

Responses to Reviewers' Comments for Manuscript ESSD-2026-102

**FineKarstAGB: A 30 m resolution aboveground biomass
dataset for Southwest China derived by upscaling
plot-level inventory using sub-meter GaoFen satellite data**

Addressed Comments for Publication to

Earth System Science Data

by

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Response Letter

Dear Editors,

Please find enclosed the revised version of our manuscript entitled “*FineKarstAGB: A 30 m resolution aboveground biomass dataset for Southwest China derived by upscaling plot-level inventory using sub-meter GaoFen satellite data*” (Manuscript ID: essd-2026-102). We sincerely thank the Topic Editor and reviewers for their continued evaluation and constructive feedback. Their positive assessment and focused comments in this round have helped us further improve the clarity and presentation of the manuscript.

We have carefully considered all comments and revised the manuscript and Supplement accordingly. The following pages provide detailed point-by-point responses in the order of the decision letter. Comments are reproduced in light-blue boxes, our replies are introduced by **Response:**, and the corresponding revisions are reported under **Changes in manuscript:**. In the tracked-changes manuscript, substantive revisions made in this revision round are shown in red, while line numbers remain black; the clean manuscript contains the same text without revision coloring.

Sincerely,

Yongqing Bai

Corresponding author, on behalf of all authors

Authors' Response to the Topic Editor

Comment 1

Move Fig. 1 to the Supplementary Information, as it mainly provides background information about the study area.

Response: Thank you for this helpful suggestion. Figure 1 was intended to illustrate differences in spatial detail among remote sensing imagery and forest parameter products at different resolutions, indicating that medium- and low-resolution data have some limitations in depicting the fine-scale spatial heterogeneity of the study area. Following your suggestion, we have moved this figure to the Supplementary Information as Fig. S1 and updated the corresponding figure references and numbering.

Changes in manuscript:

Introduction — page 2, line 55, and page 3, lines 81–84 [REVISED]

Supplementary Fig. S1 — page 3 [MOVED FROM THE MAIN MANUSCRIPT]

The former Fig. 1 has been moved to the Supplementary Information as Fig. S1. The corresponding references and figure numbering in the manuscript and Supplement have been updated accordingly.

Comment 2

Move Fig. 14 to the Supplementary Information, as it largely presents information that overlaps with that shown in Fig. 12.

Response: Thank you for this suggestion. Figure 12 was intended to provide a comprehensive comparison of how closely the spatial patterns of different AGB datasets correspond to forest structure across representative landscape types, whereas Fig. 14 focused on typical regions with pronounced differences among the datasets and the potential causes of these differences. Although the two figures were designed for different analytical purposes, we acknowledge that they contain some overlapping information. Following your suggestion, we have moved the former Fig. 14 to the Supplementary Information as Fig. S10. The associated discussion in the manuscript has also been condensed, and the corresponding figure references and numbering have been updated.

Changes in manuscript:

Supplementary Fig. S10 — page 10 [MOVED FROM THE MAIN MANUSCRIPT]

Sect. 5.1, Comparison with other AGB datasets — page 23, lines 513–515, and page 25, lines 516–521 [REVISED]

To further examine the regional discrepancies at the local scale, Fig. S10 presents detailed comparisons for Pu'er and Tongren, where pronounced differences among the AGB datasets were observed. The products of Yang et al. (2023) and Yan et al. (2023a) show broader zonal patterns, with generally higher AGB estimates in the tropical monsoon forest–rainforest zone of Pu'er and predominantly moderate-to-high values in the subtropical evergreen broadleaf forest zone of Tongren, suggesting a stronger influence of

geographic and vegetation zonation. The visible no-data gaps in Yan et al. (2023a) further suggest that forest masks that are temporally mismatched with the AGB reference year or contain classification errors may exclude areas that currently contain tree biomass. The discrepancies in Cai et al. (2024b) occur mainly in complex terrain and dense forests, consistent with the product-specific differences in reference data and input variables discussed above. Together, these local examples support the causes inferred from the regional difference patterns.

Comment 3

Remove the bullet-point format in Section 4.3 and integrate the content into one or more coherent paragraphs.

Response: Thank you for this helpful comment. The bullet-point format was originally used to distinguish the five representative landscape types and their corresponding spatial characteristics. We agree that presenting these comparisons as continuous prose improves the coherence and readability of this section. We have therefore removed the bullet-point format and reorganized the content into two coherent paragraphs while retaining the main analysis of each landscape type and its correspondence with the rows in the figure.

Changes in manuscript:

Sect. 4.3, Spatial pattern of AGB in Southwest China and typical scenarios — page 20, lines 449–454, and page 21, lines 455–461 [REVISED]

To qualitatively evaluate the capability of FineKarstAGB to delineate spatial heterogeneity, we selected five representative landscapes and compared FineKarstAGB with existing AGB datasets using GaoFen imagery, tree cover, and canopy height as references (Fig. 11). In the dense natural forests of Xishuangbanna, Yunnan (Row 1), FineKarstAGB shows AGB variations corresponding to topographic variation and apparent differences in vegetation structure, while delineating local high- and low-AGB areas in greater detail than the coarser-resolution products. In the plantation landscape of Nanning, Guangxi (Row 2), FineKarstAGB shows distinct AGB values among adjacent afforested plots, potentially reflecting differences in stand development and management.

In highly heterogeneous landscapes, FineKarstAGB represents patchy, linear, and scattered trees within the agricultural matrix of Qianxinan, Guizhou (Row 3). In the forest–shrubland mosaic of Xiangxi, Hunan (Row 4), the dataset shows local AGB differences associated with variations in vegetation height and density. In Kunming, Yunnan (Row 5), FineKarstAGB assigns biomass values to scattered urban trees, including trees along streets and in parks, despite their distribution among non-vegetated features such as buildings and roads. Together, these examples illustrate the spatial representation of FineKarstAGB across natural forests, plantations, agroforestry systems, forest–shrubland mosaics, and urban environments.

Comment 4

Provide concise and direct responses to the questions raised in the final paragraph of the Introduction.

Response: Thank you for this important comment. We agree that the questions raised in the final paragraph of the Introduction should be answered more explicitly. Regarding the first question, the use of plot-level patches allows CSMF-Net to represent fine-scale spectral and structural variation in het-

erogeneous landscapes, thereby addressing the difficulty of characterizing fragmented vegetation using individual pixels. Regarding the second question, spectral information from sub-meter GaoFen imagery is integrated with horizontal crown structure and vertical canopy-height information through the Multi-feature Cross-Attention module. The ablation experiments further showed that all three inputs contributed to model performance, with the omission of canopy height resulting in the largest reduction in performance. Regarding the third question, FineKarstAGB quantifies biomass from trees outside contiguous forests, including urban trees and scattered farmland trees. The resulting AGB estimates in non-forest areas were positively related to independent UAV LiDAR-derived canopy height. Accordingly, the Conclusions have been revised to clearly address the questions raised in the Introduction.

Changes in manuscript:

Sect. 6, Conclusions — page 28, lines 622–640 [REVISED]

To accurately estimate aboveground biomass in the highly heterogeneous forests of Southwest China, a globally critical ecoregion, this study developed a Canopy Structure-driven Multi-feature Fusion Network (CSMF-Net). Using plot-level patches allows CSMF-Net to represent fine-scale spectral and structural variation in heterogeneous landscapes. Within this framework, spectral information from sub-meter GaoFen imagery is integrated with horizontal crown structure and vertical canopy-height information through the Multi-feature Cross-Attention (MCA) module. The ablation experiments further showed that all three inputs contributed to model performance, with the omission of canopy height resulting in the largest reduction in performance. The proposed CSMF-Net achieved robust AGB estimation when evaluated against independent NFI plots ($R^2 = 0.69$, $RMSE = 28.51 \text{ Mg ha}^{-1}$). Based on this model, we produced the first fine-grained, high-spatial-resolution AGB dataset for the four provinces of Southwest China for 2024. The dataset captures the spatial distribution of AGB across natural forests, plantations, and agroforestry systems, while also quantifying biomass from trees outside forests, including urban trees and scattered farmland trees that are often overlooked in conventional large-scale AGB products. The AGB estimates in these non-forest areas were also positively related to independent UAV LiDAR-derived canopy height. This inclusion promotes more comprehensive and spatially explicit carbon accounting. Furthermore, the AGB estimates demonstrate strong consistency with three-dimensional forest structure; a comparative evaluation against UAV LiDAR CHM shows a high degree of agreement ($R^2 = 0.54$). Overall, this research establishes a reliable benchmark dataset for assessing biomass and carbon storage in one of China's most ecologically important regions. It provides spatially detailed evidence to evaluate the outcomes of major national ecological restoration initiatives, such as the Grain for Green Program and Karst Rocky Desertification Control. Moreover, the dataset offers fine-scale data support for regional carbon cycle modeling, biodiversity conservation, and sustainable forest management, contributing directly to China's long-term carbon neutrality goals.

Authors' Response to Reviewer 1

General Comment

My comments have been addressed.

Response: Thank you for confirming that your comments have been addressed. We appreciate your careful review and positive assessment of the revised manuscript.

Authors' Response to Reviewer 3

General Comment

Some questions have been resolved.

Response: Thank you for confirming that some of the questions raised previously have been resolved. We have carefully considered your remaining comments and respond to each of them below.

Comment 1

Section 3.1, Line 260: From this sentence, it is clear that the CSMF-Net model can accurately predict AGB. However, when looking at the description of this part, it always feels that these descriptions lack reliable scientific support. It seems that this is just a self-aware statement by the author. For example, compared to the traditional random forest algorithm, this model has certain advantages, but when reading these, they all make people question the credibility. It is necessary to enhance the scientific nature.

Response: Thank you for this important comment. We agree that the previous description could be interpreted as an unsupported conclusion regarding the superiority of CSMF-Net over conventional approaches. Our intention was to explain the methodological rationale for using plot-level patches rather than treating individual pixels as independent samples, rather than to claim superiority over a specific algorithm. Specifically, the patch-based representation retains the spatial context and internal heterogeneity within each plot and integrates spectral and structural patterns across multiple pixels. We have therefore removed the direct reference to Random Forest and revised the relevant statements to describe these characteristics as the intended functions of the model design rather than as definitive conclusions about its performance. The performance of CSMF-Net is evaluated separately using the independent NFI test set ($R^2 = 0.69$, $RMSE = 28.51 \text{ Mg ha}^{-1}$), while the contributions of the three

inputs are examined through the leave-one-input-out ablation experiments in Sect. 4.1.

Changes in manuscript:

Sect. 3.1, Canopy Structure-driven Multi-feature Fusion Network — page 10, lines 251–259 [REVISED]

CSMF-Net adopts a Patch-to-Point regression strategy, in which a preprocessed NFI plot-level data patch is used as input to directly predict a single AGB value and its associated uncertainty for that plot. By using a spatial patch rather than treating individual pixels as independent samples, this strategy retains the spatial context and internal heterogeneity within each patch.

In karst landscapes, vegetation distribution is extremely fragmented due to complex terrain, shallow soils, and strong lithological controls, causing individual medium-resolution pixels to frequently contain mixtures of vegetation, bare rock, and soil. Pixel-level models trained on such mixed signals may smooth local variability. In contrast, the patch-to-point framework aggregates spectral and structural patterns across multiple pixels and learns their joint relationship with plot-level AGB. This design is intended to help account for mixed-pixel effects and spatial heterogeneity within plots when estimating plot-level AGB in karst landscapes.

Comment 2

Figure 14: The meaning represented by the five-pointed star in the picture needs to be clearly stated.

Response: Thank you for pointing this out. The red five-pointed stars in the GaoFen overview panels indicate the locations of the corresponding zoomed-in areas shown in the rows immediately below. We agree that this meaning was not clearly explained in the original figure caption. As the former Fig. 14 has now been moved to the Supplementary Information as Fig. S10, we have revised its caption to explicitly define the meaning of these symbols.

Changes in manuscript:

Supplementary Fig. S10 caption — page 10 [REVISED]

Figure S10. Illustration of typical scenarios and local details showing differences between FineKarstAGB and comparison AGB datasets. The red five-pointed stars in the GaoFen overview panels indicate the locations of the corresponding local details shown in the rows immediately below. (a) GaoFen imagery, (b) canopy height, (c) FineKarstAGB, (d) Yang et al. (2023), (e) Yan et al. (2023a), (f) ESA CCI (Santoro and Cartus, 2025), and (g) Cai et al. (2024b).

Comment 3

What are the differences between Figure 12 and Figure 14? It seems that the two figures can be combined. In Section 5.2 of the discussion, based on the comparison of the spatial distribution of canopy height and biomass in the figure, it is difficult to obtain the relationship between forest structure and AGB. Moreover, the description in this section is too simplistic. Additionally, AGB is also related to other forest structure parameters, such as tree age, but this is not mentioned in the text.

Response: Thank you for this important comment. The former Fig. 12 and Fig. 14 were designed for related but different purposes. Figure 12 provides a comprehensive comparison of how different AGB

datasets represent forest structure and their spatial consistency across representative landscape types, whereas Fig. 14 focuses on typical regions with pronounced differences among the datasets and the potential causes of these differences. We acknowledge that the two figures contain some overlapping information. Accordingly, as also suggested by the Topic Editor, we have retained the former Fig. 12 in the main manuscript and moved the former Fig. 14 to the Supplementary Information as Fig. S10.

We agree that the spatial comparison of canopy height and AGB alone cannot establish a quantitative relationship between them. However, the purpose of Sect. 5.2 was not to derive such a quantitative relationship from the figures. Instead, canopy height was used as a directly observable indicator of forest vertical structure, supported by established ecological and allometric relationships showing that taller forest stands generally accumulate more biomass. The spatial comparisons were intended to illustrate this ecological correspondence and the importance of fine-scale vertical structural information for representing AGB heterogeneity. Compared with the AGB datasets of Yang et al. (2023) and Yan et al. (2023a), which were produced using 30 m canopy-height data, FineKarstAGB was generated using finer-resolution canopy-height information and shows spatial patterns that are more consistent with the local variations observed in GaoFen imagery and fine-scale canopy-height data. Nevertheless, differences among the products may also reflect their other input data and modeling approaches. We have revised Sect. 5.2 to clarify this purpose and to relate the spatial observations to the input-ablation experiments and the independent UAV LiDAR CHM assessment.

We also agree that AGB is influenced by other forest attributes, including stand age, stem diameter and wood density. Stand age was not included as an explicit spatial predictor in FineKarstAGB or in the comparison datasets considered in this study, and the spatial comparisons were therefore not intended to isolate its effect. We have added a concise statement clarifying that canopy height is not the sole determinant of AGB and that CSMF-Net combines canopy height with spectral and crown information to represent complementary factors associated with biomass variation.

Changes in manuscript:

Supplementary Fig. S10 — page 10 [MOVED FROM THE MAIN MANUSCRIPT]

Sect. 5.2, Significance of fine-scale vertical structure in characterizing AGB heterogeneity — page 25, lines 522–544 [REVISED]

Forest vertical structure, particularly canopy height, provides important information for accurately estimating AGB. Ecologically, this relationship is governed by allometric scaling, whereby tree height serves as a proxy for accumulated biomass. From a remote-sensing perspective, canopy height is also one of the most directly observable structural metrics. Numerous studies have used canopy height as an important structural variable to establish relationships between forest vertical structure and AGB or carbon stocks (Liu et al., 2023; Zhu et al., 2025).

Our study further illustrates the role of fine-scale vertical structural information in characterizing AGB heterogeneity in complex landscapes. The datasets of Yang et al. (2023) and Yan et al. (2023a) used 30 m canopy-height products to represent AGB spatial variation at a broader scale. In Fig. 11 and Fig. S10, the spatial patterns of FineKarstAGB correspond to local variations visible in the GaoFen imagery and high-resolution canopy-height data. These comparisons indicate that higher-resolution canopy-height information provides additional spatial detail for characterizing local AGB heterogeneity. This contribution is further supported by the input-ablation experiments, in which excluding canopy height produced the largest decline in model performance. FineKarstAGB also showed a positive relationship with independent UAV LiDAR-derived mean canopy height ($R^2 = 0.54$), providing additional evidence of its consistency with forest vertical structure.

AGB is not determined by canopy height alone. Stand age affects biomass accumulation during forest succession (Poorter et al., 2016), while stem diameter and wood density are also important allometric predictors of tree biomass (Chave et al., 2014). These factors may result in different AGB values among stands with similar canopy heights. Canopy height is therefore treated as an important component of forest structure rather than as the sole determinant of AGB, and CSMF-Net combines it with spectral information and horizontal crown structure. Within this multi-feature framework, fine-scale vertical structural information complements spectral and crown features by providing direct information on vegetation stature. This information is particularly important for distinguishing local biomass contrasts associated with differences in canopy height within dense forests, fragmented agroforestry systems, forest–shrub mosaics, and scattered tree cover. Thus, fine-scale canopy-height information contributes to AGB estimation and helps characterize biomass heterogeneity across structurally complex landscapes.