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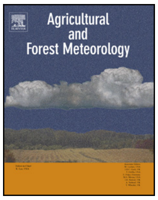

Carbon fluxes of an alpine peatland in Northern Italy

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ABSTRACT

It is widely known that peatlands are a significant carbon (C) stock. Most peatlands are located in boreal and subarctic regions of the northern hemisphere but some occur also at high altitude and, contrary to the first; their contribution in terms of carbon sequestration is far less studied. In the Alps, there are numerous small peatlands, which are threatened by increasing temperatures and an alteration of their water balance. The aim of this study was to investigate the carbon fluxes of a small-scale fen in the Alps over three years (2012–2014).

During the study period, the peatland experienced a high interannual variation in weather conditions while it acted as a carbon source based on CO_2 emissions (NEE: 180.7 ± 65.2 g C—CO_2 m^{-2} yr^{-1}) for all three years. This was mainly due to the short net C uptake period (73 ± 7 days) and high respiration. Ecosystem respiration and summer gross primary production were both very high compared to other peatlands around the world and compared to a nearby low productive grassland. In wintertime, the soil did not freeze, resulting in a slow decomposition of the organic matter. Low methane fluxes were recorded during a 10-month measurement campaign, for a total of 3.2 g C—CH_4 m^{-2} over the December 2013–September 2014 period. Our findings suggest that the interannual variability of temperature and soil water content exert a strong influence on the carbon balance of peatlands of the Alps and that could further worsen depending upon the magnitude of climate change.

1. Introduction

Peatlands contain the largest terrestrial soil carbon (C) pool in the world (Gorham, 1991). Northern peatlands store an estimated 547 (473–621) PgC (Yu et al., 2010), which is around 20% of the total amount of global soil organic carbon (IPCC, 2007), despite covering only about 3% of the land surface. Peatlands occur globally; however the biggest and most studied areas are located in the northern hemisphere (Parish et al., 2008; Schuur et al., 2015; Yu et al., 2010). Most of researched peatlands are in high latitude regions and these peatlands are studied for the vulnerability of their carbon storage, the effects of climate change and permafrost degradation (Camill, 2005; Dorrepaal et al., 2009; Frolking et al., 2001). Peatlands have been accumulating carbon for thousands of years. The decomposition of plant material is very slow due to the waterlogged soils and high recalcitrance of present *Sphagnum* mosses. The carbon can be released as the greenhouse gasses carbon dioxide (CO_2), methane (CH_4), or as Dissolved Organic Carbon (DOC) in waterbodies. Methane is only produced under anaerobic conditions (Wang et al., 2013). The emission of CH_4 in peatlands is has been linked to the presence of plants with aerenchyma, a tissue that can conduct methane from the soil to the atmosphere (Carmichael et al., 2014; Van Den Pol-Van Dasselaar et al., 1999). Aerenchyma tissue can be found mainly in sedges, so a high sedge abundance could potentially be an indicator of high methane emission (Armstrong, 1979; Gebauer et al., 1995). It is estimated that peatlands contribute to around 33% of the annual global methane efflux (ca 645 Tg CH_4 $year^{-1}$, (Carmichael et al., 2014)).

Due to climate change, pristine peatlands can be potential carbon sources (Bond-Lamberty and Thomson, 2010; Dorrepaal et al., 2009; Drösler et al., 2008; Frolking et al., 2011; Lawrence et al., 2013). The general global response of peatlands to climate change is hard to predict due to the uneven distribution of peatlands over the world, in addition to this only the most accessible peatlands are

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studied (Frolking et al., 2011). Warmer temperatures could lead to an increase in plant growth (net primary production, NPP) and an increase in ecosystem respiration (R_{eco}) (Beer and Blodau, 2007; Smith and Fang, 2010; Gong et al., 2013). The different magnitudes of these two contrasting fluxes could change peatlands from a carbon sink to a carbon source (Bond-Lamberty and Thomson, 2010; Dorrepaal et al., 2009; Lawrence et al., 2013). A difference in annual precipitation could result in a drop in the water table depth which will trigger faster decomposition of stored carbon, since more peat can be decomposed under aerobic conditions and simultaneously a reduction in CH_4 emissions (Andersen et al., 2013; Couwenberg et al., 2010; Gong et al., 2013; Jungkunst et al., 2008; Mitsch et al., 2012). On the contrary a rise in water table depth can reduce the decomposition (Murphy et al., 2009), increase the NPP (Sonnentag et al., 2010), with a positive effect on carbon accumulation, but with a negative effect in terms of increased CH_4 emissions (Lawrence et al., 2013; Petrescu et al., 2015; Vanselow-Algan et al., 2015).

To measure the net ecosystem CO_2 exchange (NEE) at an ecosystem level, the eddy covariance (EC) micrometeorological technique is typically used. This technique allows to measure turbulent fluxes, which are exchanged between vegetation canopy and the atmosphere (Baldocchi, 2003). The advantage of this method is that it continuously measures the fluxes over a long period of time (years or even decades) and in a non-destructive way. In this way, the dynamics of ecosystems can be investigated and followed over time. NEE can then be partitioned to calculate the gross primary production (GPP) and ecosystem respiration (R_{eco}).

As highlighted by Drösler et al. (2008) measurements need to be done at different peatland ecosystems, to reach a better understanding of, and to upscale the greenhouse gas balance of peatlands regionally and/or globally. The difficulty with upscaling is that peatlands occur in different types: e.g. fen, aapa mire, blanket bog and raised bog, which are reliant on different water and nutrient sources, ombrotrophic (rainwater fed) vs minerotrophic (groundwater fed) (Wheeler and Proctor, 2000). The differences in water sources, the dissolved minerals and nutrients can lead to different plant communities and therefore a different greenhouse gas balance. Measurements on pristine peatlands indicate that these untouched peatlands are mainly acting as a CO_2 sink (34.9 to 329 $g\,C{-}CO_2\,m^{-2}\,yr^{-1}$) and as a methane source (3.2 to 32 $g\,C{-}CH_4\,m^{-2}\,yr^{-1}$) (Aurela et al., 2009; Bäckstrand et al., 2010; Beetz et al., 2013; Koehler et al., 2011; Lund et al., 2010, 2007; McVeigh et al., 2014; Nilsson et al., 2008; Petrescu et al., 2015; Roulet et al., 2007; Sonnentag et al., 2010; Sottocornola and Kiely, 2010; Wu et al., 2013). On the contrary drained and managed wetlands often act as a CO_2 source (Beyer and Höper, 2015; Hatala et al., 2012). Many factors are influencing the carbon balance, such as: vegetation, hydrology, ground water level (Murphy et al., 2009), human disturbance (Hendriks et al., 2007) and climatic variability (McVeigh et al., 2014). Peatlands with a high cover of bryophytes and a low cover of vascular plants, show lower GPP than peatlands with a high vascular plant cover (Beetz et al., 2013). Since peatlands are rather widespread, the climatic conditions are very important. A comparison of different peatlands can provide more information why some peatlands are bigger carbon sources than others (Drösler et al., 2008).

In the Alpine area, numerous small peatland fens are present. In the Alps the climatic conditions for these fens to develop into raised bogs are rare. This results in an infilling of non-peatland plant species (trees and grasses) into the peatland. The peatland fens in the Alps are being threatened by rising temperatures and changes in their precipitation regime (Beniston et al., 1997; Eccel et al., 2012; Im et al., 2010; IPCC, 2013, 2007; Pepin et al., 2015; Steger et al., 2012). The predicted changes in precipitation can be opposite of sign and different in magnitude. Alpine fens are already experiencing modifications due to climate change with an acceleration of the infilling with trees (Stine et al., 2011). This is leading to the invasion of non-peatland plants typical of drier ecosystems that are turning the peatlands into grasslands and forests, with a consequent loss of both their stored soil carbon and their biodiversity (Stine et al., 2011). Tree encroachment for example is more persistent with global warming than it is with summer drought, while a combination of the two results in tree-dominated peatlands (Heijmans et al., 2013; Holmgren et al., 2015). Despite the risks and the regular occurrence of peatlands in the Alps, their carbon and water cycle has been poorly studied because peatlands represent a small part of the dominant ecosystems in the Alps (Parish et al., 2008). To our knowledge the only research on Alpine peatlands focused on their restoration and management (Ammann et al., 2013; Van Der Knaap et al., 2011) while no attempt was taken to measure the carbon fluxes with an eddy covariance system.

The objectives of this paper are (i) to investigate three years of carbon and methane fluxes of a peatland in the Italian Alps, (ii) to study the inter annual variability of the carbon fluxes and (iii) to compare the fluxes of this alpine peatland with other peatlands.

We hypothesize that the peatland will be a small carbon sink, since the vegetation of the peatland grows very fast during the growing season. We assume that the carbon taken up during this period is more than the carbon released over the rest of the year, particularly when the peatland is covered with snow and all biological processes are slowed down or stopped. We also think that the peatland will have high methane fluxes, since the peatland has a high coverage of sedges.

2. Materials and methods

2.1. Site

The study site is a 10 hectares minerotrophic relatively nutrient poor fen located at 1563 m a.s.l. on the Monte Bondone plateau (Fig. 1), near Trento, in the Italian Alps (latitude 46°01′03N, longitude 11°02′27E). The peatland is placed in a relict glacial lakebed, that was formed during the last ice age (Cescatti et al., 1999), in a saddle shaped valley with a mountain top on the eastside (Palon, 2090 m a.s.l., Fig. 1a). The runoff of the complete watershed flows on deep impermeable morainic strata, which result into seepage into the fen (Cescatti et al., 1999). This seepage enters the peatland through two inflow streams; from the fen the water discharges in a stream (Fig. 1). The average annual precipitation during 1958–2008 was 1290 $mm\,yr^{-1}$ with an average air temperature of 5.4 °C (Eccel et al., 2012). The snow-free period typically lasts from early May to late October-beginning November.

The vegetation of the area is very heterogeneous: the areas closest to the tower are mainly dominated by *Molinia caerula* forming big tussocks, while in the depressions the main vegetation consists of *Carex rostrata*, *Valeriana dioica*, *Scorpidium cossonii* and scattered *Sphagnum* spp. The southwestern area of the peatland is dominated by *Eriophorum vaginatum*, with high tussocks of *Carex nigra* covering the lower areas. *Sphagnum* spp. as well as *Trichophorum alpinum* and *Drosera rotundifolia* occur close to the outflow stream. In the eastern part of the peatland, between the two inflow streams, there are some short hummocks with *Calluna vulgaris* and *Sphagnum* section *acutifolia*. At this part of the peatland, there is no influence from the incoming streams.

In 1914, 0.35 ha of the peatland was harvested for burning by removing the peat top layer (Cescatti et al., 1999), this is still visible today (Fig. 1b). This area is mainly covered by *Campylium stellatum*, *S. cossonii* and *C. rostrata* today. The depth of the peat ranges from 0.82 m at the border (Cescatti et al., 1999; Zanella et al., 2001) to 4.3 m in the centre (Dalla Fior, 1969).