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Large interannual variability in net ecosystem carbon dioxide exchange of a disturbed temperate peatland

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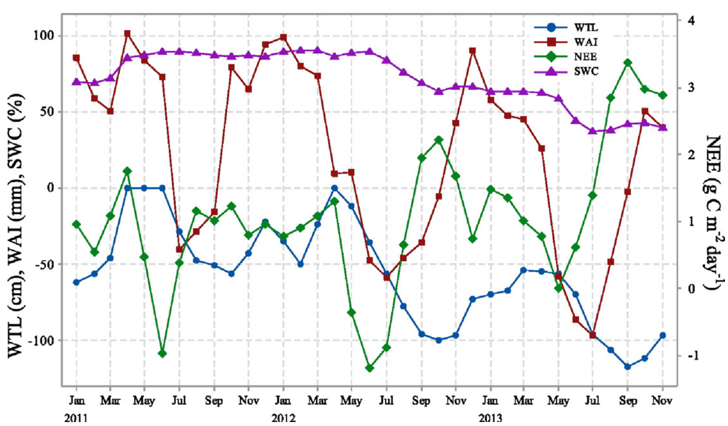
HIGHLIGHTS

- The present study appears to be the first on evaluating long-term interannual variability of NEE in a disturbed temperate peatland.
- Yenicaga peatland was a strong CO_2 source with a large interannual variability with the value of 246, 244 and 663 g C m^{-2} yr^{-1} for 2011, 2012, and 2013 respectively.
- WAI was found to be a better predictor for ER than SWC and WTL.
- T_{air}, ET and VPD were most significant variables strongly correlated with NEE, ER, and GPP.

GRAPHICAL ABSTRACT



WTL: Water table level, WAI: Water availability index, SWC: Soil water content, NEE: Net ecosystem carbon dioxide exchange.

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ABSTRACT

Peatland ecosystems play an important role in the global carbon (C) cycle as significant C sinks. However, human-induced disturbances can turn these sinks into sources of atmospheric CO_2. Long-term measurements are needed to understand seasonal and interannual variability of net ecosystem CO_2 exchange (NEE) and effects of hydrological conditions and their disturbances on C fluxes. Continuous eddy-covariance measurements of NEE were conducted between August 2010 and April 2014 at Yenicaga temperate peatland (Turkey), which was drained for agricultural usage and for peat mining until 2009. Annual NEE during the three full years of measurement indicated that the peatland acted as a CO_2 source with large interannual variability, at rates of 246, 244 and 663 g C m^{--2} yr^{-1} for 2011, 2012, and 2013 respectively, except for June 2011, and May to July 2012. The emission strengths were comparable to those found for severely disturbed tropical peatlands. The peak CO_2 emissions occurred in the dry summer of 2013 when water table level (WTL) was below a threshold value of −60 cm and soil water content (SCW) below a threshold value of 70% by volume. Water availability index was found to have a stronger explanatory power for variations in monthly ecosystem respiration (ER) than the traditional water status indicators (SCW and WTL). Air temperature, evapotranspiration and vapor pressure deficient were the most significant variables strongly correlated with NEE and its component fluxes of gross primary production and ER.

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1. Introduction

Peatlands are wetland ecosystems under saturated water conditions causing an accumulation of organic matter called peat (Parish et al., 2008). Covering 4.2 million km^2 worldwide or about 3% of the Earth's land surface (Limpens et al., 2008; Dise, 2009; Yu, 2012; McVeigh et al., 2014), peatlands are one of the largest carbon (C) pools. In pristine peatlands, water table is generally close to the surface year-round, causing anaerobic conditions (Holden et al., 2011), slow decomposition rates and gradual accumulation of organic matter (Turetsky et al., 2014). Pristine peatlands have acted as net carbon dioxide (CO_2) sinks for thousands of years (Frolking and Roulet, 2007). However, many peatlands have been disturbed by human activities, such as agricultural usage, drainage for tree planting, and peat extraction (Waddington et al., 2010; Haapalehto et al., 2014). Due to the disturbances, the peatland ecosystems may switch from sinks to sources of atmospheric CO_2. The disturbances of the hydrological regime in the peatland are the main driver of net C loss. Thus, it is important to determine how a peatland continues to be C sink or turns into a C source under what conditions. Long-term and continuous measurements provide first-hand experimental data on CO_2 fluxes, allowing us to understand drivers of interannual variability in C source and sink.

The eddy-covariance (EC) technique allows for direct and long-term observations of the exchange of CO_2, energy and water fluxes between the biosphere and the atmosphere at the ecosystem scale (Baldocchi, 2003). Although the EC technique has been increasingly used across many biome types of the world (Mauder et al., 2013), there have been a few applications of EC at peatland sites (McVeigh et al., 2014). Most peatland EC sites are located in boreal, subarctic and arctic climate zones (Sottocornola and Kiely, 2010), with very few studies reporting longer than two years of interannual variability in CO_2 fluxes (Helfter et al., 2014; McVeigh et al., 2014; Peichl et al., 2014). To the authors' best knowledge, only eleven studies have reported annual net ecosystem CO_2 exchange (NEE) for temperate climate peatlands and of these, only five studies have reported long-term (>2 years) NEE measurements (Table 1). To improve the understanding of peatland C dynamics, long-term measurements and interannual variability analysis should be extended to different climates and peatland types.

The long-term NEE studies conducted for temperate peatlands indicate that interannual variability is mostly attributed to climatic conditions. Hydrometerological changes (Olson et al., 2013), water table variations (McVeigh et al., 2014), drought (Lund et al., 2012), temperature, and growing season length (Helfter et al., 2014) have been found to regulate peatland CO_2 fluxes. Since water is a critical component for peat formation, it is not a surprise that the studies have focused on the relationship between water status, mostly water table level (WTL), and NEE and its components such as ecosystem respiration (ER) and gross primary productivity (GPP). Though no consensus has been reached, discussions on water table variations have been performed to determine whether they affect NEE by controlling primarily GPP (Dimitrov et al., 2011) or ER (Dimitrov et al., 2010). Although WTL is an important measure of peatland water status, uncertainties in its relationship to the C flux components have led to search for other water indicators such as soil water content (SWC) (Parmentier et al., 2009).

Simple statistical models are used to explore environmental drivers of peatland C fluxes. Since NEE varies in space and time due to chemical, biological and physical dynamics of the peatland (Bonneville et al., 2008), it is difficult to establish a generalized relationship between environmental drivers and C fluxes. However, it is helpful to make comparisons of environmental drivers among sites of different characteristics. Previous studies have shown robust linear relationships between ER and air temperature (T_{air}) and between C fluxes and aboveground biomass (Han et al., 2013), and multiple non-linear relationships of C fluxes to T_{air}, soil temperature, vapor pressure deficit (VPD), solar radiation (Zhao et al., 2010), and water depth (Schedlbauer et al., 2012).

So far, the majority of the related studies in the literature have been carried out for intact peatlands. Only a few studies on C fluxes were conducted in disturbed peatlands such as the Sacramento-San Joaquin Delta in California (Knox et al., 2015), Reeuwjik in the Netherlands (Veenendaal et al., 2007), and Waiketo in New Zealand (Nieveen et al., 2005), but with a measurement period of just one year or shorter.

Table 1
A multiple comparison of annual NEE values (g C m^{-2} yr^{-1}) for Yenicaga peatland versus other peatlands in temperate climate regimes.

Site	Location	Climate zone	Status	T_{mean}/PPT_{mean}	NEE	Time period	References
Schechenfilz	Southern Germany	Temperate	Intact	8.6/1127	−62	2012–2013	Hommeltenberg et al. (2014)
Atlantic Blanket Bog	Southwest Ireland	Temperate maritime	Almost intact	10.5/2467	−55.7	2002–2012	McVeigh et al. (2014)
Auchencorth Moss	Scotland, Edinburgh	Temperate	Unknown	8.3/1018	−17.5	2002–2013	Helfter et al. (2014)
Bog Lake Fen	North Minnesota, USA	Temperate	Intact	3.9/210	−38.6	2009	Olson et al. (2013)
				3.5/400	−27.7	2010	
				5.9/450	−39.5	2011	
Mer Bleue	Canada	Cool-temperate	Intact	6.5/871	−104	2006–2007	Strilesky and Humphreys (2012)
Fajemyr	Southern Sweden	Temperate	Intact	6.2/700	21.4	2005	Lund et al. (2007)
					14.3	2006	Lund et al. (2012)
					−29.4	2007	
					23.6	2008	
					−28.9	2009	
Panjin	China	Warm-temperate	Intact	8.6/631	−65	2005–2006	Zhou et al. (2009)
Degero Stormyr	Northern Sweden	Cold-temperate	Intact	1.2/523	−55	2004	Nilsson et al. (2008)
					−48	2005	
Mer Bleue	Southeast Canada	Cool-temperate	Intact	6.5/871	−40.2	1998–2004	Roulet et al. (2007)
Fochtelooer	North Netherland	Temperate	Disturbed	14.9/452	97	1994–1995	Nieveen et al. (1998)
Bog Lake Fen	North Central Minnesota, USA	Temperate	Intact	13.6/553 (May–Oct)	71 g C m^{-2}	May–Oct 1991	Shurpali et al. (1995)
					−32 g C m^{-2}	May–Oct 1992	
Yenicaga Bolu	Northwest Turkey	Cool-temperate	Disturbed	10.2/538	346	2010 (Aug–Dec)	This study
					281	2011	
					265	2012	
					627	2013	
					221	2014 (Jan–April)	