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Soil temperature synchronisation improves representation of diel variability of ecosystem respiration in *Sphagnum* peatlands

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ABSTRACT

The temperature dependence of Ecosystem Respiration (ER) is often assessed based on the temperature of one specific layer. Air temperature or temperatures in the first ten centimetres of the soil profile are the most frequently used temperatures in models. However, previous studies showed that the relationship between ER and temperature is depth dependent, making depth selection for temperature measurements an important issue, especially at short time-scales. The present study explores one possible way to assess this relationship by synchronising the ER and temperature signals and to test if the relationship between ER and temperature differs between daytime and nighttime. To do so, ER measurements were undertaken in 2013 in four *Sphagnum*-peatlands across France using the closed chamber method. The ER fluxes were measured hourly during 72 h in each of four replicates in each site. Synchronisations between ER and T signal were determined for each depth (from surface to 30 cm depth) by selecting the time-delay leading to the best correlation between ER and soil temperatures and ER was then modelled. Our results showed that: (i) the delay between ER and soil temperature is greater in peat than in mineral soils; (ii) at a daily time-scale synchronisation can improve the model representation using soil temperatures.

1. Introduction

At a global scale, Ecosystem Respiration (ER) and photosynthesis are the largest carbon (C) fluxes between the atmosphere and the biosphere, accounting for 98 and 123 PgC yr^{-1}, respectively (Bond-Lamberty and Thomson, 2010; Beer et al., 2010). By contrast the fossil fuel and cement production flux is one order of magnitude lower, at 7.8 PgC yr^{-1} (Ciais et al., 2014). Consequently, even small variations in the ecosystem fluxes may result in substantial changes in net C storage dynamics. This can have a significant effect on the global C budget, in particular on the atmospheric C concentration. The C stock in natural ecosystems is divided into two pools: vegetation, which contains 450–650 PgC, and the soil which contains 1500–2400 PgC (Ciais et al., 2014; Carvalhais et al., 2014). Across the world, the soil organic C (SOC) pool is spatially heterogeneous in terms of source and physical conditions, leading to variable storage rates between ecosystem types. Peatlands are efficient C storage ecosystems. They cover only 3% of the global terrestrial area, but contain from 270 to 455 PgC as SOC, i.e. from 10 to 30% of the world's soil C (Gorham, 1991; Turunen et al., 2002; Limpens et al., 2008). Thus, peatlands are considered as a hot spots for SOC storage, and their evolution under current environmental changes deserves attention.

As in many other terrestrial ecosystems, many factors affect ER variability in peatlands: temperature, soil water content, vegetation, and substrate supply (Luo and Zhou, 2006). All these factors are thought to be affected by global change, with unknown consequences on the C balance (Limpens et al., 2008). More specifically the temperature affect ER directly (biochemical reaction rates are related to temperature) and indirectly (vegetation, and particularly root growth, transport rates) (Luo and Zhou, 2006) and is thus largely utilized to model ER. Different temperature may be used: either air (e.g., Bortoluzzi et al., 2006), or soil temperature. The most commonly used soil temperatures are those at −5 cm (Ballantyne

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et al., 2014; Görres et al., 2014) and −10 cm (Kim and Verma, 1992; Zhu et al., 2015). In some studies, different depths are used and the selected one depends on the goodness-of-fit (Günther et al., 2014; Zhu et al., 2015). All these studies use the chamber method to measure gas fluxes and even though most studies use −5 cm soil temperature, no clear consensus exists.

The relationship between ER and temperature is often described using the Q_{10} indicator, which represents the proportional increase of a reaction rate due to a 10 °C rise in temperature. However, even if the Q_{10} seems coherent at a global scale (Mahecha et al., 2010), reported values show a significant variability at the ecosystem level (Graf et al., 2008). Because the calculated Q_{10} are not linked to a single reaction but to multiple processes, numerous issues arise (Davidson et al., 2006). Among them are the time-scale considered (Curiel Yuste et al., 2004), the depth (Graf et al., 2008) and the time-delays between ER and soil temperatures (Phillips et al., 2011).

More specifically Pavelka et al. (2007) and Graf et al. (2008) showed that the relationship between ER and temperature is depth dependent since heat transfer in the soil profile is not instantaneous and leads to a time-delay between the temperature and the ER signals. One way to deal with the time-delays might be to synchronise ER fluxes and temperature measurements according to Pavelka et al. (2007). Another issue is the difference between the daytime and nighttime ER relationship with temperature. Juszczak et al. (2012), for example, showed that there are significant differences between ER modelled with daytime and nighttime data. Assessing these differences may be important when working at a daily timescale and when treating data from eddy-covariance measurements.

Based on these previous studies, we expected that time-delays in *Sphagnum*-dominated peatlands would be significant, even in the first 10 cm depth and that they would lead to a better description of observed data once taken into account, especially through data synchronisation. To our knowledge no studies have explored the time-delay between ER and soil temperature in peatlands yet. To test these predictions, ER fluxes, during the growing season in 4 *Sphagnum*-dominated peatlands were measured in 2013. Continuous measurements over 72 h were carried out in each site using static dark chambers. Air and soil temperature were also monitored. Specifically, the relationship between ER and temperature, measured at different depths in peat was studied.

The aim of this study was (i) to highlight any time-delay at the daily timescale between ER and soil temperature at different depths in peatlands (ii) to assess the effect of synchronisation between ER and temperature in the model representation of the diel ER variations.

2. Material and methods

2.1. Study sites

The study was performed on four French *Sphagnum*-dominated peatlands: Bernadouze (BDZ, Ariège; 3.75 ha, N 42°4809, E 1°2524, 1400 m), Frasne (FRN, Doubs; 98 ha, N 46°4935, E 6°1020, 836 m), Landemarais (LDM, Ille-et-vilaine; 23 ha, N 48°2630, E 1°1054, 154 m), and La Guette (LGT, Cher; 26 ha, N 47°1944, E 2°1704, 145 m). Mean annual air temperatures and annual rainfalls were 6, 7.5, 11, 11 °C, and 1700, 1400, 870, 880 mm for BDZ, FRN, LDM and LGT respectively. During the measurements the water Table level remained constant at to −12, −7, −35 and −9 cm for BDZ, FRN, LDM and LGT.

2.2. Data acquisition

Fieldwork was conducted between July and October 2013. Four plots (replicates) with similar plant cover, were chosen at each site. For the most part the plant covers consist of *Sphagnum* spp. Four cylindrical PVC collars (diameter: 31 cm, height: 15 cm) were inserted into the peat the day before beginning the measurements. CO_2 fluxes were measured in the 4 plots once an hour in random order for 72 h. These measurements were undertaken using a closed static chamber (diameter of 30.5 cm, height of 30 cm), with a GMP343 Vaisala probe. ER was measured with a transparent chamber covered by an opaque material to avoid input of photosynthetically active radiation. Inside the chamber the air was homogenized with a fan in order to minimize concentration gradients (Pumpanen et al., 2004). Measurement lasted a maximum of 5 min with CO_2 concentration recorded every 5 s as well as the relative humidity and the temperature inside the chamber.

At each site a weather station and a data logger were set up near the plots to provide meteorological and environmental data recorded every second: air relative humidity, solar radiation, peat temperature (at −5, −10, −20 and −30 cm depth below soil surface) and surface air temperature. The latter temperature was measured at an altitude as close as possible to the top of the *Sphagnum* capitulum (considered as the zero), which considering the sensor and shelter size was about 15 cm above the *Sphagnum* capitulum. This temperature will be referred as the 0 depth in the figures.

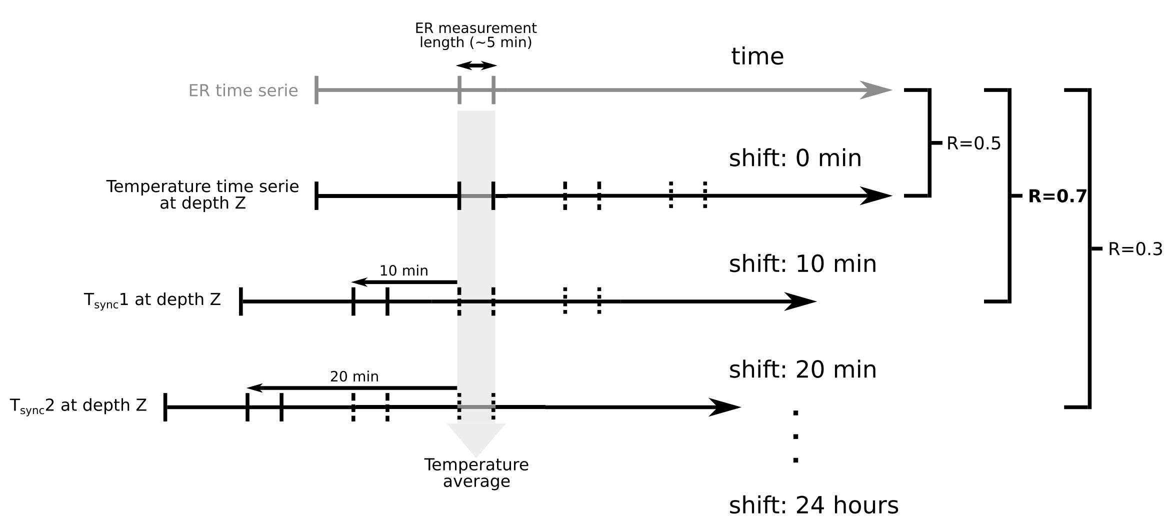

Fig. 1. Scheme of the synchronisation process between ER and temperature measurements at different depths (0 to −30 cm). For each site and temperature measurement depth the time series are shifted with 10 min steps until a 24 h shift. The correlation coefficient (R) is used to select the synchronised datasets.