GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L23804, doi:10.1029/2005GL024731, 2005

An Atlantic blanket bog is a modest CO_2 sink

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Received 22 September 2005; revised 11 October 2005; accepted 28 October 2005; published 2 December 2005.

[1] Northern peatlands contain 1/3 of the world's soil carbon pool. Blanket bogs are peatlands that occur in maritime regions where precipitation is much greater than evapotranspiration. The role of blanket bogs in C dynamics has not been quantified. We describe an investigation of CO_2 fluxes using an eddy covariance (EC) system in a pristine Atlantic blanket bog in Ireland during 2003 and 2004. This is the first multiyear study using EC techniques in a blanket bog. We found that the bog ecosystem was a CO_2 sink for five months in each year. The annual CO_2 flux had a sink magnitude of −49 (2003) and −61 g C m^{-2} (2004). These magnitudes are similar to boreal raised bogs, while higher values have been reported for boreal fens and lower for subarctic fens. **Citation:** Sottocornola, M., and G. Kiely (2005), An Atlantic blanket bog is a modest CO_2 sink, *Geophys. Res. Lett.*, *32*, L23804, doi:10.1029/2005GL024731.

1. Introduction

[2] Although Northern peatlands are generally of low productivity, they are important ecosystems because they contain up to 1/3 (455 Gt of C) of the world's estimated soil carbon (C) pool [*Gorham*, 1991]. The future of this C reservoir is of key interest as many regions (e.g., the arctic tundra) have already undergone a C status change from sink to source due to global warming [*Oechel et al.*, 2000], with an additional risk of a positive feedback. Climate warming is expected to affect peatlands hydrology [*Roulet et al.*, 1992], vegetation zones and plant composition [*Weltzin et al.*, 2003]: all factors influencing the C dynamics. For Ireland, *McGrath et al.* [2005] predict a mean monthly temperature increase between 1.25 and 1.5°C, a decrease in precipitation in summer and an increase in winter for the period 2021–2060.

[3] Many C flux studies have been carried out using the eddy covariance (EC) system during the peatland growing season only [*Shurpali et al.*, 1995] and more recently for the full year [*Aurela et al.*, 2002; *Lafleur et al.*, 2001]. Some peatlands have been found to be net sources of CO_2 [*Lafleur et al.*, 1997], others were found to be net sinks CO_2 [*Aurela et al.*, 2004; *Friborg et al.*, 2003; *Lafleur et al.*, 2003; *Nordstroem et al.*, 2001], while others were found to be a sink in one year and a source in another year [*Joiner et al.*, 1999; *Shurpali et al.*, 1995].

[4] Studies of C dynamics in peatlands have been carried out mostly in boreal bogs and fens and in sub-arctic fens [*Aurela et al.*, 2004; *Friborg et al.*, 2003; *Lafleur et al.*, 2003; *Waddington and Roulet*, 2000], some in arctic fens [*Nordstroem et al.*, 2001] but very few studies of CO_2 fluxes have been performed in blanket bogs [*Beverland et al.*, 1996; *Chapman and Thurlow*, 1996]. To our knowledge, no CO_2 measurements have been performed using the EC method in an Atlantic blanket bog over the full calendar year.

[5] Blanket bogs are ombrotrophic peatlands receiving water and nutrients only from atmospheric deposition. These ecosystems are usually in flat to moderately sloping terrain with an oceanic climate.

[6] In the global context, blanket bogs are rare ecosystems, accounting only for ca. 3% of the world peatland area [*Foss et al.*, 2001]. However, locally they are important, not only for biodiversity reasons but particularly for their role in the C balance of regions. In Ireland, out of 1.34 million hectares of peatlands (~16% of the land area), about 240,000 ha are blanket bogs [*Hammond*, 1981]. The role of this regionally large ecosystem in C dynamics has not been quantified.

[7] The objective of this study is to quantify the CO_2 source/sink status of an Atlantic blanket bog over two calendar years using the EC technique.

2. Site Description

[8] The experimental site is an Atlantic blanket bog located at Glencar, County Kerry, in Southwest Ireland (Latitude: 51°55′N, Longitude: 9°55′W) at an elevation of approximately 150 m above sea level. The characteristic feature of the bog is a spatially heterogeneous surface, with a mosaic of microforms, which differ in relative altitude, plant composition and water table level. We divided these microforms into four classes based on relative elevation: hummocks (*HU*), high lawns (*HL*), low lawns (*LL*) and hollows (*HO*). The elevation difference between the highest (*HU*) and lowest (*HO*) microform is typically 20 to 40 cm. *HO* are depressions covered by water and hollow vegetation. The microform composition inside the EC footprint was estimated as 4% (*HU*), 58% (*HL*), 25% (*LL*) and 13% (*HO*) (A. Laine et al., Ecosystem scale carbon dioxide fluxes in a blanket bog: Reliability of different methods in estimating NEE in patterned peatland, submitted to *Agricultural and Forest Meteorology*, 2005). The most common plants occurring in the bog are *Molinia caerulea* (purple moor-grass), *Schoenus nigricans* (black-top sedge), *Rhynchospora alba* (white beak-sedge), *Erica tetralix* (cross-leaved heath), *Calluna vulgaris* (common heather), *Eriophorum angustifolium* (common cotton grass), *Narthecium ossifragum* (bog asphodel) and *Menyanthes trifoliata* (buckbean). The bryophyte component is not widespread (less than 10% of the bog surface) and the dominant species include *Racomitrium lanuginosum* (woolly-hair moss) and *Sphagnum* spp. (bog mosses). The leaf area index (LAI), measured in 2005 with a PAR/LAI Ceptometer (LP-80 AccuPAR, Decagon devices, Inc.,

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USA), was between 0.2 in winter and 0.7 m^2 m^{-2} in summer. The peat depth is > 2 m in the EC footprint.

3. Methods

[9] The experimental arrangement consists of a micrometeorological station and an EC system for CO_2 flux. The instrumentation is situated in the middle of the bog with at least 300 m of uninterrupted fetch on all sides of the EC station. The ground contours within the fetch are relatively flat. The flux footprint was estimated based on a fetch to sensor height ratio of 100:1 combined with the probability density distribution of the wind direction.

[10] The micrometeorological equipment included a net radiometer (CNR 1, Kipp and Zonen, the Netherlands) and a sensor for Q, photosynthetically active radiation (PAR Lite, Kipp and Zonen, the Netherlands). Air temperature (T_a) was measured at 2 m height with a shielded probe (HMP45C, Vaisala, Finland), while soil temperature was recorded with a probe (107, Campbell Scientific, UK) at 20 cm below the *HL* vegetation (T_{soil}). Precipitation was measured with two tipping bucket rain gauges (an ARG100, Environmental Measurements Ltd., UK and an Obsermet OMC-200, Observator BV, The Netherlands). The water table (WT) depth was continuously measured with a pressure transducer (PCDR1830, Campbell Scientific, UK) placed inside a metal well, pierced all along its height. A malfunction of the WT transducer for the first 17 months of the experiment was corrected with interpolation from manual measurements (A. Laine, unpublished data, 2004). Signals from all the micrometeorological sensors were monitored every minute and averaged over a 30-minute period in a CR23X data logger (Campbell Scientific, UK).

[11] The EC system consisted of a 3-D sonic anemometer (Model 81000, R.M. Young Company, USA) and an open-path CO_2/H_2O infrared gas analyzer (LI-7500, LI-COR, USA) mounted 3 m above the *HL* vegetation. Data were recorded at 10 Hz and fluxes were Reynolds-averaged every half-hour. The 30-minute averaged EC CO_2 fluxes are defined as:

$$F_c \cong -\overline{w'\rho'_c} \tag{1}$$

where w' is the vertical wind velocity fluctuations [m s^{-1}] and ρ'_c the CO_2 density fluctuations (mmol m^{-3}). We adopted the micrometeorological convention in which fluxes from the biosphere to the atmosphere are positive. We report on the data collected for the two calendar years, 2003 and 2004.

[12] In processing the data, raw EC flux data were double rotated, so that the mean horizontal wind speed was rotated into the mean wind direction and the mean vertical wind velocity was set to zero. The vertical rotation was based on the averaged 30-minute angle between the horizontal and vertical axes. In low wind speed conditions, the estimate of the vertical angle can signal unsatisfactory outputs and so fluxes that where rotated for unrealistic angles where rejected. The CO_2 flux was then corrected for variations in air density due to fluctuation in water vapor and heat flux [*Webb et al.*, 1980]. The flux data were partitioned into day and night sets, using a short-wave incoming radiation threshold of 10 W m^{-2}. With this threshold, 46% of the two-year dataset comprised of day data. No clear correlation was found between the friction velocity (u_*) and the dry night CO_2 fluxes and so we did not apply a u_* filter. Nighttime uptake values were rejected.

[13] The time series of day and night fluxes were divided into twelve bimonthly bins over the two-year dataset and filtered for predetermined realistic threshold values for the season. Approximately 15% of the data in 2003 and 2004 were rejected during rainfall periods and within one hour after rain. After post-processing and filtering, 43.4% of the CO_2 flux data for 2003 (~60% of day and 30% of night data) and 50.6% for 2004 (~69% of day and 35% of night data) was good and suitable for further analysis. Most night data that was rejected was outside the growing season.

[14] The gaps in the time series were filled with non-linear regression equations defined using the Curve Fitting Function of MATLAB 6.5 (MathWorks Inc., USA) software for monthly (May and June 2003, March and April 2004) or bimonthly periods. For day data, the best gap filling functions were rational functions of polynomials in one variable of different orders that relate the 30-minute CO_2 flux either with air temperature (January–February and May 2003, April 2004) or with Q (all other periods). For night data an exponential Q_{10} gap filling function was defined for the full two-year period and related the half hour flux with the 20 cm deep soil temperature.

[15] In 2003, between Julian days 145 and 155 (25th May to 4th June) no data were logged due to an electricity outage. The missing meteorological data were replaced with the last 5 good days of data before the outage and the first 5 days of good data after the outage except for precipitation. Precipitation data were obtained from a comparison with the nearby Valentia weather station (~30 km west of the site, 51°56′N, 10°14′W) records. The EC system suffered a break, in 2003 between Julian day 141 and 177 (21st May to 26th June). The 36 days gap in the EC CO_2 flux was filled using gap filling equations based on meteorological measurements. Notably the missing May fluxes were determined with a function based on air temperature, defined for the first 21 good days of the month. The 26 missing flux days in June were calculated with a rational function of polynomials of degree one based on Q, derived from the averaging of the same type of function for May and July–August 2003.

4. Results

[16] The photosynthetically active radiation (Figure 1a) followed the expected pattern, with the highest monthly average values (for the day hours) in June and the lowest in December. The daytime annual Q average was 482 (2003) and 458 μmol m^{-2} s^{-1} (2004). Precipitation was abundant and frequent throughout the year (Figure 1b). The total annual precipitation was 2510 mm (2003) and 2356 mm (2004). The monthly precipitation ranged between a low of 40 mm in August 2003 to a high of 540 mm in November 2003. In 2004 the monthly variation was less extreme than in 2003 with no month experiencing rainfall less than 95 mm. At the Valentia weather station the rainfall measured in both 2003 and 2004 was slightly below the 30-year average (1961–1990).

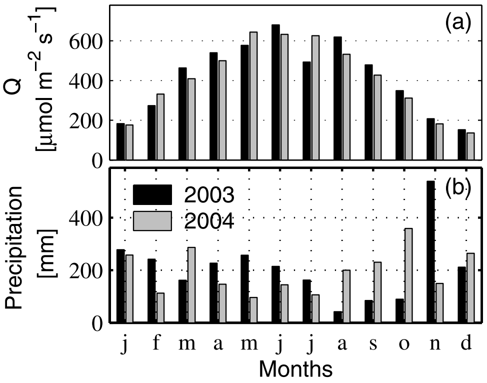

Figure 1. (a) Monthly Q, averaged for the daytime and (b) monthly precipitation during 2003 and 2004.

[17] Daily air and soil temperatures (Figures 2a and 2b) confirmed a very mild climate with little variation throughout the year. The annual average air temperature was 10.51 (2003) and 10.40°C (2004). T_a average during the May to September period was 13.60 (2003) and 13.59 °C (2004); in November–February it was 7.40 (2003) and 7.84°C (2004). The daily mean soil temperature at 20 cm depth was between 5 and 18°C. The WT (Figure 2c) remained close to the surface throughout the year. The range of WT was from 2 cm above the *LL* to about 15 cm below the *LL* surface.

[18] The monthly CO_2 flux (Figure 3) for both 2003 and 2004 showed a net uptake over the five months, May to September, and a net respiration for the four months, November to February. In both years, March, April and October showed no clear net flux, either uptake or respiration. In both 2003 and 2004, July was the month with the highest CO_2 uptake: −20 and −28 g C m^{-2}, respectively. High and similar uptakes of CO_2 for the two years were also noted in June (about −18 g C m^{-2}) and August, with −16 and −19 g C m^{-2} in 2003 and 2004.

[19] The cumulative CO_2 flux (Figure 4) showed a net uptake in 2003 of −49 g C m^{-2} yr^{-1} and in 2004 of −61 g C m^{-2} yr^{-1}. The error in the energy balance closure provided an estimate of the systematic error. The approach of *Aurela et al.* [2002] was used to estimate the random component of the error, which was much lower. The combined error estimate was approximately 35 and 30% for 2003 and 2004 respectively. The inflections points (up arrows, Figure 4) mark the beginning of the ecosystem net CO_2 uptake period that occurred at the end of April in both years. The end of the net CO_2 uptake period (down arrows, Figure 4) was late September for 2003 and mid October for 2004. The annual net CO_2 uptake was close to what was estimated for a Scottish blanket bog (−41 g C m^{-2} yr^{-1} [*Beverland et al.*, 1996]) and measured over four consecutive years in a Canadian boreal raised bog (−76, −69, −68 and −10 g C m^{-2} y^{-1} [*Lafleur et al.*, 2003]). A higher annual CO_2 balance was estimated for a boreal fen in Russia (−88 g C m^{-2} y^{-1} [*Friborg et al.*, 2003]) while generally lower values were measured in six consecutive years in a subarctic fen in Finland (−4, −21, −8, −6, −37 and −53 g C m^{-2} y^{-1} [*Aurela et al.*, 2004]).

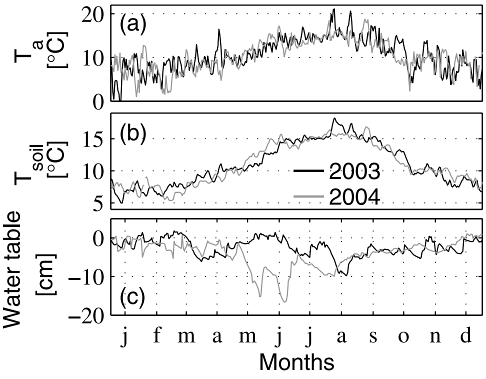

Figure 2. (a) Daily mean air temperature. (b) Daily mean soil temperature at 20 cm depth. (c) Water table variation during 2003 and 2004.

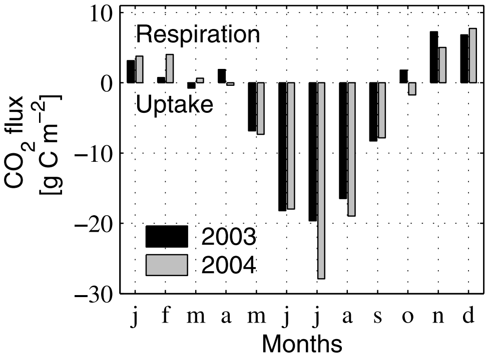

Figure 3. Monthly CO_2 flux during 2003 and 2004.

5. Discussion

[20] Previous CO_2 flux studies in northern peatlands have been performed in boreal, sub-arctic or arctic regions. All these regions experience extreme weather conditions, with a short growing season and a long winter with frozen soil and snow cover. In contrast the temperate climate of Ireland varies little throughout the year and is characterized by a long growing season and a mild winter with only rare snowfall, and typically without any occurrence of frozen soil. The present work is the first EC study in an Atlantic blanket bog, ecosystem characterized by a different climate to previous studies of peatlands in northern regions.

[21] Two years of EC CO_2 flux measurements, while too short for definitive conclusions about interannual variation, are long enough to quantify the seasonal variation of the

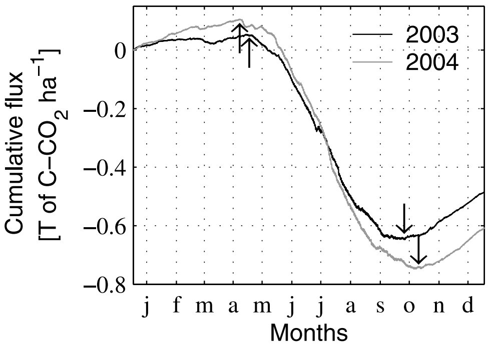

Figure 4. Cumulative CO_2 flux during 2003 and 2004.

CO_2 source/sink status of this ecosystem. The C budget of a peatland has three main components: CO_2 and CH_4 fluxes and DOC losses in streams. Our study does not report on CH_4 or DOC. However the CO_2 flux is expected to be the largest component of the C cycle [*Moore et al.*, 1998]. According to this study, the CO_2 flux pattern of Atlantic blanket bog in Ireland is, in terms of the annual balance, lower than boreal fen [*Friborg et al.*, 2003], higher than subarctic fen [*Aurela et al.*, 2004] and similar to boreal raised bog [*Lafleur et al.*, 2003]. As the water table is persistently higher in the blanket bog, decomposition was expected to be lower and therefore CO_2 uptake higher than in boreal raised bogs [*Lafleur et al.*, 2003]. However other processes are likely to reduce the impact of the water table height in terms of CO_2 uptake in the blanket bog. These are: 1) lower LAI and lower moss cover in the blanket bog, and therefore lower gross ecosystem production and CO_2 uptake compared to the boreal raised bog; 2) higher litter decomposition rate of the plant species in the blanket bog [*Aerts et al.*, 1999], and therefore lower CO_2 uptake than in the boreal raised bog.

[22] Although Glencar has a mild maritime climate, the blanket bog is a net sink for CO_2 for only five months of each year, even if some daily net photosynthesis has been measured also during the winter (data not shown).

[23] Over the two years of continuous measurement, the Glencar blanket bog showed an average net CO_2 uptake of -55 g C m^{-2} y^{-1} which is ~20% of an average annual CO_2 flux of -277 g C m^{-2} yr^{-1} in a nearby fertilized grassland for the same two years (D. Lawton et al., Observation and process-based modeling of the net ecosystem exchange and its components for a humid grassland ecosystem, submitted to *Global Change Biology*, 2005). If we extrapolate our estimate of the CO_2 fluxes at the Glencar ecosystem to the entire 240,000 ha of Irish blanket bogs, with the rough assumption that all pristine and disturbed blanket bogs have comparable CO_2 fluxes, we can estimate the annual CO_2 uptake for this ecosystem to be of the order of 0.1 Mt C yr^{-1} in Ireland.

[24] Climate change scenarios for Ireland predict a warmer climate with a decrease in precipitation in summer and an increase in winter [*McGrath et al.*, 2005]. The effects of this climate change on CO_2 fluxes is unknown, as a change in temperature and in precipitation will affect in different ways both components of the CO_2 flux, respiration and photosynthesis. Along with further EC measurements, we intend to extend this work to modeling the CO_2 flux and so evaluate some future climate change scenarios and resolve the synergies of the predicted climate change on the ecosystem CO_2 balance.

[25] **Acknowledgments.** This work has been prepared as part of the Environmental Research Technological Development which is managed by the EPA and financed by the Irish Government under the National Development Plan 2000–2006 (Grant No. 2001-CC/CD-(5/7)). We thank Caitriona Douglas of NPWS and Coillte Teoranta for permission to use the study site. We appreciate the contributions of Adrian Birkby, Kenneth Byrne, Anna Laine, Paul Leahy and Viacheslav Voronovich. Particular thanks to Mika Aurela, Thomas Foken, Peter Lafleur, Narasinha Shurpali for useful discussions. We very much appreciated the helpful reviews by Nigel Roulet and an anonymous reviewer.

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