

This manuscript presents the development of a global 30-m resolution Plant Functional Type (PFT) fractional cover dataset (PFT30) and a corresponding 500-m monthly PFT-specific Leaf Area Index (LAI) product, both spanning the period 1985–2020. The core objective is to address the scarcity of long-term, high-resolution land surface data required to quantify the impacts of land use and land cover change in Earth System Models. The authors integrate multiple high-resolution remote sensing products to minimize the assumptions typically required for PFT fraction derivation. Furthermore, the study generates a PFT-specific LAI dataset using a remote-sensing-derived phenology scheme, contrasting with the empirical approaches commonly adopted in land surface models.

The study is highly relevant to the current needs of the Earth system modeling community, offering a potential solution to the challenge of representing land surface heterogeneity. The manuscript is well structured and comprehensive, and the data products appear valuable for the community. However, the manuscript in its current form requires some revisions, primarily concerning the clarity, robustness, and thoroughness of the methodological description.

We thank the reviewer for the positive evaluation of our work and for recognizing the potential value of the PFT30 and PFT LAI datasets for the Earth system modeling community. We also appreciate the constructive comments and suggestions regarding the clarity and robustness of the methodological description. We have carefully considered all comments and revised the manuscript accordingly. Detailed responses to each comment are provided below.

Major comments:

1. The method for generating PFTs for years prior to 2000 (1985, 1990, 1995) is described too simply. The strategy of using a look-up table... based on the PFT distribution for the reference year 2000 assumes that the relationship between LCT and PFT composition was static from 1985-2000. This is a strong assumption, especially in regions undergoing active land-use change. The pre-2000 methodology needs a much more detailed explanation. The limitations of this approach must be explicitly stated in the methodology and discussed in the results/conclusions.

We thank the reviewer for this constructive comment. We agree that the pre-2000 methodology warrants a more thorough explanation, and we have substantially expanded the relevant section in the revised manuscript. Due to the lack of key remote sensing products required for sub-pixel PFT mapping before approximately 2000,

such as GFCC and MODIS VCF, the direct mapping approach used for the post-2000 period could not be applied. Therefore, an alternative strategy based on the GLC\_FCS30D land cover type (LCT) time series was adopted for the reconstruction of pre-2000 PFT distributions.

Using the 1985–2020 LCT time series, we first identified pixels whose LCT remained unchanged throughout the entire period, referred to here as “static grids”. For these pixels, the year-2000 PFT values were directly assigned to 1985, 1990, and 1995. This assumption is considered reasonable, as pixels exhibiting no LCT change over the full 35-year period, including the post-2000 era, are unlikely to have experienced substantial PFT composition changes during 1985–2000. Static grids account for approximately 85.74% of global vegetated land pixels and provide the reference samples used for constructing the look-up tables (LUTs). These static grids therefore provide the basis for inferring the PFT composition of dynamically changing pixels prior to 2000.

For pixels that experienced LCT changes (“dynamic grids”), accounting for 14.26% of global vegetated land pixels, the method assumes that their PFT composition is similar to that of nearby static pixels with the same LCT. This assumption is based on the premise that pixels sharing the same LCT within a region generally experience similar ecological and climatic conditions and therefore tend to exhibit similar sub-grid vegetation composition. Following Harper et al. (2023), multi-scale LUTs (0.025°, 0.25°, and 5°) were constructed using the statistical relationship between LCT and PFT composition derived from static grids. For each dynamic pixel, the PFT composition was assigned using the finest-scale LUT containing static-grid samples of the same LCT, with progressively coarser LUTs used when necessary. If no static pixels with the same LCT were available at any scale, static pixels belonging to LCTs within the same vegetation group in the GLC\_FCS30D classification (e.g., open forest replacing closed forest of the same type) were used before resorting to a global-scale LUT as the final fallback option.

For the years 1985, 1990, and 1995, 98.52% of dynamic vegetated pixels requiring LUT-based assignment were resolved using the finest-scale 0.025° LUT, while only 1.20%, 0.26%, and 0.02% relied on the 0.25°, 5°, and global LUTs, respectively. This indicates that the vast majority of dynamic pixels had nearby static pixels available for reference.

Due to the lack of high-resolution pre-2000 remote sensing constraints, this approach necessarily assumes that the relationship between LCT and PFT composition remained approximately stable during 1985–2000. This assumption may be less valid in regions experiencing rapid land-use change, such as tropical deforestation areas and regions of rapid agricultural expansion, where the PFT composition of a changing pixel may differ from that of nearby static pixels in 2000. These limitations are now explicitly acknowledged and discussed in the revised manuscript. The revised text reads as follows:

For the period prior to 2000, PFT data were derived following the approach of Harper et al. (2023) to reconstruct grids with dynamic land cover changes, due to the limited availability of ancillary remote sensing datasets. The main strategy is to infer the PFT composition of dynamically changing grids from neighboring static grids. Specifically, static grids (30 m grids whose LCT remained unchanged from 1985 to 2020) were first identified based on the GLC\_FCS30D land cover product. For these grids, the year-2000 PFT composition was directly assigned to 1985, 1990, and 1995, assuming that pixels without LCT change over the full period were unlikely to experience substantial PFT composition changes prior to 2000. These static grids were then used to construct statistical relationships between LCT and PFT composition. For dynamic grids, the PFT composition was assigned using the finest-scale LUT containing static-grid samples with the same LCT, with progressively coarser LUTs applied when necessary. If no static pixels with the same LCT were available at any scale, static pixels belonging to LCTs within the same vegetation group in the GLC\_FCS30D classification (e.g., open forest replacing closed forest of the same type) were used before resorting to a global-scale LUT as the final fallback option. Due to the lack of high-resolution pre-2000 remote sensing constraints, this approach assumes that the relationship between LCT and PFT composition remained approximately stable during 1985–2000.

...

While these observed patterns provide a coherent representation of fractional PFT cover change, the reconstruction of pre-2000 PFT distributions still relies on several assumptions. In particular, the approach assumes that the relationship between land cover type and sub-grid PFT composition remained approximately stable during 1985–2000, due to the lack of high-resolution remote sensing

constraints. In addition, the 5-year temporal resolution of PFT maps prior to 2000 is constrained by the update frequency of the underlying GLC\_FCS30D land cover product. These factors may introduce additional uncertainties in regions experiencing rapid land-use change, such as tropical deforestation and agricultural expansion areas. Such limitations largely reflect the scarcity of consistent high-resolution remote sensing constraints prior to the MODIS era and is therefore difficult to fully eliminate in historical PFT reconstruction.

2. About PFT LAI Allocation Algorithm. The core algorithm for deriving PFT LAI is not sufficiently justified or explained. The logic behind using grids with >80% PFT cover as "representative" to calculate Ratio\_ipft is sound in principle but its implementation is unclear. Eq. (1) is not explained. Does this method preserve the grid-level LAI? (It appears it does, as  $\sum(\text{Frac\_ipft} * \text{PFTLAI\_ipft}) = \text{GridLAI}$ ). Provide a more rigorous derivation or citation for Eq. (1). Include a statement confirming that the method is mass-conservative with respect to the input GridLAI. Meanwhile, the symbolic expressions here are not concise enough and can be optimized.

We thank the reviewer for this thorough and constructive comment. Section 2.2.2 has been revised to clarify the physical rationale and mathematical formulation of the PFT LAI allocation method. Specifically, the weighting factor  $\omega_p$  is now explicitly defined as the characteristic LAI of each PFT, estimated from near-pure pixels (fractional cover > 80%) within each 0.25° window. This serves as an observationally constrained representation of the characteristic LAI of each PFT and is used to partition the grid LAI among different PFTs. We have also added a rigorous derivation of the allocation equations. Starting from the assumption that each PFT's LAI is proportional to its characteristic LAI via a uniform scaling scalar, and applying the mass-conservation constraint that the area-weighted sum of PFT LAI must equal the grid LAI, the final allocation equation follows directly. We confirm that the method is strictly mass-conservative by construction. In addition, the symbolic notation and equation structure have been revised to improve clarity and readability. The revised text and equations are provided below:

Based on the harmonized grid LAI and PFT30 datasets, the allocation method assumes that the LAI of each PFT within a grid is proportional to its characteristic LAI  $\omega_p$ . That is:

$$\text{PFTLAI}_p = \lambda \cdot \omega_p , \quad (1)$$

where  $\lambda$  is a uniform scaling scalar shared across all PFTs within the grid. For each PFT,  $\omega_p$  was estimated as the mean grid LAI of near-pure pixels (fractional cover  $> 80\%$ ) within the same  $0.25^\circ$  window, serving as an observationally constrained representation of the characteristic LAI of that PFT for partitioning the grid LAI among different PFTs. In cases where no near-pure pixels were available for a given PFT within the target window,  $\omega_p$  was obtained from a hemispheric look-up table constructed from the mean LAI values of near-pure pixels within the corresponding climate zone. To ensure mass conservation, the PFT-area-weighted sum of PFT LAI was constrained to equal the grid LAI following Eq. (2):

$$\sum_{p=1}^{16} f_p \cdot \text{PFTLAI}_p = \text{GridLAI} , \quad (2)$$

where  $p$  denotes a specific PFT,  $f_p$  is the fractional cover of PFT  $p$ , and GridLAI is the grid-scale LAI. Combining Eq. (1) and Eq. (2), the PFT LAI is calculated as:

$$\text{PFTLAI}_p = \frac{\omega_p}{\sum_{p=1}^{16} f_p \cdot \omega_p} \cdot \text{GridLAI} . \quad (3)$$

Minor Comments:

1. In Section 2.1.7, the manuscript states that LAI4g and MODIS LAI can be combined to form a continuous long-term record. However, it remains unclear how the consistency and continuity between the two datasets are ensured in practice, particularly around the transition period. A more detailed explanation would improve confidence in the combined dataset.

We appreciate the reviewer's comment regarding the continuity between the LAI4g and reprocessed MODIS LAI datasets. We have clarified in Section 2.1.7 that the transition between the two datasets is not based on a simple concatenation of

independent products. Instead, the LAI4g product was developed with harmonization against the reprocessed MODIS LAI during their overlapping period to improve consistency between the AVHRR- and MODIS-based LAI records. The revised text reads:

Since the derivation of the GIMMS LAI4g product employed the reprocessed MODIS LAI product (2004–2020) to extend temporal coverage through a pixel-wise linear fusion approach, the resulting dataset inherits a harmonized structure across the AVHRR- and MODIS-based periods. This design follows the common practice of constructing long-term LAI records by consolidating AVHRR-era products with post-2000 satellite observations. Therefore, the transition between the LAI4g data used for 1985–2003 and the reprocessed MODIS LAI data used from 2004 onward represents a temporally harmonized long-term LAI record rather than a simple concatenation of independent datasets.

2. The spatial interpolation method used to resample LAI4g to 500 m resolution should be explicitly stated. The temporal aggregation from 15-day to monthly resolution should also be clarified.

We appreciate the reviewer's suggestion for clarification. The description of the spatial resampling and temporal aggregation procedures for the LAI4g dataset has been revised as follows:

For preprocessing, the  $1/12^\circ$  LAI4g data were resampled to 500 m resolution using bilinear interpolation to ensure consistency with the spatial resolution of the PFT LAI dataset. The half-monthly LAI4g data were then aggregated to monthly resolution by averaging the two half-monthly values for each month.

3. The use of 5-year interval PFT maps may introduce uncertainties in regions with rapid land cover change, which could be briefly acknowledged.

We thank the reviewer for this comment. We agree that the 5-year temporal resolution of the PFT maps prior to 2000 may introduce additional uncertainties, particularly in regions experiencing rapid land cover change. This temporal resolution is constrained by the update frequency of the underlying GLC\_FCS30D land cover product used for the historical PFT mapping. We have added a brief acknowledgement of this limitation in the manuscript. The revised text reads:

... In addition, the 5-year temporal resolution of PFT maps prior to 2000 is constrained by the update frequency of the underlying GLC\_FCS30D land cover product. These factors may introduce additional uncertainties in regions experiencing rapid land-use change, such as tropical deforestation and agricultural expansion areas. ...

4. **Section 2.2.1, Step 1:** "Crop PFT fraction is seen as the vegetated area in the grid if the target grid was classified as crop LCT, therefore its fraction is assigned as the remaining fraction of bare cover." This sentence is grammatically awkward and logically ambiguous. Please rephrase for clarity.

Following the reviewer's comment, we have revised the description in Section 2.2.1, Step 1 to improve clarity and correct the grammatical issues. The updated text now reads:

For grids classified as crop LCT, the crop PFT fraction was directly set to the vegetated portion of the grid, calculated as 1 minus the bare soil fraction, without considering the GFCC tree cover. For other grids, the remaining vegetated area was distributed among shrub and natural grass PFTs according to the rules described below.

5. Section 2.2.1, Step 2: It states that the shrub/grass ratio is derived from GLC\_FCS30D within 1km windows. What is done for 30m pixels if the 1km window contains no relevant LCT? A brief note on the handling of edge cases would be helpful.

We appreciate the reviewer's comment regarding the handling of edge cases in the 1 km shrub/grass ratio dataset. We have added a clarification in Section 2.2.1 describing the treatment of cases where no shrub or grass LCT exists within the  $1 \times 1$  km window.

The revised text reads:

In cases where no shrub or grass LCT was identified within the  $1 \times 1$  km window, which generally indicates very limited non-tree vegetation cover, the remaining fraction was conservatively assigned according to the land-cover condition of the target grid (e.g., shrub for tree-dominated grids and bare soil for bare or sparsely vegetated grids).

6. Lines 195-196: the statement "The fractional cover of non-vegetated types was assigned as either 0% or 100% based on the GLC\_FCS30D product" could be clearer.

Thank you for pointing this out. We have clarified the description of non-vegetated types in the manuscript to make the assignment rule explicit. The revised sentence now reads:

For each non-vegetated type, the fractional cover was set to 100% if the corresponding pixel was identified as that type in the GLC\_FCS30D product, and 0% otherwise.

7. Figure 7 subplots lack detailed captions; please specify which panel corresponds to which comparison for improved readability.

Following the reviewer's comment, we have clarified the caption of Figure 7 to improve readability. The updated caption is as follows:

Figure 1: Site-scale validation of four global PFT mapping products against site observations. Columns correspond to CoLM, ESA<sub>global</sub>, ESA<sub>local</sub> and PFT30, respectively. Rows correspond to fractional tree cover (a-d), fractional short vegetation cover (e-h), and fractional bare soil cover (i-l), respectively.

8. There are several instances of minor grammatical errors that require proofreading. Examples: "the roubustness" (line 65, typo); "lifeforms ecosystem" (line 43, should be "lifeform ecosystems" or "ecosystems with mixed lifeforms"); "photosynthetic pathways (e.g. C3 and C4)" (line 140, "e.g." is unnecessary).

Thank you for pointing this out. We have carefully proofread the manuscript and corrected the grammatical and typographical issues identified by the reviewer. The corresponding sentences have been revised as follows:

line 65: As this approach relies on indirect inference from LCT labels, its reliability depends on both the robustness of the cross-walking rules and the classification accuracy of the underlying LCT product.

line 43: Some land surface models (LSMs) used to describe land vegetation as discrete land cover types (LCTs) and applied a consistent set of parameters to mixed-lifeform ecosystems.

line 140: The 1 km WorldClim Version 2 product (Fick and Hijmans, 2017) is used to determine the photosynthetic pathways ( $C_3$  and  $C_4$ ) of grass PFTs based on the climatological monthly precipitation and temperature.

9. The study fuses 30-m PFT data with 500-m MODIS LAI. The abstract mentions a "monthly 500 m PFT LAI dataset." The methodology for upscaling the 30-m PFT fractions to match the 500-m LAI grid should be explicitly stated.

We thank the editor for this suggestion. We agree that the upscaling procedure should be described more explicitly. The manuscript (Methodology section) has been revised to clarify that the 30-m PFT fractions were aggregated to the 500-m LAI grid by calculating the fractional coverage of each PFT within each 500-m grid, thereby matching the spatial resolution of the LAI product used in this study.

10. Terminology should be used consistently. For example, in line 371, "PFT LAI values" is used, whereas "PFT LAI" is used elsewhere in the manuscript.

We thank the reviewer for this constructive suggestion. We have revised "PFT LAI values" to "PFT LAI" in Line 371, where "PFT LAI" is used to represent the variable values, consistent with the surrounding context and the rest of the manuscript.

11. The text mentions "Reprocessed MODIS v6.1 LAI" and "MODIS C6.1 LAI". Ensure the dataset version is consistent throughout the manuscript.

Thank you for pointing this out. We have standardized the terminology throughout the manuscript. All instances of "Reprocessed MODIS v6.1 LAI" and "Reprocessed MODIS C6.1 LAI" have been replaced with "Reprocessed MODIS LAI". This ensures consistent terminology throughout the manuscript.