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Peer Review File

Temporal dynamics in vertical leaf angles can confound vegetation indices widely used in Earth observations

Corresponding Author: Professor Teja Kattenborn

Version 0:

Decision Letter:

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Dear Professor Kattenborn,

Please allow us to apologise for the long delay in sending a decision on your manuscript titled "Confounding effects of leaf angle dynamics on vegetation indices - implications for monitoring vegetation from space". It has now been seen by 2 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

In particular, please ensure that your revised manuscript meets the following editorial thresholds:

* Present a robust and compelling assessment of the implications of leaf angle dynamics n the validity of vegetation indices.

* Either adapt your approach to account for variations in other vegetation properties beyond leaf angle or clearly discuss the limitations of your current approach with respect to assigning these randomly.

* Fully explain and describe you methodology, to the extent that your work is reproducible, either in the Methods section or Supplementary Information.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

Please submit your point-by-point responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred.

Important: The response to reviewers must not include any figures, tables or graphs. If you wish to respond to the reviewer reports with additional data in one of these formats, please add them to the main article or Supplementary Information, and refer to them in the rebuttal. Due to current technical limitations, any figures, tables, or graphs embedded in your rebuttal will not be included in the peer review file, if published.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:
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We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Joe Aslin

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REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

The authors reported an interesting study on the confounding effects of leaf angle dynamics (LAD) on various vegetation indices (VIs). The work is thorough and well presented. The statistical analysis of the data is comprehensive and sound. It is logical to understand why leaf angles will affect many VIs observed from space because VIs are determined by spectral reflectance which can be changed by the variation of leaf angles. However, the effects from leaf angle dynamics are also confounded by many other factors such as environmental conditions and specific plant species. The authors conducted a well-designed set of experiments and explore various relationships between LAD and VIs. Their findings are original and well-substantiated, and can serve as guidelines for developing more robust indices that can better cope with leaf angle dynamics.

The leaf angle measurements were based on the Anglecam system that was previously developed by the authors. I found the definition of the leaf angle is somewhat confusing unless the readers check into the original article of the Anglecam work. Because a proper understanding of how the leaf angle is defined in this study is required to understand some of the figures and narratives in this manuscript, I would recommend the authors to include a illustration of the leaf angle definition from their previous publication.

I would recommend the acceptance of this manuscript for publication with a minor revision.

Reviewer #2 (Remarks to the Author):

Vegetation indices (VIs) is one of the most widely used methods to estimate vegetation properties from Earth observation data. This study explores the influence of leaf angle on 124 VIs with high frequency leaf angle measurements. The study shows that leaf angle dynamics systematically confound widely applied vegetation indices. These effects are not random but tightly linked to abiotic environmental conditions. This study is interesting and meaningful, and will be inspiring for relevant readers. However, several points indeed puzzle me. I think the manuscript can be benefited from further improvement before acceptance.

Authors claim they use measurement data to reveal the imprint of leaf angle on VIs. This is also the main novelty of this study. However, other vegetation properties are randomly assigned in the radiation simulations except leaf angle. We know the vegetation properties change simultaneously but not independently. Many random combinations maybe not actually exist. This practice may distort truth and undoubtedly greatly weakens the confidence of the results.

This study attempts evaluate the influence of leaf angle dynamic on VIs. However, the △VI dynamic is missing. It may be important to show if a time-consistent influence exists.

In Fig.3 and 4, The meaning of x-axis is not clear. Please check all Figs.

In Fig.4, 124 VIs are grouped to 4 classes and evaluate the influence of leaf angle dynamic on each VI. Filtering out the most robust index for each group which is resistable to the interference from leaf angle may be meaningful for VI user communities.

L138-140 the model performance is not well, why?

This study use DL based method to measure temporal leaf angle. This is convenient but DL based method heavily rely on the quality of train samples and is difficult to transfer. In section 5.1 Retrieval of LAD dynamics, the distance and height between camera and object canopy is different, and the camera orientation is realigned. Whether this affects the stability of the measurement results? In addition, in the camera field of view, limited number of leaves are observed and other irrelevant canopy background is included (Fig. 2), which may also influence the measurements. Whether the effect of wind is exclude?

In abstract and conclusion (L225), the vertical leaf angle dynamic is mentioned, but this content not appear in the main text. Why?

In L326, the index complexity is mentioned, but its related content is missing throughout the article.

The order of supplementary Figs is chaotic, eg. L90 S2, L94 S1, L128 S5,

In addition, some expressions are imprecise. See other comments below.
(1) Author emphasizes leaf angle is perceived as static throughout the article (abstract, L41, L223). In my opinion, the leaf angle dynamic is rarely studied in the past, which is mainly due to the lack of temporal leaf angle, but not meant the leaf angle dynamic was not considered. At least, it is very convenient to introduce leaf angle dynamic into the radiation model.
(2) L31, VIs became a standard for Earth observation data analytics? It is one of the simplest methods but simplicity is not the standard. Who said VI is the black box?
(3) L35 common-sense error, visible spectrum not equal UV radiation to shortwave infrared (400–2500 nm).

(4) L40 leaf angle distributions typically refers to horizontal leaf inclination.
(5) L50 logic problem
(6) L68 what is heuristically defined LAD
(7) L132 logic problem

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Author Rebuttal letter: The author's response to these comments can be found at the end of this file.

Version 1:

Decision Letter:

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Dear Professor Kattenborn,

Your manuscript titled "Confounding effects of leaf angle dynamics on vegetation indices - implications for monitoring vegetation from space" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time, we ask that you edit your manuscript to comply with our format requirements and to maximize the accessibility and therefore the impact of your work.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Mengjie Wang
Associate Editor
Communications Earth & Environment
@CommsEarth

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

The authors have adequately addressed the questions in my comments.

Reviewer #2 (Remarks to the Author):

The author provided a comprehensive response and made thorough revisions to my questions.
This manuscript can be accepted.

Rebuttal letter COMMSENV-24-0992-T - “*Confounding effects of leaf angle dynamics on vegetation indices - implications for monitoring vegetation from space*“

Reply to comments from reviewer #1 (Remarks to the Author)

1) **The authors reported an interesting study on the confounding effects of leaf angle dynamics (LAD) on various vegetation indices (VIs). The work is thorough and well presented. The statistical analysis of the data is comprehensive and sound. It is logical to understand why leaf angles will affect many VIs observed from space because VIs are determined by spectral reflectance which can be changed by the variation of leaf angles. However, the effects from leaf angle dynamics are also confounded by many other factors such as environmental conditions and specific plant species. The authors conducted a well-designed set of experiments and explore various relationships between LAD and VIs. Their findings are original and well-substantiated, and can serve as guidelines for developing more robust indices that can better cope with leaf angle dynamics.**

   Author response: Thank you for highlighting the manuscript's importance, the quality of the text, and the statistical analysis.

2) **The leaf angle measurements were based on the Anglecam system that was previously developed by the authors. I found the definition of the leaf angle is somewhat confusing unless the readers check into the original article of the Anglecam work. Because a proper understanding of how the leaf angle is defined in this study is required to understand some of the figures and narratives in this manuscript, I would recommend the authors to include a illustration of the leaf angle definition from their previous publication.**

   Author response: Thank you very much for highlighting that the definition of leaf angles needed to be more clear. The concept of leaf angle distributions is indeed critical to the manuscript, and we followed the reviewer's suggestion and incorporated an explanatory figure (Fig. 1).

3) **I would recommend the acceptance of this manuscript for publication with a minor revision.**

   Author response: Thank you for supporting our manuscript.

Reply to comments from reviewer #2 (Remarks to the Author)

1) **Vegetation indices (VIs) is one of the most widely used methods to estimate vegetation properties from Earth observation data. This study explores the influence of leaf angle on 124 VIs with high frequency leaf angle measurements. The study shows that leaf angle dynamics systematically confound widely applied vegetation indices. These effects are not random but tightly linked to abiotic environmental conditions. This study is interesting and meaningful, and will be inspiring for relevant readers.**

   Author response: Thank you for pointing out the relevance of this study.

2) However, several points indeed puzzle me. I think the manuscript can be benefited from further improvement before acceptance.

Author response: Thank you for your thorough review, constructive criticism, and suggestions, which immensely helped improve the manuscript.

3) Authors claim they use measurement data to reveal the imprint of leaf angle on VIs. This is also the main novelty of this study. However, other vegetation properties are randomly assigned in the radiation simulations except leaf angle. We know the vegetation properties change simultaneously but not independently. Many random combinations maybe not actually exist. This practice may distort truth and undoubtedly greatly weakens the confidence of the results.

Author response: The reviewer correctly points out that we use random trait variations sampled within plausible ranges from trait databases. We are of the opinion that this approach is indeed necessary to elucidate the impact of leaf angles, where only with a decoupling of leaf angle variation from other traits the effect of leaf angles on VIs can be isolated. In general, the coordination of traits with leaf angles likely depends on factors such as species, age, tree vitality and nutrient status, and stand effects (e.g., competition). Establishing empirical relationships of leaf angles across all these aspects appears impractical. Particularly, since correlation of leaf angles with other traits is assumed to be rather low (leaf angles can vary within minutes or hours, while other traits mostly vary within weeks). However, we agree with the reviewer that this aspect warrants consideration, and we have addressed it in the discussion:

> Line 214: *Our simulations did not account for correlations between leaf angle dynamics and other plant properties. First, we excluded correlations between vertical leaf angle dynamics and other biochemical and biophysical vegetation characteristics to isolate the specific effect of leaf angles. Second, these correlations are either unknown or assumed to be relatively weak, variable across species, site and environmental conditions and difficult to obtain [15, 61]. Specifically, measuring plant properties like water content or chlorophyll content at high temporal frequencies is extremely challenging and costly. Future studies could explore the coordination between leaf angles and other plant properties by incorporating extended observation periods.*

4) This study attempts evaluate the influence of leaf angle dynamic on VIs. However, the △VI dynamic is missing. It may be important to show if a time-consistent influence exists.

Author response: It would certainly be interesting to study temporal dynamics in detail. However, we cannot visualize the temporal dynamics of 124 VIs. Moreover, the strong correlation of multiple vegetation indices (VIs) with changes in leaf angles may make plots of temporal VI dynamics somewhat redundant (Fig. 4). As can be seen in Fig. 4, the leaf angles change through time and so do the vegetation indices. We highlighted the caption of Fig. 4 to put more emphasis on the temporal representativeness:

> *Figure 4: The effect (ΔVI%) of LAD dynamics on selected vegetation indices within the vegetation season.*

Moreover, the correlation of vegetation indices with VPD, temperature, and soil humidity quantifies the temporal correlation of leaf angles and environmental conditions. If the reviewer still thinks we should add plots on temporal dynamics of selected VIs, we can do that, but for the moment, we would like to keep the manuscript and the supplementary (which, as we feel, is already very long) at a reasonable length.

5) In Fig.3 and 4, The meaning of x-axis is not clear. Please check all Figs.

Author response: Thank your for this observation. We thoroughly checked the captions of all figures and revised them where necessary. For Instance, the captions for Fig. 3 and Fig. 4 have been changed as follows:

Figure 4: *The effect (ΔVI%) of LAD dynamics on VIs for selected vegetation indices within the vegetation season. ΔVI% was calculated as the relative difference between vegetation index values derived from simulated reflectance data with and without integrating actual vertical leaf angle dynamics. For visualization, LADs were converted to average leaf angles. The VIs in the top row (NDVI, EVI, SAVI, kNDVI) are typically used for assessing the greeness of vegetation canopies, NIRv is used as proxy for the canopy structure, MCTI and MCARI for leaf chlorphyll content, while NDWI is a common proxy for leaf water content.*

Figure 5: *a): The relative effect (ΔVI%) of leaf angle dynamics on 124 vegetation indices. ΔVI% is the relative difference of vegetation index values with and without integrating actual vertical leaf angle dynamics. b) The mean of the absolute correlation per species of ΔVI with relative soil moisture and vapor pressure deficit highlights that the effect of vertical leaf angles on VIs is strongly controlled by environmental variables, which may not be related to the variable of interest (e.g. Chlorophyll content or biomass). Indices shown in Fig. 4 are highlighted with bold font.*

Figure 6: *Species-wise absolute correlations of ΔVI across all 124 vegetation indices with environmental conditons. Correlations are measured using (Pearson's r) and derived for vapor pressure deficit (VPD, kPa, left) and soil moisture at 0.05 m depth (%, right).*

6) In Fig.4, 124 VIs are grouped to 4 classes and evaluate the influence of leaf angle dynamic on each VI. Filtering out the most robust index for each group which is resistable to the interference from leaf angle may be meaningful for VI user communities.

Author response: We agree with the reviewer that the presented analysis is a useful indicator for choosing a robust index. Still, we would prefer not to highlight individual indices since, for some application fields, multiple indices share similar sensitivity and may have other advantages or disadvantages (e.g., sensitivity towards atmospheric effects). As a compromise, we emphasized that users may use our results as an orientation for choosing the right index across application types:

Line 191: *As indices are typically not designed in the context of LAD dynamics, our findings may provide a basis for choosing a robust index for monitoring vegetation properties over time, for instance, for tracking pigments, greenness, diseases, or water content (Fig. 5a).*

Textbox (discussion): *In this context, the presented comparisons of VIs across application domains (Fig. 5a) may provide a basis for selecting robust VIs for approximating different physiological and morphological plant properties. Still, ~~Moreover,~~ the capacity of a VIs for indicating certain plant properties can be highly variable and should be thoroughly tested for the application case at hand [68].*

Also note that we indicate some differences across index groups over different application fields to raise the awareness of the reader that the robustness of VIs across applications fields can be derived from Figure 5:

Line 95: *For VIs frequently used for quantifying greenness (e.g. in the context of assessing vegetation vitality, density, or productivity), we observe a considerable range of ΔVI%: NDVI = 33.7%, SAVI = 38.2%, EVI = 50.5%, kNDVI = 45.3% (Fig. 4), quantile range of 0.1 and 0.99. Similar effects are found across all application types of VIs (Fig. 5a, Fig. S3), including indices used for pigment assessments (e.g., MCARI, 28.23%) or leaf water content retrieval (e.g., NDWI = 20.68%). Thus, VIs differ in their sensitivity to LAD dynamics, affecting the specificity of a VI toward a designated target property (e.g., pigments).*

7) L138-140 the model performance is not well, why?

Author response: Thank you for highlighting that this was not clear.This is a very simple model that does not consider temporal context or legacy-effects. For instance, we do not consider how long a drought period was. We did not aim to build the most performant model for predicting leaf angle dynamics but merely aimed to highlight the species-specific effect. We slightly adapted the respective sentence for clarity:

> Line 133: *Species-wise correlations for vertical leaf angle dynamics and environmental variables (Pearson's r) ~~range from~~ showed considerable variation, with r values ranging from -0.5 to 0.6 for soil moisture, -0.19 to 0.64 for water pressure deficit, and -0.18 to 0.63 for air temperature. ~~Accordingly~~ Similarly, we demonstrate the sensitivity to tree species ~~find~~ at the example of a simple linear modeling approach, where ~~that~~ only 10% of the LAD dynamics could be explained alone by ~~and recordings on~~ temperature, soil moisture, and vapor pressure deficit~~, while~~ . However, mixed effect models that included ~~considering~~ species as random effect explained 27 % of the LAD variation.*

8) This study use DL based method to measure temporal leaf angle. This is convenient but DL based method heavily rely on the quality of train samples and is difficult to transfer. In section 5.1 Retrieval of LAD dynamics, the distance and height between camera and object canopy is different, and the camera orientation is realigned. Whether this affects the stability of the measurement results?

Author response: We are confident about the leaf angle retrieval, given its successful evaluation in Kattenborn, T., Richter, R., Guimarães- Steinicke, C., Feilhauer, H., & Wirth, C. (2022). AngleCam: Predicting the temporal variation of leaf angle distributions from image series with deep learning. Methods in Ecology and Evolution, 13(11), 2531-2545.

Still, we entirely agree with the reviewer, that the transferability of DL-methods is often challenging. This is why we optimized AngleCam for the dataset of this study. More specifically, we randomly sampled 1000 image frames from the present dataset to create new training data and thereby ensure the transferability of AngleCam. We describe this procedure in the method section:

> Line 277: *~~To~~ We retrained the AngleCam models to ensure that the ~~AngleCam~~ method is transferable to the conditions at the MyDiv site and its tree species. For this, we sampled 1000 images from the above-described time-lapse imagery. We generated LAD labels for each of these sampled images, using the visual interpretation procedure described and evaluated in Kattenborn et al. (2022). The new sample data was added to the training data described in Kattenborn et al. (2022) to retrain the AngleCam model (the updated version of AngleCam is available at: https://github.com/tejakattenborn/AngleCAM).*

With the 'realignment of the camera orientation', we rather meant an 'optimization' that only happened in very few cases. We clarified this in the text (Line 275). We did not observe signs of inconsistency in the leaf angle dynamics after servicing the cameras (we ensured this by visually checking the leaf angle time series, Fig. S2, cameras were serviced at DOY 182 and 219). Moreover, the consistency of cameras among different individuals per species highlights the consistency (Fig. S2).

9) In addition, in the camera field of view, limited number of leaves are observed and other irrelevant canopy background is included (Fig. 2), which may also influence the measurements. Whether the effect of wind is exclude?

Author response: The AngleCam method was trained with imagery that includes a variety of background features such as other canopies, buildings, or even people, which ensures that the method is robust across various scene conditions. We added a sentence to the figure caption to highlight this feature.

> *Figure 2: Workflow of revealing the impact of leaf angle dynamics on satellite-derived vegetation indices (VIs). The leaf angle observations are based on AngleCam [34], a computer vision method that was trained to derive leaf angle dynamics from plants in the foreground of plant photographs. For simplicity, the ~~leaf angle~~ dynamics of vertical leaf*

> *angles are visualized as average leaf angles, while the AngleCam method predicts leaf angle distributions between 0 to 90 degrees. The obtained leaf angle dynamics are then used as input to simulate the effect on vegetation indices (VIs) through radiative transfer models.*

We are very confident that wind is not affecting the data for the present study. First of all, measurements were recorded in 5 minute intervals. This redundancy resulted in 12 images within the considered time frame of the satellite overpass times (10:00-11:00). The leaf angle measurements obtained within this time frame were then averaged, which would compensate effects of wind or gusts on individual leaf angle measurements. We clarified this in the method section:

> Line 284: *We applied the retrained AngleCam model to all available time-lapse photos ~~imagery~~ falling within the overpass times around solar noon (10:00 - to 11:00) of typical optical Earth observation satellite missions, such as Sentinel-2, Landsat, MODIS Terra (Fig. 2). The LADs obtained from AngleCam for these time periods were averaged, resulting in an average LAD at solar noon per camera and day (Fig. S2). Through the averaging in this time period, uncertainties of individual LAD retrievals, e.g. resulting from wind or illumination effects, were effectively reduced.*

10) In abstract and conclusion (L225), the vertical leaf angle dynamic is mentioned, but this content not appear in the main text. Why?

Author response: We thank the reviewer for pointing out this unclarity. In the revised manuscript, we now consistently refer to 'vertical' leaf angles or 'vertical' leaf angle dynamics.

11) In L326, the index complexity is mentioned, but its related content is missing throughout the article.

Author response: The results on the vegetation index complexity are described in Line 124 onwards. We slightly adjusted the terminology to fit the method section, so it becomes more consistent:

> Line 118: *There is a significant trend that LAD dynamics have a stronger ~~greater~~ impact on ~~more complex~~ VIs of greater complexity (integrating more bands or arithmetic operations ~~coefficients~~), both in terms of their value range (ΔVI%, $r = 0.26$, $p < .01$) and correlation with LAD dynamics ($r = 0.33$, $p < .01$). Details on the relationship of the VI configuration and LAD effects are given in supplementary Fig. S5.*

12) The order of supplementary Figs is chaotic, eg. L90 S2, L94 S1, L128 S5,

Author response: Thank you for this observation. We rearranged the figures according to the sequence in the main text.

13) In addition, some expressions are imprecise. See other comments below.

Author response: Thank you for highlighting unclear passages. This helped to improve the flow and comprehensiveness of this manuscript.

14) Author emphasizes leaf angle is perceived as static throughout the article (abstract, L41, L223). In my opinion, the leaf angle dynamic is rarely studied in the past, which is mainly due to the lack of temporal leaf angle, but not meant the leaf angle dynamic was not considered. At least, it is very convenient to introduce leaf angle dynamic into the radiation model.

Author response: We agree with the reviewer and changed the text accordingly:

> Abstract: *The most widely used method to estimate vegetation properties from Earth observation data is Vegetation indices (VIs). However, ~~While plant canopies are often~~*

~~perceived as static,~~ temporal dynamics in vertical leaf angles can strongly alter reflectance signals and, hence, vegetation indices.

Line 223: *Vegetation indices derived from reflectance signals acquired with Earth observation satellites provide a pivotal data stream for monitoring Earth´s terrestrial vegetation dynamics. However, ~~While plants are often perceived as static structures,~~ temporal dynamics in vertical leaf angles can strongly alter reflectance signals and, hence, vegetation indices.*

15) L31, VIs became a standard for Earth observation data analytics? It is one of the simplest methods but simplicity is not the standard. Who said VI is the black box?

Author response: Thank you for highlighting that this was not entirely clear. We now argue that VIs are among the most frequently used methods for analyzing Earth observation data. Moreover, we adopted the usage of the term black box and now state that the interpretation of VIs is often a black box. We changed the sentence accordingly:

Line 30: *Although VIs are amongst the most frequently used tools ~~became a standard~~ for Earth observation data analytics, ~~but~~ in terms of their interpretability they ~~their interpretation~~ often remains a black box because the vast biochemical and structural diversity of plants makes it difficult to precisely infer ~~isolate specific~~ plant properties from reflectance spectra or derived indices (Fe´ret et al. 2017; Kokaly et al. 2009; Zeng et al. 2022).*

16) L35 common-sense error, visible spectrum not equal UV radiation to shortwave infrared (400–2500 nm).

Author response: Thank you for pointing out this error! We changed the sentence to

Line 32: *Especially the configuration of canopy structure and density is known to determine plant reflectance across the visible to the ~~full range of the visible spectrum, from UV radiation to~~ shortwave infrared spectrum (400–2500 nm), by controlling light interception probabilities and scattering processes (Hase et al. 2022; Kattenborn et al. 2019; Wu et al. 2022; Zeng et al. 2023).*

17) L40 leaf angle distributions typically refers to horizontal leaf inclination.

Author response: Throughout the revised manuscript we now refer more consistently 'vertical' leaf angles, so it should be clear that the leaf angle distribution also refers to vertical leaf angle distributions.

18) L50 logic problem

Author response: Indeed, we simplified the sentence accordingly:

Line 45: Changes in vertical leaf surface angles induced by environmental dynamics may confound ~~greatly determine dynamics in~~ reflectance signals and, hence, VIs: On the one hand, vertical leaf angle dynamics may induce perturbing dynamics to vegetation index values. For example, an apparent leaf angle-induced change of a chlorophyll index value could be falsely interpreted as an actual change in chlorophyll content.

19) L68 what is heuristically defined LAD

Author response: We changed the sentence using a more common term:

Line 63: Therefore, previous studies were limited to using loosely ~~heuristically~~ defined LAD values or sparse LAD observations of only one or very few plant species (Hase et al. 2022; Ollinger 2011).

20) L132 logic problem

Author response: The sentence was indeed confusing and we modified the sentence as follows:

Line 124: These environmentally controlled LAD dynamics are imprinted in the variation of vegetation indices ~~VI variation~~ (Fig. 4b). Consequently, the ~~so that~~ temporal dynamics of vegetation indices, such as ~~e.g.~~ a chlorophyll index, may not necessarily indicate changes in the biophysical or biochemical properties of interest, e.g. pigment contents, but might be confounded by the environmental conditions. ~~.can be determined by environmental drivers alone and do not necessarily relate to changes in biophysical and -chemical plant properties, such as pigments~~.