# Hyperspectral Satellite Imagery for Digital Twinning of Boreal Forests

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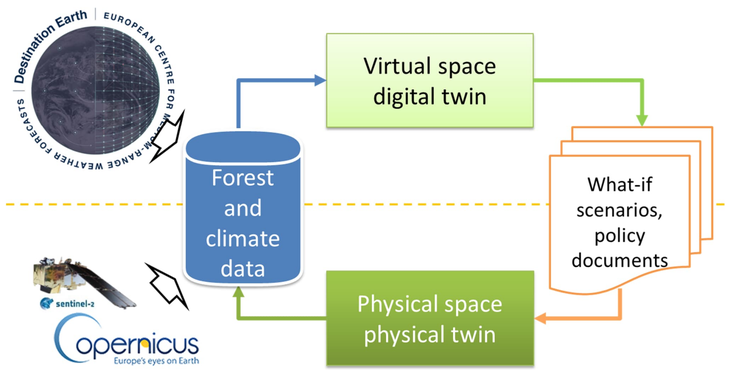
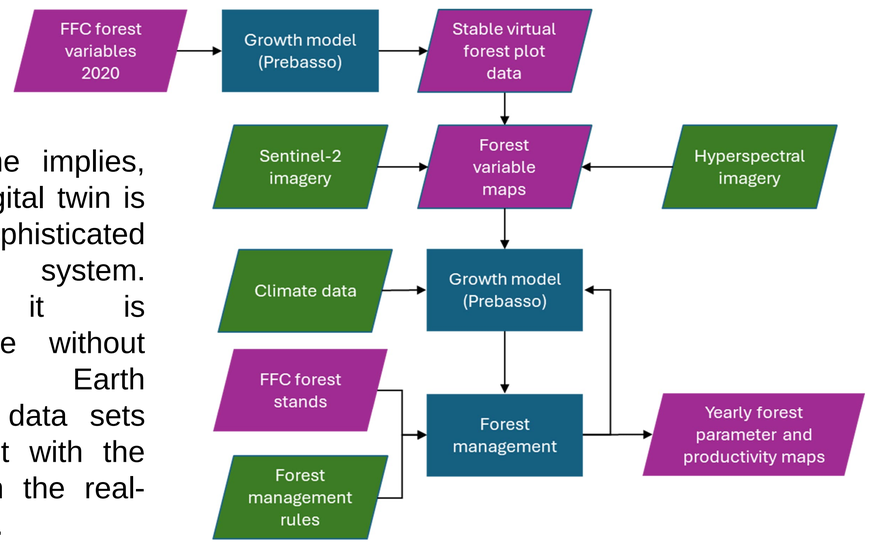
## Digital Twin

A digital twin is a dynamic digital model of a physical system, continuously synchronized with its real-world counterpart via sensor data, enabling (near) real-time simulation, monitoring, and optimization of the physical system – including what-if scenarios to predict the system's behavior in unseen situations




The EU has a flagship Destination Earth (DestinE) initiative for building a digital twin of the Earth by 2030. As a part of the initiative, VTT is leading the consortium building the digital twin of the Earth's forest – with funding from the EU and ESA.




As the name implies, the forest digital twin is a sophisticated modeling system. However, it is unconceivable without various Earth Observation data sets to connect it with the processes in the real-world forests.

The use of hyperspectral data includes, among others

- Mapping of forest structural and biochemical variables at large scales
- Following biophysical processes (photosynthesis) from space
- Providing calibration data for the productivity models
- Improving model calibration (data assimilation)

Most of these require a time series of data – not available before CHIME and SBG by ESA and NASA, respectively.

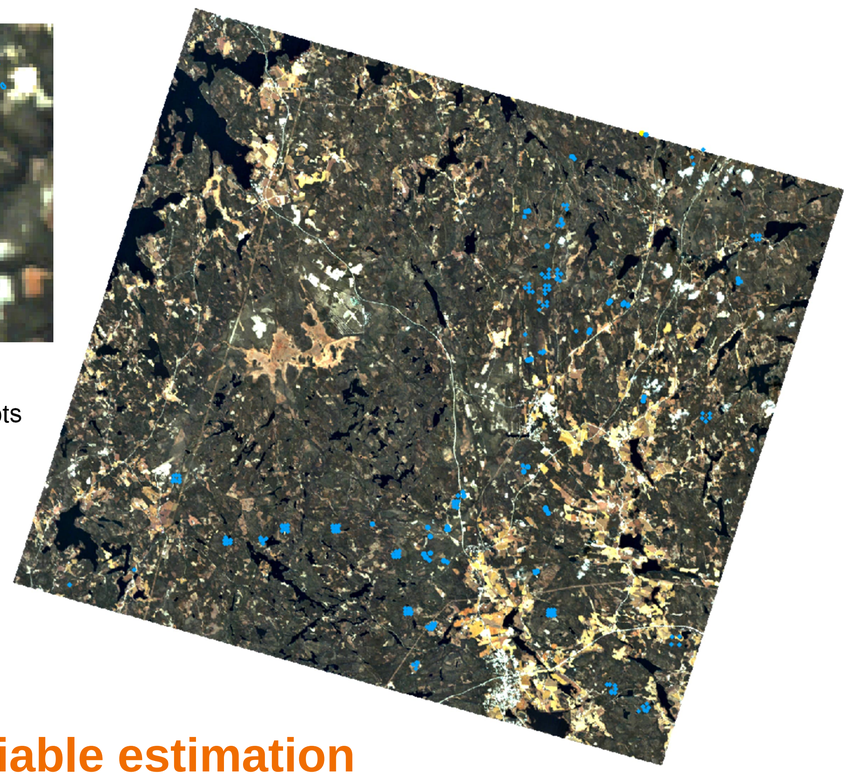
But how well is spaceborne hyperspectral data suited for the estimation of forest variables – compared with the standard Sentinel-2 multispectral? The increased spectral resolution causes a 9x tradeoff in spatial: 30 m vs 10 m pixel size.

## Study site and data

Sentinel-2 and EnMAP imaged near-simultaneously the area around the Hyytiälä forest research station in Central Finland at 12:53 and 13:06 local time, respectively, on 20 August 2023. The images are nearly cloudless. The Finnish Forest Centre (FFC, Metsäkeskus) had forest data available from 2023 and 2024 including forest measurements for 213 plots covered by cloudless data in both satellite images. The image pair has been used in previous studies for mapping LAI and canopy closure, and is presented in more detail by Juala et al. (2024, EJRS, 57, 2432975, DOI: 10.1080/22797254.2024.2432975).

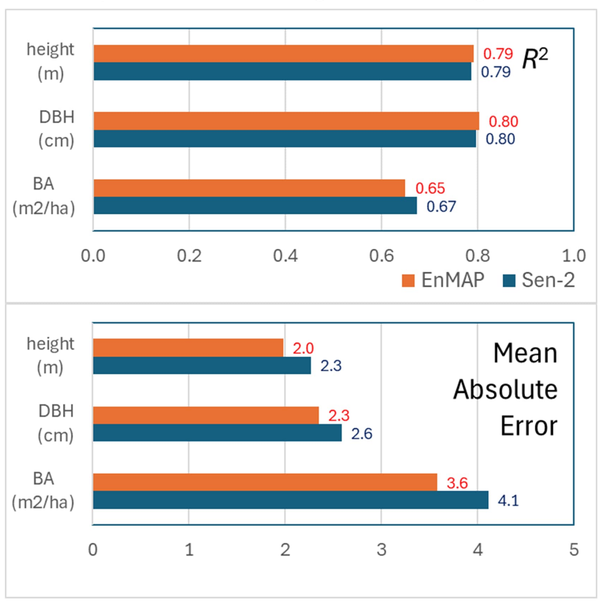

FFC measured plots of different shapes clustered in southern and eastern part of the EnMAP image.

30×30 m EnMAP scene with forest plots and a zoom-in showing the varying shape vectors of some of these.



## Forest variable estimation

Satellite data were downloaded as BOA reflectance images. For a more representative sampling of the spectral signal, EnMAP was resampled to 10 m. Plot data was split between training, validation and testing as 149:32:32. We trained a U-Net convolutional neural network to predict basal area (BA), diameter at breast height (DBH) and tree height from imagery patches in a fully-convolutional manner. Model was trained in two stages: self-supervised pretraining (spectral reconstruction for hyperspectral data or masked band prediction for Sentinel-2) followed by supervised fine-tuning using field plot measurements. Hyperspectral data: 1×1 convolutions for spectral compression followed by spatial processing; Sentinel-2: spatial convolutions with channel attention (Squeeze-and-Excitation blocks). Optimal patch size was experimentally determined to be 48×48 pixels. Area-weighted averages were used for plot-level estimates.




In the best model, EnMAP slightly outperformed Sentinel-2. The differences were minimal and the test is limited by data volume and variation range. Not enough species-level measurements were available to do predictions separately for the three overstory species in Hyytiälä (pine, spruce, birch).

## Conclusion

- **Spaceborne hyperspectral data can be matched against field plots despite coarser spatial resolution.**
- **It can serve as the baseline information source for key forest variables – with the unlocked potential for mapping biochemistry, biodiversity and vegetation functioning.**
- **True tests of the data require spatially continuous acquisitions to match the field data which is coming more readily available***

* FFC plot data may be an exception as it was recently removed from public distribution. We hope it will nevertheless be available again in the future.

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beyond the obvious