Fire in the Arctic: Current Trends and Future Pathways

ABC-iCAP Project
Technical Report 1

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Executive Summary

As fires in the Arctic are expected to be more common and more severe in the future, there is a need for detailed and readily available data on fires. Fire statistics and databases already contain crucial information for impact assessments, but there are improvements that can be made, both with respect to the data and its availability. Current estimates rely on official statistics and/or satellite observations, resulting in differing estimates for burned area. The main reason for this is that they have been developed for specific, often different, purposes. Both approaches offer important data, but the different approaches should be kept in mind when comparing the results and deriving trend analyses.

Comprehensive future scenarios, that would consider both human activity and climate change impacts, for fires and their emissions are lacking. Creating pathways discussing the human impacts to the fires is a first step towards such scenarios. In this report, three such pathways are presented: both low and high fire activity and risk pathways, and an expert judgement "best guess" pathway.

This report proposes that the larger boreal and Arctic community should consider the following steps to address both tracking and future development of Arctic fires.

Reporting and monitoring

- Most Arctic countries have good databases on fires, including wildfires. But the accessibility of the data should be improved. Databases should be more open to allow for wider use of the data, for example for research; good examples of this exist in Canada and the United States. For research purposes the data wouldn't necessarily need to be updated in real-time (as is the case for many operational uses) but could be provided annually after the fire season.
- The data itself could also be improved. While ignition type is often provided by official statistics for wildfires and open burning in agricultural landscapes, the associated characterization is often uncertain. Improving ignition source attribution as well as coordinating reporting efforts by operational agencies across the Pan-Arctic would allow for better targeting of policy and management decisions and approaches. An open-source centralized repository and/or data aggregation effort across the boreal and Arctic would improve science-driven policy recommendations.
- A general standardized fire size classification would help in understanding relationships between ignition types, fuels and ecosystems most commonly burning, emission sources, and management strategies. This report suggests a possible classification schema for the Arctic and boreal fires.
- Satellite and modeling methodologies need to be developed further to assist in detecting and characterizing (extreme) fire events in the Arctic countries, as larger fires can make ground-based assessments less feasible due to costs and smaller fires may be missed by current remote sensing systems.
- There are several global fire models, but each has been developed with different strengths and weaknesses. As such, no single best-all-round model exists, and comparison of country-level estimates to official statistics should not be made without understanding the models and methods involved.

Arctic fire pathways and scenarios

- To create emission scenarios for Arctic fires, both human activity and climate change impacts on fires need to be considered. The pathways developed in this report (considering the human activity aspect) need to be combined with climate change projections to achieve comprehensive fire emission scenarios.
- The pathways in this report can be further developed. Creating accepted SSP extensions often requires strong input from key stakeholders, e.g. interviews, workshops and/or questionnaires.

This report was produced for the EU-funded project *Arctic Black Carbon impacting Climate and Air Pollution* (*ABC-iCAP*), which promotes collaborative actions to reduce black carbon and methane emissions from specific source sectors impacting the Arctic, including open burning / wildland fires.

- Future scenarios would be based on the average for 2015-2021, especially in considering the location of fires and burned area. These baseline years represent a time period in which relatively normal fire seasons (in relation to the late 20th Century) and extreme fire seasons occurred in both the Arctic and boreal, providing a diverse sample of fire seasons. Additionally, the scenarios would expand the fires north (and elsewhere) to take account of changes in land use, ecosystems, changes in microclimates, etc. As it is not possible to predict exact locations of fires in the future, getting good estimates on burned area, ignition sources and drivers, and type of vegetation burned should be the main focus.
- The resulting emission scenarios would comprise a geospatial dataset that can be used alongside an anthropogenic emission model, such as the GAINS model, for years 2030, 2040, and 2050. These years represent the average fire year +/- five years around the target end dates, such that 2040 would correspond to the average fire activity in the period between 2035 and 2045.
- While this report considers the Arctic, other regions need a similar attention to create future scenarios in order to achieve a set of global emission scenarios for fires.

Introduction

Wildland fires in the Arctic are expected to become more frequent and more severe. In recent years, extreme fire seasons have been documented across the Pan-Arctic and boreal in five of the last seven years – including large wildfires in Greenland in 2017 and 2019 over tundra and high carbon soil landscapes and an earlier start of extreme fire seasons in 2023. Future Arctic and boreal fire regimes will experience increased fire risk though the end of this century (McCarty et al., 2021, Senande-Rivera et al., 2022). The main factors affecting the severity and frequency of wildland fires are fuels (vegetated biomass and type of biomass) and fuel condition (dryness), fire weather conditions (relative humidity, drought, precipitation), and ignition (human-caused, lightning). Climate change directly influences all of these drivers, and indirectly also some human-caused ignitions.

There is an increasing need for data on fires in the Arctic and nearby boreal ecosystems. However, official national statistics on burned area and estimates based on satellite observations often disagree, especially on a national level. Furthermore, while the fire risk is expected to increase in the future, there is a lack of air pollution and greenhouse gas emission scenarios, including descriptions of pathways for future Arctic and boreal fires, which are needed for climate and health impact modeling.

Alongside climate projections, there is a growing interest in utilizing and developing socioeconomic scenarios relevant to fire projections, as the implications of climate change for society depend also on demographic, economic and environmental developments, all of which are uncertain. Since such developments cannot be predicted with confidence, scenarios are useful substitutes for exploring alternative plausible future conditions. Scenarios can be used as a basis for depicting future socioeconomic development as well as for evaluating suitable policy responses and strategies from global to local scales. Several types of scenarios are commonly applied in climate change research and policy; but recently there are a growing number of studies that utilize the global Shared Socioeconomic Pathways (SSPs) as a framework for climate change analysis (O'Neill et al., 2020; Green et al., 2022). The SSPs are designed to convey climate change related information for the future that goes beyond just projection of greenhouse gas emissions. They describe alternative directions in which society could evolve globally over the 21st century and comprise narratives (O'Neill et al., 2017) and a set of quantified measures (Riahi et al., 2017). The SSPs are designed to support climate change research and policy but are global in their descriptions of socioeconomic developments and therefore rather generalized. Consequently, a variety of approaches have been employed for downscaling SSPs, and there have been a growing number of scientific exercises to create SSP extensions. These facilitate a more detailed sectoral or regional view of future developments for characterizing societal changes. There are studies that highlight some quantified characteristics related to SSPs of human demographic change in models (e.g., Wu et al., 2021) and in simulations for wildfires under changing climate (e.g., Knorr et al., 2016). However, an SSP-based extension that would scrutinize the linkages between the Arctic and boreal fires has not yet been created. The scope of this report is not to create scenarios or to develop a full SSP extension, but rather to identify some of the key human-induced factors, activities, and policy actions, as well as SSP related elements, that influence fire dynamics and can thus impact fire activity and risk pathways in the future. These identified factors can then be used as a starting point to further consider, through the SSP framework for instance, how socioeconomic development in the Arctic influences future fire risk.

This report is divided into two parts. The first part considers the differences between official statistics and satellite-based estimates on wildfires, presenting insights into how and why these differ. It also discusses fire size as an important metric, and how ground-based estimates can be combined with satellite observations to improve data reliability. In the second part we develop future pathways for Arctic and boreal fires, with a focus on human impacts of fires. These pathways are an important step in creating emission scenarios for Arctic fires. In the report we consider information relating to Arctic Council member states, focusing on the Arctic and boreal areas within these countries. For the U.S., the main focus is on Alaska, but relevant wildfire research and management from the contiguous US is also considered.

Tracking fires: observations and metrics

1

1.1 National statistics vs satellite-based estimates

Fundamentally, official fire statistics are collected with management in mind, i.e., to understand how resources are being allocated and labor deployed to assist with fires, to respond to fires in densely populated areas, and to understand the impact of fires on natural resource-based economic activity, such as timber and agriculture (Fernandez-Anez et al., 2021). Annual official statistics of fire activity are generally the mandate and/or the purview of a specific ministry or agency following specific spatial and temporal reporting requirements. Whereas some satellite-based models or databases are updated based on when the most recent fire observations are available, compiled at the end of fire seasons, and/or completed as historical studies for peer-reviewed journals.

Engineering constraints of satellite systems, such as sensor spatial resolution, physically limits the size of fires that can be detected; this often leads to differences between satellite-derived data and data obtained using detailed ground-based and/or incident reporting approaches applied to collect data for government statistics. Satellite-based burned area and active fire products have consistently underestimated fires in the understory of forests (Pan et al., 2020), in croplands (Zhu et al., 2017; Hall et al., 2021), and are negatively impacted by smoke and clouds (i.e., inhibit mapping of fires, Wooster et al., 2021). In a real-world setting, that means that official statistics on fire activity often include small, site-based burning (like pile burning of logs or quickly contained grass fires), intentionally set fires for land management (prescribed burning in natural ecosystems including understory of timber production), accidentally set fires (sparks from train networks, cigarettes), and arson. Satellite products are unlikely to accurately detect these fires given spatial and temporal constraints of current open-source Earth observation products from Sentinel, Landsat, MODIS, and VIIRS. Conversely, some European countries do not collect data on wildland fires if the fire is considered to be minor, with the result that burned area is documented for major events only (Fernandez-Anez et al., 2021). Furthermore, the exact location of the fire is sometimes lacking in official records, which can prevent a spatial comparison between satellite products and official statistics, limiting comparisons to total burned area only (Table 1). In general, MODIS and VIIRS fire products can produce both

Table 1. Official burned area estimates as reported by countries or regions of countries (McCarty et al. 2021) compared to independent estimates from the Global Wildland Information System (GWIS) Country Profiles (https://gwis.jrc.ec.europa.eu/apps/country.profile/); underestimations by GWIS compared to the official burned area statistics are highlighted in blue and overestimations are highlighted in orange.

Country/region	Year	Official burned area (km^2)	GWIS burned area (km^2)	Difference
Norway	2019	0.03	13	43233 %
Denmark/Greenland	2019	8	4	-50 %
Finland	2019	6	27	350 %
Sweden	2018	250	147	-41 %
Canada	2019	18389	12 831	-30 %
USA/Alaska	2019	10481	6 791	-35 %
USA/CONUS	2019	18876	21 181	12 %
Russia	2019	100785	116 420	16 %
Total		**148795**	**157 414**	**6 %**

an overestimation of burned area for individual fires across the entire pan-boreal/pan-Arctic region if burned area is assumed to be the native spatial resolution of the satellite pixel (Table 1) and an underestimation for understory burning in the boreal region and tundra regions of the Arctic (Chen et al., 2021).

1.1.1 Open-source official fire statistics

The Canadian National Fire Database (CNFDB), compiled and maintained by the Canadian Forest Service under Natural Resources Canada (NRCAN; https://cwfis.cfs.nrcan.gc.ca/ha/nfdb), includes data on all fires of all sizes since 1959. The fire location and perimeter data are generally supplied by Canadian territorial fire management agencies, unless the fires occur on lands managed by NRCAN. Data on burned areas from wildfires are updated throughout the year, allowing for tracking of the fire season in near real-time. Further, the Canada Centre for Mapping and Earth Observation and the Canadian Forest Service recently developed a new database called the National Burned Area Composite (NBAC; https://opendata.nfis.org/mapserver/nfis-change_eng.html) (Skakun et al. 2021), which aims to improve burned area records by combining the CNFDB database with an automated satellite-based method on active fires and change in vegetation from moderate to high spatial resolution (≤ 30 m) imagery. NBAC provides burned area estimates from 1986 to 2020 (Skakun et al. 2022).

The state government of Alaska maintains its own official statistics in addition to the federal dataset collected and maintained by the National Interagency Coordination Center (https://www.nifc.gov/fire-information/statistics/wildfires). This total wildland fires and size (1983-2022) data product is hosted by the National Interagency Fire Center (NIFC) and represents inputs from all 50 states. The Alaska-specific dataset is a compilation of annual wildland fire statistics from federal and state agencies operating within Alaska. The Alaska Fire Service (AFS) maintains a detailed record of all detected fire events since 1940 (https://fire.ak.blm.gov/). This database includes fire-related information such as the management office, fire name, geographical coordinates, estimated area, and ignition type/cause, with perimeters delineated from the best available data source. Perimeters may be drawn from aerial and high (10 m) to moderate (30 m to 500 m) spatial resolution satellite imagery, as well as topographic maps, with AFS noting differences in the scale and accuracy of the perimeters depending when and what source the burned areas were derived from.

Official fire statistics for Russia are available online via Rosstat (https://rosstat.gov.ru/) and Aviales (https://aviales.ru/), and are often divided by regional location, vegetation/fuel type, and ignition type. Both are based on reported burned areas from the official fire response (Glushkov et al., 2021), in essence these are the wildfires that are large enough to require an official wildland firefighting response from local to federal levels. As of September 2023 (the time of writing), these data reflect fires reported through 2021.

Finland has a resource and accident database PRONTO (https://prontonet.fi/), which contains fires, including wildfires. The database has information on ignition, burned area, fuels/land cover type, firefighting labor and resources used, etc. Information in the database comes directly from the firefighters who respond to the fire and is maintained and validated by the Emergency Services Academy Finland (Pelastusopisto).

Norway provides a historical wildfire occurrence database under the direction of the Norwegian Directorate for Civil Protection (https://www.brannstatistikk.no/brus-ui/). This fire occurrence dataset has point location and date of burn since approximately 2016, with land cover/fuels type provided by the fire and rescue service reporting system in Norway. While this dataset is hosted online, a recent publication had to request access to obtain the Norwegian fire occurrence for the years 2016-2019 (Bakke et al., 2023).

In Sweden, the Swedish Civil Contingencies Agency has a database on fires that lead to a dispatch (https://ida.msb.se/). The data is reported by the incident commander for each dispatch, and contains information on area burnt, area type, ignition cause, heat source, resources used, etc. Prescribed burns are not registered. There is a call for a more complete national database of wildfires (which should include prescribed fires) (Granström, 2023).

1.1.2 Novel Arctic fire regimes

Due to comparatively lower wildfire activity, Greenland and Iceland provide wildfire information in slightly different formats than other Arctic Council members. For example, in Iceland, the Icelandic Institute of Natural History maintains a website that provides updates on individual fire events from 2006-2021 (https://www.ni.is/is/rannsoknir/voktun-og-rannsoknir/grodureldar). For Greenland, scholarly and/or policy reports often rely on satellite-based estimates from the scientific literature to produce national-level fire estimates. The 2017 and 2019 wildfires in Greenland have been reported from Landsat-based estimates (Gosden et al., 2022). Similarly, the large wildfire in southwestern Iceland in 2006 relied on MODIS data to track the spread from wetlands and grasslands (Thorsteinsson, et al., 2011). Relatedly, as of the writing of this report, the authors struggled to find official statistics about wildfires in Denmark, which have historically been an issue in the heathland/peatland areas of North Jutland (Peter, 2001; Ketner- Oostra, Van der Peijl, and Sýkora, 2006) but are not reflected in the more recent VIIRS satellite record starting in 2011 (Cardíl et al., 2023). As wildfires will increase in frequency across the pan-Boreal and Arctic, including Iceland (University of Iceland, 2021) and Greenland (McCarty et al., 2021), how fire activity is reported could potentially model best practices from other Arctic Council members, as described in Section 1.1.1.

1.1.3 Prescribed burning, cultural burning, open burning, and human-caused fire data

Prescribed burning is a land management tool often used in forestry and timber production, grassland, heathland, and peatland management, and to reduce wildfire risk (Bowman and Sharples, 2023). For example, in countries where wildfires are rare, like Denmark, prescribed burning is used as a tool to prevent the spread of invasive coniferous species (Andreasen, Rossing, and Ritz, 2020). Many Indigenous groups across the pan-Boreal and Arctic use cultural burning to promote the health of plant and lichen targeted by browser species, like caribou and reindeer (Cogos, Östlund, and Roturier, 2021), and to propagate berries, fungi, and other wild foods (Christianson et al., 2022).

Further, open burning of crop residues and/or agricultural wastes is common throughout the boreal region and in areas that typically impact the Arctic with smoke from these fires. Open burning in the high northern latitudes occurs mainly in North America and Eurasia. Crop residue burning in the prairies provinces of Canada is still ongoing, with permitting and governance handled at the provincial level, but the area of open burning is often reported using satellite data (Thompson and Morrison, 2020). Open burning of crop residues is not officially tracked in Russia by current ministries that address forest/wildfires and is technically illegal, but can still account for as much as 13.4 million hectares every spring across southern and central Russia (Glushkov et al., 2021). In the temperate areas of the U.S., open burning is common (Pouliot et al., 2017), and state-level "Freedom to Farm" laws can treat the practice as proprietary information (McCarty, 2011; Nowell et al., 2019). In the EU, open burning of crop residues is largely illegal, so it is not included in current official statistics (EMEP/EAA, 2019). However, satellite observations observe burning in agricultural regions of Europe, although this activity is small in Nordic countries (https://effis.jrc.ec.europa.eu/apps/effis_current_situation/).

While ignition type ("human", "lightning", "mechanical equipment", "accidental" etc.) is often provided by official statistics for wildfires and open burning in agricultural landscapes, these data are often uncertain and considered "best guess" by the fire response agencies. When the ignition source is not completely known and/or verifiable, ignition types are sometimes referred to as "likely human" or "unknown". Operational agencies improving ignition source attribution as well as coordinating reporting efforts across the Pan-Arctic would allow for targeting policy and management decisions and approaches.

1.2 Technical specification of the commonly used global fire emissions models

Prevalence of fires and resulting emissions can be estimated from satellite/remote sensing data using global fire emissions models. The most commonly used fire emission models are GFED (Global Fire Emissions Database, a partnership between researchers at Vrije Universiteit Amsterdam in the Netherlands and University of California-Irvine, University of Maryland, and NASA in the US), GFAS (Global Fire Assimilation System, from the Copernicus Atmosphere Monitoring Service in the EU), and FINN (Fire Inventory from National Center for Atmospheric Research in the US); these models are widely cited in e.g., the IPCC and AMAP assessment reports and information conveyed at UNFCCC COP meetings. Each of these models uses observations from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensors aboard Terra and Aqua satellites (Stebel, 2023). In addition to MODIS, the FINN inventory uses SNPP (Suomi NPP) satellite's VIIRS (Visible Infrared Imaging Radiometer Suite) instrument. Terra, Aqua, and SNPP are polar orbiting satellites that orbit the earth 14 times a day and achieve daily coverage in the Arctic. MODIS detects fires in 1-kilometer pixels by locating changes in surface reflectance time series data whereas VIIRS has a much higher resolution of 375 meters and is currently on-board two satellites, SNPP and NOAA-20. Both MODIS and VIIRS provide burned area products with a resolution of 500 meters. Due to its higher resolution, the 375 m VIIRS active fire product is better suited to support fire management, and additionally has better nighttime performance (Schroeder et al. 2013). GFAS, GFED, and FINN are described in detail below. Ongoing activities, like the Biomass Burning Uncertainty: ReactioNs, Emissions and Dynamics (BBURNED) project (https://igacproject.org/activities/bburned) will focus on quantifying and understanding the difference between these current global fire emissions models, however the BBURNED project is still ongoing at the time of writing.

GFAS (Di Giuseppe et al., 2017) uses a top-down method that relies on MODIS-based fire radiative power (FRP) observations to produce daily estimates of dry matter burnt and emissions from biomass burning. FRP indicates the amount of fuel and energy consumption and smoke

produced. GFAS data includes information on mean altitude of particle injection and altitude of plume top, which are provided by the Plume Rise Model and IS4FIRES models. GFAS does not include VIIRS observations which means that small fires are more likely to be omitted. The model focusses on generating data for vegetation fires and aims to minimize detections from other heat sources, such as gas flaring. Data is provided gridded with a 0.1-degree spatial resolution and it is available from 2003 to present; the current version is GFASv.1.2.

GFED (Randerson et al., 2018) uses a bottom-up method by combining fire activity satellite observations with satellite-based information on vegetation productivity, to estimate burned area and resulting emissions from the burned areas. GFED utilizes both MODIS burned area and active fire products. GFED produces monthly, daily, and 3-hourly data on burned areas, carbon and dry matter emissions from fires. The data includes fractions of emissions contributed by different fire types and are provided as monthly emissions, but can be scaled to higher temporal resolution with the additional fields provided. The GFED dataset is separated into GFEDv4 burned area data that does not include small fires, and GFEDv4s emission data, which includes small fires with near real time VIIRS data. Data are available from 1997 onwards on a 0.25-degree spatial resolution. The current version is GFEDv4.1. There is a separate near real time product from 2019 onwards (GFEDv4NRT) that is consistent with GFEDv4s and utilizes VIIRS onboard SNPP and NOAA-20 satellites. A newer version, GFED5, is currently in peer-review (see https://essd.copernicus.org/preprints/essd-2023-182/) and indicates more than 50% higher global burned area than GFED4, illustrating the variability in results obtained using different models.

FINN (Wiedinmyer et al., 2023) is a bottom-up fire emissions inventory that provides daily global emission estimates of burned area, trace gases and aerosols resulting from open biomass burning. Emissions are calculated based on burned area, availability of biomass at the location, fraction of biomass burned and emission factors. The model has been developed to be used as input for modeling atmospheric chemistry and air quality. FINN data are available from 2002 to the present day and are provided as gridded files at 0.1-degree resolution; current version is FINNv2.5.

According to Wiedinmyer et al. (2023), FINNv2.5 global emissions are approximately twice as high as in FINNv1.5 on a global level, which is mainly due to the new processing method for burned areas. Use of VIIRS data adds approximately 25% percent more emissions compared to the FINN product that only utilizes MODIS. In comparison, GFAS and GFED emissions are generally lower compared to FINNv2.5. Similarly, emissions are

A note for policymakers on global fire emissions models

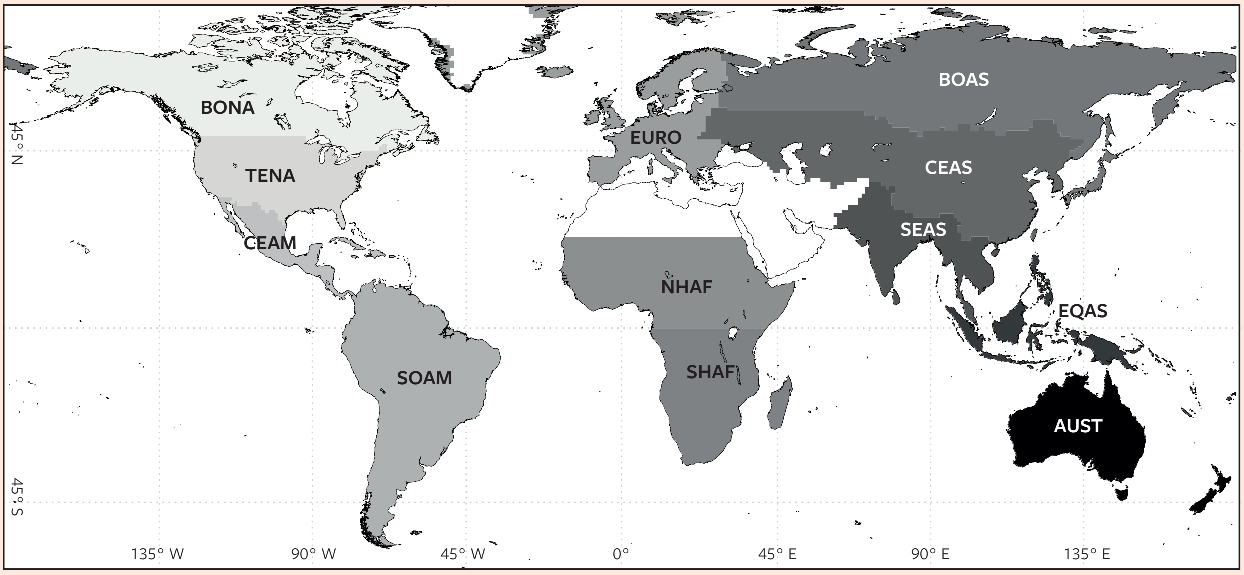


Figure 1. Regions commonly used to present global findings from fire emissions models like FINN, GFED, and GFAS (Pan et al., 2021); where BONA: boreal North America; TENA: temperate North America; CEAM: Central America; SOAM: South America; EURO: Europe; NHAF: Northern Hemisphere Africa; SHAF: Southern Hemisphere Africa; BOAS: boreal Asia; CEAS: Central Asia; SEAS: Southeast Asia; EQAS: equatorial Asia; AUST: Australia.

Global fire emissions models, like GFED, GFAS, and FINN, are useful when deriving longitudinal and/or historical patterns of fire activity and emissions for the Pan-Arctic and boreal regions. However, the spatial resolution of some of the satellite inputs (for instance, ≥ 500 m) and the global-scale resolution of the model outputs, like 0.1 degrees for GFAS, are often presented in regional outputs (Figure 1) and may not be appropriate for country-specific comparisons (Figure 2). In comparing the results from these global models to national-level official statistics, account needs to be taken of the fact that the global models are not designed for fine-scale comparisons. It is to be expected that global fire emissions models will overestimate country-specific fire emissions and/or miss small fires. These limitations imply that current global fire emissions models (circa 2021) are likely to be inappropriate for comparison with official statistics for individual countries.

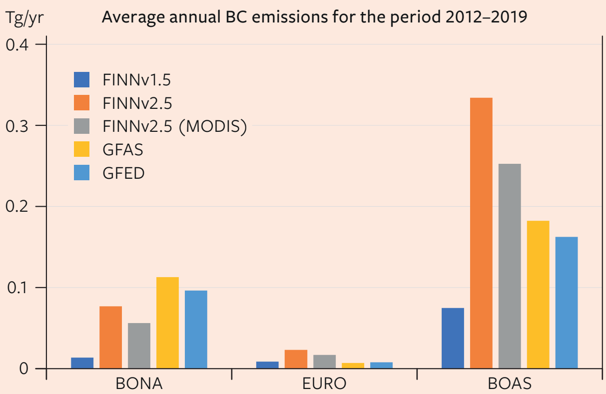


Figure 2. Comparison of annual average black carbon emissions from different versions of FINN provided by the FINN development team at NCAR and CU Boulder and estimates from GFAS and GFED (Wiedinmyer et al., 2023).

So which estimates should policymakers use? Metrics to determine the "best" global emissions model do not exist and each global emission model is optimized to improve either burned area estimates (e.g., GFED), aerosols estimations (i.e., GFAS), and/or atmospheric chemistry (i.e., FINN). By comparing estimates from all global fire emissions models, it is possible to discern trends as well as develop a consensus on extreme fire events and years (McCarty et al., 2021). Moving forward, a model synthesis approach that combines emissions from all available fire emissions models in trend analyses would produce a more complete picture of black carbon and other emissions from wildfires that impact the Arctic.

significantly higher at northern latitudes in FINNv2.5 compared to FINNv1.5. However, in Boreal North America, GFAS and GFED estimate higher BC emissions, likely due to peat fires included in model-specific vegetation types, that are absent in FINNv2.5. Improving landscape variables (as in FINNv2.5), such as vegetation or fuel type, within emissions models change the overall emissions estimates, and can significantly increase emissions for the European and Asian boreal regions (Figure 2).

1.3 Kalajoki case study: Which satellite products are most appropriate for comparison with official statistics

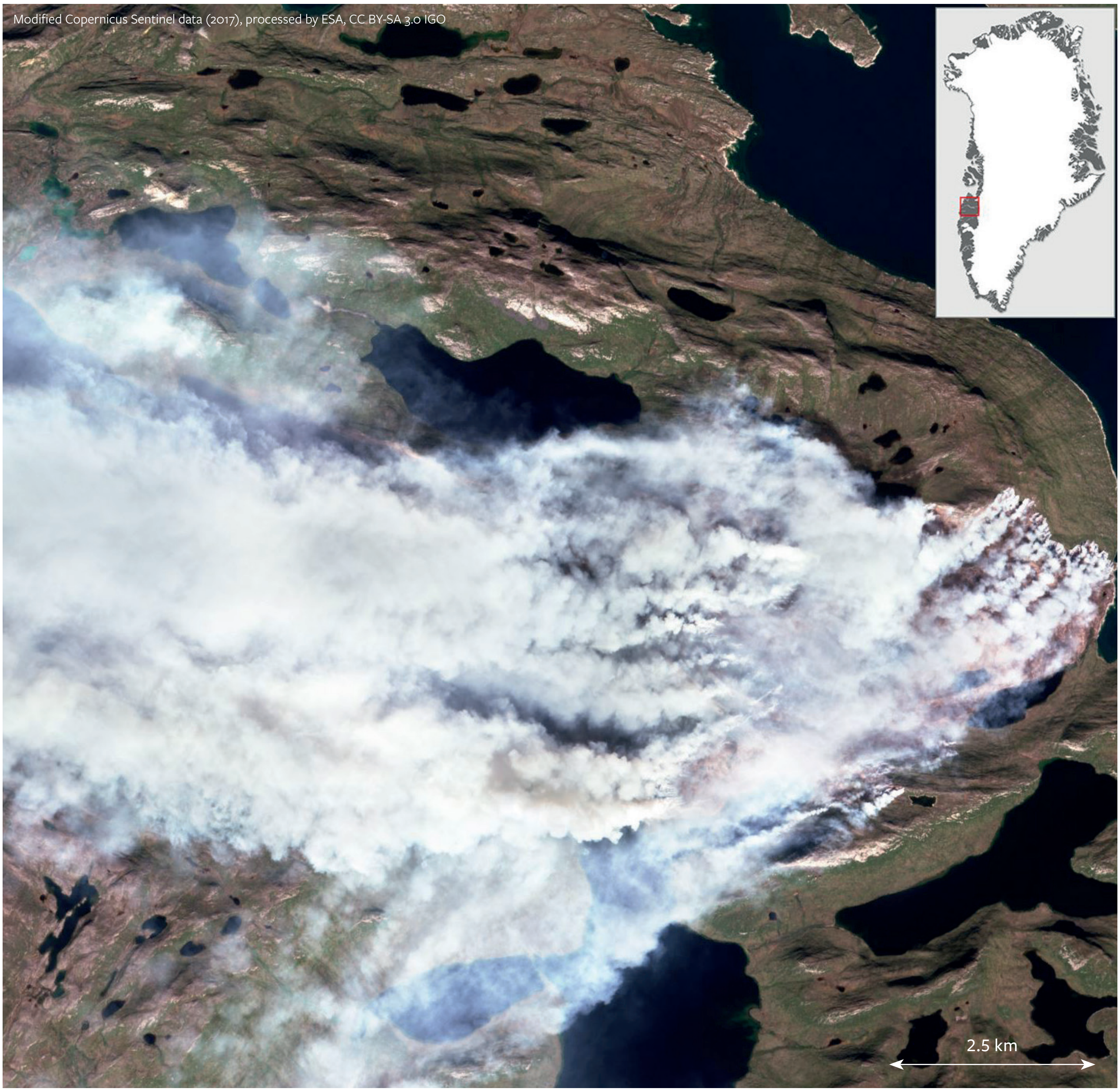
Which satellite products are appropriate for comparison with official statistics? As a case study we considered the Summer 2021 Kalajoki fire in western Finland. This fire in Kalajoki, Finland in the hot and dry summer of 2021 offers a well-documented example of a recent fire that can be used to compare the official statistics and satellite-based estimates. As previously mentioned, all global fire emissions models rely on the coarse resolution MODIS and VIIRS data, ranging in spatial resolution from 375 m to 1 km. Other open-source Earth observation data, like Landsat and Sentinel-2, are available, but lack the daily coverage of the MODIS and VIIRS active fire data. A cloud-free 10 m Sentinel-2 image of the Kalajoki burn scar was acquired on 31 August 2021 (Figure 3). Report co-author McCarty manually delineated the burn scar in GIS software several times, creating an average burned area assessment of 230 ha. Based on the PRONTO fire statistics collected by the Finnish rescue service, Pelastusopisto (https://prontonet.fi/Pronto3/online3/OnlineTilastot.htm), this Sentinel-2-derived burned area was a small overestimation of the actual 227 ha burned area estimated from in-situ measurements (Table 2). A 500 m MODIS burned area product estimated the Kalajoki burned area to be 285 ha. However, the MODIS and VIIRS active fire products that are commonly used in all global fire emissions models, such as GFAS, GFED, and FINN, produced large overestimations of the Kalajoki burned area (Table 2), as much as 10 times larger for the 1 km MODIS active fire detections if the entire pixels are assumed to be burned. If half of each 1 km MODIS pixel or 375 m VIIRS pixel is assumed to have burned, then the Kalajoki burned area estimate is 1,350 ha for MODIS and 330 ha for VIIRS, respectively.

Finnish official statistics are based on local level assessment by the fire fighters and are considered to be of high quality. Coarse resolution active fire observations from satellites commonly used in global fire emissions models are likely to overestimate small fires (i.e., fires with less than 500 ha of burned area). Of interest to policymakers is that satellite active fire observations provide locational and temporal estimates of where and when fires start and are continuing to burn with high precision and accuracy. However, translating these coarse resolution active products to actionable information on burned area that can be used for improved estimates of black carbon and greenhouse gas emissions, as well as impacts on air quality, will require rapid detection, delineation, and dissemination of moderate to high spatial

Figure 3. The 10 m true color Sentinel-2 image from 31 August 2021 of the Kalajoki, Finland burn scar (left) and the accompanying manually delineated burn scar (right).

Table 2. The PRONTO official statistics from the 10 m Sentinel-2 burned area (produced by heads-up digitizing by J. McCarty); the 500 m MCD64 MODIS Burned Area from the FIRED fire perimeter dataset; MODIS detected 27 active fires, here assumed the entire pixel burned; VIIRS detected 47 active fires, here assumed the entire pixel burned.

PRONTO official statistics	10 m Sentinel-2 burned area polygon	500 m MODIS burned area polygon	1 km MODIS active fire counts summed to area	375 m VIIRS active fire counts summed to area
227 ha	230 ha	285 ha	2700 ha	661 ha



resolution burned area. The global remote sensing community, including ESA and NASA, are moving in that direction, with a recent launch and release of the Harmonised Landsat Sentinel-2 (HSL) product that creates moderate resolution (~20-30 m) data every 2 to 3 days from approximately 2015 to present (described here: https://www.earthdata.nasa.gov/esds/harmonized-landsat-sentinel-2). Moderate to high resolution satellite coverage of the Pan-Arctic and boreal from a sensor like Sentinel-2 would result in a large original data source of ~1-2 petabytes per year analyzed (i.e., ~1 PB of data for 2020, ~1 PB for 2021, and so on) (Bauer-Marschallinger and Falkner, 2023). To fully leverage the HSL product or the 10 m Sentinel-2 data to produce a pan-Arctic and pan-boreal burned area product would likely require high performance computing (HPC) to process the large amount of data, as well as substantial training and validation data and perhaps even a semi-automated approach, such that human experts with local knowledge of High Northern latitude landscapes and fires could assess and improve a Pan-Arctic Burned Area product. From the Kalajoki case study it is clear that a higher resolution product, like one from Sentinel-2, is needed to improve and advance the mapping of and assessment of impacts of wildfires on the Arctic, but such an effort would be labor and computationally high cost. One approach could be to leverage assets and expertise of current Arctic Council working group members, as well as current Landsat-based efforts in Alaska and Canada to augment official statistics and products, but funding for work effort and dissemination of final versions of burned area data would still be a consideration. Current global fire emissions models are doing what they can with the best available active fire data, even though these coarse resolution data are likely missing smaller fires and overestimating the size of fires that are detected.

1.4 Fire size vs. fire intensity for emissions calculation and policymaking

In addition to burned area, the terms fire intensity, fire severity, burn severity and fire size are often used to estimate the impacts of fires on landscapes, as well as to calculate emissions. It is important for policymakers to note that these terminologies often have specific meanings that refer to observable phenomena in the life-cycle of a wildfire (Keeley, 1997). Fire intensity describes the process of energy being released from the burning of organic matter. Fire severity is an ecosystem-specific definition of the impacts of fire on above-ground and below-ground biomass, and often correlates well with fire intensity. Burn severity, sometimes used interchangeably with fire severity, is a scientific term commonly used in many remote sensing-based studies (Picotte et al., 2020). ***In this report, we refer to fire size, which is sometimes referred to as burned area when mapped using satellite data and products, as this is a common reporting metric by official sources and inventories and used for bottom-up emissions calculations.*** Fire intensity, fire severity, and burn severity are not routinely monitored.

Even though wildland fires tend to be larger in Canada, Alaska, and Siberia than northern Europe (Moreno-Ruiz et al., 2023), a general size classification would be helpful to better understand relationships (Grabinski & McFarland, 2020) between ignition types, fuels and the ecosystems most commonly burning, emissions sources, and management strategies. It would also allow for inclusion of new novel fire regimes in the Arctic (Evangeliou et al., 2019), such as in western Greenland, where fires range in size from 10 hectares (ha) to almost 2,400 ha (Gosden et al., 2022). The authors of this technical report propose and present below a fire size classification that is inclusive of the wildland and human-caused fire regimes across the entire Pan-Arctic/Pan-Boreal (Table 3), which may be of use for policymakers to better understand fire and fire emission dynamics, as well as to compare and pose policy-relevant science questions to global fire scientists.

Table 3. Fire size classification schema for the Pan-Arctic and Pan-Boreal.

Fire size range (in hectares or ha)	Classification label
0.1 - 200	Small-sized fires
201 - 500	Medium-sized fires
501 - 1,000	Large-sized fires
1,001+	Very large-sized fires

Fire size is important and relevant for improving emissions estimates of short-lived climate forcers and air pollution. But fire size is not the only concern for policymakers, as fire intensity and/or severity (i.e., how hot the fires burn and/or how destructive the fires are) are more relevant for assessing future damage, risk to populations, biodiversity, and infrastructure, and potentially the total carbon budget in the soils, vegetation, and terrestrial system.

As extreme fire events become more common in the Arctic tundra (Grabinski & McFarland. 2020) and also in low fire areas of managed Nordic forests, the highly detailed ground-based assessments will become less feasible due to cost (see Kalajoki case study). Satellite and modeling methodologies will need to be developed and used to assess individual fire events, large fire complexes, and impacts on the landscape and emissions. For example, current satellite-based products are based on multispectral sensors that are heavily impacted by forest canopy and clouds, thus obstructed from imaging many of the smaller ground-level fires. Future approaches will need to consider the use of synthetic aperture radar (SAR) for Arctic and boreal fire monitoring (Ban et al., 2020) and emission estimates. New mapping and modeling methods can be used to supplement ground-based approaches from national and/or provincial/state/region-based reports. For example, both Canada and Alaska (https://fire.ak.blm.gov/incinfo/aklgfire.php) combine ground, high resolution airborne, and moderate to coarse resolution satellite imagery (Loboda et al., 2017) to produce seasonal burned area estimates. Finland has detailed ground-based assessments and aerial imagery for extreme fire events. Commercial data products, like those available from Planet, MAXAR DigitalGlobe, and OroraTech could be used to produce higher temporal and spatial resolution mapping of specific wildfire events. Further, ESA's Sentinel-2 constellation can provide 10-20 m estimates for single wildfire events and/or complexes, but as of the writing of this report, no systematic burned area product exists.

Future fires: human impacts and pathways

2

Arctic fires are lacking specific future air pollution emission scenarios in both current emission models, such as GAINS (Klimont et al., 2017, AMAP 2021), and in retrospective global fire emissions models, such as FINN, GFED, and GFAS. This limits the possibility to undertake comprehensive future air pollution impact assessments that also consider wildfires. The GAINS model provides future estimates of anthropogenic emissions, for example the ECLIPSE v6 scenarios (Klimont et al., 2017, https://iiasa.ac.at/models-tools-data/global-emission-fields-of-air-pollutants-and-ghgs) as used in the most recent AMAP assessment of short-lived climate forcers (AMAP, 2021). However, for fires, the ECLIPSE datasets, developed with the GAINS model, only include emissions from agricultural waste burning.

The Fire Modeling Intercomparison Project (FireMIP) employs land-use and population density to estimate historical (from approximately 1700-2012) human-caused fires in human-dominated landscapes, such as agricultural croplands and pastures (Rabin et al., 2017; Hantson et al., 2020). The current Climate Modeling Intercomparison Project version (CMIP6) includes six scenarios of future fire emissions based on historical fire emissions (~1997-2014) derived using existing coarse-scale coupled climate-land surface models and the four SSPs. Human-dominated fire types in agricultural landscapes are then taken from FireMIP, with the main variables driving future fires considered as future increases in human population density, changes in broad types of vegetation and litter pools, and increased temperature and precipitation (Lasslop et al., 2020). In order to develop emission scenarios for future Arctic fires, climate and human activity impacts need to be taken into account in greater detail, particularly as human population density is not a reliable driver of large fires in the boreal and Arctic (McCarty et al., 2021).

Future fire scenarios would assume that climate change impacts wildfires in the future by increasing the likelihood of fire-prone conditions and lengthening of the fire season (Senande-Rivera et al., 2022), as well as increasing extreme fire weather conditions across the Pan-Arctic and pan-boreal by the 2040s (Park et al., 2023). However, human activities also influence fire dynamics in multiple ways, with some factors and characteristics more influential than others. In terms of socioeconomic development, these are, in particular, urbanization, population density and/or growth, and combined fire suppression and management capacities (Sjöström & Granström, 2023; Wu et al., 2021; Knorr et al., 2016). Moreover, various sectoral policies affect, both directly and indirectly, fire risks such as those related to land use management, agriculture (e.g. agricultural waste burning practices) and forestry. Energy-related policies (e.g., fossil fuel extraction/development and mining) can also increase human-caused fires (McCarty et al., 2021). Furthermore, incentives and different levels of training certifications, such as forestry certificates that require a certain amount of training and experience in controlled burning (e.g. “Prescribed Fire Burn Boss” (https://www.nwcg.gov/positions/rxb2) or “Firing Boss” (https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/wildfire-status/prescribed-burning/bcws_prescribed_fire_burn_boss_certification_matrix_final.pdf) related procedures in Canada and the U.S.), also play a role when estimating future fire risk. Such certification could also align, coordinate with, and learn from current Indigenous cultural burning practices, efforts, and groups seeking to reclaim and expand prescribed burning throughout much of the northern ecosystems (Hoffman et al., 2022).

In the following discussion, we describe potential fire futures for the Arctic states, which will include the northern contiguous U.S. and Alaska, as well as Greenland (Kingdom of Denmark). The emphasis is on creating future fire activity and fire risk pathways that take into account human actions and decisions regarding wildfires rather than climate change scenarios, which could be coupled in later to develop more complex climate and/or SSP pathways matrices. Descriptions of land management, land use, and policy actions plus climate change impacts will determine likely future fire rates, i.e., the level of burning per wildland fire season (a low number of fires, a medium number of fires, or a high number of fires). The human-induced factors are divided into four relevant categories: demographics, human development, fire suppression and management, and policies and incentives. In this approach, seven of the Arctic states (Finland, Sweden, Norway, Iceland, Denmark and Greenland, Canada, and the U.S.) are treated in a similar manner for the 'Lowest' and 'Highest' pathways, while the 'Best Guess' pathways are developed separately for each country. Under current strained geopolitical circumstances, the Russian Federation is considered slightly differently as information on current knowledge and conditions on the ground is lacking since February 2022. The pathways are created by using expert judgment from the author team, as well as identifying some key elements from relevant scientific literature particularly related to scenario development and recent information on wildfires in the boreal and the Arctic. A general overview of the main drivers and regional developments in the pathways can be found in the poster in Annex 1. The following sections outline the characteristics of the resulting pathways.

2.1 *We got this* – Lowest fire activity and fire risk pathway

The "We got this"-pathway (Table 4) describes the lower limit of fire risk and activity for the Arctic and boreal. In this pathway, the fire risks are reduced or even prevented, and wildland fires are tackled and fought efficiently. This results in a lower number of wildland and human-caused fires in the boreal, with smaller burned areas compared to other pathways. However, climate impacts will still increase fire activity and risk in the Arctic region and fire risk in the boreal. Thus, while some of the fire risk and fire activity can be abated, it cannot be completely abated due to climate change. Further, prescribed fire and cultural burning is a natural part of the pan-Arctic ecosystem (Christianson et al., 2022). This scenario is akin to the Maximum Technically Feasible Reduction scenario in GAINS/ECLIPSE.

Table 4. The *"We got this"* pathway

Factors	Description
Demographics (*e.g. population growth, urbanization*)	• Urbanization is well-managed and grows moderately • Managed wildland-urban interface (WUI) fire risks to control and/or lower risks • Continued global population growth could potentially increase anthropogenic ignitions or alternatively decrease ignitions and suppress fires if people concentrate in cities, converting wildlands to urban areas and decreasing rural anthropogenic pyrogenic activity (Wu et al., 2021)
Human development (*e.g. tourism, education, economical & technological development*)	• More green energy, precaution in fire-prone areas • Efficient reduction of fire risk via fuel treatments • Increased tourism in Arctic landscapes, like Greenland, increase human-caused fire ignitions but are ameliorated with fire prevention public education campaigns and policies
Fire suppression and management	• Fire suppression and management resources are in fire-smart locations including Indigenous knowledge and local fire management • High fire suppression via the population participation and official land management reducing Wildland Urban Interface (WUI) ignitions and implementing and following no-burn days or burn bans • High attack rate in fighting wildland fires • Increased prescribed and cultural burning
Policies and incentives	• Agricultural waste burning procedures limited / efficient implementation of waste burning policies • Incentives to burn are well managed and monitored • Policies in place to reduce timber- and forestry-related risks, like fires caused by timber extraction machinery/practices and increased fire risk by even-aged stands

2.2 *Let it burn* – Highest fire activity and fire risk pathway

The "Let it burn"-pathway (Table 5) describes a scenario with highest fire activity and fire risks for the Arctic. This results in a high number of fires in the boreal, with potentially large burned areas compared to other pathways. In this pathway, fire activity and risk in the Arctic region also increases due to limitations to control fire prone human activities, like tourism, timber, and fossil fuel extraction. Further, low attack rates on wildfires and less emphasis on reduction of fire risk from prescribed fire and cultural burning.

Table 5. The *"Let it burn"* pathway

Factors	Description
Demographics (*e.g. population growth, urbanization*)	• Human exposure to wildfires increases in the future mainly owing to projected population growth in areas with frequent wildfires and expansion of the WUI, rather than by a general increase in burned area (Knorr et al., 2016).
Human development (*e.g. tourism, education, economical & technological development*)	• Limited to no fire suppression because climate-driven changes increase fuel flammability and fire risk, limiting policy and wildland fire-fighting solutions • Inefficient reduction of fire risk via fuel treatments due to climate-driven changes increasing fuel flammability and fire risk, such that appropriate time periods (or windows of opportunity) to execute prescribed or restoration burning are limited such as to reduce the viability of setting these fires • Increased tourism in Arctic landscapes, e.g. on Greenland, increase human-caused fire ignitions that are not ameliorated by fire prevention public education campaigns and policies • Less green energy, more (fossil) fuel extraction in fire-prone areas
Fire suppression and management	• Limited to no fire suppression in the WUI or protected areas due to lack of public participation and official land management unable to reduce WUI ignitions or to implement and enforce no-burn days or burn bans • Inefficient attack rate of fighting wildland fires due to overwhelming scale of fire activity, not enough personnel, not enough institutional or financial resources, lack of public support • Decrease in prescribed and cultural burning
Policies and incentives	• Agricultural burning uncontrolled • Inefficient reduction of fire risk via fuel treatments due to lack of government, community, and land management agency prescribed and restoration burning treatments, such that fire policy mechanisms are not functional

2.3 *The fire will come* – Individual "best guess" fire pathways

Individual "best guess" or "The fire will come"-pathways for each Arctic state by 2050 are described below in a descriptive and semi-quantitative way. In general, 'The fire will come' pathways assume a positive linear relationship of fire activity from 2020 to 2050. The descriptive pathways are based on observed recent and extreme Arctic and boreal fire activity from 2017-2023, a baseline period that is more recent than that applied in CMIP6 or FireMIP, and scientific literature used in this report. Additional hyperlinked references are provided as needed. We have also estimated per country where this pathway is placed in relation to the 'lowest' and 'highest' fire activity and risk pathways.

United States

WE GOT THIS ——🔥—— LET IT BURN

Interior boreal forests of Alaska: wildfire may increase as fuels become drier due to climate change as well as increasing lightning strikes. Exurban growth will create increasing WUI ignition, and tourism, energy extraction, and infrastructure will continue to provide sources of human-driven ignitions. As lightning increases in the Arctic, tundra (specifically grassland) fires will become more common. Northern regions of the contiguous U.S. that currently create smoke impacts on the boreal and Arctic are likely to see increased fire risk as well. For the northern forests of the US along the Pacific and the hemi-boreal in the Great Lakes region, drier spring, summer and autumn conditions indicate increased fire risk from human and lightning ignitions. Agriculture in the northern Great Plains may intensify near the Canadian border, increasing the likelihood for open burning as one-cropping systems become double-cropping systems.

A new pilot program was introduced by the U.S. Bureau of Land Management during summer 2023 to fight fires in remote areas of Alaska - far from human population and infrastructure - as a way to limit further carbon emissions and may also lead to some reduction in total burned area.

KEY COUNTRY CHARACTERISTICS

Climate change will increase both extreme fire weather and flammable vegetation conditions for Alaska and the northern contiguous U.S. Overall, fire risk and number of fire ignitions will remain high. Prescribed and cultural burning is gaining traction as a key policy and management tool, however land tenure and fire agency management oversight in a complex mosaic of federal, state, local, tribal, and privately owned lands, coupled with a fatigued public's concern of smoke events, is still limiting widespread use of this tool.

Canada

WE GOT THIS ——🔥—— LET IT BURN

In general, hotter and drier spring and early summer weather conditions will increase wildfire risks from the Maritimes to the Pacific Ocean. Eastern mixed forests (both coniferous and deciduous) in Canada will likely see an increase in fire activity and fire risk, as increased fire weather and climatic conditions will likely outpace the transition to deciduous-dominated forests. Prescribed burning in deciduous-dominated Canada will likely be increased to prevent further climate-induced stress on sugar maple production, which could reduce fire risk in heavily managed stands for maple syrup production. Further prescribed burning and cultural burning by Indigenous communities could lower the risk of extreme wildfires by providing fuel treatments, while also increasing biodiversity, e.g., woodland caribou. Coniferous-dominated boreal forests in Eastern, Central, and Western Canada will see an increase of fire risk caused by increasing climate-driven heat and drought as well as associated bug kill/infestations, degraded permafrost and drying peat, timber and energy extraction activities, and WUI and/or exurban interface. Throughout southern Canada, grasslands will outcompete re-establishing boreal forests - creating high fire return interval regimes, i.e., annual fires on grasslands that don't allow forests to regenerate. As agriculture expands north in the Prairie Provinces, open burning in agricultural areas will likely increase. Along the Pacific coasts, 'heat domes' can cause extreme heat conditions associated with dry air that allow for extreme wildfires from any ignition source, including sparks from infrastructure like trains. As lightning increases in the Arctic, tundra (specifically grassland) fires will become more common. Land tenure is an important complicating factor in implementing more prescribed and cultural Indigenous burning - a situation that is not unique to Canada across the pan-Arctic and boreal.

KEY COUNTRY CHARACTERISTICS

Climate change will increase both extreme fire weather and flammable vegetation conditions for Canada.

Given the experience of the extreme 2023 fire season in Quebec, Ontario, and New Brunswick, so-called "less flammable" deciduous vegetation types are unlikely to decrease fire risk in southern and eastern Canada. While cultural prescribed burning may occur on reserve lands by First Nations, fire management agencies often require oversight and control, i.e., formal government (municipal, provincial, and/or federal) approval. Further, much of the rural and remote areas are considered Crown land under provincial or federal governmental statutory authority, outside the purview of formal protected forests and parks as well as First Nations reserve land.

Greenland (Kingdom of Denmark)

WE GOT THIS — LET IT BURN

Degrading permafrost and drying peat and/or carbon-rich soils will increase the amount of highly flammable ground fuels, particularly in western Greenland. As human ignition sources are the main source currently, activities like tourism (the cause of the 2017 and 2019 wildland fires) and mining may increase fire risk. As lightning increases in the Arctic, tundra (specifically grassland) fires will become more common.

KEY COUNTRY CHARACTERISTICS

Greenland is a new novel fire regime that may require innovative policy and management approaches to contain and reduce wildfire risk. It is the least well understood fire regime and ecosystem, which may require an investment in scholarly and scientific research specific to Greenland as well as co-production projects and programs with the Greenlandic population to produce culturally relevant solutions and understanding of the fire risk.

Iceland

WE GOT THIS — LET IT BURN

Iceland's current fire regime is low activity, with some documented forest, grass and peatland fires. As lightning increases in the Arctic, tundra (specifically grassland) fires will become more common. Iceland is attempting a slow reforestation effort (https://www.skogur.is/en/forestry/forestry-in-a-treeless-land/forestry-in-iceland-by-the-numbers), mainly birch, Siberian larch, Sitka spruce, lodgepole pine and black cottonwood, that could increase fire by the end of the century. Tourism is a major economic activity in Iceland, which could increase human-caused ignitions.

KEY COUNTRY CHARACTERISTICS

Iceland may become a new novel Arctic fire regime in the late 21st century, with fire risk increased by climate change and land management, specifically forest restoration efforts and risk of increasing grass and peatland fires. Like Greenland and other Nordic countries, Iceland has opportunities to prevent fires caused by tourist activity in order to maintain low fire activity overall.

Norway

WE GOT THIS — LET IT BURN

Norway's current fire regime is low activity, with some documented fires in the southern boreal forests often due to timber extraction and accidental fires caused by tourists. This will continue and potentially increase as lightning increases in the Arctic, tundra (specifically grassland) fires will become more common. Specific understanding of fire risks and further impacts on the Sami people and reindeer herding are likely needed.

KEY COUNTRY CHARACTERISTICS

Climate change will increase the likelihood of extreme fire weather, as well as potential for increased lightning activity. Human-caused ignitions (timber, tourism, accidents) are likely to continue on an increasingly flammable landscape, but remain low in the near future.

Sweden

WE GOT THIS — LET IT BURN

Boreal forest fires in managed and unmanaged timber areas will increase as summers become hotter and drier. Human ignition sources, such as timber extraction, tourism (i.e., including documented fires from small camping grills), and expanding wildland urban intermix due to exurban growth, may increase in the boreal. Peat areas will likely become sources of ignition if drained and/or dried. As lightning increases in the Arctic, tundra (specifically grassland) fires will become more common. Specific understanding of fire risks and further impacts on the Sami people and reindeer herding are likely needed.

KEY COUNTRY CHARACTERISTICS

Climate change will increase the likelihood of extreme fire weather, as well as potential for increased lightning activity. Major recent fire events have been caused by timber and tourist activities. Without policy, management, and cultural interventions, human-caused ignitions are likely to continue in an increasingly flammable landscape.

Finland

WE GOT THIS — LET IT BURN

Boreal forest fires in managed timber areas with large swathes of drained peat will increase as summers become hotter and drier. Current wildland firefighting capacity will struggle to suppress and contain ground fires (i.e., drained and/or dry peat) and ignition sources may increase with expanding wildland urban intermix due to exurban growth, vacation and summer cottages, energy infrastructure, timber extraction, and tourism. Further, even-aged timber stands of spruce will increase fire risk as diversified stands are more fire resistant. As lightning increases in the Arctic, tundra (specifically grassland) fires will become more common in Lapland. Tourism in Arctic Lapland is already an important economic activity with the likelihood of increasing in the future, which may require Lapland-specific understanding of fire risks and impacts from tourism and further impacts on the Sami people and reindeer herding.

KEY COUNTRY CHARACTERISTICS

For now, Finland's fire regimes are driven by human activity and impacts of land use (spruce-dominated even-aged timber stands and a large portion of drained peat). Climatic and weather conditions, particular hot and dry springs and summers, will increase fire risk for Finland. Timber is an important economic activity for Finland, as well as tourism, which will likely need to address wildfire risk in the imminent future to prevent extreme fire events.

Russian Federation

Limited capability to respond to fires in the remote and extremely low populated Arctic Russia as well as boreal Siberia and Far East will continue, and thus wildland fires will be permitted to burn without intervention. Due to climate change, wildfires may increase as fuels become drier, as well as a consequence of increasing lightning strikes. As lightning increases in the Arctic, tundra (specifically grassland) fires will become more common. Degraded permafrost will likely lead to more exposed dry peat Spring-time fires, which are currently not managed or assigned to specific federal ministries to fight, will continue to burn in unmanaged forests, abandoned lands, wetlands/peatlands, and croplands. Capability to respond to increasing risks is limited, and many extreme wildland fires occur in remote areas that are sparsely populated making them expensive and difficult to fight.

KEY COUNTRY CHARACTERISTICS

The geographical immenseness, compounded by the diversity of ecosystems, biomes, and economic activity (logging, energy, agriculture), means that understanding the drivers and management aspects of fires will likely require a regional approach to effectively encompass the complexity. Furthermore, current geopolitical events mean that enhanced and/or improved information, data, and knowledge from the ground is limited to researchers and observers outside of Russia. Additionally, many wildland and human-caused fires are not currently managed or fought by wildland firefighters, nor well-represented in the official public-facing data. Satellite-based remote sensing and climate/vegetation/soils/landscape models will be able to provide some insight on historical, current, and future fire events and conditions leading to increased fires.

Annex 1

Suomen ympäristökeskus
Finlands miljöcentral
Finnish Environment Institute

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ABC iCAP
Arctic Black Carbon

NASA

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Forest fires in Quebec in June 2023. Source: Société de Protection des Forêts Contre le Feu

Climate change will increase the fire activity and risk in the Arctic

- Increased lightning & drier conditions
- Longer fire seasons
- Thawing permafrost
- Transitions to grasses, moving tree line and dry peat

Other common developments across the Arctic affecting wildfires

- Expansion of agriculture further north
- More human-caused ignitions

Future pathways for Arctic forest fires

Wildfires are expected to become more common and more severe in the Arctic states due to climate change. Main cause for the fires is human activity, even in the boreal and Arctic forests. To assess the impacts of human activity to Arctic wildfires, we have created pathways for future wildfires up to 2050 for the Arctic states. We explore high and low fire activity and risk pathways for the Arctic and present our regional Best guess pathways.

We got this
Lowest fire activity and fire risk pathway

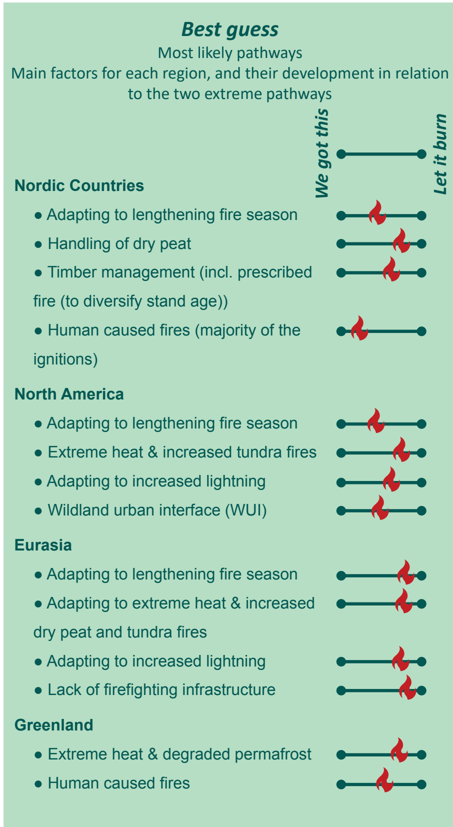
- Urban growth stabilizes, less expansion
- Wildland Urban Interface risks decrease
- More prescribed & cultural burning, high attack rates on wildfires
- Agricultural burning decreases
- Population growth stabilizes
- Reduce / prevent fires caused by tourism, accidents
- More green energy, precautions for fire-prone areas

In all pathways fire activity and risk will increase in the Arctic region and fire risk will increase in boreal region due to climate change.

Let it burn
Highest fire activity and fire risk pathway

- Limited fuel treatments
- Wildland Urban Interface risks increase
- Limited prescribed & cultural burning, low attack rates on wildfires
- Agricultural burning uncontrolled
- Limited funding for fire prevention & fighting
- Population growth in fire prone areas
- Increased tourism, limited guidance
- Less green energy, more fuel extraction in fire-prone areas

abc-icap.amap.no



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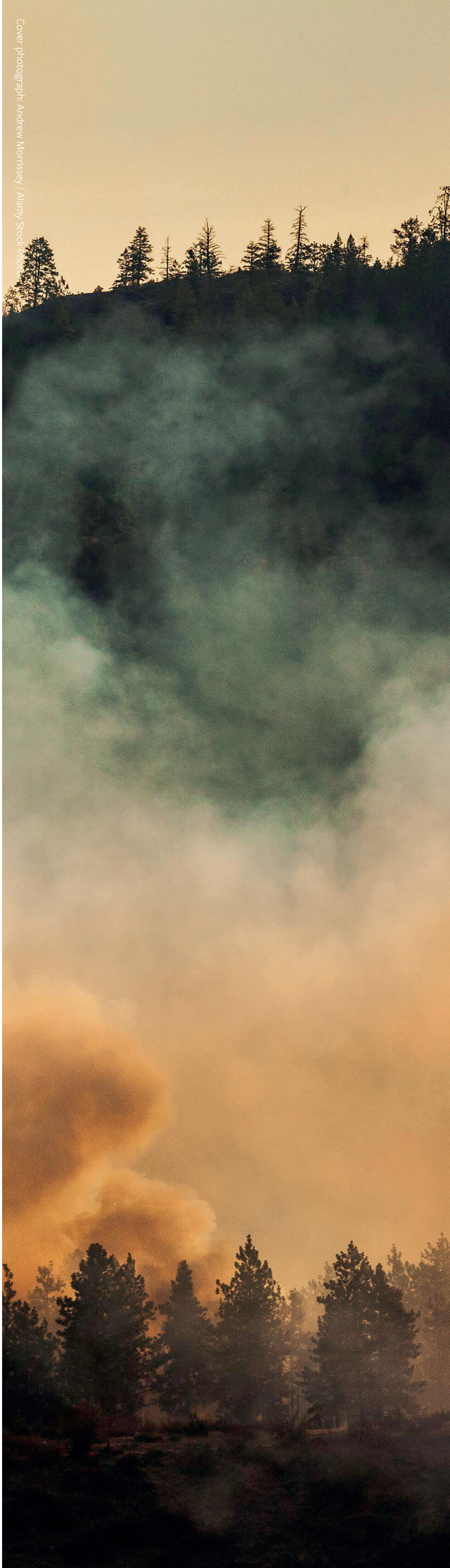

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