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# 26th IUFRO World Congress

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Photo: Björn Olin

# Fine-Grained Soil Particle Size Prediction Using GeoAI and LiDAR for Precision Harvesting Applications

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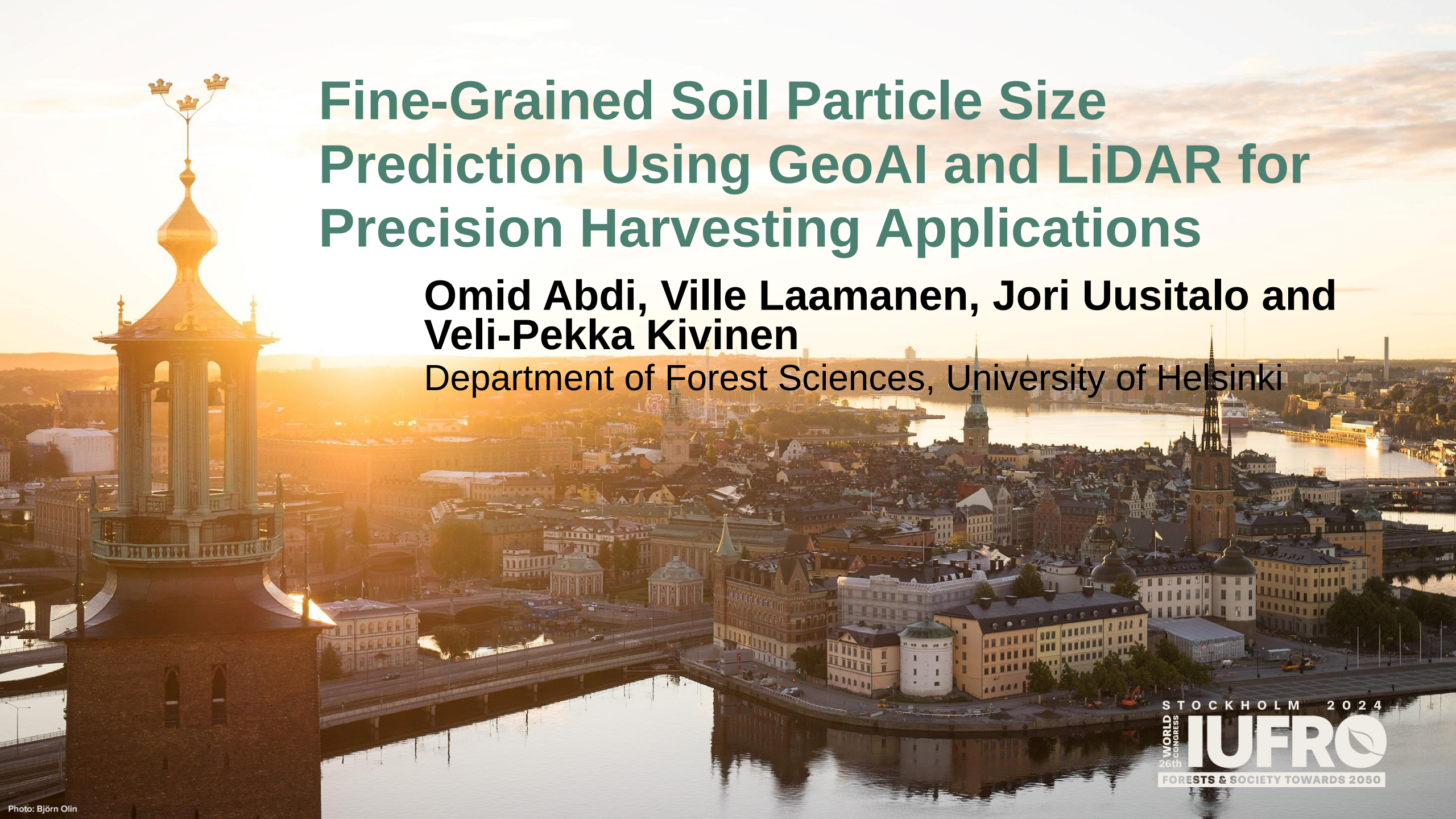
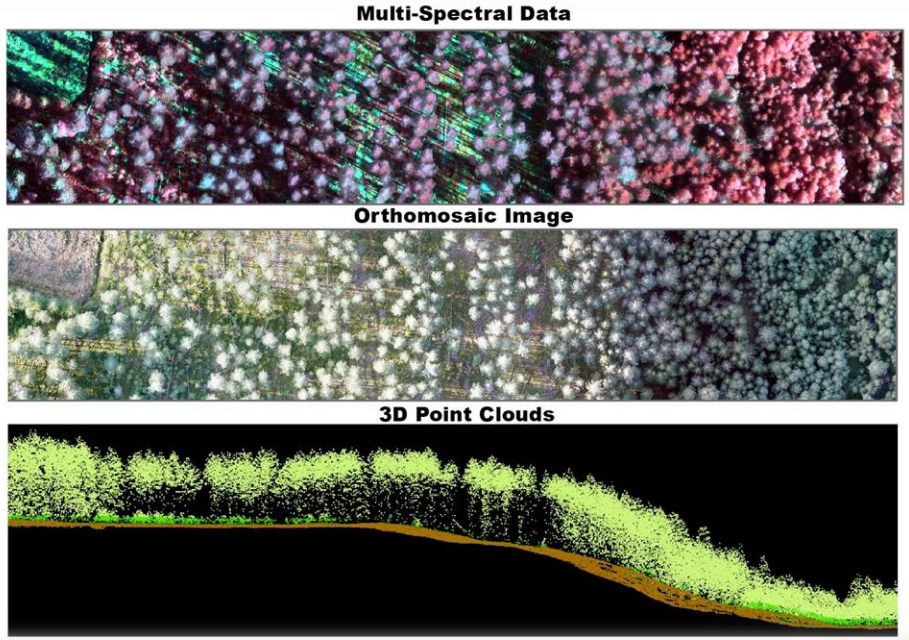


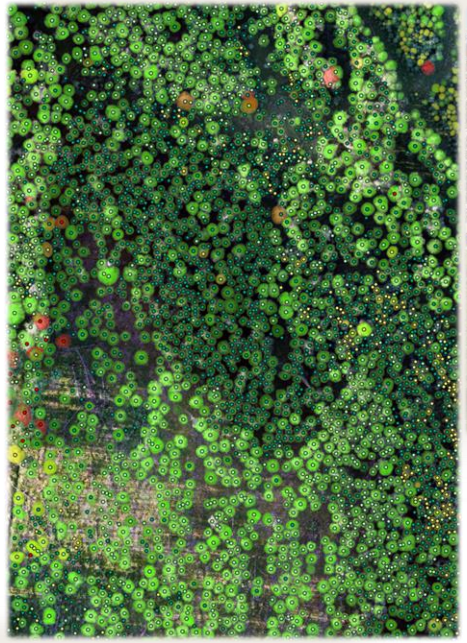
# LUOMUHAKKUU

*This work is part of the Luomuhakkuu-project that is funded by the NextGenerationEU -funds*

**Euroopan unionin rahoittama**

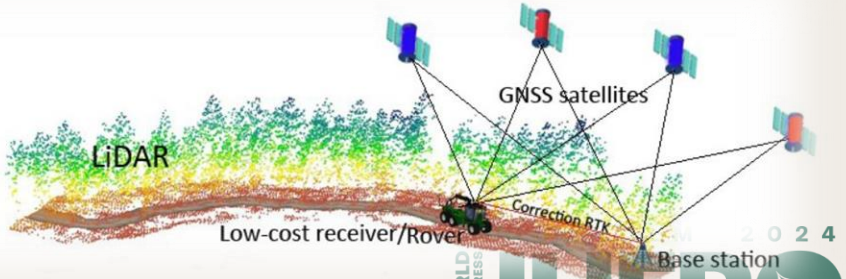
NextGenerationEU



*Single tree detection*


*Forest simulation*

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# Introduction

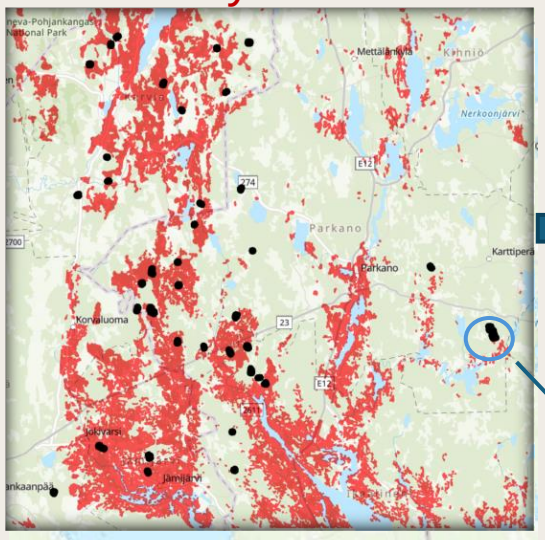
- Fine-grained soil particles (clay < 2 µm and silt < 60 µm)
- The importance of fine-grained soil particle sizes in precision harvesting (soil-bearing capacity)
- Challenges of mapping soil particles in forest (soil properties and sampling)
- Geospatial Artificial Intelligence (GeoAI) for digital soil mapping

# Objectives

- To identify the top covariates for mapping fine-grained soil particle sizes
- To develop a deep learning-based approach that utilizes high-density LiDAR data and Sentinel derivatives to estimate the values of fine-grained soils in boreal forests, Finland

# Local Prediction of Soil Particle Size

## Study Stands

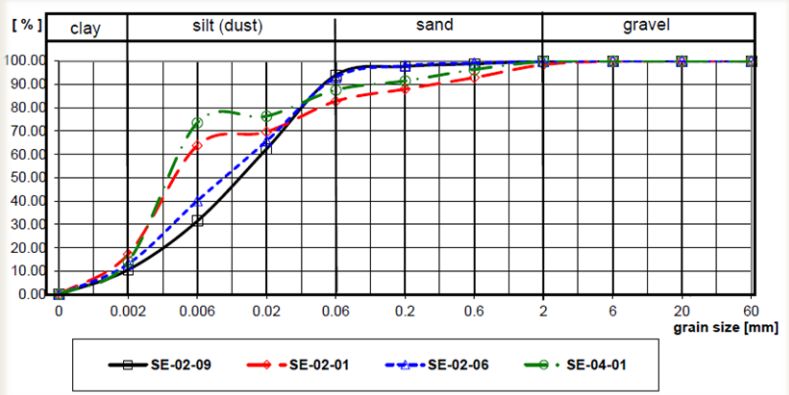




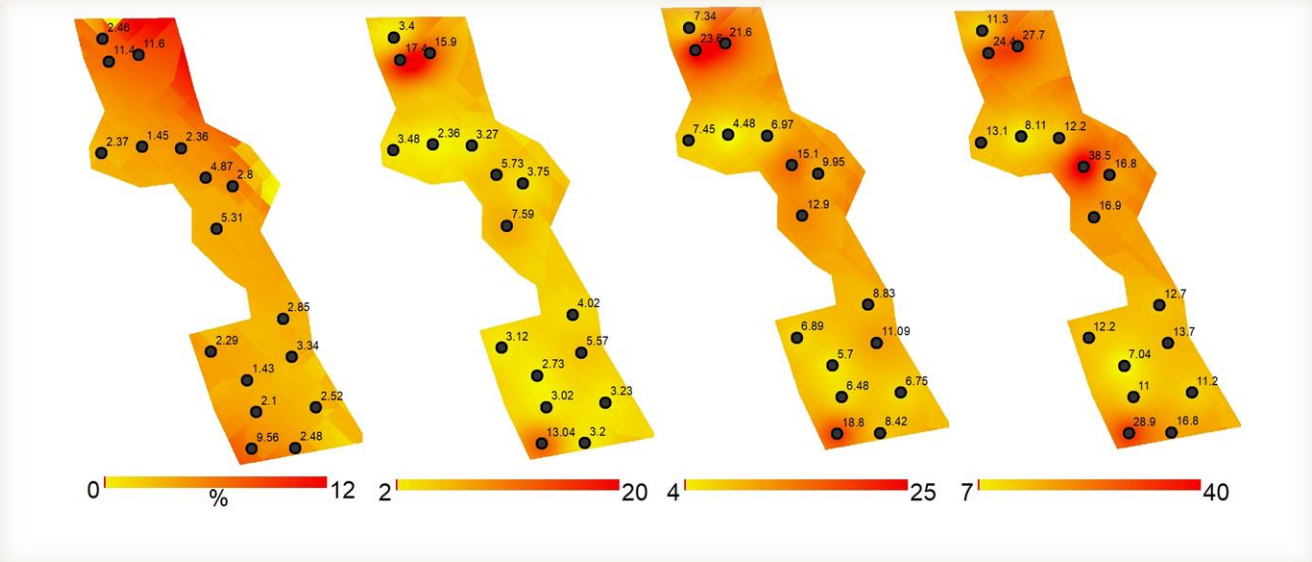
Sites: 47
Soil samples: 330

## LS 230 Laser Diffraction

## Grain Size Analysis




< 2.0 µm  2.0 – 6.0  6.0 – 20  20 – 60

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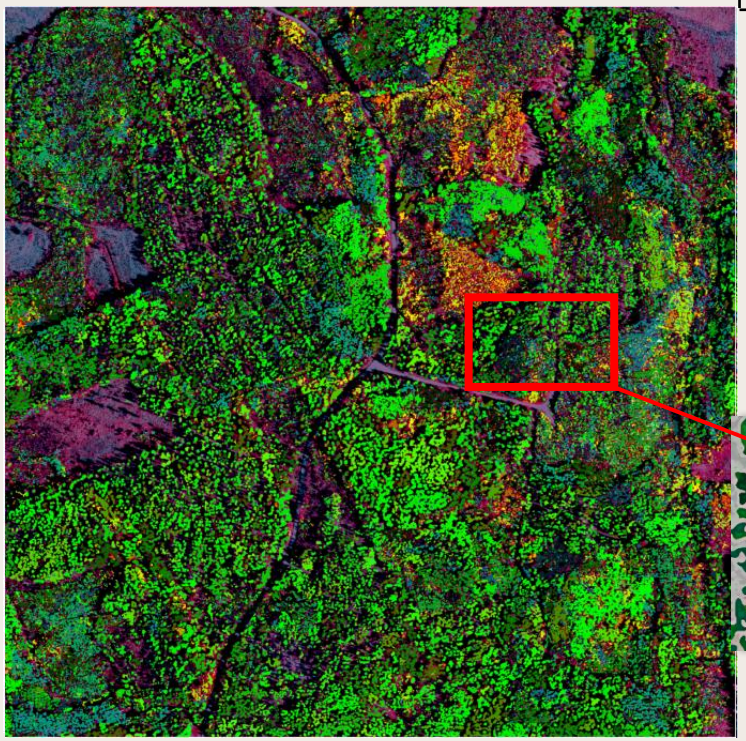
# Forest Segments (Zones)

- Tree species classification
- Tree clumping
- Segmentation
- Segments/ Zones



Open Source Data

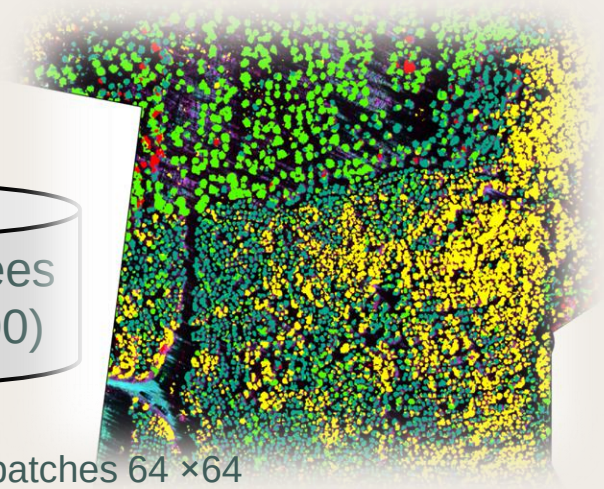
CHM (LiDAR)

IR-image (Nir-R-G)

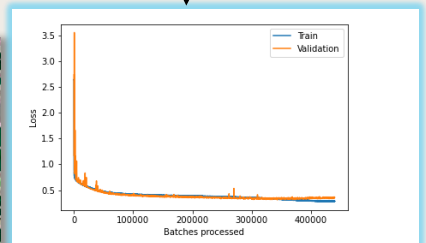
CHM-NIR-R-G

PSPNET

Single Trees (up 60,000)



Segments




**Analysis of the model**

**Per class metrics:** Pine Spruce Birch Aspen Open

| | NoData | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| **precision** | 0 | 0.859644 | 0.775792 | 0.802361 | 0.897426 | 0.885280 |
| **recall** | 0 | 0.875057 | 0.771236 | 0.786544 | 0.858977 | 0.879011 |
| **f1** | 0 | 0.867282 | 0.773508 | 0.794374 | 0.877781 | 0.882134 |

- Training data: patches 64 ×64
- Training models: Pretrained models
- Evaluate model

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# Soil Covariates

LiDAR-based

## Geomorphometry

*Accumulation Curvature*
*Curvedness*
*Gaussian Curvature*
*Horizontal Excess Curvature*
*Vertical Excess Curvature*
*Tangential Curvature*
*Ring Curvature*
*Plan & Profile Curvature*
*Difference Curvature*
*Mean & Total Curvature*
*Min & Max Curvature*
*Rotor*
*Ruggedness Index*
*Shape Index*
*Slope*
*Standard Deviation of Slope*
*Unsphericity*
*Aspect*
*Diff From Mean Elev*
*Downslope Index*
*Wetness Index*
*Roughness*
*Openness*
*Elevation (Breach Dep.)*

## Hydrology

*Average Flowpath Slope*
*Average Upslope Flowpath Length*
*Quinn Flow Accumulation*
*Hydrologic Connectivity (Upslope & Downslope)*

## Trees

*Mean Height*
*Max Height*
*Crown coverage*
*Majority of Species*
*Diversity of Species*

LiDAR (5 P)

Sentinel-based

## Soil indices

$$bi = \sqrt{(R^2 + G^2)/2}$$

$$bi2 = \sqrt{(R^2 + G^2 + NIR^2)/3}$$

$$bsi = \frac{(SWIR2 + R) - (NIR + B)}{(SWIR2 + R) + (NIR + B)}$$

$$SATVI = \left(\frac{SWIR1 - R}{SWIR1 + R + L}\right) \times (1 + L) - \frac{SWIR2}{2}$$

$$Clay\ \text{Index} = \frac{SWIR1}{SWIR2}$$

- Time series 2017- 2023 (May – November)
- Mask green vegetation (NDVI: - 0.15 – 0.20)
- Mask residuals (NBR2: - 0.15 – 0.15)

## Organisms

*TVI*
*EVI*
*SATVI*
*SAVI*
*MSI*
*GNDVI*
*GRVI*
*LSWI*
*TSAVI*
*MSAVI*
*MSAVI2*
*WDVI*
*RI*
*CI*
*TNDVI*
*WDVI*
*WDRVI*
*MYVI*
*MGVI*
*Intensity*
*CVI*

# GeoAI-based Models for Prediction of Soil Particle Sizes

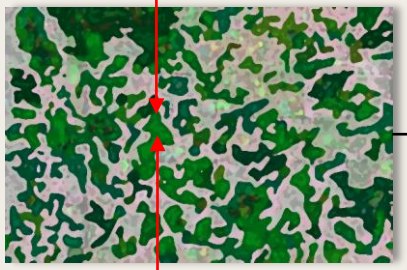
Evaluation: ME, RMSE and $R^2$

Soil Covariates

Soil Particle Sizes

Summarize Values into Zones

> 34,000



Object Features

Random Forest/ Regression

Top Covariates

< 2.0 µm

2.0 – 6.0

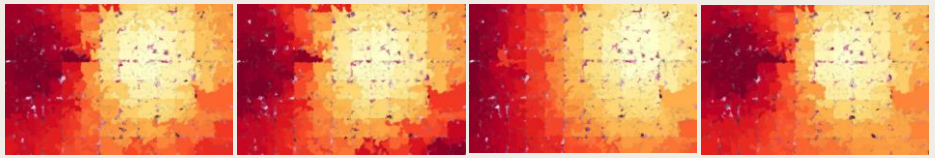
6.0 – 20

20 – 60

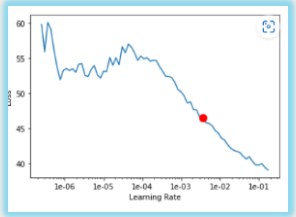
Fully Connected Neural Network

Prediction

< 2.0 µm | 2.0 – 6.0 | 6.0 – 20 | 20 – 60



Tuning models

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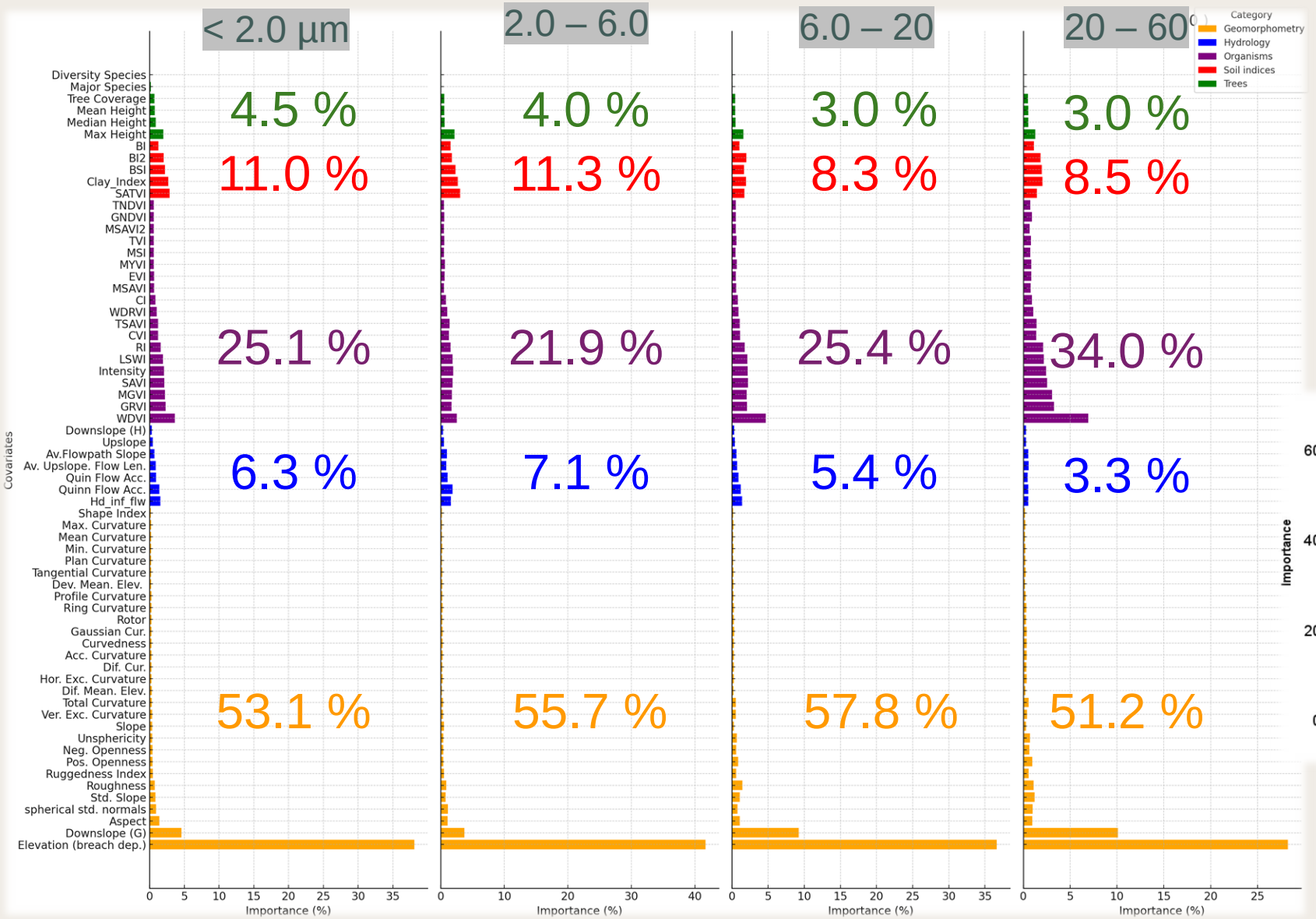
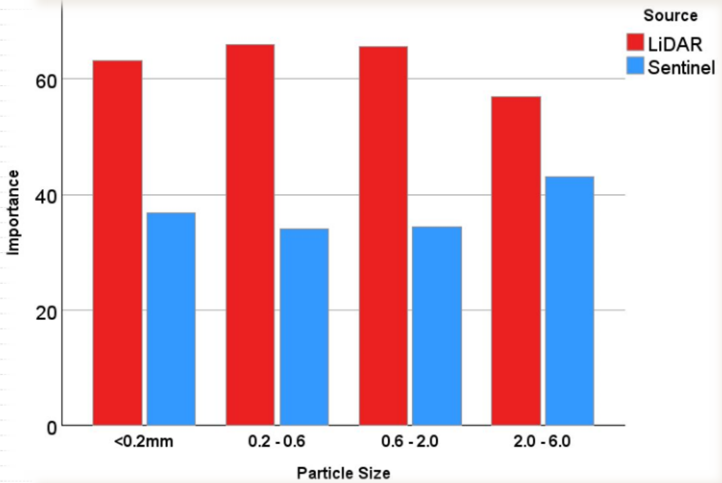
# The Importance of Covariates




## Validation Data ($R^2$)

**1**: 0.865
**2**: 0.883
**3**: 0.870
**4**: 0.859

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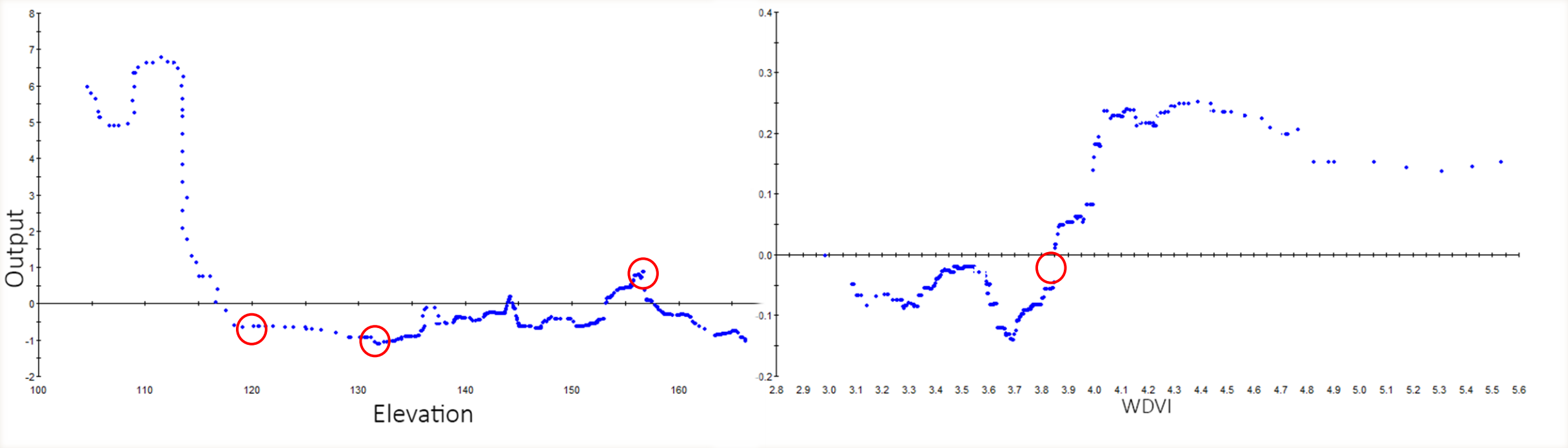
# Partial Dependency of Covariates (< 2 µm)

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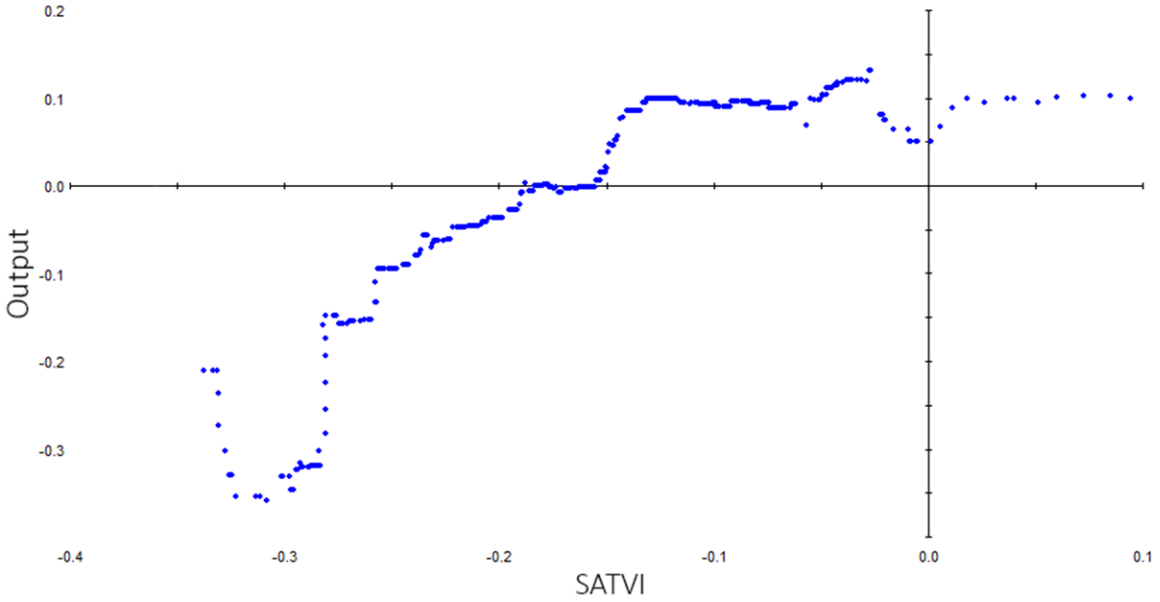


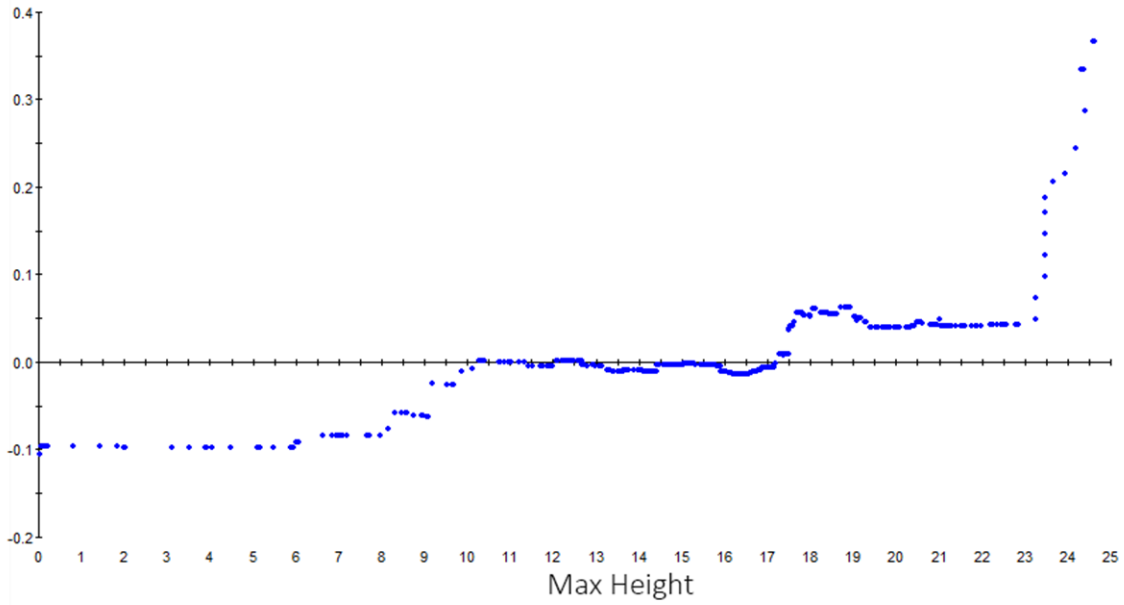


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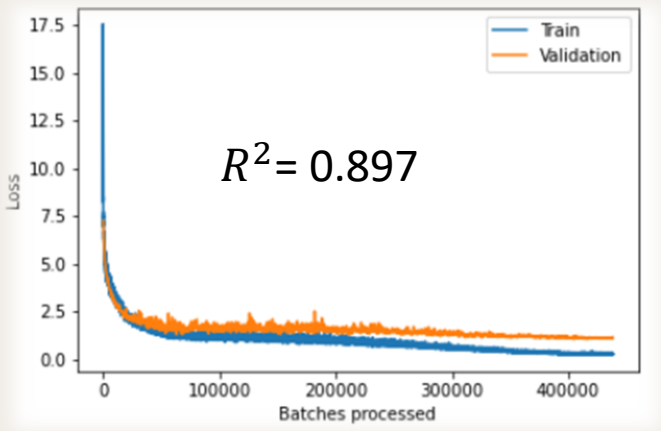
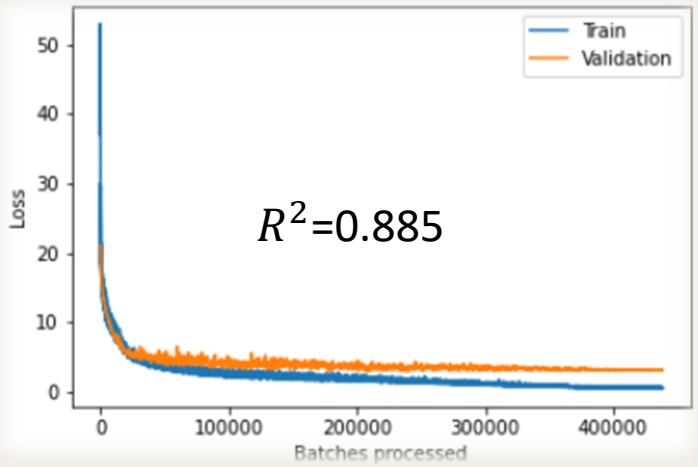
# Performance of FCNN

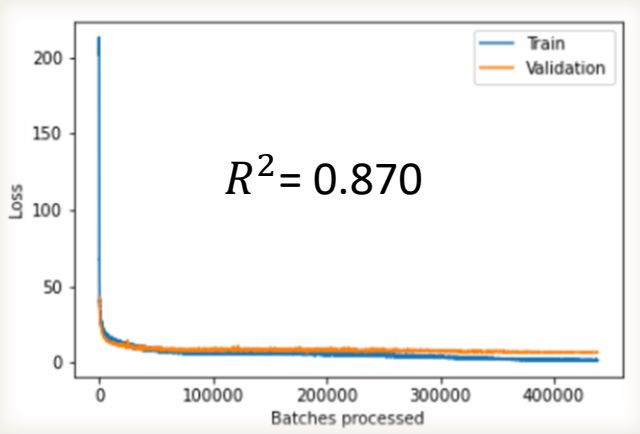
< 2.0 µm



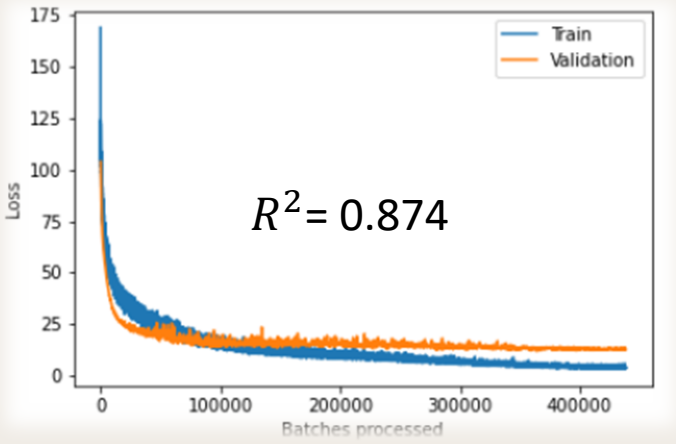

2.0 – 6.0




6.0 – 20




20 – 60

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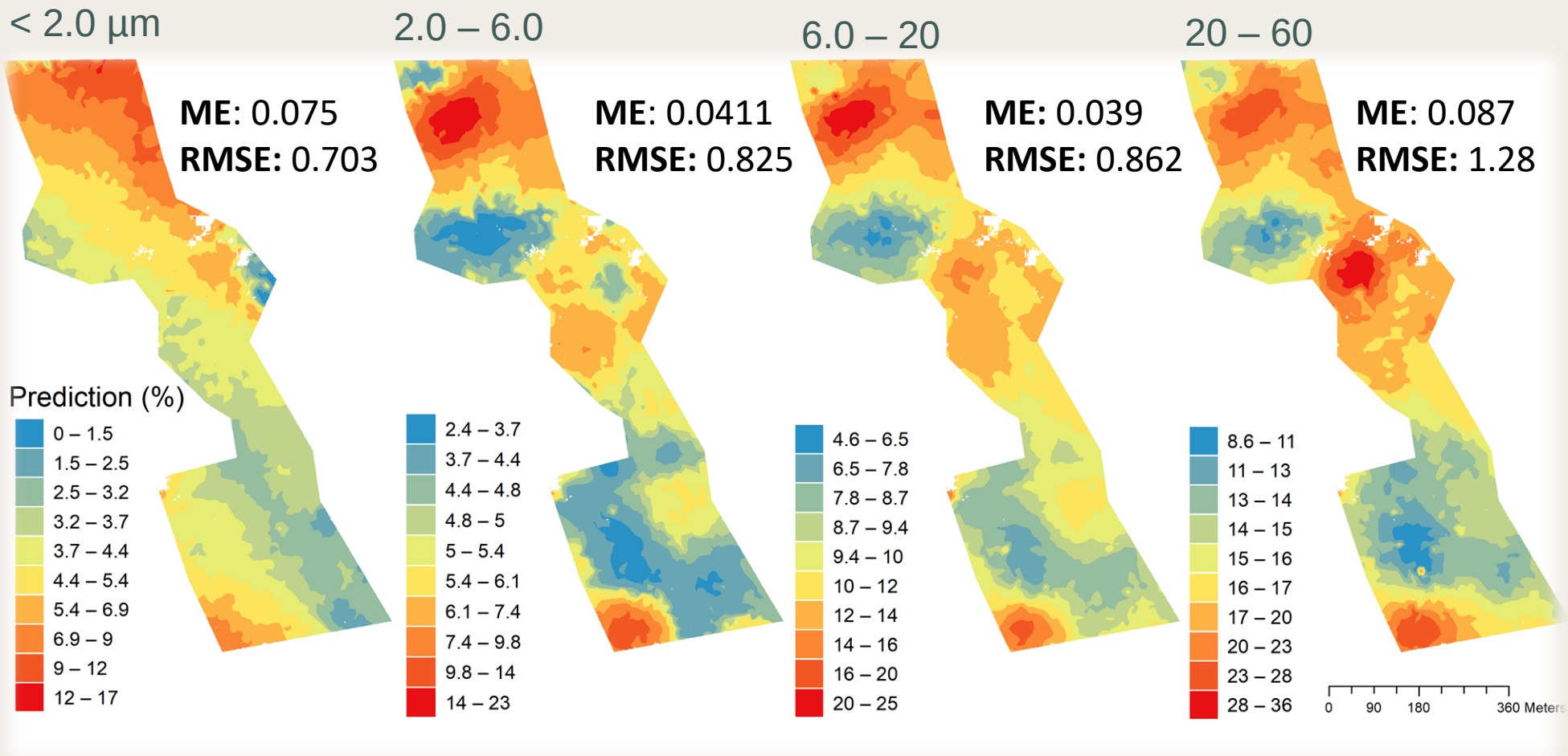
# Prediction Maps (FCNN)

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# Summary

- Local predictions of soil particle sizes have enhanced the potential for augmenting soil training data for mapping via machine learning and deep learning techniques
- LiDAR data significantly improved the extraction of various soil covariates related to geomorphometry, hydrology, and tree attributes
- Organisms-derived variables demonstrated substantial importance in mapping all fine-grained particle sizes of soil, particularly those in the 20 – 60 µm range
- The digital elevation model, after removing depressions (Breach Depression) and incorporating downslope covariates, is crucial for predicting all fine-grained particle sizes of soil
- The Random Forest model exhibited high performance in selecting top covariates for soil mapping
- The FCNN performed well in mapping fine-grained soils; however, its performance slightly declined with an increase in particle size
- Our trained models have high potential for precision harvesting, particularly in predicting soil bearing capacity

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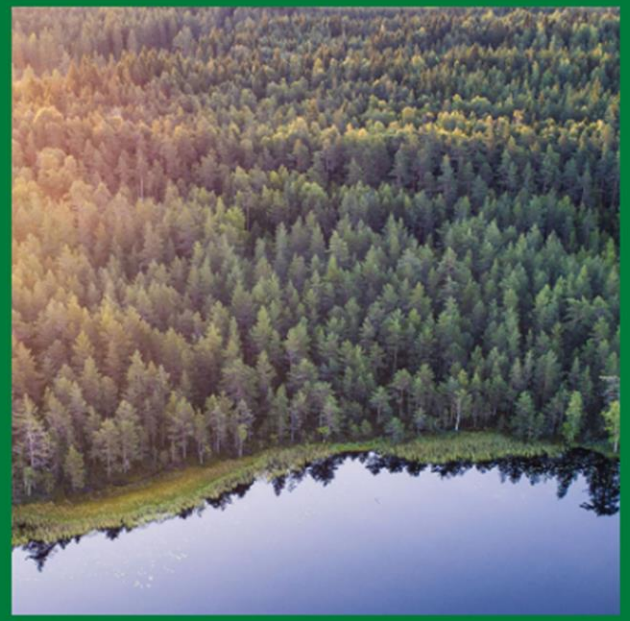
Ajankohtaista Tutkimus Tietoa hankkeesta Kumppanit Yhteystiedot



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## Luonnonmukainen täsmäpuuhakkuu

Luonnonmukaisella täsmäpuuhakkuulla tarkoitetaan puunkorjuuoperaatiota, joka ottaa huomioon luonnon omat erityispiirteet ja jossa päätöksenteko puuvalinnasta ja metsänkäsittelymenetelmästä tehdään mikrokuviotasolla. Helsingin yliopiston metsätieteiden osaston johtaman tutkimusprojektin tavoitteena on kehittää, testata ja jalkauttaa käytäntöön menetelmiä, joiden avulla metsäalan käytännön toimijat voivat toteuttaa luonnonmukaista täsmäpuunkorjuuta.

KATSO YHTEISTYÖKUMPPANIT

# Thank you!

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