Using broad-band reflectance indices to estimate carbon dioxide fluxes of a temperate mountain grassland

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BACKGROUND

Remote sensing of radiation reflected from the earth's surface on board of satellites allows monitoring the 'status' of the planet earth with reasonable spatial and temporal coverage. Here we explore the use of vegetation indices (VIs) calculated from reflectance in broad spectral regions for inferring ecosystem carbon dioxide (CO_2) fluxes. To this end we use one year of concurrent measurements of reflectance in the spectral bands of photosynthetically active radiation (PAR) and the near infrared (NIR), as well as the net ecosystem CO_2 exchange (NEE) made above a temperate mountain grassland in Austria.

METHODS

CO_2 fluxes were measured using the eddy covariance method using the same instrumentation as and following the procedures of the EUROFLUX project (Aubinet et al., 2000). Incoming total and diffuse photosynthetically active radiation (PAR) were measured by photodiodes (BF2H, Delta-T Devices Ltd, Cambridge, UK), mounted at 2 m height. Below-canopy, ground level PAR (PAR_{soil}) and reflected PAR (PAR_{refl}) were measured by a line quantum sensor and a single quantum sensor (LQS7010_Sun and QSO_Sun respectively, Apogee Instruments, Logan, USA). The pyranometers of the CNR-1 net radiometer (CNR-1, Kipp & Zonen, Delft, NL) were used for measuring the up- and down-welling global radiation (R_g, 305 to 2800 nm). Near infrared radiation (NIR) was then calculated from R_g by subtracting the PAR.

The VIs used were calculated according to Eq. 1 to Eq. 3. For modelling half hourly NEE, NEE was related to PAR using a rectangular hyperbolic model (Eq. 4).

CONCLUSION

Broad-band NDVI (and SR) correlate well with several metrics characterising the NEE of a temperate mountain grassland ecosystem. Based on these correlations a modified approach for filling gaps in the NEE time series was developed and successfully tested. Given that most of the radiation measurements necessary to calculate these broad-band vegetation indices, probably with the exception of reflected PAR, are made routinely at the majority of the existing flux towers we suggest to test the applicability of this approach at other ecosystems.

$$fPAR = \frac{PAR_{in} - PAR_{refl} - 0.85\,PAR_{soil}}{PAR_{in}} \quad \text{(Eq. 1)}$$

$$SR = \frac{r_{NIR}}{r_{PAR}} \quad \text{(Eq. 2)}$$

Tab. 1 Correlation coefficients of CO_2 flux metrics with midday means of NDVI, SR, fPAR, GAI and environmental parameters. Statistically significant correlations are shown in bold letters; all independent variables have been log-transformed.

	CO_2 flux parameters					
	NEE_{mm}	NEE_{daily}	α	R_{eco}	NEE_{1500}	GPP_{sat}
NDVI	**-0.85 *****	**-0.77 *****	**0.51 ***	**0.54 ***	**-0.91 *****	**0.91 *****
SR	**-0.84 *****	**-0.78 *****	**0.47 ***	**0.50 ***	**-0.89 *****	**0.90 *****
fPAR	**-0.80 *****	**-0.73 *****	**0.62 ****	**0.53 ***	**-0.90 *****	**0.78 *****
GAI	**-0.61 *****	**-0.50 *****	**0.67 ****	**0.74 *****	**-0.85 *****	**0.48 ***
PAR_{in}	-0.14	**-0.19 ***	0.22	**0.59 ****	**-0.57 ****	**0.60 ****
T_{air}	**-0.19 ***	-0.07	**0.51 ***	**0.81 *****	**-0.61 ****	**0.58 ****
T_{soil}	**-0.17 ***	0.01	**0.48 ***	**0.75 *****	**-0.57 ****	**0.53 ***
VPD	-0.13	**-0.18 ***	0.22	**0.56 ****	**-0.49 ***	**0.52 ***

***$p < 0.001$; **$0.001 \le p < 0.01$; *$0.01 \le p < 0.05$

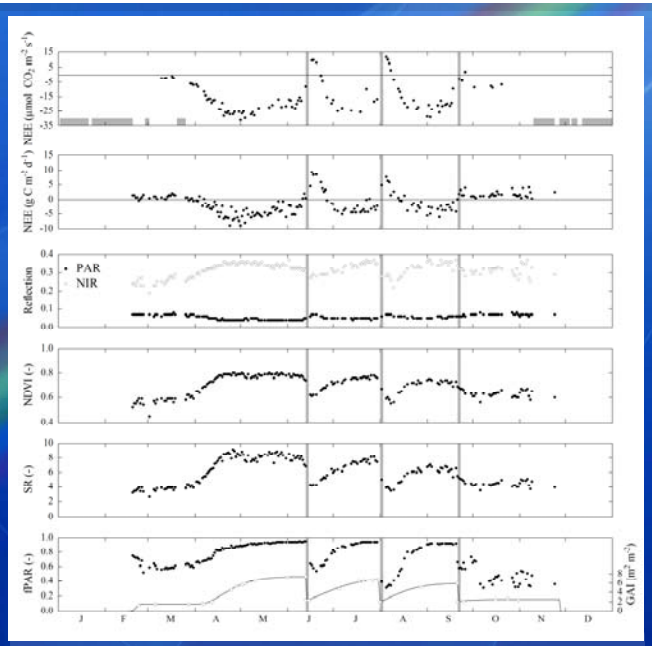

Fig. 1 Seasonal variation of midday means of NEE, daily sums of NEE, reflected PAR and NIR, NDVI, SR, fPAR and measured (symbols) and interpolated (lines) GAI. Vertical grey bars denote cutting events, horizontal ones snow cover duration.

$$NDVI = \frac{r_{NIR} - r_{PAR}}{r_{NIR} + r_{PAR}} \quad \text{(Eq. 3)}$$

$$NEE = \frac{-\alpha * PAR * GPP_{sat}}{\alpha * PAR + GPP_{sat}} + R_{eco} \quad \text{(Eq. 4)}$$

RESULTS

Our data show close relationships between several different metrics of NEE and broad-band VIs (Fig. 1, Tab. 1) derived from measured reflectances. In most cases these broad-band VIs are better predictors of NEE than other widely used metrics such as the fraction of absorbed PAR or the amount of photosynthetically active plant matter (Tab. 1). It is concluded that broad band VIs provide a suitable means to remotely infer the NEE of grassland ecosystems.

Based on the results of the regression analysis (Tab. 1) and the constraint that in order to be routinely applicable any gap-filling algorithm should rely on automatically measured input parameters only, we chose to model GPP_{sat} and α as a function of NDVI, while R_{eco} was simulated based on temperature. Together with half-hourly PAR_{in}, this allowed to replace any missing half-hourly NEE value with an estimate calculated with Eq. 4. Comparing this method with the results of our traditionally gap-filled data (NEE_{trad}; Wohlfahrt et al., 2008) good agreement was achieved (Fig. 2) – on a half-hourly basis the two approaches differed by around 2 % ($y = 0.98\ NEE_{trad} + 0.04$; $R^2 = 0.89$; $p < 0.001$), the annual sums of NEE by 16.4 g C m^{-2} y^{-1} or 17 % (-78.9 and -95.3 g C m^{-2} y^{-1}, respectively).

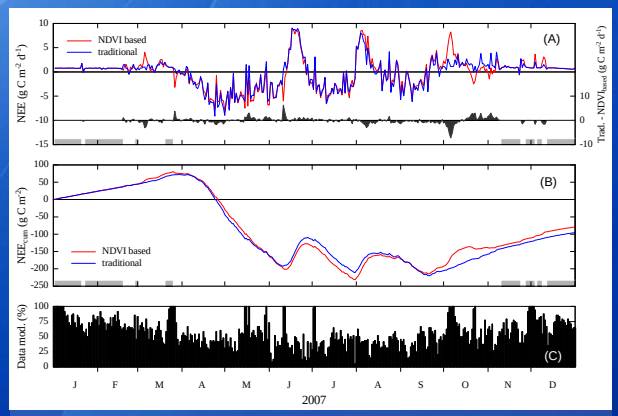

Fig. 2 (A) Comparison of daily NEE gap-filled by the traditional and the NDVI-based approach, as well as the difference between these two methods. (B) The same as (A), but for cumulative NEE. (C) Percentage of gap-filled data per day. Snow cover periods are indicated by grey horizontal bars in (A) and (B).

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