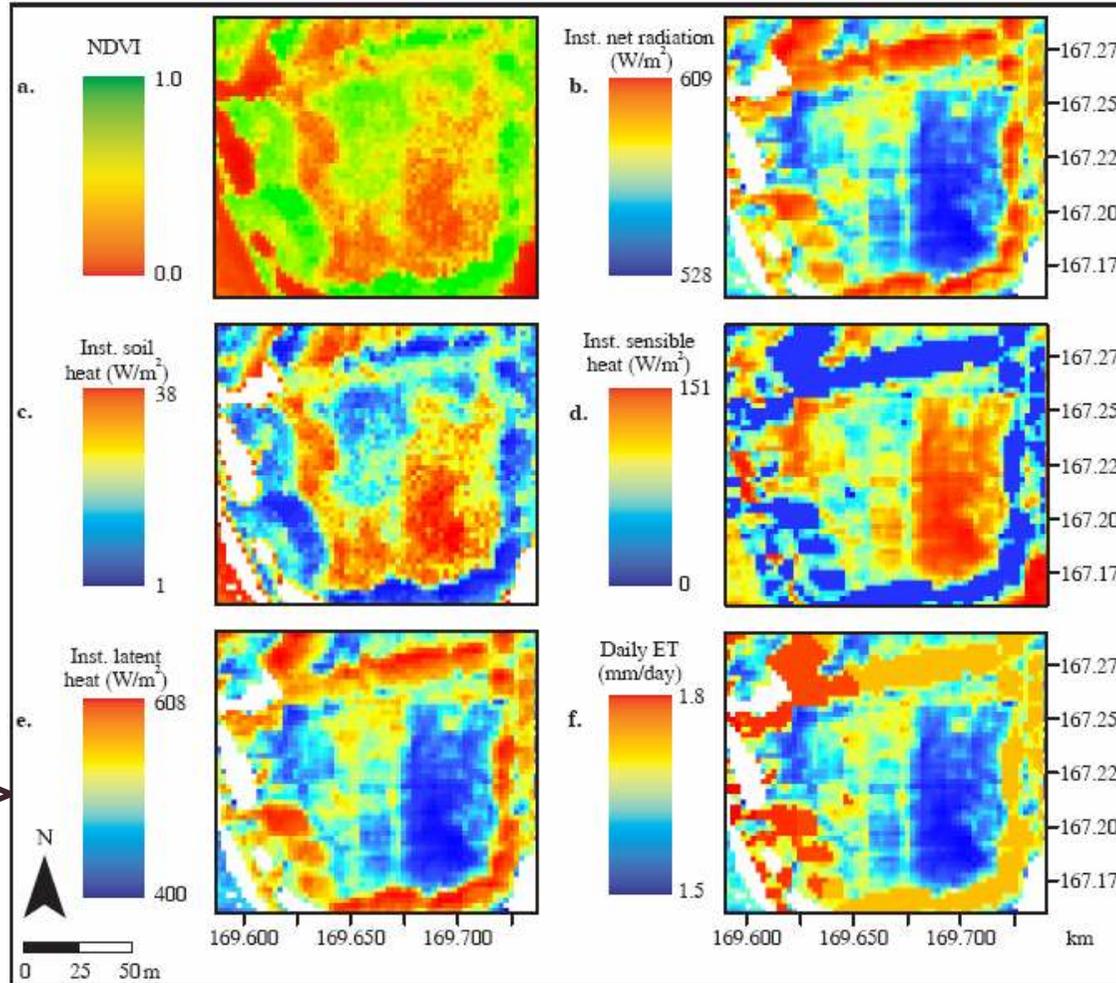
SEBAL model

# 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-trans-piration

# 2nd: Spatial distribution soil moisture



$\Lambda = 1.0237 - (0.0264/(\theta/\theta_{sat}))$ $(R^2 = 0.51, p < 10^{-4})$

y-axis: latent heat flux / (net radiation – soil heat flux) = Evaporative fraction ($\Lambda$)

x-axis: Soil moisture fraction ($\theta/\theta_{sat}$)
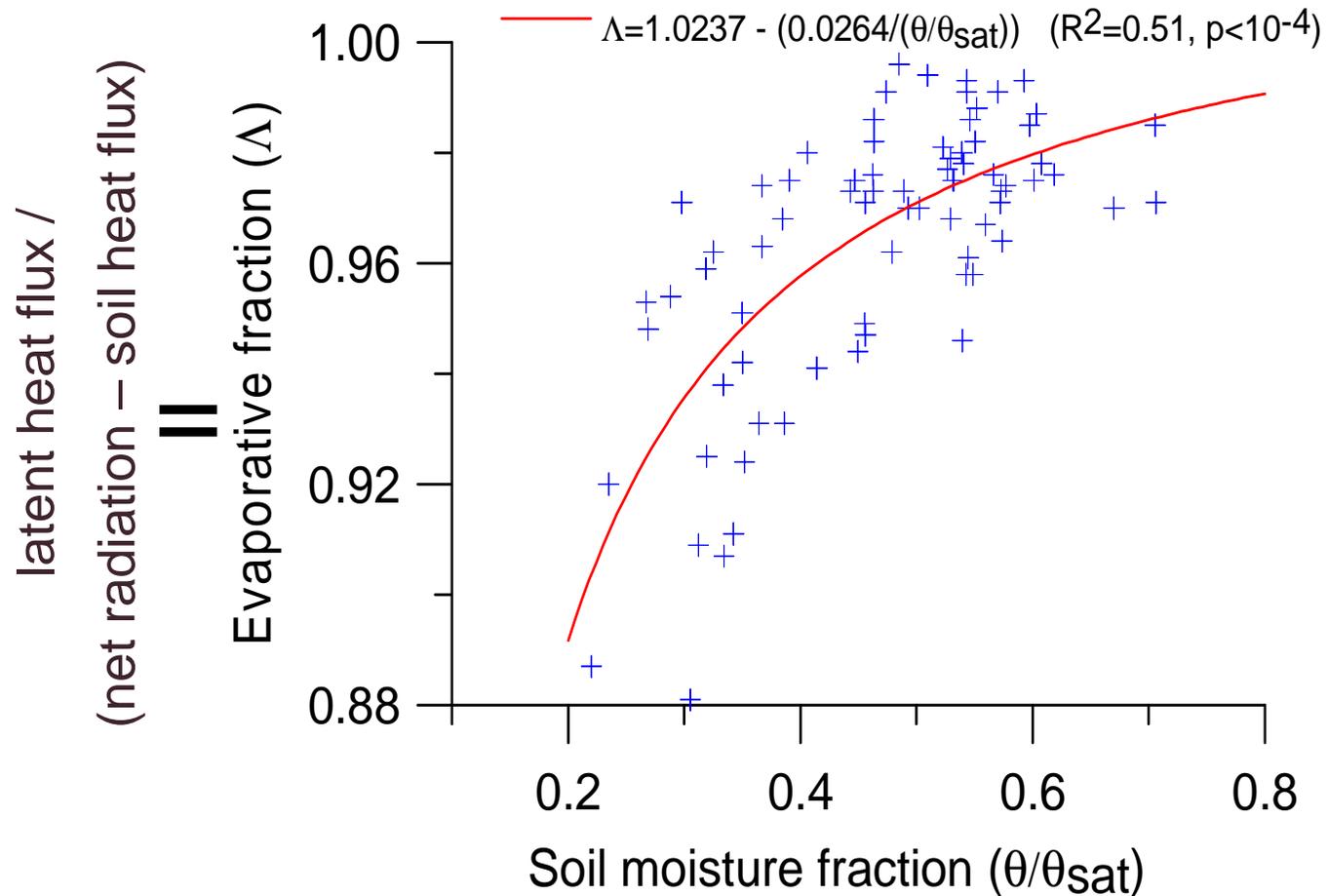
# 2nd: Spectral Signatures

De Becker et al. (1999)

Reflectance

0.5
0.4
0.3
0.2
0.1
0

*Arrhenatheretum elatioris*
*Filipendulion*
*Calthion palustris*
*Magnocaricion*
*Magnocaricion* with *Phragmites australis*
*Phragmitetalia*

Differences:

Red-edge index ⟷ max. gw depth (m)

-3  -2  -1  0  1

Correlates

Red-edge index
0.14  0.15  0.16  0.17  0.18  0.19  0.2

Median max. groundwater depth vegetation types (m)
0.00
-0.50
-1.00
-1.50
-2.00

$R^2 = 0.86$

25 percentile
Median
75 percentile

Outliers

400

W
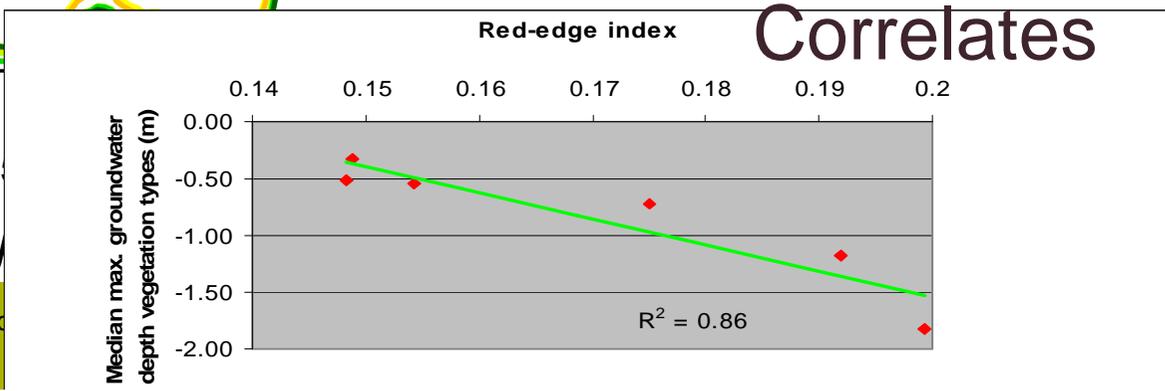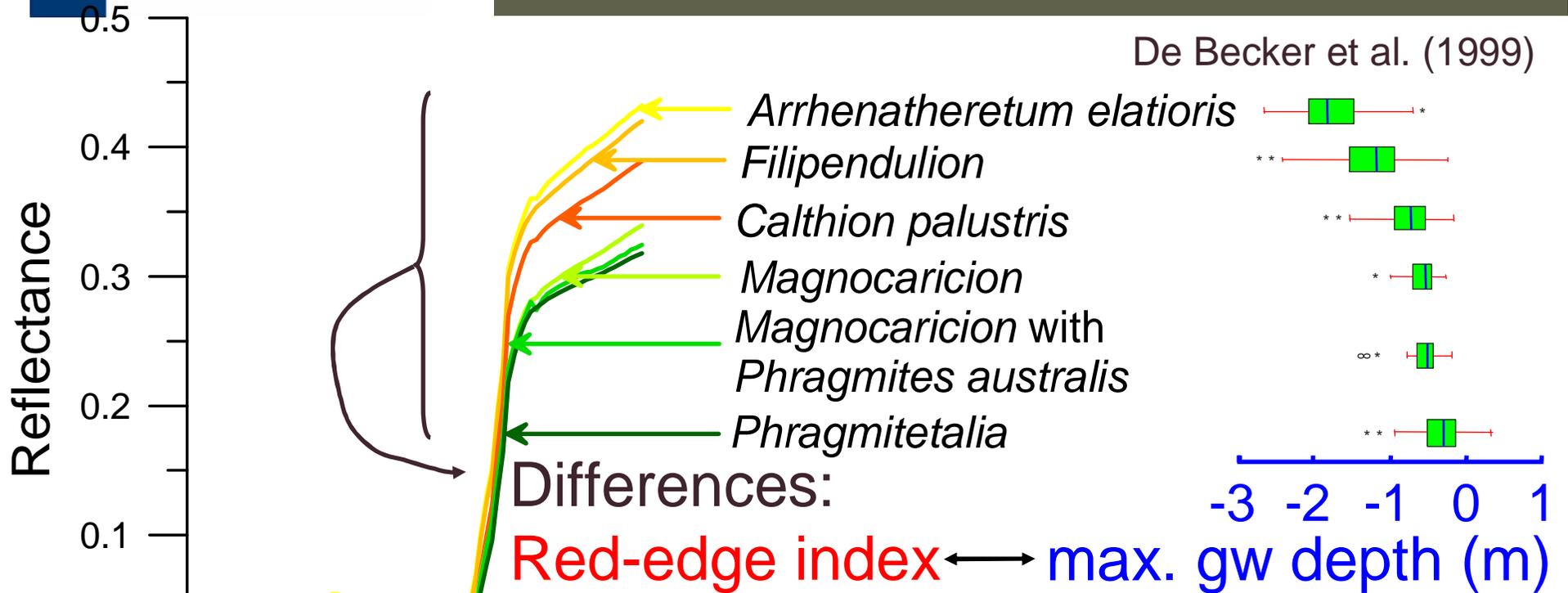
- SEBAL evapotranspiration and soil moisture simulation is successful with spatial and spectral high resolution imagery
- Evapotranspiration varies considerably over vegetation types and short distances
- The red-edge index is promising in ecohydrological (groundwater) characterization of phreatophytic vegetation

# 3rd: Mapping of Dune Valley 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
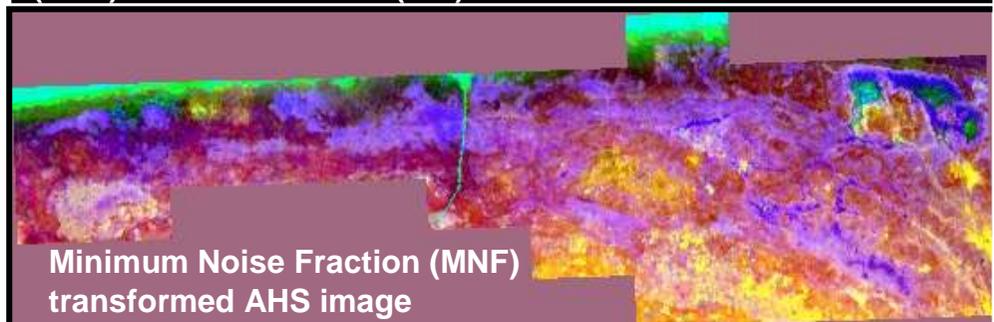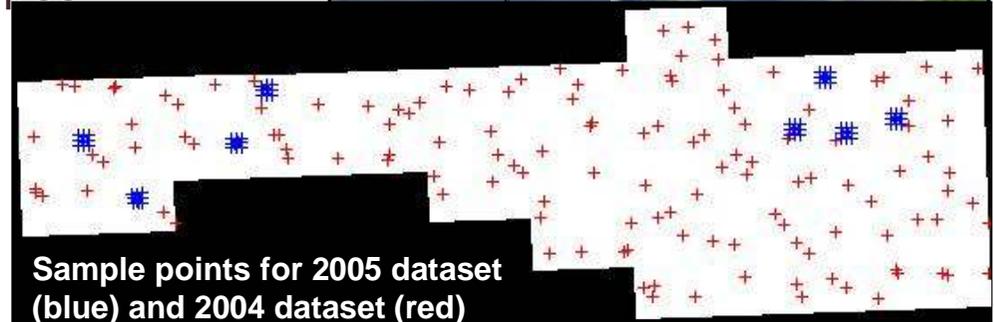- Vegetation relevees: 2004 (n=140), 2005 (n=104)

**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)

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**Study site**     **Ameland**

Sample points for 2005 dataset (blue) and 2004 dataset (red)

Minimum Noise Fraction (MNF) transformed AHS image

Meddens, A., 2006

# 3rd: Mapping of Dune Valley Vegetation

**Overall classification accuracy (%)**
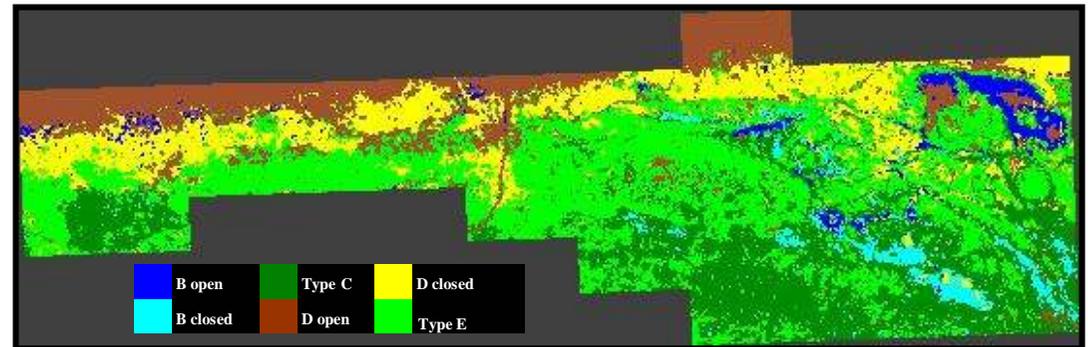
| Dataset | MLHC | MTMF |
|---|---|---|
| 2004 (n=140) | 66.9 | 69.1 |
| 2005 (n=104) | 41.4 | 44.1 |
| nr. classes | 6 | 4 |

## 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 relevees**
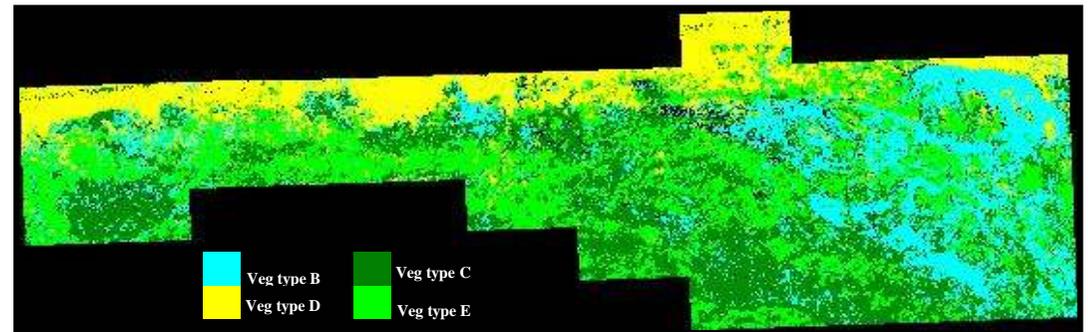


**MTMF classification using the averaged 2004 pixel spectra as endmembers**

# 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
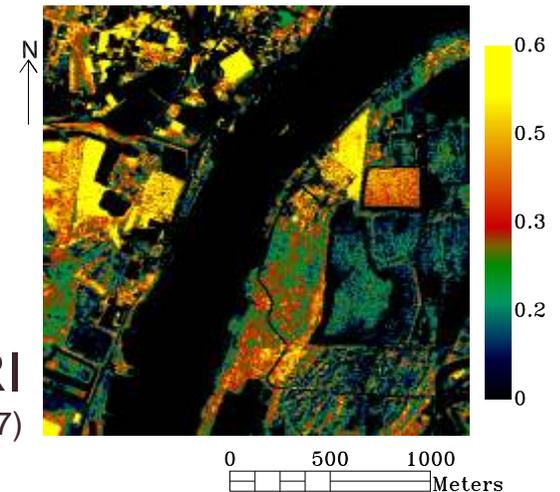- Light Use Efficiency (LUE) based method:

HyMap ANPP = (PRI) $(f_{APAR})$ $(PAR_{IC})$
PRI = Photochemical Reflectance Index
$f_{APAR}$ = fraction of absorbed photochemical radiation
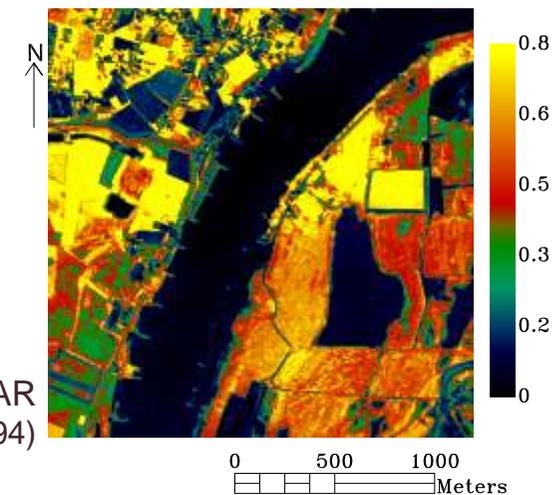$PAR_{IC}$ = Photosynthetically Active Radiation (meteo data)

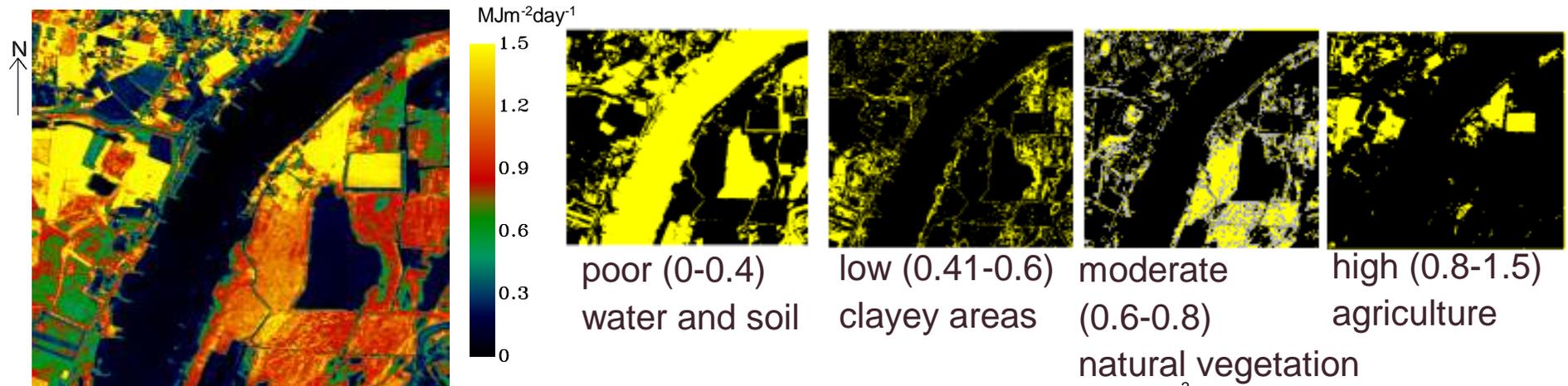- Comparison of HyMap derived ANNP with results Dynamic Vegetation Model (DVM) SMART2-SUMO2

N↑

PRI
(Gamon et al., 1997)

0    500    1000
Meters

N↑
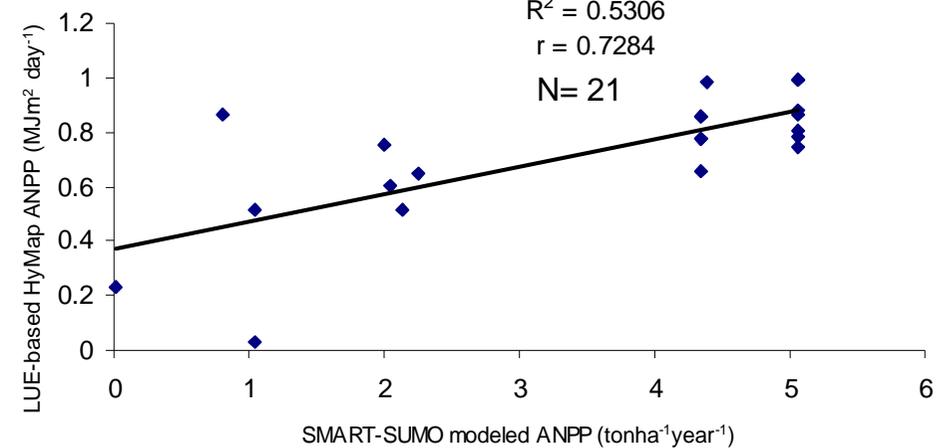
$f_{APAR}$
(Sellers, 1994)

0    500    1000
Meters

Aduaka, 2006

# 4th: Mapping ANPP and carbon storage



MJm$^{-2}$day$^{-1}$

poor (0-0.4)
water and soil

low (0.41-0.6)
clayey areas

moderate
(0.6-0.8)
natural vegetation

high (0.8-1.5)
agriculture

Application of IS for:

- Regional scale ecosystem modeling
- DVM initialization, calibration and validation
- Scenario development including human impact



$R^2 = 0.5306$
$r = 0.7284$
$N = 21$

LUE-based HyMap ANPP (MJm$^2$ day$^{-1}$)

SMART-SUMO modeled ANPP (tonha$^{-1}$year$^{-1}$)

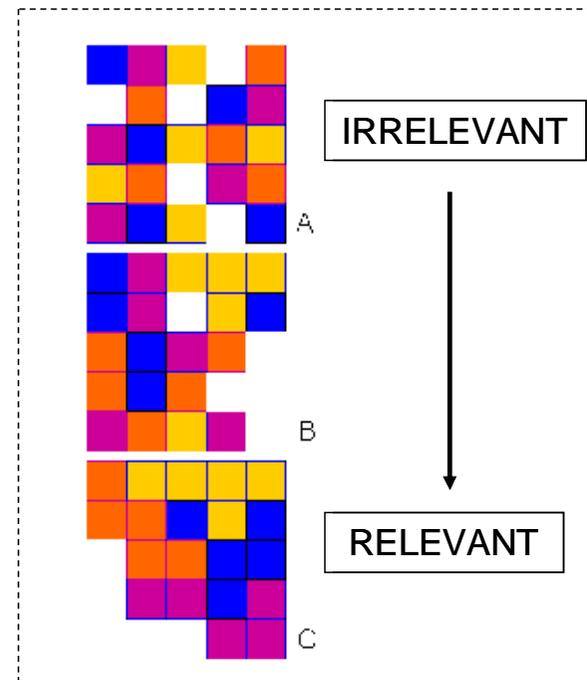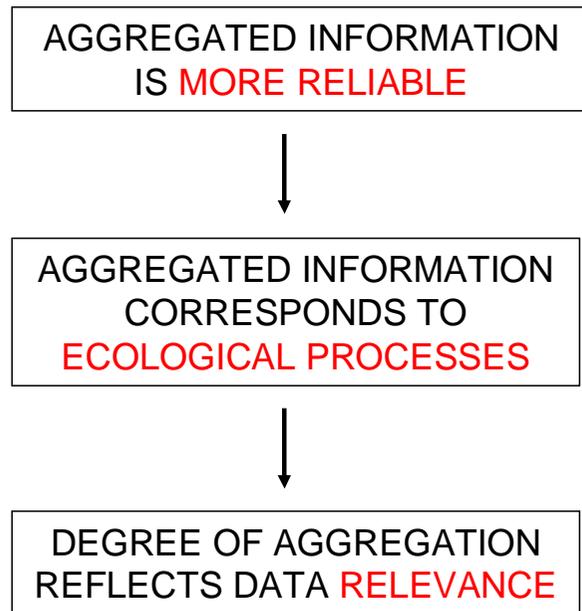**Comparison of HyMap and SMART2-SUMO2 derived ANPP**

Aduaka, 2006

# 4<sup>th</sup>: And next

- 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.)
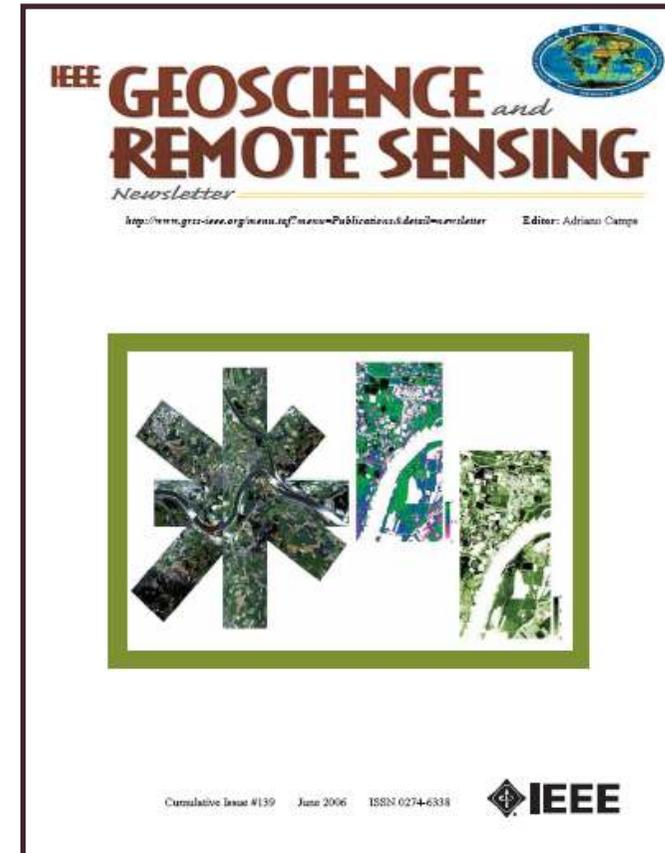


Front cover of IEEE Geoscience and Remote Sensing Newsletter June 2006:

Publication of AHS and HyMap campaign results for Millingerwaard

# 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?

Harte,
Physics
Today,
2002

# 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.

| PHYSICS/HYDROLOGY | ECOLOGY |
|---|---|
| The more you look the simpler it gets | The more you look, the more complex it gets |
| Primacy of initial conditions | Primacy of complex historical factors |
| Universal patterns; search for laws | Weak trends; reluctance to seek laws |
| Predictive | Mostly descriptive, explanatory |
| Central role for ideal systems | Disdain for caricatures of nature |

Air
10/

# 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!