

Interactive comment on “MODIS vegetation products as proxies of photosynthetic potential: a look across meteorological and biologic driven ecosystem productivity” by N. Restrepo-Coupe et al.

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We appreciate the comments and suggestions from two referees on our manuscript “MODIS vegetation products as proxies of photosynthetic potential: A look across meteorological and biologic driven ecosystem productivity”. These have greatly contributed to improved scientific rigor and clarity and have enriched the presented discussion. We have addressed all comments and proposed significant changes to the manuscript, in particular to the Introduction and Conclusion sections, details follow:

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Reviewer 2. General comments: The authors tested whether seasonality of GEP and photosynthetic potential could be captured by MODIS VIs, GPP, LAI and FPAR products across four Oz flux towers. Although this is an important topic to link satellite remote sensing data with in-situ land surface observations, I found this manuscript requires substantial improvements.

The authors should stress the novelty of this manuscript and make a compelling conclusion. The authors showed a series of figures and tables, which did not converge towards conclusion which is actually unclear. I think the conclusion is that MODIS V captured seasonality of GEP when key meteorological variables and vegetation phenology were synchronous. If this is the conclusion, this is not new as reported from a series of previous papers (e.g. Gamon et al., 1995 Ecological Applications). If this is not the conclusion, then the authors failed to deliver clear, compelling conclusion. Also I see there is no clear linkages between the title (MODIS VI as proxies of photosynthetic potential....) and conclusion.

R2C01: We propose changes to our Conclusions section (see at the end of this response) to highlight the originality and emphasize the compelling nature of our research and findings of the manuscript, that include the following:

1. Our results revealed three different environmental conditions, to be viewed as a continuum, consisting of (1) primarily meteorological-driven (solar radiation, air temperature and/or precipitation) systems (e.g. sclerophyll forests), with no statistically significant relationship between GEP and satellite derived measures of greenness; (2) biologically-driven ecosystems, where changes in the vegetation status represented by tower based measures of photosynthetic capacity drive GEP (e.g. tropical savannas); and (3) locations where meteorology and vegetation phenology are synchronous (e.g. Acacia woodland).

2. In contrast to past and current literature studies that link ecosystem productivity (GEP) and VIs at phenologically driven ecosystems (Chen et al., 2004; Guan et al.,

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2015; Huete et al., 2008; Maeda et al., 2014; Rahman et al., 2005; Toomey et al., 2015), we argue that satellite derived biophysical measures and other greenness indexes are not a measure of GEP; but rather a proxy for ecosystem structure (e.g. leaf area index - quantity of leaves) and function (e.g. leaf level photosynthetic assimilation capacity - quality of leaves). Our results should extend to other greenness measurements from remote sensing sensors, including phenocams, satellites, and in situ spectrometers.

3. We propose the parameterization of the light response curve from EC fluxes as a novel tool to obtain measures of photosynthetic potential (a proxy for vegetation structure and function) as the appropriate link to satellite derived measures of greenness. We find VIs to be statistically correlated to long term measures of phenology such as Pc and LUE rather than to variables subject to the short term responses to environmental conditions (e.g. GEP at saturation, GEPsat and quantum yield, α). This has important implications for earth system models that rely on RS products to determine maximum GEP (GEPmax – the GEPsat in our study) or quantum yield (α), as they may misrepresent vegetation seasonality and phenology.

4. We identified the main seasonal drivers of productivity over four key ecosystem types: vegetation structure and function, meteorology, or a combination of both. Moreover, we included ecosystems where the MODIS GPP product has been questioned for not being able to capture the absolute value of GPP, its' annual cycle, or in getting the right answer for the right reasons (Kanniah et al., 2009; Leuning et al., 2005). We quantified how much of the GEP seasonality could be explained by different variables (incoming radiation, temperature precipitation, or vegetation status) and then presented seasonal profiles that showed when vegetation photosynthetic potential and climate were synchronous or out-of-phase.

5. We used satellite derived vegetation indices and meteorological variables rather than in situ measurements; therefore, our findings (e.g. regressions) can be extrapolated to regional and continental scales.

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6. Reviewer 2 is correct in pointing out that our findings build upon previous work by Gamon et al. (1995) and others (Huete, 2012; Peng and Gitelson, 2012; Sims et al., 2006); however, there are clear differences between our approach and Gamon et al. (1995) (see Table 1 of this response for a cross-study comparison).

The role of photosynthetic potential is unclear. In Abstract, the authors stated "...through comparisons of ecosystem photosynthetic activity (GEP) and potential (e.g. ecosystem light use efficiency and quantum yield) with MODIS vegetation satellite products..."; however, the authors did not report anything related to photosynthetic potential in the abstract.

R2C02: We will modify the Abstract to distinguish ecosystem photosynthetic activity from measures of potential addressing the reviewer's comments (see at the end of this response).

We used the term photosynthetic potential to refer to four variables obtained from the light response curve parameterization: ecosystem light use efficiency (LUE), photosynthetic capacity (Pc), GEP at saturating light (GEPsat), and quantum yield (α). These variables were calculated to remove the effect of day length, changes in radiation environment, cold/warm periods, among other non-optimum meteorological conditions from GEP (Pc and LUE), or to normalize the conditions under which the measurements are made (e.g. α as indicator of vegetation response under diffuse radiation) –thus, they represent the canopy's ability to do photosynthesis independently of the meteorological conditions (see Section 2.2.3.).

In TBR site, EVI did not agree well with GEP (Figure 5). Then the authors compared EVI with photosynthetic potential in Figure 6, which again did not show correlation between EVI and photosynthetic potential in TBR site. Thus photosynthetic potential did not provide any insight to understand why EVI failed to capture seasonality of GEP in this site.

R2C03: At the evergreen wet sclerophyll forests, there were no relationships between

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GEP and satellite derived measures of greenness (e.g. GEP and EVISZA30, $R^2 < 0.01$ and $p = 0.93$, Figure 5b). However, p-values showed that the regression between Pc and EVISZA30 and NDVISZA30 were statistically significant and that the null hypothesis was false -the relationship is not the result of chance ($R^2 = 0.16$, $p < 0.01$; Figure 6 and Supplement Table 4). Low R^2 values can be explained by the small dynamic range of both seasonal measures of photosynthetic potential and EVISZA30 (cf. Figure 4 and Figure 6). Moreover, we showed how at this site incoming solar radiation explained 60% and a multi-linear model driven by SWdown and EVISZA30 explained 70% of the variability in GEP, indicating that this is a meteorological driven ecosystem.

Across sites we observed strong correlations among VIs and Pc. The positioning of each ecosystem along a continuum of MODIS-derived variables representing phenology confirms the usefulness of satellite products as representative of vegetation structure and function.

The title says “MODIS vegetation products as proxies of photosynthetic potential”; however, the abstract did not tell anything about photosynthetic potential and the conclusion included only a bit, which was marginal.

R2C04: We propose to modify the Abstract (in italics) to clearly define photosynthetic potential as parameters of the light response curve, thus, to address the reviewer's comment:

“... In this study, we re-evaluate the connection between satellite and flux tower data at four contrasting Australian ecosystems, through comparisons of ecosystem photosynthetic activity (GEP) and measures of potential (via parameterization of the light response curve: ecosystem light use efficiency (LUE), photosynthetic capacity (Pc), GEP at saturation (GEPsat), and quantum yield (α)) with MODIS vegetation satellite products, including VIs, gross primary productivity (GPPMOD), leaf area index (LAIMOD), and fraction of photosynthetic active radiation (fPARMOD). We found that satellite derived greenness products constitute a measurement of ecosystem structure (e.g. leaf

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area index - quantity of leaves) and function (e.g. leaf level photosynthetic assimilation capacity - quality of leaves) represented by Pc and LUE, rather than GEP...”

Inconsistent terms should be corrected. I found photosynthetic potential is unclear and confusing. R2C05: We propose to modify the Introduction text to address the reviewer's comment

“Our second objective was to derive using the light response curve different ground-based measures of vegetation photosynthetic potential: quantum yield (α), photosynthetic capacity (Pc), GEP at saturation light (GEPsat), and ecosystem light use efficiency (LUE) in an attempt to separate the vegetation structure and function (phenology) from the climatic drivers of productivity. We explored the seasonality of the four measures of photosynthetic potential (α , Pc, LUE, GEPsat) and aimed to determine if EVI was able to replicate absolute value and their annual cycle rather than photosynthetic activity (GEP), based on linear regressions...”

The authors used this term to indicate LUE and quantum yield (P2 L7-8) or LUE, quantum yield, GEPsat, and Pc (P11 L11). I think “potential” is not related to LUE; probably, it might be related to LUEmax. In P16 L6, the authors defined potential as “biophysical drivers of productivity”, which seems not related to GEPsat or Pc. Ecosystem photosynthetic activity is another confusing term. It corresponded to photosynthetic activity, productivity, or gross ecosystem productivity (GEP). I recommend using GEP consistently across the manuscript.

R2C06: GEP and photosynthetic activity are currently used synonymously in the literature. At times, in the text we used photosynthetic activity to differentiate the term from photosynthetic potential by indicating that one is the ability to do photosynthesis (potential) and differs from the activity (the result of radiation, H₂O, and CO₂ used by the vegetation to attain carbon uptake).

Uncertainty in photosynthetic potential should be incorporated. Fig 2 clearly shows the relationship between PAR and GEP is not straightforward. I can see all parameters

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(quantum yield, GEPsat, P_c , and LUE) showed large variability around the mean values. The uncertainties in each parameters might explain little correlation between EVI and photosynthetic potential in TBR site, and might help better interpret Fig 6.

R2C07: Uncertainty in estimates of photosynthetic potential and RS products were incorporated by use of Type II linear regressions that account for uncertainty in both variables. We propose to add the following text in Section 2.5 (in italics) to address the Reviewer's comments

"We fitted Type II (orthogonal) linear regressions that account for uncertainty in both variables (satellite and EC). We obtained an array of very simple models of productivity and photosynthetic potential...."

Please note we present confidence intervals (CI) for all coefficients used on the regressions (Table 3) and other measures of statistical significance (e.g. AIC) to determine if the RS greenness indices represent the absolute value, the amplitude and timing of the seasonal cycle, rather than assuming non uncertainty. on the parameterization of the light response curve or the satellite product.

MODIS LST suddenly appeared in Fig 7 and 8. I understand the authors used LST which could constrain GEP reported by Sims et al.; however, it is out of context. See the title again: "MODIS vegetation products as proxies of photosynthetic potential."

R2C08: We understand the concerns of the reviewer, thus as incorporating LSTday versus P_c may distract the reader from one of the key objectives of the study -to demonstrate RS greening indices to be measurements of photosynthetic potential. We propose to modify Fig. 8 by removing the corresponding panel LSTday versus GEP.

Specific comments: P2 L2: measured -> estimated

R2C09: Done

P2 L10-12: I do not think the authors provided results on this argument. I expected comparison between in situ LAI with satellite greenness index, and between in situ

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V_{cmax} or A_{max} with satellite greenness index.

R2C10: LAI measurements at a temporal resolution longer than a year (i.e., seasonal) are difficult to obtain due to missing periods and restricted access to some of our remote sites. We wish to emphasize that is not merely the 'quantity' of leaves, but rather, jointly 'quality' (e.g. leaf-level photosynthetic capacity) and 'quantity' (e.g. LAI) that drives the potential of the ecosystem to do photosynthesis.

We understand the parameterization of the net CO_2 assimilation rate (A) versus leaf internal CO_2 concentrations (C_i) represents the mechanistic basis behind many plant physiology models, and their parameterization (e.g. via maximum Rubisco activity or V_{cmax}) is key in determining the effects of elevated atmospheric CO_2 concentration on growth (Harley et al., 1992; Medlyn et al., 1999). However, scaling from leaf to ecosystem introduces additional uncertainty and assumes sufficient sampling from leaves from different species, age cohorts, and canopy levels (shaded versus full light). Moreover, at woodland and savannas, C3/C4/base soil percentage cover changes over the year increasing the difficulties of scaling up leaf-base measures. Some of the site locations are remote and difficult to access, thus leaf-measurements may be only available for a few periods of the year. Our study takes advantage of available eddy covariance data, as it offers continuous ecosystem level data.

P3 L25: \times -> multiplication symbol

R2C11: We used \times as multiplication symbol throughout the document

P11 L25: GEP to PAR -> GEP to APAR?

R2C12: $LUE = GEP/PAR$

Please see response to Reviewer's comments R1C07 for an extended discussion.

P13 L16: Eq 3 was not related to filtering.

R2C13: Manuscript needs to be corrected, should have stated Eq 8.

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P14 L6-16: I am curious why the authors used coarse resolution satellite estimates of SW and precipitation instead of tower based observations.

R2C14: Our intent is to construct relationships that can be scaled to regional and continental scale; therefore, we used satellite derived meteorological variables: SWdown, precipitation and LSTday. We propose the inclusion of text to the Section 2.3.2. (in italics) to address the Reviewer's concern:

"...No quality control was performed on the rain (PrecipTRMM) or short wave (SWCERES) satellite derived time series. We used satellite derived meteorological variables instead of in situ measurements as the independent variable in GEP models (see Section 2.5), thus, our findings (e.g. regressions) can be extrapolated to regional and continental scales."

P19 L27: remove a comma

R2C15: Done.

P28 L20-22: This conclusion is not true in TBR site which showed EVI did not correlate with LUE and Pc.

R2C16: Please refer to R2C03 of this response.

P43 Figure 2 caption: define Pc. Also, remove the equation of Pc in the figure which disrupts readership. The colors of dots look different. If this is true, then define; otherwise, use one colour.

R2C17: Please see uploaded figure

P44 L5: There was no "grey dashed line" in the figure

R2C18: Please see uploaded figure

Please also note the supplement to this comment:

<http://www.biogeosciences-discuss.net/12/C10054/2016/bgd-12-C10054-2016->

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supplement.pdf

Interactive comment on Biogeosciences Discuss., 12, 19213, 2015.

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	Gamon et al. (1995)	Restrepo-Coupe et al. (2015)
Time period	1-year	EC: 3+ years RS: 15+ years
Spatial scale	In situ measurements	250+ m
Proxy for photosynthetic potential and activity (method)	<ul style="list-style-type: none"> Leaf-level photosynthetic activity (A): gas exchange LAI, biomass: biometry 	Parametrization of the EC light response curve
	<p>Note that the leaf level A measurements presented by Gamon et al were scaled up to represent the ecosystem. Scaled A and GEP may or may not be related as other ecosystem components, different from leaves can contribute to GEP (e.g. soil biological crusts, branches), which can be significant (e.g. semi-arid ecosystems). Methodologically, A is a time intensive measurement and requires a high sampling that includes leaves from different age cohorts, canopy levels (shaded versus full light) if been used to scale to ecosystem level.</p>	
Vegetation indices and other photosynthetic potential drivers (method)	NDVI and simple ratio (SR) (portable spectroradiometer sampled to mimic AVHRR reflectances)	NDVI, EVI, LAI _{MODIS} and fPAR _{MODIS} (remote sensing -MODIS). Satellite derived meteorological variables: <i>LST_{day}</i> , <i>SW_{down}</i> and <i>Precip_{TRMM}</i> .
Measures of productivity	NPP (restricted to above ground primary productivity). Later scaled to represent green leaf fraction.	GEP: photosynthetic activity. Includes above and below ground primary productivity and CO ₂ used on photorespiration (Waring and Running, 1998)
Findings	The ability of NDVI to predict A is linked to a LAI threshold. Where at sparse canopies, LAI<2, NDVI is highly correlated to A. In contrast, at high LAI ecosystems, LAI>2, NDVI was insensitive to canopy structure.	We argue the ability of VIs to represent GEP is restricted to those sites where phenology is synchronous to photosynthetic activity. Thus, sites where photosynthetic potential was asynchronous or aseasonal to meteorological drives, RS products were unable to explain GEP independently of site biomass or LAI.
	Highest correlation between NDVI and maximum daily photosynthetic rates.	We found the short term response of the ecosystem (e.g. restricted by high values of VPD) showed lower correlations (GEP _{max} a proxy of maximum daily photosynthetic rates) compared to other measures of potential (LUE and P _c).

Fig. 1. Differences between Gamon et al. (1995) and Restrepo-Coupe et al. (2015)

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