British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Spatial scaling of CO_2 efflux in a temperate grazed grassland

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Introduction

Understanding CO_2 efflux from soil at different scales is important when up-scaling CO_2 measurements from plot to larger scales, but there have been few studies investigating spatial CO_2 efflux in temperate environments.
We conducted a nested analysis of variation to explore how the CO_2 efflux variation occurs between different spatial scales. We also invested the temporal variation of CO_2 efflux, including soil moisture and CO_2 efflux relationships across different soil types.

Experimental Area

The experimental area is in the Hollin Hill Landslide Observatory in Yorkshire, United Kingdom. The area has slow moving landslides particularly on steep slopes because mudstone deposits (the Whitby Mudstone) slide over the lower sandstone (the Straithes Sandstone and Cleveland Ironstone) formation. The two formations are characterized by clay at the top of the slope and sand at the bottom of the slope. In the southeast of the area sandy clays are present.
The area is grazed by sheep and has a mixed sward of *Lolium perenne*, *Holcus lanatus* and *Poa* species.

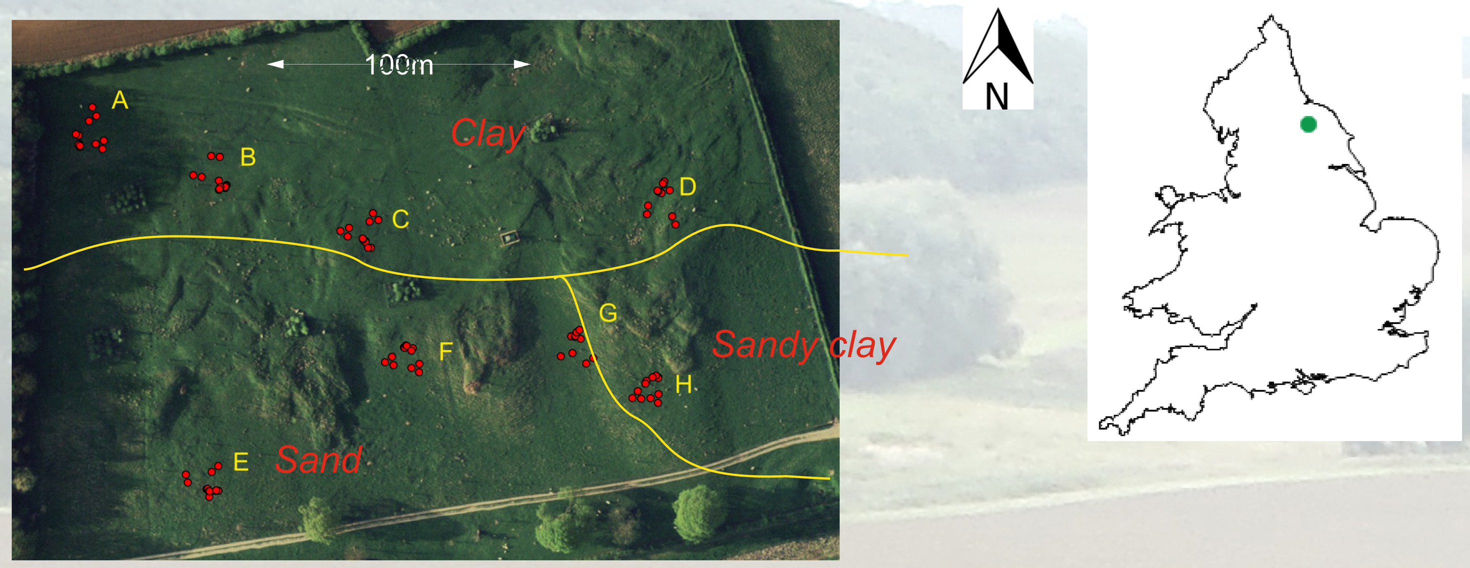

Figure 1) Aerial photo of the experimental area located in the Yorkshire Dales, England (shown as a green circle).

Methodology

The nested sampling scheme was optimized over a space of possible designs for a fixed sample size (12 points) at four levels (0.3m, 1.0m, 3.0m and 9.0m) following the optimization sampling scheme described by Lark 2010. The layout of nodes are shown in Figure 2. At each point (96 in total) a soil moisture sensor (5TE, DECAGON Devices, USA) was installed at 10 cm depth to log every 15 minutes. Above each soil water sensor, a portable closed chamber system (West Systems Srl, Italy) was used to take CO_2 flux measurements during three to four hour surveys during a dry summer and wet winter period. In addition, three automatic closed dynamic systems (Li-Cor Li-800, USA), were spaced 1 m apart and took CO_2 efflux measurements ever hour.

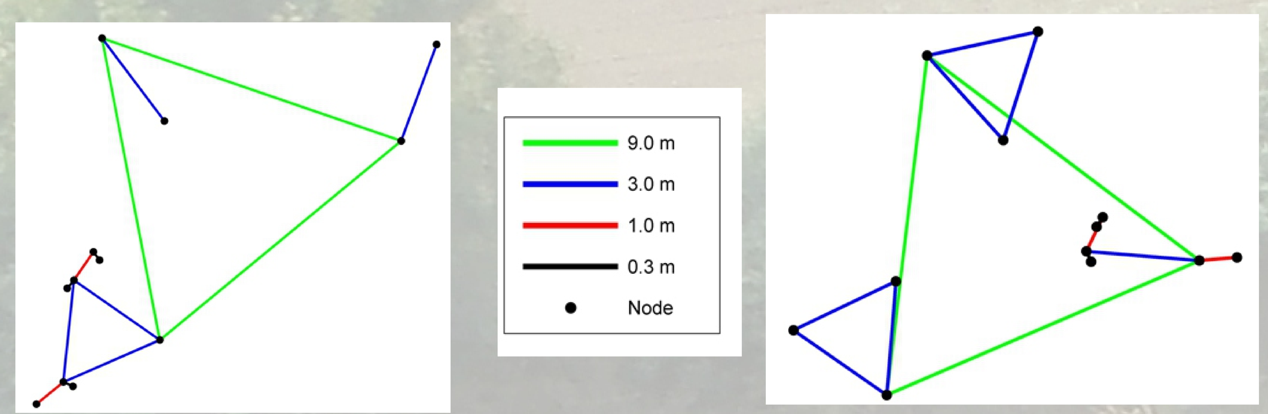

Figure 2) Layout of the optimized nested design showing how the different lag distances are arranged from a central 9m equilateral triangle

Soil moisture was also measured from the soil surface to 0.07 m (Figure 4) after each portable CO_2 measurement using a hand-held capacitance probe (ML3 ThetaProbe, Delta-T, Cambridge, UK). At the same time the permanently installed soil moisture sensor (Figure 3) recorded soil mositure at 0.1 m depth while portable CO_2 measurements were taken.

Figure 3) Installation of soil moisture sensors at 0.1 m depth at each node point.

Figure 4) Portable soil moisture measurement using a hand-held capacitance probe.

Results

Month	Spatial scales >9m	9m	3m	1m	0.3m
Aug. 2013	0.18	0	0.14	0	0.71
Sept. 2013	0.06	0	0	0	0.94
Oct. 2013	0	0	0	0.73	0.35
Feb. 2014	0.05	0	0.05	0	0.9
April 2014	0.12	0	0	0	0.89

Table 1) Spatial partitioning of CO_2 efflux variance after normal scores transform

The CO_2 efflux data were transformed to a normal distribution with the variance across all the scales being equivalent to 1. The variances were then partitioned across the different scales.
The values in red show significant variation within the spatial scale. The vast majority of the variation in CO_2 flux occurred over the smallest scale (shown in Table 1).
A previous study showed that the variation of soil moisture is divided relatively equally between the four spatial scales and the proportion of large-scale (>9m) variation increased after rainfall.

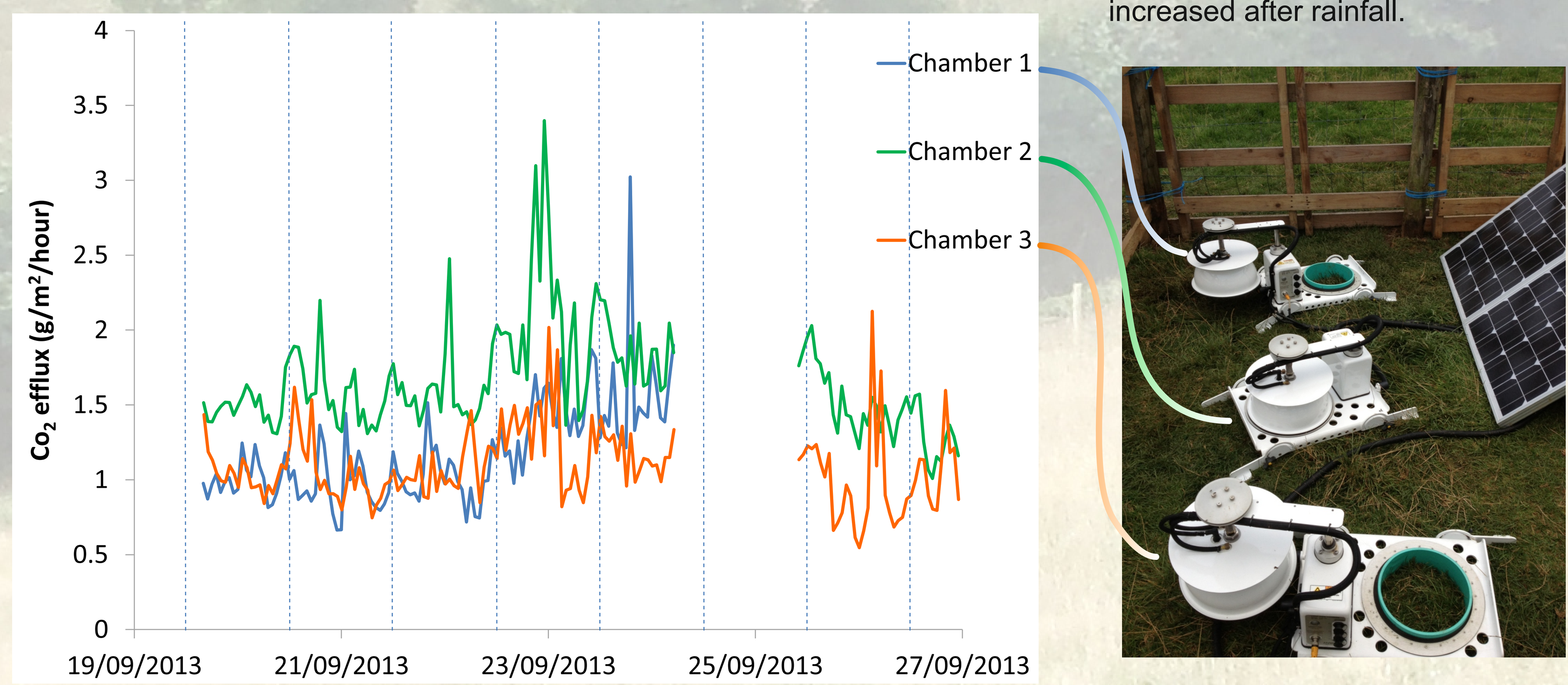

Figure 5) Temporal variability of CO_2 efflux measured by three automatic closed dynamic systems for a week during September after a relatively dry summer. The blue vertical dotted lines indicate midday.

Highest temporal variability occurred early to late evening. The temporal variability of CO_2 efflux within an hour was considered to be relatively low during the day.

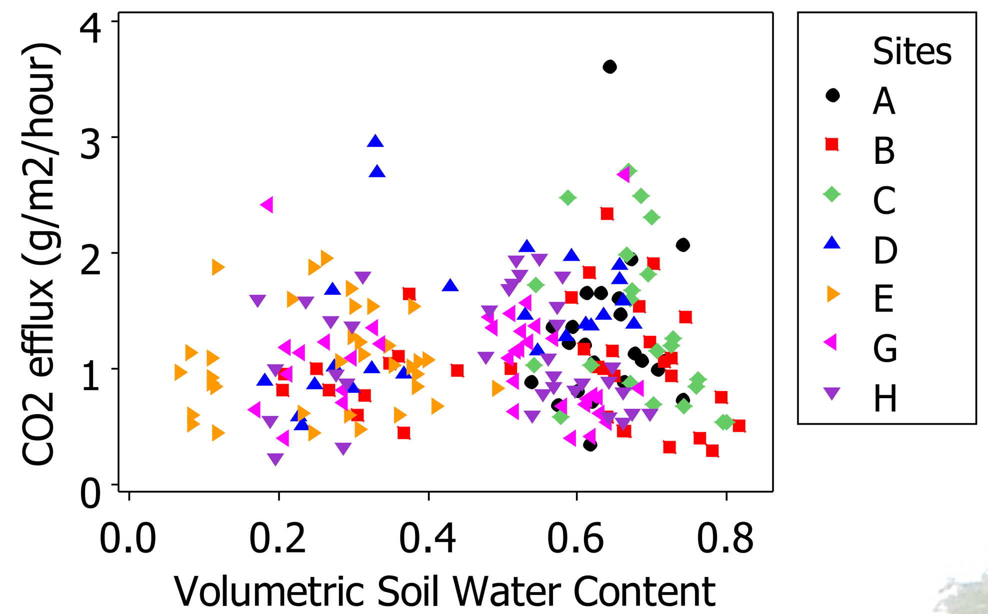

Figure 6) CO_2 efflux measured by a portable closed chamber system and soil water content measured by a hand-held soil moisture probe (averaged for 0 to 0.07 m depth) during a dry period October 2013 and wetter periods February and April 2014. The legend relates to the site groups located in Figure 1.

There is a clear distinction between the sandy soil (site E) which remains relatively dry even during wet conditions. At extreme wet and dry soil moisture conditions CO_2 efflux is low. Higher CO_2 efflux tends to occur between 0.35 to 0.65 soil water fractions.

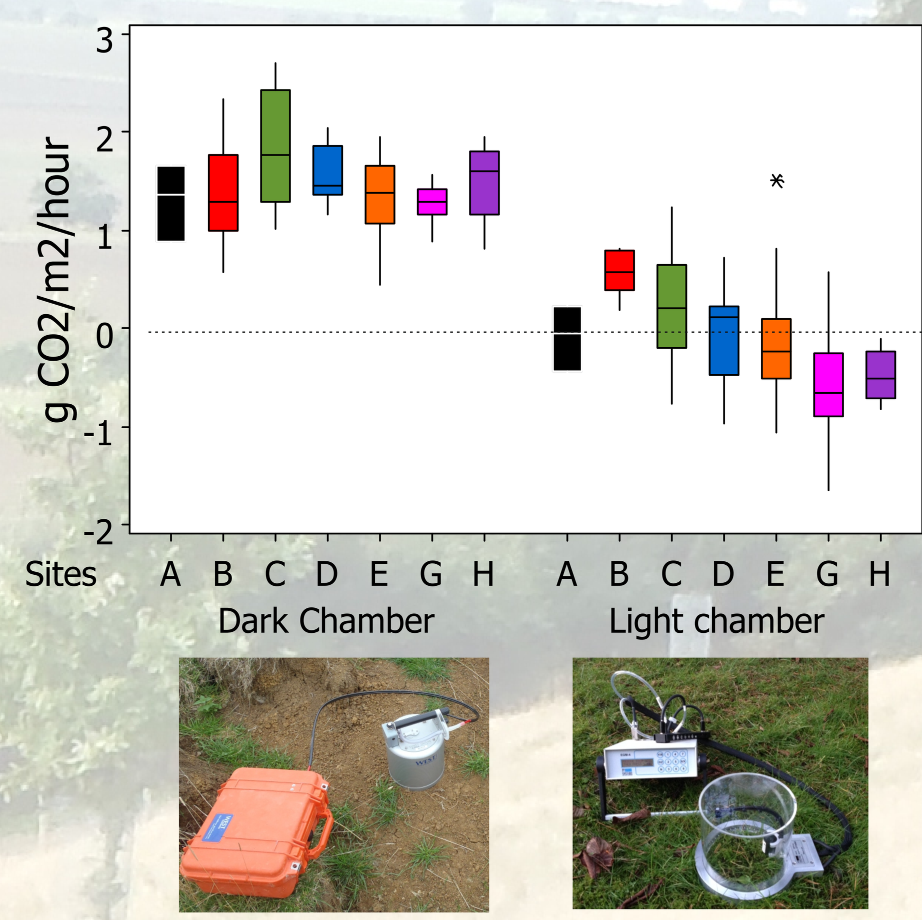

Figure 7) CO_2 efflux measured with portable closed chamber systems measured during April 2014. The light chamber measures CO_2 efflux during photosynthesis and the dark chamber measures only soil respiration. The site groups A to H are located in Figure 1.

During April 2014 after a relatively wet winter, the lower part of the hillslope, which is mainly sandy soils was a net sink to CO_2 during the day. The upper slope in particular B and C produced low levels of CO_2, even during the daytime, this may have been due to lower light conditions. There are no significant differences in soil respiration between the sites.

Conclusions

1) Soil CO_2 efflux has high spatial variation at small scales. Although there was relatively little hourly variation of CO_2 efflux, the temporal variability of CO_2 efflux from morning to afternoon was larger. This causes difficultly to compare spatial variability between the sites as they are measured over a three to four hour period. Factors which affect CO_2, such as changes in temperature and atmospheric pressure are constantly changing and such factors ("nosie") have to be taken into account when investigating spatial variability of CO_2.

2) There is no significant correlation between CO_2 efflux and Soil moisture over all sites, however there is decreased CO_2 efflux when soil are dry (<0.15 volumetric fraction) or highly saturated (>0.70 volumetric fraction).

3) The grazed temperate grassland in April was found not to assimilate all the CO_2 respired from the soil, even during sunny days. However, this is preliminary data and more field work is being done.

4) More investigation is needed and work is continuing to investigate the complexities of spatial and temporal variability in the Hollin Hill Observatory.

References
Lark R.M. 2011. Spatially nested sampling schemes for spatial variance components: Scope for their optimization. *Computers & Geosciences*, 37, 1633 -1641.

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