Wildfires are becoming bigger in the Siberian peatlands, with the 2019–2020 seasons seeing as many wildfires as the preceding 40 years.

CLIMATE CHANGE

Arctic wildfires at a warming threshold

Bigger wildfires in the Siberian Arctic signal release of more carbon to the atmosphere

By **Eric Post**[1] and **Michelle C. Mack**[2]

Vast amounts of organic carbon are stored in Arctic soils. Much of this is in the form of peat, a layer of decomposing plant matter. Arctic wildfires release this carbon to the atmosphere as carbon dioxide (CO_2) (*1*) and contribute to global warming. This creates a feedback loop in which accelerated Arctic warming (*2*) dries peatland soils, which increases the likelihood of bigger, more frequent wildfires in the Arctic and releases more CO_2, which further contributes to warming. Although this feedback mechanism is qualitatively understood, there remain uncertainties about its details. On page 532 of this issue, Descals *et al.* (*3*) analyze data from the 2019 and 2020 wildfire seasons in the Siberian Arctic and predict the extent of carbon-rich soils likely to burn in the area with future warming. Critically, they suggest that even minor increases in temperature above certain thresholds may promote increasingly larger wildfires.

Assessment of the relationship between climate warming and the frequency and extent of Arctic wildfires is complicated by several factors. Satellite data of the annual area burned by wildfires in the Arctic may require difficult-to-obtain ground-based validation to improve accuracy. Moreover, multiple factors may interact with warming in complex ways to influence fire occurrence, severity, and extent, such as lightning strikes, rainfall, and fuel load or vegetation cover. Add to this mix the uncertainty that derives from gaps in the geographic representation of data across the Arctic and the challenges seem almost insurmountable. The Siberian Arctic, for example, represents as much as 70% of the terrestrial Arctic, but year-to-year records of its burned area are sparse.

Descals *et al.* compiled multiple satellite-based estimates of the annual burned area for the Siberian Arctic from 1982 to 2020 to analyze associations between burned area and several factors (see the figure). According to their analysis across all sources of satellite data, 2019 and 2020 emerge as the biggest fire years for the Siberian Arctic, accounting for nearly half of the area burned for that region over the entire 39-year period and releasing nearly 150 million tonnes of carbon to the atmosphere. On 20 June 2020, the Russian town of Verkhoyansk set the record for the highest single-day temperature measured above the Arctic Circle (38°C) (*4*). On average, the Arctic region has warmed faster than the rest of the globe. Northern peatlands—including those in Asia, North America, and Europe—currently account for an annual carbon sink of ~100 million tonnes (*5*). The enormous carbon release of 150 million tonnes from the 2019 and 2020 Siberian

[1]Department of Wildlife, Fish, and Conservation Biology, University of California, Davis, Davis, CA, USA. [2]Center for Ecosystem Science and Society and Department of Biological Sciences, Northern Arizona University, Flagstaff, AZ, USA. Email: post@ucdavis.edu

PHOTO: AP PHOTO/IVAN NIKIFOROV

fires demonstrates how quickly northern ecosystems can switch from carbon sinks to carbon sources under the continuous warming of the Arctic.

The authors started with individual single-predictor models, which mostly show exponential increases in burnt area across the Siberian Arctic for each of the individual drivers. These include the increases in temperature, vapor-pressure deficit (the ability of the air to dry the land surface), climatic water deficit (more water being evaporated relative to precipitation), and the number of ignition events presumably related to lightning strikes. Building on the single-predictor models, the authors then created a multivariate model, which revealed that some of the single-predictor drivers can themselves be driven by an increase in temperature. For example, warming can directly increase the number of ignition events and indirectly increase plant water stress by increasing the vapor-pressure deficit. This in turn can dry deeper soil layers and contribute to plant water stress. By linking these processes and identifying the direct and indirect effects of warming on increasing burn area, Descals *et al.* provide insights into what the future of Arctic wildfires may look like under accelerating warming.

According to their analysis, warming of mean summer air temperature past a threshold of 10°C, or of mean summer surface temperature above 17°C, would cause disproportionately large increases in the extent of carbon-rich soils burned in the Siberian Arctic. However, patterns of both local warming (*2*) and vegetation change (*6*, *7*) are highly variable across the Arctic. Therefore, additional studies in other regions of the Arctic that harbor vast expanses of peatland, such as Canada and Alaska (*5*), are needed to test these hypotheses and their general applicability to the Arctic region.

It is worth considering the implications of increasingly frequent and large wildfires for the fate of carbon that is currently locked away in the permafrost soils and sediments that underlie much of the Arctic. Increased combustion of the insulating peat layer can expose more permafrost and lead to the thaw and decomposition of an even larger reservoir of organic matter, releasing carbon that has been stored underground for centuries or even millennia (*8*). Larger and more intense wildfires could substantially accelerate the release of permafrost carbon into the atmosphere (*9*), but this interaction is not considered in current forecasts of Arctic feedback to global warming (*10*). Future studies that link rigorous assessment of wildfires with the dynamics of permafrost thaw in these remote regions are therefore needed to better quantify their impact on climate. ■

REFERENCES AND NOTES

1. M. C. Mack *et al.*, *Nature* **475**, 489 (2011).
2. M. Rantanen *et al.*, *Commun. Earth Environ.* **3**, 168 (2022).
3. A. Descals *et al.*, *Science* **378**, 532 (2022).
4. M. Allen, *Eos* **102** (2021).
5. G. Hugelius *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **117**, 20438 (2020).
6. C. G. Collins *et al.*, *Nat. Commun.* **12**, 3442 (2021).
7. I. Myers-Smith *et al.*, *Nat. Clim. Chang.* **10**, 106 (2020).
8. E. A. G. Schuur *et al.*, *Nature* **520**, 171 (2015).
9. S. M. Natali *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **118**, e2100163118 (2021).
10. Intergovernmental Panel on Climate Change, *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge Univ. Press, 2021).

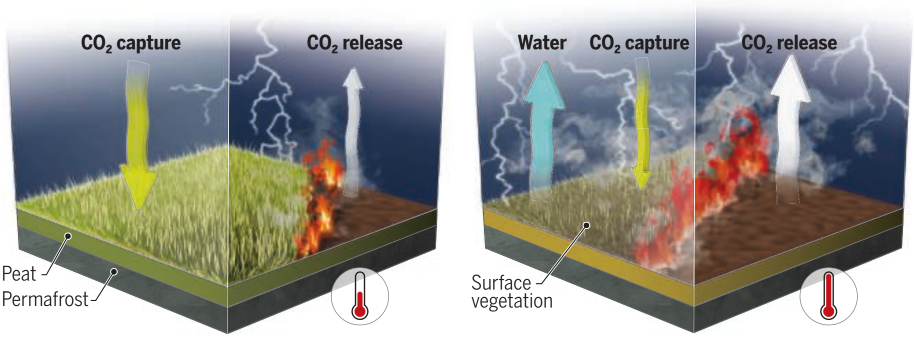
ACKNOWLEDGMENTS

The authors thank P. F. Sullivan for comments on the manuscript.

10.1126/science.ade9583

The effect of Arctic wildfires on carbon release

Arctic wildfires accelerate the release of organic carbon from the soil into the atmosphere, which can strengthen the feedback to warming.



Past
Arctic peatlands, forests, and tundra are generally carbon sinks. Cold temperatures and wet soils keep the land relatively moist, which reduces wildfire activity

Present
Higher temperatures dry the peat layer and drive more active weather systems, which lead to more frequent lightning strikes, creating larger fires that release more carbon to the atmosphere.

GRAPHIC: V. ALTOUNIAN/*SCIENCE*

NEUROSCIENCE

Gene therapy for epilepsy

On-demand inhibition of neuronal activity reduced spontaneous seizures in mice

By **Kevin Staley**

Epilepsy is the predisposition for spontaneous episodes of synchronous increases in neuronal activity, called seizures. The propensity for seizures can be reduced with antiseizure medications. But many patients do not respond (*1*), develop unacceptable side effects (*2*), or respond initially but subsequently develop tolerance (*3*). A closed-loop feedback system provides transient, on-demand treatment in response to a suprathreshold stimulus and is a potentially powerful solution to the problems of medication resistance, side effects, and tolerance (*4*). On page 523 of this issue, Qiu *et al.* (*5*) demonstrate a genetic closed-loop feedback system in mice that is designed to inhibit neurons that participate in seizure activity.

Clinically available closed-loop feedback systems use electrographic seizure detectors and intracranial electrodes; they are not capable of inhibiting neurons and can only be placed in a limited number of locations (*6*). Qiu *et al.* took a different approach to feedback: temporarily inhibiting the activity of all the neurons that participated in the last seizure. To do this, they developed a genetic strategy based on the *Fos* gene, whose expression is up-regulated by neuronal activity, including seizures (*7*, *8*).

The activity-sensitive promoter region of *Fos* was used to drive the expression of a gene encoding an inhibitory protein, voltage-gated potassium channel subunit (Kv1.1, which is encoded by *Kcna1*). Kv1.1 is opened by moderate cytoplasmic membrane depolarization (*9*). The open channel permits efflux of potassium ions and hyperpolarization of the membrane, which reduces action potential generation and neurotransmitter release by the neuron. An adeno-associated virus (AAV) vector encoding the *Fos* promoter and *Kcna1* was used to transfect neurons. When the gene therapy was expressed in cultures of mouse neurons exhibiting spontaneous synchronous activity, multielectrode arrays demonstrated a