

CEFO-2: Joint China–UK Summary of Second-Year Activities

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The second year of the China ESA Forest Observation project (CEFO-2) has strengthened the joint objective of developing a dynamic forest inventory framework for China and the United Kingdom through the integration of near-surface, airborne and satellite remote sensing. During this phase, work in both countries has moved beyond the initial establishment of baseline inventories and has concentrated more directly on the observation of change through time, the improvement of biomass estimation, and the development of methods capable of supporting future forecasting and management scenarios. Taken together, the activities undertaken in China and the United Kingdom demonstrate the value of combining detailed local measurements with scalable Earth observation approaches to deliver forest information that is both scientifically robust and operationally useful.

The Chinese research team conducted investigations across three domains. In individual tree species identification, a cognition-inspired structure-visual fusion framework was developed using multi-platform point cloud datasets, achieving species-level and genus-level classification accuracies of 86.12% and 87.49%, respectively. A Kalman filtering-based polar coordinate cross-section reconstruction method was further proposed to address point cloud thickness bias in handheld laser scanning (HLS), reducing DBH estimation RMSE from 2.48 cm to 1.96 cm. In biomass modeling, individual tree LBI–AGB models were constructed and validated across 17 major tree species in China, Oceania, and Europe, yielding R^2 values of 0.79–0.95 and RMSE of 16.41–51.93 kg. To support large-area estimation, an individual tree-to-footprint scale inference (L-IFS) framework was developed for AGB estimation using spaceborne full-waveform LiDAR systems (TECIS and GEDI), achieving a maximum R^2 of 0.82 and $R^2 \geq 0.62$ at complex terrain sites. By further integrating spaceborne LiDAR footprints

with Sentinel-2 imagery through deep neural network modeling, continuous spatial mapping of forest carbon stocks was achieved across China and the United Kingdom, with cross-validation R^2 of 0.70–0.91. In dynamic forest monitoring, a Random Forest model was developed for pine bark beetle infestation prediction in Yunnan Province using monthly cloud-free Sentinel-2 imagery, achieving prediction accuracies of 0.88–0.90 from January to March 2023.

The UK research team focused on three principal study areas: the Forest of Dean, Aberfoyle, and Thetford Forest. Tree lists derived from high-resolution airborne LiDAR enabled more granular spatial mapping of dominant species within sub-compartments, supporting detailed forest inventories including tariffing, height and diameter distributions, gap fractions, and natural regeneration. These datasets were also applied to wind risk assessment using the ForestGALES model. Recognizing that allometric relationships vary considerably across the UK due to latitudinal and longitudinal gradients, extensive mobile laser scanning was undertaken to capture site-specific DBH and stem form, which were subsequently incorporated into locally adjusted allometric models for biomass and volume estimation. An area-based analysis using a 20×20 m grid was further applied to estimate site productivity expressed as Yield Class, by combining species data from Planet satellite time series, age data from the Sub-Compartment Database, and LiDAR-derived heights. This hybrid approach enables chronosequence construction for forecasting future forest increments, with planned refinements to incorporate competition and disturbance dynamics in collaboration with Oxford partners. Additionally, a Digital Twin platform is being developed to convert remote sensing outputs into a web-based application capable of displaying spatial data, generating reports, and running alternative management scenarios tailored to diverse end-user needs.

The Chinese and UK research strands are highly complementary. China has advanced scalable LiDAR processing, forest carbon mapping, and disturbance detection, while the UK has refined structural inventories, allometric calibration, productivity analysis, and risk modelling. Together, they demonstrate that combining LiDAR-derived structural data with spaceborne systems enables high-resolution biomass estimation, and that time-series observations can reveal growth trajectories, phenological variation, and disturbance signals critical for forest management decisions. In its second year, CEFO-2 has successfully transitioned from baseline inventory development towards dynamic monitoring, model integration, and practical application, laying robust foundations for precision forestry across diverse ecological and management settings.

第二年度中国与欧空局森林观测项目进展(CEFO-2)

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中欧森林观测项目(CEFO-2)第二项目年进一步深化了中英两国的联合目标,通过融合近地面、机载与卫星遥感技术,构建面向中英两国的动态森林资源清查框架。在此阶段,双方团队研究工作均已超越初期基础清查的范畴,更加聚焦于森林变化的时序观测、生物量估算精度的提升,以及支撑未来预测分析与经营情景模拟方法的研发。中英两国的研究成果共同表明,将精细化本地测量与可扩展地球观测方法相结合,能够有效获取兼具科学严谨性与实际应用价值的森林信息。

中方研究团队围绕三个核心方向开展研究。在单木参数提取方面,利用多平台点云数据集构建了认知启发的结构—视觉融合框架,种级与属级识别精度分别达 86.12%与 87.49%;在此基础上,针对手持式激光扫描(HLS)点云厚度偏大的固有缺陷,提出基于卡尔曼滤波的极坐标截面重建方法,将胸径估计 RMSE 由 2.48 cm 降至 1.96 cm。在生物量建模方面,构建并验证了涵盖中国、大洋洲与欧洲 17 种主要树种的单木 LBI-AGB 模型, R^2 为 0.79—0.95, RMSE 介于 16.41—51.93 kg。为支撑大区域森林参数估测,研究提出单木至光斑尺度推演(L-IFS)框架,用于支持 TECIS 和 GEDI 等星载全波形激光雷达系统的 AGB 估算,最高 R^2 达 0.82,复杂地形站点 $R^2 \geq 0.62$ 。进一步融合星载激光雷达离散光斑与 Sentinel-2 连续影像,通过深度神经网络建模实现中英两国森林碳储量连续空间制图,交叉验证 R^2 为 0.70—0.91。在森林动态监测方面,利用月度无云 Sentinel-2 合成影像构建随机森林模型,对云南省松林松小蠹虫害进行概率预测,2023 年 1-3 月预测精度达 0.88—0.90。

英方研究团队聚焦三个主要研究区 Dean、Aberfoyle 和 Thetford Forest。基于 ALS 生成的单木清单,实现了小班内优势树种的精细空间制图,为包括出材率、树高与胸径分布、林隙率及天然更新在内的详细森林资源调查提供支撑,并进一步应用于 ForestGALES 风险模型的森林防风评估。考虑到英国境内因纬度与经度梯度差异显著导致异速生长关系存在较大变化,研究团队在各研究区开展了大范围移动激光扫描,获取站点特异性胸径与干形数据,并将其纳入局部校正异速生长模型,用于生物量与蓄积量估算。此外,研究综合利用 Planet 卫星时序影像获取的树种数据、小班数据库中的林龄

数据以及激光雷达反演的树高信息，采用 20×20 m 格网开展面积法分析，以材积年生长量（Yield Class）表征立地生产力，构建混合模型用于预测未来森林蓄积增量，并计划与牛津大学种群动力学合作团队共同引入竞争与干扰因子以进一步完善模型。与此同时，数字孪生平台正在将遥感分析成果转化为网络端应用，可实现空间数据展示、报告生成及面向不同用户管理需求的情景模拟。

中英双方研究高度互补。中方在可扩展激光雷达数据处理、森林碳储量制图及干扰监测方面取得重要突破，英方则在精细结构清查、异速生长关系校正、立地生产力分析及风险模型构建方面持续深化。双方研究共同表明，融合激光雷达结构数据与星载系统可实现高分辨率生物量估算，时序观测能够有效揭示生长轨迹、物候变化及干扰信号，为森林经营决策提供关键支撑。CEFO-2 在第二项目年已成功从基础资源清查迈向动态监测、模型集成与实际应用，为多元生态与管理情景下的精准林业建设奠定了坚实基础。