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BioMassters as Initial Benchmark for 3D-ABC

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The 3D-ABC project, developed within the Helmholtz Foundation Model Initiative, aims to create a foundation model for accurate mapping of global terrestrial above- and below-ground carbon stocks in vegetation and soils at high spatial resolution. The model integrates multimodal remote sensing data including Harmonized Landsat-Sentinel-2 (HLS) imagery, TanDEM-X InSAR coherence, and will also integrate climatic, topographic, and space-borne 3D lidar data. The architecture employs a multi-modal input processor, FM encoder, adaptive fusion neck, and task-specific prediction heads, trained via masked autoencoder pretraining followed by supervised fine-tuning. Training leverages JSC's JUWELS Booster and the forthcoming JUPITER exascale system.

BioMassters, a dataset that encompasses satellite imagery and associated forest biomass estimates for large-scale above-ground biomass mapping, provides an ideal initial evaluation framework for 3D-ABC for several compelling reasons.

Above Ground Biomass (AGB) estimation represents a core downstream task for carbon monitoring. BioMassters specifically targets this capability using Sentinel-1 SAR and Sentinel-2 MSI time series, modalities that overlap substantially with 3D-ABC's input data streams. This alignment allows direct assessment of whether 3D-ABC's learned representations capture vegetation structure and biomass-relevant features.

The dataset derives AGB labels from Finnish Forest Centre airborne LiDAR campaigns at 5 points per square meter density, combined with field measurements and calibrated allometric equations. This produces reference data with approximately 8% RMSE for key tree attributes, far more reliable than existing global products and essential for meaningful foundation model evaluation.

With 310,000 patches of size 224x224 covering 8 million hectares across five years, BioMassters offers the statistical power needed to assess foundation model generalization. The temporal dimension, 12 monthly observations per sample, tests whether 3D-ABC effectively captures phenological dynamics crucial for vegetation monitoring. Beyond its scale and temporal richness, BioMassters also benefits from a strong benchmarking ecosystem.

The NeurIPS 2023 competition produced well-documented baseline performance: U-TAE achieved 27.49 t/px RMSE overall, with results stratified by biomass density (15.24 t/px for low density, 37.59 t/px for high density). These benchmarks enable rigorous comparison of 3D-ABC against state-of-

the-art task-specific models.

Current global biomass products operate at 100m resolution with RMSE values of 30-50 t/px. BioMassters operates at 10m resolution, allowing assessment of whether 3D-ABC's multimodal fusion can advance both accuracy and spatial detail simultaneously.

The dataset reveals where current approaches struggle, accuracy degrades with increasing forest density due to SAR backscatter and MSI reflectance saturation. This provides a specific challenge for 3D-ABC's multi-modal fusion architecture, and in future work we will be testing whether incorporating additional modalities (particularly 3D space-borne lidar) addresses these saturation effects.

While BioMassters covers boreal forests exclusively, it establishes whether 3D-ABC's pretrained representations provide a foundation for fine-tuning to other biomes, a critical test of foundation model utility before deploying resources on global-scale evaluation, e.g. in the arctic region.

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