Response to Reviewer:

(Retype your comments in *italic font* and then present our responses to the comments)

The paper introduces the High-Quality LAI (HiQ-LAI) dataset, which is an upgraded version of the existing MODIS LAI retrievals that typically suffer from high noise levels. The Spatio-Temporal Information Compositing Algorithm (STICA) was used to create this new dataset, which incorporates pixel quality information, spatio-temporal correlation, and original retrieval to provide more accurate results. The Time-series Stability (TSS) index showed that the area with smooth LAI time-series expanded significantly across the globe, especially in equatorial regions that are known to pose challenges for optical remote sensing. The HiQ-LAI dataset outperforms raw MODIS LAI in terms of continuity and consistency, both spatially and temporally, allowing for better land surface process simulation, climate modelling, and global change research. Overall, the manuscript is well-structured, provides valuable insights into vegetation dynamics across the globe, and has the potential to enhance the quality and impact of this field of research.

However, the advantages of the proposed method for solving the noise problem of the MODIS product are not adequately demonstrated in the paper. For instance, the authors state that the previous study "overlooked spatial correlation information" and that "genuine land surface LAI anomalies (e.g., caused by forest fires) may be artificially removed, even if the LAI profile appears smoother." The paper does not provide a clear explanation of how the proposed method addresses these issues.

The methods used in this study are straightforward, but some essential points are missing in the manuscript. For instance, a brief introduction of the STICA method, the TSS metric, and some key validation methods can further improve the clarity of the manuscript.

Response: Special thanks for your positive comments and very detailed suggestions to make the paper better. Following the Reviewers' comments, we have carefully revised our manuscript, and adequately addressed all the questions and concerns that the referees have raised. Hope this revised manuscript has solved all your concerns.

In our algorithm, the quality, spatiotemporal information, and relative original observation records are fully utilized, and these pieces of information are weighted and averaged according to our fusion strategy. More robust results are obtained by considering multiple dimensions of information to compensate for the limitations of using a single information source and by preserving as real LAI anomalies as possible. Firstly, we introduce a novel quality evaluation index, MQA, to assess the quality of each pixel. The incorporation of temporal and spatial correlation also incorporates information from MQA, where the contribution of a pixel relies not only on its spatial/temporal correlation but also on its MQA value. Ultimately, the three dimensions of temporal, spatial, and the original observational value are integrated and furthest utilize the information from the original data. We anticipate that this process maximizes the preservation of genuine anomalies.

Additionally, we added a detailed description of the STICA method, the TSS metric, and some key validation methods in Sect 3.1 (red font)

"Satellite remote sensing observations are often subject to uncertainties arising from climatic factors, sensor malfunctions, and other sources, resulting in varying levels of uncertainty for individual pixels. To address this issue, this approach employed multiple indicators to evaluate the uncertainty for each pixel (referred to as MQA hereafter). These indicators encompass the algorithm path, STD LAI, and Relative Time-series Stability (TSS). The algorithm path (AP) is a crucial quality index, distinguishing between the main and backup algorithms. The main algorithm offers superior quality and precision retrieval, and the weight ratio of the main algorithm and backup algorithm is determined as 6:4 in the previous study (Wang et al., 2023). STD LAI reflects the retrieval uncertainty. The AP and STD LAI are derived from the FparLai_QC and LaiStdDev layers of the original MODIS data. The third indicator, Relative TSS (RE-TSS), indicates the fluctuation of a time series (Zou et al., 2022). Following the principle of assigning a higher weight to smaller values, STD LAI and RE-TSS are incorporated into the retrieval with the main algorithm, resulting in the generation of a new quality classification indicator, MQA. Subsequently, the Inverse Distance Weighting (IDW) method is utilized on the spatial scale to calculate the weighted average of all eligible pixels (belonging to the same land cover type) within the half-width of 4 pixels and the power exponent of 2 (Wang et al., 2023) of the target pixel. In this algorithm, the contribution of a pixel is determined not only by its spatial distance but also by its MQA value. In a word, pixels with closer proximity and higher MQA value make a more significant contribution to the target pixel. On the temporal scale, the Simple Exponential Smoothing (SES) method is employed to calculate the weighted average of all eligible pixels within the smoothing parameter of 0.5 and the half-length of 3 (Wang et al., 2023)."

"In this study, we utilized the GBOV LAI measurements from a total of 29 sites spanning from 2013 to 2021 as our ground reference LAI (Bai et al., 2019; Brown et al., 2020). A 3 km × 3 km square centered on the site location was selected as the study area (Fig. 1) so that the corresponding LAI product of each site was 36 (6 × 6) pixels. To enhance the credibility of the ground truth LAI, we filtered the ground LAI reference of these 29 sites based on the criterion that the "effective pixel" exceeded 90% and the input and output of land product value in the data aggregation process were within the specified range. This filtering process yielded a total of 818 reliable verification data points. Contrary to previous studies (Wang et al., 2023) that utilized only 2018 data from the GBOV site as a reference, this study expanded the timeline from 2013 to 2021, increased the number of sites from 24 to 29, and raised the criterion for effective pixels from 80% to 90%. These modifications were aimed at enhancing the reliability of the ground LAI data. Additionally, previous research focused on proposing and testing algorithms mainly at the tile scale, but this study migrated the algorithm to GEE for generating global long-term data series. A comparative analysis was conducted at the spatial scale to examine the global spatial distribution of LAI in February and July 2021. The mean LAI values for latitude bands were then calculated at 1-degree intervals during these specific months. Furthermore, we compared the global consistency of MODIS LAI and HiQ-LAI in 2021 using the BELMANIP V2.1 sites (445 in total) (Baret et al., 2006). Employing these sites not only reduced the computational burden on a global scale but also mitigated additional uncertainties arising from geometric registration bias and land cover misclassification. Similar to the GBOV, we selected a study area of 6 × 6 pixels centered on each site location (Fig. 1). The MCD12Q1 data in 2021 were utilized to determine the biome type of each site, which was further classified into pure pixels and hybrid pixels based on B1 - B7. The total amount of data available for comparison was 16420. Additionally, we used DIRECT V2.1 ground measurements in this research (Morisette et al., 2006; Garrigues et al., 2008). However, these data were not utilized for direct validation due to the discontinuity in the observed time series at these sites. Instead, the DIRECT V2.1 sites provided valuable reference values in Sect. 5.2. Similarly, a research area of 6 × 6 pixels was selected for each site, and we compared the R^2 and RMSE of the two products with sites across different quality grades. The analysis involved determining the RMSE reduction percentage and R^2 increase in the percentage of HiQ-LAI relative to

MODIS under various quality grades.

In this study, the Theil-Sen's slope (TS) method and Mann-Kendall (MK) test (Suhartati, 2013; Theil, 1992) were employed to extract LAI trends from the two products. The TS method computes pairwise slopes across the study period, with the median slope representing the sign and magnitude of the long-term trend. Unlike ordinary least-square linear regression, the TS trend is less susceptible to the influence of outliers. Meanwhile, the MK test is utilized to determine the significance of the trend (Kendall, 1948). The combination of TS and MK forms a robust approach for identifying trends in long-term sequential data. TS and MK are calculated as follows:

$$TS = median\left(\frac{X_j - X_i}{j - i}\right), \qquad 2000 \le i < j \le 2022 \tag{1}$$

where X_j and X_i represent the LAI value of year j and year i, respectively. If $TS > 0$ indicates an increasing trend, while indicates a decreasing trend. Following this, the MK test was applied to assess the annual mean trends for MODIS LAI and HiQ-LAI from 2000 to 2022, ensuring the statistical significance of the identified trends.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \tag{2}$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \tag{3}$$

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, \text{if } S > 0 \\ 0, \quad \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, \text{if } S < 0 \end{cases} \tag{4}$$

where S represents the sum of step function values obtained from the differences between any two distinct points within the time series, n signifies the total number of data points, m indicates the count of continuous groups in the data (duplicate data set), and t_i refers to the associated count (the number of repetitions in the ith range). Ultimately, we calculate the test statistic Z_s, when $|Z_s| > Z_{1-\alpha/2}$ means reject the null hypothesis (i.e., the absence of a trend), with α representing the significance level. In our analysis, we set $\alpha = 0.05$, with $Z_{1-\alpha/2} = 1.96$ (indicating significance at 90% and 95% confidence levels when equal to 1.65 or 1.96, respectively)."

The definition of TSS as follows:

$$TSS(t) = \frac{\left| \begin{array}{c} \left(X(t_{n+1}) - X(t_{n-1})\right) \times t_n - X(t_n) \times (t_{n+1} - t_{n-1}) - \\ \left(X(t_{n+1}) - X(t_{n-1})\right) \times t_{n-1} + X(t_{n-1}) \times (t_{n+1} - t_{n-1}) \end{array} \right|}{\sqrt{\left(X(t_{n+1}) - X(t_{n-1})\right)^2 - (t_{n+1} - t_{n-1})^2}} \tag{5}$$

where $X(t_n)$, $X(t_{n+1})$, and $X(t_{n-1})$ represent the LAI value at target moment t, the adjacent time series data obtained at the previous moment, and the next moment, respectively. The TSS denotes the deviation of a value at a given point in time from the linear interpolation line. In this study, higher TSS values indicate greater variability over time.

Minor comments:

1. Line 21: Not entirely true. See Yuan et al., for instance.

(Yuan Hua; Dai Yongjiu; Xiao Zhiqiang; Ji Duoying and Shangguan Wei; Reprocessing the MODIS Leaf Area Index products for land surface and climate modelling, Remote Sensing of Environment, 2011, 115(5): 1171-1187.)

Response: Thanks for your comments and we had overwritten this sentence as follows:

"Reprocessing MODIS LAI predominantly rely on temporal information to achieve smoother LAI profiles with little use of spatial information and may easily ignore genuine LAI anomalies."

2. Line 67: Please check the sentence.

Response: Thanks for your comments and we had overwritten this sentence as follows:

"The best retrievals are then selected using the temporal compositing method, and the 4-day or 8-day product is generated from the daily retrievals. Therefore, MODIS LAI retrievals are calculated independently for each pixel and daily. Differences in adjacent observation conditions lead to significant uncertainty in the LAI time series."

Line 85: The author may need to justify how the previous study "overlooked spatial correlation information."

Response: Maybe there is a certain misunderstanding in our expression. We had overwritten this sentence as follows: "While these methods effectively utilize temporal and QC layers information, they frequently overlook the utilization of spatial information or rely on spatial correlation as an alternative and place a greater emphasis on leveraging temporal information."

Line 197: Why did the authors choose the year 2021? Have they tested other years, such as 2015, when strong ocean modes occurred, and NH vegetation growth was notably affected?

(Bastos Ana; Ciais Philippe; Park Taejin; Zscheischler Jakob; Yue Chao; Barichivich Jonathan; Myneni Ranga B.; Peng Shushi; Piao Shilong and Zhu Zaichun; Was the extreme Northern Hemisphere greening in 2015 predictable?, Environmental Research Letters, 2017, 12(4): 044016.)

Response: We chose the BELMANIP V2.1 site to assess the global consistency between HiQ-LAI and MODIS LAI across various vegetation types in 2021 to identify vegetation types that exhibit greater consistency as well as those that diverge the most. For this purpose, we considered the Reviewer's suggestion and conducted a comparison of scatterplots representing the two products in 2015. The findings indicated that the distinction between the two products in 2015 remained relatively consistent with that observed in 2021.

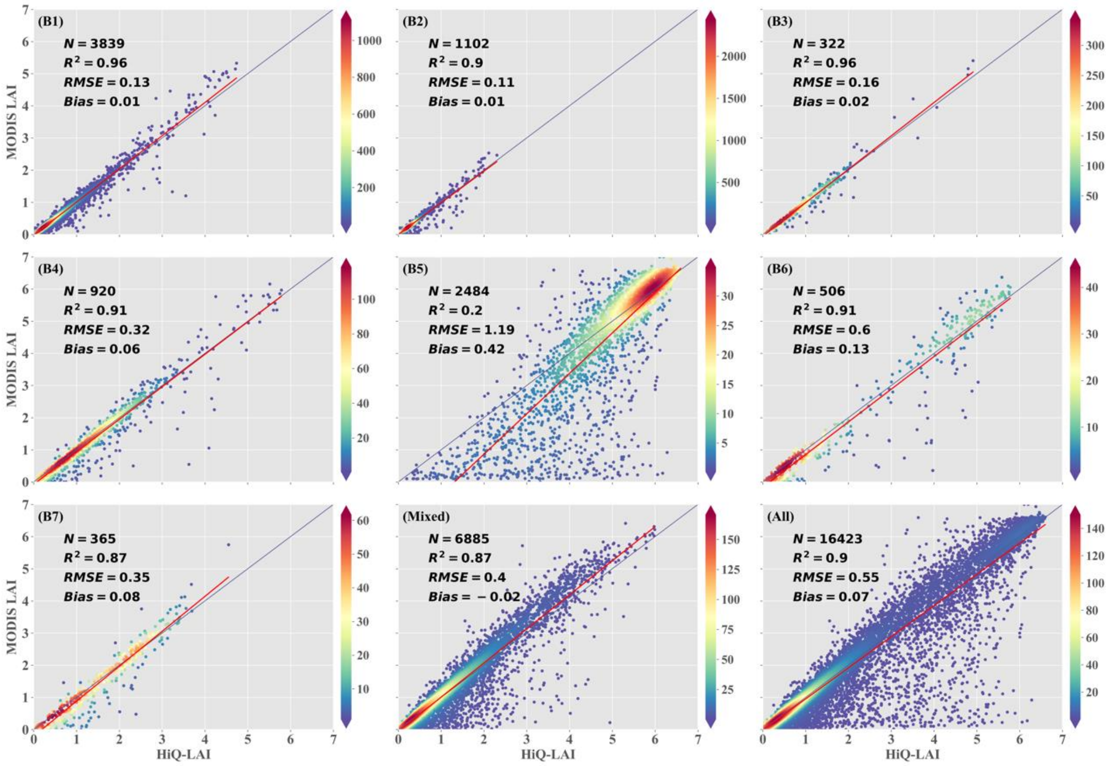

Figure. Density scatter plots comparison of MODIS LAI and HiQ-LAI in 2015.

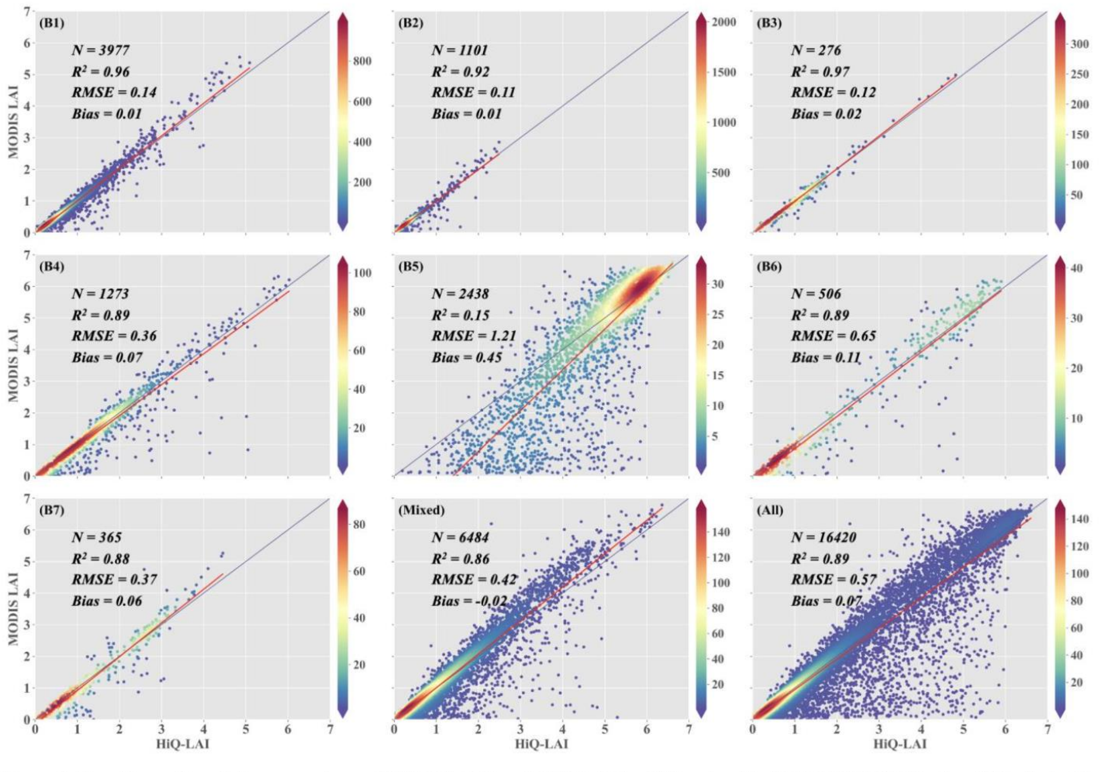

Figure 5. Density scatter plots comparison of MODIS LAI and HiQ-LAI in 2021 using the BELMANIP V2.1 sites (445 sites). B1: grass and cereal crops, B2: shrub, B3: broadleaf crops, B4: savanna, B5: evergreen broadleaf forest, B6: deciduous broadleaf forest, B7: evergreen coniferous forest, B8: deciduous coniferous forest.

Line 240: R2 should be corrected. Please check the entire manuscript. For example, see also Line 261 and 263.

Response：Thank you for pointing this out and we apologize for this point. We have checked all mathematical symbols and corrected the incorrect ones.

"The result demonstrates that, except for B5, the R^2 for other pure vegetation types exceeds 0.88, and B1 and B3 surpassed 0.95. The consistency of mixed pixels is also relatively high, as indicated by an RMSE of 0.42 and an R^2 of 0.86. However, B5 exhibits a significant disparity, with an R^2 value of 0.15."

"In the Poor-Quality level, HiQ-LAI exhibited a 17.81% increase in R^2 and an 18.99% reduction in RMSE compared to MODIS LAI."

Line 386: Please rephrase the sentence.

Response: Thanks for your comments, and we have deleted this sentence (According to another reviewer's comments).

Figure 7: Could the authors explain the presence of the unusual stripes observed in the northern high latitudes? Additionally, providing a difference map between the two would offer a more straightforward visual representation. Finally, the histogram indicates that the colors in the colorbar were not effectively used.

Response: Since the original MODIS image is missing the data of the entire latitude band in the high latitude region from December to January, this may be the reason for the obvious banding in the high latitude region. Additionally, we added the difference chart between the two products in Fig. 9 and added the color percentage values representing the top two in terms of the proportion of LAI trend value.

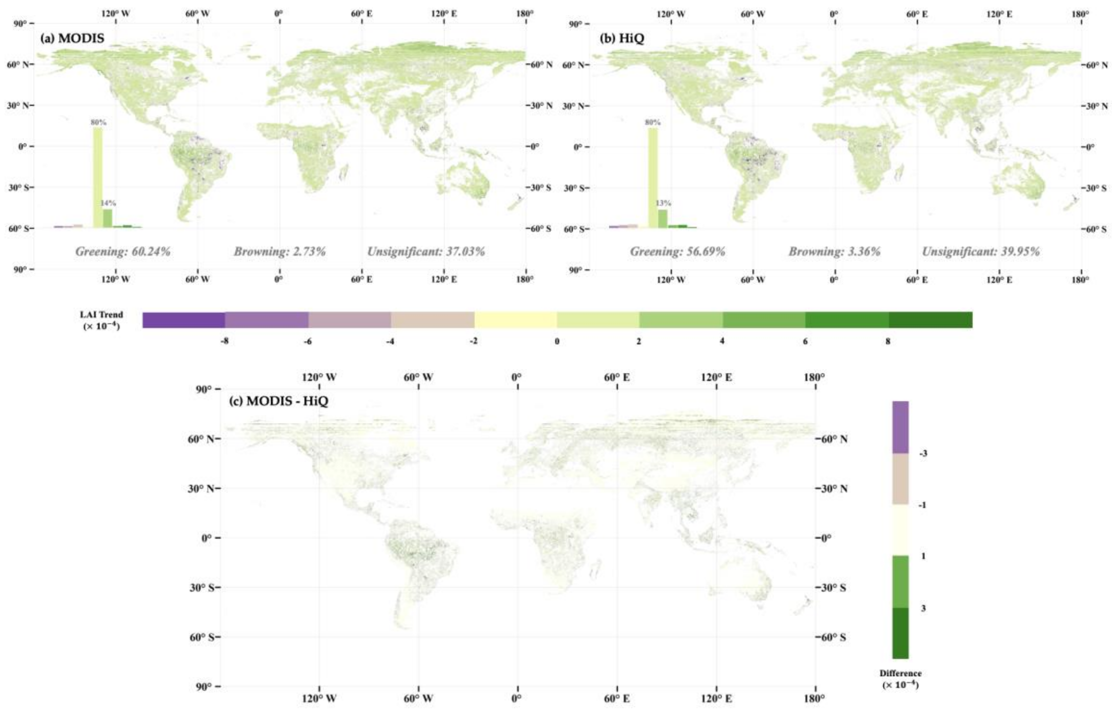

Figure 9. Global maps of LAI trends between MODIS LAI (a) and HiQ-LAI (b) during 2000 − 2022. The Theil–Sen's slope (TS) method and Mann-Kendall (MK) test were used to calculate these results. (c) Difference of LAI trends between MODIS LAI and HiQ-LAI.

Figure 9: The authors should provide more details on how the "improvement percentage of RMSE and R2" was calculated.

Response: Thanks for your suggestions, and we added a detailed description in Sect 3.2 of how the "improvement percentage of RMSE and R2" was calculated.

"we used DIRECT V2.1 ground measurements in this research (Morisette et al., 2006; Garrigues et al., 2008). However, these data were not utilized for direct validation due to the discontinuity in the observed time series at these sites. Instead, the DIRECT V2.1 sites provided valuable reference values in Sect. 5.2. Similarly, a research area of 6 × 6 pixels was selected for each site, and we compared the R^2 and RMSE of the two products with sites across different quality grades. The analysis involved determining the RMSE reduction percentage and R^2 increase in the percentage of HiQ-LAI relative to MODIS under various quality grades."

Figure 10: Please label the LAI units for the corresponding colorbars.

Response: Thanks for your comments, we added the LAI units in Fig. 12 and Fig. 13.

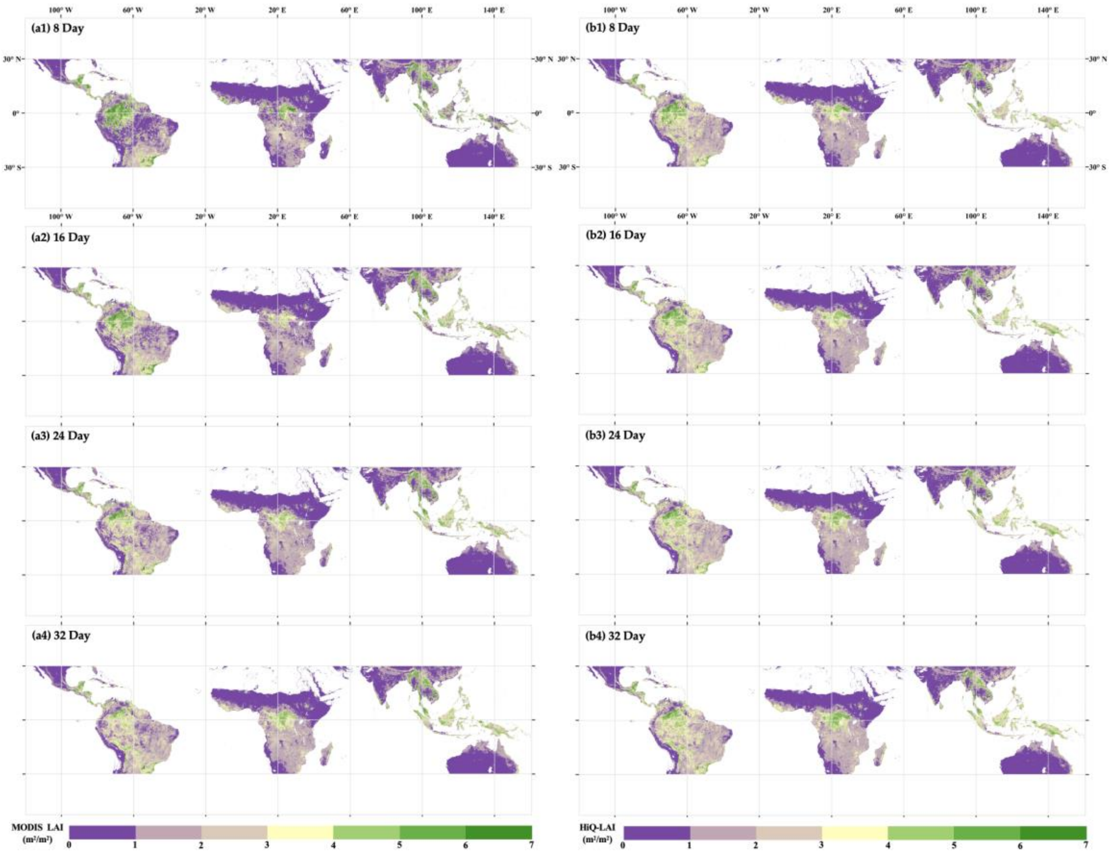

Figure 12. Spatial distribution of MODIS LAI (a1-a4) and HiQ-LAI (b1-b4) in equatorial region within different composite day.

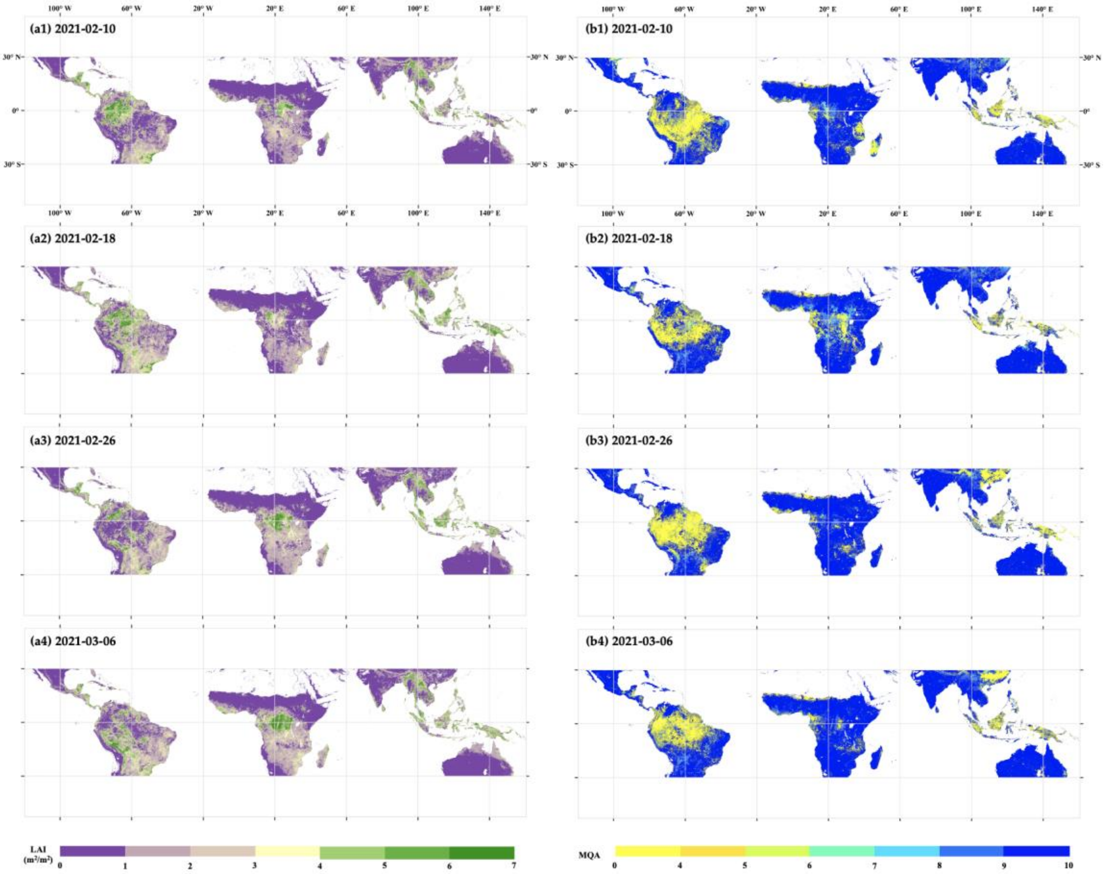

Figure 13. Spatial distribution of MODIS LAI (a1-a4) and MQA (b1-b4) values over equatorial region.

References:

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