OBSGESSION

Monitoring and forecasting forest ecosystem productivity and health under climate change and disturbances

ABOUT

This pilot investigates the functioning and resilience of European forest ecosystems under climate change and disturbance events. It focuses on monitoring forest productivity, health, and structural changes using a combination of ecological modelling and satellite observations. The pilot covers three representative forest regions: Rumperöd in southern Sweden, Berchtesgaden National Park in Germany, and the Carpathian mountain forests in Central and Eastern Europe.

CURRENT PROGRESS

Current work has focused on the Rumperöd case study and on developing a workflow for downscaling coarse LPJ-GUESS outputs using remote sensing data as fine-resolution spatial proxies. LPJ-GUESS outputs have been organized for multiple coarse grid cells and key ecosystem variables, including LAI, GPP, NPP, biomass and FPC, with additional forest-structure variables available for later stages.

Remote-sensing predictors, including Sentinel-2-derived FCOVER/LAI proxies, Sentinel-1 SAR data and DEM-derived terrain layers, have been explored as spatial information sources for the downscaling task. Initial machine-learning experiments tested several model families, including convolutional, transformer-based, graph-based, diffusion-based and hybrid architectures. These experiments provided a useful prototype and helped identify the main methodological requirements for a reliable downscaling framework.

The work also revealed important challenges that need to be addressed before operational use. This includes the need to avoid over-emphasizing coarse mean matching, reduce spatial artifacts, prevent irrealistic smoothness, and ensure that downscaled maps preserve both LPJ-GUESS consistency and realistic fine-scale spatial patterns. Based on these findings, the workflow has been improved with a cleaner decoder design, valid-data masks, interior-focused evaluation, spatial fidelity metrics, edge-aware smoothness and spatial cross-validation.

SCOPE & BACKGROUND

Forests play a crucial role in climate regulation, carbon storage, and biodiversity conservation. However, forest ecosystems are increasingly affected by climate change, extreme weather events, pest outbreaks, and other disturbances. Monitoring these impacts requires models capable of simulating ecosystem processes and predicting how forests respond to environmental stressors. The pilot therefore combines ecological models with Earth Observation data to monitor forest productivity and ecosystem functioning across large spatial scales.

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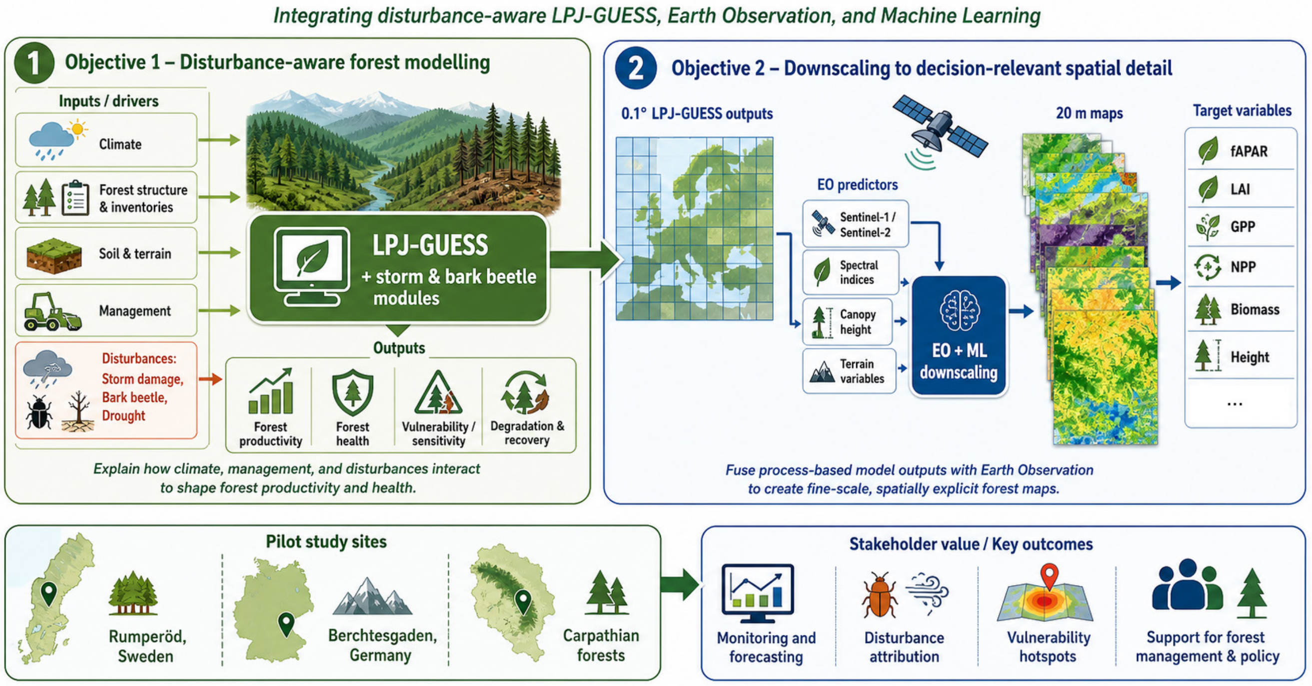

Figure 1. Overview of OBSGESSION Pilot 3 objectives. The pilot combines disturbance-aware LPJ-GUESS modelling with Earth Observation and machine learning to monitor and forecast forest productivity and health under climate change and disturbances.

DESCRIPTION

This figure summarizes the two main objectives of Pilot 3. The first objective focuses on improving LPJ-GUESS with disturbance-aware modelling, including storm damage, bark beetle dynamics, drought effects, forest structure, management, soil, terrain and climate drivers. The second objective focuses on downscaling coarse LPJ-GUESS outputs to decision-relevant spatial detail using Earth Observation and machine learning. Together, these components aim to generate fine-resolution indicators of forest function and structure, such as fAPAR, LAI, GPP, NPP, biomass and canopy height, while supporting stakeholder needs such as disturbance attribution, vulnerability mapping, monitoring, forecasting and forest management.

OBSGESSION'S CONTRIBUTION

OBSGESSION's contribution to the development of the pilot includes adapting the LPJ-GUESS dynamic vegetation model to simulate forest productivity while incorporating disturbance modules related to storms and bark beetle outbreaks. These simulations are combined with satellite data from missions such as Sentinel-1, Sentinel-2, and Landsat to improve spatial resolution and monitoring capabilities. Machine learning techniques are used to downscale coarse model outputs into high-resolution predictions of forest productivity and ecosystem structure. This integration allows the generation of spatially detailed indicators such as biomass, leaf area index, and gross primary productivity.

EXPECTED RESULTS

Expected outputs include high-resolution maps of forest productivity and ecosystem structure across the pilot regions. The pilot will also produce improved modelling approaches for predicting forest responses to climate change and disturbance events. By combining process-based models with remote sensing data, the pilot will generate spatially detailed indicators of forest ecosystem functioning and provide uncertainty estimates for these predictions.

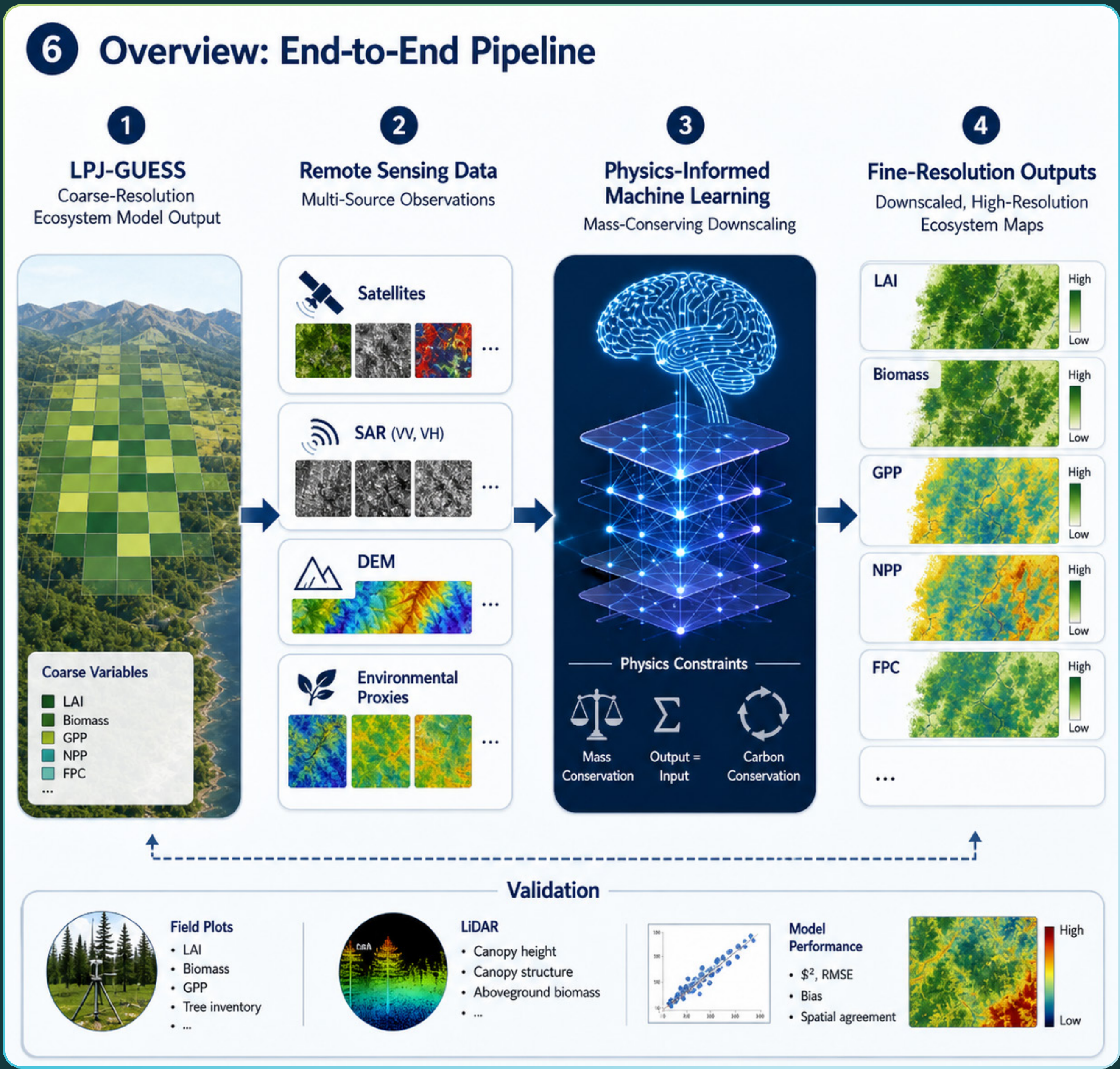

Figure 2. **End-to-end pipeline for physics-informed downscaling of LPJ-GUESS outputs**. Coarse ecosystem model outputs are combined with multi-source remote-sensing data and ecological constraints to produce fine-resolution forest maps.

DESCRIPTION

This figure presents the full machine-learning workflow used to downscale LPJ-GUESS outputs. The process begins with coarse-resolution ecosystem model variables, which are combined with remote-sensing data from satellites, SAR, DEM-derived terrain layers and environmental proxies. These inputs are processed through a physics-informed machine-learning model that applies constraints such as mass conservation, consistency between input and output, and carbon-related plausibility. The resulting products are fine-resolution maps of ecosystem variables such as LAI, biomass, GPP, NPP and FPC. The workflow also includes validation against independent observations, including field plots, LiDAR-derived canopy structure, biomass estimates and model-performance metrics, with the objective to ensure that the outputs are not only spatially detailed but also ecologically meaningful.

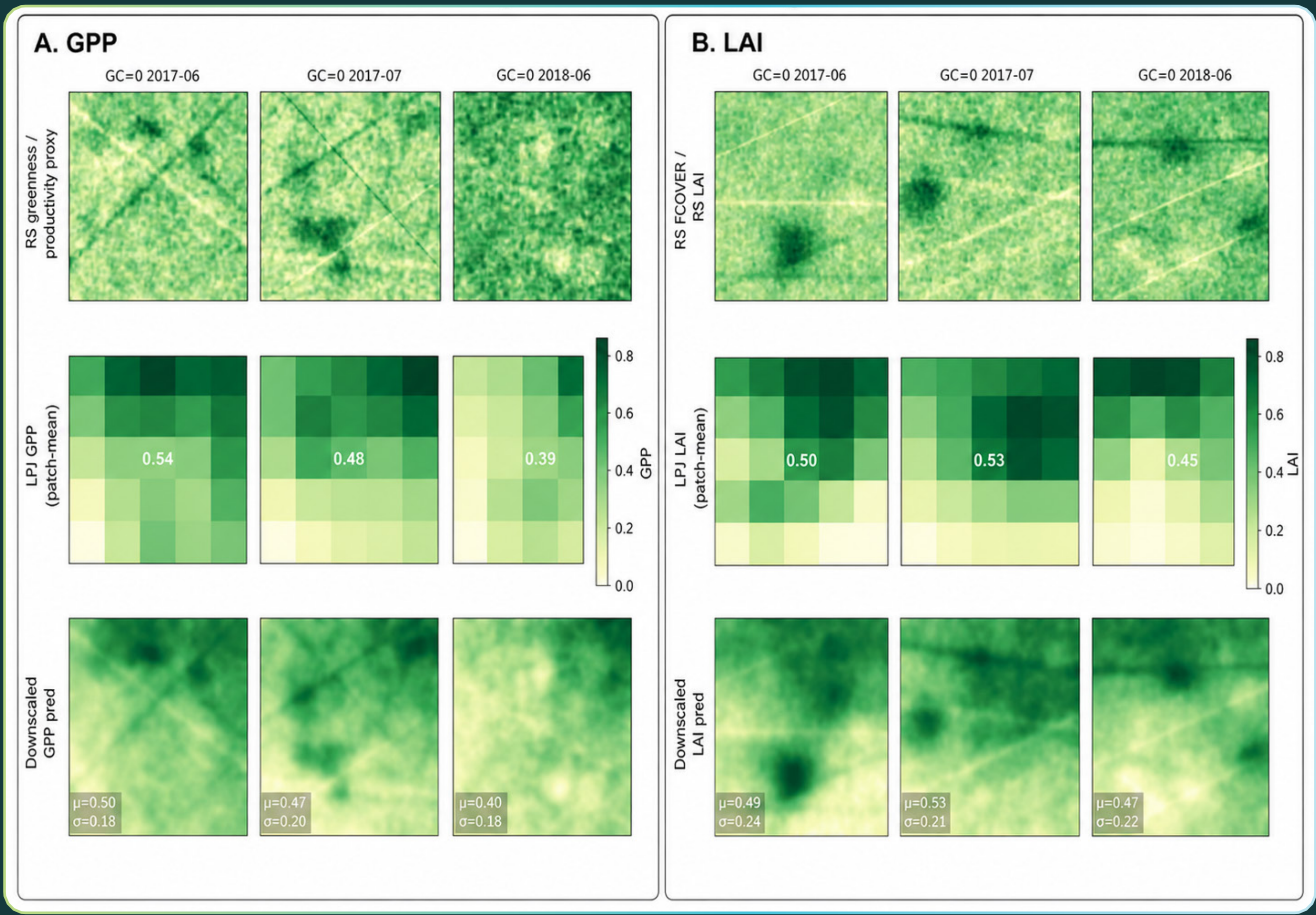

Figure 3. Examples of preliminary downscaling results for GPP and LAI. The figure compares remote-sensing proxies, coarse LPJ-GUESS patch-mean outputs, and fine-resolution downscaled predictions for selected monthly cases.

DESCRIPTION

This figure illustrates how the downscaling framework translates coarse LPJ-GUESS outputs into spatially detailed maps using remote-sensing information. For both GPP and LAI, the top row shows fine-resolution remote-sensing patterns, the middle row shows the corresponding coarse LPJ-GUESS patch-level signal, and the bottom row shows the modelled downscaled prediction. The examples demonstrate that the machine-learning approach can redistribute coarse ecosystem information into more spatially explicit patterns while keeping the predicted mean close to the original LPJ-GUESS signal. These outputs are preliminary examples and are used to assess whether the model preserves both process-based consistency and realistic spatial heterogeneity.

STAKEHOLDERS

Key stakeholders include forest management authorities, environmental agencies responsible for biodiversity monitoring, and policymakers involved in implementing the EU Forest Strategy and biodiversity policies. Researchers studying forest ecology, climate impacts, and ecosystem services are also important users of the pilot’s outputs.

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