GEOBOTANICA

Living Digital Forest Twins: AI-Based Monitoring of Biomass, Carbon and Forest Dynamics (LiFT)

In cooperation with
Ferdinand Henke, Forest to Future GmbH
f.henke@geobotanica.com

Dr. Moritz Seiler
moritz.seiler@uni-paderborn.de

27.07.2026

CO_2 CERTIFICATION OF FORESTRY PROJECTS: HOW DOES THE CERTIFICATION WORK?

GEOBOTANICA

Project Registration

- Definition of the area and objectives (e.g. afforestation on degraded land).

Baseline Calculation

- How much CO_2 would be sequestered without the project?

Monitoring & Verification

- Regular verification of the carbon store by independent bodies.

Certificate Issuance

- Tradable CO_2 certificates based on verified CO_2 sequestration.

CO_2 CERTIFICATION OF FORESTRY PROJECTS: RISKS & CHALLENGES

Permanence

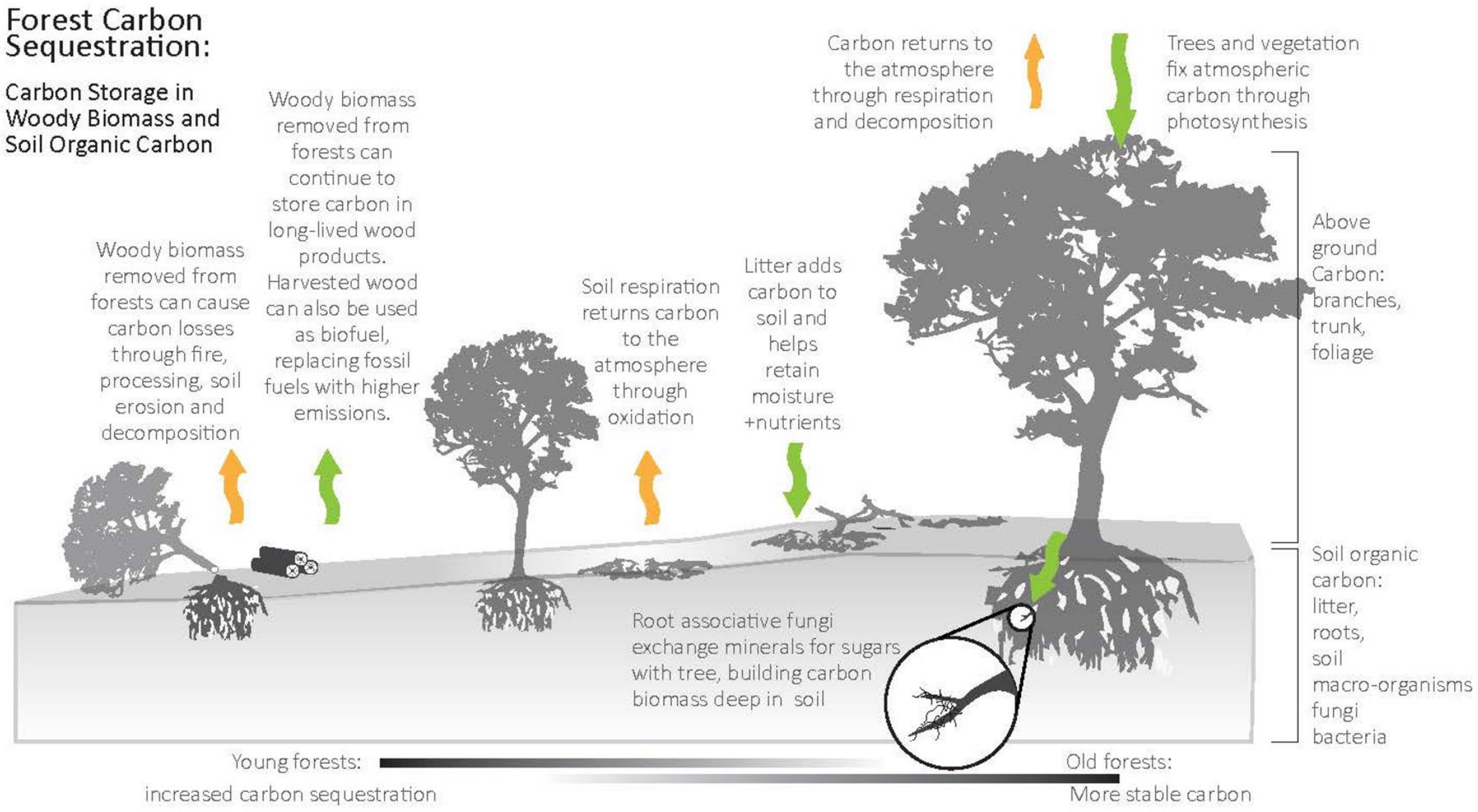
- Ensuring the forest survives in the long term (damage from fires, storms, pests).

Additionality

- The project must prove that the CO_2 sequestration would not have occurred without the certification.

Leakage Effect

- Preventing deforestation from shifting to other areas.



CO_2 CERTIFICATION OF FORESTRY PROJECTS: RISKS & CHALLENGES

Accuracy of CO_2 Calculations

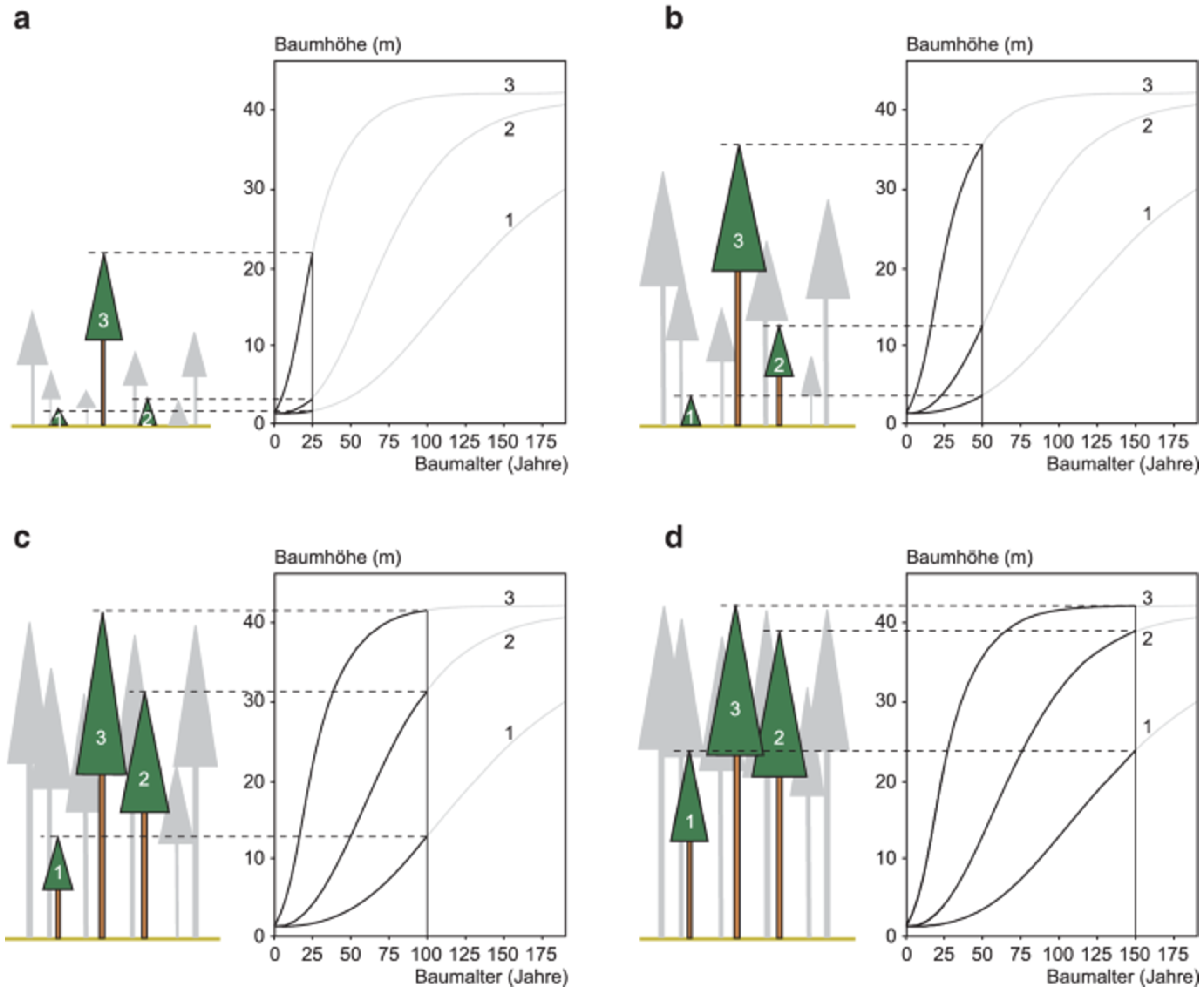
- Conventional methods are error-prone and labor-intensive.

Long-Term Monitoring Obligation

- Ensuring that the trees really do remain standing over the long term.

Data-Based Calculations

- Scientifically sound methods for measuring the CO_2 reduction.



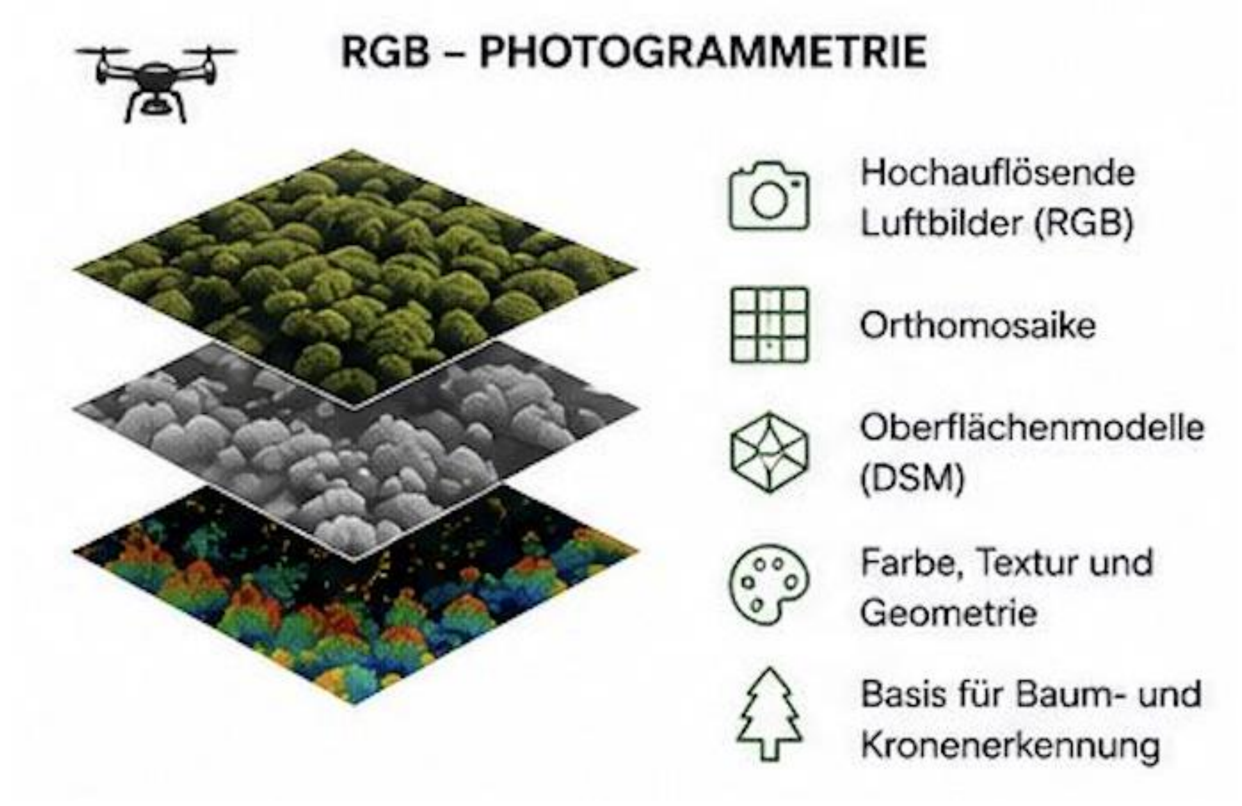
DIGITAL FOREST MODELS FOR CO_2 CERTIFICATION: FROM ESTIMATED CARBON TO MEASURED CARBON

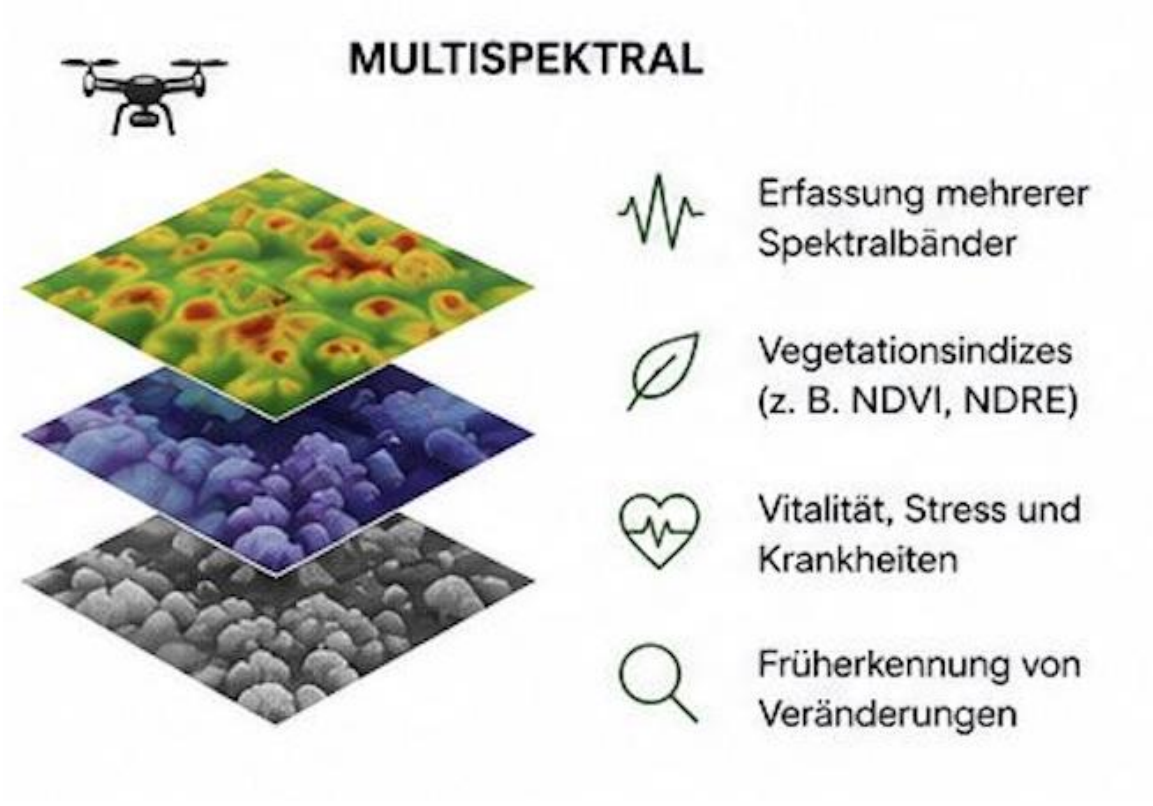
GEOBOTANICA

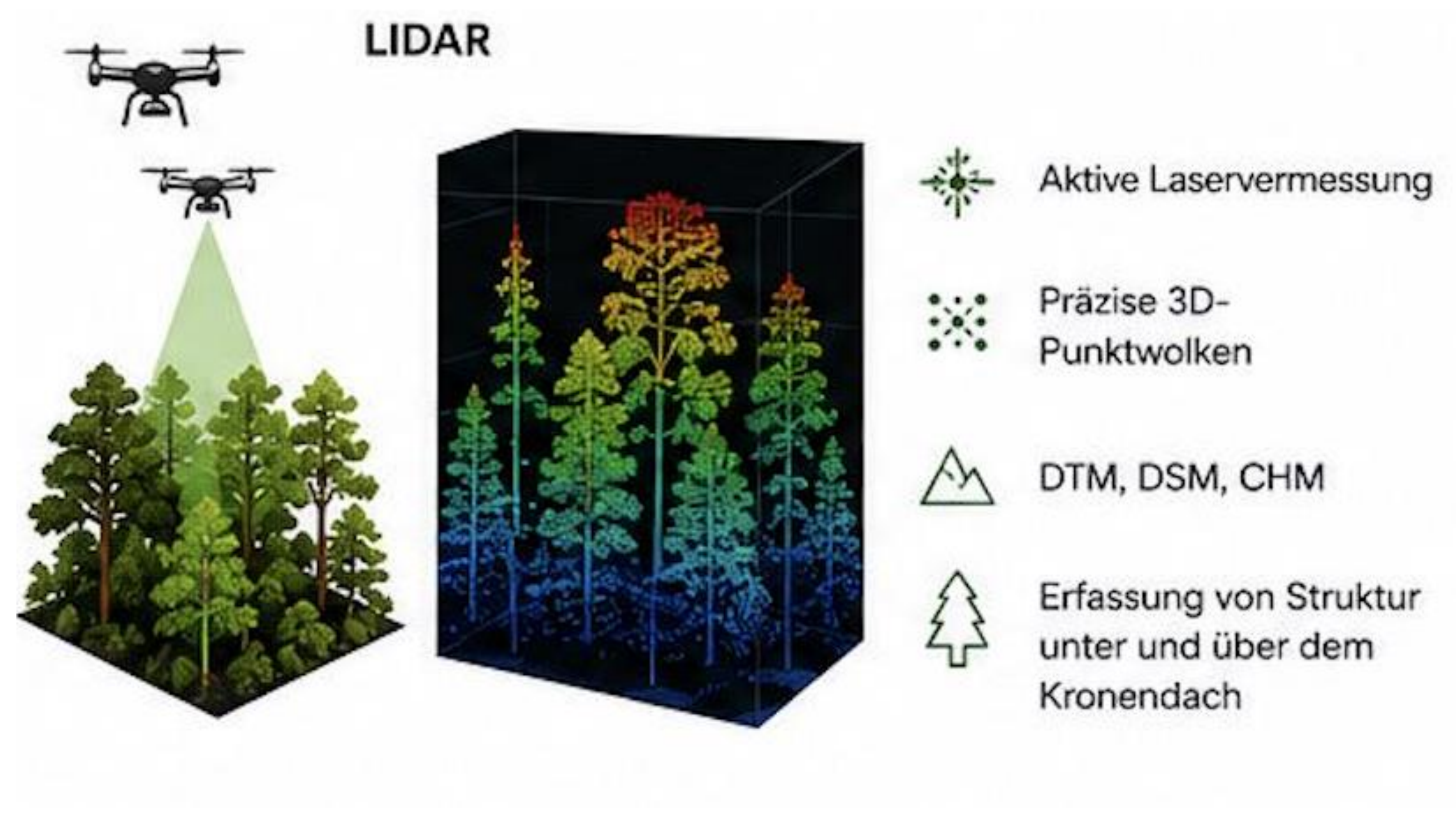
- **Carbon markets have a credibility problem:** Forestry offsets are repeatedly criticised for overstating their climate benefit. Buyers and regulators now want evidence, not estimates.
- **Conventional inventories do not scale:** Manual sample plots are slow, costly and error-prone — a few hundred measured trees stand in for millions.
- **Forests change faster than we measure them:** Drought, bark beetle and storm damage can reshape a stand within a single season; annual field campaigns miss it.
- **The technology is finally ready:** UAV imagery, multispectral sensing, LiDAR and deep learning make wall-to-wall, tree-level monitoring feasible today.

Our opportunity: turn CO_2 certification from periodic estimation into continuous, verifiable measurement — a digital forest twin that proves what a forest actually stores.

THREE COMPLEMENTARY SENSOR WORLDS







RGB Photogrammetry

- High-resolution UAV imagery
- Dense point clouds and orthomosaics
- Basis for object detection and 3D reconstruction

Multispectral Sensing

- Spectral bands beyond the visible range
- Vegetation indices (NDVI, NDRE)
- Vitality, water stress, physiological change

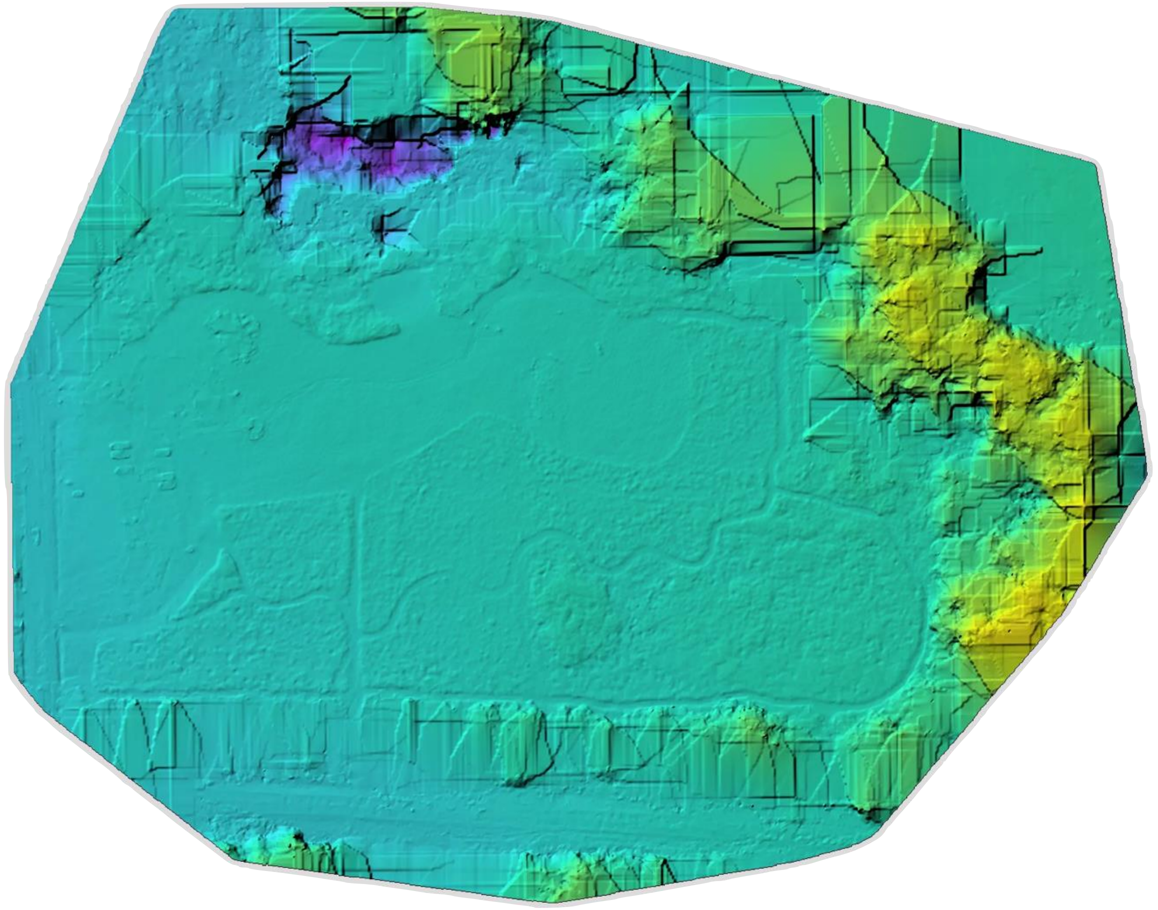
LiDAR

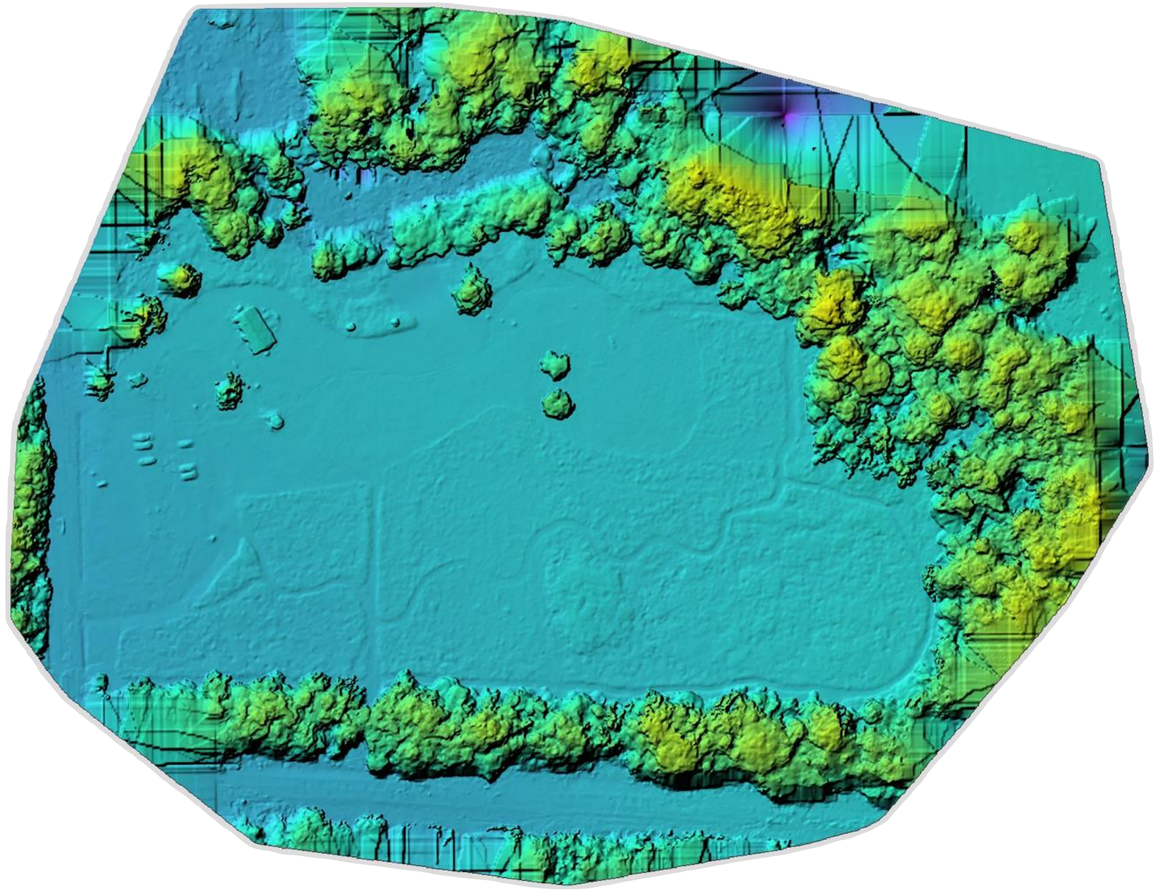
- Active laser-based distance measurement
- High-precision 3D point clouds
- Vertical structure: DTM, DSM, canopy height

Why all three: no single sensor captures the complexity of a forest stand — only the fusion of complementary data yields structural, spectral and semantic information at individual-tree level.

FROM RAW DATA TO FOREST STRUCTURE

GEOBOTANICA





1 Orthomosaic

Distortion-free, georeferenced base map — true to scale for GIS, area measurement and parcel-level analysis.

2 Terrain Model (DTM)

The bare ground surface — slope, water runoff, erosion risk and forest road planning.

3 Surface Model (DSM)

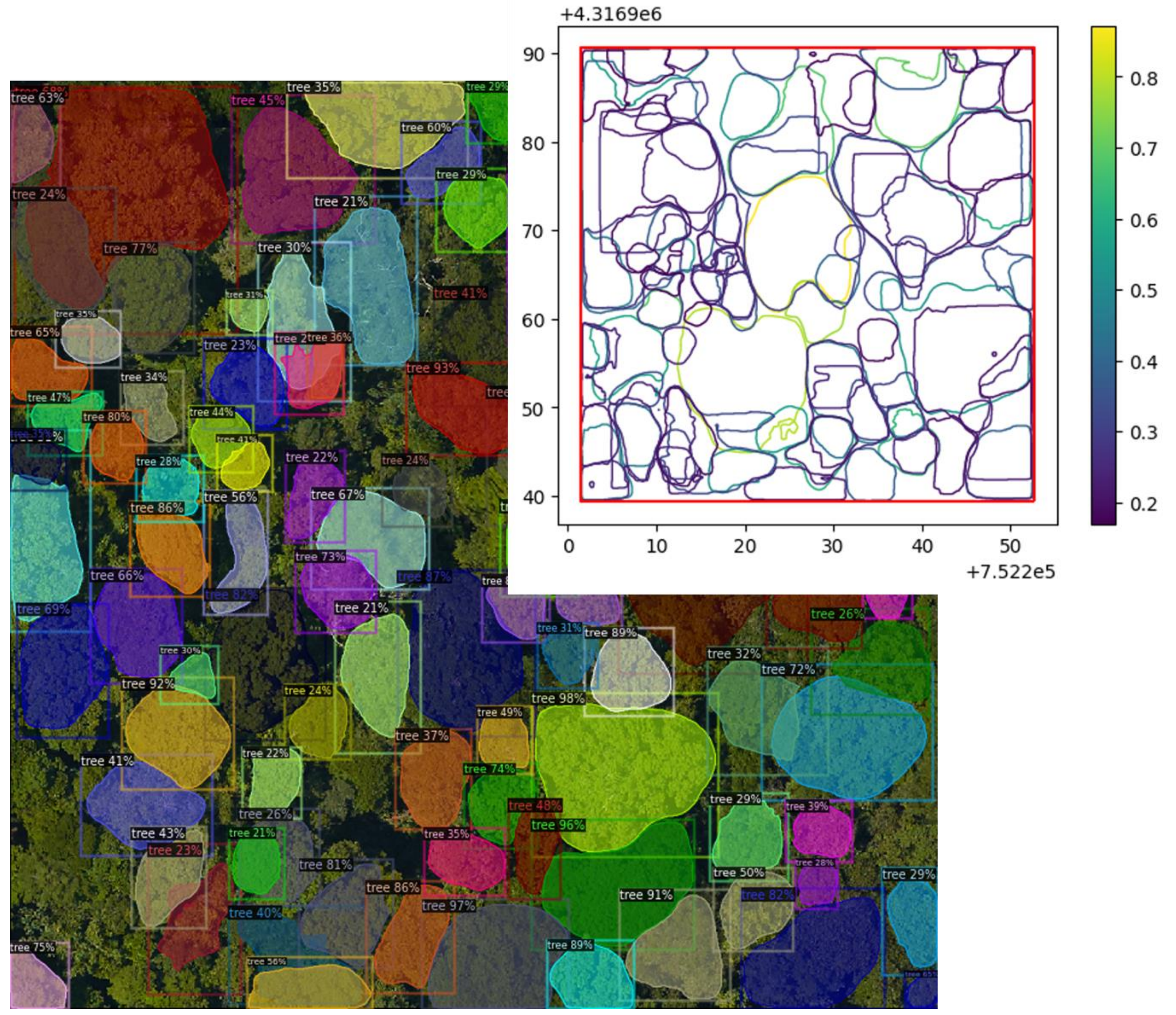
Everything standing on the ground — canopy surface, closure and structural change over time.

4 3D Forest Model

DSM minus DTM gives tree height — the basis for stand structure, timber volume and biomass.

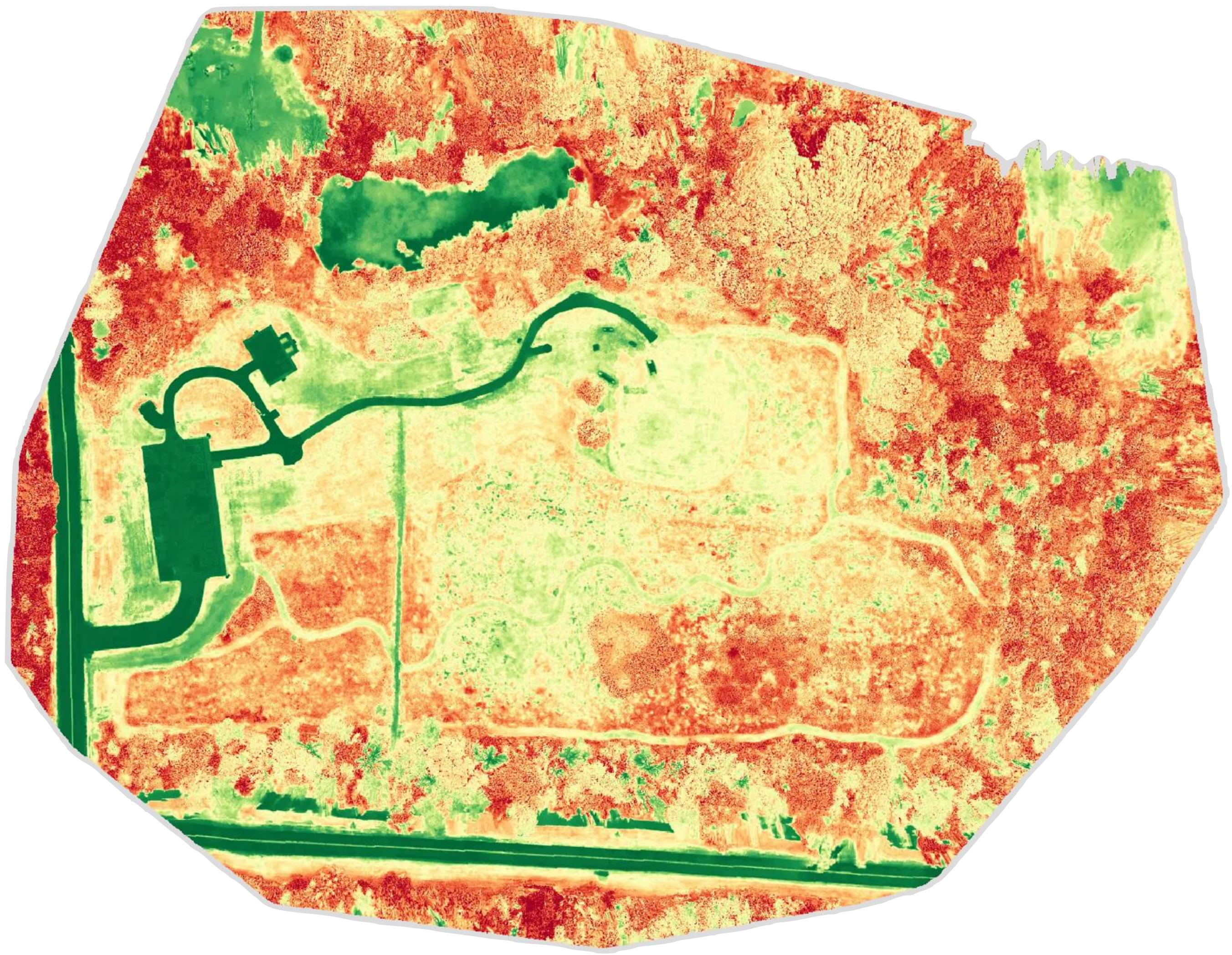
Geometry first: every biomass and CO_2 figure downstream rests on these four standardised, interoperable data products.

AI-INVENTORY AND FOREST HEALTH



AI-Based Forest Inventory

- Individual tree crowns detected automatically, even in dense stands
- Tree counts, crown segmentation and stand density per parcel
- Species and age classes derived from spectral signatures and AI models



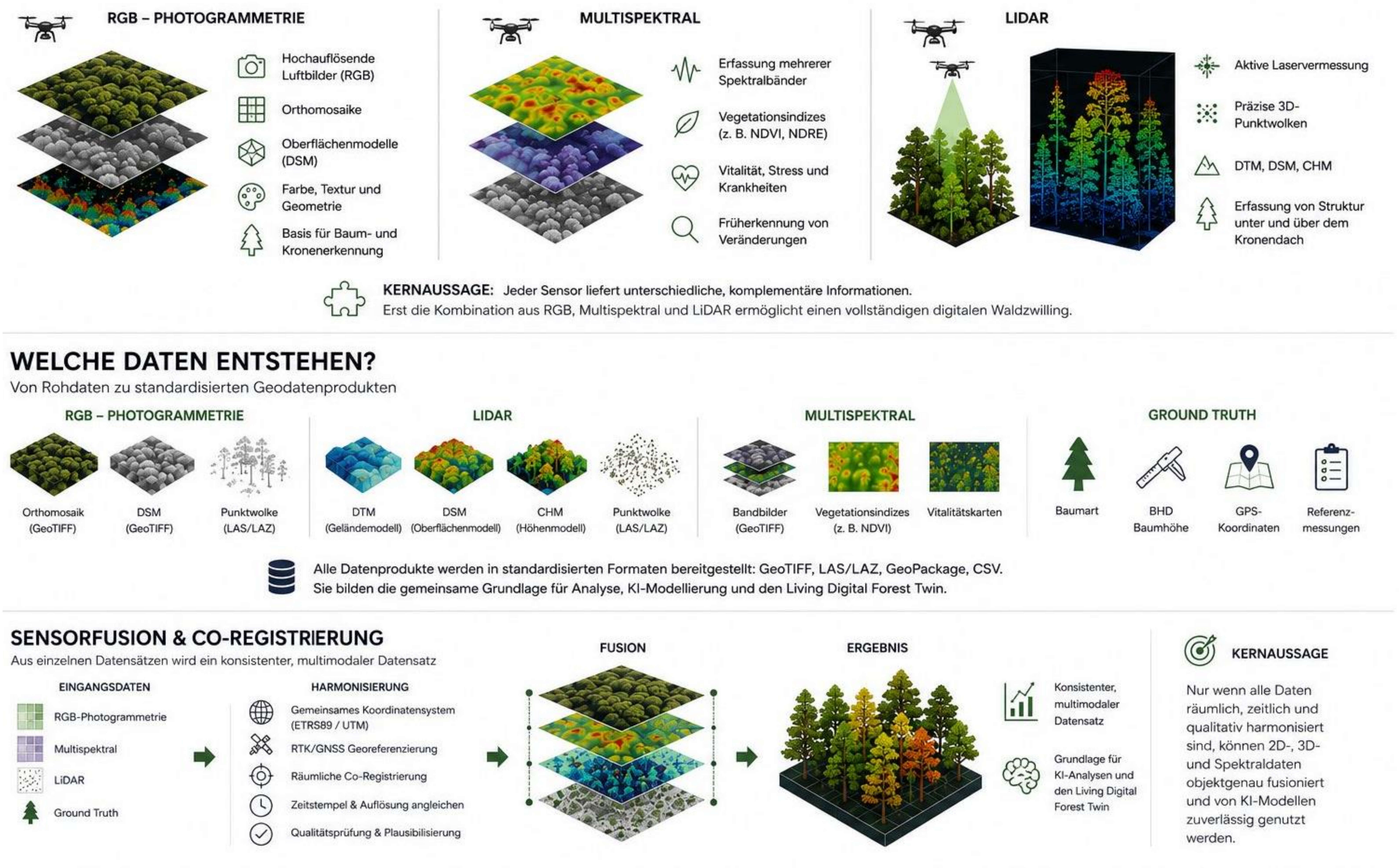
Plant Health and Change Detection

- Drought stress and pest infestation identified before damage is visible
- Vegetation indices (NDVI, NDRE) quantify vitality across the whole stand
- Comparison with historical data exposes storm, beetle and fire losses

The payoff: species, count and biomass for every tree — wall-to-wall instead of sampled, and repeatable every season.

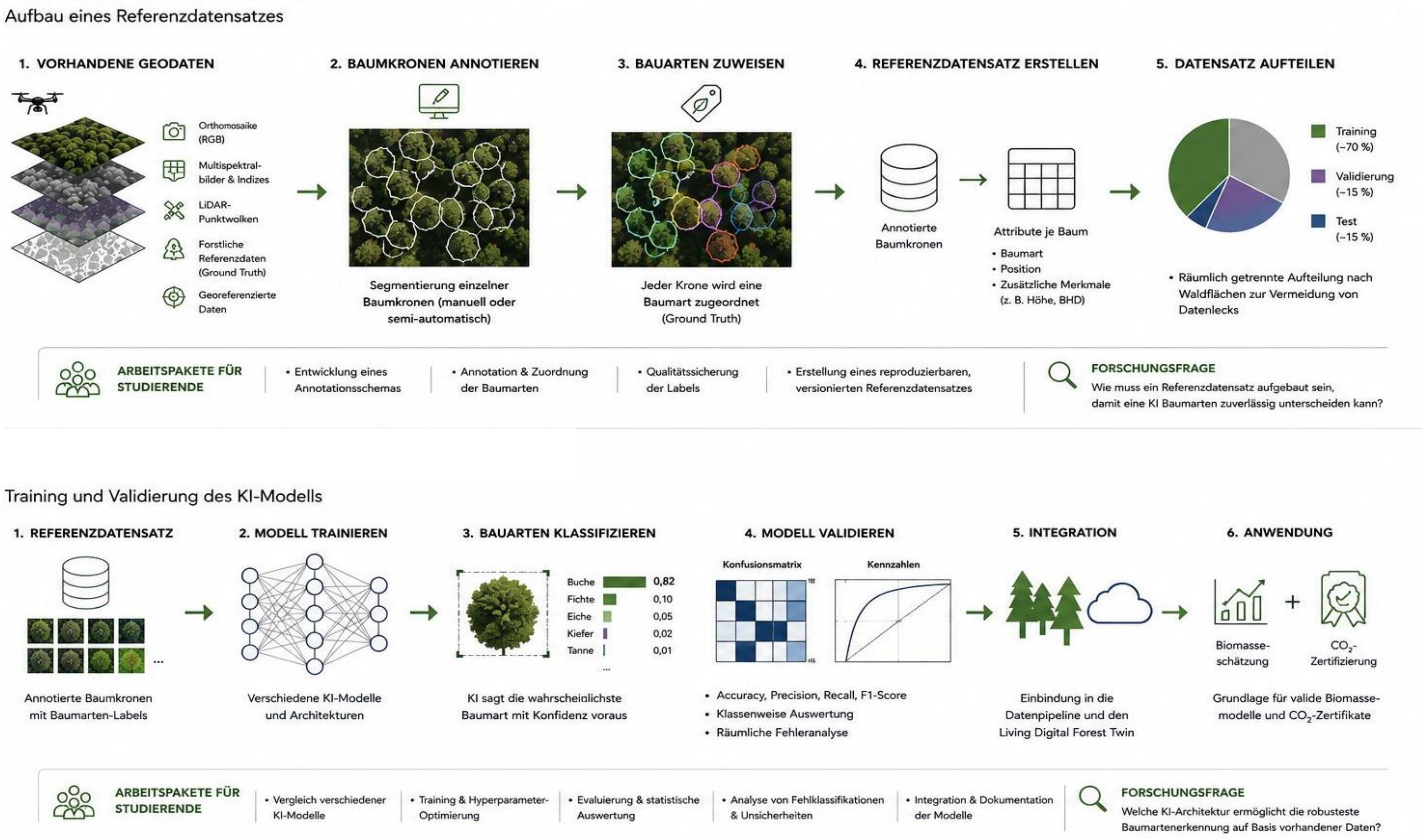
DIGITAL FOREST MODELS FOR CO_2 CERTIFICATION: THE THREE SENSOR WORLDS

Komplementäre Sensorik für ein vollständiges Bild des Waldes



DIGITAL FOREST MODELS FOR CO_2 CERTIFICATION: BUILDING A REFERENCE DATASET AND TRAINING FOR AI TREE-SPECIES RECOGNITION

GEOBOTANICA



STUDENT WORK PACKAGES: FROM REFERENCE DATASET TO VALIDATED AI

GEOBOTANICA

WP1: Building the Reference Dataset

Existing geodata → Annotate crowns → Assign species → Dataset

- Develop a standardised annotation scheme
- Build and maintain the reference dataset
- Quality-assure the tree species labels
- Split into training, validation and test data

Outcome: *A reproducible dataset every later model is trained and judged on.*

WP2: Training and Validating the AI

Reference dataset → Train model → Classify species → Validate → CO_2 pipeline

- Compare different AI architectures
- Train and optimize the models
- Assess model quality (accuracy, F1 score)
- Analyse and document misclassifications

Outcome: *A validated classifier feeding directly into biomass and CO_2 certification.*

What you take away: a citable dataset, a benchmarked model and a named contribution to a real CO_2 certification pipeline — each work package stands on its own as a thesis topic.

LIVING DIGITAL FOREST TWINS: AI-BASED MONITORING OF BIOMASS, CARBON AND FOREST DYNAMICS

GEOBOTANICA

- **Complementary sensors:** RGB, multispectral and LiDAR capture different information spaces; only their combination yields a scientifically robust digital forest twin.
- **Standardized data products:** Raw data become interoperable formats (GeoTIFF, LAS/LAZ, GeoPackage, CSV) that serve as the common basis for analysis and AI modeling.
- **Sensor fusion as the foundation:** Co-registration in a shared spatial and temporal reference system allows robust features at individual-tree level.
- **Reference data decide AI quality:** Annotated tree crowns and quality-assured species labels form the reproducible training basis.
- **Validated AI models:** Automatic tree species classification feeds directly into biomass calculation and CO_2 certification.

Overall research question: *How can an AI classify tree species from multimodal drone data in an automated, reproducible and scientifically robust way — as the basis for a Living Digital Forest Twin and valid biomass and CO_2 models?*

APPENDIX

Detailed capability slides

DIGITAL FOREST MODELS FOR SUCCESSFUL CO_2 CERTIFICATION: RECTIFIED ORTHOMOSAICS*

High-Precision Mapping

- True to scale and distortion-free for use in GIS systems.

Exact Area Measurement

- Ideal for planning forestry operations or inventories.

Visual Analysis

- Identification of tree species, damage (e.g. windthrow, beetle infestation) or stand boundaries.

Long-Term Documentation

- Comparison across multiple years is possible (e.g. for forest growth or climate impacts).

Automatic Matching with the Land Register

- Enables analyses at individual parcel level.

* A rectified orthomosaic is a distortion-free, georeferenced aerial image composed of several overlapping photographs. Perspective distortions and elevation differences are corrected, so that the image is true to scale and can be used directly for analysis.

DIGITAL FOREST MODELS FOR CO_2 CERTIFICATION: DIGITAL TERRAIN MODEL (DTM*)

GEOBOTANICA

Volume & Biomass Calculation

- Determination of timber stocks from the difference between DSM (canopy) and DTM (ground).

Erosion Control & Water Management

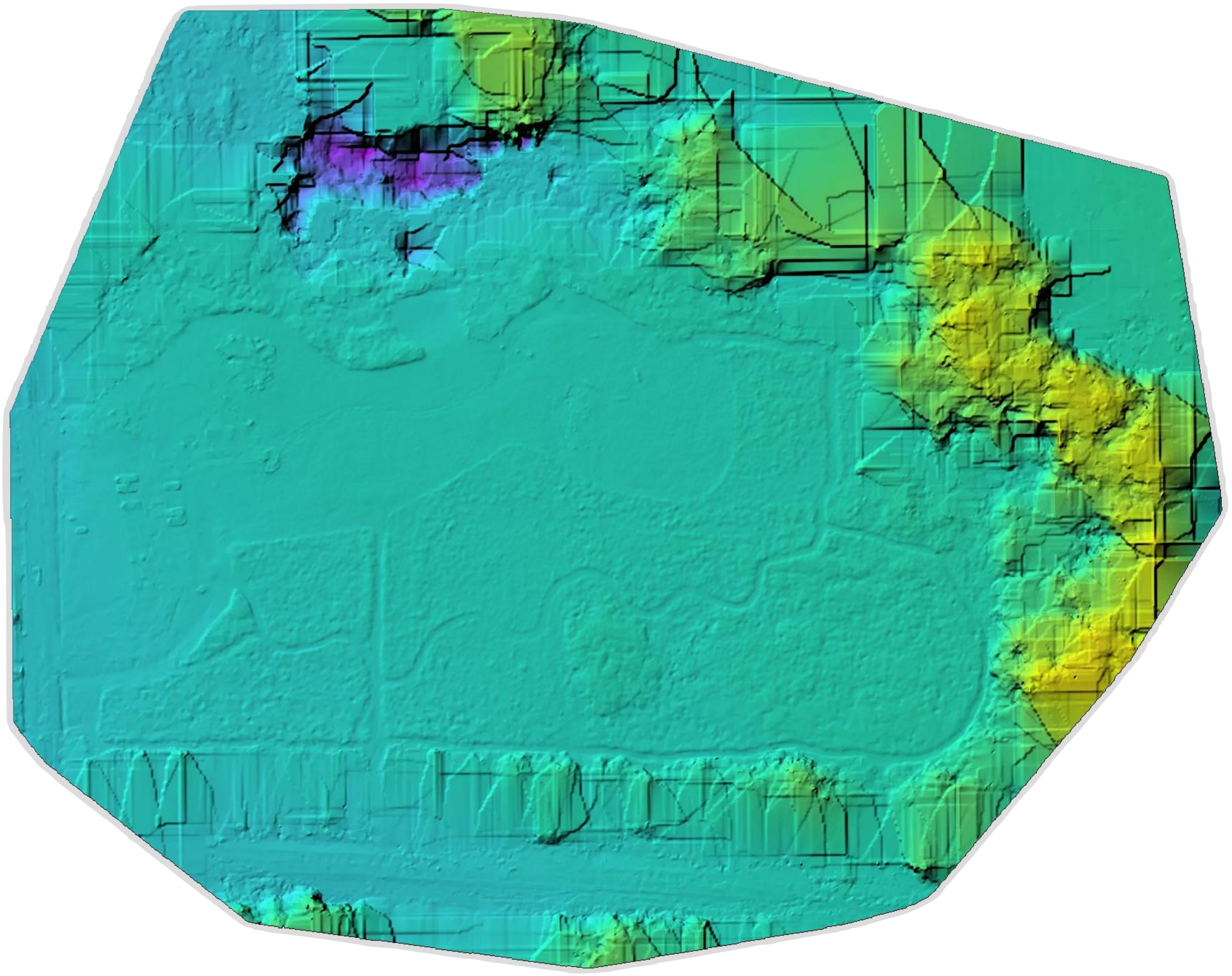
- Analyzing slope gradient & water runoff to prevent soil erosion.

Forest Road Planning

- Optimization of routes based on terrain gradient.

Damage Assessment After Storms

- Precisely recording storm damage and windthrow areas.



* A DTM is a digital representation of the earth's surface including elevation information and plays a decisive role in geodata acquisition, particularly in forestry, as it enables precise terrain analyses.

DIGITAL FOREST MODELS FOR CO_2 CERTIFICATION: DIGITAL SURFACE MODEL (DSM*)

GEOBOTANICA

Tree Height Determination

- Determining exact tree heights from the difference between DSM and DTM.

Canopy Closure Analysis

- Analysis of canopy density for forest health and CO_2 sequestration potential.

Damage Detection (Windthrow, Beetle Infestation, Fires)

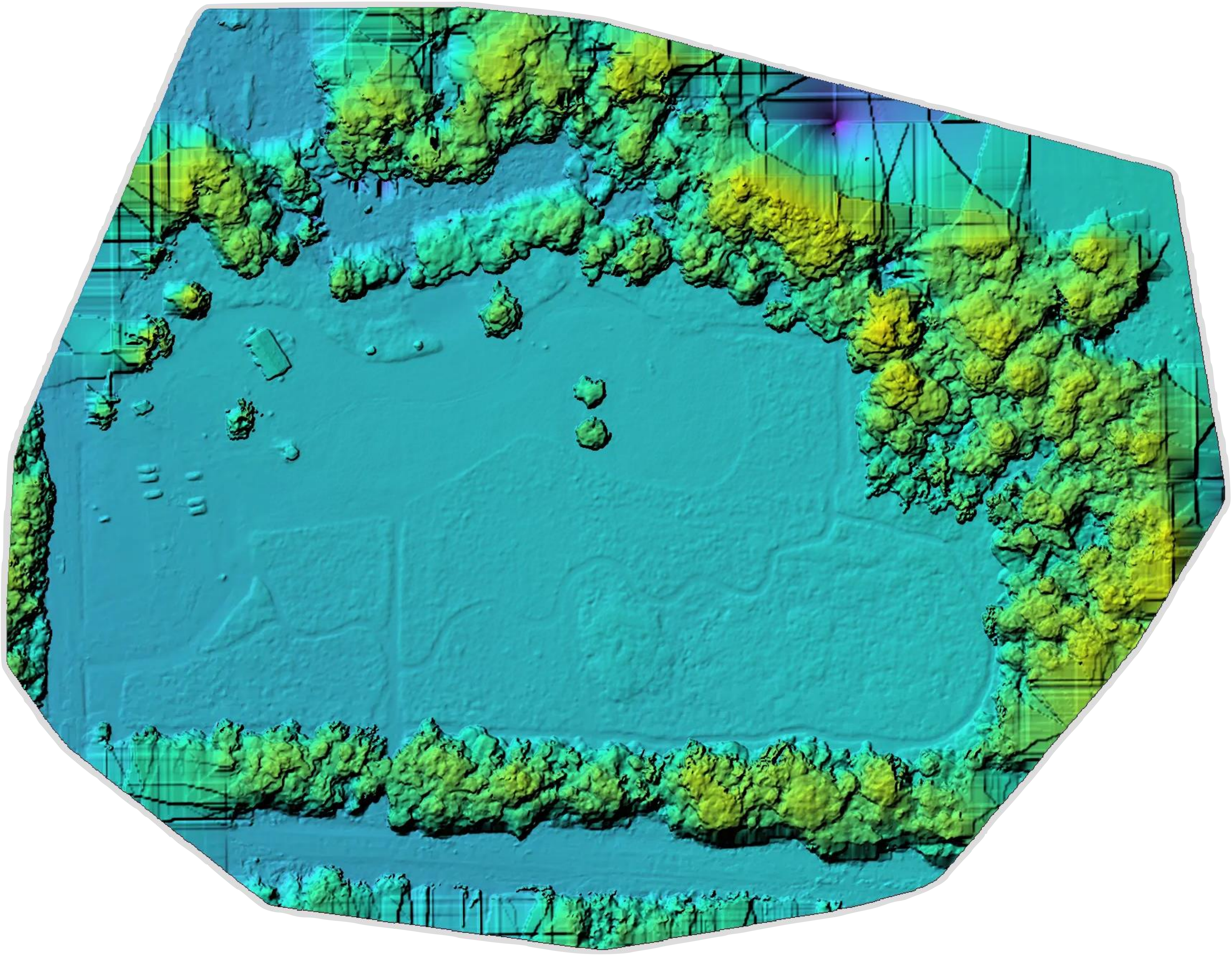
- Comparison with earlier DSM data reveals changes in forest structure
- Identification of dead or fallen trees.

Optimized Planning of Forest Roads & Machinery Logistics

- Accounting for elevation variation and obstacles.
- Improving forest road routes for timber harvesting and transport.

Shade Simulation & Light Conditions

- Analysis of sun exposure for planning afforestation.



* A DSM captures all objects located on the surface, such as trees, buildings and vegetation, together with their heights.

DIGITAL FOREST MODELS FOR CO_2 CERTIFICATION: PLANT HEALTH MAP*

Early Detection of Drought Stress & Pest Infestation

- Detecting changes in leaf chlorophyll before damage becomes visible.
- Prevention of beetle infestation (e.g. bark beetle) or fungal diseases

Targeted Forest Management & Afforestation

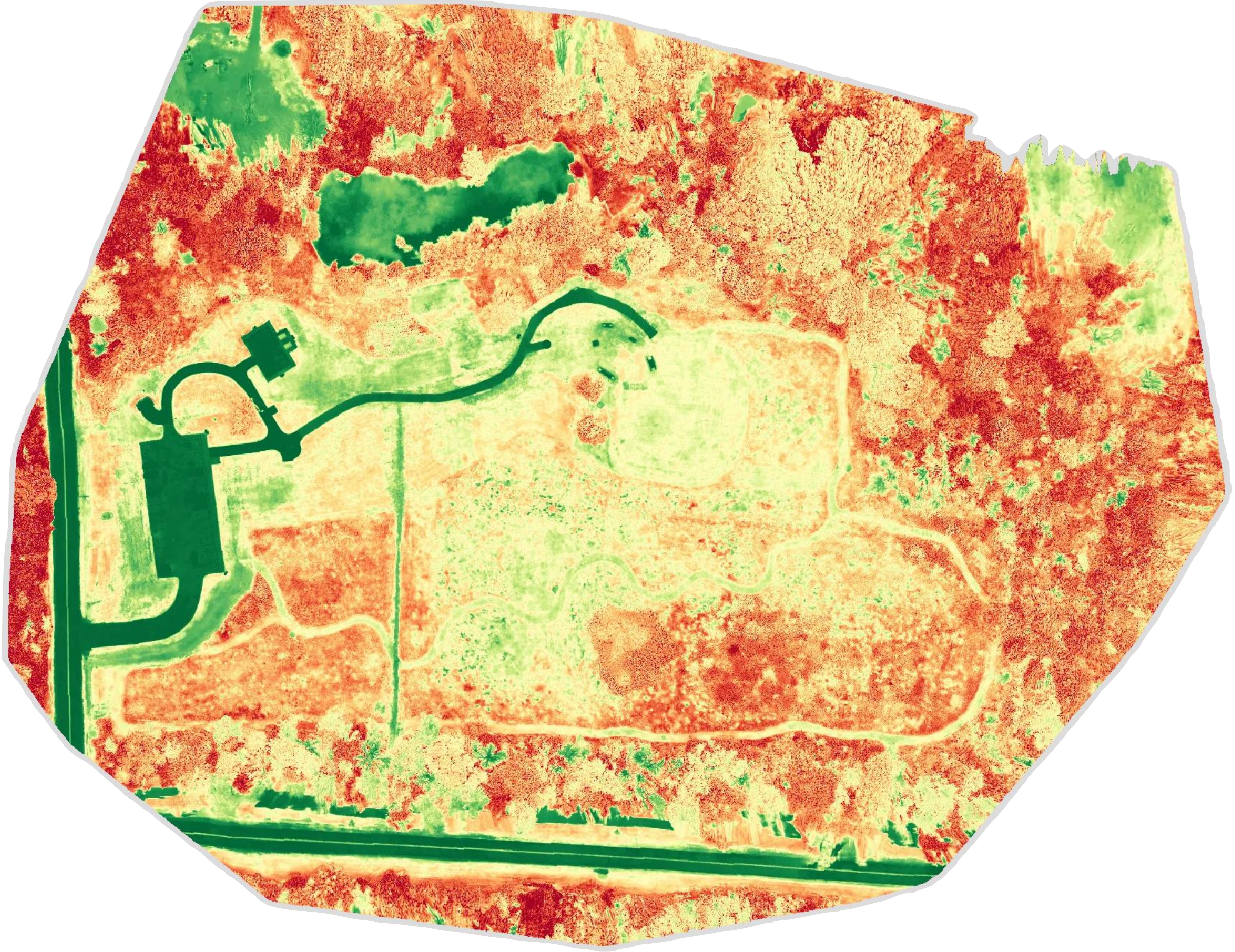
- Identification of areas with poor vitality for targeted measures.
- Optimization of irrigation and fertilization in forest cultures.

Efficient Forest Protection Measures

- Detecting fire risks caused by dry vegetation
- Early action against harmful insects

Monitoring of Afforestation & Climate Projects

- Monitoring the growth of young stands.
- Assessment of carbon storage by healthy vegetation.



* Analysis of reflectance values in the visible (RGB) and non-visible range on multispectral & hyperspectral drone or satellite imagery; calculation of various vegetation indices (e.g. NDVI, NDRE, GCI, EVI)

DIGITAL FOREST MODELS FOR CO_2 CERTIFICATION: 3D FOREST MODEL*

Precise Tree Height Measurement & Stand Structure

- Automatic identification of tree species, height classes and canopy density.
- Basis for timber volume calculation & biomass estimation.

Forest Planning & Resource Management

- Optimized harvest planning through realistic simulation of machinery routes.
- Determination of corridors, skid trails & stand gaps

Damage Analysis & Early Warning Systems

- Making storm damage & beetle infestation visible (changes in canopy closure)
- Simulation of windthrow risks through topographic analysis.

Water Management & Erosion Control

- Analyzing slope gradients to model soil resources and water runoff.
- Planning targeted protection measures for sensitive forest areas

Scientific Research and Climate Protection

- Monitoring CO_2 sequestration through biomass modeling.
- Long-term observation of climate impacts on forest structure.

* This digital 3D representation of a forest area provides a great deal of detailed information on tree heights, stand density, crown structure and topography.

DIGITAL FOREST MODELS FOR CO_2 CERTIFICATION: AI-BASED FOREST INVENTORY

GEOBOTANICA

Identification of Individual Trees

- AI detects individual tree crowns even in dense stands.
- Automatic separation of trees without labor-intensive field measurements.

Automatic Tree Counting

- Precise determination of tree density per hectare or parcel.
- Replaces manual sampling with comprehensive automated analysis

Categorization of Trees

- Age classification based on height, crown diameter & biomass.
- Tree species identification via spectral signatures and AI models.

Automatic Crown Segmentation

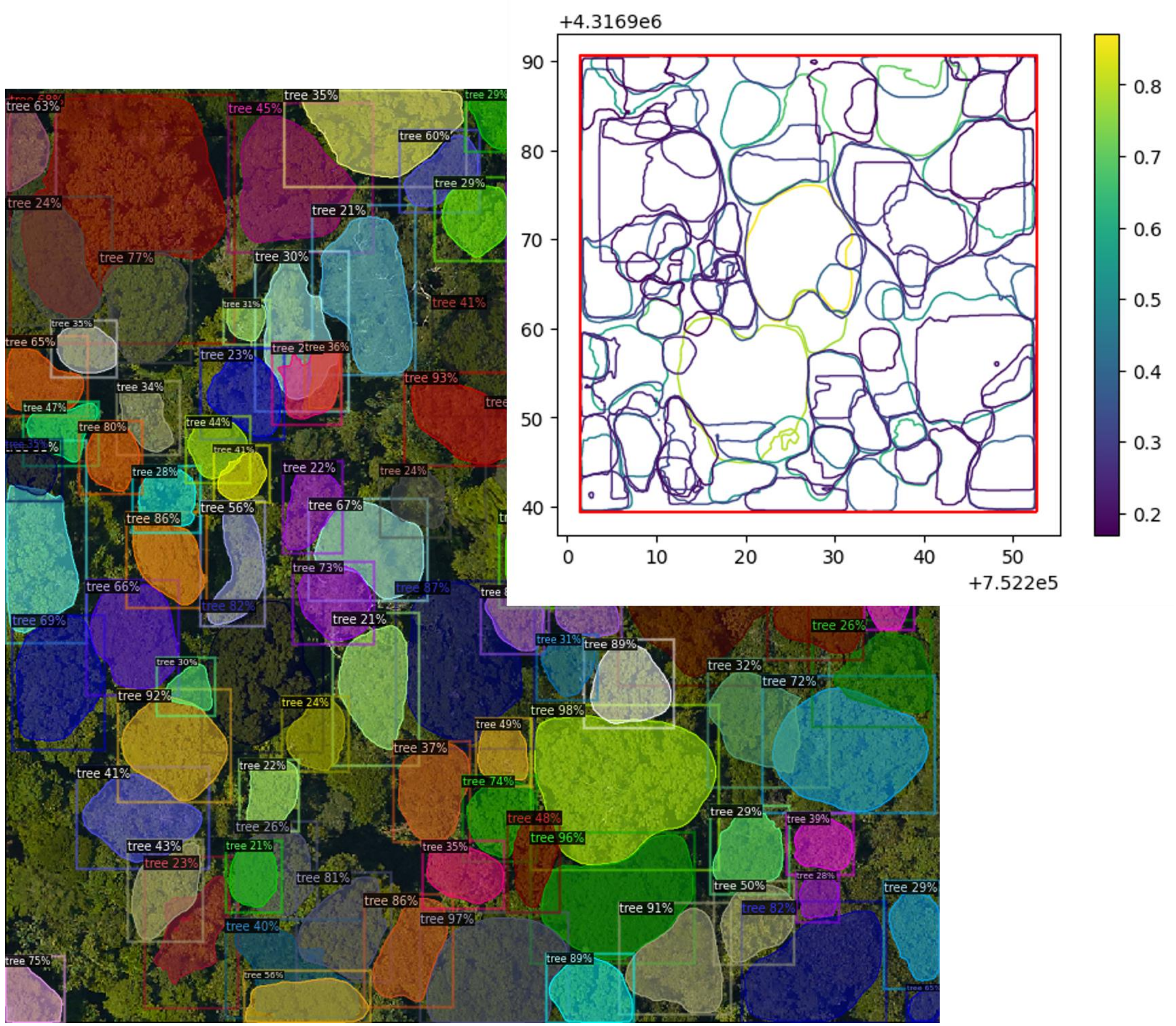
- Key basis for stand density, timber stock calculation & growth measurement.

Parcel-Level Inventory

- Critical data basis for certification & forestry subsidies.

Comparison with Historical Data & Monitoring

- Making changes in the forest stand visible over the years.
- Early detection of damage from storms, beetle infestation or drought stress.



* An AI-based forest inventory uses artificial intelligence (AI) for the automatic recording, analysis and management of forest stands and makes it possible to identify, classify and count individual trees precisely, even in dense stands.

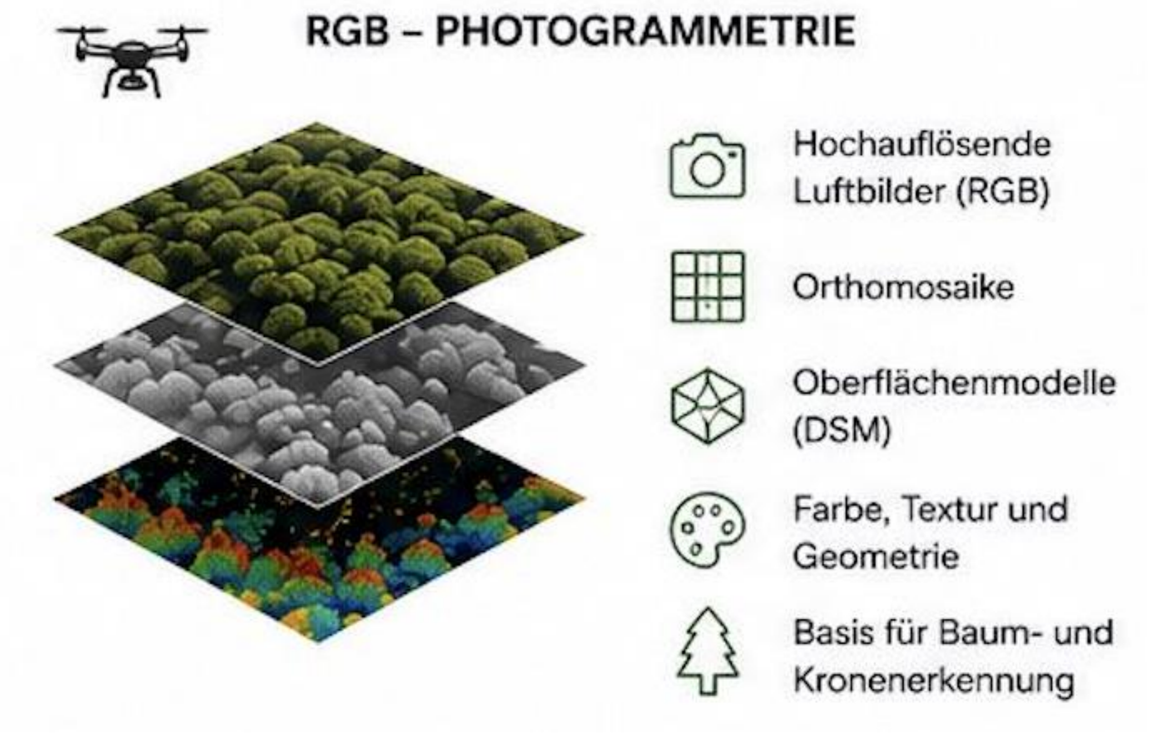
DIGITAL FOREST MODELS FOR CO_2 CERTIFICATION: AI-BASED FOREST INVENTORY

Complementary Sensor Technology as the Basis of a Digital Forest Twin

No single sensor system can fully capture the complexity of a forest stand. Only the fusion of complementary sensor data enables the consistent derivation of structural, spectral and semantic information at individual-tree and stand level.

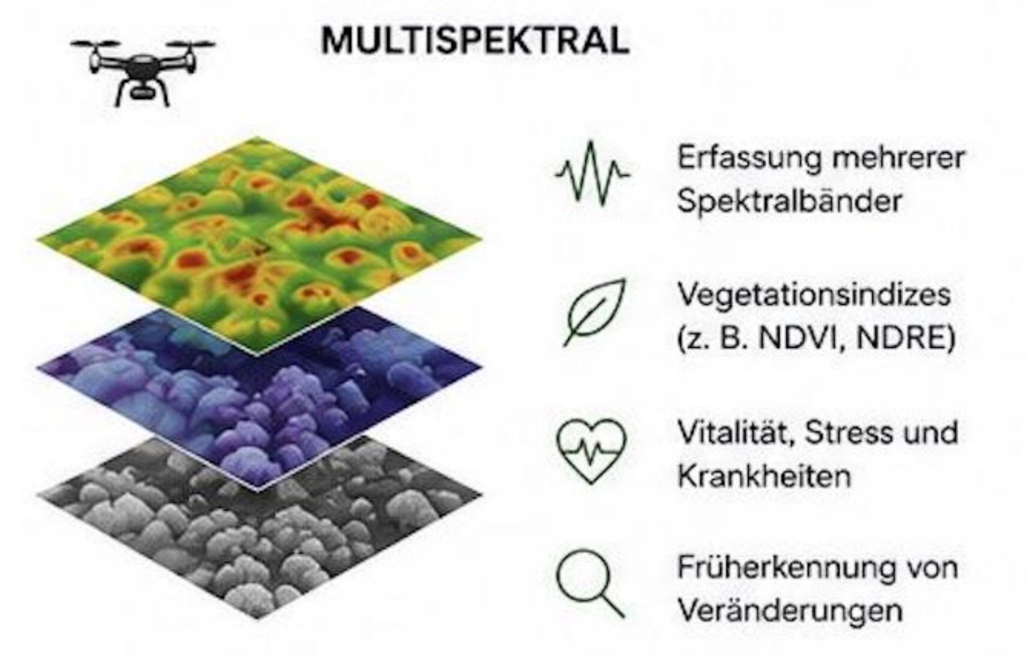
RGB Photogrammetry

- High-resolution image capture via UAV
- Reconstruction of dense point clouds and orthomosaics
- Derivation of surface models (DSM) and geometric features
- Basis for object detection and photogrammetric 3D reconstruction



Multispectral Sensing

- Capture of defined spectral bands beyond the visible range
- Calculation of vegetation indices (e.g. NDVI, NDRE)
- Quantification of vitality, water stress and physiological change
- Supplementing geometric information with biophysical properties



LiDAR

- Active laser-based distance measurement
- Generation of high-precision three-dimensional point clouds
- Derivation of DTM, DSM and Canopy Height Models (CHM)
- Capture of vertical forest structure down to individual-tree geometry