



Increasing contribution of peatlands to boreal evapotranspiration in a warming climate

Manuel Helbig^{1,42}✉, James Michael Waddington¹, Pavel Alekseychik^{2,3}, Brian D. Amiro⁴, Mika Aurela⁵, Alan G. Barr^{6,7}, T. Andrew Black⁸, Peter D. Blanken⁹, Sean K. Carey¹, Jiquan Chen¹⁰, Jinshu Chi¹¹, Ankur R. Desai¹², Allison Dunn¹³, Eugenie S. Euskirchen¹⁴, Lawrence B. Flanagan¹⁵, Inke Forbrich¹⁶, Thomas Friborg¹⁷, Achim Grelle¹⁸, Silvie Harder¹⁹, Michal Heliasz²⁰, Elyn R. Humphreys²¹, Hiroki Ikawa²², Pierre-Erik Isabelle²³, Hiroki Iwata²⁴, Rachhpal Jassal⁸, Mika Korkiakoski⁵, Juliya Kurbatova²⁵, Lars Kutzbach²⁶, Anders Lindroth²⁷, Mikael Ottosson Löfvenius¹¹, Annalea Lohila^{2,5}, Ivan Mammarella², Philip Marsh²⁸, Trofim Maximov²⁹, Joe R. Melton³⁰, Paul A. Moore¹, Daniel F. Nadeau²³, Erin M. Nicholls¹, Mats B. Nilsson¹¹, Takeshi Ohta³¹, Matthias Peichl¹¹, Richard M. Petrone³², Roman Petrov²⁹, Anatoly Prokushkin³³, William L. Quinton²⁸, David E. Reed¹⁰, Nigel T. Roulet¹⁹, Benjamin R. K. Runkle^{26,34}, Oliver Sonnentag³⁵, Ian B. Strachan³⁶, Pierre Taillardat³⁷, Eeva-Stiina Tuittila³⁸, Juha-Pekka Tuovinen⁵, Jessica Turner¹², Masahito Ueyama³⁹, Andrej Varlagin²⁵, Martin Wilking⁴⁰, Steven C. Wofsy⁴¹ and Vyacheslav Zyrianov³³

The response of evapotranspiration (ET) to warming is of critical importance to the water and carbon cycle of the boreal biome, a mosaic of land cover types dominated by forests and peatlands. The effect of warming-induced vapour pressure deficit (VPD) increases on boreal ET remains poorly understood because peatlands are not specifically represented as plant functional types in Earth system models. Here we show that peatland ET increases more than forest ET with increasing VPD using observations from 95 eddy covariance tower sites. At high VPD of more than 2 kPa, peatland ET exceeds forest ET by up to 30%. Future (2091–2100) mid-growing season peatland ET is estimated to exceed forest ET by over 20% in about one-third of the boreal biome for RCP4.5 and about two-thirds for RCP8.5. Peatland-specific ET responses to VPD should therefore be included in Earth system models to avoid biases in water and carbon cycle projections.

The boreal biome covers about one-eighth of the global terrestrial land surface area¹ and represents a mosaic of forest, peatland and lake ecosystems that comprise roughly 80%, 15% and 5% of the biome, respectively^{2,3} (see Supplementary Fig. 1). Their total above- and below-ground organic carbon stocks of ~1,000 GtC (ref. ⁴) together exceed the 860 GtC (ref. ⁵) that is currently in the atmosphere. The largest soil organic carbon stocks are located in the regions with the highest peatland coverage (Supplementary Fig. 2) and these will adjust to a warming climate through enhanced soil organic matter decomposition⁶, vegetation productivity⁷, fire, and other natural and anthropogenic disturbances⁸, all of which represent important global carbon–climate feedbacks⁹; however, the magnitude of these feedbacks is sensitive to changes in water availability^{8,10} due to the strong coupling between the carbon and water cycle in plants, soils and the atmosphere¹¹. Water availability for soil water recharge and discharge in the boreal biome is partly controlled by atmospheric water losses through evapotranspiration (ET), which comprises both evaporation and transpiration¹². Accurate projections of future ET are therefore crucial for quantifying carbon–climate feedbacks in a warming climate¹³.

Potential ET (PET) is driven by the available energy and the atmospheric vapour pressure deficit (VPD)¹⁴, the latter of which

is the difference between the saturation vapour pressure and the ambient vapour pressure and, as such, is a measure of atmospheric demand for water vapour. Globally, the VPD in the growing season (May to September) sharply increased after the late 1990s¹⁵. Increases in growing season mean daily maximum VPD (VPD_{GS}) of up to 10% have been observed in the boreal biome since the late 2000s (in comparison with the VPD_{GS} mean of 1981–2010, Extended Data Fig. 1). With a warming climate, the atmospheric demand for water vapour is expected to grow further due to a faster increase in the saturation vapour pressure—as per the Clausius–Clapeyron relationship—compared with vapour pressure¹⁶. Accordingly, Earth system models (ESMs) project an increase in VPD_{GS} at the end of the twenty-first century (2091–2100 relative to 2006–2015). A VPD_{GS} increase of $57 \pm 43\%$ (that is, 0.38 ± 0.29 kPa, median $\pm 1\sigma$) is projected for the boreal biome (Coupled Model Intercomparison Project 5 (CMIP5), see Supplementary Table 1 for data sources) under representative concentration pathway 8.5 (RCP8.5), in which anthropogenic greenhouse gas emissions continue to rise throughout the twenty-first century, whereas a VPD_{GS} increase of $25 \pm 11\%$ (that is, 0.17 ± 0.07 kPa) is projected for RCP4.5, in which emissions peak in 2040 and decline through the twenty-first century. The absolute magnitude of VPD_{GS} changes varies across the boreal

A full list of affiliations appears at the end of the paper.