Arctic warming

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When fire and ice meet

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Wildfires are raging around the globe with increasing intensity and frequency, transforming ecosystems and affecting the climate of regions far beyond. Now, a study shows that boreal forest fires are amplifying Arctic warming due to increased local solar absorption from biomass burning aerosols.

Recent years have been marked by a series of extreme wildfire events, releasing vast quantities of carbon dioxide and aerosols, destabilizing ecosystems and causing major socioeconomic damage. Boreal forests and the Arctic tundra in particular have experienced devastating fires of unprecedented scale and intensity[1]. Between 2019 and 2021, fires in Russia burned approximately 4.7 million hectares, accounting for 44% of the total burned area in the Siberian Arctic over the past 40 years and releasing record-high carbon dioxide emissions[2,3]. Similarly, Canada's 2023 wildfire season shattered records, extending across 7 months and much of the country's forested areas[4]. The burning of boreal forests has far-reaching consequences for regions beyond where fire occurs. The Arctic is especially vulnerable, as aerosols such as black carbon that are transported towards higher latitudes by wind can influence the radiative balance of the Arctic's atmosphere and sea ice below. Although the mechanisms of aerosol radiative forcing are well understood, the Arctic's unique environmental conditions mean that the overall aerosol effect on climate is particularly challenging to observe, understand and represent in models[5]. In addition, natural local Arctic aerosol processes are highly complex and deeply intertwined with ongoing environmental changes, such as the loss of sea-ice cover. Now, writing in *Nature Climate Change*, Qirui Zhong and colleagues[6] use model simulations constrained by satellite data to reveal that the rise in boreal biomass burning over the past two decades has led to a positive radiative forcing during the Arctic summer, primarily driven by increased solar absorption.

Aerosols are suspended particles in the atmosphere released by both natural and anthropogenic sources that modify the Earth's radiative budget through direct, semi-direct and indirect effects (Fig. 1). The direct effect refers to the absorption and scattering of radiation by aerosol particles. Aerosol semi-direct effect encompasses the set of ways clouds may be influenced by overlying aerosols that changes the distribution of atmospheric radiative fluxes and heating rates. The indirect effect occurs when aerosols modify the microphysical properties of clouds, affecting their reflectivity and persistence. Aerosols may also affect the reflectivity of the surface, as absorbing aerosol deposited on snow-covered areas decreases the surface albedo. Globally, aerosols have most probably made a significant negative contribution to the overall radiative forcing since the start of the industrial revolution, with aerosol–cloud interactions contributing approximately 75–80% to the total aerosol effective radiative forcing[7]. Even though there has been considerable progress in recent years in the understanding of the adjustment contribution to aerosol–cloud interactions, aerosols and their impact on cloud properties remain the most uncertain component of the anthropogenic radiative forcing[8].

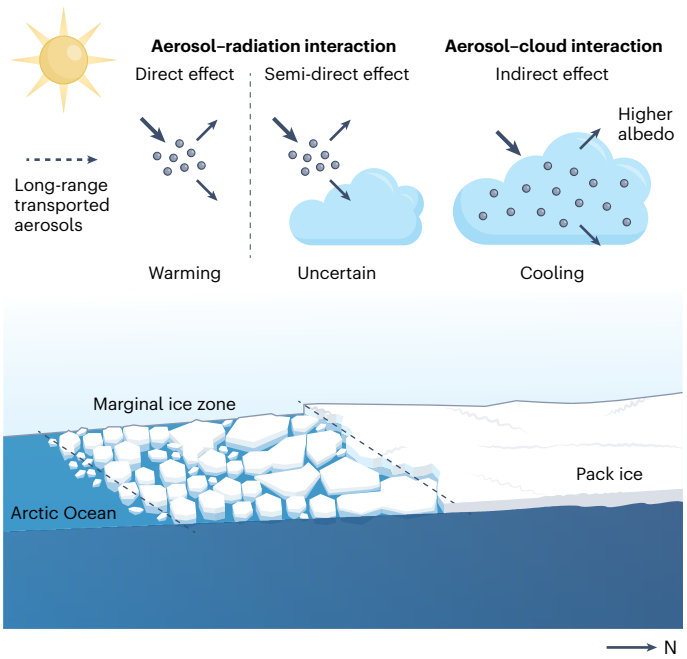

Fig. 1 | Atmospheric aerosol interactions over the Arctic Ocean. Shown are different ways aerosols can interact with clouds and radiation and their impact on the Arctic atmosphere. Aerosol–radiation interactions encompass the aerosol direct effect, which leads to warming due to absorption and scattering of solar radiation, and the semi-direct effect, which describes the way aerosols influence clouds by changing the vertical temperature and humidity profiles. Aerosol–cloud interactions describe the aerosol indirect effect whereby aerosols increase cloud albedo and lifetime via microphysical interactions, leading to cooling. The overall radiative response at the surface is also modulated by the type of surface underneath, from open ocean to the marginal ice zone with broken-up ice floes to a fully consolidated sea-ice cover.

In the past two decades, several efforts have been made to investigate Arctic aerosols and their climate impact, including two reports by the Arctic Monitoring and Assessment Programme (AMAP) on short-lived climate forcers in the Arctic, the International Polar Year in 2008, and many studies associated with field campaigns. Nevertheless, the overall contribution of aerosols to Arctic climate change remains highly uncertain. One particular challenge for models is to represent the multitude of fundamentally different aerosol processes of importance in the Arctic, such as the aerosol indirect effect on low-level clouds that are crucial for the surface energy budget[5]. Indeed, previous studies have shown that aerosols from biomass burning mostly act as a cooling agent in the Arctic atmosphere due to strong aerosol–cloud interactions in the lower troposphere[9,10]. However, these studies are

based on large-scale models that have been shown to have difficulties simulating low-level Arctic mixed-phase clouds and the aerosol size distribution, meaning that the total cloud droplet number concentration may be wrongly represented.

To address these modelling issues and gain a more detailed understanding of the impact of biomass burning aerosols on the Arctic climate, Zhong and co-authors used a global aerosol–climate model that they modified to improve the simulation of Arctic aerosols. Specifically, they increased the emitted aerosol particle size and reduced wet deposition (that is, the process by which aerosol particles are removed from the atmosphere with rainfall or snowfall) to better match observations. In addition, they incorporated satellite data on aerosol emissions and nudged the winds towards reanalysis products such that the model simulates the response to biomass burning emissions under conditions as close to observations. This is important because spurious aerosol emissions have previously been shown to lead to broad climate responses, including in the Arctic[10,11]. With this satellite-constrained model, the authors show that emissions of aerosols from boreal fires over the past two decades have had a positive effective radiative effect in the Arctic, with positive aerosol–radiation interactions outweighing negative aerosol–cloud interactions. The positive radiative effect is a result of enhanced aerosol absorption over bright surface areas such as Greenland and the central Arctic Ocean.

These results have important implications given the projected increase in wildfire severity and fire season length in the future, especially in the Northern Hemisphere[12]. Indeed, Zhong and co-authors identified an exponential relationship between temperature and boreal fire emissions, which would result in a sixfold increase in boreal emissions of biomass burning aerosols when global temperatures reach 1°C above current levels, potentially offsetting any benefit from anthropogenic black carbon mitigation efforts. However, it is important to note that these results are based on model simulations that are not fully coupled and, as such, might be missing some important processes that result from the interactions between multiple components of the climate system. In fact, the positive effective radiative forcing is only found over the ice-covered regions of Greenland and the central Arctic Ocean, whereas the rest of the globe exhibits an overall negative effective radiative forcing. It is thus possible that biomass burning aerosols would lead to global cooling and that the Arctic would also cool, despite the local positive radiative forcing. Regardless of these limitations, the work of Zhong and colleagues underscores the growing role of biomass burning aerosols in shaping Arctic climate. Further work leveraging multi-model intercomparisons and more observational constraints is required to develop a clearer understanding of the regional and seasonal characteristics of aerosol–climate interactions in a changing Arctic.

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Competing interests

The author declares no competing interests.