Tradeoffs between warming and day length on the carbon uptake period of temperate mountain grasslands

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BACKGROUND AND HYPOTHESIS

In many mountain ecosystems net carbon dioxide (CO_2) uptake is limited by the presence of a seasonal snow cover. Projected global warming, provided that melt and establishment of the winter snow cover occur earlier and later in the season, respectively, may thus be hypothesised to cause a shortening of the snow cover period and a larger net CO_2 uptake during the longer vegetation period. Earlier melt and later establishment of the seasonal snow cover, however, will occur at shorter day lengths, reducing the time of the day during which the presence of sunlight allows plants to assimilate CO_2 (Fig. 1). The extent to which this effect negates the hypothesised warming-induced lengthening of the carbon uptake period (CUP) has received little attention to date.

We investigated the beginning and end of the CUP at three mountain grassland sites in the Austrian and Italian Alps along a gradient in elevation and thus temperature and the length of the snow cover period. We hypothesise that the warming-induced lengthening of the vegetation period will be compensated most at the lowest elevation (970 m) site, where snow melt occurs close to the spring equinox when day length changes fastest (Fig. 1). In contrast, snow melt at the site with the highest elevation (2160 m) occurs closer to the summer solstice, when daily changes in day length are minimal, and we thus hypothesise that compensating effects due to day length will be smallest there (Fig. 1).

STUDY SITES AND METHODS

Three study sites in the Austrian and Italian Alps along a gradient in elevation were chosen: Neustift (970 m, 47° 07', 11° 19'), Monte Bondone (1550 m, 46° 01', 11° 02') and Torgnon (2160 m, 45° 50', 7° 34'). The three sites are situated also along a gradient in mangement - Neustift is harvested three times per year, Monte Bondone once and Torgnon is unmanaged.

At all three sites the net ecosystem CO_2 exchange (NEE) was measured by means of the eddy covariance method along with measurements of environmental drivers such as air temperature, solar radiation and snow presence.

The daily average NEE was simulated based on a phenomenological model, which takes day length (t_d) into account through the following simple relationship:

$$\overline{NEE} = \frac{\overline{NEE}_d t_d + \overline{NEE}_n (24 - t_d)}{24} \qquad \text{Eq. (1)}$$

where the subscripts d and n refer to day and night, respectively. The NEE during the day depends on the opposing influence of gross photosynthesis and ecosystem respiration, while during the night ecosystem respiration prevails. Gross photosynthesis is simulated based on absorbed photosynthetically active radiation, while ecosystem respiration is simulated to increase exponentially with temperature. Incident photosynthetically radiation is calculated from clear-sky incident global radiation and a site-specific parameterisation of atmospheric transmissivity. Phenological effects on gross photosynthesis and ecosystem respiration are taken into account through a thermal sum parameter. The winter snow cover is simulated to establish at the first precipitation event with sub-zero temperatures, while snow melt is simulated to occur after a site-specific thermal sum has accumulated.

The model is validated against measured daytime and nighttime NEE. Warming was simulated with climatological time series of air temperature by uniformly increasing air temperature between 0 and 3 K.

FUNDING

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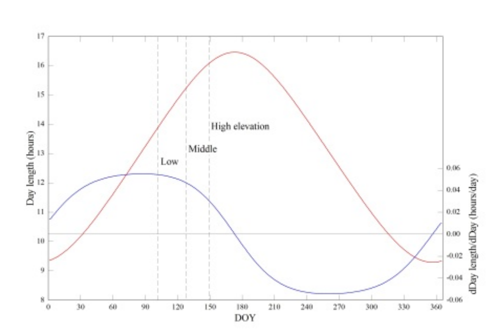

Figure 1 Seasonal course of day length (red line) and its first derivative (blue line). Vertical dashed lines indicate date of the beginning of the CUP at the low (Neustift), middle (Monte Bondone) and high (Torgnon) elevation study site.

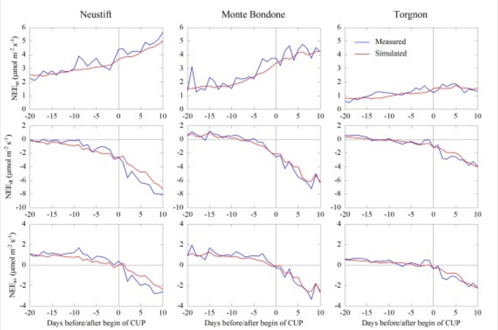

Figure 3 Measured and simulated nighttime (upper panels), daytime (middle panels) and daily average (lower panels) net ecosystem CO_2 exchange (NEE) at the three study sites.

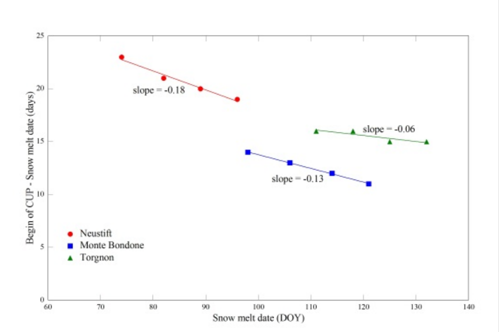

Figure 4 Time after snow melt required for the ecosystem to become a net carbon sink. Data points refer to simulations with the model for present day conditions (rightmost data point in each series) and +1, +2 and +3K warming.

RESULTS

The start of the CUP nicely followed the elevational gradient with Neustift, Monte Bondone and Torgnon becoming carbon sinks between DOY 93-114, 109-140 and 123-164, respectively (Fig. 2). The end date of the CUP did not follow the elevational gradient in temperature, but was triggered by the third and final harvest at Neustift (DOY 265-293) and occurred between DOY 265-295 and 275-294 at Monte Bondone and Torgnon, respectively (Fig. 2). On average, the model was well able to simulate both daytime and nighttime NEE and thus predicted the start of the CUP reasonably well (Fig. 3). Simulating the end of the CUP in autumn proved more difficult – the corresponding work is in progress and thus no data are shown here.

A 10 day earlier start of the CUP went along with a 32, 27 and 20 min reduction in day length at Neustift, Monte Bondone and Torgnon, respectively (Fig. 1). Simulated warming (up to +3K) caused both snow melt and the start of the CUP to occur earlier. The earlier start of the CUP, however, did not match the earlier snow melt due to concurrent reductions in day length and so the time period in between increased with warming (Fig. 4). As hypothesised this increase scaled with elevation and the timing of snow melt. A 10 day earlier snow melt caused the time period until the start of the CUP to increase by 1.8, 1.3 and 0.6 days at Neustift, Monte Bondone and Torgnon, respectively.

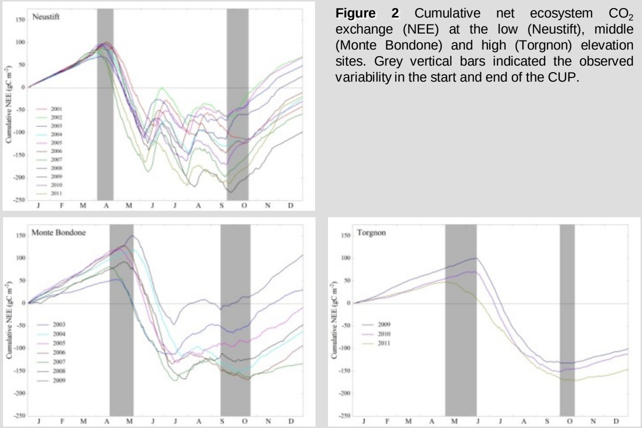

Figure 2 Cumulative net ecosystem CO_2 exchange (NEE) at the low (Neustift), middle (Monte Bondone) and high (Torgnon) elevation sites. Grey vertical bars indicated the observed variability in the start and end of the CUP.

CONCLUSIONS

As hypothesised, warming-induced earlier snow melts do not translate one-to-one to earlier starts of the CUP due to concurrent reductions in day length. The magnitude of this effect depends on the time of year when snow melt occurs. For the investigated grasslands along the elevational gradient, snow melt occurred the latest at highest elevation (Torgnon) and the start of the CUP at this site was thus most responsive to warming.

Simulating the end of the CUP in autumn is more complicated and requires further work. As seen for Neustift, where the end of the CUP is dictated by the timing of the third and final harvest, analysing the response of intensively managed grasslands to warming may require considering adaptive management scenarios.

The investigated mechanism is universal and should apply in situations where differences in the vegetation period occur at similar geographic latitude.