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Interactive comment on "Environmental controls on the greening of terrestrial vegetation across northern Eurasia" *by* P. Dass et al.

P. Dass et al.

pawlok.dass@gmail.com

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Response to reviewer comments on "Environmental controls on the greening of terrestrial vegetation across northern Eurasia" by P. Dass et al.

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0.0.1

Referee comments are referred to as 'Ref' while the respective author responses are referred to as **'AR'** (in bold). The letter 'D' represents detailed comments/response. We refer to the manuscript as 'MS'.

0.0.2 Anonymous Referee #1

The paper uses NDVI-derived GPP to estimate environmental controls on the greening of terrestrial vegetation across northern Eurasia. Such a work involves two important aspects: 1) GPP modelling and validating (if GPP not directly available), 2) linked GPP with environmental variables (statistical analysis on trends, correlation, and etc.) These two aspects are both the current research hotspots, and therefore this paper

will be interesting to many readers. However, the paper failed to describe relevant methods and models clearly. And some concepts are not clear in the paper either. I would suggest a substantial revision of the paper. General comments are as follows.

AR: We thank the reviewer for the detailed comments which helped to improve the manuscript (MS). We have described our methods and models in further details. Our detailed responses to all comments are included below:

Ref 1.1.) My major concern is how GPP data are modelled from GIMMS3g NDVI and VIP NDVI datasets. The authors did not say clearly in the paper. From P9126 L13 "GPP is estimated in a manner similar to ...", I assume the satellite derived GPP data have already been produced by other researchers and were used in this paper (as far as I know, there no such GIMMS3g derived GPP available now). But from L19 of the same page "In order to estimate FPAR ..., NDVI was temporally interpolated...", I assume the authors did the satellite GPP modelling work here in the paper. The changed verb tense confused me where the NDVI-derived GPP are from. Suggest a careful check of verb tense in the paper to make clearly what is the work done in this paper and what is used directly here.

AR 1.1: We have re-written section 2.1.2 (P4L109 - P5L152) of the revised MS where we describe how GPP was derived by Youngwook Kim and John Kimball, two of the authors of this paper, using the LUE model driven by GIMMS3g and VIP NDVI input datasets. We include more details and modify our language describing the process more explicitly. GPP was derived by the above mentioned authors using a relatively well established method applied to other studies (cited). As we have described the 'research questions' in the last paragraph of the introduction (P3L77 - P3L83), the main focus of the paper is the analysis of the primary environmental controls influencing productivity of terrestrial vegetation of northern Eurasia, rather than derivation and validation

of the GPP datasets. As a result we have described in the revision only the process by which the GPP datasets have been derived, rather than a more detailed review of the methodology and/or uncertainty of the GPP datasets. The GPP datasets used in this study are currently available through a public FTP directory (ftp://ftp.ntsg.umt.edu/pub/data/HNL_monthly_GPP_NPP/), while we have also initiated a process for transferring these data to the NASA ORNL data (DAAC) facility for long-term archiving and distribution, which will include a digital object identifier (doi) database reference.

Ref 1.2.) LUE model is the most important part in this paper, and all the consequent trend, correlation, and attribution analyses are based on how the LUE model performs. However the authors failed to give detailed model equation, parameterization, and proper and convincing validation presentations. I cannot judge if the LUE GPP models for two NDVI datasets, and parameters are proper and sufficient to draw the consequent conclusions about trends and correlations in the paper.

AR 1.2: As mentioned in AR 1.1, we have stated the equation of the model used (P5L121) and cited the papers where similar models have been used in the revised manuscript.

Ref 1.3.) Section 2.1.2 is not clear. If the long term NDVI derived GPP data are collected from somewhere and used here, you probably need to describe the data sources, references, authors and downloading websites clearly. None of your references in this section can be linked to any available long-term GPP used in your paper. Then I guess you did the LUE modelling exercise here. If so, this section should be rewrite and moved to Section 2.2 Methods

AR 1.3: In AR 1.1 we state how a detailed description of the extraction of GPP from NDVI has been provided in section 2.1.2 of the revised manuscript.

The central focus of the current paper is on the analysis of the environmental controls influencing GPP, rather than a detailed description and validation of the GPP datasets. As a result, we do not discuss the derivation but cite studies where this methodology has been previously applied. Therefore, we justify the presence of this section in the 'Data' rather than 'Methods' sections. We also provide the source of the NDVI data (P5L127 & P5L129).

Ref 1.4.) Data used for GPP modeling with LUE algorithm. What data were used for the model from ERA-Interim dataset? How were the differences in spatial resolution handled? Where and how did the authors get PAR data?

AR 1.4: As described in P4L117 of the revised MS, daily surface weather from ERA-Interim reanalysis provided the daily surface meteorological inputs for the LUE model based GPP datasets. Handling of the different spatial resolutions of these data are discussed in section 2.2.1 (P7L213 - P7L217). For other questions please see AR 1.1.

Ref 1.5.) The model results (parameterization) should be presented in this paper, better before the validation section. Also, if you used the GPP data of 10 flux site for parameterizing the LUE models, be careful if you used them again for validation.

AR 1.5: Model parameterizations have been tabulated in Table 1 of the revised MS. Also refer to AR 1.1 for more detailed explanations.

Ref 1.6.) Section 3.1 the discussion about the validation is in sufficient. The authors showed the GPP model based on LUE algorithm is better in spring and worse in autumn, but they did not discuss why. A Nash–Sutcliffe Efficiency coefficient above zero only shows the model is better than using observation mean, it does not show the model is accurate enough to draw some convincing conclusions. The last paragraph in

Section 3.1 relates this paper results to other researches, but these researches seem irrelevant to the GPP validation of this section. I do not understand what the author meat "LUE algorithms, similar to the one used for the generation of the GIMMS3g dataset". The generation of GIMMS3g (NDVI) dataset never need an LUE algorithm. There were tons of researches about GPP models using LUE concept, with satellite data as input, but the authors neglected them and did not mention in the validation discussion. Again, it is no meaning to me to talk about validation without showing some scatter plots about modelled GPP vs. tower GPP.

AR 1.6: We use the Nash-Sutcliffe Efficiency because it shows that the satellite NDVI derived GPP (modeled GPP) is a better estimate than the flux-tower based GPP (observed GPP) and thus we are justified in using the former in this study. We however also use other statistical measures of validation, namely Pearson's product moment correlation and percent bias. In response to the referee's recommendation, we also present additional model-tower GPP scatter plot (Fig. 2 of MS) and associated discussion of the validation (P8L236 & P10L287 respectively). We also cite other additional studies which have used LUE models similar to the one used in this study (P10L306 – P10L311).

Ref 1.7.) Ensemble mean : In statistics, there is a clear definition about "ensemble average". I don't think it is proper to call "ensemble mean" of two GPP values modelled from GIMMS3g NDVI and VIP NDVI. Maybe I am wrong, but I would expect an explanation from the authors.

AR 1.7: According to IPCC AR4, an ensemble is a group of parallel model runs. In this study we use GPP data from two parallel model runs which use NDVI data from two separate sources, GIMMS3g and VIP. Since there is no clear consensus about which is better or more accurate, we use the mean of the two and call the ensemble mean 'GPPsat' (P5L148) and also address the issue of uncertainty by computing and reporting the coefficient of variation (Fig. 4b).

Ref 1.8.) Captions of tables and figures are too long and are very distractive. I always get lost and don't what the authors want to show in a table or figure. Suggest a concise caption and move explanations to relevant sections.

AR 1.8: We have attempted to shorten the figure captions without removing important information.

Ref 1.9.) I am not sure if +ve and –ve are allowed in a formal publication. For a non-native English speaker like me, it took me a while to find what they mean (here is the first time I read them in a publication).

AR 1.9: We have replaced these with the words 'positive' and 'negative' wherever they occurred, especially Table 6.

Ref 1.10.) De-trended correlation analysis.: If I understand correctly, you were using annual or seasonal data in your correlation analysis. That means, for example, you have 27 spring GPP data and 27 spring temperature data for a pixel. In this way the data have been de-seasoned already, how can you further do a de-trended processing before doing correlation analysis? You will only have noise left after de-trending and de-seasoning.

AR 1.10: By 'de-trending' we mean the removal of long term trends. Because of 'climate change' a few of the variables have strong long term trends. If correlation analysis was to be carried out, then these long term trends would dominate the correlation signal. On removing the trend, we get the inter-annual variability on which the correlation analysis was applied. A detailed explanation is given in the 2nd paragraph of section 2.2.3 of the MS (P9L252 – P8L257).

Ref 1.11.) In correlation analyses, how are different spatial resolution handled?

AR 1.11: See section 2.2.1 of MS as well as AR 1.4.

Ref 1.1D.) P9126L14 mentioned twice "similar to the MODIS MOD17".

AR 1.1D: Section 2.1.2 (P4L109 – P5L152) has been re-written and repetitions removed.

Ref 1.2D.) P9126L19-20 I don't understand why the authors needed daily NDVI, so that the biome-based NDVI-FPAR relationship can be used. This sounds illogical to me.

AR 1.2D: The GPP data was derived from the LUE model at a daily time step using daily surface meteorology and daily FPAR inputs. The 16-day GIMMS3g and VIP NDVI record was first interpolated to a daily time step using temporal linear interpolation to estimate daily FPAR. The use of daily NDVI and FPAR inputs rather than coarser (8-day or 16-day) temporal composites reduces potentially abrupt step changes in the model calculations due to temporal shifts in the coarser time series canopy inputs; the daily interpolation was found to improve simulations of GPP seasonality especially during spring and fall transitional periods over northern land areas (e.g. Yi et al. 2013). A more detailed justification is provided in section 2.1.2 of the revised MS (P5L130).

Ref 1.3D.) P9127L14-15: If you call those "derived using alternative GIMMS3g and VIP NDVI inputs using a LUE model" observation-based GPP data, what are model-based GPP data?

AR 1.3D: We are sorry for the confusion and unclear language. We meant to distinguish between flux tower based and satellite NDVI based GPP. We have modified the text and have used acronyms to reflect the same throughout the

paper.

Ref 1.4D.) P9130L14. I don't understand the sentence "Strong trends in the time series examined introduces the issue of collinearity". Do you mean "trends introduce ..." or "time series introduces ...". I am lost in your grammar and I cannot see the logic here either.

AR 1.4D: The 2nd paragraph of section 2.2.3 (P9L252–P9L257) has been re-written to make the meaning clearer.

Ref 1.5D.) P9130L26. "closer" than what?

AR 1.5D: The statement has been modified (P9L264) to make the meaning clearer.

Ref 1.6D.) P9132L5, "normalized difference vegetation index" for NDVI has been given already. No need to repeat here.

AR 1.6D: Repetition removed (see Sec 3.1).

Ref 1.7D.) P9132L16, What is "above ground GPP"? Do you mean there is also "underground GPP"? Please be sure about ecology concepts? Again you might need to check P 9139 L10 "GPP refers only to above ground carbon exchange...". Such a saying about GPP sounds not correct to me.

AR 1.7D: Similar statements throughout the paper have been modified to make it scientifically correct.

Ref 1.8D.) P9132L25, If the authors say the uncertainty of the mean GPP curve is caused by the difference of two GPP values (from GIMMS and VIP respectively), how

do the compute the std from TWO value? Which pixel is used to calculate the mean and uncertainty from two GPP datasets? If the authors pooled all the spatial GPP data together to calculate the mean and std for a certain year, such an uncertainty is not caused by the difference of two datasets, instead it is spatial uncertainty. Further clarification is expected.

AR 1.8D: As described in Section 2.1.2, P5L147, the 'ensemble mean' (GPPsat), is the mean of two values, from GIMMS3g and VIP NDVI. The mean and the uncertainty (coefficient of variation) is per pixel. When we compute the regional mean we mention that clearly then we talk about the spatial uncertainty.

Ref 1.9D.) P9133L11 An increase of 34.6 $gCm^{-2}yr^{-1}$ from 1982 to 1998 (17year) is lower than 2.4 $gCm^{-2}month^{-1}10yr^{-1}$ of this paper result. The authors' claim of "higher than our estimate" is not correct.

AR 1.9D: The statement has been modified (P11L335).

Ref 1.10D.) P9133L14-15 I did not see the logic between "the higher GPP trend in summer" and "the vegetation is predominantly cold constrained" (intra-annual). Trend is an inter-annual variation, and higher summer growth activity is an intra-annual concept, no link with the trend.

AR 1.10D: Statement modified in section 3.2 (P11L325 – P11L329) to provide a better explanation.

Ref 1.11D.) P9133L22 to the end of the paragraph, the authors discussed the differences between GIMMS NDVI and VIP NDVI and claimed VIP NDVI dataset is better. However such a discussion is irrelevant to the authors' results in the paper. The authors showed in Table 2 that GPP modelled from VIP is worse than from GIMMS in

general, contrary to the authors claim based on other studies.

AR 1.11D: We do not claim that the VIP NDVI is better than the GIMMS3g NDVI. We say that the VIP NDVI attempts to resolve a few of the deficiencies of the GIMMS3g data. The statistical validation shown in the MS (Table 3 & Fig. 2) shows that the GPP derived from the GIMMS3g dataset performs marginally better than that derived from the VIP dataset when being compared with flux-tower derived GPP. This method of validation is not comprehensive, especially since we are looking into only a small region of a global dataset. Until more validation and comparisons are carried out using different metrics and looking at different spatial and temporal scales, one cannot conclude whether one dataset is actually better than the other. That is the reason why we use the ensemble mean, GPPsat, while the difference between GIMMS3g and VIP NDVI based results is used as a metric for GPP estimation uncertainty.

Ref 1.12D.) P9134L8 “More than half of the region is affected by a significant positive trend (Fig. 4a)." I cannot see “more than half of the region" from Fig. 4a.

AR 1.12D: As tabulated in Table 4, 51% of the region has a statistically significant positive temperature trend. Thus the use of ‘more than half of the region’ which has been changed in the revised MS to ‘approximately half of the region’. See section 3.3 of MS (P11L344).

Ref 1.13D.) P9134L22, Suggest cite AR5 and give a proper reference.

AR 1.13D: Did not find studies in AR5 which talked about changes in the high latitudes. We rephrased the paragraph (P12L363 – P12L376) and decided to stick with the reference since it was not too old.

Ref 1.14D.) P9134L24, also need to indicate the time span for the trend from IPCC.

AR 1.14D: Detail included (P12L364).

Ref 1.15D.) P9135L3, the period of 1982–2008 spans 27 years. Not 26. That of 1997–2008 is 12 years, correct!

AR 1.15D: Changes made (P12L371) for the new datasets analyzed in the revised MS.

Ref 1.16D.) P9137L5 “The cause... are..." verb form might be wrong.

AR 1.16D: Changes made (P14L443).

Ref 1.17D.) P9137L6-7. The positive relationship between precipitation and clouds seems contradicts Table 3, which shows more positive precipitation trends but less positive cloud trends. Why so?

AR 1.17D: Table 3 shows the long term trends while the correlation between precipitation and cloudiness discussed in section 3.5 of the MS is between de-trended (after the long term trends have been removed) variables. Thus the contradiction. An explanation has been provided in P15L478 – P15L482 of the revised MS.

Ref 1.18D.) P9151 Table 1 “whose GPP data has been used", notice plural verb form 3P9152 Table 2. The table presentation is less informative than a scatter plot for model validation purpose. The authors provided a correlation table to show the validation of their GPP model from each of the two different NDVI datasets and their mean GPP from the both datasets. I cannot see how many samples are used in the correlation analysis and their spread, therefore I cannot judge the LUE model for GPP is good or

bad (see general comments).

AR 1.18D: Scatter plots are shown (Fig. 2) in response to reviewer recommendations.

Ref 1.19D.) P9159, Fig 4 a, c, and d (except b for precipitation), for all the y –axes, I don't understand month -1 in the trend unit. Where is it from, and how are the trends of environmental variables calculated?

AR 1.19D: The unit 'month^{-1}' indicates that the respective values are monthly averages or 'per month'. The trends calculated are decadal trends, i.e. the change in value every 10 years. Discussed in section 2.2.3.

0.0.3 Anonymous Referee #2

The authors use the satellite-based GPP to examine environmental controls on vegetation greening in Eurasia. An attempt was made to look at the controlling factors of vegetation greening, an aspect which I unfortunately found rather superficial and where I expected a much more systematic approach. The topic is certainly of interest.

AR: We thank the reviewer for the detailed comments and recommendations which helped improve the manuscript and analysis. As we show in the detailed response to the reviewer's comments and recommendations, the modified analysis have made this study much more systematic and comprehensive.

Major Issues:

Ref 2.1.) GPP products. The authors used GPP from eddy covariance towers to val-

idate the two satellite-based GPP products. To be more comprehensive, the gridded GPP product developed based on a combination of FLUXNET sites, satellite indices and climate drivers (Jung et al., 2009) can be used for inferring the product performance in capturing mean spatial GPP characteristics.

AR 2.1: We added another method of validation using the gridded GPP product recommended by the reviewer, based on spatially upscaled tower observations from the FLUXNET sites. Details of this dataset are in Section 2.1.3 (P6L178 – P6185) of the revised MS. See section 2.2.2 and Fig. 3 for additional validation.

Ref 2.2.) Data inconsistency. The authors used temperature and precipitation from UDEL but cloud cover from CRU. The inconsistency because of different interpolation methods between UDEL and CRU may introduce the uncertainty into the attribution and correlation analysis.

AR 2.2: We removed the inconsistency by using CRU data (temperature, precipitation and cloudiness) for the entire analysis (except for the fire data). Details of data used in Section 2.1.4 (P7L188 – P7L193) of the revised MS.

Ref 2.3.) Correlation analysis. The simple correlation analysis between GPP and target climate driver cannot statistically remove the impacts of other climate drivers. Why the authors do not adopt the partial correlation analysis to explore the environmental controls of vegetation greening?

AR 2.3: As suggested we performed a partial correlation analysis to gain insights on the relationship between two variables while eliminating the influence of the others. See P9L264 – P9L267.

Ref 2.4.) Spatial analysis. As the authors stated, there is a high spatial heterogeneity

in GPP and climate drivers but the authors still used their spatial averages to explore the drivers for GPP changes and the correlation between climate drivers. This definitely cannot give us detailed insights into the underlying mechanisms of GPP and its changes in Eurasia.

AR 2.4: We consider it important to present our results at different spatial scales. Spatially explicit results or presentation of results in a map form illustrates the spatial heterogeneity, and are useful especially when there is a specific biome-based spatial pattern. However in certain instances, especially when there is no discernible spatial pattern, regional averages or distributions like box-plots prove to be more useful. Thus we present our results in both forms.

Minor issues:

Ref 2.1D.) p9130 line11-12: please describe it in details.

AR 2.1D: Description moved to the figure caption of Fig. 4c since there is only a single figure where a smoothing spline has been used.

Ref 2.2D.) Figure 2: to separately give the spatial pattern of two satellite-based products; there are only two products and is it meaningful to give the ensemble uncertainty?

AR 2.2D: Since there is no consensus about which is the better satellite-based product, we use the ensemble mean (mean of the two products) and call it GPPsat, for most of our analysis. These products have agreements as well as disagreements. Thus along with the ensemble mean, we show the ensemble uncertainty as well (Fig. 4b).

0.0.4 Revised Manuscript

This is attached as a supplementary PDF.