Mapping tree heights from space: A deep learning framework using dense Sentinel-2 time series and LiDAR data

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Abstract: Forests cover over one-third of Bavarian land cover and are under increasing stress from climate change-related disturbances like windstorms, droughts and bark beetle outbreaks. Hence, there is a high need for scalable and timely monitoring of forest dynamics. Current operational forest monitoring methods heavily rely on airborne laser scanning (ALS) which provides high quality canopy height models (CHMs). Spaceborne alternatives such as NASA's GEDI (Global Ecosystem Dynamics Investigation) LiDAR mission offer global coverage but the data remains noisy, unreliable in complex terrain and does not provide all to wall coverage. This creates a methodological gap for producing accurate and frequent (i.e. at least annually) canopy height information needed for monitoring. To address this challenge, we propose an operational canopy height mapping system based primarily on dense multispectral time-series from Sentinel-2 and reducing the dependency on repeated ALS acquisitions. From its orbit, Sentinel 2 has a ground repeatability of 10 days, and hence, an image is available every 10 days. We downloaded and processed all available Sentinel-2 imagery for Bavaria from 2019 to 2024 (~9 TB) by correcting it radiometrically and geometrically and regridding it into a non-overlapping datacube structure. From this datacube, we generated multi-seasonal composites and interpolated time series to capture forest phenology at the pixel level. Using the Sentinel-2 time series products created, we trained a CNN based model (Unet) with (i) high resolution ALS and (ii) GEDI waveform relative height metrics as reference data. We then assessed how training data and temporal information of the image data influence prediction at 10m resolution. Preliminary results demonstrate that integrating multi-seasonal Sentinel 2 information substantially improves model performance and that models trained with higher quality ALS based CHMs yield the most reliable canopy estimates. We thus provide a technically workable, scalable and semi-automatic forest canopy monitoring approach which - once trained for a region - uses only open-scource data, making it highly reproducible.