FROM MICROHABITAT TO ECOSYSTEM: ANALYSING THE SPATIO-TEMPORAL VARIABILITY OF SOIL CO_2 IN A KARST SHRUBLAND

European Geosciences Union General Assembly 2018

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HIGHLIGHTS

- ❑ Explored the variation of soil CO_2 in relation to its biophysical drivers.
- ❑ Used a top-down statistical analysis and a wavelet time-frequency decomposition.
- ❑ Identified poorly regarded drivers of soil CO_2 dynamics: microhabitat and wind.
- ❑ Provided new insight into soil CO_2 production and transport, and improves CO_2 emission modelling.

INTRODUCTION

Motivation

The soil CO_2 efflux (F_s) remains the least constrained component of the terrestrial carbon cycle; its estimates are still largely uncertain, mainly because of its considerable variation related to the many controlling factors that interact over different temporal and spatial scales.

Aims

- ❑ To identify the biophysical drivers of the soil CO_2 molar fraction (χ_s) and characterize their time-frequency patterns in a karst shrubland.
- ❑ To explore χ_s spatial variation with soil cover type (microhabitat).
- ❑ To estimate soil CO_2 efflux (F_s) at the ecosystem scale.

MATERIAL & METHODS

Environmental measurements

Continuous measurements during *ca.* one year:

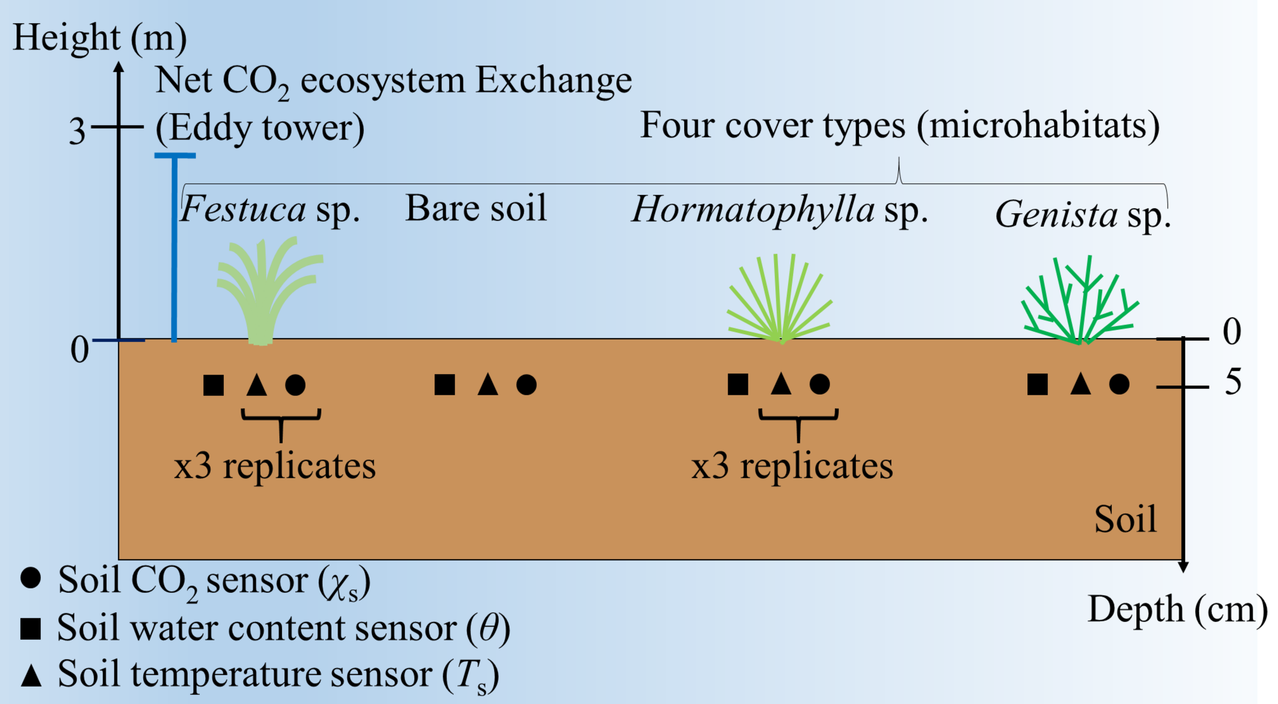

Figure 1 Experimental design.

Calculation of soil CO_2 effluxes

By applying Fick´s first law:

$$F_s = -\rho_a k_s \frac{d\chi_c}{dz}$$

Soil CO_2 efflux (F_s); Increment in CO_2 molar fraction between atmosphere and soil ($d\chi_c$); Air molar density (ρ_a); Empirical soil CO_2 transfer coefficient (k_s); Soil CO_2 sensor depth (dz).

Data analysis

- ❑ A top-down statistical protocol was used to model χ_s with environmental variables.
- ❑ A wavelet analysis was performed on main variables retained by the model.
- ❑ F_s was upscaled to the ecosystem scale by considering the fractional cover of each microhabitat.

RESULTS

Explanatory model of soil CO_2 dynamics

The χ_s dynamics was affected differently by some variables depending on seasons and microhabitats.

Table 1 Summary of fixed effects of explanatory model of soil CO_2 molar fraction

Model fixed effect	Compared factor level	β	SE	φ
Intercept		**1731.3**	1.65	1731.3
MICROHABITAT	Bare soil	0.19	3.26	1731.49
	Genista sp.	0.73	3.26	1732.03
	Hormatophylla sp.	–1.37	2.3	1729.93
SEASON	Growing	–0.09	0.36	1731.21
	Dry	0.34	0.6	1731.64
T_s^2		**2.02**	0.22	2.02
T_s		**8.67**	0.45	8.67
T_s ● SEASON	Growing	**–5.38**	0.56	3.29
	Dry	**–11.08**	1.18	–2.41
T_s ● MICROHABITAT	Bare soil	**1.48**	0.32	10.15
	Genista sp.	0.39	0.3	9.06
	Hormatophylla sp.	–0.14	0.21	8.53
θ^2		**–1.25**	0.06	–1.25
θ		**4.05**	0.3	4.05
θ ● SEASON	Growing	**1.36**	0.35	5.41
	Dry	**2.75**	0.37	6.8
θ ● MICROHABITAT	Bare soil	**2.85**	0.32	6.9
	Genista sp.	–0.15	0.28	3.9
	Hormatophylla sp.	**–0.86**	0.19	3.19
T_s ● θ		**–0.78**	0.27	–0.78
T_s ● θ ● SEASON	Growing	**6.36**	0.44	5.58
	Dry	0.92	0.65	0.14
u_*		**-0.57**	0.05	-0.57
u_* ● MICROHABITAT	Bare soil	**-0.29**	0.1	-0.86
	Genista sp.	-0.04	0.1	-0.61
	Hormatophylla sp.	**0.4**	0.07	-0.17
VPD		**-0.42**	0.07	-0.42

Bold numbers, *P*-value < 0.01; θ, soil water content; T_s, soil temperature; u_*, friction velocity; VPD, vapour pressure deficit; β, regression coefficient; SE, standard error of β; φ, the absolute fixed effect. The model takes *Festuca* sp. and inter-season as baselines.

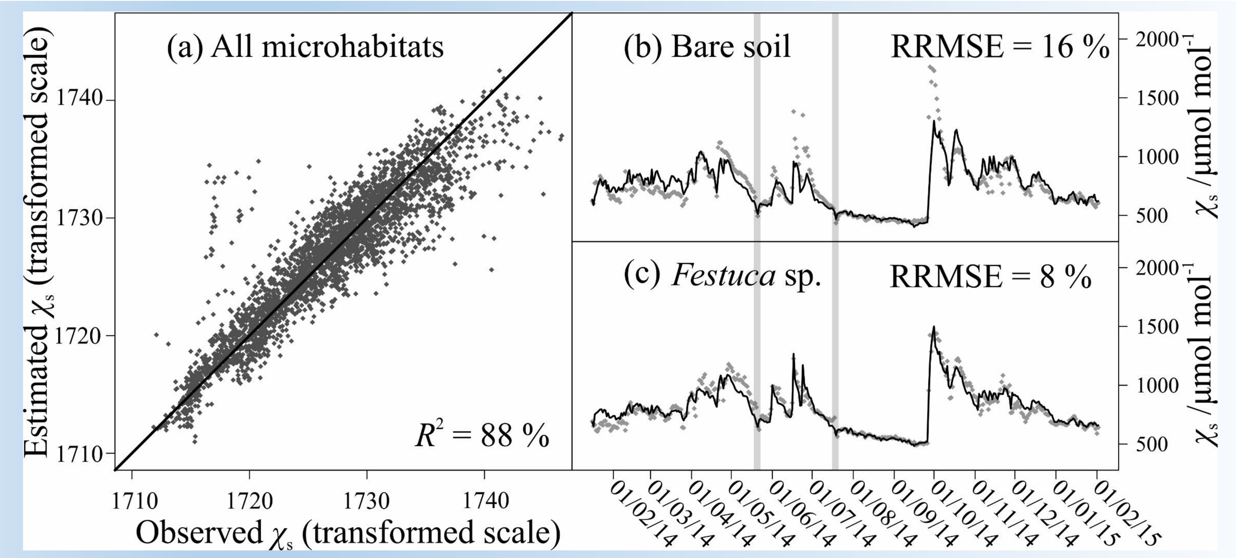

Figure 2 Values of fitted model (a) plotted against observations, (b and c) over time. Shaded areas delimit clearly identified ventilation events.

Refitting the same model after removing terms involving SEASON showed that on an annual scale, soil water content (ϑ) had a predominant effect on χ_s (φ = 6.28) compared to T_s (φ = 4.22) and that their interaction was substantial (φ = 1.99).

Time-frequency patterns of soil CO_2

- ❑ Strong influence of seasonal rainfalls on χ_{s^*}.
- ❑ Pronounced correlation between χ_s and T_s on hourly to daily periodicities and temporarily on larger periodicities, generally after rain.
- ❑ Dominant correlation between χ_s and u_* on the scale of synoptic cycles.

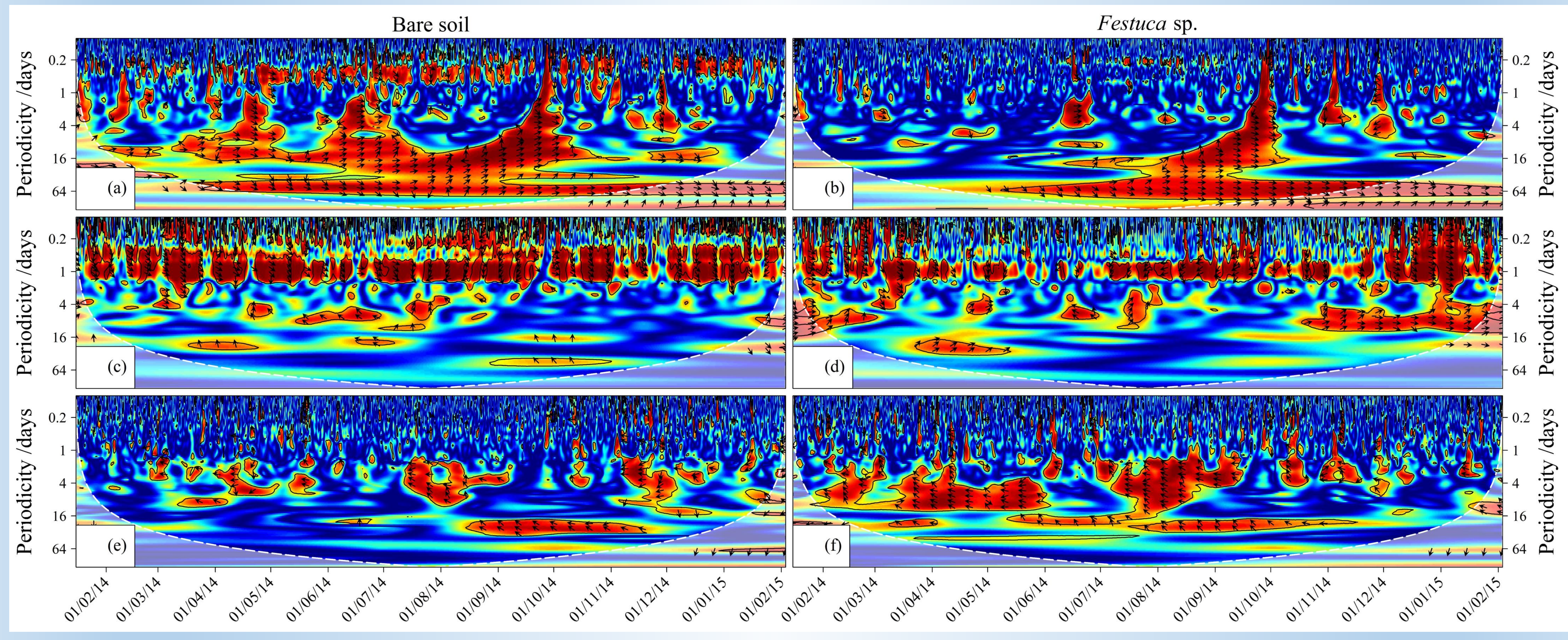

Figure 3 Wavelet coherence analysis spectra between soil CO_2 molar fraction (χ_s) and its main drivers for bare soil and a plant of *Festuca* sp. (a and b) Soil water content (ϑ). (c and d) Soil temperature (T_s). (e and f) Friction velocity (u_*). The correlation intensity varies from blue (low) to red (high).

Upscaling of F_s from microhabitat to ecosystem

In one year:

- ❑ Ecosystem-F_s was estimated to be equal to 175 ± 13 g C m $^{-2}$ whereas ecosystem respiration (R_{eco}) was estimated to be equal to 155 ± 8 g C m $^{-2}$.
- ❑ Fluxes diverged during progressive soil drying.

CONCLUSIONS

- ❑ Soil water content (ϑ) was the main driver of χ_s. Soil temperature (T_s) became the first limiting factor of χ_s only during the inter-season, but the effect of ϑ was still substantial.
- ❑ The strong interaction between T_s and ϑ confirmed that models based on temperature alone are inappropriate in water-limited ecosystems. In particular, dry and hot intervals greatly enhanced the pulsed response of χ_s to precipitation (Birch effect).
- ❑ Friction velocity was also identified as a significant predictor of χ_s dynamics.
- ❑ The microhabitat and season modulated the response of χ_s to the main identified drivers.

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Lopez, C. J. R., Sánchez-cañete, E. P., Serrano-Ortiz, P., López-Ballesteros, A., Domingo, F., Kowalski, A. S., & Oyonarte, C. From microhabitat to ecosystem: identifying the biophysical controlling factors of soil CO_2 dynamics in a karst shrubland. Accepted for publication in *European journal of soil science*.

ACKNOWLEDGEMENTS

These data were funded by the Spanish Ministry of Economy and Competitiveness projects SOILPROF [CGL2011-15276-E] and GEISpain [CGL2014-52838-C2-1-R] and the European Commission project DIESEL (PEOPLE-2013-IOF-625988). We acknowledge the DINCOS project (Biocrust Dynamics, key CGL2016-78075-P) funded by the Spanish State Plan for Scientific and Technical Research and Innovation 2013-2016, which funds the first author.