Revisions and Responses to Comments

Dear reviewer

Thanks for your reviewing and valuable comments of our manuscript entitled "***A global estimate of monthly vegetation and soil fractions from spatio-temporally adaptive spectral mixture analysis during 2001–2022***". We also appreciate you for providing insightful feedback and comments to strengthen our manuscript.

We have revised our manuscript with considering each detailed suggestion that you and reviewers have graciously provided. These major revisions include:

1 added additional validation and comparison data

2 provided a more accurate description to enhance the clarity and coherence of the presentation.

Besides these revisions, all authors checked the manuscript carefully and several minor revisions have been done to finalize the manuscript.

The following is a point-by-point response to the questions and comments delivered in your letter. For your convenience, revisions made by the authors have been highlighted in red color in the both response and revised manuscript, which could be easily checked. We hope that our revisions and responses can satisfactorily address all the issues and concerns.

This paper aims to provide a globally comprehensive record of monthly vegetation and soil fractions during the period 2001–2022 using the spatiotemporally adaptive MESMA methods at the powerful Google Earth Engine (GEE) platform. However, in my view, some issues should be resolved. Please find my detailed comments below.

Thanks for your reviewing and valuable comments of our manuscript, we have revised our manuscript with considering each detailed suggestion that you and reviewers have graciously provided.

The overall structure of this article appears to be somewhat confusing. I recommend considering adjustments to enhance the clarity and coherence of the presentation.

Thank you for your valuable feedback on the manuscript's structure, particularly emphasizing the need for reorganization. We have moved “Compared with other datasets and traditional spectral mixture analysis model” and “Uncertainties of estimates of global vegetation and soil fractions” to Section 3.2 and Section 3.3. In the Discussion section, we have improved the discussions of Advances and limitations of estimates of global vegetation and soil fractions in Section 4.1 to delve deeper into comprehensive analyses and discussions.

In your paper, you have utilized Köppen-Geiger climate classification maps Version 1, while Version 2 is also available at https://www.gloh2o.org/koppen/. Could you please provide some insights into the rationale behind selecting Version 1 over Version 2? Additionally, considering the abundance of global land cover products, what motivated the choice of MCD12Q1?

We opted for Köppen-Geiger climate classification maps Version 1 due to their widespread acceptance and usage within the scientific community at the period of our research. While Version 2 is available and might offer certain improvements or updates, our choice was based on the prevalence and familiarity of Version 1 within the research community during our study period. Moreover, we utilized this data solely to ensure that our selected representative MODIS grids encompass all climate zones. Therefore, the utilization of data from versions 1 and 2 had negligible influence.

Regarding the selection of MCD12Q1 among various global land cover products, we chose it due to its established accuracy, high spatial resolution, and comprehensive coverage. MCD12Q1 utilizes multiple datasets and robust algorithms to provide detailed and reliable land cover information, aligning well with the requirements of our study for endmember selection. Its proven consistency and compatibility with our research objectives influenced our decision in utilizing this specific product.

We have improved descriptions of Köppen-Geiger climate classification (page 5, line 124-126) and MCD12Q1 (page 5, line 132-135).

"The Köppen-Geiger climate classification is a reasonable approach to aggregate complex climate gradients into a simple but ecologically meaningful classification scheme (Beck et al. 2018). This dataset presents their widespread acceptance and usage within the scientific community."

"MCD12Q1 utilizes multiple datasets and robust algorithms, and provides detailed and reliable land cover information. It has been proven advantages in representing the global land cover structure, patterns, and dynamics, aligning well with the requirements of our study for endmember selection."

In this paper, authors selected the typical sites employed for standardized endmembers selection based on 2020 MCD12Q1. Could you elaborate on the decision-making process behind employing this particular year for standardized endmembers selection?

Thank you very much for your suggestion. We chose the MCD12Q1 data not directly for endmember selection but for identifying representative zones. Subsequently, we will carry out endmember selection in these representative regions. The criterion for selecting representative MODIS grids is a high diversity of land cover types. Therefore, we need to choose the recent available MCD12Q1 land cover dataset (in 2020) to calculate land cover diversity (page 7, line 179-180).

“Meanwhile, we also examine land cover diversity, characterized by Simpson's Diversity Index (D) of recent MCD12Q1 Version 6 product in 2020 in each MODIS grid”

When comparing your estimated vegetation and soil fractions dataset, along with NDVI, fractional PV, and NPV, against the MOD44B vegetation continuous fields product, I noticed that you specifically chose to focus on the tree and non-tree vegetation components. Could you elaborate on the reasoning behind this selective comparison?

We are aware that MOD44B covers only three components: percent tree cover, percent non-tree cover, and percent non-vegetated (bare), whereas our endmember types encompass five. We thus chose to combine tree and non-tree vegetation components as vegetated area, and then it was compared with our PV and NPV due to considerations of consistency across different classification systems.

We have refined the descriptions of comparisons (page 12-13, line 278-293).

“To verify the consistency and merits of our dataset against existing ones, we conducted comparisons with four distinct pre-existing datasets: NDVI, MOD44B Vegetation Continuous Fields product, GLASS fractional vegetation cover dataset, and GEOV Fcover dataset. NDVI is derived from monthly synthesized MCD43A4 images. Both mean values of NDVI and our estimated fractional PV across all years and months are considered for comparison. The MOD44B Vegetation Continuous Fields product provides annual information about the percent tree cover, percent non-tree cover, and percent non-vegetated within each 250-meter pixel globally (DiMiceli et al., 2015). Consequently, we compare vegetation cover proportions—sum of percent tree cover and percent non-tree cover—to the sum of fractional PV and NPV. To align spatial and temporal resolutions, we aggregated the sum of percent tree cover and percent non-tree cover to a 500-meter scale. Simultaneously, we computed monthly Fractional PV and NPV as annual averages. The GLASS fractional vegetation cover dataset, offering an 8-day temporal frequency and dual spatial resolutions of 0.05° and 500 meters, was generated using a machine learning approach correlating MODIS reflectance with fractional vegetation cover (Jia et al., 2015). In our study, the 500-meter GLASS data was utilized to validate our estimated fractions. We computed annual averages from all the CLASS fractional vegetation cover data within a year and compared it with the annual averages of Fractional PV. GEOV FCover is a 10-day product estimated through the neural network using visible, near-infrared and shortwave infrared at 1km resolution (Baret et al. 2013). We aggregate our product to a 1km spatial resolution, and compare their annual averages with the annual averages of GEOV FCover.”

Could you please provide more detailed reasons or methods explaining why you decided to verify PV and NPV as a single category in your study? Additionally, I noticed that you exclusively chose GLCVRD reference data from 2010 for validation

purposes. Could you please elaborate on the decision-making process behind selecting this specific year for validation?

As mentioned in the previous response, there isn't currently a suitable product available to validate photosynthetic and non-photosynthetic vegetation independently. Therefore, in our validation process, we conducted validation using vegetation as a combined category.

Moreover, the CLCVRD dataset has demonstrated effectiveness in global-scale land cover verification. It's important to note that this dataset spans 2003-2012 (mainly 2010), and I apologize for any misleading information in previous descriptions. Thus, this data can effectively serve for fraction validation across different years and months.

We thus improved the descriptions of validations (page 11 line 244-251) and discussed the limitations of validation datasets (page 25, line 470-481).

"Firstly, we filter the estimated fractions based on the corresponding year and month obtained from the reference data. Simultaneously, aligning the interpretations of land cover types with our endmembers, we pair them accordingly, that is, tree and other vegetation represent PV and NPV, barren stands for BS, water and shadow correspond to DA, and ice & snow denote IS. Subsequently, we reclassify these paired land cover types and calculated their percentage within 5×5 km blocks, in which we exclude cloud coverage (named no data). Additionally, utilizing these cloud-free pixels in each block, we compute the mean of fractional values for each endmember, and then compare these estimated fractions with the measured percentage of paired the reclassified land cover types to validate the reliability of our product (Fig. S4)."

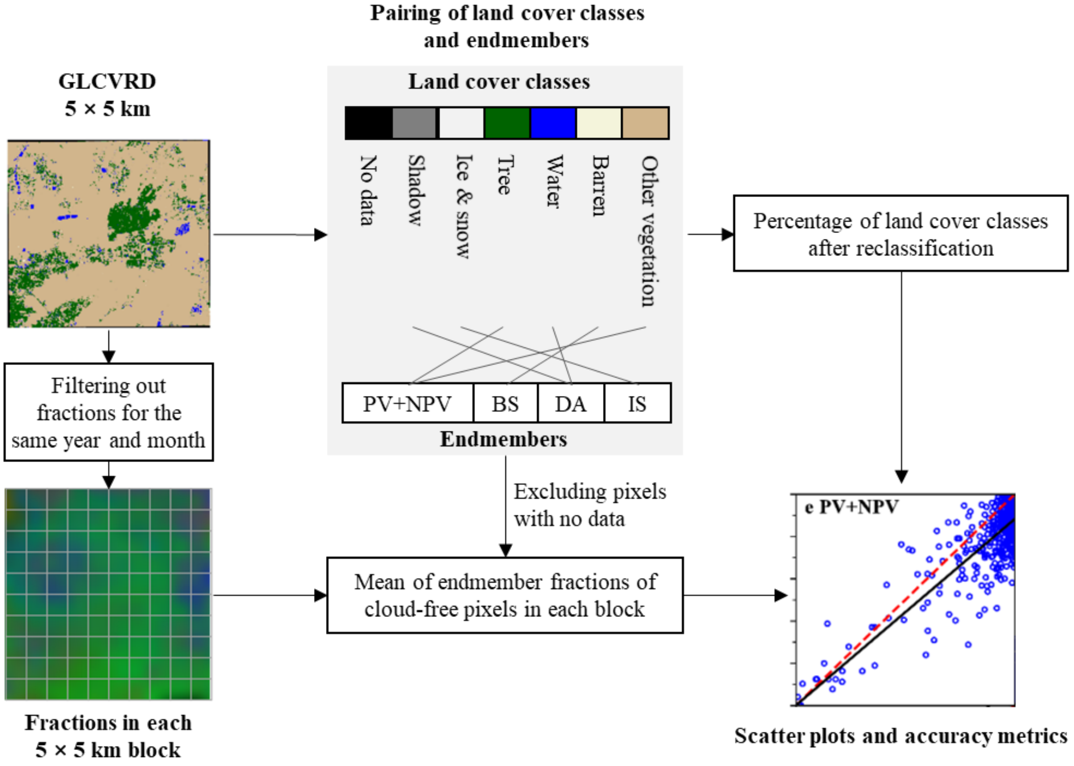

Figure S4: Procedural description for estimating fractional vegetation-soil compared to GLCVRD.

"However, due to the absence of corresponding reference data for validation, we solely rely on two high-quality land cover reference datasets for validation. Unfortunately, these datasets do not intricately characterize small-scale shadows and bare soil within complex vegetation structures. Consequently, this leads to a misconception in the validation, where our DA and BS are overestimated in low-value areas and vegetation is underestimated in high-value areas (Fig. 3, Fig.S5). Therefore, in the future, there is a need to further develop high-quality relevant reference data. Considering that MOD44B vegetation continuous fields product provides a gradation of three surface cover components: percent tree cover, percent non-tree cover, and percent bare, the dark components (i.e., shadow of vegetation and mountain, water) are not quantified. Therefore, fractional PV and NPV is overall biased high, especially in areas with PV and NPV less than 0.50 (Fig. 4b; Fig. S6b). Besides, we also observed a certain degree of underestimation in these three datasets in regions with lower vegetation cover compared to our data. This is mainly because these datasets focus solely on green vegetation, especially GLASS and GEOV Fcover (Baret et al. 2013; Jia et al., 2015), and do not accurately estimate non-photosynthetic vegetation in arid regions. The above comparisons demonstrate our precision advantage in fine extraction of multiple endmembers."

Given that your product has a spatial resolution of 500m and a monthly temporal resolution, while the MOD44B product has a spatial resolution of 250m and a yearly temporal resolution, could you please provide a detailed description of the comparison process and the methods employed between them?

Certainly, the comparison process between our product with a 500m spatial resolution and monthly temporal resolution and the MOD44B product with a 250m spatial resolution and yearly temporal resolution involved several steps and considerations.

To conduct the comparison, we first aggregated the monthly data into a yearly format to align with the temporal resolution of MOD44B. Meanwhile, we aggregated 250m MOD44B product to our data to match the spatial resolutions of our products. This allowed us to bridge the temporal gaps and ensure a meaningful evaluation despite the differing temporal frequencies.

We have improved such descriptions of comparisons (page 12-13, line 278-286).

"To verify the consistency and merits of our dataset against existing ones, we conducted comparisons with four distinct pre-existing datasets: NDVI, MOD44B Vegetation Continuous Fields product, GLASS fractional vegetation cover dataset, and GEOV Fcover dataset. NDVI is derived from monthly synthesized MCD43A4 images. Both mean values of NDVI and our estimated fractional PV across all years and months are considered for comparison. The MOD44B Vegetation Continuous Fields product provides annual information about the percent tree cover, percent non-tree cover, and percent non-vegetated within each 250-meter pixel globally (DiMiceli et al., 2015). Consequently, we compare vegetation cover proportions—sum of percent tree cover and percent non-tree cover—to the sum of fractional PV and NPV. To align spatial and temporal resolutions, we aggregated the sum of percent tree cover and percent non-tree cover to a 500-meter scale. Simultaneously, we computed monthly fractional PV and NPV as annual averages."

Please revise the abstract of this paper, some sentences are confusing. For example, line 32-34: "Sustainably managing terrestrial ecosystems requires an increased understanding of these structurally and functionally heterogeneous multi-component information and their changes, but we remain lack of such records of fractional vegetation and soil information at global scale.

Certainly! Here's a revised version for the mentioned section (page 2 line 32-35):

"Sustainably managing terrestrial ecosystems necessitates a deeper comprehension of the diverse and dynamic nature of multi-component information within these environments. However, comprehensive records of global-scale fractional vegetation and soil information that encompass these structural and functional complexities remain limited."

Abbreviations are preferably not used in the abstract of a paper, and if they are used in the abstract, the full name of each abbreviation should be presented the first time it appears. For example, Lines 44-45: "PV and NPV".

Thank you very much for your suggestion. We have revised the abbreviations from the Abstract (page 2 line 38-39).

"five physically meaningful vegetation and soil endmembers, including photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV), bare soil (BS), ice/snow (IS), and dark surface (DA), with high accuracy and low uncertainty"

Line 124: Please correct "croplands and mosaics of croplands and natural vegetation;" to "Cropland/Natural Vegetation Mosaics".

Thank you very much for your suggestion, we have revised "croplands and mosaics of croplands and natural vegetation" to "Cropland/Natural Vegetation Mosaics" (page 5 line 139)

Line 137 and 231: Please add the serial number to the formula in this paper. For example, RMSE was defined twice.

Thank you for your thorough review of our manuscript. We have redefined the Root Mean Square Error for the fitting of the MESMA model as $RMSE_{sma}$. Additionally, we have added numbering to the formulas (page 6 line 152-153).

Line 171: Why did the authors choose the threshold 'D > 0.7' in this study, and are there any references supporting this decision?

The threshold selection was based on ranking the Simpson's Diversity Index (D) of all MODIS grids. We chose the top ten grids, hence setting the threshold at 0.7. To avoid confusion, we rephrased it as (page 7 line 182-184),

"Finally, we selected the top 10 grids (i.e., h08v05, h12v12, h13v09, h16v01, h21v03, h22v02, h22v08, h24v06, h26v05, h27v06, h29v12) in terms of Simpson's Diversity Index (D) among all MODIS grids (Fig. S1a, b)"

Line 268-277: Could you please provide the location or clarification for Figure 3 i-k? I would like to ensure that all relevant chart information is accurate and accessible.

We sincerely apologize for the error in our expression. We have made the necessary corrections and also reviewed all the titles of the figures and tables

Line 331 and 348: The subtitle '4.1 Compared with other datasets and traditional SMA model' seems inconsistent with 'Figure 7: Comparisons with other datasets and LSMA models.' Could you please clarify whether the LSMA model is considered one of the traditional SMA models, and ensure consistency in the expression used?

Thank you for pointing this out. We have revised unclear expression to ensure consistency between the LSMA model and traditional SMA models in the context of the comparisons made in Figure 4. The traditional SMA models was defined as fully constrained linear spectral mixture models (page 17, line 363-369) .

"**Figure 4: Comparisons with other datasets and traditional spectral mixture analysis models. a, b**, **c**, **d** the bi-dimensional histogram of fractional endmembers and other dataset with bin size of 2%, including fractional PV against NDVI (a), fractional PV and NPV against fractional tree and non-tree vegetation of MOD44B vegetation continuous fields product (b), fractional PV and NPV against GLASS fractional vegetation cover product (c), fractional PV and NPV against fractional vegetation cover of GEOV Fcover product; **e**, **f**, the boxplot and violin plot for average of monthly $RMSE_{sma}$ for two fixed endmember spectral curves using fully constrained linear spectral mixture models, including (e) average of all spectral spectra for each endmember and (f) existing spectral spectra from Small and Sousa (2019)."

Line 378: "RESE" --> "RMSE".

We sincerely apologize for the error in our expression. We have made the corrections. All authors checked the manuscript carefully and several minor revisions have been done to finalize the manuscript.