Forest Carbon Monitoring

Forest Carbon Monitoring
toolset webinar

16.04.2026

VTT

AFRY

EUROPEAN FOREST INSTITUTE

GAMMA REMOTE SENSING

GFZ Helmholtz Centre for Geosciences

JOANNEUM RESEARCH

Luke NATURAL RESOURCES INSTITUTE FINLAND

NIBIO NORWEGIAN INSTITUTE OF BIOECONOMY RESEARCH

south pole

Terramonitor

UNIVERSITY OF HELSINKI

YUCATROTE forest modelling & analytics

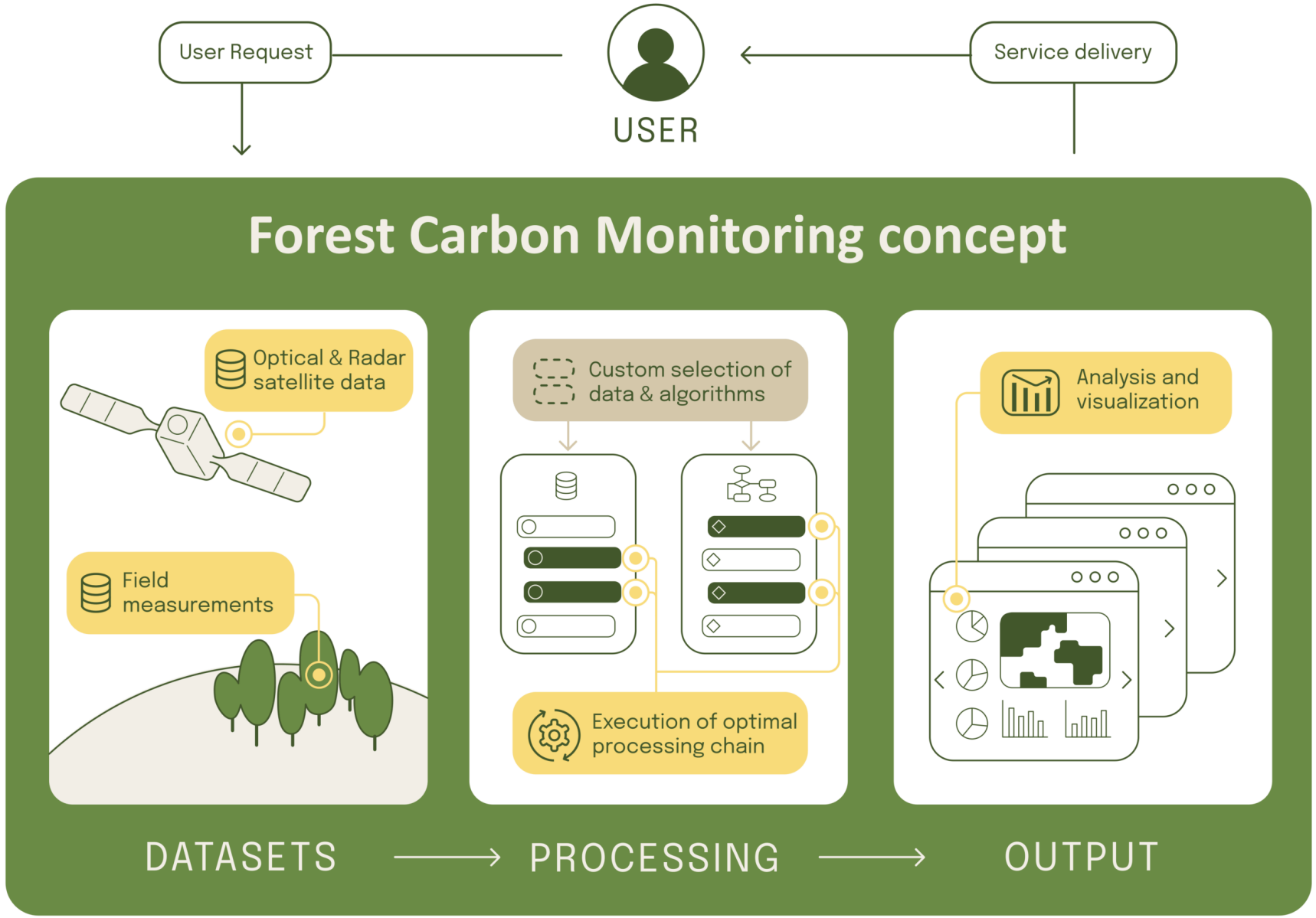
Agenda

- **FOREST CARBON MONITORING (FCM) PROJECT AND TOOLSET (10 MIN)**
- **HIGHLIGHTS OF SELECTED TOOLS (15 MIN)**
  - *Sentinel-1 preprocessing tools by Gamma Remote Sensing (5 min)*
  - *Sentinel-2 compositing tool by Terramonitor (5 min)*
  - *UNet tools by VTT (5 min)*
- **FORESTRY TEP AND ACCESS TO THE TOOLS (10 MIN)**
- **DEMONSTRATION OF RUNNING THE TOOLS (10 MIN)**
- **Q&A (15 MIN)**

FCM project and toolset

FCM objectives

1. Flexibility to user requirements
2. Integration of in-situ and EO data
3. Process-based forest ecosystem modelling + data assimilation
4. Rigorous uncertainty assessment framework



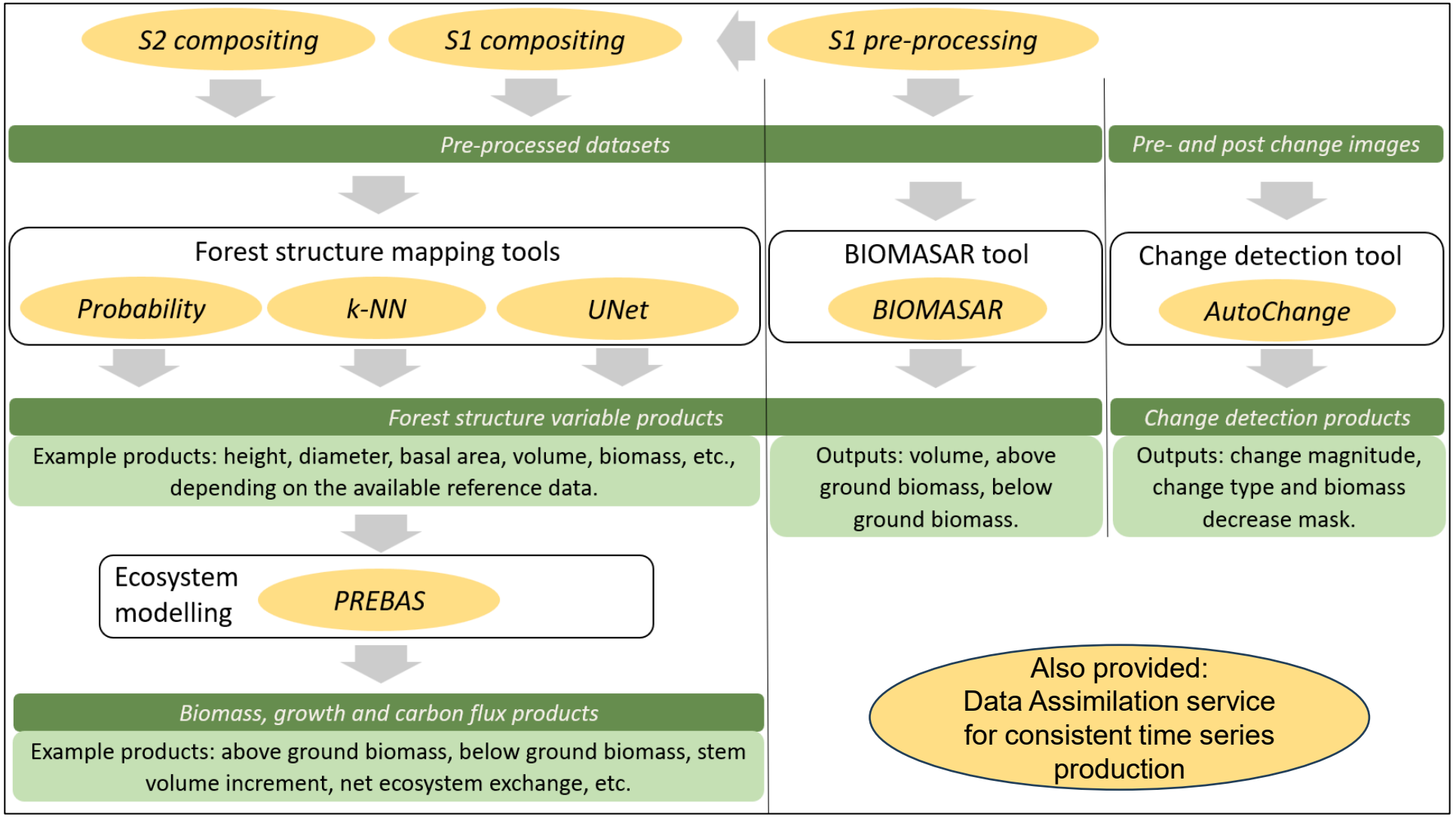
FCM toolset

Detailed descriptions in the FCM ATBD document

Pre-processing tools

Monitoring tools

Modelling tools



12 use case demonstrations

Primary EO data:

Sentinel-1 and Sentinel-2

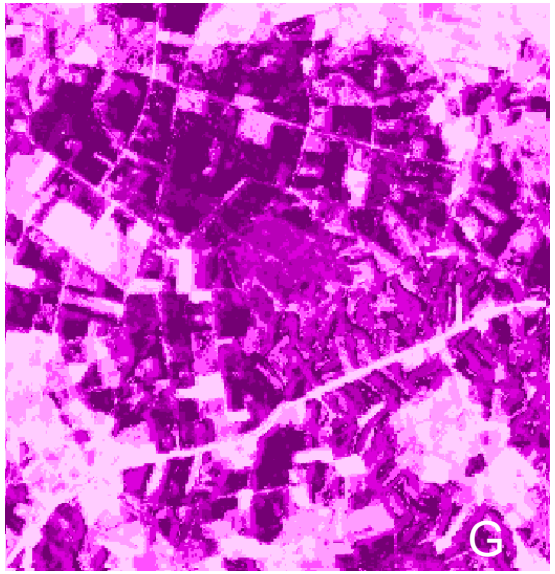
Coverage:

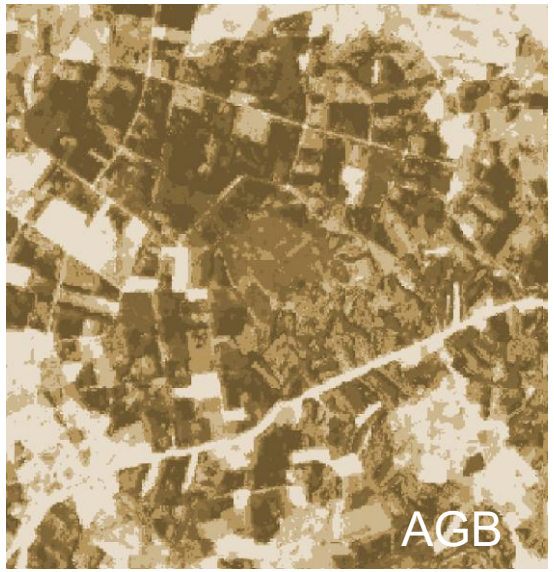
From private company forests to European wide mapping

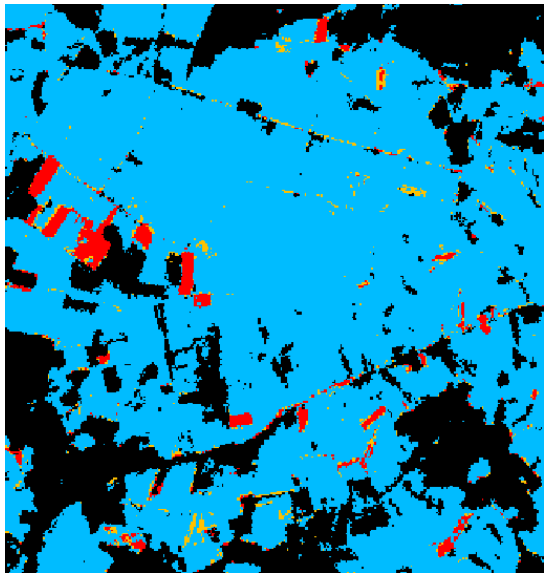
Outputs:

Over 100 products delivered to users.

Highly detailed local data with… annual frequency and…

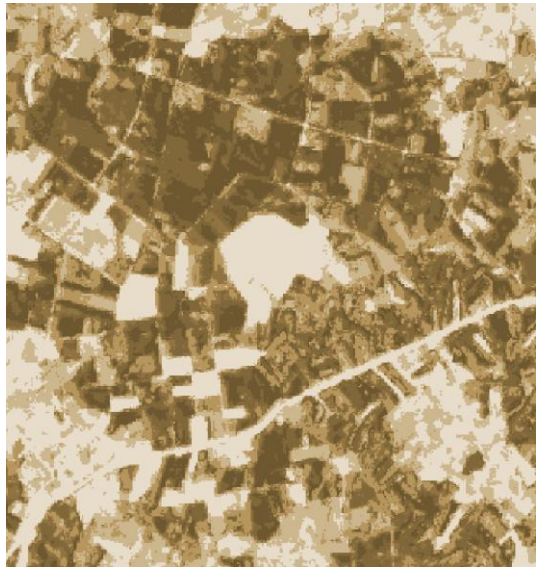


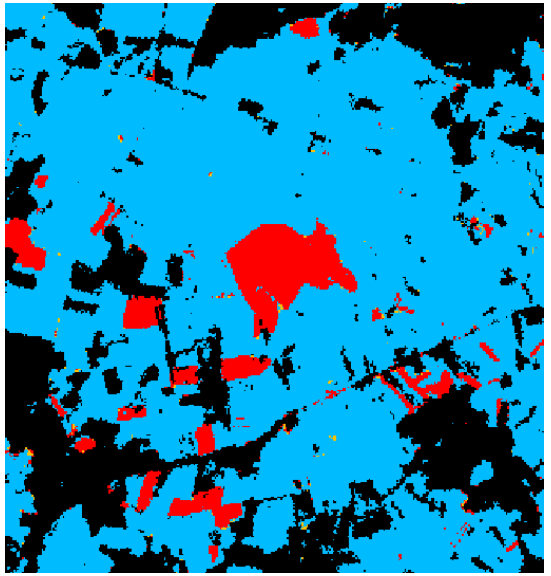




2020

Basal area	
No data (e.g. clouds)	
Non-forest	
Open forest	
≤ 5 m^2/ha	
6-10 m^2/ha	
11-15 m^2/ha	
16-20 m^2/ha	
21-25 m^2/ha	
25-30 m^2/ha	
> 30 m^2/ha	



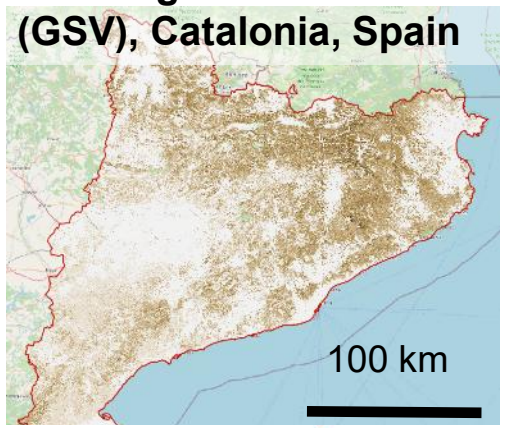


2021

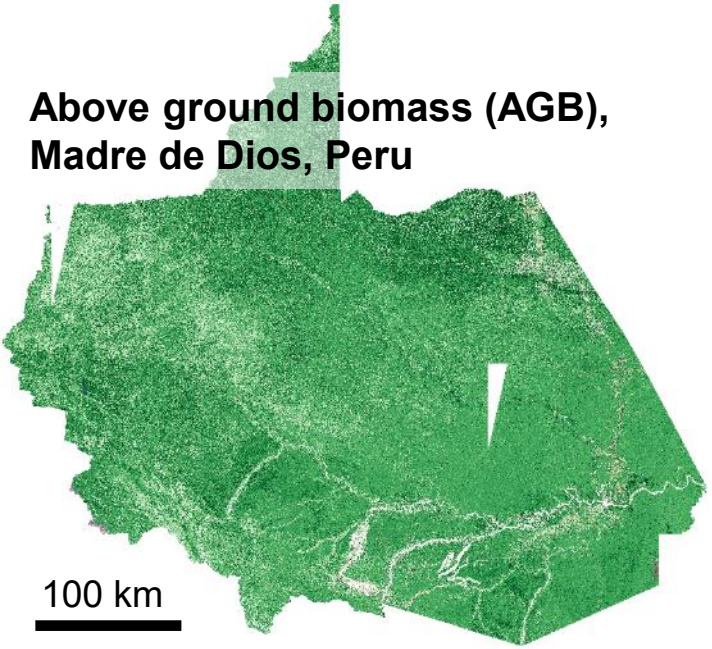
Above Ground Biomass	
No data	
Non-forest	
0-25 t/ha	
26-50 t/ha	
51-75 t/ha	
76-100 t/ha	
101-125 t/ha	
126-150 t/ha	
151-175 t/ha	
> 175 t/ha	

…large area regional to continental coverage

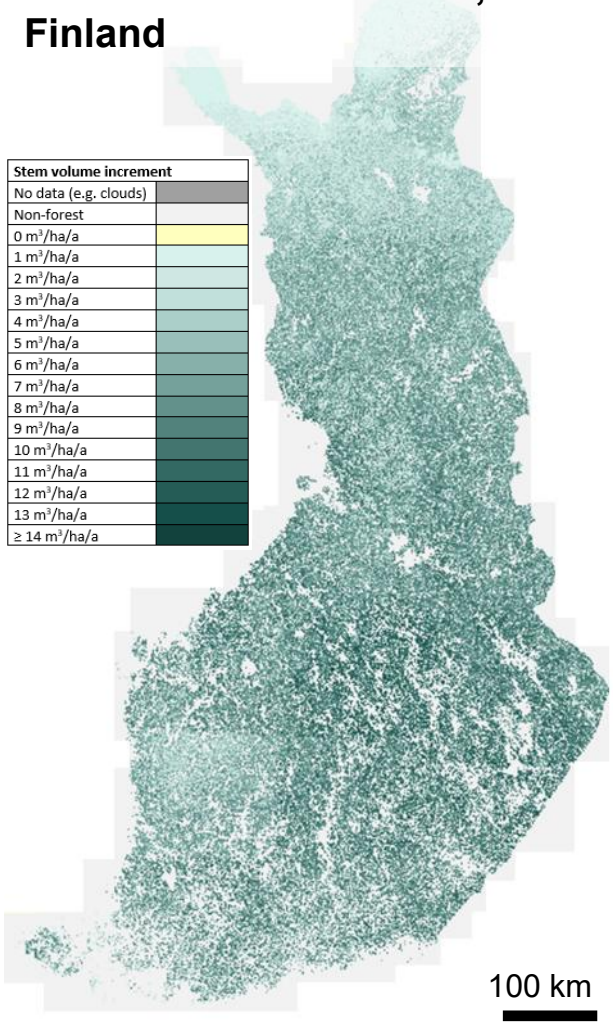
Growing stock volume (GSV), Catalonia, Spain



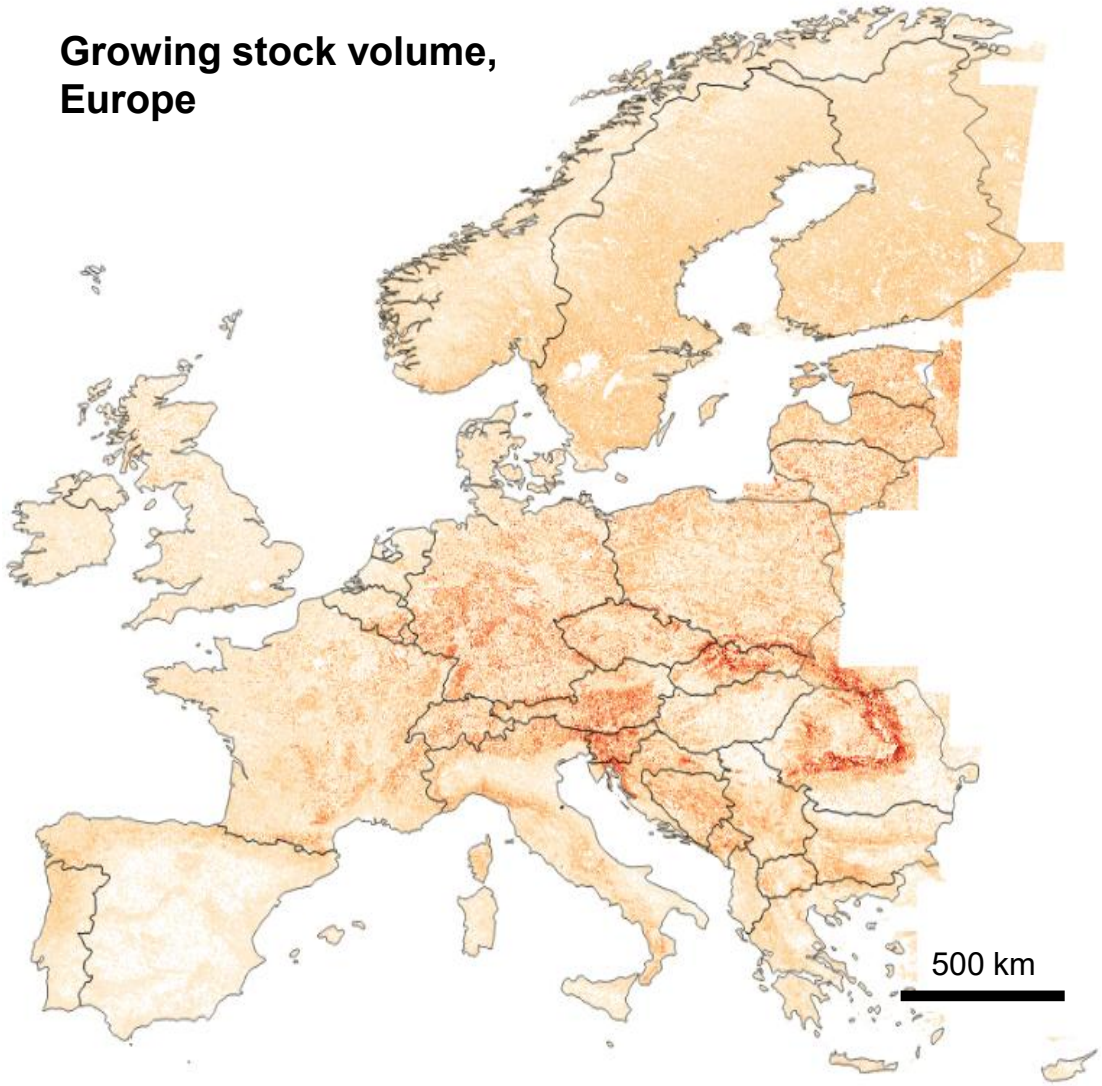
Above ground biomass (AGB), Madre de Dios, Peru



Stem volume increment, Finland

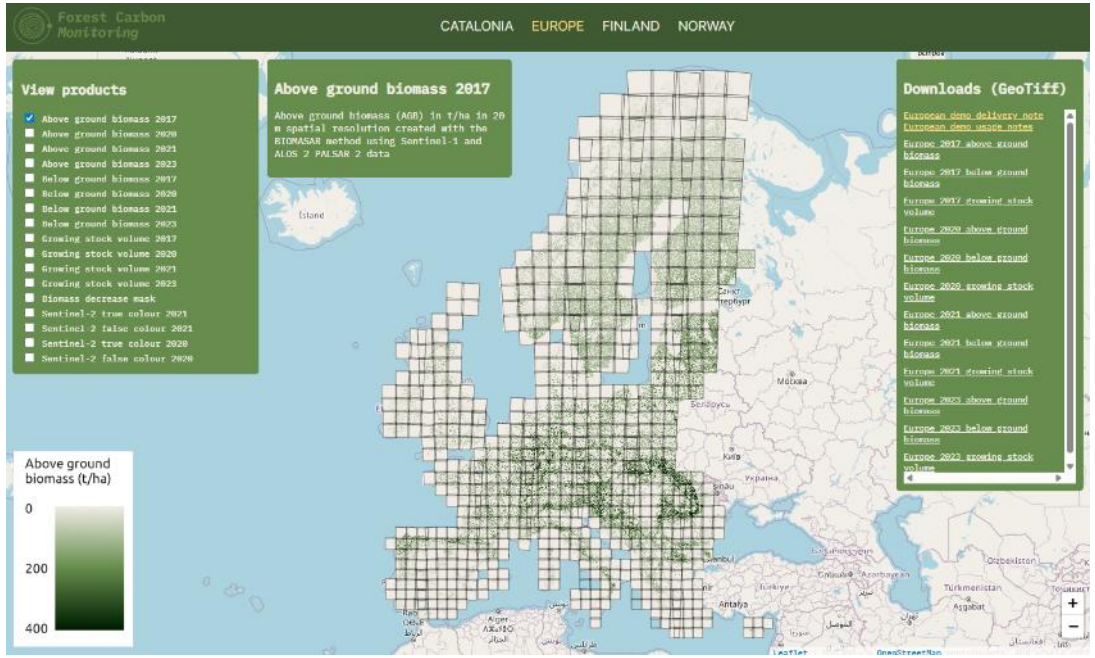


Growing stock volume, Europe



Product delivery portal for publicly available dataset

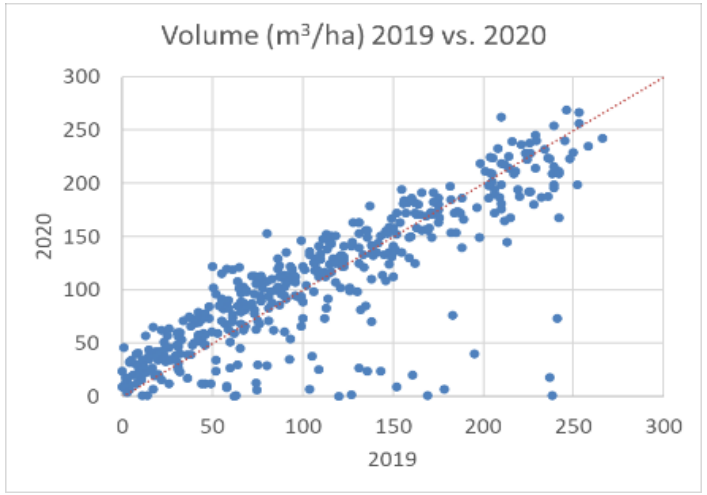
- Product viewing and downloading at: portal.forestcarbonplatform.org/



Findings on output uncertainty in use case demonstrations

Overview of the 12 use case demonstrations:

- Bias typically < 5% of the mean
- Plot level RMSE typically 20-60% of the mean
- Inter-year consistency heavily dependent on remotely sensed imagery and/or availability of annual calibration data



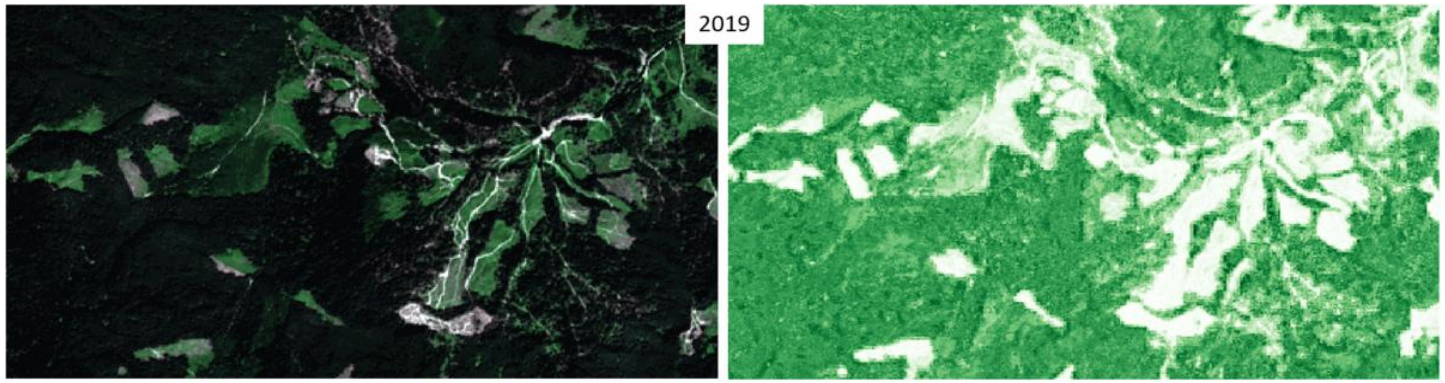
Year-to-year consistency for Volume in Galicia at stand level

Accuracy (RMSE % of mean)*

EO datasets	Traditional ML	Deep learning
Sentinel-1 only	50-80%	30-40%
Sentinel-2 only	20-60%	20-40%
Sentinel-2 + Sentinel-1 or PALSAR2	20-60%	20-40%
Sentinel-2 + Sentinel-1 + TanDEM-X coherence	20-50%	15-25%

* Typical plot level accuracy range between variables and sites.

Detailed descriptions on the levels of performance of all the tools can be found at the FCM ATBD document.



Annual time series of volume estimation in Romania

Highlights of selected tools

GammaS1Geocoding

Preprocessing tool for Sentinel-1 data, for anybody wishing to use analysis ready Sentinel-1 data, matched with Sentinel-2 tiles, in their processes.

Two services are available:

From **GAMMAS1Geocoding** we obtain for each Sentinel-2 tile covered by the selected Sentinel-1 GRD **:**

1. Amplitude files (COG) for VH and VV backscatter
2. Incidence angle files (COG)
3. Layover and shadow mask (COG)

The number of output files depends on the number of Sentinel-2 tiles a S1 scene covers (on average 10 tiles).

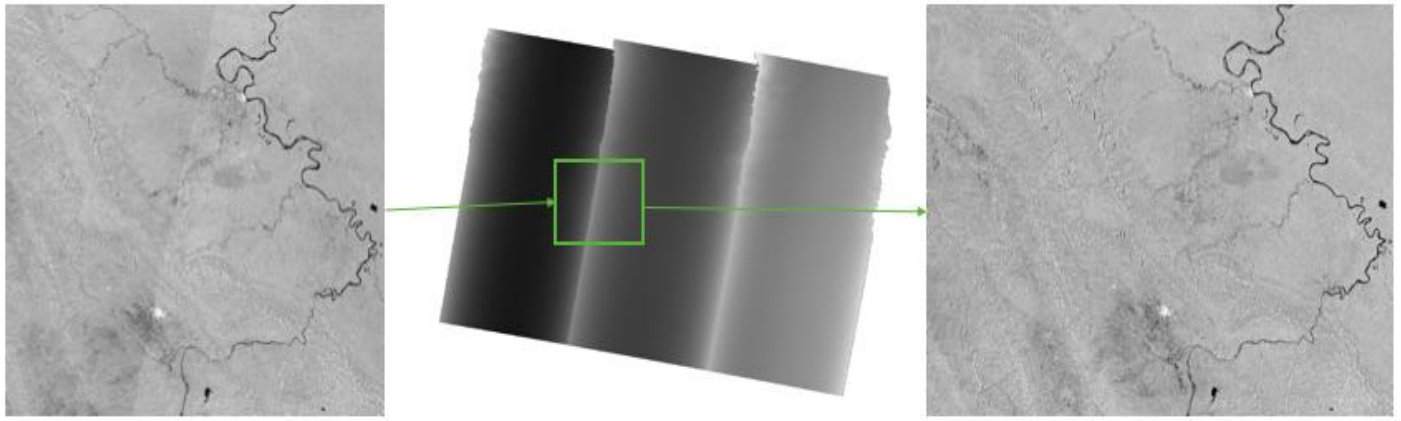
GAMMAS1composites calculates the average backscatter for VV and VH polarizations per Sentinel-2 tile.

GAMMAS1Geocoding pre-processes Sentinel-1 IW data in Ground-range Detected format with the Gamma software (www.gamma-rs.ch), a commercial package for SAR and InSAR processing. Pre-processing steps include:

1. 2 x 2 multi-looking in range and azimuth to obtain pixels with 20 x 20 m^2 ground-range pixel posting
2. compensation for the noise equivalent σ^0 (NESZ)
3. update of orbit state vectors with precision orbits provided by ESA within 20 days after acquisition
4. topographic correction to produce “terrain-flattened” γ^0 intensity images
5. geocoding and orthorectification based on the Copernicus 1-arcsecond Digital Elevation Model (DEM) to the target UTM map grid with 20 x 20 m^2 pixel size.

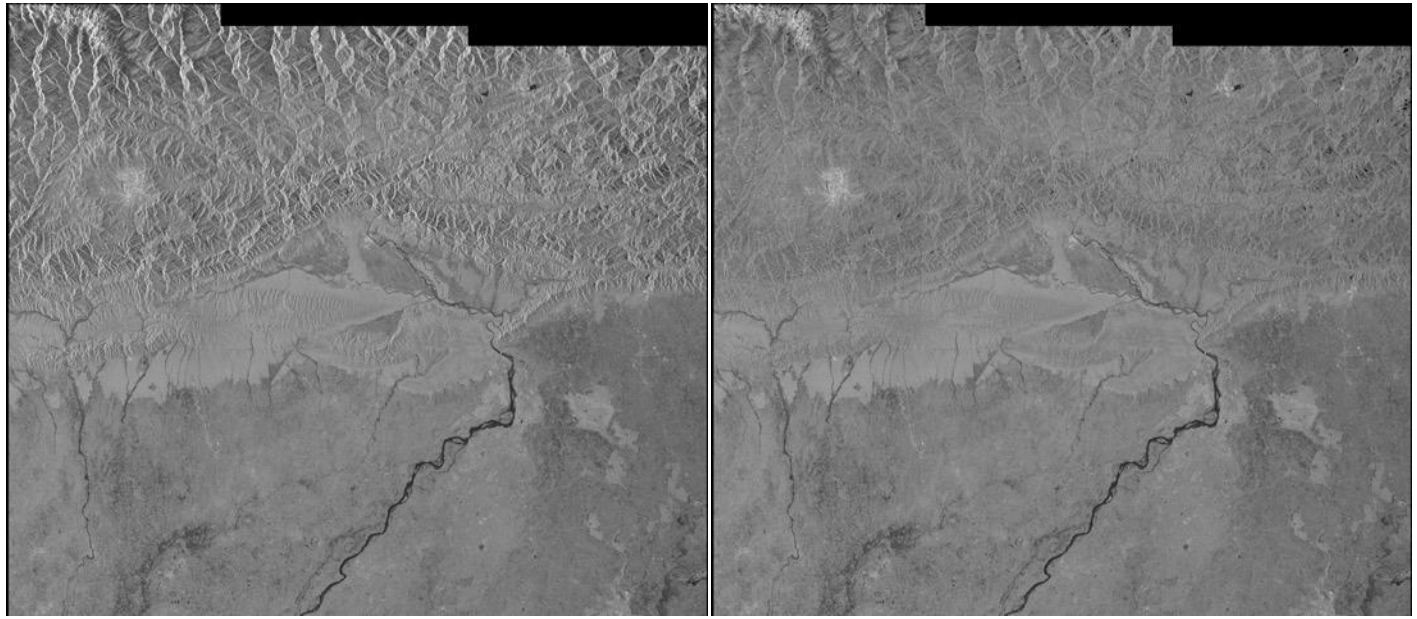
GammaS1Geocoding

NESZ compensation reduces radiometric differences in range and harmonizes backscatter between the three sub-swaths acquired by S1 in IW TOPS mode, in particular in areas of low backscatter (e.g., water surfaces).



Intensity image before (left) and after (right) subtracting the NESZ (centre)

Terrain-flattening includes pixel-area normalization (Frey et al., 2013) and conversion to γ^0 to minimize topographic effects and dependence of backscatter on the local incidence angle.

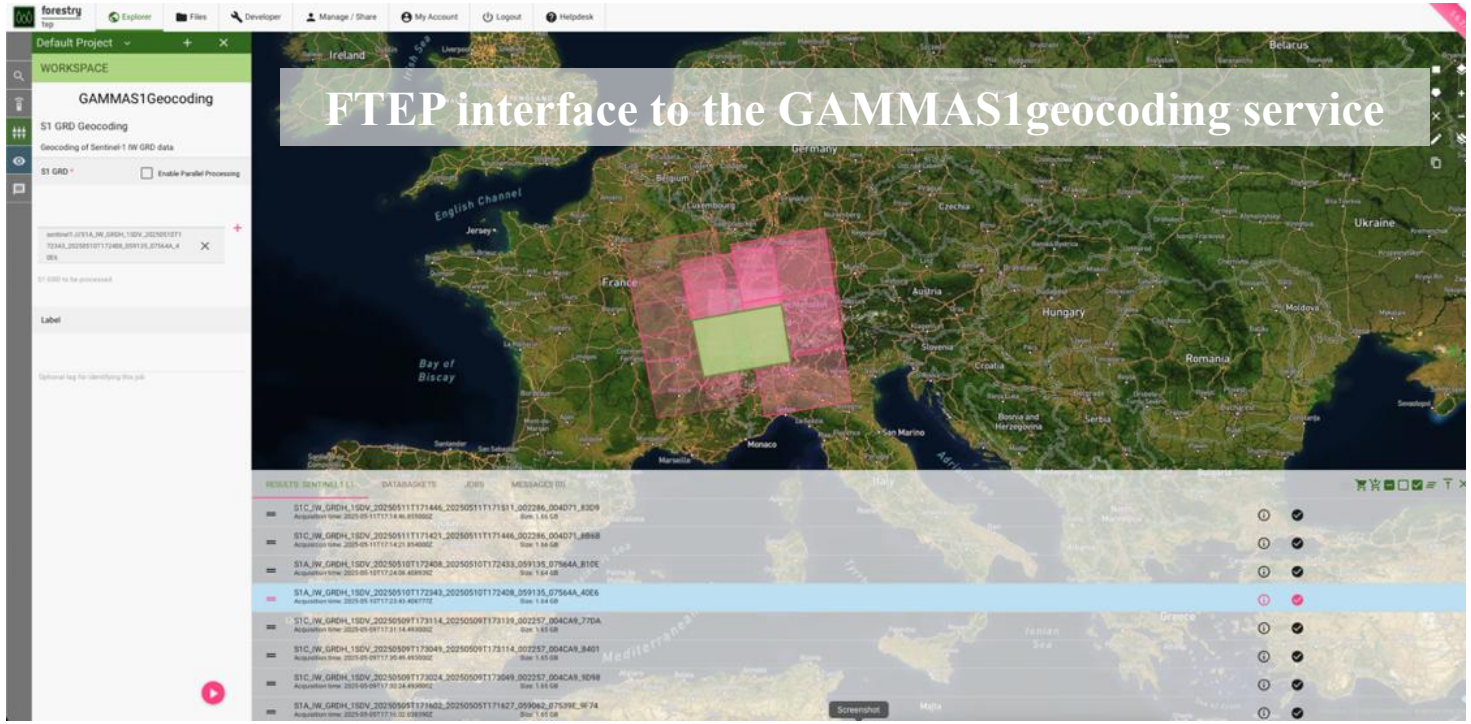


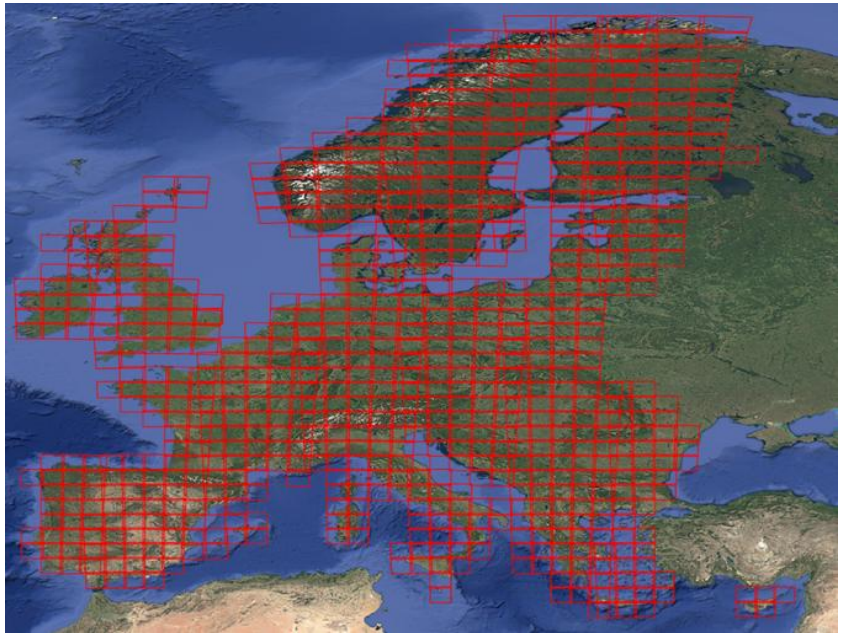
Intensity image before (left) and after (right) topographic correction.

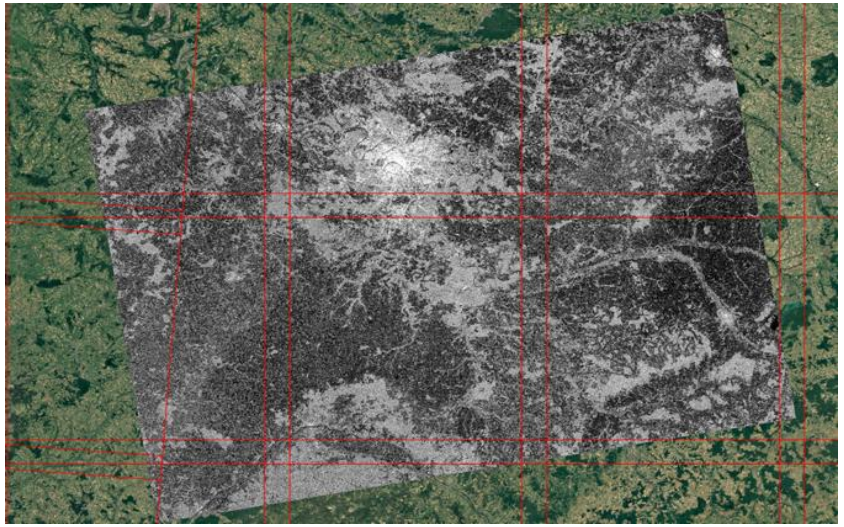
GammaS1Geocoding

- S1 pre-processing currently possible for 746 S2 UTM tiles covering Europe

- S1 Image selection and pre-processing can be done via the Forestry TEP online interface or can be orchestrated via Forestry TEP API in case many S1 images are to be processed



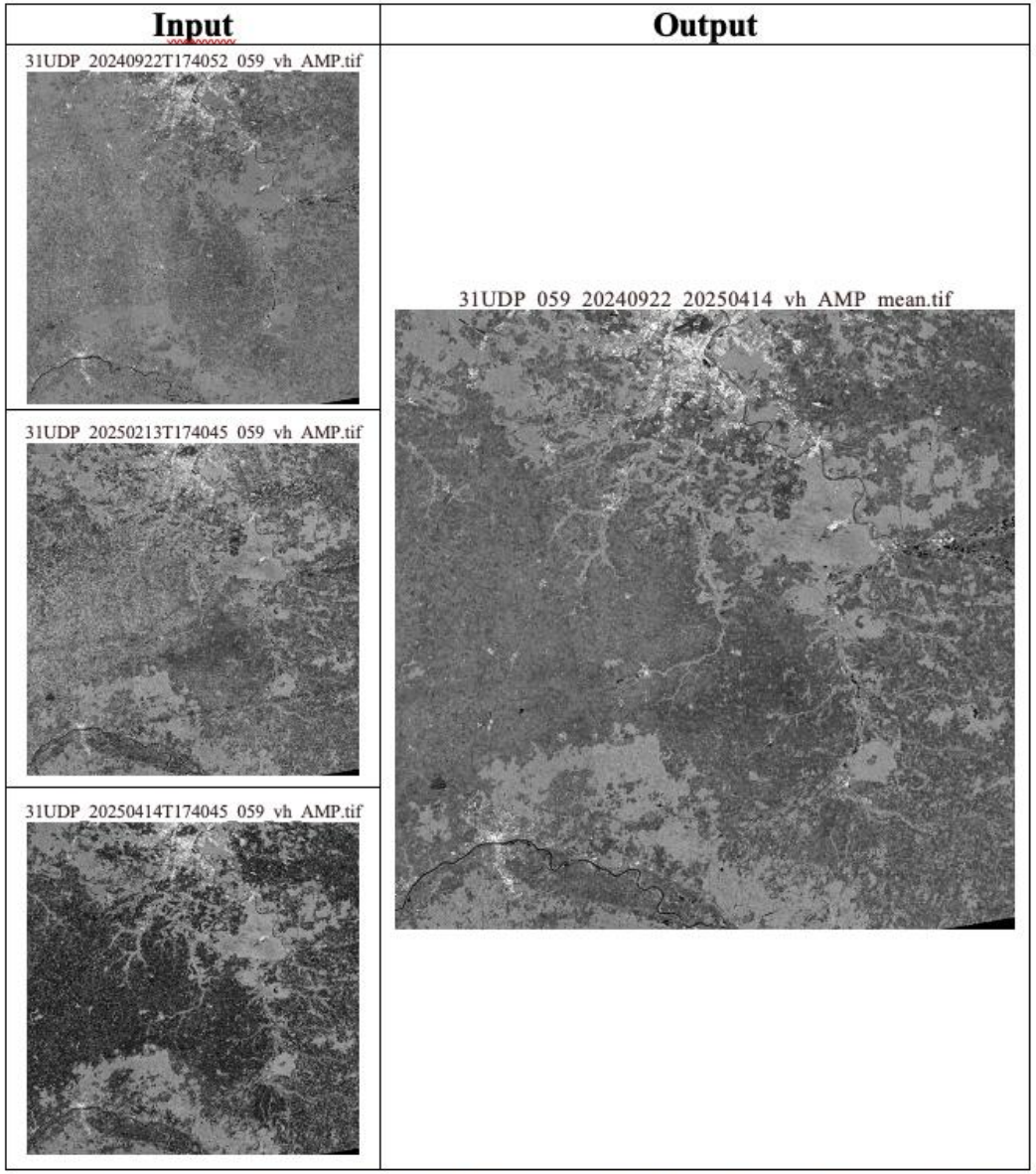




GammaS1composites

- This Forestry TEP service allows for calculating the average multi-temporal backscatter in different temporal intervals, e.g., annual or monthly

- Calculation done per S2 tile across all selected pre-processed S1 images or separately for each orbital track (relative orbit)



Multitemporal backscatter image (right) calculated from three S1 acquisitions (left).

GAMMA REMOTE SENSING

Sentinel-2 Analysis Ready Mosaic (S2ARM)

- A Docker-based processing tool designed to generate cloud-minimized, analysis-ready Sentinel-2 mosaics for forestry and land-cover applications.

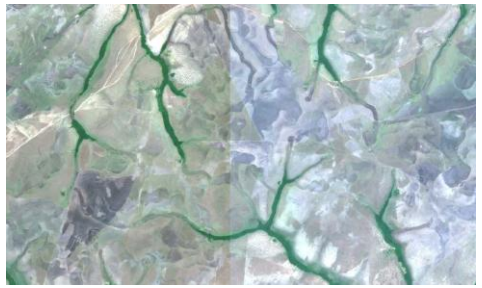
- Input data: Sentinel-2 Level-2A (BOA reflectance)
- Spatial unit: Single Sentinel-2 tile (e.g., T35VNE)
- Output: Analysis-ready GeoTiff suitable for GIS and EO analytics
- Execution environment: Docker container integrated into Forestry TEP processing workflows

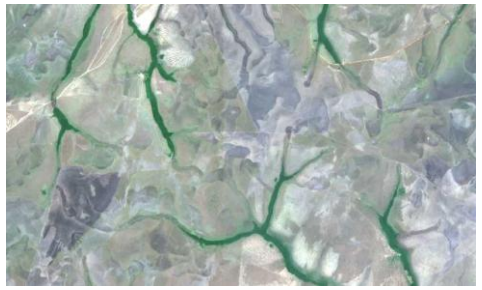
For reference: European wide mosaics for 2020 and 2021 created with this tool available for viewing and download at the FCM portal: https://portal.forestcarbonplatform.org/

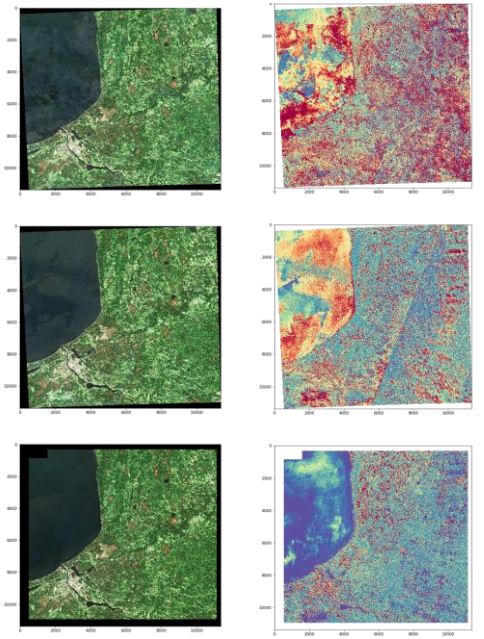
Sentinel-2 Analysis Ready Mosaic (S2ARM)

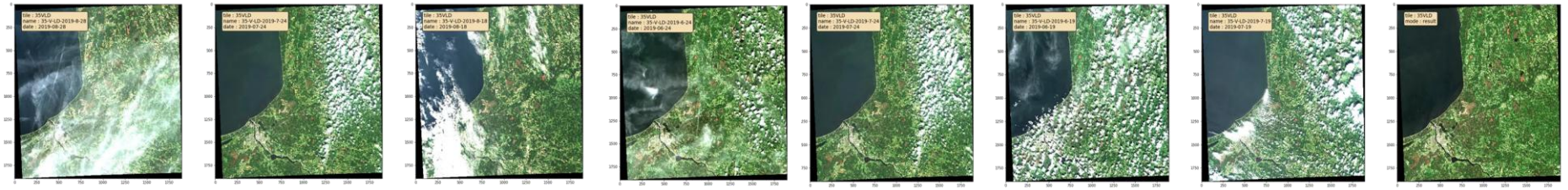
Processing chain

- Selection of best available images
- Pixelwise merging
- Multi-band composite image generation









Sentinel-2 Analysis Ready Mosaic (S2ARM)

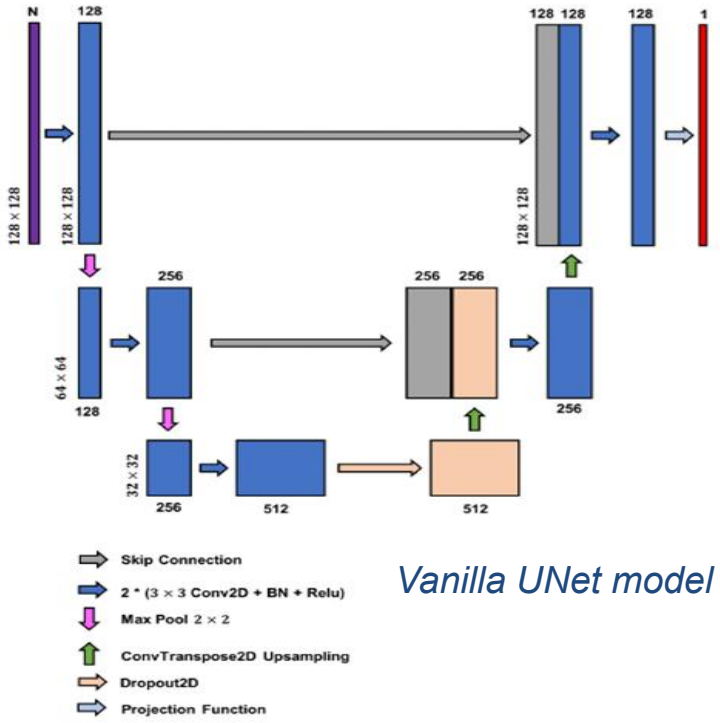
Input Parameters

Parameter Name	Description	Type / Format	Example
tile	Identifier of the Sentinel-2 tile to be processed	String (TMS grid code)	T35VNE
timeranges	Beginning and end of the time range for image selection	String	2022-05-01:2023-07-08
cloud_coverage	Maximum allowed cloud cover percentage per input scene (from metadata)	Integer (%)	20
data_coverage	Minimum allowed data cover percentage per input scene (from metadata)	Integer (%)	70
min_median_coverage	Minimum allowed median number of valid observations per pixel	Integer	4
bands	The bands to be used in the AR process	String	B02-B03-B04-B05-B08-B11-B12
resolution	Pixel resolution of the output GeoTiff	Integer (10 or 60)	10

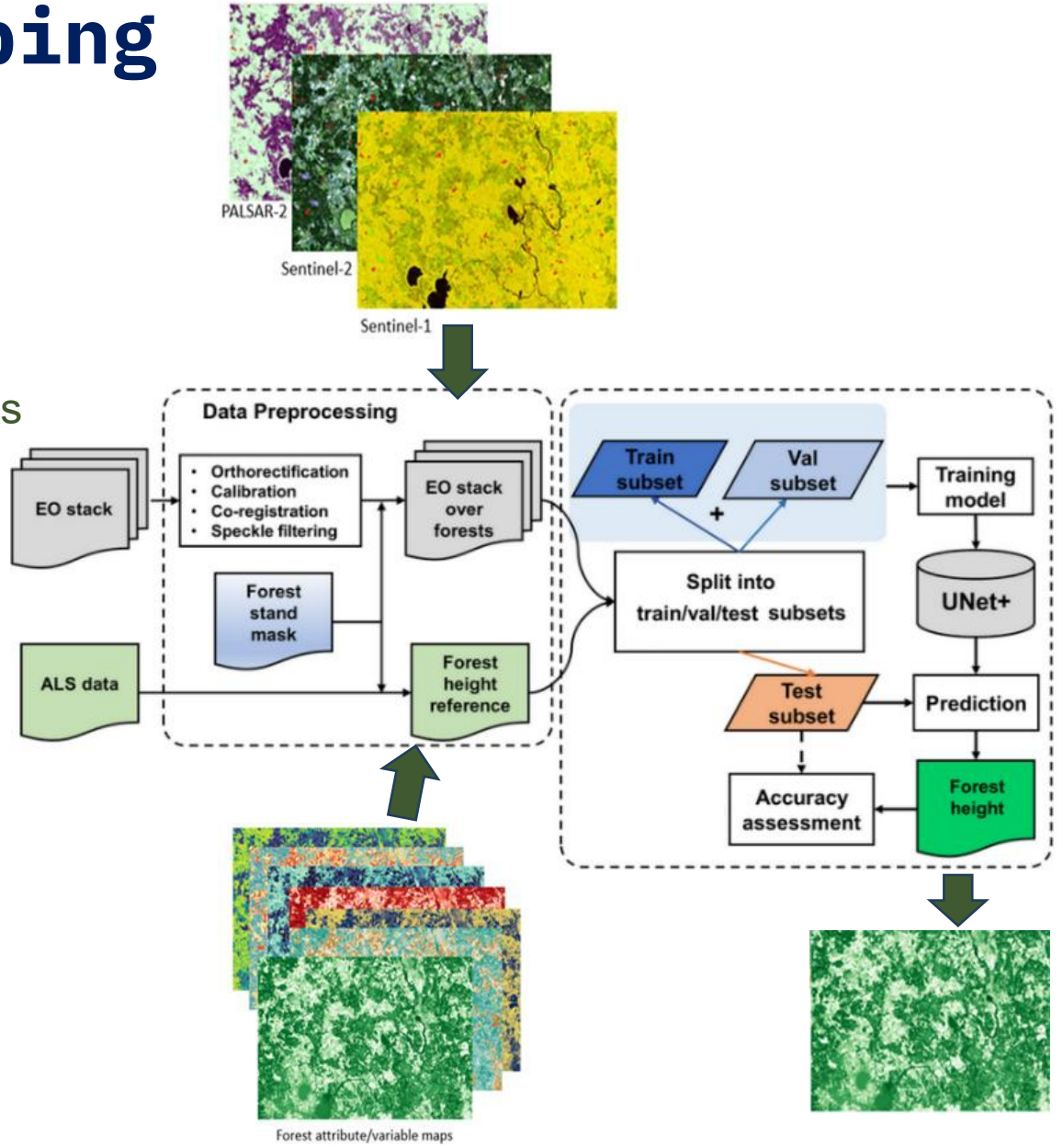
UNet tools for forest mapping

Scientific basis:

1. Vanilla UNet model using multi-source EO data
2. Training data: Forest resource maps based on Airborne Laser Scanning (ALS) data
3. Transfer of the model to target year or area with field plots



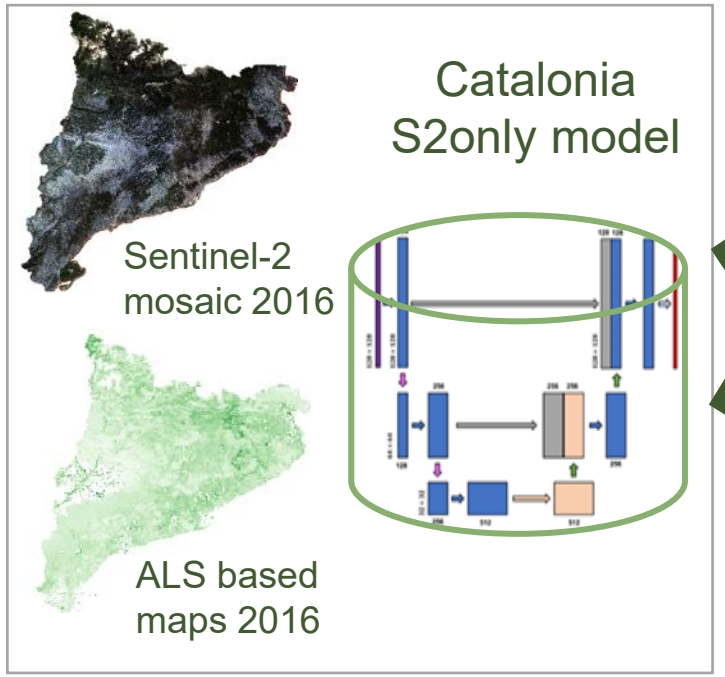
Vanilla UNet model



UNet tools application

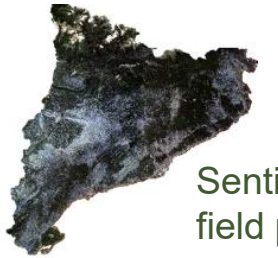
Currently available base models:

- 17 base models
  - 5 Catalonia
  - 8 Finland
  - 4 Norway
- 5 attributes
  - V, H, D, G, AGB
- 2 data combinations
  - S2 only
  - S2S1P2



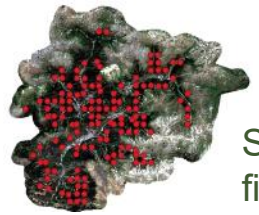
UNetFineTuning tool

Temporal transfer to 2024



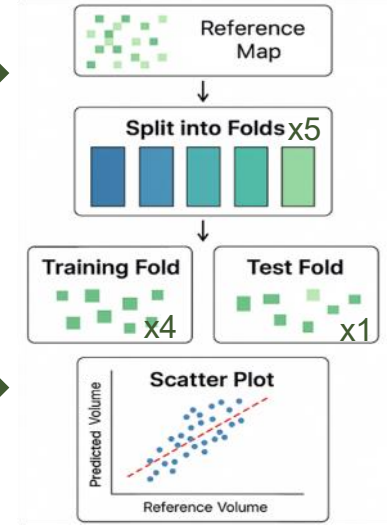
Sentinel-2 and field plots 2024

Geographic transfer to Andorra

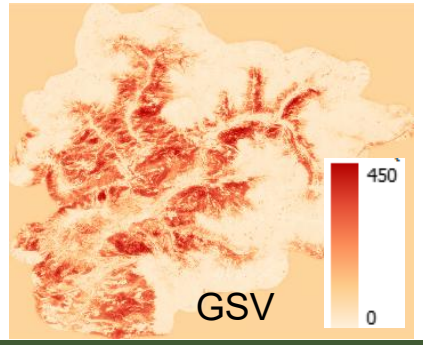


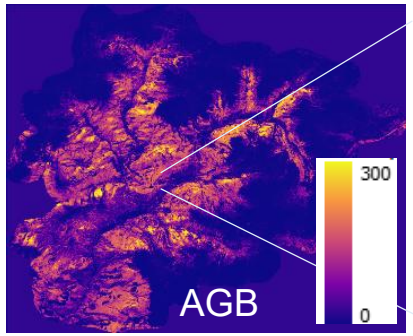
Sentinel-2 and field plots 2022

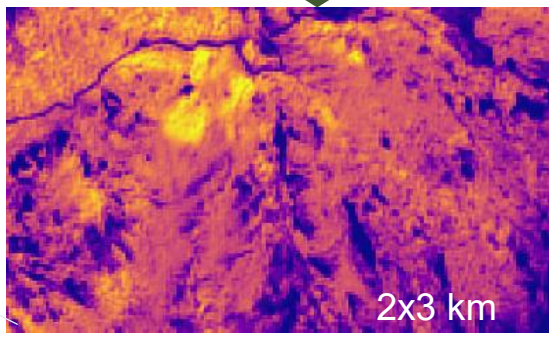
Error metrics

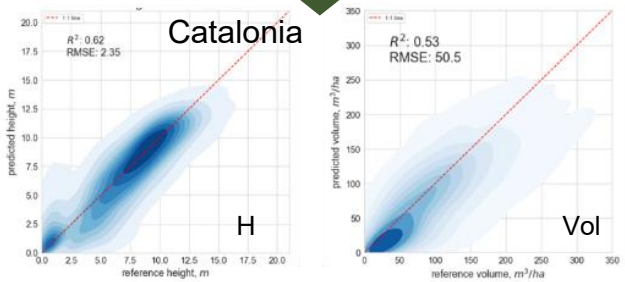


UNetPredictor tool









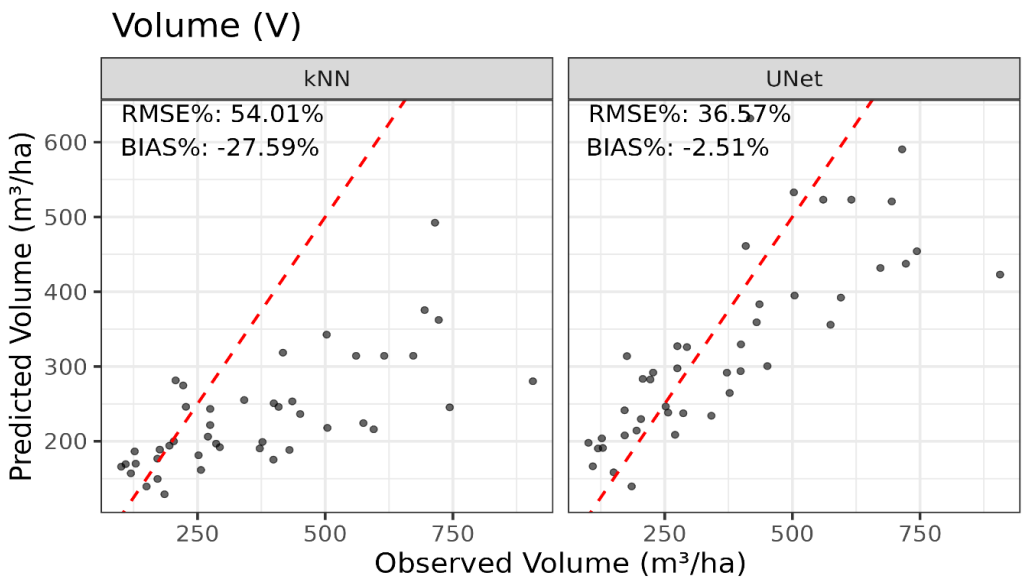
Andorra	H	D	G	V	AGB
RMSE	1.8	5.2	12.0	76.9	52.0
RMSE %	15.5	36.1	28.6	29.7	36.1
Bias	-0.3	-0.7	-0.9	-12.7	-6.7
Bias %	-2.5	-4.7	-2.1	-4.9	-4.7

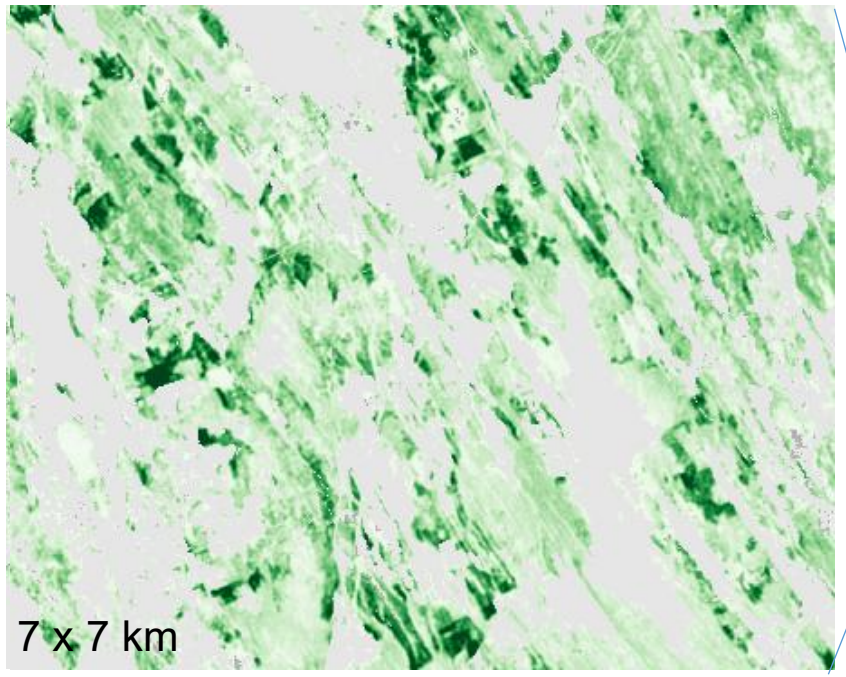
Ge et al. (2023) Deep learning models with transfer learning in boreal forest mapping using multi-source satellite SAR/InSAR and optical images, *Remote Sensing* 15: 5152. DOI: 10.3390/rs15215152

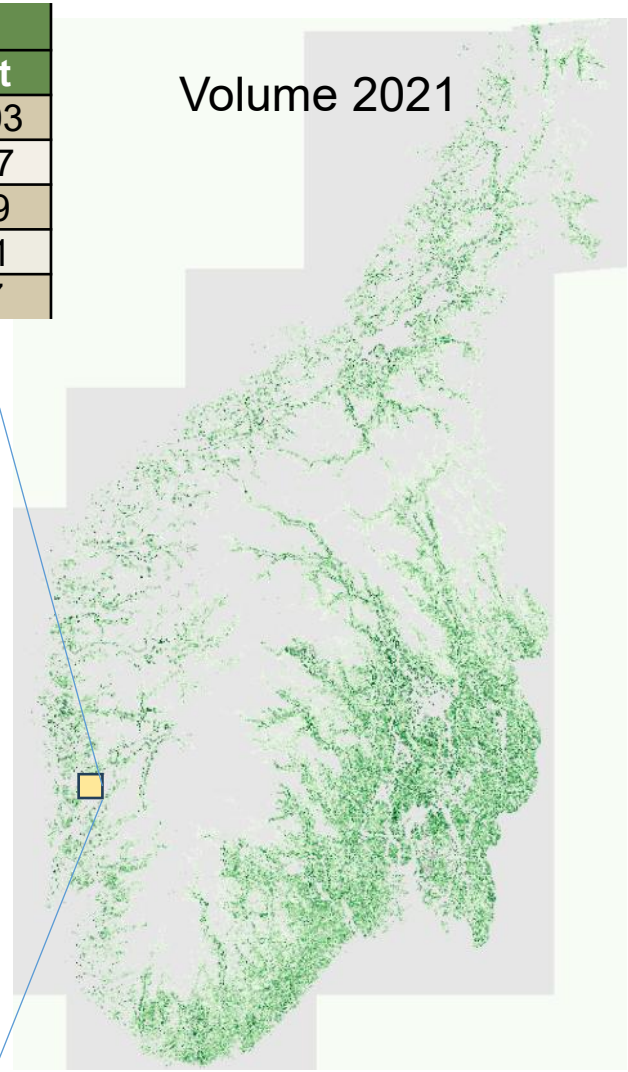
Example results from Norway use case

- Mapping of Norway (south of Trondelag) for 2017, 2019, 2021 and 2023
- Improved map accuracy compared to the k-NN method, particularly on stand level
- More information and example products at: portal.forestcarbonplatform.org/

	Plots		Stands	
	k-NN	UNet	k-NN	UNet
RMSE	85.16	66.54	165.47	112.03
RMSE %	80.0	62.5	54.01	36.57
Bias	6.15	10.78	-84.52	-7.69
Bias %	5.8	10.1	-27.59	-2.51
R^2	0.45	0.66	0.27	0.67





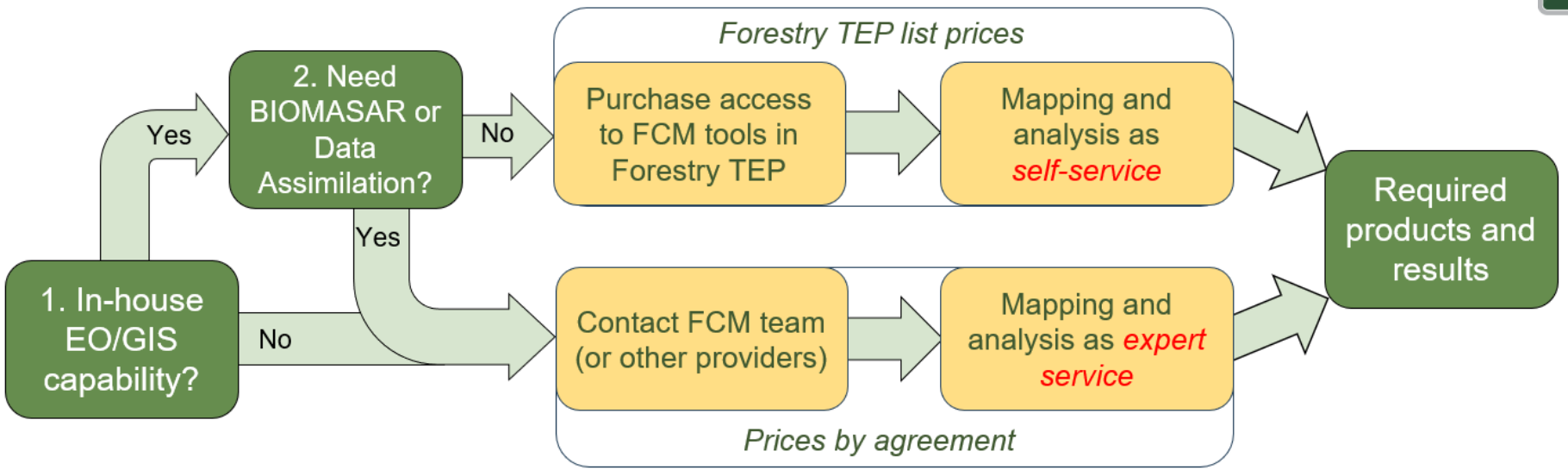


Forestry TEP and access to the tools

How to access the FCM tools

1. *Self-service:*

The users can acquire access to the FCM tools on Forestry TEP and conduct the analysis.



- The FCM use case demonstrations were implemented on Forestry TEP

forestry tep

2. *Expert service:*

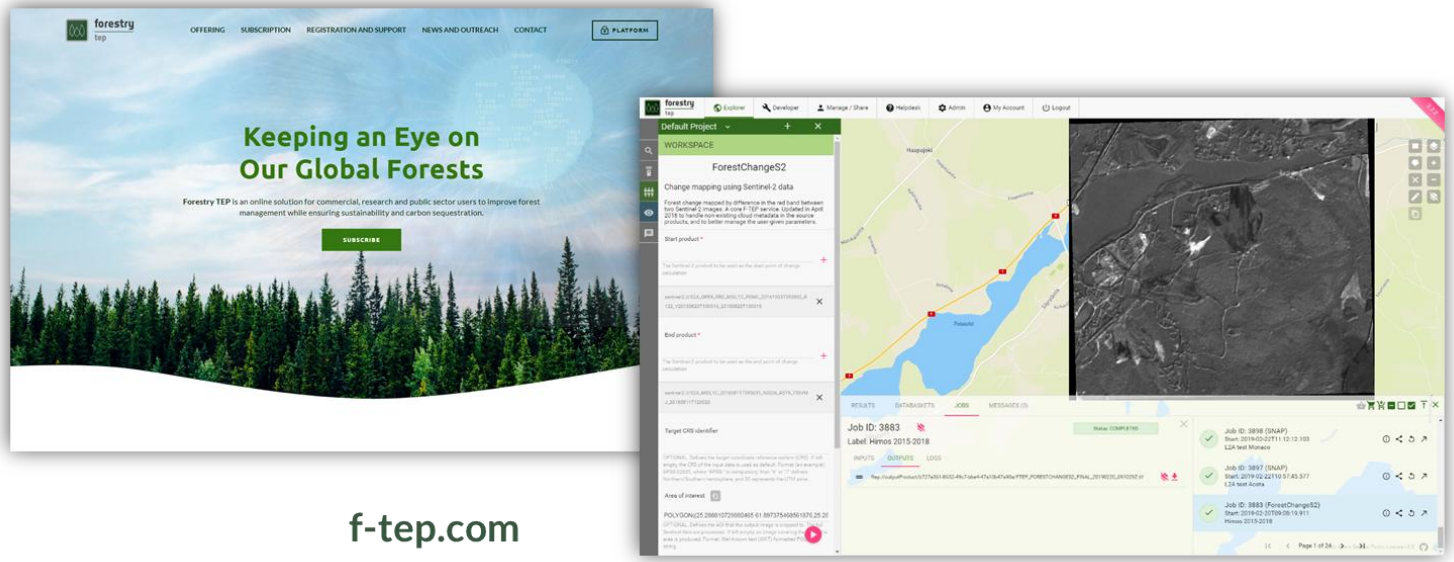
The users can purchase the mapping and analysis as an expert service from qualified service providers.

- Agreement between the user and the service provider.
- BIOMASAR and Data Assimilation offered only as expert services by

GAMMA REMOTE SENSING and YUCATROTE forest modelling & analytics

Forestry TEP – Overview

Forestry TEP is an online solution for forest analyses based on satellite data. The platform is offered primarily on a subscription basis, and individual processing services by partner providers and by VTT are additionally being introduced.



f-tep.com

Key platform features include:

- Hosted satellite data
- Hosted processing services
- Service development interface
- Multi-language support
- Scalable computing and storage
- Data uploading
- Sharing and publishing
- Interactive tools
- REST API and Python client interface for external access

Forestry TEP
Free use opportunity

- The European Space Agency (ESA) promotes the uptake of platform services via the Network of Resources (NoR), where VTT / Forestry TEP is an eligible service provider
- **For research and pre-commercial uses, users can get sponsored for free access to the platform services**

- Guidance: f-tep.com/sponsorship
- Questions? Contact us via **f-tep.com**

forestry
tep

Forest Carbon Monitoring tools on Forestry TEP

- **Probability** for classification and estimation
- **k-NN** for predicting forest properties or other variables
- **UNet** for variable prediction with UNet models and model finetuning
- **Prebasso** for forest growth and ecosystem carbon balance modelling
- **AutoChange** for change detection between multispectral images utilizing clustering

by subscription

- **GAMMAS1Geocoding** by *GAMMA Remote Sensing*
  - terrain geocoding of Sentinel 1 GRD products
- **Sentinel-2 Analysis Ready Mosaic (S2ARM)** by *Terramonitor*
  - cloud free image compositing using data from a specified time range

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Forest Carbon Monitoring tools
by subscription

Probability

ProbaCluster
ProbaModel
ProbaEstimates

+ supporting tools:
Sentinel2ToGeotiff
Fmask
ProductPostProcessing

30 h processing / m
100 GB storage

150 €
monthly

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k-NN

UNet

Prebasso

Prebasso

+ supporting tools:
ProductPostProcessing

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100 GB storage

150 €
monthly

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AutoChange

AutoChange
AutoChangeFCM

+ supporting tools:
Sentinel2ToGeotiff
ThresholdMasking
Fmask

30 h processing / m
100 GB storage

250 €
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Probability

- Probability is a classification and estimation toolset
- ProbaCluster, ProbaModel and ProbaEstimates are the included tools for producing variable estimations

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Probability	k-NN	UNet	Prebasso	AutoChange
ProbaCluster ProbaModel ProbaEstimates	kNearestNeighbours			AutoChange AutoChangeFCM
+ supporting tools: Sentinel2ToGeotiff Fmask ProductPostProcessing	*+ supporting tools:* Sentinel2ToGeotiff Fmask ProductPostProcessing LeaveOneOutMetrics			*+ supporting tools:* Sentinel2ToGeotiff ThresholdMasking Fmask
30 h processing / m 100 GB storage	30 h processing / m 100 GB storage			30 h processing / m 100 GB storage
150 € monthly	150 € monthly	monthly	monthly	250 € monthly
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k-NN

- The kNearestNeighbours tool enables predicting forest properties or other user specified target variables using the k Nearest Neighbours (kNN) algorithm

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Probability	k-NN	UNet	Prebasso	AutoChange
ProbaCluster ProbaModel ProbaEstimates *+ supporting tools:* Sentinel2ToGeotiff Fmask ProductPostProcessing 30 h processing / m 100 GB storage 150 € monthly ORDER	kNearestNeighbours *+ supporting tools:* Sentinel2ToGeotiff Fmask ProductPostProcessing LeaveOneOutMetrics 30 h processing / m 100 GB storage 150 € monthly ORDER	**UNetFineTuning** **UNetPredictor** *+ supporting tools:* Sentinel2ToGeotiff Fmask **30 h** processing / m **100 GB** storage **250 €** **monthly** **ORDER**	monthly ORDER	monthly ORDER

UNet

- The UNetPredictor tool allows forest variable prediction with UNet models
- The UNetFineTuning tool is included for finetuning the UNet model with sample plot data

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Probability	k-NN	UNet	Prebasso	AutoChange
ProbaCluster ProbaModel ProbaEstimates *+ supporting tools:* Sentinel2ToGeotiff Fmask ProductPostProcessing 30 h processing / m 100 GB storage 150 € monthly ORDER	monthly ORDER	monthly ORDER	Prebasso *+ supporting tools:* ProductPostProcessing 30 h processing / m 100 GB storage 150 € monthly ORDER	AutoChange AutoChangeFCM *+ supporting tools:* Sentinel2ToGeotiff ThresholdMasking Fmask 30 h processing / m 100 GB storage 250 € monthly ORDER

Prebasso

- Prebasso allows forest growth and ecosystem carbon balance modelling
- Can be used with either Geopackage or raster inputs

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Probability	k-NN	UNet	Prebasso	AutoChange
ProbaCluster ProbaModel ProbaEstimates *+ supporting tools:* Sentinel2ToGeotiff Fmask ProductPostProcessing 30 h processing / m 100 GB storage 150 € monthly ORDER	kNearestNeighbours *+ supporting tools:* Sentinel2ToGeotiff Fmask ProductPostProcessing LeaveOneOutMetrics 30 h processing / m 100 GB storage 150 € monthly ORDER	monthly ORDER	monthly ORDER	AutoChange AutoChangeFCM *+ supporting tools:* Sentinel2ToGeotiff ThresholdMasking Fmask 30 h processing / m 100 GB storage 250 € monthly ORDER

AutoChange

- AutoChange enables change detection between two multispectral images, utilizing K-means clustering and subdivision of clusters
- AutoChangeFCM is included for post-processing, to produce a biomass change mask, through masking the outputs based on change type and magnitude

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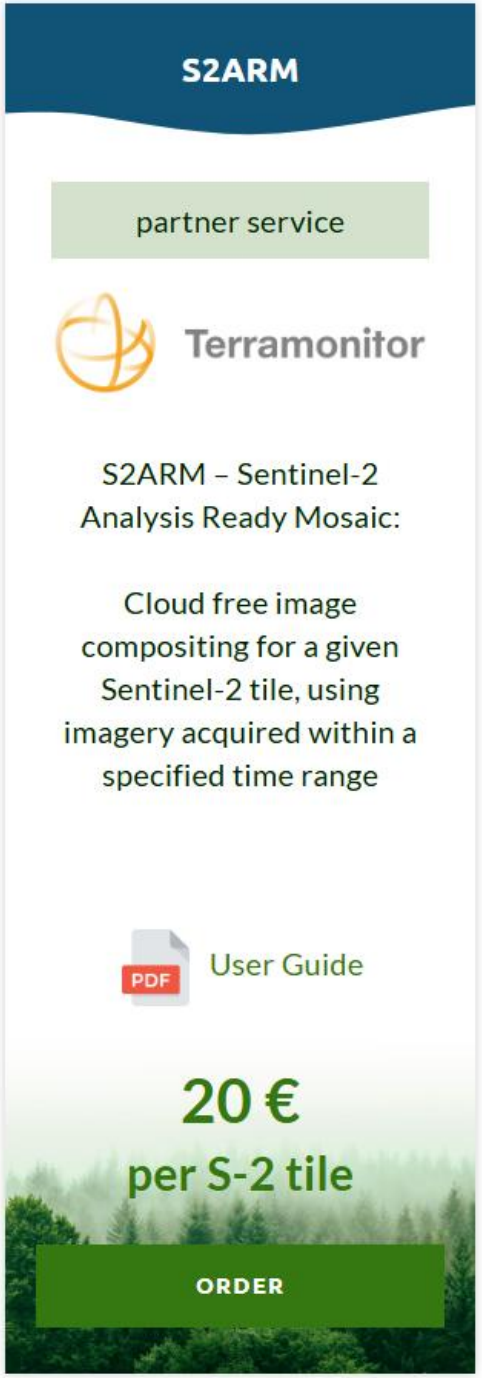

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k-NN

kNearestNeighbours

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AutoChange

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GAMMAS1Geocoding

partner service

GAMMA REMOTE SENSING

Terrain geocoding of Sentinel-1 GRD products

Add-on option (+ 2 €):
GAMMAS1composites for temporal means

Volume discounts:
20% for 1000+ scenes
40% for 5000+ scenes

User Guide

20 €
per S-1 scene

ORDER

S2ARM

partner service

Terramonitor

S2ARM – Sentinel-2 Analysis Ready Mosaic:

Cloud free image compositing for a given Sentinel-2 tile, using imagery acquired within a specified time range

User Guide

20 €
per S-2 tile

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f-tep.com/services/

esa

Forest Carbon Monitoring

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forestcarbonplatform.org

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