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Permafrost peat carbon approaching a climatic tipping point

Vast areas of carbon-dense, permafrost peatlands are known to be at risk from warming climates, but models indicate that they are closer to widespread climatic degradation than previously believed. All but the most aggressive climate mitigation scenarios will render these carbon hotspots climatically unsustainable across Europe and Western Siberia within decades.

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The question

Peatlands are landscapes in which dead plant matter is preserved at the Earth's surface, causing a slow build-up of soil carbon[1]. In vast areas of the northern permafrost zone, huge stocks of peat carbon have been protected for millennia by frozen conditions, but recent climate change leaves these landscapes and their belowground carbon at risk[2]. Compared with other soil types, peat has insulating properties that can slow thaw, and the response of permafrost peatlands to climatic warming is poorly understood. Additionally, the latest climate models project greater warming than their predecessors in northern high latitudes by the end of the 21st century[3], meaning that permafrost peat carbon might be at more imminent risk than previously believed. We sought to establish the climatic conditions required to sustain peat permafrost, and to estimate the amounts of soil carbon at risk under a range of future climate scenarios.

The discovery

We began by quantifying the ranges of climate, known as a climate envelope, suitable for peat permafrost. We fitted statistical models to observational maps of permafrost peatland distributions and modern climate. These climate-envelope models can be used to estimate where peat permafrost is likely to persist under future climate scenarios. In our study, we investigated how the future climates of northern Europe and Western Siberia might change during the 21st century, areas that presently support large areas of permafrost peatlands. We used the latest generation of climate models[3] to make projections under four possible emissions scenarios, ranging from a strong climate-change mitigation scenario to a no-mitigation, worst-case scenario. From these projected changes in future climate, we were able to identify areas that will become climatically unsuitable for permafrost peatlands during the coming decades. We then estimated the amount of peat carbon at risk by comparing the shrinking future climate envelopes to recent maps of peat soil carbon[4].

Our projections indicate that from 2040 the climates of northern Europe will no longer be cold and dry enough to sustain peat permafrost, even under the strongest mitigation scenario, indicating that permafrost peatlands there are close to a climatic threshold. Under the no-mitigation, worst-case scenario, we find that climates across almost all of Europe and Western Siberia will become unsuitable for peat permafrost from the 2060s; under moderate mitigation, they will become unsuitable by the 2090s (Fig. 1). By 2100, the disappearance of suitable climates under these scenarios could affect a total area containing 37.0–39.5 billion tonnes of peat carbon, equivalent to approximately twice the total carbon stored in European forests. However, our simulations project that strong mitigation could retain climates capable of sustaining peat permafrost in northern parts of Western Siberia (Fig. 1), a landscape containing 13.9 billion tonnes of peat carbon, by 2100.

The implications

Our results indicate that socioeconomic policies will strongly determine the timing and magnitude of climate-driven permafrost peatland thaw. We find that the climate envelope for permafrost peatlands is likely to disappear from Europe and much of Western Siberia this century under all four emissions scenarios. The onset of warmer, wetter climates in these regions has the potential to exacerbate greenhouse gas emissions from these carbon hotspots, which could further accelerate global climate change[5]. However, the rate and extent to which suitable climates are lost could be limited, and even partially reversed, by strong climate-change mitigation policies.

Once climates become unsuitable for peat permafrost, it is unclear how long it will take for these landscapes to thaw completely, and how thaw might affect their soil carbon. The insulating properties of peat soils are likely to delay permafrost thaw to some degree, but the magnitude of 21st century climate change seems likely to overcome this protection. Additionally, the net effect of thaw upon peat permafrost carbon fluxes remains a topical research question. For example, post-thaw fluxes of greenhouse gases and dissolved organic carbon might be partially — or even wholly — offset by increased plant productivity under warming climates.

Future studies should seek to improve maps of modern peat permafrost distributions in regions where observational data are currently sparse; for example, in remote regions of Canada and in central and eastern Siberia. Improved maps, either from remote sensing or field campaigns, would enable future modelling studies to make hemispheric-scale projections.

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EXPERT OPINION

The manuscript is highly interesting and a timely take on the near future of permafrost and organic carbon in rapidly warming peatlands of Fennoscandia and Western Siberia. To my knowledge, future climate suitability for the studied landforms has not been examined before at this large areal extent or with such a comprehensive set of separate peatland landforms.

A reviewer

[max 80 words, including sign-off]

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BEHIND THE PAPER

This research was originally intended to form part of my MSc thesis at Leeds University, in which I studied the past development of permafrost peatlands. I had planned to take the statistical model that I developed for the thesis and apply it to future climate simulations, to estimate the shrinking climate envelope for peat permafrost over the coming century. It quickly became clear, however, that studying the likely future of these landscapes, and their belowground carbon stocks, was far too big a question to tackle as an afterthought, and the work grew into a PhD project in its own right.

As the project grew, so did the team, with new collaborators bringing valuable skills, expertise and data. The final author list comprises both peatland scientists and climate scientists, and the work is very much a synergy of those fields. **R.E.F.**

Behind the paper only above this box

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FIGURE

Fig.1 | Shrinking climate space for permafrost peatlands. Projected areas with climates that can sustain permafrost peatlands in Europe and Western Siberia during the modern baseline period (1961–1990) and 2090–2099 following scenarios of strong climate change mitigation (scenario SSP1–2.6), moderate climate mitigation (SSP2–4.5) and no mitigation, worst case (SSP5–8.5). Our projections differentiate two types of permafrost peatland: those with frost mounds (palsas or peat plateaus), and those with polygonal surface patterns (polygon mires). © 202x, XXX

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FROM THE EDITOR

This study looks at the distribution of suitable climatic conditions for permafrost peatlands over space and time. It stands out due to its good geographic coverage over Europe and Western Siberia and use of the latest climate models. It also shows starkly the risks to these systems and the carbon they store if climate change is not mitigated." **Editorial Team,**

References only above this box

Nature Climate Change.