

Supplementary material.

Modeling Primary Production in Temperate Forests Using Three-Dimensional Canopy Structural Complexity Metrics Derived from Airborne LiDAR Data

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Supplementary information

NEON terrestrial field sites

The National Ecological Observatory Network (NEON), funded by the U.S. National Science Foundation, provides standardized, openly accessible data from a nationwide network of study sites for long-term ecological research. NEON operates 47 terrestrial field sites strategically distributed across 20 distinct ecoclimatic domains to capture the full spectrum of U.S. ecological and climatic diversity. Each site was selected with input from the ecological research community to broadly represent the ecoclimatic variability within its domain. For this study, we screened all forested sites within the terrestrial network for qualifying data. During the growing season, field crews conduct observational sampling to characterize various ecosystem parameters, including vegetation structure, across all field sites. NEON provides detailed information on management and data collection specific to terrestrial sites at <https://www.neonscience.org/field-sites/about-field-sites>.

NEON tower base plots

To directly link between meteorological data collected by eddy-covariance (EC) towers and terrestrial observations, NEON designated square “tower base” plots within the EC tower footprint at each terrestrial site, following a spatially balanced, random design. These plots are located within the dominant vegetation types, as determined from the National Land Cover Dataset (NLCD), and number between 6 and 20 per site depending on the size and dimensions of the EC tower footprint. Detailed information on the site-level sampling design for these plots is available through NEON at <https://www.neonscience.org/data-samples/data-collection/observational-sampling/site-level-sampling-design>. All tower base plots at the forested sites selected for this study were 40x40m. Vegetation structure data, including diameter-at-breast-height (DBH) measurements, are collected within (typically a subset of) these plots annually, enabling estimation of plot-scale forest productivity.

Supplementary figures

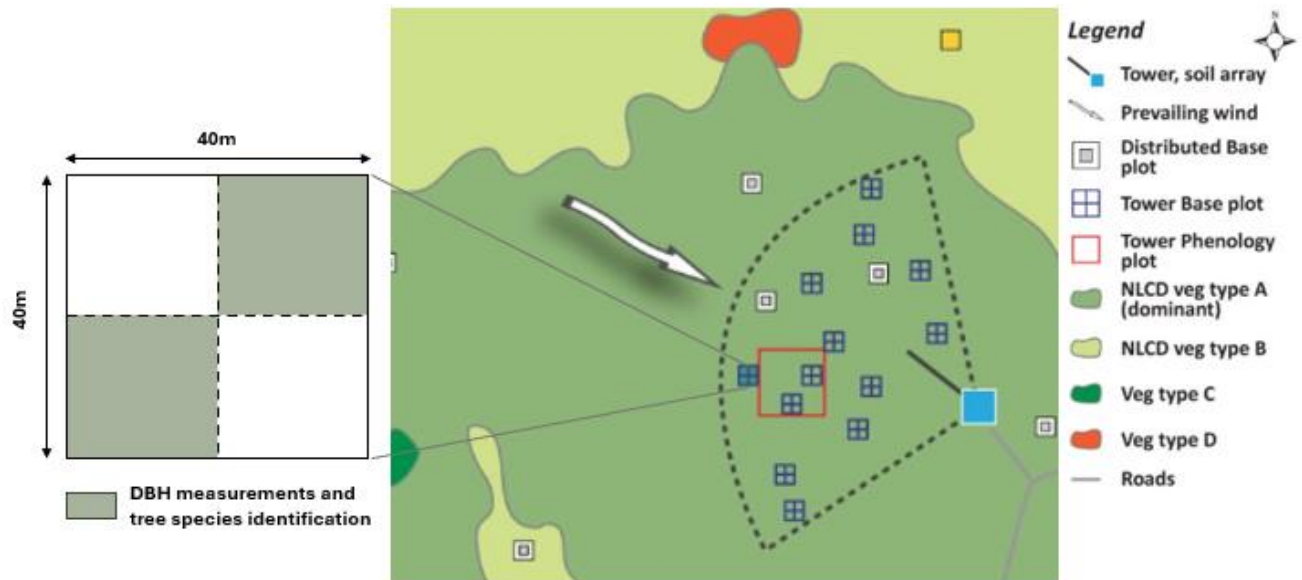


Figure S1. Right: Spatial layout of observational sampling at NEON terrestrial sites (adapted from Thorpe et al. [1]), with dotted lines marking the footprint of the meteorological/eddy-covariance (EC) tower (blue square). **Left:** Enlarged schematic of a NEON tower base plot within the EC tower footprint, showing diameter at breast height (DBH) and tree species sampled in two of four randomly selected quadrats, per NEON's sampling protocol.

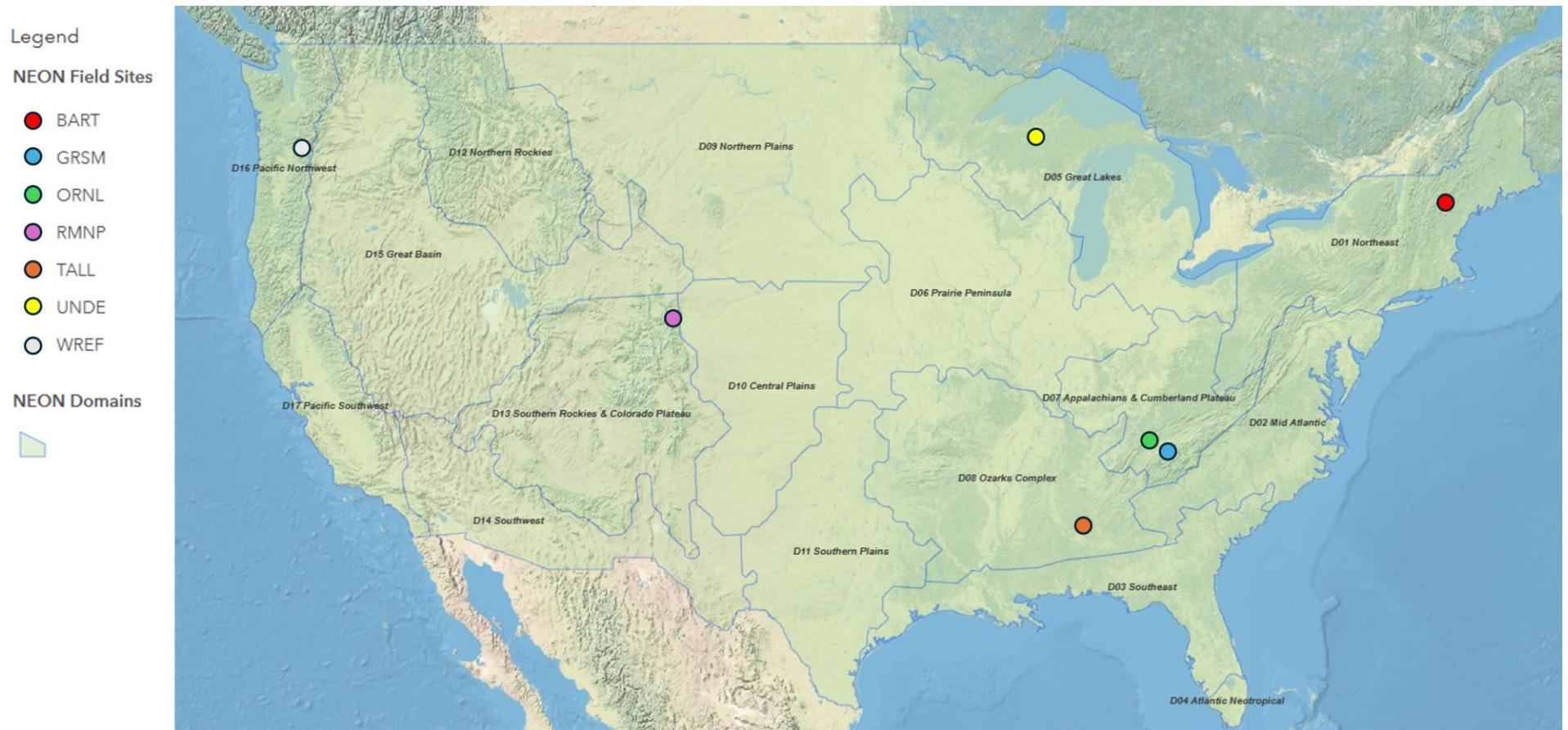


Figure S2. Mapped locations of the seven NEON temperate forest sites selected for this study [2]. The sites are spread across six ecoclimatic domains, which vary widely in climatic and topographic conditions.

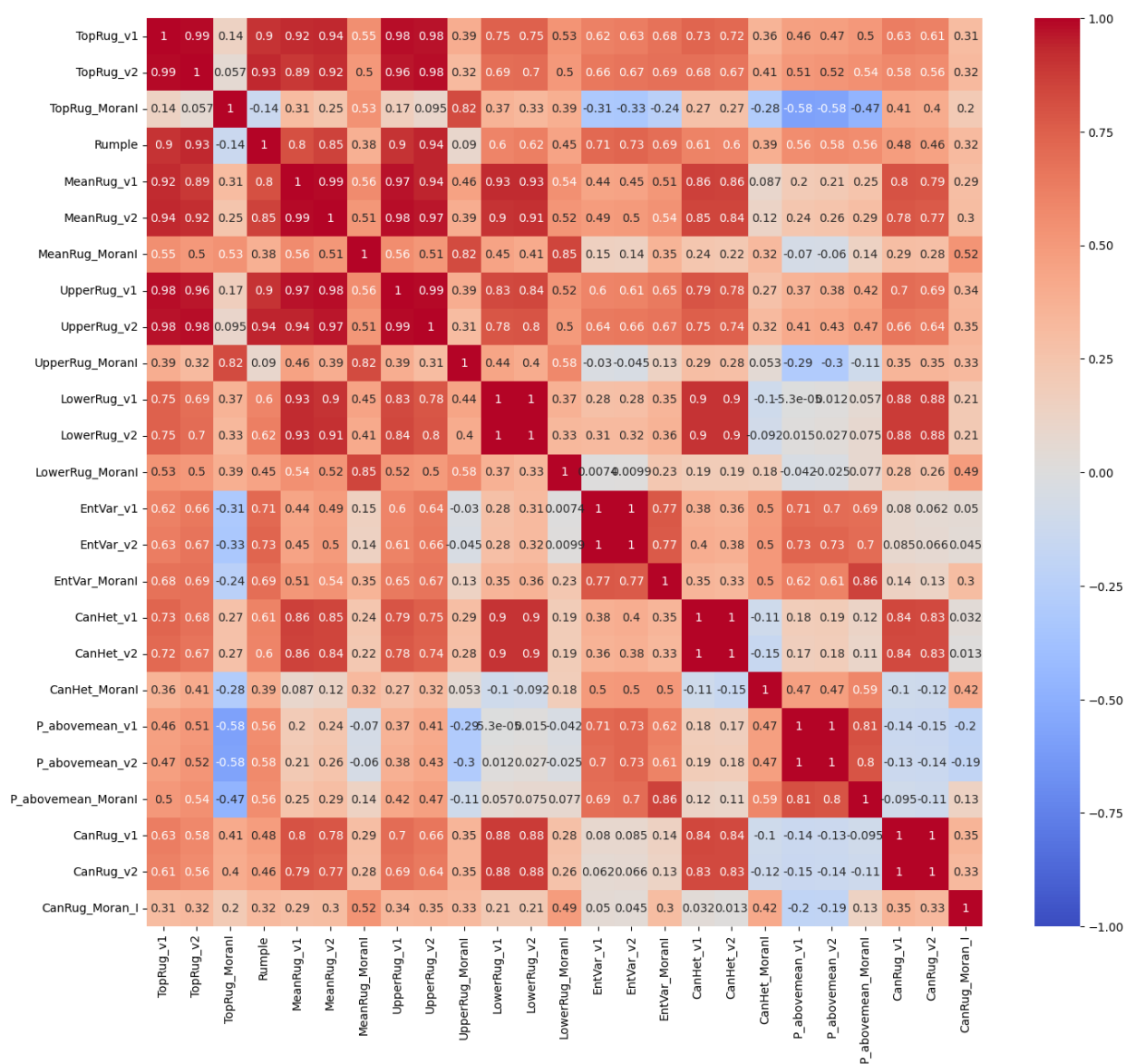


Figure S3. Correlation matrix of 3D CSC metrics derived at 1m resolution. High positive correlation can be observed between v1 and v2 of each CSC metric.

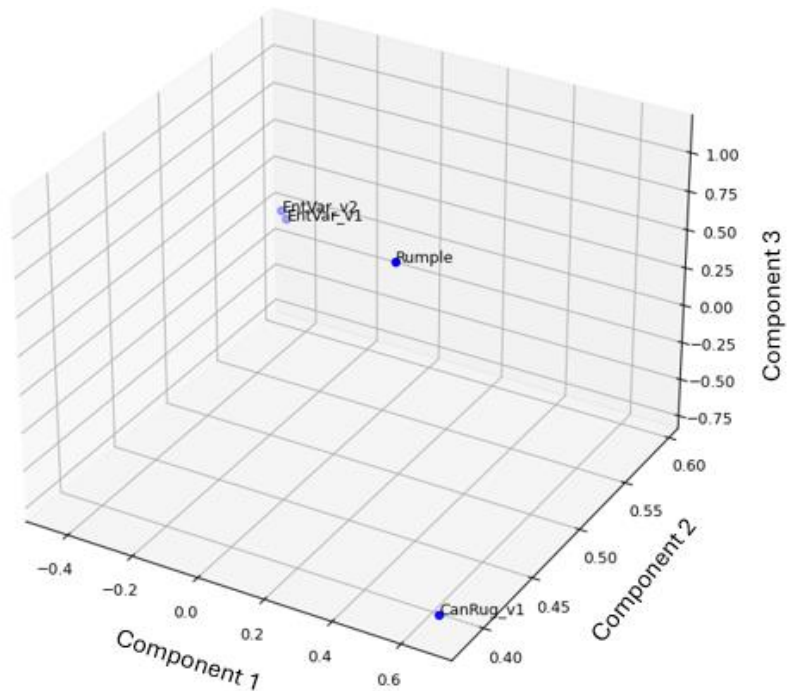


Figure S4. Loadings plot of the top candidate model (deciduous class). The variables are positioned based on their contributions to the three PLS components. Notably, *CanRug_v1* (1m) and *Rumple* (10m) are distant from the two *EntVar* (8m) variables.

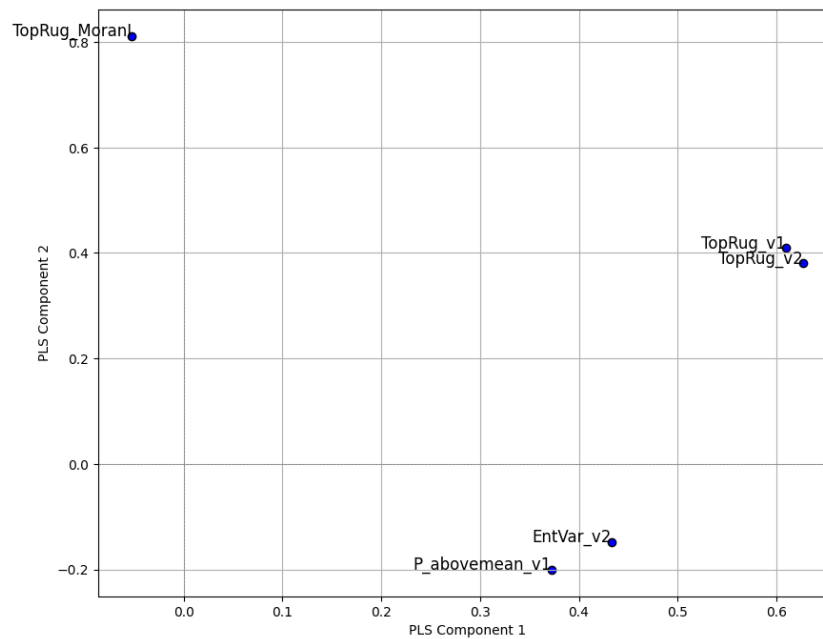


Figure S5. Loadings plot of the top candidate model (evergreen class). The variables are positioned based on their contributions to the two PLS components. *TopRug* v1 and v2 are closely clustered, indicating that they both capture the same underlying information.

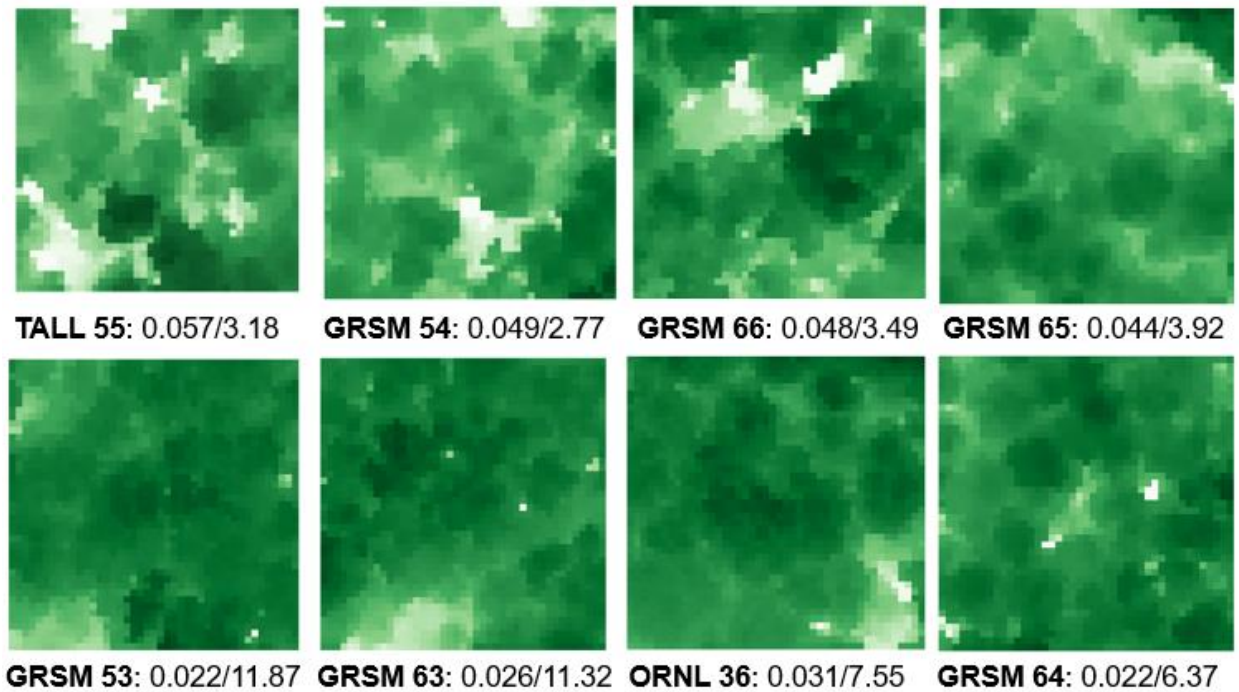


Figure S6. Top row: Canopy Height Models (CHMs) of the four plots with the highest *EntVar_v2_8m* values among those with below-mean NPP in the deciduous dataset. **Bottom row:** CHMs of the four plots with the highest NPP values among those with below-mean *EntVar_v2_8m* in the deciduous dataset. CHM pixels (1 m²) are colored using a white-to-green gradient, with darker green tones representing greater canopy height. Each CHM is annotated below with the corresponding plot ID and metric values in the format: “**Plot ID:** *EntVar_v2_8m/NPP*”.

Supplementary tables

Table S1. Summary statistics of field-derived NPP values, in megagrams per hectare per year, and the dominant canopy species [3] at each site.

Site	Minimum NPP	Maximum NPP	Mean NPP	Standard deviation of NPP	Dominant canopy species
Bartlett Experimental Forest (BART)	2.57	3.89	3.36	0.61	Red maple, yellow birch, Eastern hemlock, American beech
Great Smoky Mountains National Park (GRSM)	2.77	11.87	5.94	2.96	Yellow poplar, red maple, Eastern hemlock, sweet birch

Oak Ridge National Laboratory (ORNL)	3.18	7.55	4.53	1.58	Red maple, American beech, black tupelo, chestnut oak, white oak
Rocky Mountains National Park (RMNP)	1.96	3.80	2.50	0.67	Lodgepole pine, white spruce, subalpine fir
Talladega National Forest (TALL)	3.18	6.87	4.78	1.52	Longleaf pine, loblolly pine, red maple, sweetgum, mockernut hickory, Southern red oak
University of Notre Dame Environmental Research Center (UNDE)	1.18	5.87	3.72	1.22	Red maple, sugar maple, aspen, balsam fir
Wind River Experimental Forest (WREF)	0.47	4.66	2.37	1.49	Douglas fir, Pacific silver fir, Western Hemlock, Western red cedar

References

1. Thorpe, A. S., Barnett, D. T., Elmendorf, S. C., Hinckley, E. L. S., Hoekman, D., Jones, K. D., ... & Thibault, K. M. (2016). Introduction to the sampling designs of the National Ecological Observatory Network Terrestrial Observation System. *Ecosphere*, 7(12), e01627.
2. NEON (National Ecological Observatory Network). Field Sites Map. <https://neon.maps.arcgis.com/home/webmap/viewer.html?webmap=6396acd10aab4f0b83299911053dccfc>. (accessed 31 Oct 2024).
3. NEON, 2024. Vegetation structure (DP1.10098.001). National Ecological Observatory Network (NEON), RELEASE-2024.