Biogeosciences Discuss., 12, C10065–C10082, 2016
www.biogeosciences-discuss.net/12/C10065/2016/

Biogeosciences
Discussions
Open Access

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.

N. Restrepo-Coupe et al.

nataliacoupe@gmail.com

Received and published: 2 March 2016

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:

Reviewer 1.

The authors investigate the potential of MODIS vegetation indices (VIs) to predict gross primary production in semi-arid ecosystems of Australia. This is an important topic since GPP of such ecosystem types are indeed difficult to capture by VIs and this deserves an in depth analysis. Overall, the paper contains several interesting aspects that are worth being published. But I agree with referee #2 that the manuscript requires substantial sharpening and streamlining.

The first objective was 'to gain understanding of ecosystem behaviour' but it is not clear what is meant by that. In that regard I had expected more insights on the role of water limitation (VPD and soil moisture) on GPP and to what extent VIs can capture that or not. Water limitation is in my view perhaps the most critical point on why VIs may not 'see' the productivity response properly.

R1C01: We appreciate the reviewer's comments as they introduce the issue of water availability (soil moisture and VPD) to the discussion. We observed the greater discrepancies between VIs and GEP at Tumbarumba (AU_Tum), a site that does not show signs of water limitation (Figure 1). In this sclerophyll forest, only 3% of the 10-year time series corresponds to VPD values greater than 3 kPa, a threshold identified for a 50% reduction in LUE (Ogutu and Dash, 2013). Mean seasonal evapotranspiration (ET) at AU_Tum was 2.4 mm/day (standard deviation of 1.23 mm/day), which is substantially less than the 2001-2012 average of 6.4 mm/day PrecipTRMM (PrecipEC = 6.4 mm/day).

We acknowledge the difficulties in separating the meteorological from the biophysical contributions (photosynthetic potential) to GEP based on radiation and VPD (e.g. derivation of Pc), particularly in woodlands as these ecosystems can be highly controlled by access to soil moisture (Cleverly et al., 2013). For example, at Alice Springs Mulga site (AU-ASM), Eamus et al. (2013) reported an increase in transpiration at moderate values of VPD, whereas the rate of photosynthesis remained unaffected, signalling the complexity of the controls on carbon exchange. However, we argue that VIs represent the ‘ecosystem potential’ seasonality that can later be translated to photosynthetic activity if driven by water, temperature, light, and CO2 availability. At seasonal time scales (e.g. 16-days, monthly), our analysis looks at the biotic drivers of productivity (parameterization of the light response curve); by contrast, at shorter time scales (e.g. hourly, daily) ecosystem photosynthetic potential should be scaled to reflect resource limitations (i.e. access to soil moisture), availability (e.g. incoming radiation) and the correspondent ecosystem responses (e.g. stomatal closure, CO2 fertilization) that determine GEP.

We propose to add the following text (in italics) at section 4.1. Derivation of measures of photosynthetic potential at tropical savannas, sclerophyll forests and semi-arid ecosystems, as follows :

“In this study we were able to separate the biological (vegetation phenological signal) from the climatic drivers of productivity using eddy-covariance carbon exchange data. Using the parameterization of the light response curve we derived different measures of vegetation photosynthetic potential (α, LUE, GEPsat and Pc). At seasonal time scales (e.g. 16-days, monthly), our analysis looks at the biotic drivers of productivity, whereas at shorter time scales (e.g. hourly, daily), photosynthetic potential can be limited or enhanced by meteorological controls, thus GEP was linked to resource limitation (i.e. high VPD), availability (e.g. access to soil water) and corresponding ecosystem responses (e.g. stomatal closure, photoinhibition, and CO2 fertilization).”

Additional text is also proposed to be inserted into Section 4.2. Seasonality and comparisons between satellite products and flux tower based measurements of carbon flux: photosynthetic activity (productivity) and potential (phenology):

“Similar to Mediterranean ecosystems (AU-Cpr), in wet sclerophyll forests (AU-Tum) without signs of water limitation, the VIs were unable to replicate seasonality in GEP....”

Using precipitation from a coarse scale product does not seem appropriate to capture

water availability. I’m wondering why not observed soil moisture or simple ecohydrological metrics like cumulative water deficit (from measured precip and ET) has been used here.

R1C02: It is our intent to obtain continental-wide relationships independent from biome classification or EC drivers (e.g. ET). Thus, as we want to offer an understanding and relationships that are able to capture spatial (e.g. ecotone) and temporal changes in land cover type (e.g. drought impact). The reviewer is correct about other measures of water availability (e.g. soil moisture) being more robust as the timing and intensity of precipitation will have an important effect on whether water is available to plants. However, issues related to the identification of threshold values (e.g. not all soil moisture increases translate in a phenological response at AU_ASM (Cleverly et al., 2016)), time scales and other issues beyond the scope of this study may have an equal effect upon whether photosynthetic potential translates into activity (GEP). We believe that robust GEP models will incorporate: 1) satellite derived VIs as proxies for photosynthetic potential, 2) meteorological drivers, and 3) a mechanistic response from the vegetation to the short term variations in weather and climate, but we found the present MODIS GPP and other models to perform poorly across Australia. Future work should aim to look into different satellite products as, for example the Gravity Recovery and Climate Experiment, GRACE-total water storage (TWS), and the Soil Moisture Active Passive, SMAP-soil moisture values, among others as GEP drivers and to refine the derivation of measures of photosynthetic potential.

It has been argued that dur- ing water stressed conditions the yellowing of the herbaceous understory may act as a ‘drought indicator’ which might drive the VI in the ‘right’ direction (Sims et al 2014, GCB; Jung et al 2008, GCB). If so, the capacity of VIs to reflect GPP response would depend on the presence and density of herbaceous vegetation and the openness of the forest canopy. The colour of the leaves is influencing the VIs and this could also indicate changes of LUE.

R1C03: We agree with the reviewer that the presence and density of herbaceous vegetation and the openness of the forest canopy can drive the VI signal at savannas and open woodlands at certain times of the year (e.g. AU_How and AU_ASM, see Chen et al. (2003); Cleverly et al. (2016, Submitted); and Hutley et al. (2000). Moreover, we agree that VIs constitute a signal dominated by chlorophyll (red reflectance) and cellulose content (NIR), thus will indicate changes in LUE. However, we argue that satellite derived biophysical measures and other greenness indexes are not a measure of GEP. Instead, VIs and other biophysical products are proxies for ecosystem structure (e.g. leaf area index - quantity of leaves) and for function (e.g. leaf level photosynthetic assimilation capacity - quality of leaves). Our results should extend to other remote sensing sources, including phenocams and in situ spectroradiometers.

The authors mention repeatedly that ‘understanding’ is more impor- tant than ‘well-fitting models’ but the authors present a systematic analysis on which regression models work best (which I like!). Investigating the coefficients of these re- gression models shows often unexpected signs, e.g. GPP decreasing with VI, or the presence of intercept terms, which conceptually makes little sense. Discussing and ex- plaining these things may be a chance to make the point why ‘understanding’ is impor- tant.

R1C04: We propose to incorporate the reviewer’s suggestion into to section 4.3. Considerations for the selection of RS data to be used on GEP models and phenology validation studies, here in italics:

. . ..”The fact that a brighter soil background results in lower NDVI values than with a dark soil background for the same quantity of partial vegetation cover (Huete, 1988; Huete and Tucker, 1991) may have a positive effect in the all-site Pc versus NDVISZA30 regressions (increase R2). Thus as darkened soils following precipitation generally result in higher NDVI values for incomplete canopies (Gao et al., 2000) and may similarly suggest higher vegetation or soil biological crust activity. On the other hand, soil brightness and moisture may have a negative effect on the confidence interval of the x-intercept for the proposed relationships (e.g. Pc versus NDVISZA30, for NDVISZA30$\sim$0). Moreover, at certain times the AU-ASM and AU-Cpr sites were at the

low end of the vegetation activity range, and the observed RS signal may have been dominated by soil water content rather than by photosynthetic potential.”

The second objective was to disentangle the seasonality of ‘vegetation structure and function from climatic drivers of productivity’. The authors derive 4 metrics here (alpha, Pc, LUE, GEP_sat). I agree with referee #2 regarding the (non-optimal) nomenclature of ‘photosynthetic potential’ vs ‘activity’. I also see a conceptual problem here because all 4 metrics are actually confounded by changes in light harvesting (reflected by VIs) such that vegetation structure and functioning cannot be disentangled from eco- physiological effects.

R1C05: See R2C02

In my opinion the authors should have used PAR*VI in the light response cure fitting to account for that. I’m also wondering about the usefulness of Pc – first it seems redundant given alpha and GEP_sat, and second it requires somewhat arbitrary thresholds and site specific knowledge to compute it.

R1C06: While other more refined biophysical measures of photosynthetic potential would be ideal (e.g. chlorophyll fraction of absorbed PAR), the parameterization of the light response curve offers an insight of seasonal ecosystem form, function and phenology (Hutyra et al., 2007; Restrepo-Coupe et al., 2013; Wu et al., 2016). Pc was calculated to remove the effect of day length, changes in radiation environment, cold/warm periods, among other non optimal meteorological conditions from GEP – thus, Pc represents the canopy’s ability to do photosynthesis. We assumed optimal radiation to be equivalent to the site annual mean daytime PAR ± 100 μmol m-2 s- 1 and VPD ± 1 standard deviation. By contrast, α and GEPsat, would be characteristic of the vegetation response under conditions dominated radiation (diffuse and direct) and VPD, respectively (see Section 2.2.3).

I’m wondering why the authors did not employ the ‘classical’ approach (GPP=APAR*LUE) here to disentangle ‘biophysical’ (APAR=VI*PAR) from ‘ecophysiological' (LUE) components, which seem more straightforward and would do the job (?). For example, given GPP=VI*RAD*LUE it derives that GPP scales with VI if a) the product of RAD and LUE is nearly constant (compared to the variability of VI), or b) product of RAD and LUE is in phase with VI. I guess I'm lacking a more clear presentation and justification of a clear framework and motivation of the analysis strategy.

R1C07: For context:

GEP = APAR x ε as in Yuan et al., (2007) (Equation 1)

or

NPP = APAR x ε as in Gamon et al. (1995) (Equation 2)

where ε is the efficiency with which absorbed radiation is converted to fixed carbon (also refereed as LUE by some authors), NPP is net primary productivity, where NPP = GEP - autotrophic respiration, and APAR is the absorbed fraction of PAR.

APAR = PAR x fPAR.

where fPAR is defined as the fraction of PAR absorbed by the canopy (leaves and woody tissue) and has been correlated to NDVI (Gamon et al., 2013; Myneni and Williams, 1994).

We consider fPAR and ε to be similarly representative of the canopy structure and function; therefore, separating ε and fPAR would be problematic as both variables would be considered similar measures of photosynthetic potential. In general, models that use Eq1 assume ε to be constant and biome-dependent (Yuan et al., 2007). Moreover, the determination of ε continues to be a major challenge in ecological research (Field et al., 1998; Running et al., 2004). Our analysis offers a ground-based measure of vegetation photosynthetic potential and constitutes an attempt to derive all-site regressions between the satellite products and ecosystem form and function independently of biome type. Thus, so that ecotones and sudden land use changes such as flooding or fire may not be misrepresented when extrapolated to regional and continental scales.

Minor points: - Why were coarse scale products of radiation d precip being used?

R1C08: 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.

We propose to add text to section 2.3.2. Satellite measures of precipitation (TRMM) and incoming solar radiation (CERES), to address the Reviewer's concerns:

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

Why monthly if those are available daily? -

R1C09: We are interested on the seasonal response of the ecosystem (e.g. monthly or 16-day), away from short term responses (e.g. hourly or daily). The 16-day window is a time scale representative of important ecological processes; in particular, leaf appearance to full expansion (Jurik, 1986; Restrepo-Coupe et al., 2013).

Page 19234, line 6: R2=0.16 does not suggest a 'strong' relationship to me -

R1C10: We observed a clear improvement in the ability of the model to predict Pc and LUE rather than GEP. At the evergreen wet sclerophyll forest of AU_Tum, there were no relationships between GEP and satellite derived measures of greenness (e.g. GEP and EVISZA30 or NDVISZA30 R2<0.01 and p=0.93, Figure 5b). In contrast the regression between Pc and VIs were statistically significant, meaning the regression was significantly higher than zero (R2= 0.16, p<0.01; Figure 6 and Supplement Table 4), low R2 values can be explained by the small dynamic range of both seasonal measures of photosynthetic potential and VIs (cf. Figure 4 and Figure 6). Thus, we would change strongly to significant on the text as we showed how at this site incoming solar radiation explained 60% and a multi-linear model driven by SWdown and EVISZA30 was able to explain 70% of GEP indicating a meteorological driven ecosystem.

At Section 3.3. Relationship between EVISZA30 and measures of photosynthetic potential (α, LUE, GEPsat, and Pc):

“At the sclerophyll forest site (AU-Tum) the EVISZA30 was able to predict vegetation phenology rather than productivity. For example we observed that Pc (but not α) was significantly related...”

Page 19240 line 23: I’m not sure but I thought a brighter soil (or snow) increases ndvi (?). In any case, this is an interesting section of discussion which might be expanded (‘understanding’ why things work or not)

R1C10: We quote Huete (1988) who found “Soil brightness influences have been noted in numerous studies where, for a given amount of vegetation, darker soil substrates resulted in higher vegetation index values when the ratio vegetation index (RVI= NIR/red) or the normalized difference vegetation index[NDVI–(NIR- red)/(NIR+ red)= (RVI-1)/(RVI+l)] were used as vegetation measures (Colwell, 1974; Elvidge and Lyon, 1985; Huete et al., 1985)”.

We added text to the discussion to address the Reviewer’s suggestion see R1C04

Please note we were requested by Fluxnet and OzFlux to change the site abbreviations.

References

Chen, X., Hutley, L.B., Eamus, D., 2003. Carbon balance of a tropical savanna of northern Australia. Oecologia 137, 405–416. doi:10.1007/s00442-003-1358-5

Chen, Z.M., author, I.S.B.C., Chen, Z.X., Komaki, K., Mohamed, M.A.A., Kato, K., 2004. Estimation of interannual variation in productivity of global vegetation using NDVI data. Int. J. Remote Sens. 25, 3139–3159. doi:10.1080/0143116032000160435

Cleverly, J., Boulain, N., Villalobos-Vega, R., Grant, N., Faux, R., Wood, C., Cook, P.G., Yu, Q., Leigh, A., Eamus, D., 2013. Dynamics of component carbon fluxes in a semi-arid Acacia woodland, central Australia. J. Geophys. Res. Biogeosciences 118, 1168–1185. doi:10.1002/jgrg.20101

Cleverly, J., Eamus, D., Coupe, N.R., Chen, C., Maes, W., Li, L., Faux, R., Santini, N.S., Rumman, R., Yu, Q., Huete, A., Submitted. Soil moisture controls on phenology, productivity and evapotranspiration in a semi-arid critical zone. Sci. Total Environ. Spec. Issue Aust. Crit. Zone Obs.

Cleverly, J., Eamus, D., Van Gorsel, E., Chen, C., Rumman, R., Luo, Q., Coupe, N.R., Li, L., Kljun, N., Faux, R., Yu, Q., Huete, A., 2016. Productivity and evapotranspiration of two contrasting semiarid ecosystems following the 2011 global carbon land sink anomaly. Agric. For. Meteorol. 220, 151–159. doi:10.1016/j.agrformet.2016.01.086

Eamus, D., Cleverly, J., Boulain, N., Grant, N., Faux, R., Villalobos-Vega, R., 2013. Carbon and water fluxes in an arid-zone Acacia savanna woodland: An analyses of seasonal patterns and responses to rainfall events. Agric. For. Meteorol. 182-183, 225–238. doi:10.1016/j.agrformet.2013.04.020

Field, C.B., Behrenfeld, M.J., Randerson, J.T., Falkowski, P., 1998. Primary Production of the Biosphere: Integrating Terrestrial and Oceanic Components. Science 281, 237–240. doi:10.1126/science.281.5374.237

Gamon, J.A., Field, C.B., Goulden, M.L., Griffin, K.L., Hartley, A.E., Joel, G., Penuelas, J., Valentini, R., 1995. Relationships Between NDVI, Canopy Structure, and Photosynthesis in Three Californian Vegetation Types. Ecol. Appl. 5, 28–41. doi:10.2307/1942049

Gamon, J.A., Huemmrich, K.F., Stone, R.S., Tweedie, C.E., 2013. Spatial and temporal variation in primary productivity (NDVI) of coastal Alaskan tundra: Decreased vegetation growth following earlier snowmelt. Remote Sens. Environ. 129, 144–153.

doi:10.1016/j.rse.2012.10.030

Guan, K., Pan, M., Li, H., Wolf, A., Wu, J., Medvigy, D., Caylor, K.K., Sheffield, J., Wood, E.F., Malhi, Y., Liang, M., Kimball, J.S., Saleska, S.R., Berry, J., Joiner, J., Lyapustin, A.I., 2015. Photosynthetic seasonality of global tropical forests constrained by hydroclimate. Nat. Geosci. 8, 284–289. doi:10.1038/ngeo2382

Harley, P.C., Thomas, R.B., Reynolds, J.F., Strain, B.R., 1992. Modelling photosynthesis of cotton grown in elevated CO2. Plant Cell Environ. 15, 271–282. doi:10.1111/j.1365-3040.1992.tb00974.x

Huete, A.R., 2012. Vegetation Indices, Remote Sensing and Forest Monitoring. Geogr. Compass 6, 513–532. doi:10.1111/j.1749-8198.2012.00507.x

Huete, A.R., 1988. A soil-adjusted vegetation index (SAVI). Remote Sens. Environ. 25, 295–309. doi:10.1016/0034-4257(88)90106-X

Huete, A., Restrepo-Coupe, N., Ratana, P., Didan, K., Saleska, S., Ichii, K., Panuthai, S., Gamo, M., 2008. Multiple site tower flux and remote sensing comparisons of tropical forest dynamics in Monsoon Asia. Agric. For. Meteorol. 148, 748–760. doi:10.1016/j.agrformet.2008.01.012

Hutley, L.B., O'Grady, A.P., Eamus, D., 2000. Evapotranspiration from Eucalypt open-forest savanna of Northern Australia. Funct. Ecol. 14, 183–194. doi:10.1046/j.1365-2435.2000.00416.x

Hutyra, L.R., Munger, J.W., Saleska, S.R., Gottlieb, E., Daube, B.C., Dunn, A.L., Amaral, D.F., de Camargo, P.B., Wofsy, S.C., 2007. Seasonal controls on the exchange of carbon and water in an Amazonian rain forest. J. Geophys. Res. Biogeosciences 112, 1–16. doi:10.1029/2006JG000365

Jurik, T.W., 1986. Seasonal Patterns of Leaf Photosynthetic Capacity in Successional Northern Hardwood Tree Species. Am. J. Bot. 73, 131–138.

Kanniah, K.D., Beringer, J., Hutley, L.B., Tapper, N.J., Zhu, X., 2009. Evaluation of Collections 4 and 5 of the MODIS Gross Primary Productivity product and algorithm improvement at a tropical savanna site in northern Australia. Remote Sens. Environ. 113, 1808–1822. doi:10.1016/j.rse.2009.04.013

Leuning, R., Cleugh, H.A., Zegelin, S.J., Hughes, D., 2005. Carbon and water fluxes over a temperate Eucalyptus forest and a tropical wet/dry savanna in Australia: measurements and comparison with MODIS remote sensing estimates. Agric. For. Meteorol. 129, 151–173. doi:10.1016/j.agrformet.2004.12.004

Maeda, E.E., Heiskanen, J., Aragão, L.E.O.C., Rinne, J., 2014. Can MODIS EVI monitor ecosystem productivity in the Amazon rainforest? Geophys. Res. Lett. 41, 2014GL061535. doi:10.1002/2014GL061535

Medlyn, B.E., Badeck, F.-W., De Pury, D.G.G., Barton, C.V.M., Broadmeadow, M., Ceulemans, R., De Angelis, P., Forstreuter, M., Jach, M.E., Kellomäki, S., Laitat, E., Marek, M., Philippot, S., Rey, A., Strassemeyer, J., Laitinen, K., Liozon, R., Portier, B., Roberntz, P., Wang, K., Jstbid, P.G., 1999. Effects of elevated [CO2] on photosynthesis in European forest species: a meta-analysis of model parameters. Plant Cell Environ. 22, 1475–1495. doi:10.1046/j.1365-3040.1999.00523.x

Myneni, R.B., Williams, D.L., 1994. On the relationship between FAPAR and NDVI. Remote Sens. Environ. 49, 200–211. doi:10.1016/0034-4257(94)90016-7

Ogutu, B.O., Dash, J., 2013. An algorithm to derive the fraction of photosynthetically active radiation absorbed by photosynthetic elements of the canopy (FAPAR(ps)) from eddy covariance flux tower data. New Phytol. 197, 511–523. doi:10.1111/nph.12039
Peng, Y., Gitelson, A.A., 2012. Remote estimation of gross primary productivity in soybean and maize based on total crop chlorophyll content. Remote Sens. Environ., Remote Sensing of Urban Environments 117, 440–448. doi:10.1016/j.rse.2011.10.021

Rahman, A.F., Sims, D.A., Cordova, V.D., El-Masri, B.Z., 2005. Potential of MODIS EVI and surface temperature for directly estimating per-pixel ecosystem C fluxes. Geophys. Res. Lett. 32, L19404. doi:10.1029/2005GL024127 Restrepo-Coupe, N., da Rocha, H.R., da Araujo, A.C., Borma, L.S., Christoffersen, B., Cabral, O.M.R., de Camargo, P.B., Cardoso, F.L., da Costa, A.C.L., Fitzjarrald, D.R., Goulden, M.L., Kruijt, B., Maia, J.M.F., Malhi, Y.S., Manzi, A.O., Miller, S.D., Nobre, A.D., von Randow, C., Sá, L.D.A., Sakai, R.K., Tota, J., Wofsy, S.C., Zanchi, F.B., Saleska, S.R., 2013. What drives the seasonality of photosynthesis across the Amazon basin? A cross-site analysis of eddy flux tower measurements from the Brasil flux network. Agric. For. Meteorol. 182-183, 128–144.

Restrepo-Coupe, N., Huete, A., Davies, K., Cleverly, J., Beringer, J., Eamus, D., van Gorsel, E., Hutley, L.B., Meyer, W.S., 2015. MODIS vegetation products as proxies of photosynthetic potential: a look across meteorological and biologic driven ecosystem productivity. Biogeosciences Discuss 12, 19213–19267. doi:10.5194/bgd-12-19213-2015 Running, S.W., Nemani, R.R., Heinsch, F.A., Zhao, M., Reeves, M., Hashimoto, H., 2004. A Continuous Satellite-Derived Measure of Global Terrestrial Primary Production. BioScience 54, 547–560. doi:10.1641/0006-3568(2004)054[0547:ACSMOG]2.0.CO;2

Sims, D.A., Rahman, A.F., Cordova, V.D., El-Masri, B.Z., Baldocchi, D.D., Flanagan, L.B., Goldstein, A.H., Hollinger, D.Y., Misson, L., Monson, R.K., Oechel, W.C., Schmid, H.P., Wofsy, S.C., Xu, L., 2006. On the use of MODIS EVI to assess gross primary productivity of North American ecosystems. J. Geophys. Res. Biogeosciences 111, G04015. doi:10.1029/2006JG000162

Toomey, M., Friedl, M.A., Frolking, S., Hufkens, K., Klosterman, S., Sonnentag, O., Baldocchi, D.D., Bernacchi, C.J., Biraud, S.C., Bohrer, G., Brzostek, E., Burns, S.P., Coursolle, C., Hollinger, D.Y., Margolis, H.A., McCaughey, H., Monson, R.K., Munger, J.W., Pallardy, S., Phillips, R.P., Torn, M.S., Wharton, S., Zeri, M., Richardson, A.D., 2015. Greenness indices from digital cameras predict the timing and seasonal dynamics of canopy-scale photosynthesis. Ecol. Appl. 25, 99–115. doi:10.1890/14-0005.1

Waring, H.R., Running, W.S., 1998. Forest Ecosystems: Analysis at Multiple Scales. Academic Press, San Diego, CA, USA.

Wu, J., Albert, L., Lopes, A.P., Restrepo-Coupe, N., Hayek, M., Wiedemann, K.T., Guan, K., Stark, S.C., Prohaska, N., Tavares, J.V., Suelen Marostica, Hideki Kobayashi, Mauricio L. Ferreira, Kleber Silva Campos, Rodrigo da Silva, Paulo M. Brando, Dennis G. Dye, Travis E. Huxman, Alfredo R. Huete, Bruce W. Nelson, Scott R. Saleska, 2016. Leaf development and demography explain photosynthetic seasonality in Amazon evergreen forests. Science 45, 230–240.

Yuan, W., Liu, S., Zhou, G., Zhou, G., Tieszen, L.L., Baldocchi, D., Bernhofer, C., Gholz, H., Goldstein, A.H., Goulden, M.L., Hollinger, D.Y., Hu, Y., Law, B.E., Stoy, P.C., Vesala, T., Wofsy, S.C., 2007. Deriving a light use efficiency model from eddy covariance flux data for predicting daily gross primary production across biomes. Agric. For. Meteorol. 143, 189–207.

Abstract A direct relationship between gross ecosystem productivity (GEP) estimated by the eddy covariance (EC) method and Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation indices (VIs) has been observed in many temperate and tropical ecosystems. However, in Australian evergreen forests, and particularly sclerophyll and temperate woodlands, MODIS VIs do not capture seasonality of GEP. 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 parametrization 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 area index - quantity of leaves) and function (e.g. leaf level photosynthetic assimilation capacity - quality of leaves), rather than GEP. Our results show that in primarily meteorological-driven (e.g. photosynthetic active radiation, air temperature and/or precipitation) and relatively aseasonal vegetation photosynthetic potential ecosystems (e.g. evergreen wet sclerophyll forests), there were no statistically significant relationships between GEP and satellite derived measures of greenness. In contrast, for phenology-driven ecosystems (e.g. tropical savannas), changes in the vegetation status drove GEP, and tower-based measurements of photosynthetic activity were best represented by VIs. We observed the highest correlations between MODIS products and GEP in locations where key meteorological variables and vegetation phenology were synchronous (e.g. semi-arid Acacia woodlands) and low correlation at locations where they were asynchronous (e.g. Mediterranean ecosystems). Although, we found a statistical significant relationship between the long term measures of photosynthetic potential (Pc and LUE) and VIs, where each ecosystem aligns along a continuum, we want to highlight that EC data offer much more than validation and/or calibration of satellite data and models. Knowledge of the conditions in which flux tower measurements and VIs or other remote sensing products converge greatly advances our understanding of the mechanisms driving the carbon cycle (phenology and climate drivers) and provides an ecological basis for interpretation of satellite derived measures of greenness.

5. Conclusions Remote sensing vegetation products have been widely used to scale carbon fluxes from eddy covariance (EC) towers to regions and continents. However, at some key Australian ecosystems MODIS GPP and VIs may not track seasonality of gross ecosystem productivity (GEP). In particular, we found EVISZA30 was unable to represent GEP at the temperate evergreen sclerophyll forest of Tumbarumba (AU-Tum) and at the Mediterranean ecosystem (Mallee) of Calperum-Chowilla (AU-Cpr). This result extends across satellite products overall: MODIS GPPMOD, LAIMOD, fPARMOD, and other VIs.

We aimed for a greater understanding of the mechanistic controls on seasonal GEP and proposed the parametrization of the light response curve from EC fluxes, as a novel tool to obtain ground-based seasonal estimates of ecosystem photosynthetic potential

(light use efficiency (LUE), photosynthetic capacity (Pc), GEP at saturation (GEPsat), and quantum yield (α)). And by photosynthetic potential we refer to the presence of photosynthetic infrastructure in the form of ecosystem structure (e.g. leaf area index-quantity of leaves) and function (e.g. leaf level photosynthetic assimilation capacity - quality of leaves) independent of the meteorological and environmental conditions that drive GEP. Based on basic linear regressions, we demonstrated that MODIS derived biophysical products (e.g. VIs) were a proxy for ecosystem photosynthetic potential rather than GEP. We reported statistically significant regressions between VIs (e.g. NDVISZA30 and EVISZA30) to long term measures of phenology (e.g. LUE and Pc), in contrast to ecosystem descriptors subject to short term responses to environmental conditions (e.g. GEPsat and α). Our results should extend to other methods and measures of greenness, including VIs and chromatic coordinates from phenocams and in situ spectrometers.

We found that the linear regressions between MODIS biophysical products and photosynthetic potential converged on a single function across very diverse biome types, which implies that these relationships persist over very large areas, thus improving our ability to extrapolate in situ phenology and seasonality to continental scales, across longer temporal scales and to identify rapid changes due to extreme events or spatial variations at ecotones. We further found that saturation of fPARMOD and NDVISZA30, restricted their usefulness, except in comparatively low biomass ecosystems (savannas and arid and semi-arid savannas and woodlands).

We quantified how much of GEP seasonality could be explained by different variables: radiation (SWdown), temperature (Tair), precipitation (Precip), or phenology (VIs as proxy). Our analysis showed the relationship between RS products and GEP was only clear when productivity was driven by either: (1) ecosystem phenology and climate, synchronously driving GEP, as was observed at Alice Springs Mulga woodland (AU-ASM), and similar to many temperate deciduous locations, or (2) solely by the vegetation photosynthetic potential, as observed at the tropical savanna site of Howard

Springs (AU-How). At AU-How, radiation and temperature were constant across the year, although ecosystem photosynthetic activity (GEP) and potential (e.g. Pc and LUE) fluctuated with the highly seasonal understory. However, RS products do not follow GEP when: (3) phenology is asynchronous with key meteorological drivers such that GEP is driven by one or the other at different times of the year, as we observed at AU-Cpr; or when (4) GEP is driven by meteorology (SWdown, Tair, soil water availability, VPD, or different combinations) and photosynthetic potential is aseasonal, as observed at AU-Tum. At AU-Tum, changes in productivity were driven by SWdown„ while the ecosystem biophysical properties remained relatively constant across the year, represented by the small amplitude of the annual cycles in Pc and LUE (true evergreen forest). An understanding of why satellite versus flux tower estimates of GEP relationships hold, or do not hold, greatly contribute to our comprehension of carbon cycle mechanisms and scaling factors at play (e.g. climate and phenology, among others).

Please also note the supplement to this comment: http://www.biogeosciences-discuss.net/12/C1/2016/bgd-12-C1-2016-supplement.pdf

---

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

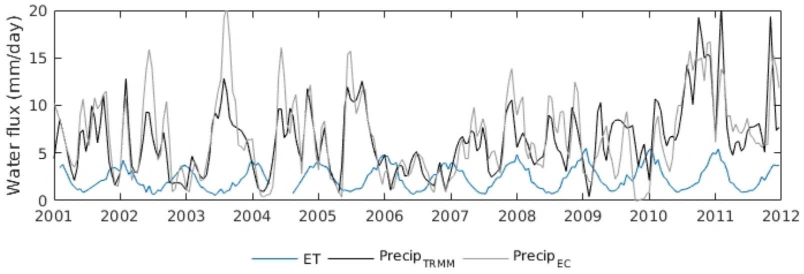

Fig. 1. Water fluxes at Tumbarumba (AU_Tum) sclerophyll forest: Evapotranspiration (ET, blue lines), satellite derived (PrecipTRMM, black lines) and flux-tower (PrecipEC, grey lines) precipitation (mm/day).