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An innovative experimental design based on Uber Hexagons for strategic IoT sensor placement across contrasting remote forest ecosystems: a proposal from the RemoTrees project

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Forest monitoring under climate change and extreme events remains constrained by the scarcity of continuous *in-situ* observations in remote areas introducing spatial bias in reference networks, weakening disturbance attribution, and limiting calibration and validation of Earth Observation (EO) products. The EU project RemoTrees addresses this limitation by developing an autonomous forest monitoring system that combines low-power IoT sensing with satellite communication tested across sites representing contrasting forest biomes.

We present the deployment framework to (i) select monitoring domains and (ii) define harmonized sensor installation on stems, in soils, and for reference radiation measurements under consistent criteria across sites. At Level-1 sites, prototypes are benchmarked against established reference instrumentation and protocols to quantify accuracy, drift, reliability, and sensitivity to environmental conditions. Resulting performance and calibration diagnostics guide the transfer to Level-2 sites, which are more remote and demanding, evaluating operational robustness and calibration stability under extreme conditions, including sensor nonlinearities, power and performance limitations, and communication reliability.

Spatial sampling is formalized through a hierarchical hexagonal tessellation based on H3 indexing. Nested hexagons define spatial units from the installation scale to the domain scale, generating an internal network with homogeneous spatial coverage and explicit neighbourhood relations and, by providing scale-compliant aggregation units aligned with EO pixel footprints and uncertainty cores, enable statistically comparable in situ–EO matching beyond single-point validation. This H3-based spatial framework links point measurements with EO products at pixel resolution and enables coherent aggregation from tree to domain while reducing reliance on single-point observations. Domain selection and installation location choice are driven by a multi-criteria spatial decision

analysis that integrates: (1) crown-scale structural phenotyping and geo-environmental covariates derived from airborne laser scanning surface models; and (2) Sentinel-2 space–time data cubes aggregated to individual crown objects, including spectral indices and biophysical/-chemical variables i.e. fAPAR, LAI, leaf chlorophyll, and canopy chlorophyll content selected for their functional linkage to photosynthesis, radiation use efficiency, and water stress as well as relatability to in situ measurements of radiation, sap flow, and radial growth. Decisions are implemented as a two-step process: minimum suitability filtering followed by a weighted, normalized composite ranking applied consistently to both domains and candidate crowns/trees, to capture intra-domain variability and optimize final tree and soil-point selection.

The resulting design turns sensor placement into an explicit, transferable multi-scale sampling scheme supporting continuous time series of key variables, including fAPAR; multispectral measurements of incident, canopy reflected and transmitted solar radiation, tree stem radial growth and motions, sap flow, soil temperature and moisture, besides air temperature and humidity below and above the forest canopy. In parallel, the workflow consolidates a traceable inventory of the monitoring domain and instrumented locations, structured as metadata for database integration and analytical use, thereby supporting cross-site comparability and transfer of the design to Level-2 deployments under FAIR principles, and interoperability between in situ and EO systems.