Satellite Imagery in Hydraulic Research – An Approach to estimate Floodplain Vegetation Roughness via open-source Satellite Data

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Outline

1) Introduction
2) Satellite Imagery in Hydraulic Research - Applications
3) Estimation of Floodplain Roughness
4) Future Laboratory Lower Saxony: Project
5) Estimation of Vegetation Parameters
6) Outlook

Introduction

Satellite data:

- High spatial and temporal resolution
- Accessibility of open source satellite data (Landsat, Sentinel)
- Accessibility via Google Earth Engine, Copernicus Hub and USGS Earth Explorer
- Satellites providing multispectral (Sentinel-2, Landsat 9, MODIS), radar (Sentinel-1) and LiDAR (ICESat-2) data

Table 1. Sentinel-2 band characteristics.

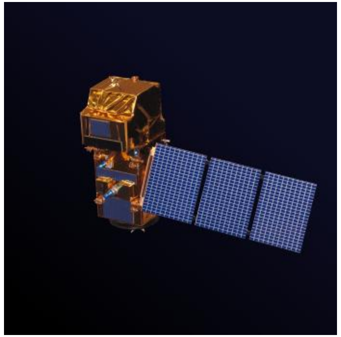
Sentinel-2 bands	Central wavelength (µm)	Resolution (m)
Band 1 – Coastal aerosol	0.443	60
Band 2 – Blue	0.490	10
Band 3 – Green	0.560	10
Band 4 – Red	0.665	10
Band 5 – Vegetation red edge	0.705	20
Band 6 – Vegetation red edge	0.740	20
Band 7 – Vegetation red edge	0.783	20
Band 8 – NIR	0.842	10
Band 8A – Vegetation red edge	0.865	20
Band 9 – Water vapour	0.945	60
Band 10 – SWIR – Cirrius	1.375	60
Band 11 – SWIR	1.610	20
Band 12 – SWIR	2.190	20

Sentinel-2 band charakteristics. Kaplan & Avdan (2017)

Introduction

Sentinel-2 data (multispectral):

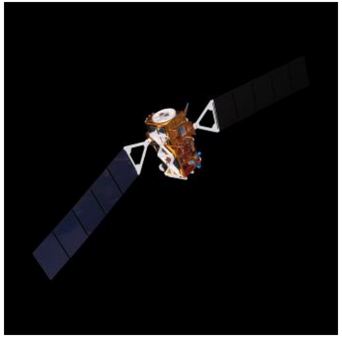
- 13 spectral bands
- Revisit time within 5 days
- Spatial resolution of up to 10m per pixel



Sentinel-2 satellite by Rama, licensed under Creative Commons Attribution-Share Alike 2.0 France

Sentinel-1 data (radar):

- C-band signal with 5.6 cm wavelength
- 4 different polarizations
- Cloud penetrating
- Sensitive to surface roughness and water content



Sentinel-1 satellite by Rama, licensed under Creative Commons Attribution-Share Alike 2.0 France

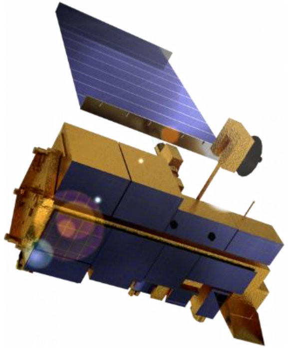
Introduction

MODIS {Moderate Resolution Imaging Spectroradiometer (multispectral)}:

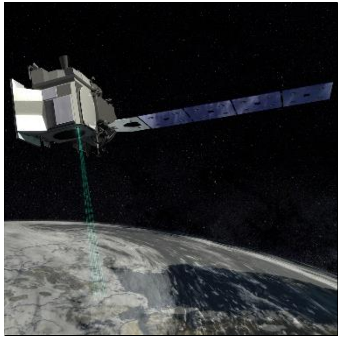
- 36 spectral bands
- Spatial resolution from 250m – 1000m per pixel
- 1-2 days revisit time

ICESat-2 (LiDAR):

- Mapping topography and ice sheet elevation
- 532nm laser pulses in 3 beam pairs along transects



MODIS satellite. Image credit: NASA (public domain)

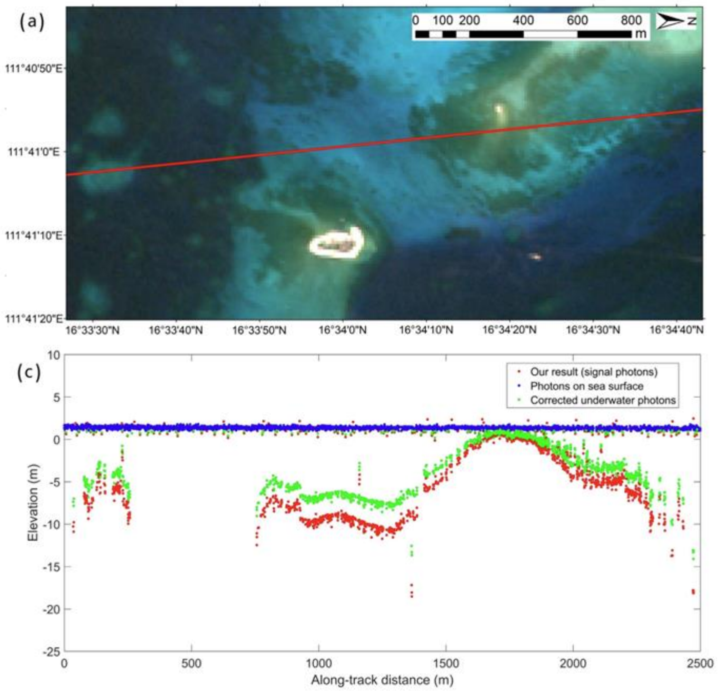


ICESat-2 satellite. Image credit: NASA (public domain)

Satellite Imagery in Hydraulic Research - Applications

Applications:

- Bathymetry

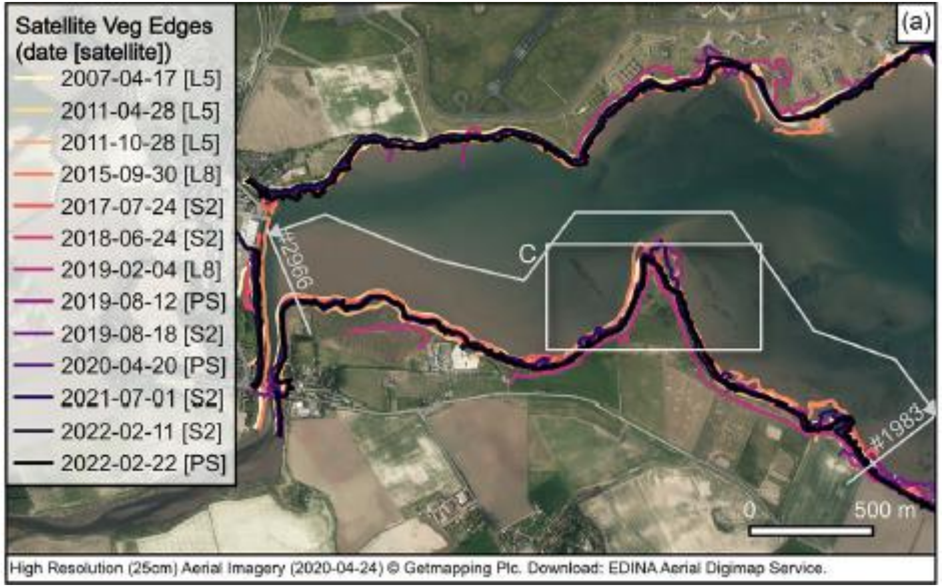


Satellite derived bathymetry using ICESat-2 LiDAR and Sentinel-2 imagery. Ma et al. 2020

Satellite Imagery in Hydraulic Research - Applications

Applications:

- Bathymetry
- Water land border detection



Near shore vegetation edges detected by satellite imagery. Muir et al. 2024

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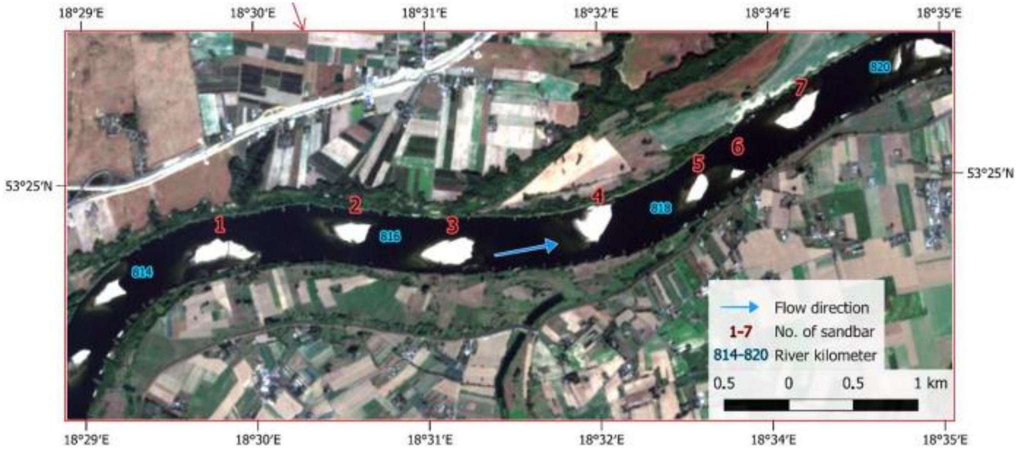
Satellite Imagery in Hydraulic Research - Applications

Applications:

- Bathymetry
- Water land border detection
- Sediment transport

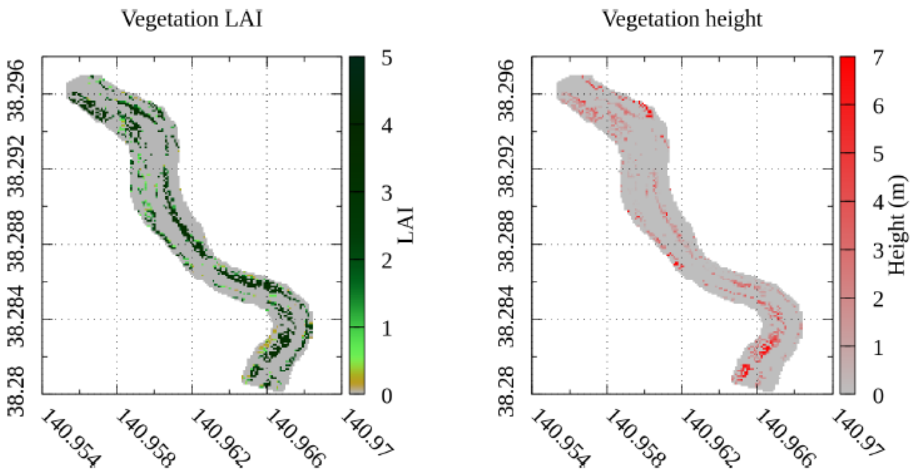


Estimation of sand bank migration via Sentinel-1 imagery. Kryniecka et al. 2022

Satellite Imagery in Hydraulic Research - Applications

Applications:

- Bathymetry
- Water land border detection
- Sediment transport
- Estimating floodplain roughness

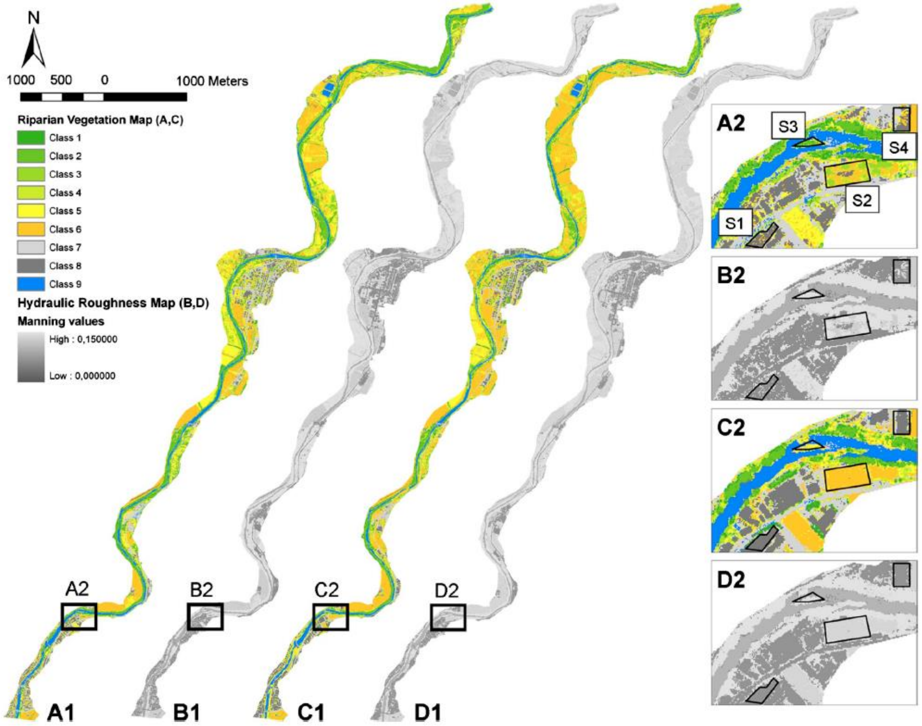


Estimation of vegetation height and leaf area (LAI) index in Fortes et al. 2024

Estimation of Floodplain Roughness

Approaches:

- Forzieri et al. 2010: Used airborne LiDAR data and commercial satellite data (Quickbird) to create a classification derived Manning`s n roughness map

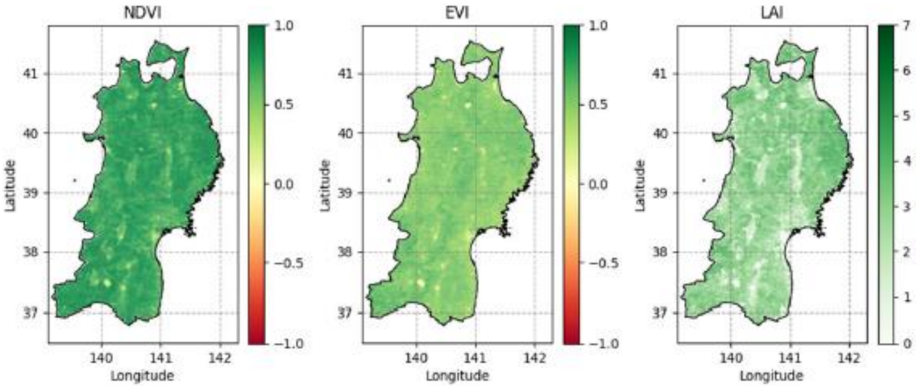


Riparian vegetation map and roughness map derived in Forzieri et al. (2010)

Estimation of Floodplain Roughness

Approaches:

- Forzieri et al. 2010: Used airborne LiDAR data and commercial satellite data (Quickbird) to create a classification derived Manning`s n roughness map
- Fortes et al. (2024 & 2025): Combination of UAV (Unmanned Aerial Vehicle) and satellite data (2024) and solely satellite data (2025) to obtain vegetation parameters for hydraulic modeling



Estimating the LAI over machine learning via Sentinel and MODIS data in Fortes et al. (2025)

Future Laboratory Lower Saxony - Project

Project:

- Funded by the center of digital innovations in Lower Saxony
- Task: Automatically create up-to-date roughness maps of floodplain vegetation
- Why: Improve flood simulations in aspect of floodplain vegetation roughness
  - ➢ Better predictions of water levels
  - ➢ Improved understanding of retention potential of floodplains

ZUKUNFTSLABOR WASSER

ZDIN Zentrum für digitale Innovationen Niedersachsen

Future Laboratory Lower Saxony - Project

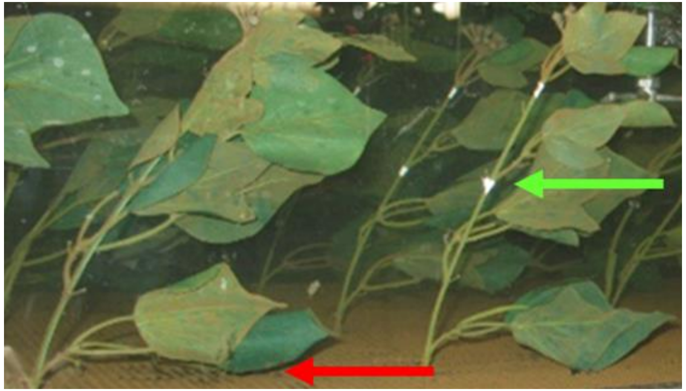
How to estimate floodplain roughness:

- Vegetation roughness is one form of form induced roughness
  - ➢ Friction factor according to Darcy-Weisbach:

$$f_{tot} = f'_{bed} + f''_{form}$$

- Approach for flexible submerged and emergent vegetation based on Järvelä (2004):

$$f''_{Pf} = 4C_{W_\chi} LAI \left(\frac{u}{u_\chi}\right)^{\chi} \frac{h}{h_{Pf}}$$



- Necessary vegetation parameters:
  - Leaf area index (LAI)
  - Vegetation species (χ , C_{W_χ})
  - Vegetation height (h_{Pf})

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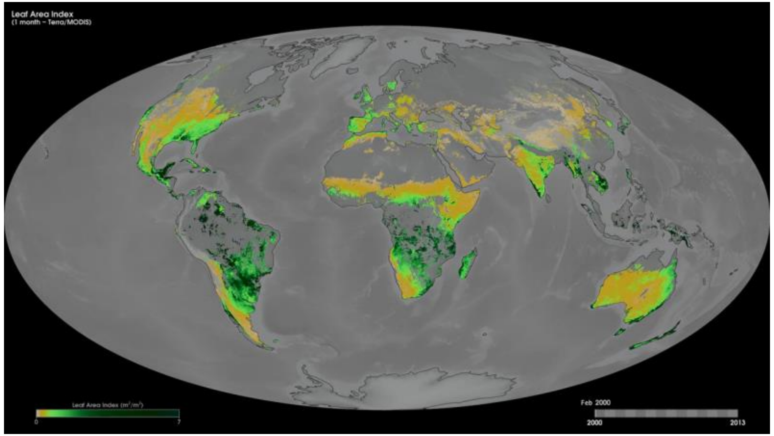
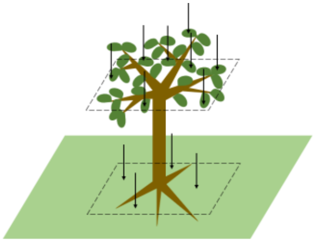
Estimation of Vegetation Parameters – Leaf Area Index

Leaf Area Index (LAI):

- describes the one sided leaf area over ground area
- Important bio-physical parameter
- Derived via radiative transfer modeling and LUT`s for the MODIS satellite (500m/pixel)





$$LAI = \frac{A_{Leaf}}{A_{Ground}} \left(\frac{m^2}{m^2}\right)$$

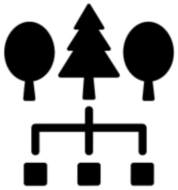
Laboratory experiments to estimate species specific parameters. Photo: Stephan Niewerth

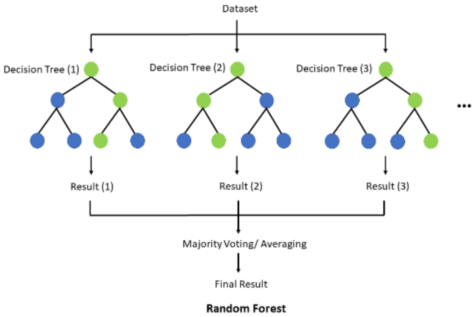
Estimation of Vegetation Parameters – Leaf Area Index

Sentinel-1 (Radar)
Sentinel-2 (multispektral)
MODIS (multispektral)

Copernicus Ground
Based Observations
for Validation

Random Forest Algorithm





Wikipedia, accessed on 25.02.2025.
https://de.wikipedia.org/wiki/Random_Forest#/media/Datei:Random_forest_explain.png

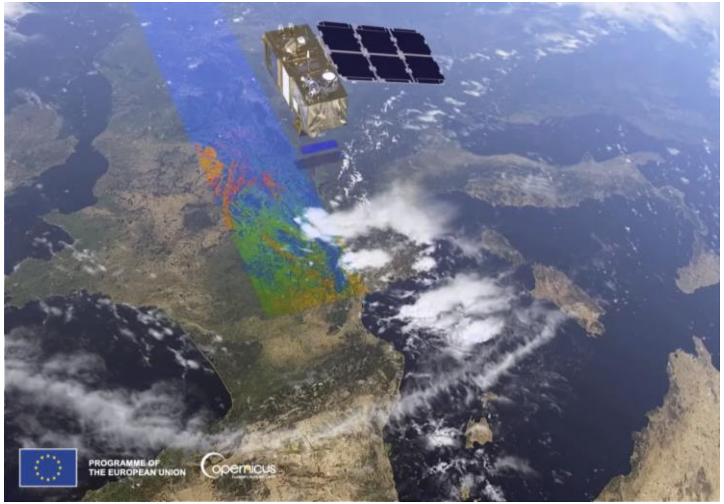


Diagram of the European Space Agency´s (ESA) Sentinel-2A multispectral Earth observation satellite. https://defence-industry-space.ec.europa.eu/sentinel-2a-extending-operations-meet-user-needs-2025-02-06_en

Estimation of Vegetation Parameters – Leaf Area Index

Input data Sentinel-2:

- Multispectral bands with 10m resolution
- Vegetation indices:

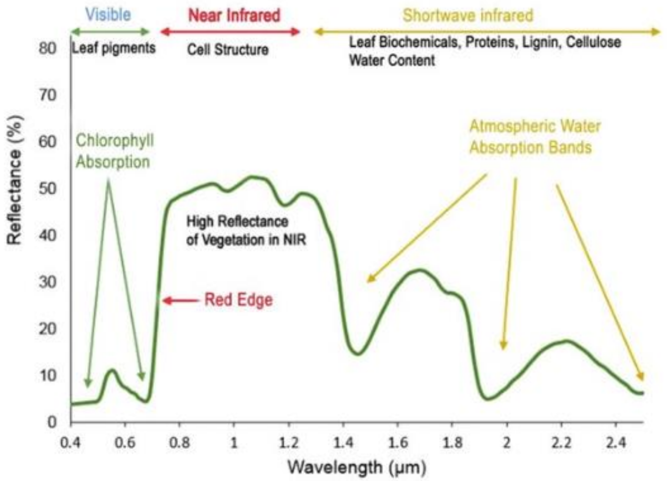
$$NDVI = \frac{B8 - B4}{B8 + B4}$$

$$RaVI = \frac{B8}{B4}$$

$$GNDVI = \frac{B8 - B3}{B8 + B3}$$

- Input data Sentinel 1 :
  - VH and VV polarization
  - Vegetation index:

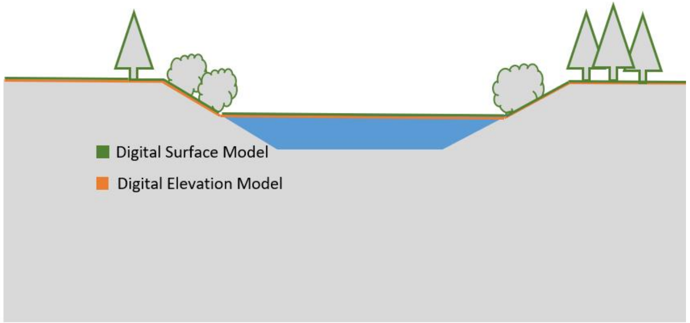
$$RVI = \frac{4VH}{(VV + VH)}$$

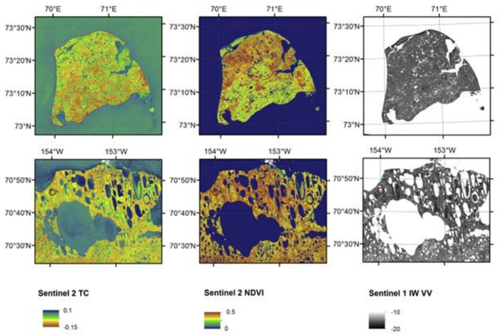


Spectral properties of vegetation. Roman & Ursu (2016)

Estimation of Vegetation Parameters – Vegetation Height

- Vegetation height by the difference between DSM (Digital surface model) and DEM (Digital Elevation Model)
- Both could be derived on transects via ICESat-2 as previously done in Fortes et al. (2025)
- Vegetation could be derived via Sentinel-1 and Sentinel-2 based neural network as in Bartsch et al. (2020)
- DEM`s could also be used by public data from Airborne Laser Scanning (ALS) campaigns by the federal department of Lower Saxony (Germany)



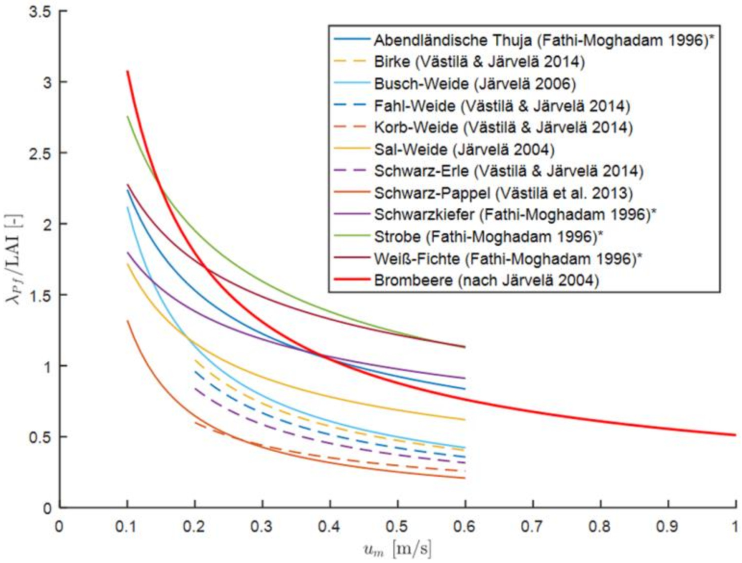


Sentinel-2 and Sentinel-1 derived input information to derive vegetation height in Bartsch et al. (2020)

Estimation of Vegetation Parameters – Vegetation Classification

To use equation of Järvelä (2004) species information is needed…

- Deriving species distribution from satellite data at this points is hardly feasible
- Therefore, vegetation classification shall be conducted using Sentinel-2 ground classes (grassland, farmland, bushes/shrubs, trees)
- Species defined parameters could be summed up to different classes
  - Rely on extensive datasets for vegetation roughness of TU Braunschweig and Aalto-yliopisto (Finland)

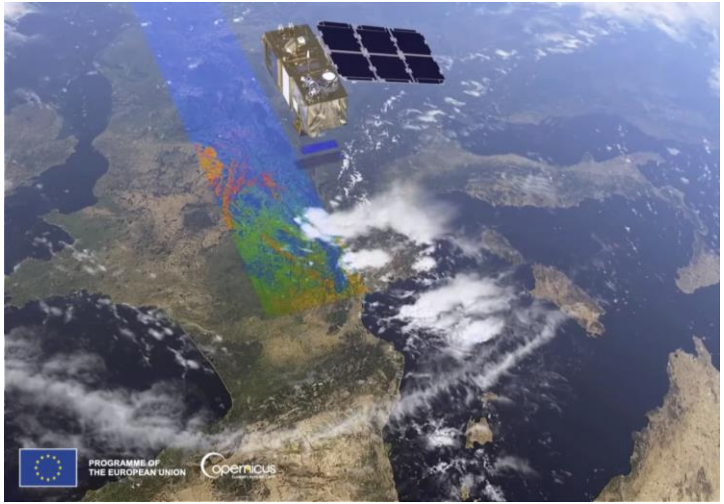


Species specific roughness factors for different species depending on the LAI

Conclusions

- Tasks:
  - ➢ Improve LAI model
  - ➢ Set up vegetation height model
  - ➢ Classification of species specific parameters based on ground class
    - ➢ Exchange to Aalto University

- Satellite data:
  - ➢ Sentinel-1
  - ➢ Sentinel-2
  - ➢ MODIS
  - ➢ ICESat-2



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