RESPONSE TO REVIEWERS' COMMENTS

Dear Prof. Tian and reviewer,

We would like to express our great appreciation to you for handling and reviewing our manuscript entitled "Vegetation photosynthetic phenology metrics in northern terrestrial ecosystems: a dataset derived from a gross primary productivity product based on solar-induced chlorophyll fluorescence" (ID: ESSD-2021-452).

Those comments were very helpful for revising and improving our manuscript. We have studied the comments carefully and have made corrections which we hope meet with approval. A revised manuscript is being submitted for your consideration. Please see below for the point-to-point response. We have also highlighted the changes we have made in blue text (not including changes to the references) in our main manuscript (i.e. the track-changes file).

We are looking forward to your further decision.

Yours Sincerely,

Jing Fang, on behalf of all authors

Reviewer 2

This study developed a photosynthetic phenology metric dataset from 2001 to 2020 with SIF-based GPP and the retrieval of phenology. This has important implications for the modeling and analysis of the global carbon cycle. However, I believe the comparison and validation approach proposed is flawed in this manuscript, making a reliable assessment challenging. Consequently, the current manuscript is not suitable for publication in the ESSD journal.

RESPONSE: We thank the reviewer for the helpful comments. For the main concern of the reviewer, we remade the phenology comparison and validation from more GPP data sources in the manuscript. Detailed explanations of the concerns can be found in the following items as responses to each concern.

The specific suggestions are as follows:

Main comments

(1) the comparison for phenology metrics: The vegetation greenness and photosynthesis are not always coupled (this is mentioned in the Introduction section). This study conducted a comparison between GPP-based and VI-based phenology metrics to prove that the GPP-based metrics outperform. In my opinion, this is not directly comparable. In contrast, GPP-based phenology metrics are based on vegetation photosynthesis activity, whereas VI-based phenology metrics (NDVI, EVI) are based on vegetation morphology, structure, and greenness. NDVI/EVI (greenness index) cannot well account for most productivity variation than GPP products. In addition, the remote-sensing VIs are derived from observation while GPP is derived from simulation. So, I suggest authors can replace VIs with multiply GPP products (excepting MODIS-GPP in this manuscript), and further comparing with SIF-based GPP.

RESPONSE: Yes, we agreed that the phenology metrics of vegetation indices (i.e. VI) were based on structure and greenness, and the phenology metrics of GPP

were based on the photosynthesis activity. The comparison from one GPP product was not enough. Adding multiply GPP products to compare was a helpful suggestion for our study. In the new manuscript, we added two additional GPP products: GLASS-GPP product (download from: http://www.glass.umd.edu/Download.html) and BESS-GPP product (download from: https://www.environment.snu.ac.kr/bess-flux). We extracted the phenology metrics of these data and we had a total of four GPP products for comparison (i.e. GOSIF-GPP, MODIS-GPP, GLASS-GPP, and BESS-GPP). Here, we introduced GLASS-GPP and BESS-GPP briefly: 'The GLASS-GPP data was generated by a light use efficiency (EC-LUE) model and the environmental variables (i.e. atmospheric CO2 concentration, radiation components, and atmospheric vapor pressure deficit) (Zheng et al. 2020). The BESS-GPP data was generated by a simplified process-based model, the Breathing Earth System Simulator (BESS), and MODIS Atmosphere and Land products (Jiang et al. 2016).', in line 145-150 (blue text). The results of phenology metrics extracted from the additional GPP products could be found in the next response.

(2) validation: The derivative datasets from EC-GPP were used for the validation. The derivative datasets from EC-GPP fall into the category of photosynthetic phenology. Hence, a tendentious validation generates a bias toward phenology metrics in the two categories. This verification is more suitable for photosynthetic phenology than for structure. The results that the accuracy of GPP-based phenology metrics outperforms the VI-based ones are not solid. Suggest authors validate photosynthetic phenology results using photosynthetic phenology observation.

RESPONSE: We also thought the EC-GPP was fallen into the category of photosynthetic phenology. As above mentioned, we added the phenology metrics from GLASS-GPP and BESS-GPP. We focused on the comparison between the different GPP products, and the VI products were only as the reference. In the revised manuscript, we remade Fig. 2 to present the comparison and validation of the multiple GPP products (see the following figure: Fig.2). Overall, the phenology

metrics of GOSIF-GPP showed the highest correlations with the phenology metrics of EC-GPP. The BESS-GPP performs slightly worse than the GOSIF-GPP. The MODIS-GPP and GLASS-GPP had larger deviations compared to GOSIF-GPP. We added the description of these results in line 283-285 (blue text).

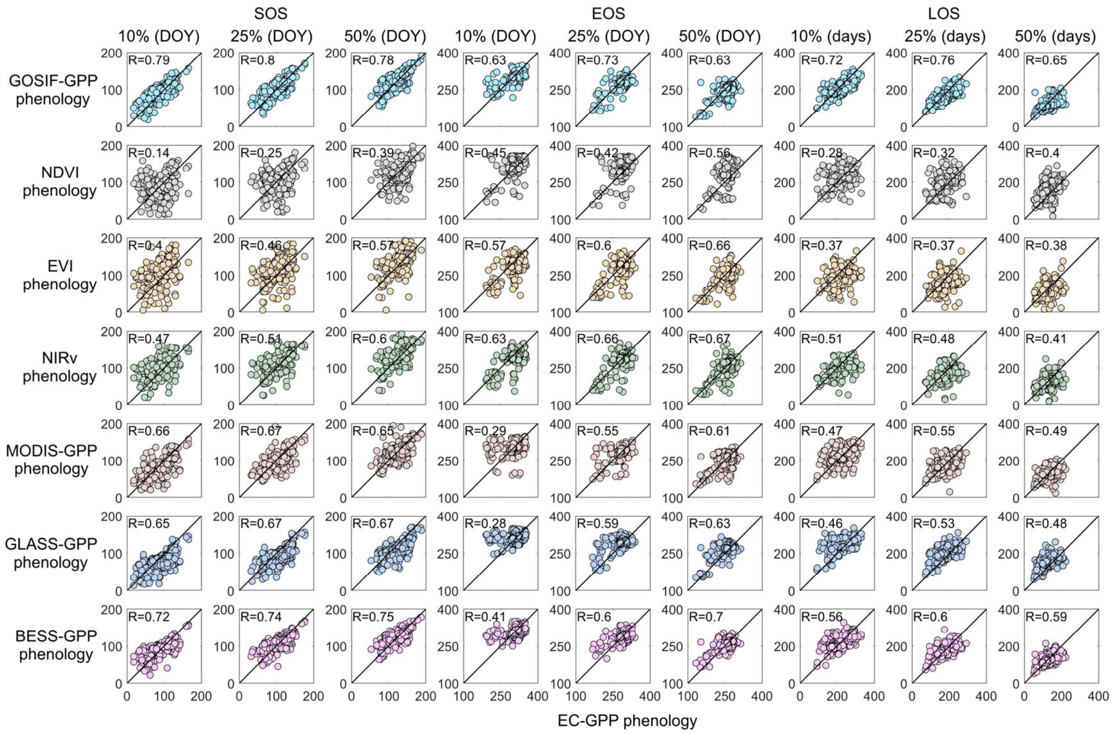

Fig. 2. The comparison of the phenology metrics retrieves from EC tower GPP (EC-GPP) and GOSIF-GPP, NDVI, EVI, NIR$_V$, MODIS-GPP, GLASS-GPP, and BESS-GPP. Each subplot has 389 site-year data. The significant correlations of all results are less than 0.05 (*p*<0.05). The solid line represents a 1:1 line. SOS: start time of the growing season; EOS: end time of the growing season; LOS: length of the growing season; DOY: day of the year; R: correlation coefficient.

(3) writing: The English writing doesn't meet the requirement of ESSD, an international academic top journal. Many redundant sentences need to be reorganized.

RESPONSE: We thoroughly checked and improved the English usage of the revised manuscript. Additionally, reviewer 1 also help us to check and correct the English in the whole of the manuscript.

Specific comments:

L100: Li and Xiao (2019) noted the global SIF products, not the GPP products. Do you want to cite this article?

Li, X.; Xiao, J. Mapping Photosynthesis Solely from Solar-Induced Chlorophyll Fluorescence: A Global, Fine-Resolution Dataset of Gross Primary Production Derived from OCO-2. Remote Sens. 2019, 11, 2563. https://doi.org/10.3390/rs11212563

RESPONSE: Thank you for checking. We updated the correct cite in line 102. We had added the reference you mentioned in the Reference list.

L107: the references do not contain Li and Xiao 2019b. I guess Li and Xiao (2019) should be cited here according to the meaning of the sentence.

RESPONSE: Sorry that we missed a reference in the manuscript. We had two references of Li and Xiao 2019, (a) was cited for the GOSIF product:

Li, X., and J. Xiao. 2019a. A global, 0.05-degree product of solar-induced chlorophyll fluorescence derived from OCO-2, MODIS, and reanalysis data. Remote Sensing 11: 517.

(b) was cited for the GOSIF-GPP product:

Li, X., and J. Xiao. 2019b. Mapping photosynthesis solely from solar-induced chlorophyll fluorescence: A global, fine-resolution dataset of gross primary production derived from OCO-2. Remote Sensing, 11: 2563.

We added (b) to the Reference list and checked the correct citations of (a) and (b) in the whole of the manuscript.

L108: Also, Li and Xiao (2019) should be cited here

Li, X.; Xiao, J. Mapping Photosynthesis Solely from Solar-Induced Chlorophyll Fluorescence: A Global, Fine-Resolution Dataset of Gross Primary Production Derived from OCO-2. Remote Sens. 2019, 11, 2563. https://doi.org/10.3390/rs11212563

RESPONSE: We had revised this citation in line 109 (blue text).

L109-111: The original spatial resolution of LULC is 500m. Please provide the details of up-scaling.

RESPONSE: Here, we used the MCD12C1 dataset (not MCD12Q1 or other datasets) as the LULC. The original spatial resolution of MCD12C1 was 0.05 degree and we did not make up-scaling (please see the description from: https://lpdaac.usgs.gov/products/mcd12c1v006/).

L128-L129: The distribution of the EC tower can be shown on the map.

RESPONSE: We had added the distribution of the EC towers in the map (see Fig. S1).

L134-135: It is to clarify whether NDVI, EVI, and NIRv have been synthesized to 8d resolution to match GOSIF-SPP and MODIS-GPP.

RESPONSE: The resolution of the NDVI, EVI, and NIRv was 1d (see line 138, blue text). We interpolated the 8-day GOSIF- and MODIS-GPP data to the daily scale (i.e. 1d) using cubic spline interpolation before the extraction (see 163-164 and Fig. 1). Therefore, the time resolution was matched.

L155-156: Please provide the detailed methods for time series interpolation.

RESPONSE: Here, we provide the description of this method: 'For the cubic spline interpolation, a tridiagonal linear system (possibly with several right-hand sides) was solved for the information needed to describe the coefficients of the various cubic polynomials that made up the interpolating spline (the detailed information could be seen the 'spline' method in Matlab).', in line 164-168 (blue text).

L162-163: Need reference.

RESPONSE: We had added Chen et al. (2004) in line 176 (blue text).

Chen, J., Jönsson, P., Tamura, M., Gu, Z., Matsushita, B., & Eklundh, L. 2004. A simple method for reconstructing a high-quality NDVI time-series data set based on the Savitzky–Golay filter. Remote sensing of Environment, 91: 332-344.

L164-166: (3) and (4) can be merged into one category.

RESPONSE: We had merged the (3) and (4).

L172-174: Need reference.

RESPONSE: We had added Richardson et al. (2018) in line 187 (blue text). Richardson, A. D., K. Hufkens, T. Milliman, D. M. Aubrecht, M. Chen, J. M. Gray, M. R. Johnston, T. F. Keenan, S. T. Klosterman, and M. Kosmala. 2018. Tracking vegetation phenology across diverse North American biomes using PhenoCam imagery. Scientific data, 5:1-24.

L174-175: Please provide necessary the details of the data processing, parameters setting, and model description. More details can be pointed to a particular article.

RESPONSE: Here, we added the description, parameters, and usage of the PELT method: 'For each photosynthesis cycle, we followed Richardson et al. (2018) to set the penalty factor and the minimum segment length of PELT as 0.5 and 14-days, respectively. The penalty factor was acted to limit the number of returned significant changes by applying the additional penalty to each prospective changepoint. The minimum segment length regulated the minimum number of days between the changepoints. The PELT method was first applied by Killick et al. (2012), and they described in detail on the calculation processes and how to find the change points in time series.', in line 187-194 (blue text).

L176: Are "penalty factor and the minimum segment" the parameters of the PELT model? What do they affect? As mentioned above, an overview of the model and its parameters are necessary.

RESPONSE: Please see the response of L174-175, we described the 'penalty factor and the minimum segment' in detail.

L197-199: Is the same method applied to EC-GPP?

RESPONSE: Yes, we applied the same method to EC-GPP. We revised the sentence to express that we used the same method: 'we retrieved the phenology of vegetation indices (i.e. daily data), MODIS-GPP (i.e. interpolating the 8-day data to the daily scale), and observed GPP from EC tower (i.e. daily data) by using the same method.'

L206-207: This sentence is too vague. Please clarify the specific objectives of uncertainty analysis. Moreover, please add the details of R and RMSE, the critical statistical indicators.

RESPONSE: To avoid make misunderstanding for the reviewer and the readers, we rewrote the sentence as: 'Previously, Li and Xiao (2019b) had assessed the quality of the underlying SIF and GPP data. In this study, we used the Monte Carlo Bootstrapping method (Efron 1992) to estimate the related uncertainties of the GOSIF-GPP phenology.', in line 225-227 (blue text). For the R and RMSE, we added the detailed description and two equations (i.e. Eqn 4 and 5) in line 220-224 (blue text).

L216: As an innovation of this study, the difference in phenology retrieving methods for phenological identification should be discussed.

RESPONSE: In the journal of ESSD, the 'Aim & Scope' was: 'Articles in the data section may pertain to the planning, instrumentation, and execution of experiments or collection of data. Any interpretation of data is outside the scope of regular articles. Articles on methods describe nontrivial statistical and other methods employed (e.g. to filter, normalize, or convert raw data to primary published data) as well as nontrivial instrumentation or operational methods. Any comparison to other methods is beyond the scope of regular articles.' (see https://www.earth-system-science-data.net/about/aims_and_scope.html).

Therefore, we compared and discussed the performances from the different datasets instead of the different methods in this manuscript.

L268: “artificial crop rotation pattern” is not a specialist vocabulary.

RESPONSE: Yes, we had revised the word to ‘crop rotation pattern’, in line 297 (blue text).

Table 1: clarify three thresholds. Figures and tables are able to “stand alone” from the body of the paper.

RESPONSE: We remade Table 1 to clarify the thresholds. The figures and tables had separated from the body of the paper.

Fig1: clarify all abbreviations

RESPONSE: We had clarified all abbreviations in Fig. 1.

Fig2: Add significant test and sample sizes, and clarify all abbreviations. Additionally, correct the dotted line as the solid line in the caption.

RESPONSE: We had added the significances and sample sizes in the caption of Fig. 2. We also clarified all abbreviations and corrected the ‘solid line’ in the caption of Fig. 2.

Fig3: Add the necessary latitude such as the North Pole and tropic of cancer. Add a brief explanation of the calculation method in the caption.

RESPONSE: We had added the necessary lines and names of latitude in Fig. 3 (see the following figure: Fig. 3). A brief explanation of the calculation method had added in the caption.

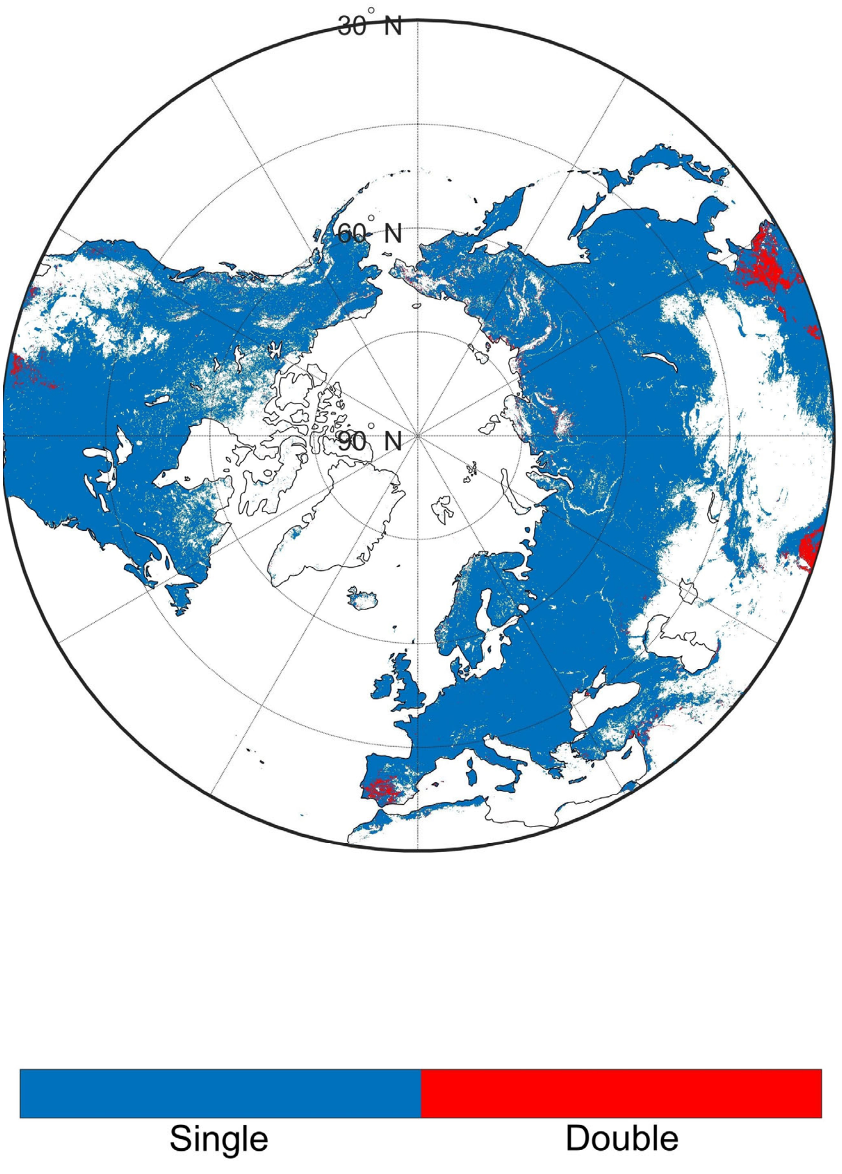

Fig. 3. The spatial distribution of the number of growing seasons in the Northern Hemisphere (0.05° spatial resolution). The double seasons mean there are two photosynthesis cycles in one year. We used the Pruned Exact Linear Time (PELT) method to detect the change points of each photosynthesis cycle.

Fig4: clarify the abbreviations, legend unit, and x-axis label.

RESPONSE: We had clarified all abbreviations and added the unit and the x-axis label.

Fig5: Clarify the abbreviations and legend unit. Moreover, suggest author put this figure into the supplementary material due to its less information and the similarity to Fig4.

RESPONSE: We had moved Fig. 5 to Fig. S2. Moreover, we had clarified all abbreviations and added the unit.

Fig6： The similar hue in blue and green is difficult to distinguish the increase or decrease of phenology metrics.

RESPONSE: Here, we used red and blue to distinguish the changes of phenology metrics more clearly than in the previous figure (see the following figure: Fig. 5).

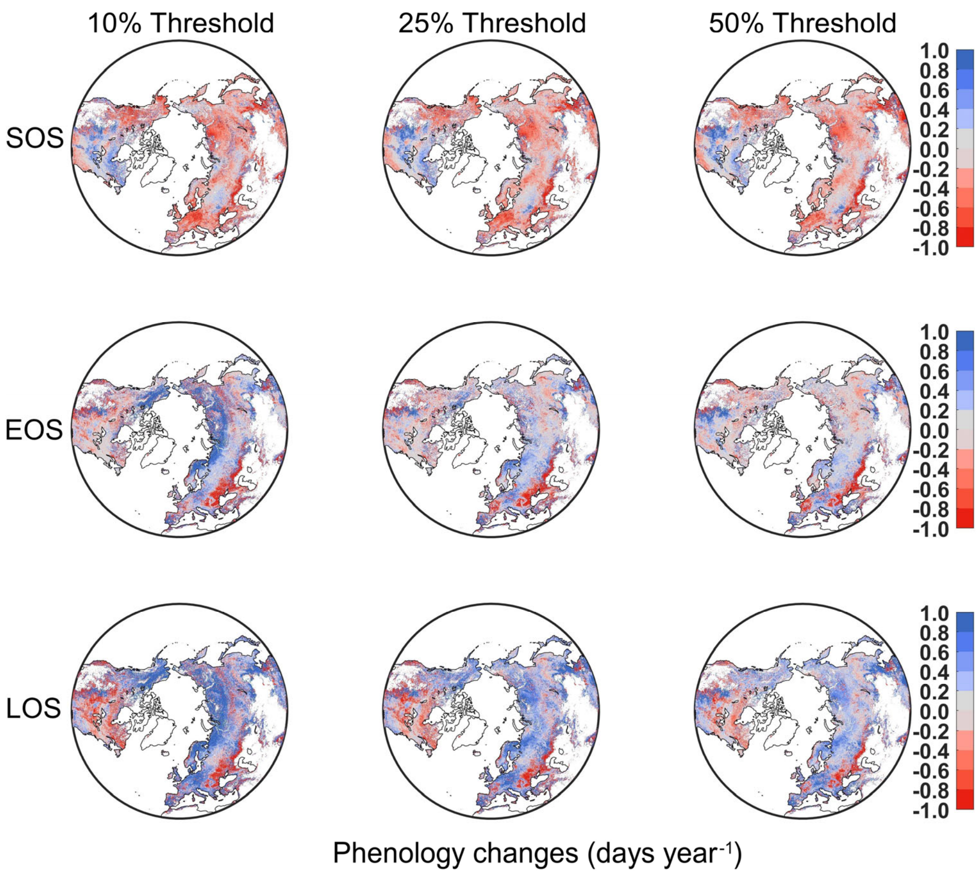

Fig. 5. Changes in photosynthetic phenology metrics in the Northern Hemisphere

over the period 2001-2020. SOS: start time of the growing season; EOS: end time of the growing season; LOS: length of the growing season.