



**Standardised baselines in the
forest sector**
**- Lessons learned from FCM and
PathFinder**

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EO for Carbon Markets
9-11 October 2024

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**Forest Carbon
Monitoring**

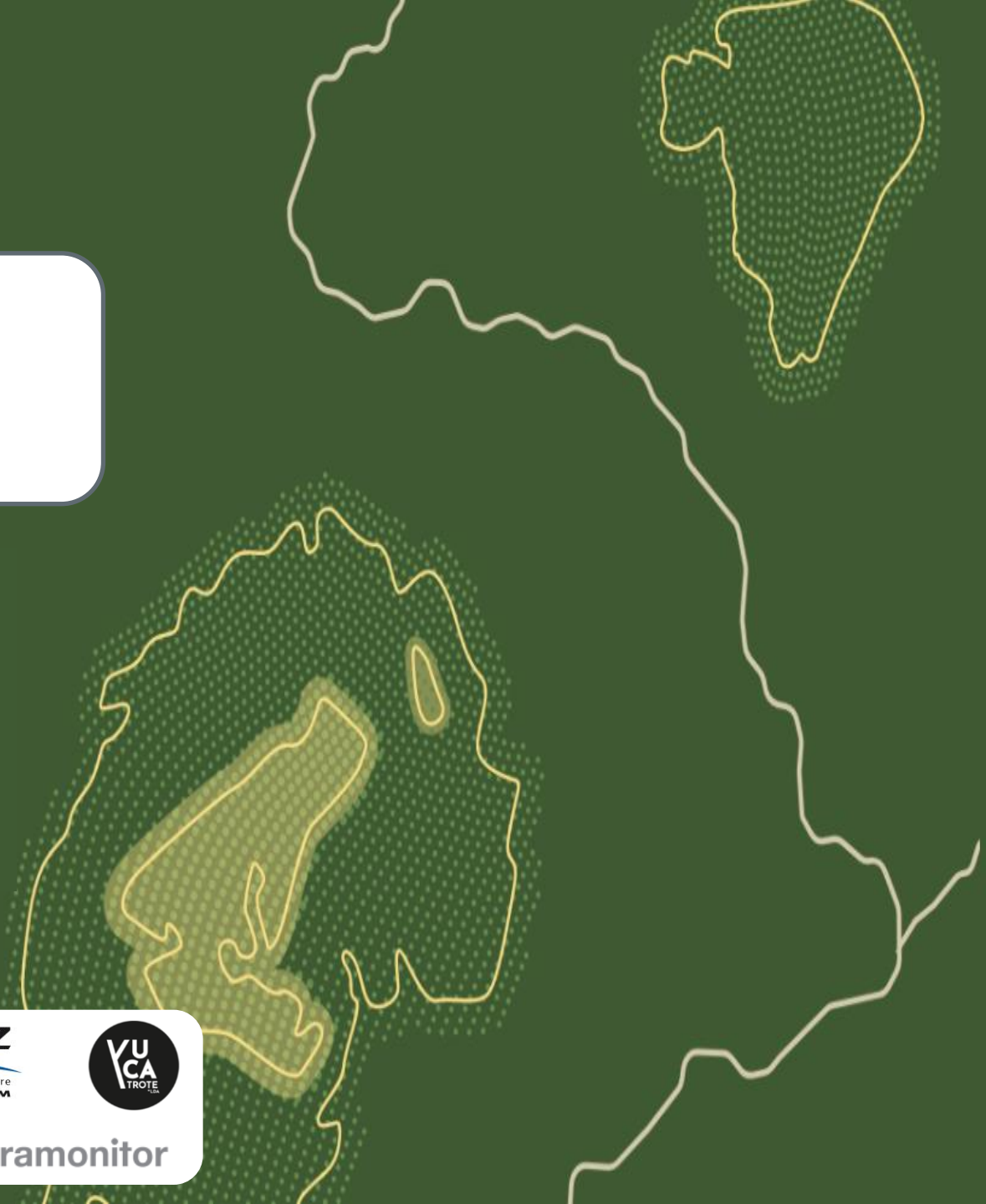
Forest Carbon Monitoring

Jul 2021-Jun 2023 + May 2024-Nov 2025

We contribute to *climate change mitigation activities* by developing a platform for *forest carbon monitoring* with high accuracy, reach and frequency



 **EUROPEAN FOREST INSTITUTE**
 **GAMMA REMOTE SENSING**
 **NIBIO**
 NORWEGIAN INSTITUTE OF BIOECONOMY RESEARCH
 **south pole**
 **GFZ**
 Helmholtz Centre POTSDAM
 **Terramonitor**
 **YUCA**
 TROTE

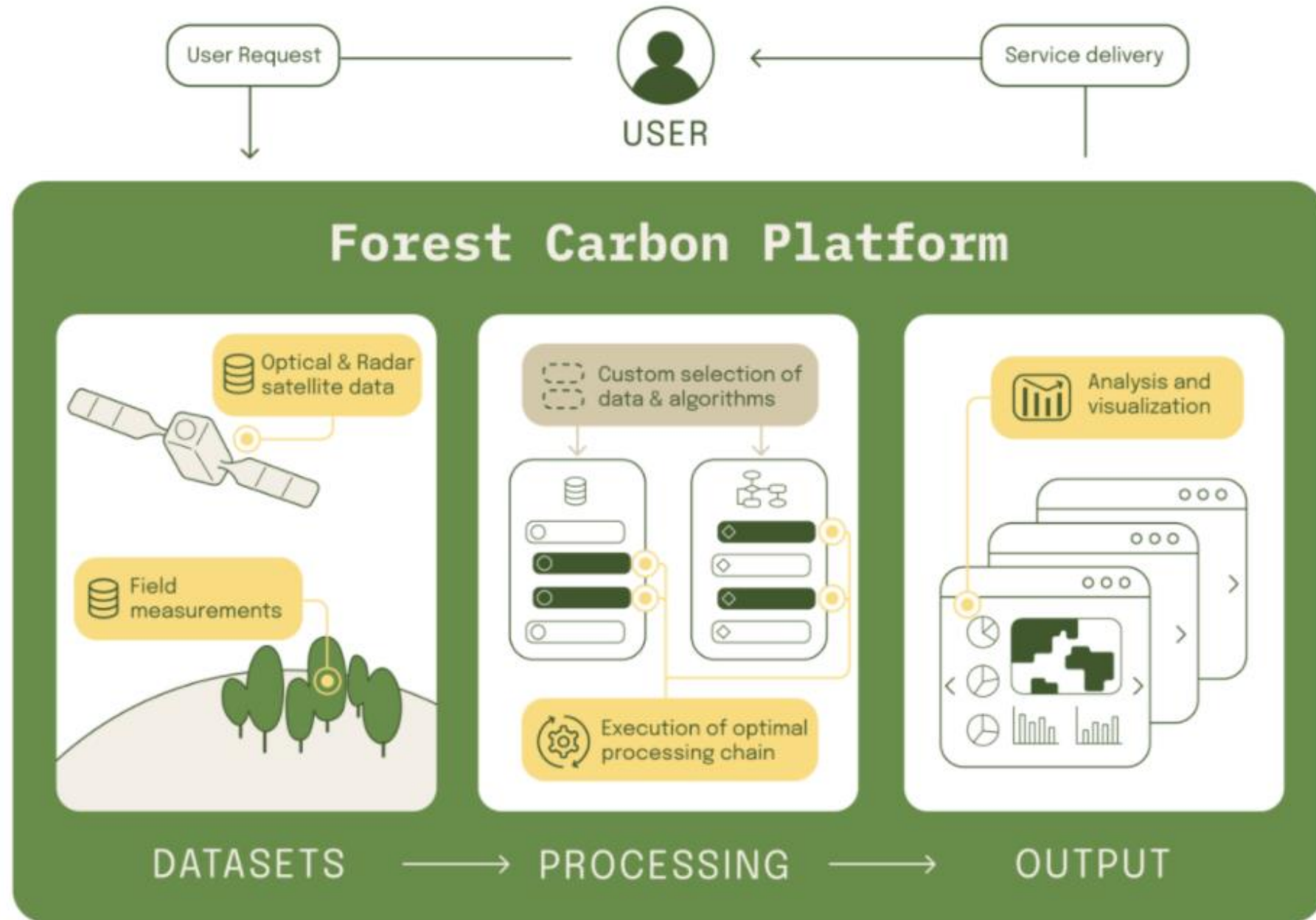


FCM concept

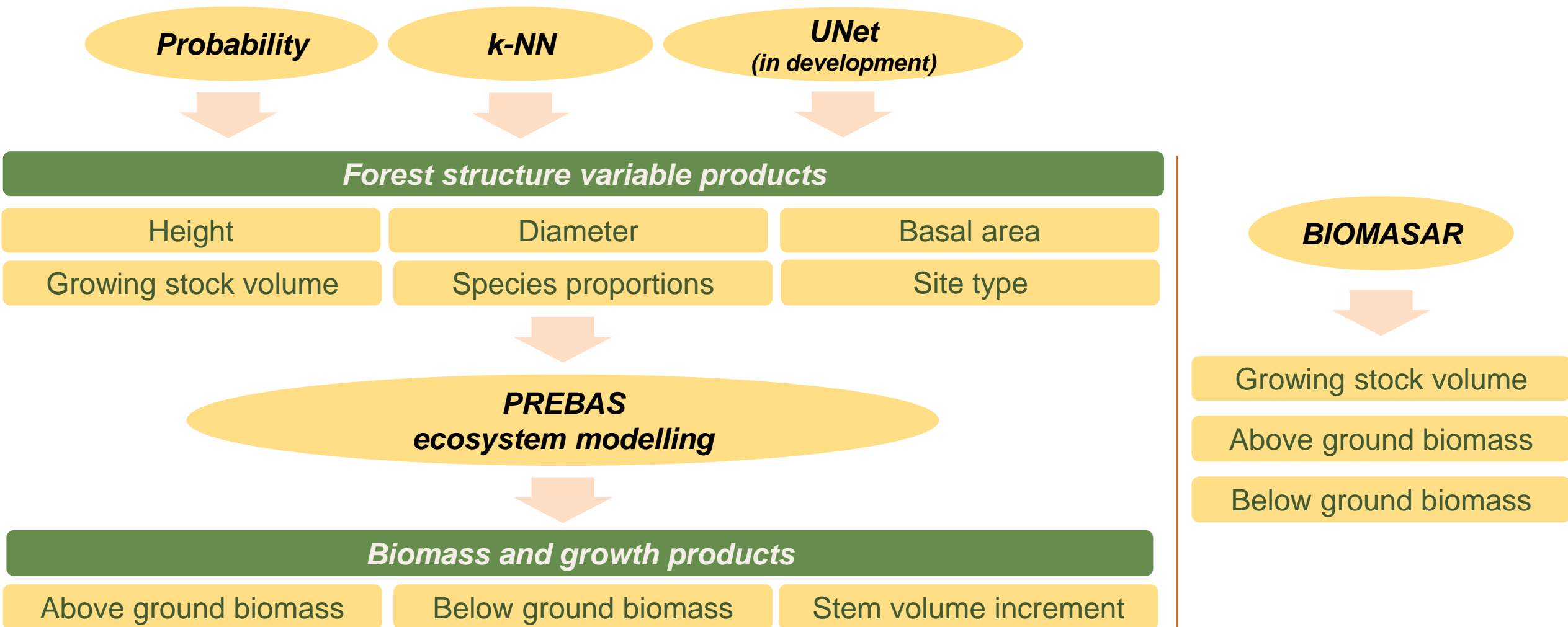
- 1 Integration of in-situ and EO data
- 2 Process-based forest ecosystem modelling
- 3 Flexibility to user requirements

Tools to be made available in Forestry TEP platform (<https://f-tep.com>)...

... and as OGC Application Packages in the NoR portal.



Forest Carbon Monitoring methods

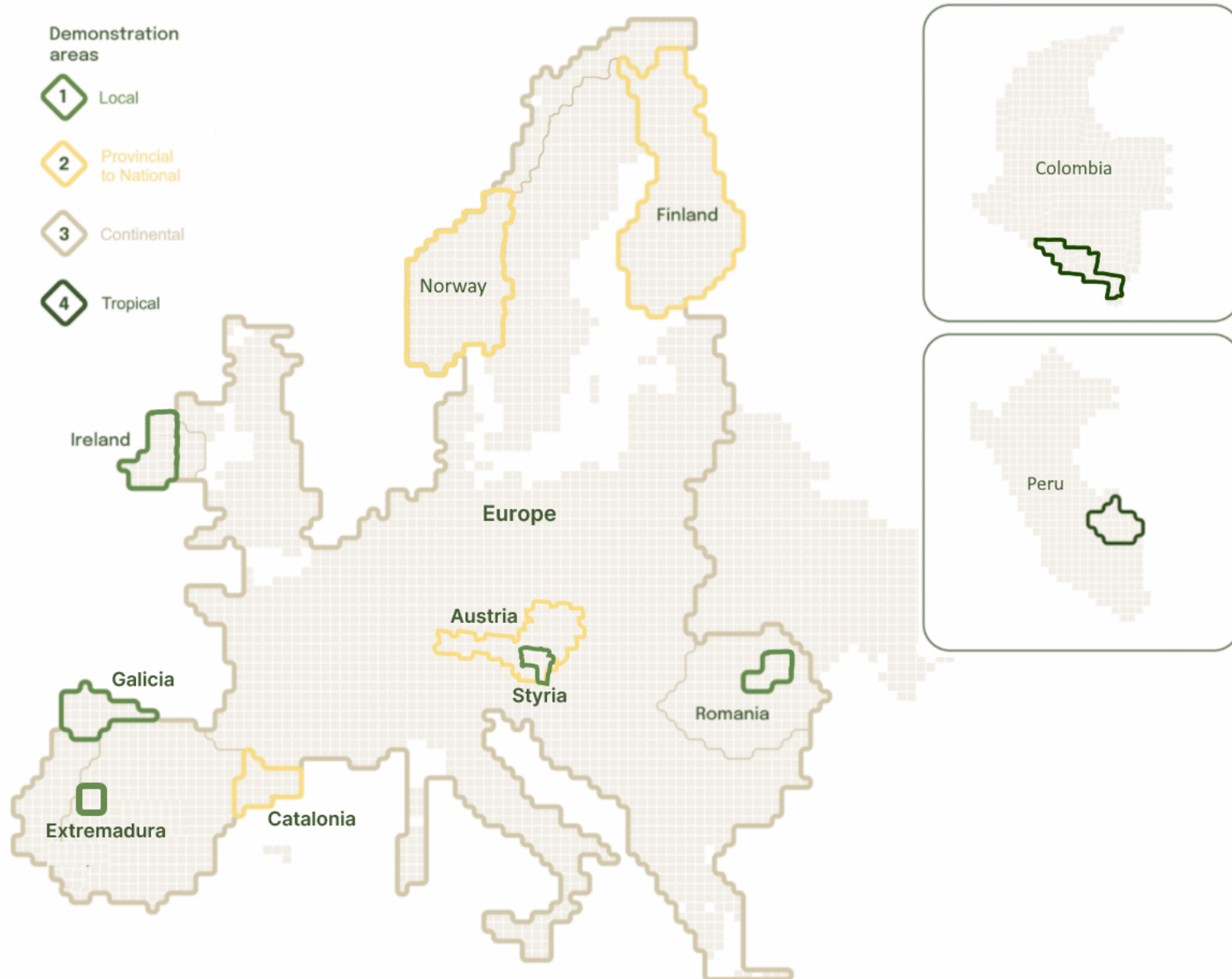


Use case demonstrations

Primary EO data:
Sentinel-1 and Sentinel-2

Coverage:
From private company forests to European wide mapping

Outputs:
Over 90 products delivered to users in the main project

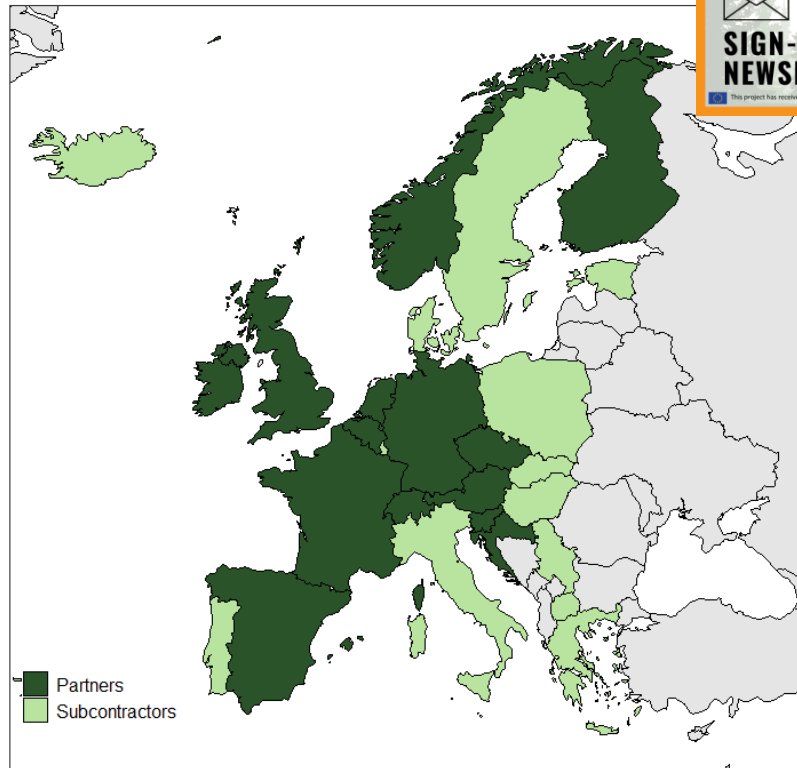


Towards a European Forest Monitoring System



■ Johannes Breidenbach

- Start: September 2022
- Duration: 4 years
- 23 Partners
- 17 supporting organizations (ICP Forests and NFIs)




CLICK ON THIS BANNER TO SIGN-UP TO OUR NEWSLETTER!

1. Innovative forest monitoring & pathway assessment system for EU GHG reporting of LULUCF
2. Advanced pathway assessments
3. Policy implementation



Towards an Integrated Consistent European LULUCF Monitoring and Policy Pathway Assessment Framework

FOREST MONITORING

Surveys Advanced field work

Mapping Estimating Modelling

REMOTE SENSING & MAPS

FORECASTING

Trade-off & synergy analysis Biogeophysical climate impacts

Land-use & forestry-management scenarios

Co-design of forest management pathways

Climate target assessment Forest monitoring & governance

POLICY



The research leading to these results has received funding from the European Union Horizon Europe (HORIZON) Research & Innovation programme under the Grant Agreement no. 101056907. This output reflects only the authors' view, and the European Union cannot be held responsible for any use that may be made of the information contained herein.

For more info:
www.pathfinder-heu.eu

Integrated mapping and estimation concept

- Full description at: <https://pathfinder-heu.eu/resources>

PathFinder Mapping and Estimation Platform

Data preparation

Earth observation (EO) data pre-processing

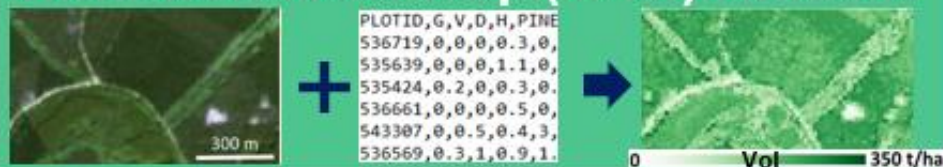


Decentralized field data pre-processing

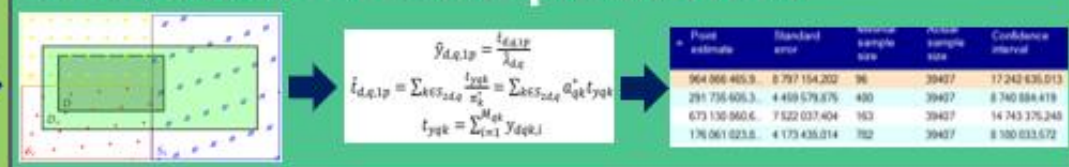
- Plot level NFI calc.
- EO value extraction
- QC steps

Mapping and estimation

Forest attribute map (10 m) creation

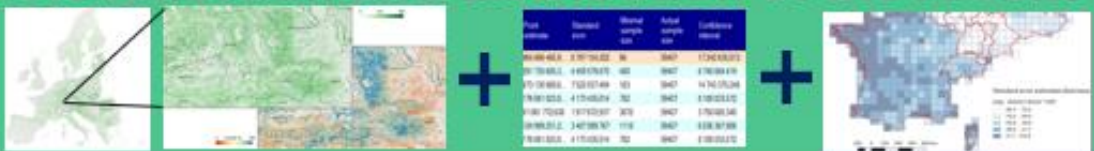


Statistical estimate production



Dissemination and communication

Visualization and distribution of the results



Enable links to FISE and national portals



Relevant findings

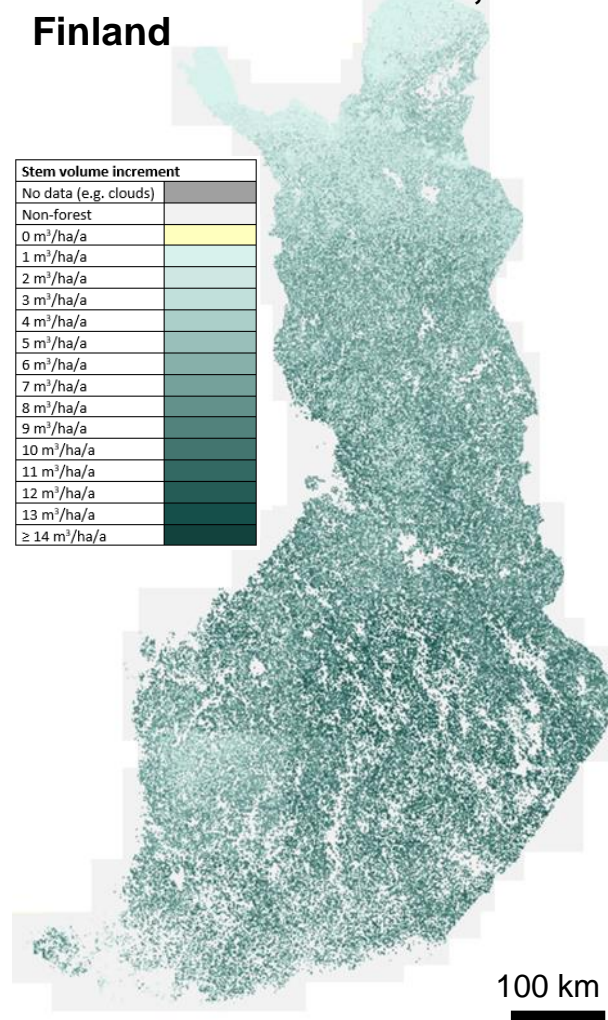
EO enables local to continental level mapping...

Growing stock volume (GSV), Catalonia, Spain

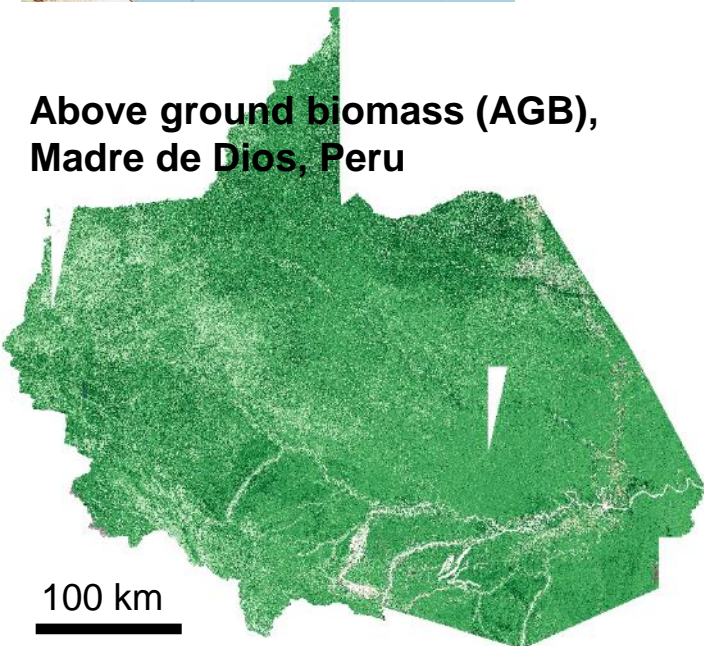


Stem volume increment, Finland

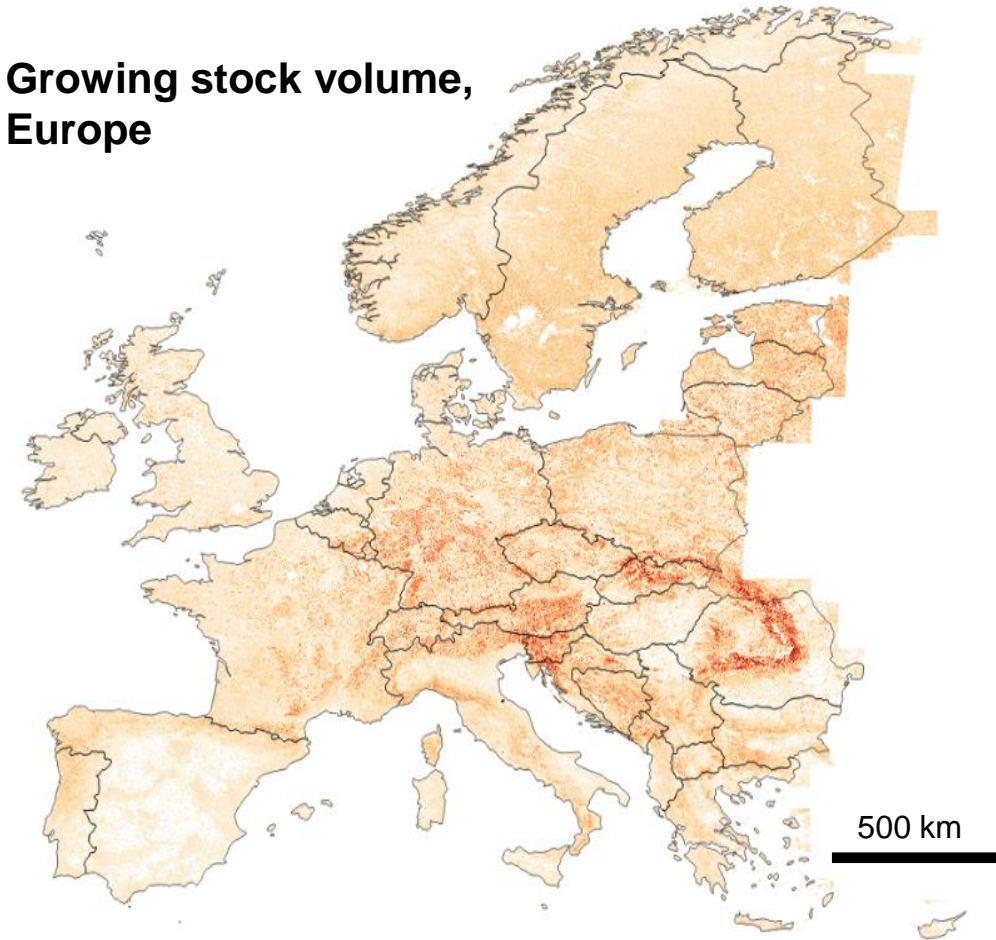
| Stem volume increment | |
|---------------------------|--|
| No data (e.g. clouds) | |
| Non-forest | |
| 0 m ³ /ha/a | |
| 1 m ³ /ha/a | |
| 2 m ³ /ha/a | |
| 3 m ³ /ha/a | |
| 4 m ³ /ha/a | |
| 5 m ³ /ha/a | |
| 6 m ³ /ha/a | |
| 7 m ³ /ha/a | |
| 8 m ³ /ha/a | |
| 9 m ³ /ha/a | |
| 10 m ³ /ha/a | |
| 11 m ³ /ha/a | |
| 12 m ³ /ha/a | |
| 13 m ³ /ha/a | |
| ≥ 14 m ³ /ha/a | |



Above ground biomass (AGB), Madre de Dios, Peru

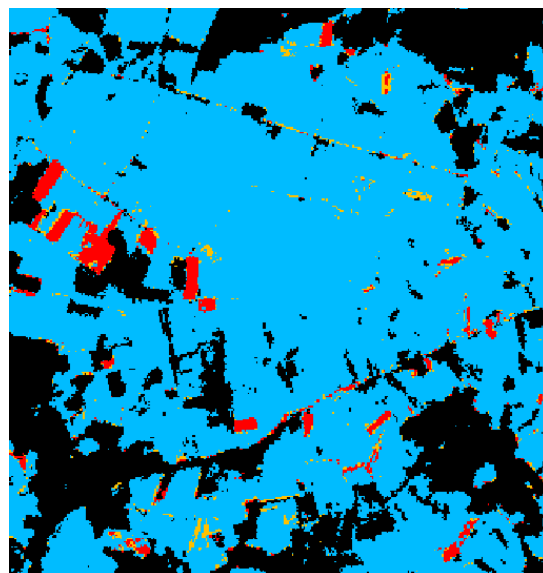
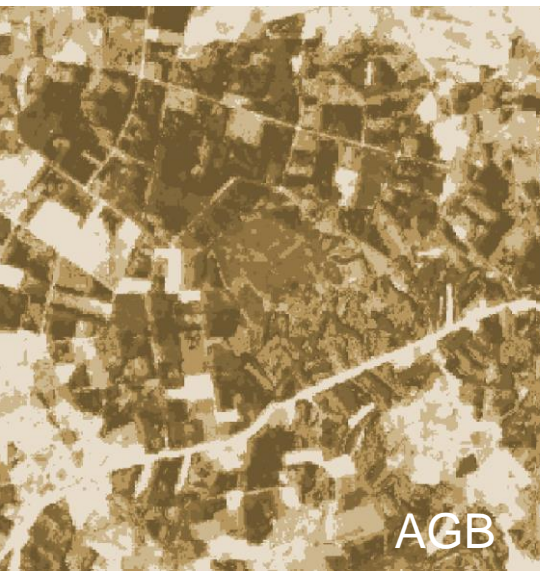


Growing stock volume, Europe



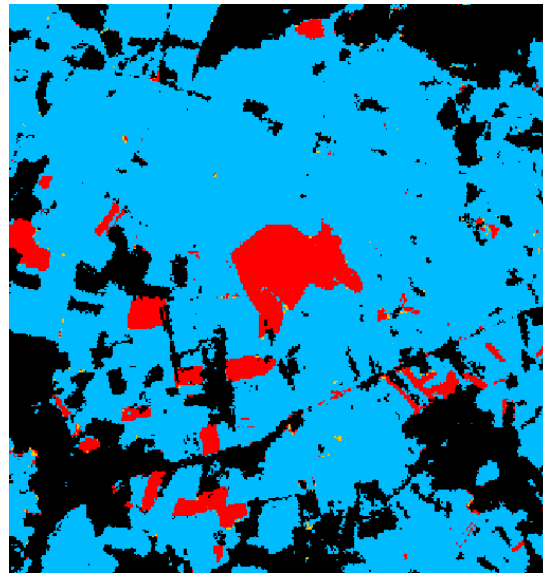
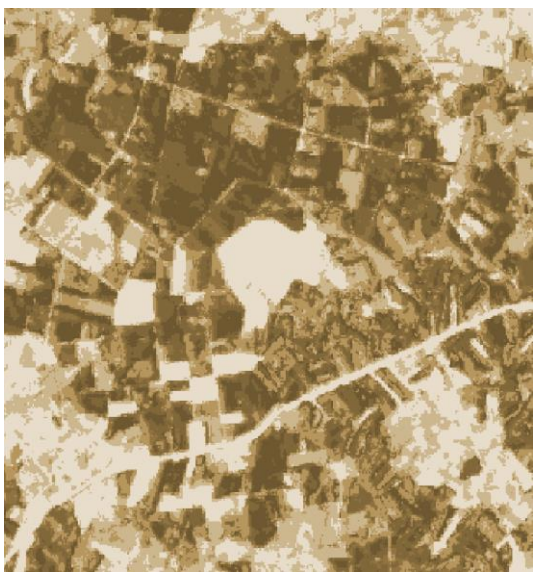
- Product viewing and downloading at: <https://portal.forestcarbonplatform.org/>

With high spatial and temporal resolution



2020

| Basal area | |
|--------------------------|------------------|
| No data (e.g. clouds) | Grey |
| Non-forest | White |
| Open forest | Yellow |
| ≤ 5 m ² /ha | Light purple |
| 6-10 m ² /ha | Medium purple |
| 11-15 m ² /ha | Dark purple |
| 16-20 m ² /ha | Very dark purple |
| 21-25 m ² /ha | Black |
| 25-30 m ² /ha | Black |
| > 30 m ² /ha | Black |



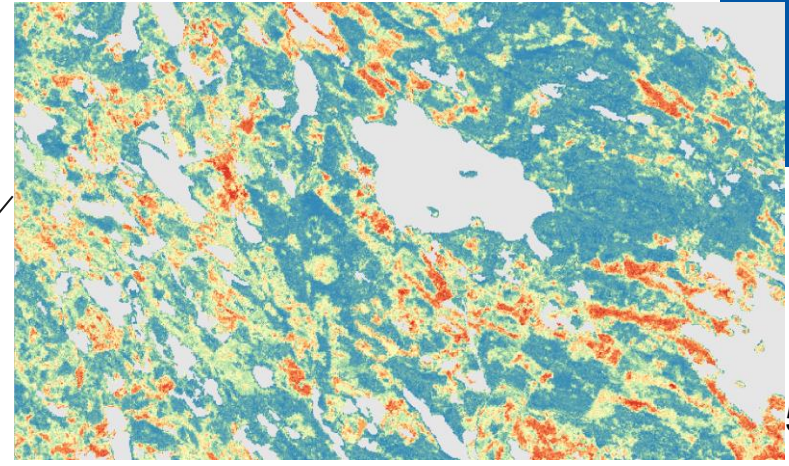
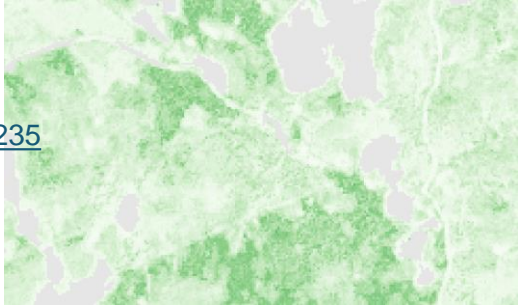
2021

| Above Ground Biomass | |
|----------------------|-----------------|
| No data | Grey |
| Non-forest | White |
| 0-25 t/ha | Light brown |
| 26-50 t/ha | Medium brown |
| 51-75 t/ha | Dark brown |
| 76-100 t/ha | Very dark brown |
| 101-125 t/ha | Black |
| 126-150 t/ha | Black |
| 151-175 t/ha | Black |
| > 175 t/ha | Black |

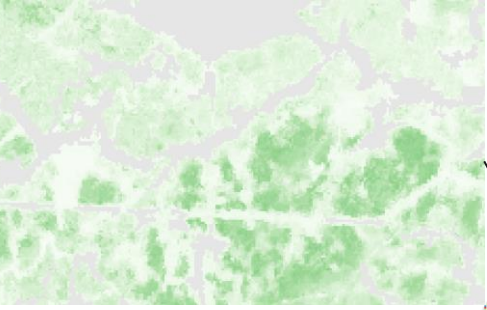
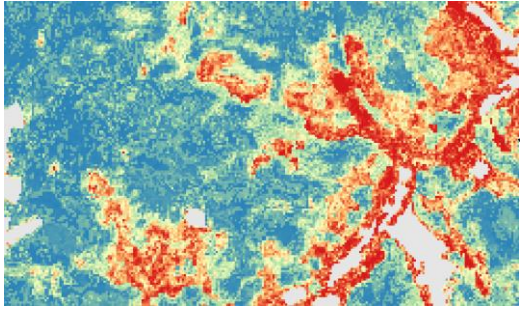
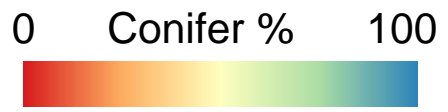
PathFinder pilot maps



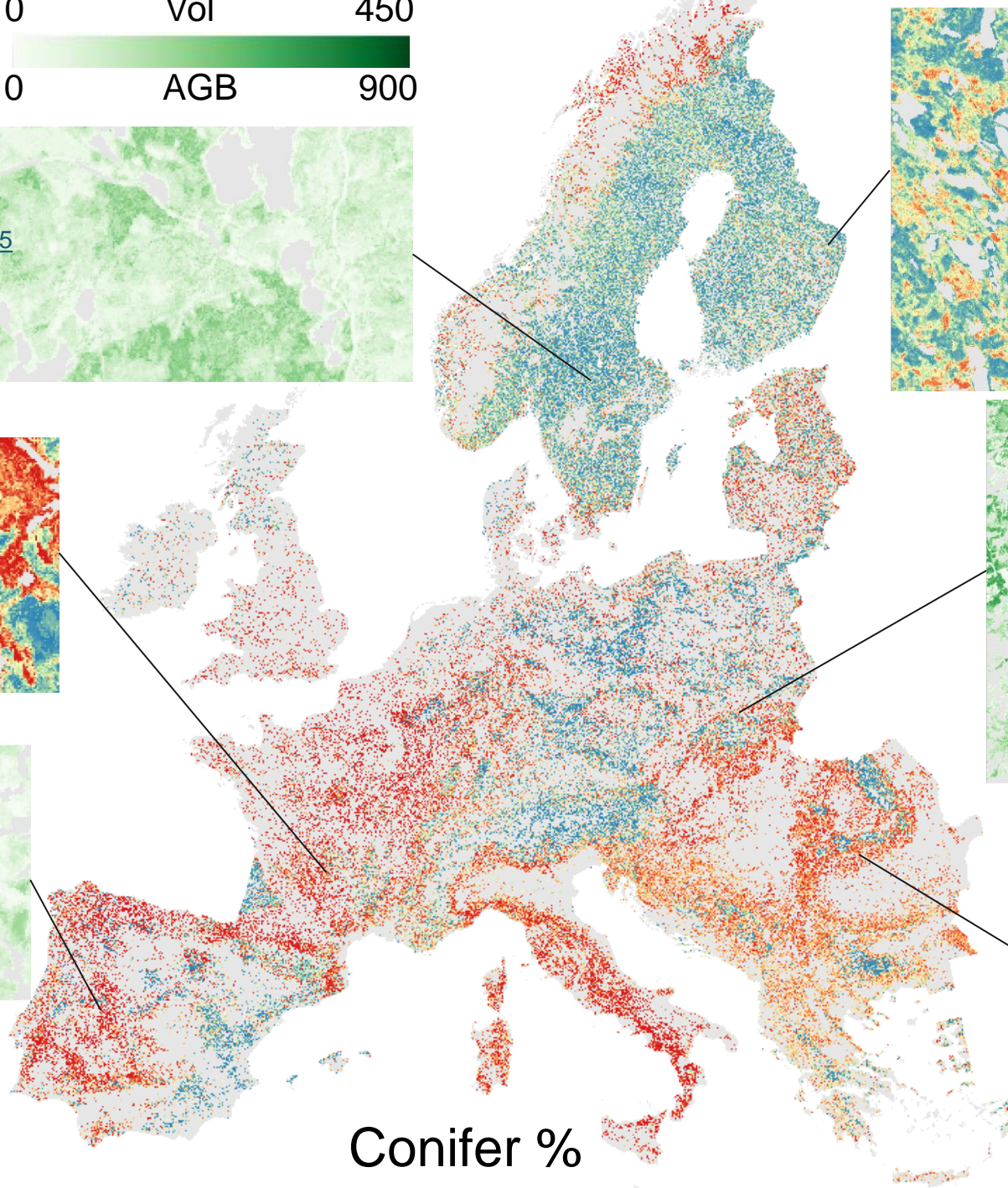
Available at:
<https://zenodo.org/records/13143235>



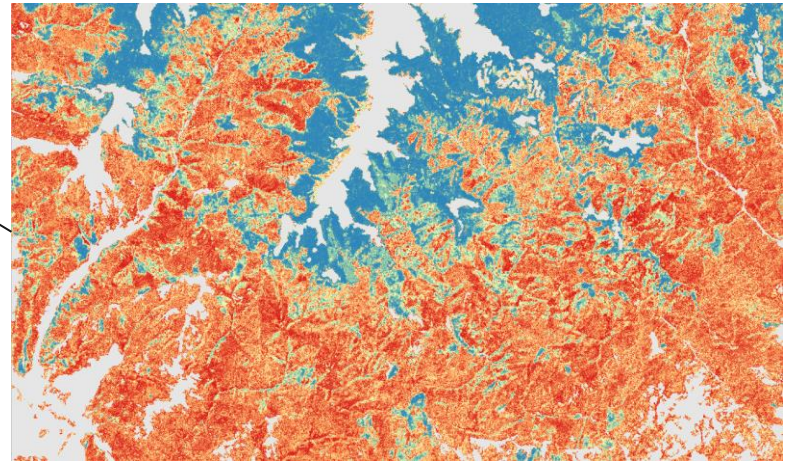
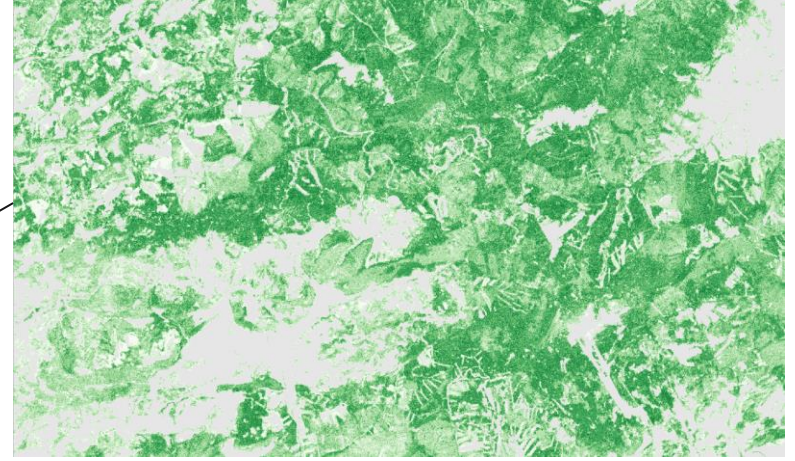
5 km x 8 km



1.5 km x 2.5 km

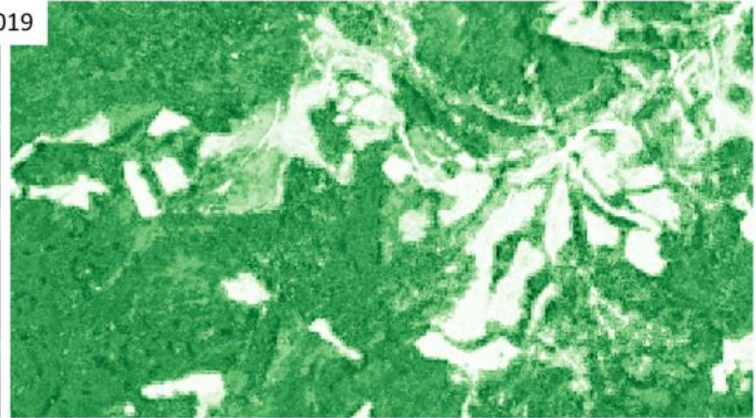
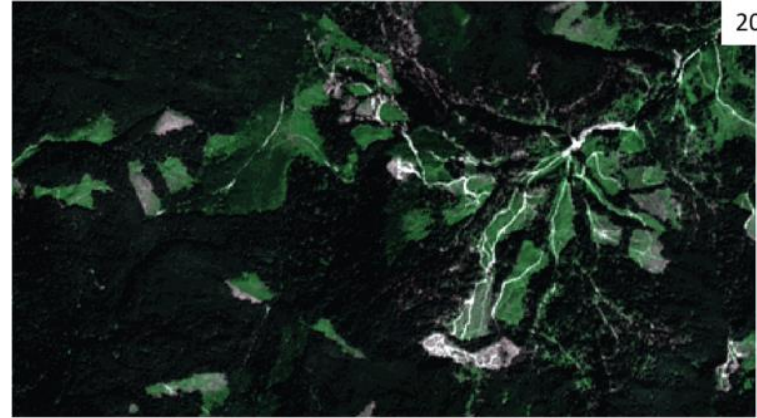


Conifer %

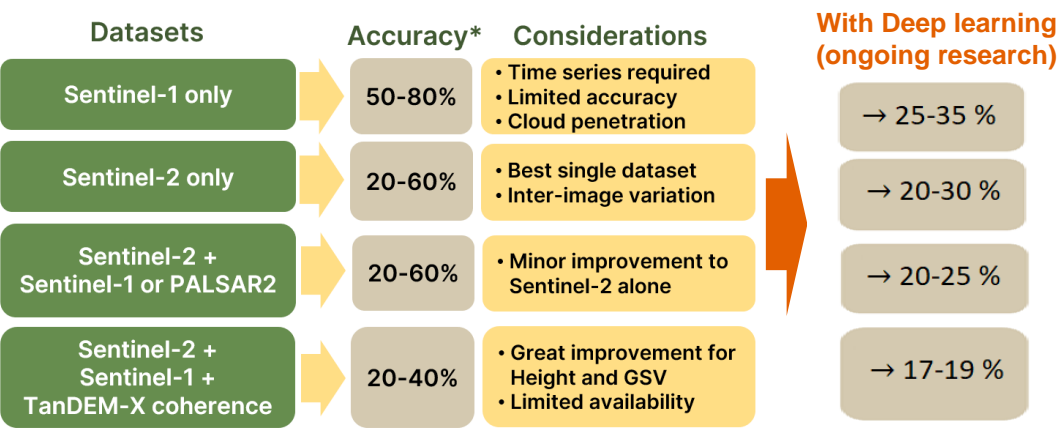


Observations on accuracy and consistency from the FCM project

- Biases typically < 4% of the mean
- Challenges: saturation at large forests and overestimation of young forests
- Plot level RMSE typically 20-60% of mean
- Inter-year consistency heavily dependent on remotely sensed imagery and/or availability of annual calibration

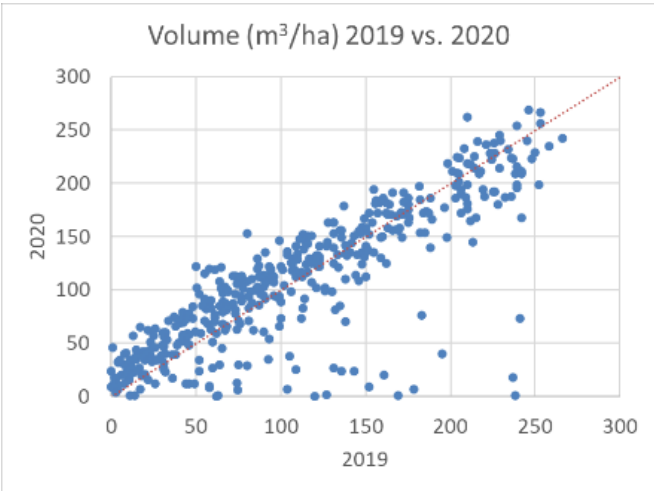
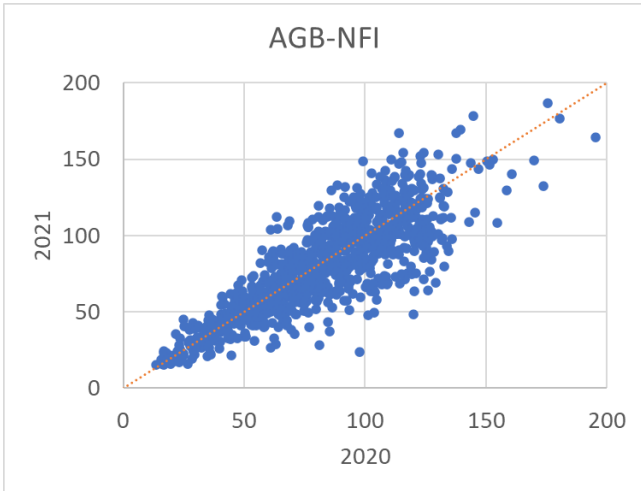


EO based approaches suitable for large area monitoring, but not (yet) for annual monitoring at plot/stand level.



* Typical plot level accuracy variation between variables and sites. RMSE % of mean.

Annual time series of volume estimation in Romania

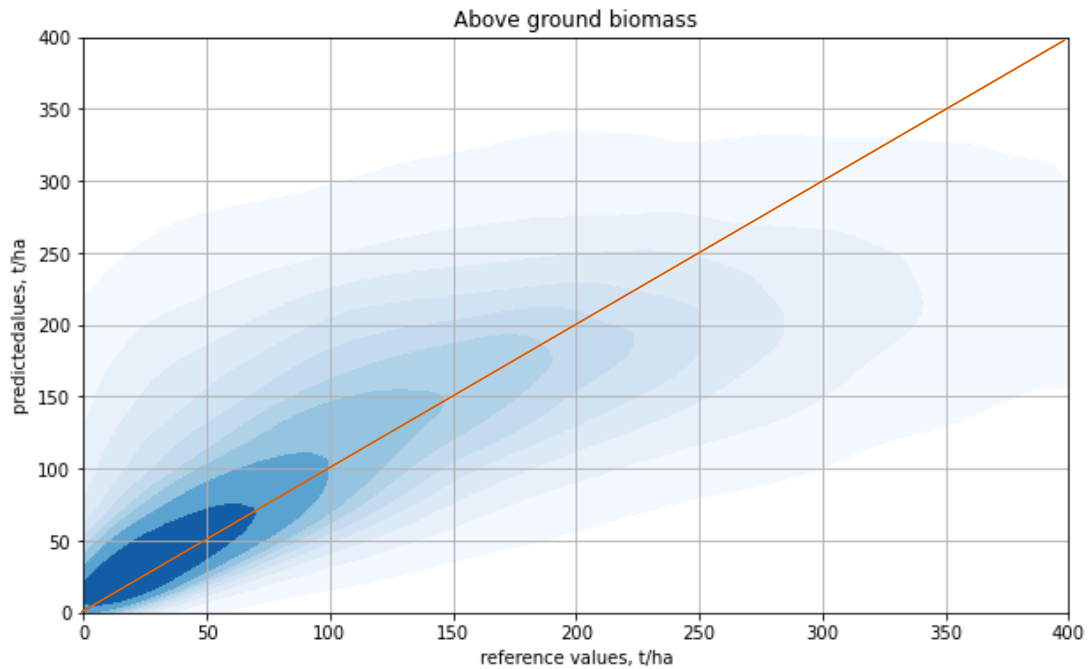


Year-to-year consistency for AGB (Catalonia) at plot level and Volume Galicia at stand level.

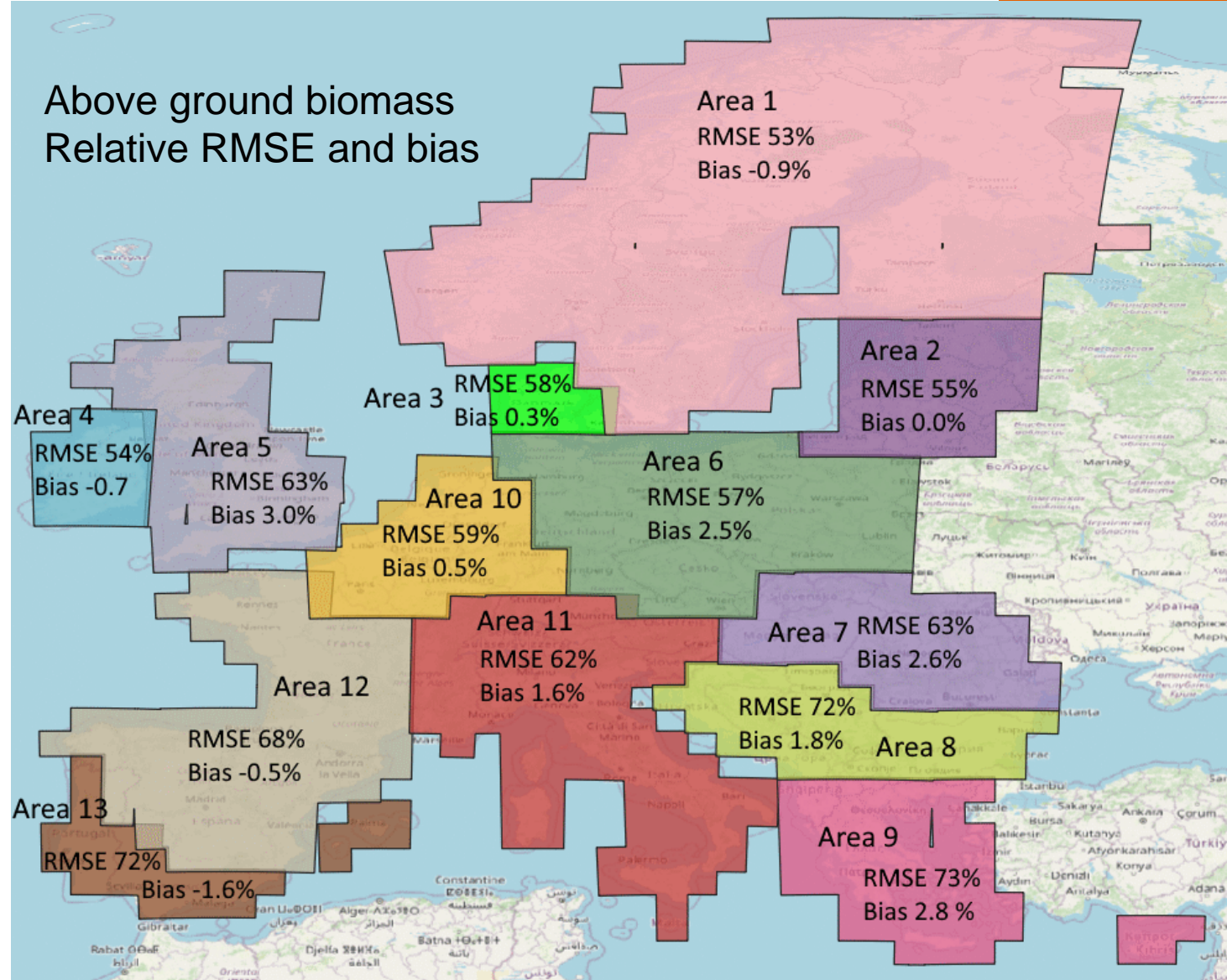
| | D (cm) | G (m ² /ha) | H (dm) | V (m ³ /ha) | BLP (%) | CP (%) | AGB (t/ha) |
|------|--------|------------------------|--------|------------------------|---------|--------|------------|
| 2020 | 18,5 | 18,5 | 86 | 92,7 | 61 | 38 | 82,2 |
| 2021 | 18,7 | 18,4 | 87 | 92,9 | 58 | 41 | 80,3 |

Average estimated forest parameters in 951 validation plots in Catalonia.

First impression on European wide map accuracy from the PathFinder Project



Density scatter plot for AGB (~150 000 plots)

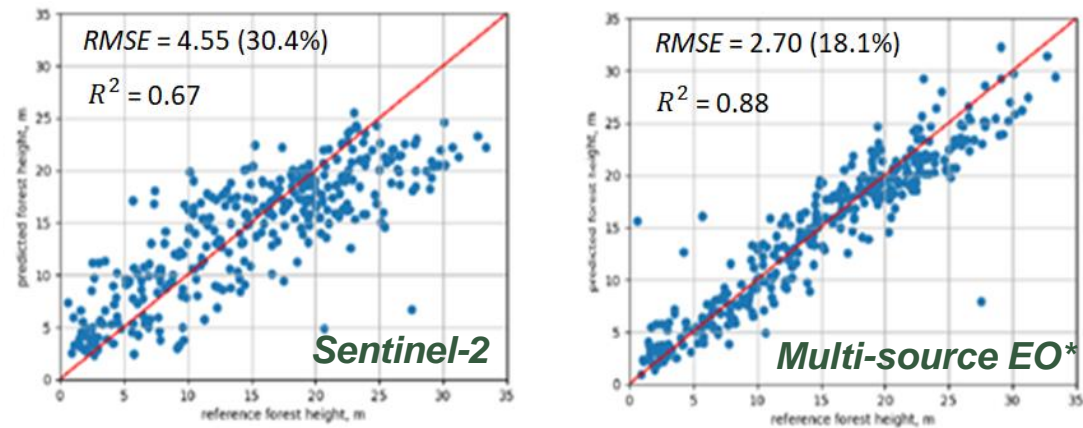


Source: Miettinen, Breidenbach et al. (2024) High-Resolution Pan-European Forest Structure Maps: An Integration of Earth Observation and National Forest Inventory Data. DOI: <https://zenodo.org/records/13143235>

Improving mapping accuracy with UNet deep learning approach and model transfer

- Models trained with Airborne Laser Scanning (or similar) wall-to-wall datasets
- High potential on forestry application with model transfer approach (limited number of field reference plots required)
- Significant improvement on accuracy metrics
- Clear reduction in saturation effect

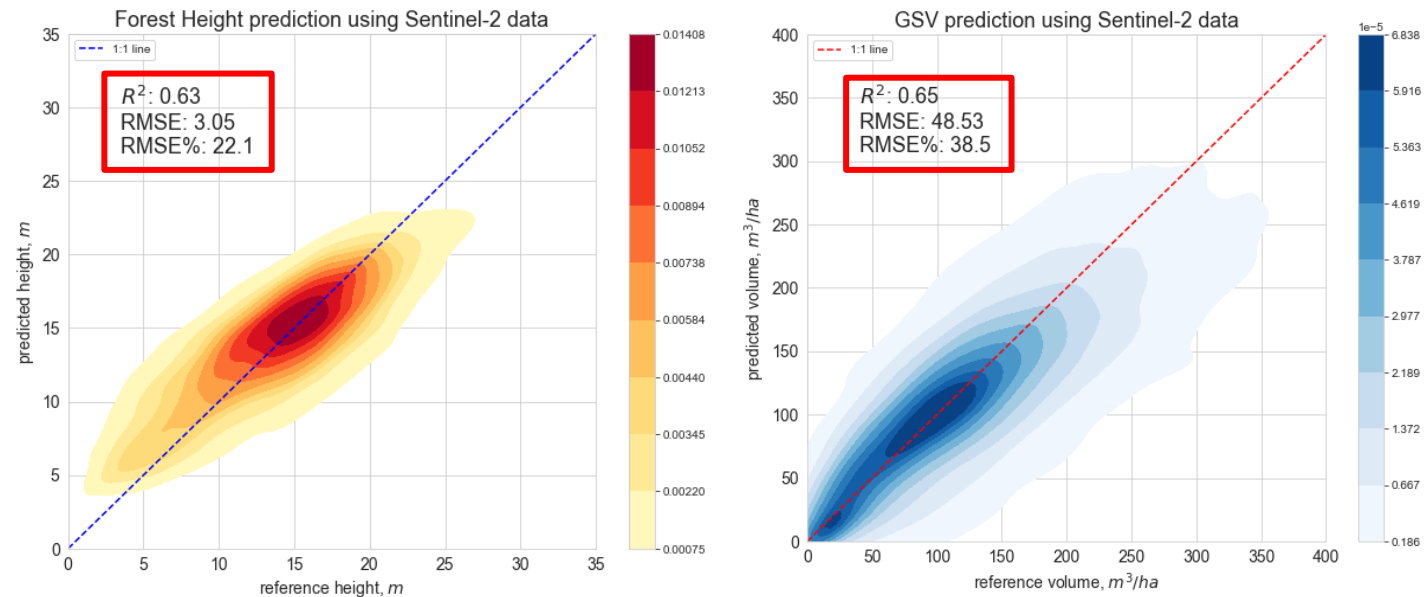
Northern Finland UNet height model transferred to Southern Finland



*Sentinel-2 & Sentinel-1 & ALOS-2 PALSAR-2 & TanDEM-X

Source: Ge et al. (2023) Deep learning models with transfer learning in boreal forest mapping using multi-source satellite SAR/InSAR and optical images, *Remote Sensing* 15: 5152. DOI: 10.3390/rs15215152

Forest variable (Height and Volume) retrieval using Sentinel-2 data, 10 m x 10 m (UNet models trained with Airborne Laser Scanning products in Finland)



Source: Antropov et al. ongoing work at FCM project, unpublished, © VTT.

Food for thought

Combined use of EO and field-based data needed

- EO is a powerful tool for timely large area monitoring with high spatial detail
- Combined use of optical, SAR and spaceborne LiDAR bring new possibilities
- New methods are improving the accuracy
- BUT!
 - With space borne EO, uncertainty is (and will remain in the near future) high for small areas



Error intervals too high for financial or legislative monitoring

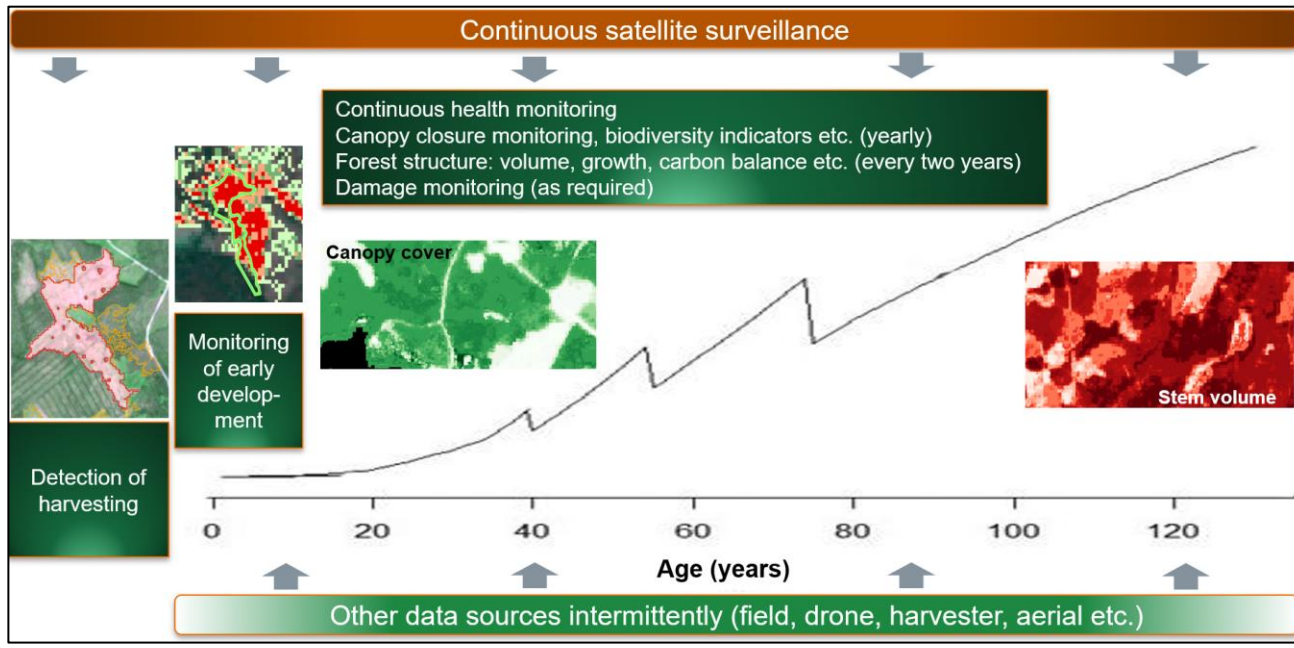
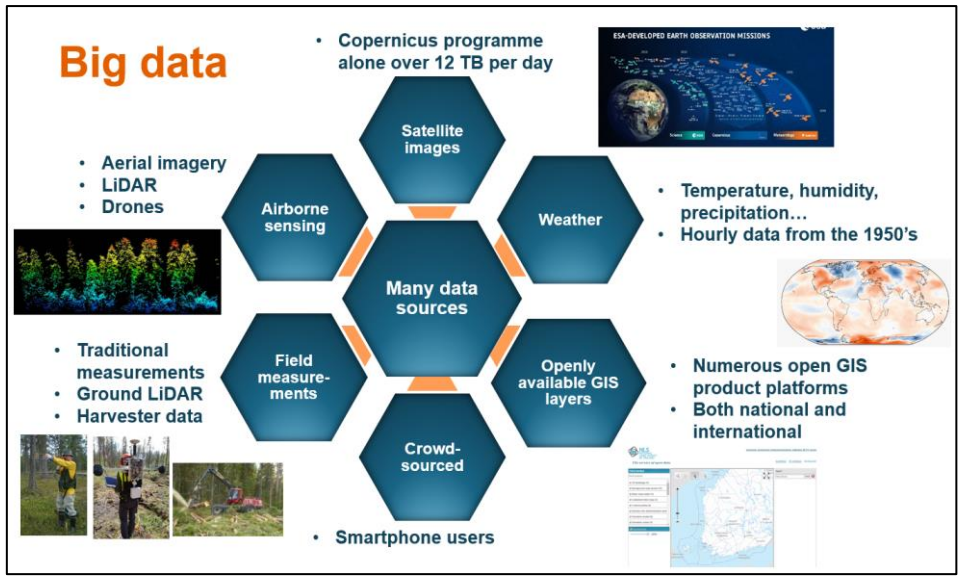
- Field reference data is crucial!
 - Required for training and accuracy assessment
 - Important to align EO based monitoring with existing field sampling-based information
 - Combined use of EO (and other remote sensing data) with field measurements networks (NFI, ICOS, ICP Forest, LUCAS)



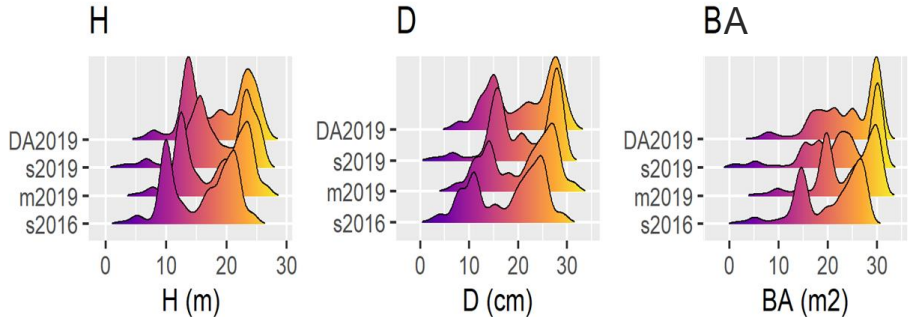
Model-assisted estimation for administrative regions

→ To be evaluated in both PathFinder and Forest Carbon Monitoring projects

Towards continuous forest monitoring



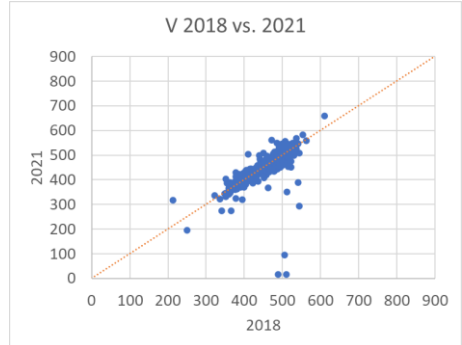
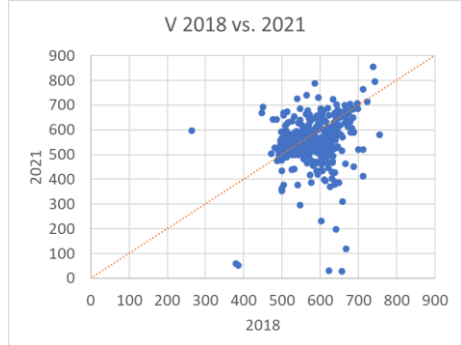
- Continuous forest monitoring system effectively combining different data sources
- Modelling and data assimilation used to align disagreeing inputs
 - To be evaluated in Forest Carbon Monitoring project
- Digital Twin of European forests
 - EU and ESA projects starting



DA2019 = Data assimilation
 s2016, s2019 = Sentinel-2
 m2019 = PREBAS model

Unpublished results, FCM,
 © Francesco Minunno

Change scatter 2018-2021 without (left) and with (right) Data Assimilation. (Not functioning correctly yet.)



Thank you!

Jukka Miettinen

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More information at:

<https://www.forestcarbonplatform.org>

<https://pathfinder-heu.eu/>

FCM example products at:

<https://portal.forestcarbonplatform.org>

PathFinder pilot maps at:

<https://zenodo.org/records/13143235>