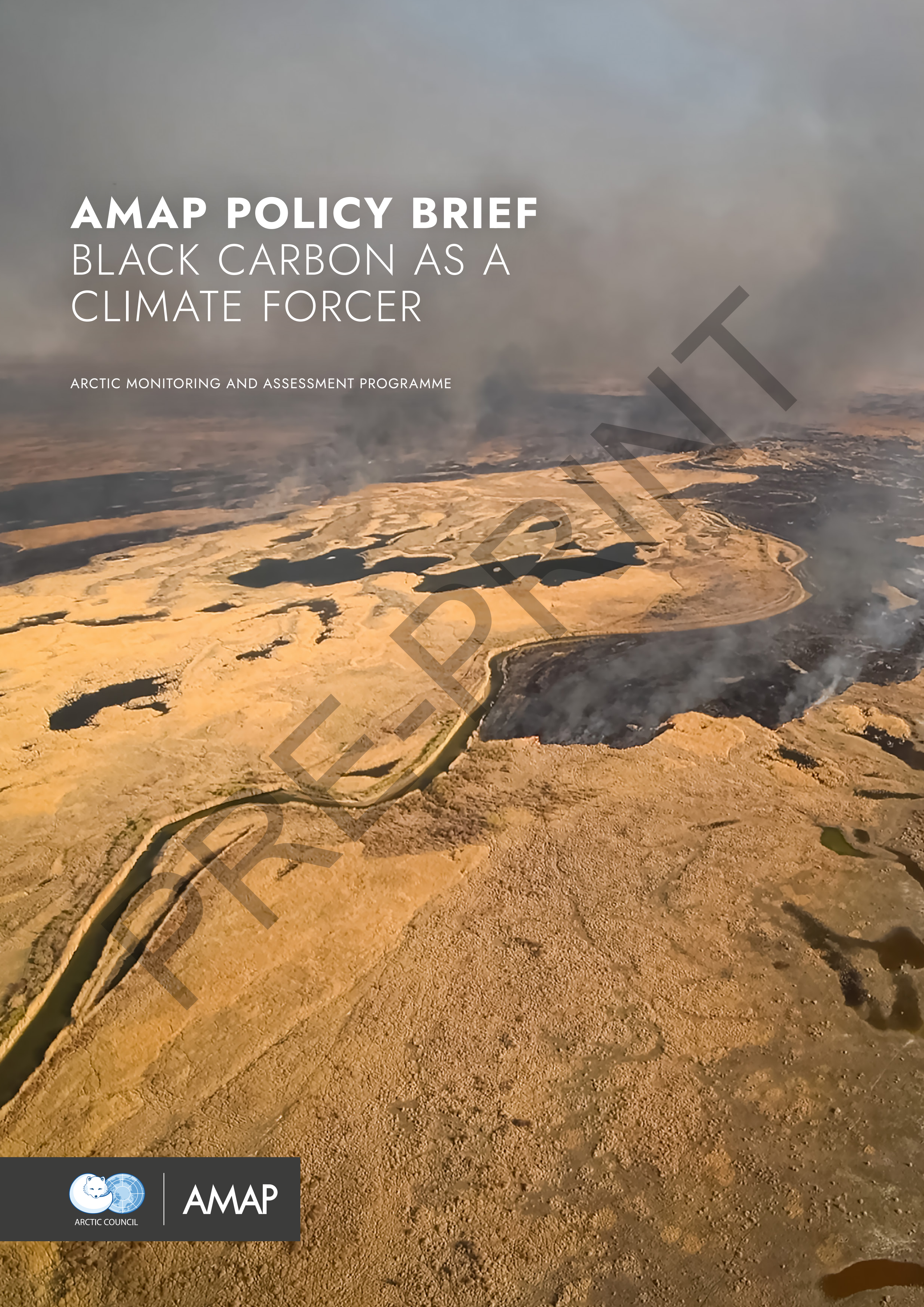


AMAP POLICY BRIEF
BLACK CARBON AS A CLIMATE FORCER

ARCTIC MONITORING AND ASSESSMENT PROGRAMME

ARCTIC COUNCIL

AMAP

POLICY RELEVANCE

Emissions of black carbon make an important contribution to global warming and have negative health impacts. AMAP's most recent assessment[1] concludes that reducing emissions of black carbon – often referred to as 'soot' – and other short-lived climate forcers (SLCFs) would reduce the rate of Arctic climate change in the short term, over the next 20–30 years, and, by improving air quality, would also significantly benefit human health globally and in the Arctic. Black carbon can be co-emitted with other atmospheric pollutants that have warming or cooling effects.

The 2021 6th Assessment Report[2] (AR6) from the Intergovernmental Panel on Climate Change (IPCC) and AMAP's 2021 assessment of SLCFs presented estimates of the potential global warming impact of black carbon emissions that appeared lower compared with AR5. However, estimates of the impact of black carbon in AR5 and AR6 are not directly comparable. AR6 reported ranges of uncertainty that implies that black carbon could even have a cooling effect. This has raised questions among some policy-makers, and the Arctic Council's Expert Group on Black Carbon and Methane (EGBCM),[3] regarding the urgency of efforts to reduce black carbon emissions, prompting AMAP to produce this policy communication.

1 AMAP, 2021a. Impacts of Short-lived Climate Forcers on Arctic Climate, Air Quality and Human Health.

2 IPCC, 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

3 Expert Group on Black Carbon and Methane, 2025. 4th Summary of Progress and Recommendations 2025.

KEY MESSAGES

KEY MESSAGE 1

BLACK CARBON EMISSIONS MAKE A SIGNIFICANT CONTRIBUTION TO GLOBAL WARMING

Black carbon is the aerosol constituent associated with a warming influence on climate.

This is the consensus from seven of the eight models used by the IPCC in AR6 and in AMAP assessments.

More recent estimates of this warming influence appear lower than earlier estimates, but the scientific consensus remains that black carbon has an important warming effect.

KEY MESSAGE 2

THERE ARE DIFFERENCES IN HOW BLACK CARBON'S CONTRIBUTION TO GLOBAL CLIMATE WARMING WAS ESTIMATED BETWEEN 2015 AND 2021

This is explained by:

- A shift from using radiative forcing (RF) to effective radiative forcing (ERF) as the metric for estimating the climate effects of black carbon (see supplementary technical explanation, text box *Radiative Forcing Metrics Explained*).
- The different sets of models used in the assessments conducted by the IPCC and AMAP in 2013-2015 and 2021 to estimate climate impacts from SLCFs and their associated uncertainties.
- New scenarios and improved methods for modelling interactions between black carbon and other atmospheric gases and aerosols.
- Different calculation approaches adopted in the AR5 and AR6 assessments, including the use of observational constraints.

The key messages of this communication regarding the likely climate impacts of black carbon on climate and air quality are that:

KEY MESSAGE 3

GLOBAL POLICIES TO REDUCE EMISSIONS OF BLACK CARBON ARE WARRANTED

Efforts should continue to reduce black carbon emissions, not least because the impact on warming from these reductions is rapid relative to reducing greenhouse gases (GHGs), including methane. Action on black carbon and other SLCFs should be viewed as a complement, rather than an alternative, to reducing emissions of carbon dioxide (CO_2), helping to slow climate change and allow other mitigation actions to take effect. Such action makes an important contribution to offsetting the warming that is 'unmasked' by reducing sulfur dioxide (SO_2) emissions and that from projected increases in black carbon emissions from sources such as wildfires.

KEY MESSAGE 4

THERE ARE CLEAR CO-BENEFITS FROM ADDRESSING BLACK CARBON, PARTICULARLY FROM IMPROVED AIR QUALITY AND REDUCED HUMAN HEALTH IMPACTS

Reducing black carbon and emissions of other SLCFs reduces incidences of disease and rates of premature death from exposure to particulate matter, and it would avoid hundreds of thousands of premature deaths worldwide. Many important sources of black carbon are also sources of other air pollutants, such as particulate matter and SO_2, that impact human health. Actions that reduce emissions of multiple pollutants, such as introducing clean energy, can be more cost effective than those targeting pollutants individually.

KEY MESSAGE 5

REGIONAL EMISSIONS OF BLACK CARBON CONTRIBUTE TO 'ARCTIC AMPLIFICATION' – THE FASTER RATE OF WARMING EXPERIENCED BY THE ARCTIC REGION COMPARED WITH THE GLOBAL AVERAGE

This is associated with the role black carbon plays in reducing reflection of incoming radiation (surface albedo) when deposited on ice- and snow-covered surfaces. AMAP's 2021 assessment of the *Impacts of Short-lived Climate Forcers on Arctic Climate, Air Quality, and Human Health* highlighted the disproportionately large role that black carbon emissions have when they occur within or close to the Arctic and confirmed that action to reduce black carbon emissions can limit Arctic warming in the near term.

RECOMMENDATIONS

1

EFFORTS TO FURTHER REDUCE BLACK CARBON EMISSIONS SHOULD CONTINUE

All current legislation to reduce air pollutants, including black carbon, needs to be fully applied and effectively implemented.

Countries are strongly encouraged to support the implementation of existing technologies that reduce black carbon emissions to strengthen current legislation. Such measures address air quality and health concerns and could partially offset increasing emissions from boreal forest fires and the Arctic warming that is unmasked following reductions in SO_2 emissions.

2

THE WORK OF THE IPCC'S SEVENTH ASSESSMENT REPORT (AR7) SHOULD BE SUPPORTED AND ENHANCED, PARTICULARLY IN CHAPTERS RELEVANT FOR FUTURE PROJECTIONS OF REGIONAL CLIMATE AND EXTREMES, BY ADVOCATING FOR THE EXPLICIT CONSIDERATION OF ARCTIC CLIMATE CHANGES DRIVEN BY BLACK CARBON FORCING

Black carbon significantly accelerates Arctic warming through both atmospheric warming and surface albedo reduction when deposited on snow and ice. However, its effects are not yet fully represented in many regional climate projections. Including black carbon forcing in AR7 would improve the accuracy of Arctic climate modelling, support more informed mitigation strategies, and strengthen global responses to regional climate extremes. IPCC messaging should better reflect differential impacts between regions of air pollutants, including black carbon, and consider new research and modelling results addressing these issues.

3

RESEARCH NEEDS TO BE FOCUSED ON BETTER UNDERSTANDING THE INTERACTIONS BETWEEN ALL SLCFS AND OTHER ATMOSPHERIC COMPONENTS

A lack of deailed knowledge about how these aerosols and gases — black carbon, organic carbon, SO_2, methane, etc. — interact with each other, and their role in cloud formation etc., is responsible for significant uncertainty in warming estimates. Addressing knowledge gaps regarding the vertical distribution of SLCFs in the atmosphere is particularly important in this respect.

Modelling activities need to be further developed to better support policy and decision-making in targeting cost-effective emission reduction strategies. Major research efforts are warranted to better understand and reduce uncertainties related to black carbon climate forcing at both regional and global scales. Emulators and machine learning provide new approaches that can be exploited in this respect.

4

MONITORING OF SLCFS, ESPECIALLY BLACK CARBON, MUST BE SUSTAINED AND ENHANCED

The modelling of climate and health impacts from black carbon and other SLCFs in the Arctic depends on continued resourcing of emissions and air monitoring in the region and globally. It is imperative that observational systems, including both satellite monitoring and ground-based observation facilities, are maintained and expanded to provide data for evaluation of emission policy effectiveness.

SUPPLEMENTARY TECHNICAL EXPLANATION

The following pages provide additional technical detail that inform the key findings and recommendations in the policy-relevant summary above. They are intended for technical advisors to policy makers.

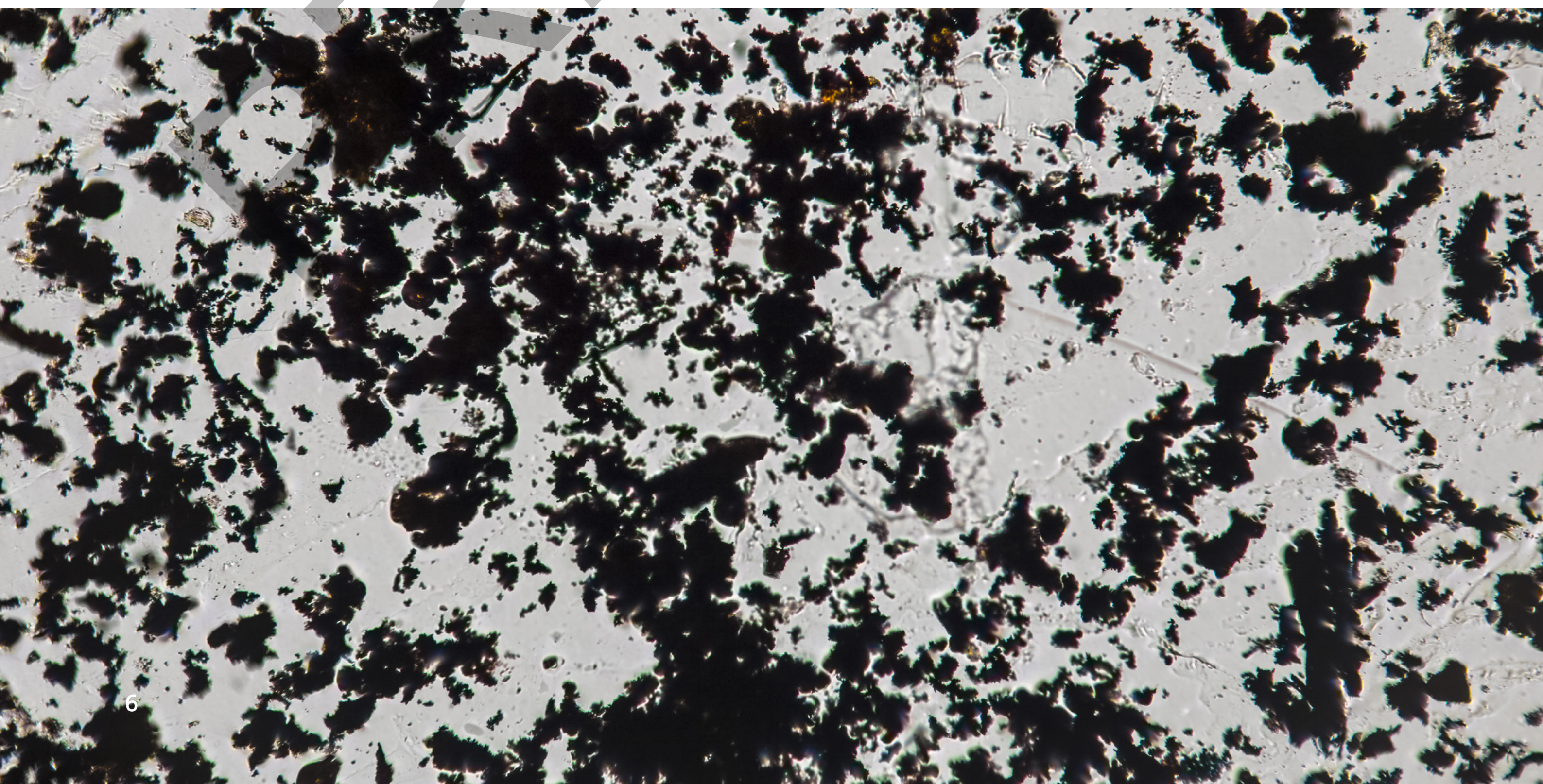
INTRODUCTION

Black carbon and other short-lived climate forcers emitted within the Arctic and at lower latitudes are making a significant contribution to warming in the Arctic and have been a subject of study by AMAP. How that contribution is likely to evolve in the future is unclear due to uncertainties in future emission scenarios and given the complexity of the climate system and of the effects (in isolation and combination) of different atmospheric pollutants, many of which are co-emitted.

Bodies such as the IPCC and AMAP rely on climate models to project the impact of emissions of short-lived climate forcers (SLCFs) into the future to help guide policy-making. Black carbon is a particularly important SLCF due to its multiple effects on climate, air quality and health. Climate models employed in the IPCC's AR6 report and those used in AMAP's 2021 assessment of SLCFs showed that black carbon emissions contribute to warming to a lesser degree than the models that informed the IPCC's 2013 Assessment Report (AR5) and AMAP's 2015 Assessment. One model in the suite used in the AR6 work suggested that black carbon could even have a cooling effect.

This apparent downward revision of the climate warming effect of black carbon between AR5 and AR6 has raised questions about the appropriate policy responses to black carbon emissions globally and in the Arctic.

This policy communication sets out to explain this revision, which is largely the result of improved methods of modelling interactions of atmospheric components, model selection, different calculation approaches, a shift from radiative forcing (RF) to effective radiative forcing (ERF) for estimating the climate effect of black carbon, and the differing scales (global versus regional) which the IPCC and AMAP are primarily addressing. It discusses the evolving understanding of the behavior and impacts of black carbon and other SLCFs and why policy should continue to emphasize rapid reductions in black carbon emissions.



WHAT IS BLACK CARBON?

Black carbon, often referred to as 'soot', is an important SLCF that is formed during combustion of fossil fuels and organic matter.

SLCFs include some greenhouse gases (GHGs), such as methane, particles, and other air pollutants that strongly influence the climate but have a relatively short atmospheric lifetime compared with carbon dioxide (CO_2). They include methane, ozone, sulphate aerosols formed from sulfur dioxide (SO_2), and black and organic carbon. SLCFs emitted to the atmosphere can have both warming and cooling impacts.

Black carbon is a component of particulates; it is a strong absorber of solar radiation and also has light-scattering properties. Particulates and aerosols can influence cloud formation, leading to cooling effects that are complex and can offset warming.

Black carbon affects the Arctic climate in the following ways:

- Emissions of black carbon in or near the Arctic absorb solar radiation and warm the atmosphere.
- Black carbon emissions at lower latitudes warm the atmosphere there, with some of that heat transported to the Arctic. The strength of the heat transport to the Arctic will depend on the relative warming within the Arctic and that at lower latitudes.
- The deposition of dark particles, such as black carbon, on snow and ice, reduces albedo, which enhances warming by decreasing the amount of solar radiation that is reflected back into space.

Black carbon can also affect air quality, impacting human and ecosystem health. Air pollution (which includes SLCFs such as black carbon) causes an estimated 7 million premature deaths globally each year.[4]

How SLCFs mix and interact with other anthropogenic and natural air components strongly influences their climate and health impacts. Changes in the amount of emissions of one atmospheric pollutant can alter the effects of other atmospheric constituents. Modelling these interactions is extremely complex, but is critical to our understanding of the impacts of SLCFs and future projections of climate warming.

This policy communication focuses on black carbon, because changes in how the climate impacts of SLCFs are modelled has led to significant revisions to estimates of the future warming potential of black carbon. Together with reductions in methane emissions, reducing black carbon emissions is an important means of mitigating global warming, with the potential to compensate for warming that would result from cutting emissions of co-emitted atmospheric climate drivers, in particular SO_2.

4 World Health Organization, Air pollution webpage, accessed November 2025.

WHAT THE IPCC AND AMAP HAVE SAID ABOUT SLCFs

In 2021, AMAP published its assessment of the impacts of SLCFs on the Arctic.[5] It used an emulator based on Earth System Model simulations to assess the impacts of regional emissions of different air pollutants, including black carbon, on radiative forcings and global and Arctic temperatures.[6]

The assessment found that black carbon, ozone, and methane contribute to Arctic warming. A significant part of the warming from CO_2 and these warming SLCFs has been masked by the cooling effects of sulphate aerosols; however, this masking has fallen over time with success in reducing SO_2 emissions to improve air quality.

These conclusions echo those found by the IPCC for the global climate impacts of SLCFs. AMAP also noted that, "for emissions of [black carbon], the global and annual mean effective aerosol radiative forcing from interactions with radiation is systematically weaker than the corresponding direct radiative forcing in the same models in 2015."[7]

AR6 estimated that black carbon contributed a global mean surface air temperature (GSAT) change of +0.06°C when comparing 2010-2019 with 1850-1900, with a range of -0.12°C to 0.25°C.[8] Note that this range includes a negative figure. This temperature metric is based on a best-estimate of effective radiative forcing – a measure of a change in the energy balance at the top of the atmosphere – of 0.11 W/m^2, with an error range of -0.20 to 0.42 W/m^2.

These figures are 75% lower than estimates of the impacts of black carbon in AR5: that estimated direct radiative forcing from black carbon of 0.40 W/m^2, with an error range of +0.05 to +0.80 W/m^2.[9]

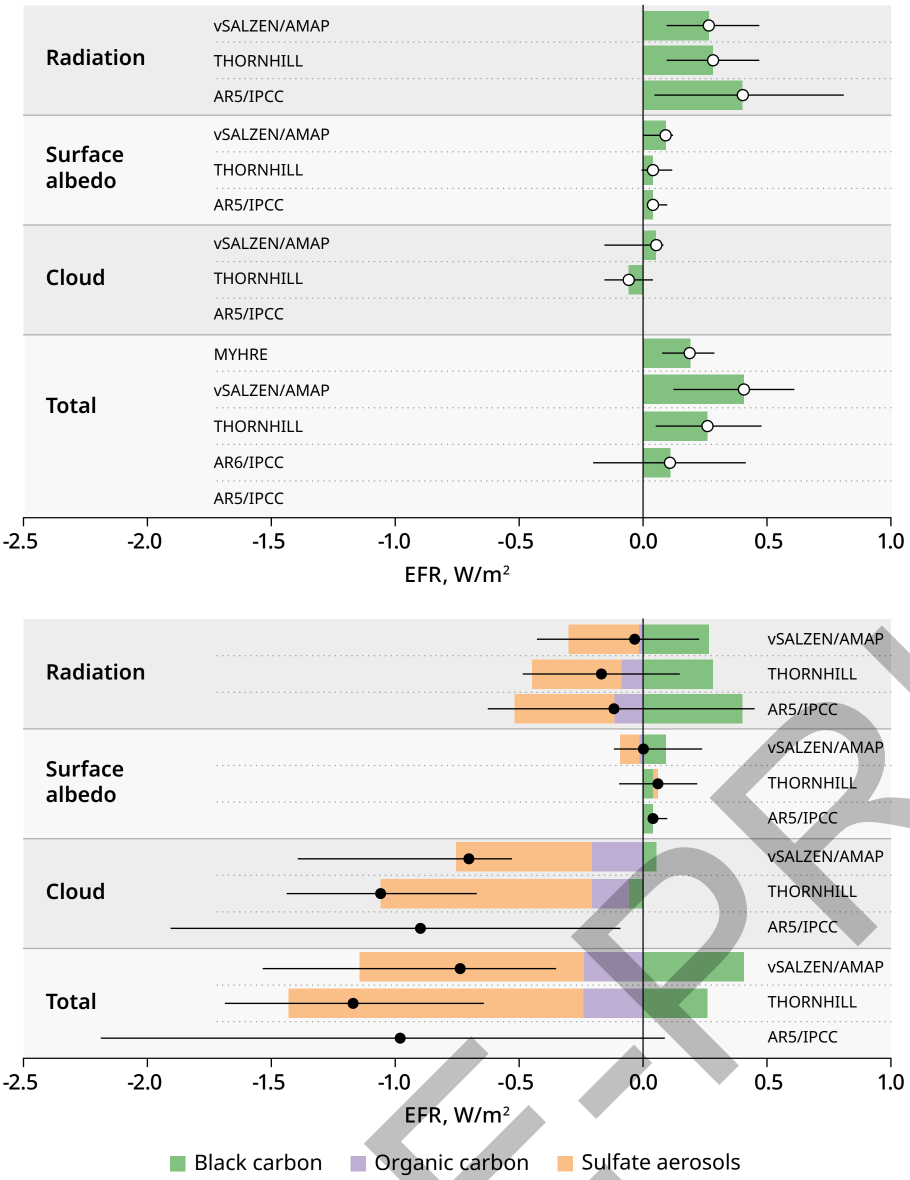
5 AMAP, 2021b. Impacts of Short-lived Climate Forcers on Arctic Climate, Air Quality, and Human Health. Summary for Policy-makers.

6 von Salzen, K., et al., 2022. Clean air policies are key for successfully mitigating Arctic warming.

7 AMAP, 2021a. Impacts of Short-lived Climate Forcers on Arctic Climate, Air Quality and Human Health, page 252.

8 IPCC, 2021. Climate Change 2021: The Physical Science Basis. The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

9 IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate, page 617.



Components of global mean aerosol effective radiative forcing.

Figure 1: Comparison of recent estimates of black carbon effective radiative forcing (upper panel) and components of global mean aerosol ERF (lower panel) from:

vSALZEN/AMAP: von Salzen et al., 2022[10] applying an emulator developed in connection with AMAP's 2021 assessment of SLCFs (AMAP, 2021),

THORNHILL: Thornhill, et al., 2020.[11]

AR6/IPCC: the IPCC sixth assessment (IPCC, 2021[12]),

AR5/IPCC: the IPCC fifth assessment (IPCC, 2013[13]) and

MYHRE: Myhre et al., 2025.[14]

Notes to graphic: *Radiative forcing estimates shown in the graphic refer to different present-day (2014–2019) relative to pre-industrial baseline (1750–1850) years, and apply different model ensembles. Global sulfur emissions used in the AMAP emulator work are lower than those used in the IPCC assessments, which partly explains differences in sulfate radiative forcings.*

Confidence intervals (error bars) are indicated by black horizontal lines. Contributions from different aerosol species are not available for cloud radiative forcing in AR5 or for surface albedo in AR6. which partly explains differences in sulfate radiative forcings. Confidence intervals (error bars) are indicated by black horizontal lines. Contributions from different aerosol species are not available for cloud radiative forcing in AR5 or for surface albedo in AR6.

10 von Salzen, K., et al., 2022. Clean air policies are key for successfully mitigating Arctic warming. (Table 3).

11 Thornhill, G.D., et al., 2020. Effective radiative forcing from emissions of reactive gases and aerosols – a multi-model comparison.

12 IPCC, 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Table 6.SM.1.

13 IPCC, Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

14 Myhre, G., et al., 2025. The warming effect of black carbon must be reassessed in light of observational constraints.

WHAT EXPLAINS THE DIFFERENCE IN WARMING FROM BLACK CARBON AS ASSESSED IN AR5 AND AR6?

The estimates of radiative forcing from black carbon in AR5 and AR6 are not directly comparable. While they appear lower in the latter, this can be explained by the following factors.

DIFFERENT SELECTION OF MODELS

Climate models are used by scientists to understand the processes and interactions that drive changes to the Earth's climate. They combine historic and projected data with complex equations that describe, for example, interactions between the oceans, atmosphere, land, and ice. This involves taking account of many factors and processes that influence incoming solar radiation, including emissions of GHGs and co-emitted air pollutants, the roles of water vapour and volcanic activity, and land cover change. With limited observations, models provide a way both to fill gaps and to investigate through future projections expected developments under defined policy scenarios.

All climate models represent real processes by mathematical equations and simplify how the climate system works, and each of them does so in unique ways. Some models capture the physics in the atmosphere, and often interactions with the oceans, including transfers of heat. Earth system models (ESMs) are more comprehensive, in that they incorporate biogeochemical processes, such as the carbon cycle, atmospheric chemistry, ocean ecology, and changes in land use.

There are trade-offs between use of simpler and more demanding models in relation to their capability to represent the real world and the computing resources they require to run. Comparing simulations from different models helps scientists understand where there is broad agreement on the impact of a chemical or a process, or where there is disagreement between models. This is reflected in model uncertainties.

The IPCC and AMAP use both ESMs and chemical transport models (CTMs) to simulate atmospheric chemistry and better understand the distribution and role of pollutants, including SLCFs, in global warming.

In its 2021 assessment, AMAP used 18 atmospheric and earth system models. AR6 uses results from many modelling groups, but its conclusions on black carbon were based mainly on eight models, one of which found a cooling impact from black carbon.

That model, MIROC6, treated black carbon as externally mixed, meaning that the particles are assumed to remain as a single, distinct chemical species. However, in the atmosphere, their surface can be partially or completely coated by other chemical species. This can have a significant effect on their absorption of solar radiation. The model also assumes relatively rapid removal of black carbon through precipitation, reducing its time in the atmosphere and therefore its radiative forcing.

NEW SCENARIOS AND IMPROVED METHODS FOR MODELLING INTERACTIONS BETWEEN BLACK CARBON AND OTHER ATMOSPHERIC GASES AND AEROSOLS

For AR5, the IPCC used climate models from phase five of the Couple Model Intercomparison Project (CMIP5), run by the World Climate Research Programme. For AR6, it used CMIP6, which included a number of enhancements and improvements which, among other things, provided a more nuanced picture of the effects of SLCFs on warming. CMIP6 better modelled the interactions of aerosols and clouds to provide a more accurate estimate of their radiative forcing, with the effect that this estimate was lower.

MOVING TO A DIFFERENT MEASURE OF RADIATIVE FORCING

The key reason for the apparent reduction in the estimated warming impact of black carbon as discussed in the AR6 and AMAP 2021 work relative to that reported in the AR5 is a move from using radiative forcing (RF) to effective radiative forcing (ERF – see text box on page 12) to measure the climate impact of black carbon.

RF is a measure of the influence of the introduction of an atmospheric climate forcer, such as black carbon, on solar radiation entering the Earth's atmosphere, in watts per square meter (W/m^2). RF provides a useful measure of the long-term change in the globally averaged temperature at the Earth's surface, measured over decades.

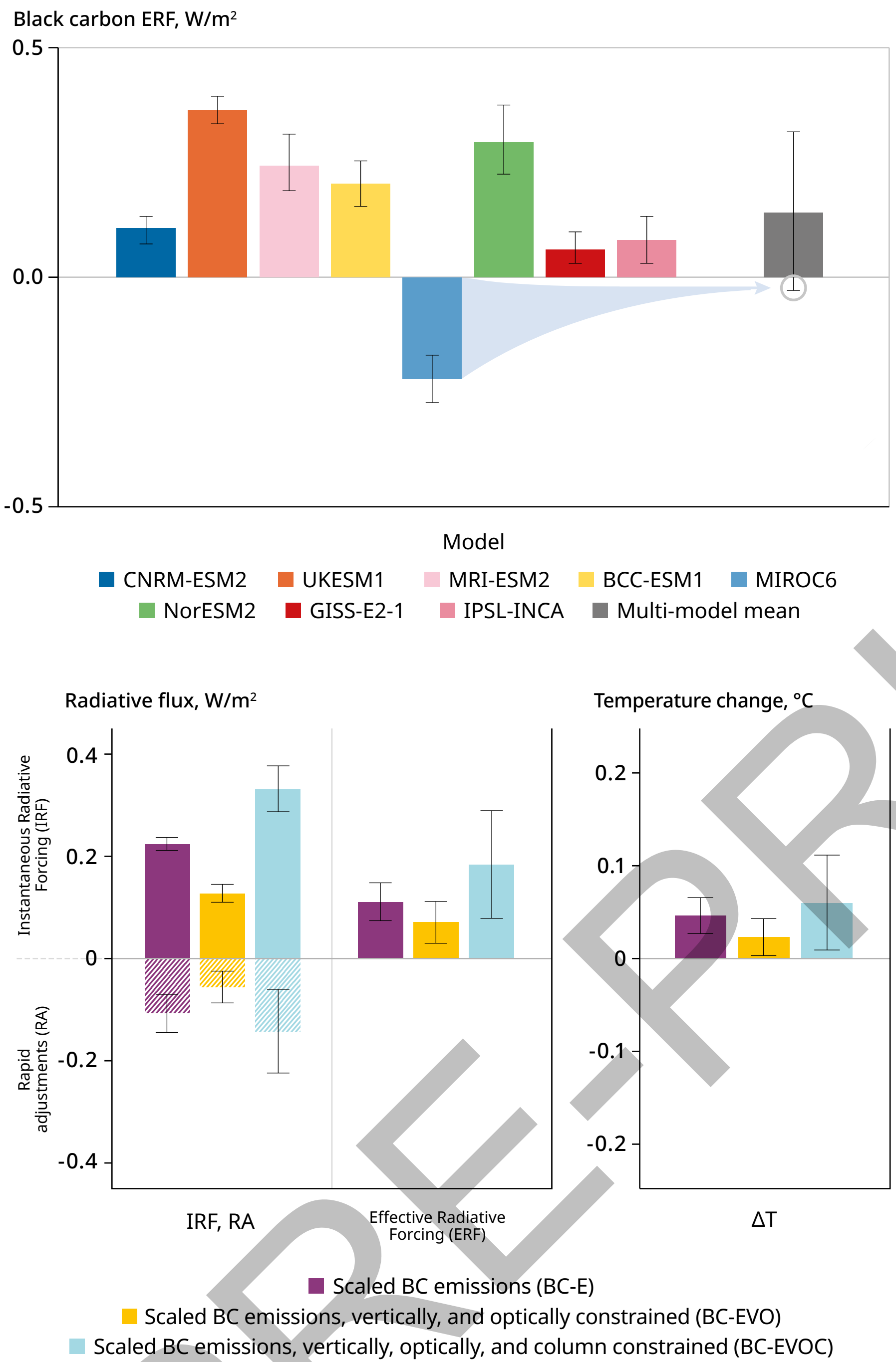


Figure 2: Contributions of black carbon to radiative forcing and surface temperature change

Upper panel: Contributions from black carbon to aerosol effective radiative forcing for models used in AR6. Source: modified from Thornhill et al., 2021.[15]

ERF interannual variability represented by error bars showing the standard error. The multi-model mean is shown with the mean value and error bars indicating the standard deviation. (https://acp.copernicus.org/articles/21/853/2021/ and https://acp.copernicus.org/articles/21/853/2021/acp-21-853-2021-supplement.pdf)

Lower panel: Results from four models estimating black carbon instantaneous radiative forcing (IRF, solid fill), the effect of rapid adjustments (RA) on black carbon radiative forcing (hatched bars) and the resulting estimates of effective radiative forcing (ERF = IRF plus RA) under three scenarios, also showing the estimates for associated surface temperature change. Source: modified from Myhre et al., 2025.[16]

RF, however, does not measure adjustments within the atmosphere in response to these forces. For example, aerosols, such as black carbon, contribute to cloud formation. Clouds can both block incoming solar radiation (reducing warming) or prevent outgoing radiation (increasing warming).

To better capture these influences, the IPCC and AMAP switched to a different metric, ERF, in the AR6 and AMAP 2021 assessment reports. ERF takes into account atmospheric responses to initial forcing, such as changes in atmospheric temperature, water vapor, and cloud cover. Since a significant portion of the positive forcing (warming) from black carbon is offset by these rapid adjustments – nearly 50%, according to a recent study (Figure 2 and footnote 15) – this has resulted in a lower estimate of its overall warming impact, although the scientific consensus is that black carbon still has a warming effect.

DIFFERENT CALCULATION APPROACHES

In AR5, observational data was used to refine estimates of the warming effects of black carbon, specifically regarding its absorption of solar radiation. This was done because models appeared to underestimate forcing attributable to this absorption compared with observations.

15 Thornhill, G.D., et al., 2020. Effective radiative forcing from emissions of reactive gases and aerosols – a multi-model comparison.

16 Myhre, G., et al., 2025. The warming effect of black carbon must be reassessed in light of observational constraints.

RADIATIVE FORCING METRICS EXPLAINED

Between AR5 and AR6, the IPCC increasingly applied effective radiative forcing (ERF) as opposed to radiative forcing (RF) as its preferred measure of how climate change drivers are expected to affect surface temperatures. It did so because ERF provides a more comprehensive representation of those effects.

RF measures changes in the energy balance at the top of the atmosphere caused by changes in climate forcers – such as the amounts of GHGs, aerosols, or solar radiation. It provides a snapshot of how surface temperatures respond to these changes.

However, those climate forcers trigger responses within the atmosphere. These 'rapid adjustments' include cloud formation, changes in water vapor and temperature, or changes in aerosol formation and behavior, which themselves lead to different longer-term temperature changes, either upwards or downwards.

ERF therefore provides a more complete picture of the effects and interactions of different climate change drivers, and more accurate predictions of eventual changes to surface temperatures. However, these interactions are complex, and some are poorly understood.

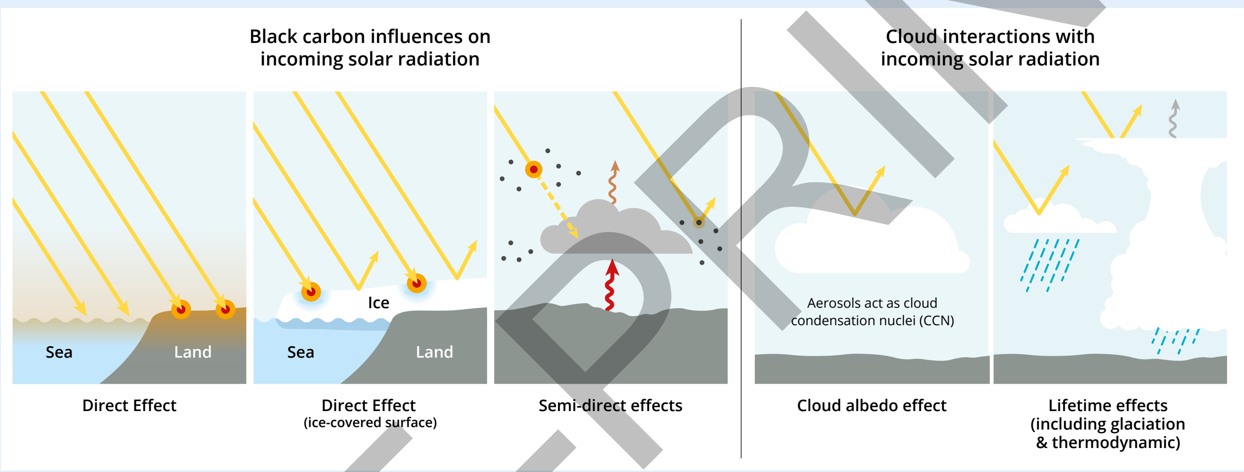


Figure 3: Direct and indirect influences of black carbon on incoming solar radiation

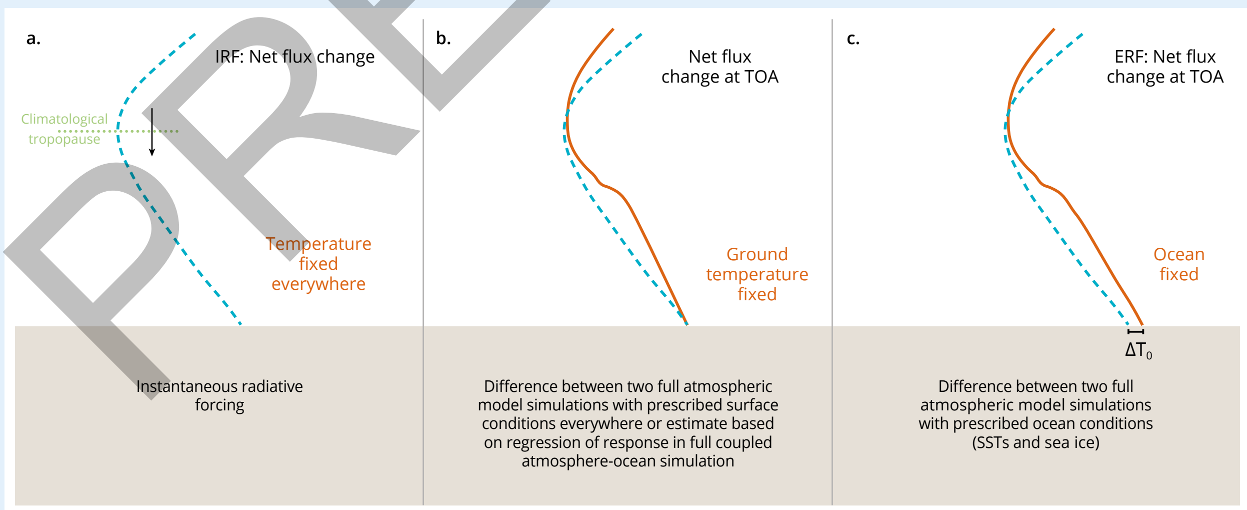


Figure 4. Schematic comparison of modelling of (a) instantaneous radiative forcing (IRF), (b) flux change when surface temperature is fixed over the whole Earth (a method of calculating ERF), (c) the ERF calculated allowing atmospheric and land temperature to adjust while ocean conditions are fixed.[17]

17 After IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate, Chapter 8, page 669.

However, more recent research led to this assessment being revised for AR6. This research examined, among other things, how representative observational sites are, how long black carbon remains in the atmosphere, and how it interacts with other aerosols.[18]

While AR6 did apply observation-based scaling to its estimate of black carbon's ERF, it applies a different scaling methodology intended to harmonize the total aerosol ERF calculated using different methods. This scaling introduces its own uncertainty and is partially responsible for reducing the black carbon ERF estimate.

REGIONAL VERSUS GLOBAL IMPACTS

There are further complexities caused by this move to using ERF. Rapid adjustments captured by ERF differ at different latitudes. As the 2021 AMAP assessment noted, ERF from interactions of black carbon with radiation in the Arctic, of 0.96W/m2 (±1.21), is much greater than the global mean of 0.08W/m2 (±1.08).[19] This contributes to Arctic amplification, which is leading to the region warming at more than three times the rate in the mid-latitudes since the mid-20th century.[20]

Part of this difference is explained by the modelled effects of black carbon on surface albedo, and specifically the warming effect of the reduction in the albedo of Arctic snow and ice caused by black carbon deposition.

In addition, some models may underestimate this albedo effect, because they only include the impact of the most recently deposited black carbon. As snow and ice melt in a warming climate, they expose black carbon deposited in previous years.

18 IPCC, 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, section 7.3.3.1.2.

19 AMAP, 2021a. Impacts of Short-lived Climate Forcers on Arctic Climate, Air Quality and Human Health, Table 8.4, page 253.

20 AMAP, 2021b. Impacts of Short-lived Climate Forcers on Arctic Climate, Air Quality, and Human Health. Summary for Policy-makers; and AMAP, 2025. Arctic Climate Change Update 2024: Key Trends and Impacts. Summary for Policy-makers.

CONCLUSIONS

MODEL UNCERTAINTY IN CONTEXT

It is important to put the relative contribution of key SLCFs into perspective and to consider the time scales of changes in emissions in relation to atmospheric lifetimes of different GHGs and SLCFs.

There is still a lack of agreement between models on the magnitude of the climate impact of black carbon. This compares with relatively good agreement regarding the climate impact of SO_2.[21]

However, almost all models project that black carbon does indeed have a warming influence. As noted above, the single case where a cooling influence was projected in the AR6 work could be explained by the different assumptions that that model made about the behaviour of black carbon.

Differences between model results can help identify processes that may be poorly represented in models and which therefore warrant further investigation. So, while such a difference is not a reason for rejecting the results of a particular model, outlying results become less significant when viewed as part of an uncertainty range based on a wider ensemble of model results.

In summary, the difference in black carbon climate impacts shown between AR5 and AR6 are small compared with the overall differences in model results and the best estimate of the net impact of black carbon on surface temperatures, both globally averaged and in the Arctic, is still warming.

WHAT DOES THIS MEAN FOR THE POLICY MESSAGING FROM AMAP?

Modelling uncertainties surrounding the climate warming role of black carbon (its radiative forcing) has prompted discussion around the extent of the benefits of action to reduce emissions of black carbon.

Although there is not unanimity among researchers, modelling results support a scientific consensus that black carbon has a warming influence both globally and in the Arctic. If emissions of SLCFs such as black carbon and methane are not reduced, the warming due to reducing sulphate emissions would become more apparent. Policy-makers would miss an opportunity to reduce sources of air pollution that contribute to disease and premature deaths. In addition, emissions of black carbon from natural and semi-natural sources (such as wildfires) are expected to increase, making it important to address anthropogenic sources.

WARMING IMPACT

Reductions in SO_2 emissions have diminished the cooling impact of sulfate aerosols in the atmosphere, 'unmasking' a significant amount of global warming – almost half of the warming seen at midlatitudes.[22] SO_2 emissions are forecast to continue to decline, contributing to 30% of warming expected by 2050, under a scenario assuming that current legislation is implemented.[23] AMAP's analysis estimated that reductions of black carbon and methane could offset the loss of SO_2's cooling effects.

Table 1. Global effective radiative forcings from aerosol interactions with radiation, surface albedo, and clouds for global emissions of sulfur, black carbon, and organic carbon in 2015, relative to a preindustrial atmosphere with no anthropogenic aerosol emissions. *Source:* von Salzen et al., 2022.[24]

Emitted SLCF species	Global effective radiative forcing (W/m^2) from aerosol interactions		
	Radiation	Surface albedo	Clouds
Sulfur	-0.28 (-0.6 to -0.12)	-0.08 (-0.11 to 0.14)	-0.55 (-1.2 to -0.5)
Black carbon	0.26 (0.1 to 0.46)	0.09 (0 to 0.11)	0.05 (-0.15 to 0.06)
Organic carbon	-0.02 (-0.16 to -0.02)	-0.01 (-0.06 to 0.06)	-0.21 (-0.24 to -0.05)

Mean values in the emulator are based on multi-model simulations conducted for the study, based on a series of simulations with regionally perturbed emissions. Confidence ranges (in brackets) are constrained by results from simulations with a capital CMIP6 multi-model ensemble, with 30-year long simulations with globally specified emission changes for 2014.

Reductions in black carbon offer the potential to deliver 'quick wins' in mitigating climate change. All except one of the models used in AR6 found that reductions in black carbon would help to reduce warming.

Reduction strategies need to consider that measures to reduce black carbon may also reduce SO_2 and other cooling components. Evaluating the net climate effect of measures is therefore necessary. Measures targeting CO_2 may, in some instances, reduce black carbon even more than targeted black carbon measures.

THE HEALTH BENEFITS OF REDUCING BLACK CARBON EMISSIONS

Reducing emissions of black carbon also delivers significant health benefits. Black carbon is a significant component of particulate matter of 2.5 micrometers or less in diameter ($PM_{2.5}$). $PM_{2.5}$ pollution, which can contribute to cardio-vascular and respiratory diseases, is responsible for an estimated 4 million excess deaths annually.[25]

The 2021 AMAP report estimated the health benefits of reducing SLCFs under two scenarios. Across Arctic Council countries, applying existing legislation that would reduce $PM_{2.5}$ and ozone pollution would avoid an estimated 60,000 premature deaths in 2030 compared with 2015; applying maximum technically feasible reductions would increase that figure to 97,000.[26] Across Arctic Council Observer countries, the corresponding figures are 540,000 and 800,000 premature deaths.[27]

Addressing air pollution can often galvanise local support for measures that also produce a climate benefit. In addition, delivering health benefits can improve the economic case for acting to reduce emissions. Integrated approaches to air quality management can thus build public and political support for measures that help meet climate goals.

LIKELY INCREASES IN NATURAL BLACK CARBON EMISSIONS

Around 40% of black carbon emissions are from sources such as forest and savannah fires that have both natural and anthropogenic causes.[28] Under all of the Shared Socioeconomic Pathway climate change scenarios in AR6, black carbon emissions are projected to increase as a result of more extensive boreal forest, grassland and peat wildfires.[29] This makes it even more important to reduce black carbon emissions from anthropogenic sources, both because anthropogenic emissions can be more readily controlled, and because they contribute to the global warming that can result in increased natural emissions from wildfires.

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21 Nordic Council of Ministers, 2023. Integrating Nordic air quality and climate policies.

22 *Ibid*, page 8.

23 AMAP's 2021 assessment's Current LEgislation (CLE) scenario assumes full implementation of national and regional air pollution legislation committed to before 2018, as well as full implementation of commitments under Nationally Determined Contributions (as of 2018) towards the Paris Agreement.

24 von Salzen, K., et al., 2022. Clean air policies are key for successfully mitigating Arctic warming. (Table 3).

25 Chowdhury, S., et al., 2022. Global health burden of ambient PM2.5 and the contribution of anthropogenic black carbon and organic aerosols.

26 AMAP, 2021b. Impacts of Short-lived Climate Forcers on Arctic Climate, Air Quality, and Human Health. Summary for Policy-makers.

27 *Ibid.*

28 Ramanathan V., and Carmichael, G., 2008. Global and regional changes due to black carbon.

29 Hamilton, D., 2024. Global warming increases fire emissions but resulting aerosol forcing is uncertain

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