HyperForest

Advanced LiDAR & airborne hyperspectral remote sensing to support forest management

HyperForest partners

KATHOLIEKE UNIVERSITEIT LEUVEN

UNIVERSITEIT GENT

vito
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Centre de Recherche Public Gabriel Lippmann

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University of Zurich

Belgian Science Policy

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Introduction

- In the framework of sustainable forest management (SFM), there is a need for **reliable data on forest parameters** such as:

tree species composition;

stand diversity;

forest vitality.

- These parameters need to be reported at regular intervals at national and international level.

Introduction

- Currently, data acquisition is done by **time-consuming and labor-intensive field campaigns** and specific aspects such as canopy structure are even difficult to directly measure.
- **Hyperspectral** (HS) and **LiDAR** remote sensing techniques offer the potential to facilitate and improve information acquisition.
- However, this potential still has to be demonstrated in **highly structured closed forests.**

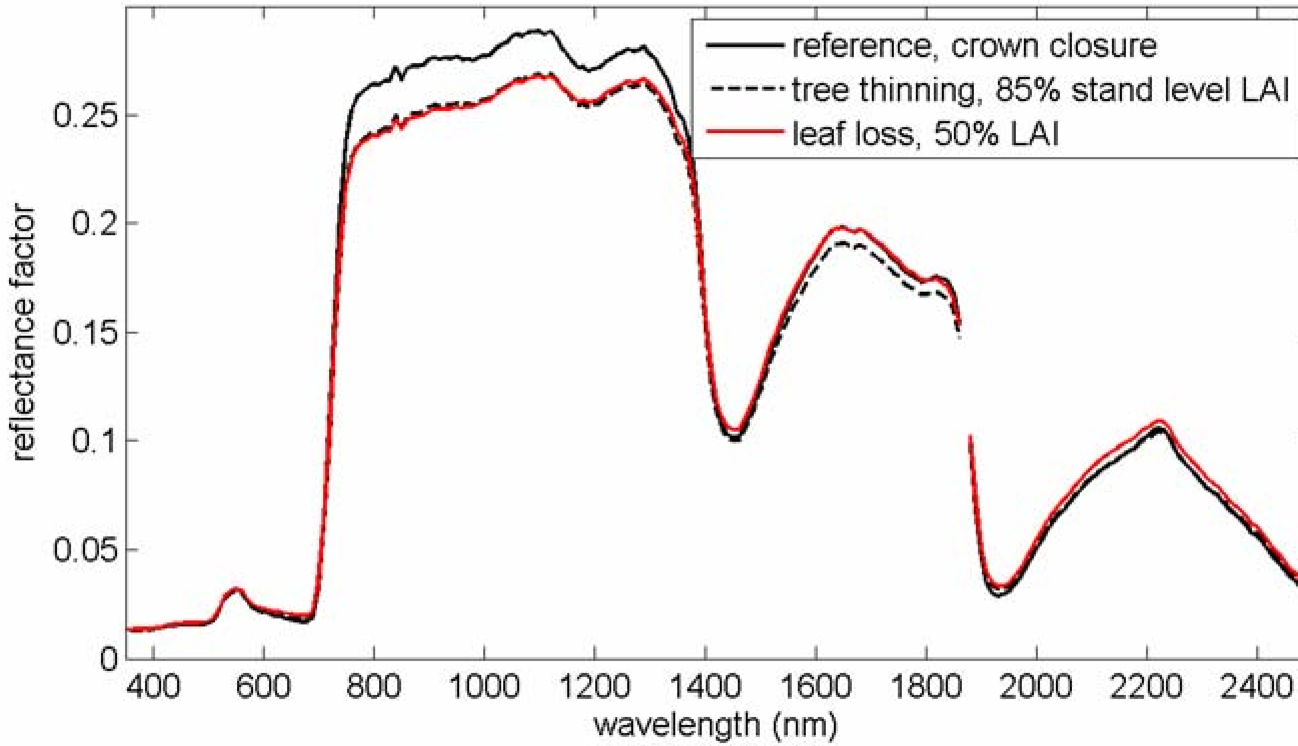
Challenge

Reference: structured forest with crown closure

- *Hyperspectral ray-tracing with pbrt*
- *Trees generated with Bionatics software*
- *Displayed: RGB as [650, 550, 450] with Gamma correction*

Sc1: thinning / uprooting by wind (-15%)

Sc2: leaf loss (50% drop in LAI)



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Main objective

- Improved **data acquisition** and **processing** for better estimation of forest parameters by **fusion of HS and LiDAR data** with focus on:

tree species composition;

stand diversity;

forest vitality.

Main objective

This requires:

- A fundamental study on the impact of 3D canopy structure variability on the hyperspectral canopy signal.
- Data fusion between ground-based/airborne LiDAR and hyperspectral datasets.
- Improvement of the established hyperspectral pre-processing chain by incorporation of 3D structure information.
- Incorporation of acquired RS data and pre-processing techniques in the development of optimized hyperspectral feature extraction.

Project overview

Measurement campaign

- **Impact of 3D canopy structure on HS signal**
- **Data fusion between RS data sets**
- **Standard/Advanced HS pre-processing**
- **Improved feature extraction from combined RS data**
- **Output dissemination**

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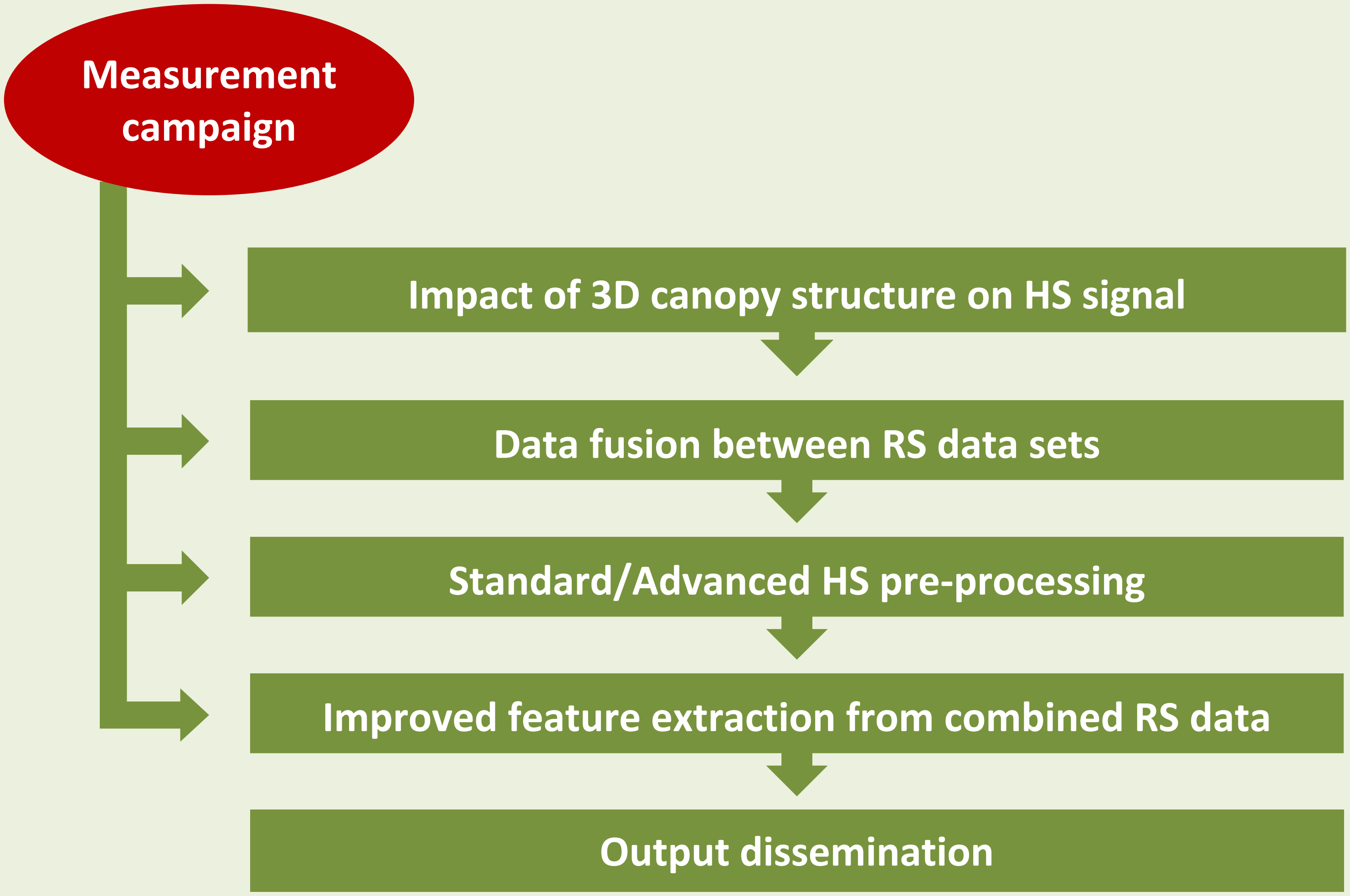
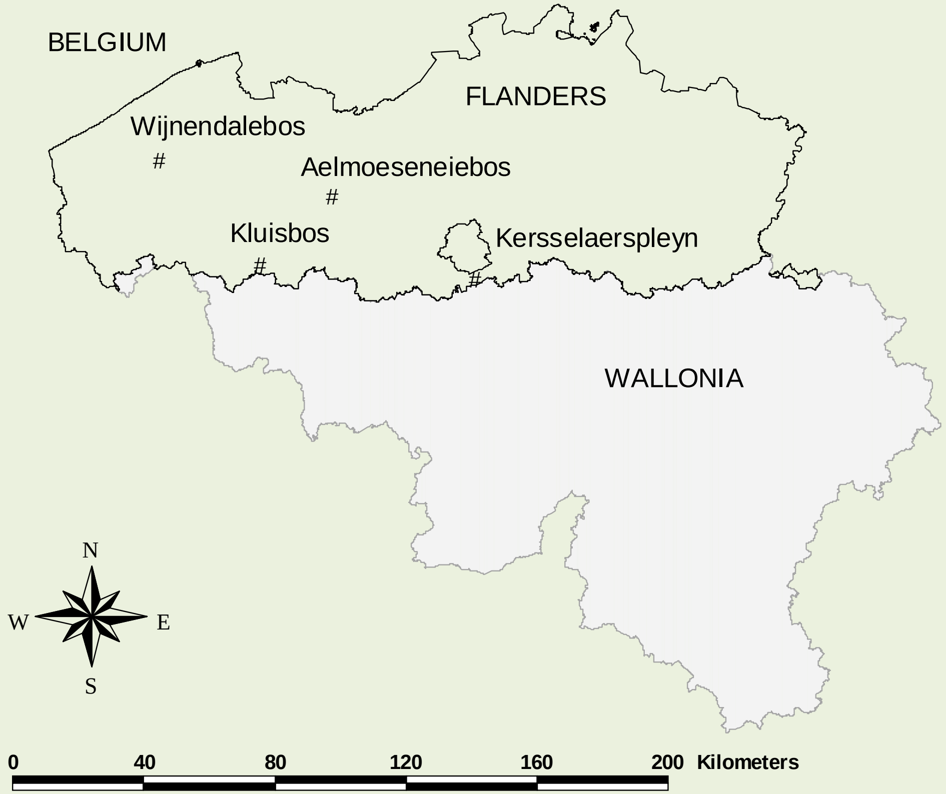
Project overview



Measurement campaign

Four test sites with increasing structural complexity:



Measurement campaign

Four test sites with increasing structural complexity:

Increasing structural complexity

1. Kluisbos
   → homogeneous beech stands;
2. Kersselaerspleyn (Sonian forest)
   → homogeneous old beech stands with larger gaps;
3. Wijnendale forest
   → mixed oak forest with maple, beech, larch, …;
4. Aelmoeseneie forest
   → mixed oak, beech, ash and larch stands (measuring tower of 40 m height).

Measurement campaign

Airborne flight campaigns

- **HS data: CASI-1500 (INTA)**
  spatial resolution: 1m
  nr bands: up to 288
  wavelength range: 380nm-1050nm
  FOV: 40° across track over 1500 pixels
  Swath width: 1000m

- **HS data – AISA Eagle (dataset – EUFAR proposal)**
  spatial resolution: 1m
  nr bands: 32
  wavelength range: 412nm-867nm
  FOV: 39,7° across track over 1024 pixels
  Swath width: 1000m

- **LiDAR data from TopoSys Sensor Harrier 56**
  spatial resolution: 1m
  range capture: full waveform
  spot diameter: 0.5m at flying altitude of 1000m
  range accuracy: 15-30cm
  point density: 10 points per m²

Measurement campaign

Field measurements

Each test site includes:

Full dendrometric inventories

- tree position;
- species composition;
- DBH all trees > 5 cm diameter;
- tree heights all trees upper canopy;
- canopy gaps (hemispheric photos);
- tree vitality (international methodology for level I forest vitality evaluation).

Dendrometric inventories

- tree position;
- species registration;
- DBH & tree height selection of trees;
- canopy gaps (hemispherical photos).

Measurement campaign

Field measurements

- In selected canopies: leaf picking and analysis (chlorophyll, water and dry matter content).

- Collection of reference data:
  1. Reference leaf reflectance and transmission measurement using field spectrometer (ASD FieldSpec3 with an integrating sphere).
  2. Measuring tower: HS signal retrieval above canopy using field spectro-radiometers (ASD, SpectraVista);

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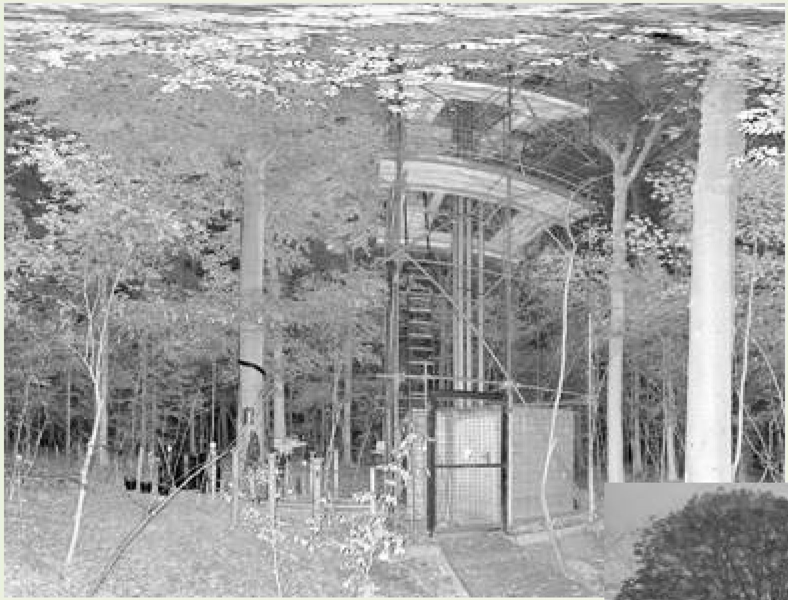
Measurement campaign

Field measurements

- In selected canopies: leaf picking and analysis (chlorophyll, water and dry matter content).
- Collection of reference data:
  3. Ground-based LiDAR structure measurements;



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Measurement campaign

Field measurements

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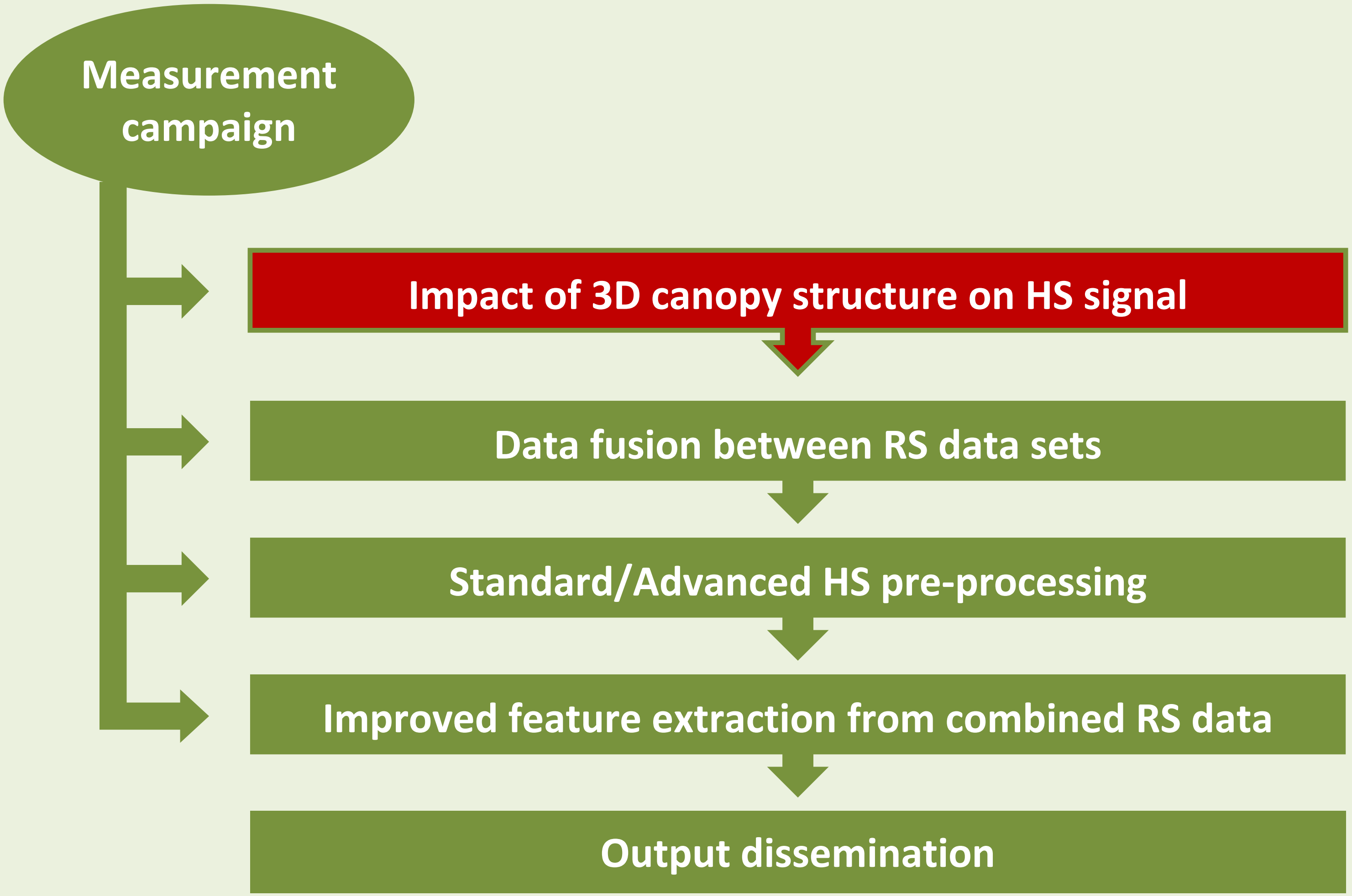
Project overview



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Impact of 3D canopy structure on HS signal




<u>Goal:</u> What is the impact of 3D canopy structure variability on the hyperspectral canopy signal?

<u>Approach:</u> Mapping and quantifying the contribution of the 3D distribution of vegetative elements to the HS reflectance signal using detailed structure data and geometrically explicit radiative transfer models

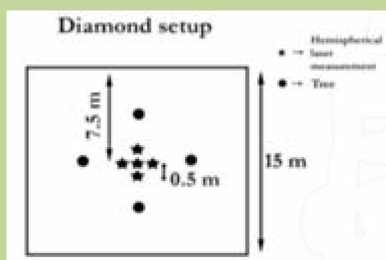
Approach

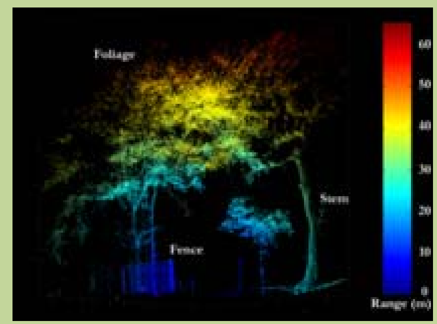
1. Detailed 3D structure description of canopy using terrestrial LiDAR technology

Hemispherical Measurement pattern

FARO LMS8800

Sampling design



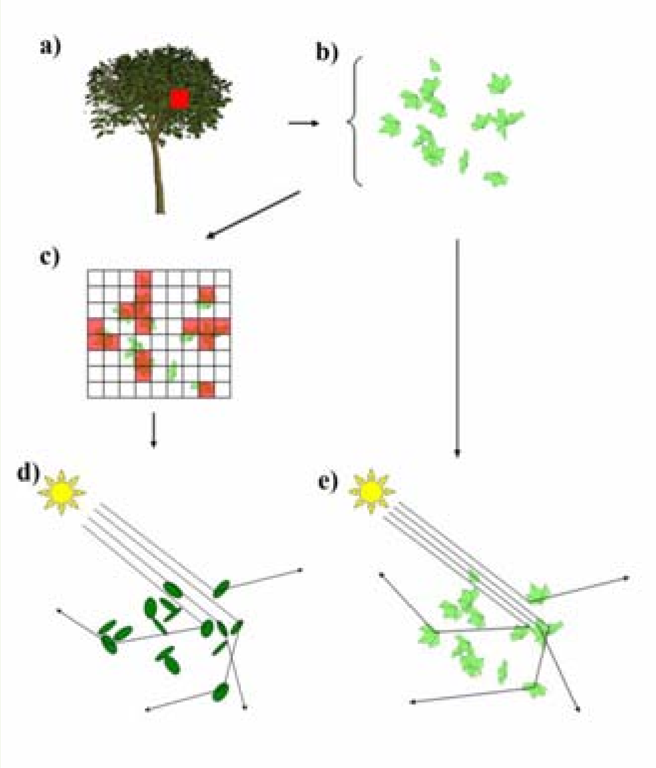


LiDAR data of high quality optimized for structural feature extraction

Approach

1. Detailed 3D structure description of canopy using terrestrial LiDAR technology

2. Model light / vegetation interactions with geometrically explicit radiative transfer models (VLIM-DART)



Voxel-based Light Interception Model (VLIM)

Use VLIM and DART model to determine the light / vegetation interactions in high detail (to cm scale ~ leaf level)

Approach

1. Detailed 3D structure description of canopy using terrestrial LiDAR technology

2. Model light / vegetation interactions with geometrically explicit radiative transfer models (VLIM-DART)

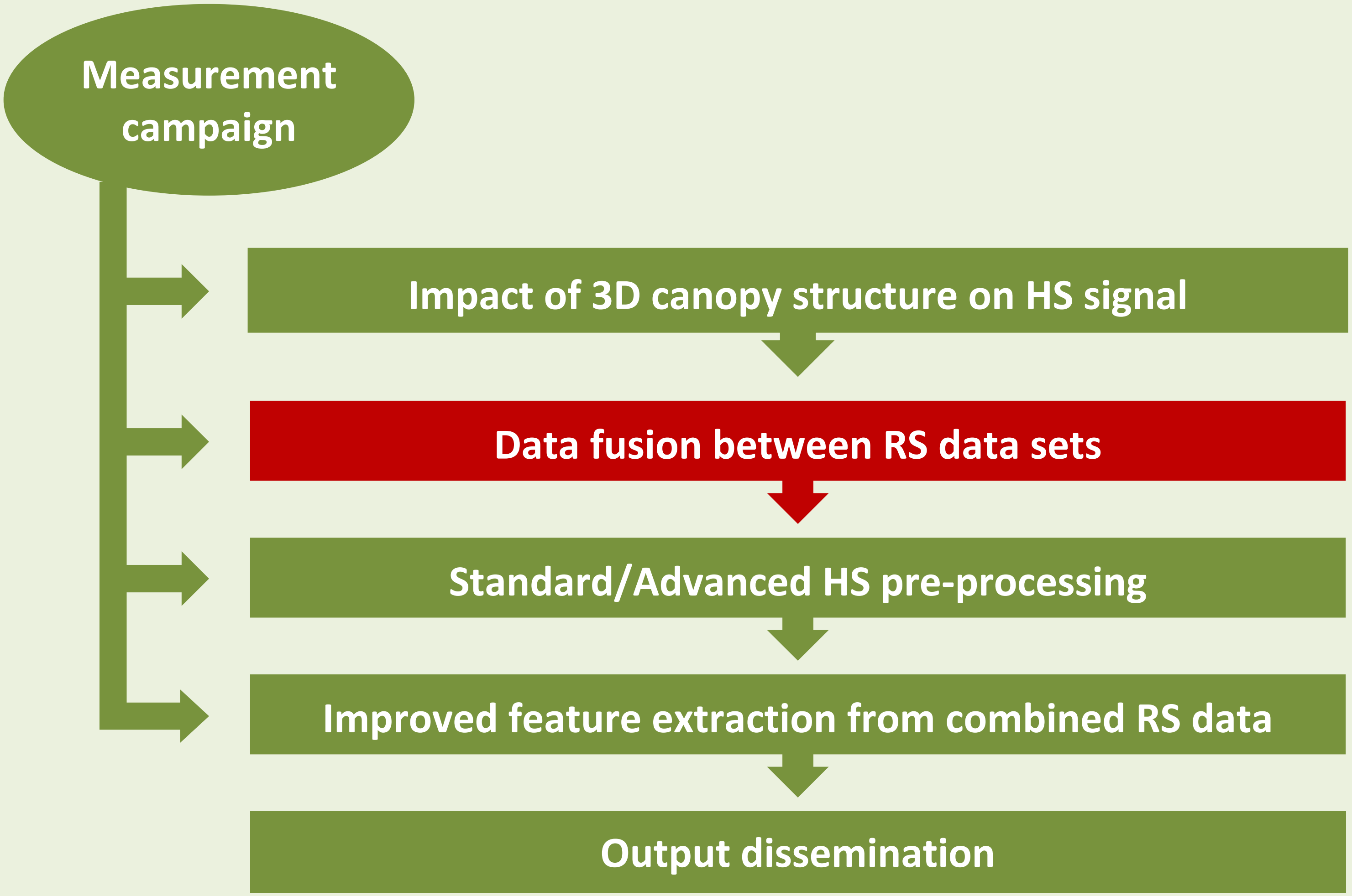
3. Identify and list vegetation structure elements which contribute most to the HS reflectance of forest canopies

HS sensor (simulated)

-Simulate BRDF effects from data derived from test-sites

-Use this information to support data fusion between terrestrial and airborne LiDAR datasets

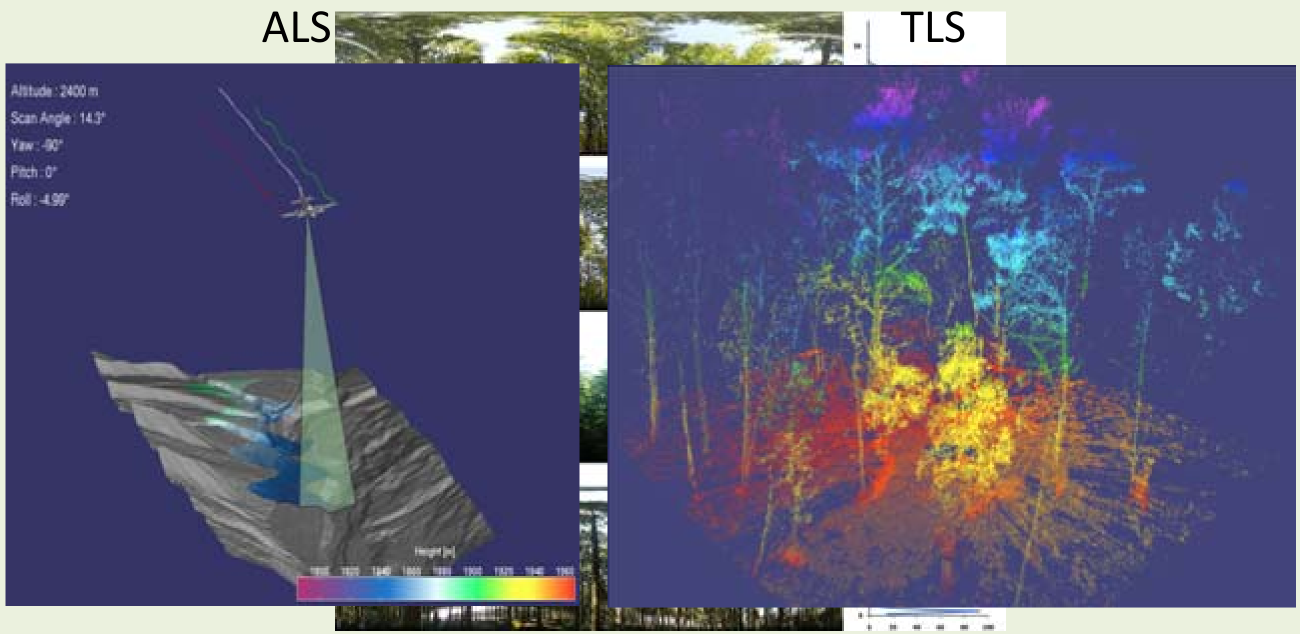
Project overview



Data fusion between RS data sets

<u>Goal:</u> How to integrate the contribution of the 3D distribution of vegetative elements in airborne hyperspectral reflectance data of forest stands

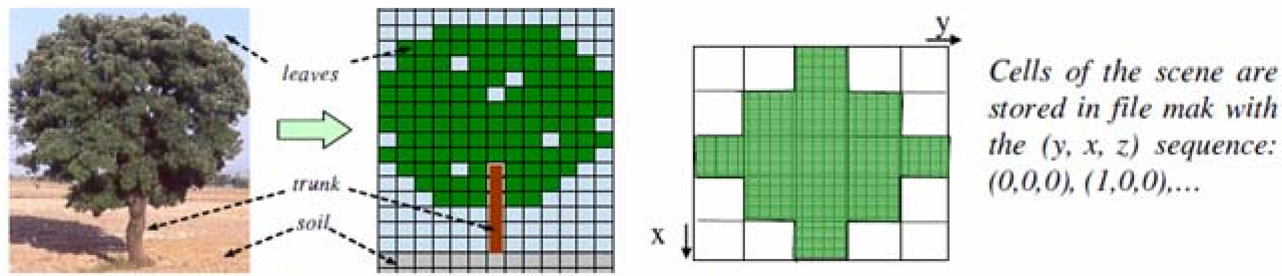
<u>Approach:</u> Creating a realistic "virtual environment" using a radiative transfer model (DART), based on derived structural canopy information (ALS). This allows assessing the impact of structure at several simplifications levels



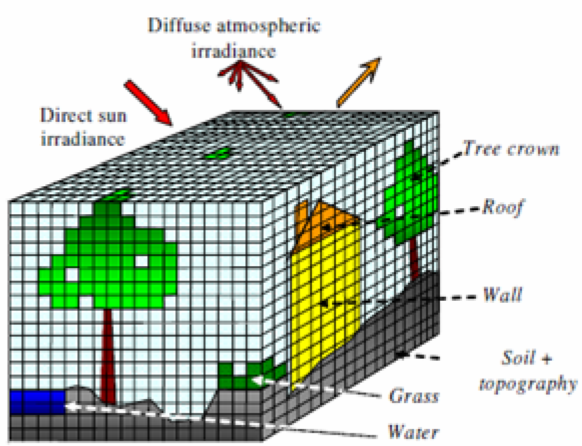
Approach

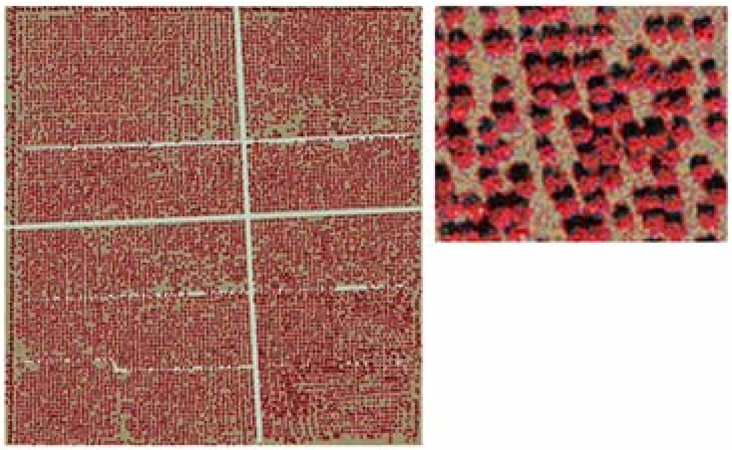
Simulation of HS data using radiative transfer modelling

Discrete Anisotrotic Radiative Transfer Modelling (DART)

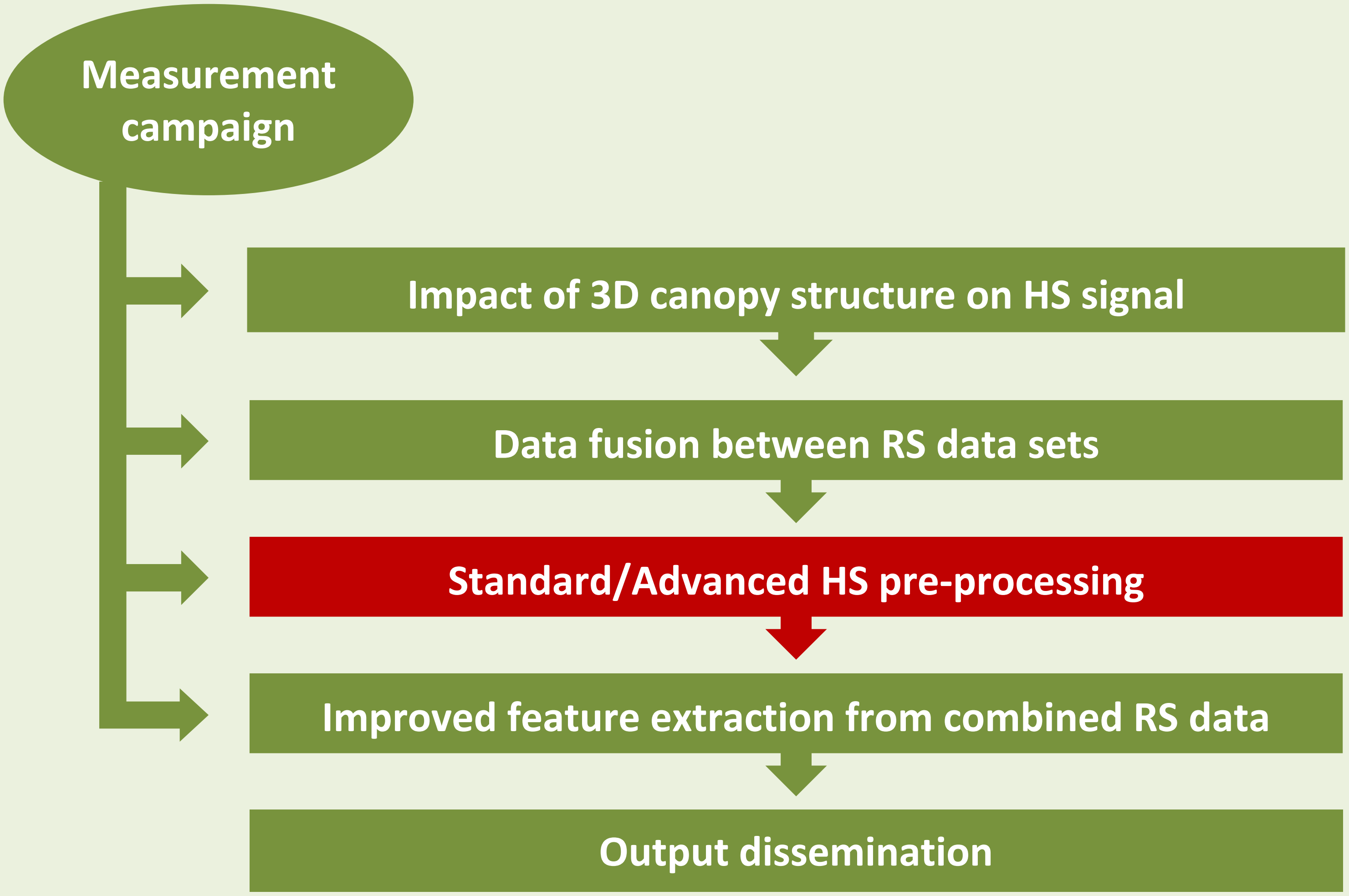


DART simulation of a tree. Vertical (b) and horizontal (c) sections.





Project overview



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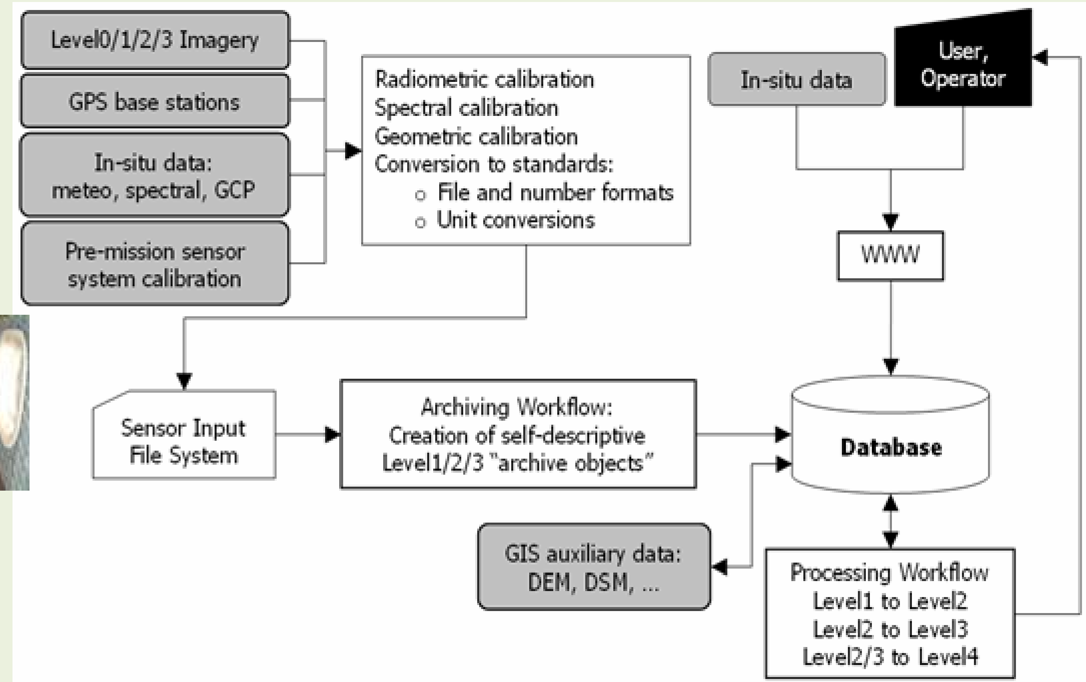
Standard/Advanced HS pre-processing

Central Data Processing Centre (CDPC)



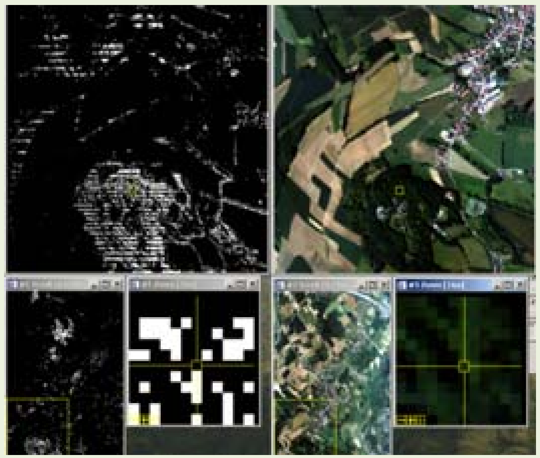
<u>Goal:</u> How to improve the current operational processing chain by integrating structure information?

<u>Approach:</u> The structure effects will be incorporated into the processing chain at three different levels.

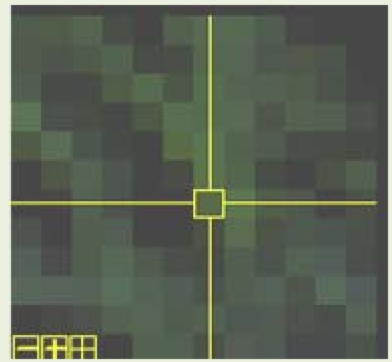
Approach

1. Visibility estimation from the imagery itself

Account for vegetation structure when deriving visibility from the image:



Left: Dense Dark Vegetation (DDV) mask
Right: Hyperspectral image

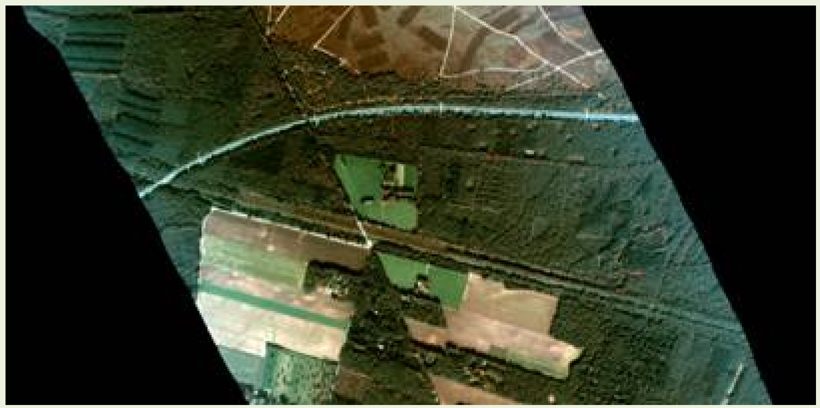


Structure influences retrieval of correct visibility values!!

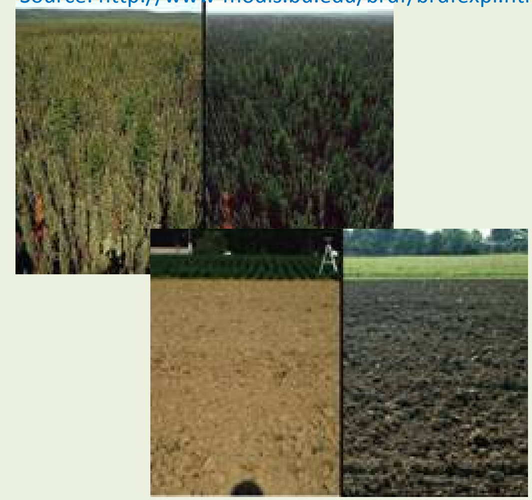
→ this allows for a more precise atmospheric correction.

Approach

1. Visibility estimation from the imagery itself
2. View and illumination angle effects seen by a HS image



Source: http://www-modis.bu.edu/brdf/brdfexpl.html



Left: back scattering (sun behind observer)
Right: forward scattering (sun opposite observer)

Optimizing the kernel based BRDF correction by taking into account forest structure:

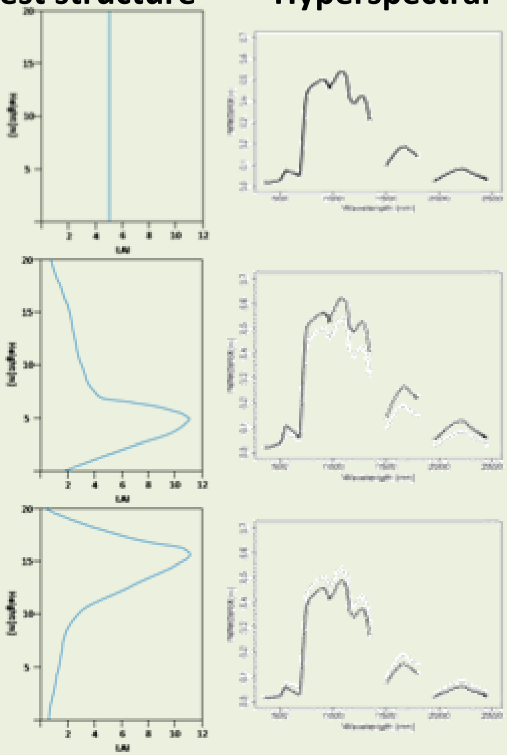
→ needed for a more accurate classification (e.g. pine, deciduous, mixed forest);
→ kernel correction coefficients depend on forest structure (e.g. via look-up table).

Approach

1. Visibility estimation from the imagery itself
2. View and illumination angle effects seen by a HS image
3. Structure normalization

The standard structure serves as the reference for the structure correction.

Forest structure **Hyperspectral**



Standard
3D Poisson distribution
(LAI = 5)

Lower level vegetation
maximum
(LAI = 5)

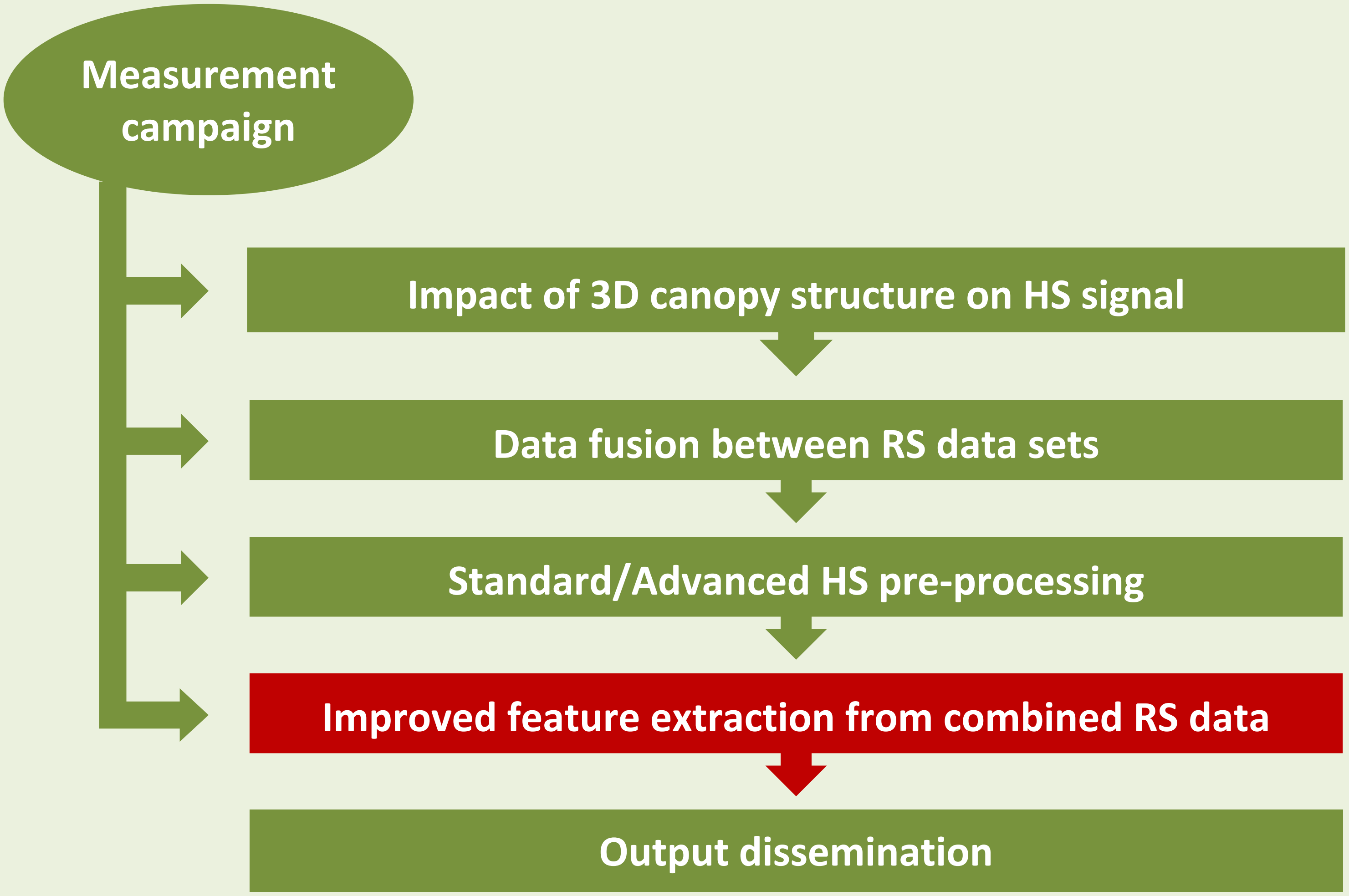
Upper level vegetation
maximum
(LAI = 5)

Correction factor for forest structure (per wavelength)

$$R'_{1\lambda} = R_{\lambda} * \alpha_{corr^{1\lambda}}$$

$$R'_{2\lambda} = R_{\lambda} * \alpha_{corr^{2\lambda}}$$

Project overview



Improved feature extraction from combined RS data

Goal: How to optimally apply/process HS images & LiDAR data in highly structured forests for a thorough forest diversity analysis?

Approach: Development of objective indicators quantifying forest diversity, defined by three components (1) tree species composition, (2) stand diversity and (3) forest vitality following three different working strategies:

1. standard pre-processed HS signal;
2. standard pre-processed HS and pre-processed airborne LiDAR data fusion sets;
3. advanced pre-processed HS signal.

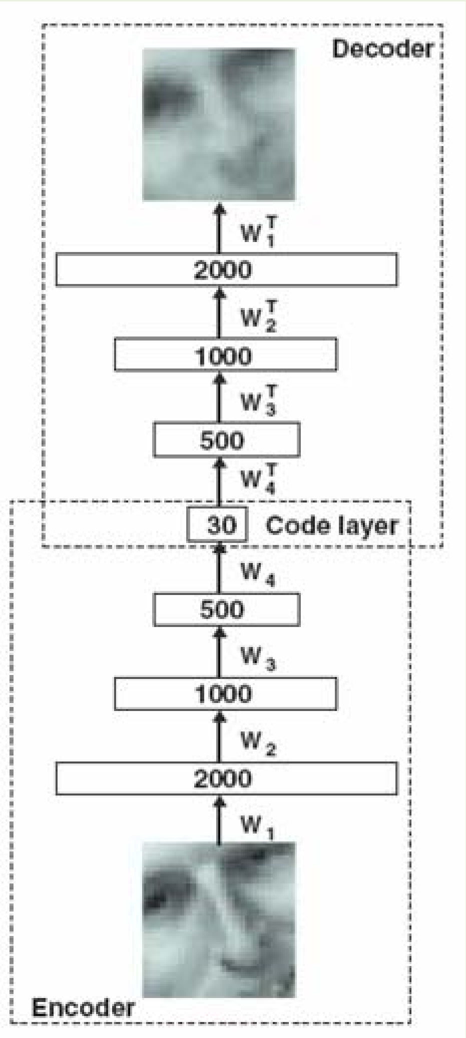
Approach

Development of an objective, robust & integrated method by implementing deep belief neural networks (DBNN)

DBNN = auto-encoder networks: a network that is trained to reproduce its input on its output – an identity mapping - by standard backpropagation of the error

Decoder network: recover the data from the code

Encoder network: transform the high-dimensional data into low dimensional codes/features



Hinton, G. E. and Salakhutdinov, R. R., 2006, Science, 313, 504-507.

assembling band selection,
band combination and classification

Approach

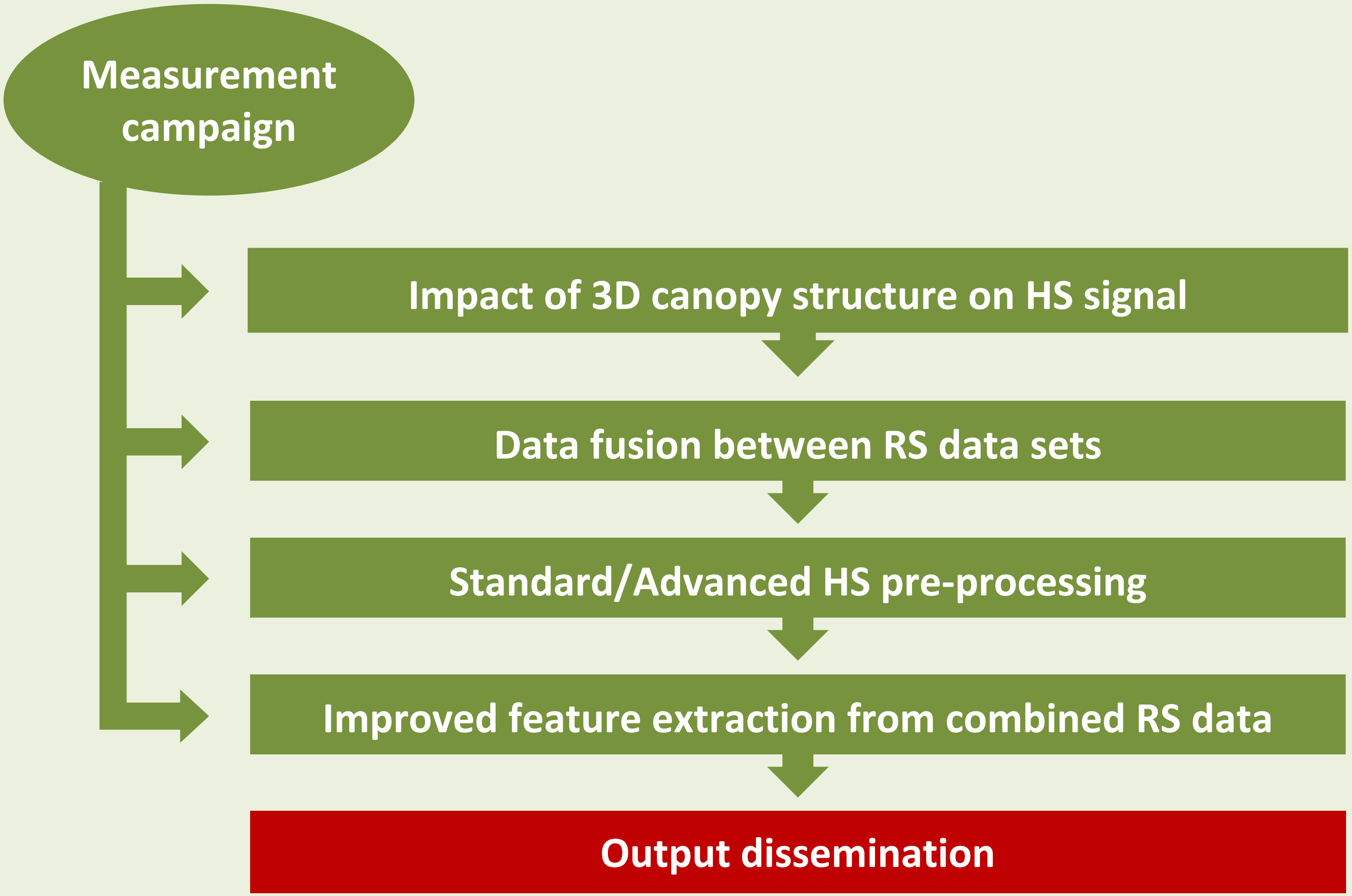
- extract the codes/features;
- intensive study of the codes and assess their potential as optimized VI;
- test the composed VI on their accuracy and reliability as proxies/indicators

for (1) tree species composition;
(2) stand diversity;
(3) forest vitality.

Varying input possibilities for DBNN (working strategies):

Standard pre-processed HS signal	Standard pre-processed HS signal & LiDAR data sets	Advanced pre-processed HS signal
↓	↓	↓
DBNN	DBNN	DBNN
↓	↓	↓
diversity indicators	diversity indicators	diversity indicators
REFERENCE	ASSET RELATED TO END-USER NEEDS?	ASSET RELATED TO END-USER NEEDS?

Project overview



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Involvement of potential end-user community and dissemination of results

Different end-users depending on the specific output:

•Output focussing on the development of techniques to improve the correction of HS data by incorporating correction algorithms for canopy roughness, etc…

→ end-users in remote sensing community.

•Output focussing on application of RS data for description and quantification (with indexes) of forest diversity parameters

→ end-users in forest surveys and ecology research;

→ periodic surveys for forest administration and policy.

•Output focussing on the application of RS data for evaluation of forest vitality.

→end-users in forest vitality monitoring.

→**INBO as customer / test-pilot.**