# Overview of the Role of Peatlands in the Global Carbon Cycle and their Role as Modifiers of Climate

**Nigel Roulet**
**Department of Geography, McGill University, 805 Sherbrooke St. W., Montreal AC H3A**
**(nigel.roulet@mcgill.ca)**

**The role of peatlands in the climate system stems from their role in the global carbon cycle, and specifically the net ecosystem exchanges of $CO_2$ and $CH_4$. Estimates vary considerably but northern peatlands store between ~ 20 and 30% of Earth's terrestrial carbon and account for between ~ 5 to 15% of the annual emissions of $CH_4$ to atmosphere. The uncertainty in the carbon store is large. The uncertainty in the $CH_4$ emissions is also large but there is some convergence of direct measurements and indirect approaches such as those from atmospheric inversion modelling.**

**Back-of-the-envelope calculations of long-term removal of $CO_2$ and emission of $CH_4$ from peatlands suggest they could represent a -0.5 W $m^{-2}$ reduction in global radiative forcing (equivalent to ~ 10 to 20% of anthropogenic climate forcing since ~ 1700). However, these estimates are based on the highly uncertain reconstruction of the distribution and growth of peatlands referred to above. To assess the role of peatlands in climate requires reconciling the rate and magnitude of ecosystem biogeochemical cycles with the lifetime and the radiative properties of trace gases in the atmosphere. Peatlands exchange three greenhouse gases whose biogeochemistry have very different rate constants and element cycling times. Two of these gases, $CH_4$ and $N_2O$ have an atmospheric chemistry and a third, $CO_2$, does not – i.e., the fate of $CO_2$ fate is completely dependent on the biology and chemistry of other terrestrial ecosystems and the oceans.**

**Understanding the processes that regulate the exchange of $CO_2$ and $CH_4$ well enough to be able to generalize for simulating the response of peatlands to environmental change, such as the direct and indirect consequences of climate and/or land cover changes, is not a trivial problem. Not only do these estimates require good descriptions of the structure and function of ecosystem biogeochemistry, but in the case of peatlands an equally good description of the physical attributes of the energy exchanges and hydrology is required. Relatively small changes in the moisture storage (5 – 10%) and temperature (2 – 3$^{o}$C), which in many other ecosystems would lead to small changes, in peatlands can cause much larger changes in the production and decomposition of C. Persistent changes in moisture (e.g., water table changes of ±5 – 10 cm) can alter the structure of the plant community that leads to orders of magnitude change in $CH_4$ exchange. While the change in the mass flux of C may be small, the change in the species of trace gas could have a profound affect. Therefore, integrated energy-water-biogeochemical models that account for the changes in not only ecosystem function but also ecosystem structure, i.e., the dynamics of peatland functional plants types, are required to assess the future role of peatlands in a changing climate.**

**Peatlands are recognized to have the characteristics of self-regulating systems and the extent of regulation is a function of the peatland type and the source of water and nutrients. However, this homeostasis that bounds peatlands has limits and if environmental change occurs too quickly and/or is too large, self-regulation may not keep up. A central question is whether climate change will push some peatlands beyond their envelope of self-regulation. Certain changes, such as the melting of permafrost, have the potential to very rapidly send the ecosystem off on a trajectory that will result in a different form of peatland with a very different structure and function.**

# Fluvial Carbon Flux Within and from Peatlands

**Joseph Holden**
School of Geography, University of Leeds, Leeds, UK (j.holden@leeds.ac.uk)

This presentation provides an overview on the links between carbon cycling and the hydrology of peatlands, focusing on the role of peatlands in the production and water borne export of dissolved and particulate carbon. Fluvial export of carbon can account for between 3 and 50% of peatland carbon export depending on the condition of the peatland and the time of year. Rain-splash assisted wind erosion of particulate carbon can also be important in some locations (Foulds & Warburton, 2007). Pathways for fluvial export include overland flow, matrix throughflow, and macropore/tunnel flow which move carbon from within the peat mass (Holden et al., 2009). Evidence is growing for the role of vegetation cover (which mediates peatland management responses) in determining the relative proportion of the dissolved organic carbon flux and some summary work will be presented. Recent work has also identified hotspots for dissolved organic carbon production and hotspots of degassing from fluvial components of the peat system such as pools, natural pipe outlets, and headwater streams. New developments in continuous monitoring of dissolved $CO_2$ in fluvial streams are assisting such determinations (Dinsmore & Billett, 2008). The paper also presents ongoing work testing automated monitoring of dissolved carbon fluxes from peatlands using field logging spectrometers that capture absorbance measurements from 200 to 800nm in each sample allowing quasi-continuous recording of humic and fulvic components of the fluvial carbon flux and SUVA. This is providing both baseflow and storm response analyses to better characterize and speciate the total dissolved organic carbon flux, which is often dominated by short-term high flow events.

There are still major unanswered questions on the fate of fluvial carbon exports from peatlands as they move from the catchment to the coast in the aquatic system. The presentation concludes by highlighting some of these challenges.

## Literature Cited

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# Interannual Variability in Peatland Carbon Balances

**Mats Nilsson**
Department of Forest Ecology and Management, SE-901 83 Umea, Sweden (Mats.B.Nilsson@sek.slu.se)

The annual Net Ecosystem Carbon Balance (NECB) of mires is made up of an intricate balance of addition and export of carbon. The addition of carbon occurs by photosynthetic carbon fixation and addition of organic carbon through water recharge from surrounding areas and precipitation. C-loss occurs by release of both carbon dioxide and methane from the mire surface to the atmosphere and by C-export through water runoff from the mire. The runoff-C loss is comprised of C in the form of total organic carbon (TOC), methane and dissolved inorganic carbon (DIC). The mire NECB is dominated by the biosphere-atmosphere exchange of $CO_2$ (NEE) and $CH_4$ and the runoff C-export.

The relative importance of the major climatic drivers differs among the different C-exchange processes. Depending on the combination of the different weather variables the different flux components might therefore either even out or strengthen the mire sink or source C-flux term. Also the relative importance of each of the dominating C-flux components for the NECB differs considerably between mire types. The same variability in weather conditions might therefore have different effect on the NECB of different mire types.

The mire NECB is normally totally dominated by the gross primary production (GPP) and the ecosystem respiration ($R_{eco}$). However, these two processes counterbalance each other resulting in a NEE of a size that may be significantly further reduced by the emission of $CH_4$ and runoff export of C. One of the master controls on the annual NEE is the length of the growing season. The effect of an earlier onset or a delayed ending of the growing season is quite different. An earlier onset results mainly in an increased GPP, while a delayed ending mainly results in an increased ecosystem respiration. The effect of interannual variability in length of the growing season depends also on the latitude, i.e., the relation between growing conditions and incoming solar radiation. An earlier spring affects GPP much more on high latitudes compared to lower latitudes.

While much of the methane production relay on plant root exudation, the interannual variability in methane emission is partly related to the variability in GPP. In addition, also the position of the water table, during the part of the year with high substrate availability and high temperature, is most important in generating interannual variability in methane emission (c.f. Granberg et al., 2001). It may also be noted that in the boreal and subarctic climate zones, the soil temperature during the growing season is significantly influenced by the vertical extent, and time of thawing, of the soil frost, i.e., differences in winter climate affects the soil climate during the growing season and thereby also methane emission.

While the climatic controls on GPP, $R_{eco}$, and methane emissions are relatively complex, the interannual variation in water runoff C-export is mainly determined by the annual discharge. While the soil flow pathways influences the concentrations of TOC, some of the interannual variability in runoff C-export also depends on the proportion runoff during base flow and episodic high flow respectively.

### Literature Cited

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# Peatland Carbon Dynamics in the Holocene: Controls, Relevance, and Implications

**Zicheng Yu*[1], Julie Loisel[1], Miriam Jones[1], and David Beilman[2]**
[1]Department of Earth and Environmental Sciences, Lehigh University, Bethlehem, PA 18015, (ziy2@lehigh.edu), [2]Department of Geography, University of Hawaii-Manoa, Honolulu, HI 96822

**In this paper we evaluate the large-scale controls and global carbon (C) cycle implications of peatland C dynamics by synthesizing available data from different regions in the world. We use three different approaches to documenting and understanding the patterns and dominant controls of peatland initiation and C accumulation during the Holocene: (1) climate envelope analysis of modern peatland distribution, (2) frequency of basal peat ages, and (3) peat C accumulation histories. Climate envelope analysis of modern peatlands based on gridded instrumental climate data provides a basis for us to constrain and delineate the "optimum" and "limit" of peatland distribution at the present. This analysis will provide useful insights into understanding peatland C dynamics in the past and projecting future trajectories in a changing climate. In this analysis we especially emphasize the role of seasonal thermal and moisture conditions in controlling production and decomposition processes in peatland ecosystems, and as a result the overall pattern of net peat accumulation. Regional and global synthesis of basal peat ages document the temporal and spatial patterns of peatland initiation and expansion on the landscape. Detailed C accumulation history allows us to analyze the vertical accumulation pattern of peatlands at site-specific and regional scales. These integrated analyses help us separate potentially different controls of vertical accumulation vs. lateral expansion in peatlands.**

**We focus our analysis on northern peatlands but also discuss peatlands from other regions to illustrate the range of variations and controls of peatland C dynamics at global scale. Northern peatlands are distributed throughout the climate domain of the boreal forest/taiga biome, but with a wide range of climate conditions (especially for temperature). Of 2380 available basal peat dates from northern peatlands, nearly half show initiation before 8000 cal yr BP. Peat-core data from sites spanning peatland climate space show large variations in apparent C accumulation rates during the Holocene, ranging from 8.4 in the Arctic to 38.0 g C $m^{-2}$ $yr^{-1}$ in West Siberia, with an overall time-weighted average rate of 18.6 g C $m^{-2}$ $yr^{-1}$ for all northern peatlands. Sites with multiple age determinations show millennial-scale variations, with the highest C accumulation generally at 11,000-8000 cal yr BP. Thus rapid expansion and C accumulation occurred in the early Holocene in northern peatlands, owing to the maximum summer and minimum winter insolation and resultant high productivity and low decomposition. However, different climate space and peatland accumulation and expansion patterns are expected and emerging from other peatland regions in the world. For example, southern peatlands (including Patagonia, New Zealand, Tasmania) have a wide precipitation range but much narrow and warm temperature conditions. Also, tropical peatlands, especially in Southeast Asia, tend to occur in high temperature (also low precipitation) ends of climate space, in sharp contrast to northern high-latitude peatlands. Preliminary peat-core data synthesis from Patagonia show that most peatlands initiated or expanded between 18,000 and 15,000 cal yr BP, probably in response to land availability after regional deglaciation. However, the highest C accumulation in Patagonia occurred during the last 5000 years, when summer insolation was highest and winter insolation was lowest in the southern hemisphere. Peatland C dynamics from all these regions contributed to the variations in atmospheric $CH_4$ and $CO_2$ concentrations during the Holocene. This synthesis of data, processes, and ideas provides baselines for understanding the sensitivity of these C-rich ecosystems in a changing climate at global scale.**

# The Ecohydrology of Disturbed Peatlands: Can Peatlands be Moved Out of their Adaptive Stability Points?

**James Michael Waddington**
School of Geography and Earth Sciences, McMaster University, 1280 Main St. W., Hamilton, Ontario,
Canada L8S 4K1 (jmw@mcmaster.ca)

As natural sources of methane and long-term sinks of carbon dioxide, peatlands play an important role in the global carbon cycle as one of the world's largest terrestrial carbon sinks. In general, peatlands have an ecohydrology characterized by a long water mean residence time and a high water table position that play a large control on stabilizing this net carbon storage function. However, the ecohydrology and natural carbon storage function of peatland ecosystems can be severely affected by human and natural disturbances such as drainage, peat extraction, drought, and wildfire. Wildfire, for example, can consume several centimeters to decimeters of surface moss and peat while altering peatland water and energy balances. Peatland drainage leads to a lower water table position, increased runoff, reduced moss productivity, and enhanced peat decomposition. Moreover, harvested peatlands have been shown to become large sources of atmospheric $CO_2$ following peat extraction. Consequently, the prevailing view is that peatlands are sensitive to disturbance and once they reach an ‘ecohydrological threshold’ abrupt changes in the ecosystem may occur relatively rapidly. The occurrence of rapid and catastrophic shifts in ecosystems and the concomitant losses in carbon have been theoretically attributed to both the existence of positive feedbacks and the bi-stability of ecosystem states and several modeling and paleoecological studies support such shifts between peatland ‘stability points’. However, many field and modeling studies investigating the impacts (and rehabilitation/restoration) of drought and disturbances such as drainage, harvesting, and wildfire suggest that peatlands are dominated by self-regulating negative feedbacks and may be resilient to at least ‘moderate’ disturbance. Here I assess our current level of understanding of the role of human and natural disturbance on peatland ecohydrology and ecosystem stability and to address the question ‘Can peatlands be moved out of their adaptive stability points?’