Short communication

Use of NDVI-adjusted PAR for predicting gross primary production in a temperate grassland in Iceland

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Keywords: Carbon flux, GPP, NDVI, PAR

INTRODUCTION

Gross primary production (GPP) is an important variable to estimate in the global carbon cycle. Estimates of GPP at regional to global scales are critical for understanding ecosystem response to an increased atmospheric CO_2 level and for providing objective information for political decisions.

The best approach for calculating GPP is through direct measurements of small areas, using either the static-chamber method or eddy covariance technique. Calculating GPP of a whole ecosystem or an entire region is on the other hand problematic. However, scaling up GPP, estimated from direct ground measurements, has increasingly played a role in ecosystem characterization (Lischke et al. 2007).

Given that vegetation productivity is directly related to the amount of solar radiation within the plant canopy (Knipling 1970), the simplest method for predicting GPP would be a mathematical function derived from a direct correlation between measured GPP and photosynthetically active radiation (PAR). Many approaches to estimate GPP have been developed based on the work of Monteith (1972), where he suggested that GPP can be expressed as a product of fraction of absorbed photosynthetically active radiation (fAPAR), incident photosynthetically active radiation (PARin) and light use efficiency (LUE), which is the efficiency of the absorbed PAR converted into biomass. Yet an estimate of solar radiation, such as PAR, is not a sufficient indicator of photosynthesis at high northern or southern latitudes because fluctuations in vegetation green mass and solar radiation are not synchronous in time.

Several studies have suggested a new remote technique to relate GPP to a product of chlorophyll-related vegetation indices (VI) and incoming photosynthetic radiation, $GPP \propto VI \times PAR_{in}$, based on Monteith's logic (Wu et al. 2009, Gitelson et al. 2006, Peng et al. 2013). Numerous vegetation indices are known to indicate the chlorophyll content of vegetation, such as the Red Edge Chlorophyll Index ($CI_{red\ edge}$), MERIS terrestrial chlorophyll index (MTCI) (Wu et al. 2009), and the most widely used Normalized Difference Vegetation Index (NDVI) developed by Rouse et al. (1974). Gitelson et al. (2006) successfully estimated GPP with chlorophyll indices, such as NDVI, and indicated GPP as a product of total crop chlorophyll content and PAR. Wu et al. (2009) also verified the utility of chlorophyll content related vegetation indices in the estimation of GPP.

The wide acceptance of NDVI, as a proxy for chlorophyll content (e.g. Gutman and Ignatov 1998), and its applicability at both ground and remote levels, make it an attractable option for use in estimating ecosystem productivity. In this study we set out to explore the feasibility of using NDVI alone or NDVI-adjusted

PAR for predicting gross photosynthesis of temperate grassland in Iceland through regular ground level measurements of GPP, PAR and NDVI.

METHODS

Study site

The study site, Mávahlíð, is a three hectare grassland located on the experimental farm Hestur in the Borgarfjörður region, West Iceland. The site was drained in 1977 for the purpose of creating rangeland. The soil is a Histic Andosol, averaging 2.45 m in depth. The dominant plant species are *Deschampsia cespitosa, Eriophorum angustifolium and Festuca rubra*, with a very dense 20-50 cm high canopy at the peak of the growing season. Mean annual rainfall and temperature (1964-94) are 936 mm and 3.3°C. As a part of a larger ongoing study on the greenhouse gas balance of the site, twenty plots were randomly chosen for replicate measurements of NDVI, CO_2 ex-change, soil water table depth and soil temperature at 10 cm. The study was initiated in May 2011 and is still ongoing. Measurements were carried out weekly during the main growing season (June – August) and biweekly and monthly during the rest of the year (September – May). For the purpose of this study we used data from the 2012 measurements season (one complete year).

CO_2 flux

For measurements of CO_2 exchange, we used the static chamber method with a portable photosynthesis system (Li 6200, LiCor, Lincoln, NE, USA) attached to a clear acrylic chamber. The chamber is 35x35x25 cm in size with a volume of 30.6 litres and a fan inside to ensure well-mixed air. At each plot CO_2 concentration in the chamber headspace was recorded every 60 s over a four minute interval. The chamber was subsequently covered and made opaque for measurement of ecosystem respiration using the same method. CO_2 fluxes were calculated from the change in headspace CO_2 concentration. For the entire site the CO_2 flux measurements took approximately 4 hours in the field during midday.

NDVI

The normalized difference vegetation index (NDVI) is based on the difference in the leaf absorbance in the red spectrum due to chlorophyll pigments and the reflectance in the infrared spectrum caused by leaf cellular structure, using the following equation:

$$NDVI=R_{nir}-R_{red}/R_{nir}+R_{red} \quad (1)$$

where R_{nir} and R_{red} are reflectance in the near-infrared and red spectral bands, respectively.

NDVI was measured using a hand held SKR 1800 Two Channel Light Sensor (Skye Instruments, Llandrindod Wells, UK) 2.0 m above ground level with a spectral footprint of 0.62 m^2. The two sensors had the centre wavelengths of 657nm and 840nm and bandwidths of 40nm and 124nm for the red and near-infrared spectral bands, respectively. At each plot at midday (10.00-15.00 LT) NDVI readings were taken of the same spot on the ground. All sky conditions, clear and cloudy, were included in the results. Boardwalks were constructed in order to prevent disturbance of the vegetation and the plots during measurements of CO_2 and NDVI.

PAR and adjusted-PAR

PAR was measured with a point quantum sensor (LI-190, Li-COR Inc., Lincoln, Nebraska, USA) attached to the site's meteorological station, 2.0 m above the ground surface. The station was equipped with a data logger (CR1000, Campbell Scientific, Logan, Utah USA) that collected hourly incoming PAR year around. In addition, PAR was measured synchronously with CO_2 flux measurements, using a quantum sensor attached to the chamber of the portable photosynthesis system. PAR values, recorded at the time of flux measurements, were then adjusted by multiplying them with scaled NDVI values where the annual lowest NDVI value equalled zero and the annual highest value equalled one. Scaling

NDVI was necessary since NDVI is not an incremental number but an index that varies between -1.0 and +1.0.

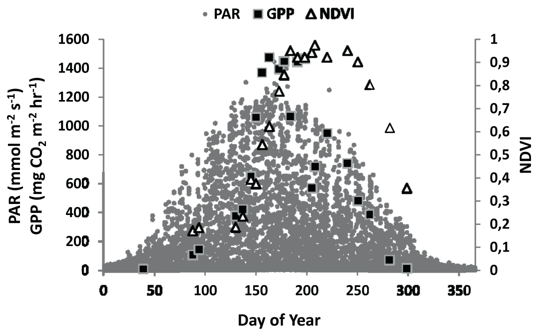

Figure 1. Annual fluctuations in measured PAR (hourly), GPP and NDVI (weekly to biweekly) at the site in 2012.

RESULTS

Hourly PAR values and intermittent measurements of NDVI and GPP for 2012 are shown in Figure 1. PAR was highest in mid-June with a value of 1444.8 mmol m^{-2} s^{-1}, while NDVI was highest in late July - early August. The early season increase in GPP corresponds to an increase in NDVI where as late in the growing season GPP was more sensitive to the availability of light (Figure 1).

In order to evaluate the usefulness of NDVI-adjusted PAR for predicting grassland GPP, correlations were run between measured GPP and measured PAR, measured GPP and measured NDVI, and measured GPP and NDVI-adjusted PAR. The results of these correlations are depicted in Figure 2. NDVI-adjusted PAR proved significantly superior (R^2=0.695, p<0.01) to PAR alone (R^2=0.353, p<0.01) in terms of correlating with measured GPP. Correlation of NDVI and GPP proved worst (R^2=0.2943), p<0.01) and is thus not shown on the graph.

DISCUSSION

Figure 1 clearly highlights the difficulty in using measurements of incoming radiation, such as PAR, as a variable for predicting GPP in terrestrial ecosystem at high latitudes. The early-season discrepancy between available light and plant greening at higher latitudes makes measurements of incoming radiation a poor predictor of GPP, as evidenced by the poor correlation depicted in Figure 2a. Hence, if measurements of PAR are to be used for predicting GPP there is a need for adjusting PAR values in accordance with development of photosynthetic tissue through the use of some indicator of plant green mass. The results shown in Figure 1 clearly indicate that NDVI is a good indicator of early-season plant greening and development and therefore could be useful in adjusting PAR for the purpose of predicting GPP. This is confirmed by the relatively good correlation shown in Figure 2b. Also notable in Figure 1 is that despite relatively high plant green mass, as indicated by NDVI, grassland GPP is reduced with diminishing light in late summer - early autumn.

There are pressing reasons for acquiring good estimates of ecosystem GPP, whether it be for a better understanding of the world's carbon cycle; for deciphering ecosystem response to global warming; or for a better estimation of ecosystem production. Acquiring a good estimate of an ecosystem's annual GPP is, on the other hand, challenging because of large seasonal and diurnal fluctuations. Presently there are methods available for continuous measurements of ecosystem carbon fluxes, such as the eddy covariance method, but these are both costly and time consuming in maintenance and hence limited in their applicability. Interspersed field measurements of GPP, such as the static chamber method, fall short because extrapolating results over the in-between-measurements period is problematic due to the high diurnal and seasonal variation in GPP. What is needed are environmental variables that are useful in predicting GPP for

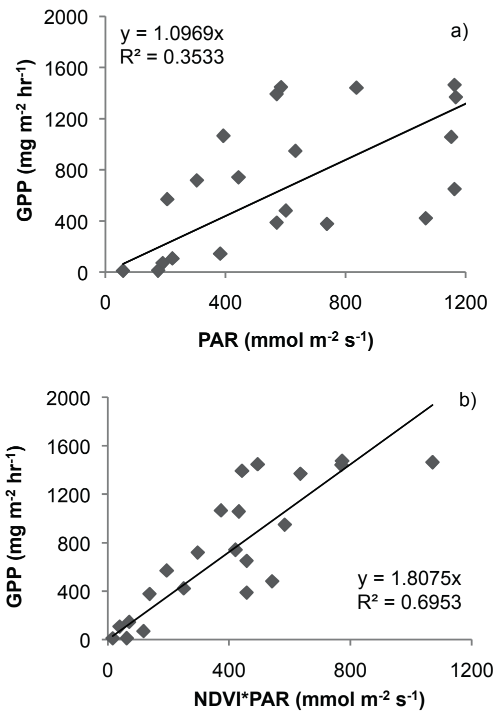

Figure 2. Linear regression between a) measured GPP and PAR, and b) meaured GPP and NDVI-adjusted PAR, in 2012.

intervals between regular field measurements, particularly in areas where applying other methods, such as eddy covariance methods, is difficult or next to impossible. Both PAR and NDVI can be monitored continuously in a reliable and inexpensive fashion and our results indicate that GPP can, in conjunction with regular field measurements, be sufficiently estimated from the product of these two variables. Additionally, since NDVI can be sensed remotely at various scales it holds promise as a tool for extrapolating measured GPP onto a larger scale.

ACKNOWLEDGEMENTS

The authors would like to thank Guðrún Óskarsdóttir and Stefanía L. Bjarnadóttir for assistance with fieldwork. Financial support for this study was provided by ISAL, Iceland.

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Received 8 April 2013
Accepted 11 March 2014