A new approach for estimating northern peatland gross primary productivity using a satellite sensor-derived chlorophyll index.

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Introduction

Long term studies of ecosystem carbon dioxide (CO_2) exchange improve our understanding of the links between carbon and climate. Carbon flux models that are largely driven by remotely sensed data can be used to estimate gross primary productivity (GPP) over large areas, but relatively little attention has been given to determining their utility in peatlands. The Earth observation sensor MODIS is commonly used to provide carbon exchange variables such as gross primary production (GPP). However, with the continuity of MODIS still uncertain, there is the motivation to extend the knowledge acquired from modelling efforts with the MODIS datasets to other sensors data. Sensors, such as MERIS (Medium Resolution Imaging Spectrometer), have the potential to provide additional information about carbon exchange processes by deriving information directly related to vegetation functional properties. The MERIS Terrestrial Chlorophyll Index (MTCI) provides information about vegetation chlorophyll content at 1 km resolution and may prove to be a promising index for assessing peatland fluxes.

Using several years of carbon flux data from two Canadian peatlands, we explore the MTCI-GPP relationship. A series of MTCI-based models are developed and tested to determine whether the inclusion of environmental variables improve upon direct relationships between the MTCI and GPP. We compare our results with those obtained from the MODIS GPP model for comparison purposes.

Study sites

We compare results for two contrasting Fluxnet Canada tower sites; the Mer Bleue peatland (2003 – 2006) and the Western peatland (2004 – 2005).

Figure 1. Location of the peatland study sites

Mer Bleue is a large open low-shrub raised bog with many evergreen species. Overstorey vegetation consist mostly of shrub canopy and the ground cover is dominated by *Sphagnum* mosses. The Western Peatland is a moderately rich treed fen. In contrast to Mer Bleue, the vegetation is largely composed of deciduous species. Stunted trees dominate the vegetation, although shrubs and a wide range of moss species, including *Sphagnum,* are also abundant (Fig.1).

Model development

A series of MTCI-based linear models were developed to explore a new approach of estimating peatland GPP from satellite data. The models were based on the use of the MTCI alone and in combination with a number of environmental/proxy variables, that are thought to have an important influence on plant carbon exchange process:

(i) GPP = a(MTCI) + b
(ii) GPP = a(MTCI x PAR) + b
(iii) GPP = a(MTCI x fPAR) + b
(iv) GPP = a(MTCI x fPAR x PAR) + b
(v) GPP = a(MTCI x LST) + b

Where PAR is photosynthetically active radiation, fPAR is the fraction of absorbed photosynthetically active radiation, LST is MODIS land surface temperature and a and b are the slope and intercept in a linear model ($y = ax + b$)

Inter-annual and seasonal dynamics of peatland ecosystems

Long term data suggest a seasonal trend in both rainfall and temperature at both sites with the summer months often being the warmest and wettest. However, the rainfall pattern at Mer Bleue during 2003 to 2005 was far less pronounced than either the long term average for the site or the rainfall pattern observed at the Western Peatland (Fig. 2b).

The growing season in 2003 at Mer Blue was characterised by very low rainfall, although the fall was unseasonably wet. A similar pattern of above average rainfall was also observed during the fall of 2006.

At both sites, differences in rainfall were mirrored in the water table position and in the inter-annual pattern in GPP, with Mer Bleue showing substantially lower productivity during the 2003 growing season (Fig. 2c & d).

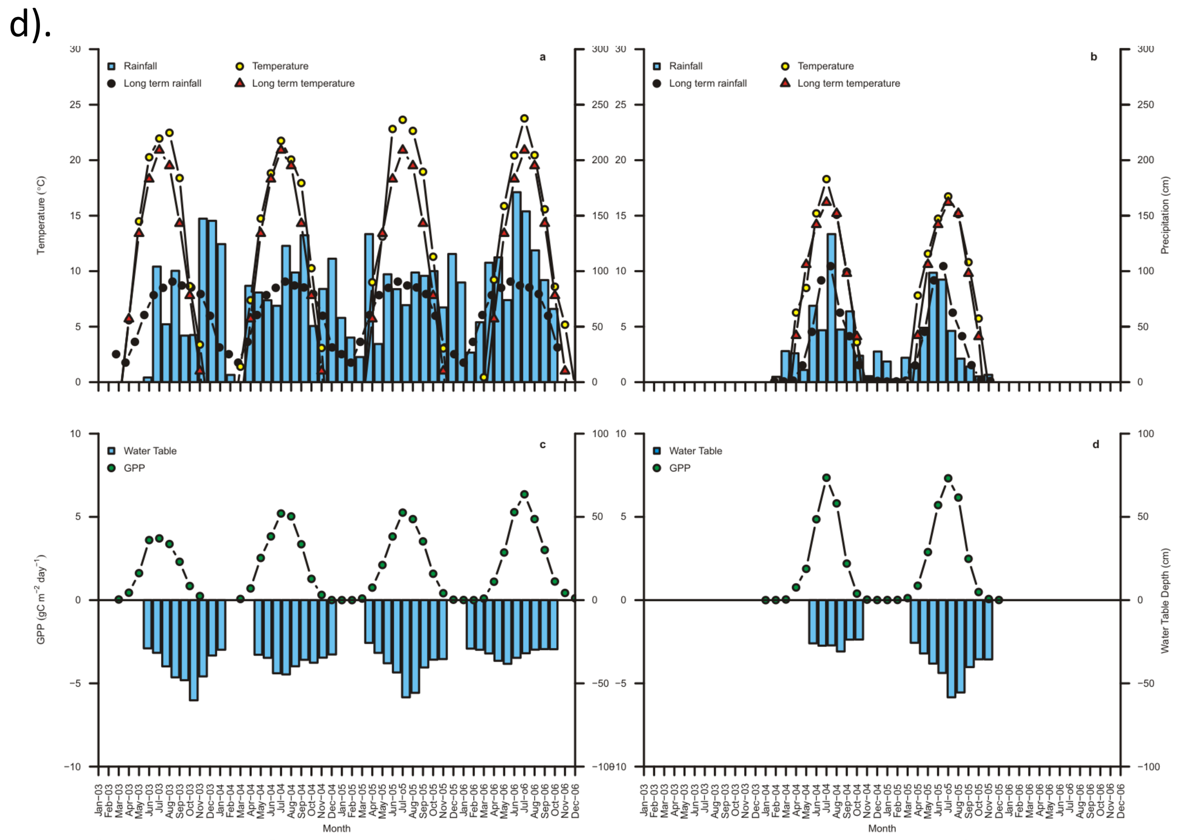

Figure 2. Seasonal monthly pattern of precipitation, temperature, gross primary productivity and water table depth below a hummock surface, during the growing season for Mer Bleue (a and c) and the Western Peatland (b and d).

Environmental controls on peatland GPP and correlations with model variables

Table 1 shows the relationships between individual variables used in model development (i.e. PAR, LST, fPAR and MTCI) and environmental variables thought to exert a controlling influence over peatland GPP (i.e. AT (air temperature) and WT (water table depth)).

LST and fPAR showed most promise as proxy variables of the two major controls on GPP, whereas PAR showed the least promise due to weak and often non significant relationships with both of the major controls of GPP (i.e. AT and WTD) and with GPP itself.

The lack of strong consistent correlations between the MTCI and PAR, LST and fPAR, coupled with the significant correlations observed between a number of these variables and the major controls on GPP, suggest that some of these variables may be able to provide additional independent information to the basic MTCI model.

Table 1. Regression statistics for linear relationships for the MTCI and environmental variables at the Mer Bleue and Western Peatland sites, against, PAR, MODIS LST and MODIS fPAR.*

		GPP ($gC\ m^{-2}\ day^{-1}$)	AT (°C)	WTD (cm)	MTCI
		r^2	r^2	r^2	r^2
Mer Bleue					
PAR	2003	0.26	ns	ns	ns
	2004	ns	0.20	ns	ns
	2005	ns	ns	0.29	ns
	2006	ns	ns	ns	ns
	2003-2006	0.07	0.06	ns	ns
LST	2003	0.77	0.57	ns	0.37
	2004	0.36	0.39	0.20	0.24
	2005	0.52	0.67	ns	0.47
	2006	0.30	0.35	0.22	0.28
	2003-2006	0.35	0.45	0.07	0.31
fPAR	2003	0.60	0.44	0.38	0.48
	2004	0.79	0.52	0.52	0.79
	2005	0.78	0.66	0.50	0.83
	2006	0.86	0.65	ns	0.80
	2003-2006	0.93	0.55	0.33	0.67
Western Peatland					
PAR	2004	ns	0.47	ns	ns
	2005	ns	0.41	0.25	ns
	2004-2005	0.15	0.43	ns	ns
LST	2004	0.29	0.59	0.24	ns
	2005	0.56	0.58	ns	0.32
	2004-2005	0.38	0.57	ns	0.16
fPAR	2004	0.63	0.23	0.21	0.76
	2005	0.67	0.41	0.50	0.55
	2004-2005	0.63	0.39	0.30	0.65

** All values are taken from the growing season defined as when GPP is >0 g C m^{-2} day^{-1} and air temperature is > 5°C; ns = not significant at the P<0.05 level*

Model results

The MTCI was strongly correlated with GPP for both peatland sites, apart from during 2003 at Mer Bleue (Fig. 3a). The addition of LST to the basic MTCI model did not significantly improve model performance as GPP was often more strongly correlated with the MTCI than with LST (Table 1). The exception to this was the year 2003 at Mer Bleue, primarily due to the presence of a stronger correlation between GPP and LST during that time period (Table 1).

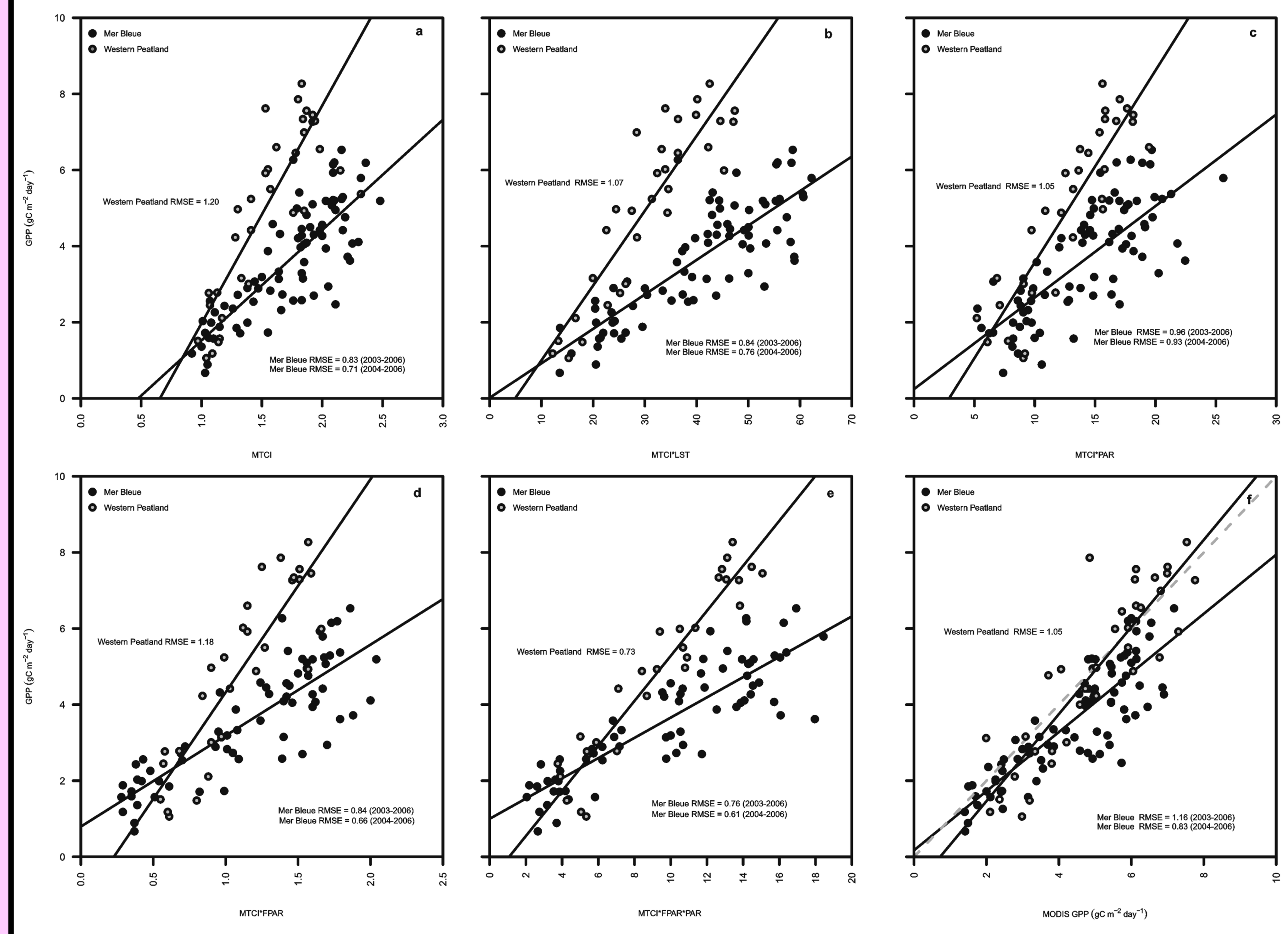

Figure 3. GPP as a function of the a) MTCI, b) product of MTCI and MODIS LST, c) product of MTCI and (PAR); d) product of MTCI MODIS fPAR); e) product of MTCI, MODIS fPAR and PAR; and f) MODIS GPP product

The product of MTCI and PAR was able to explain more variation in GPP than the simple MTCI model for 2003 at Mer Bleue, but the coefficients of determination for the other years tested at each of the peatlands were lower relative to the basic MTCI model because of the lack of significant relationships between GPP and PAR at either site (Table 1; Fig. 3c).

The addition of fPAR to the basic MTCI model resulted in small increases in the level of explained variance in GPP at both sites (Fig. 3d), although the greatest improvements were observed when both fPAR and PAR were incorporated into the initial MTCI model (Table 1 and Fig. 3e). However, improvements over the MTCI alone were relatively small (~4%) at Mer Bleue.

The strength of correlations between GPP and the MODIS GPP product were similar to those reported for a number of the MTCI models tested (Fig. 3f), although the product of MTCI, PAR and fPAR was able to explain more of the variation in GPP at the Western Peatland, than the MODIS GPP product.

The slope of the relationship differed between the two sites but were similar between years within a given site, apart from the slope of the 2003 relationship at Mer Bleue. The slope of the regression line was always greater for the Western Peatland. The MODIS GPP product behaved in a similar manner to the MTCI models, although the difference in the slope between sites was not as pronounced.

Conclusions and further work

Our results show that simple MTCI-based models can be used for estimates of inter- and intra annual variability in peatland GPP. The MTCI compares favourably with more complex products derived from the MODIS sensor on a site specific basis. The incorporation of MTCI into a light use efficiency type model, by means of partitioning the fraction of photosynthetic material within a plant canopy, shows most promise for peatland GPP estimation, outperforming all other models. However, our results also show differences in model relationships with GPP, both between sites and when water availability is reduced. Research in order to predict the variations in the slope of the relationship between MTCI-based models and GPP, and to fully account for the down regulation in carbon uptake under moisture limiting conditions, is ongoing. The current results show great promise and demonstrate that satellite data specifically related to vegetation chlorophyll content may ultimately facilitate quantification of the temporal and spatial dynamics of peatland carbon fluxes.